Session 5aAA

Architectural Acoustics and Noise: Session in Memory of Murray Hodgson I

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Chair's Introduction—8:30

Invited Papers

8:35

5aAA1. Murray Hodgson: An appreciation from a practicing acoustical consultant. John P. O'Keefe (O'Keefe Acoust., 10 Ridley Gardens, Toronto, ON M6R 2T8, Canada, john@okeefeacoustics.com)

So much of what we know about the behaviour of sound in rooms comes from studies in concert halls and reverberation rooms. Hardly everyday architectural geometry. The author first met Murray Hodgson in Cambridge when Dr. Hodgson was doing his early scale model studies on factories. Geometrically and acoustically, factories are much more akin to the day to day built environment that we inhabit. The geometry of a factory is typically long, wide and very flat with scattering elements, typically on the floor. Murray would go on to apply his work on factories to other long, low, and wide rooms. Our understanding of the acoustics of open plan offices, health care facilities, and, of course, classrooms can be traced back to his post-doctoral work in Cambridge. One is impressed how the work on factory acoustics grew to cover so much of the rooms we live in. More impressive was his ability to tackle questions that others wouldn't. Questions that acoustical consultants are often asked and really don't have an answer for yet. Noise control in naturally ventilated buildings for example. His legacy will show this work as seminal in the nascent green building type genre.

8:55

5aAA2. An overview of Murray's Hodgson indirect contribution to the acoustical community as a mentor. Banda Logawa (BKL Consultants, 308-1200 Lynn Valley Rd., North Vancouver, BC V7J 2A2, Bangladesh, logawa@bkl.ca)

During his more than 20 years of career as a professor at University of British Columbia, Murray Hodgson has inspired many of his previous students to pursue their career in various fields of acoustics, both in academia and industry. His undergraduate engineering course Acoustics and Noise Control was the first exposure to the vast world of acoustics for many of his former students. Furthermore, Murray has also supervised many students through their graduate studies. This paper will highlight Murray's indirect contribution as a mentor by summarizing the current whereabouts of his former students who are now an active member of the acoustical community in North America and around the world.

9:15

5aAA3. Some contributions of Murray Hodgson to room acoustics modeling. Vincent Valeau (Institut PPRIME UPR 3346, CNRS-Université de Poitiers-ENSMA, 6 rue Marcel Doré TSA 41105, Poitiers Cedex 9 86073, France, vincent.valeau@univ-poitiers.fr), Judicaël Picaut (LUNAM Université, IFSTTAR, AME, LAE, Bouguenais Cedex, France), and Cedric Foy (CEREMA, Laboratoire Regional de Strasbourg, Strasbourg, France)

This presentation focuses on some of the many contributions of Murray Hodgson (1952–2017) concerning room-acoustic modeling. The concepts of sound field diffuseness and diffuse reflections have always been of major interest for Murray, his studies associating most of the time numerical modeling and measurements on scale models or real-scale rooms. His most cited paper [JASA 89, 1990] proposes to include diffuse surface reflections in ray-tracing simulations, and is a milestone in room acoustics prediction as most standard room-acoustic prediction softwares now include surface diffusivity. Another extensively cited paper [App. Ac. 49, 1996] discusses the applicability of diffuse field theory according to room shape and to absorption distribution and magnitude. The conclusions of this study are still greatly useful to researchers, students, and practitioners. Another important focus of Murray's research has been the acoustics of « fitted » rooms (i.e., rooms containing many obstacles such as industrial workrooms, classrooms…), and was the topic of many of his papers. This presentation will review some contributions of Murray on this research topic.

9:35

5aAA4. Diffuseness. Michael Vorlaender (ITA, RWTH Aachen Univ., Kopernikusstr. 5, Aachen 52056, Germany, mvo@akustik.rwth-aachen.de)

In architectural acoustics and noise control, the diffuse sound field is the fundamental assumption. The key of its definition is isotropy and incoherence, thus infinitely many sound uncorrelated waves arrive from directions uniformly distributed over a sphere. The room shape and the amount and placement of absorbing and scattering surfaces and objects determine the isotropy of actual sound fields in rooms. Spatial and directional distributions of room sound fields are reviewed and discussed concerning the consequences on decay curves and on the homogeneity of sound energy density in rooms. Several references to Murray Hodgson illustrate his contributions to this field, particularly to applications to noise control in workrooms.

9:55–10:10 Break

10:10

5aAA5. Reflections on the "Topical Meeting on Classroom Acoustics" at the Acoustical Society of America's spring 2005 meeting in Vancouver. Lily M. Wang (Durham School of Architectural Eng. and Construction, Univ. of Nebraska - Lincoln, PKI 100C, 1110 S. 67th St., Omaha, NE 68182-0816, lwang4@unl.edu)

I had the pleasure of co-organizing the "Topical Meeting on Classroom Acoustics" at the Acoustical Society of America's spring 2005 meeting in Vancouver with Murray Hodgson. The topical meeting featured 26 presentations from a diverse group of international scholars; Hodgson and his research team presented seven of those. This talk will include my personal reflections from co-organizing the session with Hodgson, but also discuss the impact of the work presented by Hodgson and his students at that topical meeting. Special attention will be given to how the talks given by Hodgson and his research team demonstrate the breadth of his varied interests in classroom acoustics and point to the significant accomplishments he made in this area throughout his career. Hodgson's body of work continues to heavily influence my own and many others who study classroom acoustics.

10:30

5aAA6. Do we still need diffuse field theory? Francesco Martellotta (DICAR, Politecnico di Bari, Via Orabona 4, Bari, Bari 70125, Italy, francesco.martellotta@poliba.it)

More than twenty years after Murray Hodgson's "When is diffuse field theory applicable?" paper, we gathered more and more evidences that diffuse field is mostly a chimera. If we consider the two most important implications of the diffuse field model, i.e., sound pressure level uniform distribution and reverberation time invariance, it is quite easy to say that, based on actual measurements in a number of different spaces, such conditions are hardly found. Ideal sound diffusion requires ergodic and mixing conditions, which are not obvious to happen, particularly when sound absorption is unevenly distributed or rooms are not proportionate. So, apparently, diffuse field theory could even be dismissed in favour of more accurate approaches capable of taking into account the specific nature of each space. Nowadays, we have several instruments spanning from the many variations of the ray-tracing algorithm to the "brute force" numerical solution of the wave equation. However, such methods rely on the measurement or estimation of other coefficients that, if not properly made, may introduce even bigger inaccuracies. A critical analysis is carried out showing that diffuse field theory still represents an important way to understand sound propagation in enclosed spaces.

10:50

5aAA7. Concave surfaces and acoustics of performance spaces—Part I— Hybrid ray-image analysis. Eva M. Johnston-Iafelice and Ramani Ramakrishnan (Bldg. Sci., Ryerson Univ., 350 Victoria St., Toronto, ON M5B 2K3, Canada, ejohnstoniafelice@ryerson.ca)

Current acoustic practices deem that concave surfaces do not provide good acoustical performance. However, old cathedrals, churches, and enclosed performance spaces with concave interiors seem to perform well. Part I of the current investigation analyzes the acoustical performance of spaces with curved surfaces. The main focus of the current investigation was to research the uniformity of the sound field produced by curved surfaces by analyzing sound pressure level distribution throughout the audience space. It studied the impact of the focal plane on the overall sound distribution within an enclosed space. To analyze the effect of curved surfaces at different frequencies, three enclosed rooms with curved surfaces were used to measure the sound pressure levels throughout an audience space: the Paul Crocker Gallery in the Ryerson Architecture Building, Toronto; St. Martin-in-the-fields Anglican Church, Toronto; and Wigmore Hall, United Kingdom. The evaluations were achieved with both experimental methods, and computer simulations using hybrid-ray-image methods. Computer simulations were validated by the initial on-site measurements in the Toronto locations. After these evaluations were performed, results showed that in these conditions, the curved surfaces had minimal negative impact as perceived by the audience. The results of the investigation will be presented in this paper.

11:10

5aAA8. Concave surfaces and acoustics of performance spaces—Part II —Wave analysis. Ramani Ramakrishnan and Eva M. Johnston-Iafelice (Architectural Sci., Ryerson Univ., 325 Victoria St., Toronto, ON M5B 2K3, Canada, rramakri@ryerson.ca)

Conventional wisdom states that having concave surfaces as the envelope of any occupied space does not produce good sound. The focussing effect of concave surfaces can cause high sound pressure levels, coloration, and echoes. However, throughout history there have been many enclosed rooms with large curved surfaces as envelopes that seem to produce good acoustics. Recent research suggested that wave analysis must be undertaken to establish the impact of concave surfaces. In contrast to Part I of the current investigation, evaluation of the sound pressure level distribution, in rooms with concave surfaces, was performed by solving the governing wave equation. The main reason is that the image-ray theory is valid only at frequencies greater than the Schroeder cut-off frequency. The wave theory is used for frequencies lower than 100 Hz. Finite element modelling was applied to solve for the sound pressure level distribution within

rooms with concave surfaces. Three spaces, the Paul Crocker Gallery in Ryerson University, Toronto, St. Pauls Anglican Church in Toronto and Wigmore Hall in London were investigated in this study. The results for three low frequencies (25 Hz, 50 Hz, and 100 Hz) as well as their combination will be presented in this paper.

FRIDAY MORNING, 9 NOVEMBER 2018 SHAUGHNESSY (FE), 8:45 A.M. TO 12:00 NOON

Session 5aAB

Animal Bioacoustics: Marine Mammal Bioacoustics I

Susanna B. Blackwell, Chair
Greeneridge Sciences, Inc., 120 Tamarack Drive, Aptos, CA 95003

Contributed Papers

8:45

5aAB1. Clymene dolphin (*Stenella clymene*) whistles in the Southwest Atlantic Ocean. Juliana R. Moron (Instituto Aqualie, Av. Doutor Paulo Japiassu Coelho, n° 714 sala 202, Juiz de Fora 36033310, Brazil, julianamoron@hotmail.com), Luiz Cláudio P. Alves, Carla Viviane de Assis, Felipe C. Garcia (NAV Oceanografia Ambiental, Rio de Janeiro, Rio de Janeiro, Brazil), and Artur Andriolo (Laboratório de Bioacústica e Ecologia Comportamental - Instituto de Ciências Biológicas, Universidade Federal de Juiz de Fora, Juiz de Fora, Minas Gerais, Brazil)

The Clymene dolphin despite being endemic for the Atlantic Ocean continues to be the least known species in the genus *Stenella* without available information on their vocal repertoire in Brazilian waters. Data were obtained during mitigation and monitoring work required by IBAMA under the federal environmental licensing as conditions of the license 108/16 for the 3D seismic survey in Pará/Maranhão Sedimentary Basin process 02022.000015/2014. The species record was performed onboard the vessel Polarcus Alima with a Mseis (Night Hawk III) four-element towed array passing signals to a digital M-Audio, recording at 96 kHz/16bits. During visual and acoustic monitoring with the air-guns off, a group of approximate 80 dolphins were sighted and recorded on May 8th, 2016 (00°38'00" N, 44°45'25" O) at 3,425 m depth. The wav-files were analyzed through the spectrogram configured as DFT 2048 samples, 70% overlap and Hamming window of 1024 points generated by software Raven Pro 1.5. The results of 14 min recording allowed the extraction of 257 whistles. Minimum frequencies ranged from 5.20 kHz to 15.92 kHz (mean = 10.99 kHz); maximum frequencies ranged from 7.72 kHz to 28.04 kHz (mean = 16.16 kHz); whistle duration ranged from 0.01 s to 1.52 s (mean = 0.43 s). These results are important since they represent the first acoustic record of Clymene dolphins in Brazil.

9:00

5aAB2. Burst-pulses in East Greenland narwhals: Further evidence for unique, individual-specific vocalizations. Susanna B. Blackwell (Greeneridge Sci., Inc., 120 Tamarack Dr., Aptos, CA 95003, susanna@greeneridge.com), Outi M. Tervo (Greenland Representation, Greenland Inst. of Natural Resources, Copenhagen, Denmark), Alexander S. Conrad (Greeneridge Sci., Inc., Santa Barbara, CA), and Mads P. Heide-Jørgensen (Greenland Representation, Greenland Inst. of Natural Resources, Copenhagen, Denmark)

In August 2013–2017, narwhals from Scoresby Sound, East Greenland, were instrumented with satellite-linked transmitters and acoustic sound and movement tags (Acousonde™) over periods of up to 8 days. The records obtained provided continuous information on the whales' acoustic behavior during foraging and social interactions. Burst-pulses were the most easily recognizable non-feeding vocalization. They tended to occur near the surface and were more common in records that displayed higher rates of clicks from other individuals, i.e., records that presumably would include more social interactions with other narwhals. Over 100 burst pulses detected in eight subjects were analyzed in terms of their overall length and their pattern of successive inter-click intervals (ICIs). While overall length could be somewhat variable, the succession of ICIs was unique for each whale and could therefore have an identity-carrying function, as the signature whistle does in bottlenose dolphins and other odontocetes. The occurrence of these individual-specific burst-pulses in time and space will be examined in relation to other factors provided by the tags, such as the time of day, whale depth, presence of conspecifics, and behavioral state. [Work sponsored in part by the Greenland Institute of Natural Resources.]

9:15

5aAB3. Vocalizations of common minke whales (*Balaenoptera acutorostrata*) in an eastern North Pacific feeding ground. Jared Towers (Bay Cetology, Alert Bay, BC, Canada) and Katrina Nikolich (Biology, Univ. of Victoria, 992 Karen Crescent, Victoria, BC V8X3C6, Canada, katrinan@uvic.ca)

The minke whale (*Balaenoptera acutorostrata*) is the smallest species of baleen whale and has a cosmopolitan distribution. Despite extensive study on the vocalizations of other balaenopterids, the acoustic repertoire of minke whales is not well known. Individuals of the North Pacific subspecies of common minke whale (*B. a. scammoni*) are known to produce unique vocalizations ("boings") during their putative breeding season from fall to spring. However, no vocalizations have been previously reported for this subspecies in summer feeding grounds. We present four novel call types recorded in the presence of minke whales in Cormorant Channel, in coastal British Columbia, Canada, during the summer of 2012. These calls consist of broadband pulses, tonal wavers, downsweeps, and pulse trains. Calling rates for minke whales in this study region were very low compared to those reported for North Atlantic minke whales on their feeding grounds. We compare our candidate call types with vocalizations described for other minke whale populations and propose predation risk as a cause of the low calling rates observed for minke whales in Cormorant Channel.

9:30

5aAB4. Temporal variations in humpback whale (*Megaptera novaeangliae*) song in Monterey Bay National Marine Sanctuary, northeast Pacific. John P. Ryan (Monterey Bay Aquarium Res. Inst., 7700 Sandholdt Rd., Moss Landing, CA 95039, ryjo@mbari.org), Danelle E. Cline (Monterey Bay Aquarium Res. Inst., Moss Landing, CA), John E. Joseph (Naval Postgrad. School, Monterey, CA), Tetyana Margolina (Naval Postgrad. School, Monterey, CA), Alison K. Stimpert (Moss Landing Marine Labs., Moss Landing, CA), Karin Forney (NOAA, Moss Landing, CA), Nancy Black (Monterey Bay Whale Watch, Monterey, CA), Andrew DeVogelaere (NOAA, Moss Landing, CA), Mark Fischer (Aguasonic Acoust., Rio Vista, CA), Christopher Wahl, and Francisco Chavez (Monterey Bay Aquarium Res. Inst., Moss Landing, CA)

Using two years of nearly continuous recordings from Monterey Bay National Marine Sanctuary, August 2015 through July 2017, variations in humpback whale song are examined on diel, seasonal, and interannual time scales. The cabled hydrophone is in humpback feeding and migratory habitat at 36.7128°N, 122.186°W. Diel analyses show 69% of song during night, 23% during day, and 8% during dusk or dawn. Seasonal analyses show song absence during summer (June–August), emergence during fall (September–October), peak during late fall/winter (November–January), and highly variable detection during spring (February–May). During both years >80% of song occurred during the November–January peak. Song detection within a month reached a maximum of 58% of the time during November 2016. Song length increased ($p < 0.01$) month-to-month from the start in fall through the end of the peak in January. The months of maximum song occurrence coincide with declining visual sighting of humpbacks within Monterey Bay, consistent with seasonal southward migration to breeding habitat and/or more offshore residence. Interannual variation in song was marked by a 51% increase between the first and second years. Habitat during the first year was strongly influenced by a prolonged regional oceanic warm anomaly and the largest toxic algal bloom ever recorded in the northeast Pacific. Alternative hypotheses for the interannual difference in song detection relate to differences in humpback regional abundance, behavior, and habitat occupancy.

9:45

5aAB5. What the African naked mole-rat can tell us about mammalian hearing and acoustic communication. Catherine Barone (Anatomy & Cell Biology, Univ. of Illinois Chicago, 808 S. Wood St., Rm. 578 MC 512, Chicago, IL 60612-7308, cbaron2@uic.edu), Thomas Park (Biological Sci., Univ. of Illinois Chicago, Chicago, IL), and Sonja Pyott (Univ. medical Ctr. Groningen, Groningen, Netherlands)

African naked mole-rats are eusocial rodents that live underground in narrow burrows. Likely reflecting adaptations to their subterranean environment, naked mole-rats (NMRs) have poor high frequency hearing, relatively high auditory thresholds, and limited ability to localize sound thus providing a unique opportunity to investigate the mechanisms required for high frequency hearing and sound localization. Despite their poor hearing sensitivity, NMRs display a functional coupled auditory-vocal communication system. Prior work revealed they use 17 different vocalizations to communicate within their colonies. Due to their unusual hearing, investigation of NMRs, especially in comparison to other rodent models, provides a unique opportunity to identify features of the auditory system that underlie high frequency hearing, sound localization, and discrimination of vocalizations. Our recent anatomical characterization indicates the NMR cochlea undergoes stunted maturation of peripheral synaptic organization and altered expression of ion channels compared to other mammals. Our more recent function auditory assessments indicate multiple mechanisms that may result in their poor hearing. Overall, these studies provide a framework for comparative insight into the peripheral mechanisms required for high frequency hearing and sound localization.

10:00

5aAB6. Do singing humpback whales (*Megaptera novaengliae*) favor specific frequency bands? Christina E. Perazio (Evolution, Ecology, and Behavior, State Univ. of New York at Buffalo, Buffalo, NY, cperazio@buffalo.edu) and Eduardo Mercado (Psych., State Univ. of New York at Buffalo, Buffalo, NY)

Many species alter their acoustic signals in response to environmental or anthropogenic factors. Differential use of frequency bands may occur as a result of overlapping biotic and abiotic sounds that interfere with communication signals between conspecifics. Singing humpback whales produce units with frequencies ranging from 30 Hz to over 10,000 Hz, but may favor specific frequency bands during song production. We tested the prediction that singing humpback whales consistently produce units with energy focused in specific spectral bands by measuring the consistency of peak frequency bands in the southeastern Pacific stock G population of humpback whales in the Gulf of Tribugá, Colombian Pacific. Preliminary results document extensive use of units with peak frequencies clustered in two different bands between 300 Hz and 1000 Hz for the dominant theme, and additional peak frequency bands between 300 Hz and 3000 Hz for other song themes. These analyses will allow for further spatial and temporal comparisons across distinct population segments, and can be used in future studies to assess whether singers change their use of frequency bands in response to increased anthropogenic noise or as themes evolve over time.

10:15–10:30 Break

10:30

5aAB7. Acute motor and vocal response of humpback whales (*Megaptera novaeangliae*) to playback of amplitude-modulated noise: A method to test frequency range of hearing. Brian K. Branstetter (National Marine Mammal Foundation, 2240 Shelter Island Dr. #200, San Diego, CA 92106, brian.branstetter@nmmpfoundation.org), Mark H. H. Deakos (HDR Inc., Lahaina, HI), Keith Jenkins (SSC Pacific Code 71510, US Navy Marine Mammal Program, San Diego, CA), Brian C. Balmer (National Marine Mammal Foundation, San Diego, CA), Alan P. Ness (HDR Inc., Lahaina, HI), and Rachel Cartwright (California State Univ. Channel Islands, Camarillo, CA)

The frequency hearing range of mysticete cetaceans remains elusive despite a growing concern about the negative impacts of anthropogenic noise. A playback study was conducted in the Maui Nui region of Hawaii during March 2018. Stationary humpback whales (i.e., single singers or silent dyads) were targeted due to their predictable behavior that allowed for observations pre, during, and post-playback. Playback consisted of amplitude-modulated noise that was broadband, high-pass filtered, or 1/3 octave bandpass filtered. The animal's motor behavior was recorded by video from a swimmer positioned above the animal. Acoustic playback and acquisition was performed from a small vessel approximately 41 m to 56 m from a targeted animal. A total of 16 playbacks were conducted with estimated received levels between 116 dB–138 dB RMS (re 1 μPa). Motor responses ranged from abruptly swimming away to subtle fluke movements with a median response latency of 1.7 sec (n = 7). Vocal responses ranged from abrupt song termination to unexpected changes in song unit pattern, with a median response latency of 2.94 sec (n = 8). This novel playback methodology was effective at producing and measuring motor and vocal responses to sound and may be useful in measuring the hearing range of mysticetes.

10:45

5aAB8. Mapping the phonetic structure of humpback whale song units. Howard S. Pines (Retired, Wireless Network Business Unit, Cisco Systems, 8752 Terrace Dr., El Cerrito, CA 94530, howardpines@gmail.com)

The striking similarities of time-frequency spectrograms of voiced human speech and humpback whale vocalizations suggested a common targeted frequency-modulated phonetic basis. To map the sub-unit structure of humpback whale song units, a time-frequency contour segmentation, extraction, and classification procedure was developed and tested on streaming voiced human speech. When the procedure was applied to humpback vocalizations and the tone-pairs of the two most energetic "vocal fold" harmonic frequencies were plotted in x-y coordinates, the plot exhibited properties of an optimally structured Shannon "modem symbol constellation" diagram of 14 distinct sub-regions and 60 acoustically distinct sub-unit symbols. The humpback symbol constellation is structurally comparable to the tone-pair symbol constellations of English and Asian language vowels. The information entropy and plot of the humpback sub-unit symbol set's cumulative

probability vs. ranked frequency distribution function are nearly identical to the entropy and Zipf power law profile of the English language phoneme set. The precise specification of the sub-unit structure of more than one hundred song units analyzed to date has resulted in a three-fold expansion in the number of unique units identified in previous studies, suggesting that the "lexicon" of humpback song units is potentially much larger than cited in the literature.

11:00

5aAB9. Airborne and underwater acoustic repertoire of hooded seals (*Cystophora cristata*): Cornerstone for acoustic monitoring. Heloise Frouin-Mouy (JASCO Appl. Sci., 2305 - 4464 Markham St., Victoria, BC V8Z 7X8, Canada, heloise.frouin-mouy@jasco.com)

The hooded seal is a migratory species inhabiting the North Atlantic. They whelp and breed during mid- to late March on pack ice near Jan Mayen Island, in the Davis Strait, off the northeastern Newfoundland coast, and in the Gulf of St. Lawrence. After breeding, hooded seals return to the pack ice off eastern Greenland to moult during June and July, and then they disperse broadly for summer and fall before returning to their respective breeding areas. Passive acoustic monitoring conducted over spatial scales consistent with known and potential habitat of the hooded seal could add insight into seasonal, diel, and spatial occurrence patterns of this species. To better characterize its acoustic repertoire (notably underwater calls), airborne and underwater acoustic signals of hooded seals were recorded during their breeding season on the pack ice in the Gulf of St. Lawrence from 12 to 17 March 2018. Hood and septum noises were the predominant sounds heard from males on the ice surface. Hooded seal underwater acoustic repertoire is larger and more diverse than has been previously described. Using the dataset from an extended acoustic monitoring program along Canada's East Coast, some clues are provided about the seasonal distribution of hooded seals.

11:15

5aAB10. Vocalizations of North American river otters (*Lontra canadensis*) in two human care populations. Sarah Walkley (Univ. of Southern MS, 254 Kitchawan Rd., South Salem, NY 10590-2014, sarahnwalkley@gmail.com), Maria Zapetis (Univ. of Southern MS, San Diego, CA), and Heidi Lyn (Univ. of Southern MS, Gulfport, MS)

There is a dearth of information regarding the vocal repertoire of North American river otters (Lontra canadensis). This indicator species is cosmopolitan yet elusive, making recordings methodologically difficult in the wild. Therefore, this exploratory study uses video and audio recordings of two populations of North American river otters in human care to broaden the known vocal repertoire of river otters in various social contexts. The populations consist of a male-female and a male-male pair. This study is the first to examine the vocalizations produced in a male-male pair of river otters. Call types were acoustically distinguished based on their appearance on a spectrogram. Parameters including average duration, frequency (high, low, max, 1st quarter, center, and 3rd quarter), and power (max and average) were measured for each call. Because vocalizations are the focal point of this study, only behaviors co-occurring with vocalizations were included in the chi square analysis that showed a significant relationship between call type and behavior. Squeaks and whines were present during agonistic behaviors while chirps were produced during non-agonistic behaviors including investigating, stationary, and grooming. Results support that behavior likely plays a role in the type of calls produced by river otters in human care.

11:30

5aAB11. Temporal separation in call types found for large baleen whale species in offshore waters of the Canadian Pacific. Rianna Burnham (Univ. of Victoria, Victoria, BC V8P 5C2, Canada, burnhamr@uvic.ca)

Populations of large whale species were severely reduced by commercial whaling. Studies of repopulation and habitat use are hindered by their use of offshore waters. Passive acoustic recordings made using stationary and mobile receivers in in- and offshore waters off the west coast of Vancouver Island are used to begin to re-establish abundance and distribution patterns of these species, while outlining habitat units that may be important for population recovery. At its simplest call presence represents whale presence. Additionally, recordings show a strong temporal separation in call type employed by fin whales. Their stereotypical 20 Hz call dominates recordings from December to late February, with presence of patterned sequences representing a doublet song also. Recordings made later in the spring (March-April) show high prevalence of the 40 Hz call, described for social and foraging behaviours. These calls were most frequently heard in recordings from along the continental shelf break and in areas of topographical complexity and possible prey aggregation, such as oceanic canyons. Change in call type suggests a change in behaviour and social context of the signaler. Similar patterns were found for blue whales in this area; more B calls in winter and D calls in spring.

11:45

5aAB12. Characterizing the acoustic behavior of free-ranging Risso's dolphins (*Grampus griseus*) in Monterey Bay, California. Brijonnay C. Madrigal and Alison K. Stimpert (Vertebrate Ecology Lab, Moss Landing Marine Labs., 8272 Moss Landing Rd., Moss Landing, CA 95039, bmadrigal@mlml.calstate.edu)

Risso's dolphins (*Grampus griseus*) are a common, highly vocal odontocete species found in Monterey Bay, California, that is relatively understudied acoustically. Although several studies have focused on Risso's echolocation, there is little research on the other social sound types for this species. Apart from echolocation clicks, the two most common sound types in Risso's dolphin repertoires are whistles and whistle + burst pulse (whistle BP) vocalizations. In summer 2017, single C57 omnidirectional hydrophone (Cetacean Research Technology) deployments were conducted in Monterey Bay to record Risso's sound production during periods of slow travel and social interaction at the surface. Group composition information and surface behavioral events were also recorded to provide behavioral context. Average group sizes consisted of approximately 30 animals. We completed a total of 62 h on effort and 75 deployments. Of the 5 total hours of recordings, 43% contained vocalizations. We will describe the acoustic parameters of recorded whistle and whistle BP vocalizations of Monterey Bay Risso's dolphins, evaluate sound production rate in relationship to surface active behavior, and compare vocalizations with those of geographically isolated populations as well as sympatric odontocete species in the Bay.

Session 5aAOa

Acoustical Oceanography, Underwater Acoustics, and Animal Bioacoustics: Ocean Observatories: Laboratories for Acoustical Oceanography I

Thomas Dakin, Cochair
Ocean Networks Canada, TEF-128A 2300 McKenzie Ave., University of Victoria, Victoria, BC V8W2Y2, Canada

Kay L. Gemba, Cochair
MPL/SIO, UCSD, University of California, San Diego, 8820 Shellback Way, Spiess Hall, Room 446, La Jolla, CA 92037

Chair's Introduction—7:45

Contributed Papers

7:50

5aAOa1. An overview of non-governmental organization, passive acoustic, ocean observatory data available on the North East Pacific Coast. Thomas Dakin (Ocean Networks Canada, TEF-128A 2300 McKenzie Ave., University of Victoria, Victoria, BC V8W2Y2, Canada, tdakin@uvic.ca), Janie Wray (Fin Island Marine Inst., Hartley Bay, BC, Canada), Hermann Meuter (CetaceaLab, Hartley Bay, BC, Canada), Jordan Wilson (Pacific Wild, Bella Bella, BC, Canada), Larry Peck (Saturna Island Marine Res. and Education Society, Saturna Island, BC, Canada), Scott Veirs (Orcasound, Seattle, WA), and John P. Ryan (MBARI, Moss Landing, CA)

There are governmental (DFO, DND, NOAA, USN), commercial (typically proprietary), and non-governmental organization (NGO) passive acoustic ocean observing systems installed on the North East Pacific Coast. The NGO passive acoustic datasets span many years, four decades for OrcaLab. This presentation provides an overview of the data collected at various NGO acoustic observatories on the North East Pacific Coast. The dataset time windows, sampling rates, formats, and ancillary data are given for each NGO. Data availability, searchability, data use restrictions, and contact information are given to allow acoustic researchers to access this treasure of acoustic observatory data. NGO's include Fin Island Marine Institute, CetaceaLab, Pacific Wild, OrcaLab, Ocean Networks Canada, Saturna Island Marine Research and Education Society, Orcasound, and the Monterey Bay Aquarium Research Institute.

8:05

5aAOa2. Passive ocean sensing and soundscape analysis of the Juan de Fuca plate using the Ocean Networks Canada NEPTUNE Array. Christopher M. Verlinden (OASIS Inc., 5 Militia Dr., Clarksburg, MA 02421, cmaverlinden@gmail.com), Kevin D. Heaney (OASIS Inc., Fairfax Station, VA), Martha C. Schonau (OASIS Inc., Falls Church, VA), and Thomas Dakin (Univ. of Victoria, Victoria, BC, Canada)

The Ocean Networks Canada (OCN) deployment of a small set of acoustic recorders (4) in and around the Juan de Fuca plate provides the opportunity to observe the seasonal and long-term trends in the northeast Pacific ocean soundscape. With one receiver near the opening of the Straits of Juan De Fuca, two on the continental slope and one in deep water, we have the opportunity to evaluate the effects of local environment on the ambient sound. Wind waves and surface ships drive the low frequency ambient sound fields in most regions. These long-term recordings provide the opportunity to perform passive acoustic tomography, where the cross-correlation of the acoustic field over long time periods can provide estimates of the channel impulse response between the two hydrophones. This technique has been demonstrated experimentally at shorter ranges. The expected oceanographic observed signal from a "tomography experiment" is estimated using the ECCO4 model and the parabolic equation.

Invited Papers

8:20

5aAOa3. Overview of OOI/RSN cabled ocean observatory. Gerald Denny, Michael Harrington, Dana Manalang (Appl. Phys. Lab, Univ. of Washington, 1013 NE 40th St., Henderson Hall, Seattle, WA 98105-6698, denny@apl.washington.edu), and Deborah Kelley (School of Oceanogr., Univ. of Washington, Seattle, WA)

The summer of 2014 saw the completion of installation and first data from the cabled portion of the Ocean Observatories Initiative (OOI) Regional Scaled Nodes (RSN). Data streams live from over 130 instruments to an OOI Data Portal via telecom cables that land in Pacific City, OR. The observatory encompasses a cross-section of the Juan de Fuca plate from the coastal shelf to an undersea volcano, with instruments from 80 m to 2900 m depth. Acoustic instrumentation includes 6 broadband hydrophones (capable of 120 kHz), 5 low frequency hydrophones (to 5 kHz), two 3-frequency upward looking fisheries sonars, and 6 upward looking ADCPs. Water-borne acoustic data have also been observed in the 5 broadband (3 mHz to 10 Hz) and 7 short-period (0.1 Hz to 100 Hz) seismometers. Two new acoustic experiments will be deployed in the 2018 O&M cruise. The raw and processed data are archived and are open access to all. An overview of the types of instruments and their locations, as well as discussion of data characteristics and how to access the data, will be given. Some examples of data will be shown as well as examples of specific event characterization and ongoing uses.

8:40

5aAOa4. Low-frequency acoustic observations with cabled observatories on the Juan de Fuca Ridge. William S. Wilcock (School of Oceanogr., Univ. of Washington, Box 357940, Seattle, WA 98195, wilcock@uw.edu), Maya Tolstoy (Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY), Robert Dziak (Pacific Marine Environ. Lab., National Oceanic and Atmospheric Administration, Newport, OR), Del Bohnenstiehl (Dept. of Marine, Earth, and Atmospheric Sci., North Carolina State Univ., Raleigh, NC), Jacqueline Caplan-Auerbach (Geology Dept., Western Washington Univ., Bellingham, WA), Felix Waldhauser (Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY), and Christian Baillard (School of Oceanogr., Univ. of Washington, Seattle, WA)

In the Northeast Pacific Ocean, the NSF Ocean Observatories Initiative (OOI) and Ocean Networks Canada (ONC) operate regional cabled observatories that include a network of seismometers and hydrophones enclosing the northern half of the Juan de Fuca plate, and local observatories at two sites on the Juan de Fuca Ridge: Axial Seamount (OOI) and the Endeavour segment (ONC). At each ridge site, local networks of seismometers and hydrophones provide a tool to monitor in real time the seismic and acoustic signals associated with volcanic, tectonic, and hydrothermal processes. In 2015, Axial Seamount erupted a few months after the installation of the OOI. Following the eruption, regionally recorded T-phases were used to track a dike propagating along the Axial North Rift. Acoustic signals from impulsive sources associated with lava flows, detected eruptions in the caldera and on the North Rift. Diffuse acoustic signals were also associated with the later stages of the eruption. The low-frequency acoustic capabilities of the OOI and ONC cabled observatories are underutilized and future applications could include the reestablishment of regional acoustic earthquake monitoring, tracking eruptions in real time to guide rapid autonomous and ship-based response efforts, and enhanced studies of fin and blue whales.

Contributed Papers

9:00

5aAOa5. Adding value to big acoustic data from ocean observatories: Metadata, online processing, and a computing sandbox. Ben Biffard, Michael Morley, Maia Hoeberechts, Allan Rempel, Thomas Dakin, Richard K. Dewey, Reyna Jenkyns (Ocean Networks Canada, PO BOX 1700 STN CSC, Victoria, BC V8P 1V1, Canada, bbiffard@oceannetworks.ca),

Ocean Networks Canada (ONC) operates ocean observatories on all three of Canada's coasts. The instruments produce 300 gigabytes of data per day with over 600 terabytes archived so far. The majority of this data is acoustic, both passive (335 TB) and active (20 TB). This demonstrates the unprecedented capability of cabled observatories to provide unlimited power and data for high bandwidth, continuous data acquisition. Handling this data is a challenge. Metadata, calibration, quality control, and access must be considered. The volume of data is too great for most users to handle. Even if they could store and process it, data transfer to users' computers is a limiting, and perhaps unnecessary step. To address these challenges, ONC has developed a data portal, known as Oceans 2.0, that includes on-demand user-configurable online previewing and processing and a computing "sandbox" where users can upload their own code to process the data. The data portal is now fully accessible by web services. The sandbox is a contained, secure environment with direct access to the data. This paper will present our experience and best practices, including use cases, from acquisition to adding value to the data with these new computing methods.

9:15

5aAOa6. Low-frequency ambient noise trends of (almost) 2 decades in the northern Pacific Ocean. Rex K. Andrew (Appl. Phys. Lab., 1013 NE40th St., Seattle, WA 98105, rx.andrew@ieee.org), Bruce Howe (Dept. Ocean Res. Eng., Univ. of Hawai - Manoa, Honolulu, HI), and James Mercer (Appl. Phys. Lab., Seattle, WA)

Nearly two decades of low-frequency (20–500 Hz) ambient noise measurements at seven open-ocean sites in the North Pacific Ocean basin have revealed a complex pattern of long-term trends. The trends in the Northeastern Pacific Ocean show a significant decrease of almost 2 dB/decade. Along the Aleutian archipelago, the levels are either slightly increasing or remaining flat. Levels in two north central Pacific Ocean sites are essentially flat. Comparisons with very sparse measurements made over the last 5 decades suggest that the mid-latitude noise levels may have peaked in the 1990s. These measurements also show, however, that the noise level is still rising elsewhere. The mechanisms driving these trends appear to be more subtle than simply the number of merchant ships or the local wind speed. Climatically-influenced basin-scale acoustic propagation conditions may have an important role.

9:30

5aAOa7. Long-term monitoring of marine soundscapes: Shipping, biodiversity, and weather at a Pacific seafloor observatory. Alice Richards (Phys., Univ. of Bath, Bath, Bath and NE Somerset, United Kingdom) and Philippe Blondel (Phys., Univ. of Bath, Claverton Down, Bath, Avon and NE Somerset BA2 7AY, United Kingdom, p.blondel@bath.ac.uk)

Seafloor observatories enable long-term monitoring of marine soundscapes, modulated by weather, biodiversity, and human impacts (e.g., shipping). High-frequency (96-kHz) measurements at the NEPTUNE node of Folger Deep are processed to compare signatures of shipping and natural events over five tidal cycles, spanning several seasons (2009–2011). Independent meteorological data from local surface stations is also used. Sound levels in third-octave frequency bands centred on 63 Hz and 125 Hz are used to monitor shipping, in line with the European Marine Strategy Framework Directive (MSFD). The contribution from the busy shipping lane 40 km away is affected by the complex, shallow bathymetry, whereas local traffic can increase noise levels by up to 30 dB re. 1 μPa, with strong seasonal variation. The relative contributions of the 63 Hz and 125 Hz bands varied contrary to MSFD expectations for deeper areas. Our results match other studies in shallow, coastal environments, showing the importance of depth in interpreting changes. Principal-Component Analyses show that noise from local vessels is the most significant contributor in all seasons, and weather is the second largest, except in summer when biological noise became prevalent. Biodiversity, measured with the broadband Acoustic Complexity Index, showed a strong correlation with weather.

9:45–10:00 Break

10:00

5aAOa8. Ranking vessel noise emissions using measurements from an underwater listening station. David E. Hannay, Heloise Frouin-Mouy, Zizheng Li, and Alexander O. MacGillivray (JASCO Appl. Sci., 2305-4464 Markham St., Victoria, BC V8Z 7X8, Canada, David.Hannay@jasco.com)

Commercial shipping routes pass through important habitat areas for several species of marine mammals in the coastal waterways of southern British Columbia. The Vancouver Fraser Port Authority, through its Enhancing Cetacean Habitat and Observation (ECHO) program, has undertaken studies to develop mitigation measures that will lead to a quantifiable reduction in threats to whales resulting from shipping activities. This includes long-term measurements of vessel noise at a cabled underwater

listening station in Georgia Strait (the ECHO ULS) where JASCO, in partnership with Ocean Networks Canada, has been measuring source levels of vessels calling at the Port using JASCO's PortListen® software. PortListen® receives and processes real-time acoustic and AIS data to calculate vessel source levels using ANSI standard methods (S12.64-2009 R2014). Since September 2015, PortListen® has collected a database of thousands of source level measurements, which has been used to implement ranking system for vessel noise emissions. The ranking system uses a data-driven model to adjust the ranking of each measurement according to the vessel characteristics (e.g., size, class) and measurement conditions (e.g., speed, wind, and draft). In addition to an unweighted noise ranking, the system also provides weighted rankings for five marine mammals hearing groups using NOAA (2016) auditory weighting curves.

Invited Paper

10:15

5aAOa9. The Aloha Cabled Observatory: New Insights into hurricane generation of the seismo-acoustic noise spectrum. Rhett Butler (SOEST, Univ. of Hawaii at Manoa, 1680 East-West Rd., POST 602, Honolulu, HI 96822, rgb@hawaii.edu) and Jérome Aucan (Laboratoire d'Etudes en Géophysique et Océanographie Spatiale, Institut de Recherche pour le Développemen, Toulouse, France)

The close passage of Hurricane Lester near the Hawaiian Islands in September 2016 afforded an in-depth, close-up study of storm generation of the largest background vibrations observed planet wide. The observations at the ALOHA Cabled Observatory on the seafloor below the Hurricane, coupled with seismic sensors on Oahu, and ocean wave buoys off shore, present a detailed picture connecting the storm to the ocean and Earth. Wave interactions from a distant typhoon near Japan play an important role. Vibration energy levels observed on Oahu closely match those on the sea floor 100 km north of Oahu, where ALOHA Cabled Observatory is the world's deepest seafloor observatory at 4,728 m depth. Characteristic vibrations generated radially from the Hurricane were observed, along with unexpected transverse motions perpendicular to the radial waves. This latter observation is consistent with a broad source region extending from Hurricane Lester and generating the vibrations. Evidence for substantial scattering of the vibrations in the ocean crust is inferred, due to slanting layers and directionally varying velocities, dating back nearly 80 million years ago when the sea floor was being originally being emplaced at a Pacific mid-ocean ridge. This hurricane transit yields new knowledge on how storms vibrate the planet.

Contributed Papers

10:35

5aAOa10. Long-term marine mammal occurrence in the Distributed Biological Observatory 2010–2015. Catherine L. Berchok (Marine Mammal Lab, Alaska Fisheries Sci. Center/NOAA, 7600 SandPoint Way NE, Seattle, WA 98115, cberchok@yahoo.com), Eric K. Braen (Joint Inst. for the Study of the Atmosphere and Ocean, Univ. of Washington, Seattle, WA), Jessica Crance (Marine Mammal Lab, Alaska Fisheries Sci. Center/NOAA, Seattle, WA), Stephanie L. Grassia, Jenna M. Harlacher, Eliza G. Ives, Jessica M. Kimber, Julie A. Mocklin, Megan A. Wood, Dana Wright (Joint Inst. for the Study of the Atmosphere and Ocean, Univ. of Washington, Seattle, WA), Phyllis J. Stabeno (NOAA, Pacific Marine Environ. Lab., Seattle, WA), and Sue E. Moore (NOAA/S&T-PMEL, Seattle, WA)

The Distributed Biological Observatory (DBO) is a set of eight biological hotspot areas spanning latitudinally from the Northern Bering Sea to the Canadian Beaufort Sea. The DBO is an international collaboration between researchers from the United States, Japan, Canada, China, South Korea, and Russia that work in the Alaskan Bering, Chukchi, and Beaufort Seas; all research vessels passing through one of the DBO regions collect biophysical data (i.e., temperature, salinity, sea ice concentration and thickness, chlorophyll, nutrients, and zooplankton occurrence) along a pre-described line of sampling stations. Since the pilot study in 2010, and with funding from the Bureau of Ocean Energy Management (BOEM), the Marine Mammal Laboratory at the Alaska Fisheries Science Center of NOAA has maintained passive acoustic recorder moorings at two of the DBO regions, colocated with oceanographic moorings from the Pacific Marine Science Center (P. Stabeno). This coverage was expanded to five DBO regions in 2012, again with colocated oceanographic moorings at four of the sites. Here, an interannual comparison of the long-term mooring results from gray, bowhead, beluga, humpback, and killer whales, walrus, ribbon and bearded seals, and vessel and seismic airgun noise will be presented and compared with the sampled biophysical data.

10:50

5aAOa11. Orcasound lab: A soundscape analysis case study in killer whale habitat with implications for coastal ocean observatories. Scott Veirs (NEMES, Univ. of Victoria, 7044 17th Ave. NE, Seattle, Washington 98115, sveirs@gmail.com), Val Veirs (Beam Reach (SPC), Friday Harbor, WA), Lauren McWhinnie, Patrick O'Hara, and Gregory O'Hagan (NEMES, Univ. of Victoria, Victoria, BC, Canada)

Orcasound lab is a cabled hydrophone array located near the shoreline of Haro Strait, the core summertime habitat of the endangered southern resident killer whales (SRKWs). In 2016–2017, we began to record data continuously on local hard drives and in 2018 are archiving both lossy and lossless data 24/7 in an AWS/S3 bucket. We discuss our statistical characterization of the soundscape from these continuous audio recordings, contextualized with the AIS data (to quantify sources of ship noise) and image data (to quantify sources of non-AIS boat noise). Of particular interest to ocean observatories are our methods of establishing non-anthropogenic acoustic baselines and then ranking noise pollution sources relative to these baselines. We explore the statistical consequences of selecting different averaging times (from seconds to years) and frequency band widths (spectrum to broadband levels) when computing baselines and pollution metrics, including "delta" metrics that may be most-relevant to SRKWs. Finally, we explain how soundscape analysis (with attention to tidal, diurnal, seasonal, or decadal time variations) could be implemented with cloud-based data in near-real-time and be enriched by citizen scientists interacting with a time-stamped live audio stream and other environmental data.

Invited Papers

11:05

5aAOa12. Joint observatories following a single male Cachalot during 12 weeks —The Yukusam story. Paul Spong, Helena Symonds (OrcaLab, Alert Bay, BC, Canada, orcalab2@gmail.com), Herve Glotin (LIS, CNRS, AMU, Univ Toulon, La Garde, France), Jared Towers (Fisheries & Oceans Canada, Alert Bay, BC, Canada), lisa larsson (OrcaLab, OrcaLab, BC, Canada), Thomas Dakin (Univ. of Victoria, Victoria, BC, Canada), Scott Veirs (Orcasound.net, Seattle, Washington), Elizabeth Zwamborn (Dalhousie, Halifax, NS, Canada), james pilkinton (Fisheries & Oceans Canada, Victoria, BC, Canada), Pascale Giraudet (LIS, CNRS, AMU, Univ Toulon, Toulon, France), Val Veirs (Orcasound.net, Friday Harbor, Washington), Jason Wood (SMRU, Friday Harbor, Washington), and John Ford (Fisheries & Oceans Canada, Victoria, BC, Canada)

From 11 February to 31 March 2018, a lone male sperm whale visited coastal waters from the northeast to southern ends of Vancouver Island. This whale, named "Yukusam" after the Namgis First Nation word for Hanson Island, near where the whale was first observed and recorded, is the first sperm whale recorded acoustically in the area since 1984 and is the only sperm whale ever observed in coastal waters between Vancouver Island and continental North America. The Yukusam tracking story is a showcase for the potential of acoustic observatory collaborations. Tracking a single animal over such time and distance is remarkable. It obviously helped that Yukusam was the only sperm whale in the area, but still, the experience hints at the potential for using diverse independent observatories collaboratively. We then aim to see all the observatories running automated detection classification and location software and having all the data tied in to a public database for a total of almost 500 Gb of recordings, with labels. Supplemental material @ http://sabiod.org/yukusam

11:25

5aAOa13. Single-hydrophone automated passive acoustic ranging of fin whales at Station ALOHA. Brendan P. Rideout (Dept. of Ocean and Resources Eng., Univ. of Hawaii at Manoa, 2540 Dole St., Holmes Hall 402, Honolulu, HI 96822, bprideou@hawaii.edu) and Eva-Marie Nosal (Ocean and Resources Eng., Univ. of Hawaii at Manoa, Honolulu, HI)

This paper presents a technique for performing passive underwater acoustic ranging with data from a single hydrophone and builds upon earlier localization approaches which estimate the sound source position using times of arrival of acoustic energy traveling along direct and/or interface-reflecting paths between source and receiver. In this work, measured time differences between interface-reflecting and direct path arrival times are compared with a set of model-predicted time differences calculated over a set of candidate source ranges in a way that does not require measured arrival paths to be labeled (e.g., direct, surface bounce, bottom bounce, etc.). The modeled set with the best match to the measured data indicates the best estimate of source range. To enable the processing of multi-year data sets, the detection and localization steps are automated and, where possible, multi-threaded to improve computational efficiency on multi-core computer processors. This approach is demonstrated using 20-Hz fin whale (Balaenoptera physalus) calls recorded by the ALOHA Cabled Observatory (ACO), 100 km N of Oahu (Hawaii) in 4782 m of water.

FRIDAY MORNING, 9 NOVEMBER 2018 ESQUIMALT (VCC), 8:00 A.M. TO 10:45 A.M.

Session 5aAOb

Acoustical Oceanography and Underwater Acoustics: Experimental Assessment of Theories of Sound Propagation in Sediments I

Orest Diachok, Cochair
Johns Hopkins University APL, 11100 Johns Hopkins Rd., Laurel, MD 20723

N. Ross Chapman, Cochair
School Earth and Ocean Sciences, Univ. of Victoria, P.O. Box 3065, Victoria, BC V8P 5C2, Canada

Chair's Introduction—8:00

Invited Papers

8:05

5aAOb1. Model/data comparisons and numerical experiments for the comparison of sandy sediment models. Anthony L. Bonomo (Naval Surface Warfare Ctr., Carderock Div., 9500 MacArthur Blvd., West Bethesda, MD 20817, anthony.l.bonomo@navy.mil) and Marcia J. Isakson (Appl. Res. Labs., The Univ. of Texas at Austin, Austin, TX)

Many geoacoustic models have been proposed to study the acoustic behavior of sandy sediments to predict the propagation within the sediment and the reflection loss from waterborne waves. Sandy sediments have been described as a two-phase porous medium using the theoretical framework developed by Biot. Other proposed theories were developed under the assumption that sandy sediments

possess no effective skeletal matrix and instead describe the acoustic behavior of the sediments using grain-to-grain contacts. This talk summarizes model/data comparisons and numerical experiments in an attempt to determine which of these two theoretical frameworks is more suitable for the modeling of sandy sediments. Recommendations are made for future experiments that can aid in resolving this issue. [Work supported by ONR, Ocean Acoustics.]

8:25

5aAOb2. Seabed reflection measurement results shed light on theories of acoustic propagation in marine sediments. Charles W. Holland (Appl. Res. Lab., The Pennsylvania State Univ., P.O. Box 30, State College, PA 16804, cwh10@psu.edu), Jan Dettmer (Univ. of Calgary, Calgary, AB, Canada), and Stan E. Dosso (Univ. of Victoria, Victoria, BC, Canada)

Marine sediments are inherently a complex assemblage of solid particles (of size ranging over five orders of magnitude) with fluid-filled interstices sometimes containing gas. The mechanisms that govern the dispersive wave speeds and concomitant attenuation are still hotly debated. In order to shed light on the mechanisms and current theoretical approaches to approximating them, measurements of in-situ sediments are desirable since they provide the natural complexity desirable for testing theories against realistic sediment structures. On the other hand, in-situmeasurements present significant challenges since seabed effects must be separated from other ocean processes, e.g., water column variability, biologics and sea surface roughness, and bubbles. Seabed reflection measurements offer one way to mitigate unwanted ocean processes. Reflection-derived observations are presented that shed light on current sediment acoustic models. In addition, experiments are proposed which will further test and help guide sediment acoustics theoretical developments. [Work supported by the ONR Ocean Acoustics Program.]

8:45

5aAOb3. Modeling granular sediments—Experimental results that support the physics included in "Biot-like" models, other possible experiments that could be interesting. Kevin Williams (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, williams@apl.washington.edu)

Under the "all models are wrong but some are useful" philosophy, one may at times allow some abuse of the basic physics if the predictions are accurate. However, few would start with a flawed model when they need not. We start with a thought experiment that indicates a fundamental requirement for capturing the correct dynamics in modeling porous granular media and show that this physics is captured in Biot and Pierce/Carey models as well as models that use them as a starting point. Ocean and laboratory propagation experiments that test the predictions of those models are then described. Since other modeling choices can, given free parameters, predict both granular sound speed and attenuation, we continue by looking at both back and forward scattering results. These results further mandate the need for a model that correctly treats the sediment dynamics. Finally, we present possible additional laboratory experiments that could alter some of the most important parameters inherent in Biot-like models and thus further test the validity of the such models as starting points in granular sediment acoustics. [Work supported by the Office of Naval Research.]

9:05

5aAOb4. Laboratory and at-sea experiments using a vertical synthetic array technique to measure the sound waves propagating above and below fluid-saturated sediment interfaces. Harry J. Simpson and Brian H. Houston (Physical Acoust. Branch, Naval Res. Lab., 4555 Overlook Ave. SW, Washington, DC 20375, harry.simpson@nrl.navy.mil)

A series of measurements in the NRL shallow water laboratory were designed and conducted to measure the sound waves propagating in an un-consolidated fluid-saturated porous medium. The novel design used a pair of small receivers, one buried in the bottom and one mounted in the water column to a linear vertical positioner. The buried receiver was carefully inserted into the sandy bottom using a small water-jet, engineered to have no entrained air, to minimally disturb the bottom. The receiver pair were incrementally pulled up through the bottom or water column to map out the sound propagating from a source mounted in the water column. The position of the source was varied to measure above critical angle and below critical angle sound penetration into the bottom. Measurements of carefully smoothed and roughened interfaces were also conducted. This synthetic vertical array technique proved very successful in the laboratory and was transitioned to at-sea measurements in a variety of sandy bottom locations around Panama City, FL. The analysis and modeling of these laboratory and at-sea experiments will be discussed.

9:25

5aAOb5. An overview of the sediment acoustic models and their experimental validations. Altan Turgut (Naval Res. Lab, Acoust. Div., Code 7160, Washington, DC 20375, altan.turgut@nrl.navy.mil)

The Biot theory of acoustic wave propagation in porous media was first adapted to marine sediments by Stoll (1969). To describe the response of a slightly inelastic skeletal frame over a wide frequency range, Stoll introduced the notion of constant complex bulk and shear moduli with small imaginary parts. Stoll's model predicts f^1 frequency-dependence of attenuation at low frequencies and nearly f^2 and $f^{1/2}$ frequency-dependence at frequencies where maximum velocity dispersion occurs. Although the theory well reproduces the velocity and attenuation measurements in marine sediments, the assumption of constant complex moduli slightly violates the causality (Turgut, 1990). The more recent Grain-Shearing (GS) and Viscous Grain-Shearing (VGS) models (Buckingham, 2000 and 2007) are causal and the VGS model also predicts a frequency-dependence of attenuation like that of the Stoll model. With the selection of proper parameter values, both models predict compressional and shear-wave dispersions that are in agreement with those of previous *in-situ* and laboratory measurements. In addition, the Stoll model predicts the existence of slow compressional waves that have been observed in synthetic porous media (Plona, 1980) but not in natural marine sediments. Several reflection and in-sediment transmission experiments are discussed to facilitate the detection of slow compressional waves in marine sediments. [Work supported by ONR.]

9:45–10:00 Break

10:00

5aAOb6. Uncertainty quantification and spatial variability of velocity- and attenuation-frequency dependence along a 14-km seabed survey on the Malta Plateau. Jan Dettmer (Dept. of Geoscience, Univ. of Calgary, 2500 University Dr. NW, Calgary, AB T2N 1N4, Canada, jan.dettmer@ucalgary.ca), Charles W. Holland (Appl. Res. Lab., The Pennsylvania State Univ., State College, PA), and Stan E. Dosso (School of Earth and Ocean Sci., Univ. of Victoria, Victoria, BC, Canada)

We study compressional-wave frequency dependence of sound velocity and attenuation in the seabed by inverting reflectivity data recorded by an autonomous underwater vehicle (AUV) on the Malta Plateau along a 14-km survey track. The AUV towed a 32-hydrophone array and a source emitting signals at ~4-m intervals in two frequency bands (900–1300 and 1900–3600 Hz). The reflection data are processed in terms of reflection coefficients which results in ~1500 data sets, each with a seabed footprint of <20 m. For efficient Bayesian uncertainty quantification, a trans-dimensional particle filter is applied. The dataset provides a usable frequency bandwidth of 1000–3400 Hz to study velocity- and attenuation-frequency dependence which is modelled with viscous grain shearing theory. The trans-dimensional model allows frequency-dependence inferences as a function of depth while fully accounting for the unknown seabed stratification which substantially affects the estimates. Finally, the AUV acquisition provides the means to study the frequency-dependent seabed variability at mesoscales of several meters which are poorly understood. [Data are from CLUTTER JRP, a collaboration of ARL-PSU, DRDC, CMRE, and NRL. Research supported by the Natural Sciences and Engineering Research Council of Canada.]

10:15

5aAOb7. *In situ* measurements of compressional and shear wave propagation in marine sediments and comparison to geoacoustic models. Kevin M. Lee, Megan S. Ballard, Andrew R. McNeese (Appl. Res. Labs., The Univ. of Texas at Austin, 10000 Burnet Rd., Austin, TX 78758, klee@arlut.utexas.edu), Gabriel R. Venegas (Mech. Eng. Dept. and Appl. Res. Labs., The Univ. of Texas at Austin, Austin, TX), and Preston S. Wilson (Mech. Eng. Dept. and Appl. Res. Labs., The Univ. of Texas at Austin, Austin, TX)

In situ measurements of compressional and shear wave speed and attenuation provide direct characterization of marine sediment acoustic properties at ambient conditions, as opposed to measurements that are conducted on samples removed from the seabed. Sediment geoacoustic models, such as those based on fluid, viscoelastic, poroelastic, or suspension wave theories, relate physical properties of the seabed like porosity, grain size, and pore fluid viscosity to the wave speeds and attenuation. Other models can include the effects of gas bubble distributions, which can be associated with the presence of benthic biology or organic matter decomposition, on compressional and shear wave propagation. In this paper, we examine sediment geoacoustic models in comparison with *in situ* acoustic data from various field experiments, for sediments containing various ratios of sand, silt, clay, and organic matter. The model input parameters are partially constrained by geotechnical data obtained from core samples collected at the field experiment sites. The applicability of various models to the sediments encountered at each measurement site will be discussed. [Work supported by ONR and ARL:UT IR&D.]

10:30

5aAOb8. Speed of sound and geo-alpha in clayey silt derived from concurrent inversion of geo and bio-acoustic parameters from transmission loss data and co-located chirp sonar measurements. Orest Diachok (Johns Hopkins Univ. APL, 11100 Johns Hopkins Rd., Laurel, MD 20723, orestdia@aol.com) and Altan Turgut (Naval Res. Lab., Washington, DC)

Application of the concurrent geo and bio-acoustic inversion method (Diachok and Wales, 2005) to broadband (0.3–5 kHz) transmission loss (TL) measurements, and co-located normal incidence chirp sonar measurements provided measures of geo-acoustic properties of clayey-silt in the Santa Barbara Channel. Inversion calculations assumed that the geological environment may be characterized by the interfacial sound speed, unconsolidated layer thickness, sound speed gradient, g, and geo-alpha, α_G; and that the biological environment may be characterized by the layer depth, layer thickness, and bio-alpha (attenuation coefficient within the layer). Co-located cores provided *ground truth*; echo sounder and trawl measurements provided *biological truth*. Both the concurrent inversion and the chirp-based methods yielded approximately the same value of g, 6.5/s, in the top 9 m thick layer of clayey-silt. The value of α_G, based on TL measurements, was quite low, approximately 0.02 dB/λ, in good agreement with Holland and Dosso's (2013) only previously reported *in-situ* estimate of geo-alpha in silty-clay in this frequency-depth range. These results have important implications for estimation of geo parameters from TL measurements in biologically intense environments. Refinements to envisioned follow-on experiments will be discussed. [This research was supported by the Office of Naval Research Ocean Acoustics Program.]

Session 5aPA

Physical Acoustics: General Topics in Physical Acoustics I

Stephanie Konarski, Chair
Naval Research Laboratory, Washington, DC

Contributed Papers

9:00

5aPA1. Effective dynamic properties of random complex media. M. Mahbub Alam, Francine Luppé (Laboratoire Ondes et Milieux Complexes, Univ. of Le Havre, Le Havre, Normandie, France), Valerie J. Pinfield (Chemical Eng. Dept., Loughborough Univ., UK, Loughborough University, Loughborough LE11 3TU, United Kingdom, v.pinfield@lboro.ac.uk), and Pierre Maréchal (Laboratoire Ondes et Milieux Complexes, Univ. of Le Havre, Le Havre, Normandie, France)

In recent years, it has been demonstrated that, as particle concentration in a suspension increases, the viscous nature of the host fluid becomes more and more significant and thereby needs to be taken into consideration when calculating effective properties for acoustic propagation. One approach to the problem is to incorporate wave conversion phenomena, primarily between compressional and shear wave modes, into the models for effective properties. A self-consistent method that includes mode conversion, based on a core-shell model, has been used to determine the effective dynamic bulk modulus and mass density of random complex media consisting of spherical inclusions. The analytical expressions obtained are compared with those obtained from numerical solution of the self-consistent model equations. The contribution of mode conversion on the effective dynamic properties for particles in a viscous liquid are explored. The variation of the effective properties with frequency, volume concentration, and density contrast are also investigated numerically.

9:15

5aPA2. Experimental measurement of tortuosity, viscous, and thermal characteristic lengths of rigid porous material via ultrasonic transmitted waves. Mustapha Sadouki (Departement des Sci. de la Matière, Université Djilali Bounaama à khemis-miliana, Université Djilali Bounaama à Khemis-Miliana, Rte. Thenia el Had, Ain Defla, Khemis-miliana 44225, Algeria, mustapha.sadouki@univ-dbkm.dz)

An inverse method is proposed for measuring tortuosity, viscous, and thermal characteristic lengths of air-saturated porous material with rigid frame via ultrasonic transmitted waves at normal incidence. The equivalent fluid model is considered. The interaction between the fluid saturated the pores and the structure are taken into account in two frequency response factors: the dynamic tortuosity of the medium introduced by Johnson et *al*. and the dynamic compressibility of the air introduced by Allard. Simplified expression of the transmission coefficient is obtained in frequency domain, and this expression depends on the porosity, tortuosity, viscous, and thermal characteristic lengths. The inverse problem is solved numerically in time domain by minimizing between simulated and experimental transmitted waves. The inverted parameters are in good agreement with those obtained using conventional methods. Simulated signals are reconstructed using the optimized values found and compared with the experimental signals. Tests are performed using three different plastic foam samples having low flow resistivity. The proposed technique has the advantage of being simple, fast, and not expensive.

9:30

5aPA3. Fractional viscoelastic modelling of wave propagation in fluid-saturated marine sediments. Vikash Pandey (Ctr. for Ecological and Evolutionary Synthesis (CEES), Dept. of BioSci., Univ. of Oslo, Postboks 1080, Blindern, Oslo 0316, Norway, vikashp@ifi.uio.no)

It is shown that Buckingham's grain-shearing (GS) model [JASA (2000)] as well as its improved viscous-GS (VGS) model [JASA (2007)] can be expressed using the mathematical framework of fractional calculus. The fractional version of the standard fluid model is adopted to independently arrive at the wave equations and dispersion relations derived by Buckingham. The fractional-order wave equations obtained for the compressional waves and shear waves are relatively easier to analyse due to their closed-form representation in the fractional framework. It is also shown that the fractional calculus approach may help in bridging the disparate fields of non-Newtonian rheology and sediment acoustics, which may have actually developed independently of each other. Further, the experimental data relating wave dispersion and attenuation in marine sediments is found to match with the predictions from the fractional framework. The overall goal is to show that fractional calculus is not just a mathematical framework that can only be applied to curve-fit the observational data for complex media. In fact, it has an inherent connection to real physical processes that needs to be explored more.

9:45

5aPA4. Control and evaluation of liquid crystal molecules using ultrasound vibration. Yuki Harada (Faculty of Life and Medical Sci., Doshisha Univ., 1-3 Tataramiyakodani, Kyotanabe, Kyoto 610-0321, Japan, ctuc1005@mail4.doshisha.ac.jp), Daisuke Koyama, Hirokazu Yasui, Marina Fukui, Yuki Shimizu, Yoshiaki Shibagaki, and Mami Matsukawa (Faculty of Sci. and Eng., Doshisha Univ., Kyotanabe, Kyoto, Japan)

Nematic liquid crystals are widely used in optical devices such as liquid crystal displays and controlled by electric fields through the liquid crystal layer. The authors have proposed a technique to control the orientation of liquid crystal molecules using ultrasound vibration without indium tin oxide electrodes. An ultrasound liquid crystal cell was fabricated; it consists of a liquid crystal layer sandwiched by two glass plates having two ultrasound PZT transducers. When exciting the transducers at the resonance frequencies, the flexural vibration modes were generated on the cell and the acoustic radiation force acted to the liquid crystal molecules so that the orientation direction can be changed. The relationship between the molecular orientation and the vibration distribution of the cell was investigated from the transmitted light distribution of the liquid crystal cell under the crossed Nicol condition. In addition, the orientation of liquid crystal molecules was evaluated as ultrasonic wave velocity in the GHz range by the Brillouin scattering method. The ultrasonic wave velocity in the long axis direction of the liquid crystal molecules was higher than that in the short axis direction, which indicates the uniaxial anisotropy of the liquid crystal molecules.

10:00

5aPA5. Ultrasound manipulation of 3D dynamic user-specified patterns of particles in air. Milo Prisbrey and Bart Raeymaekers (Mech. Eng., Univ. of Utah, 201 Presidents Circle, Salt Lake City, UT 84119, mprisim@gmail.com)

Ultrasound noncontact particle manipulation (NPM) employs the convergence of the acoustic radiation force associated with an ultrasound wave field to levitate and manipulate particles in a fluid medium. We use multiple phased arrays of ultrasound transducers to dynamically manipulate a 3D pattern of particles along a user-specified trajectory. We numerically simulate the ultrasound NPM method and experimentally validate it by creating dynamic 3D patterns of expanded polystyrene particles in air, and observe good quantitative agreement. The method allows manipulating an entire user-specified pattern of particles and sub-sets of a pattern to traverse a user-specified trajectory in 3D. This experimental demonstration shows that ultrasound NPM can be implemented in engineering applications such as containerless transport and measurement, and manufacturing of engineered materials.

10:15–10:30 Break

10:30

5aPA6. Photo-thermal transient stress observed by sub-nanosecond pump-probe technique with the surface plasmon resonance. Hiromichi Hayashi, Hayato Ichihashi (Dept. of Elec. and Electronics Eng., Doshisha Univ., 1-3, Tatara Miyakodani, Kyotanabe, Kyoto 610-0394, Japan, ctwb0305@mail4.doshisha.ac.jp), Shoya Ueno (Dept. of Biomedical Information Eng., Doshisha Univ., Kyotanabe, Kyoto, Japan), and Mami Matsukawa (Dept. of Elec. and Electronics Eng., Doshisha Univ., Kyotanabe, Kyoto, Japan)

Photoacoustic microscopy (PAM) has attracted attention as a non-invasive observation tool for biomedical studies. However, the spatial resolution is unsuitable for precise imaging of a single cell due to the characteristics of the ultrasonic transducer. In recent years, the surface plasmon resonance (SPR) sensor has been reported as a technique with a high-spatial resolution and ultra-flat frequency response. SPR is expected to be the future optical detector for photoacoustic imaging. As a first trial, using a Kretschmann-configuration SPR sensor (Ag (53 nm)/BK7 glass prism), we observed the photo-thermal transient stress and the consequent change in refractive index using the sub-nanosecond pump-probe technique. The signal intensity of the thermo-elastic stress produced by the pump beam excitation was measured by changing the incident angle of the probe beam. The spot diameter of the probe beam was 5 μm. The highest intensity signal was observed at the SPR angle (46.5 deg.) of the plasmon resonance. Results suggest that the SPR sensor effectively enables the non-contact and non-destructive measurements of the thermo-elastic stress. Further researches will implement the SPR sensor for tissue characterization by attaching biological samples on the Ag surface.

10:45

5aPA7. Fast tracking of acoustic resonance frequencies in collection volumes to measure flow. Keith A. Gillis, James W. Schmidt, Jodie G. Pope, and Michael Moldover (Sensor Sci. Div., National Inst. of Standards and Technol., 100 Bureau Dr., Mailstop 8360, Gaithersburg, MD 20899-8360, keith.gillis@nist.gov)

Previously, we demonstrated accurate determinations of the mass of gas in a large collection vessel of known volume from measurements of the pressure and the resonance frequencies of a few acoustic modes. We achieved accurate mass measurements even when linear temperature gradients persisted after adding or removing gas. The change in mass Δm from before and after flow and the collection time Δt may be used to calibrate mass flowmeters. Because the resonance quality factors Q are very high (up to 30000), measuring the complex-valued frequency response using a lock-in amplifier to determine the resonance frequency is slow. This static measurement of mass requires sufficient time to elapse for transient non-linear gradients to dissipate through convection and diffusion. Here, we demonstrate a method to dynamically track the resonance frequency of a large, gas-filled collection vessel while gas is flowing into or out of the vessel. We use positive feedback to excite sustained oscillations at the desired resonance frequency without a lock-in amplifier or frequency synthesizer. As the speed of sound changes, the sustained oscillations track the changing resonance frequency f with response time $\sim 1/f$. Preliminary mass flow measurements using this technique agree with a flow standard within their combined uncertainties.

11:00

5aPA8. Ultrasonic assisted large diameter PBX substitute composites compaction and its mechanical properties. Kezhen Lyu (Inst. of Chemical Mater., No.64, Mianshan Rd.,Mianyang, Sichuan 621999, China, lyukezhen@gmail.com)

The rates of densification and density uniformity are a key performance of PBX parts. Based on ultrasonic vibration technology, this paper designs and manufactures an upper and lower 20 kHz longitudinal and radial vibration assisted molding system with a 200 mm diameter compacting part at the center axis. In this work, PBX substitute composite was successfully fabricated by pressing of powder with ultrasonic vibration and the influence of ultrasonic vibration force coupling on the mechanical properties of PBX substitute powder was investigated. Applying ultrasonic vibration to result in great rates of densification and higher efficiency of the process is expected. The effects of particle size and vibration amplitude and pressure and weight on the densification behavior and of PBX substitute powder are discussed. The results show that applying ultrasonic vibration leads to a higher relative density and an improved homogeneity, and the growth of the size of the pressed sample can be reduced with the ultrasonic vibration and the larger of static pressure, the smaller of the pressed sample size change. In addition, ultrasonic vibration has a great effect on the finer particles and the surface temperature of the sample is not obviously increased with ultrasonic vibration.

11:15

5aPA9. Sound insulation measurement in a tube with broadband pulse secondary transmission method. Mengfei Zhang, Hong Hou, and Nansha Gao (Environ. Eng., Northwestern PolyTech. Univ., 127 Youyi West Rd., Xi'an, Shaanxi 710072, China, yollar@163.com)

Based on time-domain pulse-separation method in a standing wave tube, a method using broadband pulse secondary transmission wave is proposed for sound insulation measurement in this paper. Two kinds of broadband pulse were generated, the incidence wave and *secondary transmission wave* could be obtained easily with one microphone by designing the location of microphone and sample, then acoustic parameters of sample can be calculated. An experiment was completed to verify the proposed method, when compared with time-domain pulse-separation method, a relatively good agreement between these two methods can be observed. Using the proposed method, only *one microphone position and one signal* are required. This method is simple and with good repetition, could be an effective method for sound insulation measurement. Meanwhile, the measurement uncertainty was done.

Session 5aSC

Speech Communication: Development and Clinical Populations (Poster Session)

Meital Avivi-Reich, Chair
Communication Sciences and Disorders, Northwestern University, Room 1-331, Frances Searle Building 2240 Campus Drive, Evanston, IL 60208

All posters will be on display from 8:30 a.m. to 11:30 a.m. To allow authors an opportunity to view other posters in their session, authors of odd-numbered papers will be at their posters from 8:30 a.m. to 10:00 a.m. and authors of even-numbered papers will be at their posters from 10:00 a.m. to 11:30 a.m.

Contributed Papers

5aSC1. A biomechanical model for infant speech and aerodigestive movements. Connor Mayer (Linguist, Univ. of California, Los Angeles, 7100 Hillside Ave., Apt. 108, Los Angeles, CA 90046, connormayer@ucla.edu), Ian Stavness (Comput. Sci., Univ. of SK, Saskatoon, SK, Canada), and Bryan Gick (Linguist, Univ. of Br. Columbia, Vancouver, BC, Canada)

A central question in speech acquisition is how infants are able to learn speech movements rapidly and with limited input. A relatively untested but appealing hypothesis is that some core speech movements may build on pre-existing aerodigestive movements like swallowing and suckling (e.g., MacNeilage, 2008, *The Origin of Speech*; Studdert-Kennedy & Goldstein, 2003, *Launching Language*). We will present a model of an infant tongue and palate using a 3D biomechanical simulation platform (www.artisynth.org; e.g., Stavness *et al*., 2012, *J. Biomech.* 45(16): 355–394; Gick *et al*., 2014, *Compu. Meth. in Biomech. & Biomed. Eng.: Imag. & Vis.* 2(4): 217–222). This model, generated from CT and MRI imaging data, will be capable of simulating both swallowing and simple speech movements. The results of simulations using this model will provide useful insight into infant motor control, and will help to supplement neurological, clinical, and kinematic evidence relating speech and aerodigestive movements. [Funding from NSERC.]

5aSC2. An acoustic and perceptual analysis of children's adaptation to an electropalatographic sensor. Shawn L. Nissen, Kasey Duffield, and Marissa Celaya (Commun. Disord., Brigham Young Univ., 128 TLRB, Provo, UT 84602, shawn_nissen@byu.edu)

Previous research has investigated adults' ability to adapt their speech to an electropalatographic (EPG) pseudopalate; however, less is known about how children adapt their speech to the presence of the device. This study examined the acoustic and perceptual effect of an EPG pseudopalate on six elementary school-aged children's ability to produce the fricatives /s/ and /ʃ/. Speech productions were collected at eight time intervals including before placement of the pseudopalate, at 30-min increments with the pseudopalate in place, immediately following removal of the pseudopalate, and 30 min after removal. The fricative targets were produced in a carrier phrase and during spontaneous conversation. Adaptation was evaluated by measuring the fricative duration, spectral mean, spectral variance, and relative intensity, as well as a series of perceptual ratings from 20 native English listeners. Although there was a relatively high amount of variability among and within speakers, for several children evidence of adaptation was found after 30 minutes. For some participants, full adaptation did not occur until the pseudopalate was removed. Although future research is needed, it is hoped that this study will provide a greater understanding of children's ability to adapt to the EPG pseudopalate.

5aSC3. Do children understand adults better or themselves? A perceptual study of Polish /s, ʂ, ɕ/. Marzena Zygis (Leibniz Ctr. - General Linguist, Schützenstr. 18, Berlin D-10117, Germany, zygis@leibniz-zas.de), Marek Jaskula (Westpomeranian Univ. of Technol., Szczecin, Poland), and Laura L. Koenig (Haskins Labs and Adelphi Univ., New Haven, CT)

Developmental studies of speech perception have typically used adult productions or synthetic speech as stimuli. Little is known about how children perceive their own speech, however. Further, few studies of sibilant fricative perception have explored complex sibilant inventories. This work assessed perception of the sibilants /s, ʂ, ɕ/ in 32 monolingual native speakers of Polish, 3–8 years of age. Children participated in a picture-naming task to identify minimal or near-minimal triplets with the fricatives in initial and medial position, e.g., [kasa] "cash point", [kaʂa] "groats", [kaɕa] "Cathe, prop.name." They subsequently labeled their own word productions, and the words as produced by an adult. Children's labeling was generally quite accurate for the adult speaker, with the lowest accuracy rating of ca. 75% seen in the youngest listeners. When labeling themselves, the children were less accurate, with average performance at about 50% in children younger than 55 months. Across all ages, reaction times decreased in the order /ʂ/ > /s/ > ɕ/. Future work will obtain perceptual judgments of the children's productions from other listeners and obtain acoustic measures of the fricatives to explore perception-production relationships.

5aSC4. Phoneme production by Hispanic hearing-impaired children. Tanya Flores (Lang. and Lit., Univ. of Utah, 255 S Central Campus Dr., LNCO 1400, Salt Lake City, UT 84109, Tanya.Flores@utah.edu)

This study examines the speech production of Hispanic deaf and hard of hearing (DHH) children from 4 to 8 years of age who have had delayed medical intervention. The data presented here are from the first year of data collection and will focus on the Spanish and English speech productions of the target group as compared to the productions of the control groups (Hispanic peers with normal hearing and non-Hispanic DHH peers) from the same local community. The goal of the study is to create a speech corpus of Hispanic DHH children that will be used to study various aspects of their language development. Findings will contribute to the currently limited acoustic research on minority DHH children whose home language differs from their specialized language program (in this case, English Listening and Spoken Language Program).

5aSC5. Suprasegmentals affecting fluency levels in elementary students' read-speech: Focusing on pause numbers and pause duration, speech rate, and pitch range. Hyesook Park (Graduate of Education, Yonsei Univ., 1599-1885 50 Yonsei-ro Seodaemun-gu, Seoul 0372, South Korea, pss7078@daum.net)

The purpose of this study was two-fold: 1) to rate the unrated Korean elementary students read-speech (from K-SEC) 2) which and to what extend suprasegmentals—pause numbers and duration, speed rate, and pitch range—would affect the degrees of fluency. To do, 5 raters evaluated 3069 read-speech data into 5 proficiency levels and 500 data were randomly selected for analyzing pause numbers and duration, speed rate, and pitch rage with Praat. The result showed the speech rate is the most influential factor. It means the most fluent readers (5 levels) tend to have the highest speech rate. The next factor is pause duration; the more fluent, the less pause duration one has. Also, statistical regression analysis shows pause numbers and pitch range are not statistically meaningful factors to rate the fluency levels in Korean elementary students read-speech. At the end of this study, some suggestions of the pronunciation drills for Korean elementary students were discussed based on the result of the study.

5aSC6. Global measures of early vocalizations in infants with CP in Taiwan as references to perceptual ratings. Chia-Cheng Lee (Speech and Hearing Sci., Portland State Univ., 1831 SW Park St., Apt 112, Portland, OR 97201, cl9@pdx.edu), Li-mei Chen (Foreign Lang. and Lit., National Cheng Kung Univ., Tainan, Taiwan), Chin-Ting Liu (National Chin-Yi Univ. of Technol., Taichung City, Taiwan), Ray D. Kent (Univ. of Wisconsin–Madison, Madison, WI), Yung-Chieh Lin, Li-Wen Chen, and Ching-Yi Cheng (National Cheng Kung Univ., Tainan, Taiwan)

The present study investigated reliable global measures that can be used to screen/assess infants at-risk for speech problems due to cerebral palsy (CP). Three measures were used in this study: mean duration of utterances, mean duration of syllables, and vocalization rate, which are suggested as likely points of divergence from typical development in infants with CP. Recordings of 9 months and 21 months of ten infants who were at risk of CP and seventeen 9-month-old typically-developing (TD) infants were coded. Naïve listeners filled out a questionnaire about a perceptual evaluation of speech samples of these infants after listening to the first 50 utterances with little background noise in each recording. The questions included, for example, resonance, hoarseness, breathiness, loudness, and tremor. Results of the three measures did not show statistically significant differences between the groups. However, descriptive analyses showed that infants with CP at 9 months produced longer utterances and syllables than when at 21 months. Infants with CP also produced shorter utterances and syllables and fewer vocalizations per minute than TD infants. Furthermore, the correlation between the results of the three measures and perceptual ratings was examined in search for other global measures and to refine the questionnaire questions.

5aSC7. Quantifying the effects of background babble on preschool children's novel word learning in a multi-session paradigm. Meital Avivi-Reich, Megan Y. Roberts, and Tina M. Grieco-Calub (Commun. Sci. and Disorders, Northwestern Univ., Rm. 1-331, Frances Searle Bldg. 2240 Campus Dr., Evanston, IL 60208, m.avivireich@northwestern.edu)

Common daily environments often contain background noise, such as background talkers, that may impose challenges on auditory based learning, including the learning of new words. Extant data on the effects of background noise on novel word learning, however, have shown mixed results. One possible reason for this observation is that most studies assess the effect of background noise in a single session. The present study aimed to add to this body of work by employing a multi-session paradigm to explore the effects of background babble, presented at 0 dB signal-to-noise ratio, on novel word learning in 3-year-old children (n = 8). Children were exposed to two stories presented digitally, each story containing four novel CVC words. Children were exposed to both stories, one in quiet and one in the presence of four-talker babble. After each story, receptive word learning was quantified with a four-alternative-forced-choice task, and expressive word learning was quantified by the number of novel labels correctly produced when their corresponding objects were shown to the children. Results suggested that children's receptive and expressive word learning improved by session; however, greater improvement was observed for the words exposed in quiet. The results and their implications will be further discussed.

5aSC8. Automated episode selection of child continuous speech via blind source extraction. Marisha Speights (Commun. Disord., Auburn Univ., 1199 Haley Ctr., Auburn, AL 36849, mls0096@auburn.edu), Keith D. Gilbert (Speech Technol. & Appl. Res. Corp., Lexington, MA), Joel MacAuslan, and Richard Goldhor (Speech Technol. & Appl. Res. Corp., Bedford, MA)

Commonly, in both research and clinical conditions in which speech recordings are collected from children, the non-targeted adult speech and the targeted child speech are simultaneously recorded during conversational turn-taking tasks, and the utterances of all talkers are audible on every channel of the recording. As a result, the intended analysis of the targeted speaker becomes encumbered by the requirement for a human analyst to identify and mark the episodes in the recording where the targeted speaker is the only active sound source. Blind source extraction (BSE) techniques are utilized here to automatically deliver the isolated child's speech, even when the child's and adult's speech overlap, or when extraneous interfering noise is present. To test the performance of the BSE methods for automated episode selection in child continuous speech, ten typically developing children were each recorded speaking thirty-three sentences in the turn-taking scenario with four microphones placed in the environment. Correlation between the numbers of human-marked episodes identifying the target speakers to the machine-selected episodes was examined. Results of the Pearson correlation indicate there is a significant positive association between hand counts and BSE machine counts ($r = 0.85$, $p < 0.01$).

5aSC9. Perception of talker height and sex from children's voices. Peter F. Assmann, Michelle R. Kapolowicz (School of Behavioral and Brain Sci., Univ. of Texas at Dallas, MS GR 41, Box 830688, Richardson, TX 75075, assmann@utdallas.edu), and Santiago Barreda (Linguist, Univ. of California, Davis, Davis, CA)

Several recent studies have investigated the ability of listeners to judge the height of adult talkers from their speech. Here, we examine the perception of talker height from a sample of /hVd/ syllables spoken by children ranging in age from 5 through 18 years, with 3 talkers of each sex at each age level. Twenty college students judged the height and sex of the talker for each trial. Perceptual estimates of height were moderately correlated with actual height (for males, $r = 0.78$; for females, $r = 0.67$). Consistent with our recent findings concerning the perception of talker age [Barreda & Assmann, JASA-EL 143(5), EL361, 2018], listeners' judgments of talker height appear to incorporate assumptions about talker sex and the relationships between speech acoustics and veridical height for male and female talkers of different heights. For example, when older girls were misidentified as boys, their height was likely to be underestimated. This behavior results in predictable error patterns in height judgments from speech: in situations where talker sex is misidentified, listeners apply the "wrong" acoustic model to estimate talker height, leading to correlated error patterns between apparent height and sex.

5aSC10. Perceptual restoration of interrupted speech in typically-developing school-age children: Effect of interruption rate. Beula M. Magimairaj (Commun. Sci. and Disord., Univ. of Central Arkansas, 201 Donaghey Ave., Conway, AR 72035, bmagimairaj@uca.edu) and Naveen K. Nagaraj (Audiol. and Speech Pathol., Univ. of Arkansas for Medical Sci., Little Rock, AR)

Auditory closure, the ability to fill-in missing information involves bottom-up and top-down influences. There is a lack of systematic studies on children's interrupted speech perception (ISP). We measured 8- to 11-year-old typically developing children's restoration of sentences using the ISP paradigm. We used two interruption rates with noise-filled and unfilled interruptions, respectively. Sentences from the Bamford Kowal Bench

Speech-in-Noise Test were gated with 50% duty cycle square wave at 2.5 and 5 Hz. For the noise-filled condition, silent intervals were filled with speech noise. Preliminary analysis on 33 children has been completed and 40 more children are scheduled complete participation. Accuracy of keyword recognition was subjected to 2 (interruption rate: 2.5 vs. 5 Hz) X 2 (noise-filled vs unfilled) repeated measures ANOVA. Overall, main effect of interruption rate, $F(1, 32) = 500$, $p < 0.0001$ and filler noise was significant, $F(1, 32) = 289$, $p < .00001$. Recognition scores for noise-filled conditions were better than unfilled for both 2.5 Hz (mean difference = 27.2) and 5 Hz (mean difference = 5.03) conditions. Larger perceptual restoration at 2.5 Hz compared to 5 Hz may indicate greater reliance on lexical knowledge at 2.5 Hz to restore speech than on phonemic restoration.

5aSC11. Children's susceptibility to irrelevant speech on a selective attention task: What role does working memory play? Naveen K. Nagaraj (Audiol. and Speech Pathol., Univ. of Arkansas for Medical Sci., 2801 S. University, Suit 600, Little Rock, AR 72204, nnagaraj@uams.edu) and Beula M. Magimairaj (Commun. Sci. and Disord., Univ. of Central Arkansas, Conway, AR)

Irrelevant speech effect (ISE) is well studied in adults; however, limited studies have explored ISE in children. We examined individual differences in working memory (WM) capacity on ISE due to proactive interference and interference from the irrelevant channel using a dichotic selective attention task. Eighty-six 7- to 11-year-old children were tested. Two streams of digits were presented (to-be-ignored and to-be-attended) to investigate both proactive and irrelevant channel interference in quiet and in speech babble. The irrelevant channel interference was estimated by tracking the response from the to-be-ignored ear. Proactive interference corresponded to participants reporting previously presented stimuli. Children's WM capacity was measured using the Woodcock Johnson Auditory WM task and an experimental complex memory span task. Based on the attention control theory of WM, it was predicted that both irrelevant channel interference and proactive interference would be negatively related to children WM capacity. Results showed no such correlation between WM capacity and ISE, which may have been due to the inverse relation between the two types of interference. This is because proportion of total errors that corresponded to proactive interference was positively correlated with WM, whereas irrelevant channel interference was negatively correlated with children's WM capacity.

5aSC12. Advancing clinical group verification framework for screening child speech sound disorders using "text-independent" i-Vectors. Prasanna V. Kothalkar (Jonsson School of Eng. and Comput. Sci., Ctr. for Robust Speech Systems, UT Dallas, 800 W Campbell Rd., Richardson, TX 75080-2277, prasanna.kothalkar@utdallas.edu), Johanna M. Rudolph, Christine Dollaghan, Jennifer McGlothlin, Thomas F. Campbell (Commun. Disord., Univ. of Texas at Dallas, Dallas, TX), and John H. L. Hansen (Jonsson School of Eng. and Comput. Sci., Ctr. for Robust Speech Systems, UT Dallas, Richardson, TX)

I-Vectors are the current state-of-the-art feature representation in acoustic event identification tasks such as speaker recognition, language recognition, etc. They are referred to as identity vectors since they represent a unique quality of the speaker and have been useful for detecting adult speech pathologies . Speech Sound Disorders (SSDs) affect between 3% and 16% of US children and are difficult to detect due to the presence of developmental speech sound errors. We have been working to automate the process of speech screening. Our dataset consists of 29, single word recordings from 165, 3–6 year old children and was collected using an iOS application. Children were assigned to clinical groups using a percentage consonants correct growth curve model. Sixty-four children were classified as exhibiting an SSD, the rest as exhibiting normal speech acquisition. To achieve our purpose, we first introduced our clinical group verification framework using Gaussian Mixture Models. We extended the framework to screen the children's speech based on single words using "text-dependent" i-Vectors, along with L2-logistic regression and Gaussian backend machine learning classifiers. This improved the algorithms' accuracy. In the current study, we modified our offline post-processing algorithms within the framework, which provided excellent results for "text-independent" i-Vectors. Apart from the algorithms, we also present detailed visual analysis of the classifier score transformation, during the post-processing phase.

5aSC13. Velopharyngeal control for speech in children with cochlear implants: Nasalance data in vowel and consonant segments. Laura L. Koenig (Haskins Labs and Adelphi Univ., 300 George St., New Haven, CT 06511, koenig@haskins.yale.edu), Areti Okalidou (Univ. of Macedonia, Salonika, Greece), and George Psillas (Dept. of Medicine, Aristotle Univ. of Thessaloniki, 1st Univ. ENT Clinic of Ahepa Hospital, Thessaloniki, Greece)

Children with hearing loss before the development of their phonological system display various kinds of atypical speech production characteristics. Cochlear implants (CIs) can lead to improved speech production, although children may vary considerably in their outcomes. Past work suggests that one effect of hearing impairment is poor control over the velopharyngeal system, but little direct data exist to show how CIs improve velopharyngeal function for speech. This work presents nasometer data for Greek-speaking children with CIs, ages 4–16 years, along with age- and gender-matched typically-hearing children. Children produced bisyllabic words varying in stress position and in the type of initial stop consonant: Nasal, voiceless unaspirated, and voiced (which, in Greek, may be produced as prenasalized). The nasal and oral microphone signals from the nasometer were labelled in Praat to demarcate consonantal and vocalic regions. Preliminary analyses on the whole words suggested that children with CIs are comparable to hearing controls for words beginning with nasal consonants, but differed for words with oral consonants. This presentation will present durations and average nasalance over segmental (consonantal and vocalic) regions, permitting more fine-grained assessment of velopharyngeal control.

5aSC14. Quantifying expressive word learning in the presence of background speech. Katherine M. Simeon, Katie Schramm (Commun. Sci. & Disord., Northwestern Univ., 2240 Campus Dr., Frances Searle Bldg. Rm. 2-381, Evanston, IL 60208, ksimeon@u.northwestern.edu), Katherine Gordon (Childhood Deafness, Lang. and Learning, Boystown National Res. Hospital, Omaha, NE), and Tina M. Grieco-Calub (Commun. Sci. & Disord., Northwestern Univ., Evanston, IL)

Children acquire novel word-object pairs rapidly and with few exposures via *fast-mapping* (Carey & Bartlett, 1978). However, everyday environments contain background noise that interferes with children's formation of phonological representations of words. Existing research has not consistently shown disruption of receptive word learning by background noise when implementing a closed-set, forced-choice paradigm. In contrast, Riley & McGregor (2012) found that background noise disrupted expressive word form representation. The present study extends this prior work by investigating the effects of background speech on expressive word learning in preschool-aged children. Three-to-four-year-old children performed a fast-mapping task in quiet and in the presence of two-talker speech presented at a +2 dB signal-to-noise ratio. Children viewed short animations whereby novel objects were verbally labeled. Children were then tested on each novel label-object pair with a tiered expressive recall task (Gordon & McGregor, 2014). For each object, children were asked to verbally produce its novel label. If children were unable to name the object, they were prompted with the label-initial sound (e.g., cueing) or given a closed-set of potential labels from which to choose the correct one. This presentation will discuss how depth of expressive word learning can vary in quiet and noisy environments.

5aSC15. Children's ratings of vocal emotion intensity depend on the emotion spoken and speaker familiarity but not acoustic parameters. Tawni B. Stoop, Peter Moriarty, Michelle Vigeant, Rick Gilmore (Penn State Univ., State College, PA), Pan Liu (Penn State Univ., Dept. of Psych., Western Interdisciplinary Res. Bldg., Rm. 2172, London, ON N6A 5B7, Canada, pliu261@gmail.com), and Pamela Cole (Penn State Univ., State College, PA)

Scherer (1986) documented the acoustic parameters associated with adults' perceptions of discrete vocal emotions. We investigated physical and psychological factors that influence children's ratings of discrete vocal emotions using stimuli that approximated naturally occurring speech,

including familiarity with the speaker. Specifically, we presented 52 7- and 8-year-olds with one side of a brief phone conversation spoken in happy, angry, sad, and non-emotional prosodies by both the child's mother and another child's mother, unfamiliar to the target child. As a group, the familiar and unfamiliar mothers' prosodies did not differ in fundamental frequency (F0), F0 standard deviation, or speech rate—acoustic parameters that are most identified with angry, happy, and sad prosodies. Children accurately recognized the emotion spoken: They rated angry stimuli as more angry than happy or sad. Regression analyses indicated that speaker familiarity predicted children's intensity ratings even after the target acoustic parameters were taken into account, but this effect was moderated by speaker emotion, such that children rated their mothers as more intensely angry than unfamiliar mothers. The findings suggest that their mother's angry voice holds psychological significance for children that is not explained by variations in its most salient acoustical properties.

5aSC16. Perception-production relations in residual speech errors before and after biofeedback training. Heather M. Campbell, Laine Cialdella, and Tara McAllister Byun (Communicative Sci. and Disord., New York Univ., 665 Broadway, 9th Fl., Fl. 6, New York, NY 10012, heather.campbell@nyu.edu)

Rhotics are among the latest-emerging, most frequently misarticulated sounds in acquisition of American English (Smit *et al*., 1990). Children with residual speech errors (RSE) affecting rhotics may be unable to perceive differences between their own accurate and inaccurate productions (Shuster, 1998). Visual biofeedback may be an efficacious treatment approach for these children because it can bypass deficient auditory-perceptual channels (Shuster *et al*., 1995). Previous research has shown a relationship between accuracy in perceiving and producing rhotic targets in typically developing (TD) children (McAllister Byun & Tiede, 2017). We used the same methods to measure rhotic perception and production in a sample of 75 children with RSE. Based on previous literature (e.g., Hearnshaw *et al*., 2018; Rvachew & Jamieson, 1989), we hypothesize that children with RSE will show poorer perceptual abilities on average than TD children, but that they will show a similar degree of association between perception and production. Second, we will test whether changes in auditory acuity take place after a period of biofeedback treatment for RSE. Finding such changes would suggest that biofeedback may have its effect not only by retraining a target motor plan, but also by helping children update their auditory targets.

5aSC17. Perseverance measured in children's oral reading. Jared Bernstein, Jian Cheng (Analytic Measures Inc., 1330 Tasso St., Palo Alto, CA 94301, jared413@stanford.edu), and Ahmed Magooda (Comput. Sci., Univ. of Pittsburgh, Pittsburgh, PA)

Do struggling readers score lower on reading tests in part because they get discouraged or slow down? Schools track reading progress in grades K-4 by measuring oral reading fluency (ORF) as students read aloud. The usual ORF measure is accurate reading rate, which is reported in words correct per minute (WCPM). Computer recognition and processing of speech has automated the scoring of oral reading and enabled new analyses of reading performance, particularly concurrent scoring of shorter text units such as paragraphs, sentences, and words that occur within a passage that is read for comprehension. Do stronger readers perform more consistently within a passage and across passages during a test, while stuggling readers do not persevere. If true, then some conventional reading tests may conflate perseverance with basic reading skills. We have read-aloud data from 600 students in grades 1–5, but now only compare quintile 2 to quintile 4 in a sample of 100 fourth grade students. We find among both reader groups that passage performance tends not to diminish across passages late in a test, but remains roughly constant. However, within each text passage, the fast readers tend to slow down and the slower readers tend to speed up.

5aSC18. Speech accommodation across communication partners by adolescent speakers. Kathryn Connaghan and Zachary Kopp (Commun. Sci. & Disord., Northeastern Univ., 360 Huntington Ave., Forsyth Bldg. - Rm. 226, Boston, MA 02115, kconnaghan@mghihp.edu)

Communication context has considerable impact on speech production, with speakers accommodating their speech based on the needs and attributes of their communication partner. For instance, speakers demonstrate acoustic-phonetic convergence, wherein they alter their speech characteristics to converge with those of their communication partner (e.g., Borrie & Liss, 2014). This speech modulation promotes closeness, shared identity, and communication effectiveness. While documented in adult speakers, the occurrence and presentation of speech accommodation throughout development is unclear. The current study compared the acoustic characteristics of speech samples produced by adolescent speakers in isolation versus in response to communication partners. Twelve neurotypical male adolescents (13–17 years) read sentences aloud with and without pre-exposure to speech recordings collected from four speakers varying by age and sex. Acoustic correlates of rhythm and prosody were compared across elicitation conditions. As a group, the participants significantly modulated their peak fundamental frequency and intensity across some conditions. Convergence was evaluated with bivariate correlations between exposure and response utterances. The highest correlation was observed for speech rate with the adult male, though unique patterns of convergence were observed across participants. Further study of speech accommodation by individuals with speech disorders may inform interventions to support successful social interactions.

5aSC19. Vocal changes across disease progression in amyotrophic lateral sclerosis (ALS). Jordan Green, Kathryn Connaghan (Commun. Sci. & Disord., MGH Inst. of Health Professions, 36 First Ave., Boston, MA), (kconnaghan@mghihp.edu), Yana Yunusova (Speech-Lang. Pathol., Univ. of Toronto, Toronto, ON, Canada), Kaila Stipancic (Commun. Sci. & Disord., MGH Inst. of Health Professions, Boston, MA), Sarah Gutz (Harvard Univ., Boston, MA), and James Berry (Massachusetts General Hospital, Boston, MA)

Amyotrophic lateral sclerosis (ALS) is a neurodegenerative disease characterized by loss of muscle strength and function. The speech systems (respiratory, phonatory, velopharyngeal, and articulatory) are frequently affected, causing speech and swallowing impairments. Changes to voice production are often reported. These changes include altered fundamental frequency, phonatory instability, and the development of breathy or harsh voice quality (see Green *et al*., 2013 for review). While acoustic studies of speakers with ALS have demonstrated voice dysfunction, the findings have been variable in the type and direction of change across individual speakers. The current investigation seeks to further explicate vocal dysfunction and change in ALS by exploring promising acoustic phonatory measures across disease progression. Participants with and without ALS were audiorecorded at multiple time points while producing sustained vowels and connected speech. Acoustic analyses include traditional phonatory measures extracted from vowel prolongations (fundamental frequency, jitter, and shimmer) and newer measures of phonation across connected speech (e.g., cepstral peak prominence). Voice metrics are compared between speaker groups and across time points. It is anticipated that the findings will support the development of valid and reliable measures to mark disease onset and progression, thereby facilitating intervention and mitigating the devastating impact of ALS.

5aSC20. Fricative productions of Mandarin-speaking children with cerebral palsy: The case of five-year-olds. Chin-Ting Liu (Lang. Ctr., National Chin-Yi Univ. of Technol., Taichung City, Taiwan), Li-mei Chen (National Cheng Kung Univ., Tainan, Taiwan), Katherine C. Hustad, Ray D. Kent (Univ. of Wisconsin - Madison, Madison, WI), and Chia-Cheng Lee (Portland State Univ., 1831 SW Park St., Apt. 112, Portland, OR 97201, cl9@pdx.edu)

The age means between cerebral palsy children (CPs) and typically developing children (TDs) were not ideally matched in previous studies targeting the fricative productions of Mandarin-acquiring CPs (Liu *et al*., 2017, 2016). Therefore, in this study, age-matched CPs (N = 8, Mean = 5;6)

and TDs (N = 8, Mean = 5;6) were recruited. Six acoustical parameters (frication duration, rise time, and first to fourth spectral moments) of the five Mandarin Chinese voiceless fricatives (labiodental, alveolar, alveolo-palatal, velar, and retroflex) produced by the participants were compared. The results from Mann-Whitney U tests indicated that, for the labiodental, alveolar, alveolo-palatal, and retroflex fricatives, the values from frication duration, rise time, and first and second spectral moments produced by CPs were generally significantly lower than those produced by TDs. The current results from age-matched groups were different from previous studies and suggested that: 1) CPs tended to have a more posterior constriction site and a more restricted lingual constriction area with the passive articulator; 2) the third and fourth spectral moments were less effective in quantifying the differences between the two groups. Future studies are suggested to observe the fricative productions from older or younger age-matched groups so that the fricative developmental trajectory of Mandarin-acquiring CPs can be faithfully depicted.

5aSC21. Acoustic analysis of the speech of patients with oral cancer: A methodological investigation comparing speech stimuli derived from different clinical outcome measures. Agnieszka Dzioba (Surgery, Univ. of AB, 8440 112 St., Edmonton, ON T6G 2BT, Canada, adzioba0@gmail.com), Daniel Aalto (Commun. Sci. and Disord., Univ. of AB, Edmonton, AB, Canada), Hadi Seikaly (Surgery, Univ. of AB, Edmonton, AB, Canada), and Jana Rieger (Commun. Sci. and Disord., Univ. of AB, Edmonton, AB, Canada)

Background: Oral cavity cancer and its treatment reduce the quality of speech. Clinicians often utilize a variety of outcomes measures to assess speech function of patients with oral cavity cancer reducing the comparability of formant results due to differences in linguistics and phonetic contexts. **Objective:** To evaluate the degree of agreement in vowel space size in a F1-F2 plane, when comparing speech stimuli selected from a controlled environment (i.e., /hVd/ context) to speech stimuli segmented from two clinically available speech outcome measures in patients treated for cancer of the oral tongue. *Methods:* Voice recordings of nine patients treated with primary surgery for cancer of the oral cavity who attended functional assessment appointments (pre-operatively, and at 1-, 6-, and 12-months post-operatively) were analyzed. Agreement between vowel space size obtained from /hVd/ phrases and other speech assessments were compared using linear correlations and t-tests. *Results:* Vowel space size derived from /hVd/ phrases correlates strongly with corresponding estimates from other speech tasks ($r = 0.72$ to 0.82, $p < 0.0001$). The other tasks had significantly reduced vowel space sizes compared to /hVd/ ($t = 4.7$ to 5, $p < 0.0001$). *Conclusion:* Vowel space size estimates based on different speech tasks are mutually comparable and may offer insight to oral cancer speech production acoustics.

5aSC22. Tongue position during speech as a function of palatal anatomy: Controls and glossectomy patients. Maureen Stone, Elise Tigani, Elise Tigani (Univ. of Maryland Dental School, 650 W. Baltimore St., Rm. 8207, Baltimore, MD 21201, mstone@umaryland.edu), Junghoon Lee (Johns Hopkins Medical Institutions, Baltimore, MD), Jonghye Woo (MGH, Boston, MA), and Jerry L. Prince (Johns Hopkins Univ., Baltimore, MD)

This study examined the effect of palatal anatomy on tongue position during the complex speech movement seen in the motion from /ʃ/ to /l/ in "shell." The study was interested in whether subjects with flatter/narrower palates would use more tongue anteriority than those with higher/wider palates. Anteriority is the percent of the tongue anterior to the first molar. Low palate speakers may use more anteriority due to less space in the palatal vault. The speech task "a shell" requires complicated deformation between the /ʃ/, which elevates the sides of the tongue, and the /l/, which lowers the sides, elevates the tongue tip, and retracts the root. In the past, palate effects have been shown to explain idiosyncratic subject differences. Palate height explained the use of apical vs laminal /s/. Palate width affected the anteriority of tongue position in cancer patients after glossectomy surgery. Therefore, this study examined 16 controls and 8 glossectomy patients. Initial measurements show more anteriority for patients than controls. In addition, patients with a large overbite (vertical overlap between upper and lower incisor) had more anteriority due to a smaller front cavity.

5aSC23. The acoustic consequences for sibilants produced by glossectomies compared to healthy controls. Christine H. Shadle (Haskins Labs., 300 George St., New Haven, CT 06511, shadle@haskins.yale.edu), Maureen Stone (Neural & Pain Sci. and Orthodontics & Pediatrics, Univ. Maryland School of Dentistry, Baltimore, MD), and Wei-Rong Chen (Haskins Labs., New Haven, CT)

Glossectomy surgery affects the ability to elevate the tongue tip (Grimm *et al*, JSLHR v.60, 3417–3425, 2017), which is known to affect production of /s/. Interestingly, /ʃ/ is less affected by glossectomy surgery. In this study, the acoustics of normal and aberrant /s/ and /ʃ/ were characterized using three parameters developed for normal adults and adolescents. Main spectral peak (F_M) indicates place of constriction. Amplitude difference (A_D) indicates degree of sibilance. LevelD indicates relative energy between high and mid-frequencies, reflecting source changes. Subjects were two patients and three healthy controls for whom acoustic, perceptual, and MRI data existed. The controls were matched by gender and vocal tract size to the patients. The corpus included three words and four VCV syllables where C was /s, ʃ/. Results showed the male patient, whose /s/ tokens were perceived as /ʃ/, had low F_M values for /s/. The female patient had more varied and less severe errors. She produced perceptually-distinct /s/ and /ʃ/ and showed normal means but larger variances for /s/ than /ʃʃ/ parameters. Overall, the acoustic parameters match both the perceptual and articulatory (MRI) results, and help to explain the detailed effects of glossectomy surgery on the post-surgery productions. [Work supported by NIH CA-133015.]

5aSC24. Diphthong productions in speakers with Parkinson's disease across speaking modes. Yunjung Kim (Louisiana State Univ., 86 Hatcher Hall, Baton Rouge, LA 70803, ykim6@lsu.edu) and Austin R. Thompson (Louisiana State Univ., Baton Rouge, LA)

Several vowel acoustics parameters (e.g., second formant frequency (F2) slope, vowel space area) are known to significantly contribute to speech intelligibility in dysarthria (Kim, Kent, Weismer, 2011; Lansford & Liss, 2014). Particularly, F2 slope has been identified as an important predictor of speech intelligibility regardless of underlying neuropathologies of dysarthria (Kim, Weismer, Kent & Duffy, 2009). The current study focuses on intra-speaker modifications of F2 slope in speakers with Parkinson's disease (PD) voluntarily elicited across three speaking modes, less clear, conversational, and more clear speech, in recognition that prior work has mostly focused on inter-speaker comparisons. Varying speech clarity was our interest, given its wide use as an efficient behavioral therapeutic approach in clinic. Twenty speakers (10 PD, 10 neurologically healthy) were asked to read diphthongs embedded in real words. Diphthongs were chosen because they require a significant change in configuration of vocal tract and, therefore, are sensitive to the presence/severity of dysarthria. In the presentation, distributions of F2 slope 1) between PD and healthy speakers, and 2) across speaking modes within each speaker will be discussed. In addition, articulatory data will be presented for part of the speakers from whom kinematic data were obtained using the electromagnetic articulography (EMA) system.

5aSC25. Enhancing speech adaptation to a palatal perturbation using ultrasound visual biofeedback. Guillaume Barbier (Université de Montréal, Université de Montréal, École d'orthophonie et d'audiologie, C.P. 6128, succursale Centre-ville, Montreal, QC H3C 3J7, Canada, barbier_guillaume@orange.fr) and Douglas Shiller (Université de Montréal, Montreal, QC, Canada)

Prior clinical studies suggest that visual biofeedback of the tongue (e.g., ultrasound) may enhance the treatment of speech disorders, but outcomes have been mixed, likely due to variability in both the clinical profiles of participants and the way in which treatments have been carried out. Understanding the true potential of this clinical tool requires a clearer

sense of how visual biofeedback interacts with speech motor control. Here, we present a novel experimental approach that mimics the conditions of clinical treatment for speech disorders while maintaining a high level of consistency and control over the speech-learning task. The procedure involves altering the vocal tract of typically developing talkers using a palatal prosthesis to perturb /s/-production in combination with the controlled application of ultrasound biofeedback. As participants practice and improve their speech, changes in articulatory movements are examined using acoustic and kinematic measures. The present study compared a control group (n = 10) receiving only auditory feedback during speech practice with a group receiving visual biofeedback (n = 10). Results indicate an effect of biofeedback, in particular in the retention of learned motor patterns, indicating that talkers integrate real-time visual feedback of tongue movement into the sensorimotor processes driving speech adaptation.

5aSC26. The impact of melodic intonation therapy on rate and fundamental frequency in a client with Palilalia. Christina C. Akbari (Commun. Disord., Arkansas State Univ., P.O. Box 910, State University, AR 72467, cakbari@astate.edu)

Palilalia is a rarely documented speech disorder associated with Parkinson's disease, stroke, epilepsy, etc. Palilalia is characterized by an increased rate of speech along with repetitions of words, phrases, or sentences. Only one published article has discussed treatment of Palilalia. Helm (1979) utilized a pacing board to help his 54-year-old client speak slower and reduce his repetitions. The participant touched the divided board with his fingers as he produced each syllable. This board reportedly slowed the patient's speech. Melodic intonation therapy (MIT) was designed to help individuals with aphasia communicate more effectively (Sparks & Holland, 1976). MIT involves intoning propositional phrases and sentences using a limited range of musical notes to produce utterances along with tapping to keep the rhythm. Speech productions with MIT resulted in slower, more lyrical productions in comparison to spontaneous speech (Sparks & Holland). MIT incorporates aspects of pacing and rhythm that could be effective in slowing speech rate. This study utilized a single-subject design involving a 42-year-old male who experienced an anoxic brain injury. Speech samples from therapeutic sessions were collected and analyzed. The results indicated significant differences in terms of rate and fundamental frequency between spontaneous utterances and those produced using MIT strategies.

5aSC27. Predicting scores on the Montreal cognitive assessment from a spontaneous speech sample. Alan A. Wisler, Annalise Fletcher, and Megan J. McAuliffe (New Zealand Inst. of Lang., Brain and Behaviour, NZILBB, Univ. of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand, alanwisler@gmail.com)

This presentation examines acoustic and linguistic measurements taken from 521 older participants. The aim was to examine the relationship between measurements derived from spontaneous speech and participants' scores on the Montreal Cognitive Assessment (MOCA). Though both speech measurements and MOCA scores have been shown to be predictive of mild cognitive impairment, there has been little exploration in the literature of the relationship between these two domains. Participants completed the MOCA assessment and were prompted to describe an early childhood memory. The lexical complexity analyzer toolkit was used to extract a range of measurements to assess the lexical density, sophistication, and variation in each participant's storytelling passage. For the acoustic analysis, we drew a subset of the features from the Interspeech 2010 Paralinguistic Challenge set and included measures of duration and speaking rate. A least absolute shrinkage and selection operator (LASSO) approach was used to model the relationship between acoustic, lexical, and demographic information and participants' MOCA scores. Using the covariance test statistic we identified six important variables: one lexical, three acoustic and two demographic. This reduced model explained 18.06% of the variance in participants' MOCA scores. This R^2 value was validated on a held out set of 121 participants.

5aSC28. The effect of noise on the intelligibility of electrolaryngeal speech. Kimberly McNicholl, Steven R. Cox, Alexandra Chill (Commun. Sci. and Disord., Adelphi Univ., Hy Weinberg Ctr. 136, Garden City, NY 11530), (scox@adelphi.edu)

The electrolarynx (EL) is a hand-held device used for voice and speech production following surgical removal of the larynx. Many individuals who have their larynx removed begin using an EL in the immediate, postsurgical period. Unfortunately, EL speech is known to be poorly understood in quiet listening conditions when compared to laryngeal and alaryngeal speech methods. However, there is a dearth of research studying the effects of background noise and its impact on the intelligibility of EL speech. The purpose of this study, then, was to investigate how well naïve listeners identify EL speech in quiet and noise conditions. Ten EL speakers were recorded while reading 10 sentences containing five keywords per sentence. Twenty listeners were asked to orthographically transcribe 50 sentences each while listening to the EL speakers' recordings. Preliminary data indicate that listeners identified 76% of keywords (*Mdn* = 78%; *SD* = 5%, *range*= 69–80%) in quiet compared to 60% of keywords (*Mdn* = 63%; *SD* = 10%; *range* = 44–69%) in noise. Implications and future directions will be discussed.

5aSC29. Visual-aerotactile perception and congenital hearing loss. Charlene Chang (Speech and Audiol. Sci., Univ. of Br. Columbia, 2177 Wesbrook Mall, Vancouver, BC, Canada, charlenechang94@gmail.com), Megan Keough, Murray Schellenberg, and Bryan Gick (Linguist, Univ. of Br. Columbia, Vancouver, BC, Canada)

Previous research on multimodal speech perception with hearing-impaired individuals focused on audiovisual integration with mixed results. Cochlear-implant users integrate audiovisual cues better than perceivers with normal hearing when perceiving congruent [Rouger *et al*. 2007, PNAS, 104(17), 7295–7300] but not incongruent cross-modal cues [Rouger *et al*. 2008, Brain Research 1188, 87–99), leading to the suggestion that early auditory exposure is required for typical speech integration processes to develop (Schorr 2005, PNAS, 102(51), 18748–18750). If a deficit of one modality does indeed lead to a deficit in multimodal processing, then hard of hearing perceivers should show different patterns of integration in other modality pairings. The current study builds on research showing that gentle puffs of air on the skin can push individuals with normal hearing to perceive silent bilabial articulations as aspirated. We report on a visual-aerotactile perception task comparing individuals with congenital hearing loss to those with normal hearing. Results indicate that aerotactile information facilitated identification of /pa/ for all participants ($p < 0.001$) and we found no significant difference between the two groups (normal hearing and congenital hearing loss). This suggests that typical multi-modal speech perception does not require access to all modalities from birth. [Funded by NIH.]

5aSC30. Testing and evaluation paradigms for assistive hearing devices. Ram Charan M. Chandra Shekar (Cochlear Implant Lab. – Ctr. for Robust Speech Systems (CRSS), Dept. of Elec. Eng., Erik Jonsson School of Eng. and Comput. Sci., Univ. of Texas at Dallas, 7780 McCallum Blvd., Apt. No 26307, Dallas, TX 75252, RamCharan.ChandraShekar@utdallas.edu), Hussnain Ali, and John H. L. Hansen (Cochlear Implant Lab. – Ctr. for Robust Speech Systems (CRSS), Dept. of Elec. Eng., Erik Jonsson School of Eng. and Comput. Sci., Univ. of Texas at Dallas, Richardson, TX)

Research interfaces and assistive hearing devices (RI/AHD) enable investigators to perform perceptual studies and develop effective sound processing strategies for cochlear implant (CI) and hearing aid (HA) devices. Several concerns exist regarding safe and reliable operation of RI/AHDs, for example, safety, reliability, possible hazards, accuracy, and their long-term consistency. Recently, CRSS-CILab at UTDallas has developed a mobile RI (CCi-MOBILE) for unilateral and bilateral HA/CI devices. In this study, a comprehensive testing and evaluation strategy is proposed to investigate the behavior of RI/AHDs that addresses safety concerns, reliability of hardware/firmware design, hearing-comfort, subjective sound-quality, and range of human-driven settings, as well as diverse types of acoustic exposure. Furthermore, a characteristic risk-hazard analysis is performed including diagnosis

and categorization of the severity level of the associated safety concerns by probing pulse characteristics from each electrode, e.g., current-level, pulse-width, charge per phase, frame-period (for stimulation-rate), inter-phase gap (IPG), and several other parameters. The CCi-MOBILE RI is employed in this study to demonstrate the utility of the proposed testing and evaluation paradigm. The described practices could potentially serve as a blue-print to characterize future RI for AHDs and several other personalized listening devices based on safety, reliability, listening comfort/perception, and subjective sound quality.

5aSC31. Salience of cochlear implant users' speech rate. Valerie Freeman (Dept. of Commun. Sci. and Disord., Oklahoma State Univ., 042 Murray Hall, Stillwater, OK 74078, valerie.freeman@okstate.edu)

Speech rate-matching is a form of rapid accommodation in which speakers adapt their speech rates to match their interlocutor's previous utterance. Such responsiveness may contribute to rhythmic convergence between speakers throughout a conversation. However, little is known about interactions between typical speakers and those with speech or hearing difficulties. In recent work, prelingually deaf cochlear implant (CI) users were poorer rate-matchers than their peers, but it was unclear whether interlocutors accommodated toward CI users' speech rates, which can vary widely between individuals. A follow-up study adapted procedures from work in which participants rate-matched toward fast- and slow-talking Parkinson's patients. Surprisingly, people did not rate-match to either CI users or controls. This study explores one possible explanation: that differences in speech rate were not salient enough for participants to modify their own rates in response. Following previous procedures, participants (a) alternated hearing CI users' sentences and reading other sentences, (b) rated CI users' utterances as fast, slow, or neither, and (c) repeated the first task with different stimuli. Results will show whether participants were able to identify differences in speech rate (when prompted) and whether they improved in speech rate-matching after speech rate was brought to their attention.

FRIDAY MORNING, 9 NOVEMBER 2018 RATTENBURY A/B (FE), 9:00 A.M. TO 11:45 A.M.

Session 5aSP

Signal Processing in Acoustics: General Topics in Signal Processing II

Edward Richards, Cochair
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Michael J. Bianco, Cochair
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Contributed Papers

9:00

5aSP1. Mathematical properties of generalized Bessel functions and application to multi-tone sinusoidal frequency modulation. Parker Kuklinski (Naval Undersea Warfare Ctr., 1176 Howell St., Newport, RI 02841, parker.s.kuklinski1@navy.mil) and David A. Hague (Naval Undersea Warfare Ctr., North Dartmouth, MA)

The generalized Bessel function (GBF) is a multi-dimensional extension of the standard Bessel function. Two dimensional GBFs have been studied extensively in the literature and have found application in laser physics, crystallography, and electromagnetics. However, a more rigorous treatment of higher-dimensional GBFs is lacking. The GBF exhibits a rich array mathematical structure in regards to its partial differential equation representation, its asymptotic characterization, and its level sets. In this talk/paper, we explore these properties and connect spectral and ambiguity function optimization of a multi-tone SFM signal to finding the location of the roots of these generalized Bessel functions.

9:15

5aSP2. Two-dimensional high-resolution acoustic localization of distributed coherent sources for structural health monitoring. Tyler J. Flynn and David R. Dowling (Mech. Eng., Univ. of Michigan, Ann Arbor, 1231 Beal Ave., Ann Arbor, MI 48109, tjayflyn@umich.edu)

Many high-resolution techniques exist for localizing acoustic sources; however, most of these methods suffer when applied to data containing spatially separated coherent signals. The Spectral Estimation Method with Additive Noise (SEMWAN) is an existing beamforming technique for high-resolution localization of incoherent monopole sources in low SNR environments. SEMWAN utilizes a reference measurement to subtract, and thereby suppress, background noise, but its performance suffers for cases involving mutually-coherent sources—such as a distributed radiating source. SEMWAN has previously been extended to one-dimensional coherent source scenarios by implementing the additional step of subarray averaging. This extra processing step

reduces *coherent* background signatures and thereby permits localization of small acoustic changes (e.g., localized damage) provided a known baseline array recording is available. This presentation discusses the extension of this approach to two-dimensional problems using Cartesian planar arrays. Experimental results using multiple coherent sources and a remote receiver array (with varying numbers of elements and subarray geometry) at frequencies from 1.0 to 10 kHz are analyzed and compared to simulation results. Application of this technique for localization of mechanical changes in a 30-cm-square aluminum plate is also addressed. [Sponsored by NAVSEA through the NEEC and by the US DoD through an NDSEG Fellowship.]

9:30

5aSP3. Explorations of *in-situ* source localization in the deep ocean using frequency difference matched field processing and matched autoproduct processing. David J. Geroski (Appl. Phys., Univ. of Michigan – Ann Arbor, Randall Lab., 450 Church St., Ann Arbor, MI 48109, geroskdj@umich.edu) and David R. Dowling (Mech. Eng., Univ. of Michigan, Ann Arbor, MI)

Matched field processing (MFP) is a well-known technique for source localization in challenging environments. MFP involves correlating array-recorded fields with calculated replica fields developed from knowledge of the acoustic environment. Incomplete knowledge of the environment causes mismatch between measured and calculated fields, and this mismatch can cause MFP to fail at relevant ranges and frequencies in the deep ocean. Given that the severity of this mismatch increases with frequency, a proposed remedy to the mismatch problem is to analyze the frequency-difference autoproduct of the recorded field, rather than the field itself. The phase of the frequency-difference autoproduct is expected to mimic that of an out-of-band field at a selectable below-band frequency, thereby mitigating the severity of the mismatch at in-band frequencies. This autoproduct is then matched either to a replica field at the below-band frequency, or to an appropriate calculated autoproduct field. This presentation explores these methods, and higher-order corrections, to localize moored sources using data from the North Pacific Acoustic Library. Localization statistics are presented based on the closest moored source, 130 km from the receiving array with a signal bandwidth from 200 to 300 Hz. [Sponsored by ONR.]

9:45

5aSP4. Using coherence to improve calculation of active acoustic intensity. Mylan R. Cook, Joseph S. Lawrence, Kent L. Gee, Scott D. Sommerfeldt, Tracianne B. Neilsen, and Michael C. Mortenson (Phys. and Astronomy, Brigham Young Univ., N201 ESC, Provo, UT 84602, mylan.cook@gmail.com)

The Phase and Amplitude Gradient Estimator (PAGE) method was developed as an alternative to the traditional method for calculating energy-based acoustic measures such as active acoustic intensity [E. B. Whiting *et al*. J. Acoust. Soc. Am. **142**, 2208–2218 (2017)]. While this method shows many marked improvements over the traditional method, such as a higher valid frequency bandwidth for broadband sources, contaminating noise can lead to inaccurate results. Both the traditional method and the PAGE method can perform poorly when microphone pairs exhibit low coherence, whether caused by noise or by imprecise measurements. By using a coherence weighting in the least-squares pressure gradient calculations, where the weighting can vary across frequency, better estimates of the pressure gradient can be obtained, which in turn yield more accurate results for intensity. Additionally, a coherence-based approach may be used to mitigate the negative impact of contaminating noise, most especially for uncorrelated contaminating noise. These improvements, though requiring a greater amount of computation time, can be integrated into the PAGE method processing procedures to create a more stable method for calculating acoustic intensity. [Work supported by NSF.]

10:00

5aSP5. Application of time-domain near-field acoustical holography to the high-order ambisonics presentation of moving sound sources. Jorge A. Trevino Lopez, Shuichi Sakamoto, and Yôiti Suzuki (Res. Inst. of Elec. Commun., Tohoku Univ., 2-1-1 Katahira, Aoba-ku, Sendai, Miyagi 9808577, Japan, jorge@ais.riec.tohoku.ac.jp)

High-order ambisonics (HOA) is a sound field reproduction method based on results from near-field acoustical holography (NAH). As such, it is formulated in the frequency domain; this assumes a stationary acoustic field. This presentation applies a recent time-domain formulation of NAH by Attendu and Ross. The approach is based on the linear deconvolution along the spatial coordinates and samples the Green's function in the time and spatial domains, as opposed to the Fourier domain. Our contribution is an application of these ideas to overcome the problems inherent in the HOA reproduction of non-stationary sound fields, in particular those of moving sound sources. In practice, the rendering of moving sound sources is approximated by assuming they are stationary within short temporal windows. The approximation, while useful for slow-moving sources, cannot recreate the Doppler shift and results in discontinuities along the temporal structure of the sound field. On the other hand, the proposed method does not impose any constraints on the motion of the sound sources. Unlike conventional HOA, the proposal cannot be formulated as a simple filter bank; however, numerical experiments show that fast moving sources exhibit the expected Doppler shift.

10:15–10:30 Break

10:30

5aSP6. Resolving range aliasing in Omega-K synthetic aperture beamforming. Timothy Marston (APL-UW, 1013 NE 40th St., Seattle, WA 98105, marston@apl.washington.edu)

The Omega-K algorithm is a beamforming algorithm that exploits Stolt migration in the wavenumber domain to focus stripmap synthetic aperture data. Because of its efficiency and its inherently broad-band properties it has been a common solution for synthetic aperture beamforming problems, especially in situations where trajectory perturbations are small and computational resources are limited. The algorithm is commonly divided into two stages: a bulk compression stage leveraging a phase multiplication in the wavenumber domain (sometimes used in isolation for resonance and shadow enhancement), which focuses data at the scene center, and Stolt migration which brings the entire scene into focus. For systems with very broad beamwidth the bulk compression stage can lead to spatial aliasing for close range scatterers, causing a loss of spatial spectrum information and increased noise. The cause of this frequently overlooked aliasing problem, its manifestation in SAS images, and methods for its avoidance will be discussed and demonstrated using both simulations and ClutterEX17 sonar data.

10:45

5aSP7. Designing waveforms with desired ambiguity function mainlobe and sidelobe structure. David A. Hague (Naval Undersea Warfare Ctr., 1176 Howell St., Newport, RI 02841, david.a.hague@gmail.com)

In active sonar, a transmit waveform's ability to resolve closely spaced targets in range/Doppler and distinguish weak targets in the presence of a stronger one are determined by the mainlobe and sidelobe structure, respectively, of the waveform's broadband ambiguity function (BAF). While it is

often difficult to derive precise closed form expressions for the sidelobe structure, the mainlobe structure can be quite accurately modeled. The contour of the BAF's mainlobe is well approximated by a coupled ellipse, or ellipse of ambiguity (EOA). The EOA parameters determine the mainlobe width in range and Doppler as well as the degree of range-Doppler coupling. If the waveform's modulation function is known the EOA parameters may be calculated in closed form. The multi-tone sinusoidal frequency modulated (MTSFM) waveform possesses a modulation function that is represented using a Fourier series expansion. The coefficients are utilized as a set of tunable parameters that can be modified to synthesize waveforms with specific characteristics. This research presents closed form expressions for the MTSFM's BAF EOA parameters. Simulations demonstrate that the EOA parameters facilitate the design of MTSFM waveforms with desirable mainlobe and sidelobe characteristics.

11:00

5aSP8. Deconvolved conventional beamforming for a planar array and Cramer Rao bound. Yiting Zhu, T. C. Yang, Xiang Pan (School of Information and Electron. Eng., Zhejiang Univ., Zhe Rd. 38, Hangzhou, Zhejiang 310027, China), (panxiang@zju.edu.cn)

It is well known that the beam power output of conventional (delay and sum) beamforming (CBF) can be expressed as the convolution of the source distribution and the response of the beamformer to the point source. Consequently, the original source distribution can be recovered by deconvolution, yielding not only improved direction of arrival (DOA) estimation in terms of a narrower beam width and suppressed side lobes but also higher array gain than CBF (the deconvolution gain) as demonstrated by Yang for a uniformly spaced line array (ULA) [T. C. Yang, 10.1109/ JOE. 2017. 2680818]. In addition, the method is insensitive to signal mismatch and snapshot deficient problems in comparison with other high resolution methods such as minimum variance distortionless response (MVDR). In this paper, we extend the Richardson-Lucy algorithm for deconvolution to a planar array where the signal can be coming in any direction. Simulation analysis as well as experimental data will be presented to study the beam width and array gain as a function of number of receivers, the frequency of the incoming signals including narrow and broad band signals, and the ability to reject interference. We also calculate the Cramer-Rao bound to compare with the experimental result.

11:15

5aSP9. Study on the problem of coherent source resolution with same frequency for the coprime array. Jidan Mei, Dajun Sun, Yuyuan Zhou, and Junjie Shi (Acoust. Sci. and Technol. Lab.,College of Underwater Acoust. Eng., Harbin Eng. Univ., Shuisheng Bldg., Harbin Eng. University 1004, No. 145, Nantong St., Nangang District, Harbin 150001, China, meijidan@hrbeu.edu.cn)

The coprime sensor array (CSA) can achieve the same resolution capability as an equally spaced half-wave array even using fewer array elements. For single-target, CSA can achieve good anti-grating lobe effect. When there are multiple coherent sources of the same frequency, there still are overlaps between the main lobes and grating lobes of the subarray from different sources, and between the grating lobes and grating lobes of different subarray. In some cases, the strong grating lobes can interfere discriminating the azimuth and quantity of targets. This paper focuses on the multi-targets discrimination problem of CSA for the same frequency coherent source. A processing algorithm of CSA coherent sources is presented. This method uses iterative processing methods to detect and remove strong targets one by one. Then, reconstruct the spatial spectrum of each single target. Finally, recombine the spatial spectrum by each single target spatial spectrum after sidelobe suppression processing. This method can well remove the grating lobe of multiple targets. It is also applicable to the situation when the grating lobe is higher than the weak target peak under strong and weak contrast conditions. The performance of the method was simulated and the results confirmed the feasibility of the method.

11:30

5aSP10. Ultrasonic endoscope in the form of a bundle of elastic rods for imaging in aggressive liquids. Sergey Tsysar, Suren Petrosyan (Phys. Faculty, Moscow State Univ., GSP-1, 1-2 Leninskie Gory, Moscow 119991, Russian Federation, sergey@acs366.phys.msu.ru), Victor D. Svet (Acoust. Inst., Moscow, Russian Federation), and Oleg A. Sapozhnikov (Ctr. for Industrial and Medical Ultrasound, Appl. Phys. Lab, Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105)

Modern ultrasonic imaging systems demonstrate high quality of the images obtained in non-aggressive media. Direct application of traditional systems under critical conditions, for example, at high temperature, in the presence of chemically active media or an increased level of radiation, is often impossible. We propose an approach based on the concept of an ultrasound endoscope to remotely display the area of interest through a long beam of solid rods. Each rod serves as a waveguide that carries an ultrasonic pulse from one end located in an aggressive medium to the other end located at a distance in favorable conditions. The diameter of the rods is less than half the wavelength to ensure that the ultrasonic pulses used to form the image propagate as the lowest-order longitudinal mode, which is non-dispersive and much faster than other possible modes (bending and torsional motions). The feasibility of the proposed concept is illustrated by numerical modeling and experiments. The results of studies of the 1024-channel waveguide system of megahertz range made of a bundle of stainless steel rods are presented. The obtained images of millimeter-sized scatterers in water demonstrate high resolution of the proposed system. [This work was supported by the RSF grant 17-72-10284.]

Session 5aUW

Underwater Acoustics, Acoustical Oceanography, Signal Processing in Acoustics, and Physical Acoustics: Sediment Acoustics–Inferences from Forward Modeling, Direct, and Statistical Inversion Methods III

Charles W. Holland, Cochair
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Stan E. Dosso, Cochair
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Chair's Introduction—8:00

Invited Papers

8:05

5aUW1. Ship of opportunity noise inversions for geoacoustic parameters of a layered mud-sand seabed. Dag Tollefsen (Norwegian Defence Res. Est. (FFI), Boks 115, Horten 3191, Norway, dag.tollefsen@ffi.no), Stan E. Dosso (School of Earth and Ocean Sci., Univ. of Victoria, Victoria, BC, Canada), and David P. Knobles (KSA LLC, Austin, TX)

This paper considers the use of broadband noise from ship sources of opportunity in statistical inference for geoacoustic parameters of a layered seabed via a trans-dimensional Bayesian matched-field approach, with applications to data collected with a bottom-moored horizontal array in the 2017 Seabed Characterization Experiment conducted on the New England Shelf. The approach samples probabilistically over possible model parameterizations (number of seabed layers) and provides uncertainty estimates of seabed model parameters (sediment geoacoustic profiles). Approaches to accounting for (unknown) ship source level directionality when combining data from varying ship aspects to the array are addressed. Sediment parameter estimates from the inversions are compared with direct measurements from sediment cores and other geophysical data collected in the experiment area.

8:25

5aUW2. Seabed geoacoustic inversion using a hydrophone equipped underwater glider. Yong-Min Jiang (Res. Dept., NATO - STO - Ctr. for Maritime Res. and Experimentation, Viale San Bartolomeo 400, La Spezia 19126, Italy, yong-min.jiang@cmre.nato.int), Stan E. Dosso (Earth and Ocean Sci., Univ. of Victoria, Victoria, BC, Canada), and Charles W. Holland (Appl. Res. Lab., The Penn State Univ., State College, PA)

The reflection coefficient at the sea floor as a function of grazing angle contains seabed geoacoustic properties that are crucial for predicting sound propagation accurately. NATO—STO—CMRE has developed a new technique for remote sensing the seabed reflection coefficient using underwater gliders equipped with passive acoustic payloads. This technique was applied during ONR sponsored Seabed Characterization Experiment conducted on the New England Mud Patch, USA, in March 2017. The reflected field was measured between grazing angles of 3.5 to 260, and frequency band of 2–20 kHz by an omni-directional hydrophone equipped Slocum glider, with the assistance of a broadband acoustic source. The data were analyzed both in time and frequency domains to obtain the reflection coefficient as a function of grazing angle at different frequencies. Ray tracing was also employed to fine tune the grazing angle information. Finally, Bayesian geoacoustic inversion of the reflection data at different frequencies was carried out. As a preliminary inversion attempt, the reflection data were modeled assuming a plane wave reflection coefficient. [*Work funded by NATO-Allied Command Transformation, Office of Naval Research and Office of Naval Research—Global.*]

8:45

5aUW3. Seabed roughness measurement using the multibeam-subbottom-profiler SBP120. Samuel Pinson (SHOM, SHOM, 13 rue du chatellier, Brest 29200, France, samuelpinson@yahoo.fr), Benjamin Barbier (SHOM, Brest, France), Charles W. Holland (Appl. Res. Lab., The Pennsylvania state Univ., State College, PA), and Yann Stéphan (SHOM, Brest, France)

In a recent paper [Pinson *et al*., J. Acoust. Soc. Am. 143, 2622–2631], theoretical interface echo scintillation, time-of-arrival variance, and angle-of-arrival variance have been derived as a function of the roughness autocorrelation function. Those parameters have been obtained under the Kirchhoff and small-roughness approximation by including integration over the source and receiver arrays in the Helmholtz-Kirchhoff integral. In this communication, we present the first roughness inversion results of at-sea recorded data based on the seabed-specular-echo fluctuation analysis. The data were recorded with the multibeam-subbottom-profiler SBP120 during the CALIMERO 2004 experiment campaign in the Gulf of Lion. [Research supported by the ONR Ocean Acoustics Program.]

9:05

5aUW4. Observations of resonances and antiresonances in modal propagation over muddy sediment layer. David R. Dall'Osto (Acoust., Appl. Phys. Lab. at Univ. of Washington, 1013 N 40th St., Seattle, WA 98105, dallosto@apl.washington.edu) and Peter H. Dahl (Acoust. and Mech. Eng., Appl. Phys. Lab., Univ. of Washington, Seattle, WA)

Measurements of signals generated over the New England mud patch, an area of ocean roughly 70 m deep characterized by a 10 m thick surficial mud-layer, by the Intensity Vector Autonomous Recorder (IVAR) are presented. IVAR is a bottom deployed system that measures both potential and kinetic energy roughly 1.2 m above the seafloor. Data originate from signals generated by a towed J15 source (transmission in the 50–500 Hz band), and signal underwater sound (SUS) MK-64 explosive sources, both part of the SCE17 signal set, and individual modes are identified by their unique Doppler shifts and/or through time-frequency analysis of dispersion. The density contrast between water and mud manifests a concentration kinetic energy in the water column, specifically when the water/mud interface intersects a node of the vertical mode functions. Following the work of Tolstoy (JASA 28(6), 1182–1192, 1956), data observations are fit to a representative sediment model through coupling two reduced waveguides, one representing the water column and the other the layered sediment, at their lattice points. The persistence of a resonance, which occurs at intersecting lattice points, is examined in terms of the range dependence in water depth and sediment structure.

9:25

5aUW5. Characterization of bottom parameters in the New England Mud Patch using geophone and hydrophone measurements. Gopu R. Potty (Dept. of Ocean Eng., Univ. of Rhode Island, 115 Middleton Bldg., Narragansett, RI 02882, potty@egr.uri.edu), James Miller (Dept. of Ocean Eng., Univ. of Rhode Island, Narragansett, RI), Ying-Tsong Lin, Julien Bonnel, Arthur Newhall (Appl. Ocean Phys. and Eng., Woods Hole Oceanographic Inst., Woods Hole, MA), David P. Knobles (Knobles Sci. And Anal., LLC, Austin, TX), and Preston S. Wilson (Mech. Eng. Dept. and Appl. Res. Labs., The Univ. of Texas at Austin, Austin, TX)

Measurements of acoustic pressure and particle velocity were made during the Seabed Characterization Experiment (SCEx) in the New England Mud Patch south of Cape Cod in about 70 meters of water. The University of Rhode Island and Woods Hole Oceanographic Institution deployed the "geosled" with a four-element geophone array, a tetrahedral array of four hydrophones, and several hydrophone receive units (SHRUs). In addition, a new low frequency source, interface Wave Sediment Profiler (iWaSP) was deployed to excite interface waves (Scholte waves). The iWaSP system consists of a source to generate the interface wave and a four-element accelerometer receive array. Modal arrivals from broadband sources (SUS and CSS) on geophones and hydrophones will be presented and compared. The individual arrivals on the sensors will be identified though seismo-acoustic modeling. Based on the propagation paths of the various waves (compressional, shear and Scholte waves), geoacoustic parameters will be estimated. Seismic data collected at the location will be used to constrain the model parameters in the inversion. Sediment data from cores, other *in-situ* measurements and inversions using other types of data will be used to compare and validate our inversions. [Work supported by Office of Naval Research.]

9:45–10:00 Break

Contributed Papers

10:00

5aUW6. Geoacoustic inversion using cross correlation function of low-frequency ambient noise in the Shallow Water 2006 Experiment. Marina Yarina, Boris Katsnelson (Marine GeoSci., Univ. of Haifa, Abba Khouchy Ave. 199, Haifa 3498838, Israel, marina-malysheva@autorambler.ru), Jixing Qin (Inst. of Acoust., Chinese Acad. of Sci., Beijing, China), Oleg A. Godin, and Tsu Wei Tan (Naval Postgrad. School, Monterey, CA)

In this paper, results of measurements and analysis of the cross correlation function (CCF) of the ambient noise field in a low frequency band (10–200 Hz) are presented. Records of the noise were obtained by single hydrophones (SHRUs) in the Shallow Water 2006 (SW06) experiment on the New Jersey continental shelf during about a month. Five SHRUs were placed approximately along a straight line perpendicular to the coastal line, distances between adjacent hydrophones were 5–8 km, ocean depth was 80–100 m. Analysis of the experimental data was carried out by calculating time-frequency diagrams of CCFs for different pairs of SHRUs, with subsequent mode filtering on the basis of the warping transform. Theoretical calculations of mode parameters for comparison with the experiment were done using different waveguide models, including the geoacoustic models previously proposed for the area of SW06 by other authors based on active source data. [Work supported by BSF-NSF grant.]

10:15

5aUW7. Passive acoustic characterization of the ocean bottom using a horizontal array of hydrophones. Tsu Wei Tan (Phys. Dept., Naval Postgrad. School, 833 Dyer Rd., Bldg. 232, Monterey, CA 93943-5216, ttan1@nps.edu), Oleg A. Godin (Phys. Dept., Naval Postgrad. School, Monterey, CA), Boris Katsnelson, and Marina Yarina (Marine GeoSci. Dept., Univ. of Haifa, Haifa, Israel)

Cross-correlation functions (CCF) of ambient and shipping noise recorded by two hydrophones are known to contain valuable information about the propagation environment. This paper investigates the feasibility of quantitatively characterizing the seafloor using interferometry of the ambient noise data obtained with SHARK array during the Shallow Water 2006 (SW06) experiment. SHARK array contained 32 near-bottom hydrophones, which formed a horizontal line array with nominal hydrophone separation of 15 m. Noise CCFs have been calculated between elements of the horizontal array as well as between each element of the array and a single-hydrophone near-bottom receiver approximately 3.6 km away. Sound propagation between elements of the array has been interpreted in terms of direct and reflected ray arrivals and possibly refracted (head wave) arrivals originating at interfaces within the bottom. CCFs on the longer propagation paths between the array and the single-hydrophone receiver are controlled by

waveguide effects and have been interpreted in terms of adiabatic normal modes. The warping transform of spectrograms of the measured CCFs has been used to separate the modes. Analysis and interpretation of the normal mode dispersion curves retrieved using the warping transform will be discussed. [Work supported by NSF and BSF.]

10:30

5aUW8. Geoacoustic inversion of the pressure gradient data using a single vector sensor. Junjie Shi (Acoust. Sci. and Technol. Lab., Key Lab. of Marine information Acquisition and Security, College of Underwater Acoust. Eng., Harbin Eng. Univ.; Naval Acad., Shuisheng Bldg., Nangang District, Harbin 150001, China, junejieshi@outlook.com), Dajun Sun (Acoust. Sci. and Technol. Lab., Key Lab. of Marine information Acquisition and Security, College of Underwater Acoust. Eng., Harbin Eng. Univ., Harbin, China), Stan E. Dosso (Univ. of Victoria, Victoria, BC, Canada), and Qingyu Liu (Naval Acad., Beijing, China)

A vector sensor has the capability of obtaining the acoustic field involving the sound pressure and three-dimensional particle velocities simultaneously, which means that there exists a potential to extract deep information for further applications like direction of arrival (DOA), positioning, classification, geoacoustic inversion, etc. This paper applies a nonlinear Bayesian approach to the pressure gradient data for geoacoustic properties of South China Sea, about which the experiment took place in July of 2013 in South China Sea of nearly 90 m depth. Recorded linear frequency modulation (LFM) signals of the pressure and vertical particle velocity are windowed and processed together to estimate the pressure gradient in the vertical direction at multiple frequencies as the observation data. After the optimal sediment model is selected based on BIC (Bayesian Information Criterion) using adaptive simplex simulated annealing (ASSA), delayed rejection adaptive Metropolis (DRAM), a Markov chain Monte Carlo (MCMC) sampling method, is used not only to provide a maximum *a-posteriori* (MAP) parameters estimates but also to quantify the parameters uncertainties and inter-parameter relationships. [Work supported by the National Natural Science Foundation (Grant No. 61531012).]

10:45

5aUW9. Sequential bottom parameter estimation using blind deconvolution of sources of opportunity in ocean waveguide. Xuedong Zhang (Inst. of Acoust., Chinese Acad. of Sci., No. 21 North 4th Ring Rd., Beijing 100190, China, zxd@mail.ioa.ac.cn), Nicholas C. Durofchalk (Georgia Inst. of Technol., Annville, PA), Lixin Wu (Inst. of Acoust., Chinese Acad. of Sci., Beijing, China), and Karim G. Sabra (Georgia Inst. of Technol., Atlanta, GA)

This paper investigates the performance of sequential bottom parameter estimation based on ray-based blind deconvolution (RBD) of sources of opportunity using both numerical simulations and the 2016 Santa Barbara Channel (SBC) experimental recordings of shipping noise for ranges up to several kilometers. The RBD algorithm relies on estimating the unknown phase of the random sources to approximate the source-to-array channel impulse responses (CIR) by wideband beamforming along a well-resolved ray path [Sabra *et al*., JASA, 2010, EL42-7]. The power ratio of the direct and bottom-bounced arrivals is processed to infer the bottom reflection loss and is utilized to invert for the bottom parameters. Usually, the estimated bottom reflection loss is not accurate enough as the estimated CIR is noisy. Sequential parameter estimation uses a state space model for predicting and correcting the bottom parameters as the estimated bottom reflection loss values become available. This approach is a robust estimation tool employing predictions from previous estimates and corrects stemming from models that relate bottom parameters to the bottom reflection loss. Inversions results for the SBC experiment were also performed with conventional active sources to validate the inversion obtained with RBD of sources of opportunity.

11:00

5aUW10. Segmentation of underwater acoustic images by FCM with EMD. Sakthivel M. Santhanam (Electronics and Commun., Peri Inst. of Eng. and Technol., Rajiv Gandhi Salai, OMR Kalavakkam, Chennai, Tamil Nadu 603110, India, sakthivels@ssn.edu.in) and Somasekar K. (Electronics and Commun., Peri Inst. of Eng. and Technol., Chennai, India)

In recent years, there is an expanding enthusiasm for studying the seabed structure. The investigation of seabed has numerous applications, for example, protest recognition, exploration of natural resources, angling, analyzing the composition of residues, etc. In oceanic examinations, submerged objects location is a standout amongst the most basic errands. This emphasizes the necessity of image segmentation, which divides an image into parts that have strong correlations with objects to reflect the actual information collected from the real world. Image segmentation is the most practical approach to virtually all automated image recognition systems. Clustering of numerical data forms the basis of many classification and system modelling algorithms. The purpose of clustering is to identify natural groupings of data from a large data set to produce a concise representation of a system's behaviour. In this paper, Empirical Mode Decomposition (EMD) picture upgrade procedure has been utilized to enhance the nature of sonar pictures and Fuzzy C means (FCM) clustering method is used for underwater image segmentation. The result of EMD is compared with histogram equalization and Contrast stretching. EMD with K-means and EMD with FCM is compared and the exploratory outcomes demonstrate that the proposed technique can acquire exact outcomes and enhances operational productivity.

Session 5pAA

Architectural Acoustics and Noise: Session in Memory of Murray Hodgson II

Nicola Prodi, Cochair
Dept. of Engineering, University of Ferrara, via Saragat 1, Ferrara 44122, Italy

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David S. Woolworth, Cochair
Roland, Woolworth & Associates, 356 CR 102, Oxford, MS 38655

Invited Paper

1:15

5pAA1. Optimization of the acoustic treatments in order to achieve the Italian minimum environmental criteria (CAM) for classrooms. Umberto Berardi (DAS, Ryerson Univ., 350 Victoria St., Toronto, ON M5B 2K3, Canada, uberardi@ryerson.ca), Gino Iannace, and Amelia Trematerra (Seconda Universita' di Napoli, Aversa, Italy)

A recent Italian legislation has established the Minimum Environmental Criteria (CAM) for working environments. With regard to schools, adequate acoustic comfort targets are required in terms of noise control and acoustic quality. Schools must comply with the UNI 11532 for their reverberation (T), clarity (C_{50}) and speech intelligibility (STI). In classrooms, the following values are required: T<0.7s, C_{50}>0dB and STI>0.6. In sports facilities such as gyms or swimming pools, the requirements are T<1.5 s, C_{50}>-2 dB and STI>0.5. To achieve these objectives, the insertion of acoustic treatments is often unavoidable. Acousticians commonly use the perfectly diffused theory to calculate the amount of need sound-absorbing material to comply with current legislation. The purpose of this work is to evaluate the optimal position in which to place the minimum amount of sound-absorbing treatments to reach CAM. Some university classrooms are used. These classrooms have a marble floor and plastered walls and, at 1.0 kHz, have T values between 2.5s and 4.5s, C_{50} between 3 dB and -0.5 dB, and ST between 0.34 and 0.47. Using an acoustic software, it was possible to estimate the minimum quantity and the optimal placement of the sound-absorbing panels to insert to reach the CAM of these classrooms.

Contributed Paper

1:35

5pAA2. Speech-in-noise research: From classrooms to Canadian Armed Forces operational environments. Ann Nakashima (Defence Res. and Development Canada, 1133 Sheppard Ave. West, Toronto, ON M3K 2C9, Canada, ann.nakashima@drdc-rddc.gc.ca), Jane Cai (Univ. of Toronto, Toronto, ON, Canada), and Oshin Vartanian (Defence Res. and Development Canada, Toronto, ON, Canada)

The importance of speech intelligibility in learning and occupational environments is evidenced by the abundance of research in room acoustics and auditory communication. In addition to environmental factors such as background noise and reverberation, individual factors including the presence of hearing loss, wearing of hearing aids and hearing protection devices (HPDs), and language proficiency must be considered. Previous work in these areas has provided a benchmark for the study of communication in complex, high noise environments. For Canadian Armed Forces (CAF) members, the high noise levels inside aircraft, armoured vehicles and sea vessels demand the use of HPDs and integrated radio communication systems. This presentation will summarize our research on speech understanding in noise and multi-talker environments using different communication headsets, simulated hearing loss and language proficiency. We will focus on our recent studies of communication between native (L1) and non-native (L2) English speakers, which is applicable to the CAF due to the relatively high percentage of L2 membership. L2 speakers obtained lower scores on speech-in-noise tests than L1 speakers for both radioed and face-to-face speech, despite having a high level of language proficiency. Preliminary results of an investigation of cognitive load for L2 listeners will also be presented.

Invited Papers

1:50

5pAA3. Effects of background noise, talker's voice, and speechreading on speech understanding by primary school children in simulated classroom listening situations. Mary Rudner (Dept. of Behavioural Sci. and Learning, Linköping Univ., Linköping, Sweden), Viveka Lyberg-Åhlander (Dept. of Clinical Sci., Logopedics, Phoniatrics and Audiol., Lund Univ., Lund, Sweden), Jonas Brännström (Dept. of Clinical Sci., Logopedics, Phoniatrics and Audiol., Lund Univ., Malmö, Sweden), Jens Nirme (Lund University Cognit. Sci., Lund Univ., Lund, Sweden), Margaret K. Pichora-Fuller (Psych., Univ. of Toronto, 3359 Mississauga Rd., Mississauga, ON L5L 1C6, Canada, k.pichora.fuller@utoronto.ca), and Birgitta Sahlén (Dept. of Clinical Sci., Logopedics, Phoniatrics and Audiol., Lund Univ., Lund, Sweden)

In the primary school classroom, children are exposed to multiple factors that combine to create adverse conditions for listening to and understanding what the teacher is saying. Four experiments were conducted to investigate the combined effects of background babble noise (quiet vs. noise), voice quality (normal vs. dysphonic), and speechreading (audio-only vs. audio-visual cues) on speech understanding in 245 eight-year old children. Comprehension was tested using narratives from the test of Clinical Evaluation of Language Fundamentals. Background babble noise was composed of several children talking. Visual speech cues were presented using a digitally animated talker. Vocal loading was used to induce a dysphonic (hoarse) voice. Speech understanding was reduced by even low levels of babble noise, but compensated by visual cues. Dysphonia did not significantly reduce comprehension scores, but it was considered unpleasant. There was some evidence that performance in adverse conditions was positively associated with individual differences in cognitive executive function. Overall, these results suggest that multiple factors combine to influence speech understanding and listening effort for child listeners in the primary school classroom. The constellation of these room, talker, modality, and listener factors should be taken into account in the planning and design of educational and learning activities.

2:10

5pAA4. Research trajectories in classroom acoustics: Investigating children perception beyond accuracy. Nicola Prodi (Dept. of Eng., Univ. of Ferrara, via Saragat 1, Ferrara 44122, Italy, nicola.prodi@unife.it)

In a prospective discussion with Murray Hodgson earlier in 2003 in Ferrara, we agreed that much further insight should be gained in the perception of room acoustics for speech, and classrooms were the main area of common interest. In fact several metrics have been in use since long to assess listeners' accuracy, either objectively or subjectively. Unfortunately, these tools are not effective in tracking the listening effort, which may occur even if accuracy is high. Thus, an extension of the analysis beyond acoustically and accuracy-oriented indicators is required to grasp information on the multi-faceted construct of listening effort. In the field of audiology a framework for listening effort was developed and several psycho-physiological and behavioral quantities have been proposed. None of them is considered exhaustive, and different quantities are sensitive to peculiar aspects: for instance, the slowing down of response time in adverse conditions is thought to trace an increase of processing load. Applying this knowledge in the field of room acoustics may fill the gap in the evaluation and design of rooms for speech communication. In this work, the results achieved so far will be presented and applications in the field of classroom acoustics will be outlined too.

2:30

5pAA5. Learning and interacting in noisy classrooms: what background noise measures and subjective teacher perceptions tell us about the challenges for students who are hard of hearing. Janet R. Jamieson (Educational & Counselling Psych., & Special Education, Univ. of Br. Columbia, Faculty of Education/ECPS, University of Br. Columbia, 2125 Main Mall, Vancouver, BC V6T 1Z4, Canada, janet.jamieson@ubc.ca), Brenda Poon (School of Population and Public Health, Univ. of Br. Columbia, Vancouver, BC, Canada), and Anat Zaidman-Zait (School of Education, Tel Aviv Univ., Tel Aviv, Israel)

The negative impact of noisy classrooms can impede academic performance for even typically hearing children. The purpose of this qualitative study was to investigate the impact of noisy classrooms on the social and academic experiences of deaf and hard-of-hearing students, who are increasingly educated alongside their hearing peers. First, background noise levels were measured in 11 kindergarten-Grade 7 classrooms in which children with hearing loss were placed, during the first $1\frac{1}{2}$ hours of one school day. Based on the ongoing activities and background noise levels, predictions were made as to when the children would likely experience the most and least adverse listening conditions. Second, teachers were interviewed to obtain their perspectives of the learning and socialization experiences of the children with hearing loss. Overall, there was striking consistency between the predicted difficulties based on objective acoustic measures and perceived difficulties based on teachers' subjective perspectives. Thematic analysis of the interviews revealed the following major themes concerning the students with hearing loss: difficulty hearing instruction; missing out on social communication with peers; and difficulty recognizing and managing transitions. Overall, these findings suggest that background noise in elementary school classrooms negatively impacts listening, learning, and social interaction for students with hearing loss.

Contributed Paper

2:50

5pAA6. Verification of average absorption coefficients—A follow-up on one of Murray Hodgson's Classroom Acoustics Projects. Katrina Scherebnyj (BKL Consultants Ltd., #308,1200 Lynn Valley Rd., North Vancouver, BC V7J 2A2, Canada, scherebnyj@bkl.ca)

Twelve years ago, multivariable linear-regression analysis techniques were used with data from over a hundred UBC classrooms to estimate the "average" absorption coefficient of typical surfaces in classrooms. The purpose of the work was to obtain accurate estimates that could be used in the design of new classrooms, to better predict the early-decay time[1]. The current paper applies the results from the previous work to new classrooms, outside UBC. Detailed information is known regarding the surface types and absorption coefficients used in these classrooms. Measurements of the early decay times have also been taken. Comparisons are made between the early-decay times predicted using standard absorption coefficients, the

"average" absorption coefficients from the UBC classrooms, and measurements. [1] Hodgson M., Scherebnyj K. Technical note—*Estimation of the absorption coefficients of the surfaces of Classrooms.* Applied Acoustics 67 (2006) 936–944.

Invited Papers

3:05

5pAA7. Trajectories in classroom acoustics: The vocal behaviour of teachers. Arianna Astolfi (Energy, Politecnico di Torino, Corso DC degli Abruzzi, 24, Turin 10124, Italy, arianna.astolfi@polito.it)

Classroom acoustics was one of the main research themes of Murray Hodgson, which I had the chance to know in Rome, at the ICA Conference in 2001, when I was at the beginning of my working path, and to further have as scientific converser in many other occasions. In Ferrara, in 2003, he concluded his presentation of a course on classroom acoustics with the hint that the teachers' voice problems should have been object of future studies. I have been working on this matter for seven years and this work summarises the results and the perspectives related to the assessment of teachers' vocal behaviour. In particular, teachers' voice monitoring during daily working activities has been recently based on wearable vocal analysers equipped with contact sensors, which allow for measuring parameters related to vocal effort, vocal loading and also to voice quality. Results obtained during experimental campaigns that took place in the last years, from kindergarten to university, and that involved healthy and unhealthy teachers, are presented in this work. The relationships with classroom acoustics, both in terms of noise and too low or excessive reverberations, and the subjective outcomes of the teachers, are also discussed.

3:25

5pAA8. Cross-modal effects of noise and thermal conditions on indoor environmental perceptions. Wonyoung Yang, Hyeun Jun Moon, and Myung-Jun Kim (Dept. of Architectural Eng., Dankook Univ., #318, Eng. 1 Bldg., 152 Jukjoen-ro, Suji-gu, Yongin, Gyeonggi 16890, South Korea, wyang@dankook.ac.kr)

Realistic thermal conditions with various humidity levels have been considered to examine cross-modal effects of noise and thermal conditions on indoor environmental perceptions. Subjective assessments of temperature, humidity and acoustics were conducted with 26 subjects under combined environments of seven thermal conditions (18°C: RH 30, 60%, 24°C: RH 27, 43, 65%, 30°C: RH 30, 60%), two noise types (fan and babble noises) and five noise levels (45, 50, 55, 60, and 65 dBA). Three-minute moderate noise exposure did not affect temperature or humidity sensations. However, temperature and humidity levels affected loudness, annoyance, and acoustic preferences. Men were more sensitive to hot sensations than women, and women were more sensitive to arid sensations than men. Women were more sensitive to noise levels than men. Gender differences were also found in terms of different types of noise. Men were found to be significantly less sensitive to fan noise than women. Even though psychoacoustic parameters were affected by indoor thermal conditions; thermal parameters were not affected by short-term moderate noise. The combined effect of various types of noise and temperature is still unclear, and this will be considered in a future larger cohort study.

Session 5pAB

Animal Bioacoustics: Marine Mammal Bioacoustics II

Jesse C. Turner, Chair
SMRU Consulting, 400 Emmerling Pl, Friday Harbor, WA 98250

Contributed Papers

1:00

5pAB1. Antarctic type C killer whale (*Orcinus orca*) call repertoire from McMurdo Sound, Ross Sea. Rebecca Wellard (Ctr. for Marine Sci. and Technol., Curtin Univ., GPO Box U1987, Perth, WA 6845, Australia, becwellard@gmail.com), Robert Pitman (Antarctic Ecosystem Res. Div., Southwest Fisheries Sci. Ctr., National Marine Fisheries Service, La Jolla, CA), John Durban (Marine Mammal and Turtle Div., Southwest Fisheries Sci. Ctr., National Marine Fisheries Service, La Jolla, CA), and Christine Erbe (Ctr. for Marine Sci. and Technol., Curtin Univ., Bentley, WA, Australia)

Killer whales (*Orcinus orca*) are found in all oceans of the world. In Antarctic waters, five ecotypes have been described, each displaying distinct differences in morphological features, foraging behaviours, habitat and diet preferences, and genetic structure. Acoustic recordings of Type C killer whales were collected between December 2012 and January 2013 in McMurdo Sound, Ross Sea, Antarctica. Spectrograms of acoustic data were examined for characteristic patterns of Type C vocalizations and a call type catalogue was produced. We measured acoustic parameters of each call type for both whistle and burst-pulse sounds and we then compared call features of Type C animals to those of other killer whales described in the Southern Hemisphere. Analysis of calls revealed that Type C killer whales produce a large number of biphonations and complex calls with multiple frequency-modulated and pulsed components. The limited accessibility of Antarctic regions year-round makes passive acoustic monitoring (PAM) a very effective tool to derive information on ecotype-specific distribution and seasonal occurrence. This study provides new information on the call repertoire of Type C killer whales, investigates the potential use of PAM to study Antarctic ecotypes, and also examines utilising call repertoire as a reliable diagnostic tool for identifying sympatric ecotypes in Antarctic waters.

1:15

5pAB2. Characteristics of Guiana dolphins (*Sotalia guianensis*) burst-pulse sounds emitted during different surface activity rates in Rio de Janeiro's coast. Mariana Barbosa (Programa de Pós Graduação em Ecologia e Evolução, Rio de Janeiro State Univ., Rua São Francisco Xavier 524, Maracanã, Rio de Janeiro, Rio de Janeiro 20550-013, Brazil, marib66@gmail.com), Lis Bittencourt, Luciana Andrade, Tatiana Bisi, José Lailson-Brito, and Alexandre d. Azevedo (MAQUA - Laboratório de mamíferos aquáticos e bioindicadores, Rio de Janeiro State Univ., Rio de Janeiro, RJ, Brazil)

Burst-pulses are still the least studied signals in delphinid acoustic repertoire. In this study, acoustic data were gathered in two Rio de Janeiro coastal bays where groups of Guiana dolphins can be found regularly. The acoustic equipment consisted of a C54XRS hydrophone (-155.8 dBV, 0.006 Hz a 203 kHz) and a Fostex digital recorder (192 kHz sampling rate). During each recording, the surface activity rate of the group was classified as being high or low. Burst-pulses were analyzed using SoundRuler software. Fifty signals were randomly selected and the values for duration (low = 143.9 $\pm$ 145.4; high = 82.2 $\pm$ 74.8), interpulse interval (low = 2.81 $\pm$ 1.92; high = 1.34 $\pm$ 1.35), number of pulses (low = 52.6 $\pm$ 55.7; high = 71.6 $\pm$ 64.5), peak frequency (low = 37.4 $\pm$ 2.5; high = 38.5 $\pm$ 3.2), and minimum frequency (low = 15.4 $\pm$ 6.5; high = 6.7 $\pm$ 5.3) were measured. Additionally, a Mann-Whitney U test compared all acoustic parameters of burst-pulses emitted during both surface activity rates. Significant differences between activity rates were found for interpulse interval ($p<0.01$) and minimum frequency ($p<0.01$). This scenario could indicate that some burst-pulse parameters are related to group arousal and behavior.

1:30

5pAB3. Seasonal patterns in marine mammal vocalizations in the western Canadian Arctic. William D. Halliday (Wildlife Conservation Society Canada, Wildlife Conservation Society, 169 Titanium Way, Whitehorse, YT Y1A 0E9, Canada, whalliday@wcs.org), Stephen J. Insley (Wildlife Conservation Society Canada, Whitehorse, Br. Columbia, Canada), and Xavier Mouy (Jasco Appl. Sci., Victoria, BC, Canada)

The Arctic marine environment is changing rapidly through a combination of sea ice loss and increased anthropogenic activity. Given that these changes can affect marine animals in a variety of ways, understanding the spatial and temporal distributions of Arctic marine animals is imperative. Here, we use passive acoustic monitoring to examine the presence of marine mammals in the western Canadian Arctic, where we have had recorders deployed near the communities of Sachs Harbour and Ulukhaktok, Northwest Territories, Canada. At both sites, we documented bowhead and beluga whales during the ice-free season, bearded seals throughout the ice-covered season and during their mating season, and ringed seals throughout the year. The sites also had different patterns in marine mammal presence, where we found whales later into the year at Ulukhaktok than at Sachs Harbour, and ringed seals vocalized much more at Ulukhaktok than at Sachs Harbour. These patterns in vocal activity at both sites help to document the presence of each species in the western Canadian Arctic, and serve as a baseline for future monitoring in the region. Next steps in this project involve deploying at more sites throughout the region to more comprehensively monitor marine mammals in the region.

1:45

5pAB4. Description of seasonal acoustic occurrences of humpback and minke whales in South Africa and Antarctica. Fannie W. Shabangu (Agriculture, Forestry and Fisheries, Fisheries Management, 13 Barlinka Ave., Tableview, Cape Town, Western Cape 7441, South Africa, fannie.shabangu@yahoo.com)

Seasonal acoustic occurrences and diel singing patterns of humpback whale (*Megaptera novaeangliae*) songs and Antarctic minke (*Balaenoptera bonaerensis*) whale are described using acoustic recordings from the west coast of South Africa and Maud Rise, Antarctica. Acoustic data were recorded from early 2014 to early 2017. Acoustic occurrences (i.e., presence) of humpback and minke whale sounds were identified through visual scrutiny of spectrograms of recorded data. Environmental conditions associated with humpback whale song occurrences were ranked according to their model-predicted relative importance. In South Africa, humpback whale songs were detected from June to December but peaked in September. In Antarctica, humpback whale songs were detected from March to May (singing peaked in April). Minke whale sounds were only recorded in 2014, between June and September in Antarctica and between September and November in South Africa. Humpback whales were more vocally active at

night in all recording sites whereas minke whales were more vocally active during the day. This is the first study to describe the seasonal acoustic occurrences of humpback and minke whales off the west coast of South Africa. Such knowledge could be essential for the conservation and management of these species in both South Africa and Antarctica.

2:00–2:15 Break

2:15

5pAB5. Development of beluga calf calls (*Delphinapterus leucas*) in the first six months of life. Audra Ames (Fundación Oceanogràfic, C/ Eduardo Primo Yúfera (Científic), 1B, Valencia, Valencia 46013, Spain, aames@oceanografic.org), Jason Wood (SMRU Consulting, Friday Harbor, WA), and Valeria Vergara (Ocean Wise Conservation Assoc., Vancouver, BC, Canada)

As part of an ongoing effort to understand beluga mother-calf communication and impacts of anthropogenic noise on neonate calls, we investigated a male beluga calf's vocal development at Oceanogràfic, using a calibrated digital hydrophone with a sampling rate of 256 kHz. His initial vocalizations were broadband pulse-trains with upper frequency limits reaching $\geq$128 kHz on his first day of life, higher than reported by earlier studies limited by lower sampling rates. Over the calf's first six months, pulsed trains were the predominant call type, increasing significantly in peak and first quartile frequencies and pulse repetition rate during this period. First and third quartile frequencies also increased significantly over the calf's first month, indicating an early and continuous shift in pulse train energy distribution towards higher frequencies. While mixed and tonal calls appeared sporadically in the calf's first month of life, they were not common until his third month, when they comprised 13% of his vocalizations. Additionally, estimated source levels of the calf's calls increased throughout his first month, but were lower than those for adult belugas. This, coupled with the progressive shift in energy distribution, has important implications regarding a neonate's ability to compensate for noise.

2:30

5pAB6. Sperm whale inter-pulse intervals and size: The anomaly called Yukusam. Jesse C. Turner, Jason Wood (SMRU Consulting, 400 Emmerling Pl, Friday Harbor, WA 98250, jt1@smruconsulting.com), and Jared Towers (Bay Cetology, Alert Bay, BC, Canada)

Yukusam is the name given to a male sperm whale who was first documented off northeastern Vancouver Island in February 2018. He spent several weeks in this area before traveling south to the inland waters of the Salish Sea in late March 2018. Sperm whale clicks have been used as a proxy to determine overall size by using the time difference of arrival between the initial noise pulse and its reflections within the spermaceti organ. Different equations have been derived in order to use this Inter-Pulse Interval (IPI) to estimate overall length. Here we use Yukusam's usual clicks recorded from the Lime Kiln hydrophone on the west side of San Juan Island (WA State, USA) to compare IPI-based length estimates with visual observations. Photo and video documentation indicate that this whale is ~15 m in length. Our initial acoustic results indicate that equations in the literature underestimate his length by at least a few meters. The potential reasons behind these anomalies are explored in this presentation.

2:45

5pAB7. Song production by the eastern North Pacific right whale, *Eubalaena japonica*. Jessica Crance, Catherine L. Berchok (AFSC/NMFS/NOAA, Marine Mammal Lab, 7600 Sand Point Way NE, Seattle, WA 98115, Jessica.Crance@noaa.gov), Dana Wright, Arial Brewer, and Daniel Woodrich (Joint Inst. for the Study of the Atmosphere and Oceans, Univ. of Washington, Seattle, WA)

This paper describes unique, stereotyped, gunshot songs produced by the eastern North Pacific right whale (NPRW, *Eubalaena japonica*). Four unique songs were documented over eight years (2009–2017) and five separate locations in the southeastern Bering Sea. Similar to songs reported for other species, each NPRW song consists of a hierarchical structure of 1-3 different repeating phrases comprised predominantly of gunshot calls (though other call types were occasionally present). Songs were detected every year from July through early January. All four song structures remained consistent over eight years. Two different songs often occurred simultaneously; the same song never occurred simultaneously at the same location. However, the detection of the same song on the same day and time at two locations 310 km apart indicates multiple animals can produce the same song. These songs were localized to individual male NPRWs using directional sonobuoys; it remains unknown if females also sing. We hypothesize that these songs may be a reproductive display similar to song in other mysticetes. Although singing has not been documented in congeneric right whale species, songs presented here fit the classification of song attributed to other cetacean species. Possible functions of these songs and their management implications will be discussed.

3:00

5pAB8. Investigation of the context of humpback whale non-song calls in the North Atlantic. Mikala Epp and Gail Davoren (Biology, Univ. of MB, 66 Chancellors Circle, Winnipeg, MB R3T 2N2, Canada, eppm34@myumanitoba.ca)

Humpback whales display behavioural plasticity in their foraging behaviours and non-song calling behaviours. Prey type appears to be associated with some of the variation in foraging behaviours and, thus, may also be related to variation in use of non-song calls related to foraging. Our goal was to compare non-song calls from two regions and identify any call types that occur in only one of the regions. We used recordings from stationary hydrophones within two foraging grounds: from the northeast Newfoundland coast, where capelin is the main prey; and the Gulf of Maine, where herring and sand lance dominate the diet. These areas are sympatric and foraging groups are thought to be from the same breeding aggregation, suggesting that call type differences would not have a genetic-basis. Most of the call types were the same across both areas, as has been found across many foraging grounds, but a small number of call types and call sequences were heard in only one of the two regions. We hope to use multi-sensor tag data and video recordings to help identify the contexts of these calls to further determine whether non-song call variation can be linked to prey type.

3:15

5pAB9. Differential hearing sensitivity in the adaptive background in a beluga whale. Vladimir Popov, Dmitry Nechaev, Alexander Supin, and Evgeniya Sysueva (Inst. of Ecology and Evolution, 33 Leninskij Prosp., Moscow 119071, Russian Federation, popov.vl.vl@gmail.com)

The ability of the auditory system to maintain high differential sensitivity in the adaptive background was investigated in a beluga whale (*Delphinapterus leucas*). Adaptive background was a train of tone pips following one another at a rate of 1 kHz. Each pip consisted of eight carrier cycles of 64 kHz. Every 128 ms, the train of pips was interrupted for 16 ms and replaced with a test signal (16-ms series of the same tone pips as in the adaptive background, but of another level). The level of the test signals varied from -15 to +20 dB relative the level of adaptive background. Evoked potentials (the rate following response, RFR) produced by the test signals were recorded. Increasing of adaptive level led to RFR thresholds growth. The 10-dB rising of adaptive signals intensity level led to 7.8 dB rising of test signal threshold. The response amplitude dependence on the test stimulus level was almost independent of the level of the adaptive background. Thus, the beluga's auditory system displayed high sensitivity to the change in acoustic signal level in the high-level background. [This study was supported by the Russian Foundation for Basic Research (Grant No. 18-04-00088).]

Session 5pAOa

Acoustical Oceanography and Underwater Acoustics: Experimental Assessment of Theories of Sound Propagation in Sediments II

Orest Diachok, Cochair
Johns Hopkins University APL, 11100 Johns Hopkins Rd., Laurel, MD 20723

N. Ross Chapman, Cochair
School Earth and Ocean Sciences, Univ. of Victoria, P.O. Box 3065, Victoria, BC V8P 5C2, Canada

Invited Papers

1:00

5pAOa1. Laboratory experimental assessment of models for elastic wave propagation in marine sands. Masao Kimura (Poro-Acoust. Lab., 1115-22 Miyakami, Shimizu, Shizuoka, Shizuoka 424-0911, Japan, mk45@nifty.com)

Laboratory experimental research on the models for elastic wave propagation in marine sands has been performed. The speed dispersion and attenuation of compressional and shear waves using water-saturated unconsolidated glass beads and sands have been measured. The measured compressional wave speed dispersion and attenuation could be predicted by using a gap stiffness model incorporated into the Biot model (the BIMGS model) in the range of $kd \leq 0.5$ (k: wavenumber in water, d: grain diameter) and by using the BIMGS model plus multiple scattering effects in the range of $kd \geq 0.5$. The temperature and grain size dependence of shear wave speed dispersion and attenuation has been measured. The results showed the validity of the BIMGS model. Furthermore, the empirical equations for the tortuosity, permeability, and pore radius, which are important parameters in the Biot and modified Biot models, were derived. Finally, new laboratory experiments on the dependence of the compressional wave speed and attenuation on the temperature, and the effect of grain size distribution on speed dispersion and attenuation that may shed new light on the validity of the models will be suggested.

1:20

5pAOa2. Ocean sediments and the Biot theory. Nicholas P. Chotiros (ONRG, 86 Blenheim Crescent, Ruislip HA47HB, United Kingdom, nicholas.p.chotiros.civ@mail.mil)

The surficial ocean sediment is usually a granular medium, therefore it is a porous medium and follows Biot's theory. It predicts one shear wave and two compressional waves, called the fast and slow waves. This sets it apart from the acoustic theories of uniform media (solids or fluids) which permit only one compressional wave. The fast wave is similar to the compressional wave in a solid or fluid. The slow wave is unique to porous media, it is difficult to detect and its presence in the ocean sediment is controversial. There is indirect evidence of the Biot slow wave: The deviation of the acoustic reflection coefficient of the ocean sediment from Rayleigh's reflection equation, can be explained in terms of the Biot slow wave. Direct detection of the Biot slow wave has been reported in some porous media, particularly sintered glass beads. However, its detection in unconsolidated media such as water saturated sand needs more work. Direct measurement of its properties is desirable. Simulations suggest that it could explain some unusual behavior of finely layered sediments. Finally, due to natural granularity, there should be a continuous conversion between the fast and slow waves that is missing from current models.

1:40

5pAOa3. Observation of Biot compressional waves of the second kind in granular soils. Koichi Nakagawa (Faculty of Sci., Osaka City Univ., 3-3-138 Sugimoto, Sumiyoshi-ku, Osaka City, Osaka Prefecture 558-8585, Japan, knaka@kind.ocn.ne.jp), Kenichi Soga (Dept. of Civil and Environ. Eng., Univ. of California, Berkeley, Berkeley, CA), and James K. Mitchell (Dept. of Civil and Environ. Eng., Virginia Tech, Blacksburg, VA)

The compressional wave of the second kind predicted theoretically by Biot was observed in granular soils using triaxial testing system. This theory models both the individual and coupled behavior of soil skeleton and pore fluid using the properties of pore space and elastic constants of the solid, pore fluid and solid skeleton. The wave is characterized by its large damping and hence detection of the wave in the laboratory is difficult. This difficulty was overcome by adopting highly sensitive sensor, signal stacking and appropriate filtering. The propagation of the P- and S-waves in granular materials was measured under different confining pressures and in both dry and saturated conditions. The phase of the Biot wave was the opposite to that of the P- and S- waves in all observed. According to the theory, the Biot wave results from the out-of-phase movement of the soil skeleton and pore fluid. The measured Biot wave velocities agree well with the theoretical values computed using the properties and parameters which were obtained primarily from laboratory tests. The good agreement demonstrates that the theory is valid for granular soils.

2:00–2:15 Break

2:15

5pAOa4. On an attenuation obeying a frequency power law. Michael J. Buckingham (Scripps Inst. of Oceanogr., Univ. of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0238, mbuckingham@ucsd.edu)

An attenuation obeying a frequency power law scales as $|\omega|^{\beta}$, where ω is angular frequency and β is a real constant. According to the strain-hardening shear-wave equation in the grain-shearing theory, the attenuation of the shear wave supported by a marine sediment follows a frequency power law. The associated dispersion formula, which is a causal transform, predicts that the phase speed is also a power law and that the product of the phase speed and the attenuation divided by ω is a constant, independent of frequency. From the dispersion formula, along with the conditions that the phase speed and attenuation must both be positive and the propagation factor must exhibit conjugate symmetry, it follows that the exponent β can take only certain values that fall in well-defined intervals extending indefinitely with no upper or lower limit. However, to satisfy the requirement that Green's function be causal, β is further constrained to lie in the interval [0.5 1), under which condition the Green's function is maximally flat at the time the source is activated. With other values of β the Green's function is non-causal, exhibiting non-zero values at times preceding the onset of the source. [Research supported by ONR.]

2:30

5pAOa5. Viscosity-based theory of phase velocity and attenuation of sound in mud consisting of water and flocculated clay particles. Elisabeth M. Brown (Mathematical Sci., Rensselaer Polytechnic Inst., Troy, NY 12180, browne6@rpi.edu), Allan D. Pierce (Cape Cod Inst. for Sci. and Eng., East Sandwich, MA), and William L. Siegmann (Mathematical Sci., Rensselaer Polytechnic Inst., Troy, NY)

Recent theory of authors ascribes attenuation in typical marine mud sediments to be caused by viscous interaction of sea water with embedded silt particles. Influence of underlying clay matrix is regarded as passive and of minor importance. Present paper considers silt-less mud where clay particles are flocculated to a card-house structure, with the flocculation hypothesis yielding a porosity of 90%. During the passage of a sound wave, Vander-Waals forces between platelets cause the matrix to move to-and-fro as a unit; viscous forces are insufficient to cause the matrix to move perfectly with the water. The silt-less theory assumes that the local force on the matrix is the sum of the viscous forces on the platelets in the matrix. Forces on clay particles, which are thin platelets, are given by a low-Reynolds flow theory initiated by Stokes, and further developed by Oberbeck, Lamb, and Brenner. For each particle there is a characteristic frequency inversely proportional to the platelet thickness, which turns out to be extremely high for clay. Consequently, at acoustic frequencies, the clay matrix moves nearly in lock-step with the fluid motion associated with the sound wave. The inevitable very-small slip leads to an attenuation that is proportional to the square of the frequency, but which is very small compared with that of mud with embedded silt-particles. Current idealized theory results in prediction of attenuation inversely proportional to viscosity and of nearly constant phase velocity. [Work supported by ONR.]

2:45

5pAOa6. A micro-mechanical model for the Biot theory of acoustic waves in a fully saturated granular material. Luigi La Ragione, Giuseppina Recchia (Dipartimento di Scienze dell'Ingegneria Civile e dell'Architettura, Politecnico di Bari, Via Jacini, 11, Bari, BA 70125, Italy, luigi.laragione@poliba.it), and James T. Jenkins (Dept. of Civil and Environ. Eng., Cornell Univ., Ithaca, NY)

In the context of the classical Biot theory for acoustic waves in a fully saturated granular material, we improve upon the constitutive relation of the solid phase by means of micro-mechanical modeling. This is needed to explain discrepancies on the dependency of the frequency with the sound speed attenuation and dispersion between present models and experiment. The micro-mechanical provides a more detailed description of the interaction between the particles and water and gives an expression for the stress of the entire aggregate based upon micro mechanical parameters such as coordination number (average number of contacts per particle), porosity, material properties. The aggregate is modeled as a collection of particles that are stiffer than the water; so in the particle fluid interaction, idealized by a Standard Linear Solid model, only the compressibility of the water is taken in account. The possibility to include a deviation of the particle motion from the classical affine deformation is explored. Predictions of the sound speed attenuation and dispersion are provided in the context of a uniaxial deformation.

3:00

5pAOa7. Estimating muddy seabed properties using ambient noise coherence. David R. Barclay (Oceanogr., Dalhousie Univ., Dept. of Oceanogr., PO Box 15000, Halifax, NS B3H 4R2, Canada, dbarclay@dal.ca), Dieter A. Bevans, and Michael J. Buckingham (Marine Physical Lab, Scripps Inst. of Oceanogr., La Jolla, CA)

During the Seabed Characterization Experiment, a multi-institutional field effort held at the New England mud patch, the autonomous passive acoustic lander Deep Sound made a series of ambient noise measurements from the seafloor. The instrument platform carried four hydrophones, arranged in an inverted 'T' shape with three spaced in the horizontal and two in the vertical, and landed on the seafloor with the bottom phones 30 cm above the interface. Pressure time series, vertical and horizontal noise coherence (directionality), were recorded continuously for periods of 9 hours over the acoustic bandwidth of 5 Hz to 30 kHz, along with the local temperature, conductivity, and depth. An analytical Pekeris waveguide noise model was fitted to the data in order to determine the bulk sound speed, sheer speed, density, and frequency dependent attenuation in the bottom fluid half-space. Acoustic properties of the mud were determined by comparing the data to the output of a range independent noise model, featuring a realistic multi-layered seabed. [Research supported by ONR.]

3:15

5pAOa8. Coherent processing of ocean ambient noise for sediment profiling and head-wave detection using a vertical line array in the Santa Barbara Channel. Lanfranco Muzi and Martin Siderius (Elec. and Comput. Eng., Portland State Univ., 1900 SW 4th Ave., Ste. 160, Portland, OR 97201, muzi@pdx.edu)

In this study, sediment profiling using the passive fathometer and the head-wave phenomenon are investigated. Head waves are created by waves propagating in sediments parallel to the water-sediment interface (possibly at a speed higher than the water sound speed), and propagating back in the water at critical angles. Ocean ambient noise recorded by a vertical line array is processed using a generalization of the known "passive fathometer." The technique can detect coherent time-separated arrivals at specific angles that are consistent with the propagation of head waves. The arrivals structure detected at endfire provides information on the sediment layering, while the head wave can be used to estimate the sediment sound speed, and may provide information about the attenuation. The technique is demonstrated using simulation and data from the Santa Barbara Channel Experiment of 2016, using both natural noise generated at the surface, and—for the first time—the noise generated by a ship. [Work supported by the Office of Naval Research, Ocean Acoustics Program.]

3:30

5pAOa9. MUD, the next generation in acoustic backscatter sediment measurements. Todd D. Mudge (ASL Environ. Sci. Inc, 1-6703 Rajpur Pl., Victoria, BC V8M 1Z5, Canada, tmudge@aslenv.com), Gwyn Lintern (Pacific GeoSci. Centre/NRCan, Victoria, BC, Canada), David Lemon, and Keath Borg (ASL Environ. Sci. Inc, Victoria, BC, Canada)

Detection and classification of sediments within rarely occurring turbidity flows is challenging, in part because of the acoustic absorption and scattering within the dense suspended sediments. A new calibrated acoustic backscatter echosounder, the Multifrequency Ultrasonic Device (MUD^{TM}), was deployed from 13 to 16, May 2018, at about 120 m

water depth within Bute Inlet, Canada. The MUD prototype (1.2 MHz, 769 kHz and 200 kHz) was deployed in a tautline mooring which included a passive acoustic recorder, an ADCP, CT sensor and OBS sensor. The frequencies for the prototype were selected to allow for a compromise between good acoustic range and penetration into dense flows with the potential for particle size discrimination. Preliminary analysis of the data indicates the presence of three turbidity flows over a two-hour period with speeds of up to 2.5 m/s. As anticipated, the lower frequencies did better in penetrating through the dense turbidity flow. This suggests that it will be possible to use inversion of the acoustic backscatter to estimate sediment concentrations within the dense head of the turbidity flow. Multifrequency inversion techniques will be applied to the less dense portion of the flow to estimate particle size distributions.

FRIDAY AFTERNOON, 9 NOVEMBER 2018 SAANICH 1/2 (VCC), 1:00 P.M. TO 3:20 P.M.

Session 5pAOb

Acoustical Oceanography, Underwater Acoustics, and Animal Bioacoustics: Ocean Observatories: Laboratories for Acoustical Oceanography II

Bruce Howe, Cochair
Ocean and Resources Engineering, University of Hawaii, 2540 Dole Street, Holmes Hall 402, Honolulu, HI 96822

Brendan P. Rideout, Cochair
Department of Ocean and Resources Engineering, University of Hawaii at Manoa, 2540 Dole St., Holmes Hall 402, Honolulu, HI 96822

Invited Papers

1:00

5pAOb1. Acoustic mapping of ocean currents using moving vehicles. Chen-Fen Huang, KuangYu Chen (Inst. of Oceanogr., National Taiwan Univ., No. 1, Sec. 4, Roosevelt Rd., Taipei 10617, Taiwan, chenfen@ntu.edu.tw), Sheng-Wei Huang, JenHwa Guo (Dept. of Eng. Sci. and Ocean Eng., National Taiwan Univ., Taipei, Taiwan), and Naokazu Taniguchi (Hiroshima Univ., Taipei, Taiwan)

With the increased availability of highly maneuverable unmanned surface and underwater vehicles, abundant ocean environmental data can now be collected. Most environmental surveys by unmanned vehicles conduct point measurements of the ocean properties along survey lines. This study uses tomographic techniques to extend the survey area covered by the autonomous vehicles and obtain a synoptic ocean current distribution. An acoustic reciprocal transmission experiment was carried out on June 27, 2017, in ChaoJing Bay nearby Keelung City, where the water depth varies from 20 m to 65 m. A total of three tomographic sensors were deployed and they were installed on an AUV, a fishing boat, and a bottom-moored buoy. Reciprocal acoustic transmissions between the mobile platforms were used to estimate ocean currents, which required accounting for the Doppler effects on the acoustic arrival patterns and the resulting differential travel times. The estimated areal currents show consistency with the ADCP current measurement from the boat when the covered area was near the deeper water.

1:20

5pAOb2. Inversion of range-dependent ocean environmental parameters using radiation noises of an Autonomous Underwater Vehicle. Wen Xu, Ming Zhang, and Yuanxin Xu (Zhejiang Univ., No. 38, Zheda Rd., Hangzhou 310027, China, wxu@zju.edu.cn)

Moving platform is playing an increasingly important role in ocean observatories. We previously reported some field testing results of using the radiation noises of an Autonomous Underwater Vehicle (AUV) as the sound source to invert the range-independent SSP. To incorporate source motion effects, the forward model based on the waveguide Doppler and normal mode theory was applied to compute the replica field, and to resolve the adjacent Doppler shifted frequencies, an analytical solution of the forward model and its simplified version were obtained for arbitrary signal integration intervals with a monochromatic source. In this paper, we reformulate the matched-field inversion problem into a state-space model to track the range-dependent environmental parameters and moving source parameters along the AUV path with the constantly updated measurement equations. Performances of several sequential filters, including extended Kalman, unscented Kalman, and particle filters, are compared. Note that at each point of the track, the estimate is the average from the source to the receiver; by doing the inversion sequentially with AUV moving, one can get the parameter estimate at individual points (sections). This process is equivalent to iteration over space, while iteration over time is considered as a solution to an under-determined inverse problem.

1:40

5pAOb3. Observations and Feynman path integral analysis of acoustic fluctuations from the 2010-2011 Philippine Sea experiment. John A. Colosi, Chis Miller (Dept. of Oceanogr., Naval Postgrad. School, 833 Dyer Rd., Monterey, CA 93943, jacolosi@nps.edu), Peter F. Worcester, Matthew A. Dzieciuch (Scripps Inst. of Oceanogr., La Jolla, CA), and Tarun K. Chandrayadula (India Inst. of Technol., Chennai, Tamil Nadu, India)

Six acoustic sources arranged in a pentagon with a central point transmitted broadband signals in the frequency range 200–300 Hz to a water column spanning vertical array in the Philippine Sea from Spring 2010 to Spring 2011. The propagation ranges were 128, 210, 224, 379, 396, and 449 km. Observations of phase and intensity variance as well as vertical coherence were obtained for several ray identified wavefronts. These observations are compared to Feynman path integral theory predictions utilizing Garrett-Munk internal wave spectral fits to *in-situ* measurements of temperature, salinity, and current. The observations and theory suggest that the three shortest ranges are in the unsaturated regime while the three longer ranges are in the partially saturated regime. Vertical coherence lengths are well predicted by theory. Implications for future experiments designed to observe internal wave spectra acoustically will be discussed.

1:55

5pAOb4. Philippine Sea deep water acoustic observations : A new test for acoustic wave propagation through random media models. Tarun K. Chandrayadula (Ocean Eng., IIT Madras, 109 B Ocean Eng., IIT Madras, Chennai, Tamil Nadu 600036, India, tkchandr@iitm.ac.in), John A. Colosi (Oceanogr., Naval Postgrad. School, Monterey, CA), Peter F. Worcester, and Matthew Dzieciuch (Univ. of California San Diego, La Jolla, CA)

A primary goal of the Philippine Sea (2010–2011) experiment was to test the ability of models to predict stochastic acoustic fluctuations. The experiment had six different sources transmitting broadband pulses (200 Hz–300 Hz) to a water column spanning vertical line array. The transmission ranges varied from 130 km to 450 km, and took place across a 250 km x 250 km area. The observations are a new opportunity for two reasons. First, the source frequencies are twice that of the previous experiments that used less than 100 Hz. Second, the oceanography is more dynamic than previous sites in the North Pacific with energetic mesoscale and internal tide variability. This talk uses acoustic mode observations to analyze both broadband and narrowband statistics. Narrowband comparisons focus on mode energy estimates at different frequencies, and these results are compared with the Colosi-Morozov model. Broadband observations focus on mode pulse temporal spreads and these results are compared to predictions from a hybrid cross frequency transport theory approach.

2:10

5pAOb5. Information content of ship noise on a drifting volumetric array for passive environmental sensing. Jacquelyn S. Kubicko (U.S. Coast Guard, U.S. Coast Guard Acad., New London, CT 06320, jkubicko@gmail.com), Christopher M. Verlinden (Marine Physical Lab., Scripps Inst. of Oceanogr., Univ. of California, San Diego, La Jolla, CA), Karim G. Sabra (Georgia Inst. of Technol., Atlanta, GA), Jit Sarkar (Marine Physical Lab., Scripps Inst. of Oceanogr., Univ. of California, San Diego, La Jolla, CA), Brendan Nichols, James S. Martin (Georgia Inst. of Technol., Atlanta, GA), and Aileen Fagan (U.S. Coast Guard, New London, CT)

This study investigates the information content of ship noise received on a drifting volumetric array of hydrophones in shallow water marine environments for the purposes of conducting acoustic thermometry or other environmental inversions. Passive inversions for physical oceanographic parameters are conducted using travel time differences, determined by cross-correlating ship noise received on hydrophones suspended beneath drifting buoys. Ships are tracked using the Automatic Identification System (AIS). Information content gained from the inversion is assessed using traditional a-posteriori error analysis. Numerical simulations using a standard normal mode propagation model are used to test limitations of the proposed approach with respect to frequency band, drifting receiver configuration, precision and accuracy of the inversion results, along with sensitivity to environmental and position mismatch. Performance predictions using this model are compared with results from a field experiment using at-sea data collected off the coast of New London, CT in Long Island Sound. Information gathered using passive acoustic inversion methods on drifting arrays can be used to constrain general circulation models (GCMs), in coastal environments, where ship noise is ubiquitous, environmental data are sparse, and the oceanography is dynamic and important for understanding large-scale ocean processes.

Invited Paper

2:25

5pAOb6. Using ships of opportunity for array element localization and relative channel impulse response estimation. Kay L. Gemba, Jit Sarkar, Bruce Cornuelle, William S. Hodgkiss, and William A. Kuperman (MPL/SIO, UCSD, 9500 Gilman Dr., Mail Code 0238, La Jolla, CA 92093-0238, gemba@ucsd.edu)

The uncertainty of estimating relative channel impulse responses (CIRs) obtained using the radiated signature from a ship of opportunity is investigated. The ship observations were taken during a 1.4 km (11 min) transect during the Noise Correlation 2009 (NC09) experiment. Beamforming on the angle associated with the direct ray-path yields an estimate of the ship signature, subsequently used as a matched filter. Relative CIRs are estimated every 2.5 s independently at three vertical line arrays (VLAs) for a total of 270 observations per VLA. The estimated relative arrival-time uncertainty is inversely proportional to source bandwidth and CIR signal-to-noise ratio, and reached a minimum standard deviation of 5 μs (approximately 1 cm). The direct-path relative arrival-times are used to construct time series for each VLA element across the 11 min observation interval. The overall structure of these time series compares favorably with that predicted from an array element localization (AEL) model that exhibits sensitivity on the order of centimeters. The short-term standard deviations calculated on direct-path (7 μs) and bottom-reflected-path (17 μs) time series are in agreement with the estimated arrival-time accuracies. The implication of these observed arrival-time accuracies in the context of making sound speed perturbation and bottom-depth estimates is discussed.

Contributed Paper

2:45

5pAOb7. Acoustics on the roadmap for an Integrated Arctic Observing System. Hanne Sagen and Stein Sandven (Polar Acoust. and Oceanogr. Group, Nansen Environ. and Remote Sensing Ctr., Thormøhlensgt 47, Bergen 5006, Norway, hanne.sagen@nersc.no)

The current status of the ocean *in situ* observing system in the Arctic are addressed in the EU funded Integrated Arctic Observation System (INTAROS). We describe how multipurpose acoustic systems can contribute to fill gaps and to establish an optimized Pan Arctic Ocean Observing System. A brief presentation of the steps from a series of experiments in the Eastern Arctic towards the upcoming pan-arctic Coordinated Arctic Acoustic Thermometry Experiment are given. How we can use this experience to ensure that multipurpose Arctic observation system will get on in roadmap for an Arctic Observing System? Any sustainable ocean observing systems in the Arctic depend on long-term funding, and that funding mechanisms other than research programs should be used for this. To achieve this, we need to engage with stakeholder groups outside the scientific community. How can this be done?

Invited Paper

3:00

5pAOb8. The feasibility of a multipurpose acoustic network in Baffin Bay. Eric Rehm (Takuvik, Université Laval, 1045, av. de la Médecine, local 2078, Pavillon Alexandre-Vachon, PQ, QC G1V 0A7\6, Canada, eric.rehm@takuvik.ulaval.ca), Brian D. Dushaw (Nansen Environ. and Remote Sensing Ctr., Seattle, Washington), Lee E. Freitag (Woods Hole Oceanographic Institution, Woods Hole, MA), Kevin D. Heaney (OASIS Inc., Fairfax Station, VA), Scott Carr (JASCO Appl. Sci., Dartmouth, NS, Canada), Thomas Dakin (Ocean Networks Canada, Victoria, BC, Canada), David Fissel (ASL Environ. Services, Inc., Victoria, BC, Canada), and Garry J. Heard (Defense R&D Canada, Dartmouth, NS, Canada)

Operating autonomous underwater vehicles at high latitudes is a challenge because ice cover prevents the use of GPS or data communications. As a result, our scientific observations are biased towards late spring, summer, and early autumn when ships can navigate and autonomous platforms can safely surface. To address this problem, we studied the feasibility of a basin-scale multipurpose acoustic network called the "Baffin Bay Acoustic Navigation and Communication System" (BBANC). BBANC would deploy broadband low frequency sources and receivers, offering one-way communication, acoustic positioning, and acoustic thermometry services. Passive acoustic listening elements would support the study of marine mammal communication and ambient noise from ships, ocean-based resource exploitation, and ice dynamics, as well as gate acoustic source operation in the presence of marine mammals. We describe the challenges and design parameters for such a system, as well as define additional acoustic and remote sensing measurements required to complete a system design. Drawing from a large database of Baffin Bay hydrography, we present simulations of under-ice sound speed conditions, ice properties derived from satellite remote sensing and upward looking sonar data, and modelled acoustic propagation paths in an ice-covered Baffin Bay. We also assess the feasibility of non-coherent and coherent communication.

FRIDAY AFTERNOON, 9 NOVEMBER 2018 COLWOOD 1/2 (VCC), 1:00 P.M. TO 3:45 P.M.

Session 5pPA

Physical Acoustics: General Topics in Physical Acoustics II

Anthony L. Bonomo, Chair
Naval Surface Warfare Ctr., Carderock Div., 9500 MacArthur Blvd., West Bethesda, MD 20817

Contributed Papers

1:00

5pPA1. Strong nonlinear coupling between two cavitation bubbles in an acoustic field. Vikash Pandey (The Res. Ctr. for Arctic Petroleum Exploration (ARCEx), UiT The Arctic Univ. of Norway at Tromsø, Postboks 1080, Blindern, Oslo 0316, Norway, vikashp@ifi.uio.no)

Strong nonlinear coupling comes into play between cavitation bubbles as a result of their individual oscillatory behavior in a strong acoustic field. Such a nonlinearity may play a significant role in the evolution of a bubble; from its inception to the violent collapse, in particular, in a system of multi-bubbles. The nonlinearity may also drive the bubble system to a chaotic regime, hence making the system inherently unpredictable, though deterministic. Ironically, nonlinearity has often been ignored in most of the scientific studies due to the complexity that it introduces in the theory and the resulting numerical solution. The nonlinear coupling in the simplest case of two cavitation bubbles is studied using the Keller-Miksis equation (KME). The governing KME is solved numerically assuming spherical symmetry and coupling of the bubble oscillations. Also, the role of initial conditions is examined in sufficient detail to explore the additional aspects of bubble dynamics. Further, it is found that the secondary Bjerknes force differs significantly from the predictions when nonlinearity is ignored. It is believed that these results may have implications in industries where the phenomena of acoustic cavitation, bubble cloud dynamics, and sonoluminescence are encountered.

1:15

5pPA2. Void fraction inference in cavitating fuel injector flows. Lucas K. Watson, Huy K. Do, Sheryl Grace, Emily Ryan, and R. G. Holt (Mech. Eng., Boston Univ., 110 Cummington Mall, Boston, MA 02215, Lkwatson@bu.edu)

It has been shown that hydrodynamic cavitation within fuel injectors plays a significant role in their performance, with the desirable effect of broadening the resultant fuel spray. Experiments are challenging owing to the relatively small geometries, high pressure, and high Reynold's number (Re) associated with such flows. Previous studies have observed cavitation in optically transparent nozzles at slower flows. By utilizing acoustic and vibration measurement techniques cavitation activity may be measured in a steel fuel injector at more practical Re flows used in applications. We report here experimental measurements taken using a laser vibrometer and a commercial fuel injector. Previous studies have demonstrated a resonant frequency shift as a function of injection pressure. Among competing hypotheses, our working hypothesis is that this shift is the result of mass unloading of cantilever mode oscillations of the fuel injector. The dynamic void fraction caused by cavitation activity within the fuel injector can then be inferred from the measured frequency shift. We report measurements of mode shapes and frequencies for static and flowing fuel injectors as functions of the flow rate.

1:30

5pPA3. Simulated cavitation noise from strong nonlinear coupling in a multi-bubble system. Vikash Pandey (Ctr. for Ecological and Evolutionary Synthesis (CEES), Dept. of BioSci., Univ. of Oslo, Postboks 1080, Blindern, Oslo 0316, Norway, vikashp@ifi.uio.no)

The mutual nonlinear coupling between cavitation bubbles in a bubble cloud has often been blamed for the complex nature of the cavitation noise. This noise is undesirable for two reasons. First, it affects the source air-gun signature which is crucial in later stages of seismic signal processing. Second, the generated noise may fall in the same frequency regime which is used by some types of whales for communication, and therefore interfere. The complete nonlinear theory of bubble interaction is used to solve the governing Keller-Miksis equation (KME) to simulate the experimentally observed cavitation noise. A qualitative comparison is made with the results from other scientific investigations and interesting inferences are drawn. It is believed that the findings reported here may have implications in the air-gun array design in seismic exploration industry since air-guns are the indirect source of cavitation noise. It may also have an impact on the study of communication systems in marine mammals.

1:45

5pPA4. Study of the refraction of sound by shear and boundary layers. David Francoz (AeroDynam. Aeroelasticity Acoust. Dept., ONERA, The French Aerosp. Lab, ONERA, 29 Ave. de la Div. Leclerc, Châtillon 92320, France, david.francoz@onera.fr), Renaud Davy, Patrice Malbequi (AeroDynam. Aeroelasticity Acoust. Dept., ONERA, The French Aerosp. Lab, Châtillon, France), Emmanuel Julliard (Turbomachinery Noise Sources Team Acoust. Dept., Airbus Operations S.A.S., Toulouse, France), and Michel Roger (Ctr. for Acoust. Res., ECL, CNRS-LMFA, Écully, France)

Performing accurate acoustic measurements in aerodynamic wind tunnel is a challenge of great interest for the aeroacoustics community. Hence aeroacoustic measurements could be obtained in the same facility under the same aerodynamic conditions. This paper shows the refraction effects to be taken into account during aeroacoustics measurements in a closed test section, including flows up to high subsonic Mach numbers. In closed wind tunnel, the wall-mounted microphones are either flush-mounted or recessed in a cavity to avoid perturbations from the boundary layer. Besides, due to the wall, interference pattern generated by reflections occur. Thus, the acoustical wave front is strongly modified compared to the open test section configuration. Numerical computations, using the ONERA's sAbrinA-v0 CAA code solving the Euler's equations, allow us to accurately characterize the influence of a shear layer (recessed microphones) and of a boundary layer (flush-mounted microphones) and measurement setups, on the radiation from a monopolar source in the presence of a rigid wall. The CAA computations are made in the range 1 kHz to 10 kHz and for different boundary/shear layers thicknesses. The paper details a comparison between the Amiet's model and the CAA computations. The comparisons are in a good agreement despite the absence of a wall in the Amiet's model.

2:00

5pPA5. Guided shear waves and solitons in nonlinear viscoelastic materials. Emilien F. Dilly (Joint Dept. of Biomedical Eng., Univ. of North Carolina at Chapel Hill and North Carolina State Univ., 45, Rue d'Ulm, Paris, Ile de France 75005, France, efa.dilly@gmail.com), François Coulouvrat (Institut Jean Le Rond d'Alembert, CNRS, Paris, France), Bharat Tripathi, and Gianmarco Pinton (Joint Dept. of Biomedical Eng., Univ. of North Carolina at Chapel Hill and North Carolina State Univ., Chapel Hill, NC)

The nonlinear propagation of elastic waves in soft solids, such as gelatin or brain, can easily give rise to shocks. Previous experimental and theoretical studies have described planar, focused, one dimensional, two dimensional polarized shear wave propagation in these media, as well as acoustic non linear propagation in wave guides. Here we present the behavior of guided shear waves in solid plates. A model based on a quasi-modal wave decomposition is described as well as a Fourier-based numerical solution that takes into account nonlinear, attenuating, dispersive, guided propagation. A mixed conventional time-space and Fourier domain numerical method is used to determine harmonic generation with propagation. These numerical solutions are validated by a comparison with experimental data for plane waves in gelatin and brain. It is then shown how the nonlinearity and dispersion due to the guiding geometry can act together to assist the formation of shocks. The model also predicts, similarly to fiber optics physics, that nonlinearity can give rise to a self phase modulation, which under specific conditions can be compensated by the dispersion resulting from the waveguide. It is shown that the model therefore predicts the existence of solitons -both theoretically and numerically.

2:15–2:30 Break

2:30

5pPA6. Reflection of finite amplitude acoustic wave from a vapor-liquid interface. Takeru Yano (Osaka Univ., 2-1, Yamada-oka, Suita 565-0871, Japan, yano@mech.eng.osaka-u.ac.jp)

We numerically investigate the reflection of finite amplitude acoustic wave from a vapor-liquid interface and resulting evaporation or condensation flow induced by the reflected wave on the basis of the kinetic theory of gases. As an initial condition, we consider the finite amplitude plane acoustic wave propagating in a vapor bounded by the liquid layer of the same molecule as the vapor. The governing equation of wave motion in the vapor is the Boltzmann-Krook-Welander equation and the boundary condition at the interface is the complete condensation condition. The Boltzmann-Krook-Welander equation is numerically solved with a finite difference method. As a result, we clarify the reflection law of finite amplitude wave at the interface, which determines an evaporation or condensation flow established after the wave reflection.

2:45

5pPA7. Acoustic streaming in a channel a moderate streaming Reynolds number. Charles Thompson, Kavitha Chandra (ECE, UMASS Lowell, 1 Univ Ave., Lowell, MA 01854, charles_thompson@uml.edu), and Allan D. Pierce (Cape Cod Inst. for Sci. and Eng., East Sandwich, MA)

In this work, the generation of acoustic streaming in a rigid walled channel is examined. At low values of the streaming Reynolds number, the time-averaged fluid motion in the channel follows that given by Rayleigh. However, departure from the aforementioned result ensues as the magnitude of the streaming Reynolds number increases. Higher order nonlinear corrections to the Rayleigh streaming solution is given and are expressed in terms of a regular perturbation sequence in nondimensional particle amplitude. It is shown that the reduction in the amplitude of the axially directed streaming velocity is a function of the streaming Reynolds number.

3:00

5pPA8. Formation of cylindrical shock wave in two-phase liquid layer with free surface. Valeriy Kedrinskiy and Ekaterina Bolshakova (Physical HydroDynam., Lavrentyev Inst. of HydroDynam., Russian Acad. of Sci., Lavrentyev Prospect 15, Novosibirsk 630090, Russian Federation, kedr@hydro.nsc.ru)

Numerical model for formation of 1D cylindrical shock-wave (SW) in a liquid layer with a free surface is considered. The liquid states are pure water and distilled water containing free micro-bubbles (1.5 ö¥m, 10^6 cm^{-3}). The SW initiation is performed on the axis by giving the pulse of mass velocity as the exponent for maximal amplitudes from 60 to 20 m/s. A two-phase mathematical model is the system of equation describing average pressure, velocity and density (including the Rayleigh-type equation). For pure water, the distributions of maximal amplitudes both from the axis along the radius for SW and from free surface up to the axis of symmetry for rarefaction wave (RW) were calculated. The distribution of maximal amplitudes of positive SW and negative RW along the radius appears to be completely symmetric. It was shown, the SW amplitude decreases proportionally to $r^{-0.45}$ (within 3 cm from axis) and then asymptotics ($r^{-0.72}$) is registered. The increase of RW amplitude during propagation to the axis is a cumulative effect. In two-phase model of distilled water the cavitation begins behind the RW front. Beginning from free surface, the volumetric gas concentration increases in 300 initial values (maximum velocity 60 m/s).

3:15

5pPA9. Thickness measurement of rigid porous material through reflected acoustic waves at Darcy's regime. Mustapha Sadouki (Departement des Sci. de la Matière, Université Djilali Bounaama à khemis-miliana, Université Djilali Bounaama à Khemis-Miliana, Rte. Thenia el Had, Ain Defla, Khemis-miliana 44225, Algeria, mustapha.sadouki@univ-dbkm.dz)

In this work, an inverse method is proposed for measuring the thickness of air-saturated of rigid porous material using the reflected acoustic waves at Darcy's regime. The equivalent fluid model is considered. The interactions between the structure and the fluid are taken into account in two frequency response factors; the dynamic tortuosity of the medium introduced by Johnson *et al*. and the dynamic compressibility of the air introduced by Allard. A simplified expression of the reflection coefficient is obtained at the Darcy's regime (very low frequencies), this expression is independent of the frequency and depends only on the thickness and the flow resistivity of the porous medium. The inverse problem is solved numerically by minimizing between the simulated and experimental reflected signals; the reconstructed values found of the thickness of porous samples with different resistivity are in good agreement to those obtained using direct measurements.

3:30

5pPA10. Acoustic wave propagation in orthotropic porous silicon with specific pore shapes. Xiaoyue Gong, Julien Bustillo, Laurianne Blanc, and Gaël Gautier (GREMAN UMR 7347, INSA CVL, Univ. of Tours, 3 Rue de la Chocolaterie, INSA-CVL, Blois, Loire-et-Cher 41000, France, xiaoyue.gong@insa-cvl.fr)

In the literature, porous materials are normally treated as isotropic media. In this case, analytical solutions for wave velocities and attenuations as a function of frequency have been given by M. A. Biot. Nevertheless, porous silicon (PSi) synthesized using electrochemical manufacturing is generally highly anisotropic. Then, it can be considered as orthotropic. In order to optimize acoustic applications using PSi, it is necessary to take account to this anisotropy. In early works, by using FEM simulations, skeleton elastic constants have been computed for five PSi pore shapes and different porosities. In this work, the "Gedanken experiments" have been implemented and compliance tensors have been calculated. By inverting the compliance tensor, the elastic parameters of fluid-saturated PSi have been calculated. Moreover, geometrical parameters such as tortuosity, permeability and characteristic length of pores have been simulated. The wave equations can be deduced by combining Biot's theory and Christoffel's equations, and have been solved by using the simulation results. Then, the phase velocity and attenuation variations, according to frequency, were studied. The results for five different pore shapes have been compared and the differences show that the shape strongly influences wave propagation.

FRIDAY AFTERNOON, 9 NOVEMBER 2018 RATTENBURY A/B (FE), 1:00 P.M. TO 3:30 P.M.

Session 5pSP

Signal Processing in Acoustics: General Topics in Signal Processing III

Dieter A. Bevans, Chair

Marine Physical Laboratory, Scripps Institution of Oceanography, 9500 Gilman Dr., La Jolla, CA 92093-0238

Contributed Papers

1:00

5pSP1. Ultrasonic phased array total focusing method based on sparse deconvolution. Bei Yu, Yujian Mei (Zhejiang Univ., No. 38, Zheda Rd., Xihu District, Hangzhou City, Zhejiang Province 310027, China, yubei@zju.edu.cn), Haoran Jin (Nanyang Technolog. Univ., Hangzhou, ZheJiang, China), Eryong Wu, and Keji Yang (Zhejiang Univ., Hangzhou City, China)

Ultrasonic phased array total focusing method (TFM) has been widely used in the field of non-destructive testing (NDT) as an advances post-processing imaging algorithm. It shows great potential in defect detection and characterization. However, due to the small number of excitation elements and large amount of collecting data, its temporal resolution and imaging efficiency need to be improved. To overcome these disadvantages, an ultrasonic phased array total focusing method based on sparse deconvolution has been proposed in this paper. Based on the actual situation of ultrasonic testing, a regularized sparse deconvolution model has been established. The Bayesian theory is used to add low-probability prior information to the deconvolution model. At the same time, the sparse deconvolution optimization algorithm proposed in this paper is used to solve the sparse deconvolution model. Compared with ordinary phased array total focusing method, this algorithm reduced the calculation amount and improved the temporal resolution. The performance of the proposed method is proved by simulation and experimental comparison. The results verify that the proposed method has higher resolution and imaging efficiency.

1:15

5pSP2. High-resolution space-time spectral estimation method for array signal based on deconvolution. Wei Guo and Shengchun Piao (Harbin Eng. Univ., Harbin, Heilongjiang 150001, China, guowei1030@hrbeu.edu.cn)

Conventional beamforming and classical spectral estimation methods are widely used in array signal processing to estimate the angular and frequency spectrum, respectively. But the spectra provided by these algorithms appear as low resolutions and high side lobes because of the limited array aperture and the number of snapshots. Then a multi-dimensional window function is defined, which is composed of the snapshot number and array aperture. Based on the theories of space-time joint spectral estimation, the multi-dimensional power spectrum about the azimuthal angle and frequency of array signal can be deduced as the convolution of the multi-dimensional power spectrum of the true signal and the power spectrum of the multi-dimensional window function. Therefore, the deconvolution algorithm can be introduced to remove the influence from the window function to recover the power spectrum of the true signal which is considered to be received from the infinite time and space. It is illustrated from simulations and experimental data processing that the deconvolution method can greatly improve the angular and frequency resolutions of the multi-dimensional spectrum, suppress the side lobes and provide extra signal-to-noise ratio, which can be applied for multi-target identification and weak signal detection.

1:30

5pSP3. Time delay estimation based on cross power spectrum with Doppler compensation. Xue Han (Harbin Eng. Univ., Rm. 1317 Shuisheng Bldg., No.145 Nantong St., Harbin 150001, China), Wei Guo (Harbin Eng. Univ., Harbin, Heilongjiang, China), and Shengchun Piao (Harbin Eng. Univ., Harbin, China, psc828@foxmail.com)

Time delay estimation is an important topic in underwater acoustic field. However, the Doppler phenomenon caused by relative movement between the source and receivers can arise errors in time delay estimation. In order to deal with this problem, a time delay estimation method based on cross power spectrum with Doppler compensation in frequency domain is proposed in this paper. The proposed method separates the Doppler compensation from the time delay estimation rather than estimates them jointly. The results of simulations and experimental data processing show that this method can improve the estimation accuracy of time delay with the influence of Doppler phenomenon.

1:45

5pSP4. Study on inversion of medium velocity change distribution based on code interference. zhiguang qi (School of Marine Sci. and Technol., Northwestern PolyTech. Univ., Xi'an 710072, China, 18073150314@163.com), Hong Hou (School of Marine Sci. and Technol., Northwestern PolyTech. Univ., Xi'an, Shaanxi, China), and Nansha Gao (School of Marine Sci. and Technol., Northwestern PolyTech. Univ., Xi'an, China)

We introduce a method that was proposed in recent years to monitoring micro geological change. The contents of this technology include the extraction of green function from background noise, the theory of code wave interference and the distribution of sensitive nuclei. We extract the green's function from the background noise and get time delay, and then establish the sensitive nuclear distribution according to the physical characteristics of the measured medium and get the medium velocity variation distribution finally. Now we have carried out the code wave interference experiment of Panjin oilfield .In the process of oil exploitation, the vibration wave velocity can be changed due to the change of medium, which can be monitored by the code wave interference. 10 seismographs are set in the range of 1km x 3km oilfield and continuous collection of data is not less than two months, and map of the speed of the oil field working face as a function of time is obtained through the background noise code wave interference method.

2:00

5pSP5. Simulated target insertion for automatic target recognition performance estimation. Jeannine Abiva and Julia Gazagnaire (Naval Surface Warfare Ctr., Panama City Div., 110 Vernon Ave., Panama City, FL 32407, jeannine.abiva@navy.mil)

To support automatic target recognition (ATR) algorithm development as well as predict their performance in various operational environments, there is a need for more realistic sonar data that captures environmental effects that are not only difficult to model using physical acoustical models but expensive to measure in the real world. Previous target insertion efforts have focused on high frequency imaging sonar. As such, these efforts effectively combine only the magnitudes of the real and simulated data. This effort will focus on low frequency sonar, and the goal is to retain the phase by combining the complex data where possible. Maintaining the phase allows us to take advantage of the resonant frequency information available in the lower frequency bands, which is lost when the magnitudes are summed. In this effort, several approaches to inserting simulated target data into real sonar data will be investigated. Typically, there are no shadows in the low frequency images; therefore, none of the approaches investigated here take shadows into account. For each method, an analysis will be carried out to evaluate how the simulated targets behave compared to real targets. These analyses will be performed on real and simulated image snippets, gradients of snippets, and the frequency content of the target scattering response or acoustic color plots. The analysis will include several statistical measures which will be used to compare snippets of real and simulated targets as well as backgrounds of their immediate surroundings.

2:15–2:30 Break

2:30

5pSP6. Assessing the accuracy of head related transfer functions in a virtual reality environment. Joseph A. Esce and Eoin A. King (Mech. Eng., Univ. of Hartford, 200 Bloomfield Ave., West Hartford, CT 06117) (eoking@hartford.edu)

While graphics and visual representations for Virtual Reality (VR) systems are very well developed, the manner in which audio signals and acoustic environments are recreated in a VR system is not. In the case of audio spatialization, the current approach makes use of a library of standard head related transfer functions (HRTFs), i.e., a user selects a generic HRTF from a library, with limited personal information. It is essentially a "best-guess" representation of that individual's HRTF. This limits the accuracy of audio developments for virtual reality. This paper reports on results from localization tests to determine the capabilities of a generic HRTF used in a VR environment. Volunteers entered a VR world, and an invisible sound source made a short bursts of white noise at various position in the room. Volunteers were asked to point to the location of the sound source, and results were captured to the nearest millimeter using the VR's motion tracking system. It is proposed that future versions of this experimental methodology will enable the development of a pseudo-personalized HRTF, unique to each individual VR user.

2:45

5pSP7. Estimating the flight parameters of a moving airborne source using one hydrophone. Boxuan Zhang, Yixin Yang, Xijing Guo, and Ningning Liang (Northwestern PolyTech. Univ. School of Marine Sci. and Technol., 127 West Youyi Rd., Beilin District, Xi'an 710072, China, kiwinan@163.com)

The low frequency tone noise of the turboprop aircrafts can be discovered more easily under water than the broadband continuum spectrum noise due to its higher intensity. Ferguson and Lo provided a method based on a single hydrophone for estimating the four flight parameters, including the source frequency, velocity, altitude and CPA time (the time when the source passes the closet point of approach), using the variation of the instantaneous frequency (IF) of a single tone over time [Ferguson and Lo, IEEE J. Oceanic Eng., 24(4):424–435 (1999)]. Therefore, the performance of their method is

largely determined by the precision of the IF estimates, which were obtained by using the short-time Fourier transform (STFT). In this paper, the polynomial chirplet transform (PCT), which models the change of the IF over time as a polynomial, is used instead of STFT to provide more accurate IF estimates. Moreover, multiple tones are used to improve the precision of the flight parameter estimates. The performance improvement is demonstrated by simulations and an experiment carried out near the Sanya coast in May, 2018.

3:00

5pSP8. Source localization based on matrix filter and sparse asymptotic minimum variance. Yahao Zhang, Yixin Yang, and Long Yang (Northwestern PolyTech. Univ. School of Marine Sci. and Technol., 127 West Youyi Rd., Beilin District, Xi'an 710072, China, yahaoZhang@126.com)

Wideband direction of arrival (DOA) estimation plays an important role in passive sonar signal processing. Recently, sparsity-based DOA estimation method has attracted considerable attention because of its high resolution in the condition of few snapshots and low signal-to-noise ratio. However, the localization accuracy is seriously affected by the interferences. Matrix filter (MF) has been widely used in passive sonar systems as a useful tool to passband the targets-of-interest while attenuating the interferences, but the output of the MF seriously affected subsequent DOA estimation when the power of the interferences after filtering is still stronger than the weak targets. In this paper, a method based on MF and sparse asymptotic minimum variance (SAMV) is given to localize the weak targets in a strong interference environment. The given method improves the ability of SAMV on weak targets localization and achieves high localization accuracy even in the condition that the power of the interferences after filtering remains stronger than the weak targets, which is verified by simulation and experimental results.

3:15

5pSP9. Bottom-laid targets imaging and classification using a synthetic circular array. Ting Zhang and T. C. Yang (Zhejiang Univ., Office 431, Xindian Bldg., Yuquan Campus, 38 Zheda Rd., Xihu district, Hangzhou 310027, China, zhang_ting@zju.edu.cn)

Detection and classification of bottom-laid targets in littoral area represents a serious problem for the navies of the world. It has been shown based on past acoustic research that the backscattered field carries a lot of information about the subject in terms of frequency and angular distribution if ensonified over a wide range of distance and can thus be used to different a mine from a stone or one type of mine from the other, referred to as acoustic color image. A circular array is more advantageous compared to a planar array as circular patterns maximize the aperture, and due to its high angular resolution, one can search and classify multiple targets at the same time. While it is difficult to deploy a large circular array since one does not know where is the target and the circular array needs to have a large diameter. Therefore, in this work, one will demonstrate effective bottom-laid targets imaging and classification using a synthetic circular array, which is created by a towed line array. We will study the concept of the proposed system and make simplified assumptions in order to obtain a crude estimate of the system performance.