Monitoring Air-Sea Exchange Processes Using the Ambient Sound Field

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LONG-TERM GOAL

The ambient sound field in the ocean contains information about processes producing the sound. At higher frequencies, above 1 kHz, much of the sound is produced locally by air-sea exchange processes such as wave breaking, wind and precipitation. Furthermore, ambient bubble populations can modify these sound fields in predictable ways. By learning to listen to the ambient sound field, we will be able to develop a method for measuring these phenomena using inexpensive, robust and convert sensors (passive hydrophones).

SCIENTIFIC OBJECTIVES

Measuring air-sea exchange processes is a critical component of predicting mixed layer development and establishing the flux of heat, momentum, water and gas between the atmosphere and oceans. Several of these processes, for example, wave breaking, precipitation and sub-surface bubble populations, are notoriously difficult to measure, in part because of the difficult environment at the air-sea interface. These same processes are responsible for much of the locally-generated underwater sound above 1 kHz. Thus, it is possible to identify surface conditions by listening to the ambient sound (Nystuen and Selsor, 1997). By measuring these processes acoustically, their contribution to mixed layer development, and their influence on other exchange processes can be studied. Conversely, predicting ambient sound levels given environmental weather conditions will be much improved.

APPROACH

Five ambient sound data sets have been collected or acquired. These data sets, one coastal and the rest oceanic, are being used to develop and test the acoustic classification of weather (Nystuen and Selsor, 1997), and in particular, to use the inversion of the ambient sound field to detect and quantify rainfall at sea. The first data set is a comprehensive record of the sound generated underwater by rainfall in a shallow pond from Miami, FL. These data are 1-second resolution 0-50 kHz sound spectra from over 800 rain events during a 17 month period. Collaborating data includes rain measurements from several types of automatically-recording rain sensors (Nystuen et al. 1996; Nystuen 1997a; 1998). A second data set includes oceanic ambient sound measurements (provided by D. Farmer, IOS) recorded during the 90-day long ONR-sponsored ASREX experiment in the North Atlantic during the winter of 1993/1994. These data were recorded from a sub-surface mooring. Ancillary data include sub-surface acoustic backscatter, sub-surface bubble measurements and various surface measurements, e.g., temperature, salinity, waves, humidity, etc. The third data set is from a series of autonomous acoustic

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drifters air-deployed in various regions around the world. A co-located passive microwave satellite (SSM/I) data were acquired for comparison to the drifter data (Nystuen, 1997). A fourth data set is from a sub-surface mooring in the North Sea (Zedel et al. 1998) and a fifth data set has just been collected from the South China Sea.

WORK COMPLETED

The Miami, FL rainfall data set has been analyzed to document the potential and the limitations of the acoustical inversion to quantitatively measure raindrop size distribution within rain (Nystuen, 1997a; 1998). The drifter data set has been analyzed to validate acoustic wind speed measurements and rainfall detection by comparison to passive microwave satellite data (Nystuen, 1997c). The ASREX data set has been partially analyzed to produce a climatic-type rainfall record for the duration of the experiment and to provide rainfall rate data for process studies on the influence of rain on other air-sea exchange processes. The ASREX data also demonstrate the potential of using the ambient sound field to quantitatively estimate ambient bubble populations in the near-surface layer of the ocean. Two acoustic rain gauges (ARGs) were designed, built, tested and deployed on deep ocean surface moorings. Data from their deployment in the South China Sea Monsoon Experiment (SCSMEX) demonstrate the robustness and potential of acoustical weather classification to measure air-sea fluxes. Vandalism is a serious problem for surface instrumentation at sea. The ARGs on the SCSMEX mooring, covert and undetected 20 m underwater, were the only instrumentation to survive an act of piracy, and continued to provide data for the experiment after the attack.

RESULTS

Because different raindrop sizes produce sound underwater by different physical mechanisms, the underwater sound can be decomposed into components associated with each drop size category. These drop size categories have been carefully documented and show that the acoustic inversion can be used to identify changing drop size distributions within rain, potentially allowing classification of rainfall type (convective, drizzle, stratiform). Rainfall rate, the most often desired end product, is determined by summing the contribution from each drop size category. When compared to five other types of automatic rain sensors, the acoustical measurement is correlated to the other gauges with a correlation coefficient of roughly 0.9. The single most important factor affecting the acoustic measurement is the presence or absence of very large raindrops (over 3.5 mm diameter) within the rain. These drops are extraordinarily loud underwater and dominate the sound field when present. If these very large raindrops are not properly detected and accurately counted, then the smaller drop size populations are poorly estimated. In particular, the medium raindrop size category (1.2-2.0 mm diameter) is relatively quiet underwater, and consequently, relatively hard to measure acoustically. In contrast, the small raindrops (0.8-1.2 mm diameter) are relative loud underwater and easily detected acoustically.

The first step in the analysis of oceanic ambient sound data is to identify the present surface weather conditions (wind, drizzle, heavy rain, ambient bubbles present) (Nystuen and Selsor, 1997). Oceanic ambient sound measurements from 15 autonomous surface drifters were compared to passive microwave satellite (SSM/I) measurements of surface wind speed, atmospheric liquid water (cloud and rain drops) and rainfall (Nystuen, 1997c). The correlation between acoustic and satellite wind speed estimates was 0.91 (254 data points). The acoustic wind speed measurement showed no regional or environmental variability, but was biased low compared to the satellite measurement by 0.8 m/s. Of 21 acoustically detected precipitation events (both drizzle and heavier rain), the satellite measurements confirmed 19 (90% detection rate). Given unproven algorithms and the mismatch of temporal and spatial sampling by the drifter and the satellite sensors, quantitative comparisons are difficult to evaluate. The wind speed threshold for acoustic detection of light rain and drizzle is 8-10 m/s (Nystuen, 1997c; OASIS data analysis).

The second oceanic data set, from ASREX, was analyzed to produce a 90 day record of the rainfall. An estimated 477 mm of rain fell, including 5 storms with more than 20 mm of rain accumulation. The temporal detection of rain (drizzle 3.0 % of the time; heavier rain 2.4% of the time) are the type of statistics needed by climatologists (Petty, 1995). Not only do these data demonstrate the potential for climatological rainfall measurements, they also allow the first opportunity to examine the influence of rainfall on other air-sea processes, for example, near surface salinity, surface waves, gas exchange, etc. In particular, 1-m salinity measurements showed very large "fresh water" fluxes during extended periods of light rain/drizzle, but had a very different character during heavier rain when the winds were higher. There is a suggestion of surface wave damping by rain. The ASREX data set also shows evidence of bubble injection into the mixed layer by rain. Whenever rain occurs during high wind speed (over 10 m/s) conditions, the spectral slope above 10 kHz steepens, an indication of bubbles being mixed downward deeply enough to change the ambient sound field. By examining the change in spectral slope, quantitative estimates of near-surface void fraction compare well to active void fraction measurements. The deep injection of these bubbles into the mixed layer suggests possible enhanced gas exchange during these conditions (heavy rain during high winds).

IMPACT/APPLICATIONS

Analysis of the ambient sound field to provide important air-sea exchange measurements is a technology that should lead to important advances in our understanding of the physics of the air-sea interface. The measurement is simple, robust and covert. It can be made from small, autonomous drifters, or larger surface moorings. The measurements of wind, precipitation and bubbles are difficult to make by more conventional means, and are critical components of vital air-sea fluxes of heat, water, momentum and gas that drive the interaction of the atmosphere and the ocean. Coupled air-sea models are currently the weakest of the numerical models needed to analyze and forecast environmental (weather) conditions on small, regional and global scales. These modelers have identified the need for data, especially of wind and rain, to develop and verify these models.

TRANSITIONS

The Tactical Oceanography Warfare Support (TOWS) program at NRL has sponsored the development of air-deployable autonomous drifters (Selsor, 1993). Navoceano and NOAA are now deploying these sensors on a regular, but limited, basis (about 20 per year). The NOAA National Data Buoy Center is interested in "no-moving-parts" sensors for wind and precipitation. They are actively exploring the potential application of this technology for their platforms. As part of the NOAA Pan-American Climate Studies (PACS) program, acoustic rain gauges (ARGs) were mounted on one of the NOAA Tropical Atmosphere Ocean (TAO) array moorings and on the SCSMEX mooring. These data show that the acoustic measurements are complimentary to the existing instrumentation. It is proposed that the acoustic sensors become a regular component of the NOAA TAO tropical ocean mooring array, and are regularly deployed as part of other large oceanic field experiments. ARGs are planned to be part of the NASA Tropical Rain Measuring Mission (TRMM) surface validation field program.

RELATED PROJECTS

Acoustical Rainfall Analysis, sponsored by the Ocean Sciences Division, Ocean Instrumentation, of the National Science Foundation, broadly overlaps this project. The goal of this NSF project is to develop the acoustical inversion technology to provide a means of making oceanographic rainfall measurements. The initial phase of this project has just concluded. A follow-on project is proposed.

Determination of surface rainfall drop size distribution" is sponsored by the NOAA Pan-American Climate Studies (PACS) program, applies the acoustical weather analysis technology to obtain climatic rainfall data. This project sponsored the design, development and deployment of 2 ARGs. These instruments recently returned data from the SCSMEX experiment. Additional long-term measurements are proposed.

Validation of Acoustical Rainfall Measurements" is sponsored by the NASA TRMM Program Office. The two ARGs built as part of the PACS project will be redeployed during a field program at Kwajalein Island in the summer of 1999. This will provide additional ambient sound field data with which to develop and test inversion theories.

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