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Observational Research in Air/Sea Interaction

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ABSTRACT

Winds over the oceans are crucial to the understanding of global climate, air/sea interaction, and weather prediction. A key tool for oceanic wind measurement in the 1990's and beyond will be spaceborne radar scatterometry, a proven technique for all-weather observation of *vector* winds. While wind scatterometry is a well developed technique, further research into the geophysical model function relating radar backscatter and the near-surface wind vector is needed.

To support this research we are developing an innovative tower-based radar scatterometer system capable of directly measuring both the ocean radar backscatter and the short and long wave field simultaneously. The development heavily involves a number of graduate and undergraduate students. The completed instrument will be used in extended field experiments to study air/sea interaction. We expect data from the instrument to lead to better understanding air/sea interaction and to advancements in radar scatterometry.

INTRODUCTION

Winds over the oceans modulate *all* air-sea fluxes and thus are crucial to the understanding of global climate and air/sea interaction. The limitations of conventional techniques, however, will require increased reliance on remote sensing to measure oceanic winds. In 1978, the SeaSat Scatterometer (SASS) demonstrated that *vector* winds over the ocean could be measured from space using radar scatterometry. The dramatic success of SASS has led to the development of advanced scatterometers by both the United States (NASA) and the European (ESA) Space Agencies. However, further improvements in the models relating radar backscatter and wind are needed.

A wind scatterometer does not directly measure the wind. Instead, it measures the normalized radar cross-section (σ^0) of the ocean's surface from which the wind is inferred. Using multiple measurements of σ^0, the wind vector is inferred using a "geophysical model function" which relates the radar backscatter and the vector wind. σ^0 is primarily a function of wind-generated capillary waves but is modulated by long gravity waves and other environmental parameters [e.g., (Colton, 1989)]. However, the details of this modulation are not fully understood.

Because the underlying physics of ocean scattering remains poorly understood, a theory-based geophysical model function has been illusive. However, remarkably successful empirical model functions based on tower- and aircraft-based as well as spaceborne measurements have been developed [e.g., (Bracalente et al., 1978) and (Wentz, Peteherych, Thomas, 1984)] though further research is required [see (Colton, 1989)].

Most empirical studies to date have used fixed frequency scatterometer systems without wave field measurement capability. Recently, Schuler et al. (1991) demonstrated that long wave fields could be directly measured by a radar using a $\Delta\mathbf{k}$ multi-frequency technique. Using this technique measurements of the long wave field and σ^0 can be made using the same radar system. This will enable detailed studies of the influence of the background wave field on σ^0 in order to further understand the modulation of σ^0 by the wave slope and swell direction. Understanding the sensitivity of σ^0 to the background wave field is crucial to the development of improved geophysical model functions.

To support research into geophysical model functions, we are developing an innovative radar scatterometer system which will make simultaneous measurements of the long wave field, the short wave field, and σ^0 over the full bandwidth of 2–18 GHz. Our project, funded by the NASA Innovative Research Program extensively involves both undergraduate and graduate students. In this paper we briefly describe the radar scatterometer system design with emphasis on its innovative nature, our current status, and the role of students in developing and deploying the system.

DESIGN DESCRIPTION

In this brief paper it is impossible to describe the design of the proposed system in any depth. However, in this section we provide an overview of the system. A simplified block diagram for the system is shown in Figure 1. Key goals for the instrument are measurement accuracy and system reliability. We plan to use off-the-shelf equipment wherever possible to ensure a low-cost, low-risk design.

The chief innovations in this instrument are (1) a continuous, very wide operational bandwidth and (2) a frequency-independent antenna illumination pattern. While most of the design techniques to be used in the instrument have been previously demonstrated, integrating all of these elements into a single, integrated system represents an innovation in tower-based scatterometer system design, i.e., the instrument is an integrated *system* for the study of ocean scattering, simultaneously measuring σ^0, long and short waves, and environmental parameters. Because of the integrated system nature of the instrument, the system can be deployed either separately or in conjunction with other instruments.

The instrument will be a multi-octave FM CW (homodyne) radar using a $\Delta\mathbf{k}$ technique for long wave spectrum measurement (Shuler et al., 1991). An FM homodyne design was selected to permit simultaneous transmission and reception,

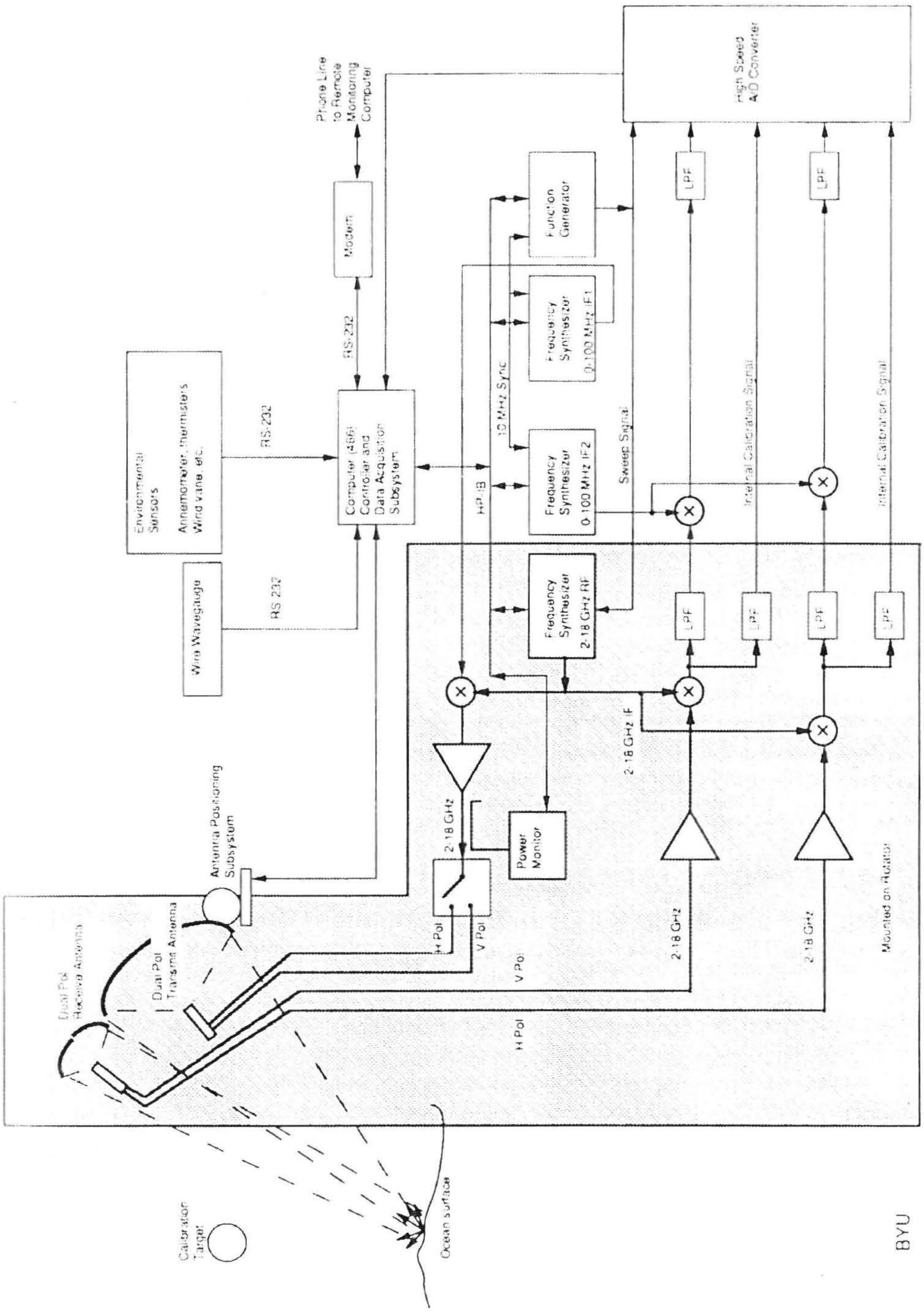

FIGURE 1 Conceptual block diagram.

allowing for very short range operation (required for a tower) at minimal cost and complexity. This also simplifies external calibration since a calibration target can be placed on the tower close to the radar. Spectral diversity is obtained as a side effect of the rapid scanning of the operational frequency and the multiple tones. Scanning in azimuth will permit measurement of the long wave directional spectrum. The low-power transmitted signal consists of two closely spaced (10–50 MHz) tones which are swept over the 2–18 GHz operational bandwidth to provide both spectral diversity and multiple frequency observation. The received signal consists of the return echo from the ocean surface (which will have been dispersed in time and frequency) and transmitter leakage. The received signal is mixed with the RF center frequency of the transmitted signal and filtered. Due to the time-of-flight of the return echo, there is a net frequency offset in the return echo. This permits filtering out any contaminating leakage from the transmitted signal as well as providing additional range resolution. The filtered return echo power provides the measurement of σ^0. The two closely spaced tones in the transmitted signal are used to measure the long wave spectrum using the beat frequency (see Shuler et al., 1991). Rapidly scanning the operational bandwidth provides the essentially instantaneous σ^0 measurements and spectral diversity for the long and short wave spectrum measurement. The short wave spectral estimate is based on a Bragg scattering model. A very wide frequency range with multiple incidence angle capability will permit measurement of the Bragg spectrum from small waves ranging from approximately 1.5 to 15 cm.

To cover the desired frequency range, very broad-band off-the-shelf signal generators and mixers will be used. The antenna represents a new design developed especially for this project. A dual antenna system (one antenna for transmit and one for receive) will be used. The dual-pol transmit antenna consists of a 3 foot elliptical cross-section reflector with a sinuous feed. The antenna is designed to provide essentially constant 5° beamwidth over the entire operational bandwidth. The conventional dual-pol receive antenna will have a larger beamwidth than the transmit antenna and will be boresighted with the transmit antenna. A custom antenna pointing system is being developed to provide both azimuth and elevation pointing.

Calibration will be provided using both internal calibration loops and an external calibration target. Two internal calibration loops will be used. The first, which will operate continuously, will directly measure the receiver/transmitter gain using the coupling between the transmit and receive antennas. The second loop feeds the transmitter directly into the receiver to make a precise RF gain measurement. For external calibration a fixed calibration target will be mounted so that the antenna positioner can target it. The calibration target will be used to verify pointing and measure the end-to-end system gain. In operation the radar will periodically make both internal and external calibration measurements.

The entire system will be controlled by a 486-based PC system which will also handle data collection and real time data processing. The computer will also collect data from the meteorological and ocean sensors. These sensors will include anemometers; wind vanes; pressure, temperature, and humidity sensors; and an experimental wire wave gauge.

DISCUSSION

As of this writing, we are at the end of the first year of this three-year project. The transmit antenna has been fabricated by a commercial company. The remainder of the instrument is being developed at Brigham Young University with the assistance of a number of graduate and undergraduate students.

For example, the antenna positioning system is being developed as part of the undergraduate Integrated Product and Process Design program in the Mechanical Engineering Department as one of a number of senior Capstone projects. The Capstone project provides senior students with realistic design projects with design requirements, deadlines, and budgets. This program at Brigham Young University has been very successful. Five undergraduate students in mechanical engineering and one in electrical engineering will design, fabricate, and test the positioner under the close supervision of several faculty members. The final positioner and environmental enclosures for the electronics will be completed in April 1993.

The RF electronics, the environmental sensor collection subsystem, and the instrument computer control system are being developed in the Electrical and Computer Engineering department. Under our direction two graduate students have successfully breadboarded and tested key RF circuits, validating the RF electrical design. They are now developing the control software. Using a prototype antenna positioner and communication band antennas, a breadboard of the full scatterometer system (but with only a single receiver channel) has been built and successfully tested.

A graduate student is currently developing a capacitative wire wavegauge array and data processing algorithms to support the verification experiments planned for the initial deployment at a nearby freshwater lake. Other environmental sensors (i.e., air temperature, wind speed, wind direction, and rain have been purchased from commercial suppliers. A senior student has integrated these sensors into the data collection computer system.

We are making good progress in the instrument development and anticipate integration and testing of the completed instrument in the summer of 1993. After engineering deployments at nearby lakes, an extended deployment in the Guld of Mexico is planned. A rich data set containing a variety of conditions is anticipated to support research in ocean scattering and air/sea interaction.

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