Studies of Atmospheric and Oceanic Phenomena with the NASA Scatterometer

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INTRODUCTION

The ocean and the atmosphere are coupled by the transport of momentum which is governed by the wind shear, but measurements of wind are sparse over most of the ocean. The ocean and the atmosphere are turbulent fluids with non-linear interaction; processes at one scale affect processes at other scales. Spaceborne sensors are the only potential means of measurement at adequate temporal and spatial scales.

A few decades ago, marine radar operators encountered noise on their radar screens which obscured small boats and low-flying aircraft. They termed the noise "sea clutter". This clutter was the backscatter (reflection) of the radar pulses by the rippling waves on the ocean's surface. The idea of remote sensing of ocean surface winds was based on the belief that these surface ripples are in equilibrium with the local winds. The microwave scatterometer sends microwave to the ocean surface and measures the backscatter from which ocean surface wind speed and direction are derived.

The ocean surface is largely covered by clouds, but the atmosphere and its cloud are almost transparent to microwave and the scatterometer can measure wind under both clear and cloudy conditions. While the radiometer, a passive sensor, can measure wind speed, the scatterometer, an active sensor, has the proven capability of measuring both wind speed and *direction* at the broadest range of conditions.

NASA SCATTEROMETER

The National Aeronautics and Space Administration (NASA) Scatterometer (NSCAT) was successfully launched into a near-polar, sun-synchronous orbit on the Japanese Advanced Earth Observing Satellite (ADEOS) in August 1996 from Tanegashima Space Center in Japan. The six antennas of NSCAT send microwave pulses at a frequency of 14 GHz to *the Earth's* surface and measure the backscatter. The antennas scan two 600-km bands of the ocean which are separated by a 330-km data gap. From NSCAT observations, surface wind vectors can be derived at 25-km spatial resolution, covering 77% of the ice-free ocean in one day and 97% of the ocean in two days.

TYPHOON AND EXTRATROPICAL TRANSITION

During its first few days of the ocean observing mode, starting 15 September 19%, NSCAT monitored the evolution of the twin typhoons Violet and Tom in the western North Pacific. They moved north from the tropical ocean where they were born, acquiring the features of mid-latitude storms, with developing frontal structures, increasing asymmetry, and introduction of dry air into the core of the typhoons. While Violet hit Japan, causing destruction and death, Tom merged with a mid-latitude trough and evolved into a large extratropical storm with gale-force winds [1].

By superposing NSCAT wind field on the maps of integrated water vapor from the Special *Sensor* Microwave / Imager (SSM/I), Tom can be distinguished from the extratropical cyclones by the high water vapor (and diabatic heating generated by latent heat release) concentrate in the core, from 15th to 17th of September. During this period, NSCAT also observed vigorous cyclogenesis at 35°N, north of Tom. These activities were missed largely by the numerical weather forecasts of the National Oceanic and Atmospheric Administration because of their coarse resolution. The spacebased data show much less water vapor in these extratropical cyclones compared with Tom, with higher value in the warm sector between the fronts, but not at the core. Tom speeded upon the 18th and moved toward the northeast. On September 19, it moved into the trough at 35°N. It lost much of the water vapor during this process, but still kept unusually high water vapor at the frontal location, compared with previous extratropical cyclones. This high water vapor was clearly observed by SSM/I in the next few days as the system resulting from Tom moved east. NSCAT data also indicate strong winds above 25 m/s for this extratropical system that resulted from Tom.

We understand relatively little of the extratropical transition of tropical cyclones because of the complex thermodynamics involved. Since the transition usually occurs over the ocean, there has been very little measurements of it. Yet the mid-latitude storms resulting from tropical cyclones usually have strong winds and heavy precipitation. The transition is a fascinating science problem, but it also has important economic consequences. The transition occurs over the busiest trans-ocean shipping lane, and when the resulting storms hit land, they usually cause devastation to populated areas. Spaceborne microwave scatterometer and and radiometer help to reveal the large amount of energy carried over from the tropical cyclone to the extratropical regions.

MONSOON

Monsoons are the seasonal changes of winds forced by continent-ocean temperature contrast. Their onset, intensity, and retreat vary greatly, and the variation has strong economic impact and may cause severe human suffering. Over land the consequences of monsoon are, perhaps, well observed, but the breeding ground over the ocean has been insufficientl y monitored, and scatterometer has the potential of making a contribution. The Asian monsoon has a strong influence over a large portion of the world's population, yet it is much less studied and understood than the Indian Monsoon [2].

The annual variation of monsoons at two locations on 19"N, one in the Bay of Bengal at 90E and the other in the South China Sea at 115"N are examined Time series, starting 1992, of wind speed and direction from NSCAT and ERS-1 scatterometer are plotted with the precipitable water from SSM/I and sea surface temperature derived by blending observations of the Advanced Very High Resolution Radiometer (AVHRR) within situ measurements. In the Bay of Bengal, the wind direction changes gradually from northerly during winter to southwesterly in summer, with moistening of the atmosphere and warming of the ocean. The strength of the wind increases dramatically in June, signifying the onset of summer monsoon, with sharp increase in precipitable water but slight cooling of the ocean. There is a relative quick reversal of direction in September and drop in strength, but ord y gradual drying and cooling of the ocean. In the South China Sea, there is a much clearer and more dramatic onset of the winter monsoon in late September or early October, with large increase in wind speed, decrease in precipitable water and sea surface temperature. The wind direction changes sharply from south I southwesterly to northeaster y. The onset of summer monsoon appears to be more gradual, over a period February to April. In the South China Sea, the winter monsoon is much steadier than the summer monsoon; in summer the monsoon is often interrupted by storms.

EQUATORIAL KELVIN WAVES

The main advocacy of the scatterometer used to come from the oceanographers who want to study wind-driven ocean circulation. One of the most interesting areas to study wind-driven ocean circulation is the equatorial waveguide, where the wind effect is directly felt. The equatorial Pacific has received much attention because winds has been postulated as the precursor of an important climate signal - the El Nino and Southern Oscillation [3]. The climatological annual cycles were removed from three types of spacebased data to compute the interannual anomalies. NSCAT zonal wind components show that there are strong westerly wind anomalies around the date-line in late December, 1997. It started a downwelling Kelvin waves traveling east across the equatorial Pacific which was observed as positive sea level anomalies by the TOPEX/Poseidon altimeter. When the Kelvin waves reach the eastern Pacific, anomalous sea surface temperature anomalies were observed by the AVHRR.

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