THE POTENTIAL IMPACT OF SCATTEROMETRY ON OCEANOGRAPHY: A WAVE FORECASTING CASE

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1. INTRODUCTION

Surface wind stress is the primary driving force for oceanic motions. With a few exceptions, most notably the tides and the thermohaline circulation, physical oceanography might be defined as the study of the ocean's response to the mechanical forcing generated by the winds. This encompasses the generation of surface waves, the currents and surges produced by storms, and the large scale oceanic circulation that influences climate. It is perhaps self-evident that the task of understanding and predicting these responses is made vastly more difficult, if not impossible, by our ignorance of the forcing function. It is for this reason that satellite borne scatterometers hold out the promise of revolutionizing all aspects of physical oceanography: for the first time we will have global synoptic wind stress fields with resolution on scales of less than 100 km.

The focus of this short report is on the potential impact of scatterometry on surface wave prediction, but we first briefly comment on the opposite extreme, the large scale. Modeling of the seasonal and interannual variations in the ocean circulation is (at present) a hindcasting problem in which all historical wind data may be utilized. Even in this case data coverage is often inadequate to answer zero order questions. For example, two very recent studies of the North Equatorial Countercurrent (Meyers, 1980; Busalacchi and O'Brien, 1981) present calculations of the Sverdrup transport of this current - a linear function of the wind stress curl - that differ by a factor of two. An explanation has been proposed for the

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economically catastrophic El Niño phenomena that suggests that the anomalous warmings on the coast of South America occur in response to the relaxation of the winds in the western Pacific. (Wyrtki, 1975). Existing data is inadequate to clearly establish the time sequence of these events: it is possible that for some Los Niños the relaxation of the winds does not precede the coastal warming.

Storm surge and surface wave modeling are, most importantly, prediction problems (although there is increased interest in hindcasting studies as inputs to the design of off-shore structures). These synoptic timescale oceanic features are more directly and locally related to the wind than is the more physically complicated large scale circulation. The wind field to drive these prediction models must be forecast; errors in the model output are largely attributable to errors in the winds.

2. SIMULATION STUDY

In order to assess the potential impact of marine surface wind data on numerical weather prediction (NWP), a series of observing system simulation experiments has been performed at the Goddard Laboratory for Atmospheric Sciences (Cane et al, 1980). Care was taken to duplicate the spatial coverage and error characteristics of conventional surface, radiosonde, ship and aircraft reports. These observations, suitably degraded to account for instrument and sampling errors, were used in an analysis-forecast cycle resembling those in use in major meteorological centers. A series of five 72-h forecasts were then made using the analyzed fields as initial conditions. The forecast error growth was found to be similar to that in operational numerical forecasts.

Further experiments simulated the time-continuous assimilation of remotely sensed marine surface wind or temperature sounding data in addition to the conventional data. The wind data were fabricated directly for model grid points intercepted by a SEASAT-1 scatterometer (SASS) swath and were assimilated into the lowest active level (945 mb) of the model using a localized successive correction method (SCM). The temperature sounding experiment assimilated error free data fabricated along actual Nimbus orbits. Forecasts were made from the resulting analysis fields and the impact of the simulated satellite data was assessed by comparing these forecast errors with those of the control forecasts.

The results of these experiments for the lowest layer wind and for the surface pressure are shown in Figures 1 and 2, respectively. There are notable impacts in the extratropical northern hemisphere, particularly in the data sparse North Pacific and in North America, downstream of the Pacific. The assimilation of error free sounder data (again by the SCM) gave impacts comparable to the wind data, suggesting that surface wind data alone may be as valuable as

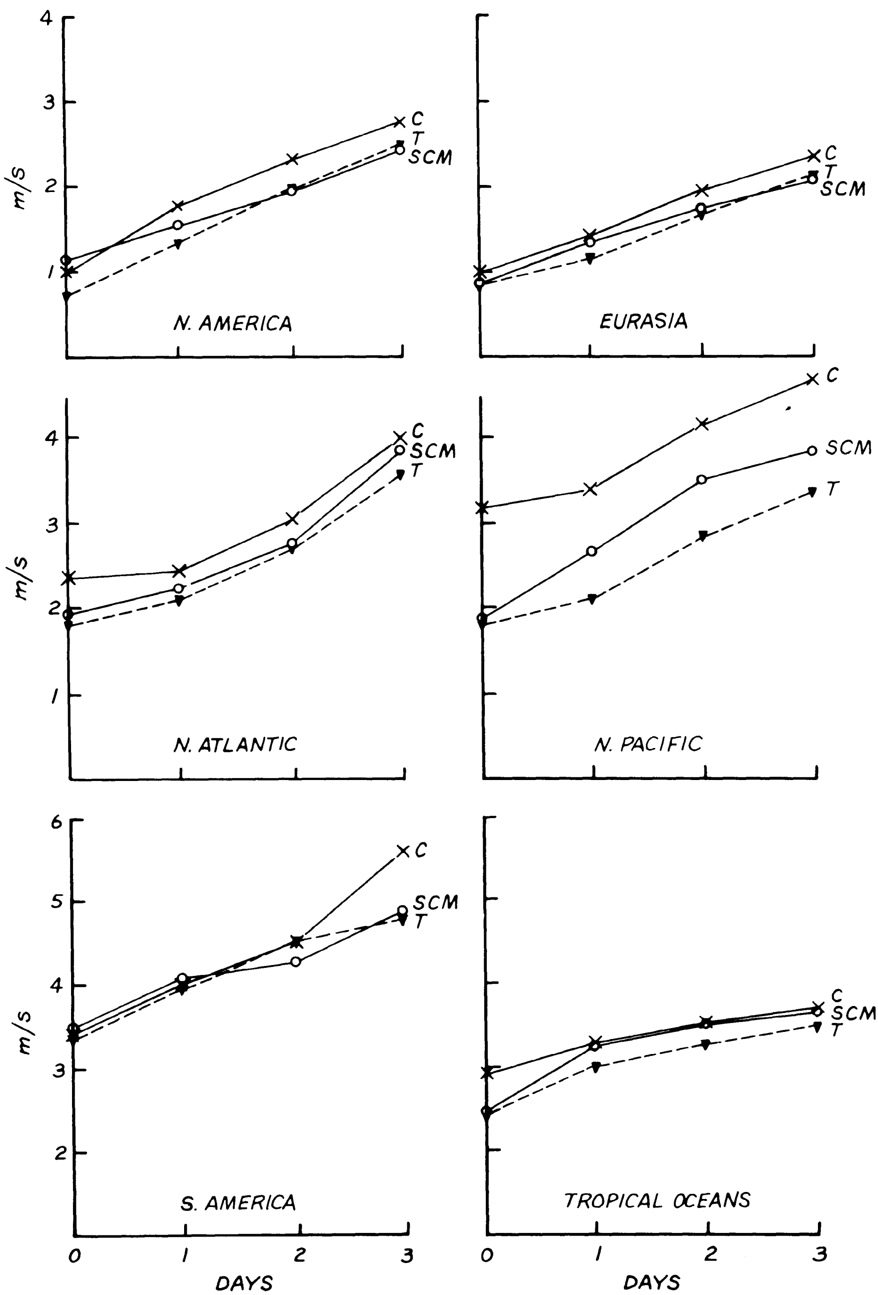

Fig. 1: Simulation study of U9 forecast error growth in lowest level zonal winds for control (C), perfect SASS winds (SCM) and perfect temperature sounder (T).

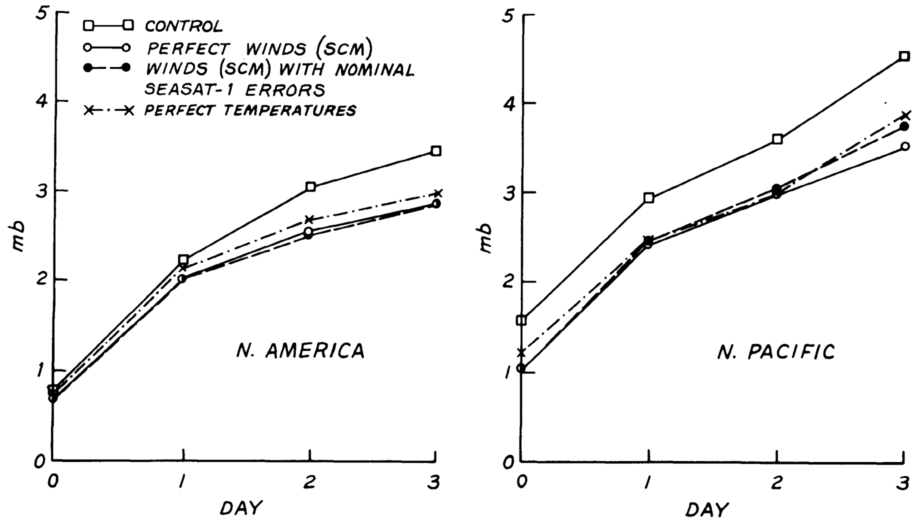

Fig. 2: Simulation study of forecast error growth in surface pressure for control, perfect SASS winds, and SASS winds with nominal SEASAT-1 errors of ± 2 m/s, ± 20°.

temperature soundings for numerical weather prediction. Figure 2 also shows that the effect of nominal SASS errors (± 2 m/s in magnitude, ± 20° in direction) on the impacts derived from wind data were negligible (at least insofar as these errors are uncorrelated). Available SEASAT results indicate that the operational SASS errors are of this magnitude. Examination of the individual cases shows that the impacts result from improvement in the forecast of specific features rather than a uniform global improvement.

3. THE QE II STORM

On September 11, 1978 the oceanliner Queen Elizabeth II encountered 30 m/s winds and 39 ft. seas. This storm caused about $50,000 in damages, including bent bow rails and torn hull plates; about 20 passengers were injured. The fishing trawler Capt. Cosmo reported 15 to 20 ft. waves off Georges Bank late on the 8th; she vanished on the 9th with the Coast Guard unable to find a trace of the boat or crew. The QE II storm provides a particularly dramatic example of a feature that would have been better defined by satellite wind measurements. It is perhaps surprising to find such a situation in the well traveled North Atlantic shipping lanes.

Gyakum (1980) has collected ship logs and other data that allow a better definition of the QE II storm than is possible from the information available to weather forecasters in real time (see below). This storm is an example of what Sanders and Gyakum (1980) term a "bomb": an oceanic extra-tropical cyclone that deepens explosively. Deepening rates of 50 mb in 12 hours are apparently not unusual. Bombs occur most frequently near the Gulf Stream and Kuroshio currents and in the east central North Pacific Ocean; within each region several may occur in one cold season. They are clearly a serious hazard to shipping and are largely responsible for weather related loss of life and shipping on the high seas.

The physical mechanisms responsible for the explosive development of bombs are not presently understood. The most plausible explanation points to the importance of convective heating associated with thunderstorms, not unlike processes at work in hurricane formation. If this is the case, then even high resolution NWP models will fail to capture the explosive deepening stage of bombs because the physics of convective scale systems and processes are poorly represented in these models. It is unlikely that scatterometer data will allow NWP models to anticipate the development of bombs until the relevant physics is better understood. (The data may perhaps contribute to achieving this understanding). However, the satellite data could provide early detection of bombs which would otherwise be missed or poorly diagnosed in the conventional marine data base, even in active shipping lanes. Early detection would contribute to improvements in forecasts in at least two ways: first, marine forecasters and ship routers would be made aware of the severity of these systems much sooner -- short range marine forecasts would thereby improve; second, NWP models would be provided a better initial state specification during the deepening stage. Updating at this stage can be viewed as a substitute for the convective-synoptic handover in scales of energy, which is so poorly modeled at present. This updating must lead to vastly improved weather and state of sea analyses and forecasts in the 1-5 day range.

The early stages of the QE II storm provide an example. At 12 GMT on September 9 (about the time the Capt. Cosmo was lost) Gyakum's (1980) analysis shows the storm developing southeast of Cape Cod. The National Meteorological Center analyst had only a single report indicating high winds. Lacking corroboration, he misplaced the low center and underestimated its intensity. (There was a SEASAT orbit passing over the storm center at this time.) At this stage the storm was probably of too small a scale and too early in its evolution for the NWP model to develop it correctly, but a better analysis would have been of value to marine forecasters.

By 12 GMT on the 10th the storm is fully developed. Thanks to the availability of a barograph trace (see Gyakum, 1980) from a ship (the Euroliner) which passed near the center of the storm at 12 GMT on Sept. 10, 1978, we have solid evidence of the extreme intensity of the storm at a time when the operational analysis (Figure 3) has seriously mislocated and understated the storm. Figure 4 is our

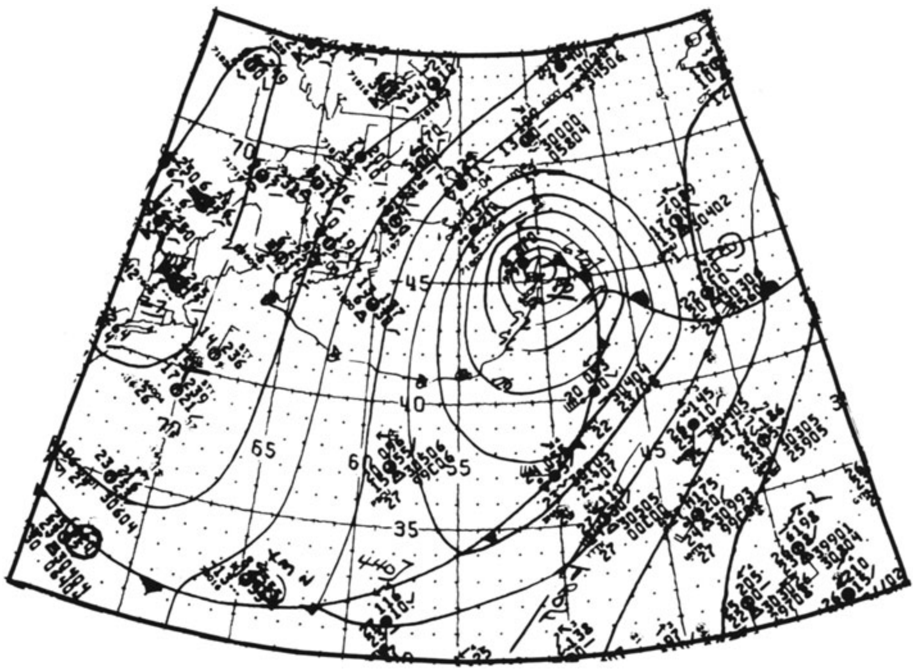

Fig. 3: Operational NMC surface pressure analysis for 12 GMT Sept. 10, 1978.

reanalysis which incorporates the Euroliner report. The central pressure is 20 mb lower (960 vs. 980) and since the scale of the system is the same, our analysis implies surface winds higher by a factor of two. Figure 4 also shows the boundaries of a SASS swath which is available and is in excellent position to reveal the structure, intensity and location of the storm at this time.

Both the real world storm and the forecast storm filled by about 20 mb in the 24 hours from 12 GMT on the 10th to 12 GMT on the 11th. It is clear that the poor specification of initial conditions provided by the NMC analysis for the 10th is responsible for the poor 24-hour forecast (Figure 5) for the 11th (cf. the verification analysis, Figure 6). The winds are forecast to be less than 15 m/s instead of the observed maximum of 25 to 30 m/s. It was at about this time that the QE II was battered by strong winds and heavy seas. Because the preceding NMC analyses had underestimated the surface winds by about a factor of two, especially in the southern quadrant of the system (compare Figures 5 and 6), their wave analysis misforecast the significant wave heights: where the QE II reported 39 ft. waves the forecast was for 10 ft. waves. The QE II turned south to avoid the storm at 8 GMT on the 11th. With better guidance such evasive action would have been taken earlier, avoiding damage and injury.

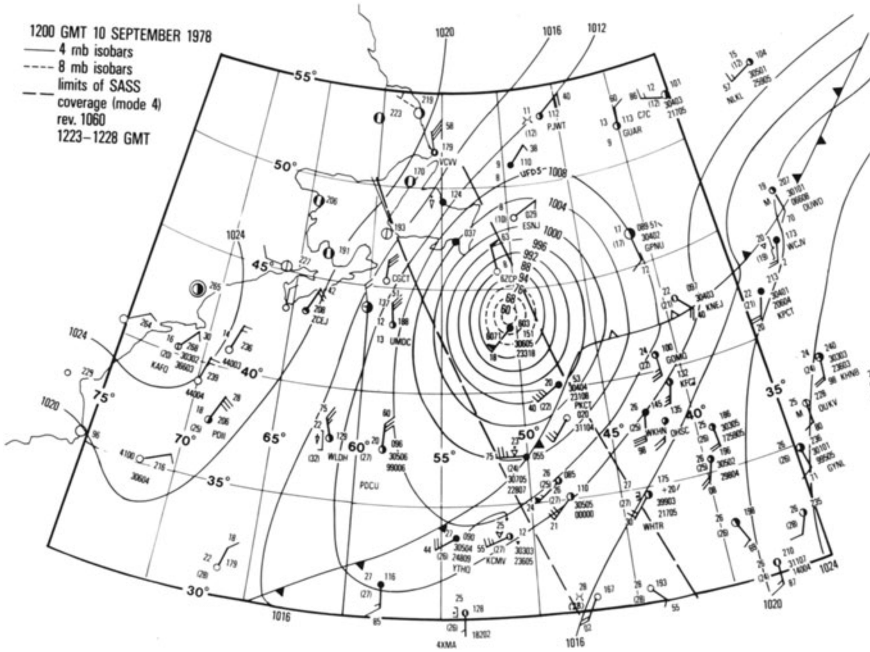

Fig. 4: Reanalysis of surface pressure, incorporating additional data, for 12 GMT Sept. 10, 1978. SASS swath indicated.

In summary, a simulation study suggested that SEASAT wind data will have a notable impact on numerical weather forecasts, especially for surface winds. Since poor surface wind analyses are known to be the largest source of error in wave forecasting, it follows that sea state predictions will be greatly improved. The study indicated that impacts resulted from better definition of specific features. The QE II storm is a real world example of such a feature: it was poorly specified by the data base available to the NMC analysis, resulting in a poor weather forecast and an even worse wave forecast. The QE II storm is an instance of a class of rapidly developing systems that are often poorly forecast and are responsible for much loss of life at sea. In the near future we will use the scatterometer data available for the QE II case to obtain a realistic assessment of its impact on numerical weather forecasts.

4. ACKNOWLEDGEMENTS

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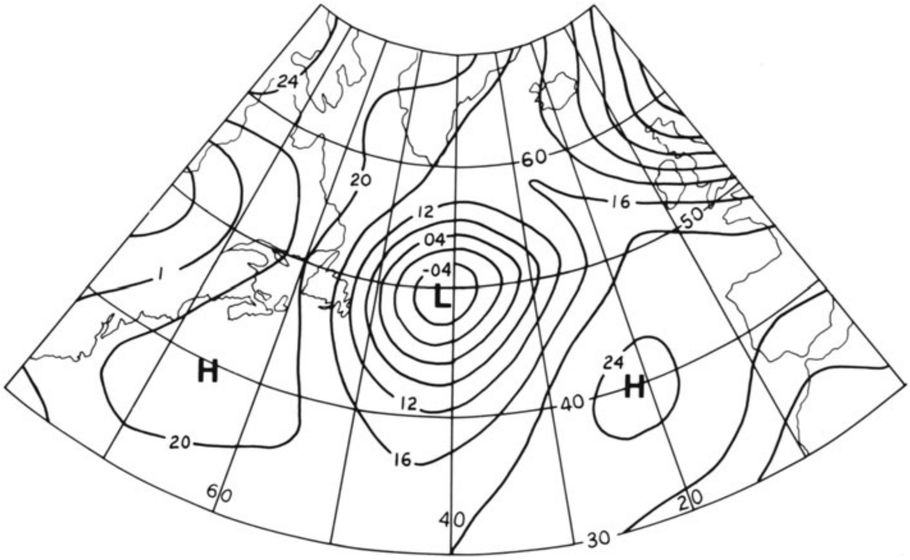

Fig. 5: NMC hemispheric LFM 24 h surface pressure forecasts valid 12 GMT Sept. 11, 1978.

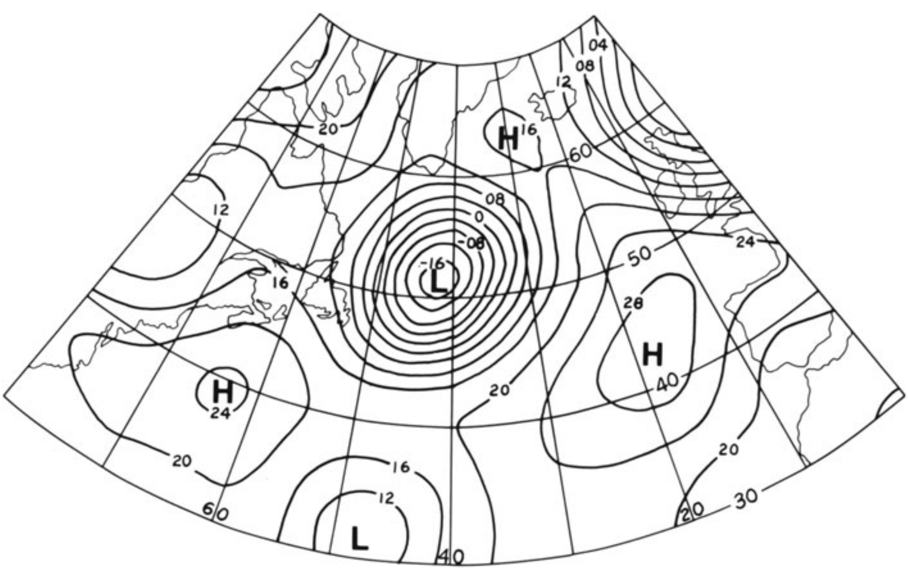

Fig. 6: NMC verifying surface pressure analysis, valid 12 GMT, Sept. 11, 1978.

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