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SCATTEROMETER CAPABILITIES IN REMOTELY SENSING GEOPHYSICAL
PARAMETERS OVER THE OCEAN: THE STATUS AND THE POSSIBILITIES

R. A. Brown

University of Washington
Department of Atmospheric Sciences

In accordance with a venerable remote sensing, and personal, tradition, this discussion will oscillate between the real and the speculative.... between the verified capability and the likely operational possibilities for the microwave sensors. I doubt that there exist simple relations between a single microwave return and a geophysical parameter for all practical conditions, e. g. between the scatterometer (SCATT) brightness and wind vectors or radiometers and Sea Surface Temperature. In fact, each fails in special circumstances due to increasing importance of some additional geophysical variable. However, this is no absolute limitation---the number of independent geophysical parameters is finite, even small. It may mean that a combination of sensors will be sufficient to define an operational set of geophysical parameters. Or perhaps simply an occasional buoy measurement will be needed to establish an absolute value.

If the desired geophysical parameters were linked in direct proportion, then only one sensor would be needed. For instance, the oceanic surface stress would give the mixed layer flow in the ocean, the air-sea fluxes and the wind profile in the atmospheric boundary layer. Indeed, the wind generated surface roughness in the 1-6 cm wavelength; the longer waves comprising the steady "sea state"; and the SST are all sufficiently interrelated that microwave brightness has been accurate to some degree in relating to each. Still, any dynamic oceanographer or atmospheric scientist can rattle off a dozen reasons why the capillary scale ocean waves are not uniquely related to the wind in the Planetary Boundary Layer (PBL). Nevertheless, verification experiments have shown that successful simple linear correlations do exist. I have been involved in studying the verification and physical mechanisms of the SCATT relation to wind or stress, so the following is from this perspective. Perhaps similar problems beset all electromagnetic remote sensing relations.

The SEASAT Scatterometer (SASS) fortunately had two surface wind verification experiments, the Gulf of Alaska Experiment (GOASEX) and the serendipitous Joint Air Sea Action Experiment (JASIN) in the North Atlantic. Detailed analysis of these two experiments indicated two unexpected things to me: (1) SASS determines winds on a large scale average to ± 2 m/s and has the potential to determine the direction to ± 20 deg. (2) The

surface verification capability is only marginally better than this. Thus, the routine operational capability for determining winds over the ocean conventionally is considerably less than the SCATT potential. So we have the problem that the complete capability of a satellite microwave sensor is not discernable by the surface measurements. Yet the empirical correlations between sensor signal and measured geophysical parameter, which makes up the sensor algorithm, is established using these insufficient measurements. One way around this lack of point by point verification is to look for integrated effects.

We can amass many points by creating surface windfields from conventional data (National Weather Service (NWS) pressure charts; ship and buoy data...) and build up statistical comparisons with SCATT data. This has been done for the base experiments, and is summarized in figure 1. Since derived windfields from conventional data without dedicated scientific ships and buoys is significantly worse, this verification product is essentially completed. Further information is being sought from comparing different sensors with a careful eye to the limitations of each. There are other papers summarizing these efforts. We have directed our efforts toward seeking implied verification from investigating the sensor ability to discern singular features, such as fronts in particular, but also tight cyclones, low or high pressure centers. If we assume that the SCATT footprint individual values are accurate, then features with variability on the scale of 20-50 km would be discernable. The first indications, from a weak front in JASIN, were encouraging (Brown, 1982). The characteristic of the brightness signal and the correlated multiple wind vector plots showed change along a line which more clearly defined the frontal location than did conventional analysis. In this respect, we are looking at sensor capabilities beyond wind sensing. Since sensor wind measurement accuracies cannot be evaluated with direct surface measurements, some measure of theory is needed to guide the empirical parameterization process, i. e. the algorithm development. There exists a mixture of relevant theoretical developments and observational facts which may help in understanding the physics involved and suggest some new operational capabilities for the SCATT.

1) The wind field over the ocean and the corresponding bulk flux coefficients, $C_D = \tau / \rho U^2$, $C_H = H_0 / \rho \Theta_* U$ (where τ and H_0 are surface stress and heat fluxes, ρ is density, Θ_* is a temperature parameter and U is wind, usually at 10 m), are not constant with respect to variation in wind, PBL stratification or humidity effects. The state of the art variation of the drag coefficient with these variables is shown and discussed.

2) Wind momentum obviously goes into long wave production. This must be related in a fairly constant way to the short wave energy for the linear algorithm to work. In some cases, such as behind fronts, the long wave steady state may not be attained. From the Storms Response Experiment (STREX) some data is shown to illustrate this effect.

In other cases, spurious swell may intrude. In this case, the relation to short waves is not understood and we had better hope that the effect is small. One can note that the short waves must result from a dynamic wind shear instability at or near the surface with wavelength rather independent of stratification. Also, the common observation of windrows, wherein convergence zones exhibit short wave suppression, suggests that surface tension is a factor. Here is a link between momentum transfer and SST effects on the resulting wave structure which has yet to be sorted out.

3) The flow in the PBL has distinctly different regimes. For $U > 7$ m/s, instabilities and large scale coherent structures exist in the flow, modifying the fluxes. This may be related to a discontinuity observed in the linear wind versus SASS brightness relations. It is possible that this fact led to the consternation at the SEASAT II workshop where one algorithm fit the linear relation below critical wind velocities and the other above. A single linear relation is inadequate to fit the two disparate regimes. There probably exist similar problems in other algorithms.

While the final parameterization scheme may evolve to two patched linear segments by itself, the theoretical knowledge may facilitate things, and offers physical justification.

4) When the complete, multivector plot of possible SASS wind vectors is examined, distinct changes in character occur in association with corresponding mesoscale wind and ocean wave phenomena, such as fronts and local storm activity. Some specific examples have been identified and are shown in figure 3. The accuracies and abilities of Scatt compared to conventional analyses in locating fronts is evident from this figure.

5) When the Scatt windfield---with its current verified accuracy--- is used as input to the state of art PBL model--- with its current verified accuracy---a geostrophic windfield, with error bars, is produced. The corresponding barotropic surface pressure map can be constructed. A comparison between this and conventional

weather service maps over the ocean can be made.

6) Specific storm fronts were flown through by the NOAA P-3 aircraft in or near the PBL during STREX. Some unexpected indications of strong wind and stress variation in the vicinity of a front were found.

In this experiment, comparison between the P-3, the NCAR Electra and the NASA Convair 990 Scatt measurements were made in very high winds. Scatt versus aircraft stress and winds are summarized. Variations and measurement errors in both terms were significant. However, it is clear that the variation of fluxes (heat and momentum) across a front is significant on the Scatt resolution.

In summary, extensive comparison between surface measurements and satellite Scatt signal and predicted winds show successful wind and weather analysis comparable with conventional weather service analyses. However, in regions often of the most interest, e. g. fronts and local storms, inadequacies in the latter fields leaves an inability to establish the satellite sensor capabilities. Thus, comparisons must be made between wind detecting measurements and other satellite measurements of clouds, moisture, waves or any other parameter which responds to sharp gradients in the wind.

The ability of the sensors to distinguish dynamic regions in the wind and stress fields is a separate capability, of practical use in supplementing conventional analyses right now.

It seems likely, at least for the windfields and the derived surface pressure field analysis, that occasional surface measurements are required to anchor and monitor the satellite analyses. These should be permanent, calibrated high accuracy point measurements. Their averaging times must be made compatible with the satellite sensor measurement. Careful attention must be paid to the complex fields which contain many scales of turbulence and coherent structures affecting the averaging process. It also seems likely that the satellite microwave system is capable of replacing the conventional point observational/numerical analysis for the ocean weather.

