Testing the Diagnosis of Marine Atmospheric Boundary Layer Structure from Synthetic Aperture Radar

Todd D. Sikora
United States Naval Academy
572M Holloway Rd.
Annapolis, MD 21402
Phone: (410) 293-6561 Fax: (410) 293-2137 Email: sikora@usna.edu

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LONG-TERM GOALS

My long-term goal is to continue to test and refine a similarity-based method for the extraction of marine atmospheric boundary layer (MABL) fluxes from synthetic aperture radar (SAR) wind imagery of the sea surface. Thus far, I have implemented this method on seventeen SAR wind images from off the east coast of the United States using bulk-derived statistics from coincident buoy data as ground-truth. Agreement is encouraging. The rate of acquisition of SAR wind imagery available to me has increased. Imagery is available over the Gulf of Alaska as well as off the east coast of the United States, in conjunction with the National Oceanic and Atmospheric Administration (NOAA)-sponsored Storm Watch / Alaska SAR Demonstration (http://fermi.jhuapl.edu/sar/stormwatch/index.html).

Therefore, the potential for robust testing of the method will continue. Questions I wish to address include the influence of the surface wave state, the synoptic and mesoscale meteorological environment, pixel size, and the averaging window size of the SAR wind imagery on the performance of the method.

OBJECTIVES

Young et al. (2000) presents a method based on Monin-Obukhov and mixed-layer similarity theory that uses the variance of SAR-derived wind imagery in the presence of statically unstable MABLs to generate diabatic wind imagery and, in the process, calculate several MABL statistics including the Obukhov length (L) and the surface buoyancy flux (B). Young et al. (2000)'s data set is limited to low wind speed and small air-sea temperature difference environments. My objective is to extend the work of Young et al. (2000) to environments with a larger range of wind speeds and air-sea temperature differences. No *in situ* turbulence data are concurrent with the SAR data set used my research. However, several NOAA National Data Buoy Center (NDBC) buoys are present in the imaged areas. Therefore, my objective is to compare SAR-derived MABL statistics to those produced by the Tropical Ocean-Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (COARE) 2.5 Bulk Flux method (Fairall et al. 1996) which uses the buoy data as input. In this light, my research should be viewed as a test of a method that, if successful, can compete with COARE 2.5-buoy estimates of MABL statistics.

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APPROACH

The key variable used as input for the SAR method is the variance of the wind imagery resulting from MABL convection. This variance (σ_u^2), combined with the SAR-derived MABL depth estimate (z_i) (via the technique presented in Sikora et al. (1997)) and the SAR-derived friction velocity (u_*) (via the wind imagery, the log wind law, and the Charnock relation), is used to calculate an L in the convective limit;

$$L = -z_i / (((\sigma_u / u_*)^2 - 4) / 0.6)^{3/2} . \quad (1)$$

L is in turn used to calculate a diabatic drag coefficient (c_d) via

$$c_d = (k / (\ln(z / z_o) - \Psi_m (z / L)))^2 . \quad (2)$$

In Eq. 2, k is von Karman's constant (0.4), z is the instrument height, z_o is surface roughness length calculated following Smith (1988), and Ψ_m is the stratification function given by Paulson (1970). c_d is combined with u_* to produce a diabatic wind speed image. The family of equations are solved by iteration, with refined values of L resulting in refined values of the wind speed. Convergence is rapid. B is obtained by solving the formal definition of L for that quantity,

$$B = -\frac{u_*^3 T_v}{Lkg} , \quad (3)$$

where T_v is the surface virtual temperature in absolute units and g is the acceleration of gravity.

The SAR imagery are converted to wind imagery using the technique described in Thompson and Beal (2000). Caution must be taken during the transfer from normalized radar cross section (NRCS) to wind imagery. For one, the relationship between NRCS and wind speed is highly dependent on the near-surface wind direction. The near-surface wind direction over the ocean can be quite variable, especially at high resolution in convective environments. Moreover enhanced or decreased backscatter due to oceanographic, as well as speckle noise can contaminate the SAR wind estimate (Mourad et al. 2000). Thus, when converting SAR imagery to wind imagery, it is usually desirable to apply some spatial smoothing. This smoothing minimizes contaminating variance while still providing a resolution high enough to preserve MABL convective signatures. I adopt the recommendation found in Thompson and Beal (2000) and Mourad et al. (2000) of smoothing to a 300-m pixel size; however, additional research is needed to test the validity of the choice.

All buoy averaging times for the data used in the COARE 2.5 method are 8 min and are calculated just prior to the top of an hour. Therefore, the buoy averages correspond almost identically in time with the SAR overpasses. Using the 8-min average buoy wind speeds and invoking Taylor's hypothesis, portions of each resulting wind image are cropped in such a way that the spatial data from the resulting sub-scene can be compared to the temporal data of the buoy. These square sub-scenes range in size from 17.6 to 51.8 km^2 and are used as input for the SAR method.

WORK COMPLETED

Task 1. Select appropriate SAR-derived wind imagery from in-house collection at The Johns Hopkins University Applied Physics Laboratory (JHU/APL).

Task 2. Cross reference SAR-derived imagery with collocated buoy data.

Task 3. Generate comparisons of SAR and bulk-derived marine atmospheric boundary layer statistics

Task 4. Present current research and preliminary results at International Geoscience and Remote Sensing Symposium, 2000

RESULTS

I have exhausted the original east coast RADARSAT SAR data set that I proposed to employ. That data set spanned 1996 to 1997. Preliminary results can be found in Sikora et al. (2000). Figure 1 shows expanded results from that research.

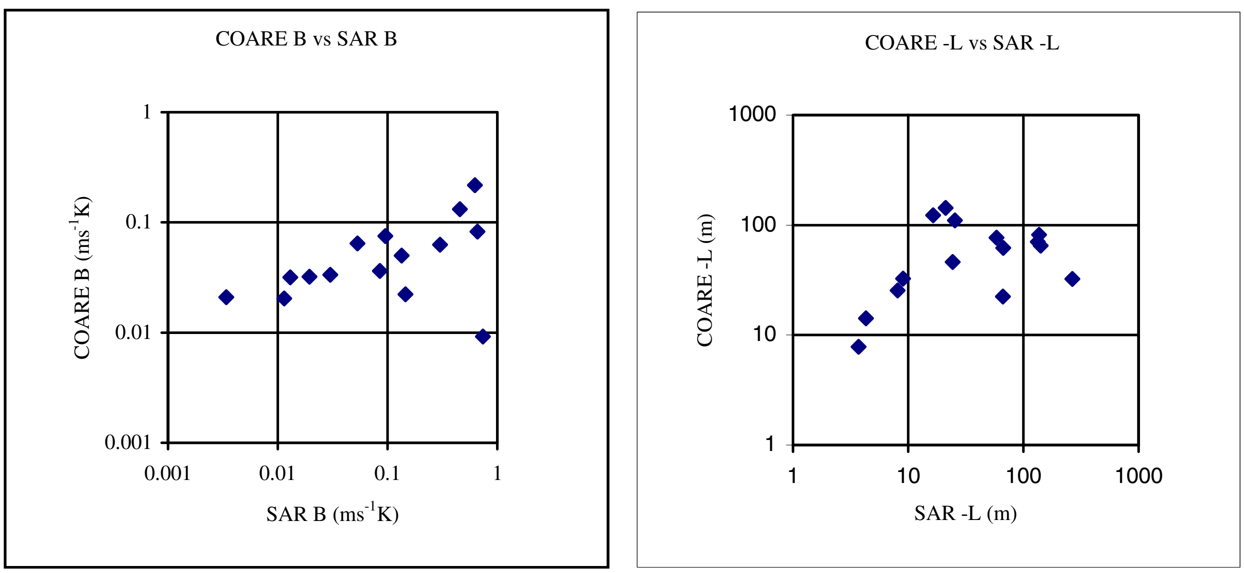

Figure 1. Comparisons of SAR- and COARE 2.5-derived -L and B.

As can be seen, agreement between the two methods is encouraging. More scatter exists in the comparison of -*L*s than *B*s. In general, the SAR method underestimates the results of the COARE 2.5 method at smaller –*Ls* and *Bs* while at larger –*Ls* and *Bs*, the opposite is true. Future work will address questions designed to reveal the causes for the observed differences.

IMPACT/APPLICATIONS

The above-mentioned SAR-MABL similarity theory techniques have the potential to provide accurate MABL flux measurements at a very high resolution. Verification of the usefulness of these techniques is important to those communities that would benefit from their implementation such as synoptic-scale and mesoscale operational numerical weather prediction.

TRANSITIONS

Pierre D. Mourad and I have recently been awarded a grant from NASA to extend this research to the equatorial Pacific. The NASA research will therefore compliment my ONR-funded work. The potential exists for examining SAR imagery coincident with *in situ* turbulence data. Therefore, there is the potential to reveal errors in both the SAR and COARE 2.5 method associated with the breakdown of Monin-Obukhov similarity theory due to the presence of young seas and swell (Donelan et al. (1997).

RELATED PROJECTS

The research described herein is also being reported under a separate ONR grant number, namely N0001400WR20192.

The continuation of my research relies on RADARSAT SAR imagery collected as part of the Storm Watch / Alaska SAR Demonstration. Much of this imagery is already in-house at JHU/APL and freely available to me. Additional imagery is archived each day. Scientists at JHU/APL convert these SAR images to wind speed images. In this respect, my research is coordinated with that of Dr. Donald R. Thompson of JHU/APL. His ONR-funded research is focused on scattering issues related to the extraction of wind speed from SAR imagery. Dr. Thompson has found cases where SAR-derived wind spectra differ significantly from corresponding *in situ* spectra. It is believed that some of the observed differences are due to the fact that fluctuations in the SAR imagery, especially at the shorter spatial scales, can be caused by complicated scattering and surface-wave hydrodynamic processes as well as by direct wind variation. These non-direct wind-related fluctuations in the SAR imagery are produced, for example, by pixel-to-pixel changes in the surface tilt or by changes in the spectral density of short surface waves due to hydrodynamic modulation that varies across the phase of the longer waves. Dr. Thompson is attempting to understand how to more accurately characterize and isolate these two different processes as well as to research other possible mechanisms for the observed differences.

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