Observations of wind stress response to sea surface temperature perturbations with synthetic aperture radar

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Abstract

Our purpose is to detect ocean surface features, specifically oceanic thermal fronts, through analysis of SAR (synthetic aperture radar)-derived wind stress fields. Fine-resolution measurements of near-surface wind speeds over the Gulf Stream region of the Northwest Atlantic were made using SAR images collected by RADARSAT-2. Linear statistical relationships between the wind stress curl and divergence to the crosswind and downwind components of the SST gradient field were used to derive a new method for detecting Gulf Stream thermal fronts from Synthetic Aperture Radar (SAR) imagery. In particular, sea surface temperature front features, as suggested by corresponding AVHRR and MODIS images, are evident in both of the wind stress curl and divergence fields.

The Gulf Stream provides energy, which is transported from the tropics to middle and high latitudes, to maintain the heat flux exchange between the ocean and atmosphere, thus affecting the entire troposphere. In terms of climatic tendencies, Minobe et al. [2008] suggest that surface wind convergence associated with low pressure and enhanced rain occur on the offshore flank of the Gulf stream SST (sea surface temperature) front, whereas surface wind divergence associated with high pressure occurs on the onshore flank of the front. Wind convergence and divergence is closely associated with surface winds that occur across an SST front, ultimately affecting middle and upper tropospheric dynamics. Therefore, the curl and divergence of the wind speed (or wind stress) are important factors related to SST variations of the Gulf Stream [*Small et al*, 2008].

The curl and divergence of wind stress are linearly related to the crosswind and downwind components of the SST gradient, respectively [*Chelton et al*., 2001; 2004]. O'Neill et al. [2003] suggest that different responses to the crosswind and downwind SST gradients between curl and divergence may result from secondary circulations which produce significant perturbations in the surface wind near SST fronts. The magnitudes of the curl and divergence of wind stress vary in both temporal and spatial domains [*O'Neill et al*., 2005]. The SST induced wind stress perturbations are larger than associated wind speed perturbations. They also found that two sources of SST induced wind stress curl and divergence perturbations are the nonlinear stress- wind relationship and spatial gradients in SST induced wind speed, respectively [O'*Neill et* *al.*, 2009].

It is well known that QuikSCAT wind vector (resolution of 25 or 12.5 kilometers) and MODerate Resolution Imaging Spectroradiometer (MODIS) or the Advanced Very High Resolution Radiometer (AVHRR) SST products (resolution up to ~4 kilometers) can be used to study air-sea interactions and analyze climate and weather phenomena related to ocean surface features of the Gulf Stream. It is also well known that synoptic scale atmospheric fronts can be analyzed with synthetic aperture radar (SAR) [*Young et al.*, 2005; *Alpers et al.*, 2007] on the fine spatial scales in the MABL [*Sikora et al.*, 1995; *Beal et al.*, 1997]. In fact, an airborne Ku-band high resolution scatterometer was used to measure ocean backscatter signatures across the Gulf Stream [*Nghiem et al.*, 2000]. It was found that the vertical polarization backscattering normalized radar cross section (NRCS) difference is more than 5 dB with 9^{o}C discrepancy across the SST front. Thus, Gulf Stream SST fronts should be detectable by SAR.

Although it is not possible to directly determine the Gulf Stream thermal features with the SAR backscatter RCS, the objective of this study is to present a method to determine the Gulf Stream edges. Recent studies show the coupling between winds and the SST response to the local heat fluxes and local marine weather. Thus, the wind speed, wind stress and their curl and divergence are factors in studying air-sea interactions in the Gulf Stream region. Our objective is to explore the link between the curl and divergence of wind or wind stress and Gulf Stream fronts.

We present a method to infer Gulf Stream thermal fronts from SAR images. The importance of this methodology is that MODIS and AVHRR cannot see through clouds, whereas SAR can penetrate most cloud formations. Based on the linear relationship between SST gradients and wind stress variations, a methodology is presented to detect Gulf Stream thermal fronts using only variations in SAR-derived divergence and curl wind stress fields. Both divergence and curl of wind stress fields are needed in analysis of the coupling between wind stress and SST fields on the thermal fronts. Clearly, any time- lag between the images containing SST gradients and those containing SAR-derived wind stress variations will diminish the accuracy of the methodology because these features continue to develop during the time discrepancy.

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