Air-Sea Interaction Studies of the Indian and Pacific Oceans

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LONG-TERM GOALS

This proposal consists of three individual self-contained projects. A common component of all tasks is the utilization of satellite imagery to extract surface currents. The three projects are listed as the following tasks:

Task 1: Air-Sea Interactions Impacting the North Arabian Sea Circulation

Task 2: Satellite Observations of Flow Encountering Abrupt Topography

Task 3: Observations of Surface Signatures in the South China Sea

The long term goal of this project is to employ satellite SAR imagery to the quantitative analysis of monsoons, internal waves, ocean surface features, and surface currents. To achieve this, a variety of satellite SAR sensors with different frequencies, multi-polarizations and different imaging modes are used to determine which combination of the above capabilities could provide the best solution.

OBJECTIVES

For simplicity we provide only the three primary objectives of each task.

a) **Task 1:**
   i. To determine the characteristics of monsoons with satellite SAR imagery.
   ii. To determine surface current properties over dominant circulation features.

iii. To examine the impact of the fresh water flux on SAR backscatter data and could it be used to describe the rain intensity.

b) Task 2:

i. To complement the acquisition and analysis of conventional radar intensity images and other data by direct high-resolution imaging of surface current fields from space by along-track InSAR.

ii. To improve our understanding of the radar imaging mechanism of internal waves by analyzing along-track InSAR derived surface current fields in combination with conventional SAR intensity imagery and in-situ data.

iii. To determine the characteristics of backscatter at topographic encounters with SAR imagery.

c) Task 3:

i. To understand the detection of scattering objects in different oceanic processes and atmospheric conditions.

ii. To determine the limitations of detections of different surfaces, length scales and different materials.

iii. To explore which imaging modes and polarizations provide the highest rate of detections.

APPROACH

Task 1: High resolution SAR data will allow monitoring of ocean processes in the North Arabian Sea circulation region due to current and/or meteorological forcing at a resolution greater than previously possible. Satellites can provide data sets as frequent as every two days of the following:

a) Wind speed, direction, curl, divergence and gradients at a resolution of 500 m or less which exceeds any other observational capability.

b) Surface pressure fields at 1 km resolution or less.

c) Significant wave height on a 1 km resolution or less.

d) Estimates of the ocean surface current gradient and divergence on a 500 m resolution. When mapped these provide locations of fronts and spatial structure not possible from altimetry based products.

Recent studies demonstrated that the SAR normalized radar cross-section identified features in the surface current field are similar to the current divergence from SST data, and mean square slope from sun glint imagery. Other studies have also shown that a current gradient can be obtained. When these data are assimilated into a very high resolution ocean model the accuracy of current analyses should be markedly improved.

Surface Roughness Dependence:

The centimetric waves riding on larger waves and swell changing to different air-sea interaction conditions are correlated to the radar backscatter. Rain on the ocean surface adds additional mass and this added mass effect tends to smooth out the roughness, hence the backscatter goes down. Attemps will be made to acquire SAR and TRMM near simultaneously over an area with and without rain to assess the impact of the rain and rain intensity on the normalized radar cross-section (NRCS). This approach will be useful during the different phases of monsoon passages to study the near surface flow and roughness variability.

Satellite SAR data – wind and wave measurements:
The development of high-resolution SAR wind and wave retrieval algorithms has allowed the application of these data to a variety of operational and scientific problems. However, most of the existing approaches have been developed and extensively validated only under moderate to low sea state and wind conditions. The purpose of this proposed program is to refine the capabilities to utilize a SAR as a validation tool for monsoon prediction models, generating high resolution wind and wave estimates around the storm center to compare to monsoon model predictions. This will be especially important over regions of intense fresh water flux or rain.

Task 2: ***Along-Track Interferometry***
The along-track interferometric synthetic aperture radar (along-track InSAR, ATI) was first proposed by Zebker and Goldstein (1987) and demonstrated by American scientists with an airborne system developed by NASA-JPL (Thompson and Jensen, 1993; Graber *et al.*, 1996). After further airborne ATI experiments (e.g., Romeiser, 2005), first demonstrations of current measurements from space with data from a space shuttle experiment (Romeiser *et al.*, 2005, 2007), and a number of theoretical studies (e.g., Romeiser and Runge, 2007), first satellites with experimental ATI capabilities are now becoming available for current measurements at freely selectable test sites during missions of several years. The ATI technique exploits the fact that phase differences between two complex SAR images acquired with a time lag of a few milliseconds are proportional to Doppler shifts of the backscattered signal due to line-of-site target velocities. This way, line-of-sight velocity images can be obtained at full SAR resolution. However, as discussed by Romeiser and Runge (2007), some spatial filtering (and a corresponding loss of spatial resolution) is always required to obtain velocity estimates of reasonable accuracy. To acquire two SAR images from the same antenna location within a few milliseconds, an ATI system uses two antennas which are separated in flight (along-track) direction by a corresponding distance.

Spaceborne ATI Capabilities
According to theoretical results presented by Romeiser and Runge (2007), the ATI capabilities of the German satellite TerraSAR-X, which was launched in June 2007 and which can be switched to experimental split antenna modes, will be comparable to the ATI capabilities of SRTM. Also TerraSAR-X suffers from an unfavorably narrow along-track antenna separation. A clear advantage of TerraSAR-X lies in its pure along-track InSAR layout without an antenna separation component in cross-track direction. This layout ensures that the InSAR phases will not be contaminated with contributions associated with the surface topography, and it facilitates the absolute calibration of measured velocities.

ATI Observations of Internal Waves
To resolve typical current patterns over internal waves, a spatial resolution on the order of 100 m or better will be required; the aforementioned effective resolution of 1,000 m expected from TerraSAR-X will not be sufficient. The TerraSAR-X stripmap images with much higher (on the order of 3 m)

original pixel resolution and the current patterns of internal waves varying on short scales in one direction only, while they are almost constant over long distances along the crests, offer an opportunity to estimate the surface-induced currents from internal waves. The fact that orbital currents of internal waves should be aligned with their direction of propagation can be exploited for a quasi-two-dimensional current retrieval like in the river case.

Task 3: Ship detection has long been of interest, initially with the goal of collision avoidance. The crow's nest was the first creation developed to address this problem, first making an appearance in 1807 (Wikipedia, 2013). German engineer Christian Hülsmeyer demonstrated a basic radar system for detecting ships up to 3,000 meters away in 1904 (Hollmann, 2007). Taylor and Young of the U.S. Naval Aircraft Radio Laboratory (now called the Naval Research Lab) demonstrated ship detection with radar on the Potomac in 1922 (IEEE Global History Network).

Ships are large objects that provide plenty of surface area to reflect sunlight or microwaves incident upon them. Not surprisingly, maritime vessels themselves generally provide the strongest signals when imaged. Large ships with their distinct structures and metallic materials often provide strong direct reflection and contrast the ocean background well (Pichel et al., 2004). But this is not always the case. Another feature on occasion can better illustrate the presence of a ship: wakes. Wakes can be very large and distinct features and indicating the presence of a vessel (Mallas and Graber, 2013). Observing ships in satellite images not only means seeking the vessel itself, but also observing how the ship interacts and modulates the surface of the ocean.

Ships provide large targets for satellites to observe, namely the hull and superstructures. These large structures have lines and patterns that indicate man-made objects that humans can contrast against the generally random and cluttered background of the ocean. The structures provide corners and edges that strongly reflect microwaves of a SAR sensor. Direct observation of the ship target itself is the most likely ship observable. Sometimes wakes can be an easier signature to observe especially due to the satellites overhead perspective. Wakes can persist for hours (given favourable environmental conditions) and therefore can sometimes be many kilometers long (Vesecky et al., 1982). On occasion, especially with a fast small moving vessel, a wake feature is clearly present in the image yet no vessel is observed.

A wake, given that a vessel is underway, is assumed to be present at some level. The amplitude of the wake is dependent on a variety of variables: vessel speed, vessel size, hull structure, etc. Also, while the term wake implies a single entity, wakes are actually interactions of several different phenomenon and can be quite complex in structure. Generally a wake can consist of a Kelvin wake, a turbulent wake, and a transverse wake (Figure 1). The Kelvin wake may be generated by either the bow or stern of the vessel or both. Depending on the size of vessel the two wakes may be distinctly visible or merge into one V-shaped Kelvin wake pattern. All of these features may not be present or observable. Also, structures of the wakes are symmetrical in nature (the bow wake, for example). It may be possible that only one arm of the Kelvin wake is observable, say the starboard arm for a given image, while the opposite side is not.

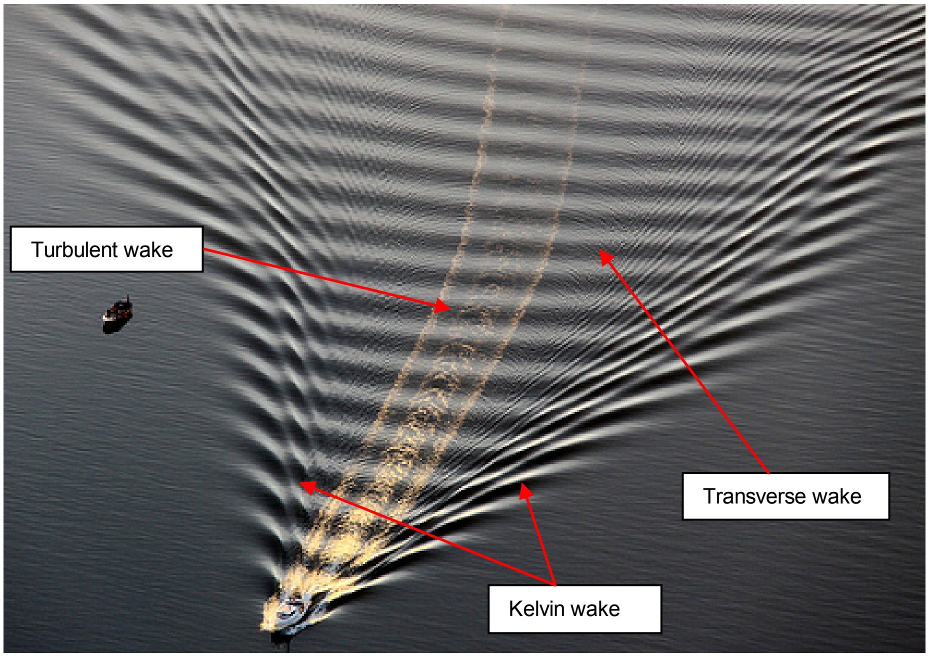

Figure 1: Optical image of a ship wake showing the different wave patterns produced by a ship. The bow wave is oriented at the Mach angle of 19o 28' and the transverse wake are circular waves emanating from the ship's stern. © 2009 Chris Goldberg used by permission.

Interestingly, wakes can consist of both disturbed water (like waves from a Kelvin wake) and quiescent water (like the slick surface created by turbulent wake) (Peltzer et al., 1987). So wake signatures can consist of regions with two opposite phenomenon. The practical effect of this that wakes can both increase the signal return for some portions of the wake (a bright feature in the image) and reduce the signal return for the another (dark feature in the image). Complexity of the wake features can provide a challenge to the human observer, not to mention the difficulty in developing computer-aided and automated algorithms.

Environmental conditions can play a large role in the ability to observe a vessel. Winds and waves can take a normally serene background and create strong returns in both EO and SAR sensors. This situation can create "false-alarms" in the observation of ships, making the actual ship difficult to distinguish from the background (Mallas and Graber, 2013). The environmental conditions can disperse wake features. Waves can cause a pitching and rolling of the vessel, creating smeared lines in SAR images.

WORK COMPLETED

In progress.

RESULTS

None yet. Project just started.

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