Jason-2 with WSOA

Observing the Ocean
with a Wide-Swath Altimeter

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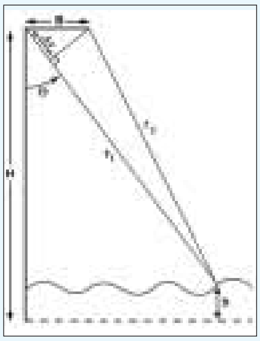

Figure 1. Geometric concept used for radar interferometry.

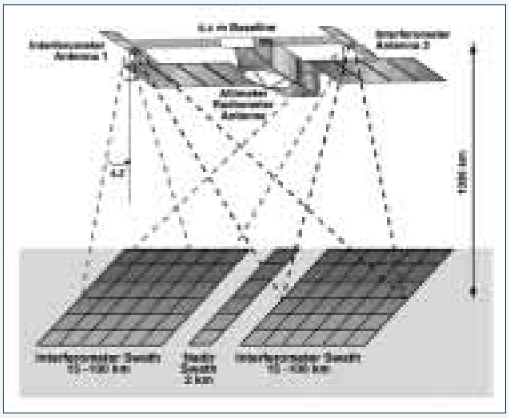

Figure 2. Conceptual operation of the WSOA instrument to measure a 200-km swath.

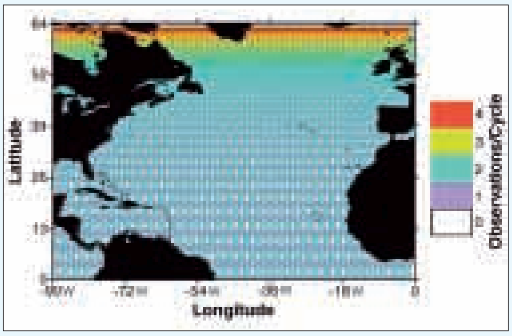

Figure 3. Coverage map for WSOA showing the number of observations per 10-day cycle for a 200-km swath.

A satellite radar altimeter provides profiles of sea-surface height along the satellite's ground tracks with a spatial resolution of 6-7 km. Such profiles are used to derive information about ocean surface currents and the marine gravity field. However, this essentially one-dimensional measurement does not provide a complete picture of the vector field of ocean currents and gravity anomalies. Only the cross-track component of the surface current velocity and the along-track component of the gravity anomaly have been well sampled by altimetry observations. In order to map the sea-surface height in two dimensions with comparable resolutions, a new type of radar instrument has been developed at JPL using the principle of radar interferometry. The new measurement will be made over a swath 200 km wide, providing an image of sea-surface height instead of a profile. This new instrument is called Wide Swath Ocean Altimeter (WSOA). The reader is referred to Fu [2003] for a comprehensive description. Only a brief synopsis is given in this article.

Measurement Principle and Mission Design

WSOA measures the relative delay between the ocean-reflected signals from two antennas separated by a "baseline distance". The range measurements from the two antennas and the baseline form a triangle that can be used for determining the location of the target in the observation plane (Figure 3). The measurement triangle is made up of the baseline B, and the ranges from the target to the two antennas, r_1 and r_2. The baseline is known from the design and construction of the instrument, and from the spacecraft attitude. The range r_1 is determined by system timing measurements. The range difference between r_1 and r_2 is determined by measuring the relative phase shift ϕ between the two signals. This phase shift is related to the range difference Δr by the equation $\phi=2\pi\Delta r/\lambda$, where λ is the radar wavelength. The additional information required for determining the target location-the incidence angle θ-can be obtained from the range difference by means of the relationship $\phi = 2\pi B \sin(\theta)/\lambda$. Given these measurements, the height h above a reference plane can be obtained using the equation $h = H - r_1 \cos(\theta)$, where H is the altitude of the satellite determined from orbit ephemeris.

Shown in Figure 2 is the proposed configuration of WSOA as part of a Jason-class altimeter mission, which is OSTM/Jason-2 in the present case. With a deployable 6.4-m baseline (limited by the dimension of the Jason spacecraft), the K_u-band interferometry system will be integrated with the standard Jason instrument package: K_u- and C-band altimeters, a three-frequency radiometer, a DORIS receiver and a GPS receiver.

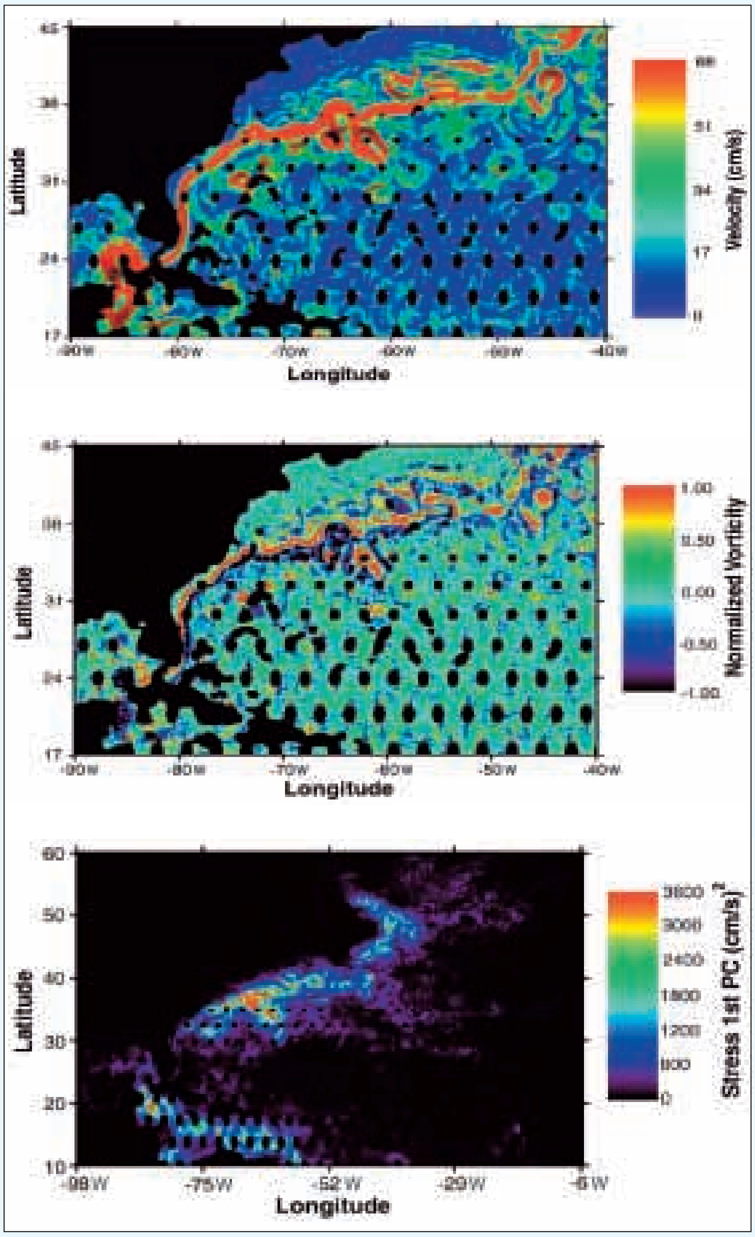

Figure 4. Sample geophysical data products from the WSOA instrument: (a) geostrophic velocity; (b) relative geostrophic vorticity; (c) Reynolds stress tensor.

The interferometric antennas have beams illuminating both sides of the nadir track to produce a total swath width of 200 km, when optimally oriented. However, for the flight demonstration of WSOA on OSTM/Jason-2, some reduction in coverage will occur due to the steering requirements of the platform.

Measurement Performance

The instrument's spatial resolution is determined by the size of the antenna beam in the direction perpendicular to the baseline direction, and by the system bandwidth (or intrinsic range resolution) in the direction parallel to the baseline direction. For the WSOA system, the first resolution is 11 km, while the intrinsic range resolution varies from about 500 m in the inner swath to about 100 m in the outer swath. The height estimates measured at these resolutions are noisy, so noise is reduced by averaging all measurements within a box. The topographic results will be plotted on a 15-km grid. Figure 3 shows the coverage of WSOA in the Jason 10-day repeat orbit. Note that a substantial portion of the ocean surface is covered more than once.

The accuracy of WSOA measurements, prior to calibration, is governed by the systematic errors in the knowledge of the spacecraft's pointing direction and the signal's phase. These errors vary gradually over the orbit and have known geometric signatures. Such errors can be minimized by calibration using the nadir altimeter measurement, which is insensitive to the pointing and phase errors, as well as by calibration using the crossover differences between the ascending and descending WSOA measurements. A simulation experiment was performed to estimate the measurement accuracy, based on simulated sea-surface height from a high-resolution ocean model and the WSOA measurement system including the calibration approach mentioned above. The results indicate an RMS error of 4-5 cm (increasing from the inner edge to the outer edge of the swath) for a single-pass measurement at 1/sec data rate

Figure 4 shows examples of the velocity magnitude and relative vorticity fields retrieved from the simulated data from an ocean model. The ability to calculate vector

velocities at every point within the WSOA swath affords the possibility of calculating flow-related quantities, such as the Reynolds' stresses. Figure 4 shows an example of potential data products from WSOA.

Raw WSOA measurements have an along-track (cross-radar-look) resolution of 12 km (limited by the interferometric antenna size), and a cross-track (along-radar-look) resolution of 1 km (limited by the transmission bandwidth and data downlink capacity). For most oceanographic applications, the cross-track measurements are averaged spatially to reduce measurement errors for more accurate observations at coarser resolution.

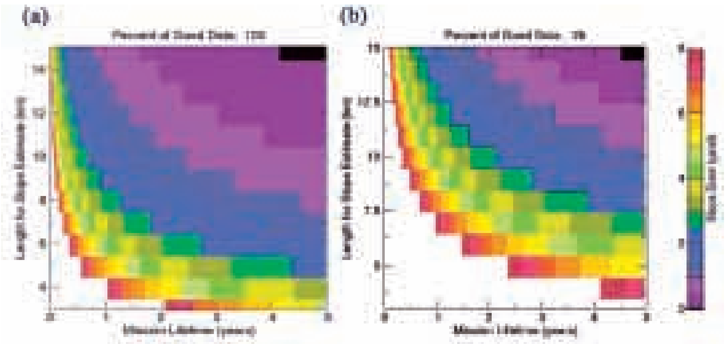

Figure 5. (a) Cross-track slope accuracy as a function of averaging time and distance used to estimate the slope. The parameter space which meets the one micro radian requirement is colored in shades of purple. The parameter space which improves current measurements is roughly given by the area shaded in blue. This figure assumes that 100% of the data are available for estimating the slopes. (b) The same as (a), but this figure assumes that only 25% of the data are available for slope estimation.

In order to retain the high spatial resolution for geophysical applications, one could retain the intrinsic instrument resolution of 1 km in the cross-track direction to reduce errors for estimating the time-invariant surface slopes. The resulting data have a resolution of 1 km in the cross-track direction and 15 km in the along-track direction. Because of the inclination of conventional altimetric satellites, the measurement of sea-surface slope is much less accurate in the cross-track direction than the along-track direction. WSOA measurements will significantly improve our knowledge of the east-west component (roughly in the cross-track direction for most satellite altimeters) of sea-surface slope, which has an error larger than 5 micro radians at latitudes less than 50° [Sandwell et al., 2001].

Figure 5a shows the expected slope accuracy as a function of the spatial scale used for the estimation and averaging time. The purple regions correspond to regions where the required accuracy of one micro radian is achieved for geophysical applications [Smith and Sandwell, 2004]. The blue regions correspond to regions where the data would represent an improvement over currently available data. Notice that for a minimal mission duration of two years, the smallest resolvable wavelength which meets the accuracy requirement is ~20 km, but data improvements are observed down to wavelengths of ~13 km. If the mission lifetime is five years, the smallest resolvable wavelength which meets the requirements is ~15 km, while improvements in performance are observed down to wavelengths of ~8 km.

Figure 5a assumes that all data will be available and useful for the estimation. In reality, due to satellite yaw steering, which will be used on the OSTM/Jason-2 mission, it is likely that the number of useful points might be reduced. As a pessimistic estimate, we assume that only one-quarter of all points are useful for estimation (this corresponds to the worst-case yaw steering scenario, where only the data without yaw steering are useful for the slope estimation). The estimated slope error for this case is shown in Figure 5b. The performance after four years for the degraded case is equivalent to the performance after two years using all the data. Nevertheless, a performance of two micro radians would still represent a significant improvement in our current knowledge of the east-west component of sea-surface slope.

References

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