Littoral Antenna Deconvolution for a Microwave Radiometer

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Abstract -- The standard on orbit data processing used by all current and upcoming satellite altimetry missions TOPEX/Poseidon, GEOSAT Follow On, and Jason-1) results in a radar altimeter footprint which is generally much smaller than the footprint of the microwave radiometer that is used to correct for path delay of the radar signal by tropospheric water vapor and clouds. As a result, the quality of ocean topology retrievals can be compromised in coastal environments even when the altimeter itself is still operating nominally. For example, the diameter of the TOPEX altimeter footprint is 3-5 km at typical wind speeds, but the radiometer has a 35 km footprint at 21 GHz. Because of this size disparity, wet path delay corrections are generally not considered reliable within approximately 50 km of a major coastline. We present here an antenna deconvolution procedure which is specifically intended to improve near-coastal retrieval of the wet tropospheric path delay correction by satellite altimeters. The procedure has immediate applications with archived and current TOPEX/Poseidon data, and will be applicable to the upcoming GFO and Jason-1 missions, for the imaging of ocean currents and tides in the littoral zone.

OVERVIEW OF APPROACH

There are numerous approaches which have been taken to antenna resolution enhancement by deconvolution. We have selected an optimal estimation procedure. Optimal estimation uses a weighted average of the direct formal inversion of the antenna convolution integral, together with the a priori mean value of the image. Weighting is with respect to the noise in the image, in the case of the formal inversion, and with respect to the statistical variability of the image, in the case of the a priori mean. This approach is particularly well suited to cases in which: 1) the mean value of the image has strong features with high spatial frequency content; and 2) the statistical variability of the image can be determined accurately. Altimeter missions use exact repeat orbit crossings of the high contrast ocean/land boundaries. In addition, statistical analysis of the radiometer data at the coastline crossings over the course of a mission provides a reliable estimate of their climatological variability. For both of these reasons, optimal estimation is a natural candidate approach. Details of the design of our deconvolution algorithm, together with a summary of our data base of climatological variability in the littoral zone, are presented. Before-and-after results of the deconvolution are also shown.

DESCRIPTION OF OPTIMAL ESTIMATOR

The antenna temperature (TA) measurements made by a radiometer are the result of a convolution of its antenna power pattern with the true angular distribution of the brightness temperature (TB). For the case of a nadir viewing satellite-born radiometer, the convolution integral can be discretized as a linear operator

$$TA = A*TB \qquad (1)$$

where TA is a vector of measurements lying along the ground track of the radiometer, A is an appropriate discrete (matrix) approximation to the antenna radiation pattern, and TB is a discrete approximation to the true brightness temperature distribution. For the case of the TOPEX Microwave Radiometer (TMR), data are sampled every 5.8 km of along-track motion by the satellite, and so a natural discretization for TB and A is in integral units of 5.8 km. The spatial resolution assumed for TB determines the degree of enhanced spatial resolution that results from the deconvolution process. We consider here a maximum resolution enhancement, in which TB is defined every 5.8 km.

Direct inversion of (1) by minimum squared estimation (MSE) is defined by

$$TB = (Atrans*A)^{\wedge}\text{-}1*Atrans*TA \qquad (2)$$

where Atrans is the transpose of A. The numerical stability of a direct MSE inversion of this kind, and its tolerance of measurement noise in TA, is significantly improved by constraining the inversion by use of a Tikhonov relaxation parameter. We use the first derivative of TB as our constraining measure. The resulting constrained MSE inversion is given by [1]

TB = (Atrans*A + gamma*Ktrans*K)^-1*Atrans*TA (3)

where K is a linear operator which discretely approximates the first derivative of TA, and where gamma is an adjustable relaxation parameter that determines the degree to which the first derivative of TB is constrained. In practice, gamma represents a trade-off between spatial resolution and sensitivity to noise. Equation 3 can be written more compactly as

TB = M*TA (4)

The sensitivity of TB to noise in TA is characterized by its covariance, according to the following relationship

Cmse = M*Cta*Mtrans (5)

where Cmse is the covariance of TB that results from a constrained MSE inversion and Cta is the covariance of TA. If the degree of deconvolution that is attempted in (3) is too severe and/or if the relaxation parameter, gamma in (3), is too small, then the noise in TB can be unacceptably small. This noise can be corrected to some degree by combining the constrained MSE estimate of TB with an a priori estimate based on climatology. A climatological mean value for TB can be extracted from a large data base of TB at a particular location. In our case, we have done so for particular coastal crossings. The MSE and mean TBs are combined as a weighted average using the optimal estimation algorithm, which weights each contribution according to its inverse variance [2]

TBopt = (Cmse^-1+Cclim^-1)^-1*
(Cmse^-1*TB+Cclim^-1*TBclim) (6)

where Cclim and TBclim are the climatological covariance and mean, derived from a large data base of coastal crossing by TMR at a particular location.

Examples of the standard deviation and mean TB at the Peruvian coastal crossing located at LAT=14.82S, LON=75.60W are shown in Figure 1. The standard deviation represents the square root of the main diagonal of Cclim. Cclim is assumed to be diagonal here, in order to allow the optimal estimator as much freedom as possible in deconvolving the variations between adjacent 5.8 km pixels in TB.

RESULTS OF THE DECONVOLUTION

On example of the direct MSE deconvolution of TA is shown in Figure 2 and 3. The relaxation parameter, gamma in (3) is varied from 10^-1 to 10^-3. The deconvolved TB can be seen to more sharply locate the coastline (located at along track relative position 0 km in the figures) as the relaxation is lowered (smaller gamma). However, the noise in TB also increases with lower gamma. A closer look at the littoral region immediately before land crossing, in Figure 3, reveals that most of the small variations in the deconvolved TB are also present, but to a much smaller extent, in the raw (undeconvolved) TMR TBs. This suggests that these variations are not noise artifacts, but rather are actual small scale variations in the ocean brightness distribution. Note that significant land contamination of the raw TBs begins at 50-75 km away from land, but that the deconvolution has remove much of it as near as 15-25 km from land. Judging from the magnitude of the main diagonal elements of Cmse, we select gamma=10^-2 as a reasonable compromise between noise sensitivity and spatial resolution.

An example of the optimal estimator is shown in Figure 4. We use a relaxation value of gamma=10^-3, and impose additional constraints on the stability of the inversion via the climatology terms in (6). Shown in the figure are the MSE direct inversion, the climatological mean, and the combined optimal estimate. The corresponding climatological covariance was shown in Figure 2. The optimal estimate is midway between the other two, in this case, because the noise multiplication caused by the direct inversion has raised the variance of the MSE estimate up to a level comparable to the climatological variability. In a more mature deconvolution algorithm, the climatological mean used at this step in the processing would be more dependent on the particular satellite overpass under examination.

References

[1] Twomey, S., “On the numerical solution of Fredholm integral equations of the first kind by the inversion of the linear equation produced by quadrature.” J. Assoc. Comput. Mach., 15, 100, 1968.

[2] Rogers, C.D., “Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation,” Rev. Geophys. Space Phys., 14, 609, 1976.

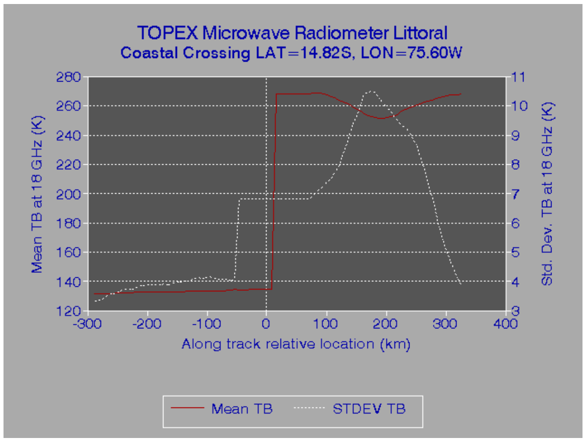

Figure 1. Climatology Statistics

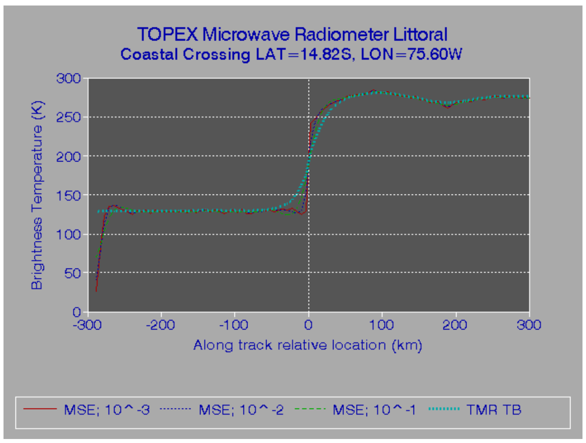

Figure 2. Direct MSE Inversion

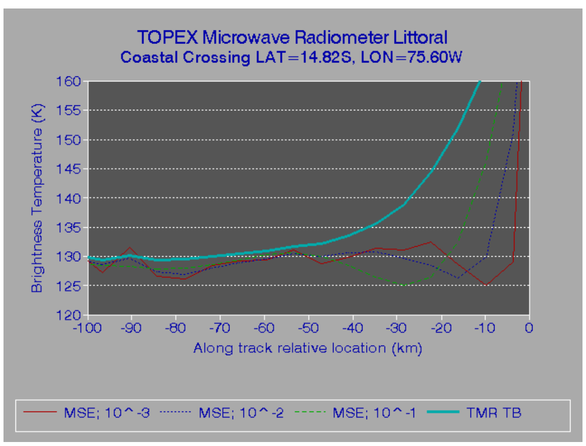

Figure 3. Direct MSE Inversion – close up

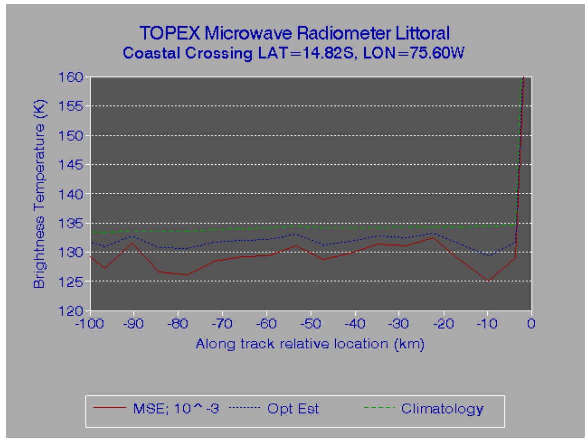

Figure 4. Optimal Estimate