Improved characterisation of Rossby wave propagation by means of the 3-D Radon Transform applied to T/P data

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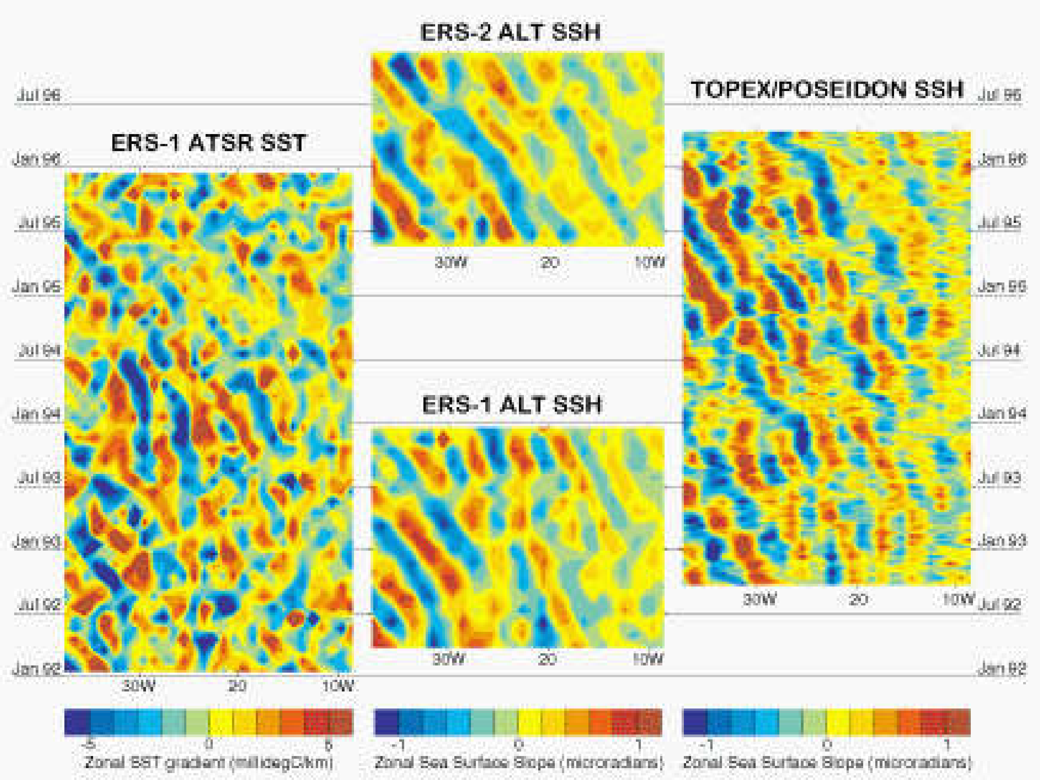
OBSERVING ROSSBY WAVES FROM SATELLITES

Rossby Waves (RW) are very difficult to detect with classical in situ oceanographic techniques, but can be seen from satellites.

Their surface signature can be observed in the Sea Surface Height (SSH) anomaly field measured by a highly accurate radar altimeter such as TOPEX/POSEIDON (T/P).

RW also affect the thermal structure of the upper layer, so in principle it is possible to observe them also in Sea Surface Temperature (SST) measured by an infrared radiometer. ERS satellites have both instruments, altimeter and radiometer.

Due to their mainly zonal propagation, RW are immediately detected in longitude/time plots of SSH or SST fields as diagonal alignments of crests and troughs



Propagation of Rossby Waves at 34°N in the North Atlantic as seen in Altimetry and SST (Cipollini et al., 1997)

2-D TECHNIQUES

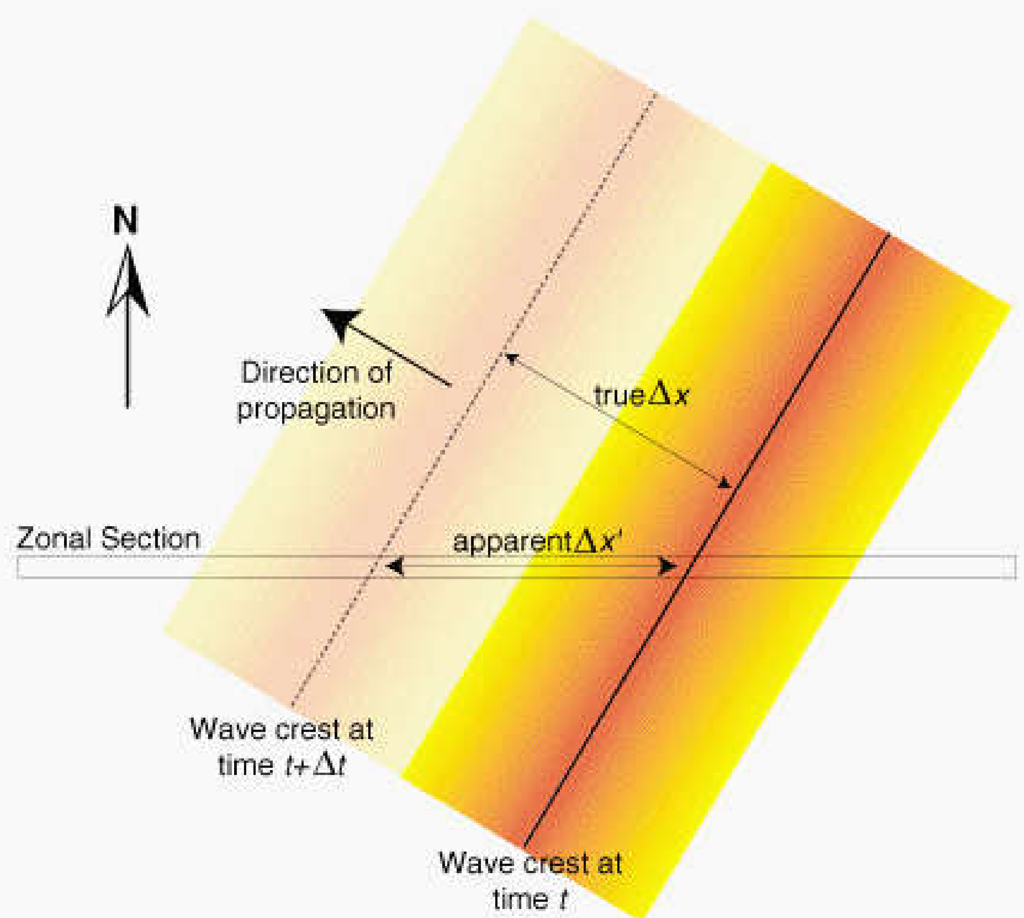
A 2-D FFT analysis of the longitude/time plots infers the properties of the single components (which could correspond to different RW modes), seen as single spectral peaks.

The Radon Transform (RT), a projection of an image at a given angle θ, can successfully be applied to the l/t plots to find the θ for which the projected energy is maximum. This gives an objective estimate of the main propagation speed as seen trough a zonal section of the data.

WHY GO 3-D??

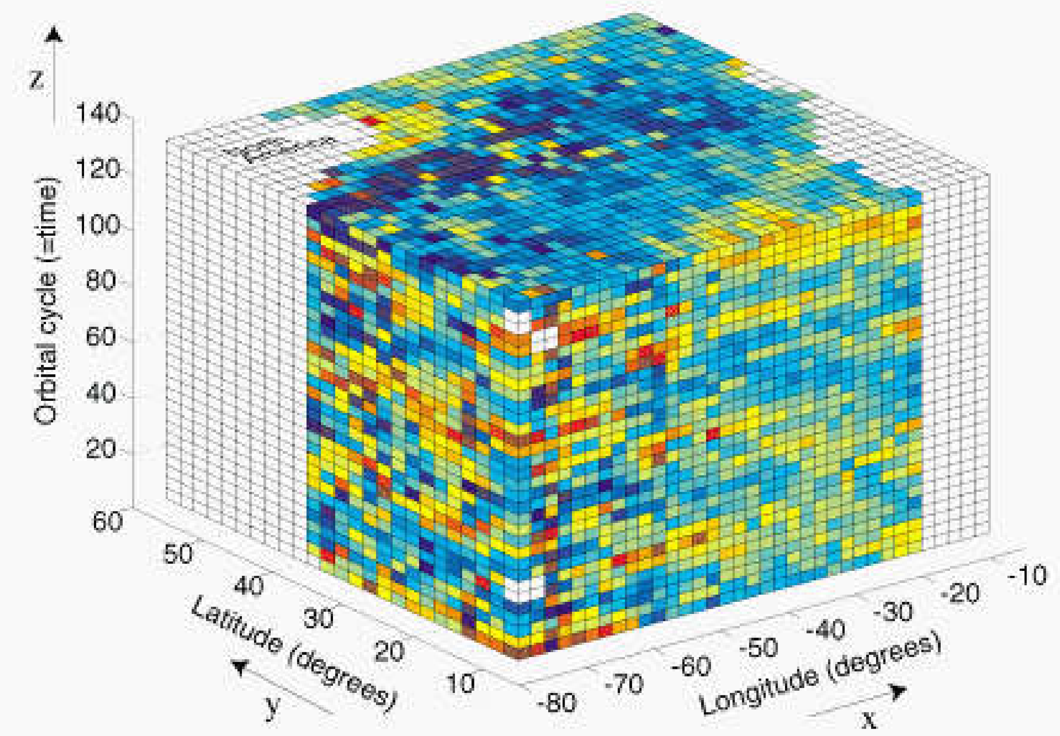
The speed at which RW propagate is a very important parameter to understand their effect on climate. This has recently been object of major research (see for instance Chelton and Schlax, 1996). In the N Atlantic, we have found speeds which are consistently 50-100% higher than those obtained from the classical linear theory. New theories (Killworth et al., 1997) reduce this discrepancy, but the effect of bottom topography on the speed is still under investigation. We need to estimate it accurately

Unfortunately, the zonal sections used in the standard 2-D longitude/time plots reveal only the apparent speed as seen along the section (see figure below). Moreover, they do not give any indications on possible deviations of the direction of propagation from pure westward.



Overestimation of the propagation speed as seen through a zonal section: $\Delta x'/\Delta t > \Delta x/\Delta t$

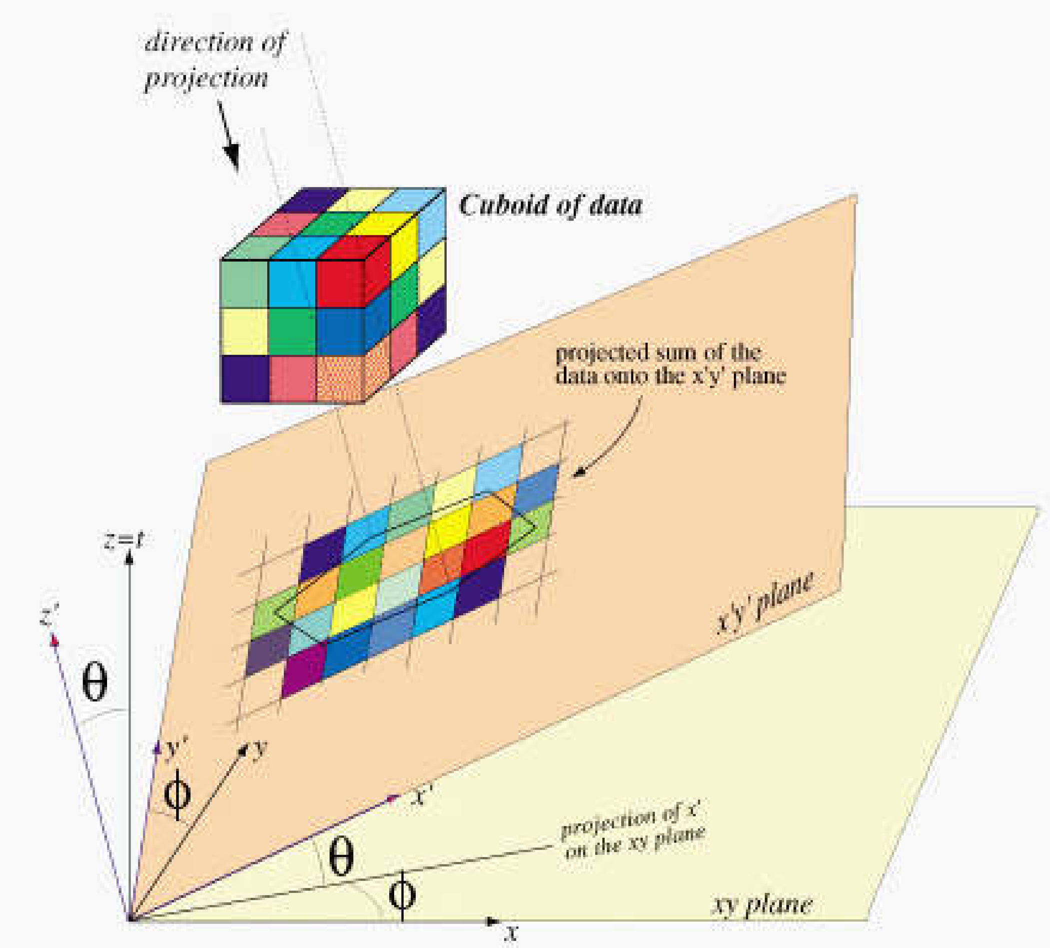
To study the directional properties of RW and estimate their real speed we have to start looking at **cuboids** of data, not just slices. Consequently, we have to use 3-D techniques as the three-dimensional Fast Fourier Transform and the three-dimensional Radon Transform (3-D RT)



The cuboid of gridded altimeter data

THE 3-D RADON TRANSFORM

The 3-D Radon Transform of a cuboid of data is the projected sum of the data on a plane, defined by angles θ,ϕ as in the figure below:

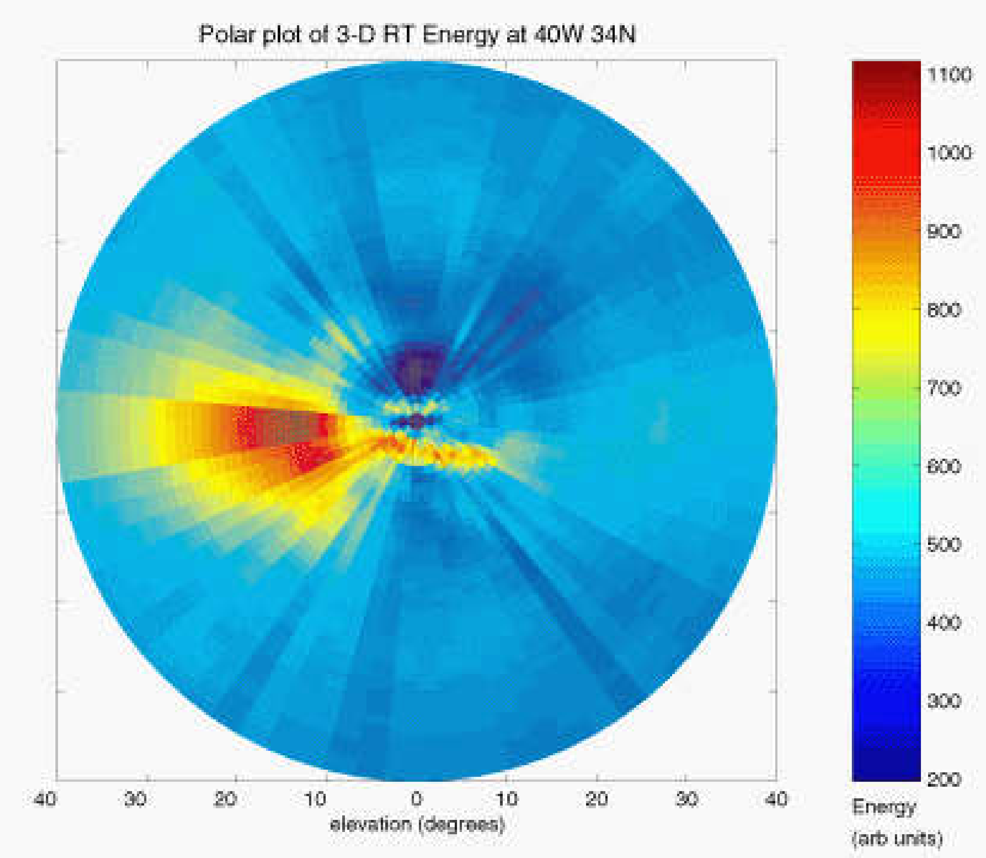


Definition of 3-D Radon Transform

HOW TO USE THE 3-D RT?

In our space (long x lat x time), we build a 9°x9°xn (n is the number of available satellite cycles) sub-cuboid around every location, and we look for the values θ_m, ϕ_m which maximise the energy of the 3-D RT. This identifies the plane which is orthogonal to the main direction of propagation of crests and troughs in the sub-cuboid.

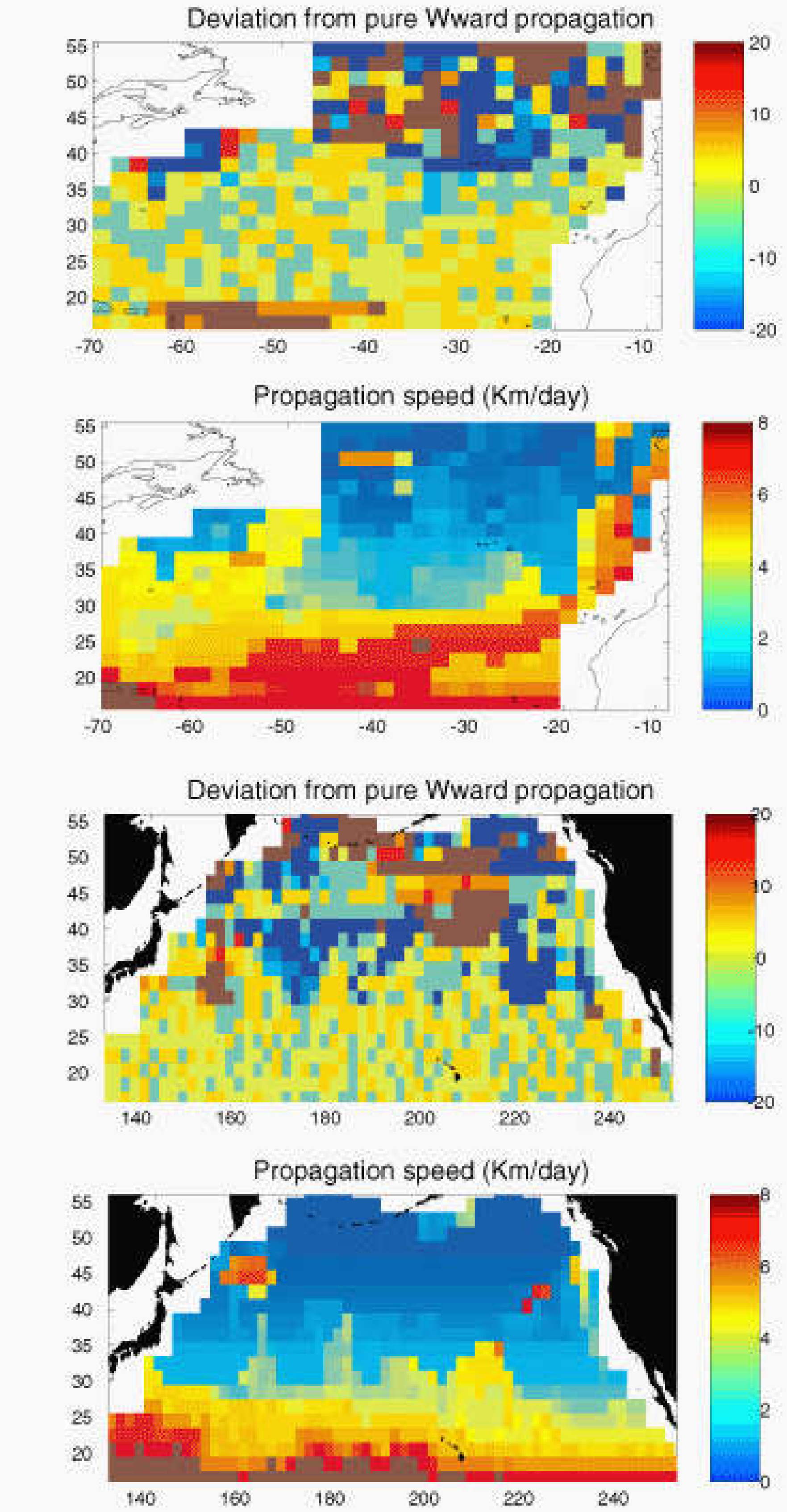
The angle ϕ_m is the direction of the main propagating signal and θ_m is directly related to its speed. Around 40°W, 34°N, for instance (see figure), we find a very distinct peak with ϕ_m =180° (pure westward) and θ_m=13°, which corresponds to a main propagation speed of 2.1 km/day. We can easily apply the same scheme in every location in the major oceanic basins and thus estimate the local directional properties.



An example of a polar plot of the 3-D Radon Transform Energy around a given geographical location

RESULTS FROM THE 3-D RT

In many places the main propagating signal from the 3-D RT analysis is already Wward, however results shown here (see the next column) have been obtained with the additional constraint of selecting the main signal among only those propagating within ±20° from pure westward.



A FEW COMMENTS

- The 3-D RT method successfully detects Rossby waves and allows us to study their directional properties
- No simple effects of topography on the direction of propagation can be observed in the N Atlantic and N Pacific
- In the most energetic waveguide around 34°N in the Atlantic, RW seem to slow down while approaching the Mid-Atlantic Ridge and speed up once they have past the ridge.
- In the N Pacific, some structures in the speed field need further investigation - do not appear to be immediately related to topography