Extratropical planetary wave propagation characteristics from the ATSR global Sea Surface Temperature record.

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ABSTRACT

The purpose of this paper is to examine the surface thermal signatures of extratropical baroclinic Rossby waves (a special class of planetary waves) in the ocean and measure their propagation speed. We show that the global sea surface temperature (SST) record produced by the Along Track Scanning Radiometer (ATSR) flown on the ERS-1 satellite between August 1991 and April 1996 contains clear evidence of wave propagation in all parts of the world oceans and at many latitudes. The characteristics of the propagating signals, which are examined in detail in the paper, match those expected for baroclinic Rossby waves. Not only can they be compared with those retrieved from altimeter observations of Sea Surface Height, but also they can help the understanding of the coupling between ocean and the atmosphere. We also look at how the signals vary in both space and time in the data record. We conclude that the ATSR data are a valuable source of information about the speeds of Rossby wave propagation, their variability, and how they might affect climate.

1. Introduction

Planetary waves are the result of the propagation of perturbations in the layered structure of the ocean as it adjusts to the disturbance of isopycnal surfaces. The character of Rossby waves is governed by a restoring mechanism based on the meridional gradient of planetary vorticity. Their speed is governed by the Coriolis parameter, being maximum at the equator and decreasing polewards. Rossby waves provide a mechanism for transferring information about disturbances across the oceans, typically over a long time scale of the order of several years.

It is possible that Rossby wave activity could complete an air-sea interaction feedback loop that gives their propagation characteristics a wider interest to ocean and atmosphere dynamicists and climate scientists. Such feedback could influence the timing and periodicity of quasi-oscillatory features such as the El Niño - Southern Oscillation (ENSO) phenomenon, as suggested by Graham & White (1998) and Kirtman (1997). Rossby waves may also contribute to the influence of El Niño on global Weather and climate. Jacobs et al. (1994) found that wave-like signals in model and altimeter data appeared to influence the re-routing of the Kuroshio extension 10 years after the 1982-83 El Niño, thus impacting climate anomalies over a wide region of the Western Pacific. They concluded that the ocean, as well as the atmosphere has a role in widely broadcasting the climatic influence of what is initially a regionally localised phenomenon. White et al (1998) further demonstrated the possibility of coupling between oceanic Rossby waves and the overlying atmosphere. They concluded that it is the SST signal associated with Rossby waves rather than the SSH anomaly which mediates this relationship.

The studies mentioned above emphasise the importance of gaining a better knowledge of Rossby wave characteristics in the ocean.

Whereas most of the modelling studies of large-scale oscillations rely on theoretical models of Rossby wave propagation, the comparison between theory and observations exhibits consistent discrepancies, as shown in the next section. In addition, the use of SST data to observe Rossby wave propagation has the potential to help us gain a much better understanding of the air-sea interaction processes involved. In this paper we will demonstrate the usefulness of the ATSR data to study planetary wave propagation characteristics, and help draw conclusions as to their precise role in the air-sea interaction feedback loop.

2. Data Sources and Processing

For the purpose of this study the ATSR-1 monthly mean data from August 1991 to April 1996 were obtained from Rutherford Appleton Laboratories (RAL). The first 4 years of data are in the form of a CD (Murray, 1995), and the final 9 months were obtained from the RAL ATSR website.

In order to isolate possible SST signatures of planetary waves from the regular variability of the seasonal cycle, the SST anomaly distributions for each month were evaluated by subtracting a climatic mean SST field for each month of the year. For this purpose, global ocean Surface Temperature Atlas (GOSTA) was used (Bottomley et al., 1990). This is derived from 30 years of global ship and buoy data collected between 1951 and 1981. Although this introduces a bias due to the surface skin effect, and sampling differences within half-degree grid cells, it is not a problem, since it is the spatio-temporal variability of the SST anomaly, rather than its absolute value, which is of primary importance here. Figure 1 shows an example of the ASST-GOSTA anomaly field for April 1992. Wavelike perturbations of SST are apparent in several regions, but a single image cannot reveal whether or not these are propagating features. For this a time series must be examined (see next section).

3. Initial Observations and Patterns

To study the propagation characteristics in the datasets, we need to analyse time series. For this purpose, and keeping in mind the zonal (east to west) propagation characteristics of Rossby waves, we produced longitude-time (Hovmuller) plots for every latitude between 5 and 50• north and south of the equator. On studying these images, we found diagonally propagating features in all ocean basins at most latitudes. Examples of global longitude-time plots are shown in figure 2. On looking at these images a number of features are apparent. Firstly, there are striking differences in the speed of propagation of features between Ocean basins (figures 2a &b) and within them with a general trend of speeding up as they travel westwards. There are also a number of mid ocean boundary features, particularly apparent in figure 2a. In addition in some regions, an annual and/or seasonal signal is noted (figure 2c). Another area of interest is the Southern Ocean, whereby vertical features (figure 2d), and in some areas, these features appear to be travelling eastward (figure 2e).

This initial analysis showed that the observed features correspond to non dispersive waves whose phase speed increases with latitude. This suggests that these features are likely to be the surface signatures of Rossby waves. In order to verify that the thermal signatures observed in the ATSR record indicate a real a geophysical phenomenon and are not an artefact of the dataset or of the processing scheme, we examined also AVHRR data, and found similar propagating signals (see Hill et. al., 1999).

4. Analytical Methods

The speed at which waves propagate in a longitude-time plot is given by the slope of the alignments of crests and troughs in the plot itself. This in some cases can be approximately determined by eye. For a more objective estimation of the propagation speed, we applied a Radon Transform technique to our longitude-time plots, as done by Chelton and Schlax (1996), Cipollini et al. (1998), Hill et al. (1999). The Radon Transform (Radon, 1917; Deans, 1982) is the projected sum of the image (the longitude-time plot) at a given angle. When the angle is orthogonal to the main direction of the alignments of crests and through in the image, the projected sum has maximum energy. So, looking at the angle which maximises the energy corresponds to identifying the main speed of propagation. A more detailed description of the implementation of the technique is given in Hill et al. (1999).

5. Results and Discussion

a. Detectability of westward-propagating signals

On looking at the images in detail, although the propagation signatures are almost ubiquitous, there are significant variations in their clarity of the signatures. They are found to be clearest between 25 and 40•S, in a region of strong meridional temperature gradient. The underlying mechanisms which cause this are further explained in Hill et al. (1999). In addition, where western boundary currents are present, Rossby waves do not show up at all.

Due to the coarse temporal resolution of this dataset, there are limitations as to the speed of waves readily detected. This means that at less than 5• north and south of the equator, planetary waves are travelling too fast to be detected by dataset, and at less than 20•, the return is patchy.

b. Variations with latitude

Results from the supervised Radon Transform analysis showing variations in Rossby wave speed with latitude are shown in figure 3 &4. Figure 3 is a plot of zonally averaged observational data against the linear theory, and the modified theory (Killworth, 1997). This clearly shows that the observational data show the same general trends, but find significantly lower speeds than the theory at low latitudes. This is likely to be due to the coarse temporal resolution of the dataset, which means that the lowest order (fastest) baroclinic Rossby waves are not detectable, and a higher order is being measured.

c. Variations with Longitude

Zonal variations in the properties of the signal are also visible. Firstly, in a number of regions, more than one speed was clearly visible. This is likely to reflect a number of different modes of Rossby waves propagating at different speeds. Secondly, speed of propagation tends to increase westwards across ocean basins. This is consistent with linear theory. In addition, a number of mid ocean boundaries are visible (figure 3a). When compared to seafloor bathymetry, it is clear that mid ocean ridges have a significant effect on Rossby wave propagation, causing to major effects. Mid ocean Generation, and Mid ocean Dissipation of waves. Their effect depends on ridge width and wave frequency (See Wang & Koblinski , 1996 and Hill et al., 1999).

The results in the Southern Ocean are also very interesting. In a number of regions eastward propagating Rossby waves were evident, and in some areas, vertical features or “standing waves” are evident. It was concluded that these features could be attributed to interaction with the circumpolar current.

d. Variations with Time

Initial analysis of the data shows evidence of temporal variations in some regions (figures 2a & b). On a number of plots, a strong seasonal signal is evident. However these tend merely to disrupt the signal rather than affect its propagation. In addition, certain images appear to exhibit annual changes in speed (figure 2c). The most likely explanation is that different wave modes are apparent in different years, perhaps because the forcing is slightly different. The thermal anomalies propagating at different speeds could nonetheless have an important role in air-sea interaction feedback.

A longer dataset, however, needs to be analysed to determine any possible periodicity or pattern to these variations.

e. Conclusions and limitations of work so far..

This paper highlights the usefulness of the ATSR ASST data in studying the thermal signatures of planetary wave propagation. The wave speed analysis, although followed the broad scale pattern of theoretical speeds, was consistently slower at low latitudes, where the higher order, slower modes of Rossby waves seem to be favoured. This may be attributed to the coarse monthly sampling which is unlikely to be able to distinguish the fastest baroclinic mode of the waves. A number of features in the data suggested interannual variability in propagation speeds. However the dataset length was too short to distinguish any significant periodicity or pattern.

6 . Work in Progress and Future Avenues of Investigation.

Currently, we have three avenues of investigation. Firstly, try to improve our speed analysis at low latitudes, by processing the ATSR 10-arcminute dataset to look at increasingly finer timescales, and thus attempt to distinguish the fastest baroclinic mode of Rossby waves. Secondly, analyse the effect of the bathymetry meridional as well as the zonal aspect, to determine how the bathymetry as a whole affects propagation characteristics, and its precise effect on propagation speeds. Thirdly, process the ATSR-2 dataset to increase the timescale we are looking at to 8 years (1991-1999) and thus attempt to distinguish periodicity in the variations noted in a previous section.

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Figure Captions

Figure 1 Sea surface monthly mean anomaly from April 1992 ASST-GOSTA

Figure 2 Longitude time plots for a) 30•S, b) 36•S, c)20•N, d)46•S, e) 49•S

Figure 3 Map of phase speeds (calculated from supervised Radon Transform)

Figure 4 Plot of latitude against phase speed comparing zonal mean detected speeds with Killworth et al (1997) modified theory.

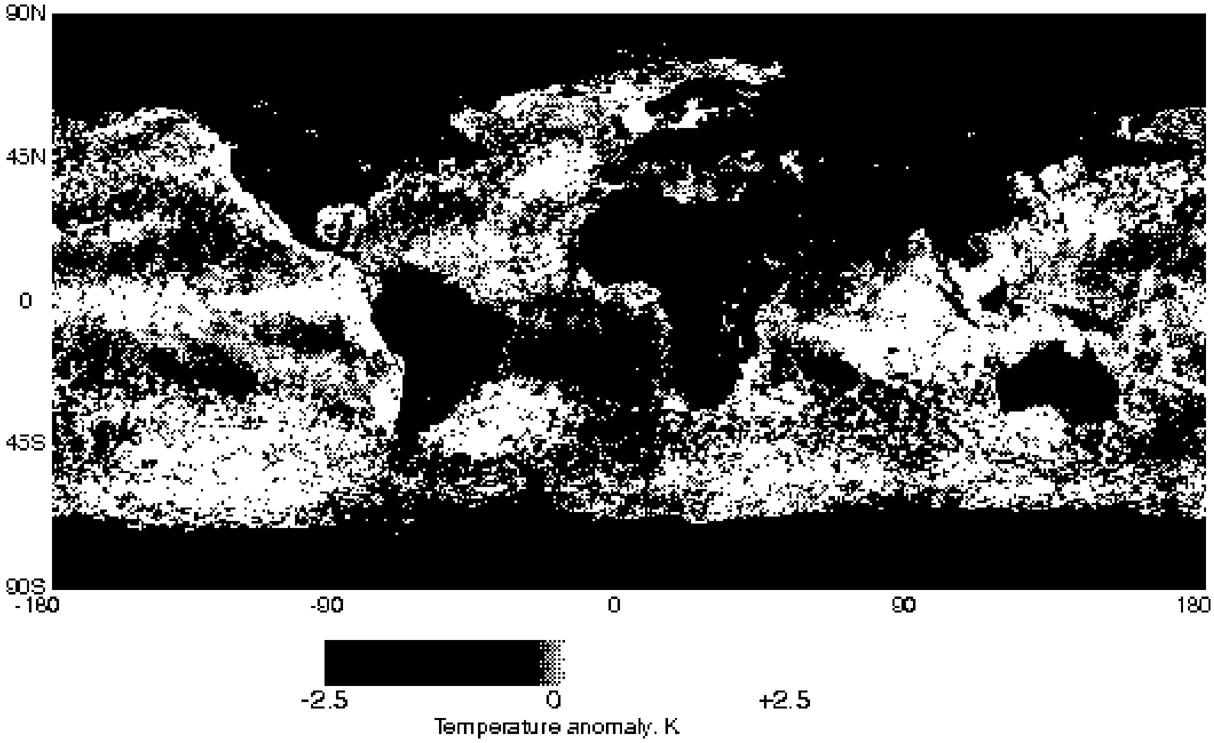
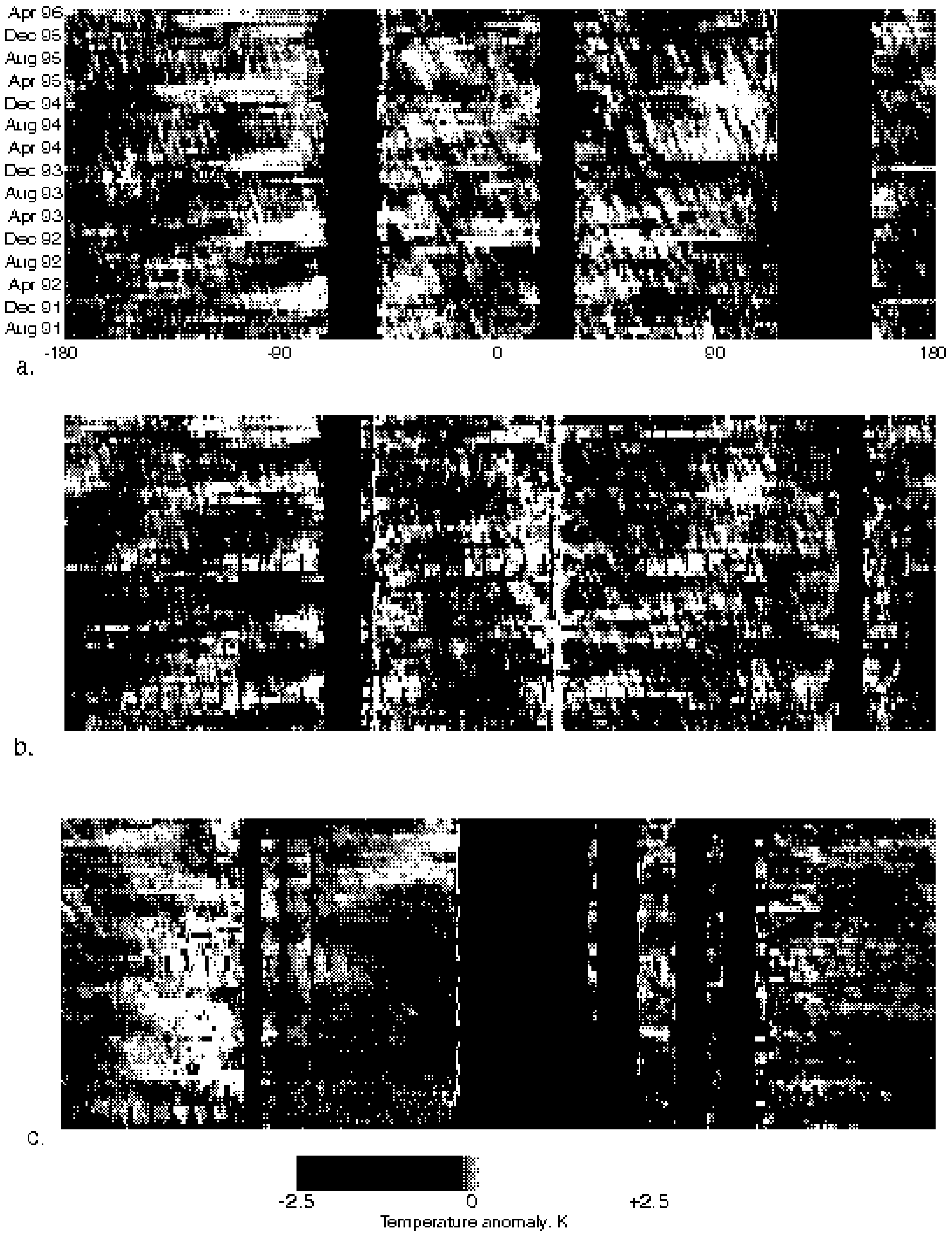


Figure 1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a.
b.
c.
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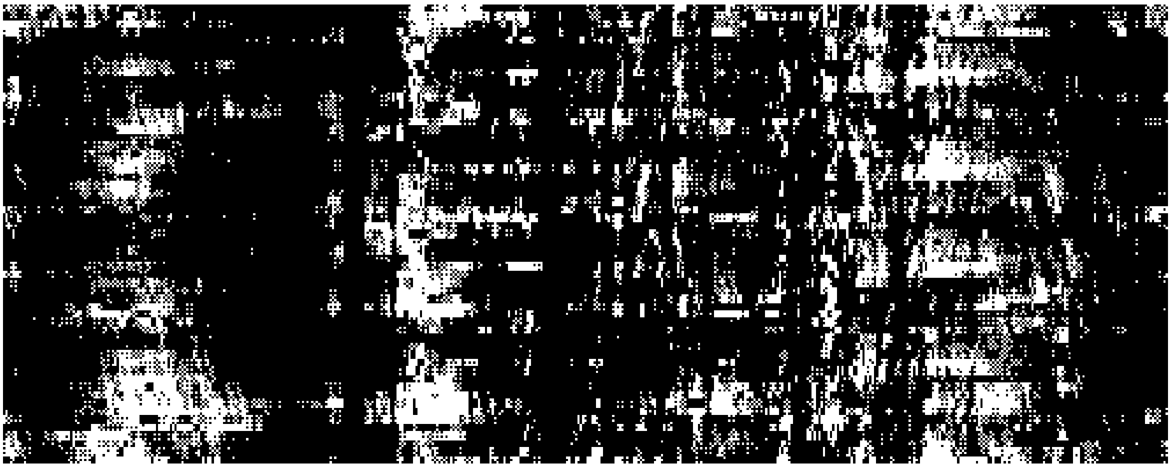
+2.5
Temperature anomaly, K

Figure .2



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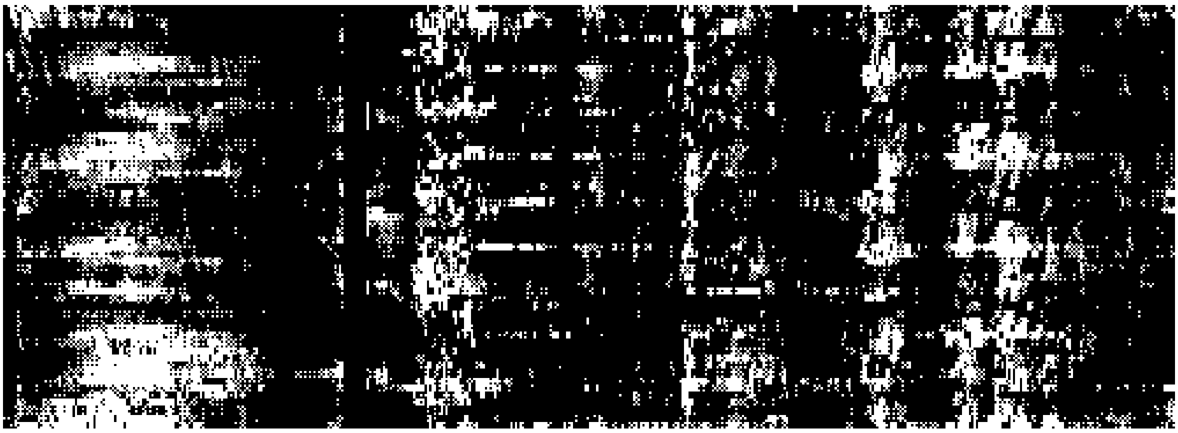

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Figure 2

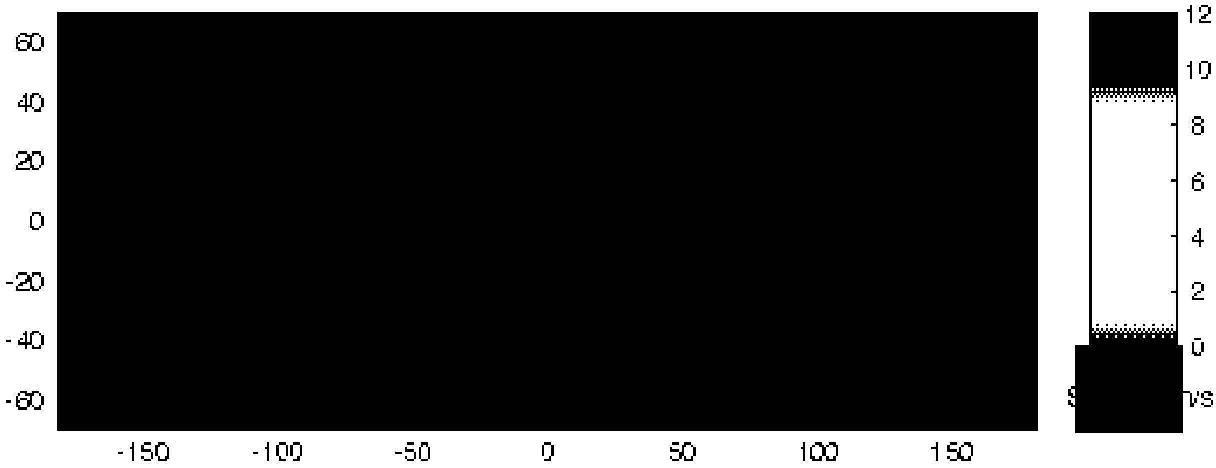

Figure 3

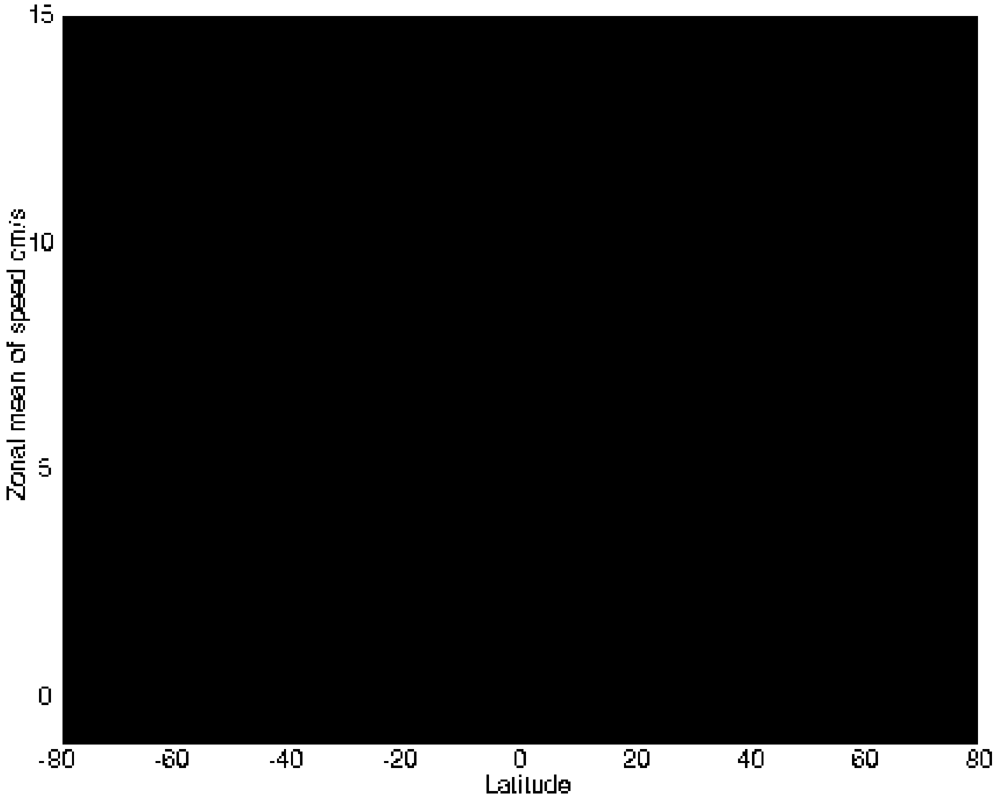

Figure 4