Application of the Empirical Mode Decomposition Technique to Scott Base MF Radar Data

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Abstract

This study examines the utility of the Empirical Mode Decomposition (EMD) technique to separate the horizontal wind field observed by the Scott Base MF radar, into its constituent parts made up of the mean wind, gravity waves, tides and planetary waves. Analysis suggests that EMD effectively separates the wind field into a set of Intrinsic Mode Functions (IMFs) which can be related to atmospheric waves with different temporal scales effectively without any necessity to make *apriori* assumptions about the period of the waves. Examination also suggests that this technique also has the ability to highlight amplitude and frequency modulations in these signals. Closer examination of the resultant IMFS highlights amplitude modulations associated with dominant periods close to 12 hours which are suggested to be related to a nonlinear wave-wave interaction between the semi-diurnal tide and a planetary wave.

The EMD technique is applied to Monte-carlo simulations of white- and red-noise processes. Statistical analysis of the resultant IMFs show them to differ significantly from those derived from the observational data. Thus, application of the EMD technique to the MF radar horizontal wind data can be used to prove that this data contains information on internal gravity waves, tides and planetary wave motions.

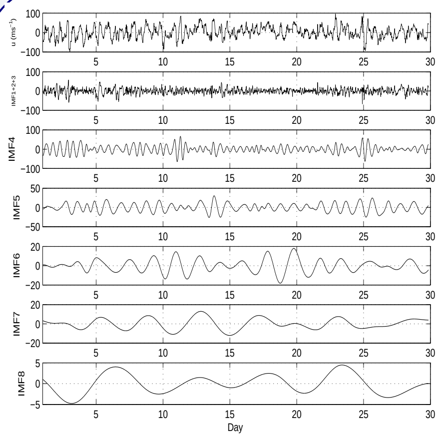

Figure 1 – The results of application of the EMD technique to the zonal wind time series observed by the Scott Base radar at 90 km in January 2006 are displayed. The upper panel in this figure displays the original time series. The second panel contains the summation of the first to third IMFs, the third panel contains the fourth IMF, the fourth panel the fifth IMF etc.

Introduction

Empirical Mode Decomposition (EMD) is a signal processing technique developed to allow non-stationary and non-linear time-series to be examined (Huang et al., 1998). It has already been proven to be remarkably effective in several areas of geophysical research (see articles in Huang and Shen (2005)). The technique is essentially defined by a recursive 'sifting' algorithm for adaptively representing signals as sums of zero-mean amplitude- and frequency-modulated components called intrinsic mode functions (IMFs). The present study applies the EMD technique to data from the Scott Base MF radar system. The objective is to examine the techniques potential to separate the constituent parts of the observed wave field: mean wind, gravity waves, tides and planetary waves.

Using the statistical method described in Wu and Huang (2005), the observational IMFs are shown to differ significantly from those derived from white- and red-noise processes. This method is used to identify whether the Scott Base radar system can observed internal gravity waves. The utility of the Hilbert-Huang spectrum in the examination of wave properties and wave interactions is then displayed. In particular, the similarity between output of the Hilbert-Huang spectrum and the continuous wavelet transform is shown.

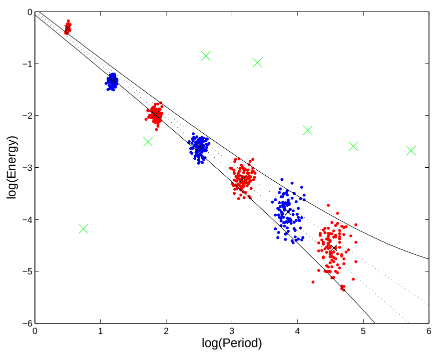

Figure 2 – Log-log diagram of the energy and dominant period of the different intrinsic modes identified by the EMD technique. The separation between observations (green crosses) and Monte-Carlo simulations of white-noise (red and blue dots) displayed in this figure indicate that a range of atmospheric waves can be observed in the Scott Base MF radar data. The full and dotted lines indicate the theoretical bounds (99 % and 75 % limits) within which white-noise should fall.

Results

Figure 1 displays the result of applying the EMD technique to the time series of zonal winds observed at 90 km during January 2006. The upper panel displays the original time series, the second contains the summation of the ensemble means of the first to third IMFs, the third panel contains the ensemble mean of the fourth IMF, the fourth panel the ensemble mean of the fifth IMF etc. Note EMD decomposes this month long time-series at 15 minute resolution into 8 separate intrinsic mode functions and a residual which represents the trend over the month. The first to third IMFs have been combined as each mode has dominant periods below 8 hours: they are therefore associated with internal gravity waves and instrumental noise. The dominant period of the fourth and fifth IMFs are associated with periods near 12 and 24 hours, and are therefore related to the semi-diurnal and diurnal tides respectively. The sixth IMF and higher are related to periods above 2 days and are related to planetary waves. It should be noted that these wave modes, semi-diurnal and diurnal tides and 2 day planetary waves, are frequently observed in the Scott Base MF radar data (Baumgaertner et al., 2005). The fact that the EMD technique decomposes the zonal wind time series into a set of physically meaningful modes (without any necessity to define a basis function) gives us confidence that the technique is of significant utility.

To examine the utility of the MF radar data to observe these different wave motions, a technique discussed in Wu and Huang (2005) is utilized. This method allows the IMFs obtained from data to be differentiated from those which result from noise processes which are uniformly or normally distributed. Figure 2 displays a log-log diagram of the normalized versions of the energy and dominant period of the different intrinsic modes identified by the EMD technique. The full lines in Figure 2 represent the theoretical range of values within which 75 and 99 % of the Monte-Carlo simulations produced using purely white-noise should occur. The red and blue dots indicate the result of one hundred Monte-Carlo simulations of white-noise. The green crosses in Figure 2 represent the value of the energy and the dominant period of IMFs which result from application of the EMD technique to the MF radar time series. Examination of Figure 2 indicates that the IMFs produced by application of the EMD technique to the MF radar zonal wind data are significantly different from the simulated and theoretical expectations for a white-noise process. The separation between these IMFs indicates that all the IMFs (which have previously been related to atmospheric waves) are statistically different from white-noise.

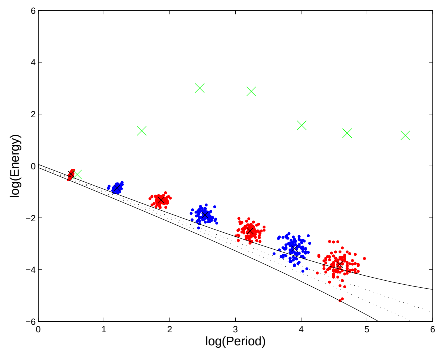

Figure 3 – Log-log diagram of the energy and dominant period of the different intrinsic modes identified by the EMD technique. The separation between observations (green crosses) and Monte-Carlo simulations of red-noise (red and blue dots) displayed in this figure indicate that a range of atmospheric waves can be observed in the Scott Base MF radar data. The full and dotted lines indicate the theoretical bounds (99 and 75% limits) within which white-noise should fall.

Results (continued)

Figure 3 displays a similar analysis to that described previously but for a red-noise simulation (red-noise is identified by a Fourier spectrum with increasing power for decreasing frequency). The full lines in Figure 3 again represent the range of values within which 75 and 99 percent of the simulations produced using purely white-noise occur and are displayed for comparison purposes. We note that the Monte-Carlo simulations for red-noise processes lie marginally above the theoretical lines for white-noise processes as would be expected theoretically. However, the values associated with the IMFs, other than the first, produced by analysing the MF radar data are still well separated from the Monte-Carlo simulations; this suggests that the data is also significantly different from a purely red-noise process. Thus, application of the EMD technique provides proof that the Scott Base MF radar is sufficiently sensitive to observe internal gravity waves, tides and planetary waves.

Figure 4 (a) displays the amplitude modulation (observed previously) in the form of a Hilbert-Huang spectrum. The colour of the lines indicate the amplitude of the mode as a function of time. The form of the line represents the variation of the instantaneous period of the IMF as a function of time (see Huang and Shen (2005) for details). As an aid to interpreting the H-H spectrum, Figure 4 (b) displays the continuous wavelet transform for the same dataset. Comparison of Figure 4 (a) with Figure 4 (b) suggests that the amplitudes obtained by the two methods at specific points in the time-period parameter space are similar. It should be noted that this similarity only results when the Morlet basis function is used as the 'mother wavelet' in the continuous wavelet transform. The H-H spectrum allows a useful alternative way to examine frequency- and amplitude- modulated signals.

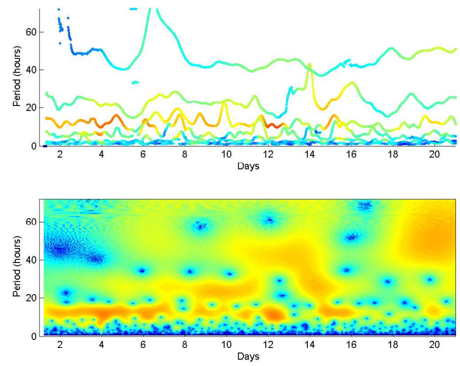

Figure 4 – A skeleton diagram of the Hilbert-Huang spectrum (a) and a contoured continuous wavelet transform (b) applied to the time series of zonal winds observed at 90 km by the Scott Base MF radar over the period 1st to 20th January 2006.

Conclusions

This study suggests that careful application of the Empirical Mode Decomposition (EMD) technique can decompose a time-series into physically meaningful modes. In this case, the dominant IMFs obtained from the MF radar data are associated with a range of atmospheric waves, namely gravity waves, tides and planetary waves. Application of the techniques described in Wu and Huang (2005) allows us to show that the output when the EMD technique is applied to the Scott Base MF radar data is significantly different from that which could result from white- and red-noise processes, respectively. Thereby indicating that the MF radar measurements are able to observe the gravity wave field for the first time.

Acknowledgments

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