# 1.17 DIAGNOSTIC ANALYSIS OF SOLAR VARIATION IMPACTS ON THE LOWER ATMOSPHERE

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**ABSTRACT**

*A diagnostic analysis approach was performed to search for the possible solar variation impacts on the lower atmosphere. The diagnostic approach was based on the normal mode instability analysis of a simple two-level baroclinic model. It was assumed that the solar radiation changes would have a high probability of showing low Earth atmosphere consequences through wave energy changes. Given about 0.1% variation in total solar irradiance over 11-year cycle, the solar variation, if observable, would likely modulate the thermal structures of the atmospheric layers. The resultant modulation could be propagated into other layers via the intrinsic dynamics of the atmosphere. The diagnostic analyses showed the two-level model is suitable to explain this variation, at a first-order approximation, for detecting the thermal solar variation signature via wave energy shifts in the lower atmosphere. It was found that the thermal changes in both vertical (static instability) and horizontal (baroclinic instability) directions could be reflected in the wave energy shifts of the troposphere and the lower stratosphere. The two level model indicates that as the atmospheric stability changes the wave energies should shift to compensate for the change in stability. This study showed a pattern in the stability and energy structures between the solar maximum and solar minimum years. This paper summarizes the results of the wave energy analysis that compared solar maximum and minimum years for three solar forcing timescales: the 11-year solar sunspot cycle, the annual cycle (due to astronomical geometry changes causing variations in solar output as received at the Earth), and the 28-day solar rotational cycle. The basic data set used in the analysis was the NCEP/NCAR (National Center for Environmental Prediction/National Center for Atmospheric Research) Reanalysis Data. The solar radio flux (10.7 cm) was employed as the proxy for solar short wave output since observed values were available daily for the entire 50 plus year record of the Reanalysis Data.*

## 1. INTRODUCTION

A normal mode decomposition of the temperature fields of the lower atmosphere was accomplished using Fourier analysis. The analysis was accomplished by latitude and pressure level. The decomposition was performed in terms of the energy within each wave or groups of waves by a power spectrum analysis. Since the power spectrum is the wave amplitude squared, the power spectrum allows the energy in the atmospheric waves to be tracked to determine whether any significant changes in the wave energy patterns can be observed. The wave energy patterns were compared to known solar forcing cycles to determine whether any of the wave energy shifts may be associated with solar output changes.

## 2. THE 11-YEAR SOLAR CYCLE

The 11-year solar cycle is defined by changes in the sunspot number. Solar maximum and solar minimum years are defined based on the peak values of the observed sunspot numbers. For this analysis, only the sunspot maximum and sunspot minimum years were used. Within the NCEP/NCAR Reanalysis Data there are 5 solar cycles. Each solar maximum was paired with the preceding solar minimum year for consistently throughout the analysis.

Figure 1 shows the annual average wave energies for a typical solar minimum (1986) and solar maximum (1989). In this figure, note the significant change in the energies at solar minimum versus solar maximum. The change is primarily identified by the red area in wave numbers 1 through 3 in 1986 and the lack of a corresponding feature in the solar maximum year 1989. This shift in the wave energies is characteristic of all five solar maximum versus solar minimum comparisons in the data set. Figure 1 also shows that the strongest planetary and Rossby waves are those with the lowest wave numbers as would be expected. The lower wave energy threshold was arbitrarily set at 0.1 and generates the edge of the ‘wave envelope’ shown in the figure as ‘blue’.

A feature of note is that the southern hemisphere is always less energetic than the northern hemisphere on an annual average basis. This may reflect either increased thermal gradients or possibly increased surface stress (more land mass) in the northern hemisphere.

Figure 2 shows the static (thermal) and wind shear stabilities for the both the troposphere and stratosphere. Both are more stable during solar minimum years. Green lines are for solar minimum and the orange lines are for solar maximum. Figure 2 depicts the average of all five solar maximum years versus the average of all 5 solar minimum years. This analysis was accomplished on an annual mean basis (horizontal lines) and a daily basis (smoothed with a 45-day running mean). Both the averaged daily values and annual mean values show increased stability during solar minima over solar maxima. This is consistent with the basic premise of the two level baroclinic model physics which suggests that increased stability will shift energy into the long waves. Note: there are apparent ‘boundary effects’ at the top of the stratosphere, bottom of the troposphere and near the tropopause. The graphics shown are for pressure levels sufficiently far from the ‘boundary interactions’ to be representative of the ‘mid-layer’ flow in the troposphere and the stratosphere.

The general conclusion is that a the 11-year solar cycle can be seen in the wave energy analysis and it is consistent with the basic physics in the two level baroclinic model.

## 3. THE ANNUAL CYCLE

Since the atmospheric wave energy change shows an obvious association with the 11-year solar forcing, the annual cycle should show similar results. The annual cycle has a strong seasonal component driven by astronomical geometry. The slight eccentricity of the Earth’s orbit produces about a 6 percent variation in the solar irradiance received at the Earth because the Sun is closer to the Earth in January than it is July. Since this variation is large compared to the change in the 11-year solar cycle irradiance, the same stability trends should be observed in the annual cycle as with the 11-year wave energy trends.

Figure 3 shows the 1986 solar minimum and the 1989 solar maximum based on daily wave energies. Each day of the year is shown on the horizontal axis and the wave numbers are shown on the vertical axis. The wave energies are colored as shown by the associated color scale.

Figure 3 shows strong wave energies at solar maximum (1989) in only one peak in the winter and smaller peaks in the fall. In contrast, the solar minimum wave energies show several strong sets of wave energies which provide more consistency in the level of the long wave energy across the winter months. In addition, the energies in the short waves follow the shape of the stability curves shown in Figure 2. This suggests that stability plays a key role in the basic state of the atmosphere with the changing solar flux acting as a modulator to shift the atmospheric wave energies. Shifts in the atmospheric wave energies would drive the hemispheric weather pattern to a new configuration resulting in impacts to forecasts via weather systems changes.

The general conclusion is that the annual cycle is consistent with wave energy changes observed in the 11-year solar variability. Also, the annual stability changes reflect shifts in the wave energy spectra consistent with the two level baroclinic model physics at the first order (increased stability should result in more energy in the longest waves).

## 4.0 THE SOLAR ROTATIONAL CYCLE

The solar rotational cycle is approximately 27 to 28 days. The Sun rotates at different rates by latitude since it is a gaseous body. The average rotation rate is in the 27 to 28 day range. To determine whether there was a possible solar rotational connection with the lower atmosphere, the atmospheric waves were grouped by wave numbers 1 through 3, 4 through 9 and 10 through 16. The wave numbers groups were summed and averaged in 30 degree latitude bands. A five year solar maximum average and a five year solar minimum average were computed. The difference between the 5-year solar maximum and minimum averages is shown in Figure 4.

The differences which are prominent during solar minimum are shown in blue while the differences that were strong at solar maximum are shown in green. Figure 4 highlights key structures that appear to be persistent from one solar cycle to the next. All the solar maximum years individually turned out to have stronger February energies for example. In Figure 4, the green area indicates stronger wave energies during solar maximum for February.

Another key feature is the alternating colors of blue and green across the entire year. This suggests that there are persistent features in the Earth’s atmosphere that are modulated by the solar flux. Note that the oscillation period of the features is dependent on the wave number. Wave numbers 1-3 show a longer oscillation than wave numbers 4-9, for example. This suggests that the superposition of atmospheric waves may obscure or enhance solar impacts based on changes in the atmospheric wave energy spectrum.

In addition, the alternating pattern shown in Figure 4 for wave numbers 4-9 is approximately one month in length. This suggests that wave numbers 4-9 could be the cause of any atmospheric periodicity that may be associated with the solar rotational cycle.

The general conclusion is that persistent wave energy features are visible in the solar mean differences between solar minimum and solar maximum. The persistent differences alternate in a pattern where one wave energy feature is preferred during increased solar activity and the other is preferred during decreased activity. The period of wave numbers 4-9 is consistent with a possible solar forcing that could be carried in those atmospheric wave numbers.

## 5.0 SUMMARY

A wave energy analysis of the NCEP/NCAR Reanalysis Data was performed to determine whether solar forcing could be observed in the atmosphere that was consistent with known solar forcing cycles (11-year, annual, and 27-day). The wave energy analysis showed a preference for higher wave energies in solar minimum years compared to solar maximum years. The change in atmospheric stability also matched the expectation of the simple two level baroclinic model – as the stability increased, the energy in the long waves increased. In addition, changes in the

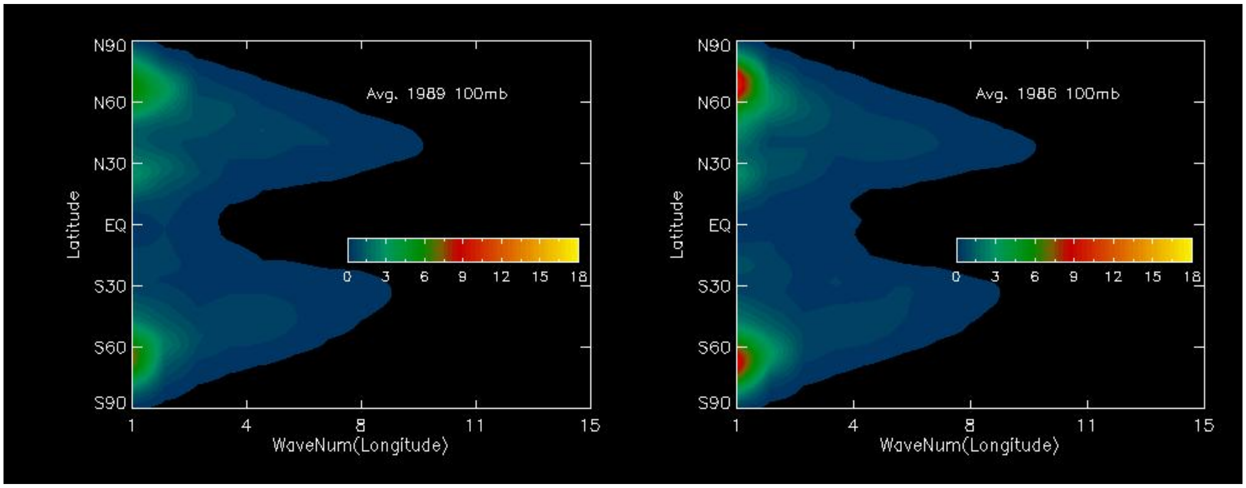


FIGURE 1. A comparison of the annual average wave energies at a typical solar maximum (1989) is on the left and at a solar minimum (1986) on the right. Note the stronger wave energies at solar minimum (denoted by the red area) in the longest waves. Also note that the northern hemisphere has higher wave energies than the southern hemisphere (subtle difference in this graph).

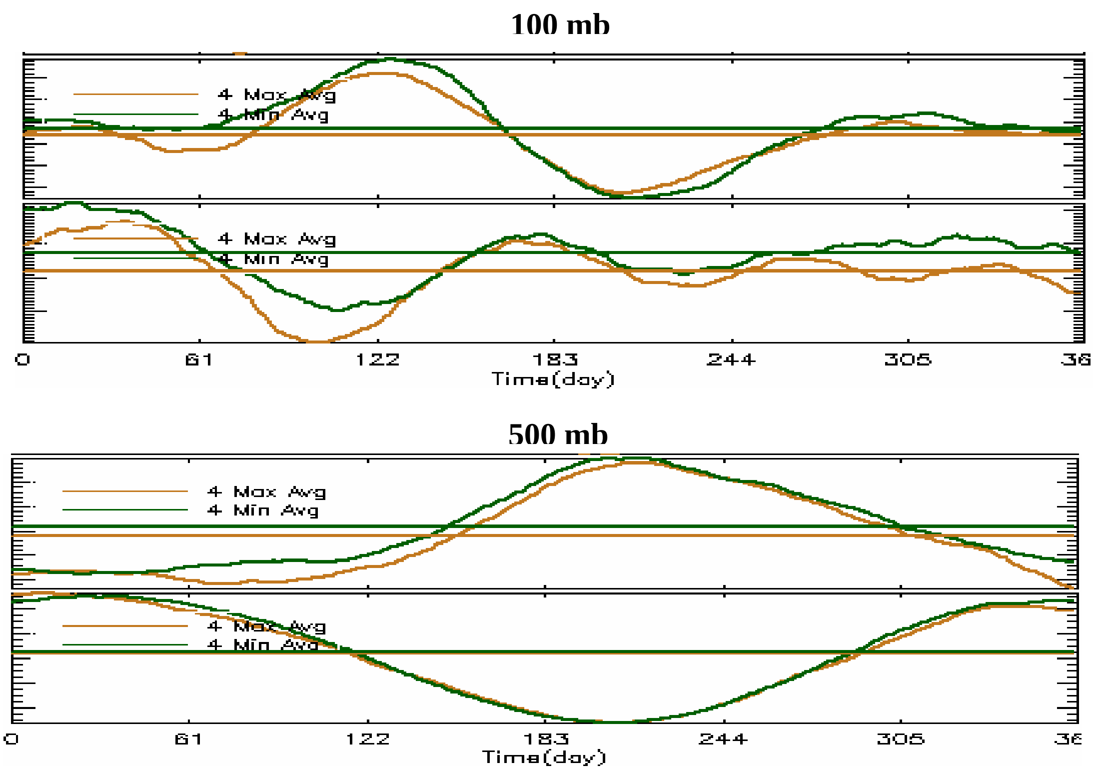


FIGURE 2. A comparison of the 100 mb and 500 mb annual stability curves. Green is for solar minimum and orange is for solar maximum. The figures above show the zonal average for 30-60 degrees north latitude. The horizontal lines show the annual mean while the curved lines show the daily means with a 45-day smoothed running mean applied. The top graphic in at each level is the static (thermal) stability while the bottom graphic for each level shows the shear stability. The general conclusion is that the atmosphere in the mid-latitudes is more stable at solar minimum than solar maximum regardless of the stability factor used.

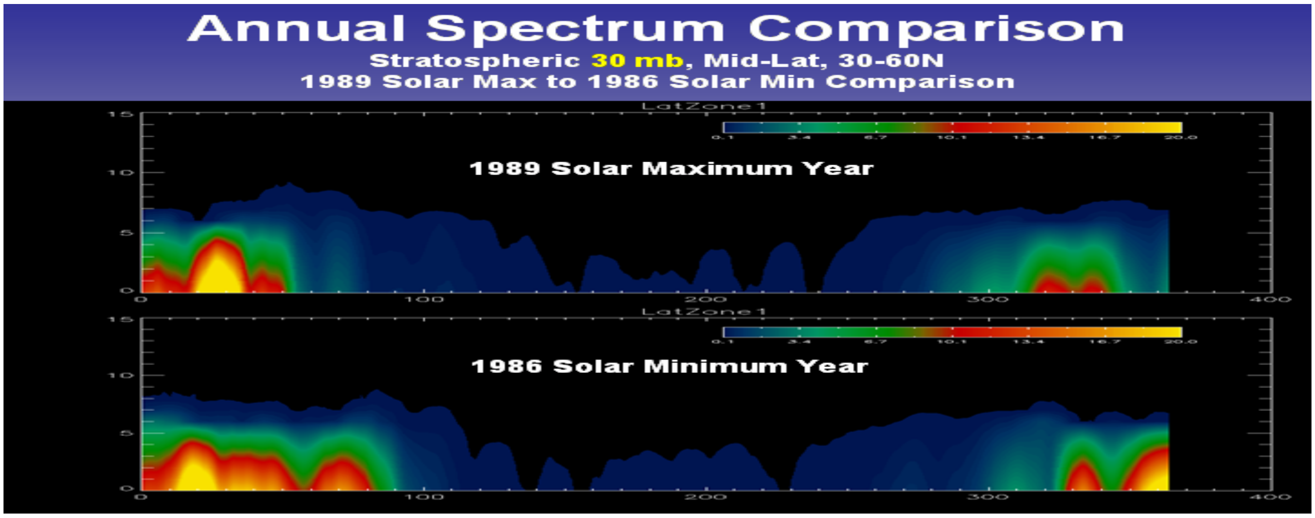


FIGURE 3. Shows the change in the wave energies from solar minimum (1986) to solar maximum (1989) based on a daily wave energy analysis. Wave number is plotted on the vertical scale, day of the year on the horizontal scale and the wave energies are color coded per the color bar on the graphic. The energy change is typical of all five solar maximum versus solar minimum comparisons accomplished. Solar minimum shows more consistent and stronger wave energy patterns throughout the winter months. Also, the wave energies decrease in the summer months and increase in the winter months. This is consistent with the stability change shown in Figure 2. This effect is shown for the 30 mb level. However, the effect is observed at all levels in the troposphere and stratosphere.

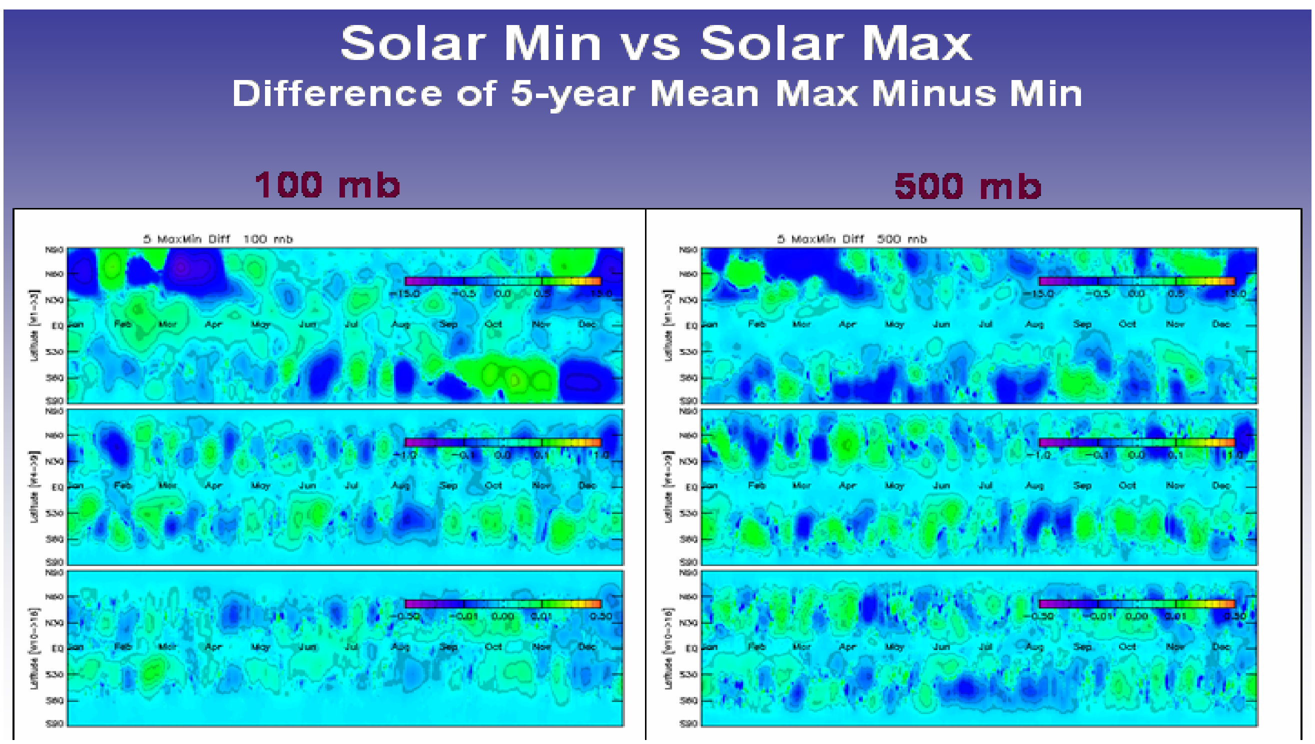


FIGURE 4. Shows the 5-year mean difference of the solar maximum and solar minimum wave energy spectra. Features stronger at solar maximum are green and features are stronger at solar minimum are blue. The top graph at each level is wave numbers 1-3, the middle graph is for wave number 4-9 and the bottom graph is for wave numbers 10-16. The alternating patterns suggest persistent features in the atmosphere are modified by solar flux changes. Waves 4-9 produce a pattern with an approximate monthly period and may be associated with solar rotational flux changes.

annual seasonal cycle were also consistent with this concept. More energy was visible in the long waves during solar minimum compared to solar maximum. Also, the annual wave energy spectrum followed the same trend in terms of mean annual stability and the shifts to the higher long wave energies (comparison of Figure 2 to Figure 3). A possible 27-28 day solar impact was observed in the wave energy analysis when it is broken into groups of waves. The approximately monthly solar forcing periodicity is observed in wave numbers 4-9. While more work is required to definitively demonstrate that wave numbers 4-9 are the cause of this variation, this analysis suggests that a consistent mechanism that couples Sun-Earth interactions on multiple scales may be possible.

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