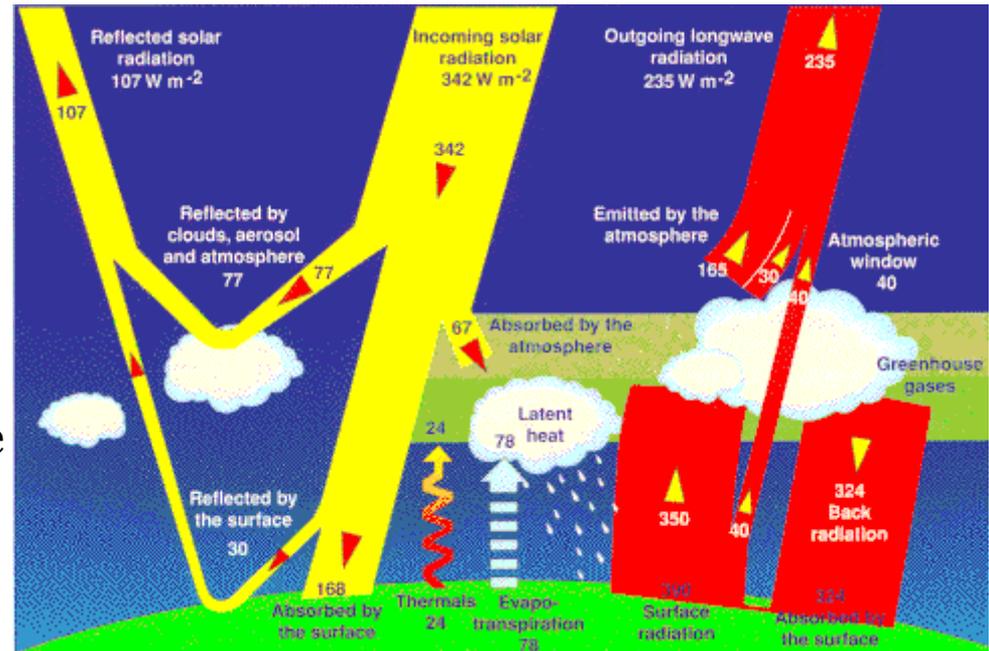


Solar Variability and the Effects on the Earth's Atmosphere

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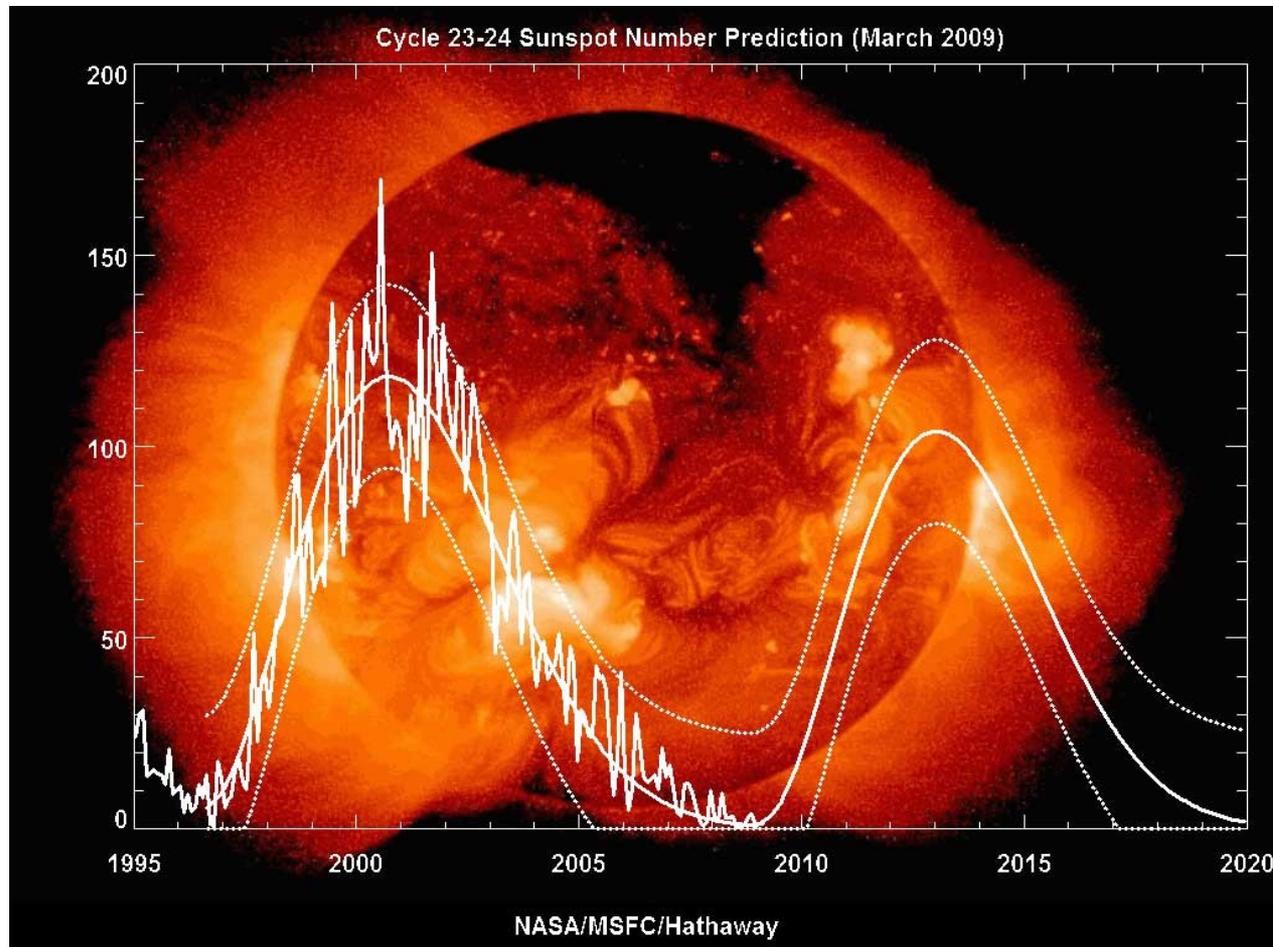
Introduction

- It is known that the Earth's climate is dependent on the Sun as its primary source in radiative energy. It is also known that the Sun goes through minimum and maximum cycles, involving variability in the Sun's magnetic field, temperature, and sunspots. This variation has little effect on the sun as a whole, with as little as one tenth of a percent of the total solar irradiance experiencing change. However, the Earth maintains a fine balance of radiative energy, and how these cycles impact the Earth's climate is still a topic of research.
- My goal for this study is to determine on what scale this solar variability affects the Earth's atmosphere, in order to lead to a greater understanding of Sun-Earth interaction and the climatological effects thereof.



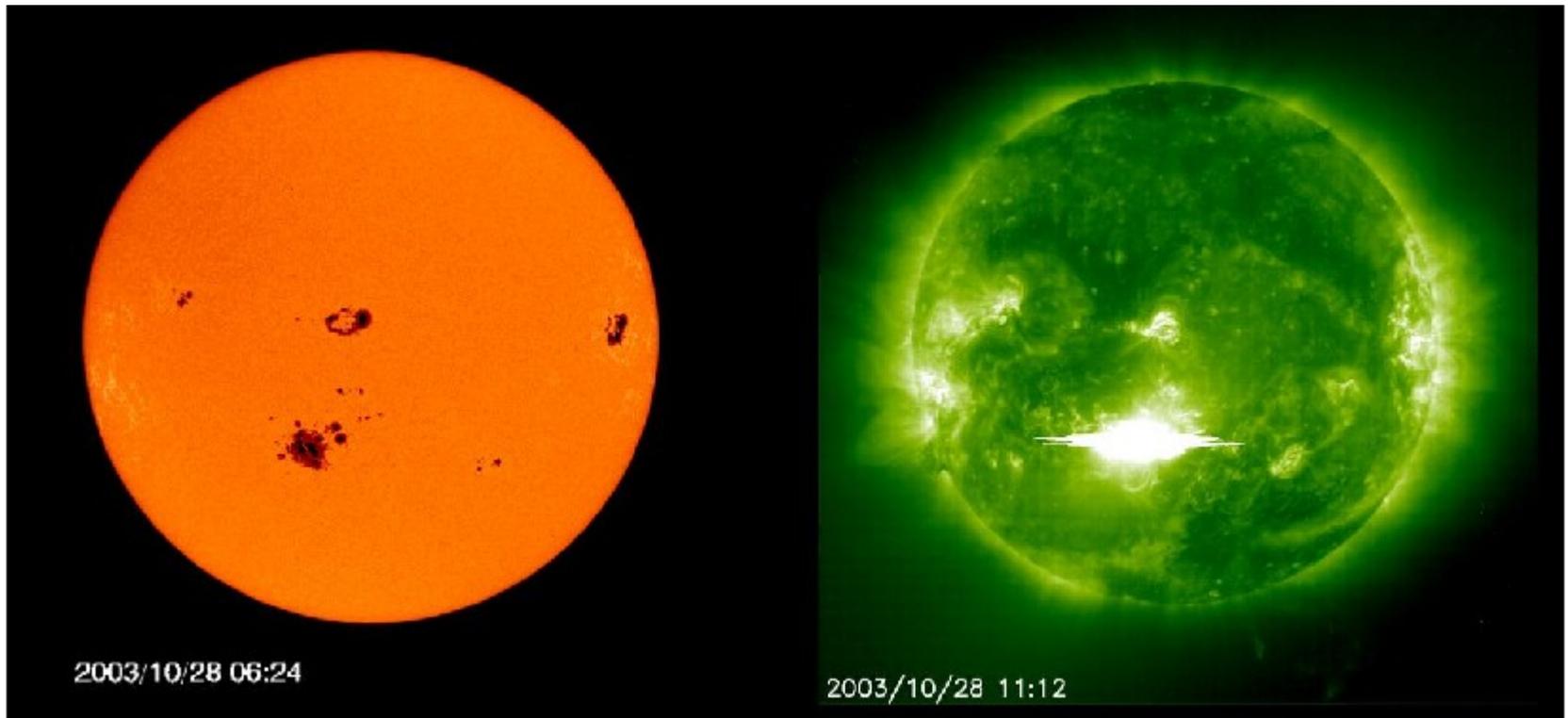
Sunspots

- Sunspots follow the magnetic cycle of the sun, which spans from the maximum number of sunspots to the minimum . Each oscillation lasts about 11 years and they coincide with the 22 year cycle of sun's magnetic field.

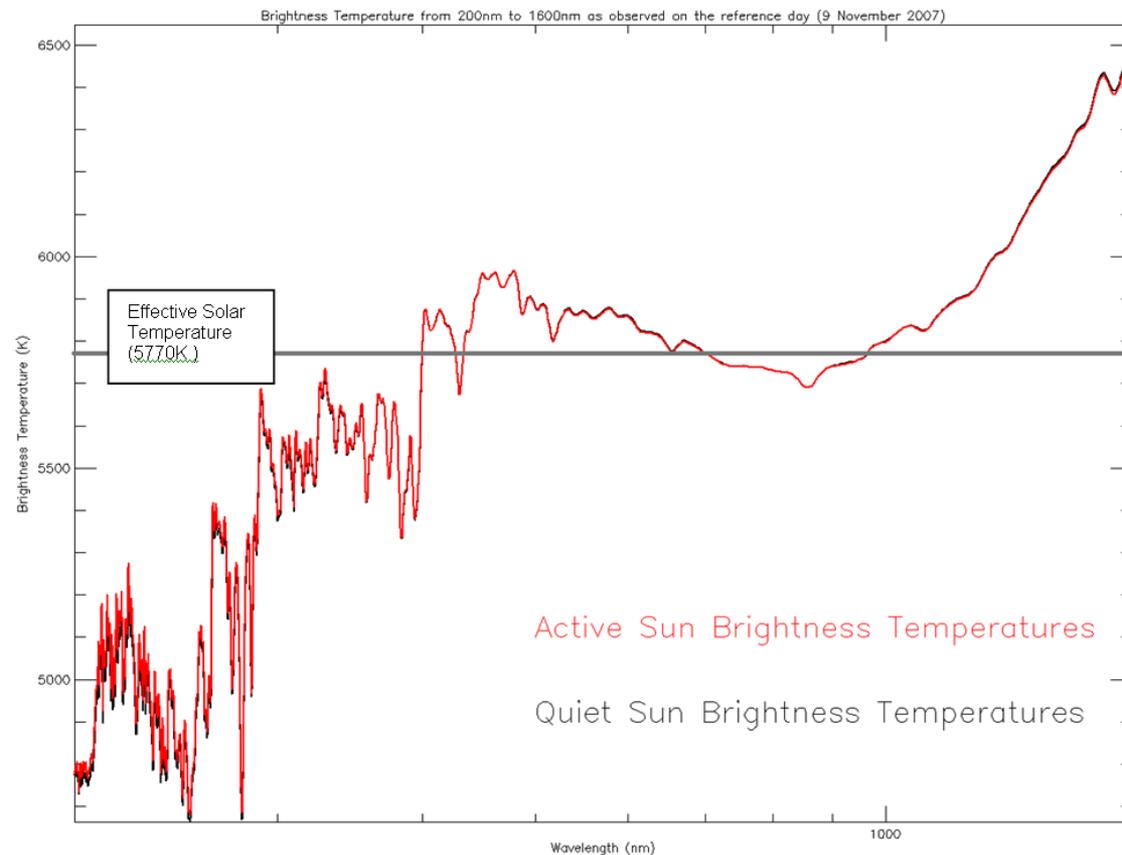


What does that mean for the planet?

- The sun produces light from the ultraviolet to the infrared, but these different wavelengths will affect the planet differently.

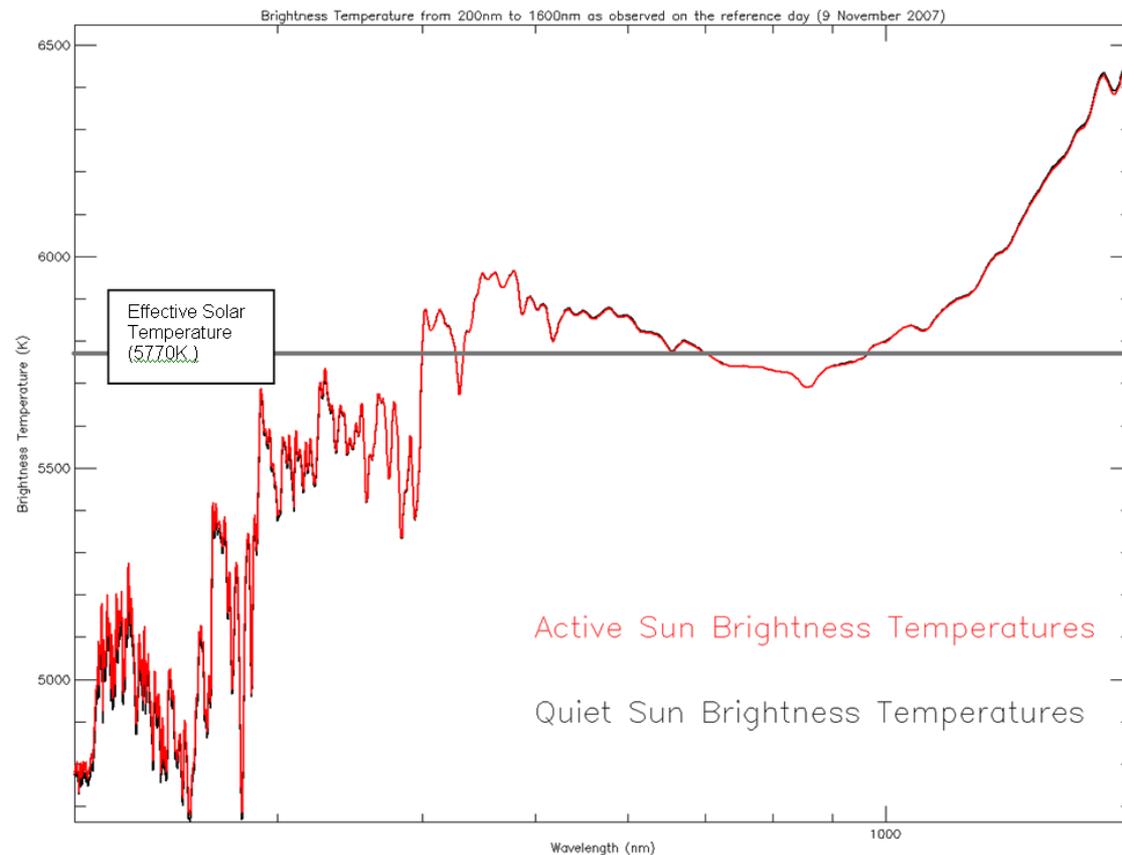


Brightness Temperature



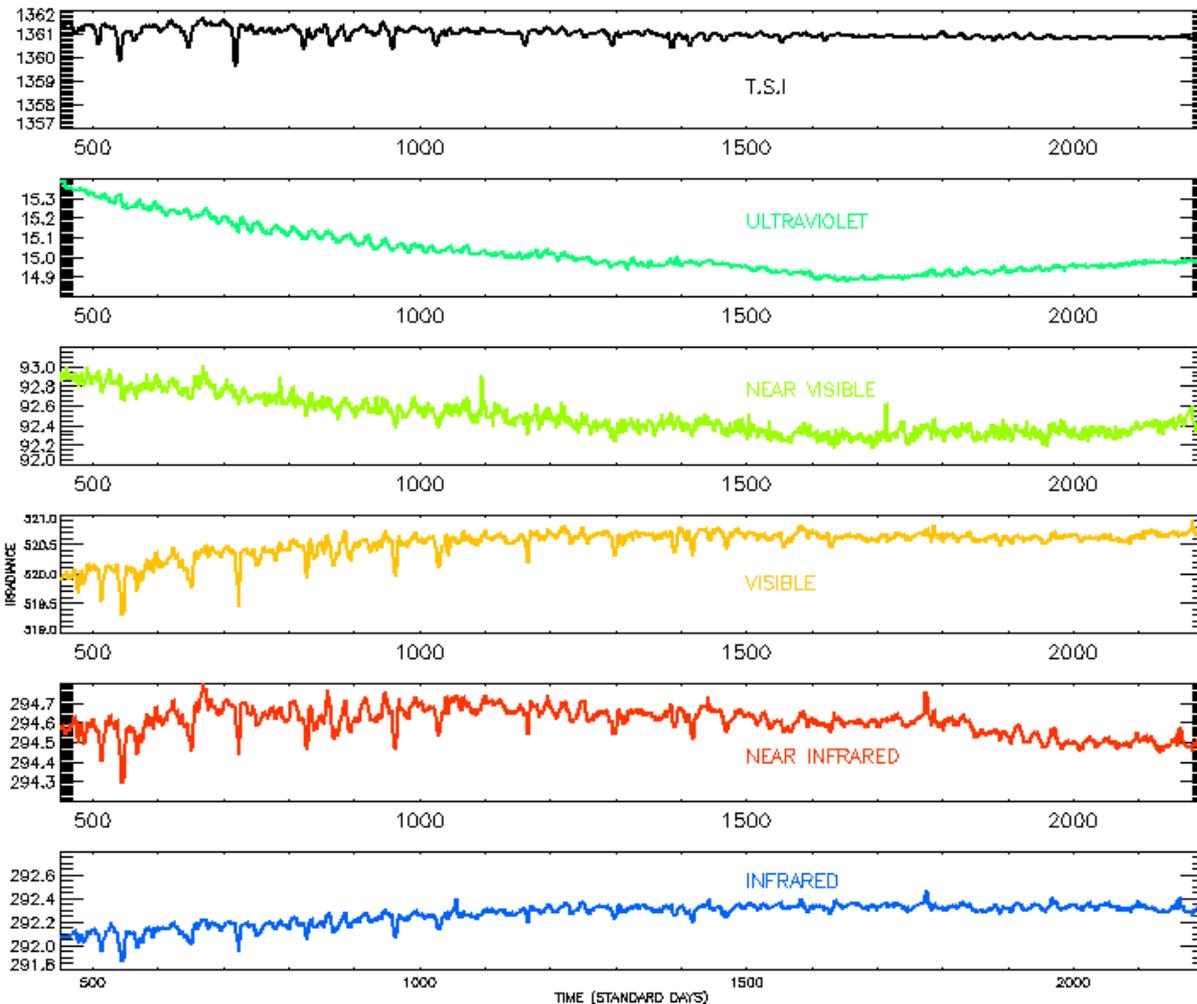
- The Sun acts as a 'near' black body object. At certain temperatures, a perfect black body would have a maximum set wavelength. This is shown in Wein's Displacement Law: $T * \lambda_{max} = 2.898 * 10^6 \text{ nm K}$. Since the Sun acts as a 'near' black body, it follows a very similar trend to Wein's Displacement Law.
- When the Sun is viewed over all wavelengths, it is clear that that the two areas of maximum brightness temperatures are in the visible and infrared regions Infrared rays are good indicators of temperature. Visible and infrared wavelengths are mostly produced in the Sun's photosphere as shown in the graph (Fig 1a) of effective solar temperature of the Sun.

Brightness Temperature



- Included in the graph is the effective solar temperature of the Sun. Effective temperature is the temperature a black body would need to produce an irradiance of 1361 W m^{-2} as observed in TSI (i.e. by solving the Stefan-Boltzmann equation).
- Both the visible and the infrared wavelengths are above the effective solar temperature, meaning they brighten as solar activity lessens. However, the ultraviolet and near infrared are below the effective solar temperature, so these wavelengths experience a dimming effect as solar activity lessens.

A look at irradiance across the wavelengths



Observations:

The Total Solar Irradiance (T.S.I) begins to approach $1361 \text{ W}\cdot\text{m}^{-2}$ as the sun enters solar minimum.

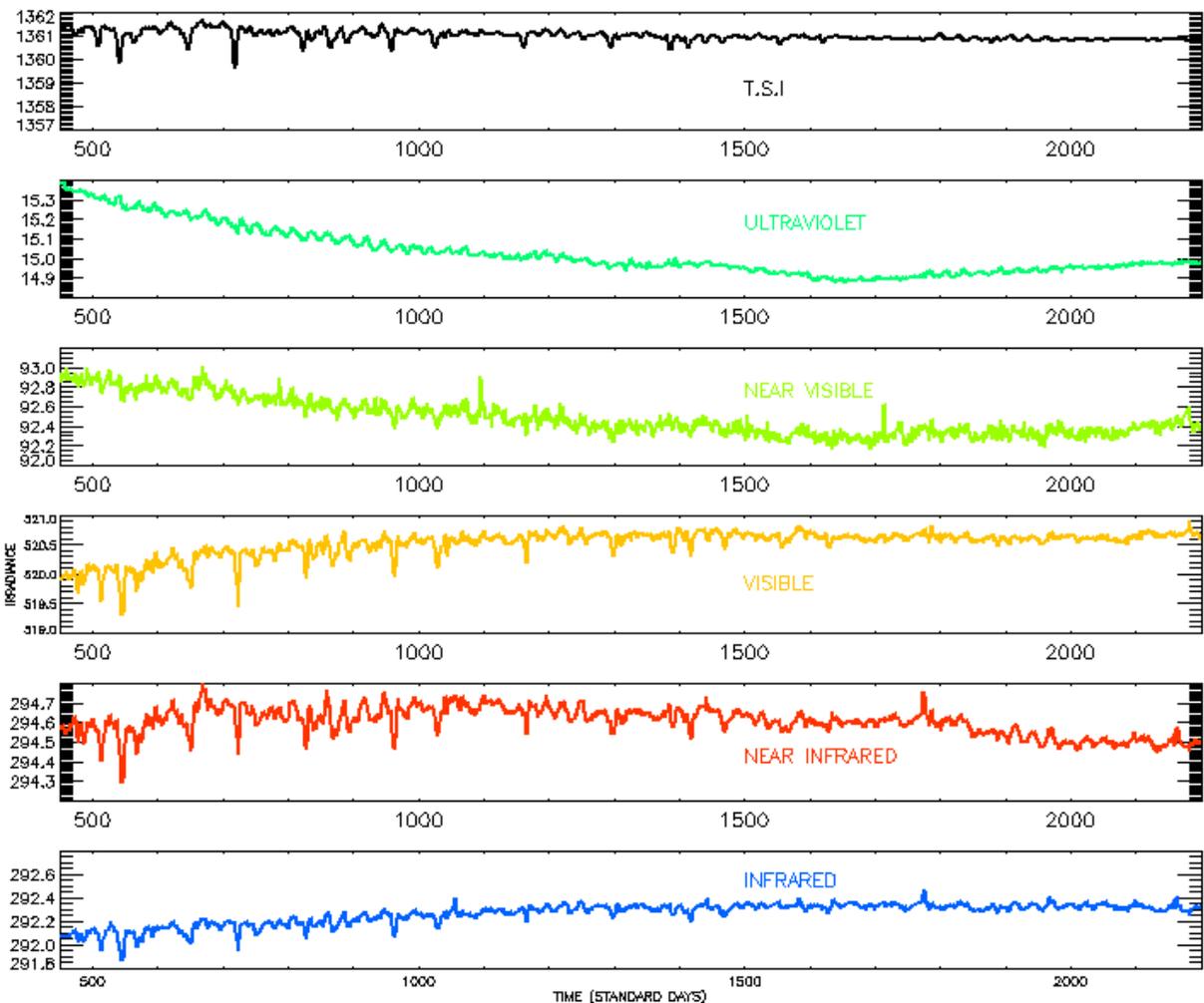
Both the ultraviolet and near visible wavelengths have a clear decreasing trend.

The visible wavelengths display an increase in irradiance.

Infrared wavelengths show an increase.

Data taken from Solar Irradiance Monitor (SIM) and Total Irradiance Monitor (TIM) instruments on the *SORCE* satellite

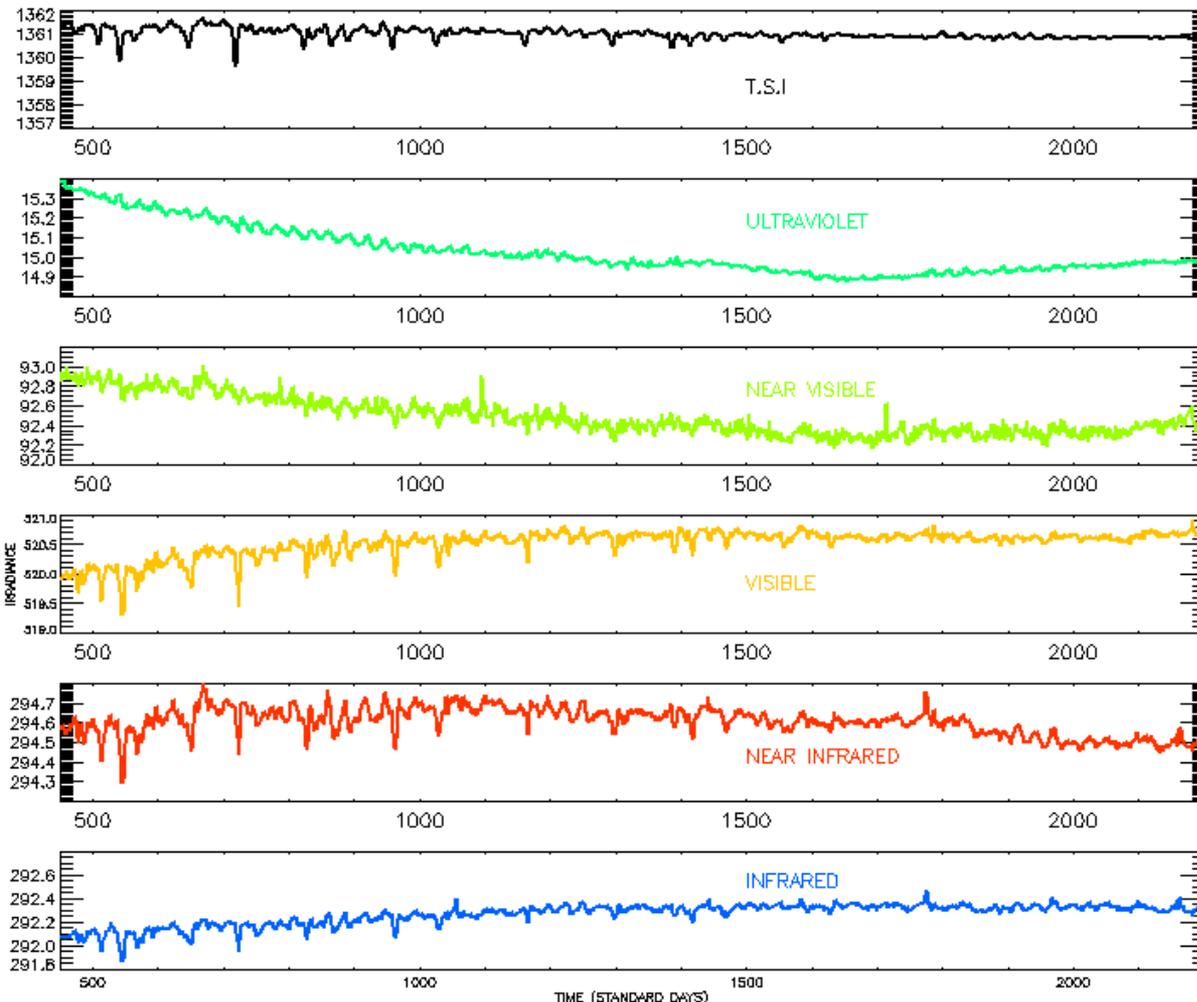
A look at irradiance across the wavelengths



- The total solar irradiance (T.S.I.) shows more variation when more active regions are present. In the absence of active regions, the T.S.I. shows little solar variability.
- The SIM and TIM data show an approximate 0.8% decrease in irradiance in the ultraviolet and near visible wavelengths as solar variability weakens.

Data taken from Solar Irradiance Monitor (SIM) and Total Irradiance Monitor (TIM) instruments on the *SORCE* satellite

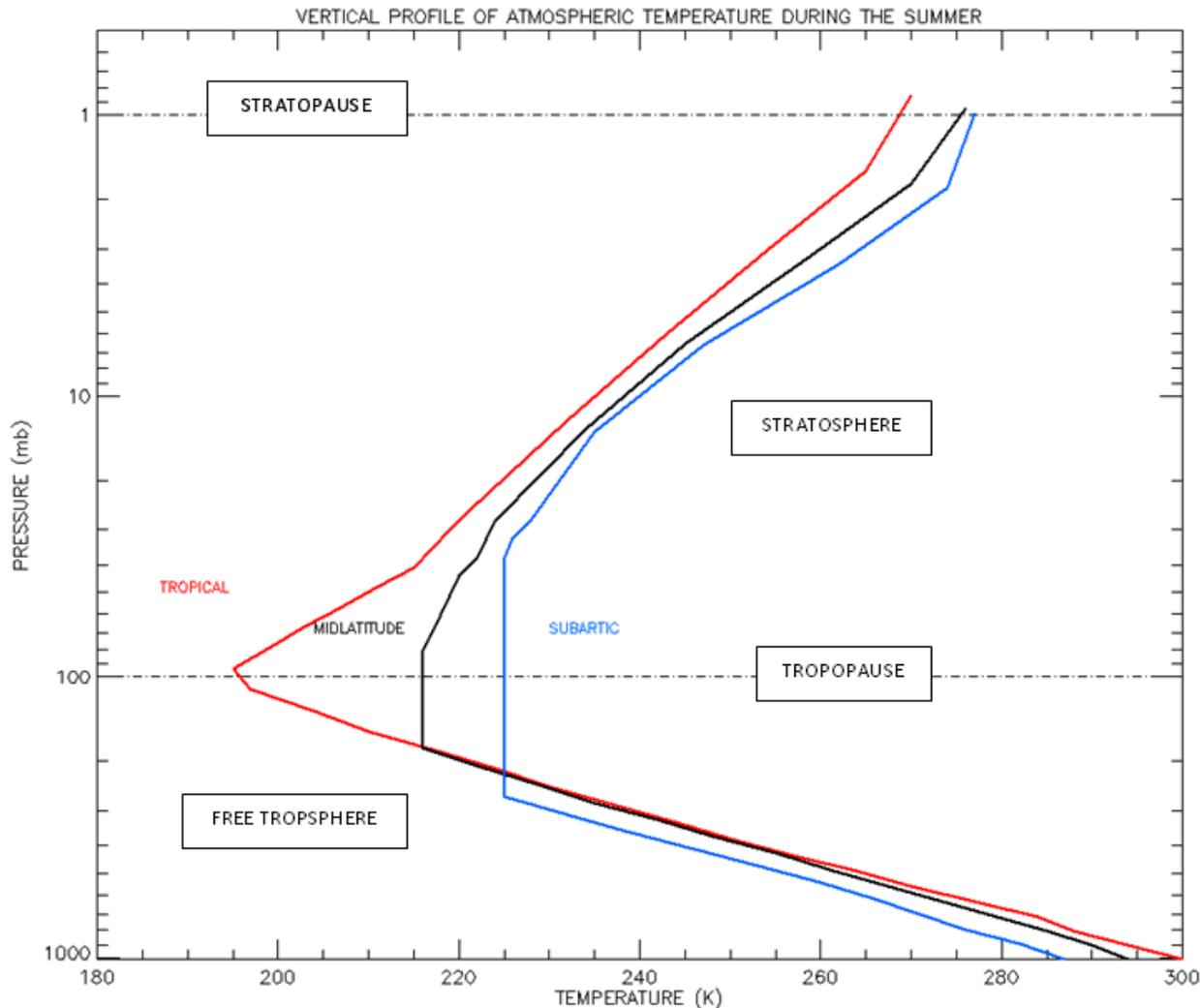
A look at irradiance across the wavelengths



- The visible and infrared wavelengths show the opposite effect during the solar cycle with a nearly compensating effect.
- The irradiance of the infrared wavelengths shows how the temperature of the “surface” of the sun has changed in this time.

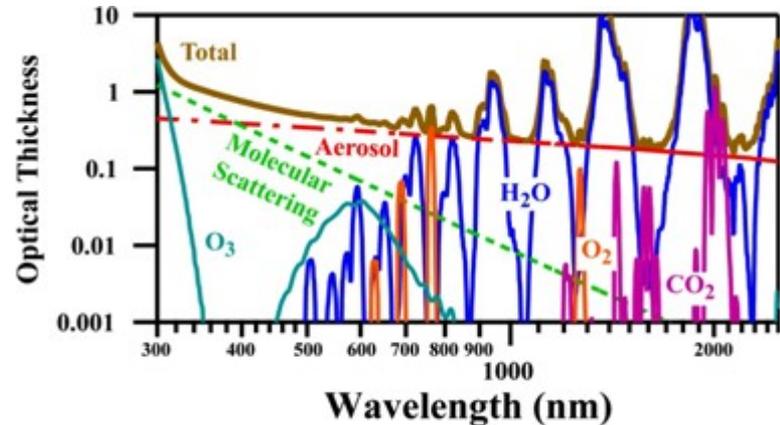
Data taken from Solar Irradiance Monitor (SIM) and Total Irradiance Monitor (TIM) instruments on the *SORCE* satellite

Layers of Earth's atmosphere.

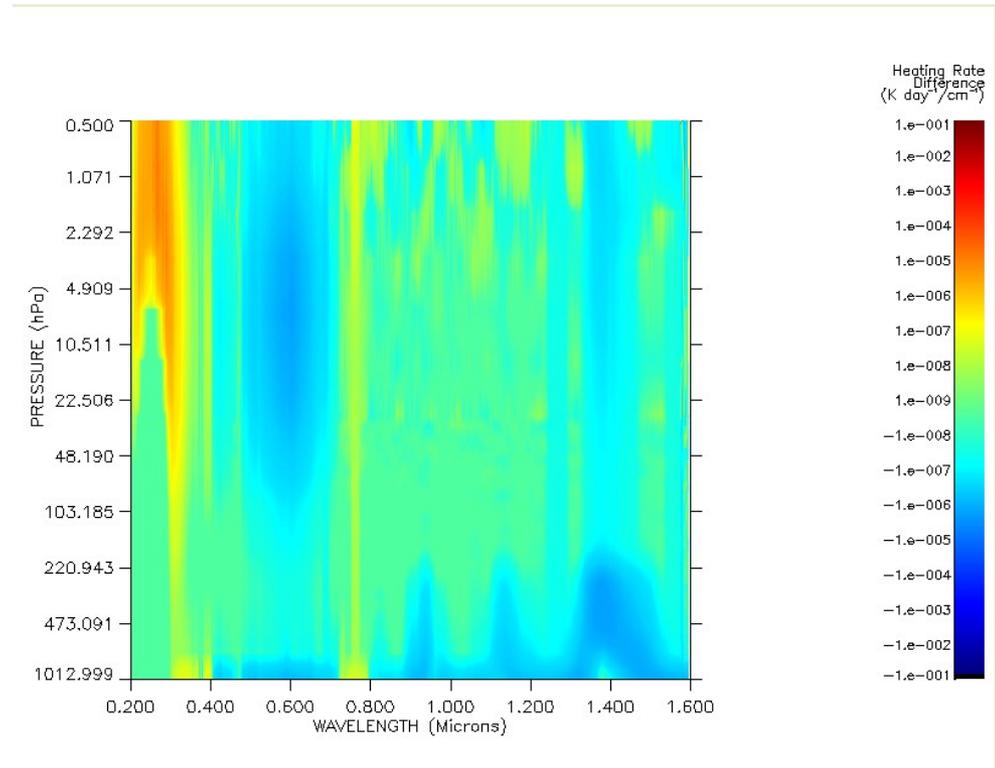


- The atmosphere displays different temperature trends throughout its layers.
- However, the general inclination of profiles across the globe is very similar: warming through the free troposphere, and cooling in the stratosphere due to the production of ozone.

Absorption bands and heating rates

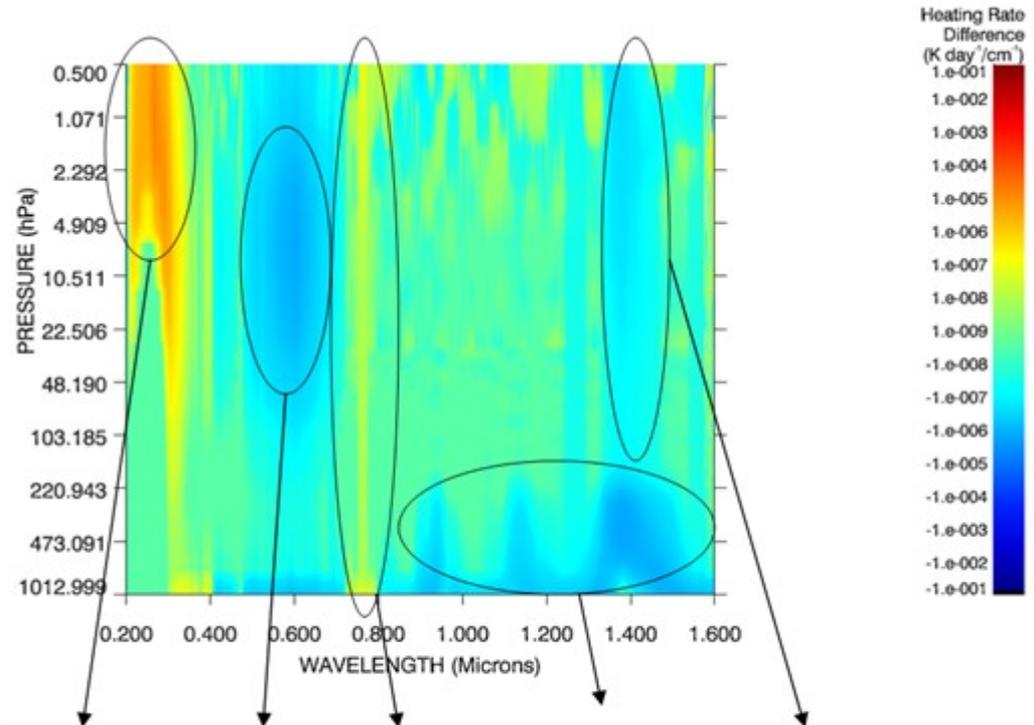


- The lower graph shows the absorption bands of several atmospheric gases. The higher graph displays the differential heating rate between of the quiet sun and another average ten day period when the sun was active.
- This graph will also show the change in heating rates of different wavelengths at different heights.



Absorption Bands

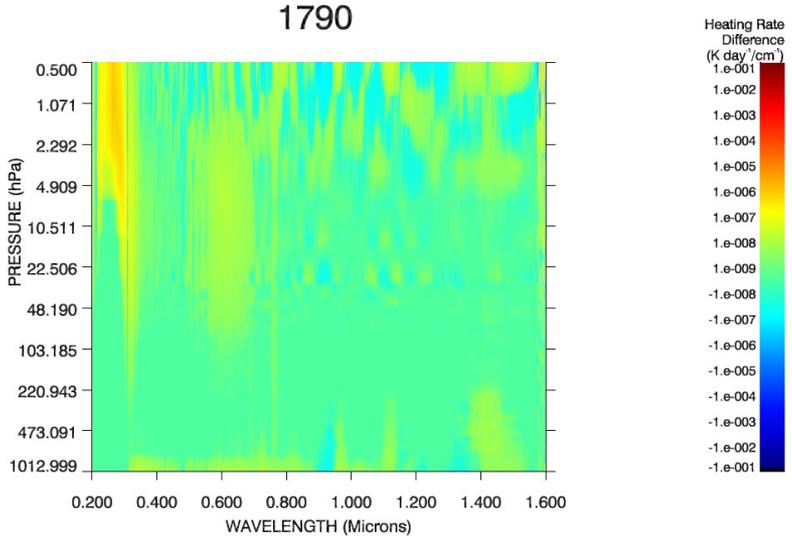
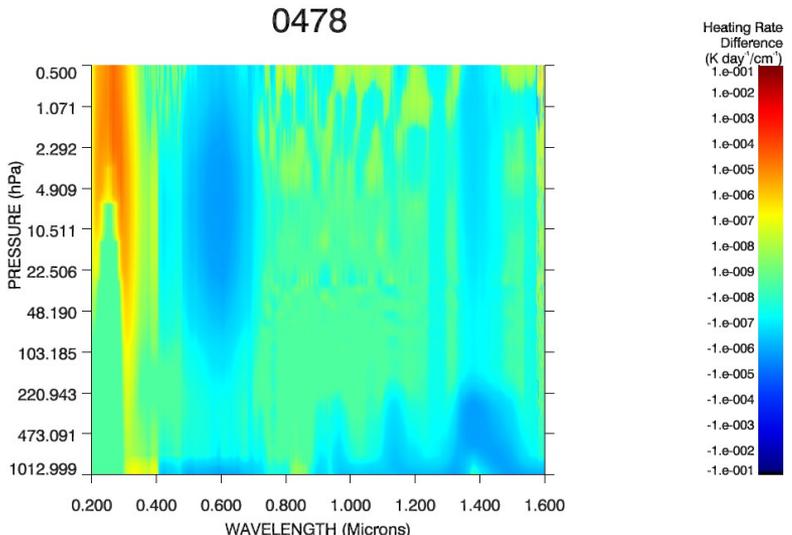
- When the absorption bands from the graph on the left are applied to the graph on the right, different gases can be identified on the graph on the right.
- By absorbing these different wavelengths, these gases created a heating rate. A heating rate is the radiatively induced rate of change of temperature due to the absorption or emission of radiation within the gas.



O₃ (Huggins Band) O₃ (Chappuis) O₂ Water Vapor CO₂

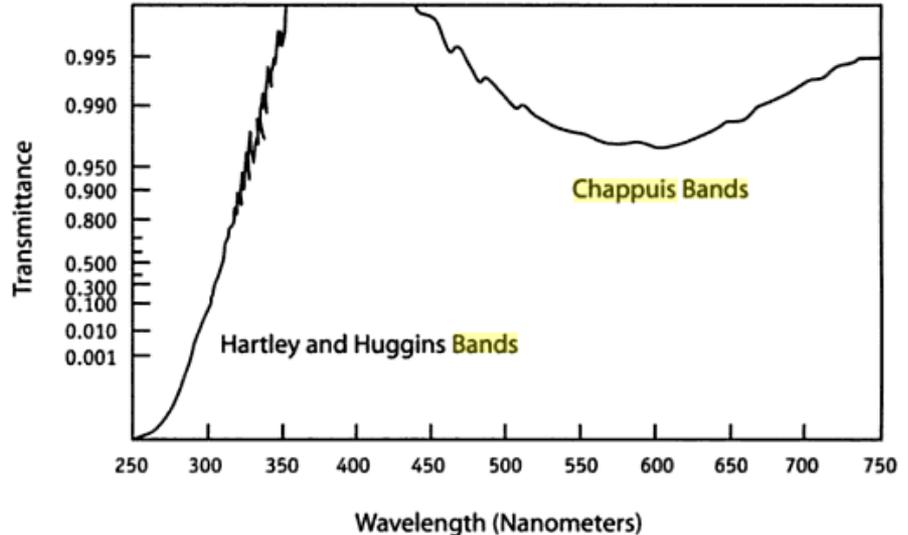
Changes in Absorption Bands

• There is a clear difference from the active sun (2004/05/16, *SORCE* Day 478) to the near quiet sun (2007/12/19, *SORCE* Day 1790) when compared to a reference solar minimum case (2007/11/09, *SORCE* Day 2030) as shown by the changes in absorption bands in Figure 2c.

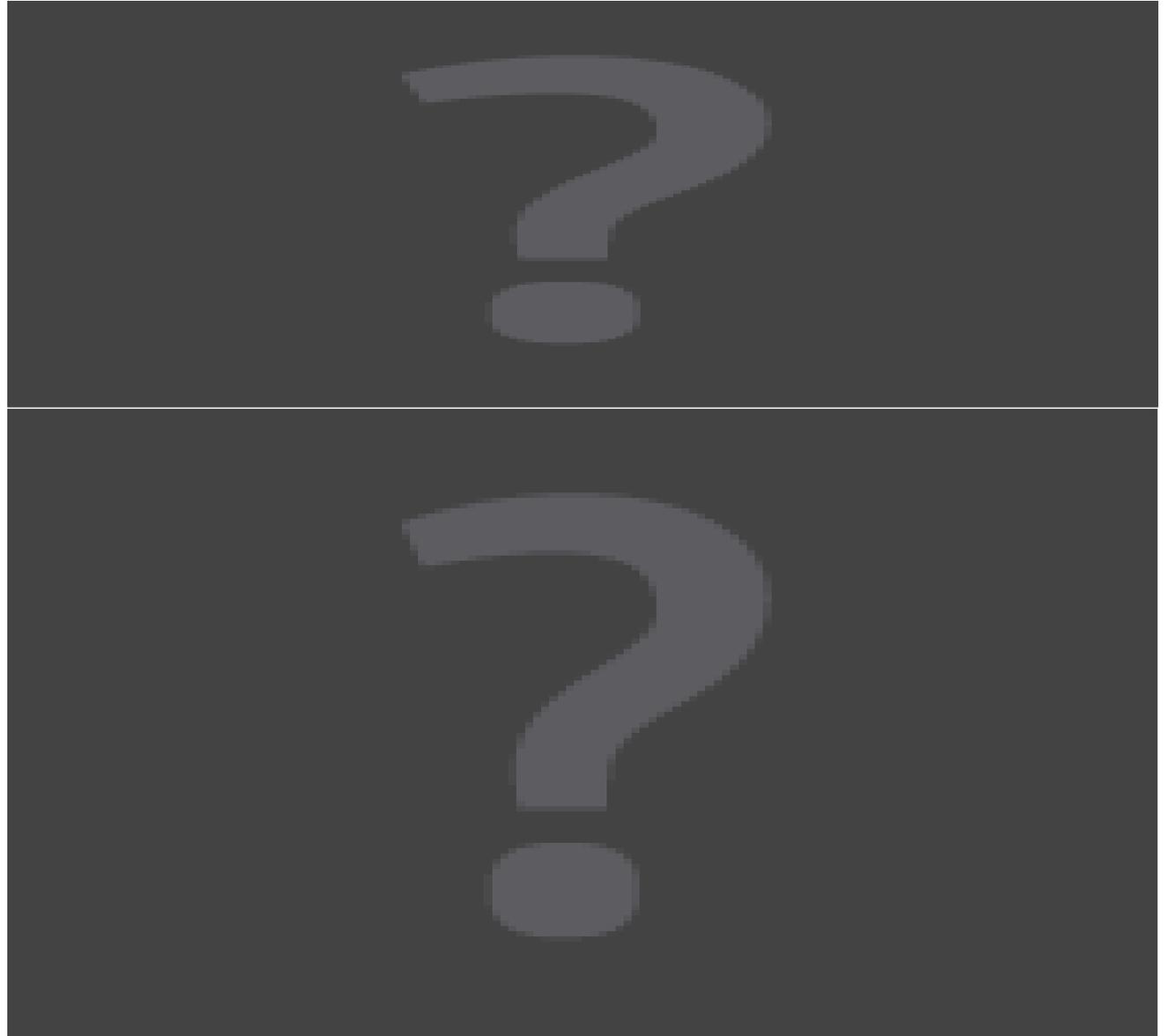


• The dominant solar cycle variations in the free troposphere are due to the different heating rates of water vapor and the UVB wavelengths, as seen at approximately 0.300 Microns.

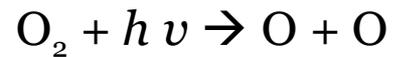
• In the stratosphere, the dominant differences are stronger heating rates of the Huggins ozone band, the stronger negative heating rates of the Chappuis ozone band and the more negative CO₂ absorption



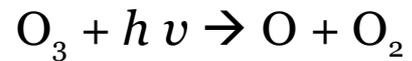
Changes in Absorption Bands



Formation of Ozone:

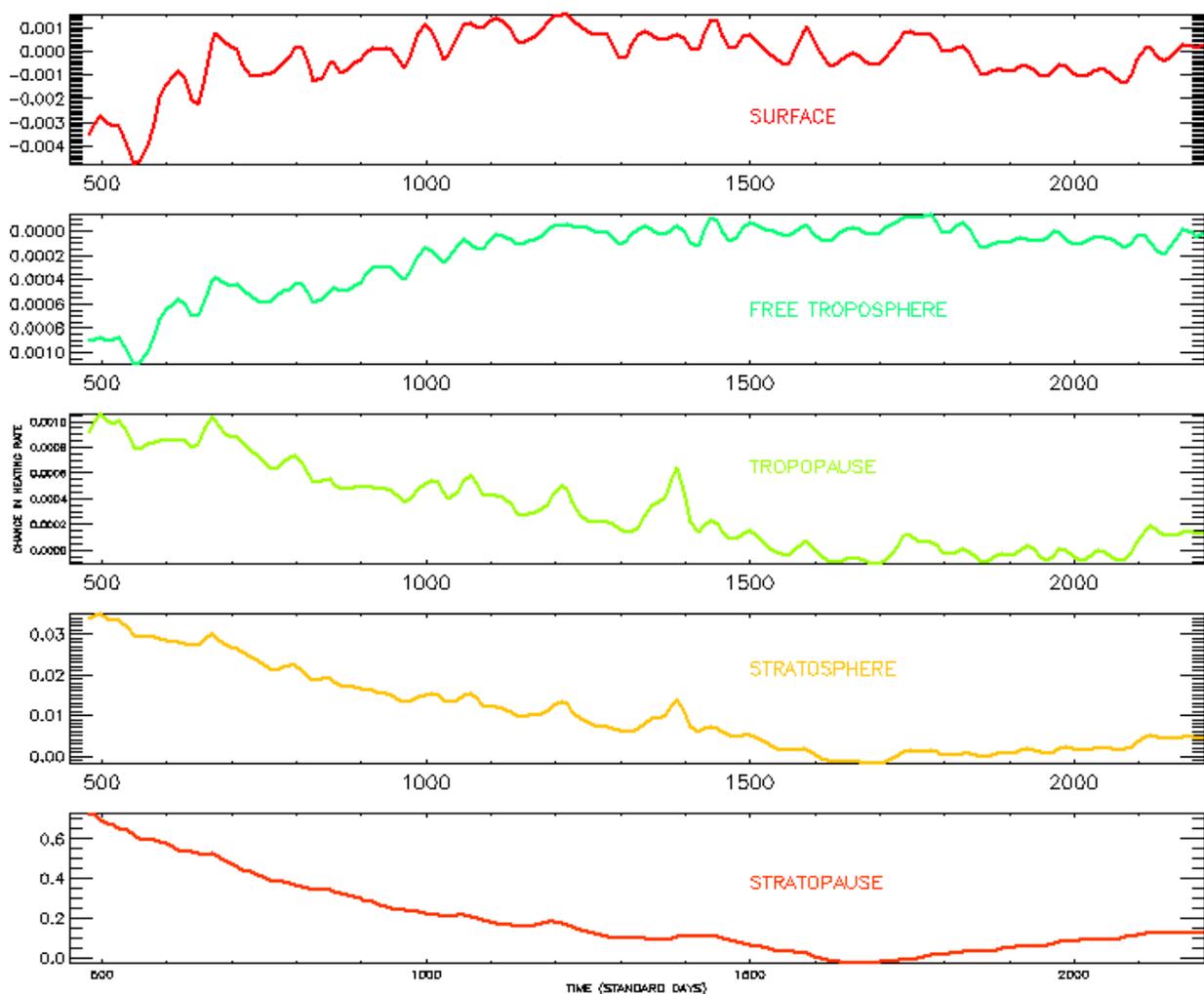


Destruction of Ozone:



Variations in heating rates in the different layers in the Earth's atmosphere as the Sun enters solar minimum.

This graph reflects the impact of solar variability on the various layers of the atmosphere.



- The surface and free troposphere display similar changes; both share an increasing trend as well.
- From the tropopause into the upper atmosphere, the heating rates share similar trends; they all decrease with the reduced amount of solar active regions.

Integrated difference in heating rates

- This was calculated so that all wavelengths can be included and the change in heating rates in the free troposphere and stratosphere can be emphasized. Each line represents a different averaged standard day. This was done to emphasize the change in heating rate as the sun entered solar minimum.
- The structure of the atmosphere can also be seen in the graph, as well. At the tropopause (100 mb), most of the heating rates begin to increase at a greater rate. The lower troposphere is characterized by a wide range of heating rates due to the presence of water vapor.



Conclusion

Through the effort of this research, it has been determined that the variations on the sun play a direct role in the Earth's atmosphere; whether it be during solar minimum, when water vapor in the lower free troposphere has an increased heating rate due to the increased amounts of infrared produced by the sun, or during solar maximum, when ozone in the stratosphere has an increase in heating rate due to the increased amounts of ultraviolet light produced by active regions. However, this research raises questions pertaining to climate. To what effect will a prolonged solar minimum or maximum have on the Earth's climate? Will the change in heating rates of the atmosphere have an effect on the oceans? Will the increased amounts of UVA and UVB during solar maximum threaten plant, animal, or human life? Though these questions cannot be answered through this study alone, the data gathered could be used in future research in an effort to find the answers.