# SPARC SOLARIS & HEPPA Intercomparison Activities: Possible Feedbacks of the Pacific Climate Response to 11-Year Solar Forcing on Lower Stratospheric Ozone at Tropical and Subtropical Latitudes


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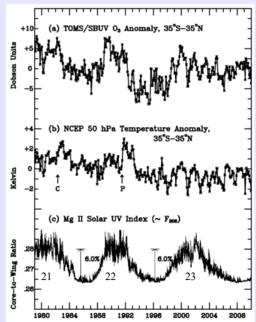
## I. Motivation/Introduction:

Currently, observational evidence exists for responses to 11-year solar forcing in both the stratosphere and troposphere. For example, there is a response of ozone and temperature in the upper stratosphere that has a direct photochemical and radiative origin. There is also a solar cycle variation of ozone and temperature in the tropical lower stratosphere that apparently has an indirect dynamical origin [1]. There is also some (controversial) evidence for a response to 11-year solar forcing in the Pacific climate system [2,3]. It is therefore of interest to investigate further the existence of an 11-year Pacific climate response and its relationship, if any, to the stratospheric response. Here we first apply multiple linear regression methods to estimate both the stratospheric response and the troposphere-ocean response in the Pacific sector. We then investigate whether dynamical feedbacks from the Pacific climate response could be contributing significantly to driving the observed lower stratospheric response (``bottom-up'' mechanism).

## II. Data Description:




To characterize the stratospheric ozone response, we use a combination of TOMS/SBUV column ozone data over the 1979-2009 period (obtained from the Goddard Space Flight Center internet site) and SAGE II ozone profile data over the 1984-2003 period (Provided by F. Wu and W. J. Randel). To characterize the stratospheric temperature response, we use both NCEP/NCAR and ERA-40 Reanalysis data. To characterize the troposphere-ocean response, we use Hadley Centre sea level pressure and sea surface temperature data over the 1900-2009 period.

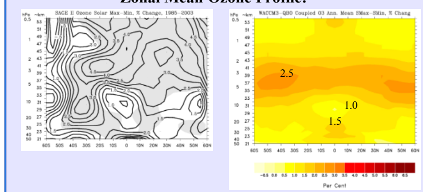
## III: Analysis Method:

We apply a multiple linear regression (MLR) statistical model that includes up to 7 explanatory variables: Linear trend, equatorial QBO winds at 30 and 10 hPa, volcanic aerosol density, ENSO N3.4 index, solar cycle (either Mg II UV index for stratospheric analyses or international sunspot number for troposphere-ocean analyses), and a change-of-trend term to account for a possible change in the long-term trend in the mid-1990's. The residuals (data minus statistical model) are modeled as a first-order autoregressive process and the autoregression coefficient $\rho$ is estimated after an initial application of the MLR model. The time series and all explanatory variables are then transformed as as described in ref. [4]: $x(t) \rightarrow x(t) - \rho \cdot x(t-1)$. Finally, the MLR model is rerun using the transformed variables and $2\sigma$ uncertainties are estimated using standard methods [5].

*In all figures in this poster, regions where the solar response is significant at the $2\sigma$ (95% confidence) level are indicated by shaded areas (black & white plots) or by areas enclosed by heavy dark lines (color plots).*

## IVa: Results: Stratospheric Response

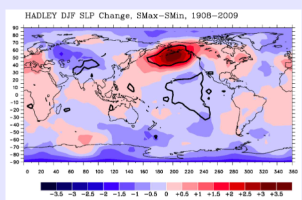
**Zonal Mean Ozone Profile:**



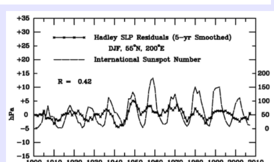

The observed annually averaged ozone response is positive throughout most of the stratosphere. For comparison, the ozone response calculated from a simulation using WACCM3 coupled to CCSM3 with an imposed QBO (analysis done by Christian Blume and Katja Matthes) agrees qualitatively with the observational result in many respects. However, the observed lower stratospheric response is larger and extends to higher latitudes. This suggests a reduction of the mean meridional (Brewer-Dobson) circulation (BDC) near solar maxima that is not fully simulated in the model.

## IVb: Results: Troposphere-Ocean Response

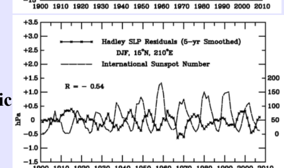
The best evidence for a statistically significant response is obtained using sea level pressure data for the N.H. winter (DJF) season. This agrees with results by previous authors [e.g., 2,6]. Statistically significant responses (enclosed by dark lines) are obtained in two Pacific regions: An area centered on the Gulf of Alaska and an area in the central tropical Pacific. The response can be characterized as ``La Niña-like'' because the climatological Aleutian low is weakened, on average, at solar maximum, as occurs during a La Niña event. The plots on the right compare a smoothed SLP time series at these two locations (after removing trend, volcanic, and ENSO contributions using the statistical model) with sunspot number over the 1900-2009 period.



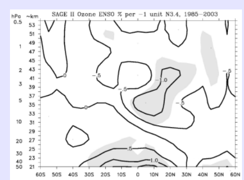

Gulf of Alaska Location:

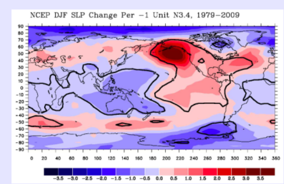



Central Pacific Location:




## V: Comparison With Corresponding ENSO Responses:






Shown are the MLR estimated responses of ozone (left) and sea level pressure (right) during DJF to a moderate La Niña event (change of N3.4 by -1 unit). During a La Niña event, the B-D circulation is weakened, which results in an ozone increase in the tropical lower stratosphere and a small decrease in the middle stratosphere. The SLP response is characterized by a weakened Aleutian low, which reduces the wave forcing of the BDC.

## VI. Interpretation and Conclusions:

The statistically estimated SLP response to 11-year solar forcing (Panel IVb) resembles that observed during a moderate La Niña event (Panel V). In particular, during a La Niña event, the Aleutian low is weakened and shifted westward, on average. This reduces the wave forcing of the BDC, which results in an ozone increase in the tropical lower stratosphere (Panel V). We therefore expect that the Pacific climate response will also, on average, tend to reduce the BDC near solar maxima relative to solar minima. This may contribute somewhat to amplifying the observed lower stratospheric ozone response [7] (Panel IVa). However, as also shown in Panel IVb, the observed SLP variation in the Gulf of Alaska region during DJF is quite irregular, even after applying the statistical model to remove non-solar sources of interannual variability. For example, during the most recent solar maximum, the SLP was lower than average. ``Bottom-up'' forcing was therefore probably more important for the solar cycle total ozone variation during cycles 21 and 22 than during the most recent cycle 23 (Panel II).


## VII. References:

[1] Hood, L. L., In *Solar Variability and its Effect on the Earth's Atmospheric and Climate System, AGU Monograph Series, J. Pap et al., eds.*, AGU, Washington, D. C., p. 283-304, 2004. [2] van Loon, H. et al., *JGR*, doi:10.1029/JD007378, 2007. [3] Meehl, G. et al., *Science, 325,* 1114-1118, 2009. [4] H. Garny et al., *Atmos. Chem. Phys., 7,* 5611-5624, 2007. [5] von Storch, H. and F. W. Zwiers, *Statistical Analysis in Climate Research,* Cambridge Univ. Press, pp. 494, 2002. [6] Roy, I. and J. Haigh, *Atmos. Chem. Phys., 10,* 3147-3153, 2010. [7] Hood, L. L. et al., *JGR, 115,* doi:10.1029/2009JD012291, 2010.