Living with a Star Program
Abstracts of Awarded Proposals

Sun-Climate Focused Research Team

Terry Nathan, University of California, Davis (trnathan@ucdavis.edu)
Eugene Cordero, San Jose State University, (cordero@met.sjsu.edu)
Linton Floyd, Interferometrics (linton.floyd@nrl.navy.mil)
Rolando Garcia, NCAR (rgarcia@ucar.edu)
Lon Hood, University of Arizona (lon@lpl.arizona.edu)
Charles Jackman, NASA/GSFC (jackman@assess.gsfc.nasa.gov)
Judith Lean, NRL (jlean@ssd5.nrl.navy.mil)
David Rind, GISS (drind@giss.nasa.gov)
John McCormack, NRL (john.mccormack@nrl.navy.mil)
Jeff Morrill, NRL (morrill@shogun.nrl.navy.mil)
Cora Randall, University of Colorado (randall@lasp.colorado.edu)

ABSTRACTS

CO-PIs: Terrence Nathan/University of California, Davis, Eugene Cordero, San Jose State University

Proposal Title: *Modeling the Climate System's Response to the 11-Year Solar Cycle*

Abstract: Observational and global modeling evidence both point to the stratosphere as the intermediary for communicating variations in solar irradiance to the troposphere. The observational evidence indicates that interactions between the quasi-biennial oscillation (QBO) and stratospheric ozone may provide a pathway for linking the 11-year solar cycle to long-term climate variability; the global modeling evidence shows that the solar cycle signal may be amplified by stratospheric ozone to affect the extratropical planetary waves. How the solar cycle modulates the interactions between the QBO, stratospheric ozone, and extratropical planetary waves remains largely unknown. This is due in part to the inability of global climate models to produce a realistic QBO. In view of the importance of the QBO to the solar cycle problem and global climate, the proposed research will assimilate the QBO and its interactions with solar induced ozone perturbations into the Whole Atmosphere Community Climate Model (WACCM). This will permit us to address our central objective: to provide improved understanding and more accurate numerical simulations of atmospheric quasi-decadal variability associated with the 11-year solar cycle. In addressing this objective we shall employ a unified work flow that combines basic research, numerical modeling, and observational validation. The basic research will employ tropical and extratropical mechanistic models to help identify mechanisms that may provide a pathway for linking the solar cycle signal to variations in climate. Attention will be focused on developing a better understanding of how solar cycle induced variations in stratospheric ozone modulates the interactions between the QBO, stratospheric ozone and planetary waves. The numerical modeling will involve assimilating the QBO into the WACCM; the output will be analyzed with a suite of diagnostics; including Eliassen-Palm fluxes, refractive indices, and singular value decomposition. The modeling simulations will be validated by comparing the WACCM output with observations. The proposed research addresses the primary goal of NASA, the Office of Space Science, and the Living with a Star Program: to develop scientific understanding of the Sun-Earth system and its impact on terrestrial climate.

PI: Linton Floyd/Interferometrics, Inc.
Proposal Title: *Solar UV Irradiance Variation during the Solar Cycle*
Abstract: Analysis of terrestrial climate data have shown effects of the solar activity cycle (e.g., Quasi Decadal Oscillation). Variations in the solar ultraviolet (UV) irradiance are one likely cause because of UV absorption in the Earth's various atmospheric layers. Recent climate simulations based on realistic models of atmopheric processes involving solar UV irradiance have shown that solar UV variation can cause significant terrestrial climate changes. Begun in 1978, space-based measurements of solar UV irradiance are often difficult to interpret because of uncertainties in the long-term responsivity calibration of the measuring instruments. Generally, the solar variations are large compared to these uncertainties for the shortest wavelengths (e.g. < 200 nm), but decline for longer wavelengths until ~300 nm where instrumental trends inevitably dominate. The goal of this research is to determine the solar cycle variation of the solar UV irradiance from the available data from several experiments. For each solar UV experiment and time period, the solar cycle variation will be determined. For wavelengths where the solar cycle can be observed directly, the solar cycle variation for rising or falling phases of the solar cycle will be directly calculated from the calibrated data. For longer wavelengths where instrumental trends dominate the solar variation, presence of the solar signal, as represented by the MgII core-to-wing ratio index and where possible the Photometric Sunspot Index, will be detected and the solar cycle variation inferred. The results will be interpreted in the context of and will be compared with the results of state-of-the-art synthetic solar spectrum models.

PI: Rolando Garcia/NCAR
Proposal Title: *Studies of the Atmospheric Impact of 11-Year Solar Variability Using the Whole Atmosphere Community Climate Model*
Abstract: NCAR's Whole Atmosphere Community Climate Model (WACCM) will be used to study the impact of 11-year solar variability form the troposphere to the lower thermosphere. The model domain extends from the ground to ~150 km, and includes fully interactive chemical, dynamical and radiative processes over this range of altitude. We propose a series of integrations over 8-10 simulated solar cycles to establish the statistical significance of the results, and help elucidate the physical mechanisms responsible for atmospheric variability on 11-year time scales; this approach is especially important in the troposphere and lower stratosphere, where solar signals are expected to be small. In addition to the model, we will use NASA satellite observations (UARS, TIMED, SNOE, etc.), plus ground-based observations, to specify the variability of solar irradiance and particle precipitation over the 11-year solar cycle, to validate model results, and to help elucidate the mechanisms whereby solar variability impacts the state of the atmosphere.

PI: Lon Hood, University of Arizona
Proposal Title: *Solar Induced Variations of Stratospheric Ozone: Improved Observational and Diagnostic*
Abstract: The objective of the proposed work is to more completely determine and interpret the observed stratospheric ozone response to solar variability on both the 11-year and 27-day time scales as a function of altitude, latitude, and season. On the 27-day time scale, we will apply correlative and regression methods to (a) determine the altitude dependence of 27-day ozone responses in the lower stratosphere using a combination of SAGE II, UARS MLS, and EOS

Aura MLS data; (b) determine the dependence of the 27-day response on latitude, season, and QBO phase in the upper stratosphere using primarily Version 8 SBUV(/2) ozone profile data; and (c) distinguish statistically among possible solar forcing mechanisms (e.g., solar UV flux, solar and magnetospheric particle fluxes, Galactic cosmic ray flux). On the 11-year time scale, we will apply a multiple regression statistical model to re-evaluate the 11-year solar UV induced response of stratospheric ozone using three complementary and independent data sets: (1) the recently released Version 8 SBUV(/2) ozone profile data set extending from 1979 through 2003 (with anticipated updates); (2) the recently completed Version 19 UARS HALOE data set extending from October 1991 through August of 2005; and (3) the SAGE II ozone profile data set extending from 1984 through 2000. We will also explore use of the HALOE and SAGE II data as external calibrations for the SBUV(/2) data. In order to diagnose the physical causes of the observed 11-year ozone response, we will carry out statistical analyses of other HALOE measured quantities (e.g., NO + NO2, temperature) and will study the results of collaborative two- and three-dimensional model simulations. We will specifically collaborate with Drs. John McCormack of NRL and Dan Marsh of NCAR for this purpose. Preliminary comparisons of a recent 50-year simulation of the NCAR WACCM v. 3 model, which includes no QBO but incorporates the effects of energetic particle inputs and uses observed sea surface temperatures as a lower boundary condition, shows that the model 11-year ozone response is similar to the observed response. As stated in the LWS TRT Summary (Appendix A.21 of the ROSES-2005 NRA), ``LWS will provide understanding of the effects of solar variability on terrestrial climate change . . .''. The observed solar cycle variation of stratospheric ozone is a fundamental constraint on sun-climate models that include stratospheric effects of solar ultraviolet and energetic particle inputs. The observed ozone response to 27-day solar UV forcing is also a basic constraint on sun-climate models. In addition, the need for the proposed research in the near future and the expectation of a significant scientific impact are supported by: (a) the recent availability of improved long-term remote sensing data sets including the Version 8 SBUV(/2) and UARS HALOE data sets; and (b) preliminary comparisons of the observed 11-year ozone variation with a recent 3D model simulation showing a potentially very good agreement. The latter comparisons indicate that the planned approach toward using collaborative model simulations for a variety of solar inputs and boundary conditions to identify causal mechanisms will be fruitful.

PI: Charles Jackman/Goddard Space Flight Center
Proposal Title: *Solar Proton Events and their Atmospheric Dynamical Influence*
Abstract: This investigation will be directed towards two aspects of atmospheric dynamics and solar proton events. The first part will focus on the influence of solar proton events on atmospheric dynamics, including the temperature and wind changes caused by the events. Several very large solar proton events in the past thirty-five years have created significant perturbations in the polar mesosphere due to substantial ozone decreases and Joule heating over a couple of days. A few of these events also caused polar upper stratospheric ozone decreases of over 10% for a period of several weeks. The dynamical changes resulting from these short-term (days) and long-term (weeks) influences from solar protons will be investigated with two different models, the TIME-GCM (Thermosphere Ionosphere Mesosphere Electrodynamics - General Circulation Model) whose domain is from 30 to 500 km and the WACCM (Whole Atmosphere Community Climate Model) whose domain is from the ground to 140 km. The second part of the investigation will focus on the transport of the perturbed atmospheric

constituents, caused by solar protons, for weeks to months past the events. The transport for the specific time periods of study will be generated from meteorological data sets and will be used in the GSFC Two-dimensional Photochemistry and Transport Model whose domain is from the ground up to 90 km. A third part of the investigation will focus on some of the uncertainties in the model computations that are particularly relevant to the solar proton-induced atmospheric perturbation. Model results from all parts of the investigation will be compared to satellite and ground-based measurements, whenever possible.

PI: Judith Lean, Naval Research Laboratory, David Rind, Goddard Institute for Space Studies
Proposal Title: *The Sun's Role in Decadal Climate Change since 1980, and in the Last Century*
Abstract: The goal of this research is to differentiation the recent climate response to solar variations from other natural and anthropogenic sources of climate variability. GCM simulations will be compared with observations (globally, geographically and vertically). The GISS Middle Atmosphere Global Climate Model (GCMAM) will be used to simulate climate the response to solar and other sources of variability. Differences between solar max and solar min conditions for temperature and ozone using the 23- and 53- layer models, evaluated with full spectral irradiance variations (120 nm to 100,000 nm), will be compared. Increased UV radiation during solar max conditions produces more ozone, and together they produce greater heating and temperature in the mid to upper stratosphere. Other forcings are being modeled similarly, and with finer resolution versions of the model, for comparisons with observations.

PI: Jeff Morrill/Naval Research Laboratory
Proposal Title: *A Model of Long-Term Variability of Solar UV and EUV Irradiance*
Abstract: Studies of climate and ozone variability have shown the need for detailed knowledge of long-term solar UV/EUV spectral irradiance variability. The proposed research will derive estimates of the long-term solar UV and EUV spectral irradiance using Ca II K images and a solar irradiance model developed under an earlier NASA/LWS TR&T research grant. That model uses Ca II K images observed by Big Bear Solar Observatory and model results are currently being validated by comparison to observed full disk irradiance spectra from UARS. By using digitized versions of the Mt Wilson Observatory (MWO) Ca II K film archive and spectra measured from the SKYLAB film archive estimates of the solar UV irradiance spectrum can be derived over the wavelength range from ~ 120 to ~400nm. In addition, by using the calculated Mg II index as a proxy for shorter wavelength emissions we will provide irradiance values in the EUV. Use of the SKYLAB and MWO archives coupled with more recent photoelectric Ca II K observations will yield estimated UV/EUV spectra that will span the time period from 1915 through the present thus providing estimated values over nearly a century. These estimated spectra will be valuable as inputs to long-term models of climate and ozone variability as well as Martian photochemistry. Currently, a preliminary set of digitized versions of the MWO photographic solar images has been acquired from the National Geophysical Data Center. In addition, a more comprehensive analysis and improved digitization of the MWO photographic archive is presently underway as part of a NASA funded project. Once available, we will use these improved MWO images to generate the final set of estimated spectra. An initial component of this proposal will be to upgrade the current irradiance model to include wavelengths below 200nm and to validate model results with measured UV and EUV. Once completed, the resulting estimated spectra will be used to address unresolved questions surrounding current long-term reconstructions of solar variability.

PI: Cora Randall, University of Colorado
Proposal Title: *Implications of Energetic Particle Precipitation for the Stratosphere*
Abstract: We propose to combine satellite data analysis and global modeling to investigate the effects of solar cycle variations in energetic particle precipitation (EPP) on the stratosphere. Precipitating particles continually penetrate the earth's upper atmosphere, producing odd nitrogen. During the polar night, if dynamical conditions are appropriate, the odd nitrogen so produced can descend to the stratosphere where it participates in the catalytic cycles responsible for controlling ozone distributions. While this has been known for decades, the implications for stratospheric ozone have never been quantified, and these effects are routinely neglected in three-dimensional global models. Nevertheless, observational evidence suggests that even under moderate levels of solar activity, EPP affects stratospheric ozone. The goal of this proposal is to investigate the effects of EPP on stratospheric ozone distributions, variability, and trends, and the resulting implications for studies of long-term change in the upper troposphere and stratosphere. To accomplish this, the proposed work has two main objectives: (1) Analyze the historical and continuing data base of stratospheric ozone and NOy satellite measurements to correlate variability in these constituents with solar cycle variations in EPP; and (2) Incorporate EPP into a global chemistry climate model to quantify EPP effects on stratospheric NOy and ozone distributions, and to investigate corollary effects on atmospheric composition and dynamics. Through the combined use of satellite data and modeling, the proposed work is directly responsive to the current NASA ROSES Research Announcement and Living With a Star (LWS) program objectives. It targets the NASA exploration objective "To understand and protect our home planet" by addressing "the role of solar variability in climate and stratospheric chemistry", one of the primary focus topics designated by the LWS Targeted Research and Technology Science Definition Team.

PI: John McCormack, NRL
Proposal Title: *Investigating the Influence of the 11-Year Solar Cycle on Dynamics Using a High Vertical Resolution Zonally Averaged Photochemical-Dynamical Model of the Middle Atmosphere*
Abstract: This research will examine the interannual variability in ozone and temperature with the CHEM2D zonally averaged photochemical transport model of the middle atmosphere (15-85 km altitude). CHEM2D model simulations are used to study the effects of solar ultraviolet (UV) variations on middle atmospheric photochemistry and dynamics over both the 27-day and 11-year cycles. These model simulations also include internal sources of interannual variability such as the quasi-biennial oscillation (QBO) in equatorial stratospheric zonal winds and changes in the planetary wave forcing of the mean meridional circulation in the middle atmosphere. This research has demonstrated that the 11-year solar cycle can modulate the behavior of the QBO, thus offering a possible physical mechanism through which the upper stratospheric response to solar UV variations can produce a broader climate signal. Future work will test various proposed feedback mechanisms that may augment the lower stratospheric response to solar UV variations and thus help to reconcile model estimates of solar cycle variability in ozone and temperature with observational estimates.