Abstracts of the Solar Influences on Global Change Research and Analysis Program

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Anyamba, Ebby / General Sciences Corporation
An Exploration of the Relationship Between Intraseasonal Variations in Cosmic Ray Flux and Global Weather Parameters

This proposal seeks to establish the relationship between intraseasonal oscillations in global weather parameters and similar oscillations in cosmic ray flux. Global intraseasonal oscillations with periods in the range of 10 to 90 days strongly modulate world wide weather. These oscillations are recognized as important components of the global general circulation. However, to date, there is no unified theory that explains their existence and characteristics. Recent studies on sun-weather relationships have shown strong correlations between changes in global cloud cover and changes in cosmic ray flux over a solar cycle. This result supports a proposed mechanism of solar-modulated forcing of climate and weather that involves the ionization effects of cosmic rays on cloud formation. The study will use daily cosmic ray flux data recorded by ground-based neutron monitors, TOVS satellite cloud data, and model reanalyses of temperature and wind fields. Results from this study will advance our understanding of the origins of intraseasonal oscillations and could contribute to the improvement of long-range weather prediction techniques.

Baliunas, Sallie L. / Harvard-Smithsonian Center for Astrophysics
Constraints on Variability of Brightness and Surface Magnetism on Time Scales of Decades to Centuries in the Sun and Sun-like Stars: A Source of Potential Terrestrial Climate Variability

We propose to estimate the total solar irradiance (TSI) change and its climatic impact over centuries. The method is to consider an ensemble of 70 sunlike stars whose photometric (Stromgren b and y passband) and chromospheric Ca II (H and K) fluxes have been measured for an activity cycle or longer. The decade-scale records of many sunlike stars considered together are presumed to represent random phases of longer-term variations of one sunlike star.

This proposal has several activities: (1) to continue the photometric and Ca II monitoring of 70 sunlike stars so that the records extend for at least a decade; (2) to begin surveying Ca II and photometric fluxes of a larger sample of 300 sunlike stars; (3) to design and implement a new calibration procedure for the Ca II flux records that should allow the detection of very low amplitude (~1%) rotation modulation, cycles, and subtle cycle-to-cycle changes; (4) to define better the properties of a "sun-like" star and improve the sample by removing unsuitable targets; (5) to analyze flux records for inter- and intra-cycle variability using wavelet analysis modified for our unevenly-sampled records; (6) to analyze correlated photometric and chromospheric flux variations over cycles; (7) to link such variations to solar magnetic and total irradiance changes; (8) to construct, via century-scale solar magnetic activity records, an estimate of TSI variations; (9) to estimate the biases due to the use of the available observations of sunlike stars in making an estimate of TSI changes; and (10) to estimate the climatic impact of TSI changes using a low-resolution energy-balance climate model.

In order to focus on understanding the natural climate variability, and limit the effect of recent increases in anthropogenic greenhouse gases, the proposed effort would use a 1000-year record of solar magnetism (e.g., determined from 14 C and 10 Be records) ending around 1850.

Brasseur, Guy P. / National Center for Atmospheric Research
Model Predictions of Interactions between Solar and Anthropogenic Perturbations in the Earth's Atmosphere

The chemical composition and the physical structure of the Earth's atmosphere are changing in response to variations in solar radiation, the release of anthr opogenic gases and other external forcing, including volcanic eruptions. Because of the nonlinear nature of the physics and chemistry of the global climate system, the atmospheric response to each of these external inputs may affect the others. The multiple sources of variability also make it difficult to isolate the atmospheric response to a particular external forcing change. For example, episodic volcanic eruptions can enhance or mask the changes in the lower and middle atmosphere associated with the solar cycle. We propose to assess the response of the atmosphere to variations in the incoming solar radiation and in chemical forcing of human origin, and to quantify the reciprocal influences between solar induced and anthropogenic perturbations. More specifically, we will assess the response of the middle and lower atmosphere to the 11-year solar cycle using existing 2-D and 3-D chemical/radiative/dynamical models, and to compare model predictions with analysis of observations. We will also investigate the response to the 27-day solar variation and plan an extensive comparison of model results with SME, MLS, and SBUV ozone measurements. We will analyze carefully observed and calculated changes in the mesospheric region, because previous analyses have revealed that this region is very sensitive to both solar variability and anthropogenic forcing. The numerical models will then be used to determine the separate and combined responses of the atmosphere to changes in composition and solar activity levels, under conditions of high and low volcanic aerosol loading. Using a coupled 3-D chemical/dynamical model extending from the surface to 80 km altitude, we will examine to what extent dynamical processes could amplify the atmospheric response and propagate the "solar signal" to lower altitudes. We will investigate whether changes caused by human activities affect the way the atmosphere responds to natural perturbations induced by solar variability and volcanic eruptions.

Chapman, Gary A. / California State University, Northridge
A Proposal to Characterize and Understand the Sources of Solar Total and Spectral Irradiance Variability

Overall objectives and strategy: A fundamental problem in understanding solar variability is the understanding of the effects of magnetic fields at the Sun's surface and their effect on the flow of energy associated with the growth and decay of active regions throughout the solar cycle. Significant insight can be had only through a better understanding of the sources of solar irradiance variations seen in total and spectral observations from satellites. One of our main objectives is to support NASA spacecraft by obtaining precise photometric images in selected wavelengths to compare with spectral and total irradiance data from satellite instruments such as SOLSTICE, SUSIM and ACRIM-2 on UARS; VIRGO on SoHO, and others to be launched in the near future. We need to better understand the relative contributions to variations in spectral and total solar irradiance (TSI) made by sunspots, faculae and the (magnetic) photospheric network. The possibility of variations in the quiet sun must be thoroughly investigated. Variations in TSI from ACRIM-2/UARS and VIRGO/SoHO will be compared with photometric sunspot and facular data from the San Fernando Observatory (SFO), Big Bear Solar Observatory (BBSO), the NSO/PSPT's and any other source of precise photometric images. A key science question is to fully understand why the average solar irradiance is highest during the peak of solar activity when the average sunspot area is greatest. Past work at SFO and elsewhere have shown faculae to be a major part of the answer to this question. Faculae and bright network are a source of irradiance enhancement and it appears that the irradiance, it not the total energy, from faculae exceeds the deficit of sunspots by 30-50%. Modeling the TSI from ERB/Nimbus-7 and ACRIM-1/SMM for approximately 4-year and 1-year intervals, respectively, resulted in an excellent fit using digital photometric full-disk images from SFO in the red for sunspot deficits and in the K-line for facular excesses. We found the multiple correlation coefficient was R2 = 0.838 for 745 days for Nimbus-7 data with a daily rms residual noise of ±0.21 W/m2. This is to be compared with the noise in the Nimbus-7 data of ±0.19 W/m2. Using NOAA-9 for a faint network proxy signal improved the R2 to 0.887. We also refined two corrections to the total irradiance scale of ERB/Nimbus-7.

We will continue to analyze photometric images to obtain sunspot, umbral and facular areas and irradiance fluctuations using full-disk photometric images from the CFDT1 (5" pixels) and CFDT2 (2.5" pixels). These data will then be used to produce a record of modeled irradiance changes for the period covered by the grant for all useable days (typically about 250 days a year). Data from both telescope/photometers will be critically compared to ACRIM-1, ACRIM-2, Nimbus-7 and SOLSTICE data, as well as new data from SoHO, using also the core/wing ratio from NOAA-9/SBUV2, UARS/SOLSTICE Mg II, or other network proxies when appropriate. We will seek to improve the spot and facular data and to produce the best possible irradiance models. We will continue daily operation of both CFDT1 and CFDT2 in support of satellite irradiance experiments.

Foukal, Peter V. / Cambridge Research & Instrumentation, Inc.
Improved Models of Solar Irradiance Variation from Analysis of Space-Borne Radiative Flux Measurements, and of Solar CaK Emissions Between 1905-Present

The most important obstacle to accurate reconstruction of the sun's total and ultraviolet irradiances during the past period of global warming, has been the lack of direct information on the changing areas of bright magnetic structures in the sun's photosphere and chromosphere, prior to 1947 when daily CaK plage area and 10.7 cm solar microwave measurements were initiated. An important step forward has been provided by our recent digitization of the Mt. Wilson Observatory daily CaK spectroheliograms, extending from 1984 back to 1905. We have measured time series of plage areas, and also of area enhancements in the active network on these images, which we expect to complete through 1998 by digitizing Sac Peak spectroheliograms later this year. These time series provide an important opportunity to construct more physically based and accurate models of the three solar inputs of most direct interest in global change studies. One of these, a proxy extension of the F10.7 index prior to 1947, which is of great importance to thermospheric modeling, is being carried out under our present NSF grant. We propose in the first year of this project to construct an improved empirical model of total irradiance, using space-borne pyrheliometry obtained since 1978 to calibrate our empirical model. In the second year of the project we propose to focus on construction of a family of models of UV variation at wavelengths in the range between approximately 160-340nm of greatest interest to ozone photochemistry. These would use NASA spectroradiometry, primarily from the SOLSTICE and SUSIM instruments, to calibrate the variations in projected area of solar magnetic structures in terms of spectral irradiance variations.

Fox, Peter A. / National Center for Atmospheric Research
Variability of the Internal Structure of the Sun with Probable Terrestrial Consequences

This proposal envisions the study of variations of the internal structure of the Sun which occur as a consequence of the changes of the internal magnetic fields due to the dynamo process. These variations can affect the output of the solar radiative energy, and thus may affect the terrestrial climate. The study is primarily theoretical in nature, but it is solidly anchored in an extensive set of observations which are only becoming available in recent times from space platforms (UARS and SOHO), from balloon observations (SDS), and from ground-based observatories (GONG, BISON, ECHO, PSPT, etc.). The proposed work is a multidisciplinary effort which includes data analysis, modeling, model fitting, and forecasting. The expected outcome of this work is a robust understanding of the nature of subphotospheric solar variability and its possible role in climate change.

Goode, Philip R. / New Jersey Institute of Technology
Earthshine Measurements of Global Atmospheric Properties

The Earth's climate depends on the net sunlight deposited on the globe, which is critically sensitive to the Earth's albedo. A global and absolutely calibrated albedo can be determined by measuring the amount of sunlight reflected from the Earth and, in turn, back to the Earth from the dark portion of the face of the Moon (the "earthshine" or "ashen light"). Such data provide a critical complement to satellite data. We propose to advance our investigation into the systematic determination of the Earth's albedo through the measurement of earthshine with two parallel efforts.

First, we will continue to observe from Big Bear Solar Observatory (BBSO) using our earthshine "coronagraph," and analyze the resulting data. BBSO is a site characterized by cloudless skies and excellent seeing. The products of our proposed efforts will be a four-year collection of albedo data, containing the 18 months already in hand, as well as an analysis of the relation of the albedo to satellite derived cloud-cover data. We propose to extend the observations to measurements of the infrared component of the earthshine, which will represent a significant expansion of the wavelength band in which the Earth's albedo has been determined. The albedo data will also enable us to quantitatively assess the global effects of transient phenomena such as volcanic eruptions and El Nino Southern Oscillations (ENSOs), in addition to providing details on seasonal and secular variations. Finally, the data in hand cover the solar activity minimum which is just ending, and the three years of new data will cover the rising phase of the new cycle, allowing us to determine the level of solar cycle dependence. These products are all significant for climate models.

Second, we will extend our modeling of earthshine by using more recent scene models (giving surface character and fractional cloud cover) developed for the Earth Radiation Budget Experiment (ERBE) satellite observations and corresponding general circulation model (GCM) derived cloud and snow/ice covers to simulate both earthshine and the Earth's Bond albedo (ratio of total light reflected in all directions to the total incident light). The integrated albedo obtained from our observations will provide a unique check on how well the models represent the surface and cloud components of the albedo.

Hood, Lon L. / University of Arizona, Tucson
A Comparison of Observations and GCM Simulations of the Quasi-Decadal

Oscillation

The application of general circulation models (GCM's) to assess the contribution of long-term solar variability to climate change should be preceded by validation on shorter, more observable, time scales. Recent statistical regression analyses of satellite remote sensing data have begun to establish the properties of a quasi-decadal oscillation (QDO) of the stratosphere and upper troposphere that may be solar in origin. The upper stratospheric oscillation is qualitatively consistent with a direct response to solar spectral irradiance variability at UV wavelengths associated with the 11-year solar activity cycle. The lower stratospheric and upper tropospheric oscillation has properties that suggest an indirect response, involving non-linear wave-mean-flow interactions, to the upper stratospheric oscillation. Such a mechanism is possible if relatively weak solar UV forcing can affect the selection of preferred internal modes or climatic regimes in the winter stratosphere. More detailed analyses demonstrate that any successful GCM simulation of the quasi-decadal oscillation requires inclusion of the tropical and extra-tropical quasi-biennial oscillation (QBO) as well as ozone transport and radiative-photochemical feedbacks, in addition to direct photochemical and radiative forcing of the upper stratosphere by solar UV radiation.

We propose to apply a new (and slower) version of the Goddard Institute for Space Studies (GISS) GCM that includes improved photochemistry and ozone transport in order to simulate more accurately the observed QDO. The model has 4° x 5° resolution with 31 vertical layers extending from the surface to 85 km. An earlier version of the model with realistic solar UV forcing has been found to reproduce approximately several observed characteristics of the lower stratospheric QDO. For example, an observed subtropical maximum in the QDO amplitude near 30° latitude in winter is qualitatively simulated. The new model output will be compared in detail with statistical analyses of global satellite measurements covering the last several decades. It is expected that this procedure will identify remaining discrepancies, leading ultimately to a more accurate model simulation of the quasi-decadal oscillation. The model may then be more confidently applied to assess solar contributions to climate change.

Hulver, Michael L. / Argonne National Laboratory
Solar Influences on Global Change: Effects of Orbital Variations (Milankovitch Cycles) on Insolation, Climate, and Greenhouse Warming

Given current concerns on greenhouse gas emissions and their possible effects on global climate, in order to evaluate anthropogenic-driven change, it is imperative that we understand the natural variability of both solar irradiance and regional/global climates. While the sun is thought to have increased its total output by ~3% over the past 300 million years, much larger variations in received solar radiation (up to 30% at some latitudes) are induced by changes in the Earth-Sun distance and seasonality over thousands of years. These orbital parameter (precession, obliquity, and eccentricity) cycles, often called Milankovitch cycles, periodically alter the seasonal distribution of insolation, causing geologically high-frequency climate changes (Berger, 1980). Fundamental eccentricity cycles have periods of about 100 kyr and 400 kyr, obliquity about 41 kyr, and precession about 20 kyr. The atmosphere accommodates these changes in insolation by adjusting circulation patterns, shifting associated climate patterns, and, in the process, causing climate cycles.

A specific range or succession of climates at a locality during an insolation cycle is intrinsically associated with its location and (paleo)geography, rather than its position in the insolation cycle. Different parts of the earth's surface will undergo different climatic successions. For any given location, the wettest or driest phases within a climate cycle are not associated with a particular phase of an insolation cycle. What this means, for example, is that tropical areas may get drier, while mid-latitude areas get more humid, or one mid-latitude area may get wetter while another one gets drier.

We propose to run Global Climate Models (GCMs) for the Early Permian (present CO2), mid-Cretaceous (high CO2), and Pleistocene-Holocene with variations in solar insolation as proscribed by changes in orbital parameters. By using methodologies currently being developed by the PI at ANL, climatic parameters from GCM results will be used to generate model lithostratigraphic sequences, which will then be compared with real-world geologic data. In this way, we can directly evaluate the effects of solar variability on the earth's climate at geologic timescales.

We propose to examine these GCM model runs in the context of past versus present climate variability. Maxima and minima within local, hermispheric, and global climate cycles (i.e., local precipitation, hemispheric mean temperature), as recorded in the more distant geologic past, can becompared with Quaternary climatic and stratigraphic data. We will quantify past climatic variations as a function of orbitally forced seasonal insolation variability. We will thus be able to evaluate how present climate, and climate changes likely to be induced by anthropogenic CO2, fit into and compare with the natural range of climate variation expected for our current position within the orbital insolation cycle. Interpretation and correlation of insolation cycles to the geologic record will provide insight into specific effects and patterns of climate change, such as sea-level fluctuation, desertification, flooding frequency, or hurricane distribution.

We recognize that the Earth is a dynamic system with continuous climate change, and rigorous testing of GCM's through orbital cycles using the geological record may permit us to better evaluate, and thus improve, global climate models. In turn, this would help us to better understand global climate and possible human-induced changes.

Ko, Malcolm K. / Atmospheric and Environmental Research
Understanding the Climatic Response to Solar Irradiance Variations

For the proposed work, we will identify the climate signals (changes in temperature in the lower stratosphere and surface temperature) from solar variation through a combination of modeling and data analyses. Our approach is to concentrate on the monthly mean behavior over the 11-year solar cycles. Our contention is that understanding the response in the decadal time will provide the key for understanding the responses at other time scales. Previous studies using general circulation models have concentrated on the direct effects due to changes in irradiance. Our analyses make use of zonal-mean models and will separate the direct effects due to variations of solar irradiance from the indirect effects associated with the changes in stratospheric ozone and dynamics. This will complement the previous works. The ability to clearly identify the effect of solar variation on climate would enable us to better attribute observed climate changes to specific causes. Such knowledge would also help in planning strategy for future mitigation of global warming.

In the first year of the study, we will use observed monthly mean changes in total solar irradiance, variations in solar UV, and ozone distributions in the stratosphere over the past two solar cycles (1978-1996) in a two-dimensional energy balance climate model to compute the changes in temperature. A number of numerical experiments will be performed using combinations of the actual time series of monthly mean variations (in total irradiance, solar UV and ozone) in the time period and the averages of the monthly mean over the same period. The different temperature time series generated in the different experiments will be compared with the observed temperature to identify the direct and indirect signatures from solar variations. Since the observed ozone variations over the time period were also caused by effects other than solar variations (e.g., change in chlorine and bromine contents in the stratosphere, and changes in aerosol surface area from volcanic eruptions), we will use a two-dimensional chemical-transport model to compute the changes in ozone that can be attributed to changes in the solar cycle. The model calculated ozone variation will be used in the energy-balance model to generate temperature time-series to help identify the temperature signal from the indirect effect.

The work will be extended in the second and third years to include analyses of the surface temperature. In addition, we will use the interactive 2-D Climate Chemistry model to identify the changes in stratospheric dynamics that accompany the solar variations.

The proposal also includes an education/outreach component in section VIII.

Marcus, Steven L. / Jet Propulsion Laboratory
Modeling of Decade-to-Century Scale Solar Irradiance Forcing on the Climate System

Reliable long-term (i.e. intercycle) measurements of solar irradiance changes by satellite are not yet available; hence, solar effects on decade-to-century scale climate change must be inferred through the comparison of solar proxies with the climate record. Existing proxies are based on the correlation of observable solar features with past temperatures, however, and the lack of a physical underpinning for the resulting irradiance reconstructions makes it difficult to infer past or future solar influences with confidence.

In addition, solar proxies provide only a temporal profile of irradiance variations, whose absolute magnitude can be only loosely constrained by comparison with Sun-like stars.

We propose to address these problems by formulating solar irradiance proxies more closely related to the physical properties, such as the intensity of turbulent convective/ diffusive motions within and below the photosphere, which are believed to be responsible for decade-to-century variations in solar luminosity. Proxy indicators for turbulent motions in the Sun include spot and spot group lifetimes and solar cycle decay rates; by compiling available data sets on these phenomena and studying their relationships using enhanced (non-Brownian) diffusive models, we will derive a physically-based proxy irradiance series for use in climate studies. We will also investigate the use of geomagnetic and auroral data, including aa index series available since 1874, to calibrate past irradiance determinations in terms of modern satellite measurements, and thereby to extend absolute irradiance reconstructions back to the Maunder Minimum and previous Grand Minima.

These reconstructed irradiance series will be used in conjunction with anthropogenic forcing as input to a suite of energy-balance (upwelling-diffusion) and non-linear "box" models of the climate system, in order to quantitatively evaluate the relative importance of solar variations for global climate change, and their implications for estimates of climate sensitivity based on comparisons with the instrumental temperature record.

Mariska, John T. / Naval Research Laboratory
Solar Extreme Ultraviolet and Soft X-Ray Forcing of Upper Atmospheric Chemistry and Dynamics

The objectives of this proposal are to develop a new model for the solar soft X-ray irradiance variability at wavelengths below 50 Å and to use that model to study the production and transport of NO in the Earth's middle and upper atmosphere.

Our new irradiance variability model will use synthetic spectra and full-disk images of the Sun to calculate the solar soft X-ray irradiance at arbitrary spectral resolution. The synthetic spectra for various solar features, such as the quiet Sun and active regions, will be computed from a database of atomic physics parameters and emission measure distributions validated with SOHO CDS observations. The relative contributions of the various solar features to the irradiance will be determined primarily from Yohkoh SXT images. With this new irradiance model and existing one- and two-dimensional models of atmospheric photochemistry and transport, we will compute NO densities in the upper and middle atmosphere over a solar cycle and make extensive comparisons with observations. These calculations should lead to an improved understanding of the production and transport of NO in the Earth's atmosphere - an important indicator of the solar forcing of upper atmospheric chemistry and dynamics.

This research is directly relevant to the Solar Influences on Global Change Research and

Analysis Program's stated objective of enhancing our understanding of the role of solar variability in terrestrial climate change. We will address a key question regarding the indirect solar forcing of climate by modeling solar X-ray variations and their impact on upper atmospheric chemistry and dynamics. Furthermore, we will conduct modeling studies to determine the chemical and dynamical coupling of the upper atmosphere to the middle atmosphere.

This research will make extensive use of data from NASA supported missions, such as the Solar and Heliospheric Observatory, Yohkoh, and the Upper Atmospheric Research Satellite.

Rind, David / Goddard Institute for Space Studies
Understanding Direct and Indirect Influences of Solar Irradiance Variations on Past, Present and Future Climate Change

We propose to evaluate the influence of total and spectrally-discriminated solar irradiance variations on the climate of the past 500 years, and the prospective climate for the next 100 years. The experiments build upon work already completed with separate funding that has investigated various components of total (i.e., spectrally integrated) solar radiation and climate sensitivity. The approach is to utilize satellite observations, including Upper Atmosphere Research Satellite (UARS) and Nimbus 7 solar data, together with historical sunspot and cosmogenic isotope (14C and 10Be) records to refine the representation of total, UV, visible and near-IR since 1500 A.D. General circulation model simulations utilizing the GISS Global Climate Middle Atmosphere Model (GCMAM) will then be run from that date through the present with several different forcings: total solar irradiance variations alone; and spectrally-discriminated solar variations, with and without ozone response. Both the direct and an indirect potential effect of solar forcing will thus be investigated. A companion experiment will incorporate changes in trace gases (CO2, methane, N2O, CFCs and ozone) and estimated aerosol effects for comparison in both magnitude and spatial/altitudinal discrimination with the solar forcing; this will then provide a direct assessment of anthropogenic versus solar influence in this model. The experiments will subsequently be continued to 2100 A.D. with possible solar variations defined by the range of 14C and 10Be fluctuations over the past 10,000 years. While such a projection is by nature speculative, it can provide an estimate of the range of possible solar influences on climate change. Trace gas and aerosol projections through 2100 A.D. from IPCC will likewise be utilized, allowing for comparison of future potential anthropogenic versus solar influences.

Rusch, David W. / University of Colorado, Boulder
An Investigation of the Effect of Particle Ionization on the Earth's Middle

Atmosphere and its Role in Global Change

We propose to investigate the coupling between the upper and middle atmosphere by the production and transport of nitric oxide (NO), its subsequent reaction with stratospheric ozone, and the ensuing impact on climate. We will use a collection of data from several satellite missions and ground-based instruments, as well as 2- and 3-dimensional models to study the long-term consequences of solar particle effects on the global odd nitrogen content of the middle atmosphere. Atmospheric and particle data from the Polar Ozone and Aerosol Measurement (POAM) II, the Stratospheric Aerosol and Gas Experiment (SAGE) II, the Halogen Occultation Experiment (HALOE), the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX), the Solar Mesosphere Explorer (SME), and other space based instruments, as well as surface observations of NO2, will be combined to develop observational evidence for the upper/lower atmosphere connection. Models will be used to quantify the results theoretically and to estimate the effects on global climate change. This proposal addresses the significance of solar-generated particle impacts affecting the atmospheric densities of odd nitrogen and ozone, a key question in separating the effects of solar and anthropogenic forcing of the Earth's climate. The results will be compared to the expected climate forcings from other natural and anthropogenic processes to assess the significance of the solar energetic particle input on the global system.

Ruzmaikin, Alexander A. / Jet Propulsion Laboratory
Noise Amplification of Solar Influences on Earth's Global Climate

We propose an observational and theoretical study to understand the mechanism by which weak solar variability could affect terrestrial global climate. The suggested mechanism, based on the concept of stochastic resonance, involves cooperative forcing of the climate by noise and solar signal. Our objectives include

establishing the role played by the atmospheric and external noise in amplification of solar variability signals, including the 11-year variations.

selecting the primary signals by which solar variability, amplified by the noise, affects the global climate.

developing simple models of solar signal amplification by noise.
To accomplish these objectives we will use NASA data on solar irradiance, geomagnetic activity, interplanetary particles and fields to compare solar inputs to the Earth's atmosphere with the data on the Earth's global temperature and other climate measures. We will apply the wavelet technique to uncover the transient nature of possible correlations between the solar forcing and the Earth's climate variability.

There were many climate studies that included either noise or external periodic forcing. It is now time to investigate the simultaneous cooperative forcing of climate by noise and periodical (or other regular) signals on all time scales. This is in accord with the recommendation 2 in the 1994 report of the National Academy of Sciences on Solar Influences on Global Change: "Conduct exploratory modeling and observational studies to understand climate sensitivity to solar forcing."

Shindell, Drew T. / Columbia University
A Comparison of Observations and GCM Simulations of the Quasi-Decadal Oscillation

The application of general circulation models (GCM's) to assess the contribution of long-term solar variability to climate change should be preceded by validation on shorter, more observable, time scales. Recent statistical regression analyses of satellite remote sensing data have begun to establish the properties of a quasi-decadal oscillation (QDO) of the stratosphere and upper troposphere that may be solar in origin. The upper stratospheric oscillation is qualitatively consistent with a direct response to solar spectral irradiance variability at UV wavelengths associated with the 11-year solar activity cycle. The lower stratospheric and upper tropospheric oscillation has properties that suggest an indirect response, involving non-linear wave-mean-flow interactions, to the upper stratospheric oscillation. Such a mechanism is possible if relatively weak solar UV forcing can affect the selection of preferred internal modes or climatic regimes in the winter stratosphere. More detailed analyses demonstrate that any successful GCM simulation of the quasi-decadal oscillation requires inclusion of the tropical and extra-tropical quasi-biennial oscillation (QBO) as well as ozone transport and radiative-photochemical feedbacks, in addition to direct photochemical and radiative forcing of the upper stratosphere by solar UV radiation.

We propose to apply a new (and slower) version of the Goddard Institute for Space Studies (GISS) GCM that includes improved photochemistry and ozone transport in order to simulate more accurately the observed QDO. The model has 4° x 5° resolution with 31 vertical layers extending from the surface to 85 km. An earlier version of the model with realistic solar UV forcing has been found to reproduce approximately several observed characteristics of the lower stratospheric QDO. For example, an observed subtropical maximum in the QDO amplitude near 30° latitude in winter is qualitatively simulated. The new model output will be compared in detail with statistical analyses of global satellite measurements covering the last several decades. It is expected that this procedure will identify remaining discrepancies, leading ultimately to a more accurate model simulation of the quasi-decadal oscillation. The model may then be more confidently applied to assess solar contributions to climate change.

Wang, Pao K. / University of Wisconsin, Madison
Critical Review of Chinese Research on the Solar Influences on Climate

We propose to collect and critically review the scientific research papers published in Chinese language on the subject of solar influences on climate. Solar influences on global climate can be of long term nature and to verify the rather complicated relation between them it is desirable to have long term data. One of the places in the world that have both long term solar and climate data available is China due to the availability of long and continuous historical records. Chinese scientists have taken advantages of these data and performed substantial research on the relation between solar activity and climatic change in historical time. Their findings can be important for the validation of any theories about sun-climate relation since their studies often cover a long time span and wide spatial coverage. Some of their results may provide new insights for future NASA observational planning. Unfortunately, their results are mostly published in Chinese journals which, due to the language difficulty, are largely inaccessible to the English-speaking research communities. The proposed study will produce a document containing the scientific summary of their research findings and important data sets used by them.

White, Warren B. / University of California, San Diego
Quantitative Assessment of the Integrated Response in Global Heat and Moisture Budgets to Changing Solar Irradiance

We propose to conduct a quantitative assessment of global responses in oceanic and tropospheric heat and moisture budgets from 1955-1996 to changing total solar irradiance (i.e. measured at the top of the atmosphere and penetrating to the sea surface as changing solar radiative forcing) on decadal, interdecadal and longer timescales. Recently, we examined time sequences of basin- and global-average upper ocean temperature for 90 years from 1900-1989 at the sea surface and for 40 years from 1955-1994 (White et al., 1997), finding them associated with changing solar radiative forcing in two separate frequency bands, with periods ranging from 8-13 years and 18-25 years, occurring at phase lags of 30°-45°, and confined to the upper 40-120 m of ocean. The Stefan-Boltzmann black-body radiation law predicts that observed changing solar radiative forcing of the upper ocean of 0.2 Watt m^-2 on decadal and interdecadal timescales yield changes in global-average sea surface temperature (SST) of 0.06°K, with radiative equilibrium achieved at phase lags ranging from 45°-60°. Yet, the magnitude of this predicted change is about half that observed (i.e., ranging from 0.08°-0.14°K) in SST, while the phase is about twice that observed. This suggests that sensible-plus-latent heat exchange across the air-sea interface plays a role in balancing the global-average upper ocean heat storage response to changing solar radiative forcing, and so affects the heat and moisture budgets of the overlying troposphere. Indeed, White and Cayan (1998) found an internal mode of Earth's interdecadal variability (presumably arising from coupled interactions within Earth's ocean-atmosphere-terrestrial system) associated with global symmetries (e.g., warm tropics, increased westerlies, cool extra-tropics, intensified oceanic gyre transport) that are not only consistent with the global scale of changing solar radiative forcing but are phase locked to it over the 90 years of record. Moreover, we suspect that much of the difference in amplitude of the solar-irradiance response between observations and the simple Stefan-Boltzmann model can be accommodated by considering vertical-average upper-ocean temperature (UOT) rather than SST. Consequently, we hypothesize that the response of global-average heat stored in the upper ocean to changing solar radiative forcing modifies the global hydrologic cycle in the atmosphere, with feedbacks between ocean and atmosphere modulating global-average temperatures and moisture responses. We propose that feedbacks at work on these global-average responses are comparable and similar to those associated with global warming scenarios associated with increasing greenhouse gas and aerosol concentrations.

To test these hypotheses, we will utilize the Scripps Institution of Oceanography (SIO) reanalysis of upper ocean temperature profile dataset to establish the global-average depth-average UOT (and corresponding heat storage) response to changing solar radiative forcing for 40-years, conducting this as a function of season. We will combine this with the National Center for Environmental Prediction (NCEP) reanalysis of tropospheric variables, historical and satellite observations of precipitation from NCDC and the University of East Anglia, and the U.S. Geological Survey (USGS) archives of streamflow records from the US and international sources to seek balances between changing solar radiative forcing of the upper ocean, changing upper ocean heat storage, changing long-wave back radiation and sensible-plus-latent heat flux to the overlying troposphere and its subsequent change in heat storage, moisture content, and radiation to space. The impact of this atmospheric response on changing terrestrial precipitation and streamflow and subsequent feedbacks to the ocean and atmosphere will also be investigated. We will stratify this global-average analysis zonally to discern transports of heat and moisture between the tropics and extratropics, the former exhibiting a relatively uniform SST response to solar-irradiance changes and the latter exhibiting nearly-compensating positive and negative SST responses. This stratification will permit a focus on measuring the changing net meridional flux of vertical-integrated heat and moisture associated with changes in tropical hydrological cycles on decadal and interdecadal timescales. Over continents, we will seek to establish balances between changing moisture flux convergence and changing area-integrated precipitation and streamflow. If we can demonstrate that the tropics are a source of solar-induced changes in heat and moisture for the extra-tropics, this would be in resonance with one of the delayed-action oscillator hypotheses for Earth's internal mode of interdecadal variability (White and Cayan, 1998), offering a set of thermodynamical mechanisms (i.e., a phenomenology) through which changing solar irradiance can tune Earth's internal modes of decadal and interdecadal variability. We will also consider whether changing solar irradiance is associated with other solar influences effecting global-average westerlies winds and albedo directly (Haigh, 1996; Svensmark and Friis-Christensen, 1996). Finally, we will apply what we will have learnt on decadal and interdecadal timescales to the quantitative assessment of changing global-average ocean-atmospheric-terrestrial heat and moisture budgets associated with global warming observed over the past 100 years (Reid, 1991), attempting to partition the influence of changing surface radiative forcing between trends in solar irradiance and in greenhouse gas and aerosol concentrations (IPCC, 1995).

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Variability of Clouds Over a Solar Cycle

One of the most controversial aspects of climate studies is the debate over the natural and anthropogenic causes of climate change (IPCC, 1990, 1996). Historical data strongly suggest that the Little Ice Age (from 1550 to 1850 AD, when the mean temperature was colder by about 1 °C) was most likely caused by variability of the sun and not greenhouse molecules (e.g. CO_2). However, the known variability in solar irradiance and modulation of cosmic rays provides too little energy, by many orders of magnitude, to lead to climate changes in the troposphere. The conjecture is that there is a "trigger mechanism." This idea may now be subjected to a quantitative test using recent global datasets.

Using the best available modern cloud data from International Satellite Cloud Climatology Project (ISCCP), Svensmark and Friis-Christensen (1997) found a correlation of a large variation (3-4%) in global cloud cover with the solar cycle. The implied forcing on climate is an order of magnitude greater than any previous claims. Are clouds the long sought "trigger mechanism"? This discovery is potentially so important that it should be corroborated by an independent database, and furthermore, it must be shown that alternative explanations (i.e. El Nino) can be ruled out. We propose to use the ISCCP data in conjunction with the Total Ozone Mapping Spectrometer (TOMS) data to carry out an in depth study of the cloud trigger mechanism.

This proposal is based on the recognition that the ISCCP and TOMS data can provide corroborative and complementary information on interannual cloud variability in such a way that we may make significant (and unique) contributions to one of the most exciting problems in current research in global change science: climate forcing by the solar cycle. Our principal objectives are formulated as two projects:

Task I: VARIABILITY OF CLOUD OPTICAL THICKNESS OVER A SOLAR CYCLE

Task II: THE CAUSES OF THE VARIABILITY OF CLOUDS OVER A SOLAR CYCLE

The tasks are built on the considerable expertise and experience of the Caltech/JPL modeling group in analyzing large satellite datasets for signatures of global environmental change to our planet. Task I will concentrate on a critical evaluation of the calibration of the ISCCP optical depth data in order to extract a reliable record of their secular variations. In this task we will bring to the ISCCP data the same approach for calibration that has been successfully applied to the TOMS data. We have eight years of overlap (1983-1990).

In Task II we propose, using the ISCCP cloudiness data and the confirmed ISCCP cloud optical thickness data (obtained from Task I), to carry out an independent and rigorous test of the influence of the solar cycle on clouds. This work will provide a critical evaluation of the correlation of a large variation in global cloud cover with the solar cycle. We propose to examine: (a) geographic and temporal pattern of the cloud anomalies and correlations with El Nino events and anomalies in the cosmic ray fluxes using empirical orthogonal functions, (b) anomalies associated with different types of clouds (e.g. cirrus versus cumulus), and (c) correlation between cloud anomalies and sporadic solar energetic events (e.g. Polar Cap Absorption).
