Sun-Climate Symposium

"Multi-Decadal Variability in Sun and Earth during the Space Era"

Nov. 10-13, 2015 * Savannah, Georgia

Abstracts – Oral Presentations

Tuesday, November 10

Symposium Kick-off Keynote

Validity of Today's Solar Irradiance Measurements to Future (100 years) Climate Studies

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Total and spectral solar irradiance are primary climate data records (CDR's). Because of absorption and scattering by our intervening atmosphere accurate measurements of the Sun are only realized from space observations beginning in about 1978. The accuracies of measurement programs are limited by unidentified and uncertain on-orbit instrument degradation. Nevertheless, from numerous observing programs solar variability has been established for short and intermediate times scales, with additional clear indications of decadal variability associated with the 11-year solar cycle.

But how will today's measurements stand the test of time and compare to those made far into the future? Total Solar Irradiance (TSI) measurements relate directly to the primary SI standards — Watt and meter (squared), and should compare well (100 ppm) to future TSI. Although Solar Spectral Irradiance (SSI) also relates to SI, its accuracy is lower and strongly wavelength dependent, and moreover tracking instrument response further decreases the accuracy.

There is one technique that shows great promise, a method that circumvents tying measurements to SI, and additionally accounts for instrument degradation. That method directly compares the Sun to an ensemble of bright, blue stars. This technique uses a single instrument — same optics and detectors — to observe the Sun and stars differing by orders of magnitude in brightness (10^8 in the UV). The Solar Stellar Irradiance Comparison Experiment (SOLSTICE) has now flown twice — UARS from 1991 to 2005 and SORCE from 2003 to the present. This talk will consider the success and limitations of the SOLSTICE UV irradiance data record.

Session 1. Total Solar Irradiance (TSI) Measurements and Modeling

SATIRE-S Reconstruction of TSI and SSI since 1974

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We describe the latest SATIRE-S model reconstruction of TSI and SSI, which spans over the period of 1974 to 2015. The model relates variation in solar irradiance on timescales greater than a day to the occurrence and evolution of magnetic structures on the photosphere, inferred from solar observations. We made use of full-disc magnetograms from the KPVT, SoHO/MDI and SDO/HMI. We cross-calibrated the various magnetogram data sets to yield a single, consistent input time series covering the period of 1974 to 2015. Modelled TSI exhibits a solar cycle minimum-to-minimum decline over the successive minima of 1986, 1996 and 2008, in agreement with the PMOD composite record. The reconstruction is also consistent with available UV SSI records at the wavelengths where they are stable enough to reveal the underlying solar cycle modulation.

New Re-Calibrated Sunspot Numbers and the Past Solar Output

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For the first time since its creation by R. Wolf in 1849, the reference Sunspot Number series was submitted to a critical end-to-end revision. Given the large disagreement with the widely used Group Number, a more recent equivalent long-term sunspot index, this second series was also entirely revisited and reconstructed. Both re-calibrated series were officially released in July 2015.

After summarizing the diagnostics and the corrections brought to those reference series, we explain the main changes relevant to long-term reconstructions of the solar irradiance and particle output. Past discrepancies between the Sunspot and Group number series have largely been eliminated. Now, both series indicate that solar activity varied between rather constant limits since the Maunder Minimum, without a steady upward trend up to the mid-20th century. Detailed corrections in the sunspot number over the last decades and the extension of the past Group number from 1995 up to 2015 also lead to a closer match between the multi-century sunspot record and modern direct solar measurements.

This epochal revision thus provides a stronger base for extrapolating the current direct flux and irradiance measurements over secular scales, backward and potentially forward. We finally discuss new key objectives to be pursued in coming years to build on and to extend those improved sunspot data series: detailed sunspot catalogs, digital historical archives, image-based sunspot indices and advanced sunspot-based proxies.

Total Solar Irradiance Reconstruction over the last 300 Years

Stijn Nevens *[stijn.nevens@meteo.be] and Steven Dewitte, Royal Meteorological Institute of Belgium, Brussels*

The quantification of the TSI variability is important to understand whether the Sun can have a significant influence on climate change on Earth. A careful analysis of the TSI space measurements over the last 30 years indicates that within a measurement uncertainty of 0.1 W/m² decade the long term TSI variation can be fully explained by the 'magnetic ingredients' of sunspots and facula associated to the 11-year solar activity cycle. Further analysis of the Ca II K index measured from Mount Willson observatory for the last 100 years and of the revised sunspot time series for the last 300 years indicates that contrary to the long-held paradigm of a 'modern grand solar maximum' we are currently in the minimum of a long-term modulation of the amplitude of the 11-year cycle; this amplitude modulation has a periodicity around 100 year.

Modeling TSI Variations using Photometric Images from the San Fernando Observatory

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Photometric observations at the San Fernando Observatory beginning in 1986 have been able to precisely model variations of satellite measurements of the Total Solar Irradiance (TSI) with a daily uncertainty of approximately 100 ppm. The precise modeling of satellite TSI variations is only possible if the quiet Sun is not variable. Examples of modeling efforts with several spacecraft experiments will be discussed.

A New Record of Total Solar Irradiance from 1610 to Present

Odele Coddington[1] *[Odele.Coddington@lasp.colorado.edu], Judith Lean*[2]*, Peter Pilewskie*[1]*, Marty Snow*[1]*, Doug Lindholm*[1]*, and Greg Kopp*[1]

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We present a new climate data record (CDR) model of total solar irradiance (TSI) from 1610 to the present, including associated time dependent uncertainties in the model estimates. This CDR was developed by the University of Colorado at Boulder's Laboratory for Atmospheric and Space Physics (LASP) and the Naval Research Laboratory (NRL) as part of the National Oceanographic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) CDR Program, where the data, source code, and supporting documentation are archived. TSI variability is constructed using models based on changes from quiet Sun conditions due to bright faculae and dark sunspots on the solar disk. The magnitude of the irradiance change is determined from linear regression of the proxy Mg II index and sunspot area indices against the approximately decade-long solar irradiance measurements made by the Total Irradiance Monitor (TIM) on the SOlar Radiation and Climate Experiment (SORCE). We discuss the model formulation, uncertainty estimates, and operational implementation including quarterly updates. We compare the modeled TSI with the measurement record and with other solar irradiance models and discuss efforts to improve the data record and account for model assumptions in the uncertainty estimates. Planned improvements include the use of future solar irradiance measurements from the Total and Spectral Solar Irradiance Sensor (TSIS) mission, considerations of different proxies for representing sunspot darkening and facular brightening, and assessment of the impact of different sunspot number records on TSI over multi-decadal scales as simulated by a flux transport model.

TSI and Ly-α Reconstruction Back to 1915 Based on Sunspot Area from RGO, Ca-II Data from Mt. Willson and the 4-Component Proxy Model Calibrated 1978-2015

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The 4-component proxy model uses the photometric sunspot index (PSI), determined from sunspot area, position and contrast on the disk, the Mg II index and separated into a short- and long-term component and the open magnetic field (OPF) during each minimum of activity. This model with PSI, Mg II long- and short-term and OPF explains 84% of the variance of TSI and with Mg II long- and short-term and OPF 95% of Ly-α during the period 1978-2015. Its calibration can be used to go back in time with PSI, determined from the Greenwich data back to 1874, the Mg II index, converted from Ca-K (deduced from Ca images observed at Mount Wilson since 1915) and the open magnetic field, available back to about 1880 from e.g. the aa index. The results show that the minima of TSI are much more varying than those of Ly-α by a factor of 2-3. The reason for this difference is the origin of the radiation coming for TSI from the photosphere and for Ly-α from the chromosphere. The magnetic field of the former may not be well represented by Mg II index and/or depend also on other effects, whereas for the latter the Mg II index is representing the magnetic field in the chromosphere.

The PREMOS/PICARD TSI Record: Comparison to other instruments and the 2013/2014 TSI-composite

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PREMOS/PICARD was measuring until March 4, 2014, when the PICARD mission was switched off. The second half of 2013 and beginning of 2014 is the time when there was a transition of TSI radiometers: From ACRIM-III, VIRGO, PREMOS, and TIM to VIRGO, TIM and TCTE. During this time the radiometers showed a remarkable disagreement. This presentation will evaluate the behavior of PREMOS in comparison to the other radiometers and possibly conclude on a recommendation for the 2013/2014 TSI-composite.

The Value of the Solar Constant

Steven Dewitte *[steven@meteo.be] and Stijn Nevens, Royal Meteorological Institute of Belgium, Brussels*

The determination of the absolute value of the TSI – also known as the Solar Constant – is a problem of metrology. Our new best estimate of 1362.9 +/- 0.9 W/m² at solar minimum is derived from the revised absolute value measured by the DIARAD/SOVIM instrument on the ISS in 2008. Compared to earlier versions of the DIARAD TSI evaluation we apply a new method for the determination of the so-called non-equivalence between electrical and optical power. This new evaluation method was validated during a laboratory measurement campaign at the LASP TRF facility in 2013. During this same campaign we identified an underestimation of the irradiance measured by the LASP TRF cryogenic radiometer, which after elimination of all other possible causes can only be attributed to an underestimation of the amount of scattering and diffraction occurring around the LASP TRF primary aperture. Since the TIM/SORCE space radiometer has a similar geometry and TSI evaluation method as the LASP TRF cryogenic radiometer, this suggests that the TIM/SORCE radiometer measures a too low TSI value.

Wanted: A TSI Measurement Record

Greg Kopp *[Greg.Kopp@lasp.colorado.edu], Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder, CO, USA*

Researchers using solar irradiance data for long-term studies such as needed for understanding climate would like a single time series of the total solar energy incident on the Earth over the spacecraft measurement era. That’s exactly what they had in the late 1970’s, and life was easy (albeit incorrect). Then that second total solar irradiance (TSI) instrument flew. Currently solar irradiance data users are offered slightly differing results from over a dozen space-borne instruments, at least three data-based composites, and empirical solar models. Fortunately the benefits from multiple instruments have far outweighed the complexities introduced by their disparate measurements and have improved our understanding of the “correct” TSI values. But rather than make the researchers using these data choose between the different records, it is the responsibility of the irradiance community as a whole to provide a more unified “community consensus composite” to data users in other fields.

The teams representing all currently operating and several past TSI instruments as well as solar irradiance modelers have come together to provide such consensus. This effort involves analyzing the existing and past instrument data records, agreeing on an overall absolute value for these measurements, and creating a new composite time series over the space-borne measurement era with time-dependent uncertainties. I will give an overview of the changes in the TSI measurement record over the SORCE era, summarize the current results of this new composite effort, and discuss plans for completing this work.

Making of Composites Out of Multiple Observations: The new Total Solar Irradiance and MgII index composites

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Reconstructing past solar activity critically depends on present direct observations of the total solar irradiance (TSI) and of proxies such as the MgII index. Recently, two teams have been working on making new composites out of existing observations: an ISSI TSI team, and the SOLID project for reconstructing solar spectral irradiance. Both aim at combining all available observations via rigorous, reproducible, and unbiased methods that include estimated time-dependent uncertainties.

Here we present preliminary results from both teams, and concentrate on the making of the TSI composite (1980-today) and the MgII index composite (1978-today). Our approach consists of first decomposing all observations into multiple time scales, and merging these before building the composite. Knowing the uncertainties of the individual instruments is critical, so we developed a methodology for estimating these from the observations only. Finally, we discuss the composites' uncertainties at various time scales, which are important for understanding the significance of long-term variations of the solar radiative output.

Session 2. Sun-Climate Connection: Top-down and bottom-up couplings

Interpreting Correlation and Multi-Regression Analyses of Solar Cycle Impacts

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For some fields and locations in the atmosphere, for example ozone in the tropical mid to upper stratosphere, the response to the solar cycle can be easily detected from observations and understood from basic physics. At other locations and for other fields, a solar cycle response is sometimes evident but the physical or coupled processes that lead to it are not so straightforward. In these cases, it is important to examine the analysis method to determine the reliability of the deduced solar response. This presentation will discuss some of the factors that can lead to spurious solar responses, including short data record, dependence on season of the atmospheric response to all forcing processes, and over-generous attribution of statistical significance.

The Response of the Stratosphere to the 11-Year Solar Cycle, the Quasi-Biennial Oscillation, and the Pacific Decadal Oscillation

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Assessing and distinguishing between natural climate variability and anthropogenic forcing, and quantifying their relative contributions to climate change is a formidable challenge. The Sun is Earth's primary source of energy, providing a global average irradiance that is four orders of magnitude greater than the largest secondary energy source, Earth's interior heat flux. One of the difficulties in assessing the solar response is the fact that several internal modes of variability are present which can prevent accurate detection. Here the response of the stratosphere to the 11-year solar cycle, the Quasi-Biennial Oscillation (QBO), and the Pacific Decadal Oscillation (PDO) is investigated using the Whole Atmosphere Community Climate Model (WACCM). When analyzing transient and fully coupled simulations that include observed greenhouse gases, varying solar spectral irradiance, and an internally generated QBO, a persistent wintertime solar response in the polar vortex when stratifying by QBO phase is not found. Results contradict conclusions drawn from observational data over the period 1953-2012. The PDO is defined as the leading mode of sea surface temperature variability in the North Pacific, oscillating on decadal timescales. Changes in the PDO are linked to changes in precipitation, temperature, sea-level pressure, and geopotential heights. Investigating a pre-industrial control simulation with solar average conditions, the PDO also influences the stratosphere, with a weaker polar vortex in the PDO (+) phase. Some evidence also points to possible modulation of the PDO by the solar cycle, which may provide an additional pathway for the Sun to impact decadal climate.

The 11-Year Solar Cycle Signature on Wave-Driven Dynamics in WACCM

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This study describes the 11-year solar cycle influences on gravity waves and the wave-driven circulation and using 51-year simulations of the Whole Atmospheric Community Climate Model (WACCM). Solar cycle influences are estimated by calculating the difference between perpetual solar maximum and minimum simulations. WACCM simulations show statistically significant responses of temperatures and winds in the Southern Hemisphere (SH) in high latitudes from winter to spring seasons. At solar maximum, the monthly-mean, zonal-mean temperature in the SH from July to October is cooler (-2 to -5 K) in the stratosphere and warmer (+3 to +6 K) in the mesosphere and the lower thermosphere (MLT). In solar maximum years, the SH polar vortex is more stable and its eastward speed is about 10 m s^{-1} greater than during solar minimum. The eastward changes in zonal winds propagate downward and poleward from July to October in the SH. Associated with these changes in the zonal winds, both vertical and meridional components of EP fluxes show negative responses to the solar cycle. Because of eastward changes in zonal winds, the propagation of eastward gravity wave activity to the MLT is reduced; this results in a net westward response of gravity wave drag to the 11-year solar cycle, peaking at ~10 m/s/day in the SH high-latitude MLT. The changes in gravity wave change the wave-induced residual circulation, and this contributes to a warming of ~3–6 K in the MLT region. Solar cycle influences on gravity wave variations obtained from SABER will also be presented.

Why Does the Positive Phase of NAO Pattern Appear Preferentially in the Declining Phase of the Solar Cycle?

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Several studies have examined the relation between different parameters of solar activity and variability in the Northern Hemisphere winter climate. While most studies indicate solar modulation of tropospheric and stratospheric circulation and surface temperature, opinions on the exact mechanism and the solar driver differ. Proposed drivers include, e.g., total solar irradiance (TSI), solar UV radiation, galactic cosmic rays, magnetospheric energetic particles etc. While some of these drivers are difficult to distinguish because of their closely similar variation over the solar cycle, other suggested drivers have clear differences in their solar cycle evolution. For example, geomagnetic activity and magnetospheric particle fluxes peak in the declining phase of the sunspot cycle, in difference to TSI and UV radiation which more closely follow sunspots. Using 13 solar cycles (1869-2009) we study winter surface temperatures and North Atlantic oscillation (NAO) during four different phases of the sunspot cycle: minimum, ascending, maximum and declining phase. We find significant differences in the temperature patterns between the four cycle phases. Surprisingly, the clearest pattern of the temperature anomalies is not found during sunspot maximum or minimum, but during the declining phase, when the temperature pattern closely resembles the pattern found during positive NAO. We find the same pattern during the low sunspot activity cycles of 100 years ago, suggesting that the pattern is largely independent of the overall level of solar activity.

Validation of the Global Distribution of CO_2 Volume Mixing Ratio in the Mesosphere and Lower Thermosphere from SABER

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The Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on board the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) satellite has been measuring the limb radiance in 10 broadband infrared channels over the altitude range from ~ 400 km to the earth surface since 2002. The kinetic temperatures and CO2 volume mixing ratios (VMRs) in the mesosphere and lower thermosphere have been simultaneously retrieved using radiances in the 15 and 4.3μm bands of CO_2 under non-local thermodynamic equilibrium (non-LTE) conditions. This paper presents results of a validation study of the SABER CO_2 VMRs obtained with a 2-channel, self-consistent temperature/CO_2 retrieval algorithm. Results are based on comparisons with coincident CO_2 measurements made by the Atmospheric Chemistry Experiment-Fourier Transform Spectrometer (ACE-FTS) and simulations using the Specified Dynamics version of the Whole Atmosphere Community Climate Model (SD-WACCM). The SABER CO_2 VMRs are in agreement with ACE-FTS observations within reported systematic uncertainties from 65 to 110 km. The annual average SABER CO_2 VMR decreases from a well-mixed value above ~80 km. Latitudinal and seasonal variations of CO_2 VMRs are substantial. SABER observations and the SD-WACCM simulations are in overall agreement for CO2 seasonal variations, as well as global distributions in the mesosphere and lower thermosphere. Not surprisingly, the CO_2 seasonal variation is shown to be driven by the general circulation, converging in the summer polar mesopause region and diverging in the winter polar mesopause region.

Increasing Carbon Dioxide Concentration in the Upper Atmosphere Observed by SABER

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Carbon dioxide measurements made by the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument between 2002 and 2014 were analyzed to reveal the rate of increase of CO_2 in the mesosphere and lower thermosphere. The CO_2 data show a trend of ~5% per decade at ~80 km and below, in good agreement with the tropospheric trend observed at Mauna Loa. Above 80 km, the SABER CO_2 trend is larger than in the lower atmosphere, reaching ~12% per decade above 110 km. The large relative trend in the upper atmosphere is consistent with results from the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS). On the other hand, the CO_2 trend deduced from the Whole Atmosphere Community Climate Model (WACCM) remains close to 5% everywhere. The spatial coverage of the SABER instrument allows us to analyze the CO_2 trend as a function of latitude for the first time. The trend is larger in the northern hemisphere than in the southern hemisphere mesopause above 80 km. The agreement between SABER and ACE-FTS suggests that the rate of increase of CO_2 in the upper atmosphere over the past 13 years is considerably larger than can be explained by chemistry-climate models.

Attribution of the 11-Year Solar Cycle in Lower-Stratospheric Temperature and Ozone

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The effects of the 11-year solar cycle on ozone and temperature in the stratosphere have been well documented. In the tropics the observed response consists of statistically significant warming and ozone increase in the upper (~50 km) and lower (~25 km) stratosphere. Several chemistry-climate models reproduce this double-peak in the temperature and ozone response. However, there are concerns about the origin of the lower peak due to potential aliasing with ENSO events or volcanic eruptions.

We focus on the attribution of the solar cycle in lower-stratospheric temperature and ozone time series from reference simulations performed with the chemistry-climate model SOCOL within the framework of IGAC/SPARC Chemistry-Climate Model Initiative. The solar cycle is attributed in a classical way using a multiple linear regression model with statistical rigorousness in terms of residual modeling. In addition, we analyze three sensitivity simulations to examine the influence of sea surface temperatures and volcanic eruptions on the lower stratospheric solar cycle signal.

Our results show how the solar signal is strongly affected by volcanic eruptions, following the large Mt. Agung volcanic eruption in 1963. This implies that the lower-stratospheric temperature and ozone response is not purely solar in origin. Therefore, its proper characterization requires either longer time series or periods not contaminated by volcanic aerosols. We explain how the solar signal could be misattributed to another signal due to their collinearity (aliasing) and how the amplitude of the signal may be dependent on the method of analysis.

Surface Temperature and Planetary Albedo Responses to Total and Spectral Solar Forcing on Multi Decadal Time Scales in GISS GCMAM

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We examine climate responses to solar variations, focusing on possible roles of cloud feedback on Sun-climate interactions. We apply two reconstructed spectral solar forcing scenarios, one based on SIM (Spectral Irradiance Monitor) observations, the other based on the SATIRE (Spectral And Total Irradiance REconstruction) model, as inputs to the GISS (Goddard Institute for Space Studies) GCMAM (Global Climate Middle Atmosphere Model) to examine the climate responses on multi decadal time scales. There are no clear 11-year solar forcing signals in surface temperature. However, both solar forcing scenarios induce large multi-decadal surface temperature responses. We examine planetary albedo responses to global surface temperature variations for both control run and the run with solar variations. We found that the planetary albedo is negatively correlated with the surface temperature for both experiments. The correlation coefficient between the planetary albedo and surface temperature for SIM based solar forcing is -0.38 compared to -0.50 for SATIRE solar forcing. Those correlation coefficients are about 1.5 times larger than those for control runs. This supports and reinforces earlier studies showing how cloud feedback plays an important role in Sun-climate interactions.

Relationship Between Solar Parameters and Typhoon/Thunderstorm Occurrences with One-Month Periodicity

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It has been pointed out that atmospheric activity has ~27-day periodicity, which implies the connections between solar activity and the Earth's climate since the rotation period of the sun near its equator is 27 days. However, the spatial extent of such variations and the relationship between the different areas in global scale were unclear. We show a close relationship between globally synchronized thunderstorm/cloud activities in the tropical latitudinal range and solar parameters with ~one-month periodicity for a certain half year, using lightning data, a proxy of thunderstorm activity, obtained by the global radio wave network and a proxy of cloud amount, Outgoing Longwave Radiation. It is reported that the thunderstorm activity in Asia Maritime Continent (AMC) shows a

seesaw correlation with the cloud in Western Pacific Warm Pool (WPWP). This variation is also obviously synchronized with intensity variation of cosmic ray. It is also confirmed that these cloud increases in WPWP well coincide with minimum pressure of typhoons or tropical storms in focused WPWP area (130-145 deg E), according to Typhoon Index provided by Joint Typhoon Warning Center (JTWC) of the US Navy. Such relationships cannot be explained by simple existing theories or phenomena, such as Madden Julian Oscillation, and may require the consideration of solar effect on the climate.

Wednesday, November 11

Session 3. Climate Changes during the Space Era

Solar Forcing of Industrial Era Climate Change

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The latest IPCC Assessment reported that solar forcing has played a relatively minor role in driving global mean climate change during the industrial era, while noting that solar forcing may have nevertheless contributed substantially to regional changes. I will present the rationale for some of those primary conclusions as well as the role of solar forcing over various shorter intervals within the modern era. Finally, I will discuss ongoing research examining the impact of solar forcing on atmospheric dynamical variability and the mechanisms that underlie these impacts.

Earth's Radiation Imbalance Observed from Space

Norman G. Loeb *[Norman.G.Loeb@nasa.gov], NASA Langley Research Center, Hampton, VA, USA*

In an equilibrium climate, there is a balance between how much of the sun's incident radiation is absorbed by Earth and how much thermal infrared radiation the Earth emits to space. Perturbations to Earth's top-of-atmosphere (TOA) radiation budget resulting from changes in atmospheric composition (e.g., greenhouse gases, aerosols), changes in solar irradiance, and changes in surface albedo due to land use cause an imbalance in Earth's TOA radiation budget. Currently, the Earth's energy imbalance (EEI) is approximately 0.6 Wm^{-2} due mainly to human activities, which is driving global warming. This presentation will provide a brief overview of EEI and its critical role in climate science. The presentation will also discuss how satellite instruments such as SORCE and CERES (Clouds and the Earth's Radiant Energy System) are being used along with in-situ measurements of ocean heat content anomaly tendency from the Argo network to quantify and track changes in EEI.

Solar Forcing of the Earth's Climate on Multi-Decadal Time Scales

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At the beginning of the 21st century the Earth's global temperature trend leveled off to a plateau, called the climate hiatus. One of the potential contributors to this climate change could be the extended, deep minimum of solar activity associated with the low solar irradiance input to the Earth. The current extended, deep minimum of solar variability and the extended minima in the 19^{th} and 20^{th} centuries (1810-1830 and 1900-1920) are consistent with minima of the Centennial Gleissberg Cycle (CGC), a 90-100 year variation of the amplitude of the 11-year sunspot cycle observed on the Sun, solar wind, and at the Earth. The CGC has been identified in the Total Solar Irradiance reconstructed for over three centuries. The Earth's climate response to the prolonged low solar irradiance involves heat transfer to the deep ocean with a time lag longer than a decade. The CGC minima, sometimes coincidently in combination with volcanic forcing, are associated with severe weather extremes. Thus the 19th century CGC minimum, coexisted with volcanic eruptions, led to especially cold conditions in United States, Canada and Western Europe ("a year without summer"). We identify the timing and spatial pattern of the Earth's climate response that allows distinguishing the solar forcing from other climate forcings.

Climate and Ozone Layer in the Future: Implications of Grand Solar Minimum

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Global warming is one of the main threats to mankind. There is high probability that anthropogenic greenhouse gases have become the dominant factor, however natural factors such as solar variability cannot be neglected. Solar activity varies in regular 11-year solar cycles. Longer periods of decreased solar activity are called Grand Solar Minima.

We investigate the effect of proposed Grand Solar Minimum in the 21st and 22nd centuries on terrestrial climate and ozone layer. The model used is SOCOL-MPIOM, which is global climate model ECHAM5 with implemented MEZON chemistry, coupled with ocean model MPIOM. For greenhouse gases and ozone depleting substances we used RCP4.5 scenario. Three simulations were performed with the only difference in solar forcing: reference run (with repeated 11-year solar cycles) weak drop and strong drop in solar irradiance, for period of 200 years (2000-2200).

The results show an increase of global surface temperature in all solar scenarios. Average global temperature showed difference of about 0.6 K at the end of running period between reference run and strong-drop run. Ozone holes are recovering in all three solar scenarios. However, in case of weak or strong drop in solar forcing, total ozone column doesn't get recovered to 1960-1980 values at the end of the simulated period.

Trends and Solar Cycle Signals of CO and CO_2 in the MLT

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Observations of CO and CO_2 in the mesosphere and lower thermosphere (MLT) over the past dozen years suggest that the long-term trend of CO_2 is much larger than can be explained from increases due to anthropogenic emissions. Specifically, measurements made by the ACE-FTS instrument indicate that, at altitudes between 90 and 105 km (~ 10^{-3} - 10^{-4} hPa), the long-term trend in CO_X (CO + CO_2) is ~8% per decade, which is substantially larger than the anthropogenic trend documented at lower altitudes (~ 5% per decade). Recently, similar results have been obtained for CO_2 alone from observations made by the SABER instrument onboard the TIMED satellite. Because the abundance of CO_2 (and CO) in the MLT is strongly influenced by the solar cycle, it is important to determine whether multiple linear regression (MLR) might produce spuriously large trends when applied to short time series. That is, in the presence of a large solar signal in CO_2, MLR could fail to distinguish properly the true long-term trend from 11-year variability. We have investigated this question using NCAR's Whole Atmosphere Community Climate Model (WACCM) and show that, while a larger solar cycle signal is indeed present in the model, it is unlikely to produce the observed large trend in the MLT when applied to time series of 10-12 years, such as those available from ACE-FTS and SABER.

Past and Future Climate of Thermospheric Density: Solar and Anthropogenic Influences

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In this presentation, we review thermospheric climate and its dependence on solar irradiance, geomagnetic activity, and atmospheric greenhouse gases. The thermosphere is heated primarily via absorption of solar far (100–200 nm) and extreme (10–100 nm) ultraviolet irradiance and energy input associated with geomagnetic activity, and cooled mainly via infrared emission by CO_2 and NO. Changes in the balance of heating and cooling cause the thermosphere to expand (more heating or less cooling) or contract (less heating or more cooling), so that density at a given altitude increases or decreases, respectively. Variation in solar UV irradiance is the dominant influence on thermospheric density, which at 400 km altitude typically increases by an order of magnitude from solar minimum to solar maximum. There is strong evidence that the thermosphere is contracting in response to anthropogenic increases in CO_2; this effect is relatively small but monotonic. We also examine the record-low thermospheric density that occurred during the Cycle 23/24 minimum, and discuss its attribution (and uncertainty thereof) to forcing by solar irradiance, geomagnetic activity, and CO_2 increases. Finally, we project thermospheric climate 200 years into the future, using solar activity scenarios built from past behavior and representative concentration pathways of atmospheric CO_2. The future behavior of the thermosphere will affect the evolution of the increasing orbital debris population, because atmospheric drag is currently the only mechanism by which debris are removed from orbit. We briefly discuss how the range of possible future thermospheric states may affect debris mitigation and remediation strategies.

Session 4. Solar Spectral Irradiance (SSI) Measurements and Modeling

New Results on the Stratospheric Ozone Response to Solar Spectral Irradiance Variability

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One of the main ways that the Sun may influence our climate is through a ‘top-down’ mechanism initiated in the tropical stratosphere where absorption of solar ultraviolet (UV) light by ozone is largest. The magnitude of the solar cycle change in UV spectral solar irradiance, particularly in the UV, is fundamental in determining the magnitude of the climate response, but solar cycle UV changes are highly uncertain: the SOlar Radiation and Climate Experiment (SORCE) have shown much larger solar cycle UV changes than observations from the Upper Atmosphere Research Satellite (UARS). This uncertainty limits our knowledge of the Sun’s influence on our climate.

We present results from a nudged chemistry climate model of the solar cycle ozone response using different input solar irradiance datasets. This approach allows us to distinguish photochemical from transport influences and also avoids the problems associated with the detection of a solar signal in observations using standard statistical techniques. We compare our results with new merged ozone datasets and find that the solar cycle signal in the ozone datasets is more consistent with the UARS and modelled spectral irradiance changes than the SORCE observations. These results are of significance since it is important to determine and apply the most appropriate solar spectral variability in climate models to gain the clearest understanding of the impact of past and future solar variability on global and regional climate.

Construction of a SORCE-Based Solar Spectral Irradiance (SSI) Record for Input into Chemistry Climate Models

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We present a research program to produce a solar spectral irradiance (SSI) record suitable for whole atmosphere chemistry-climate model (CCM) transient studies over the 2001-2015 time period for Solar Cycle 23 and 24 (SC23-24). Climate simulations during this time period are particularly valuable because SC23-24 represents the best-observed solar cycle in history – both from the perspective of solar physics and in terms of Earth observation systems. This record will be based predominantly on the observed irradiance of the SORCE mission as measured by the SIM and SOLSTICE instruments from April of 2003 to the present time. The SSI data record for this proposed study requires very broad wavelength coverage (115-100000 nm), daily spectral coverage, compliance of the integrated SSI record with the TSI, and well-defined and documented uncertainty estimates. While the majority of the record will be derived from SORCE observations, extensions back to the SC23 maximum time period (early 2001) and closure of critical gaps in the SORCE record will be generated employing the Fontenla et al. (2015) Solar Radiation Physical Model (SRPMv2). Since SRPM is a physics-based model, estimates of the SSI for wavelengths outside the SORCE measurement range can also be included. Thus a comparative study of SORCE observations with SRPMv2 provides meaningful insight into the nature of solar variability critical for subsequent Earth atmospheric modeling efforts.

Spectral Solar Irradiance Requirements for Earth Observing Sensors Operating in the Ultraviolet to Shortwave Infrared

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The spectral solar irradiance measurement requirements of Earth observing instruments are driven by the required target uncertainties of their derived science products. In the ultraviolet to shortwave infrared region (i.e. 230nm to 2500nm), science product uncertainties define the fundamental radiance or reflectance measurement requirements of the instruments and are influenced by the target accuracies of the geophysical processes to be measured and their specific applications (i.e. from process to climate studies). For many Earth remote sensing instruments, such as MODIS, VIIRS, OMPS, et al, operating in the reflected solar wavelength region, on-orbit calibration is performed in a reflectance mode, employing on-board targets with known bidirectional scatter distribution functions or well-characterized Earth targets. Generation of radiance products from these instruments requires knowledge of the spectral solar irradiance over each of the instrument bands producing typical radiance uncertainties of 3 to 5% (k=1). Climate applications (e.g., CLARREO and TRUTHS) impose approximately a 10X more stringent requirement on the uncertainties of instrument measurement of reflectance and radiance and, by inference, requirements on spectral solar irradiance. Intercomparisons of radiance measurements produced by international satellite instruments and the production of long time series data sets require the adoption of an SI-traceable, solar irradiance spectrum with lowest uncertainty. For the latter, this is particularly critical in the event of loss of overlap of on-orbit satellite measurements. This presentation will examine spectral solar irradiance measurement requirements with respect to a number of Earth remote sensing applications and scenarios and will discuss the importance of SI-traceability. The presentation will conclude with a brief summary and perspective on the spectral solar irradiance panel review held on September 17 and 18, 2014 at LASP.

On the Stability of Solar Spectral Irradiance Records

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Solar spectral irradiance (SSI) measurements have been acquired in space since the 1960's. These data are of extreme importance to assess the variability of the Sun in the last decades as well as to understand how its magnetic activity affects its radiative output, and therefore to constrain solar variability further in time. However, these data sometimes disagree among themselves or with our expectations deduced from well known observed proxies, and it is then hard to disentangle instrumental effects from possible solar effects.

In the context of the European collaborative project SOLID (First European comprehensive SOlar Irradiance Data Exploitation) project, we will present results regarding a common assessment of the mid- and long-term (> 1yr) SSI variations observed by all instruments since the 60's, focussing on the ultraviolet wavelength range, where more instruments have been operating.

Our approach consists in attempting to reproduce each solar irradiance dataset by a combination of proxies, and the starting assumption is therefore that solar proxies contain enough information to reconstruct the SSI variability with a satisfactory precision; we note that this is different from comparing each dataset with an already defined proxy-based model.

We used the (dis)agreement between the observed and modeled SSI to provide an independent measure of the stability of the SSI dataset. We will present the stability assessment of all irradiance datasets as well as some detailed cases.

Using F10.7 and Other Activity Indices to Examine Continuity of Solar Activity Cycles

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At earlier SORCE Workshops we described the use of comparisons between solar activity indices to detect subtle changes in solar behaviour and differences between solar activity cycles. The main indices used were F10.7 and International Sunspot Number. The principle conclusion drawn from the analysis is that starting in the 1980's, in Cycle 21, there was a small excess of F10.7 over the value expected on the basis of sunspot number. This was interpreted as a higher level of activity in the chromosphere and corona compared with that at the photosphere. This difference grew in Cycles 22 and 23, culminating in a marked excess in a weak Cycle 24. At the time of the last SORCE Workshop, Cycle 24 was still in "full swing". This presentation is a consequence of two factors: firstly we are further into Cycle 24, which has shown a surge in activity, and secondly, the Solar Influences Data Centre (Belgium) has revised and recalibrated the International Sunspot Number record. This revision has strongly affected the study. In this presentation we will discuss the impact of the changes to the sunspot number record and the update of the study to the current point in the cycle.

Quasi-Periodic Variations in Radiative Output Driven By Activity Band Interactions

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Solar magnetism displays a host of variational timescales of which the enigmatic 11-year sunspot cycle is most prominent. Recent work has demonstrated that the sunspot cycle can be explained in terms of the intra- and extra-hemispheric interaction between the overlapping activity bands of the 22-year magnetic polarity cycle. Those activity bands appear to be driven by the rotation of the Sun's deep interior. Strong quasi-annual variability in the number of flares, coronal mass ejections, the radiative and particulate environment of the heliosphere is also observed. We infer that this secondary variability is driven by surges of magnetism from the activity bands. Understanding the formation, interaction and instability of these activity bands will considerably improve forecast capability in space weather and solar activity over a range of timescales.

Spectral Irradiance Changes in Cycle 24: Inter-comparing Aura/OMI, SORCE/SIM and SORCE/SOLSTICE

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Exploiting the excellent stability of the Ozone Monitoring Instrument (OMI, onboard the Aura satellite, launched in 2004), we follow both short-term (solar rotation) and long-term (solar cycle) changes of the spectral solar irradiance (SSI) between 265-500 nm during the current Cycle 24. We find that the magnitudes and spectral dependencies of short- and long-term SSI changes are generally consistent. Comparison of this data set with previous observations shows good repeatability of the SSI variability patterns over Solar Cycles 21-24. The SSI changes detected by OMI closely agree with predictions from the NRLSSI2 model, as well as with concurrent results from the GOME-2 instrument (onboard the METOP-A satellite). We compare the OMI data with Cycle 24 variations determined from SORCE SIM and SOLSTICE measurements.

SOLSPEC onboard the International Space Station: Absolute Solar Spectral Irradiance in the Infrared Domain and Comparison with Recent Solar Models

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Onboard the SOLAR payload of the International Space Station (ISS), the SOLSPEC spectrometer measures the solar spectral irradiance (SSI) from 170 to 2900 nm. This instrument uses lamps to monitor its behavior in orbit. In particular, it employs two tungsten ribbon lamps in the IR domain (1000-2900 nm). The infrared absolute irradiance scale was determined from preflight laboratory calibration measurements and the in-flight measurements gathered at first light in April 2008. We reported a systematic discrepancy between SOLAR-ISS measurements and the ATLAS 3 spectrum obtained from SOLSPEC observations onboard the shuttle-ATLAS missions with a discrepancy reaching 10 % at 1800 nm. If confirmed such a discrepancy would have strong implications for the Total Solar Irradiance (TSI) and the brightness temperature of the lower solar photosphere. However, the onboard lamp and solar data time series show that the IR spectrometer did not reach its permanent regime at first light but only after several months of operation. The solar data at first light and in permanent regime show a difference, which is wavelength dependent. Using that difference (or the data in permanent regime), we show that the SOLSPEC-ISS IR spectrum is consistent with the ATLAS 3 spectrum within their combined uncertainties. We present the properties of that corrected spectrum in terms of its contribution to TSI, the photospheric temperature, and comparisons with independently measured IR spectra from ground-based and on-orbit platforms.

The absorption coefficient of the negative ion of hydrogen has its minimum around 1600 nm so that measurements at this wavelength provide a unique opportunity to probe the deepest layers of the solar photosphere. Thus the comparison between the IR measurements and model predictions is of particular interest for understanding the structure of the solar photosphere. We present a comparison of the corrected spectrum with theoretical spectra calculated with radiative transfer codes COSI and ATLAS9 and discuss different physical mechanisms which can affect the absolute level of the IR irradiance.

Demonstrating the Sensitivity of Long-Term Photometric Trends to the Center-to-Limb Profile

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It has been reported (Preminger et al., 2011) that the disk-integrated contrast of visible solar continuum images varies out of phase with the solar cycle, in contrast to surface-magnetism models of spectral irradiance and SOHO/VIRGO measurements in the visible continuum, but in qualitative agreement with SIM visible-band measurements. Since only relative photometry is possible from the ground, contrast measurements are made with respect to a center-to-limb intensity profile. Using nine years of full-disk red and blue continuum images from the Precision Solar Photometric Telescope (PSPT) at the Mauna Loa Solar Observatory (MLSO), we examine the sensitivity of deduced cycle-related irradiance trends to the center-to-limb profile definition employed. We find that the disk-integrated continuum contrast, and the integrated contrasts of the internetwork, network, and active network separately, are highly sensitive to the center-to-limb definition employed. The sensitivity of the center-to-limb profile itself to changes in the Sun's surface magnetism in turn depends on how the profile is constructed, and different center-to-limb algorithms yield contradictory cycle related contrast trends. Radiometric imaging is required to determine the true center-to-limb variation of magnetic structures and unambiguously measure their contributions to solar spectral irradiance variations.

Modeling the Solar Atmosphere: Spectral Irradiance Synthesis for the Period 2010-2015

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Recent progress has been made in constructing atmospheric models that reproduce the observed center-to-limb solar spectra emitted from the various components of both quiet and active regions. We use these results to calculate the solar spectral irradiance (SSI) at any time, given the state of the solar disk, i.e., given by the observed components of quiet and active regions located at various heliocentric angles. These components are determined directly from images at various wavelengths, and in the current decomposition scheme 9 feature types are considered.

The analysis of many images obtained by the Solar Dynamics Explorer/Atmospheric Imaging Assembly (SDO/AIA) produced daily masks of the solar disk, indicating the location of regions of various activity. From these we have computed the relative area and position on the disk occupied by the features that describe the state of the solar disk at any time during the current solar cycle.

Using the spectra of the key solar surface features produced by detailed models of these features by the Solar-Stellar Radiation Physical Modeling system version 2 (SRPMv2), together with the masks, we computed the SSI during the period 2010-2015. We show the resulting SSI as function of time in several wavelength bands, from the UV to the far-IR. We also show how the various solar features contribute to the SSI and to its variation over the current solar cycle 24.

Recent progress in the understanding of molecular photo-dissociation UV opacity solved the outstanding issues in the previous models and calculations, and now the SSI results are fully consistent with the observations. These results include the significant variation of the near-UV spectrum that affects ozone photo-dissociation in the Hartley band, and the overall opposite trends with the solar cycle of the visible and UV SSI variations.

The current methods and models are the culmination of the project Radiative Inputs from the Sun to the Earth started in 1995 by a collaborative team led by O. R. White. Longer-term reconstructions can now be carried out using extensive imaging data that exists from early in the 20th century to the present.

NLTE Calculation of the SOlar spectrum with CRoss-influence of solar ATmospheric structures (SOCRAT)

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I will present the new SOCRAT project, which consists of an adaptation of the COSI code developed at PMOD/WRC to represent 3-D effects in the radiative transfer using cross-influence between different atmospheric structures, which simplifies the calculations to a 1.5-D model instead of 3-D. I will first present the motivations behind this project, such as the disagreement between reconstructed and observed spectra in the infrared and UV, and the oxygen crisis. I will then describe the implementation and present some preliminary results.

A Different View of Solar Spectral Irradiance Variations: Modeling Total Energy over Six-Month Intervals

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A different approach to studying solar spectral irradiance (SSI) variations, without the need for long-term (multi-year) instrument degradation corrections, is examining the total energy of the irradiance variation during six-month periods. This duration is selected because a solar active region typically appears suddenly and then takes five to seven months to decay and disperse back into the quiet Sun network. The solar outburst energy, which is defined as the irradiance integrated over the six-month period and thus includes the energy from all phases of active region evolution, could be considered the primary cause for irradiance variations. Because solar cycle variation is the consequence of multiple active region outbursts, understanding the energy spectral variation may provide a reasonable estimate of the variations for the 11-year solar activity cycle. The moderate-term (6-month) variations from the Solar Radiation and Climate Experiment (SORCE) instruments can be decomposed into positive (in-phase with solar cycle) and negative (out-of-phase) contributions by modeling the variations using the San Fernando Observatory (SFO) facular excess and sunspot deficit proxies, respectively. These excess and deficit variations are fit over 6-month intervals every 2 months over the mission, and these fitted variations are then integrated over time for the six-month energy. The dominant component indicates which wavelengths are in-phase and which are out-of-phase with solar activity. The results from this study indicate out-of-phase variations for the 1400-1600 nm range, with all other wavelengths having in-phase variations.

Solar Rotational Modulations of Spectral Irradiance and Correlations with the Variability of Total Solar Irradiance

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In the present paper, we characterize the solar rotational modulations of spectral solar irradiance (SSI) and compare them with those of TSI. Since 2003 to present, daily measurements from SORCE enable us to identify solar rotational modulation of TSI and SSI at wavelengths between 120 to 2400 nm, over one hundred cycles. The SORCE measured solar irradiances are analyzed using the EEMD (Ensemble Empirical Mode Decomposition) method to determine the phase and amplitude of 27-day solar rotational variation in TSI and SSI. The mode decomposition clearly identifies 27-day solar rotational variations in SSI, and there is robust wavelength and time dependence in the phase of the rotational mode relative to that of TSI. The rotational variations of VIS and NIR are in-phase with that of TSI, but the modes in UV region are not always in-phase with that of TSI when the phase shifts between those of UV and VIS exist. While it is questionable that the visible (VIS) to near infrared (NIR) portion of the solar spectrum has yet be observed with sufficient accuracy and precision to determine the 11-year solar cycle variations, the short-term variation independent of the two solar cycles in which they are embedded, show distinct solar rotational modulations at each wavelength. The phases of the rotational modes obtained from SORCE SSI are compared with those from SATIRE-S SSI. The comparison is in good agreement in UV (λ<400 nm) and NIR (700 nm <λ<400 nm) regions.

Thursday, November 12

Session 5. Societal Impacts from Climate Change and Solar Variability

Climate Change Accuracy: Observing Requirements and Economic Value

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Higher than normal accuracy is required to rigorously observe decadal climate change. But what level is needed? How can this be quantified? This presentation will summarize a new more rigorous and quantitative approach to determining the required accuracy for climate change observations (Wielicki et al., 2013, BAMS). Most current global satellite observations cannot meet this accuracy level. A proposed new satellite mission to resolve this challenge is CLARREO (Climate Absolute Radiance and Refractivity Observatory). CLARREO is designed to achieve advances of a factor of 10 for reflected solar spectra and a factor of 3 to 5 for thermal infrared spectra (Wielicki et al., Oct. 2013, BAMS). The CLARREO spectrometers are designed to serve as SI traceable benchmarks for the Global Satellite Intercalibration System (GSICS) and to greatly improve the utility of a wide range of LEO and GEO infrared and reflected solar passive satellite sensors for climate change observations (e.g. CERES, MODIS, VIIIRS, CrIS, IASI, Landsat, SPOT, etc.).

Providing more accurate decadal change trends can in turn lead to more rapid narrowing of key climate science uncertainties such as cloud feedback and climate sensitivity. A study has been carried out to quantify the economic benefits of such an advance as part of a rigorous and complete climate observing system. The study concludes that the economic value is ~ $12 Trillion U.S. dollars in Net Present Value for a nominal discount rate of 3% (Cooke et al., 2013, J. Env. Sys. Dec.). A brief summary of these two studies and their implications for the future of climate science will be presented.

Atlantic Coastal Impacts of Global Warming

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We summarize several current and expected impacts of global warming, and then focus on regional sea level rise along the east coast of the United States. Ocean height has remained roughly steady for the past 6,000-8,000 years. In recent decades, though, global warming has begun to thermally expand the oceans, and melt sea ice and land ice. If all ice sheets and glaciers in the world melt, sea level will be 212 ft (65 m) higher than today. Sea level is expected to continue to rise for at least 1,000 years. Sea level rise will typically be gradual, but high tides, storms, and erosion can rapidly change shorelines. Today's extreme tide will be tomorrow's routine high tide, and in the next few decades will produce routine tidal flooding in many cities along the US East Coast of the Atlantic Ocean. Storm surges that ride on top of high tides, as happened during Hurricane Sandy, will amplify extreme coastal flooding.

Session 6. Variability of the Sun-like Stars

The Art of Science and the Physics of Sun-Like Stars

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Nearly six decades of observations of Sun-like stars at two different observatories (Mount Wilson and Lowell) allow unique insights into stellar dynamos, the use and maintenance of astronomical instruments, and the management and curation of very large time-domain data sets. The most recent published results from the Solar-Stellar Spectrograph (SSS) project at Lowell are from 2009; those from Mount Wilson are from 1995. With collaborators from HAO now leading the effort, we are conducting a full analysis of the current SSS data, now augmented by several more years of observations after our earlier publications, and supplemented to the extent possible by the MWO time series. I will review the present results, as well as the lessons in practicing science learned from sixty years of maniacally observing the same objects. These lessons provide clear guidance for future observational and theoretical programs, and I will discuss initial efforts to implement these.

The Sun and the Kepler Solar-Type Stars: Quiescence and Flaring

Hugh Hudson *[hhudson@ssl.berkeley.edu], Space Sciences Laboratory/University of California – Berkeley, CA, USA; and University of Glasgow, Scotland, UK*

The Kepler database contains many solar-type stars, some of which turn out to host "superflares" beyond the scale of the known solar flares themselves, notably the Carrington event. The superflares appear mostly on stars with non-solar patterns of quiescent variability. These stars neither show sunspot "dips" as on the Sun, nor variability on short time scales due to faculae. In the solar case the time-series variance due to faculae can rival that of the sunspot deficits. These mismatches in the quiescent variability cannot be explained by differing inclination angles relative to the stellar equators. I discuss these properties in the context of what they may teach us about solar extreme events and about the behavior of magnetic modulation of stellar irradiance variations in general.

Heinrich Schwabe's Holistic Detective Agency

Philip Judge *[judge@ucar.edu] and Ricky Egeland, High Altitude Observatory (HAO), National Center for Atmospheric Research (NCAR), Boulder, CO, USA*

We know that decadal solar and stellar brightness changes are intimately tied to the varying global-scale magnetic field. Exactly how this intimacy works remains a classic “Who-Dunnit”. Prof. Dynamo, the perpetrator responsible for Schwabe and Hale's magnetic sunspot cycle and the co-conspirator who converts the magnetic variations to brightness changes are still on-the-run. In 1987 the late Douglas Adams published his “thumping good detective-ghost-horror-who dunnit-time travel-romantic-musical-comedy-epic” from which the title of this talk was purloined. We argue that unsolved detective story of Prof. Dynamo has elements of “ghost-horror-time travel-comedic-epic”-ness about it. We also make the case that the search for Prof. Dynamo must be a holistic one. That is, we must not study the Sun in isolation. In this talk we will try to follow the scent using physical principles and data that are “Elementary”. We try to identify useful paths upon which to send in future sleuths and bloodhounds.

The Ups and Downs of Alpha Centauri and Friends

Thomas Ayres *[Thomas.Ayres@colorado.edu], Center for Astrophysics and Space Astronomy (CASA), University of Colorado, Boulder, CO, USA*

A recent addition to the stellar cycle toolbox is the use of orbiting X-ray and UV telescopes (such as Chandra and HST) to explore how the highest energy (T~1-10 MK) “coronal” emissions evolve over a stellar activity cycle. Only a few stars have been observed persistently by this technique – nearby Alpha Centauri A (G2V) and B (K1V) are the best examples – but the preliminary results are encouraging, in helping us understand how the much more extreme X-ray variations (compared with Ca II) come about. I will discuss the existing high-energy observations of stellar cycles, but mainly focus on the X-ray time series of the Alpha Cen stars, which extends back two decades and involves three different high-energy observatories. I also will describe the past nearly five years of semiannual high-resolution FUV spectroscopy of A and B by Hubble’s Space Telescope Imaging Spectrograph (covering spectral territory similar to the IRIS solar UV spectral imager). I will highlight important lessons learned from these comparisons, and pitfalls to be avoided.

Photometric Variations of 290 Sun-Like Stars 1993-2015

Wes Lockwood[1] *[gwl@lowell.edu] and Greg Henry*[2]

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Strömgren *b* (472 nm) and *y* (551 nm) differential observations of 290 Sun-like F, G, and K field stars continue on four 0.8m automatic photometric telescopes (APTs) at Fairborn Observatory. The project began on one APT in 1993 and rapidly expanded to four. The observing list centers on 61 stars with *B-V* colors and chromospheric activity levels very similar to the Sun. The project is a high-precision successor to previous work at Lowell Observatory 1984-2000. The robotic observations show that low-level variability is ubiquitous at levels as low as the Sun's 0.07% cyclic total irradiance variation. By also including Ca II H&K observations from the Mount Wilson and Lowell Observatories, we have mapped long-term patterns of photometric variability and chromospheric activity. We will describe the limitations of detectability imposed by comparison star variability. As an example of a star close to the detection limit, we will show our photometric and chromospheric evidence for cyclic variability of the solar twin 18 Scorpii.

Session 7. Challenges and Opportunities in Solar Observations

SUITS/SWUSV: A Solar-Terrestrial Space Weather & Climate Investigation

Luc Damé [1] *[luc.dame@latmos.ipsl.fr], Alain Hauchecorne*[1]*, and the SUITS Team*

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We present the SUITS/SWUSV microsatellite mission investigation: "Solar Ultraviolet Influence on Troposphere/Stratosphere, a Space Weather & Ultraviolet Solar Variability" mission. SUITS/SWUSV was developed to determine the origins of the Sun's activity, understand the flaring process (high energy flare characterization) and onset of CMEs (forecasting). Another major objective is to determine the dynamics and coupling of Earth's atmosphere and its response to solar variability (in particular UV) and terrestrial inputs. It therefore includes the prediction and detection of major eruptions and coronal mass ejections (Lyman-Alpha and Herzberg continuum imaging) the solar forcing on the climate through radiation and their interactions with the local stratosphere (UV spectral irradiance measures from 170 to 400 nm). The mission is on a sun-synchronous polar orbit 18h-6h (for almost constant observing) and proposes a 7 instruments model payload of 65 kg - 65 W with: SUAVE (*Solar Ultraviolet Advanced Variability Experiment*), an optimized telescope for FUV (Lyman-Alpha) and MUV (200–220 nm Herzberg continuum) imaging (sources of variability); SOLSIM (*Solar Spectral Irradiance Monitor*), a spectrometer with 0.65 nm spectral resolution from 170 to 340 nm; SUPR (*Solar Ultraviolet Passband Radiometers*), with UV filter radiometers at Lyman-Alpha, Herzberg, MgII index, CN bandhead and UV bands coverage up to 400 nm; HEBS (*High Energy Burst Spectrometers*), a large energy coverage (a few tens of keV to a few hundreds of MeV) instrument to characterize large flares; EPT-HET (*Electron-Proton Telescope – High Energy Telescope*), measuring electrons, protons, and heavy ions over a large energy range; ERBO (*Earth Radiative Budget and Ozone*) NADIR oriented; and a vector magnetometer. Complete accommodation of the payload has been performed on a PROBA type platform very nicely. Heritage is important both for instruments (SODSIM and PREMOS on PICARD, LYRA on PROBA-2, SOLSPEC on ISS, …) and platform (PROBA-2, PROBA-V, ...),

leading to high TRL levels (>7). SUITS/SWUSV was designed in view of the ESA/CAS AO for a Small Mission; it is now envisaged for a joint opportunity CNES/NASA with Europeans and Americans partners for a possible flight in 2021.

The EUV and X-ray Irradiance Sensors (EXIS): GOES-R and Beyond!

Marty Snow *[marty.snow@lasp.colorado.edu], Francis Eparvier, Andrew Jones, William McClintock, and Tom Woods; Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder, CO, USA*

The Laboratory for Atmospheric and Space Physics (LASP) is delivering four instrument packages to NOAA for inclusion on the GOES-R series of spacecraft. These instruments will provide measurements of soft X-rays and three bands in the ultraviolet. The three channels of the Extreme Ultraviolet Sensor (EUVS) will include coronal emissions (Fe XV at 28.4 nm), transition region (HI Lyman alpha at 121.6 nm), and the Mg II index at 280 nm. These three channels will be used to create a proxy model that covers the 5 to 127 nm range. This operational model will be produced on a 30 second time cadence and will be available to the public in near real time. In this talk I will describe the measurements that will be used to create this proxy model.

Bragg Soft X-rays Spectrometers: Our future missions

Marek Stęślicki *[sm@cbk.pan.wroc.pl or steslicki@gmail.com], Janusz Sylwester, Marek Siarkowski, and Żaneta Szaforz; Space Research Centre, Polish Academy of Sciences, Warsaw, Poland*

After years of intense studies, the basic physical processes of energy release in the plasma of solar corona are still not well known. The most promising tool allowing the study of physical conditions in the energetic coronal sources is spectroscopy. In the multi-million degree solar corona, the atoms are highly ionized, up to the helium- and/or hydrogen-like ionization stages. Hot plasma contribute to emission spectra in the range between 0.1 and 50 nm, i.e. the soft X-ray range. Observed line profiles depends on local plasma conditions prevailing in active regions and flares (T in the range between 1 and 50 MK). Spectral information completed by the polarimetry and Dopplerometry constitute a powerful tool to diagnose the properties of the hot plasma in the atmosphere of our star.

In this context, I will present two space instruments (ChemiX and SOLPEX) currently under construction at the Space Research Centre of Polish Academy of Sciences designed to observe in detail the solar soft X-ray spectra and perform unique polarimetry measurements.

Modeling Solar Irradiance with the DKIST

Serena Criscuoli *[scriscuo@nso.edu], AURA – National Solar Observatory, Boulder, CO, USA*

Recent magneto hydrodynamic simulations indicate that phenomena and structures occurring at spatial and temporal scales not resolved with modern instrumentation should be taken into account when modeling solar irradiance. The new generation 4 meter Daniel K. Inouye Solar Telescope will offer a unique opportunity to observe and characterize such features. For this reason one of the DKIST Science Use Cases is dedicated to the understanding of solar irradiance. After a brief summary of DKIST observing capabilities, I will illustrate how the scientific community can contribute to the development of this science use case through the submission of proposals for future observations.

Total and Spectral solar Irradiance Sensor (TSIS) Project Overview

Candace C. Carlisle *[Candace.c.carlisle@nasa.gov], NASA Goddard Space Flight Center, Greenbelt, MD, USA*

The main objective of the Total and Spectral solar Irradiance Sensor (TSIS) is to acquire measurements to determine the direct and indirect effects of solar radiation on climate. TSIS total solar irradiance measurements will extend a 37-year long uninterrupted measurement record of incoming solar radiation, the dominant energy source driving the Earth's climate and the most precise indicator of changes in the Sun's energy output. TSIS solar spectral irradiance measurements will determine the regions of the Earth's multi-layered atmosphere that are affected by solar variability, from which the solar forcing mechanisms causing changes in climate can be quantified.

TSIS includes two instruments: the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM), integrated into a single payload. The TSIS TIM and SIM instruments are upgraded versions of the two instruments that are flying on the Solar Radiation and Climate Experiment (SORCE) mission launched in January 2003. TSIS was originally planned for the nadir-pointing National Polar-orbiting Operational Environmental Satellite System (NPOESS) spacecraft. The TSIS instrument passed a Critical Design Review (CDR) for NPOESS in December 2009. In 2010, TSIS was re-planned for the Joint Polar Satellite System (JPSS) Polar Free Flyer (PFF). The TSIS TIM, SIM, and associated electronics were built, tested, and successfully completed pre-ship review as of December 2013.

In early 2014, NOAA and NASA agreed to fly TSIS on the International Space Station (ISS). In the FY16 President's Budget, NASA assumes responsibility for the TSIS mission on ISS.

The TSIS project includes requirements, interface, design, build and test of the TSIS payload, including an updated pointing system, for accommodation on the ISS. It takes advantage of the prior development of the TSIS sensors and electronics. The International Space Station (ISS) program contributions include launch services and robotic installation of the TSIS payload onto an ISS Express Logistics Carrier, mission operations, and communications. Total and Spectral solar irradiance data products will be produced, calibrated, and made publically available through the Goddard Earth Science Data and Information Services Center (GES DISC).

The NASA GSFC TSIS project at GSFC is responsible for project management, system engineering, safety and mission assurance, and engineering oversight for the TSIS payload. The TSIS project has contracted with the University of Colorado Laboratory for Atmospheric and Space Physics (LASP) for the design, development and testing of TSIS, support for ISS integration, science operations of the TSIS instrument, data processing, data evaluation and delivery to the GES DISC.

TSIS will be delivered to Kennedy Space Center for integration in 2017, with launch and installation onto ISS planned for late 2017-early 2018. After a 90-day check-out period, NASA plans five years of TSIS operations.

A Compact Solar Spectral Irradiance Monitor for Future Small Satellite and CubeSat Science Opportunities

Erik Richard [1] *[Erik.Richard@lasp.colorado.edu], Dave Harber[1], Joel Rutkowski[1], Paul Smith[1], Joey Espejo[1], Jacob Sprunck[1], Ginger Drake[1], Nathan Tomlin[2], and John Lehman[2]*

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The accurate and continuous measurement of solar spectral irradiance (SSI) is recognized as being increasingly important to advancing our understanding of the solar influence on Earth's climate. Recent SSI measurements are providing critical inputs in evaluating and improving present climate-chemistry models, however they are not yet of sufficient accuracy to stand alone without overlapping records – gaps in the observational record, caused by future mission delays or early failures of existing missions, effectively destroy our ability to link records from different instruments into a continuous, long-term climate quality record. Recent advancements in calibration facilities and techniques make it now possible to improve significantly the accuracy and traceability of future SSI observations and assure quantification of uncertainties as input to increasingly more sophisticated climate models. Following SORCE, the *Total and Spectral Solar Irradiance Sensor* (TSIS) *Spectral Irradiance Monitor* (SIM) is the next generation, space-borne SSI radiometer that is scheduled to be operational on the International Space Station (ISS) in late 2017. The instrument has been designed, characterized, and calibrated to achieve unprecedented levels of absolute accuracy ($u_c \leq 0.2\%$ combined standard uncertainty) and high spectral stability (0.01-0.05% per year *correctable* relative uncertainty) across a continuous wavelength region spanning 200 – 2400 nm (96% of the total solar irradiance). Unfortunately, restructuring and delays in the implementation of TSIS to assure future continuity of SSI records are further compounding the problem of introducing large measurement gaps in achieving a long-term record. Given these concerns, we have recently started a new development program for an instrument concept that will mitigate potential risks associated with large mission delays resulting in observational data gaps by developing a cost effective, reduced-size SSI radiometer.

The compact SSI monitor (CSIM) will cover 200-2400 nm with the required SI-traceable accuracy and on-orbit stability to meet the solar input measurement requirements defined in the Earth Science Decadal Survey for establishing benchmark climate records. Building upon our experiences and resources from the TSIS SIM program, the instrument will reduce the cost, size, and characterization/calibration schedule of an SSI monitor with SI-traceable absolute calibration at the 0.2% uncertainty level (k=1) while maintaining the TSIS-level high relative stability. System level performance characterizations and final end-to-end absolute irradiance calibration/validation will be accomplished with the LASP Spectral Radiometer Facility (SRF), a comprehensive LASP-NIST jointly developed spectral irradiance calibration facility utilizing the SIRCUS tunable laser system tied to an SI-traceable cryogenic radiometer. The completed, flight-ready instrument will be cross-calibrated with the TSIS SIM and will potentially mitigate data continuity risks associated with future mission delays by offering an instrument with implementation flexibility for alternative flight opportunities, including ride share and hosted payloads, small satellites, and dedicated CubeSat missions – a rapidly emerging technology for low cost orbital science.

The RAVAN CubeSat Mission: Progress toward a new measurement of Earth outgoing radiation

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The Earth radiation imbalance (ERI) is the single most important quantity for predicting the course of climate change over the next century. The Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat mission, funded by NASA's Earth Science Technology Office, will demonstrate a small, accurate radiometer that measures top-of-the-atmosphere Earth-leaving fluxes of total and solar-reflected radiation. Coupled with knowledge of the incoming radiation from the Sun, a constellation of such measurements would aim to determine ERI directly. The objective of

RAVAN is to establish that a compact radiometer that is absolutely calibrated to climate accuracy can be built and operated in space for low cost. The key technologies that enable the radiometer are: a vertically aligned carbon nanotube (VACNT) absorber and a gallium fixed-point blackbody as a built-in calibration source. VACNTs are exceedingly black and spectrally flat, making them ideal radiometer absorbers. We present an overview of the mission, progress toward fabrication and calibration of the RAVAN radiometer, and plans for CubeSat hosting and launch (anticipated in 2016). RAVAN will help enable the development of a constellation Earth radiation budget mission that can provide the measurements needed for superior predictions of future climate change.

Continuous Constellation for Total and Spectral Solar Irradiance in the next 35 Years

Thomas Sparn *[tom.sparn@lasp.colorado.edu] and Peter Pilewskie, Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder, CO, USA.*

This presentation will explore the TSSI Operational Monitoring Constellation (TOMC), a proposed implementation concept to reduce the cost and risk of the follow-on to the TSIS-2 mission, and the collection of the Total and Spectral Solar Irradiance (TSSI) Climate Data Record (CDR). TOMC is based on our success with SORCE mission, the current and ongoing TSIS-1 development and new developments in the launch vehicle and low-cost spacecraft arena.

The keys to this concept are: 1) a very capable and low cost bus design, 2) the roll out of several small low-cost launch vehicles (for example: the “Super Strypi (SPARK)” Missile), and 3) a 25 year plan to provide continuous TSSI CDRs with a constellation of overlapping spacecraft efficiently controlled by the LASP Operations Center and existing data processing system.

By managing all of the interfaces within one organization, with efficient yet streamlined NASA oversight following the SORCE model, and using our existing low cost space-mission operations center and data production system, we can accomplish 22 years of continuous TSSI CDR production for less than ten million USD per year over the 25 year implementation of the program.

Overview of the NASA Solar Irradiance Science Team (SIST) Program

Matthew DeLand[1] *[matthew.deland@ssaihq.com] and David Considine*[2]

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Solar irradiance data sets, both total and spectrally resolved, are a key input parameter for understanding the forcing mechanisms that act on the Earth’s climate and atmosphere. The spectral coverage and temporal duration needed for such data sets exceeds the measurement capabilities and lifetime of any single satellite instrument. NASA requested “…the development of consistent multi-instrument/multi-platform space-based data sets of solar irradiance” in Fall 2014, and recently selected 7 proposals to comprise the Solar Irradiance Science Team (SIST). This presentation will briefly review the research planned for the highly complementary SIST investigations, and also discuss the goals of the SIST project. We hope to build on the work currently under way in related efforts, such as the European SOLar Irradiance Data Exploitation (SOLID) project.

Friday, November 13

Session 8. Next Generation Observing Systems for Climate Records

The CLARREO Climate Benchmarking Mission: The Absolute Radiance Interferometer (ARI) is a proven prototype for the Infrared portion of the full observing capability

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The NASA Climate Absolute Radiance and Reflectivity Observatory (CLARREO) will use highly accurate, spectrally resolved infrared emission and reflected solar measurements to quantify global trends in the climate of the Earth (Wielicki *et al.*, BAMS, 2013). This year, the resources for a CLARREO Pathfinder/Tech Demo flight of both IR and reflected solar instruments on the International Space Station (ISS) were included in the 2016 President's recommended budget.

The technical readiness for this ISS mission has been proven by NASA supported instrument developments, including that of the Absolute Radiance Interferometer (ARI), a prototype for the infrared portion of CLARREO. ARI was developed by our group teamed with the Anderson Group at Harvard University and ABB of Quebec, Canada (supported by the NASA Earth Science Technology Office, ESTO).

The ARI instrument measures absolute spectrally resolved infrared radiance (3.7-50 µm) with ultra-high accuracy (< 0.1 K 3-sigma brightness temperature). Resolving spectral lines allows ARI to provide products for climate trending with much higher information content than those from current radiation budget measurements. The key new aspect of the ARI instrument is the On-orbit Verification and Test System (OVTS) for proving its accuracy on-orbit by reference to International Standards (SI).

The ISS provides a platform well suited to unbiased temporal sampling below 52 degrees latitude, and intercalibration of operational sounding instruments that give good polar coverage. Therefore this pathfinder mission will be capable of initiating the CLARREO benchmark record.

The Earth Climate Hyperspectral Observatory: Advances in Climate Change Detection, Attribution, and Remote Sensing

Peter Pilewskie *[peter.pilewskie@lasp.colorado.edu], Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder, CO, USA*

Future satellite missions to monitor global change require the establishment of high-accuracy spectrally resolved benchmark data records of reflected shortwave radiation for trend detection and attribution. Not surprisingly, these same attributes also provide substantial improvements in the retrieval of microphysical and optical properties of clouds and aerosols over current discrete-band observations. The NASA Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission, currently in pre-formulation, defines a set of fundamental direct observations of spectrally resolved reflected shortwave and emitted longwave radiation, and GNSS radio occultation in order to detect climate trends and to test and improve climate prediction models. The Earth Climate Hyperspectral Observatory (ECHO), a proposed pathfinder mission to CLARREO, focuses on measuring spectrally resolved Earth-reflected shortwave radiation over a spectral range that comprised approximately 95% of the solar radiative energy incident at the top-of-atmosphere.

This paper will report on the ECHO requirements specifically directed at objectives related to cloud and aerosol remote sensing, and more generally, characterizing the physical parameters responsible for the observed spectral and temporal variability in a benchmark data record. These objectives are centered on targeted remote sensing and data assimilation analyses to derive the dominant contributors to the observed spectral, temporal, and spatial perturbations in the reflected shortwave signal. Specific improvements in the retrieval of cloud and aerosol properties due to increased spectral coverage, spectral resolution, and radiometric accuracy will be discussed.

Long-Term Observations of the Upper Atmosphere

Martin G. Mlynczak *[m.g.mlynczak@nasa.gov], NASA Langley Research Center, Hampton, VA, USA*

The past 40 years have been a "golden age" for observations of the stratosphere, mesosphere, and lower thermosphere. Beginning with the Nimbus satellites mid-1970's and continuing until the present day, numerous dedicated satellites and specific instruments have been flown to measure the thermal structure and chemical composition of the Earth's middle atmosphere. Largely driven by the need to understand ozone, which is the main radiative driver in the middle atmosphere, missions were routinely flown to study this fascinating region. Today, two aging NASA satellites (AURA, at 11 years, and TIMED at 14 years) are the last satellites providing comprehensive data from the tropopause into the thermosphere. The SAGE III mission will launch in 2016 and will largely focus on stratospheric ozone and aerosols for climate. Thus middle atmosphere science is facing the likely prospect of a gap in data, especially in the mesosphere and lower thermosphere. Despite compelling scientific questions, many related to long-term global change, there are presently no new missions or instruments under development to continue critical global data records of temperature, ozone, water vapor, carbon dioxide, and energetics in the middle atmosphere. In this talk we present a concept for an infrared limb sounder that can continue legacy measurements and add significant new science at low cost and existing high technical readiness. The MASTER instrument will be presented as well as possible candidate complementary instrument concepts that could form the basis of a new mission combining data continuity and scientific exploration of the upper atmosphere.

Early Results from the First Year of Operations of the OCO-2 Mission

David Crisp[1] *[david.crisp@jpl.nasa.gov] for the OCO-2 Science Team*

[1] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*

The NASA Orbiting Carbon Observatory-2 (OCO-2) was successfully launched on 2 July 2014 and joined the 705 km Afternoon Constellation (A-Train) on August 3, 2014. Its 3-channel imaging grating spectrometer was then cooled to its operating temperatures and a series of calibration and validation activities was initiated. Since early September of 2014, this instrument has been returning almost one million soundings each day over the sunlit hemisphere. As expected, about 13% of all soundings are sufficiently cloud free to yield full-column estimates of the column-averaged CO_2 dry air mole fraction, X_{CO2}, with single-sounding random errors are between 0.5 and 1 ppm at solar zenith angles as large as 70 degrees. With almost a year of data in hand, global X_{CO2} maps are starting to reveal some of the best known features of the atmospheric carbon cycle. X_{CO2} enhancements co-located with fossil fuel emissions in eastern U.S. and eastern China are most obvious in the fall, when the north-south X_{CO2} gradient is small. Enhanced X_{CO2} associated with biomass burning in the Amazon, central Africa, and Indonesian is also obvious in this season. From late May to mid-July, OCO-2 maps show a 2-3% reduction in X_{CO2} across the northern hemisphere, as the land biosphere rapidly absorbs CO_2. As the carbon cycle community continues to analyze these OCO-2 data, quantitative estimates of regional-scale emission sources and natural sinks are expected to emerge. This presentation will summarize the OCO-2 mission status, early products, and near-term plans.

An Active Approach to Climate Data Records

***Graeme L. Stephens** [Graeme.Stephens@jpl.nasa.gov], Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*

The emergence of active sensors on satellites and the growing record of observations being collected from them, together with the possibility of extending these data records with new active-sensor missions in the future, present opportunities to develop new forms of climate data records. This talk will review progress in active sensing highlighting data records developed from TRMM and the extension to GPM, CloudSat and CALIPSO and the extension of these observations by EarthCARE, the scatterometer record and the highly successful radar altimeter data that has produced a twenty-plus year record of sea level. Some focus of the talk will revolve around you it is important to integrate active sensor data records with passive sensor records illustrated with the example of how CloudSat and CALIPSO data support the analysis of energy budget data records.

Looking at the Entire Sunlit Earth from the L1 Point; The very first results

***Alexander Marshak**[1] [Alexander.Marshak@nasa.gov] and Jay Herman[2]*

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The NOAA Deep Space Climate Observatory (DSCOVR) spacecraft was launched in February 2015 and in June 2015 achieved its orbit at the first Lagrange point or L1, 1.5 million km from Earth towards the Sun. There are two NASA Earth observing instruments onboard: the National Institute of Standards and Technology Advanced Radiometer (NISTAR) and the Earth Polychromatic Imaging Camera (EPIC). NISTAR is a set of 3 high-precision cavity radiometers and one diode detector designed to detect the total emitted and reflected energy from the Earth (from UV to IR) in the near backscatter direction. Its goal is to study the Earth's energy balance from this unique view angle of L1 and use the data to fill in a missing portion of similar data obtained in low earth orbit. EPIC views the entire sunlit Earth from sunrise to sunset at scattering angles between 165° and 176° with 10 narrowband filters: 317, 325, 340, 388, 443, 552, 680, 688, 764 and 779 nm. The expected main EPIC products will be total ozone amount, UV and visible aerosol properties, scene reflectivity, vegetation properties, and cloud height. In our presentation, we discuss the uniqueness of L1 observations of diurnal variation of aerosols, clouds, and vegetation for the entire globe and show the first preliminary science results.

Century-Long Monitoring of Solar Irradiance and Earth's Albedo Using a Stable Scattering Target in Space

***Ricky Egeland** [egeland@ucar.edu], High Altitude Observatory (HAO), National Center for Atmospheric Research (NCAR), Boulder, CO, USA*

An inert sphere of a few meters diameter, placed in a special stable geosynchronous orbit in perpetuo, can be used for a variety of scientific experiments. Ground-based observations of such a sphere, "GeoSphere," can resolve very difficult problems in measuring the long-term solar irradiance. GeoSphere measurements will also help us understand the evolution of Earth's albedo and climate over at least the next century. I will review the high-precision solar and stellar measurements that motivate the case for GeoSphere, as well as the expected scientific results and technical challenges for this proposed experiment.

What Spatiotemporal Sampling is Needed to Determine Earth Radiation Imbalance from GEO-MEO-LEO Constellation?

Dong L. Wu *[dong.l.wu@nasa.gov], NASA Goddard Space Flight Center, Greenbelt, MD, USA*

Earth Radiation Imbalance (ERI) at the top of atmosphere (TOA) is a difficult variable to measure, requiring not only accurate and stable radiometers but also sufficient spatiotemporal sampling from multiple platforms. Assuming future radiometers (e.g., RAVAN) can provide accurate (0.3 W/m^2) radiance measurements, what is the minimum number of constellation satellites from GEO, MEO and LEO platforms that can measure the daily EBI better than 0.5 W/m^2? In this study we present a preliminary OSSE study using the MERRA TOA data to evaluate the best sampling strategy for the ERI measurements. We find that the GEO and MEO platforms produce the most accurate ERI measurements with efficient use of the platforms, as few as seven-satellite constellation. At the GEO and MEO orbits, Earth is seen like an exoplanet, allowing a total power radiometer to capture most of its irradiance and use of several radiometers to measure its outgoing radiation fluxes. The study shows that the samplings at poles are critical for the accurate determination of ERI due to strong seasonal variations of the TOA albedo at high latitudes. It is also found in the study that the equatorial GEO satellites may be better distributed unevenly in longitude so as to sample cloud-induced albedo variations more efficiently. The results from this study yield a promising solution to the ERI problem, and support development of accurate (<0.3 W/m^2) radiometers for future ERI observations from GEO-MEO constellation.

Overview of the Current and Future Missions for NASA's Earth Science Division

Cheryl Yuhas *[cheryl.l.yuhas@nasa.gov], NASA Headquarters, Washington, DC, USA*

The NASA Earth Science mission portfolio responds to national priorities and input from the Earth science community; this talk will cover the current portfolio of operating missions, including the results of the recently-completed 2015 Senior Review, and the missions in development and formulation. The programmatic status of recent developments in the Earth Venture Program, SORCE, RBI, TSIS and CLARREO will be provided.