Variability of mesospheric water vapor above Bern in relation to the 27-day solar rotation cycle

Presenting Author: **Martin Lainer**

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We investigate the solar-terrestrial response of mesospheric water vapor from a mid-latitudinal observation site at the 27-day solar rotation cycle time scale. Eight years of water vapor profile measurements above Bern (46.88°N/7.46°E) by the microwave radiometer MIAWARA are used to study prominent oscillation features. The spectral data analysis shows enhanced oscillations in the 27-day period band above 0.1 hPa during the rising sunspot activity of solar cycle 24. Aura MLS observations of H2O support these results by showing a similar behavior. The relationship between mesospheric H2O and the solar Lyman-alpha flux is studied by comparing the similarity of their temporal oscillations. The H2O variability is negatively correlated to the solar Lyman-alpha oscillation with a correlation coefficient of up to -0.3 to -0.4, and the phase lag is 6-10 days on 0.04 hPa. The confidence level of the correlation is 99 %. Additionally we compute cross-wavelet transform (XWT) and wavelet coherence (WTC). The latter shows significant (two sigma level) correlations occurring intermittently in the 27 and 13-day band with variable phase lock behavior. Large Lyman-alpha oscillations appeared after the solar super-storm in July 2012 and the H2O oscillations show a well pronounced anti-correlation. The competition between advective transport and photo-dissociation loss of mesospheric H2O may explain the sometimes variable phase relationship of mesospheric water and solar Lyman-alpha oscillations. Generally, the WTC analysis indicates that solar variability causes observable photochemical and dynamical processes in the mid-latitude mesosphere.

The Sunspot Number and the role of the Specola Solare Ticinese in Locarno

Presenting Author: **Renzo Ramelli**

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The Sunspot Number (SSN) is probably the most widely used time series related to the solar activity and its cyclic variation. It represents one of the longest directly measured series in science and covers a time span of about 400 years. Several studies in the scientific literature report comparisons of the SSN with different kinds of scientific records, including eg. climatological records. Sunspot observations and counting are carried out since 1957 at the Specola Solare Ticinese in Locarno. The observations in Locarno still play an important role in the determination of the internationally recognized SSN.

The magnetism of the solar atmosphere as revealed by the Hanle effect

Presenting Author: **Luca Belluzzi**

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During the last years, it has been clearly established that the magnetic field plays a key role in essentially all the most interesting phenomena that are observed in the solar atmosphere. Some of these phenomena, such as flares or coronal mass ejections, are characterized by the release of enormous quantities of energy, and are of high relevance for the Sun-Earth interaction. Nonetheless, our empirical knowledge of the intensity and orientation of the magnetic fields present in the solar atmosphere is still largely unsatisfactory, and mainly limited to the deepest layers (photosphere). One of the main reasons for this regrettable situation is that the Zeeman effect, which is by far the most powerful and widely-applied tool for magnetic field diagnostics in astrophysics, turns out to be of limited utility for investigating the weak and tangled fields that are present in the outer layers of the solar atmosphere (chromosphere, transition region and corona), and that also fill large part of the \"quiet\" solar photosphere. In this talk, I will provide a general overview of another, less familiar physical mechanism that has great potential for magnetic field diagnostics in astrophysics: the Hanle effect. I will briefly recall its physical background, I will point out its main pros and cons, and I will present a series of investigations, which exploit this mechanism, that are currently carried out at the Istituto Ricerche Solari Locarno.

Research at Istituto Ricerche Solari Locarno

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Specola Solare Ticinese and Istituto Ricerche Solari Locarno are institutions dedicated to the study of solar physics. In particular IRSOL is concentrating its efforts in the field of spectropolarimetry, a topic intrinsically related to the study of the solar magnetic field. The way to address this issue based on observations, theoretical interpretation, and numerical modeling is described, and the main research topics are summarized.

The Influence of Middle Range Energy Electrons on Atmospheric Chemistry and Regional Climate

Presenting Author: **Pavle Arsenovic**

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We investigate the influence of Middle Range Energy Electrons (MEE or ring current; typically 30- 300 keV) precipitation on the atmosphere using the SOCOL3-MPIOM chemistry-climate model with coupled ocean. Model simulations cover the 2002-2010 period for which ionization rates from the AIMOS dataset and atmospheric composition observations from MIPAS are available. Results show that during geomagnetically active periods MEE significantly increase the amount of NOy and HOx in the polar winter mesosphere, in addition to other particles and sources, resulting in local ozone decreases of up to 35 %. These changes are followed by an intensification of the polar night jet, as well as mesospheric warming and stratospheric cooling. The contribution of MEE also substantially enhances the difference in the ozone anomalies between geomagnetically active and quiet periods. Comparison with MIPAS NOy observations indicates that the additional source of NOy from MEE improves the model results, however substantial underestimation above 50 km remains and requires better treatment of the NOy source from the thermosphere. A surface air temperature response is detected in several regions, with the most pronounced warming occurring in the Antarctic during austral winter. Surface warming of up to 2 K is also seen over continental Asia during boreal winter.

The contribution of energetic particle precipitation to ozone and surface climate trends.

Presenting Author: **Eugene Rozanov**

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We applied atmosphere-ocean chemistry-climate model (AOCCM) SOCOL to simulate the changes in ozone layer and surface climate during the first half of 20th century, which is characterized by steady increase of the solar activity. The performed ensemble simulations are driven by anthropogenic and natural forcing taken in different combinations. The forcing from energetic precipitating particles includes NOx and HOx production by auroral and radiation belts electrons, solar protons and galactic cosmic rays. The ionization rates inside the model domain (below 80 km) and influx of NOx from the thermospheric source were taken from the dataset prepared for IPCC CMIP-6 project. The comparison of the ozone and climate evolution obtained from the performed model experiments allows estimating the contribution of energetic particles to the observed warming during earlier 20th century. Preliminary results showed that the contribution of radiation belt electrons to the surface climate is rather small. The analysis of the influence from auroral electrons is ongoing.

Modeling of the middle atmosphere response to 27-day solar irradiance variability.

Presenting Author: **Timofei Sukhodolov**

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The solar rotational variability (27-day) signal in the Earth's middle atmosphere has been studied for several decades, as it was believed to help in the understanding of the Sun's influence on climate at longer timescales. However, all previous studies have found that this signal is very uncertain, likely due to the influence of the internal variability of the atmosphere. Here, we applied an ensemble modelling approach in order to decrease internal random variations in the modelled time series. Using a chemistry-climate model (CCM), SOCOLv3, we performed two 20-member 3-year long (2003-2005) ensemble runs: with and without a rotational component in input irradiance fluxes. We also performed similar simulations with a 1-D model, in order to demonstrate the system behavior in the absence of any dynamical feedbacks and internal perturbations. For the first time we show a robust correlation between the solar rotation and the stratospheric tropical temperature time-series. We show tropical temperature and ozone signal phase lag patterns that are in agreement with those from a 1-D model. Pronounced correlation and signal phase lag patterns allow us to properly estimate ozone and temperature sensitivities to irradiance changes, which are found to be in agreement with recent sensitivities reported for the 11-year cycle. Applying a similar approach for temperature reanalysis data and modelling results without a rotational component reveals that the atmosphere can produce random internal variations with periods close to 27 days even without solar rotational forcing, which complicates the extraction of this signal from observational time-series.

Influence of solar activity on the occurrence of weather types over Europe from 1763 to 2009

Presenting Author: **Mikhaël Schwander**

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A new daily weather types time series is used to analyze the influence of solar activity on European weather patterns. This new weather type classification is a reconstruction of an existing classification (CAP9) used by MeteoSwiss and computed from 1957 onward using ERA-40 and ERA-Interim reanalyzes dataset. Our new method uses early instrumental data from European weather stations to reconstruct the CAP9 classification. The new classification (CAP7) contains 7 types and covers the period 1763-2009. This new time series of weather types is used to study the impact of the 11-year solar cycle on European tropospheric weather. For this, changes in the frequency of occurrence of the weather types are analyzed. The sunspot number time series allows us to analyze changes in weather types over almost 250 years. The solar activity is divided in 3 classes (low, moderate, high) for January, February and March using subjective thresholds (33rd and 66th percentiles). The days in the 3 solar activity classes are then classified according to the CAP7 weather types. The results show a reduction in the frequency of occurrence of westerly and west-southwesterly types under low solar activity for the period 1763-2009. We observe also a higher frequency of easterly, northerly and high pressure types. Under high solar activity there is no significant changes in the types frequencies. A look on different periods over the 250 years shows a high variability in the frequencies and the solar signal varies over the time for most of the types. The within types difference is also investigated with composites computed with ERA-40/-Interim from 1958 to 2009. On average the mean sea level pressure tends to be lower over the Northeast Atlantic and Scandinavia under high solar activity. To extend the analysis, simulations from the SOCOL-MPIOM model are used. The impact of the 11-year cycle on the troposphere is analyzed as well as the low frequency solar activity. The simulations only partly confirm the results found in the reanalyzes.

Magnetohydrodynamic Simulations at IRSOL

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At the Istituto Ricerche Solari Locarno (IRSOL), we carry out radiation magnetohydrodynamic numerical simulations of the solar atmosphere and convection zone. These serve for the interpretation and for predictions of polarimetric measurements. The talk is intended to give a brief overview on the simulation activities at IRSOL.

Assessment of the reliability of TSI-reconstructions by comparing PREMOS/PICARD TSI values to other TSI data series

Presenting Author: **Werner Schmutz**

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The PREMOS/PICARD instrument monitored total solar irradiance (TSI) from July 2010 to April 2014. During this period other TSI instruments showed divergent trends large enough to mask, or exacerbate, a multi-decadal trend in the Sun's output. We present the complete PICARD mission TSI time series and provide an inter-comparison with other instruments operating during the same period.

Solar irradiance variability: knowns and unknowns

Presenting Author: **Natalie Krivova**

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Reconstructions of past solar irradiance variability are crucial to our understanding of solar influence on climate. They are only possible with the help of suitable models, which in turn require thorough understanding of the mechanisms of this variability. With the advance of such models, also the past reconstructions are becoming more reliable. Nevertheless, the remaining uncertainties spread out when extrapolating back over long periods of time, amplified by the increasingly poorer quality and reliability of the available data that bear information on past solar activity. The prophesying skills of such extrapolations are even more limited. We will discuss the progress and the reliability of irradiance models on various time scales.

NuSTAR X-ray observations of high altitude post-flare loops one day after a solar flare

Presenting Author: **Matej Kuhar**

Matej Kuhar [1]

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We present X-ray observations of highly occulted (~300 arsecs) post-flare loops observed one day after the flare observed with the NuSTAR telescope. The observations were performed on December 11th 2014, in coordination with SDO/AIA and FOXSI-2. The time evolution of the emission in different AIA channels reveals characteristics of the EUV-late phase event, with NuSTAR observations being the first time that this phenomenon has been observed in X-rays. The NuSTAR spectrum is well represented by an isothermal source of temperature in the range 3.8-4.6 MK and emission measure 0.3-1.7 x 10^46 cm^-3. The flare energetics of the long lasting EUV and X-ray emission are also discussed.

Solar Spectral Irradiance Reconstruction on Millennial Timescale

Presenting Author: **Chi-Ju Wu**

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Variation in solar total and spectral irradiance are considered to be among the main factors influencing Earth's climate system although the mechanisms are not yet fully understood. Solar total irradiance represents the total flux of solar radiative energy entering Earth's climate system, whereas the spectral irradiance describes the distribution of this energy over the spectrum. Solar spectral irradiance in the UV band in particular, is of special interest since it governs chemical processes in the middle and upper atmosphere. On timescales of the 11-year solar cycle or shorter, solar irradiance is measured by space-based instruments while models and proxies of solar activity are needed to reconstruct solar irradiance on longer timescale. We employ the SATIRE-M model (Spectral And Total Irradiance Reconstruction over millennia) to reconstruct solar total and spectral irradiance from decadal radionuclide isotope data such as 14C and 10Be stored in tree rings and ice cores, respectively. The latest progress of solar irradiance reconstruction over the last 9000 years will be presented.

Non-magnetic photospheric bright points in 3D simulations of the solar atmosphere

Presenting Author: **Flavio Calvo**

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We carry out numerical radiation magnetohydrodynamics high-resolution simulations of the near surface layers of the Sun using the facilities at CSCS. The simulations reproduce the well known granular structure of the solar surface with excellent fidelity. Simulations with magnetic fields also reproduce magnetic bright points in the intergranular space as is observed on the Sun. Simulations without magnetic fields show tinier non-magnetic bright points, which have not been observationally detected so far but our simulations predict their existence.

Response of the AMOC to reduced solar radiation – the modulating role of atmospheric-chemistry

Presenting Author: **Christoph Raible**

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The influence of reduced solar forcing (grand solar minimum or geoengineering scenarios like solar radiation management) on the Atlantic meridional overturning circulation (AMOC) is assessed in an ensemble of atmosphere-ocean-chemistry-climate model simulations. Ensemble sensitivity simulations are performed with and without interactive chemistry. Without chemistry-climate interaction the AMOC is intensified in the course of the solar radiation reduction, which is attributed to the thermal effect of the solar forcing: reduced sea surface temperatures and enhanced sea ice formation increase the density of the upper ocean in the North Atlantic and intensify the deepwater formation. In simulations with chemistry-climate interactions a second, dynamical effect on the AMOC is identified which counteracts the thermal effect. This dynamical mechanism is driven by the stratospheric cooling in response to the reduced solar forcing, which is strongest in the tropics and leads to a weakening of the Northern polar vortex. In simulations with interactive chemistry, these stratospheric changes are strongly amplified by the reduction of stratospheric ozone. By stratosphere-troposphere interactions, the stratospheric circulation anomalies induce a negative phase of the Arctic Oscillation in the troposphere, which is found to weaken the AMOC through wind stress and heat flux anomalies in the North Atlantic. Neglecting chemistry-climate interactions in model simulations may therefore lead to an overestimation of the AMOC response to solar forcing.

DETECTION AND CHARACTERIZATION OF SMALL-SCALE HEATING EVENTS IN THE SOLAR ATMOSPHERE FROM 3D-MHD SIMULATIONS AND THEIR POTENTIAL ROLE IN CORONAL HEATING

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Aiming at better understanding the mechanism(s) responsible for the coronal heating we focus on analyzing the properties of the magnetically generated small-scale heating events (SSHEs) in the solar atmosphere. We present a comprehensive method to detect and follow SSHEs over time in 3D-MHD simulations of the solar atmosphere. Applying the method we are able to better understand the properties of the SSHEs and how the plasma in their vicinity responds to them. We study the lifetime, energy and spectral signatures and show that the energy flux dissipated by them is sufficient to heat the corona. Ultimately, these results will be important for the coordinated scientific exploration of SPICE and EUI along with other instruments on board Solar Orbiter.

Solar brightness variations on multiple timescales

Presenting Author: **Alexander Shapiro**

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We model the variability of solar brightness on timescales from minutes to decades. Calculations with the MURAM code, which performs 3D simulations of flows in the near-surface layers of the Sun, are utilised to model solar brightness variations linked to the convection. Brightness changes due to the solar surface magnetism are calculated with the SATIRE-S model relying on the high-cadence solar imagery from the Helioseismic and Magnetic Imager onboard the Solar Dynamics Observatory. We find that solar granulation and surface magnetic field can jointly explain solar brightness variations on all timescales it has ever been measured (albeit 5-minute oscillations from p-modes). We also present a comparison of our model to the empirical models of solar irradiance variations.

A new generation of Compact Lightweight Absolute Radiometers (CLARA) for space borne TSI observations

Presenting Author: **Benjamin Walter**

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Continuous and precise Total Solar Irradiance (TSI) measurements are indispensable to evaluate the influence of short- and long-term solar radiative emission variations on the Earth's energy budget. The existence of a potentially long-term trend in the suns activity and whether or not such a trend could be climate effective is still a matter of debate. The Compact Lightweight Absolute Radiometer (CLARA) is one of PMOD/WRC's future contributions to the almost seamless series of space borne TSI measurements since 1978. The overall goal of the CLARA experiment is to continue the TSI data record with high accuracy and precision. CLARA will be one of three payloads of the Norwegian micro satellite NORSAT-1, along with Langmuir probes for space plasma research and an Automatic Identification System (AIS) receiver to monitor maritime traffic in Norwegian waters. The launch of NORSAT-1 was planned for April 2016 but was postponed for an indefinite period due to unforeseen issues with the launcher. We present the design and calibration of CLARA, a new generation of active cavity Electrical Substitution Radiometers (ESR) comprising the latest radiometer developments of PMOD/WRC: i) A three-cavity design for degradation tracking and redundancy, ii) a digital control loop with feed forward system allowing for measurement cadences of 30s, iii) an aperture arrangement to reduce internal scattered light, iv) a new cavity and heatsink design to minimize non-equivalence, size and weight of the instrument. The ultimate goal when developing and building an absolute radiometer is to eliminate or minimize disturbing effects like the lead heating, diffraction or scattered light effect limiting the measurement uncertainty. These effects together with the basic radiometer properties like the aperture area defining the area of solar irradiance to be measured can be calibrated on a component-level to provide SI (International System of Units) traceability of the TSI measurements. Alternatively, a radiometer can be end-to-end calibrated against a SI-traceable primary standard cryogenic radiometer. We present both a component level calibration of CLARA providing an overview on the improvements that were achieved with the latest radiometer developments, and an end-to-end calibration of CLARA against the SI traceable cryogenic radiometer of the TSI Radiometer Facility (TRF) in Boulder (Colorado). The combined measurement uncertainty for the TRF calibrated SI-traceable CLARA flight instrument is 489 - 509 ppm (k = 1) depending on the measuring channel.

Strategies for effective monitoring of Total Solar Irradiance

Presenting Author: **Wolfgang Finsterle**

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Total Solar Irradiance (TSI) is the dominant source of energy in the Earth's climate system and the only significant input to the radiation budget of the planet. Even small changes in the TSI may affect the global temperature. Monitoring of the TSI is therefore essential to understand, reconstruct, and eventually predict natural climate change. PMOD/WRC follows a strategy for producing accurate and precise TSI time series from on a fleet of light-weight and relatively cheap TSI radiometers in space. The latest design of our CLARA (Compact and Light-weight Absolute Radiometer) focuses on easy adaptability to virtually any mission profile in order to increase the number of launch opportunities, while minimizing or even eliminating many known sources of measurement uncertainty. Currently there are three CLARA missions in active development; on the Norwegian micro-satellite NORSAT1, ESA's research and technology platform PROBA3, and the large Chinease Earth Observation (EO) mission FY-3E. By virtue of their monitoring purpose, EO programs often comprise a series of consecutive missions and are therefore particularly interesting for long-term TSI measurements. We will present the technical and operational concepts that make the CLARA design so flexible and how it is adapted to the three mission profiles of NORSAT1, PROBA3, and FY-3E. Furthermore we will provide an outlook on future improvements of the CLARA design to further reduce the measurement uncertainty.

An new observational solar spectral irradiance composite

Presenting Author: **Margit Haberreiter**

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Variations of the spectral solar irradiance (SSI) are an important driver for the chemistry, temperature and dynamics of the Earth's atmosphere and ultimately the Earth's climate. Due to the sparce and scattered SSI observations it is important to establish tools to derive a consistent SSI composite. Here we present such a composite that has been derived with a systematic apporach using all available observations, filling in periods of missing data and taking into account the time-dependent uncertainties of each indiviual dataset. The atmospheric response of the SSI composite is compared to the response of available reconstruction models.

X-ray observations of solar flares

Presenting Author: **Marina Battaglia**

Marina Battaglia [1]

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X-rays are one of the main diagnostics of particle acceleration, particle transport, and plasma heating in solar flares. I will give an overview of current research, present some highlights from 14 years of Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) observations and give a short outlook to the future of solar X-ray observations.

The e-CALLISTO network

Presenting Author: **Christian Monstein**

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A low cost solar radio spectrometer, CALLISTO and the network e-Callisto, are presented. CALLISTO is a frequency-agile receiver based on cheap, commercially available consumer electronics. Its major characteristic is the low price for hardware and software, and the short assembly time, two or more orders of magnitude below existing spectrometers. The instrument is sensitive at the physical limit and extremely stable. The native frequency range is 45 MHz up to 870 MHz, and the width of individual channels is 300 kHz. A total of up to 800 measurements can be made per second. The output of the spectrometer is stored in FIT-files, one per 15 minutes of observation. All files from all observatory sites are archived at a central data-server a FHNW in Switzerland and everyone has full access to all data back to 2002. The spectrometer is well suited for solar low-frequency radio observations pertinent for space weather research, radio monitoring and outreach. More than 120 instruments of the type were constructed until now and put into operation at 67 sites, distributed over the whole planet. Several copies of CALLISTO were put into operation in view of IHY and ISWI. A few representative antenna setups and recent observations, made at different locations are presented. Detailed information and data access here: http://e-callisto.org/

Solar Variability and its Effects on Earth

Jürg Beer, Eawag

The solar system consisting of eight planets orbiting around the central star, the Sun, was formed about 4.5 billion years ago. Since then the Sun played a fundamental role in the evolution of life on Earth and as the main driver of the climate system.

However, the Sun is also a variable star which changes many of its properties on time scales ranging from seconds to million of years. In spite of the impressive technological and scientific progress made during the past decades our understanding of the solar variability and its effects on Earth is still very rudimentary. Interestingly, it is also the technological progress which makes the modern society increasingly vulnerable to strong abrupt events on the Sun.

Constraining solar irradiance changes using ozone: Uncertainties and limitations

William Ball, PMOD/WRC

The magnitude of ultraviolet flux changes over the solar cycle is uncertain, despite decades of observations from multiple instruments. Solar flux changes directly impact stratospheric chemical concentrations and temperatures. Stratospheric ozone has also been observed for multiple decades and contains a solar cycle signal. Through our current understanding of how ozone concentration depends on solar ultraviolet flux, especially over the tropics, it is in principle possible to constrain the solar irradiance variability using ozone observations. However, there are large uncertainties that remain in such an approach, one of which depends strongly on the ozone data itself. We discuss differences and future work needed to resolve these uncertainties.

Decadal Climate Variability: the Role of the Stratosphere and the Ocean

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Abstract: Quasi-decadal variability in solar irradiance has been suggested to have substantial effects on Earth's climate at regional scales. In the North Atlantic sector, the 11-year solar signal has been proposed to project onto a pattern resembling the Arctic Oscillation/North Atlantic Oscillation which maximizes by a lag of a few years due to ocean-atmosphere coupling processes. However this relationship has not yet been supported by climate model simulations with realistic observed forcings. Its detection is further complicated since quasi-decadal fluctuations of the North Atlantic Oscillation can be intrinsically generated by the coupled ocean-atmosphere system.

Atmospheric dynamical investigations further suggest that the 11-year solar cycle synchronizes the internally generated quasi-decadal North Atlantic Oscillation variability through the downward propagation of the solar signal from the upper stratosphere to the surface. The results point out that both solar UV forcing as well as air-sea interaction processes are key influencing factors of quasi-decadal natural climate variability.