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Abstracts

Influence of Middle Range Energy Electrons on Atmospheric Chemistry and Climate

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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 chemistry-climate model with coupled ocean SOCOL3- MPIOM. The model simulations cover the 2002-2010 period for which ionization rates from the AIMOS dataset and observations on atmospheric composition by MIPAS are available. The results show that during the geomagnetically active period MEE produce significant increase of the amount of NOy and HOx in the polar winter mesosphere, in addition to the other particles and sources, resulting in local ozone decrease by up to 35 %. These changes are followed by an intensification of the polar night jet, as well as mesospheric warming and stratospheric cooling during geomagnetically active periods. The contribution of MEE also substantially enhances the difference in the ozone anomalies between geomagnetically active and quiet periods. The comparison with MIPAS NOy observations indicates that the additional source of NOy from MEE improves the agreement, however substantial underestimation above 50 km remains and requires better treatment of the NOy source from the thermosphere. Surface air temperature response is detected in several regions, with the most pronounced warming in the Antarctic during austral winter. Surface warming of up to 2 K is also seen over continental Asia during boreal winter.

Model CRAC:EPII for atmospheric ionization due to precipitating electrons: yield function and applications and comparison with a parametrization model

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A new model of the family of CRAC models - CRAC:EPII (Cosmic Ray Atmospheric Cascade: Electron Precipitation Induced Ionization) is presented. The model calculates atmospheric ionization induced by precipitating electrons and uses the formalism of ionization yield functions. The CRAC:EPII model is based on a full Monte Carlo simulation of electron propagation and interaction with the air. It explicitly considers various physical processes, namely pair production, Compton scattering, generation of Bremsstrahlung high energy photons, photo-ionization, annihilation of positrons and multiple scattering. Propagation of precipitating electrons and their interactions with air is simulated with the GEANT4 simulation tool PLANETOCOSMICS code using NRLMSISE-00 atmospheric model. Ionization yields are computed and compared with an analytical parameterization for various energies of incident precipitating electrons, using simulated fluxes of mono-energetic particles. The results from the simulations are collected in look-up table representing the ionization yield function that allows one to compute ionization due to precipitating electrons for a given altitude and location considering a given electron spectrum. Application of the model for computation of ion production during electron precipitation events using spectra from balloon-born measurements is presented.

Centennial reconstruction of energetic electron precipitation

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Energetic electrons precipitating (EEP) into the atmosphere are an important part of space environment with considerable interest, e.g., because of their impact on atmosphere and climate. The most systematic series of direct EEP measurements is provided by the polar orbiting NOAA/POES satellites, which have measured EEP for more than 3 solar cycles since 1979, and whose data have recently been recalibrated for various instrumental problems. The time interval covered by the NOAA/POES satellites is still far too short to study the centennial variation of EEP and its atmospheric and climatic effects. However, it is long enough to study the connection between EEP and solar/geomagnetic activity and its solar cycle variation, which yields the possibility to estimate EEP back in time using geomagnetic observations. Here we discuss the relationship between the EEP and the various measures of geomagnetic activity, and present a statistical model that allows us to estimate the precipitating energetic electron fluxes in three energy ranges (>30 keV, >100 keV and >300 keV) from the late 19th century to present.

A critical assessment of different sunspot number reconstructions using cosmogenic radionuclide archives

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Reconstruction of a homogeneous and reliable series of sunspot number (SN) from the available archives has been a topic of great interest. Different scientific groups produced their own SN records. However, these efforts are not free of uncertainties, since they are subject to different processing technics of independent observations. Here we use the version 2.0 of the international SN and four group SN series, by Hoyt and Schatten (1998), Lockwood et al. (2014), Svalgaard and Schatten (2015), and Usoskin et al. (2015) to reconstruct the open solar flux, then the modulation potential and lastly the production of cosmogenic radionuclides 14C and 10Be, inside the Earth's atmosphere, and 44Ti in meteorite bodies. The reconstructed production rates are then compared to the cosmogenic radionuclide archives. From this study we conclude that the group SN series showing lower levels of solar activity, during the period of Maunder and Dalton Minima, agree better with the archives of cosmogenic radionuclides.

Reconstruction of the heliospheric cosmic ray modulation in centennial scales: empirical modelling

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Solar magnetic activity affects the flux of galactic cosmic rays (GCRs) within the heliosphere, in a process called heliospheric modulation. This occurs through the interactions between GCR particles with the expanding solar wind, the heliospheric magnetic field (HMF) and the heliospheric current sheet (HCS). Reconstruction of the GCRs modulation in the past is important for the understanding of the behavior of the Sun on different time scales and to identify solar activity patterns. This requires realistic models that combine both theory and observations. Toward this direction, we have developed an empirical model to reconstruct the HCS tilt angle in the past, based on its cyclic behavior, as observed during the last solar cycles. We have also developed a semi-empirical model of GCRs heliospheric modulation by considering different heliospheric parameters. The model has been tested against the production of cosmogenic radionuclide, such as 14C and 10Be.

Structure of the photospheric magnetic field during sector crossings of the heliospheric magnetic field

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The heliospheric magnetic field (HMF) consists of sectors of either toward the Sun or away from the Sun oriented magnetic field lines, separated by the heliospheric current sheet (HCS). This HMF sector structure reflects the magnetic field of the solar corona, which has its origin in the underlying photosphere. Accordingly, as earlier studies have shown, the sector structure observed in the heliosphere, has a corresponding large scale structure in the photospheric field. Here we study the structure of the photospheric field expected to produce the HMF sector crossings observed at the Earth. We use the measured solar wind speed to calculate the transit time of the solar wind from the Sun to 1 AU. The sector crossings observed at Earth are mapped back to the photosphere to get the corresponding photospheric field structure. The photospheric field is obtained from the daily level-3 magnetograms measured at the Wilcox Solar Observatory from 1976 onwards. Earlier studies suggest that the HMF sector boundaries observed at 1 AU are often related to Hale bipolar regions in the photosphere. We analyze this correspondence separately in different solar cycle phases and for different solar cycles. We find that the structure of the photosphere corresponding to the HMF sector crossings, and the existence and properties of Hale bipolar regions varies significantly with solar cycle and cycle phase.

The Major Solar Eruptive Event in July 2012: Defining Extreme Space Weather Scenarios

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A key goal for space weather is to define severe and extreme conditions that might plausibly afflict human technology. On 23 July 2012 solar active region 1520 (∼133°W heliographic longitude) gave rise to a coronal mass ejection (CME) with an initial speed that was determined to be >3000 km/s. The eruption was directed away from Earth toward 144°W longitude. STEREO-A sensors detected the CME arrival only about 18 hours later (∼2055 UT) and made in situ measurements of the solar wind and interplanetary magnetic field. We have posed the question of what would have happened if this interplanetary event had been Earthward directed. Using a well-proven geomagnetic storm forecast model, we find that the 23-24 July event would almost certainly have produced a geomagnetic storm that was comparable to the largest events of the 20th Century (Dst ∼ -500nT). Using plausible assumptions about seasonal and time-of-day orientation of the Earth's magnetic dipole, the most extreme modeled value of storm-time disturbance would have been Dst=-1182nT. This is considerably larger than most estimates of the strength of the famous Carrington storm of 1859. This finding has far-reaching implications because it demonstrates that extreme space weather conditions such as those during March of 1989 or September of 1859 can happen even during a modest solar activity cycle (such as the one presently underway). It is argued that this extreme event could be utilized by the space weather community to assess likely severe space weather effects on technological systems such as the electric power grid.

Study of Joy's law based on Debrecen tilt angle datasets

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A refined form of the well known Joy's law has been formulated by using the new Debrecen tilt angle datasets. These data are compared with other tilt angle datasets and several determination methods help to make the material reliable. It has been found that the latitudinal distribution of the tilt angles is not merely a monotonously increasing function, but it has a plateau between the latitudes of about 15-25 degrees, where the toroidal field is the strongest. This may provide new constraints for the theoretical investigations about the mechanisms contributing to the observable tilt angles.

Impact of the solar tachocline on the long term magnetic cycle in a global MHD simulation

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Achieving long-term, cyclic magnetic modulations in global MHD simulations of the solar convection zone is proving to be difficult due to numerous aspects, both physical and numerical. The addition of a stably stratified layer underneath the convection zone proved to stabilize and enhance the solar magnetic cycle (Ghizaru et al. 2010). Recent studies indicate that the impact of this stable layer is quite considerable on the dynamics occurring in the convection zone (Lawson et al. 2015). In this presentation, I will show multiple simulations in which a single parameter in the stable layer has been modified with respect to our reference simulation. I will then elaborate on the consequences of such modifications on the simulation and demonstrate the necessity of having a stable layer in order to be a step closer to reproducing data similar to those collected from the Sun.

Some (Solar) surprises from studying (other) stars

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Despite decades of effort, we still do not have a universally accepted, predictive theory of how the Sun generates its cyclical magnetic field. Many distinct dynamical ”building blocks” – operating within the bulk of the convection zone, in the tachocline of shear at its base, or near the Solar surface – are widely thought to play roles. Both observations and numerical simulations are helping to build our intuition about how each of these processes may act, but many puzzles remain. I will review some of what we have learned about these ”building blocks” by studying dynamos in stars other than the Sun – and will comment on the implications these findings may have for understanding the magnetism of our nearest star, too.

Does a cosmic ray—cloud link operate at local spatial scales?

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A hypothesized link between the solar-modulated cosmic ray (CR) flux and Earth's cloud cover is still a debated topic in solar-terrestrial physics. Recently, the experimental and modeling studies suggest that influence of ion-induced nucleation on clouds is globally very small or negligible. Additionally, it was shown that the incorrect methods of assessing the statistical significance may have produced false positive results and erroneous conclusions in some past studies. However, there still remains an open question with regards to whether or not cloud properties are influenced by CR under some specific atmospheric conditions (i.e. second-order) and over limited areas where small variations in cloud condensation nuclei (CCN) may have a large impact on clouds. Such case may be marine stratocumulus clouds in areas of low aerosol concentrations that may be sensitive to small changes in CCN (e.g. as demonstrated by the phenomena of ship tracks). Using daily timescale epoch-superpositional (composite) analysis during Forbush decrease events, and robust Monte Carlo significance testing, cloud cover and properties are analyzed over oceans where such conditions occur with the aim of testing for an observable CR—cloud response. This work has been supported by the ESF project PoKRet and the Croatian Science Foundation project SOLSTEL.

The long term variability of the Sun: Physical processes and mechanisms

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In this talk I will present an overview of some of the possible physical processes which are responsible for the long-term variability of the Sun.

Recent Solar Spectral Irradiance Observations

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The knowledge of the solar spectral irradiance (SSI) and its variability are essential parameters for space weather and space climate studies. We present here recent SSI observations from the UltraViolet (UV) to the Near-InfraRed (NIR), performed by European instruments such as the PREMOS and SES radiometers onboard PICARD, the Virgo radiometer onboard SoHO, and the SOLSPEC spectrometer onboard the International Space Station. This contribution aims at presenting the final SSI product for each instrument, corrected for non solar features as well as for degradation, which could be used for space climate purposes. These SSI observations will be compared to other observational data sets, namely the SOLSTICE and SIM instruments onboard SORCE. While there is an excellent correlation for the UV spectral ranges, the level of confidence is rather low for the visible and NIR especially considering medium (< 5 years) and long time scales. Finally, the SSI observations will be directly compared to modeling data sets, such as SATIRE and COSI.

Examination of historical spectroheliogram archives

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Our knowledge of the evolution of the surface magnetic field of the Sun in the pre-satellite period is very limited. Further valuable information can potentially be provided by the full disc Ca II K specroheliograms that have been regularly recorded since 1907. Several such data sets have been digitized, but the data suffer from various problems including the lack of photometric calibration. We present a new method to account for most of the problems that affect historical Ca II K spectroheliograms and to perform photometric calibration of the images based on the information about the quiet Sun stored in them. We test the performance of the proposed method on synthetic images, obtained by introducing various artefacts into the modern spectroheliograms, and present preliminary results from the historical archives.

Enhancement of High Energy Electron Fluxes and the Variation of the Atmospheric Electric Field in the Antarctic Region

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High-energy electron precipitation in the high latitude regions enhances the ionization of the atmosphere, and subsequently increases the atmospheric conductivities and the vertical electric field of the atmosphere near the ground as well. The High-Energy Electron Flux (HEEF) data measured by the Feng-Yun III meteorological satellite are analyzed together with the data of near-surface atmospheric vertical electric field measured at the Russian Vostok Station.Three HEEF enhancements are identified and show that when the HEEF increases to a certain level, the local atmospheric vertical electric field near the ground can show some relative respose. The time of the response of the electric field to the HEEF enhancement is about 3.7 to 4 days (delaytime).

The new Sunspot Number in focus

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The release of the first revised version of the International Sunspot Number in July 2015 spawned a wave of regained interest for this unique record of the long-term solar activity.

In this talk, we summarize the primary corrections included in this first recalibration and also consider the remaining uncertainties and potential improvements to be considered for future work. As several new analyses were published recently, some of them even proposing alternate versions of the sunspot number series, we review the new ideas and methods that emerged and we discuss and analyze some flaws or weaknesses in those new attempts. We also illustrate why a clear distinction must be made between the sunspot number and the group number, in spite of their apparent similarity.

This welcome multiplication of new prototype series gives evidence of the rekindled vitality of this field of research but it does not lead (yet) to a completely convincing series and it illustrates the lack of consensus on key properties. In order to address this unsettled situation now and for future upgrades, we implemented a version-tracking scheme in the WDC-SILSO data archive and we launched the idea of a scientific advisory committee under the auspices of the IAU. We describe the current plans and status and conclude on some reflexions about conditions needed for constructive progress in this new framework.

Comparison of New and Old Sunspot Number Time Series

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Four new sunspot time series have recently been published: a backbone-based group number in Svalgaard and Schatten (2016; referred to here as SS; 1610-present), a group number series in Usoskin et al. (2016; UEA; 1749-present) that employs active day fractions from which it derives an observational threshold in group spot area as a measure of observer merit, an abbreviated provisional group sunspot series in Cliver and Ling (2016; CL; 1841-1976) that removed flaws in the Hoyt and Schatten normalization scheme for the original relative group sunspot number (RG; 1610-1995), and a corrected Wolf (international, RI) number in Clette and Lefèvre (2016; SN, 1700-present). Despite quite different construction methods, the four new series agree well after about 1900. Before 1900, however, the UEA time series is lower than SS, CL, and SN, particularly so before about 1885. Overall, the UEA series most closely resembles the original RG series. Comparison of the UEA and SS series with a new solar wind B time series (Owens et al., 2016; 1845-present) indicates that the UEA time series is too low before 1900. We point out incongruities in the Usoskin et al. (2016) observer normalization scheme and present evidence that this method underestimates group counts before 1900. In general, a correction factor time series, obtained by dividing an annual group count series by the corresponding yearly averages of raw group counts for all observers, can be used to assess the reliability of new sunspot number reconstructions.

Effects of the changing geomagnetic field on the atmosphere

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The strength and orientation of the Earth's magnetic field play an important role in the upper atmosphere, through effects on ionospheric conductivity, plasma transport processes, and Joule heating. The overall weakening of the Earth's magnetic field that has taken place over the past century, in combination with local changes in orientation, has had a significant effect on the climate of the upper atmosphere. I will give an overview of these climatic changes and the mechanisms responsible for them, based on simulations with the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model and the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM). Furthermore, recent simulations with the Whole Atmosphere Community Climate Model eXtension (WACCM-X) show that the mesosphere, stratosphere, and troposphere also respond to century-scale magnetic field changes, at least during December-January-February. It appears that these responses arise from dynamical processes that communicate the changes initiated in the upper atmosphere downwards via wave-mean flow interactions. These new results will also briefly be discussed.

Unexpectedly long-lived 1-million degree EUV fans, extending up to 3 solar radii

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The EUV telescope PROBA2/SWAP has been observing the solar corona in a bandpass near 17.4 nm since February 2010. SWAP's wide field-of-view provides a unique and continuous view of the extended EUV corona up to 2-3 solar radii. By carefully processing and combining multiple SWAP images, low-noise composites were produced that reveal large-scale, EUV-emitting, coronal structures. These extended structures appear mainly above or at the edges of active regions and typically curve towards the poles. As they trace out the 1-million-degree solar corona and persist for multiple Carrington rotations, they give an interesting view on how the coronal magnetic field is structured between 1.3 and 2-3 solar radii, in the gap between SDO/AIA's FOV and typical lower boundaries of coronagraph FOVs. With the help of magnetic field models, we analyse the geometry of the extended EUV structures in more detail and compare with sporadic EUV coronagraph measurements up to as close as 1.5Rs. The long-term evolution of the SWAP coronal fans over the rising phase and maximum of Solar Cycle 24 is analysed to catch a glimpse on what makes them appear or disappear. We also explore the opportunities that Solar Orbiter's future observations will bring.

Systematic regularity of hemispheric sunspot areas during solar cycles 9-24

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Solar magnetic activity varies with time in the two hemispheres in different ways. The hemispheric interconnection of solar activity phenomena provides an important clue to understanding the dynamical behavior of solar dynamo actions. In this report, several analysis approaches are proposed to analyze the systematic regularity of hemispheric asynchronism and amplitude asymmetry of long-term sunspot areas during solar cycles 9-24. It is found that, 1) both the hemispheric asynchronism and amplitude asymmetry of sunspot areas are prevalent behaviors and are not anomalous, but the hemispheric asynchronism exhibits a much more regular behavior than the amplitude asymmetry; 2) the phase-leading hemisphere returns back to the identical hemisphere every 8 solar cycles, and the secular periodic pattern of hemispheric phase differences follows 3+5 solar cycles, which probably corresponds to the Gleissberg cycle; and 3) the pronounced periodicities of (absolute and normalized) asymmetry indices and line of synchronization (LOS) are not identical: the significant periodic oscillations are 80.65, 20.91, and 13.45 years for the LOS values, and 51.34, 8.83/8.69, and 3.77 years for the (absolute and normalized) asymmetry indices. The analysis results improve our knowledge on the hemispheric interrelation of solar magnetic activity and may provide valuable constraints for solar dynamo models.

CIR-XL recurring for several years

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The heliospheric magnetic flux is determined from the radial component of the magnetic field vector measured onboard interplanetary space probes. Earlier Ulysses research has shown remarkable independence of the flux from heliographic latitude. Here we are investigating whether any longitudinal variation exist in the 50 year long OMNI magnetic data set. When determining the heliographic longitude of the plasma source, correction was applied for the solar wind travel time. Significant recurrent enhancements of the magnetic flux was observed during the declining phase of the solar cycles. These flux enhancements are associated with co-rotating interaction regions (CIR) lasting several years. The recurrence period is slightly faster than the Carrington Rotation rate. The same, long lasting recurring features can be observed when plotting the deviation angle of the solar wind velocity vector from the radial direction. However, the deviation angle is small - in order of a few degrees - and cannot account for the observed flux increases. An increase of the magnetic field is clearly caused by the plasma compression associated to CIRs. Comparing interplanetary data with synoptic maps of the coronal magnetic field (PFSS modell) and coronal temperature data of ACE, we came to the possible explanation that these long-term structures are caused by fast speed solar wind originating from coronal holes. This results supports the idea that magnetic field lines from coronal holes spread out and reach to low latitudes as well. The recurrent longitudinal variation of the magnetic flux during the declining phase of the solar cycle has impact on the modulation of cosmic rays as well as on the frequency and intensity of space weather events.

Long-lasting active longitude on the Sun and its terrestrial impac

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Heliospheric open magnetic flux was determined from the OMNI database. The fluxes were mapped back to the source surface of the solar wind. Significant recurrent enhancements of the flux were observed in the declining phase of cycle 23, lasting for several years. The recurrence time was slightly shorter than the Carrington rotation period. It is shown that the high magnetic flux is due to solar wind propagation effect, as a consequence of the plasma compression associated with slow wind-fast wind interfaces at CIRs. The open magnetic flux density correlates with disturbances in the terrestrial magnetic field, characterised by AA index. Therefore, recurrent structures in the AA index are also seen when the index is mapped back to the solar wind source surface. This finding suggests that space weather events may show periodicity of about 27 days during the declining phase of solar cycles.

Reconstruction and homogenization of the Wolf series from 1849 to 2015

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The Wolf series is not well documented. In particular, the original raw daily values of the sunspot group numbers, the numbers of individual spots, the calibration factors and the data reduction methods needed for a thourough homogenization testing and correction of the series are not known. For the published Wolf numbers of the years 1849 to 1877, we reconstructed the corresponding group and spot numbers and the k-factors used by Wolf to reduce the raw observation to his own scale, based on some unpublished manuscripts from the archive of the former Swiss Federal Observatory in Zurich and placed them on the website http://www.wolfinstitute.ch of the Rudolf Wolf Society. Thus, we published for the first time the hitherto unknown original observations of Rudolf Wolf with the 83/1320 mm Fraunhofer refractor and with the 40/700 mm Parisian refractor for the years 1855 to 1869. A statistical analysis revealed, that the observations of Rudolf Wolf remained stable for the years considered, but had significant lower scales than previously assumed. Based on some newly digitised observations of the years 1877 to 1894, we reconstructed for the years 1849 to 1893 the Wolf series backwards using Alfred Wolfer as primary standard observer. Thus, the effects of the known diminishment of Wolf's eyesight during the years 1877 to 1883 could be corrected, resulting in a considerable lowering of the level of the Wolf series before 1883. We introduced the scale of the Wolf series measured through the long-term ratio between the Wolf number and the group number as a new tool for homogenization testing and correction and found, that the Wolf series may be homogenized by reducing the long-term instrumental scales of each observer to the standard scale of Alfred Wolfer. In this paper we study the validity of this approach further, since it allows the calibration of individual sunspot countings without the need of comparing observations with a standard observer which simplifies the homogenization of the Wolf series considerably. Thus, we

correct the course of the Wolf series during the Waldmeier period 1945 to 1980 and recalibrate, based on some newly digitized original raw observations of the Zurich observers at the 83/1320 mm Fraunhofer refractor, the transition of the Zurich series to the International series for the years 1975 to 2015.

Long term variabilty of the solar dynamo

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We apply the test-field method to simulations of solar-like convection dynamo, which exhibit long term variability in the intensity and structure of the magnetic field as well as cyclic activity resembling the observed stellar behaviour. In particular the convection models include epochs, which resemble grand minima, extended periods of regular cycles and epochs when the parity between the northern and southern hemispheres switch between symmetry and anti-symmetry. Our aim is to apply the test field method to samples spanning each of these three epochs and to compare the structure of the dynamo. We expect to gain additional insight into the mechanisms, which drive the standard cyclic dynamo as well as how these are disrupted to give rise to long term anomalies. Further, we will apply the resulting test-field transport coefficients to the mean field dynamo model to examine the veracity of the mean field approach to explaining the dynamo.

Reconstruction of the long-term variations of the parameters and structure of the solar wind from geomagnetic data

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Due to the lack of hydrostatic equilibrium between the thermal expansion and gravity confinement, the solar corona is continuously expanding, filling the whole heliosphere with solar coronal plasma – the solar wind. Embedded in this background solar wind are transient structures like coronal mass ejections (CMEs) and high speed solar wind streams (HSS). The long-term variations of the parameters of the background solar wind and of the abundance and parameters of CMEs and HSS can provide, from the solar side perspective, information about the long-term variations of the solar activity and can place constraints on solar dynamo theories, and from the terrestrial side perspective – estimations of the solar influences on the Earth's system. Direct observations of the solar wind and its constituents are only available since the beginning of the "space era" in the sixties of the last century when in situ measurements became available by space-borne instruments. However the Earth, like the other Solar system planets, is all of the time bathed by the solar wind and its transients, which interact with the planet's magnetic field and disturb it. Here we demonstrate what information can records of geomagnetic activity give us about the parameters and structure of the solar wind.

The errors in sunspot group heliographic positions

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The errors in sunspot group heliographic positions available in web pages of National Data Geophysical Center are investigated. The analysis focused on the occurence of the outliers in extreme latitude and longitude deviations that are measured as the difference between the absolute maximum and minimum recorded heliographic positions. The histograms these deviations show that the groups always move less than five degrees in latitude and less than fifteen degrees in longitude. From the remaining groups about 85% contain the outliers in latitude or longitude positions. Moreover, about 90% of all errors are detected for years 1977-2014.

Extreme CME Events from the Sun

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Coronal mass ejections (CMEs) can be regarded as extreme events in terms of their origin as well as their heliospheric consequences if they meet certain criteria. These eruptions are expected to originate from the largest active regions possible on the Sun and associated with the largest X-ray flare with severe consequences: the largest solar energetic particle event, the fastest IP shock, the highest solar wind speed, and the largest geomagnetic storm. Historically, there were only 15 CMEs that had shocks reaching Earth in less than 24 h, including the Carrington event of 1859 September 1. This talk provides an overview of the largest historical events and a discussion on how extreme the CMEs can get based on extrapolations.

On the UV contrast of solar magnetic features and variations of small magnetic fields

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The knowledge of solar irradiance and its temporal variations is an important issue for climat modeling and space weather. However, mesurements of TSI and SSI are difficult and suffer from weaknesses (as, for example, insufficient temporal and spectral coverage) ; it is therefore necessary to model the TSI and SSI to obtain complete time series and to validate the observations. Irradiance models use magnetograms to distinguish the different magnetic structures of the Sun. The contribution of each structure is determined using a theoretical spectrum for each of these structures. The goal of our work is to put observational constraints on these theorical spectra at UV wavelengths. To do so, we use magnetograms from the HMI instrument onboard SDO and solar images at 30.4 nm, 160 nm and 170 nm from the AIA instrument, also onboard SDO. These data enable us to study the contrast of magnetic structures in function of their position on the Sun and of the value of the magnetic field. We also take advantage of this work to study the evolution in time of the noise of the solar magnetogram.

High-Intensity Long-Duration Continuous AE Activity (HILDCAA) and associated effects on Earth's outer radiation belt

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High-intensity long-duration continuous AE activity (HILDCAA) events have been shown to be associated mostly with high-speed solar wind streams (HSSs) [Hajra et al., JGR, 118, 5626, 2013]. These geoeffective events, by definition [Tsurutani and Gonzalez, PSS, 35, 405, 1987], have peak AE intensities > 1,000 nT and continue for more than 2 days when AE values do not drop below 200 nT for more than 2 h at a time. The events occur either in the recovery phases of the geomagnetic storms caused by corotating interaction region (CIR) or are independent of the storms. HILDCAAs are caused by the southward component of interplanetary Alfvén waves embedded within the HSSs. Recent studies show that HILDCAA events are associated with generation of relativistic (MeV) electron acceleration in the Earth's outer radiation belt [e.g., Hajra et al., GRL, 41, 1876, 2014]. The relativistic electrons are known as "killer electrons" for their hazardous effects to orbiting spacecraft. In the present talk, we will present a detailed study on the geomagnetic characteristics and interplanetary causes of the HILDCAA events as well as the solar cycle and seasonal dependences of the events. It will be shown that the ground-based AE observations during HILDCAAs may potentially be used to predict by > 1 day advance the acceleration of radiation belt relativistic electrons at geosynchronous orbit. Relativistic electron acceleration and decay timescales will be provided for wave-particle investigators to attempt to match their models to empirically derived values. The latter results can be found in Hajra et al. [ApJ, 799, 39, 2015].

Identifying and tracking solar coronal holes from synoptic EUV maps of SOHO/EIT and SDO/AIA images

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Coronal holes are regions of open magnetic field lines and the source of fast solar wind. understanding the evolution of coronal holes is critical for solar magnetism as well as for accurate space weather forecasts. Long-term occurrence of coronal holes gives important information for solar dynamo and space climate studies. Solar wind models are dependent on the size and location of the holes on the solar disk. Coronal holes are best seen in images of coronagraphs at the solar limb. On the other hand, coronal holes are rather difficult to determine on the solar surface, e.g., because they appear differently in different wavelengths. The size, shape, intensity and contrast of any given hole are not the same when using different observing filters. We study here the synoptic EUV images at three different wavelengths of 195/193 A,171 A and 304 A measured by SOHO/EIT and SDO/AIA instruments. We aim to identify the coronal holes from these images, using an automated routine based on the statistical properties of the measured pixel intensities and a dynamical division of images into sub-images. We present here the method and the first results obtained for coronal hole properties from these two databases.

Solar wind and sudden stratospheric warmings

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Sudden stratospheric warmings (SSWs) are caused by rapid amplification of atmospheric waves that are forced by large-scale mountain systems. These can lead to unusually cold weather over the central and eastern U.S. and Eurasia even as the Arctic and western U.S. warm. SSWs have become more frequent during the past two decades. This may be associated with increased autumn snow cover across Eurasia and more frequent negative polarity of the North Atlantic Oscillation (NAO). Although several theories examine why SSWs might occur, none explain why five major SSWs occurred during 1998–2002 but no major SSWs occurred in the Northern Hemisphere through nine consecutive winters of 1990–1998. Recent studies have shown that the NAO, Eurasian snow cover and the El Niño-Southern Oscillation may impact considerably on SSWs. However, what controls their variability? We present a chain of processes through which the solar wind as one of the possible drivers of inter-annual variability may affect the stratospheric polar vortex and climate variability. We show that at times of strong solar wind the stratospheric polar vortex strengthens and is centred near the North Pole while at times of weak solar wind and negative NAO phase the polar vortex weakens. Warm air from the subtropics is then carried into the Arctic and rapid amplification of planetary waves propagating upwards may cause displacement or even splitting of the weak vortex and increase the frequency of SSWs. When the vortex is pushed towards North America, strong meridional circulation allows more cold polar air to build up over North America and Eurasia and leads to very snowy winters and extreme weather events. Understanding relationships between the solar wind and climate variables has potential for improving seasonal weather forecasts.

A new method to estimate contributions of coronal mass ejections and high-speed streams to geomagnetic activity

L. Holappa[1], K. Mursula[1], T. Asikainen[1]

(1) University of Oulu

We study local geomagnetic indices from 26 stations using the principal component (PC) and the independent component (IC) analysis methods. We demonstrate that the annually averaged indices can be accurately represented as linear combinations of two first components with weights systematically depending on latitude.

We show that the annual contributions of coronal mass ejections (CMEs) and high speed streams (HSSs) to geomagnetic activity are highly correlated with the first and second IC. The first and second ICs are also found to be very highly correlated with the strength of the interplanetary magnetic field (IMF) and the solar wind speed, respectively, because solar wind speed is the most important parameter driving geomagnetic activity during HSSs while IMF strength dominates during CMEs.

These results help in better understanding the long-term driving of geomagnetic activity and in gaining information about the long-term evolution of solar wind parameters and the different solar wind structures.

An Examination of Two Definitions of The Coronal Hole Using High Speed Streams Events

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There are two definitions of coronal hole. One is that coronal holes are dark regions on the solar disk, observed from the EUV or the soft X-ray filter; the other one is that coronal holes are regions of fieldlines which extend far into the interplanetary space (also known as open magnetic regions). The center of coronal hole is thought to be the source region of high-speed streams. Therefore we estimate the locations of sources of high speed streams events, and compare them with the locations of coronal holes determined by the two definitions. Coronal holes of the first definition are determined from synoptic maps of SDO/AIA with 193A; coronal holes of the second definition are determined based on the Potential Field Source Surface (PFSS) model. The high speed streams events are selected from the ACE/RTSW data. For each event, we trace the particles of high speed streams back to the solar surface to estimate the position of the source. We check whether or not the central region of a coronal hole corresponds to the source of high speed streams. Result shows that coronal holes defined by the open magnetic regions have a better agreement to the sources of the high-speed solar wind.

Solar Extreme Events

H. Hudson[1]

(1) SSL/UC Berkeley

Solar Extreme Events

Hugh S. Hudson

The past few years have seen striking developments in the development of proxy information regarding extreme solar events, which I summarize here. These include the discovery of clear radioisotope signatures on the basis of annual averages in tree rings and corals, and the availability of systematic stellar photometry - including ”superflares” - from the Kepler satellite. I will put these into the solar context, which has gradually been growing more complete as the space age ages and data become more accurate.

Solar induced variability in the thermosphere over the last 70 years

L. Hunt[1], L.A. Hunt, J.M. Russell III, M. Mlynczak[1], The Saber Science Team

(1) NASA Langley Research Center

We have reconstructed the global infrared energy budget of the thermosphere going back now 70 years. The reconstructions are based on measurements of infrared cooling by the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on the NASA TIMED satellite. Standard solar and geomagnetic indices (F10.7, Ap, and Dst) are used in multiple linear regression fits to the observed SABER cooling rate time series. Extant databases of the solar and geomagnetic indices from 1947 are used to reconstruct the time series of radiative cooling by carbon dioxide and nitric oxide. This reconstruction allows us to examine the variability of the energy budget of the thermosphere over five complete solar cycles (19-23) and part of cycle 18. We find that the total energy radiated by the thermosphere is remarkably constant from one solar cycle to the next. The difference between the smallest and largest values in infrared thermospheric power over a solar cycle is less than 25%. The small differences in radiated power from one solar cycle to the next imply that the difference in "geoeffective solar energy" is also less than 25%. These results imply that, from the perspective of the thermosphere, and the energy deposited within it, that solar cycles are not really that much different from one to the next. We suggest that quantitative metrics such as the ones described here are necessary to fully assess the true nature of solar cycle strength and variability.

Variation of ultra-low frequency waves in solar wind and on ground over solar cycle 23

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We studied the ULF (ultra-low frequency) power at a ground magnetometer station of high latitude over the solar cycle 23 and its correlation with the ULF wave power within solar wind at L1. ULF waves affect several magnetospheric and heliospheric processes: they can dissipate, accelerate and redistribute particles, thus driving instabilities and heating gas.

We determined the ULF wave power in the near-Earth solar wind at L1 using data of MAG and SWE experiments on-board Advanced Composition Explorer (ACE) spacecraft and at Kevo ground station for years 1998–2008. The hourly power of the ULF waves was computed in the Pc5 frequency range 2–7 mHz. Correlation between the ULF power within solar wind magnetic field, the ULF power of solar wind speed and ULF power on ground was determined.

The correlation of the solar wind and ground ULF wave power was best in 2003 but it was strong for most of the studied period. The peak in ULF wave power was found to occur in late 2003 in both solar wind and on ground. The ULF power in winter exceeded the ULF power in other seasons, in particular during the declining phase of the solar cycle 23.

Reconstruction method of sunspot positions from observations of H. Flaugergues in the end of the 18th century

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The series of sunspot observations by Honoré Flaugergues covers the period 1788–1830. They were carried out in Viviers, France, but we have very scant knowledge of the type of telescope he used for his solar observations and few details of the technique applied. Typically, the observations of Flaugergues are transit times of the solar disc as well as of sunspots through different wires. We distinguish two approaches to the orientation of the wires: (a) a set of oblique wires and (b) two perpendicular wires. However, there is no information about the angular orientation, especially of the oblique wires, and about the direction of motion of the solar disc. We selected several individual observations to examine to what extent one can reconstruct positions of sunspots on the solar disk from the original notes. We show that the suggested method allows us to unambiguously extract sunspot positions and track them in successive observations. The obtained results demonstrate a very reasonable level of accuracy and consistency of Flaugergues's observations that makes further processing highly valuable for the understanding of the nature of solar activity in the period of the Dalton Minimum.

Statistics of tilt angles of bipolar solar regions

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We investigate various properties associated with the tilt of isolated magnetic bipoles in magnetograms taken at the solar surface. We show that bipoles can be divided into two groups which have tilts of opposite signs, and reveal similar properties with respect to bipole area, flux and bipolar moment. Detailed comparison of these physical quantities shows that the dividing point between the two types of bipoles corresponds to a bipole area of about 300 millionths of the solar hemisphere (MHS). The time-latitude distribution of small bipoles differs substantially from that for large bipoles. Such behaviour in terms of dynamo theory may indicate that small and large bipoles trace different components of the solar magnetic field. The other possible viewpoint is that the difference in tilt data for small and large bipoles is connected with spectral helicity separation, which results in opposite tilts for small and large bipoles. We note that the data available do not provide convincing reasons to prefer either interpretation.

Mechanisms for grand minima in dynamo active convectively turbulent flows

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(3) MPS Göttingen
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(5) HAO
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Direct numerical simulations have recently advanced to a level where solar-like dynamo solutions can be found. Some of these solutions exhibit also irregularities over time, and some grand minima type -events can be isolated. Even though the models are still operating in a parameter regime far from the real Sun, the models provide a laboratory for inspecting the possible mechanisms behind the irregular behavior. In this presentation, we discuss two different scenarios (turbulent convection with a solar-like dynamo solution and more rapidly rotating models with large-scale vortices) producing such events.

Variations in CME Deflection and Rotation over the Solar Cycle

C. Kay[1], N. Gopalswamy[1]

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Understanding the trajectories of coronal mass ejections (CMEs) is essential as they tend to be the drivers of the most significant space weather effects. This include accounting for any deflections, which can affect whether a CME impacts Earth, and rotations, which can affect the orientation of a CME's magnetic field. Using Forecasting a CME's Altered Trajectory (ForeCAT, Kay et al. 2013, 2015), a model for CME deflection and rotation based upon magnetic forces from the background solar magnetic field, we determine the variation in CME deflection and rotation throughout the solar cycle. Magnetic deflections cause CMEs to move toward the Heliospheric Current Sheet (HCS), away from coronal holes. Accordingly, the deflections should vary in magnitude and direction as the solar magnetic field increases in strength and the HCS becomes more inclined and the coronal holes extend to lower latitudes as the solar cycle proceeds from solar minimum toward solar maximum. We find that rotation tends to align CMEs with the HCS, and the amount of rotation increases near solar maximum.

Solar and Heliospheric Prerequisites For The Occurrence of Extreme Storms

E. Kilpua[1], N. Olspert, A. Grigorievskiy, Y. Liu, R. Kataoka, M. Käpylä, E. Tanskanen, H. Miyahara, J. Pelt

(1) University of Helsinki

In this presentation we will discuss the conditions at the Sun and in the interplanetary medium favorable for the generation of extreme space weather storms. Our analysis using an extensive geomagnetic index AA data set spanning over 13 solar cycles shows that the correlation between the storm occurrence and the strength of solar cycle decreases from a clear positive correlation with increasing storm magnitude towards a negligible relationship. Hence, also quieter Sun can launch super-storms (e.g., Carrington storm in 1859) and our results also suggest that extreme eruptions are related to the evolution of the toroidal component of the large-scale solar magnetic field. We will further discuss the “perfect storm scenario”, a combination of circumstances that lead to the unusually strong coronal mass ejection (CME) detected at the STEREO-A spacecraft on July 2012 and the importance of CME interactions with the ambient large-scale solar wind structures.

Prediction of long-term solar activities based on fractal dimension method

R.S. Kim[1]

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The fractal dimension is a quantitative parameter describing the characteristics of irregular time series. In this study, we use this parameter to analyze the irregular aspects of solar activity and to develop a method, which enables to predict the maximum sunspot number in the following solar cycle. For this, we consider various solar indices including sunspot numbers and total solar irradiance from the first solar cycle as well as several solar emissions of F10.7 (2.8 GHz), Lα and so on. We then estimate their cycle variations of the fractal dimension by using Higuchi's method (Higuchi 1988) and compare them to maximum sunspot number variation. As a result, we find that there are strong inverse relationships between the fractal dimensions of some solar indices and the maximum sunspot number. For each solar index, we try to understand how and why it shows its own irregularity expressed by fractal dimension. Our research can be used to establish a prediction method for the following solar cycle.

Ionization and NO production in the polar mesosphere during high speed solar wind streams

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(2) Korea Astronomy and Space Science Institute

High-speed solar wind streams (HSS)reaching the Earth have been identified as an important cause of energization and pitch-angle scattering of high-energy electrons in the magnetosphere. Statistical studies by satellite-borne instruments have demonstrated the characteristics of this effect in terms of integral fluxes for precipitating electron energies of several hundred keV. Statistical studies using riometers have provided an indication of the ionospheric response, but without height resolution. The new results presented here, first combine computations of ion production rate profiles with a mesospheric ion-chemistry model,to demonstrate consistence between the statistical energetic electron fluxes and the statistical riometer results. Then computed ionization/ion-chemistry profiles are combined with observations of cosmic-noise absorption to model electron density and NO production profiles during specific events. These are compared with incoherent-scatter, VHF-radar and satellite NO profiles from the Odin satellite. VHF-radar provides evidence for enhanced ionization reaching as low as 55 km in the mesosphere and lasting for up to 15 days after HSS arrival. For the case of several recurrent HSS in Austral winter 2010, strong increases of NO down to 75 km were observed over Antarctica about 10 days after the arrival of the HSS. These were of the same order of magnitude but slightly larger than could have been expected from direct production by energetic electron precipitation.

Modern Measurements of Solar Irradiances

G. Kopp[1]

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Solar irradiance variability on multi-decadal and multi-century timescales provides inputs for Earth climate research and for understanding secular variations in the Sun itself. Historical solar irradiance reconstructions based on indicators of past solar activity currently provide the best estimates of long-term solar variability. These historical reconstructions are tied to solar irradiance observations over the space-borne measurement record. The current 37-year uninterrupted measurements of total solar irradiance provide the best available knowledge of the energy powering Earth's climate system. Spectral solar irradiance measurements spanning the visible and near-infrared commenced 13 years ago and provide inputs to Earth atmospheric/chemistry models for understanding climate dynamics and to models of the solar atmosphere associated with different types of activity. The more modern instruments contributing to these records provide much higher levels of accuracy and stability than demonstrated by previous ones, and future instrument designs and calibration capabilities will improve the measurement record further. I will assess the existing total- and spectral-solar irradiance measurement records and discuss plans for future such measurements to improve these solar climate data records.

Polarity comparison between the coronal PFSS model field and the heliospheric magnetic field at 1 AU over solar cycles 21-24

J. Koskela[1], I. Virtanen[1], K. Mursula[1]

(1) University of Oulu

The solar coronal magnetic field forms an important link between the underlying source in the solar photosphere and the heliospheric magnetic field (HMF). The coronal field has traditionally been calculated from photospheric observations using various magnetic field models between the photosphere and the corona, in particular the potential field source surface (PFSS) model. Despite its simplicity, the sector structure predicted by the PFSS model generally agrees quite well with the heliospheric observations, and competes very well with the predictions of more elaborate models.

We make here a detailed polarity comparison between the predictions of the PFSS model and the HMF observed at 1 AU. We use the photospheric field measured at the Wilcox Solar Observatory (WSO), SDO/HMI, SOHO/MDI, and SOLIS, and the HMF measured at 1 AU collected within the OMNI-2 dataset. This database covers solar cycles 21-24. We use different source surface distances and different numbers of harmonic components in the PFSS model. We find an optimum polarity match between the coronal field and the HMF for source surface distance of 3.5 Rs. Increasing the number of harmonic components beyond the quadrupole (n=2) does not essentially improve polarity agreement. This indicates that the large scale structure of the corona, given by the lowest two harmonic components is responsible for the agreement with the HMF at 1 AU, while the small scale structure, given by the higher harmonic components, is greatly modified or damped away between corona and 1 AU. We also discuss the solar cycle evolution of polarity match and find that the PFSS model prediction is most reliable during the declining phase of the solar cycle.

A new database for solar irradiance datasets

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(1) LPC2E, CNRS & University of Orléans

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 have developed an irradiance database by assembling all available data and providing additional values to them. We first have identified and replaced gaps and outliers in irradiance datasets. We then have computed uncertainty on the short- and longer- time scale variability, refereed as precision and stability respectively. The aim of this work is to provide the community with a global and homogeneous assessment of the irradiance data. We will present the database and discuss the assumptions and methods used to quantify the uncertainty on the measured irradiance variability,

Why should we care about small flares ?

M. Kretzschmar[1]

(1) LPC2E, CNRS & University of Orléans

Solar flares radiate energy at all wavelengths, but are best observed at « hot » (coronal) wavelengths where the contrast is larger. Consequently, the flare classification relies on soft X-ray observations made by the GOES 0.1nm-0.8nm passbands. There are however evidence that most of the flare energy is radiated by the colder layers of the Sun, in particular in the chromosphere, and at longer wavelengths. We have investigated if the contribution of « chromospheric emissions » changes with the size of the flares as measured in Soft X-rays. We used high-cadence TSI measurements and chromospheric extreme-ultraviolet (EUV) observations by SDO/EVE and found evidences for a larger contribution of the chromospheric radiation when considering smaller soft X-ray flares. In other words, the ratio of chromospheric to coronal emission appears to increase when going from X-class flares to smaller flares. This study opens the way for a contribution of small flares to solar irradiance variations. We will detail our analysis and discuss its limitations and implications.

An empirical model of the solar irradiance Lyman-alpha profile

M. Kretzschmar[1], M. Snow[2], W. Curdt[3]

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(3) MPI for Solar System Research, Germany

The Lyman-alpha line is the strongest line of the solar spectrum and considerably affects the interplanetary medium and the atmosphere of planets. The full Sun (irradiance) Lyman-a profile has been measured only occasionally. The SUMER instrument onboard SOHO has measured this irradiance profile by observing the scattered Lyman-a light. We used this measurements to parametrize the line profile and developed a proxy model of its evolution in time. We will detail the model construction and its performances, and present time-series of the Lyman-a profile in time.

Reconstructions of past solar irradiance

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State-of-the-art models relating variability of the solar irradiance to solar surface magnetism are quite successful in reproducing measured irradiance changes, where these latter are reliable. Extrapolation of the models into the past is, however, aggravated by the lack and the poorer quality of the appropriate proxies of solar magnetic activity. Thus reconstructions of the past irradiance changes have to rely on less detailed, less reliable and more indirect data. An overview of the current knowledge of solar irradiance variability over the last millennia will be given.

Hemispheric Asymmetry of Solar Cycle Activities

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(1) Nagoya University

The prolonged last solar minimum and current weak maximum suggest that the recent solar activity shows some peculiar features of dynamo compared to that in the previous several decades. In this talk, we will focus on the symmetricity of solar dynamo with respect to equator, and discuss about the relationship between the hemispheric asymmetry and the variability of solar activity in order to understand the cause of the recent peculiar cycle. First, we review the observational studies of hemispheric asymmetries for various structures and dynamics; sunspots, polar magnetic field, integrated photospheric magnetic field, solar flares, solar wind and heliospheric current sheet, etc. These observations indicated that the solar activities systematically create the hemispheric asymmetries. Second, based on the flux transport dynamo model, we try to explain the cause of the asymmetry from the theoretical point of view. The numerical simulations indicate that the competitive action between the dipole-type component and the quadrupole-type component of magnetic field determines the asymmetry. The asymmetry inherently appears as a result that the dynamo solution falls into one of the two different attractors, in which the cycle phases of the dipole-type and quadrupole-type components shift a half of pi from each other. Finally, on the basis of the reviews for observations and theories, we will discuss about the causal relationship between the hemispheric asymmetries and the peculiarity of solar cycle.

Coronal Mass Ejection over Solar Cycles 23 and 24: a statistical view

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It is now well established that coronal mass ejections (CMEs) play a major role in the heliosphere, starting from the corona to interplanetary space and interacting with planets, possibly impacting their climate. The almost uninterrupted observations by the LASCO coronagraph onboard SOHO since January 1996 have allowed an unprecended view of CMEs over almost two solar cycles 23 and 24. The ARTEMIS-II catalog based on their automatic detection on high-quality calibrated synoptic maps of the corona offers an unbiased dataset free of selection effects. It is thus possible to perform an unbiased statistical analysis of their properties and investigate how they evolve with solar activity. We will present the results for occurence and mass rates, waiting times, position angle, angular width, kinetic energy, and mass flux first globally and then separately for the two solar cycles 23 and 24 emphasizing the differences. We will further compare the statistical properties of CMEs with those of the standard indices of solar activity such as the international sunspot number (SSN), the sunspot area (SSA) and the radio flux at 10.7 cm (F10.7) as well as those of their potential progenitors, flares and eruptive prominences.

Uncertainties in the Sunspot Number

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The International Sunspot Number (SN) recently underwent an extensive makeover (Clette et al., 2014, 2015,2016). In this context, a first estimation of the error bars related to this well-known measurement of solar activity was added. Uncertainties are important for a statistical assessment of the sunspot number records, and they are crucial for properly merging multiple observations into one single composite record (Dudok de Wit et al., 2016).

Few studies have investigated uncertainties in the SN, as they are difficult to estimate. Uncertainties can belong to different categories. Accuracy (differences in absolute calibration and instrument bias) and stability ,(associated with long-term drifts), are taken care of by the k-factors, and are not in the scope of this study. We focus on the effect of random errors, which are usually associated with precision and repeatability, namely how close independent measurements are when made under identical conditions.

These random errors can be inferred from a time series analysis of SN records, we call these time domain errors, and they are mostly related to the precision. A second type of error arises when comparing different observers, and considering their dispersion.

Here we present these time domain errors and dispersion errors and study their comparative behaviours to understand where they stem from and how to infer them for different sunspot series (Sunspot Number, Number of groups, Number of spots) and over different timescales (daily, monthly and yearly series).

Interestingly, at high SSN, it seems it is not the Sun that is dominating the uncertainties, but observational errors. At first glance we could say that at high SSN, the grouping of different active regions between observers might create this bias. As it turns out, the number of spots presents the most similarities with the level of uncertainties: the ability of observers to count all the spots is put to the test during high activity phases.

Recovering a sunspot catalogue for the period 1914-1920 from Madrid

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We have made a machine-readable version of the sunspot catalogue made by the Spanish astronomer M. Aguilar from 1914 to 1920 in the Astronomical Observatory of Madrid. Although various catalogues containing information on sunspots and sunspot groups have been available for almost 150 years, the contents and conventions can vary greatly from one source to another. Thus, availability of multiple sources is very important to assess the relative uncertainties in the identified quantities. This recovered catalogue presents an invaluable source of comparison with the Royal Greenwich Observatory (RGO) data, and helps shed more light on the link between the RGO sunspot group classification and the more modern classifications of sunspot groups.

Properties of butterfly diagram wings since the early 19th century

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The latitudinal evolution of sunspot emergence over the course of the solar cycle, the so called butterfly diagram, is a fundamental property of the solar dynamo. We use sunspot group data from two sources, the RGO/USAF/NOAA(SOON) compilation of sunspot groups in 1874–2015 and the sunspot groups in 1825–1867 from the recently digitized sunspot drawings by Samuel Heinrich Schwabe. These data allow us to study the properties of the butterfly diagram wings during sunspot cycles 7-10 and 12-23. We present a new, robust method to separate the hemispheric wings based on long gaps in sunspot group occurrence. Separation of wings allows for a more detailed study of solar cycle evolution compared to the common way of studying solar cycles. We analyse the individual wings with respect to their number of groups, their lengths, the overlap of successive wings, and the hemispheric differences between the northern and southern wings. We find, e.g., that: - The cumulative number of sunspot groups within a wing is around 50-100% more intense during the Modern Grand Maximum (cycles 18-20) than in the 19th century (cycles 7-10). - The overlaps of two successive wings are systematically longer in the northern hemisphere for cycles 7-10, and in the southern hemisphere for cycles 16-22. - There is a hemispheric asymmetry in the total number of sunspot groups in the wings, which depicts a long-term variation with a roughly centennial period, superimposed by a sub-dominant shorter (roughly 5-cycle) oscillation.

Modulation of Solar Wind Energy Flux on Global Tropical Cyclone Activity

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Studies on solar-climate connection have been conducted by several decades, however, most of them focused on the effects of solar total irradiation energy. As the second major terrestrial energy source, solar wind energy flux exhibits a more significant long-term variation, such as 11 years. However, its link to the global climate change is rarely concerned and still unclear. Tropical cyclone activity, acting as a fundamental and important aspect of the Earth's weather and climate system, has been causing more and more attentions. Here we show the close relationship between the total energy flux input from the solar wind into the Earth's magnetosphere and the long-term variation of the global tropical cyclone activity during 1963–2012. From the global perspective, the duration and accumulated cyclone energy both increase gradually since 1963 and start to decrease after 1994. Compared to the nearly invariable solar irradiation, the ever-increasing sea surface temperature and the El Nino/Southern Oscillation, the solar wind energy flux represents a better correlation with the global tropical cyclone activity. Furthermore, the tropical cyclone is more intense when the geomagnetic activity was more active.

Examining the forces and kinematics of coronal mass ejections in the interplanetary space

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Coronal mass ejections (CMEs) are highly energetic solar eruptive events. They are the main driver of space weather disturbance. If they reach Earth, they can cause hazard and disruptions to modern life. Therefore, the prediction of their arrival at Earth is an important subject in the space weather research. An accurate prediction of when and whether a CME would reach Earth relies on a correct formulation of the equation that governs its motion. One commonly used prediction method is drag-based model. It is formulated under the assumption that the CME propagation through the interplanetary space is governed by drag forces alone, with all other forces negligible. This assumption has never been justified, and may not be valid because any object that experiences only drag force would eventually stop relative to the background medium. The objective of this work is to test the validity of this assumption, and to clarify the role the drag force plays in the CME kinematics. We use a physical model implemented with a complete equation of motion to compute the forces acting on a CME fluxrope during its propagation from the Sun to Earth. The results can reveal how different forces change with the distance from the Sun.

Coronal Magnetic Field Energy Storage: Limits on the Size of the Largest Eruptions

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The question of whether so-called superflares (energies from 1e33-1e35 ergs) could occur on the Sun is of great interest scientifically. There are also obvious practical (space weather) implications. Shibata et al. (2013) suggested that flares on the order of 1e34 ergs could occur every 800 years on the Sun, while Schrijver et al. (2012) argued that the magnetic energy for such a flare would require a sunspot 20 times greater then ever observed, and that 1e33 ergs was a practical upper limit for flares.

Major solar eruptions such as X-class flares and very fast coronal mass ejections originate in active regions on the Sun. The energy that powers these events is believed to be stored as free magnetic energy (energy above the potential field state) prior to eruption. Therefore, the maximum free energy that can be stored in an active region bounds the largest possible eruption that can emanate from it. Using line-of-sight or vector magnetograms, the maximum energy that can be stored in a region can be estimated with the aid of the Aly-Sturrock theorem. We have investigated the active regions where the largest flares in the last 30 years have originated. We have found six cases where the maximum free energy is on the order of or greater than 1e34 ergs. Our results suggest that 1e34 erg solar flares cannot be ruled out based on magnetic energy storage.

Sunspot databases of the Debrecen Observatory

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We present the sunspot data bases and online tools available in the Debrecen Heliophysical Observatory: the DPD (Debrecen Photoheliographic Data, 1974 -), the SDD (SOHO/MDI-Debrecen Data, 1996-2010), the HMIDD (SDO/HMI-Debrecen Data, HMIDD, 2010-), the revised version of Greenwich Photoheliographic Data (GPR, 1874-1976) presented together with the Hungarian Historical Solar Drawings (HHSD, 1872-1919). These are the most detailed and reliable documentations of the sunspot activity in the relevant time intervals. They are very useful for studying sunspot group evolution on various time scales from hours to weeks. Time-dependent differences between the available long-term sunspot databases are investigated and cross-calibration factors are determined between them.

QBO-dependent relation of geomagnetic activity and northern annular mode during the 20th century

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Several earlier studies have shown that geomagnetic activity (GA) affects the winter-time northern annular mode (NAM), the dominant circulation pattern in the Northern Hemisphere during winter. GA in this instance is considered to be a proxy for energetic particle precipitation into the atmosphere. It has also been found that the quasi-biennial oscillation (QBO) modulates the relationship between GA and NAM. However, some of the earlier studies in this regard have been mutually conflicting, with some studies suggesting a stronger positive relation in the easterly phase of the QBO, while other studies suggest a stronger positive relation in the westerly phase of the QBO. Here we study the QBO-GA-NAM relationship using a QBO reconstruction covering the whole 20th century. We find that the QBO modulation of the GA-NAM relation is temporally variable, which explains the earlier, seemingly differing results. Positive GA-NAM relation is observed in the late winter and easterly QBO phase at 30 hPa during the whole 20th century. We also find that the QBO at 30 hPa represents the Holton-Tan relation for the surface circulation better than QBO at 50 hPa, and that the Holton-Tan relation is only observed during early/mid winter, while an anti-Holton-Tan relation is found in the late winter for strong geomagnetic activity. These results emphasize the variable but systematic response of NAM to energetic particle precipitation during the entire 20th century, and underline the importance of considering the preconditioning of the atmosphere when studying the solar-related effects upon climate.

Surface flux transport simulations. Inflows towards active regions and the modulation of the solar cycle.

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Aims. We investigate the way near-surface converging flows towards active regions affect the build-up of magnetic field at the Sun's polar caps. In the Babcock-Leighton dynamo framework, this modulation of the polar fields could explain the variability of the solar cycle. Methods. We develop a surface flux transport code incorporating a parametrized model of the inflows and run simulations spanning several cycles. We carry out a parameter study to test how the strength and extension of the inflows affect the amplitude of the polar fields. Results. Inflows are seen to play an important role in the build-up of the polar fields, and can act as the non-linearity feedback mechanism required to limit the strength of the solar cycles in the Babcock-Leighton dynamo framework.

The Hallstatt and Eddy Cycles in Solar Activity over the past 22 Millenia

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The Hallstatt (∼2300 y) and Eddy (∼975 y) Cycles are the longest authenticated periodicities in the 10Be and 14C cosmogenic data covering the past 10,000 years. Examination of those records shows that the maxima in the Hallstatt cycle in the cosmogenic data corresponds to recurrent episodes of Grand Minima (low solar activity) such as that which occurred in the interval 1050 - 18200 CE (the Oort, Wolf, Spoerer, Maunder and Dalton Grand Minima). On the other hand, the Hallstatt minima in the cosmogenic data correspond to extended periods (∼1000 y) with few or no Grand Minima (persistent high amplitude solar cycles). That is- the Hallstatt cycle as observed in the cosmogenic data indicates that there is a 2300 y periodicity in the amplitude of the 11y cycle in solar activity. The temporal resolution of the cosmogenic data decreases prior to 13,000 BP however other archives such as sea floor sediments provide adequate resolution to augment our studies of the Hallstatt and Eddy cycles further into the past. We examine the persistence and phase stability of these periodicities over the past 22 millenia.

The Onset Phases of Large Grand Solar Minima

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The annual cosmogenic 10Be and 14C data show that the onset phases of both the Maunder and Spoerer Grand Minima took the form of five 11 year cycles in intensity superimposed on a steady secular increase that extended over >50 y. We have previously shown that the ratio of the maximum to minimum of the heliospheric magnetic field (HMF) during the 11-year cycles during the Maunder Minimum was similar to the present day value. We examine the 10 largest Grand Minima during the past 10,000 y and find that slow onset phases extending over a number of solar cycles are a common feature. This suggests that the solar magnetic fields in the solar dynamo diminish in strength in a gradual but predictably persistent manner over 4-5 solar cycles at the commencement of large Grand Minima. By way of comparison, the return to substantial solar activity appears to be more rapid (~2 solar cycles). We conclude by summarising the experimental facts that must be met by any model of the solar dynamo that is proposed to explain the long term behaviour of solar activity.

Total solar irradiance as measured by the SOVAP radiometer during the solar cycle 24

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From the SOlar VAriability Picard (SOVAP) data, we obtained a new time series of the Total Solar Irradiance (TSI) from 2010 to 2014. These TSI observations will be compared to others observational data sets, namely the TIM radiometer onboard SORCE, PREMOS onboard Picard, and VIRGO/DIARAD onboard SoHO. We will also perform a direct comparison between the SATIRE-S semi-empirical model and the SOVAP data. Finally, we will perform a comparison between the Solar Spectral Irradiance (SSI) at 782 nm as measured by the SES sensor onboard Picard and the TSI as measured by the SOVAP radiometer.

Multiradionuclide evidence for the solar origin of the cosmic-ray events of AD 774/5 and 993/4

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The origin of two large peaks in the atmospheric radiocarbon (14C) concentration at AD 774/5 and AD 993/4 is still debated. There is consensus, however, that these features can only be explained by an increase in the atmospheric 14C production rate due to an extraterrestrial event. Here we provide evidence that these peaks were most likely produced by extreme solar proton events, based on several new annually resolved 10Be measurements from both Arctic and Antarctic ice cores. Radionuclides are produced in the atmosphere through different reaction pathways which require incoming particles of different energies. We thereby use ice core 36Cl data in pair with our 10Be dataset, both radionuclides having different peak response energies, to show that these solar events were characterized by a very hard energy spectrum. These results imply that the larger of the two events (AD 774/5) was at least five times stronger than any other solar event recorded during the satellite era. Our findings highlight the importance of studying the possibility of severe solar energetic particle events and to better assess their occurrence probability.

The rails inside the Sun and the butterflies that ride them

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One of the biggest obstacles we face for understanding the solar cycle (and the dynamo that drives it) is our lack of information regarding the structure and evolution of the internal magnetic field. One of the most important puzzles that remains unsolved is the nature of large-scale magnetic flux transport; namely the relative importance of advective transport (meridional flows) vs. turbulent transport (diffusion and pumping). In this presentation we will review recent studies that use the characteristics of the solar cycle butterfly wings to address this question. In particular we will discuss the fact that all hemispheric cycles follow the same latitudinal path, and decay the same way. These results suggest a dynamo that is insensitive to meridional flow variations and which is operating in a very high diffusivity regime. Putting these results together, we will discuss the factors that determine a hemispheric cycle's amplitude and finalize with the implications this has for solar cycle prediction.

Asymmetry in the solar hemispheric poloidal and toroidal cycles

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The hemispheric solar cycles are different in their time profiles and intensities. It can be observable an alternating variation of the time profiles which means that the northern activity leads during four Schwabe cycles while the southern one leads during the next four cycle. This variation can also be recognized in the magnetic field reversal data which indicates that this is a long term property of the entire solar dynamo mechanism. My latest results based on the Greenwich Photoheliographic Results and Debrecen Photoheliographic Data which cover cycles 12-24 extended by the earlier Staudacher's and Schwabe's data as well as the data of Spörer covering cycles 1-4 and 7-10 and 10-11.

HCS shift over 100 years

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Heliospheric current sheet (HCS) is the continuation of the coronal magnetic equator into space, dividing the heliospheric magnetic field (HMF) into two sectors. Because of its wavy structure, the HCS is also called the ballerina skirt. Several recent studies have proven that the HCS is southward shifted during about three years in the declining to minimum phase of the solar cycle. This persistent phenomenon of the HCS southward shift, also called the Bashful ballerina, has been verified by several different data bases, including the satellite measurements of the HMF since 1960s collected in the OMNI data, by the Ulysses, Pioneer and Voyager probes in different parts of the heliosphere since mid-1970s, by ground-based and satellite observations of the photospheric magnetic field by several different instruments since mid-1970s, by the properties of solar polar jets, etc. Moreover, the geomagnetic observations of the daily variation at high latitudes can be used to study this phenomenon before the satellite era, now over roughly the last 100 years. Here we review these observations and discuss the evolution of the HCS shift in time, as well as its implications.

The New Sunspot Number Series in Comparison to Cosmogenic Radionuclide Based Solar Activity Reconstructions

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The solar modulation of galactic cosmic rays leads to variations in the production rates of cosmogenic radionuclides such as 10Be and 14C. These particles can be measured in tree rings (14C) and ice cores (10Be), and thus be used for solar activity reconstructions far back into the past. However, cosmogenic radionuclides are not only influenced by solar variability but also by climate effects on the deposition processes into natural archives. Such climate effects have led to disagreeing 10Be records for the past centuries and to disagreeing reconstructions of solar activity based on cosmogenic radionuclides. Records from Greenland ice cores appear to indicate a strong increase in solar activity during the recent centuries while Antarctic records indicate high but not exceptional solar activity during the second part of the 20th century. Here, we review the available 10Be records with respect to their agreement and disagreement with the new sunspot number series. The new sunspot number series agrees very well with previously published and updated 14C-based as well as Antarctic 10Be-based reconstructions of past solar activity

Strong variations of 14-C around AD 775 and AD 1795 - due to solar activity

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The strong 14-C increase in data with 1-yr time resolution in the AD 770s (e.g. Miyake et al. 2012) is still a matter of debate, e.g. a solar super-flare. In the last three millennia, there were two more strong rapid rises in 14-C - around BC 671 and AD 1795, all embedded in similar evolution of solar activity, as we can show with various solar activity proxies; secular evolution of solar wind plays an important role. The rises of 14-C - within a few years each - can be explained by a sudden strong decrease in solar modulation potential leading to increasing radioisotope production. The strong rises around AD 775 and 1795 are due to three effects: (i) very strong activity in the previous cycles (i.e. very low 14-C level), (ii) the declining phase of a very strong Schwabe cycle, and (iii) a phase of very weak activity after the strong 14-C rise - very short and/or weak cycle(s) like the suddenly starting Dalton minimum.

For the AD 770s, we critically review all known oriental and occidental aurora reports from AD 731 to 825 and find 39 likely true aurorae. There were two aurorae in the early 770s observed near Amida (now Diyarbakir in Turkey near the Turkish-Syrian border); they indicate a relatively strong solar storm. However, it cannot be argued that those aurorae (geo-magnetic latitude 43 to 50 degrees) could be connected to solar super-flares causing the 14-C: There are several reports about low- to mid-latitude aurorae at 32 to 44 degrees in the 760s and 790s in China and Iraq - always without 14-C peaks. We can reconstruct the Schwabe cycles around AD 774/5 with 14-C and aurorae, then we can show that AD 775 lies in the declining phase of a previously strong Schwabe cycle. There is also a lack of aurorae from about AD 774 to 793; from investigating all historic reports about celestial phenomena in that period, we could not find any unusual.

We also discuss the frequency of super-flares on sun-like stars as observed with the Kepler satellite and compare it with the Sun.

In addition, we show that the recent 10-Be data with quasi-annual time resolution (Miyake et al., Sigl et al.) cannot be considered as evidence for a solar super-flare, partly because of strong variations from data set to date set, so that the systematic Be-10 errors and/or timing errors are large.

Telescopic sunspot observations by Marius and others 1611-1620

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To investigate whether we now enter a Maunder-like grand minimum, we have to compare the current situation with the time around the start of the Maunder minimum. Sunspot observations in the 1610s are of particular importance and relevance, because they are shortly before the start of the Maunder Grand Minimum. While the Maunder Minimum is usually dated from 1645 to 1715, Vaquero & Trigo (2015) argue that what they call the "Extended Maunder Minimum" would have started in 1618 during or around a Schwabe cycle minimum around that time. We have studied the sunspot record of that time in detail.

Hoyt & Schatten (1998) present lists with information about sunspot detections (number of groups) and spotlessness (as well as non-observations) for all observers they found - based partly on previous compilations by Wolf. Recent solar activity studies for the past four centuries are based on their compilation. In addition to 12 observers listed by Hoyt & Schatten (1998) for the 1610s, we see at least six more astronomers with datable spot observations. Furthermore, while Hoyt & Schatten (1998) argue that Simon Marius would have observed from mid 1617 to the end of 1618 almost every day, but would have never seen a spot, we can show with the original reports by Marius that he observed since Aug 1611 with a lot of sunspot detections until fall 1617, and that he found much less spots from fall 1617 to spring 1619. The data base by Hoyt & Schatten (1998) has more errors in the 1610s, as we show for Harriot, Scheiner, Malapert, Saxonius, and Tarde. We also compare drawings from Jungius with the observations by Harriot, Galilei, and Marius. In contrast to what is specified in Hoyt & Schatten (1998), Marius and Schmidnerus are among the earliest datable telescopic sunspot observers (since 1610 Aug 3, Julian).

It is undispensible to go back to the original observational records (written often in Latin). We discuss diverse problems with the historic transmission

- especially we point to the fact that drawings are embedded often in text corpus, which has to be consulted for full and correct understanding and further information. Even generic statements like those by Marius can be very fruitful: the statements by Marius allow to constrain the timing of first telescopic Schwabe cycle.

The active day fraction is high from 1611 to 1616 (1.0 to 0.9), but then drops to much lower values 1617 to 1620. Telescopic sunspots records by Malapert from 1618 to 1621 show that the last low-latitude spot was seen in Dec 1620, while the first high-latitude spots were noticed in June and Oct 1620 (based on reports and drawings), so that the turnover from one Schwabe cycle to the next (minimum) took place around that time, also consistent with records about naked-eye spots and likely true aurorae.

Solar active regions complexity effects on Geo-Space environment

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We employ the Mount Wilson Classification to study the effect of solar Active Regions (ARs) magnetic complexity on Geo-Space environments. Magnetic field of the sun is disturbed in ARs and these areas frequently host solar explosive activities, such as solar flares and coronal mass ejections (CMEs). Mount Wilson scheme classifies ARs based on their magnetic topology from the more simple one (α) to the most complex one (βγδ). Several studies have been shown that the stronger flares and CMEs which play a crucial role in the space weather prediction, are mostly associated with more complex regions. In this study, we compared our substorms list with magnetic complexity data to analyze the ARs magnetic complexity effect on the near-Earth magnetic activity.

N-S asymmetry of the solar magnetic field from polar jets

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Solar jets observed with the Extreme Ultra-Violet Imager (EUVI) and COROnagraphs (COR) instruments aboard the STEREO mission provide a tool to probe and understand the magnetic structure of the corona. Since the corona is a low-beta plasma environment, jets during their propagation trace the magnetic field lines. We discuss the North-South asymmetry of the magnetic field of the Sun as inferred from measurements of the deflection of polar coronal hole jets when they propagate throughout the corona. We measured the position angle at 1 and at 2 solar radii for the 79 jets based on the STEREO ultraviolet and visible observations, and we found that the propagation is not radial. The average jet deflection is studied both in the plane perpendicular to the line of sight, and, for a reduced number of jets in the three dimensional (3D) space. The deflection of jets results to be larger in the North than in the South, with an asymmetry which is consistent with the N-S asymmetry of the heliospheric magnetic field inferred from the Ulysses in situ measurements.

A trigger for «non-triggered» substorms. A role of ULF waves

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In our previous study it was shown that substorms might occur under parameters of the interplanetary magnetic field (IMF) conditions typical for undisturbed days ("non-triggered substorms"). Meanwhile, amplitudes of geomagnetic fluctuations in Pc5/Pi3 (1-4 mHz) frequency range is several times higher for these days than for non-substorm days. The present study is undertaken into analysis of fluctuations of the magnetic field parameters in the interplanetary space and magnetosphere in order to reveal the origin of the observed pre-substorm variations registered in high-latitude ground observations and examine a role of ULF waves in energy transfer from the solar wind to the magnetosphere.

Centennial variations in the heliosphere

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Direct spacecraft measurements of the solar wind and heliospheric magnetic field have been performed near-continuously for the over 60 years. The solar wind is seen to vary over all observed time scales, from sub-seconds to decades, with strong evidence of secular trends. In order to fully assess the longer-term variations, it is necessary to use proxy data. Approximately 170 years of geomagnetic data can be used to provide extremely accurate reconstructions of the near-Earth solar wind speed and the heliospheric magnetic field intensity on annual time scales, and consequently the open solar flux. Prior to 1845, it is necessary to go to more indirect proxies for solar wind conditions. Sunspot number can be used with simple empirical relations and open solar flux modelling to provide estimates of the near-Earth conditions back to $\sim$1610. Of course, such reconstructions are only as accurate as the sunspot records which underpin them, but by taking an ensemble approach, the uncertainties can be both reduced and quantified. Extending further back in time is possible through the use of cosmogenic isotope records in natural reservoirs such as tree trunks and ice cores. Teasing out the solar wind signal requires detailed modelling of the Earth system and hence the time resolution is generally sub-annual and the uncertainties greater than with geomagnetic and sunspot methods. Nevertheless, the long-term evolution of the solar magnetic field can be inferred over nearly 10,000 years.

Long term variability in solar cycle and particle fluxes as measured by NOAA POES

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The Medium Energy Proton and Electron Detector (MEPED) onboard the Polar Orbiting Operational Environmental Satellites (POES) consists of two proton telescopes, one viewing nearly radially outward from Earth (the 0o detector) and the other viewing antiparallel (Space Environment Monitor-2) or perpendicular (SEM-1) to the satellite's velocity (the 90o detector). The detectors experience radiation damage and become degraded after a couple of years. The satellites operational period is often more than 10-15 years. In order to prolong the quantitatively use of the data, it has been of major importance to correct the energy thresholds with time. By comparing accumulated integral flux from a new and an old satellite at the same magnetic local time (MLT) and time period, Sandanger et al. [2015] established a set of correction factors for 4 of the SEM-2 satellites. Based on these correction factors, Ødegaard et al. [2016] found that the rate of degradation depended on both the solar cycle and the flux measured by the detector. Using this dependence, they established an important method that has the power of correcting the entire NOAA POES dataset independent of comparable simultaneous satellites. More than 2 solar cycles of corrected proton flux data is here presented and evaluated.

Mechanisms for producing Grand Minima: a short review

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The sunspot record shows that in the mid of the 17th century our Sun underwent a grand minima episode, the so called Maunder Minimum. During this period, solar magnetic activity reached historical low amplitudes with signs of disruption of the sunspot cycle. Moreover, solar activity reconstructions based on cosmogenic isotopes suggest that this type of quiescent magnetic activity periods are recurrent in our star and occur in average every 2 to 3 thousand years. This means that grand minima episodes are a typical characteristic of the dynamic system behind the solar magnetic field, i.e. the dynamo process. This in itself represents a challenge to theory.

In this talk I'll briefly review some of the physical mechanisms that can contribute to the occurrence of grand minima. As we will see, most of the mechanisms are model dependent but one thing that almost have in common is that they need some source of perturbation to trigger grand minima.

Interpreting irradiance distributions of sub-resolved magnetic structures using high-resolution 3D MHD simulations

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We present initial results of studies aimed at understanding the impact of the unresolved magnetic field distribution on the solar spectral radiative output of one-arcsecond pixels typical of full-disk imaging. Using high-resolution 3D MHD simulations (from MURaM code) and spectral synthesis (with the RH code), we examine the emergent spectra at wavelengths spanning from visible to infrared of atmospheres computed with differing imposed mean magnetic fields. Decomposing the simulations into one-arcsecond photospheric patches (pixels), we examine the underlying magnetic substructure consistent with the same pixel mean-field measurement and the corresponding variation in spectral output. We present in detail the distributions of the pixel substructure intensities and magnetic field over specified wavelength bands and the implications for irradiance modeling.

Latitudinal variation of geomagnetic activity in solar cycle 24

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Geomagnetic observations in Greenland have been analyzed for the ascending phase and sunspot maximum of the solar cycle 24 (2010-2014). Large magnetic field disturbances were observed although the solar cycle 24 has been the weakest in terms of the sunspot number in roughly a hundred years. Large magnetic field gradients (dH/dt) are measured throughout the examined time interval, the spring of 2012 being the most disturbed one. The most disturbed latitudes are located around 72 degrees (geomagnetic latitude) for all seasons as well as deep in the polar cap around 85 degrees. The latitudinal coverage of the disturbances is largest in summer. Then seasonally averaged disturbances of 0.10 nT/s or more are observed at 9 stations out of 13, covering latitudes from 65 to 84 degrees. While in winter only four stations, covering mainly latitudes 71 to 72, measure average disturbances of 0.10 nT/s or more. The annual changes are largest in the southernmost Greenland station NAQ and smallest in the northernmost station THL. Furthermore, the monthly disturbances at the station Bear Island (BJN) in the Scandinavian International Monitor for Auroral Geomagnetic Effects (IMAGE) magnetometer network show about two thirds of the disturbances in Greenland when taken from the same geomagnetic latitudes i.e. at station Kangerlussuaq (STF). As a follow up to this study we will continue to investigate latitudinal variation by means of new measurements. These will include newly digitalized measurements from several sources.

Can we study Coronal Mass Ejections without a coronagraph?

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SoHO with LASCO has provided us an invaluable tool to observe and study the CMEs for more than 20 years, STEREO has improved such observations by adding, together with the coronagraphs, a heliospheric imager. However, SoHO is an old mission and from the two STEREO spacecraft we have just one left. Also, it is uncertain when a new mission with similar capabilities will be available. How would we be able to know when a CME is happening if we don't have a way to observe it? We propose to use EUV global waves as a proxy to characterise CMEs.

The Future of Solar Activity Forecasts

W.D. Pesnell[1]

(1) NASA

Solar activity forecasts range from minutes to decades. The long-term forecasts are needed for spacecraft planning and electrical grid construction. One example is the accurate orbits needed to avoid collisions in the increasingly crowded orbits near the Earth. That makes predicting the drag on satellites in low-Earth orbits one of the most important uses of these forecasts. Solar activity comes from the Sun's magnetic field, which is generated by the solar dynamo. A true understanding of the solar dynamo would allow us to predict when and where flares will occur as well as the level of solar activity years into the future. We have anticipated the level of activity in upcoming cycles since the 11-year sunspot cycle was identified in 1843. The last four sunspots cycles have had many published predictions using a wide variety of methods. But all of the cycles had a wide range of predicted amplitudes. I will talk about the current state of solar cycle predictions, the skill of the predictions of Solar Cycle 24, and anticipate how those predictions could be made more accurate in the future.

Solar-cycle Variability of Coronal Mass Ejections and the Solar Magnetic Field

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Coronal mass ejections (CMEs)cause the most dangerous space weather effects on Earth. Compared to cycle 23, CMEs with angular widths >30° have been observed to occur at a higher rate during solar cycle 24, per sunspot number. According to two CME catalogues that cover the LASCO/C2 and C3 fields of view, the enhanced CME rate began shortly after the cycle 23 polar field reversal, in 2004, when the photospheric polar fields returned with a 40% reduction in strength and the interplanetary radial magnetic field became about 30% weaker. This result is consistent with the link between anomalous CME expansion and the heliospheric total pressure decrease reported by Gopalswamy et al. The contrasting solar magnetic field and CME statistics of cycles 23 and 24 provide an opportunity to explore further the cycle-dependence of CME behaviour.

Long-term trends in chromospheric activity

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Long-term synoptic observations of the Sun in the resonance line of Ca II K, H-alpha and several other "chromospheric" spectral lines form the fundamental databases for a variety of retrospective analyzes of the state of the solar magnetism. The regular observations of Ca II K began at the end of 1904 at the Kodaikanal Observatory in India (their intensity calibrated data set starts in 1907), and in 1915 at the Mount Wilson Observatory (MWO), USA. The MWO observations were stopped in 1985, and the Kodaikanal observations continued with at least three different setups till mid-2013. In early 1970s, the National Solar Observatory (NSO) at Sacramento Peak (USA) started a program of daily Sun-as-a-star observations in the Ca II K line. The Sac Peak observations stopped on 1 November, 2015, and the time series is now continued using SOLIS/ISS observations. Historical observations in H-alpha spectra line (filtergrams and drawings) were used to identify the large-scale flux systems and the neutral lines of large-scale magnetic field in solar chromosphere. In addition to study of long-term variations in the chromospheric activity, the H-alpha data contribute to understanding the polar field reversals in past cycles, and the origin of sectors in the interplanetary magnetic field. We will discuss the proxies of solar chromospheric activity derived from these data, and present various long-term trends found in these proxies over the period of several solar cycles.

The impact of Space Climate and Weather on the Atmospheric Global Electric Circuit (GEC)

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Atmospheric electricity is one of the oldest fields of research in the geophysical sciences, dating back to the 1700s when the first electric fields were detected in the atmosphere. In the 1920s the Carnegie research vessel made many measurements of the potential gradient above the oceans, and found a universal diurnal variation in the electric fields, independent of geographical location and local time. It was proposed that these fields were related to global thunderstorm activity. With the discovery of ions in the atmosphere, atmospheric currents were also detected flowing continuously to the Earth. Then with the discovery of the ionosphere, a schematic model was developed describing the Earth-ionosphere system as a charged spherical capacitor, with a leaky dielectric between the plates of the capacitor. The global circuit is now known to be influenced by phenomena on many different spatial and temporal scales. In this presentation connections between space climate/weather and the global electric circuit will be presented, derived from ground-based measurements conducted in Israel.

Long-term changes in the magnetosheath: Solar wind drivers and magnetospheric effects

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We investigate the long-term variability of the solar wind - magnetosphere - ionosphere coupling focusing especially on the anomalously quiet period during the deep solar minimum in 2008-2010. Using several coupling functions described in the literature, we focus on the long-term changes in the solar wind driving and the dependence of the driver functions on the long-term variability of the individual plasma and interplanetary magnetic field characteristics. As all plasma entering the magnetosphere is processed through the bow shock and the magnetosheath, their properties add to the complexity of the solar wind - magnetosphere coupling. Data from the THEMIS 5-spacecraft mission processed in the magnetosphere - interplanetary medium reference frame is used to demonstrate that the magnetosheath properties also exhibit long-term variability associated with the solar cycle evolution, and study their solar wind parameter and driver function correlation. Especially, we focus on the Poynting flux component normal to the magnetopause, which is a measure of the energy input from the magnetosheath into the magentosphere. The IMAGE magnetometer chain extending from Estonia to Svalbard with good latitudinal coverage is used to examine the long-term variability of the geomagnetic activity, and correlate the results with those observed in the magnetosheath and in the solar wind.

Yearly storm rates in 1933-2014

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The classical storm index, the Dst index, has recently been extended to cover the years since 1932. We use the newly constructed Dxt index (extended Dst index) to study the properties of magnetic storms in 1933-2014. In particular, we study the annual occurrence of storms of different intensity and compare the long-time variation of their relative occurrence fractions. We also classify the storms according to their drivers since 1964, and study the absolute number and the relative fraction of storms of different size related to the main drivers, coronal mass ejections and high-speed solar wind streams.

The dynamo origin of solar spectral irradiance variations

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Solar spectral irradiance variations are the end result of a series of processes beginning with dynamo generation of the magnetic field, continuing with the evolution of the field by interaction with convection and its concentration into semi-descrete structures in the solar photosphere, and ending with the consequent reconfiguration of the solar atmosphere. The relative importance of these processes to spectral variability likely depends on the wavelength of the radiation being considered. We present some recent developments that illustrate these processes and their influence on solar radiative output: recent global dynamo models which suggest that bolometric variability may be induced by cyclic modulation of large scale convective transport, photospheric modeling and observations which indicate that the spectral output of magnetic elements depends on their magnetic environment, and controversial spectral irradiance measurements that agree with simple arguments based on magnetic field dependent changes in the mean atmospheric stratification. We conclude by suggesting that future progress in understanding the solar origin of spectral irradiance variations requires moving beyond current sun-as-a-star TSI and SSI measurements, instead employing a new generation of telescopes capable of radiometric imaging.

Long-term trends in properties of sunspots

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We present measurements of sunspot intensity, area, and magnetic field strength from 1999 until 2016. We analyze a sample of 400 sunspots and compare the present cycle 24 with the previous one. We observed full Stokes maps of sunspots at high spatial resolution in the near infrared using the Tenerife Infrared Polarimeter at the German Vacuum Tower Telescope, the GREGOR Infrared Spectrograph, and the Facility Infrared Spectropolarimeter at the Dunn Solar Telescope. The magnetic field strength is derived from the Zeeman splitting of Stokes-V profiles. We take into account the center-to-limb variation of umbral intensities and apply a correction to compensate the variation of magnetic sensitivity of different spectral lines. We used then the homogenized sample to study the cyclic and long-term variations in sunspot parameters. The field strength and brightness of sunspots show a cyclic variation with the phase of the solar cycle. Comparing statistics of all spots, we find that on average sunspots in cycle 24 have a magnetic field strength some 80 G weaker than in the previous cycle. We discuss implications of this long-term trend for the properties of sunspots in the next cycle.

The first documented space weather event that perturbed the communications networks in Iberia

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In this work we review the first space weather event that affected significantly a number of communications networks in the Iberian Peninsula and that took place on 31th October 1903 (during the ascending phase of solar cycle 14, the lowest since the Dalton Minimum). We describe the widespread problems that occurred in the telegraph communication network in both midlatitude countries (Portugal and Spain), that was practically interrupted from 09:30 to 21:00 LT. Different impacts on telegraphic communication are described and shown to be dependent on the large-scale orientation of the wires. Moreover, in order to put these results into a wider context we provide measurements of the concurrent geomagnetic field that are available from the observatories of Coimbra (Portugal) and San Fernando (Spain) and confirm the simultaneous occurrence of large geomagnetic disturbances. In particular, the magnetograms recorded in Coimbra show a clear and large amplitude storm sudden commencement (SSC) around 04:30 LT. The main phase (with a H maximum range of $\sim$420 nT) started approximately one hour later and lasted for almost 10 hours, suggesting that the IMF was strongly southward for long time.

Extreme Space Weather Events: Probabilities and Uncertainties

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(1) Predictive Science

Extreme space weather events, such as the Carrington event of 1859, are, by definition, rare. Because of this rarity, estimating their rates of occurrence, as well as the uncertainty associated with these estimates, can be difficult, if not impossible. This is compounded by the fact that an event may be considered extreme with respect to one parameter, but not to another. In this talk, I review our best probabilistic estimates for the likelihood of another Carrington event (or worse) occurring within the next decade. This depends crucially on an assumption concerning how the events are distributed in severity. To address this, we consider: power-law, log-normal, and stretched-exponential distributions. Although there is considerable variability, we estimate the probability of another Carrington event occurring within the next 10 years to be 2-12%. This suggests that Carrington-type events are, at most, as likely to occur as other so-called “100-year” catastrophes. Unlike most other disasters, however, the societal consequences of another Carrington-like event will likely be felt globally, not merely regionally.

Treatment of the sun-related effects in climate and atmospheric models: status and development

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The interest to the solar influence on climate was enhanced by widely discussed possibility of the grand solar minimum emergence in the 21st century. Several papers describing the simulations of the future climate changes caused by a weakening of the solar activity have been already published. The results demonstrate general consensus in the obtained global mean temperature changes, while the disagreement on regional/seasonal scales is substantial. The reasons of this disagreement could be related to the applied scenarios for the solar forcing agents and different treatment of the sun-related effects in climate models. It is well known that the simulation of the climate response to solar variability requires well defined set of forcing agents, properly designed modules to transform direct solar effects to internal model variables and model ability to reproduce entire chain of the physical processes responsible for the propagation of the initial effects in time and space. Many of these aspects have been under active evaluation leading to better understanding of the climate response to solar variability and more accurate projections of solar impact on future climate. In this talk I will review the recent progress reached in several directions including the refinement of the spectral solar irradiance variability, importance of middle range energy electrons, treatment of the auroral electrons, galactic cosmic rays and extreme solar proton events, accuracy of the heating and photolysis rates calculation codes as well as the representation of top-down mechanism of solar impact propagation. I will also discuss potential implications of these developments on future climate projection.

Terrestrial effects of the extreme solar energetic particle event of 774-775 AD

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A severe solar energetic particle storm, which took place in 774-775 AD, was the greatest one over at least 11 millennia. This offers a unique opportunity to test the existing models and assess a potential impact on the Earth's atmosphere for a realistic worst case scenario. Here we present a systematic analysis of this severe event using the available data and up-to-date models. First we reproduce the observed variability of cosmogenic isotope 10Be in four different ice cores from Greenland and Antarctica, thus confirming the validity of the models and the assessment of the event. We present evidence, by the shape of the 10Be signal that the event likely occurred during the boreal autumn season. Next, we calculated the amount of nitrate deposited in polar ice cores and compared those with the observations. We show that, contrary to some earlier claims, even such an extreme solar storm cannot produce a notable nitrate deposition spike. Finally, we assess the possible effect of this uniquely strong event on the Earth's atmosphere and found that it could greatly perturb the polar stratosphere for several years and to modulate the surface weather during the subsequent northern hemisphere winter.

Solar Influence on the Earth's Climate on Centennial Time Scale

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At the beginning of the 21st century the Earth's global temperature trend decreased leveling almost 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 19th and 20th 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. However the timing and spatial pattern of the Earth's climate response allows distinguishing the CGC forcing from other climate forcings.

Superflares on Sun-like Stars

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Many stars show flares similar to solar flares, and often such stellar flares are much more energetic than solar flares. The total energy of a solar flare is typically 10^{29} - 10^{32} erg, whereas there are much more energetic flares (10^{33} - 10^{38} erg) in stars, especially in young stars with rapid rotation. These are called superflares. Recently, Kepler observations revealed that superflares with energy of 10^{34} – 10^{35} erg (100 – 1000 times of the largest solar flares) occur with frequency of once in 800 – 5000 years on Sun-like stars with slow rotation, which are similar to our Sun. These superflares are usually associated with large spots with area A = 10^{3} – 10^{5} in unit of one millionth of solar hemisphere, much larger than normal sunspots (with area A= 100 – 1000) on the Sun. Spectroscopic observations by Subaru telescope confirmed that some of the Sun-like stars have actually large spots and slow rotation. It has become clear that superflares can occur on slowly rotating Sun-like stars because very large star spots can be generated in these slowly rotating stars, though frequency is very small. We review recent progress of the observations of superflares on Sun-like stars with some discussion on the theory of superflares.

Characterization of grand minima in a spherical-2D non-kinematic mean-field dynamo model

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Recent progress in the development of global MHD simulations of solar convection has significantly improved our understanding of the solar dynamo. However, even for the longest-duration extant such simulations, it is not yet possible to properly characterize the long-term variations of the magnetic cycles developing therein. In this context, we construct a non-kinematic axisymmetric mean field dynamo model where the Lorentz force is implemented on the azimuthal flow component and act as the saturation mechanism for the dynamo. This new model also covers a full meridional plane and includes a full alpha-tensor in addition to the differential rotation profile, both both extracted from Eulag-MHD(HD). The resulting dynamo models support a wide range of magnetic solutions where intermittency, amplitude modulation and grand minima are observed. I will present solutions showing some of those features along with its corresponding torsional oscillation.

Estimates of the ice edge position in the Barents sea mirrors the solar activity since 1579.

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The first oil-boom in Europe was based on oil from whales captured north of 79N in a period of reduced sea ice in the Arctic 1680-1790. The near extinction of the bowhead whale stock near Svalbard during this time was followed by a period of rapid increase in the extent of summer (August) sea ice commencing around 1790, when the ice edge moved some 500 km southwards to the southern tip of Spitsbergen (around 76N) within just av few years. This coincided with the Dalton solar activity minimum. The period of heavy summer ice lasted until approximately 1910, after which the ice again retreated northward. Since the 1980s the summer ice edge has once again occurred north of 80N, and bowhead whales are back north of Svalbard. Based on logbooks from whalers and early explorers, supplied by airplanes and satellites in modern times, it has been possible to estimate the location of the ice edge between Svalbard and Franz Josefs land (20-45E) for the period 1579 -2015. The location of the ice edge mirrors the solar activity, showing the Maunder and Dalton minima, and a shorter minimum around 1910 before the modern maximum with a peak after 2000. The ice edge correlates with the Hoyt Schatten TSI reconstruction calibrated with ACRIM satellite data (r=0.66) from about 1720. Subtraction of an ice-edge-TSI model shows a linear movement of the ice edge one degree north per century, which may be interpreted as an effect of the precession of the Earth's orbit. Before 1720 there are gaps in the data,. The ice edge was often far south between 1610 and 1720, but there were years within the Maunder minimum with very little ice, either due to increased solar activity or special climate conditions.

The effect of weighting and group over-count on the Sunspot Number.

L. Svalgaard[1]

(1) Stanford University

Although Brunner began to weight sunspot counts (from 1926), whereby larger spots were counted more than once, he compensated for the weighting by not counting enough smaller spots such as to maintain the same reduction factor (0.6) as Wolfer to reduce the count to Wolf's original scale. Waldmeier in 1947 formalized the weighting (on a scale from 1 to 5) of the sunspot count made at Zurich and its auxiliary station Locarno. This counting method inflates the relative sunspot number over that which corresponds to the scale set by Wolfer (and matched by Brunner). I re-counted some 60,000 sunspots on drawings from the reference station Locarno and determined that the number of sunspots reported were 'over counted' by $\sim$40% on average, leading to an inflation (measured by an effective weight factor) in excess of 1.2 for high solar activity. In a double-blind parallel counting by the Locarno observer Cagnotti, we determined that my count closely matches that of Cagnotti's, allowing us to determine from direct observation the daily weight factor for spots since 2003 (and sporadically before). The effective total inflation turns out to have two sources: a major one (15-17%) caused by weighting of spots and a minor one (3-4%) caused by the introduction of the Zurich classification of sunspot groups which increases the group count by 7-8% and the relative sunspot number by half that. We find that a simple empirical equation (depending on the activity level) fits the observed factors well, and use that fit to estimate the weighting inflation factor for each month back to the introduction of effective inflation in 1947 and thus to be able to correct for the over-counts and to reduce sunspot counting to the Wolfer method in use from 1893 onwards.

Calibration of the Sunspot and Group Numbers Using the Waldmeier Effect

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The Waldmeier Effect is the observation that the rise time of a sunspot cycle varies inversely with the cycle amplitude: strong cycles rise to their maximum faster than weak cycles. The shape of the cycle and thus the rise time does not depend on the scale factor of the sunspot number and can thus be used to verify the constancy of the scale factor with time as already noted by Wolfer (1902) and Waldmeier (1978). We extend their analysis until the present using the new SILSO sunspot number (version 2) and group number and confirm that the scale factors have not varied significantly the past 250 years. The effect is also found in sunspot areas and in an EUV (and F10.7) proxy (the daily range of a geomagnetic variation). The result is that solar activity reached similar high values in every one of the (17th,) 18th, 19th, and 20th centuries, supporting the finding that there has been no modern Grand Maximum.

Evolution of Alfvénic fluctuations during solar cycle 23

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Solar wind high-speed streams carry interplanetary magnetic field fluctuations in different time scales and different periodicities. We examine solar wind Alfvénic fluctuations (ALFs) and how they evolve over the solar cycle 23. Alfvénic solar wind fluctuations are found throughout the solar cycle, but they are fastest, most frequent and geo-effective in the declining phase of the cycle, when the number of high-speed streams at the Earth´s vicinity increases rapidly. We find a rapid transition from the predominance of slow (< 400 km/s) ALFs in 2002 to fast (> 600 km/s) ALFs in 2003, in coincidence with the rapid increase of substorm activity from late 2002 to early 2003. The Alfvénicity of solar wind increased by 40% from 2002 to 2003. After the transition the fast ALFs occur twice per solar rotation while in previous year only four fast ALF intervals were detected. Increase of solar wind Alfvénicity by 40% from 2002 to 2003, and transition from slow to fast Alfvén fluctuations coincide with the increase of auroral substorm intensity by 28% and substorm frequency by 43%.

Solar influence on North Atlantic climate

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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. This relationship has however not yet been univocally 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. In a recent study, we compared two fully coupled multi-decadal ocean-atmosphere chemistry-climate simulations which either included or suppressed solar forcing variability. While the North Atlantic Oscillation index displayed a quasi-decadal variability mode in both experiments, the one including the 11-year solar cycle showed a statistically significant solar/North Atlantic Oscillation index coherency lagged by 1-2 years. Atmospheric dynamical investigations further suggested 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 troposphere – or "top-down" mechanism. We will further discuss our findings with regard to the recent investigations of the solar signal in the CMIP5 historical simulations, which revealed no significant NAO response to the solar cycle. Finally, we will propose future research directions which may help to improve our understanding of solar influences on the stratosphere and regional climate.

Reconstruction of Photospheric Plasma Motions and Eddy Magnetic Diffusivities in Solar Active Regions

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(1) Université de Montréal

The Resistive Minimum Energy Fit (MEF-R; Tremblay & Vincent, 2014) is a method to infer photospheric plasma motions from magnetic field reconstructions, Doppler shift observations and a Lagrangian minimization. An eddy magnetic diffusivity accounting for subgrid fluctuations is also adjusted. We present a study of AR12158 using SDO/HMI data from September 10 to 13 2014. This active region produced an X1.6 solar flare on September 10 2014 with an associated Earth-directed coronal mass ejection. Inferred vertical flows match the observed Doppler velocities. We examine the correlation between microturbulent velocities and inferred eddy magnetic diffusivities.

Mesospheric ozone destruction by high-energy electron precipitation during pulsating aurora

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Energetic particle precipitation into the atmosphere is known to create excess amounts of odd nitrogen and hydrogen. These in turn destroy mesospheric and upper stratospheric ozone in catalytic reaction chains, either in situ at the altitude of energy deposition, or indirectly after transport to other altitudes and latitudes in the case of odd nitrogen, which has long lifetime in the absence of sunlight. Here we report evidence of ozone destruction due to a single event of pulsating aurora early in the morning local time, given by measured data about the source of pulsating aurora and ionisation in the atmosphere. We model the effect of high-energy electron precipitation on ozone using the detailed coupled neutral and ion-chemistry model SIC (Sodankyla Ion Chemistry model). We find significant variations, notably at the sunset time following the precipitation, due to odd hydrogen related chemistry. As pulsating aurora at high latitudes is a frequent phenomenon with spatially and temporally wide coverage, we anticipate that pulsating aurora may play a significant role in causing upper atmospheric chemical variations. Thus it might be important to take the process into account when estimating solar variability driven upper and middle atmospheric changes in climatic models.

New calibrated sunspot group series since 1749

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The largest uncertainty of the long sunspot-number series is related to the "calibration" of the visual acuity of individual observers in the past. A traditional way for calibration is a daisy-chain regression method, which may lead to a significant bias and error accumulation. Here we present a novel method for calibrating the visual acuity of the key observers to the reference data set of Royal Greenwich Observatory sunspot groups for the period 1900 – 1976, using the statistics of the active-day fraction. The observational thresholds is defined for each observer relative to the reference data set. As a result, a new calibrated series of sunspot group numbers is obtained, without any daisy-chain regression. The new series displays secular minima around 1800 (Dalton Minimum) and 1900 (Gleissberg Minimum), as well as the Modern Grand Maximum of activity in the second half of the twentieth century. The new result is fully consistent with the 'classical' group sunspot number series (Hoyt and Schatten, 1998) after 1830 but suggests a slightly higher activity before 1830. On the other hand, it implies that a recent correction by Clette et al. (2014) and Svalgaard and Schatten (2016) overestimated sunspot activity before 1900.

New reconstruction of solar activity during the Holocene: the Hallstatt cycle

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Here we present a new reconstruction of solar activity over the past nine millennia using a multi-proxy approach. We used records of the 14C and 10Be cosmogenic isotopes, current numerical models of the isotope production and transport in Earth's atmosphere, and available geomagnetic field reconstructions, including a new reconstruction relying on an updated archeo- and paleointensity database. A new reconstruction of the geomagnetic dipole field moment, referred to as GMAG.9k, is built for the last nine millennia. A conservative list of grand minima and maxima is provided. We show the long-term (multi-millenial) changes, related to the Hallstatt cycle, ≈2400-year quasi-periodicity, in both the 14C and 10Be based series. This Hallstatt cycle thus appears to be related to solar activity. We also show that the occurrence of grand minima and maxima tends to cluster near highs and lows of the Hallstatt cycle, respectively.

Evolution of solar wind turbulence and intermittency over the solar cycle

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Solar wind is a natural, near-by plasma physics laboratory, which offers possibilities to study plasma physical phenomena over a wide range of parameter values that are difficult to reach in ground-based laboratories. Accordingly, the solar wind is a subject of many studies of, e.g., intermittency, turbulence and other nonlinear space plasma phenomena. Turbulence is an important feature of solar wind dynamics, e.g., for the energy transfer mechanisms and their scale invariance, solar wind evolution, the structure of the heliospheric magnetic field (HMF), particle energization and heating, and phenomena related to solar wind interaction with planetary plasma systems. Here we analyse high resolution measurements of the solar wind and the heliospheric magnetic field provided by several ESA and NASA satellites, including ACE, STEREO, Ulysses and Cluster. This collection of satellites allows us to compile and study nearly 20 years of high-resolution solar wind and HMF measurements from the start of solar cycle 23 to the current declining phase of solar cycle 24. Long-term studies require homogeneity and, therefore, we pay great attention to the reliability and consistency of the data, in particular to instrumental defects like spin harmonics and the purity of the solar wind against possible contamination in the foreshock by magnetospheric ions. We study how the different key-descriptors of turbulence like the slope of the power law of power spectral density and the kurtosis of the fluctuations of the heliospheric magnetic field vary over the solar cycle.

The Maunder Minimum: some recent progress

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The Maunder Minimum (1645-1715 approximately) was a period of very low solar activity and a strong hemispheric asymmetry, with most of sunspots in the southern hemisphere, corresponding to the special mode of a Grand minimum. In the last months, some works have been published obtaining a better assessment of this period: (i) the asymmetry index has been calculated using old observational data (confirming a strong hemispherical asymmetry in this period); (ii) historical observations of some main astronomers have been revisited; (iii) a redefinition of the Maunder Minimum period with the core "Deep Maunder Minimum" spanning from 1645 to 1700 (that corresponds to the Grand Minimum state) and a wider "Extended Maunder Minimum" for the longer period 1618–1723 that includes the transition periods have been proposed; (iv) a large fraction of no-spot records may be unreliable in the conventional database; (v) the active day fraction remained low throughout the MM; (vi) the solar cycle appears clearly during the core MM (length of the solar cycle appears 9±1 years); and (vii) the magnitude of the sunspot cycle during MM is assessed to be below 5-10 (in the group sunspot number scale).

Monitoring the solar radius from the Royal Observatory of the Spanish Navy during the last quarter of millennium

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The solar diameter has been monitored at the Royal Observatory of the Spanish Navy (nowadays, Real Instituto y Observatorio de la Armada) almost continuously since its creation in 1753 (i.e., during the last quarter of a millennium). In this contribution, after a painstaking task of collecting data in the historical archive of this institution, we here present the data of the solar semi-diameter from 1773 to 2006. These data were analyzed to reveal any significant long-term trends, but no such trends were found. Therefore, the data sample confirms the constancy of the solar diameter during the last quarter of millennium (approximately) within instrumental and methodological limits.

Modeling the solar cycle effect of radiation belt electron precipitation on the atmosphere

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Energetic particle precipitation (EPP) affects the middle atmosphere in the polar regions. The ionization caused by precipitating electron and protons ionize and dissociate atmospheric molecules, which leads to e.g. ozone changes through ion chemistry. Ozone is an important minor species for atmospheric dynamics (e.g. temperature) as it absorbs a large part of the solar UV radiation and also acts as an infra-red cooler. EPP-related ozone changes in the mesosphere and stratosphere have been linked to ground-level Arctic climate variability over solar cycle time scales. One of the outstanding issues in EPP research is the role of so-called medium-energy or radiation belt electrons (RBE, E = 30-1000 keV). Especially the solar cycle effect is largely unknown due to temporal or quality limitations of the available satellite observations. In this paper, we present a new approach to model the RBE effects on the atmosphere. Based on corrected data from the MEPED instruments on board POES satellites, we have fitted a electron flux model using the magnetic Ap index as the driving parameter. Applying a reconstructed Ap record from the Climate Model Intercomparison Project (CMIP6), the flux model can be used to characterize RBE over the past 165 years. We have used the RBE forcing record and the Whole Atmosphere Community Climate Model (WACCM) to simulate its atmospheric and climate effects over a period of several solar cycles. We will present preliminary results from these simulations.

Scaling of photospheric magnetic field observations

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Photospheric magnetic field has been routinely observed since 1950s, but calibrated digital data exist only since 1970s. The longest uniform data set is measured at the Wilcox Solar Observatory (WSO), covering 40 years from 1976 onwards. However, the WSO instrument operates in very low spatial resolution and suffers from saturation of strong fields. Other, higher resolution instruments like those at NSO Kitt Peak (KP) offer a more detailed view of the solar magnetic field, but several instrument updates make the data less uniform. While the different observatories show a similar large scale structure of the photospheric field, the measured magnetic field intensities differ significantly between the observatories. In this work we study the photospheric magnetic fields and, especially, the scaling of the magnetic field intensity between six independent data sets. We use synoptic maps constructed from the measurements of the photospheric field at Wilcox Solar Observatory, Mount Wilson Observatory (MWO), Kitt Peak (KP), SOLIS, SOHO/MDI and SDO/HMI. We calculate the harmonic expansion of the magnetic field from all six data sets and investigate the scaling of harmonic coefficients between the observations, using WSO as the standard to be scaled to the other observatories. We investigate how scaling depends on latitude and field strength, as well as on the solar cycle phase. We find that scaling factors based on harmonic coefficients are in general smaller than scaling factors based on pixel-by-pixel comparison or histogram techniques. This indicates that a significant amount of total flux is contained in the high harmonics of the higher resolution observations that are beyond the resolution WSO. We note that only scaling factors based on harmonic coefficients should be used when using the PFSS-model, since the other methods tend to lead to overestimated values of the magnetic flux. The scaling of the low order harmonic coefficients is typically different than for higher terms. The most problematic harmonic is the axial quadrupole term, which is known to be noisy and to suffer from observational limitations (e.g., the vantage

point effect). We did not find significant solar cycle variation in the scaling factors.

Surface flux transport simulations of the solar magnetic field from 1978 to 2010

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We simulate the evolution of the solar photospheric magnetic field between 1978 and 2010 using a surface flux transport model. We use synoptic maps of the radial photospheric field from the Kitt Peak solar observatory from CR 1664 (January 1978) until CR 2006 (August 2003) and from the SOHO/MDI instrument from CR 2007 until CR 2104 (November 2010) as input to the simulation. The simulation model identifies the active regions in the input observations and uses them to simulate the evolution of the emerging flux taking into account differential rotation, meridional circulation and diffusion. We find that the simulations agree with the observations quite accurately at low and mid latitudes, but at high latitudes there are large differences. We find that the simulated polar fields give a more systematic and realistic representation of the actual photospheric field, e.g., during the period of polar field reversal, when Kitt Peak observations are plagued by the vantage point problem. Simulations also disagree with Kitt Peak observations in mid to late 1980s when there are known errors in Kitt Peak observations.

Connecting the solar dynamo below the surface with ejection of twisted magnetic fields above the surface

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Observations show that the Sun sheds mass through twisted magnetic flux configurations, like Coronal Mass Ejections (CMEs). Conventionally, CMEs are modeled by adopting a given distribution of magnetic flux at the solar surface and letting it evolve by shearing and twisting the magnetic field at its footpoints at the surface. Of course, ultimately such velocity and magnetic field patterns must come from a realistic simulation of the Sun's convection zone, where the field is generated by dynamo action. Therefore a unified treatment of convection zone and CMEs is needed. I will present the result of simulations using a model of a two-layer setup. In the lower layer a twisted magnetic field is generated by dynamo action and erupts to the upper layer, representing a simplified corona. These ejection occur in regular and irregular intervals depending on the type of dynamo driving. We tentatively associate these events with coronal mass ejections on the Sun because of their morphological form. On one hand, the amount of helicity in the driving flow is crucial to generate and drive the ejection outward. This has also implication for the probability of superflares occurrence on other more rapid rotating stars. On the other hand, also dynamo action benefits substantially from the presence of ejection of magnetic helicity leading to stronger magnetic fields. Furthermore, in simulation of stratified turbulence, we find the formation of bipolar magnetic flux concentrations, which resample some properties of spots on the Sun. In case, where the turbulence is helical enough, it lead to the generation of a large magnetic field, which partly get ejected out of the domain.

Twenty Years of Space Observations of the Solar Corona with the SOHO/LASCO Coronagraph

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The LASCO coronagraph onboard SOHO has been imaging the solar corona since January 1996,that is 20 years as of today, and thus covering almost two complete solar cycles. It gives us a unprecedented insight of the evolution of the solar corona which reflects to a larger extent the magnetic activity of the Sun and is the source of the solar wind and transient events interacting with planets, possibly impacting their climate. We will report on the evolution of the corona and its large scale structure through various parameters, such as its radiometry and its three-dimensional electron density. The temporal variations will be compared with standard solar indices and various proxies of solar activity, both from LASCO and other instruments, in order to identify the driving mechanisms that control the activity of the corona.

Solar total and spectral irradiance reconstruction over last 9000 years

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The Sun is the most important external energy source for Earth and can affect its climate. The mechanisms of this influence are not fully understood yet, but solar total and spectral irradiance are among the prime suspects. Solar total irradiance describes the total flux of solar radiative energy entering Earth system, and spectral irradiance its spectral distribution and in particular the amount of the UV radiation, which is important for chemical processes in the atmosphere. On timescales of the 11-year solar cycle and shorter, solar irradiance is measured by space-based instruments while models are needed to reconstruct solar irradiance on longer timescale. The SATIRE-M model (Spectral And Total Irradiance Reconstruction, M for Millennia) is employed in this study to reconstruct solar irradiance from decadal radionuclide isotope data, such as 14C and 10Be stored in tree rings and ice cores, respectively. We present total and spectral irradiance reconstructed over the last 9000 years.

FPI observations of nighttime mesospheric and thermospheric winds in China and their comparisons with HWM07

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We analyzed the nighttime horizontal neutral winds in the middle atmosphere (~87 km and ~98 km) and thermosphere (~250 km) derived from a Fabry-Perot Interferometer (FPI), which was installed at Xinglong station (40.2°N, 117.4°E) in central China. The wind data covered the period from April 2010 to July 2012. We studied the annual, semiannual and terannual variations of the midnight winds at ~87 km, ~98 km and ~250 km for the first time and compared them with Horizontal Wind Model 2007 (HWM07). Our results show: (1) At ~87 km, both the observed and model zonal winds have similar phases in the annual and semi-annual variations. However, the HWM07 amplitudes are much larger. (2) At ~98 km, the model shows strong eastward wind in the summer solstice resulting in a large annual variation while the observed strongest component is semiannual. The observation and model midnight meridional winds agree well. Both are equatorward throughout the year and have small amplitudes in the annual and semiannual variations. (3) There are large discrepancies between the observed and HWM07 winds at ~250 km. This discrepancy is largely due to the strong semiannual zonal wind in the model and the phase difference in the annual variation of the meridional wind. The FPI annual variation coincides with the results from Arecibo, which has similar geomagnetic latitude as Xinglong station. In General, the consistency of FPI winds with model winds is better at ~87 km and ~98 km than that at ~250 km. We also studied the seasonally and monthly averaged nighttime winds. The most salient features include: (1) The seasonally averaged zonal winds at ~87 km and ~98 km typically have small variations throughout the night. (2) The model zonal and meridional nighttime wind variations are typically much larger than those of observations at ~87 km and ~98 km. (3) At ~250 km, model zonal wind compares well with the observation in the winter. For spring and autumn, the model wind is more eastward before ~ 3:00 am but more

westward after. The observed nighttime zonal and meridional winds on the average are close to zero in the summer and autumn, which indicates a lack of strong stable tides. The seasonal averaged FPI zonal and meridional winds coincide well with the model winds at 87 km and $\sim$98 km. The consistency of FPI zonal wind with model wind at $\sim$250 km is better than the meridional wind.

A new method of predicting the probability distribution of solar X-ray flares

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We study the latitudinal and longitudinal distribution of solar X-ray flares, separately for the northern and southern hemispheres. The latitudinal distribution of flares during each butterfly wing (the solar cycle in one hemisphere) roughly follows a 2nd degree polynomial. The level of flare activity has a positive correlation with the highest flare latitude of the corresponding wing, which can be used to estimate the flare activity of the starting solar cycle. The longitudinal distribution of flares has been found to favor two active longitude (AL) bands, which rotate differentially. The yearly best-fit values of the rotation parameters of ALs were found to have a quasi-periodicity of 80-90 years. Based on this information, we have simulated the height and latitude distribution of solar flares over the solar cycle 24, and depicted them as probability distribution maps.

Correlation between solar variability and variations of the Earth temperature from centuries to ten thousand years

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The solar impact on the Earth's climate change is a long topic with intense debates. In this study, two data sets are adopted to investigate the periodicities of both solar variability and variations of the Earth's temperature as well as their correlations based on the wavelet analysis and cross correlation method. The first one data is in time scale of centuries before 2012, and mainly consists of directly observed data, while the second one is the reconstructed data during the past 11,000 years before modern industry. We found some evidences of the potential solar influences on the Earth's temperature change. On centuries, solar activity and the Earth's temperature have some resonant cycles, such as the 22- and 50-year period. During the past 100 years, solar activities showed a clear increasing tendency that corresponded to the global warming of the Earth (both land and ocean) very well. Especially, the ocean temperature has a slightly higher correlation with solar activity than the land temperature. For the time scale of ten thousand years, it is found that the variations of sunspot number (SSN) and the local temperature of Antarctica (TA) had common periodicities, such as the 208 year (yr), 521 yr, and $\sim$1000 yr cycles. The millennial variation of SSN led that of TA by 30–40 years, and the anti-phase relation between them kept stable nearly over the whole 11,000 years of the past. As a contrast, the correlations between CO2 and TA were neither strong nor stable. All these results support that solar variability should have non-ignorable effects on the Earth's climate change, especially before the modern industrial time.

Heartbeat of the Sun derived with Principal Component and Symbolic Regression analysis and prediction of solar activity on a millennium timescale

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We derive two principal components (PCs) of temporal magnetic field variations over the solar cycles 21–24 from full disk magnetograms covering about 39% of data variance, with $\sigma = 0.67$. These PCs are attributed to two main magnetic waves travelling from the opposite hemispheres with close frequencies and increasing phase shift. Using symbolic regression analysis we also derive mathematical formulae for these waves and calculate their summary curve which we show is linked to solar activity index. Extrapolation of the PCs backward for 800 years reveals the two 350-year grand cycles superimposed on 22 year-cycles with the features showing a remarkable resemblance to sunspot activity reported in the past including the Maunder and Dalton minimum. The summary curve calculated for the next millennium predicts further three grand cycles with the closest grand minimum occurring in the forthcoming cycles 26–27 with the two magnetic field waves separating into the opposite hemispheres leading to strongly reduced solar activity. These grand cycle variations are probed by $\alpha - \Omega$ dynamo model with meridional circulation. Dynamo waves are found generated with close frequencies whose interaction leads to beating effects responsible for the grand cycles (350–400 years) and super-grand cycles (2000 years) superimposed on a standard 22 year cycle. This approach opens a new era in investigation and confident prediction of solar activity on a millenium timescale.

List of participating authors