Sodankylä Geophysical Observatory

Reports

4^{th} Workshop on Long-Term Changes and Trends in the Atmosphere

Sodankylä Geophysical Observatory

Sodankylä, Finland

4^{th} – 8^{th} September 2006

Abstracts

Edited by Thomas Ulich and Anna-Liisa Piippo

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Thule Institute, University of Oulu, Oulu, Finland

IAGA - International Association of Geomagnetism and Aeronomy

ICMA - International Commission on Middle Atmosphere

CAWSES - Climate And Weather of the Sun-Earth System

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11:05-11:10	**J. Emmert and M. Jarvis**: Welcome address on behalf of the CAWSES Trend Panel
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14:30-14:50 **K. Georgieva**: Long-term changes in the correlation between solar and geomagnetic activity

14:50-15:10 **T. V. Barlyaeva and D. I. Ponyavin**: Solar and volcanic impact on climate change: Results of EMD and cross wavelet analysis

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14:50-15:10 **C.-F. Enell, E. Turunen, T. Turunen, Th. Ulich, A. Seppälä and P. T. Verronen**: The effect of variable solar short-wave radiation on the concentration of nitric oxide in the MLT region

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L. Backman, L. Thölix, S.-M. Ojanen and J. Damski: Long-term chemistry-transport model simulations of middle atmospheric ozone

A. Seppälä, E. Kyrölä, L. Backman, V. Sofieva and S. Hassinen: Polar mesospheric ozone 2002-2006 from GOMOS/Envisat

M. Ern, M. Krebsbach, P. Preusse, K. Fröhlich, P. Hoffmann, C. Jacobi, T. Schmidt and J. Wickert: GW-CODE: Gravity wave coupling processes and their decadal variation

A. K. Steiner, G. Kirchengast, M. Borsche, U. Foelsche and Th. Schöngassner: Comparison of upper air temperatures from MSU/AMSU and CHAMP radio occultation data

A. G. Elias and M. Zossi de Artigas: Long-term changes in the geomagnetic Sq field

M. Zossi de Artigas, P. Fernandez de Campra and E. Zotto (pres. A. G. Elias): Long-term changes of the H range at low and mid-latitudes

17:45-18:00 Bus transfer from SGO to the hotel

18:30-19:30 Old wooden church of Sodankylä open for visitors (free of charge)

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15:30-15:45	Exchange groups
15:45-16:45	Group 1: visit to the EISCAT radar and ionosonde Group 2: visit to the Meteorological Observatory
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19:00-21:30	Conference dinner
21:30-22:00	Bus transfer from the farm to the hotel

Thursday, 7th September 2006

08:10-08:25 Bus transfer from the hotel to SGO

08:30-10:00 **Session 9** Chair: M. Jarvis

08:30-09:00 **J. Bremer**: Long-term trends in the ionospheric E and F1 region (solicited)

09:00-09:30 **J. Emmert**: Thermospheric density trends derived from satellite drag (solicited)

09:30-10:00 **C. Jacobi, P. Hoffman, D. Kürschner and K. Fröhlich:** Trends in MLT region winds and planetary waves (solicited)

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10:40-11:00 **P. Hoffmann, C. Jacobi, N. Jakowski, A. Pogoreltsev and C. Borries**: CPW-TEC: Planetary waves and their long-term variability seen in ionospheric total electron content

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11:20-11:50 **A. G. Elias and N. Ortiz de Adler**: Earth magnetic field variation effects on long-term trends in the F2 layer

12:00-14:00 **Lunch**

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14:30-15:00 **J. Lastovicka, A. V. Mikhailov, Th. Ulich, J. Bremer, A. D. Danilov, A. G. Elias, N. Ortiz de Adler, R. Abarca del Rio, A. J. Foppiano and E. Ovalle**: Long-term trends in foF2: result of a comparison of various methods

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16:00-17:15 **Session 12** Chair: Th. Ulich

16:00-16:30 **L. Alfonsi, A. De Santis and G. De Franceschi**: Geomagnetic and ionospheric data analysis over Antarctica: a contribution to the long-term trends investigation (solicited)

16:30-16:50 **M. Jarvis and A. Kovaleva**: Changing chemistry between East and West Europe?

16:50-17:10 Open problem discussion: F2-region trends; chair: J. Lastovicka

17:10-17:45 General discussion and closing of the workshop

18:00-18:15 Bus transfer from SGO to the hotel

Friday, 8th September 2006

08:40-08:55	Bus transfer from the hotel to SGO - optional
11:10	**Departure** (Bus leaves for Rovaniemi Airport and town centre)
11:20	Bus collects remaining participants from the hotel
13:00	Arrival at Rovaniemi Airport
13:30	Arrival at Rovaniemi Centre
11:30-12:30	**Lunch** (optional, for those staying longer)

We will arrange transportation to Sodankylä according to needs and agreements with SGO's and personal cars. The observatory closes at 16:00h and you are welcome to use SGO facilities at least until then.

Impact of middle-atmospheric composition changes on greenhouse cooling in the upper atmosphere

R. Akmaev[1], V. Fomichev[2] and X. Zhu[3]

[1] *CIRES, U. Colorado, Boulder, CO, USA*
[2] *York U., Toronto, Ontario, Canada*
[3] *Jons Hopkins U., Laurel, MD, USA*

The greenhouse effect, commonly associated with lower-atmospheric warming, manifests as cooling in the middle and upper atmosphere. Carbon dioxide is the main cooler and its continuing rise has been demonstrated to result in dramatic temperature reductions, particularly in the thermosphere. In a hydrostatic atmosphere, the cooling is associated with a density decrease at a given height. The stratospheric ozone depletion documented in satellite observations since 1979 and a steady increase of water vapor are also expected to introduce a net cooling in the middle atmosphere primarily via a reduced solar heating and increased emissions in the infrared, respectively. These effects are simulated with the global Spectral Mesosphere/Lower Thermosphere Model (SMLTM) extending approximately from the tropopause to over 200 km. Climatological distributions of the radiatively active gases are prescribed in the model, which makes it suitable for studies with imposed realistic trends in CO_2, O_3, and H_2O approximately corresponding to the period 1980-2000. Although confined to the stratosphere, the ozone depletion has a profound cooling effect on mesospheric temperatures, which is comparable to or exceeding that of the CO_2 forcing. The water vapor cooling appears to play a secondary but non-negligible role, especially in the overall density reduction in the lower thermosphere. The additional hydrostatic contraction of the colder middle atmosphere is predicted to result in a local maximum of the density decline near 110 km of up to 6.5% per decade over the twenty-year period.

Geomagnetic and ionospheric data analysis over Antarctica: a contribution to the long term trends investigation

L. Alfonsi, A. De Santis, G. De Franceschi

INGV-Vigna Murata 605, 00143 Rome-Italy

The long-term behaviour of the F2 plasma frequency observed by some ionospheric observatories at mid and high latitudes reveals negative trend. The trend rate is variable and it is higher over Antarctica. By selecting data under quiet magnetic conditions, the trend is still negative and comparable with that at middle latitudes confirming the geomagnetic control on the F2 layer. A rapid decrease of some important physical and statistical quantities related to the geomagnetic field over the whole globe and mainly in Antarctica is also shown that, together with other recent results published in literature, suggests a possible imminent geomagnetic reversal or excursion. A possible link between these findings is explored and discussed for future deeper investigation.

Long-term chemistry-transport model simulations of middle atmospheric ozone

L. Backman, L. Thölix, S.-M. Ojanen and J. Damski

FMI, Helsinki, Finland

Global middle atmospheric simulations have been performed with the FinROSE chemistry-transport model (FinROSE-CTM) using the 6 hourly ECMWF ERA-40 and operational analysis winds and temperatures. The temporal and spatial distribution of ozone, covering the period 1957-2005, was analyzed and compared to ozone soundings. The simulation covers the evolution of the stratospheric ozone depletion as well as a two decades period of pre-ozone loss years.

The simulations were run with a horizontal grid resolution of 10x5 deg (long-lat) at 32 levels up to 0.1 hPa. The model features detailed middle atmospheric chemistry including a detailed parameterization for heterogeneous processing on/in PSCs and liquid binary aerosols, and PSC sedimentation and a NAT-rock parameterization. The chemistry scheme includes 27 long-lived species/families, and 14 species in photochemical equilibrium with about 200 reactions.

Despite of some reported problems in the ERA-40 data the ozone distribution and variability in the model data seem reasonable, at least in a qualitative sense, based on comparisons with ozone sounding, satellite and climatology data.

Solar and volcanic impact on climate change: Results of EMD and cross wavelet analysis

T. V. Barlyaeva and D. I. Ponyavin

St. Petersburg State University, Institute of Physics, St. Petersburg, Russia

Long-term climate time series, volcanic activity and solar proxies are studied using wavelet transforms and Empirical Mode Decomposition. Cross wavelet technique is applied to examine coherence and phase relationships between various time series on interannual scale and to find solar signal in climatic data. Time-frequency patterns reveal near synchronous periodicities and the global quasi-oscillations. Patterns display also transient correlations and nonlinear impact of solar activity on climate. Historic periods in the past and regions of significant solar influence on climate are found. The last 70 years since 1930's demonstrate unusual sensitivity of climate response to solar output. This result is discussed in conjunction with the problem of unprecedented level of sunspot activity and global warming in the late 20th century.

Modeling global change induced trends in ionized components from the troposphere to mesosphere

G. Beig

Indian Institute of Tropical Meteorology, Pashan, Pune, India

Global change resulting from man-made activities is a topic of great concern in recent years. Such influences are not only confined to temperature and neutral chemical composition but are most likely to extend to ion chemistry and spread from surface to the upper atmosphere. The ion chemistry of 3 different regions namely troposphere, stratosphere and mesosphere are different from each other. Although mesospheric ion models exist for quite sometime, models for stratospheric and tropospheric ions have been proposed only recently and hence obviously the question to study global change induced forcing is relatively a new problem. We have used a model to qualitatively estimate the global change induced perturbation in tropospheric ion composition. It is demonstrated that the tropospheric ion composition would undergo a drastic change in course of time due to variation in their parent neutral compounds (pyridine, picoline, lutidine, ammonia, acetone, acetonitrile), concentration of which are most likely to increase rapidly due to man-made activities. Model also predicts that in all likelihoods, pyridinated cluster ions are fast rising to dominate throughout the troposphere in future.

In the stratospheric and mesospheric regions, for a doubled CO_2 scenario, we find that the total ionization density does not change appreciably and the maximum variation is found to be around 15% at 70 km and -5% near 35 km. However, the distribution of individual ions shows a considerable variation (up to about 100%) throughout the middle atmosphere. The concentration of water cluster ions increases below about 85km, above this height it starts to decrease sharply with height. The concentration of NO^+ ions in the mesospheric region shows an overall decrease. In the stratospheric region for a doubled CO_2 scenario, it is found that only one family of negative ions, called NO_3-core ions, dominate instead of two families in the normal case. The magnitude of variation in stratospheric positive ion composition is less as compared to negative ions. The % changes in NPH ions are found to be around 10% at 40km which increases sharply with altitude.

Climate and weather of polar mesospheric clouds

U. Berger and F.-J. Lübken

IAP Kühlungsborn, Germany

In summertime, layers of icy particles form in the high latitude mesopause region at altitudes between 82 and 92 km poleward of 50° latitude, causing the phenomena of noctilucent clouds (NLCs) and polar mesospheric summer echoes (PMSEs). The strong simularities of the spatial and seasonal occurrence zones of NLCs and PMSEs make it highly likely that both phenomena have a common cause.

In the frame of climate studies we explored the morphology of these ice clouds combining modelling and observational studies in order to investigate the major physical processes. e.g the microphysics of icy particles, the interaction of ice particles with atmospheric background water vapour, the sensitivity of ice formation and cloud brightness due to variable thermal conditions, the role of turbulence processes in PMSE and NLC, effects of 3-d transport, etc.

Our model approach allows an insight into the different phenomena of NLCs and PMSEs, their highly variable structure what we call ‘ice cloud weather.’ The paper tries to give a better understanding of the role of these ice clouds as an indicator of future and past climate changes.

Association between Solar Proton Events and pressure decreases in the winter northern troposphere

J. Bochnicek[1], P. Hejda[1] and R. Huth[2]

[1] *Geophysical Institute AS CR, Prague, Czech Republic*
[2] *Institute of Atmospheric Physics AS CR, Prague, Czech Republic*

Veretenko and Thejll (JASTP 66 (2004), 393-405) studied relations between the increase of solar energetic proton flux and the change in tropospheric pressure and temperature of the winter Northern Hemisphere in the period 1980 – 1989 and have shown that increased SEP flux used to be associated, with delay 1-3 days, with the pressure decrease in the region between Greenland and Iceland, and that the core of the decrease moves eastward and fills in. Our contribution is extension of these studies over years 1990 – 2003 and is based on the daily grids ds195.1 (temperature, pressure and wind fields) produced by NCAR and on wind fields from CGER METEX. Good agreement with the results by Veretenko and Thejll confirms robustness of this phenomenon.

Lower atmosphere can be also affected by particles accelerated during strong geomagnetic storms. We show that the response is similar but the delay is between 5 and 8 days.

Long-term trends in the ionospheric E and F1 regions

J. Bremer

Institute of Atmospheric Physics, Kühlungsborn, Germany

The most essential source of information about long-term variations in the ionospheric E and F1 regions are ground based ionosonde measurements. Data of such observations have been derived at many different ionospheric stations all over the world since partly more than 50 years. Mainly the standard parameters foE, h'E, and foF1 can be used for trend analyses. Two main problems have to be considered in these analyses. Firstly, the data series have to be homogeneous, i.e., the observations should not be disturbed by artificial steps due to technical reasons or changes in the evaluation algorithm. Secondly, the strong solar and geomagnetic influences upon the ionospheric data have carefully to be removed by an appropriate regression analysis. Otherwise the small trends in the different ionospheric parameters cannot be detected.

The trends derived at individual stations differ markedly without a clear dependence on geographic or geomagnetic latitude. Nevertheless, the mean global trends estimated from the trends at the different stations show some general behaviour (positive trends in foE and foF1, negative trend in h'E), which can at least qualitatively be explained by an increasing atmospheric greenhouse effect (increase of CO_2 content or of other greenhouse gases) and decreasing ozone values. The positive foE trend is also in qualitative agreement with rocket mass spectrometer observations of ion densities in the E region. First indications could be found that the changing ozone trend (before about 1979, between 1979 until 1994, and after about 1994) can modify the estimated mean trend at least in foE.

Long-term changes and trends (over the last 100 years) in geomagnetic and solar activity

M. Clilverd[1], Th. Ulich[2], H. Rishbeth[3] and E. Clarke[4]

[1] *BAS, Cambridge, England*
[2] *SGO, Sodankyla, Finland*
[3] *University of Southampton, Southampton, England*
[4] *BGS, Edinburgh, Scotland*

The clearest periodicity exhibited by solar activity is the quasi 11-year Schwabe cycle. However, over longer timescales, many other periods influence the overall levels of solar activity. Over much of the last 100 years solar activity has shown an increasing trend following a quiet period at the beginning of the 1900's. Will these high levels of solar activity continue or should we expect a period of low solar activity in the future?

Solar activity, often defined by sunspot number, disturbs near-Earth plasmas, and as a result affects the Earth environment in many varied ways. Periodicities in solar activity can influence the frequency and intensity of space weather events. Increased solar activity through EUV irradiance reduces the lifetime of low-Earth-orbiting satellites by increasing the neutral density of the atmosphere (≈150-1000km). Geomagnetic storms closely follow solar activity changes and also produce short-term variations in neutral density, composition, and enhance ionospheric current systems. Individual geomagnetic activity events tend to produce greater relative depression of F2-layer electron density in a solar cycle with lower F10.7 than in ones of higher F10.7. Clearly, long-term variations in solar activity are communicated to the Earth's atmosphere in many complex ways.

Long-term trends in the correlation between daytime and night-time values of foF2

A. Danilov

Institute of Applied Geophysics, Moscow, Russia

A new ionospheric phenomenon is described: a significant negative correlation between the daytime (1400 LT) and night-time (0200 LT) values of the midlatitude F2-layer critical frequency. Vertical sounding ionosonde observations for a dozen stations in Europe and Russia were analyzed to reveal the morphological pattern of the phenomenon. It was found that negative correlation between foF2 (02LT) and foF2 (14LT) exists only under specific geophysical conditions. The value of the correlation coefficient r(foF2) may be in some cases high enough and reach – (0.7¸0.8). The value of r(foF2) demonstrates a well pronounced seasonal variations, the highest negative values being observed during equinoxes. It is also found that r(foF2) depends on geomagnetic activity: the value of r(foF2) is the highest for quiet days (Ap < 6¸8), decreasing with an increase in the geomagnetic activity. For a fixed limitation on Ap, the value of r(foF2) depends also on solar activity: the magnitude of the negative value of r(foF2) increases with an increase of the annual mean F10.7 and decreases with a decrease of geomagnetic latitude. The revealed morphology may be related to the equinoctial transition in thermosphere and ionosphere, which is due to summer/winter changes in the thermospheric circulation. Analysis of long series of the vertical sounding data shows that there is a long-term trend in r(foF2) which may be interpreted in terms of the thermosphere parameter long-term changes. The possible causes of this trend and its relation to other ionospheric and thermospheric trends are discussed.

Earth magnetic field variation effects on long term-trends in the F2 layer

A. G. Elias and N. Ortiz de Adler

Universidad Nacional de Tucuman, Tucuman, Argentina

The intrinsic Earth magnetic field presents long-term variations, which could affect the ionosphere maximum electron concentration. Using experimental data, long-term trends in foF2 (a measure of the maximum electron concentration) of several worldwide ionospheric stations are estimated in the present work. Data was arranged according to the different months and hours, which amounts to 288 trend values for each station. A daily and seasonal pattern is observed. This pattern and the trend magnitude are not entirely compatible with the greenhouse effect over the ionosphere. Through theoretical approximations and empirical models, foF2 trends due to long-term variations in the Earth magnetic field are assessed. Theoretical and experimental foF2 trend values are compared. The Earth magnetic field, in some cases, would produce trends similar in magnitude to those observed. It can also explain some seasonal and daily variation patterns observed in foF2 trend values.

Long-term variation of strong geomagnetic storms and its effect on ionospheric and telluric currents

A. G. Elias[1] and V. M. Silbergleit[2]

[1] Universidad Nacional de Tucuman, Tucuman, Argentina
[2] Universidad de Buenos Aires, Buenos Aires, Argentina

Geomagnetic storms affect electric currents in the ionosphere, which in turn induce electric fields that drive telluric currents in the Earth. Strong geomagnetic storms long-term changes are analyzed in the present work together with the expected variations in ionospheric and telluric currents, which may have effects on the Earth surface environment (such as electrical systems, pipelines). The present study, which intends to contribute to the understanding of the near space coupling to the Earth, will be carried out using physics-based models of the magnetosphere, ionosphere and Earth conductivity.

Long-term changes in the geomagnetic Sq field

A. G. Elias and M. Zossi de Artigas

Universidad Nacional de Tucuman, Tucuman, Argentina

The cooling of the mesosphere and thermosphere due to an increase in greenhouse gases concentration may induce trends in the ionospheric E layer, which in fact have been already observed. In the present work, the daily range of geomagnetic Sq field is analyzed to detect long-term changes, which may arise due to the observed trends in the E layer. Since Sq field variations are a manifestation of ionospheric current systems which flow between 90 and 200 km, trends in the E layer would possibly induce trends in Sq. foE data together with the hourly H component of the geomagnetic field for several mid and low latitude stations averaged for the five quietest days of each month were used for the present analysis.

Thermospheric density trends derived from satellite drag

J. Emmert

Naval Research Laboratory, USA

Several recent studies of long-term orbital tracking data have indicated that thermospheric densities are declining at a rate of about 2–6% per decade, in a manner that is qualitatively consistent with predicted effects of increasing greenhouse gas concentrations. We review the results from the orbital drag studies and consider potential sources of uncertainty. In particular, we discuss the removal the strong solar-induced component from the density time series to obtain a secular trend. Orbit-derived density measurements show a F10.7-dependent bias relative to empirical density models; this bias is predominantly characterized by a sharp drop-off of the data-to-model density ratios at very low solar activity levels. We investigate several potential causes of this bias, as well as approaches to correct the bias and improve the specification of the solar cycle dependence.

The effect of variable solar short-wave radiation on the concentration of nitric oxide in the MLT region

C.-F. Enell[1], E. Turunen[1], T. Turunen[1], Th. Ulich[1], A. Seppälä[2]

[1] *Sodankylä Geophysical Observatory, Sodankylä, Finland*
[2] *Finnish Meteorological Institute, Helsinki, Finland*

A current important issue in the understanding of the mesosphere-lower thermosphere (MLT) region is that most models underestimate the observed concentrations of nitric oxide (NO).

We therefore propose to study the effect of the highly variable solar extreme UV (EUV) and X-ray irradiances on the concentration of nitric oxide in the MLT region by interpreting the accurate electron density measurements made possible by a modern research ionosonde, the new Sodankylä Alpha Wolf (SAW). SAW is a fully digital continuous-wave chirp sounder which is much more sensitive than our previous ionosonde - hence it makes accurate electron density monitoring possible both for extremely quiet and moderately disturbed conditions.

We here compare SAW measurements for selected events in the winter of 2005-2006 with results from our 1-dimensional, coupled ion and neutral chemistry model SIC (Sodankylä Ion Chemistry), run with EUV and X-ray input data available from e.g. the TIMED and GOES satellites.

GW-CODE: Gravity wave coupling processes and their decadal variation

M. Ern[1], M. Krebsbach[1], P. Preusse[1], K. Fröhlich[2], P. Hoffmann[2], C. Jacobi[2], T. Schmidt[3] and J. Wickert[3]

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The project GW-CODE, as part of the DFG priority program CAWSES, focuses on the coupling of atmospheric layers from the troposphere to the middle atmosphere through gravity waves, and their variability on the decadal time scale. To this end long-term data sets of gravity wave activity are derived from satellite measurements (SABER, GPS) as well as modelling is performed (Warner and McIntyre parameterisation scheme, GROGRAT), and effects of gravity waves on the global circulation are simulated in a GCM (COMMA-LIM) using different parameterisation schemes. Results are presented of the analysis of temperature variances from GPS radio occultation measurements, of a SABER gravity wave climatology, and of recent progress in numerical modelling/parameterisation of gravity wave sources and propagation.

Long-term changes in the correlation between solar and geomagnetic activity

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In the last century both solar activity as measured by the sunspot number and geomagnetic activity measured by the aa-index have increased. However, their correlation in the 11-year sunspot cycle has been steadily decreasing, while the lag has increased from 0 years in the beginning of the XX century to 3 years in the last cycles. Their long-term correlation has also decreased: in the last three decades solar activity has remained more or less constant while geomagnetic activity has continued growing. The long-term evolution of the correlation between sunspot number and geomagnetic activity is very similar to the long-term changes in the correlation between sunspot number and global temperature, so maybe they have a common reason. Two types of solar agents are mainly responsible for geomagnetic disturbances: coronal mass ejections (CMEs) whose number and intensity is proportional to the number of sunspots, and high speed solar wind (HSSs) from long-lived coronal holes, not related in any way to sunspots. The relative impact of different solar drivers to geomagnetic activity mainly depends on their number. We demonstrate that the long-term decrease in the correlation between sunspot and geomagnetic activity in the 11-year cycle as well as in the last century is mainly due to the increasing number of high speed solar wind streams on the declining phase of the sunspot cycle, which we suppose to be determined by the long-term changes in the tilt angle of the heliospheric current sheet. On the other hand, the tilt angle is related to the modulation of the galactic cosmic rays, which are considered the most probable mediator between solar activity and climate. Therefore, the use of the sunspot number as a proxy for solar activity strongly underestimates the role of the Sun for the global warming observed in the last century.

Northern hemisphere winter 2005/2006, solar/geomagnetic activity and the QBO-phase

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In this winter many European countries bore the brunt of the most severe winters in the last 50 years. Several factors have contributed to the regional cold wave, in particular, a high-pressure system over Siberia and Eastern Europe, which enabled the arrival and establishment of the cold air from the Arctic over Europe from the north-east. In the same season the geomagnetic activity measured by ?Kp was the lowest since 1932, i.e. over the whole period covered by Kp index, and solar activity was very low as well. Average value of ?Kp in the winter season 2006 was equal to 11.6 and average value of R was equal to 10.4.

This coincidence is not accidental. Our analysis of winter tropospheric fields, carried on the NCAR data set ds195.5 in the interval of years 1952-2004, indicated that winter periods with low geomagnetic and solar activity are characterized by filling in of the Icelandic Low (NAO is negative), weakening of the zonal flow over North Atlantic and strengthening of the meridional flow from north over Europe. The contribution deals also with the role of the QBO-phase, stratospheric vortex and the “atypical” winter period 1997.

Planetary waves and their long-term variability seen in ionospheric total electron content

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Propagation of planetary waves to the thermosphere/ionosphere is analysed on the basis of stratospheric analyses, mesospheric radar wind and temperature measurements, and regional TEC maps over the higher middle northern and southern polar latitudes. Case studies show that planetary waves are simultaneously found in the middle atmosphere and ionosphere. Numerical modelling of the middle atmosphere using the COMMA-LIM circulation model is performed to analyse the possible impact of tidal modulation on the penetration of PW effects into the thermosphere. The project is part of the German Priority Program "CAWSES" of the Deutsche Forschungsgemeinschaft. It aims at the construction of an upper atmosphere planetary wave climatology, and the detection of long-term variability of waves in both hemispheres.

Trends in MLT region winds and planetary waves

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Long-period oscillations in the period range 2-30 days, interpreted as planetary wave (PW) signatures, have been analysed using daily mesosphere/lower thermosphere wind measurements near 95 km over Collm (52°N, 15°E) in the time interval 1979-2005. Strong interannual and interdecadal variability of PW are found. Since the 1990s, a tendency for larger zonal amplitudes compared to meridional ones, has been observed. Thus, long-term trends are visible only after 1990, which are positive in the zonal component, but negative in the meridional component. The solar cycle effect is weak, only a possible increase of the 10- and 16-day waves in winter is seen. No clear correlation of PW with mean winds are visible, except for possible long-term trends.

Climatological variations in the ionosphere and upper atmosphere

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Understanding the climatology of the ionosphere and upper atmosphere is prerequisite to identifying anthropogenically-induced or naturally-occurring secular trends. In the upper atmosphere the huge impact of solar variability means that a climatology must include not only the long-term mean but also the solar cycle and seasonal variations. To produce a climatology, which covers as large an altitude range and spatial area as possible, data from a variety of observational techniques have to be used. As part of CAWSES WG 4.4 objectives, a survey of available data and techniques for the neutral upper atmosphere has been undertaken and a similar survey for the ionised atmosphere is underway. Combined, these two surveys will summarize the climatological and long-term data needs of the scientific community and point to future observational requirements.

Changing chemistry between East and West Europe?

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Bremer (1998) showed there to be a difference between the long-term trend in the altitude of the ionospheric F-region peak either side of the 30E longitude line over Europe. This phenomena is examined in more detail using station pairs and preliminary results suggest that, firstly, there is a longitudinal differential in ionospheric long-term change in both E and F regions and, secondly, that chemistry may play a role.

Climatic trends of the temperature, zonal mean flow, and stationary planetary waves in the NCEP/NCAR re-analysis data

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The detail analysis of the climatic trends in the zonally averaged temperature, zonal mean wind, and activity of the stationary planetary wave with the zonal wave number 1 (SPW1) in January has been made. The results obtained present that there exist noticeable climatic changes of the temperature in the lower atmosphere, which are different at the low and high latitudes. These changes cause the corresponding changes of the positions and intensity of the tropospheric jets, and finally the changes of the propagation conditions of the SPW1. The calculations of the SPW1 propagation form the troposphere into the upper atmosphere performed with the linearized model using the zonal mean flow distributions which are typical for the 60th of the XX and for the beginning of XXI century support this assumption and show that during the last 40 years the propagation conditions “in averaged” improved, and the calculated amplitude of the SPW1 in the stratosphere and mesosphere of the winter hemisphere increased substantially. The analysis of the amplitudes of the zonal wind perturbations for the SPW1 extracted from the NCEP/NCAR data supports the results of simulation and shows that there exists some increase in the SPW1 activity in the lower stratosphere during the last years indeed. These changes in the amplitudes are accompanied also by an increase in the interannual variability of the SPW1.

Trends and periodicities in NLC and related phenomena

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Noctilucent clouds (NLC) are the highest clouds in the Earth's atmosphere, observed close to the mesopause at 80-90 km altitudes. Visual NLC observations have been recorded in Europe and in Russia for several decades with varying degrees of detail. During a much shorter period, automatic cameras on the ground have been used to monitor NLCs , and the closely related 'Polar Mesospheric Clouds (PMC), and 'Polar Mesosphere Summer Echoes' (PMSE) have been monitored by satellites and ground-based radars , respectively.

Some 10 years ago there was a widespread belief that the visual NLC observations from NW Europe showed a very large increase from the 1960's to the 1990's but this turned out to be untrue – no significant trend was in fact discernible. At the same time, careful analysis of the longest, sufficiently detailed, ground-based NLC records (Moscow 1962-2005) does not show any significant trend. Small trends in PMC brightness have, however, been reported from satellite observations.

It has been found that periodicities including tidal periods (PMSE), 5-day periods (PMSE, NLC, PMC) and decadal cycles (NLC, PMSE) strongly affect conditions at NLC heights. In addition, combination of the Moscow NLC records with the detailed records from Denmark (1983-2005) shows that the characteristic longitudinal scale of NLC fields is less than 800 km, so that further wave effects must be important.

In out review we will consider how the observed shorter periodicities (5-day or less) and longitudinal variation might affect annual 'mean' statistics and examine whether reported decadal cycles and 'trends' can be physically interpreted.

Long-term changes in atmospheric circulation and their relation to solar activity

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General atmospheric circulation is the system of atmospheric motions over the Earth on the scale of the whole globe. Two main types of circulations have been identified: zonal - characterized by low amplitude waves in the troposphere moving quickly from west to east, and meridional when stationary high amplitude waves are observed and the meridional transfer is intensified. The prevailing type of circulation is related to global climate. In years with zonal circulation, the temperatures are higher than average over most of midlatitudes, while meridional circulation is associated with warmer high latitudinal regions and transfer of cold air to midlatitudes. Based on many years of observations, certain "circulation epochs" have been defined when the same type of circulation prevails for years or decades. Here we study the relation between long-term changes in solar activity and prevailing type of atmospheric circulation.

Ozone trends and interannual variability in the arctic lower stratosphere

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Long-term changes in Arctic ozone profiles are of considerable interest, because the Arctic lower stratosphere is directly affected by chemical ozone depletion. Ozone is also a greenhouse gas whose radiative forcing is depending on its vertical distribution. Therefore, the long-term changes in ozone profiles are not only important to the Earth UV shield, they are of considerable climatic interest too. However, the information on long-term changes in ozone over the Arctic is limited as there are only a few regular measurement programs of ozone profiles that have sufficient length and measurement frequency for long-term data studies. In this study we have first constructed an ensemble data set based on available long-term ozonesonde measurements from the Arctic from the period 1989-2003. The data set was made homogeneous by applying corrections for the changes in operational procedures. The results from test flights made in Sodankylä were used to apply the altitude dependent corrections to the ozone sonde profiles. Secondly, in order to explain the trends and interannual variability, a multilinear regression model was applied to the ensemble ozone sonde data. We found that a model using the following explanatory variables in the stratosphere: average tropopause height, the calculated volume of polar stratospheric clouds, 100 hPa eddy heat flux averaged over 45-70 N, and the mean aerosol backscatter in 200-100 hPa range, was able to explain 65 -95 % of the observed variance throughout the stratosphere depending on the altitude in January-April. The proxies account for the changes in the synoptic scale dynamical processes, the vortex ozone depletion, the ozone transport through meridional circulation, and the Pinatubo aerosol effect, respectively. At altitudes between 50 and 70 hPa it can be estimated that chemical polar ozone depletion accounted for up to 50 % of the March ozone variability. The model suggests that negative trends in lower stratosphere prior to 1997 can be attributed to the combined effect of dynamical changes, impact of Pinatubo aerosols and to winters of relatively large chemical ozone depletion. Since 1996-1997 the observed increase in lower stratospheric ozone can be attributed primarily to dynamical changes.

Ozone changes and trends at northern high and middle latitudes: The results from the EU project CANDIDOZ

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The main objective of CANDIDOZ project (2002-2005) was to understand the driving mechanisms behind the observed ozone changes and trends. To achieve this we selected the best long-term ozone data sets available, satellite based as well as ground based, and the most recent long term meteorological reanalyses data sets by ECMWF and NCEP, which were used together with advanced multiple regression models and Chemistry Transport Models, in order to assess the relative roles of chemistry and transport in ozone changes.

The overall synthesis from the individual analyses (altogether 13) shows clearly one common feature in the NH mid latitudes and in the Arctic: Almost monotonic negative trend from late 1970s to mid 1990s followed by a relative recovery after that. An inflection point seems to appear around 1993 in the NH mid latitudes and somewhat later, around 1996 in the Arctic. A similar change can be also seen in the trends of the Arctic vortex characteristics. Furthermore, all individual analyses point to the changes in dynamical drivers, such as residual circulation represented by EP- or heat-flux from troposphere to stratosphere in mid-/high latitudes, playing a key role in the observed turnaround together with closely associated heterogeneous ozone chemistry represented by PSC volume multiplied by Equivalent Effective Stratospheric Chlorine (EESC). Synoptic scale processes represented by new equivalent latitude proxy or by conventional tropopause altitude or 250 hPa height have also been powerful drivers of recent recovery in lowermost stratosphere, regionally. In most long term studies where the comparison was made EESC, which since mid 1990s has been levelling off as a consequence of Montreal protocol and its amendments, was observed to represent ozone loss due to gas phase chemistry better than a simple linear trend. Some influence in recent ozone recovery was also attributed to the solar cycle no. 23.

Emerging pattern of global change in the upper atmosphere

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In the upper atmosphere, greenhouse gases produce a cooling effect, instead of a warming effect observed in the troposphere. Increases in greenhouse gas concentrations are expected to induce substantial changes in the mesosphere, thermosphere, and ionosphere, including a thermal contraction of these layers. Here we construct for the first time a framework of observed global change in the upper atmosphere, based on trend studies of various available parameters. The picture we obtain is qualitative, and contains several gaps and a few discrepancies, but the overall pattern of observed long-term changes throughout the upper atmosphere is consistent with model predictions of the effect of greenhouse gas increases. Both consistent results and those where there are some discrepancies will be presented in more details. Together with the large body of lower atmospheric trend research, our synthesis indicates that anthropogenic emissions of greenhouse gases are affecting the atmosphere at nearly all altitudes between ground and space.

Long-term trends in foF2: results of a comparison of various methods

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Results of various authors on long-term trends in foF2 and their interpretation do not reveal a consistent pattern. Therefore a joint analysis of one carefully selected data set was performed by six teams, which used different approaches to trend determination. High-quality data of station Juliusruh (54.6°N, 13.4°E) for noon (average from 10-14 UT) were used for the period of two solar cycles from minimum to minimum (1976-1996). Various methods provide results, which differ to some extent, even when one co-author applies different methods. Another source of differences is application of various ways of removal (or at least large suppression) of the effect of solar (and geomagnetic) activity. Nevertheless finally most teams obtained quite comparable results. Interpretation of the observed trends is not unique – co-authors consider either the long-term change in geomagnetic activity, or anthropogenic effects to be predominantly responsible for trends. There is some generally accepted output from the joint analysis. All trends are either negative or insignificant. Data corrections with sunspot number (R), F10.7 adjusted to the Sun-Earth distance, observed F10.7, adjusted E10.7 and observed E10.7 result in somewhat different trends; the observed F10.7 and E10.7 appear to be the best correcting factor. The trends in foF2 are very small, of the order of –0.01 MHz/year, much smaller than the solar cycle effect and, therefore, sensitive to the solar activity correction. The Juliusruh dip angle increased very little over the period 1976-1996 and the possible impact of that increase on trends is negligibly small. Discrepancies between co-authors will be reported, as well.

Simulation of past and future secular trends in the middle atmosphere, 1950-2050

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The NCAR Whole Atmosphere Community Climate Model has been used to perform ensembles of long-term simulations to investigate atmospheric trends between 1950 and 2050. The historical simulations are in reasonably good agreement with estimates of secular trends determined from satellite and ground based observations. In particular, stratospheric temperature and ozone trends are well reproduced. The model shows no significant trend in temperature near the mesopause, which is also consistent with observations. However, the large trends in water vapour observed in both satellite and ground-based observations are not well reproduced, but it appears that other sources of low-frequency variability (not included in the model) may contribute to water vapour trends. Ensembles of WACCM simulations have also been extended to 2050 under two scenarios of trends in radiatively active gases and ozone depleting compounds. The first simulations use the IPCC A1b emissions scenario, while the second set holds carbon dioxide, methane and nitrous oxide constant at 2000 levels (while following the A1b scenario for halogenated compounds). These simulations indicate significant changes in ozone and temperature will occur throughout the stratosphere and mesosphere over the next 50 years.

Ionospheric long-term trends: If the geomagnetic control concept and the greenhouse hypothesis can be reconciled

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The ionospheric F2-layer parameter long-term trends are considered from the geomagnetic control concept and the greenhouse hypothesis points of view. It is stressed that long-term geomagnetic activity variations are crucial for ionosphere long-term trends as they determine the basic natural pattern of foF2 and hmF2 long-term variations. The geomagnetic activity effects should be removed from the analyzed data to obtain real trends in ionospheric parameters, but this is not done usually, therefore the resultant trends turn out to be strongly “contaminated” with the geomagnetic activity effects. Real residual foF2 trends which are free to a great extent of geomagnetic activity effects are very small and usually statistically insignificant. Just a thermosphere cooling which is accepted as an explanation for the neutral density decrease cannot be reconciled with negative foF2 trends revealed for the same period. A more pronounced decrease of O/N2 ratio is required which is not provided by empirical thermospheric models. The observed density decrease comprises of two parts – one is due to direct thermosphere cooling and the other - to atomic oxygen abundance decrease presumably resulted from disturbed thermospheric circulation. Thermospheric cooling practically cannot be seen in foF2 trends due to a weak NmF2 dependence on neutral temperature, therefore foF2 trends are mainly controlled by geomagnetic activity long-term variations. Long-term hmF2 variations are also controlled by geomagnetic activity as both parameters NmF2 and hmF2 are related by the F2-layer formation mechanism. But hmF2 is very sensitive to neutral temperature changes, so strongly damped hmF2 long-term variations observed at Slough after 1972 may be considered as a direct manifestation of the thermosphere cooling. Earlier revealed negative hmF2 trends in western Europe where magnetic declination $D < 0$ and positive trends at the eastern stations ($D > 0$) can be related to westward thermospheric wind whose role has enhanced due to a competition between the thermosphere cooling (CO_2 increase) and its heating under increasing geomagnetic activity after the end of 1960s.

Latitudinal variation of foF2 hysteresis for solar cycles 20, 21 and 22

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Noon foF2 monthly median values for equinoctial months of solar cycles 20, 21 and 22, from several worldwide stations were analyzed. For each solar cycle the difference between foF2 for a given Rz in the falling branch of the cycle and the corresponding value of the rising branch is evaluated. The average difference for the whole solar cycle is considered as the hysteresis magnitude, which is found to vary systematically with geomagnetic latitude. It is positive between 40ºS and 40ºN, with minimum values at equatorial latitudes and maximum at mid-latitudes on either side of the equator. For latitudes greater than 50º, negative values are observed. This pattern is the same for every cycle but with different magnitudes. Cycle 20, with a maximum Rz around 120, presents the lowest hysteresis magnitudes, while solar cycles 21 and 22, with maximum Rz around 190, present similar hysteresis magnitudes and greater, on average, than those of cycle 20. For mid-latitudes the hysteresis values are around 0.5 MHz. For low and high latitudes it can be around 2 MHz, which represents 20% of foF2 at high latitudes. Although the phenomenon of ionospheric hysteresis has been known for a long time, a linear relationship between foF2 and Rz is used in forecasting and long-term trend estimations. While the inclusion of the hysteresis into long-term ionospheric predictions remains questionable, in long-term trend assessments it may induce spurious trends in filtering processes.

The influence of decadal zonal ozone variability in the stratosphere on the coupling of atmospheric layers

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The decadal changes of longitude dependent total ozone during the 80ies and 90ies of the last century showed a high variability in wintertime. From a sensitivity study with different ozone distributions of the lower stratosphere, in the frame of the general circulation model ECHAM4, we know that a positive feedback process appeared which increased locally the radiative forcing of ozone by a factor of about ten linked with a strong influence on the dynamics and the coupling of the stratosphere and troposphere.

Here, we report on a study with the GCM MAECHAM5 to examine the effect of radiation perturbations induced by zonally varying ozone in the whole stratosphere on the dynamics of the stratosphere and related coupling with the lower mesosphere and upper troposphere. Especially, the results reveal a decadal shift in the polar vortex, which induce changes in the distribution of the process of Rossby wave propagation and breaking.

On the Observed Changes in Upper Stratospheric and Mesospheric Temperatures from UARS HALOE

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Temperature versus pressure or T(p) time series from the Halogen Occultation Experiment (HALOE) of the UARS satellite have been extended and re-analyzed for the period of 1991-2005 and for the upper stratosphere and mesosphere in 10-degree wide latitude zones from 60S to 60N. Even though sampling from a solar occultation experiment is somewhat limited, it will be shown to be quite adequate for developing both the seasonal and longer-term variations in T(p). Multiple linear regression (MLR) techniques were used in the re-analyses for the seasonal and the significant interannual, solar cycle (SC-like or decadal-scale), and trend terms. A simple SC-like term of 11-yr period is fitted to the time series residuals after accounting for the seasonal and interannual terms. Significant SC-like responses are found for both the upper mesosphere and the upper stratosphere. The phases of these SC-like terms have been checked for their continuity with latitude and pressure-altitude, and in almost all cases they are directly in-phase with that of standard proxies for the solar flux. The amplitudes of the significant SC-like terms vary from 0.3 to 2.1 K with the largest response occurring at 30N and 0.02 hPa (near 74 km). Significant cooling trends are found at middle latitudes of the middle to upper mesosphere and at tropical latitudes of the upper stratosphere.

Polar Mesospheric Ozone 2002-2006 from GOMOS/Envisat

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GOMOS (Global Ozone Monitoring by Occultation of Stars) is a stellar occultation instrument on board the European Space Agency's Envisat satellite. GOMOS measures transmission of light through the Earth's atmosphere in the limb direction. From these transmissions it is possible to retrieve vertical profiles of ozone, NO2, NO3, H2O, O2, aerosols, and neutral air in the stratosphere and mesosphere. The altitude range for the ozone retrievals is 10-100km with a sampling resolution better than 1.7km. GOMOS makes several hundred occultations in a day, and because of the used stellar occultation technique, measurements from both day and night side of the atmosphere can be obtained. Since the launch of Envisat in 2002, more than 300 000 occultations have been measured.

We will present GOMOS observations of mesospheric ozone during the winter periods of years 2002-2006 in both the arctic and antarctic polar regions.

QBO, volcanic, solar, and long-term signals in the past 25-year simulation of the middle atmosphere by the chemistry-climate model of Meteorological Research Institute

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Ensemble middle atmosphere simulation of the past 25-year from 1980 to 2004 has been made with a chemistry-climate model (CCM) of Meteorological Research Institute (MRI), using the REF1 scenario of Chemistry Climate Model Validation (CCMVal) Activity for SPARC. The boundary conditions and external forcings include observed SST, greenhouse gases, halogens, bromines, volcanic aerosols, and solar irradiance variations. Four members have been integrated from different initial conditions. The dynamical module MRI-CCM is a spectral global model of T42 truncation with 68 layers extending from the surface to 0.01 hPa (about 80 km), wherein the vertical spacing is 500m above 100 hPa in the stratosphere. The chemistry-transport module treats 34 long-lived species including 7 families, and 15 short-lived species with 79 gas phase reactions, 34 photochemical reactions and 9 heterogeneous reactions on polar stratospheric clouds and sulfate aerosols. Transport scheme is a flux form semi-Lagrangian type in the vertical and, at once, a simple semi-Lagrangian type in the horizontal with cubic interpolation. It should be stressed that the MRI-CCM can reproduce a realistic QBO of about 31-month period for wind and ozone. Multiple linear regression analysis has been made on the simulation result to analyze QBO, volcanic, and solar signals as well as long-term signals including trend. It is found that MRI-CCM can realistically reproduce not only observed trend of temperature and ozone but also observed short-term signals associated with QBO, volcanic aerosols, and solar irradiance variations.

Peculiarities of long-term trends of surface temperature in Antarctica and their possible connection with outer belt electron precipitation

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Deep geographic isolation of the Antarctic continent from the major global industrial zones provides excellent opportunity to reveal natural tendencies in the Earth's climate dynamics by analysis of meteorological observations data in the Antarctica. Both experimental and model explorations of long-term trends of surface temperature in various places in Antarctica indicate with definite certainty presence of a vast area of climate warming around the Antarctic peninsula which strongly contrasted with clearly expressed tendency to cooling in other parts of Antarctica. This area of climate warming is the most intensive one in the whole Southern hemisphere and it is comparable with similar climate warming places in the Northern hemisphere (Alaska and Eastern Siberia). This phenomenon attracts close attention of the world scientific community but its real origin remains to be insoluble so far. Among many factors, which could explain existence of area of climate warming in this region the scientists mention peculiarities of atmospheric circulation around the Antarctic peninsula, influence of the El Nino effect, dynamics of cloud formation in the area etc. However, none of these explanations could be considered as a complete solution of the problem.

In this report we attract attention to a fact that the global maximum of the outer belt energetic electron precipitation is localized in a narrow longitudinal belt centered in the Weddell Sea i.e. in the area of climate warming in the Southern hemisphere. It was shown by several explorers that energetic resources of this electron precipitation are sufficient to change temperature regime of the stratosphere and troposphere. Possible sequence of physical processes, which could contribute to appearance of permanent area of climate warming around the Antarctic peninsula are discussed in this report.

Comparison of upper air temperatures from MSU/AMSU and CHAMP radio occultation data

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The principal source of satellite-based upper air temperature records for the last ≈25 years was the Microwave Sounding Unit (MSU), since 1998 also the Advanced MSU on U.S. NOAA satellites. The MSU/AMSU channels provide information on layer-average stratospheric and tropospheric temperatures based on measurements of Earth's microwave emission at different frequencies. Comparisons of upper air temperature show discrepancies not only with respect to radiosonde data but also between MSU datasets stemming from different retrievals. MSU data are provided by two main groups, the University of Alabama in Huntsville (UAH) and Remote Sensing Systems (RSS), CA, USA. Based on the same input data, the main issues addressed differently by the groups are the inter-calibration between the series of satellites and the correction for diurnal drift in their construction methodologies.

In this respect the Global Navigation Satellite System (GNSS) radio occultation (RO) technique offers new possibilities by providing high quality observations of the atmosphere in an active limb sounding mode. Besides high accuracy and vertical resolution in the upper troposphere and lower stratosphere region one of the most important properties regarding climate studies is the long-term stability due to intrinsic self-calibration. Based on RO observations of the German/U.S. research satellite CHAMP since late 2001, RO based temperature climatologies have been constructed at the Wegener Center/Uni Graz.

We performed a comparison of the most recent MSU temperature records from UAH (version 5.2) and RSS (version 2.1) with CHAMP RO climatologies based on monthly means within the last five years (2001 to 2005). In addition, we compare to synthetic MSU temperatures from radiosonde data (HADAT2) as provided by the Hadley Centre, U.K. In order to enable comparison with MSU data we use static mean global weighting functions to compute synthetic MSU temperatures from the RO data. We focus on the lower stratosphere channel (T4) and the troposphere/stratosphere channel (T3), the latter only provided by RSS. The weighting functions are applied to zonal mean RO temperature climatology profiles at pressure levels with 10° latitudinal resolution. For further reference also a synthetic MSU record is computed based on ECMWF analyses. The results will be discussed as time series of globally averaged temperature as well as for the tropics (20°S to 20°N) and the northern and southern hemisphere extra-tropics.

Chasing trends in noisy ionospheric data: the Sodankylä Ionosonde

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About a solar cycle and a half ago it was suggested that while changes of the chemical composition of the lower atmosphere will lead to "global warming" in the troposphere, they will be accompanied by "global cooling" in the mesosphere and lower thermosphere. Since the 1930s, and most comprehensively since the IGY in 1957, the ionosphere has been monitored regularly by vertical ionospheric sounders (ionosondes). These radars make rather straightforward measurements of ionospheric properties and the results are readily available in electronic form.

Here we use high-quality measurements from the Sodankylä ionosonde to point out problems in determining the long-term behaviour of such data sets. We show that in some sense the observed trends do depend on the way they are obtained. Special emphasis is given to low-pass filtering. Finally, we propose a search and comparison scheme for trend-finding.

Evaluating trend models

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Trends in the ionosphere may offer important insight into climate change. Long-term records offer unique, near global history of the ionosphere, which may provide insight into changes over the last sixty years. However, the complexity of the data make trend evaluation challenging. Two issues will be covered: data quality and statistical techniques. Data quality issues are particularly important in ionospheric data near the beginning and ends of the records. Statistical techniques must incorporate what is known about the physics of the ionosphere and the limitations of the measurements. Approaches to identify proper statistical models will be discussed. The ramifications of not using physically based statistical models will be presented. For the ionospheric data, two of the most important issues are the non-linear nature of the data and changes in instrumentation. Finally, how do we evaluate the uncertainties on any derived trends? Statistical uncertainties offer one approach to assessment of trends, but scientific understanding can offer additional information which can be more important.

The search for signs of recovery of the ozone layer

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Evidence of mid-latitude ozone depletion and proof that the Antarctic ozone hole was caused by humans spurred policy makers from the late 1980s onwards to ratify the Montreal Protocol and subsequent treaties, legislating for reduced production of ozone-depleting substances. The case of anthropogenic ozone loss has often been cited since as a success story of international agreements in the regulation of environmental pollution. Although recent data suggest that total column ozone abundances have at least not decreased over the past eight years for most of the world, it is still uncertain whether this improvement is actually attributable to the observed decline in the amount of ozone-depleting substances in the Earth's atmosphere. The high natural variability in ozone abundances, due in part to the solar cycle as well as changes in transport and temperature, could override the relatively small changes expected from the recent decrease in ozone-depleting substances. Whatever the benefits of the Montreal agreement, recovery of ozone is likely to occur in a different atmospheric environment, with changes expected in atmospheric transport, temperature and important trace gases. It is therefore unlikely that ozone will stabilize at levels observed before 1980, when a decline in ozone concentrations was first observed.

Long-term changes of the H range at low and mid-latitudes

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To assess long-term trends and periodicities in the daily range of the horizontal component of the geomagnetic field, H, the discrete wavelet transform, using the Daubechies function, was applied. Among a variety of techniques, which are available for analysing trends, wavelet analysis has emerged in the last decade as a useful statistical tool for this purpose. The geomagnetic field display variations caused by magnetospheric processes, the ring current and current systems flowing in the ionosphere. The expected trends in the ionosphere caused by the cooling of the mesosphere and thermosphere due to an increase in greenhouse gases concentration, would induce trends also in the H-range. The monthly mean of the H daily-range for several mid and low latitude stations were used for the present analysis. Possible causes for the observed variabilities and their connection to some atmospheric parameters long-term variations are discussed.

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