International program SCOSTEP – VarSITI

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Abstract
The worldwide SCOSTEP project "Variability of the Sun and Its Terrestrial Impact" (VarSITI, 2014-2018) consists of four projects covering essentially the whole solar-terrestrial physics: SEE (Solar Evolution and Extrema); MiniMax24/ISEST (International Study of Earth-affecting Solar Transients); SPeCIMEN (Specification and Prediction of the Coupled Inner-Magnetospheric Environment); ROSMIC (Role Of the Sun and the Middle atmosphere/thermosphere /ionosphere In Climate). All four projects are briefly described, particularly project ROSMIC, where I am co-chair of one of four working groups. Possibilities of participation of Czech and Slovak scientists in VarSITI, currently the only worldwide project dealing with solar-terrestrial relations in full extent, are briefly discussed.

Abstrakt
Celosvětový projekt SCOSTEP „Variabilita Slunce a její dopad na Zemi" (VarSITI, 2014-2018) sestává ze čtyř projektů pokrývajících v podstatě celou fyziku vztahů Slunce-Země: SEE (Vývoj Slunce a extrémy); MiniMax24/ISEST (Mezinárodní studium slunečních „transients" ovlivňujících Zemi); SPeCIMEN (Specifikace a předpovědi okolí vnitřní magnetosféry); ROSMIC (Role Slunce a střední atmosféry(termosféry/ionosféry v klimatu). Všechny čtyři projekty jsou stručně popsány, zvláště projekt ROSMIC, kde spolupředsedám jedné ze čtyř pracovních skupin. Jsou rovněž krátce diskutovány možnosti účasti českých a slovenských vědců ve VarSITI, v současnosti v jediném globálním projektu zabývajícím se vztahy Slunce-Země v plném rozsahu.

1. Introduction

Solar-terrestrial relations are very complex. They include solar physics, particularly solar outputs in the form of solar radiation and solar wind including high-energy particles, physics of interplanetary space through which the solar transients and the interplanetary magnetic field (IMF) are propagating, physics of the magnetosphere, which in a complex chain of phenomena transfers part of the solar wind energy into lower layers of Earth's atmosphere, physics of the ionosphere, which is heavily affected by phenomena of space weather and space climate transferred through the magnetosphere, physics of the upper atmosphere (thermosphere and mesosphere), which is closely related to ionospheric physics as for response to space climate and space weather, physics of the lower atmosphere and meteorology with not well known impacts of space weather and climate on terrestrial weather and climate. The impact of solar activity and space weather and climate on our modern technologies, both satellite-based and ground-based, and potentially on or related to VarSITI may be found in VarSITI Newsletters (until now 9 issues were published), which on human health, is of significant practical importance for our everyday life.

Complex investigations of solar-terrestrial relations are the aim of the Scientific Committee for Solar-Terrestrial Physics (SCOSTEP). SCOSTEP is doing this job via organizing big international worldwide projects. The current project of SCOSTEP is "**Var**iability of the **S**un and **I**ts **T**errestrial **I**mpact" (VarSITI, 2014-2018). VarSITI cover majority of the above mentioned areas of solar-terrestrial research. Its leaders are K. Shiokawa (Japan) and K. Georgieva (Bulgaria). VarSITI consists of four projects covering essentially the whole solar-terrestrial physics: **SEE** (**S**olar **E**volution and **E**xtrema); MiniMax24/ **ISEST** (**I**nternational **S**tudy of **E**arth-affecting **S**olar **T**ransients); S**PeCIMEN** (**Spe**cification and Prediction of the **C**oupled **I**nner-**M**agnetospheric **En**vironment); **ROSMIC** (**R**ole **O**f the **S**un and the **M**iddle atmosphere/thermosphere/ionosphere **I**n **C**limate). More detailed information about VarSITI can be found at the VarSITI website: http://www.varsiti.org/. Information on scientific activities, on meetings and other useful information are available at: http://www.isee.nagoya-.ac.jp/topics/2016/VarSITI_Newsletter_Vol8.pdf. First

VarSITI symposium was recently (6-10 June 2016) held in Albena, Bulgaria.

2. SEE (Solar Evolution and Extrema)

The project is chaired by P.C. Martens (USA), D. Nandi (India) and V.N. Obridko. Goals and objectives of the project are as follows:

(1) Reproduce magnetic activity as observed in the Sunspot record, including grand minima and extended minima in dynamo simulations.

(2) Amalgamate the best current models and observations for solar spectral and wind output over the Earth's history.

(3) Determine the size and expected frequency of extreme solar events; flares and CMEs.

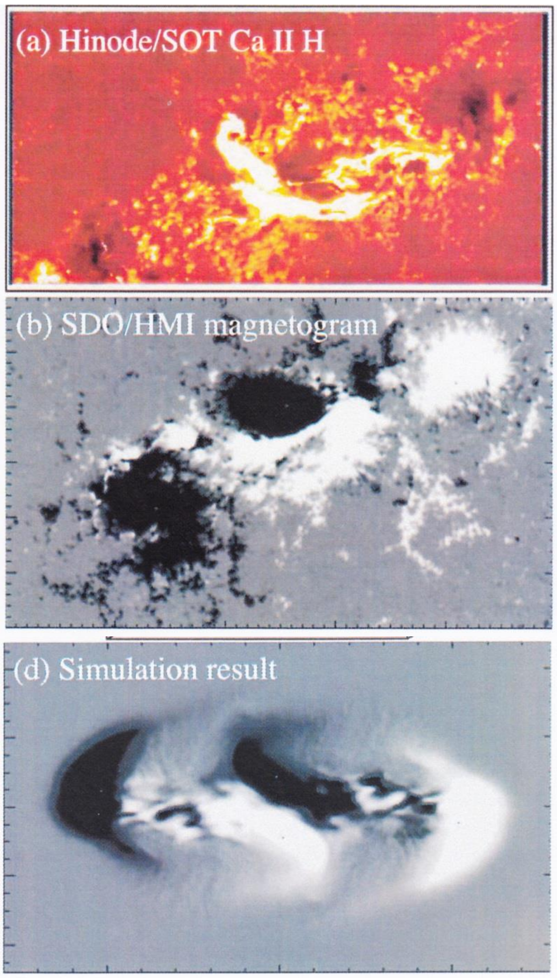

Fig. 1. Observation and simulation of NOAA AR 11158 (February 2011). (a) Hinode observation of an M2.2-class event. (b) SDO observation of a surface magnetic field: white and black indicate positive and negative polarities, respectively. (d) Simulation - a magnetic configuration similar to the observation. Adopted from Toriumi et al. (2014).

Expected outcomes of SEE:

(a) Dynamo Models for the near future, including a pre-diction for cycle 25, or for an upcoming grand minimum.

(b) A timeline of solar activity spectral radiation, wind, CME's -from the Earth's formation up to the present.

(c) A frequency distribution and near term likelihood pre-diction of extreme events.

An example of SEE results is observation and simulation of NOAA AR 11158 (February 2011) shown in Fig. 1. The simulated surface magnetic configuration (Fig. 1d) is similar to that observed by SDO. Even though simulation and observations do not provide identical results, basic similarity is evident.

3. MiniMax24/ISEST (International Study of Earth-affecting Solar Transients)

Whereas SEE is focused on physics of the Sun and its surface, ISEST deals mainly with propagation of solar transients like ICME (interplanetary counterpart of CME) through the interplanetary medium toward the Earth. The project is chaired by J. Zhang (USA), M. Temmer (Austria) and N. Gopalswamy (USA).

The aim of ISEST is to understand the origin, propagation and evolution of these solar transients through the space between the Sun and the Earth, and develop the prediction capability for space weather. Particular emphasis will be placed on the weak solar activity prevailing in Solar Cycle 24 (MiniMax24). The observational campaign MiniMax24 was already run.

ISEST has five working groups:

WG 1 (Data) identifies all Earth-affecting ICMEs during the STEREO era (2007– to – date) and their solar sources. WG1 will identify and characterize also other Earth affecting transients, including solar flares, SEPs and CIRs.

WG 2 (Theory) aims to understand the structure and evolution of CMEs as well as the origin of CMEs and their magnetic rope structure.

WG 3 (Simulation) will provide a global context for CME events investigated by WG1. WG3 will use existing 3D MHD models including ENLIL, COIN-TVD, H3DMHD and SWMF.

WG 4 (Campaign) is dedicated to campaign events. The participants will integrate theory, simulations and observations in order to understand the chain of cause-effect activities from the Sun to Earth for a small number of carefully selected events.

WG 5 (Bs-challenge): The presence of southward magnetic fields, Bs, in ICMEs and CIRs is the most important factor in producing geomagnetic storms. WG5 aims to predict the intensity and the duration of the Bs in ICMEs upon arriving at Earth.

Examples of results of MiniMax24/ISEST:

Observations and continuous tracking of CMEs from the Sun to the Earth is done by a suite of space telescopes, including those from SOHO, SDO, STEREO Ahead/Behind, ACE and WIND. Figure 2 illustrates this monitored propagation of CMEs from the Sun to the Earth.

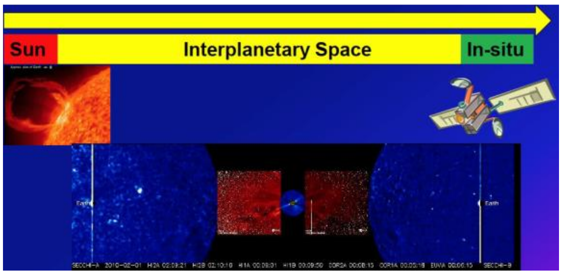

Fig. 2. The observations from the Sun to Earth: solar activity, evolution of the transients in the interplanetary space and effects on Earth's space environment (Zhang, 2016).

A very important task is the prediction of CME arrival at 1 AU. The time of arrival prediction errors (2010-2013) are shown in Fig. 3 for the Empirical Shock Arrival model (ESA – green - oldest), static drag-based model (DEM - red), and advanced drag-based model (blue - newest). The quality of predictions of time of CME arrival is evidently improving but it still is not sufficiently satisfactory.

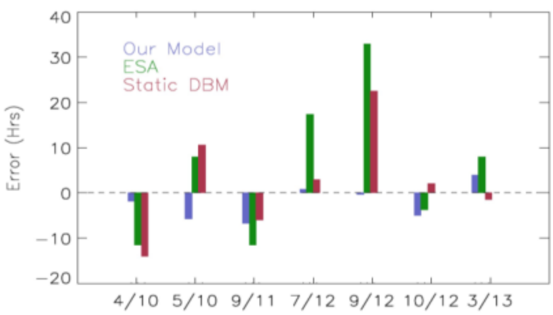

Fig. 3. The time of CME arrival prediction errors are shown for the Empirical Shock Arrival model (ESA – green, oldest), static drag-based model (DEM - red), and advanced drag-based model (blue, newest) - after Zhang (2016).

4. SPeCIMEN (Specification and Prediction of the Coupled Inner-Magnetospheric Environment)

Whereas SEE is focused on physics of the Sun and its surface and ISEST on propagation of solar transients, SPeCIMEN deals with the next part of the solar-terrestrial chain, with the magnetosphere, particularly with the inner magnetosphere, which is more complicated and less understood than the outer magnetosphere and the magnetopause region. The project is chaired by J. Bortnik (USA) and C.J. Rodger (New Zealand).

The inner magnetosphere is an area where both satellite-based and ground-based measurements can significantly contribute to progress. The main scientific question of SPeCIMEN is: Can the state of the Earth's inner magnetosphere be specified and predicted to high accuracy, based on inputs from the sun and solar wind?

The expected outcome of SPeCIMEN is a series of coupled, related models that quantitatively predict the dynamical evolution of the inner magnetospheric state (radiation belts, ring current, cold plasma distribution, plasma sheet, convection electric field, and so on).

Figure 4 illustrates how many satellites provide or provided data for investigations of the inner magnetosphere in frames of SPeCIMEN.

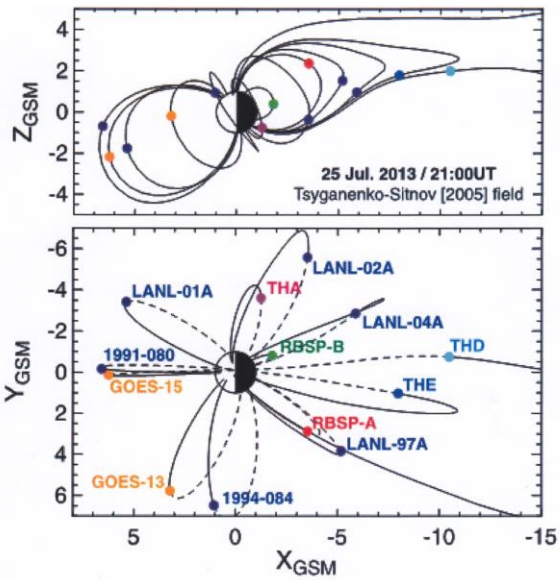

Fig. 4. Various satellites whose data can be used for SPeCIMEN investigations (Turner et al., 2015).

5. ROSMIC (Role Of the Sun and the Middle atmosphere/thermosphere/ionosphere In Climate)

Last but not least is the project ROSMIC, biggest among VarSITI projects in terms of the number of participants. It deals with the sub-end part of the solar-terrestrial chain, with the ionosphere, thermosphere and mesosphere. The project is chaired by F.-J. Lübken (Germany), A. Seppälä (Finland) and W.E. Ward (Canada).

ROSMIC is directed toward identifying the effects of external forcing on and predicting the effects of internal changes to the atmosphere/ionosphere. Its goals and objectives are to understand the impact of the Sun on the terrestrial middle atmosphere/lower thermosphere /ionosphere (MALTI) and Earth's climate and its importance relative to anthropogenic forcing over various time scales from minutes to centuries. The anticipated out-come of this work is the development of a better under-standing of the impact of solar activity on the entire atmosphere, relative to anthropogenic forcing and natural long term variability.

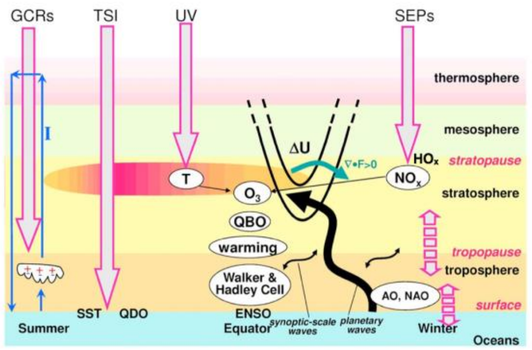

Fig. 5. Mechanisms of solar influence on the Earth's atmosphere (after Gray et al, 2010).

ROSMIC has four working groups:

(1) Solar influence on climate, chaired by B. Funke (Spain), A. Krivolutsky (Russia) and T. Woods (USA).

(2) Coupling by dynamics chaired by T. Nakamura (Japan), C. Stolle (Germany) and E. Yigit (USA).

(3) Trends in the mesosphere and lower thermosphere (MLT) chaired by J. Laštovička (Czechia) and D. Marsh (USA).

(4) Trends and solar influence in the thermosphere chaired by D. Pallamraju (India) and S. Solomon (USA).

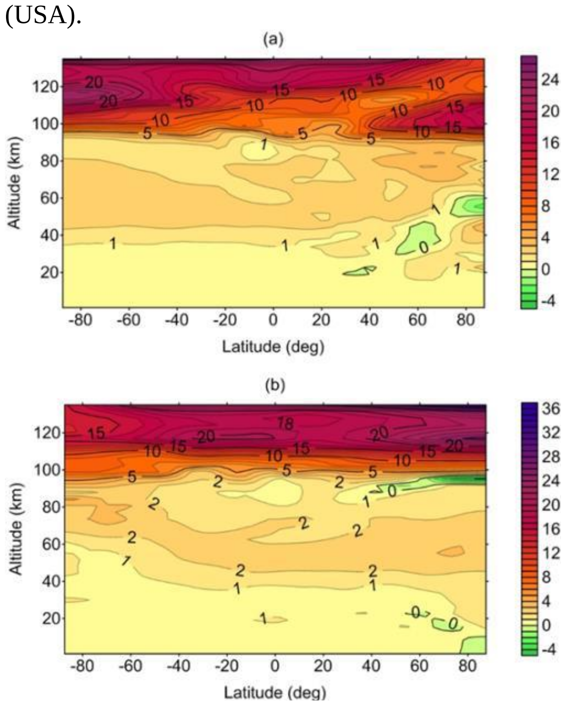

Fig.6. Changes in temperature caused by solar cycle in January (a) and July (b) (simulations with ARM), after Krivolutsky et al. (2015).

Some results of WG1 ROSMIC:

Global circulation model of the Troposphere-Middle Atmosphere-Lower Thermosphere (ARM) was used to simulate the thermal and wind response to solar cycle-induced UV variations. Effect of solar cycle in temperature substantially increases with altitude both in winter and summer, as Fig. 6 shows.

Simulations with model ARM show that atmospheric response to solar cycle has a visible non-zonal character with the amplitude of about 5 K in the troposphere for the winter season. The effect is smaller for summer due to the trapping of planetary waves (PWs) at lower altitudes. The link between the solar UV variability and the middle and low atmosphere strongly depends on the ozone and PWs activity.

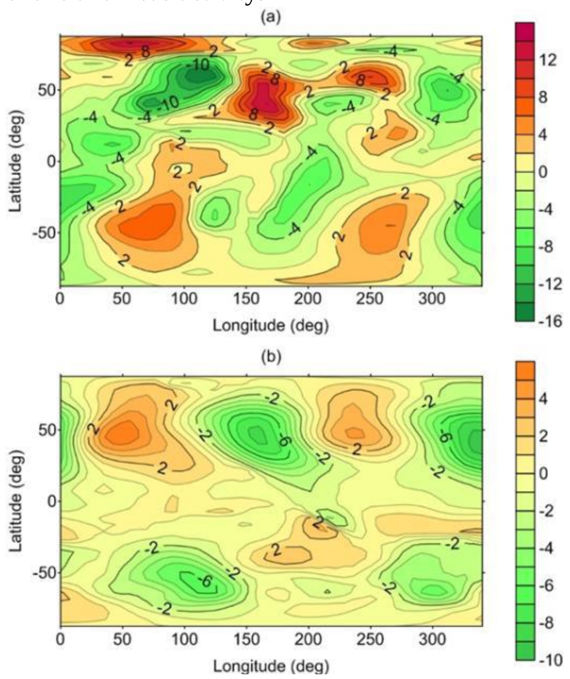

Fig. 7. Changes in temperature at 5 km caused by solar cycle in January (a) and July (b) (simulations with ARM) as a function of latitude and longitude (Krivolutsky et al., 2015).

Some results of WG3 ROSMIC:

Even though a qualitative agreement between models and observations of long-term trends in the upper atmosphere was reached relatively long ago, models systematically provided weaker trends than observations (e.g., Laštovička et al., 2012). Only very recently it was found by satellite observations that the trend of increase of the carbon dioxide (CO_2 - main driver of trends in the whole atmosphere) in the lower thermosphere is substantially stronger than expected, than is that at surface, and that was used in models. Modeling of CO_2 profile shown in Fig. 8 yields CO_2 trend, which is about half of the observed trend in the lower thermosphere. However, modeling with the observed CO_2 trend resulted in even quantitative agreement of observed and modelled trends in thermospheric density, which indicates that using of "old" CO_2 trends is probably the main cause of past quantitative disagreement between observed and modelled trends in the upper atmosphere.

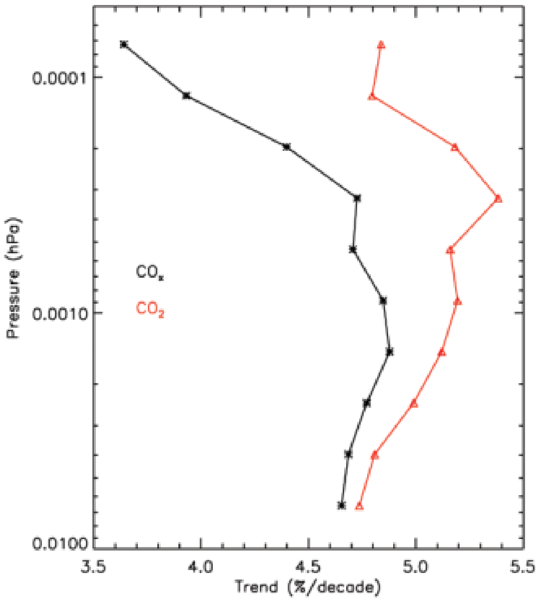

Fig. 8. Trends of CO2 and COx (CO2+CO), in percent per decade, after Laštovička et al. (2016).

Another interesting result concerns the effect of solar/geomagnetic activity on thermospheric cooling by nitric oxide (NO – main cooler of the thermosphere; the second main cooler is CO_2) shown in Fig. 9.

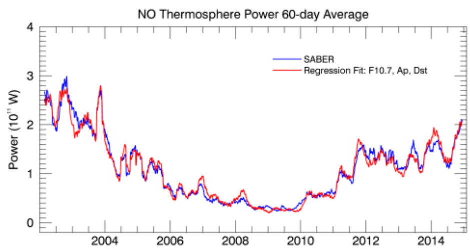

Fig. 9. Multiple regression fit (red curve) using F10.7, Ap, and Dst to the observed time series of thermospheric radiative cooling by nitric oxide measured by the SABER instrument from 2002 to 2015 (blue curve). The multiple correlation coefficient is 0.985. After Laštovička et al. (2016).

Figure 9 shows that the multiple regression fit (red curve) using F10.7, Ap, and Dst to the observed time series of thermospheric radiative cooling by nitric oxide measured by the SABER/ TIMED instrument from 2002 to 2015 (blue curve) is excellent. Strong solar cycle effect is clearly visible – the max-min difference is about a factor of 10 (one order of magnitude). The observed NO cooling may be used as a proxy for thermospheric weather.

Further interesting result concerns the meridional wind at heights from the middle stratosphere up to the lower mesosphere. Figure 10 shows that in this height interval (10 hPa – middle stratosphere, ~30 km; 1 hPa - upper stratosphere; 1 hPa – lower mesosphere, ~61-65 km) the meridional wind forms two cores of much stronger meridional wind, red northward and blue southward. They are a response of total wind to the Aleutian pressure high located between these two cores – wind blows along the pressure high. This is only wintertime phenomenon.

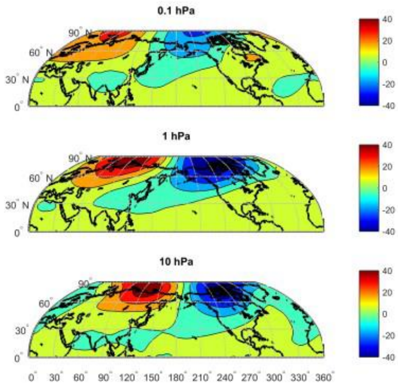

Fig. 10. The MERRA climatology of meridional wind (scale in m/s) for January at 0.1 hPa (upper panel), 1hPa (middle panel) and 10 hPa (lower panel), 1979-2012. Positive values (red) are for northward wind, negative values (blue) are for southward wind.

Long-term trend in the meridional wind at 10 hPa, 50-55ºN, January is significant at the 99% level in the "core" areas but insignificant elsewhere. It is negative during the period of ozone depletion development (1970–1995) but positive after the ozone trend turnaround (1996–2012) (Kozubek et al., 2015). This points out to limitations of "zonal mean" approach used often by modelers in stratospheric investigations.

6. Conclusions

VarSITI is a worldwide research project focused on complex investigations of the influence of Sun on Earth. It is now in the middle and various results have already been achieved, which means that the project is running apparently well.

I do not have information which Czech and Slovak scientists take part in VarSITI but for those who are interested in it is still time to become member of various VarSITI projects and their working groups. Do not hesitate to do it.

Acknowledgement

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