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Science rationale for CAWSES (Climate and Weather of the Sun–Earth System): SCOSTEP's interdisciplinary program for 2004–2008

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Abstract

An international program called Climate and Weather of the Sun–Earth System (CAWSES) has been developed by the Scientific COmmittee on Solar–TErrestrial Physics (SCOSTEP) for the study of integrated Sun–Earth system science to be conducted over the period 2004–2008. This program aims to significantly enhance our understanding of the space environment and its impacts on life and society. The main functions of CAWSES are: (a) to help coordinate international activities in observations, modeling and theory crucial to achieving this understanding; (b) to encourage involvement of scientists in both developed and developing countries in such efforts; and (c) to provide educational opportunities for students at all levels. Such multi-nation, multi-technique studies are absolutely essential for an understanding of the short term (space weather) and the long term (space climate) variability throughout the entire solar–terrestrial domain, for its societal applications and for tracking global changes in climate and ozone. The CAWSES program has been organized under four science Themes: (i) Solar Influence on Climate; (ii) Space Weather: Science and Applications; (iii) Atmospheric Coupling Processes; (iv) Space Climatology. Progress on some of these Themes can only be achieved through conducting carefully planned experimental campaigns with the data being assimilated in coupled physics based models. An end-to-end modeling capability is the ultimate goal of solar–terrestrial science. We hope these aspects will help us also in our Capacity Building efforts which is the fifth Theme under the CAWSES program – particularly in developing countries. In this paper, we will highlight some of the aspects of CAWSES science and attempt to discuss how different specialities in various research fields can be brought together with a well-defined purpose of understanding the interdependencies of the Sun–Earth system as a single entity.

Keywords: Solar influence on climate; Space weather; Atmospheric coupling processes; Space climatology

1. Introduction

There are both purely scientific and applications motivations for identifying and producing an improved understanding of variations in the Sun–Earth system. The Earth, solar system, and beyond provide the cosmic environment in which humankind lives. The quest for applying research and technological tools to secure a better understanding of the human environment is perennial. Achieving sufficient understanding of our solar–terrestrial environment is of great practical significance. There is evidence that changes in the Sun potentially influence climate on the Earth. Also the heightened sensitivity of increasingly sophisticated technology to fluctuations in the solar–terrestrial environment makes it even more important to be able to forecast adverse conditions, or analyze the features of the disturbed system that cause operational problems.

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CAWSES will foster a scientific approach to understanding the short term (space weather) and the long term (space climate) variability of the integrated solar–terrestrial environment, and for studying its societal applications. These include human activities in space, the need for increased reliability of technological systems whose performance depends on the state of the solar–terrestrial environment, and global changes in climate and ozone. Education will also play an important part in CAWSES.

Although presently the solar–terrestrial environment is often thought of in terms of separate physical domains, such as the Sun, heliosphere, magnetosphere, thermosphere–ionosphere, middle atmosphere, and the lower atmosphere climate system; in fact, the solar–terrestrial environment is a system whose state at any given time and at any specific location typically results from a linkage of multiple physical processes that occur simultaneously or sequentially in many domains. For example, variability on decadal time scales permeates the terrestrial and space environments. There are multiple solar sources of this variability. The rise and fall of Sun's 11-year activity cycle causes changes in thermospheric temperature and density. Significant changes also take place from the cumulative effects of geomagnetic storms on the Earth that are initiated by the Coronal Mass Ejections (CME) that originate on the Sun. Clouds of charged particles associated with CMEs propagate through the heliosphere and input energy into the magnetosphere and the polar regions of the Earth; the flux of such energetic particles are controlled by the Interplanetary Magnetic Field (IMF) orientation. As the occurrence of CMEs vary with the ascending and descending phases of the solar cycle, so do the magnetospheric storm effects on the Earth. Solar wind modulation of the interplanetary environment alters the interaction of the magnetosphere and upper atmosphere with energetic solar particles and galactic cosmic rays, and produces additional fluctuations within terrestrial regimes.

CAWSES builds on the experience of SCOSTEP's several successful international programs. Some past SCOSTEP programs have been comprehensive, such that virtually all of SCOSTEP's energy was dedicated to the implementation of one large program. Examples of these were International Magnetospheric Study (IMS) from 1976 to 1979; Solar Maximum Year (SMY) from 1979 to 1981; Middle Atmosphere Program (MAP) from 1982 to 1985; and Solar–Terrestrial Energy Program (STEP) from 1990 to 1997. These were followed by four smaller programs over the next several years: STEP-Results, Applications, and Modeling Phase (S-RAMP); International Solar Cycle Study (ISCS); Planetary Scale Mesopause Observing System (PSMOS) and Equatorial Processes Including Coupling (EPIC). The CAWSES program, targeted initially for the period 2004–2008, builds on this successful history of SCOSTEP and aims to cohesively bring together various research areas that have often been studied separately so far in SCOSTEP's history.

In the following sections, we will briefly discuss the timeliness, scientific objectives and the progress thus far of the CAWSES program, which we hope, will provide a flavor of the usefulness and appropriateness of this program. This brief overview will also provide some basic information on the CAWSES science, which will make one appreciate the ambitious, complex and interdependent nature of investigations that this program aims to achieve. Further information on this program can be obtained from the CAWSES website at http://www.bu.edu/cawses where one can also find the *CAWSES News* which is published twice a year to keep the community abreast of latest developments.

2. Timeliness of the CAWSES program

We are living in an era when an unprecedented suite of spacecraft is presently observing the solar–terrestrial system. These spacecraft, which carry an array of new technology instruments, together with advances in theory and computer modeling, and ground-based observations in existing and new locations, have greatly improved our understanding of how the variable Sun drives changes in geospace, the atmosphere and possibly climate.

Several countries are proposing to implement substantial national programs in solar–terrestrial physics. CAWSES would help mobilize action on those proposals and will offer an opportunity for voluntary coordination between their programs. This properly defined international SCOSTEP program would also help the science communities in nations without space programs and those that have difficulty in implementing desired solar–terrestrial programs. Recent progress in Internet Technology now facilitates effective international collaborations that will benefit CAWSES. The leveraging of intellectual resources within the framework of a properly posed SCOSTEP program would articulate new directions for future solar–terrestrial research involving observations, modeling and applications. CAWSES would help coordinate national activities in all these areas. The CAWSES program has received fairly enthusiastic support from many countries in its first year of inception, which to us indicates the timeliness, and hopefully, effectiveness of the program.

The CAWSES Program will assist many international programs that are being organized either in a part of the science focus area of CAWSES such as the International Living With A Star (ILWS), or as celebrations of the 50th anniversary of IGY (International Geophysical Year) such as the IHY (International Heliophysical

Year http://ihy.gsfc.nasa.gov/), IPY (International Polar Year http://www.ipy.org/) and the eGY (electronic Geophysical Year http://www.egy.org/) during 2007–2008. Considering the broad scientific objectives of CAWSES that are described below, it is felt that a successful CAWSES program will also benefit the organization and implementation of these other international programs mentioned above.

3. CAWSES objectives

An end-to-end understanding of solar–terrestrial physics is the ultimate goal of CAWSES so that physical processes can be tracked throughout the entire Sun–Earth system. To begin with, the CAWSES program's science objective will be to significantly increase our understanding of scientific processes that resolve fundamental science questions which address inter-relationships between the Sun and the Earth's climate and weather. Some of these are:

- Can we link the end-to-end processes that produce geoeffective coronal mass ejections, facilitate their transfer through the heliosphere, their interaction with the magnetosphere, and the production of geomagnetic storms that affect the atmosphere?
- Can we identify evidence for long-term variations of solar luminosity related to solar activity and resultant impacts on global change, compared with other climate change mechanisms?
- To what extent are the magnetosphere and the ionosphere–thermosphere systems modulated by solar activity on long time scales, including the solar cycle, and how do variations driven by different processes interact with dynamical and radiative forcing processes from below?
- Can we reconcile apparent responses of the middle and lower atmosphere to solar activity, identify the physical mechanisms in comparison with anthropogenic influences, and estimate future ozone changes?

To achieve the science objectives described above, CAWSES will embark on a multifaceted approach such as:

- Articulate timely outstanding scientific questions in the connected Sun–Earth system, particularly in cooperation with other ICSU (International Council for Science) programs.
- Coordinate international aspects of specific national programs when the participating nations find this desirable.
- Provide a forum to bring together the international solar–terrestrial science community to help define future programs.
- Continue to help developing nations to participate meaningfully in international solar–terrestrial programs.
- Provide scientific inputs for the purpose of specifying the environment for technological systems whose performance critically depends on the state of the solar–terrestrial domain.
- Provide a coordinated environment in which computer modelers work within observational and analytical programs to achieve validated, reality-based end-to-end models of the entire Sun–Earth system, and then assist in the transition to applications.
- Provide scientific inputs that help ensure human safety in space, since humans will be spending increasing amounts of time there in the future.
- Contribute solar–terrestrial information to the Global Change community.
- Systematically review the quality of solar–terrestrial databases and derived information and improve metadata for solar–terrestrial products so that they meet scientific community needs.
- Actively help international science education by providing solar–terrestrial information to the international educational community and promote scientist-and-student interactions.
- Guide the World Data Center system of ICSU in providing needed STP data and information collecting, processing and archiving services in the modern Internet era.

To facilitate achieving the science objectives of CAWSES, (such as those mentioned above) this program has been organized under four science Themes: (i) Solar Influence on Climate; (ii) Space Weather: Science and Applications; (iii) Atmospheric Coupling Processes; (iv) Space Climatology. Each Theme is dealt with by a minimum of two or more Working Groups. In the following sections, the domain and objectives of each Theme is described followed by a brief description of the interaction among different Themes.

4. Theme 1: Solar Influence on Climate

Sun is the fundamental source of energy that allows life and its environment to exist and flourish on Earth. It is therefore important that we understand and monitor how Sun's energy output varies and study the effects of those variations on Earth's climate and environment. One of the greatest science policy issues facing us today is to understand how human activities are altering Earth's climate so that appropriate actions can be taken to reduce the harmful effects and to mitigate them as far as possible. In order to attribute and predict changes in climate due to human-induced activities it is essential that we have confidence in our ability to separate out changes caused by human activity from changes caused by natural variations. The contribution of Sun's variations to recent climate change, such as the surface temperature increases and extreme weather events is still very uncertain. Furthermore, there are other factors determined by solar activity that have little influence on radiative forcing but may produce particular geographical patterns of response.

Recent improved measurements from a total of nine satellite instruments over the past 25 years have placed the observational record of the 11-year variations in Total Solar Irradiance (TSI) on a firmer footing (Frohlich and Lean, 1998, and update on http://www. pmodwrc.ch/). Satellite observations and their assimilation into numerical models, such as in the recently produced ERA-40 dataset from the European Centre for Medium range Weather Forecasting (http://www.ecmwf.int/research/era), provide extremely valuable datasets for the investigation of the 11-year solar variation impacts on our climate (Haigh, 2003). However, observational studies of the link between TSI and climate parameters such as temperatures, rainfall, circulation, etc. are still problematic. This is primarily due to the relatively short data record of the satellite observations compared with the 11-year cycle length, combined with the large natural variability in climate parameters associated with, for example, volcanic eruptions, the North Atlantic Oscillation (NAO) and El-Nino/Southern Oscillation (ENSO), which makes detection of the solar signal very difficult. With no reliable direct measurements of TSI having been made before the satellite era, studies of the role of solar variability in determining historical climate rely on reconstructions of TSI based on proxy solar activity indicators. Over the past decade, different groups used varied methods to arrive at this reconstruction as shown in Fig. 1. Hoyt and Schatten (1993) (orange line) used solar cycle length, L, Lean et al. (1995) (blue shade) and Lean (2000) (grey shade) used a combination of sunspot number R and 11-year means of sunspot number, R_{11}, Solanki and Fligge (1999) (yellow line) used a combination of R and L, and Lockwood and Stamper (1999) used coronal source flux, F_s in the reconstructions. There are large uncertainties in these reconstructions, mainly in the component ascribed to variability in the background 'quiet' Sun, and further advances in these studies are necessary to provide the input required for climate studies.

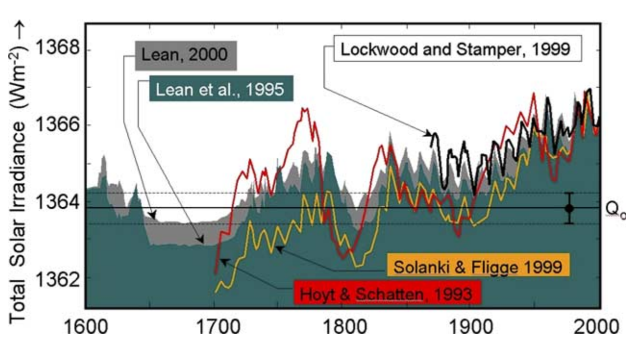

Fig. 1. Total solar irradiance variability using different reconstruction algorithms. (Q_0 is taken from Lockwood and Foster, Private Communication, 2004).

The mechanism(s) for the transfer and possible amplification of the small variations in TSI down through the Earth's atmosphere to the surface where they can affect our climate is still unclear. Candidate mechanisms include changes in ozone heating associated with UV variations, which affect tropospheric circulations through direct impact at the tropopause (Haigh, 1996; Larkin et al., 2000) or indirectly through modifying the winter stratospheric circulation (Kodera, 1995; Gray et al., 2004), cosmic ray influence on cloud cover and albedo (Marsh and Svensmark, 2000), solar energetic particles and their effect on chemistry (Jackman et al., 2000) and global electric field effects (Tinsley, 2000). Because of this lack of understanding, current climate models that are employed for climate assessments (e.g., IPCC, 2001) probably do not adequately represent the essential mechanisms. Indeed, recent model/data comparisons show that they tend to underestimate the solar contribution to climate change over the past 150 years (Stott et al., 2003).

Under this Theme, work will be carried out to review and or investigate the following inter-related goals, which will shed more light on various aspects of this Theme. These include:

- updating of TSI, ozone and climate parameters for the latest solar cycle;
- understanding of what is required for long-term TSI reconstructions;
- analyses of the solar components of variability in a number of climate and ozone datasets;
- general circulation model simulations including coupled stratospheric chemistry;
- understanding of the 27-day solar rotation on stratospheric chemistry;
- new ideas concerning the link between solar influence on the tropical upper stratosphere and the polar lower stratosphere, including the link to the Quasi-Biennial Oscillations (QBO) in zonal stratospheric winds above the equator;
- understanding of how heating perturbations to the tropical lower stratosphere influence tropospheric climate;
- understanding of the processes whereby ionization of the atmosphere by cosmic rays might influence cloud development.

To effectively address issues such as those described above, this Theme has been organized under two Working Groups:

WG 1.1: Assessment of evidence for solar influence on climate;
WG 1.2: Investigations of the mechanisms for the solar influence on climate.

5. Theme 2: Space Weather: Science and Applications

Physical processes on the Sun, the Earth, and the environment in between, all vary continuously. Changing magnetic fields in the solar atmosphere, driven by an interior dynamo, causes solar variability. Solar variability in the EUV radiation, energetic particle fluxes and solar wind conditions cause significant changes in the composition and temperature of the space environment, modulated by heliospheric and geomagnetic field orientations. The resultant alterations of energy output and organization, in the form of electromagnetic and particle radiation and structure of the interplanetary magnetic field, and solar wind plasma, induce terrestrial variability in the form of temperature, composition and particle populations at altitudes from the Earth's surface to the near-Earth space environment. Space weather refers to such effects on the medium from Sun to Earth due to solar activity on time scales ranging from minutes to years.

Such a knowledge of the space environment will be of immense use to improve the utilization of space resources and cope with several space anomalies. Significant economic and societal benefits can result from improved knowledge of the variable space environment in which satellites operate, accurate and timely forecasts of space weather, and coordination of data, models, and information about satellite failures to support postevent analyses. Much of the early framework for the development of this Theme and results from research can be found in publications such as the Implementation Plan for the US National Space Weather Program (2000) and the AGU Space Weather Monograph (2001).

The top-level goals of the space weather Theme are to foster collaborations between national space weather efforts worldwide where such joint efforts enable progress in our ability to: (1) identify critical inputs to specify the geospace environment at a level needed to minimize impacts on technology, human society and life; (2) support the development worldwide of dependable, robust models that predict conditions in geospace based on quantitative understanding of the entire Sun–Earth system and all of its interacting components.

To achieve these goals, Theme 2 will use two interwoven research strategies. It will provide a test bed for a series of new space weather data products based on international collaboration, called "One-Earth" maps or time-series. A "One-Earth" map integrates a key space weather observation from a worldwide distribution of ground-based sites into a single time-dependent global map of space weather quantities or brings together an uninterrupted time-series of solar observations. The first of these "One-Earth" maps will focus on the ULF wave index and mass-loaded magnetospheric density. Other maps might include: uninterrupted time-series of Hα images, cosmic ray ground events, ground-induced currents (GICs), gravity waves, peak densities of the ionospheric F-region and scintillations, and global positioning system (GPS) total electron content (TEC) observations with enhanced spatial resolution.

Another key focus of the CAWSES space weather theme is the organization of international campaigns, where the investigations of key science issues are enhanced or enabled by the availability of "One-Earth" maps or time-series. Valuable outputs of these international space weather campaigns are expected to be: (1) comprehensive Sun-to-Earth geophysical data sets essential for investigating the physics and dynamics of the evolving geospace system; (2) coordinated analysis efforts to utilize these comprehensive data sets; (3) associated global modeling efforts that enable progressive improvements through the iterative interaction between models and the comprehensive "campaign" data sets.

Different working groups have been formed to focus various science and technology issues within Theme 2. They are:

WG 2.1: Enhanced resolution worldwide GPS TEC maps;
WG 2.2: CAWSES/IAGA/GEM worldwide magnetospheric observations;
WG 2.3: Solar observations;
WG 2.4: Continuous solar Hα observations;
WG 2.5: Worldwide space weather applications;
WG 2.6: Models, simulations and data assimilation;
WG 2.7: Worldwide coordinated data analysis.

Currently there are several satellites that monitor solar activity, and those that measure Earth's magnetospheric, ionospheric and thermospheric response to such activity. Also, there is a constellation of GPS satellites, which is used to monitor the propagation environment of the ionosphere and a globally distributed ground-based suite of instruments for carrying out space weather investigations. All these assets will be employed to monitor Sun-to-Earth relationships during conditions of geomagnetic activity and during quiet times. Such investigations will generally be conducted in a campaign mode such that as many experiments as possible could be utilized for a focused investigation of different parts of the Sun–Earth system. One such campaign was held during March–May, 2004. There were two components of the campaign: (1) a space weather interval from March 25 to April 6; (2) an atmospheric coupling interval that spanned from March through May 2004.

The atmospheric coupling experiments were carried out under the auspices of a program entitled Coupling Processes in the Equatorial Atmosphere (CPEA) led by S. Fukao of Kyoto University, Japan. The emphasis of CPEA studies is on understanding the dynamical coupling processes in the equatorial atmosphere – from the troposphere to the ionosphere. Several optical and radio measurements were carried out during this campaign. The radars that participated in the campaign include the Equatorial Atmosphere Radar (EAR) located on the geographic equator in Indonesia in a region of very strong convection, the MU radar in Kyoto, the MST radar located at Gadanki, and the VHF radar at Trivandrum in the Indian sector and radars at Jicamarca and Piura in the American sector. Intense field aligned irregularity echoes were observed by the EAR. Conjugate station optical studies were conducted between Darwin in Australia and Sata in Japan. Such conjugate studies showed bubble structures in the red line nightglow emissions at both these (conjugate) locations indicating a symmetric evolution of the plasma irregularities under certain conditions (Otsuka et al., 2004). The CPEA program serves as an important research area of interest to both Themes 2 and 3. (For further information on CPEA, please visit: http://www.kurasc.kyoto-u.ac.jp/cpea/.)

Several interesting phenomena occurred during the first CAWSES Space Weather campaign. At the beginning of the interval, a high-speed stream in the solar wind was observed on March 25 and peaking on March 27. The solar wind speed, proton density and IMF B_z are shown in panels 1–3 from the top in Fig. 2. An enhancement of the outer radiation belts late on March 28 followed the peak of the high-speed stream with some time delay (panel 4). A C3-class flare erupted on March 31 at 21:53 UT (observed by GOES 10 and shown in panel 5) and a slow CME was observed by SOHO/LASCO moving toward Earth at 220 km/s. The CME took almost 3 days to hit the Earth on April 3 at 14:14 UT triggering a moderate magnetic storm (indicated in panel 6). A magnetically quiet interval (April 1–2) preceded the storm which could be used as a baseline measurement for comparison with other days of the campaign. The leading edge of a high-speed stream hit the Earth on April 5 triggering another moderate storm. The more modest SYM-H index values in the interval March 25–31 are associated with magnetic substorm activity triggered by fluctuating magnetic fields within the high-speed stream interval. We provide below some of the initial results to emphasize the potential for research within this Theme. They include the following:

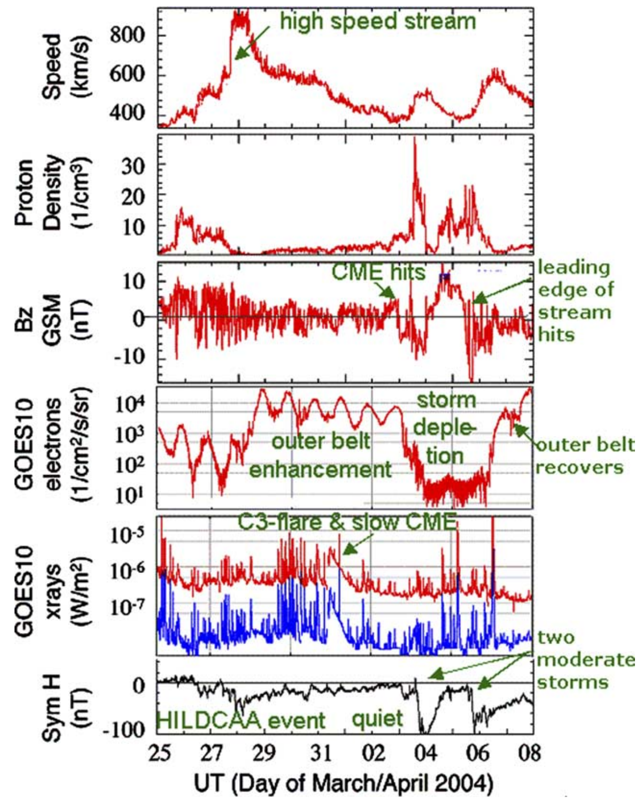

Fig. 2. Solar activity during the first CAWSES space weather campaign. The solar wind speed and density as well as the z-component of the interplanetary magnetic field are quick look data from the ACE spacecraft. The GOES 10 data are provided by NOAA/SEC. The SYM-H index is provided by the World Data Center C2 for Geomagnetism in Kyoto, Japan.

- Unusual undulating auroral forms appeared during both of these moderate storm intervals along with triggering of equatorial bubbles (Paxton, 2004; Private Communication).
- Development of prompt penetration electric fields observed from quiet to active conditions (Anderson, 2004; Private Communication).
- New evidence for penetration of the effects of subauroral polarization stream electric fields to E-region heights (Goncharenko, 2004; Private Communication).
- Superdense plasma sheet on April 3 observed at geosynchronous orbit (Thomsen, 2004; Private Communication).
- Ionospheric data assimilated into the GAIM model to create a global 3D map of the ionosphere based on ionosondes and TEC data (Sojka, 2004; Private Communication).
- Storm enhanced density plume, positive storm effects and subauroral electric field enhancements at Millstone Hill Radar (Huang and Foster, 2004; Private Communication).
- Highest levels of odd nitrogen in the stratosphere ever observed by the UARS satellite (launched, 1994) with corresponding depletions in ozone (Randall, 2004; Private Communication and J. Russell III, 2004; Private Communication).

Interest is high in collecting as complete a data set as possible. The plan is to provide a clearinghouse at the CAWSES website (http://www.bu.edu/cawses) for observation, theory, modeling and data assimilation associated with the first CAWSES campaign. Several such campaigns will be held in the future under this Theme to advance our understanding of space weather and its impacts on technological systems.

6. Theme 3: Atmospheric Coupling Processes

The domain of this Theme encompasses the regions between the radiation-dominated thermosphere (above) and the troposphere (below), where life exists. This Theme seeks to further our understanding of how upward propagating effects might affect the upper atmosphere–ionosphere as well as how downward propagating effects influence regions at and below the altitude levels of energy inputs. Ozone residing in the stratosphere protects biological species from exposure to harmful solar UV radiation. The middle atmosphere is the region of the most significant anthropogenic effect identified as yet in the solar–terrestrial system, namely the Antarctic ozone hole. This, and the apparent global depletion of ozone, prompted policy making that led to the Montreal Protocol. If surface, or near-surface, inputs are to affect the middle atmosphere and the upper atmosphere–ionosphere, they must propagate upward through the various atmospheric regions. In particular, waves propagate upward through the atmosphere, thunderstorms influence the Earth's electric circuit, and chemical compounds are transported upward, undergoing chemical transformations as they do so.

Some salient results obtained so far provide clear experimental evidence on the dynamical coupling between different regions of the atmosphere. For example, Fig. 3 shows the results from temperature measurements at 54°N latitude from various lidars, wherein temperature enhancements are seen first at high altitudes and then move down to lower altitudes (up to 20 km) with time (Alpers et al., 2004). Similarly zonal mean wind reversals are seen in the mesosphere first, which then move to lower altitudes (Fig. 4). Systematic measurements such as these are extremely essential in understanding the role of gravity waves and tides in such vertical couplings in the atmosphere (see, for example Fritts and Alexander, 2003).

Solar energy inputs to the terrestrial system, both radiative and corpuscular, and magnetospheric inputs affect the atmosphere in many ways. They can initiate wave disturbances that propagate downward. They can alter the upper atmosphere's chemical composition, which influence the atmosphere's conductivity and dynamics that have significant effects even in the meso-

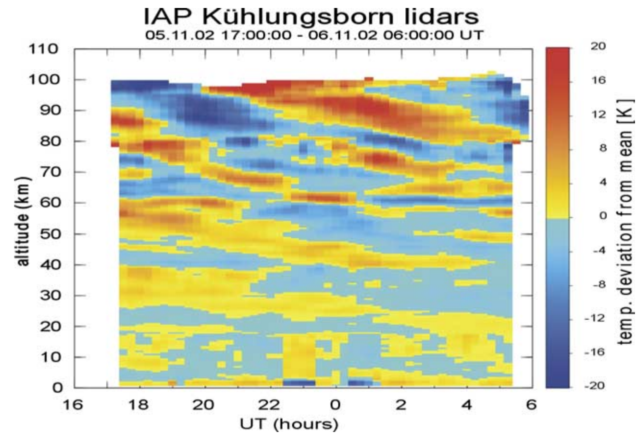

Fig. 3. Lidar measurements of the downward propagation of temperature structures associated with the upward propagation of gravity waves (Alpers et al., 2004).

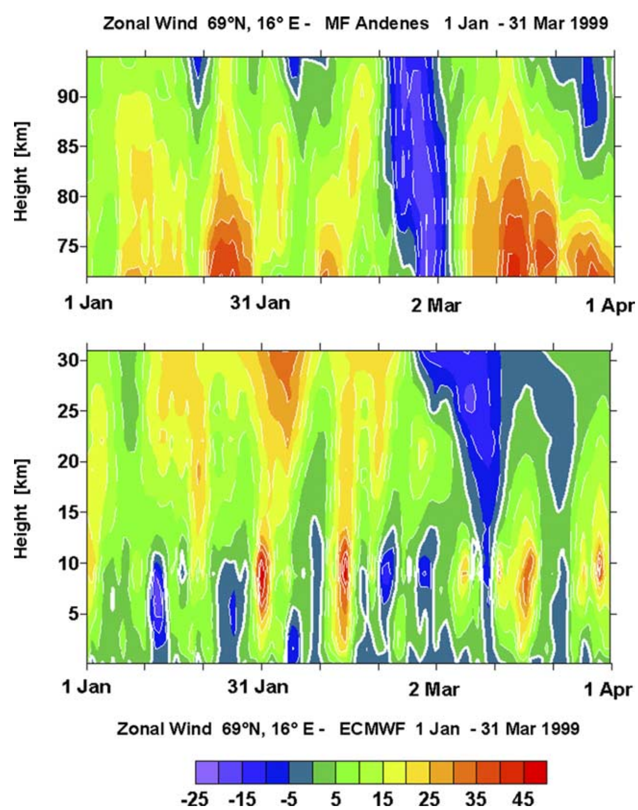

Fig. 4. Zonal wind measurements showing that sometimes direction reversals in the mesosphere may precede those in the stratosphere and troposphere (F.J. Luebken, Private Communication, 2004).

sphere and the troposphere (see, for example Labitzke and van Loon, 1998; Brasseur, 1993; Haigh, 1994; Cubasch et al., 1997; Baldwin and Dunkerton, 2001; Callis et al., 2001; Berger and von Zahn, 2002; Sinnhuber et al., 2003). There are some unique phenomena in the upper atmosphere, for example Noctilucent Clouds (NLC) which are influenced from above and below (Lübken et al., 2004). To understand these different aspects of atmospheric coupling, three Working Groups have been established. They are:

WG 3.1: Dynamical coupling (planetary waves, gravity waves, tides, turbulence) and its role in the energy and momentum budget of the middle atmosphere;
WG 3.2: Coupling via photochemical effects on particles and minor constituents in the upper atmosphere: solar–terrestrial influences and their role in climate;
WG 3.3: Coupling by electrodynamics including ionospheric–magnetospheric processes.

7. Theme 4: Space Climatology

The main aim of this Theme is to provide data necessary to study the Climatology of the Sun–Earth System. Therefore, this Theme will emphasize the use of long-term effects that are of the order of a solar rotation period and longer. There will be a critical review of the original observations and also their interpretation. The different Working Groups under this Theme are:

WG 4.1: *Solar irradiance variability*: Topics of study include the possible secular trend of observed TSI, the short-term variability of TSI and the Spectral Solar Irradiance (SSI), time-dependent spectra for SSI (IR to EUV) which can be used in climate models, time series for Photometric Sunspot Index (PSI) and proxies such as Magnesium Ion Index (MgII) for general use, extension of proxies for irradiance variability to cover the last 1000 years, and definition of a climatology of CMEs and solar wind as far as they influence the Earth's environment on time scales longer than the 27-day rotational period of the Sun.

WG 4.2: *Heliosphere near Earth*: Topics of study are: geomagnetic field and interplanetary magnetic field and its variability during the last 1000 years, cosmic rays with their relation to solar activity and variability during the last 1000 years, and historical auroral data as support for the long-term variation of solar activity.

WG 4.3: *Radiation belt climatology*: studies on the evolution of radiation belts and interrelationships between the radiation belts and the geomagnetic field will be the focus of this working group. This study will be first initiated by developing a long-term radiation belt database which will then be used to construct the next generation radiation belt model that will be used for both science and technology development. Such studies will help in our understanding of the control of solar activity on the radiation belt structure and the dynamical behavior of the radiation belts owing to the occurrence of magnetic storms.

WG 4.4: *Climatological variations of the ionosphere and the upper-atmosphere*: (with International Association of Geomagnetism and Aeronomy (IAGA) and International Commission on Middle Atmosphere (ICMA) liaison): Climatological variations refer to changes in the mean state of a system including long-term trends. The mean state is defined within a given parameter space. For the purposes of WG 4.4, the upper atmosphere is the region between the stratopause ($\sim$50 km) and 1500 km. The ionosphere is defined as the ionized portion of the atmosphere within this region. Specific as this definition is, it still leaves a large overlap between other CAWSES Themes and Working Groups as well as other ongoing international research efforts. This WG will be addressing the important issue of identifying key data sets for analytical focus, establishing their quality, promoting their longevity, and if necessary creating documentation of these efforts. The WG 4.4 will work closely with Theme 3 to form their fourth Working Group 3.4 to describe long term trends on atmospheric parameters (see Beig et al., 2003 for trends of mesospheric temperature).

One of the main objectives of Theme 4 will be to identify solar, magnetospheric, ionospheric, thermospheric and mesospheric parameters that will be of interest to a large cross-section of people from school children to senior researchers. The emphasis will be in having the over-all Theme 4 Committee quality control the climatology of the data sets identified earlier. A CD will be created with these chosen datasets for public dissemination. Currently there are many on-going individual, national, and international efforts to identify these climatologies in the different disciplines. It is envisioned that this CD will bring selected quality-controlled datasets together in one place. The scientific work of interpreting these climatologies will be an on-going effort and one with which many of the CAWSES Working Groups will be actively involved.

8. Inter-relationship among the CAWSES science Themes

Solar influence on the climate affects various regions, especially the stratosphere and lower atmosphere. There are several effects such as the photochemical (e.g., ozone variations), wave (e.g., planetary wave), and particle effects on the minor constituents such as NO_x in these regions that need to be understood to address the overall objective of understanding the climate on the Earth in response to solar influences. Also, the information obtained on the long-term variability along the Sun–Earth direction (for example, global electric field, solar energetic particle effects, heliospheric structure and the Galactic Cosmic Ray (GCR) shielding) has useful applications for the magnetosphere and the ionosphere–thermosphere system science. In addition, information obtained or data reconstructions on the long-term variability of the solar parameters (for example, the total solar irradiance and spectral variability) are needed as inputs in modeling the space climatology. There are several questions regarding the interactions of solar flux (both particle and photon) on the tropospheric–stratospheric circulation patterns such as, North Atlantic Oscillations (NAO), Arctic Oscillations (AO), El-Nino/Southern Oscillation (ENSO), Quasi-Biennial Oscillations (QBO), stratospheric warming, densities of trace gases, etc. In addition, it is of immense interest to learn how deep in the atmosphere the effects of geomagnetic disturbances are registered. It is known that the winds and temperatures of the upper atmosphere vary with solar cycle, which need to be quantified. Such information is essential in understanding the coupling of the upper atmosphere to the lower atmosphere (for example, through downward transport of chemically active species, for instance). The 'One-Earth maps' of different observables that are being contemplated as part of the space weather Theme could play an important role in the understanding of space climatology.

Some of these inter-relationships among the different Themes are depicted in a schematic (Fig. 5). The rectangles represent different Themes and the ovals depict the processes by which the respective Themes are coupled. The heads of the arrows point to the direction of the flow of information or interaction. The scientific processes listed in the ovals are merely typical candidates for investigation and this does not in any way rule out other parameters that need to be investigated.

9. Theme 5: Capacity Building and Education

The CAWSES program will take advantage of the advances in computing and electronic communications that are reshaping so much of the world to assist and enhance the CAWSES science in different nations. During the various international conferences and symposia that occur periodically, considerable effort will be given to proposing CAWSES science related workshops in which scientists from all nations, especially from developing nations, will be encouraged to participate. Such events will provide a good opportunity for capacity building and education of the next generation of scientists. During the formulation period for CAWSES, the SCOSTEP Bureau, National Adherents, and Scientific Discipline Representatives voted to devote a portion of SCOSTEP's financial support for CAWSES to Capacity Building and Education.

A first such effort is the establishment of the CAWSES AOPR (Asia, Oceania and Pacific Rim) Office in Taipei, in July 2004. This Office will also support activities of the AOPR Center in Simulation and Modeling of

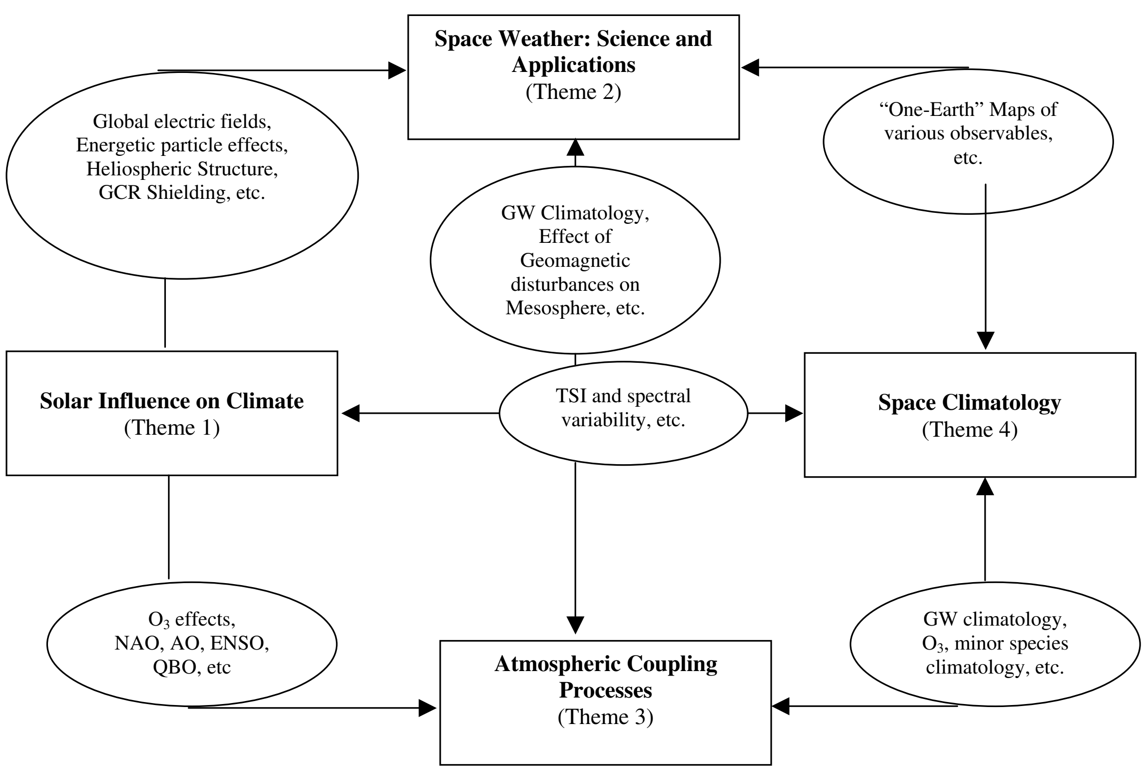

Fig. 5. Schematic of the inter-relationship among the different Science Themes of CAWSES. The rectangular boxes indicate the different Themes. The ovals contain typical scientific problems or issues that couple the two CAWSES Themes connected by arrows. The arrowhead depicts the direction of propagation of information and or data. It should be noted that the science issues included in the ovals are only examples of many others that could be chosen.

the Sun–Earth System. The Center will fuse together the simulation and modeling activities in different institutions in Taiwan into a coherent effort to interact with other centers in the AOPR region. It will serve as a training center for young scientists through mini-workshops, particularly in the South Asian region.

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