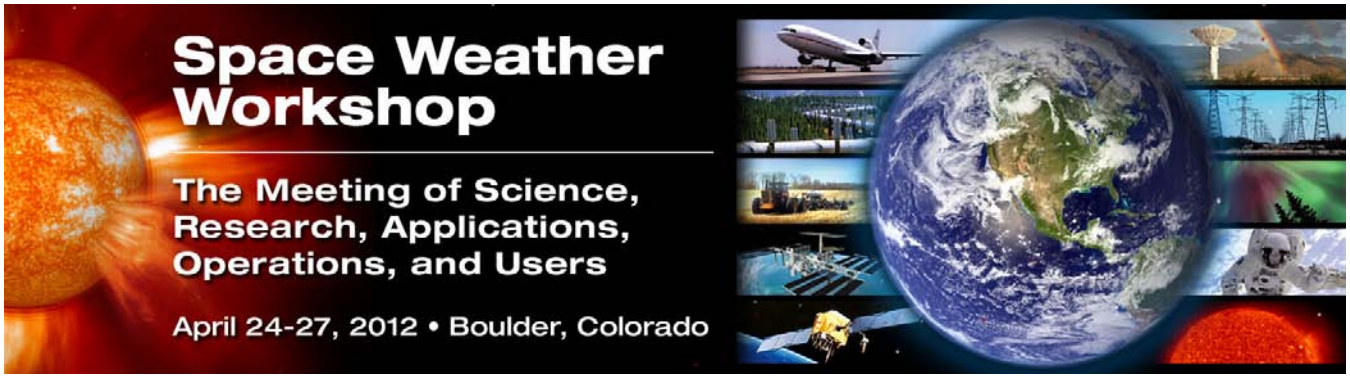


Millennium Hotel – Boulder, Colorado
April 24 – 27, 2012

The 2012 Space Weather Workshop will again bring together the diverse elements of the space weather community. Representatives from research centers, the commercial space weather services sector, international organizations, and several federal government agencies will participate in a variety of sessions relevant to space weather. Topics include:

- The economic effects of geomagnetic storms on electric utilities, commercial aviation services and satellite navigation systems such as GPS.
- The international coordination of space weather activities from space weather service organizations around the globe.
- Advances in space weather modeling, and the emerging needs of the operational and forecasting community.
- The development and implementation of spacecraft and instruments of value for both research and operations.
- Recent research regarding solar cycles past and present and long term trends in space weather.

In addition to the plenary sessions there will be poster sessions and a roundtable discussion about growing the space weather enterprise. The roundtable consists of a panel represented by distinguished members of the public and private sector. The panel discussion is preceded by a keynote presentation from Conrad C. Lautenbacher, Jr., Vice President, Science Programs, CSC, and former NOAA Administrator. The Wednesday evening banquet will feature Dr. Madhulika (Lika) Guhathakurta, from NASA, speaking about the international response to the growing impacts of space weather.

Space Weather Workshop 2012 is co-sponsored by the NOAA Space Weather Prediction Center, the NSF Division of Atmospheric Science, the NASA Heliophysics Division, and the NASA Space Radiation Analysis Group.

http://www.spaceweather.gov/sww

Activities and Resources

Welcome to the 2012 Space Weather Workshop!

Meeting Events

The Conference begins at 8:30 am each morning in the Grand Ballroom of the Millennium Harvest House Hotel. There are afternoon poster sessions as well as afternoon talks. Please check the agenda carefully as times may vary each day.

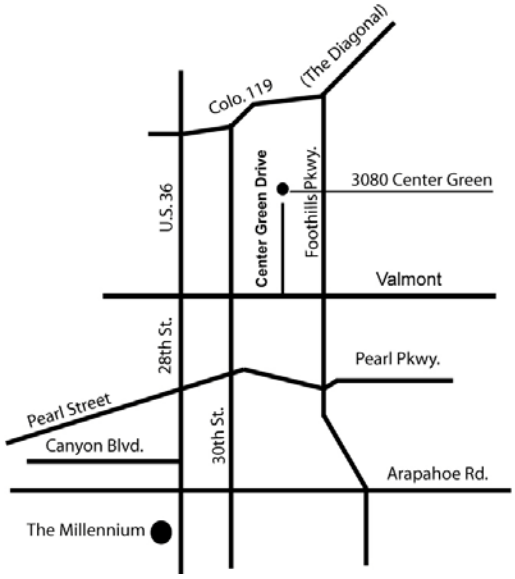
Posters

All posters will be available for viewing during the three full days of the conference. They will be grouped by subject in the Millennium and Century Rooms on the first floor. Authors will be at their posters for one of the three afternoon poster sessions according to the schedule in the agenda.

Poster Authors: You are asked to display your poster before noon on Tuesday. Posters will be grouped by subject (see the number associated with your poster listed in your packet). You are requested to attend the session where your topic is covered. There will be a few Internet drops for your computer in the poster session rooms. Posters should be taken down before 6:00 pm on Thursday.

Workshop Banquet

On Wednesday, April 25, there will be a banquet held at the **UCAR Center Green 1 Building,** 3080 Center Green Drive, Boulder, CO, from 6:00 – 8:30 pm. This is a great time to meet your fellow attendees and many of the Space Weather Prediction Center (SWPC) staff over food and spirits. Appetizers and dinner will be served from 6:00 – 7:30 pm. The evening will culminate with a special presentation by Dr. Madhulika (Lika) Guhathakurta, titled A One-World Response to the Growing Threat of Space Weather.



Commercial Sector Dinner

The Commercial Sector Meeting and Dinner will be held on Thursday at the Millennium Hotel, Boulder Creek Living Room, starting at 6:00 pm. If you would like to attend, please contact Susan Baltuch, at the registration desk, no later than Wednesday noon. You will be responsible for paying for your dinner.

Lunch Breaks

You will be responsible for your own lunches during the week. Lunch breaks are flexible enough for you to enjoy one of the several restaurants within walking distance (out the main entrance and down the street to the left).

Logistics

Registration

Registration will be held in the Sunshine Room on the Second floor of the hotel. Help with conference logistics is available at the registration desk. The hotel front desk can also help with arranging services.

Messages

If your office needs to reach you during the business day, please call the hotel at 303-443-3850, and ask to be connected to the Sunshine Room. You may also ask the hotel front desk to take a message. Messages will be posted near the registration desk. For other business services contact the hotel front desk.

Phones

Pay phones are located in the lobby of the hotel.

Email Access

The Sunshine Room and the Millennium Room will have internet access computers available during the conference. Please share time on them with your colleagues. Wireless will also be available throughout the conference rooms. A printer will be available in the Sunshine Room.

The Millennium has computer kiosks located throughout the hotel on which guests may access email. These computers can print to the front desk where you may also receive/send faxes and make copies. There is a fee for the computer kiosk use. There is free wireless access in the lobby of the hotel.

Tours of the Forecast Center

Tours of the SWPC Forecast Center will be given on Wednesday and Thursday. A shuttle bus will depart the Millennium Hotel at 1:15 pm each day. The Forecast Center is just a 10 minute drive from the Hotel. A sign-up sheet will be available at the registration desk. A temporary pass will be provided to each visitor at the entrance to the site. All foreign nationals will need to complete a form at the registration desk in the Sunshine Room at least 24 hours before the visit and present their passport at NOAA Security. All other visitors will need a valid ID.

Evaluation

You will find a conference evaluation in your packet. We are interested in learning how the Space Weather Workshop met your expectations, so please leave your response at the registration desk before you leave.

2012 Space Weather Workshop Agenda

Tuesday, April 24

8:30 **Opening Remarks** – Louis Uccellini, NOAA/ National Weather Service/ National Centers for Environmental Prediction

8:40 **State of the Space Weather Prediction Center** – William Murtagh, NOAA/ NWS/ SWPC

9:00 **Solar Cycle 24 – How is it progressing and where is it going?** – Douglas Biesecker, NOAA/ NWS/ SWPC

9:20 **Demonstration of the Advanced Weather Interactive Processing System (AWIPS) for Space Weather - R2O/O2R Capabilities -** Michelle Mainelli**,** NOAA/ National Weather Service/ National Centers for Environmental Prediction

9:30 – 12:00 **Space Weather Effects on Satellites - Chairs: Janet Green/ Terry Onsager**

9:30 **Satellite Meeting Overview -** Janet Green, NOAA/NGDC

9:45 **Radiation Effects on Satellites - A JPL Perspective -** Henry Garrett, Jet Propulsion Laboratory, California Institute of Technology

10:00 **Break**

10:20 **SPACECAST: A new European Service to Forecast the High Energy Electron Flux in the Radiation Belts -** Richard Horne, British Antarctic Survey

10:35 **The Impact of Space Weather on Inmarsat Satellite Fleet Operations -** Mark Dickinson, Inmarsat

10:50 **Paradigm and Space Weather -** Brian Swinburne, Paradigm

11:05 **Profound Change of the Near-Earth Radiation Environment Caused by Solar Superstorms -** Yuri Shprits, UCLA - Presented by Richard Horne

11:20 **Satellite Roundtable Discussion**

12:00 **Lunch**

1:00 - 3:00 **Poster Session - Solar and Interplanetary Research and Applications**

3:00 - 5:00 **Aviation and Space Weather - Chairs: Joseph Kunches/ Jennifer Meehan**

3:00 **Delta's Hazard Avoidance Procedures & Use of Space Weather Information** -Tom Fahey and Gregg Scott, Delta Airlines

3:15 **Eurocontrol Space Weather Activities -** Emilien Robert, Eurocontrol

3:30 **Federal Aviation Administration -** Steve Albersheim, FAA

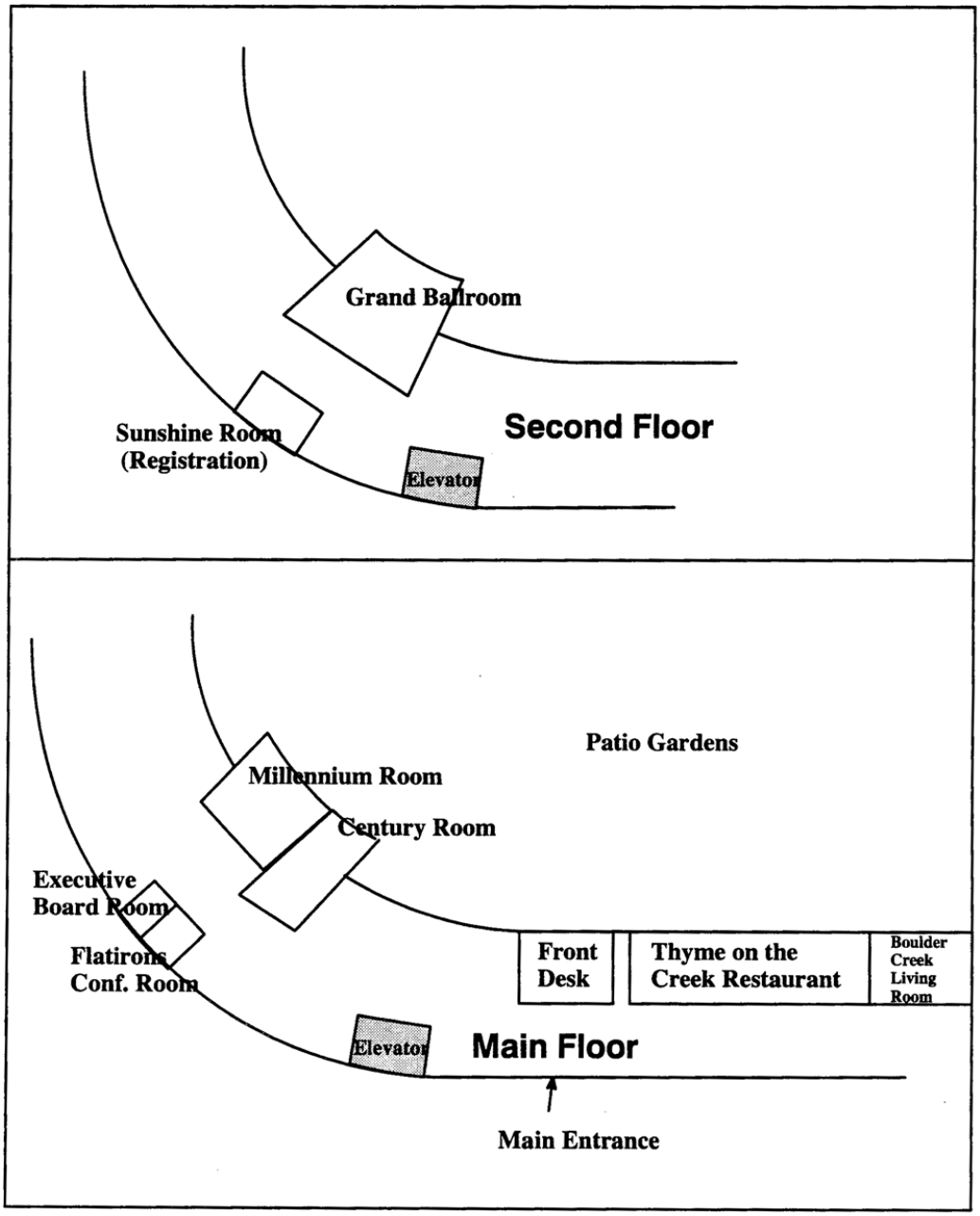
3:45 **Radiation Protection in Aviation: The Importance of Space Weather -** Matthias Meier, German Aerospace Center (DLR)

4:00 **Potential Space Weather Impacts and Needs for Commercial Space Operations in the Near Future -** Karen Shelton-Mur, FAA

4:15 **Aviation Roundtable Discussion**

5:00 **End of Session**

Meeting Rooms at the Millennium Hotel



Wednesday, April 25

8:30-10:00 **Commercial Space Weather Interest Group Roundtable Session: Growing the Space Weather Enterprise**

Keynote Speaker:
Dr. Conrad C. Lautenbacher, Jr., Vice President, Science Programs, CSC –
"Growing the Space Weather Enterprise – Improving Community Visibility"

Panelists:
Dr. Tamara L. Dickinson, Senior Policy Analyst, Office of Science and Technology Policy, Executive Office of the President: "Progress in Space Weather Policy"

Mr. Jon Turnipseed, Head of Safety, Virgin Galactic: "The Future of Space Tourism and Space Weather"

Moderator and Organizer:
Dr. Devrie Intriligator, Director, Space Plasma Laboratory,
Carmel Research Center, Inc.

10:00 **Break**

10:20 - 11:20 **Agency Activities - Chair: Brent Gordon/ Bill Murtagh**

10:20 **National Weather Service -** Louis Uccellini, NOAA/National Weather Service/ National Centers for Environmental Prediction

10:40 **Air Force Weather Update -** Col. John Egentowich, USAF

11:00 **NASA Heliophysics Division -** Barbara Giles, NASA

11:20 **Space Weather Research at the National Science Foundation -** Richard Behnke, National Science Foundation

11:40 **NASA Space Radiation Analysis Group- Space Radiation Protection, Space Weather, and Exploration -** Kerry Lee, NASA

12:00 **Lunch**

1:00 - 3:00 **Poster Session - General Research/ Operations and Magnetospheric Research and Applications**

3:00 - 3:20 **Decadal Survey - Chair: Howard Singer**

3:00 **Space Weather and the Next Solar and Space Physics Decadal Survey -** Daniel Baker, University of Colorado, Boulder

3:20 - 5:00 **International Coordination of Space Weather Activities - Chairs: James Head/ Terry Onsager**

3:20 **State Department Engagement with the International Space Weather Community -** James Head, U.S. State Department

3:40 **Space Weather Impact on Critical Infrastructures: Activities at the European Commission's Joint Research Centre -** Elisabeth Krausmann, European Commission, Joint Research Centre

4:00 **Space Environment Support to NATO Space Situational Awareness: Advances by the NATO Research & Technology Organisation SCI-229 Task Group -** Mauro Messerotti, INAF-Astronomical Observatory of Trieste

4:20 **United Kingdom - Recent Space Weather Activities and Plans in the U.K. -** Mike Hapgood, RAL Space - Rutherford Appleton Laboratory

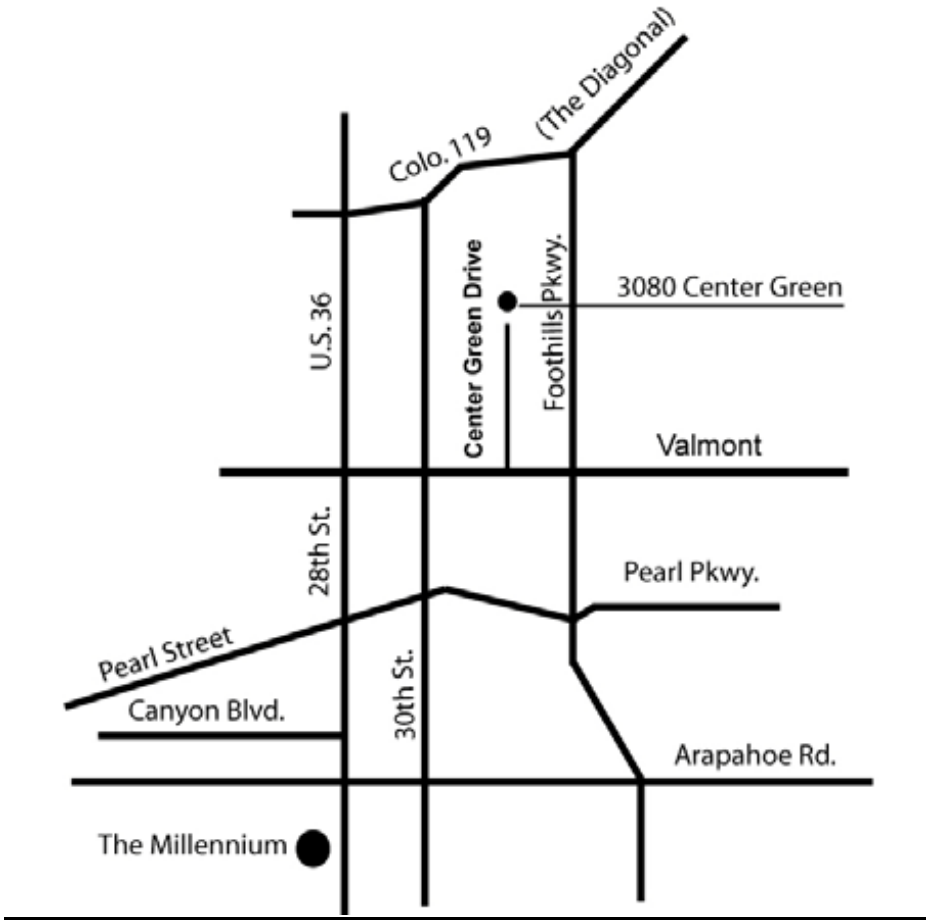
4:40 **World Meteorological Organization (WMO) and International Space Environment Service (ISES) Activities -** Terry Onsager, NOAA/ Space Weather Prediction Center

5:00 **End of Session**

6:00 - 9:00 **Reception Dinner at UCAR Center Green Campus, Bldg. 1**

Special Guest Speaker: Dr. Madhulika (Lika) Guhathakurta -

A One-World Response to the Growing Threat of Space Weather



Thursday, April 26

8:30 - 10:10 International Coordination of Space Weather Activities - Chair: Terry Onsager

8:30 **Japanese Space Weather Activities and Asia Oceania Space Weather Alliance -** Shinichi Watari, National Institute of Information and Communications Technology

8:50 **Activities of Korean Space Weather Center -** Jae-Hyung Lee, Korean Space Weather Center

9:10 **The Brazilian Space Weather Program - EMBRACE - Inauguration Year -** Joaquim E R Costa, National Institute for Space Research (INPE)

9:30 **International Service Provider Update**

9:50 **Break**

10:20 - 12:00 Space Weather Prediction Modeling - Chair: Howard Singer

10:20 **Solar Active Longitude and Active Level Estimation -** Huaning Wang, NAO, Chinese Academy of Sciences

10:40 **WSA-Enlil in Operations at the National Weather Service: Experiences, Results and Developments -** George Millward, NOAA/ Space Weather Prediction Center

11:00 **The NOAA Space Weather Prediction Testbed-** Rodney Viereck, NOAA/ Space Weather Prediction Center

11:20 **Operational Dst from Real-Time Data Streams and Forecast Algorithms -** W. Kent Tobiska, Space Environment Technologies SWD

11:40 **Assessment of Ionosphere/Thermosphere Models in Low Solar Flux Conditions for the CCMC CEDAR Challenge -** Barbara A. Emery, HAO/NCAR

12:00 **Lunch**

1:00 - 3:00 Poster Session - Ionospheric Research

3:00 - 3:20 Transiting Science to Applications- Chair: Jeff Shoup

3:00 **Lessons Learned from Successful Earth Science Research-to-Applications Efforts -** James Spann, NASA

3:20 - 5:00 Geomagnetic Induced Currents - Chair: Chris Balch

3:20 **North American Electric Reliability Corporation -Geomagnetic Disturbance Taskforce -** Mark Lauby, North American Electric Reliability Corporation

3:40 **U.S. Geological Survey Geomagnetism Program Product Status -** Carol Finn, U.S. Geological Survey

4:00 **Solar Shield Project - Updates and Future Challenges -** Antti Pulkkinen, Catholic University of America at NASA/GSFC

4:20 **Solar-Flare Induced Disturbances in the U.S. Electric Grid and their Economic Impact -** Sarah Mitchell, Lockheed Martin

4:40 **FEMA Federal Interagency Response Planning -** Donald Daigler, FEMA

5:00 **End of Session**

6:00 - 9:00 **SWPC / Commercial Space Weather Interest Group / ACSWA Dinner and Summit (by invitation)**

Friday, April 27

8:30 - 10:10 **Modeling - Chair: George Millward**

8:30 **Modeling the Structure of the Solar Corona and Inner Heliosphere Using CORHEL -** Pete Riley, Predictive Science, Inc.

8:50 **The Air Force Data Assimilative Photospheric Flux Transport (ADAPT) Model -** Charles Arge, Air Force Research Laboratory

9:10 **A Solar Energetic Particle Event Model for WSA-ENLIL -** Janet Luhmann, Space Sciences Laboratory, University of California, Berkeley

9:30 **Community Coordinated Modeling Center: Addressing Needs of Operational Space Weather Forecasting -** Masha Kuznetsova, NASA Goddard Space Flight Center

9:50 **Assessing Geospace Models for Use in Space Weather Operations -** Howard Singer, NOAA/ Space Weather Prediction Center

10:10 **Break**

10:40 - 11:40 **Ionosphere Variability- Chair: Tim Fuller-Rowell**

10:40 **Measuring Ionospheric Irregularities Globally by the Rate of TEC Index and GNSS Networks - Xiaoqing Pi, NASA Jet Propulsion Laboratory**

11:00 **3D Modeling of Equatorial Spread F - Joe Huba, Naval Research Lab**

11:20 **Data Assimilation at Multiple Spatial Scales - Cathryn Mitchell, Universtiy of Bath**

11:40 - 12:00 **Solar Cycle - Chair: Douglas Biesecker**

11:40 **The International Sunspot Index: Past, Present and Future - Frederic Clette, SIDC - Solar Influences Data Analysis Center**

12:00 **End of Conference**

Speaker Abstracts

Tuesday, April 24

8:30 **Opening Remarks** – Louis Uccellini, NOAA/National Weather Service/ National Centers for Environmental Prediction

8:40 **State of the Space Weather Prediction Center** – William Murtagh, NOAA/NWS/SWPC

9:00 **Solar Cycle 24 – How is it progressing and where is it going?** –Douglas Biesecker, NOAA/NWS/SWPC

In 2008, the panel charged with the official prediction of the timing and intensity of Solar Cycle 24 issued its consensus forecast. Four years later, we assess how that prediction is panning out and show what the prospects are for at least the next few years of Solar Cycle 24. The main issue to be addressed is whether the prediction of a peak smoothed sunspot number of 90 in May, 2013 is still in the cards. Of particular note in this solar cycle is that the southern hemisphere is lagging significantly behind the northern hemisphere in contributing to the monthly sunspot totals. We will briefly raise the question of whether sunspot number is an appropriate quantity to be forecast by the panel. Whatever the future of cycle 24 holds, recent months have given a taste of the impacts space weather can have. We will finish with a brief review of some of the more significant activity from the current cycle and the impacts that have been seen thus far.

9:20 **Demonstration of the Advanced Weather Interactive Processing System (AWIPS) for Space Weather - R2O/O2R Capabilities -** Michelle Mainelli**,** NOAA/ NWS

Over the last several years, the National Weather Service has undergone a software convergence effort to align the local Weather Forecast Office (WFOs) and the National Centers for Environmental Prediction (NCEP Centers). This effort includes the migration of the Space Weather Prediction Center's imagery, data, and model visualization tools to the next-generation of the Advanced Weather Interactive Processing System (AWIPS II). A demonstration will given to the Space Weather Workshop attendees focusing on the newly migrated capabilities of the system, such as solar imagery display and manipulation, and how the system will enhance R2O/O2R capabilities in the future.

9:30 – 12:00 **Space Weather Effects on Satellites - Chairs: Janet Green / Terry Onsager**

9:30 **Satellite Meeting Overview-** Janet Green, NOAA/NGDC

Satellites operating in near Earth space are subjected to intense electron and proton radiation that can degrade spacecraft performance or cause complete failure. The radiation intensity near Earth fluctuates dramatically depending on the current space weather conditions. In response to this environmental threat to this aspect of the world's technological infrastructure, NOAA is enhancing its support for understanding and resolving satellite anomalies caused by space weather. The NOAA Space Weather Prediction Center provides real time measurements of the space radiation intensity and issues alerts, warnings and watches when warranted by the current threat conditions. Now, the NOAA National Geophysical Data Center is complimenting this effort by providing additional data, products, and expertise for post- satellite anomaly assessment, resolution, and improved satellite design. We report on the outcome of the Satellite Anomaly Mitigation Stakeholders Meeting held in conjunction with this year's Space Weather Workshop which has brought together commercial and government parties interested in developing strategies for identifying and mitigating satellite anomalies caused by space weather.

9:45 **Radiation Effects on Satellites - A JPL Perspective -** Henry Garrett, Jet Propulsion Laboratory, California Institute of Technology

JPL missions for NASA are exposed to a variety of space environments and effects. Of particular concern are radiation effects due to total dose, single event upsets, displacement damage, and latchup. Of increasing concern are the effects of radiation-induced internal electrostatic discharge or IESD. These effects have been observed on JPL spacecraft and are a cause of concern in the development of the ultra-reliable spacecraft that JPL is noted for. This talk will briefly present an overview of JPL's requirements in this area and examples of some of the common problems JPL has encountered as a result of radiation effects. It will conclude with a discussion of our requirements

for space weather and where we feel future work should be concentrated. Radiation is a problem for spacecraft but, with an integrated design approach and careful attention to forecasting and operational procedures, it can be limited in its impact of spacecraft performance.

10:20 SPACECAST: A new European Service to Forecast the High Energy Electron Flux in the Radiation Belts - Richard Horne, British Antarctic Survey

Solar activity can trigger sporadic bursts of energetic particles in the solar wind and increase the number of high energy (MeV) particles trapped inside the Earth's radiation belts. These high energy particles cause damage to satellites and are a hazard for manned spaceflight and aviation. They are difficult to predict due to uncertainties over the basic physical processes, and the need to access reliable data in real time. Here we describe a new forecasting service to help protect satellites on orbit. The SPACECAST project is funded by the European Union Framework Programme 7 (Project 262468) and helps to protect space assets from high energy particles in the electron radiation belts and in solar energetic particle events by developing European dynamic modelling and forecasting capabilities. A new high energy electron forecast service was made publically available on the 1st March 2012. The service uses a database server operated by DHC in Belgium that collects magnetic indices and solar wind parameters in near real time and distributes them to modelling centres in Cambridge UK and Toulouse France. Two independent computer models are used to forecast the high energy electron flux throughout the outer radiation belt for up to 3 hours ahead. The model results are collected by the DHC server, post-processed and displayed on the SPACECAST web site (http://fp7-spacecast.eu/) in the form of panel plots and movies. A satellite risk index for deep dielectric charging at geosynchronous orbit is also updated every hour. The process is fully automated and runs at hourly intervals. We will also briefly describe the next phases of the project, to include low energy electron forecasts, modelling of Solar Energetic Protons and a service to calculate radiation effects.

10:35 The Impact of Space Weather on Inmarsat Satellite Fleet Operations - Mark Dickinson, Inmarsat

Inmarsat currently operates a fleet of 11 geostationary telecommunication satellites, the oldest of which were launched over 21 years ago. The presentation will describe the short and long term operational impacts due to the space environment. The design requirements placed on the satellite manufacturers to minimize the operational impact from space weather related events and Inmarsat's use of space weather notification services will also be described.

10:50 Paradigm and Space Weather - Brian Swinburne, Paradigm

Paradigm, the world leader in secure commercial military satellite communications, has a long heritage in spacecraft operations. This paper discusses Paradigms experiences with space weather effects on SKYNET/NATO spacecraft operated in the GEO region and provides an overview of mitigation practices put in place to ensure resilient service provision. Paradigm also highlights areas where space weather service providers could work with operators to help improve prediction and mitigation of adverse weather effects on spacecraft operations.

11:05 Profound Change of the Near-Earth Radiation Environment Caused by Solar Superstorms - Yuri Shprits, UCLA- Presented by Richard Horne

We present simulations of the inner and outer radiation belts using the Versatile Electron Radiation Belt (VERB) accounting for radial, pitch-angle, energy, and mixed diffusion. Qusi-linear diffusion coefficients are computed using the Full Diffusion Code (FDC) due to day-side and night-side chorus waves, magneto-sonic waves, phasmaspheric hiss waves, EMIC and hiss waves in the regions of plumes, lightning generated whistlers, and anthropogenic whistlers. The 3D VERB code simulations are validated by on reanalysis results and also validated using CRRES observations. . The outer radiation belt is often enhanced during storms while the inner belt is usually considered to be unaffected by geomagnetic activity. During the most recent Halloween superstorms, the extreme erosion of the plasmasphere allowed particles to be transported closer to the Earth where they were locally accelerated. Modeling, which now includes transport with resonant acceleration and loss processes and mixed diffusion, shows a rather good correspondence with observations. In this study, we use the same version of the VERB code to model a storm stronger than the Halloween storms, which most likely occurred in the past and may occur in the future. Our simulations indicate that during such a strong event, electrons will be transported into the heart of the inner zone, where they will be accelerated by chorus waves. When the plasmapause extends to larger distances, electrons accelerated by resonant wave-particle interactions in the inner radiation belt will find themselves in a very different plasma environment and strong fluxes may persist for several years after such a storm. Such intensification of the near-Earth plasma environment would substantially decrease satellite lifetimes at LEO. The

radiation mitigation strategy for satellites operating in the inner belt should include a consideration of the potential for a dramatic increase in the near-Earth radiation. Such intensification of the near-Earth radiation environment may be truly devastating and would substantially decrease the lifetimes of meteorological, communication, and military satellites.

3:00 - 5:00 Aviation and Space Weather - Chairs: Joseph Kunches / Jennifer Meehan

3:00 Delta's Hazard Avoidance Procedures & Use of Space Weather Information - Tom Fahey and Gregg Scott, Delta Airlines

Delta operates flights between the U.S. and Asia westbound and to a lesser degree eastbound that utilize routes which pass within approximately 700 nautical miles of the North Pole.

Delta Flight Dispatchers and Meteorologists coordinate very closely during preflight planning routing selections for all weather hazards. The information produced by the Space Weather Prediction Center (SWPC) is used for routing decisions based on anticipated impact on human radiation exposure and or HF radio communication disruptions. Delta Meteorology's role is to act as a subject matter and to summarize both current and forecasted space weather conditions. Flight Dispatchers are responsible for preparing flight plans which includes route and flight levels to be flown as well as amount of fuel to be loaded, taking into account space weather impacts. Delta flight crews are responsible for reviewing the proposed flight plan and adjusting in coordination with Flight Dispatcher both preflight as well as en route, if deemed necessary.

Delta Meteorology issues Outlooks once or twice per day, as well as Alert messages through the Turbulence Plot (TP) system when level 3 or higher is reached for Solar Radiation Storm or Geomagnetic and Advisory messages for level 3 of higher Radio Blackouts. Pre-flight and en route, dispatchers and crews will take action to mitigate the impacts of these events using the information provided by these products.

Recent 2012 examples of Delta re-routings due to space weather activity are provided and the cost due to flying less than optimum routes are provided. Recommendations for consideration will also be provided regarding Performance Values and Space Weather Forecasting.

3:15 Eurocontrol Space Weather Activities - Emilien Robert, Eurocontrol

Aviation operations, including navigation, surveillance and timing, rely more and more on GNSS services. Concerning navigation, ICAO has decided on the objective to move from ground radio navigation aids based operations to GNSS based operations for all phases of flight. GNSS is already widely used for the cruise part of the flight and is being further developed for the approach and landing operations. The surveillance domain follows the same trend. GNSS based services already enhance radar systems and an increasing part of the surveillance domain will rely on GNSS services in the coming years. A less familiar but still very important application is the use of GNSS as a time reference. GNSS is already used for some radar and multilateration synchronization and an increasing number of networks will rely on GNSS time. GNSS performances under nominal ionosphere condition are already well known. However, before moving further on these GNSS services, the aviation community has to better assess GNSS performances under abnormal ionosphere conditions.

EUROCONTROL launched a study in 2009 to assess the impact of the ionosphere on the ECAC GNSS aviation operations. Using existing GNSS ground station networks (IGS, EGNOS, EDCN, EUREF...), the ionosphere is going to be monitored during the next period of maximum solar activity. These ionosphere measurements will be used to confirm the ionosphere threat model developed for the GBAS application but also to model the ionosphere events that may impact the other GNSS services. These threat models will be applied to the characteristics of the current and future GNSS receivers and the impact of the ionosphere on the GNSS performances will be assessed. Then, the GNSS performance degradation will be compared to the aviation operation requirements. Some mitigations means, internal or external to the GNSS receiver will also be evaluated.

This paper will present EUROCONTROL methodology used for that ionosphere study and may detail some preliminary results.

3:30 Federal Aviation Administration - Steve Albersheim, FAA

3:45 Radiation Protection in Aviation: The Importance of Space Weather - Matthias Meier, German Aerospace Center (DLR)

The occupational radiation exposure of aircrew members is the result of cosmic rays at aviation altitudes as a natural radiation source and has been legally regulated in the European Union for more than a decade. The radiation field is generated by interactions of primary high-energetic particles of galactic and solar origin with atoms in upper layers of the Earth's atmosphere. The intensity of the galactic radiation component depends on altitude, geomagnetic latitude and solar activity varying within an 11-year cycle, the minimum of which corresponds to the highest radiation exposure due to the reduced shielding of this component by the interplanetary magnetic field, which is modulated by the solar wind, i.e. the solar activity.

Furthermore, SPEs (Solar Particle Events), which are often referred to as solar flares in aviator's jargon, can temporarily generate a significant increase in the corresponding dose rate at aviation altitudes. A prerequisite for such an increase is the elevated particle flux at higher energies. Consequently, the investigation of the energy spectrum of the impinging particles is of paramount importance for the assessment of the impact of SPEs on the radiation exposure at aviation altitudes.

4:00 Potential Space Weather Impacts and Needs for Commercial Space Operations in the Near Future - Karen Shelton-Mur, FAA

The Commercial Space Launch Act of 1984 as amended (CSLA), authorizes the Secretary of Transportation to license a launch, a reentry, or the operation of a launch site carried out by a U.S. citizen or within the United States. On Dec 23, 2004, Congress gave the FAA's Office of Commercial Space Transportation (AST) the authority to regulate human space flight during launch and reentry. However, AST currently has no authority to regulate on-orbit activity.

Recent developments in commercial space transportation such as NASA's Commercial Orbital Transportation System (COTS) and Commercial Crew Development (CCDEV) program are expected to stimulate efforts within the commercial sector to aid in the development of cost-effective transportation capabilities to transfer cargo and crew to low-Earth orbit (LEO) and the International Space Station (ISS). Once LEO capabilities are demonstrated by commercial companies, it is anticipated that LEO flights will be expanded to include space flight participants (private citizens). The expansion of commercial space activities into LEO will expose more humans to the harsh space environment than ever before.

This talk will discuss potential space weather impacts and needs for commercial space operations in the near future.

Wednesday, April 25

8:30-10:00 Commercial Space Weather Interest Group Roundtable Session: Growing the Space Weather Enterprise

Keynote Speaker:

Dr. Conrad C. Lautenbacher, Jr., Vice President, Science Programs, CSC –
"Growing the Space Weather Enterprise – Improving Community Visibility"

As we near the peak of activity in the current solar cycle, publicity and interest in space weather has increased. Several solar storms have made headlines and there is increased public understanding of the importance of space weather to all segments of the economy. This presentation will highlight some of the important events and achievements across the space weather community, discuss their current status, and examine ways we can work together for better understanding and funding. It is particularly important to highlight the value of having both healthy and vibrant private and public sector organizations and discuss the respective roles they play in developing the entire community.

Panelists:

Dr. Tamara L. Dickinson, Senior Policy Analyst, Office of Science and Technology Policy, Executive Office of the President: "Progress in Space Weather Policy"

Mr. Jon Turnipseed, Head of Safety, Virgin Galactic: "The Future of Space Tourism and Space Weather"

Moderator and Organizer:
Dr. Devrie Intriligator, Director, Space Plasma Laboratory, Carmel Research Center, Inc.

10:20 - 11:20 Agency Activities - Chair: Brent Gordon/ Bill Murtagh

10:20 National Weather Service - Louis Uccellini, NOAA/National Weather Service/ National Centers for Environmental Prediction

10:40 Air Force Weather Update - Col. John Egentowich, USAF

The U.S. Air Force is responsible for providing operational space weather support to all elements of the Department of Defense (DoD). The Air Force Weather Agency carries out this mission with its 24/7 space weather operations center that supplies tailored products to warfighters around the globe. Their alerts, advisories, warnings, forecasts and other tailored products rely upon a synergistic combination of ground and space-based sensor data and environmental models that enable more informed decision-making by operational commanders.

This presentation will describe the Air Force's role as the DoD's Space Weather provider, highlight recent accomplishments, and give examples of how its tailored space weather products can mitigate impacts to DoD missions. It will also emphasize partnerships with other agencies that Air Force Weather relies upon to exploit all available space weather expertise for the upcoming solar maximum and beyond. In particular, Air Force Weather is an active member of the Office of the Federal Coordinator for Meteorology's National Space Weather Program, which facilitates interagency coordination and data sharing in order to modernize our national space weather capabilities.

11:00 NASA Heliophysics Division - Barbara Giles, NASA

11:20 Space Weather Research at the National Science Foundation - Richard Behnke, National Science Foundation

11:40 NASA Space Radiation Analysis Group- Space Radiation Protection, Space Weather, and Exploration - Kerry Lee, NASA

Management of crew exposure to radiation is a major concern for manned spaceflight – and will be even more important for the modern concept of longer-duration exploration missions. The inherent protection afforded to astronauts by the geomagnetic field in Low Earth Orbit (LEO) makes operations on the space shuttle or space station very different from operations during an exploration mission. In order to experience significant radiation-derived Loss of Mission (LOM) or Loss of Crew (LOC) risk for LEO operations, one is almost driven to dictate extreme duration or to dictate an extreme sequence of solar activity. Outside of the geo-magnetosphere, however, this scenario changes dramatically. Exposures to the same event on the ISS and on the surface of the Moon or in free space may differ by multiple orders of magnitude. This change in magnitude, coupled with the logistical constraints present in implementing any practical operational mitigation make situational awareness with regard to space weather a limiting factor for our ability to conduct exploration operations.

With these differences in risk to crew, vehicle and mission in mind, we present the status of the efforts currently underway as the required development to enable exploration operations. The differences in the operating environment as crewed operations are extended beyond LEO are changing the way we think about the lines between "research" and "operations." The real, practical work to enable a permanent human presence away from Earth has already begun.

3:00 - 3:20 Decadal Survey - Chair: Howard Singer

3:00 Space Weather and the Next Solar and Space Physics Decadal Survey - Daniel Baker, University of Colorado, Boulder

The Space Studies Board of the National Academies established a Survey Committee to develop a comprehensive science and implementation strategy for solar and space physics research that updates and extends the Board's prior solar and space physics decadal survey, The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics (2003). The new Decadal Survey is broadly assessing the field of research in solar and space physics to determine the current state of the discipline, identify the most important open scientific questions, and propose the measurements and means to obtain them so as to advance the state of knowledge during the interval 2013-2022. The study implements a 2008 Congressional directive to NASA for the fields of solar and space physics, but also will address research in other federal agencies. Research in this field seeks to understand:

- the dynamical behavior of the Sun and its heliosphere;
- the dynamical behavior of the space environments of the Earth and other solar system bodies;
- the multiscale interaction between solar system plasmas and the interstellar medium; and
- energy transport throughout the solar system and its impact on the Earth and other solar system bodies.

Research in solar and space plasma processes also provides insights into analogous processes in more distant objects of astronomical interest. In addition, great strides in research equipment and data systems, theory, and numerical models offer the prospect of understanding this interconnected system well enough to develop a predictive capability for operational support of civil and military needs and systems. This latter understanding provides the underpinning for our rapidly developing field of space weather, which will be addressed in this presentation. The 2013-2022 Survey is presently undergoing review and should be available to the community in May 2012.

3:20 - 5:00 International Coordination of Space Weather Activities- Chairs: James Head/Terry Onsager

3:20 State Department Engagement with the International Space Weather Community - James Head, U.S. State Department

The United States National Space Policy of 28 June, 2010 emphasizes international cooperation in conducting space activities, citing numerous examples of the global benefits derived thither. The policy directs the Secretary of State "to carry out diplomatic and public diplomacy efforts to strengthen understanding of, and support for, U.S. national space policies and programs and to encourage foreign use of U.S. space capabilities, systems, and services." The State Department is implementing this policy guidance via reinvigorated engagement with the international community. One of the areas well-suited for international cooperation involves both research and operational aspects of space weather.

The Office of Space and Advanced Technology (SAT) has responsibility for international aspects of civil space cooperation within the State Department. SAT has maintained technical competence in the area of space weather for many years. SAT engagement in space weather includes the United Nations, the World Meteorological Organization, and numerous bi-lateral space dialogues.

SAT leads US participation in the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS), which has standing agenda items on the International Space Weather Initiative and on the Long-term Sustainability of Space Activities. Terms of Reference for the latter, adopted in June 2011, include an expert working group dedicated to space weather. SAT leads US participation on that expert group. In February 2012, the Scientific and Technical Subcommittee of the UNCOPUOS adopted a US proposal to create a new standing agenda item on Space Weather.

SAT participates in the WMO's Inter-programme Coordination Team for Space Weather and is becoming involved in the National Weather Service's interactions with the WMO. SAT also provides support for cooperation agreements between NOAA and agencies in other nations. Additionally, SAT is engaging with the European Space Agency on space weather cooperation as part of the broader US-EU space dialogue. Finally, SAT is working within the U.S. Government to craft strategic goals for international cooperation in space weather, with the intent of developing a strategic plan that could be adopted by a large segment of the international space weather community.

3:40 **Space Weather Impact on Critical Infrastructures: Activities at the European Commission's Joint Research Centre -** Elisabeth Krausmann, European Commission, Joint Research Centre

Extreme space weather is of increasing concern for many modern space- and ground-based infrastructures. There is evidence that space weather can damage or destroy these infrastructures, or disrupt the services they provide. In light of the potential for catastrophic failure and the forthcoming solar maximum, the Joint Research Centre (JRC) of the European Commission decided to take an active role in raising awareness of the space-weather risk in the European Union. Consequently, the JRC, in collaboration with the European Commission's Directorate General Enterprise and Industry, organized the "Space-Weather Awareness Dialogue" in Brussels, on 25-26 October 2011, which brought together about 70 representatives of the space-weather community, European industry, government agencies and European Union institutions. The participants discussed the potential effects of extreme space weather on different types of infrastructures in space and one the ground and tried to identify the scientific, operational and policy challenges for reducing the related vulnerability of critical infrastructures. The main conclusions of this event will be presented. In addition, the JRC has launched new or intensified existing scientific activities on assessing the space-weather threat to critical infrastructures in support of European Union policy in the field of critical infrastructure protection. An overview of these activities will be provided.

4:00 **Space Environment Support to NATO Space Situational Awareness: Advances by the NATO Research & Technology Organization SCI-229 Task Group -** Mauro Messerotti, INAF- Astronomical Observatory of Trieste

As a follow-up of the successful preparatory work carried out by a dedicated Exploratory Team, in the framework of which a definition of NATO SSA was elaborated, the Systems Concepts and Integration Panel of the NATO Research and Technology Organization (RTO) approved a three-year study (SCI-229; 2011-13) on Space Environment Support to NATO Space Situational Awareness (SSA).

Goal of this study is the in-depth analysis of all categories of space-originated perturbing agents that can impact on space-based and space-related military assets.

The SCI-229 research task group (TG) is organized into three Focus Groups, each of them dealing with a specific topic, i.e. Space Weather, Near Earth Objects, and Space Debris. However, for a precise operational choice aimed at facilitating the analysis and the dissemination of results, the study will not address any classified aspects of the sub-domains.

In this work we will provide an overview of the projects with specific attention to the analysis carried out so far, which will be adequately schematized by means of concept maps as a knowledge basis for a prototype expert system (SENECA, Space ENvironment Effects Advisor) to be used as an educational and training tool for NATO space planners. A brief description of the architecture of the system and of its basic working principles will be provided.

4:20 **United Kingdom - Recent Space Weather Activities and Plans in the U.K. -** Mike Hapgood, RAL Space - Rutherford Appleton Laboratory

The past two years have seen major growth of interest in space weather from a number of communities within the UK. It is no longer the preserve of a few specialists in the research and user communities, but has become an important topic for policy-makers. This, in turn, is driving a virtuous circle of increased interest from end users, service providers and research funders. A particular highlight is the inclusion of severe space weather in the new UK National Risk Register, published in January 2012. This is formal recognition that space weather is a natural hazard whose extremes must be considered within the processes that ensure national resilience against a wide range of hazards, both natural and human. Thus there is a continuing programme of work to refine our understanding of the impacts of space weather on the UK, to focus research efforts on gaps in knowledge, to raise awareness amongst all affected groups and to develop operational responses to space weather. This talk will outline the current state of UK work and our plans for future work, both within the UK and with international partners.

4:40 **World Meteorological Organization (WMO) and International Space Environment Service (ISES) Activities -** Terry Onsager, NOAA/ Space Weather Prediction Center

The growing global interest in space weather has led to numerous international activities that are serving to foster cooperation and increase opportunities. This coordination is important for our data infrastructure, our research developments, and the provision of operational services. The International Space Environment Service (ISES) has

been the primary organization engaged in the international coordination of space weather services since 1962. ISES now consists of 14 Regional Warning Centers distributed around the globe. More recently, the World Meteorological Organization (WMO) has become active in facilitating the international coordination of space weather observations, products, and services, working closely with ISES and other organizations. Through the WMO Inter-Programme Coordination Team on Space Weather (ICTSW), observational requirements for space weather have been defined, an initial of assessment of gaps in observing capabilities has been conducted, and an international Space Weather Product Portal has been established for operational space weather products. The NOAA Space Weather Prediction Center is working closely with these and other organizations to broaden the engagement in space weather around the world. This presentation will describe the roles of these organizations in promoting space weather and the opportunities we have for advocacy through them.

Thursday, April 26

8:30 - 10:10 International Coordination of Space Weather Activities - Chair: Terry Onsager

8:30 Japanese Space Weather Activities and Asia Oceania Space Weather Alliance - Shinichi Watari, National Institute of Information and Communications Technology

In Japan, the National Institute of Information and Communications Technology (NICT) operates a forecast center as part of the International Space Environment Service (ISES). Radio Research Laboratories (present NICT) started the forecast and warning services for HF communication in December, 1949. This activity has been maintained within the present forecast center. The forecast center also issues forecasts on flare and geomagnetic activities at 0600UT in Japan. These daily reports are delivered by web-page and e-mail. The forecast center will also issue a Presto report at the onset of a geoeffective event. Several new services are provided using the Space Weather Cloud Computing System whose large storage capacity enables it to handle observation data and simulation data together.

Each forecast center of the ISES currently exchanges flare and geomagnetic activity forecasts called UGEOA. It is easier to compare the performances of each forecast center using these forecasts because the forecasts are made according to the same definition. We evaluate those forecasts and open the result through web-page (http://seg-web.nict.go.jp/cgi-bin/forecast/eng_forecast_score.cgi) with agreement of each forecast center.

Now NICT makes an effort to lead the Asia-Oceania Space Weather Alliance (AOSWA) with collaboration of other ISES forecast centers in this region. The subject of the AOSWA is to make a regional linkage of data exchanges, collaborative research, and practical information of operations of space weather forecast service. The first AOSWA workshop was held in Chiang Mai, Thailand between 22 and 24 February, 2012. This is the first regional/international workshop for researchers and operators of space weather forecasts in Asia-Oceania countries. The second AOSWA workshop will be hosted in China next year.

8:50 Activities of Korean Space Weather Center - Jae-Hyung Lee, Korean Space Weather Center

The Korean Space Weather Center (KSWC), of the National Radio Research Agency (RRA), is the national institute which is the official source for space weather alerts and warnings in Korea. The KSWC is also a Regional Warning Center of the International Space Environment Service (ISES).

With the increasing importance of the space weather and to minimize the socio-economic damage from it, RRA established KSWC in Jeju Island in 2011. KSWC monitors the solar activity, predicts the impacts and delivers the information of forecasting and alert to many customers of broadcastings, telecommunications, satellite operations and other related agencies and industries.

KSWC has fully equipped ground based observation systems and services the data through the center's website of http:// www .spaceweather .go .kr. KSWC also develops prediction models and is conducting many other activities to reinforce the capacity of space weather forecasting services that are essential to safeguarding critical national infrastructures.

As a goal, KSWC is continuing to strengthen partnerships with international organizations and foreign agencies. As part of RRA's close partnership with NOAA, a KSWC staff member has been trained at NOAA's Space Weather Prediction Center (SWPC). To further fortify international cooperation, since April 2011, KSWC has been a

member of the World Meteorological Organization (WMO) Inter- programme Coordination Team on Space Weather.

9:10 The Brazilian Space Weather Program - EMBRACE - Inauguration Year - Joaquim E R Costa, National Institute for Space Research (INPE)

The Brazilian Space Weather program (EMBRACE) is aimed to establish a "Space Weather Information and Prediction Center" at National Institute for Space Research (INPE). It is a program that started in 2008 with a five year installation plan. In 2012, the program plans to establish ground based monitoring systems that consists of solar radio telescopes, conjugate point ionospheric sounders, GNSS receivers, magnetometer arrays, optical imagers, radio frequency radars, as well as ground induced current sensors, ionospheric modeling and IT applications on the web. The program has a focus on monitoring the regions of the equatorial Ionosphere and the SAGA (South Atlantic Geomagnetic Anomaly). The main concerns are to model peculiarities of the Brazilian Ionosphere such as equatorial electrojet, the ionization anomaly and the plasma bubbles and the consequences for radio propagations.

New observation plants were constructed in Brazil to accommodate the installation and operation of instruments for monitoring and to support forecasting. The EMBRACES's program included the acquisition of ground equipment for observing the Sun, Interplanetary Medium (muons), Ionosphere and GIC. In 2012 the solar observations, the ionosondes, TEC sensors throughout Brazil are already being received at the operation center (also concluded) and some applications are already shown in the web with search engines and real time monitors.

Specific applications to the ionosphere are being built through the model of Sheffield (SUPIM) and others are under study. Dynamic maps of TEC, scintillations, and ionospheric model predictions are already available daily.

9:30 International Service Provider Update

10:10 - 12:00 Space Weather Prediction Modeling - Chair: Howard Singer

10:10 Solar Active Longitude and Active Level Estimation - Huaning Wang, NAO, Chinese Academy of Sciences

There are two active longitudes separated by 180 degrees for X-ray flares of any class. The concept that X-ray flares occur more often near the two active longitudes than sunspots do, and that the non-axisymmetry of the longitudinal distribution of X-ray flares increases with the X-ray flare class, has been known for tens of years. This fact means that stronger solar activities occur more preferentially at certain longitudes.

Previous statistical analyses of a large number of SOHO/MDI full disk longitudinal magnetograms provided a result that demonstrated how responses of solar flares to photospheric magnetic properties can be fitted with sigmoid functions. A logistic model reveals that these fitted sigmoid functions can be employed to estimate active level of solar active regions.

10:30 WSA-Enlil in Operations at the National Weather Service: Experiences, Results and Developments- George Millward, NOAA/ Space Weather Prediction Center

The WSA-Enlil model of the solar wind entered formal operations at the National Weather Service (NWS) in December 2011 after a two year transition effort by staff at the NOAA Space Weather Prediction Center (SWPC). The purpose of the operational system is to give SWPC forecasters a 2-5 day prediction of the arrival at Earth of Solar wind structures, most importantly Coronal Mass Ejections (CMEs) as these provide the leading cause of significant Geomagnetic activity and Space Weather. In developing the system we determined that accepted 'cone' formulations for deriving CME inputs from analysis of 'halo' Coronagraph images are problematic in many real-world situations. In working to rectify this problem we developed a 'three-view' system which calculates CME parameters by utilizing concurrent Coronagraph observations from the STEREO A, B and SOHO spacecraft, and models the emerging CME as an expanding three-dimensional Lemniscate (or 'tear-drop') structure. The resulting operational CME Analysis Tool (CAT) reduces uncertainty in CME direction and propagation speed by both utilizing images from multiple viewpoints but also by making best use of the often sparse data available in the real-time mode needed for Space Weather operations. Results and experiences from our first 6 months of operation will be described as will our future plans for development.

10:50 The NOAA Space Weather Prediction Testbed - Rodney Viereck, NOAA/ Space Weather Prediction Center

The Space Weather Prediction Center has the three primary functions of research, development, and operations. Following in the footsteps of other applied research activities within NOAA, the space weather research function has been captured in a new entity called the Space Weather Prediction Testbed (SWPT). The SWPT provides the operational Space Weather Forecast Office with new and improved products and data. It spans the so called "valley of death" between research and operations capturing the most relevant and useful research results from outside NOAA and transitions them to operations (R2O). It also captures the needs and requirements of the operational Forecast Office and translates them into suggested research activities for other agencies to consider (O2R). In this presentation I will provide an overview of the SWPT and the projects that are currently underway in each of the primary space weather realms: solar, heliosphere, magnetosphere, and ionosphere/thermosphere. I will outline the current high priority research needs driven by unmet requirements of the Space Weather Forecast Office. Included will be a discussion of the criteria for evaluating and selecting research models and data for possible transition to operations. I will also outline the plans and objectives for future of this newly formed applied research organization.

11:10 Operational Dst from Real-Time Data Streams and Forecast Algorithms - W. Kent Tobiska, Space Environment Technologies SWD

Dst, the disturbance storm-time index for the magnetospheric ring current, is a ground-measured indicator of the perturbation to Earth's main magnetic field. Its variability derives from changes in the ring current energy density driven by solar wind coupling with the terrestrial magnetosphere. This coupling energizes plasma captured from solar wind and ionospheric sources, producing a temporarily trapped particle population that forms the variable ring current. Coupling tends to be most effective during the passage of fast interplanetary coronal mass ejections. However, less energetic ejecta associated with moderate and large X-ray, non-CME, flaring events, i.e., the inhomogenous strings and density filaments in coronagraph imagery, can also produce significant ring current variability. We report on the successful implementation of multiple streams of real-time Dst from several institutions and we also describe significant advances in forecasting Dst. In addition to Dst derived from ENLIL/CONE modeling (Stream A), the *Anemomilos* data-driven, deterministic algorithm uses three observables to provide information about solar ejecta geoeffectiveness as it departs the Sun (Stream B). The *Anemomilos* forecast algorithm has been tested for most of its components for every hour in 6-month time frames in 2001 and in 2005, i.e., for active and quiet solar conditions. An operational system derived from these methods is being developed to enable current epoch specification and forecast Dst to 6 days in the future. Dst is one of the geomagnetic drivers to the JB2008 thermosphere density model that has greatly improved the specification of mass density for low Earth orbit satellite operations; the real-time and forecast Dst described here supports the operational implementation of JB2008.

11:30 Assessment of Ionosphere/Thermosphere Models in Low Solar Flux Conditions for the CCMC CEDAR Challenge - Barbara A. Emery, HAO/NCAR

The performance of Ionosphere/Thermosphere (IT) models during the solar minimum period from November 2007 to January 2008 (07325-08020) is evaluated for climatology, while December 13-15, 2006 (06347-349) is evaluated for a storm case. The climatology period was separated into high-speed stream (HSS) and moderate Kp (>=2) and low-speed and low Kp (<=1) conditions. The physical parameters selected are median values of the electron peak density and the height of this peak from COSMIC LEO satellites, median total electron content (TEC) from GPS satellites around 20,000 km observed at many ground stations from MIT, JPL, and IGS, neutral densities from CHAMP at 400 km and the satellite altitude (~350km) as well as ascending and descending node averages, global mean daily neutral densities from satellite drag analyses, and observed and estimated ion drifts at Jicamarca, Peru. Most of the IT models have been run at the Community Coordinated Modeling Center (CCMC) at the Goddard Space Flight Center (GSFC) using appropriate geophysical inputs. Double resolution TIEGCM model runs using TIMED satellite SABER and TIDI temperature and wind lower boundary conditions are also evaluated. We examine 5 degree geographic latitude and 5-25 degree geographic longitude bins located in 8 longitude swaths with good ground TEC coverage. Percent deviations of model values from data are evaluated along with other metrics to better understand the strengths and weaknesses of various empirical, first principles, or assimilation ionosphere or coupled IT models.

3:00 - 3:20 Transiting Science to Applications - Chair: Jeff Shoup

3:00 Lessons Learned from Successful Earth Science Research-to-Applications Efforts - James Spann, NASA

Drawing from the demonstrated success of transitioning NASA observations and investigations to decision makers world wide and national weather offices through the SERVIR and SPoRT programs in Earth Science, a list of things that worked and recommendations are presented that apply to the space weather. The SERVIR program is a partnership of NASA and the US State Department USAID that provides decision-making tools to developing nations across the globe using NASA and other space-based observations. The Short-term Prediction Research and Prediction Center (SPoRT) is a NASA project to transition unique observations and research capabilities to the operational weather community to improve short-term forecasts on a regional scale. It has established a close partnership with various NOAA National Weather Service offices across the country.

3:20 - 5:00 Geomagnetic Induced Currents - Chair: Chris Balch

3:20 North American Electric Reliability Corporation -Geomagnetic Disturbance Taskforce - Mark Lauby, North American Electric Reliability Corporation

The highly complex, interconnected North American power grid has provided a long record of reliable, secure delivery of electric power. However, solar storm or geomagnetic disturbance (GMD) events have demonstrated their ability to disrupt the normal operations of the power grid. The most recent example in North America occurred in March 1980, when a GMD led to the collapse of the Hydro-Quebec system, leaving more than six million people without power for nine hours. Understanding the effects of GMD on bulk power systems and the ability of the industry to mitigate their effects are important to managing system reliability.

The North American Electric Reliability Corporation (NERC) conducted an assessment in response to findings in the *High Impact, Low Frequency Event Risk to the North American Bulk Power System* (March 2010) report, which found the best approach to HILF events was through an organized combination of industry-led task forces and initiatives. The GMD Task Force implemented that approach for study of geomagnetic disturbances. In this presentation, we will discuss the findings of the GMD Task Force.

3:40 U.S. Geological Survey Geomagnetism Program Product Status - Carol Finn, U.S. Geological Survey

The mission of the U.S. Geological Survey (USGS) Geomagnetism Program is to monitor the Earth's magnetic field. The program operates a network of 14 ground-based observatories that provide high quality, near real-time magnetic field measurements. These data are used for a wide variety of science applications, including for space weather. In order to build upon the role that the USGS has traditionally played in natural-hazard science, over the past few years the Geomagnetism Program has hired new staff to pursue space-weather research and to develop operational space-weather products. The USGS now provides a real-time, 1-minute, storm-time disturbance index (Dst) service through the Program's website. Work is also progressing on real-time K indices and other measures of localized geomagnetic disturbance. Recently, the USGS Geomagnetism Program has partnered with the North American Electric Reliability Corporation (NERC) and the Electric Power Research Institute (EPRI) to produce one-dimensional (1D) models of earth structure for all of the main physiographic regions of the continental US. These 1D models of the Earth's resistivity can be used to calculate the geo-electric field that drives Geomagnetically Induced Currents (GICs).

4:00 Solar Shield Project - Updates and Future Challenges - Antti Pulkkinen, Catholic University of America at NASA/GSFC

The Solar Shield project is a collaborative effort between the Electric Power Research Institute (EPRI) and NASA Goddard Space Flight Center (GFSC). The central objective of the project whose initial development was funded by the NASA Applied Sciences Program is to utilize state-of-the-art space physics models in forecasting of geomagnetically induced currents (GIC) in the North American high-voltage power transmission system. In Solar Shield, an extensive pool of coupled space physics models hosted at the Community Coordinated Modeling Center (CCMC) at NASA GSFC is used. The utilized models propagate information obtained from the remote solar observations to the interplanetary medium, from the interplanetary medium to the Earth's magnetosphere and ionosphere and eventually all the way down to the surface of the Earth and GIC. The two-level forecasting system

provides both 2-3 day lead-time and 30-60 minute lead-time forecasts.

In this paper, a brief overview and the future outlook of the Solar Shield system is given. In particular, new advances such as usage of ensemble CME simulations and the extension of the global MHD-based forecasts to low-latitude locations are discussed. The system will also be applied to studies of extreme GIC scenarios, which are of major current engineering interest. Performance of the system over the past couple years is also briefly reviewed.

4:20 Solar-Flare Induced Disturbances in the U.S. Electric Grid and their Economic Impact - Sarah Mitchell, Lockheed Martin

Large solar explosions are responsible for space weather that can impact technological infrastructure on and around Earth. Such impacts are generally known to occur in association with unusually large, infrequent solar events. We find that impacts also occur in association with much more common solar events based on a statistical analysis of disturbances in the US electric grid reported to the U.S. Department of Energy between 1992 and 2010. We also find a significant increase in disturbance rates following major solar activity. The strength of that modulation tends to increase with the magnitude of solar activity. We conclude that overall, ~4.0% of grid disturbances are associated with relatively common M- and X-class flaring. Other space weather around times of such flaring adds at least as many grid disturbances. As none of the grid disturbances were officially attributed, in whole or in part, to space weather, our study reveals an unrecognized susceptibility of the US electric grid. We use an industry study to estimate the average cost to the U.S. economy of space weather induced grid disturbances to be on the order of $5 billion/y to $8 billion/y.

4:40 FEMA Federal Interagency Response Planning - Donald Daigler, FEMA

Friday, April 27

8:30 - 10:10 Modeling - Chair: George Millward

8:30 Modeling the Structure of the Solar Corona and Inner Heliosphere Using CORHEL - Pete Riley, Predictive Science, Inc.

CORHEL (CORrona-HELiosphere) is a coupled suite of models and tools for modeling: (1) the ambient solar corona and solar wind; and (2) the dynamic effects of simple coronal mass ejections (CMEs) as they propagate through the inner heliosphere. It is driven primarily by the observed photospheric magnetic field, as specified by synoptic magnetograms from one of six different observatories, and produces a range of output including reconstructions of both remote solar observations, such as EIT images, as well as in situ measurements, such as flow speed and magnetic field strength at the location of Earth. CORHEL provides the user with a variety of models to accomplish their goals, ranging from the simple empirically-based WSA model to a full thermodynamic model, which includes energy transport in the form of radiative losses, anisotropic thermal conduction, and coronal heating. CORHEL solutions can be obtained from our website (www.predsci.com) or the CCMC (ccmc.gsfc.nasa.gov), the latter being able to produce "runs on request." In this talk, we summarize the current status of CORHEL, plans for future improvements, and the challenges that remain in being able to faithfully reproduce the global structure of the inner heliosphere. CORHEL is supported by CISM (NSF) and the LWS Strategic Capabilities Program (NASA, NSF, and AFOSR).

8:50 The Air Force Data Assimilative Photospheric Flux Transport (ADAPT) Model - Charles Arge, Air Force Research Laboratory

As the primary input to all coronal and solar wind models, global estimates of the solar photospheric magnetic field distribution are critical to space weather forecasting. These global magnetic maps are essential for accurate modeling of the corona and solar wind, which is vital for gaining the basic understanding necessary to improve forecasting models needed for Air Force and civilian operations. Over the last several years AFRL, in collaboration with Los Alamos National Laboratory (LANL) and the National Solar Observatory (NSO), has been developing a model that produces much more realistic estimates of the instantaneous global photospheric magnetic field distribution than that provided by traditional photospheric field synoptic maps. The Air Force Data Assimilative Photospheric flux Transport (ADAPT) model is a photospheric flux transport model, originally developed at NSO, that makes use of data assimilation methodologies developed at LANL. The flux transport model evolves the

observed solar magnetic flux using relatively well understood transport processes when measurements are not available and then updates the modeled flux with new observations (available from both the Earth and the far-side of the Sun) using data assimilation methods that rigorously take into account model and observational uncertainties. In this talk I provide an overview of the ADAPT model followed by several examples of how the model is being used for improving space weather forecasts.

(ADAPT is supported by a grant from the AFOSR (Air Force Office of Scientific Research))

9:10 A Solar Energetic Particle Event Model for WSA-ENLIL - Janet Luhmann, Space Sciences Laboratory, University of California, Berkeley

The ongoing development and testing of the WSA-ENLIL model with cone CME material injections provides the possibility of regular modeling and forecasting of realistic ICME shocks. These results are unique in their ability to include effects of interactions with ambient solar wind structure, with the caveats that any effects of the CME ejecta magnetic fields are not (yet) included, and that the model does not include the potentially important coronal (<20 Rsun) portions of the shock. Nevertheless, the time-dependent MHD code results can be used as a framework for developing SEP (Solar Energetic Particle) event models consistent with the case under study. Special WSA-ENLIL model products can be generated that can be used to both parameterize the time and space dependent shock source and to track the observer-connected magnetic field lines that nominally constrain the particle paths. We show some results from cases where we derived key WSA-ENLIL 'data' on the shock evolution and field geometry that are applied to a first-order shock-source particle transport code. Our modeled SEP events illustrate the importance of the shock history and connectivity in SEP event modeling. They also serve as a general demonstration of possible SEP event enhancements to routine WSA-ENLIL-cone model applications.

9:30 Community Coordinated Modeling Center: Addressing Needs of Operational Space Weather Forecasting - Masha Kuznetsova, NASA Goddard Space Flight Center

Models are key elements of space weather forecasting. The Community Coordinated Modeling Center (CCMC, http://ccmc.gsfc.nasa.gov) hosts a broad range of state-of-the-art space weather models and enables access to complex models through an unmatched automated web-based runs-on-request system. Model output comparisons with observational data carried out by a large number of CCMC users open an unprecedented mechanism for extensive model testing and broad community feedback on model performance. The CCMC also evaluates model's prediction ability as an unbiased broker and supports operational model selections. The CCMC is organizing and leading a series of community-wide projects aiming to evaluate the current state of space weather modeling, to address challenges of model-data comparisons, and to define metrics for various user’s needs and requirements. Many of CCMC models are continuously running in real-time. Over the years the CCMC acquired the unique experience in developing and maintaining real-time systems. CCMC staff expertise and trusted relations with model owners enable to keep up to date with rapid advances in model development. The information gleaned from the real-time calculations is tailored to specific mission needs. Model forecasts combined with data streams from NASA and other missions are integrated into an innovative configurable data analysis and dissemination system (http://iswa.gsfc.nasa.gov) that is accessible world-wide. The talk will review the latest progress and discuss opportunities for addressing operational space weather needs in innovative and collaborative ways.

9:50 Assessing Geospace Models for Use in Space Weather Operations - Howard Singer, NOAA/ Space Weather Prediction Center

Working together with NASA's Community Coordinated Modeling Center (CCMC), NOAA's Space Weather Prediction Center is in the process of assessing Geospace models to determine which model (or models) is ready for transition to operations. These models, driven by real-time solar wind observations, will provide forecasters with guidance about levels of regional geomagnetic activity and rapid changes in activity (dB/dt) that affect power utilities and other customers. In the future, there is also the potential to serve additional customers by using these models to provide ancillary products such as those related to the specification of the auroral oval and geosynchronous conditions. To determine which geospace model (or models) is ready for transition to operations; SWPC and CCMC are working together with our partners, including model developers and the US Air Force. In addition to discussing customer needs for improved geospace activity products, in this presentation we will describe the models under consideration, the metrics that are being used for model evaluations, the selection process, and recent results.

10:40 - 11:40 Ionosphere Variability - Chair: Tim Fuller-Rowell

10:40 Measuring Ionospheric Irregularities Globally by the Rate of TEC Index and GNSS Networks - Xiaoqing Pi, NASA Jet Propulsion Laboratory

The rate of total electron content (TEC) index (ROTI) is applied to measurements of ionospheric irregularities that cause ionospheric scintillation. ROTI can be obtained by processing GPS data available from thousands of standard geodetic-type Global Navigation Satellite System (GNSS) receivers stationed globally and regionally. This enables us to take advantage of available and developing GNSS networks and overcome the difficulty in use of specialized scintillation receivers to monitor global irregularity activities. This presentation will highlight the use of GPS data to produce ROTI maps showing global activity of ionospheric irregularities. The development of real-time ROTI maps will also be presented that utilizes the NASA real-time global differential GPS network managed and operated by JPL and also contributed by the international partners.

11:00 3D Modeling of Equatorial Spread F - Joe Huba, Naval Research Lab

Post-sunset ionospheric irregularities in the equatorial F region were _rst observed by Booker and Wells (1938) using ionosondes. This phenomenon has become known as equatorial spread F (ESF). During ESF the equatorial ionosphere becomes unstable because of a Rayleigh-Taylor-like instability: large scale (10s km) electron density `bubbles' can develop and rise to high altitudes (1000 km or greater at times). Understanding and modeling ESF is important because of its impact on space weather: it causes radio wave scintillation that degrades communication and navigation systems. In fact, it is the focus of the Air Force Communications/Navigation Outage Forecast Satellite (C/NOFS) mission. We will describe 3D simulation results from the NRL ionosphere models SAMI3 and SAMI3/ESF of this phenomenon. In particular, we will examine the causes of the day-to-day variability of ESF which is an unresolved problem at this time. Additionally, we will discuss the impact of relaxing the assumption of equipotential _eld lines and considering 3D electrodynamics.

11:20 Data Assimilation at Multiple Spatial Scales - Cathryn Mitchell, Universtiy of Bath

Ionospheric imaging and data assimilation on a global scale have to deal with the sparsity of the data across certain regions and with the intermittent and patchy nature of certain events. The most challenging regions are the polar and auroral latitudes.

The MIDAS algorithm at Bath has a set of optional inversion methods such as least squares and Kalman filter that run at a fixed resolution. This is acceptable for imaging electron density and TEC across a region of high and relatively dense data sets such as across Europe or the USA but is not optimal for regions of varying density of data coverage. Such regions need a physics-based data assimilation scheme whereby the model incorporation is designed to compensate for the missing data.

The talk describes recent developments to MIDAS to track the movement of ionospheric plasma in the high latitude and polar regions as a step towards a full data assimilation algorithm that could be used to provide a short-term forecast of strong gradients in total electron content and scintillation.

11:40 - 12:00 Solar Cycle - Chair: Douglas Biesecker

11:40 The International Sunspot Index: Past, Present and Future - Frederic Clette, SIDC - Solar Influences Data Analysis Center

The past evolution of the solar cycle is recorded primarily in the sunspot number, based on visual sunspot counts made over the past 4 centuries. This presentation reviews the past history of this reference index, still currently used in hundreds of scientific publications every year. We then describe how the international sunspot index is established nowadays by the SIDC-Brussels, based on extended statistics over a worldwide network of more than 80 stations. As the sunspot index provides a unique time series allowing to connect modern solar observations to the distant past and to constrain the latest dynamo models, we consider its long term stability and the relation with other parallel solar activity indices or fluxes. This comparison reveals a few open issues remaining in the early part of the series, which are the topic of an ongoing series of dedicated workshops. It also demonstrates that over the last century, the index kept an accuracy that is comparable to other recent "impersonal" indices. We finally show how recent discrepancies between Ri and several solar indices during the peculiar cycle 23 may actually shed light on a global anomalous fading and vanishing of small sunspots after the year 2000, thus acting as an indicator of true

physical changes inside the Sun. This will lead us to the future uses and extensions of this traditional index, which can address key science topics of the 21st century, like the solar forcing on the Earth climate.

Acronyms

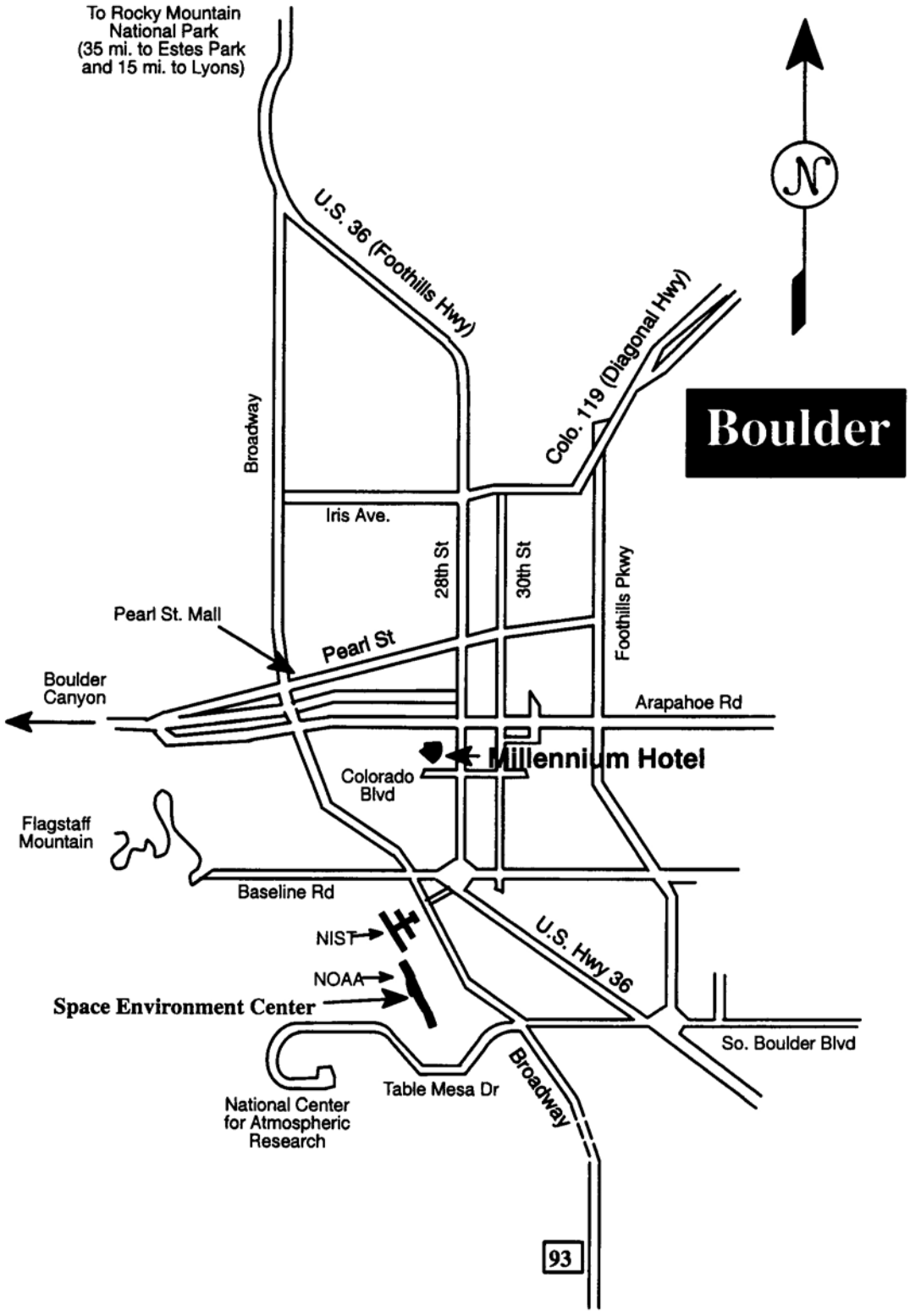
ACE	Advanced Composition Explorer
ADAPT	Air Force Data Assimilative Photospheric flux Transport
AE/9-AP-9	Radiation/ Plasma Model
AFRL	Air Force Research Laboratory
AFSPC	Air Force SPace Command
AFWA	Air Force Weather Agency
AIA	Atmospheric Imaging Assembly
AMIE	Assimilative Mapping of Ionospheric Electrodynamics
AMPERE	Active Magnetosphere Polar Electrodynamics Response Experiment
AMS	American Meteorological Society
ARMAS	Automated Radiation Measurement for Aviation Safety
AST	FAA's Office of Commercial Space Transportation
ASTRA	Atmospheric & Space Technology Research Associates LLC
BDA	Brazilian Decimetric Array-Solar Radio Telescopes
CAPS	Communication Alert and Prediction System
CAS	Chinese Academy of Sciences
CASS	Center for Atmospheric and Space Science
CCDEV	Commercial Crew Development
CCMC	Community Coordinated Modeling Center, NASA
CDAAC	COSMIC Data and Archive Center
CIRES	Cooperative Institute for Research in Environmental Sciences
CISM	Center for Integrated Space Weather Modeling
CMA	China Meteorological Administration
CMIT	Coupled Magnetosphere, Ionosphere, Thermosphere
C/NOFS	Communications/Navigation Outage Forecasting System
C/No	Carrier to Noise ratio
COMS	Communication, Oceanic, and Meteorological Satellite
CORHEL	CORrona-HELiosphere
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
COTS	Commercial Orbital Transportation System
CPWG	Cross Polar Working Group
CRCM	Comprehensive Ring Current Model
CSLA	Commercial Space Launch Act
CSPAR	Center for Space Plasma and Aeronomic Research
CSSAR	Center for Space Science and Applied Research
CTIM	Coupled Thermosphere Ionosphere Model
CTIPe	Coupled Thermosphere Ionosphere Plasma Sphere Electrodynamics
DARN	Dual Auroral Radar Network
DIMS	Data Information and Management System
DMSP	Defense Meteorological Satellites Program
DOD	Department of Defense
DREAM	Dynamic Radiation Environment Assimilation Model
DSCOVR	Deep Space Climate Observatory
Dst	Geomagnetic Disturbance Index
EDP	Electron Density Profiles
EIS	Electric Infrastructure Security
EMBRACE	Brazilian Space Weather Study and Monitoring Program
EMC	Environmental Modeling Center, NOAA

EMP	Electromagnetic Pulse
EPRI	Electric Power Research Institute
ESA	European Space Agency
ESD	Electrostatic Discharge
ESTEC	European Space Research and Technology Center
EUV	Extreme Ultraviolet
EVE	Extreme Ultraviolet Variability Experiment
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FISM	Flare Irradiance Spectral Model
FOC	Full Operational Capability
GAIA	Ground-to-top model of Atmosphere and Ionosphere for Aeronomy
GAIM	Global Assimilation of Ionospheric Measurements
GEO	Geosynchronous Satellite / Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GEM	Geospace Environment Modeling
GFS	Global Forecast System
GGCM	Geospace General Circulation Model
GIC	Geomagnetically Induced Currents
GIP	Global Ionosphere-Plasmasphere
GLA	General Lighthouse Authorities (of the United Kingdom and Ireland)
GLE	Ground Level Event
GMD	Geomagnetic Disturbance
GMDTF	Geomagnetic Disturbance Task Force
GMKF	Gauss-Markov Kalman Filter Model
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GSFC	Goddard Space Flight Center, NASA
HAF	Hakamada-Akasofu-Fry (solar wind model)
HAO	High-Altitude Observatory
HEO	High Earth Orbit
HMI	Helioseismic and Magnetic Imager
HMO	Hermanus Magnetic Observatory
ICAO	International Civil Aviation Organization
ICSWIAS	International Committee for Space Weather Impacts to Aviation Safety
ICTSW	WMO's Inter-Programme Coordination Team on Space Weather
IDEA	Dynamics through Earth Atmosphere
IESD	Radiation-induced internal Electrostatic Discharge
IFM	Ionosphere Forecast Model
IGS	International GNSS Service
IGY	International Geophysical Year
IHY	International Heliophysical Year
IMAGE	Imager for Magnetopause-to-Aurora Global Exploration
IMO	International Maritime Organization
INTERMAGNET	International Real-time Magnetic observatory Network
IPS	Interplanetary Scintillation
ISES	International Space Environment Service
ISOON	Improved Solar Optical Observing Network
ISS	International Space Station

ISWA	Integrated Space Weather Analysis
ISWI	International Space Weather Initiative
JPDO	Joint Planning and Development Office
JPL	Jet Propulsion Laboratory, NASA
JSC	Johnson Space Center, NASA
KACST	King Abdulaziz City for Science and Technology
KCC	Korea Communications Commission
KMA	Korea Meteorological Administration
KSEFC	Korean Space Environment Forecast Center
KSWC	Korean Space Weather Center
LANL	Los Alamos National Laboratory
LASP	Laboratory for Atmospheric and Space Physics
LEO	Low Earth Orbit
LMSAL	Lockheed Martin Solar and Astrophysics Laboratory
LOC	Loss of Crew
LOM	Loss of Mission
LWS	Living with a Star
LYRA	Large Yield RAdiometer
MDI	Michelson Doppler Imager
MHD	Magneto Hydro-Dynamics
MURI	Multidisciplinary University Research Initiative
NADIR	Neutral Atmosphere Density Interdisciplinary Research
NAIRAS	Nowcast of Atmospheric Ionizing Radiation for Aviation Safety
NASA	National Aeronautics and Space Agency
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction, NOAA
NCSW	National Center for Space Weather (China)
NEO	Near Earth Objects
NERC	North American Electric Reliability Corporation
NESDIS	National Satellite Data and Information Service, NOAA
NEXT	Iridium 2nd Generation Satellite Constellation
NextGen	Next Generation Air Transportation System
NICT	National Institute of Information and Communications Technology (Japan)
NGDC	National Geophysical Data Center, NOAA
NOAA	National Oceanic and Atmospheric Administration
NSO	National Solar Observatory
NSF	National Science Foundation
NSFC	National Natural Science Foundation of China
NSSTC	National Space Science and Technology Center
NSTP	National Satellite Technology Program (Saudi Arabia)
NSWP	National Space Weather Program
NTRIP	Networked Transport of RTCM via Internet Protocol
NWS	National Weather Service, NOAA
OFCM	Office of the Federal Coordinator for Meteorology
ONR	Office of Naval Research
OpenGGCM	Open Geospace General Circulation Model
PCA	Polar Cap Absorption
PNT	Positioning, Navigation, and Timing
PROBA	PRoject for OnBoard Autonomy
RAC	Radiation Auroral Clutter
RBSP	Radiation Belt Storm Probes

RIMS	Solar Radio Interference Measuring Sets
RO	Radio Occultation
RPC	Rapid Prototyping Center
RRA	Radio Research Agency (Korea)
RTK	Real Time Kinematic
RWC	Regional Warning Center
SAGA	South Atlantic Geomagnetic Anomaly
SAT	Department of State's Office of Space and Advanced Technology
SC (23/24)	Solar Cycle
SCINDA	Scintillation Network Decision Aid
SDO	Solar Dynamics Observatory
SEALION	Southeast Asia Low Latitude Ionospheric Network
SEEFS	SSA Environmental Effects Fusion System
SEIEG	U.K. Space Environment Impact Expert Group
SEP	Solar Energetic Particle
SEPC	Space Environmental Prediction Center
SPoRT	Short-term Prediction Research and Prediction Center
SET	Space Environment Technologies
SHINE	Solar, Heliospheric, and INterplanetary Environment
SIDC	Solar Influences Data Center
SITEC	Sudden Increases in Total Electron Content
SMEI	Solar Mass Ejection Imager
SpaceWOC	Space Weather Operations Center, USAF
SPE	Solar Proton Events
SRAG	Space Radiation Analysis Group, NASA
SRB	Solar Radio Burst
SRS	Solar Radio Spectrograph Radiometer
SSA	Space Situational Awareness
SSCC	Space weather Service Centre
SST	Space Surveillance and Tracking
STEREO	Solar TErrestrial RElations Observatory
SWACI	Space Weather Application Center –Ionosphere
SWAP	Sun Watcher with Active Pixels
SWC	Space Weather Center
SWE	Space WEather
SWL	Space Weather Laboratory
SWENET	Space Weather European NETwork
SWFL	Space Weather Forecast Laboratory
SWFO	Space Weather Forecast Office
SWMF	Space Weather Modeling Framework
SWPC	Space Weather Prediction Center, NOAA
TEC	Total Electron Content
TIEGCM	Thermosphere Ionosphere Electrodynamic General Circulation Model
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TIMEGCM	Thermosphere-Ionosphere Mesosphere Electrodynamics General Circulation Model
TP	Turbulence Plot
UCAR	University Corporation for Atmospheric Research
UNBSS	United Nations Basic Space Science
UN-COPUOS	United Nations Committee on the Peaceful Use of Outer Space
USAF	United States Air Force

USGS	United States Geologic Survey
USTAR	Utah Science Technology and Research Program
UVI	Ultraviolet Imager
VERB	Versatile Electron Radiation Belt
WAM	Whole Atmosphere Model
WHI	Whole Heliosphere Interval
WIGOS	World Meteorological Organization Integrated Global Observing System
WIS	WMO Information System
WMO	World Meteorological Organization
WSA	Wang-Sheeley-Arge Model


To Rocky Mountain National Park (35 mi. to Estes Park and 15 mi. to Lyons)
U.S. 36 (Foothills Hwy)
Colo. 119 (Diagonal Hwy)
N
Boulder
Broadway
Iris Ave.
28th St
30th St
Foothills Pkwy
Pearl St. Mall
Pearl St
Boulder Canyon
Arapahoe Rd
Millennium Hotel
Colorado Blvd
Flagstaff Mountain
Baseline Rd
NIST
NOAA
Space Environment Center
U.S. Hwy 36
So. Boulder Blvd
Table Mesa Dr
Broadway
National Center for Atmospheric Research
93