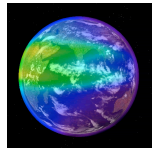
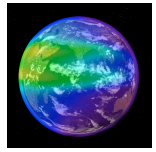


Communication Alert and Prediction System (CAPS) - operational space weather for HF and satcom users

Space Weather Workshop April 30, 2008

CAPS web site: http://terra1.spacenvironment.net/~ionops/



CAPS team

Dave Bouwer, *Space Environment Technologies*

Odile de la Beaujardiere, *Air Force Research Lab*

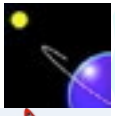
Vince Eccles, *Space Environment Corporation*

Pete Engelmann, *SPARTA*

John Retterer, *Air Force Research Lab*

Robert Schunk, *Space Environment Corporation*

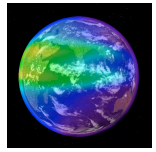
Matt Taylor, *IPS MeteoStar*



W. Kent Tobiska, *Space Environment Technologies*

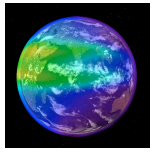
Dave VandenHeuvel, *IPS MeteoStar*

CAPS web site: http://terra1.spacenvironment.net/~ionops/



The problems

- **COST:** Jet fuel is the largest operating expense for airlines - *(LA Times, April 12, 2008)*
  - in 2007 one major carrier paid $6.7B for aviation fuel compared with $2.7B in 2003
  - since 2007, a year later, aviation fuel price has increased an **additional 76%**
- **SAFETY:** Hemispheric HF outages due to solar flares impact missions for
  - up to **200,000** troops - *(2008 estimated U.S. deployment in Iraq and Afghanistan)*
  - first responders - *(Sep 7, 2005 X17 flare during Katrina rescue)*



Commercial aviation polar routes

Polar route usage is increasing

- Total 1998 flights were less than 10 for 2-3 carriers
- Total 2008 anticipated traffic is **>8000 flights for 13 carriers**
- Asian carriers are experiencing the largest growth with **one plane per day being added** during the next 5 years
- These routes have the advantage of reducing time and fuel due to prevailing West-East headwinds
- Polar routes typically fly northward of 82N latitude

CAPS web site: http://terra1.spacenvironment.net/~ionops/

Commercial aviation routing incident

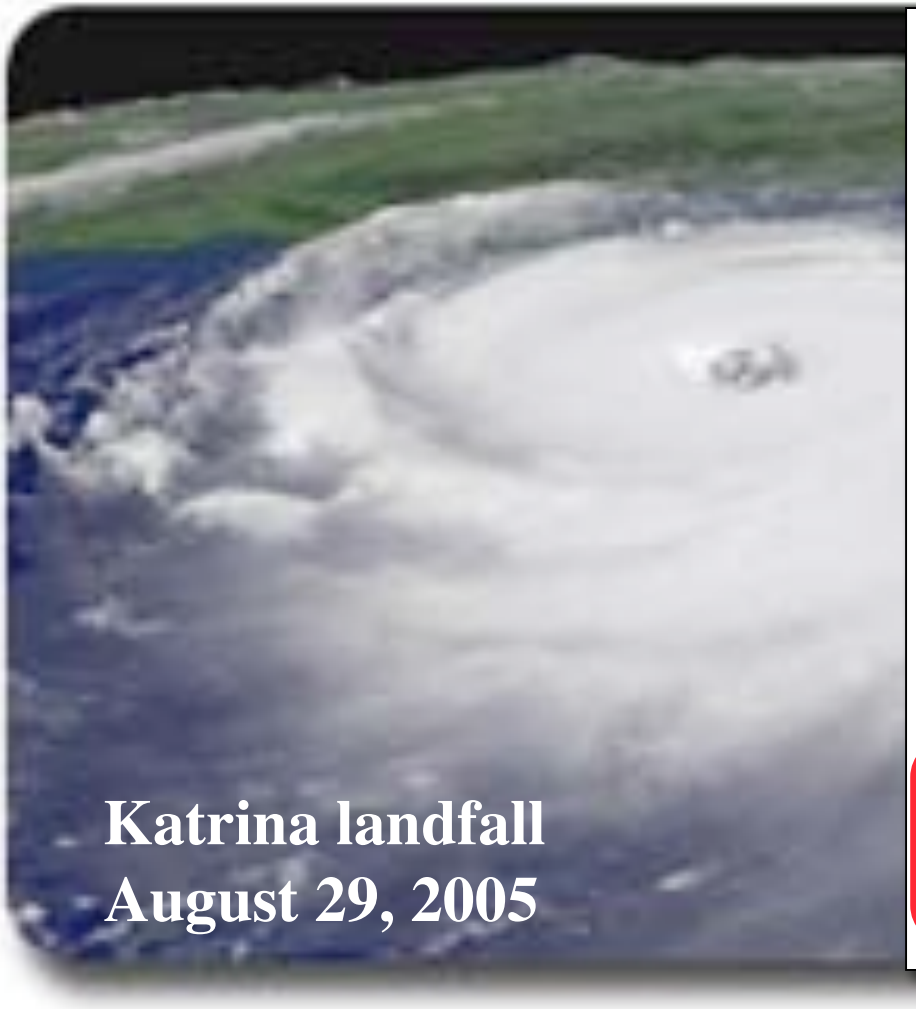
September 7, 2005 1931 UT

- a major X17 flare occurred - the 4th largest in 15 years
- the event created a complete radio blackout on the sunlit hemisphere of the Earth
- a Chicago to Hong Kong flight on a polar route 3 was forced to divert to Anchorage at a schedule penalty of 180 minutes that cost additional flight crew time and required more fuel
- per incident-plane costs for route diversions start at $1/4 million

CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*

Katrina first responders were affected



From: <secproducts@noaa.gov>
Date: September 7, 2005 7:36:05 PM GMT+00:00
To: <ktobiska@spacenvironment.net>
Subject: Space Weather Bulletin

Official Space Weather Advisory issued by NOAA Space Environment Center
Boulder, Colorado, USA

SPACE WEATHER ADVISORY BULLETIN #05- 7
2005 September 07 at 01:31 p.m. MDT (2005 September 07 1931 UTC)

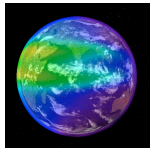
**** POWERFUL SOLAR FLARE ERUPTS ****

One of the largest solar flares on record occurred today, September 07. Very active Region 808 produced a powerful X17 flare (R4 on the NOAA Scale) observed on the NOAA GOES satellite at 07/1740 UTC (September 07, 1:40 p.m. EDT). This flare, the 4th largest in the last 15 years, erupted just as the Region 808 sunspot cluster was rotating onto the visible disk of the sun. Intense radio emissions were also associated with this flare. A very bright and fast coronal mass ejection was observed on coronagraph imagery; however, the material was not Earth directed. An S1 - S2 radiation storm is expected following this eruption, but is not expected to begin until late on September 07 or early September 08.

This event created a complete blackout of high frequency communications on the daylit side of Earth. Communications used by emergency services along the Gulf Coast may have experienced problems due to this flare. Low frequency navigation systems may also have experienced a period of significant degradation.

9 days later

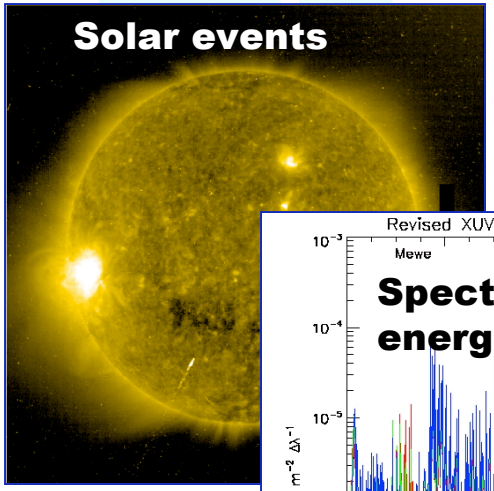
CAPS web site: http://terra1.spacenvironment.net/~ionops/



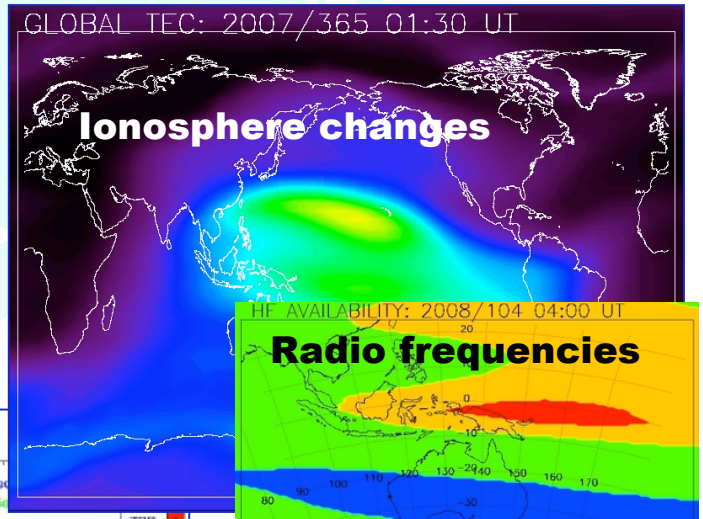
What is CAPS?

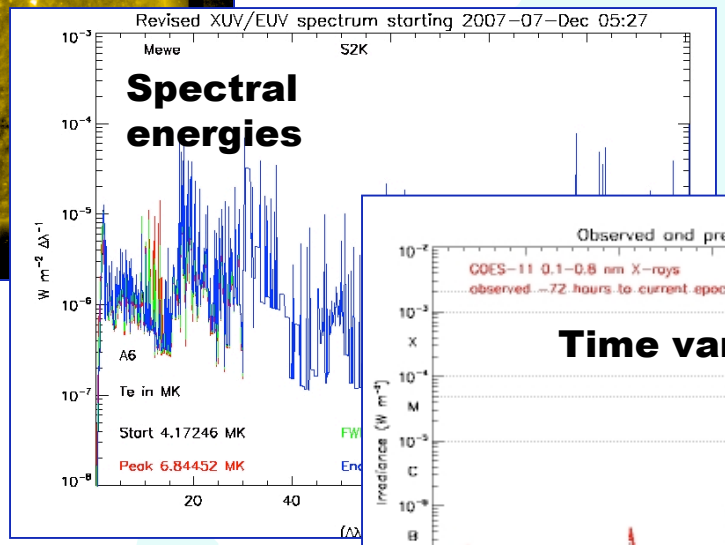
CAPS web site: http://terra1.spacenvironment.net/~ionops/

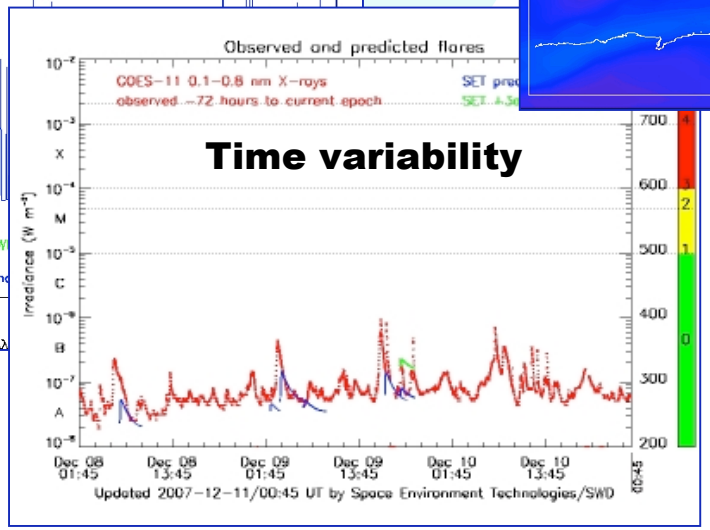
CAPS is an end-to-end system

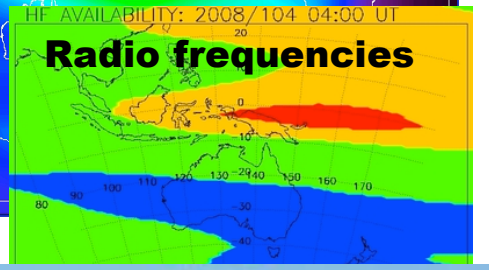


solar-ionosphere coupling affects HF communications

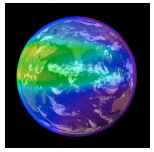








CAPS web site: http://terra1.spacenvironment.net/~ionops/

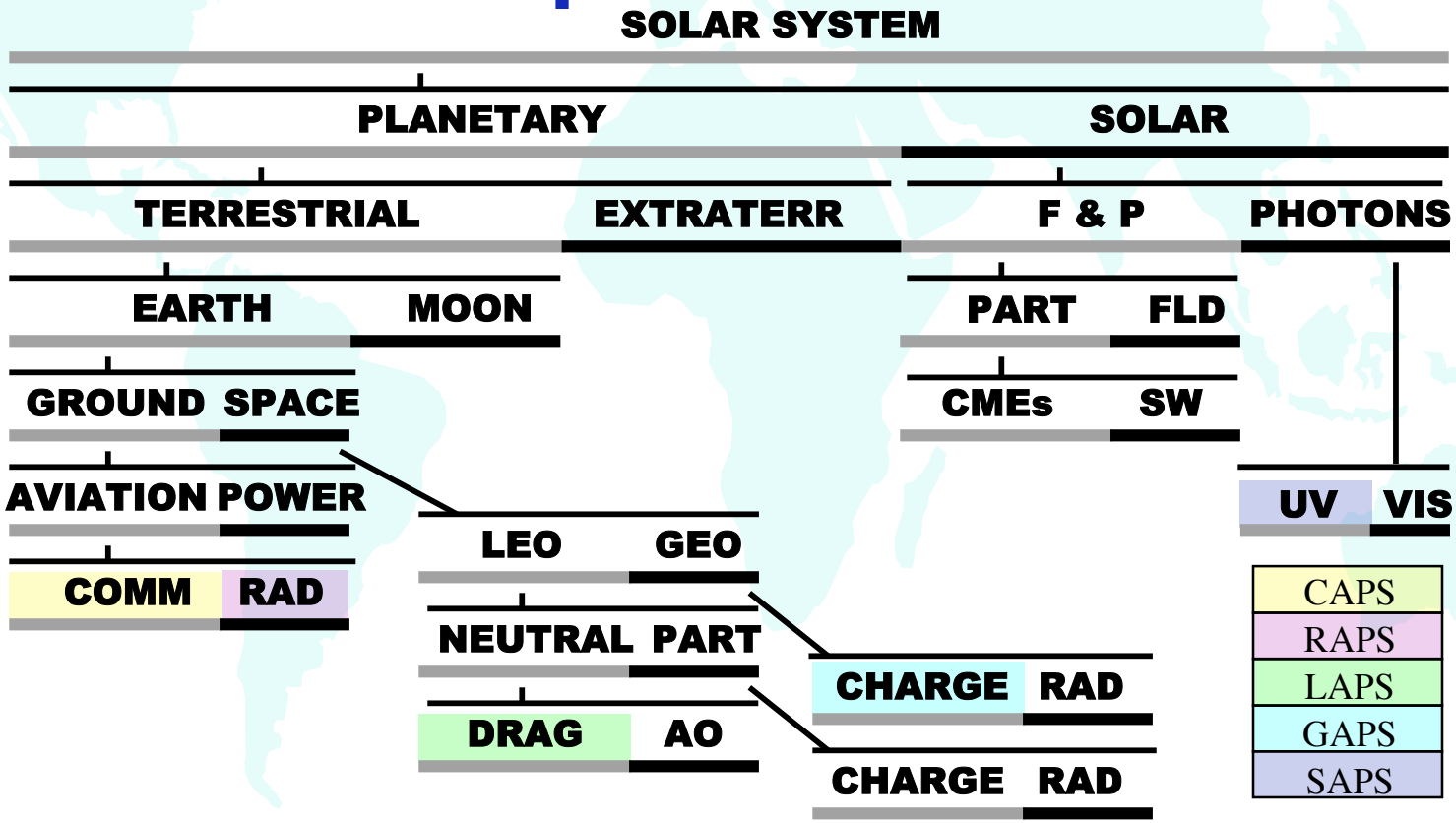


CAPS is a response to the *National Space Weather Program Assessment Committee's* recommendation to strengthen the science-to-user chain

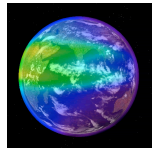
1. CAPS maintains and strengthens both targeted and strategic space weather research
2. CAPS transitions research models into operations for specific users
3. CAPS is an example of the private sector that supplies products and services

CAPS web site: http://terra1.spacenvironment.net/~ionops/

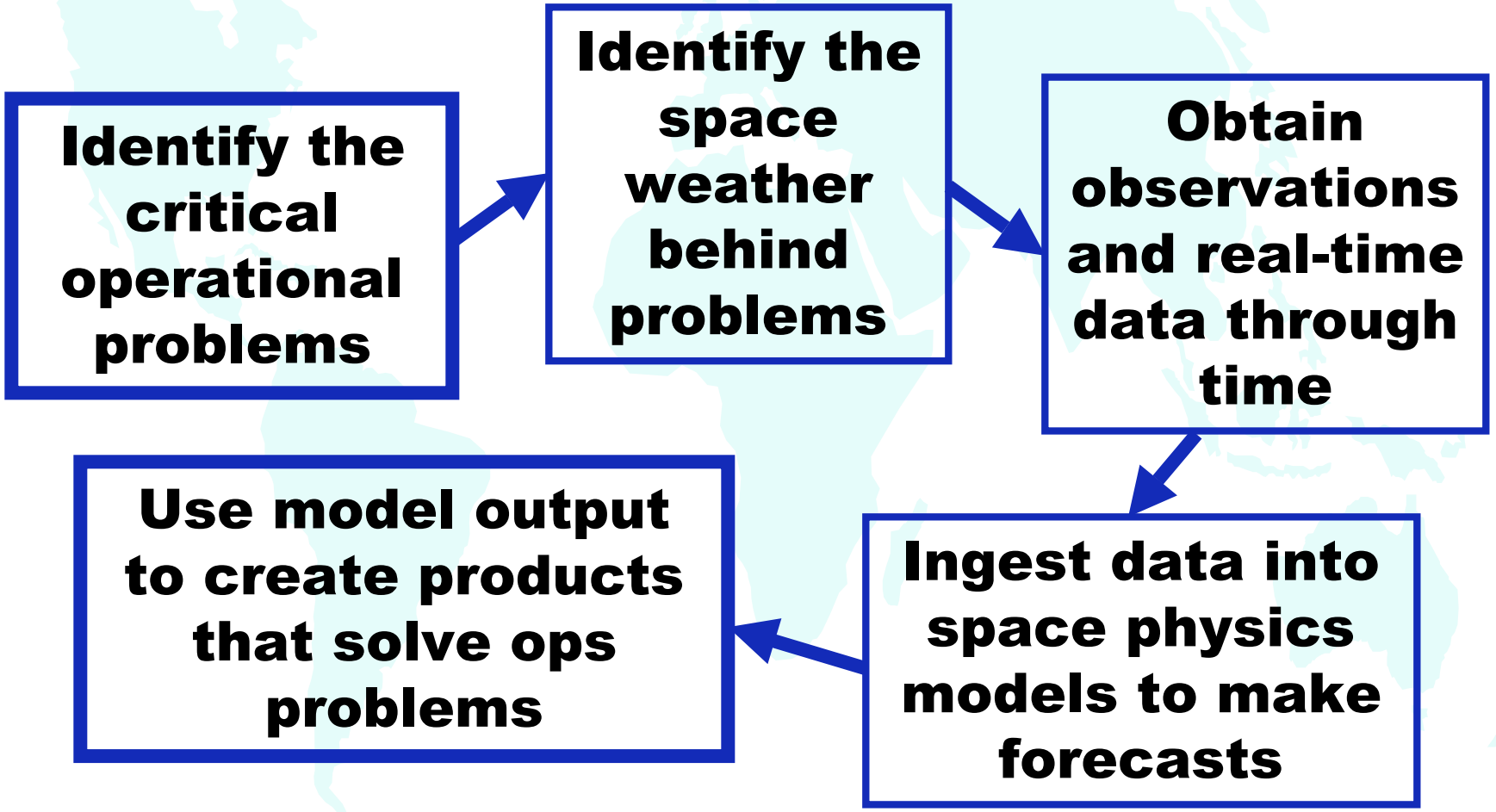
Putting CAPS in context - *operational management* of space weather



CAPS web site: http://terra1.spacenvironment.net/~ionops/

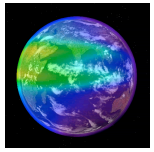


CAPS uses a proven methodology

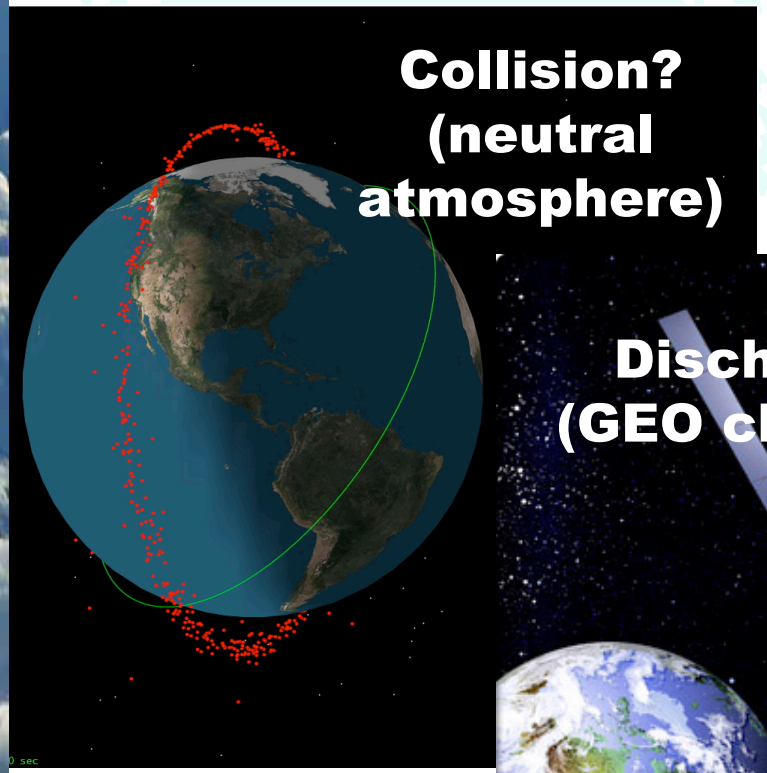


CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*

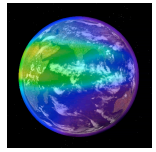


CAPS solves 1 of 3 large operational problems

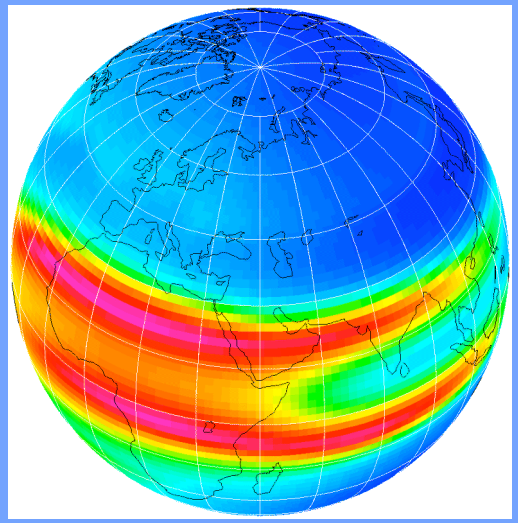
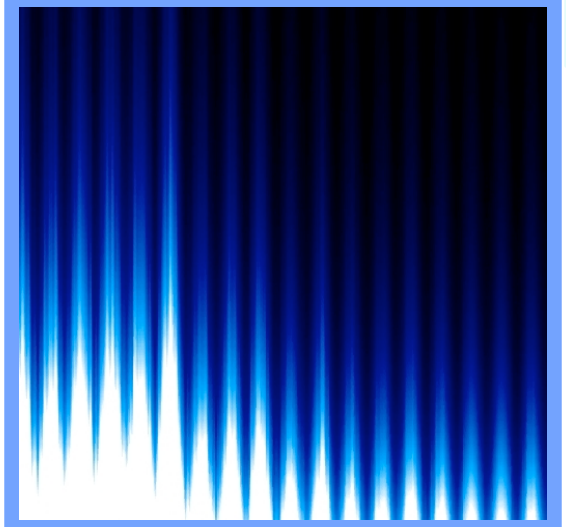
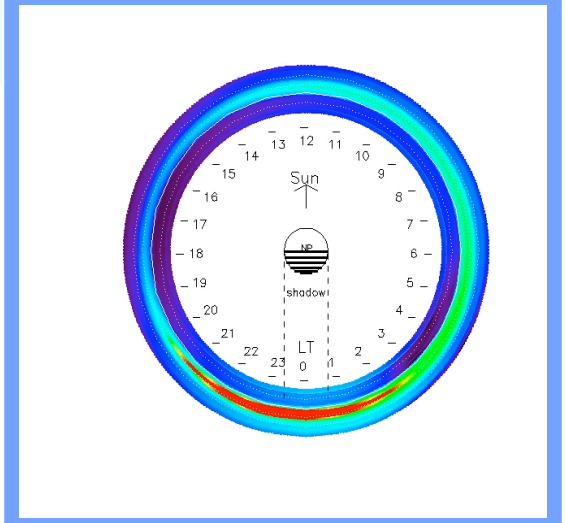


CAPS web site: http://terra1.spacenvironment.net/~ionops/

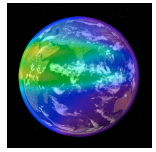
CAPS - *Communication Alert and Prediction System*



Space physics model "workhorses" provide solutions

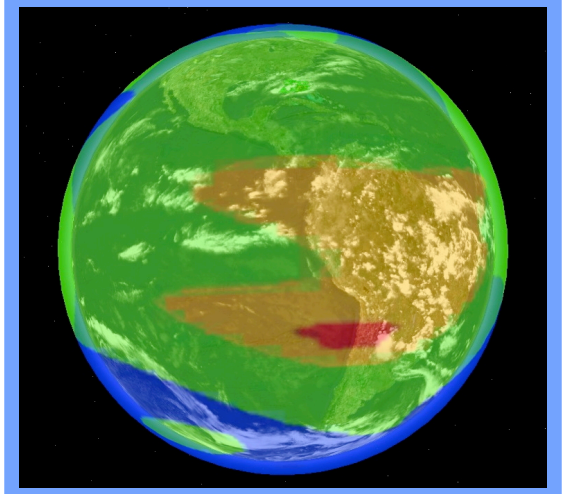
GAIM/IFM	JB2006/2008	GEOPOT08
		
Ionosphere	**LEO neutral atmosphere**	**GEO particles**

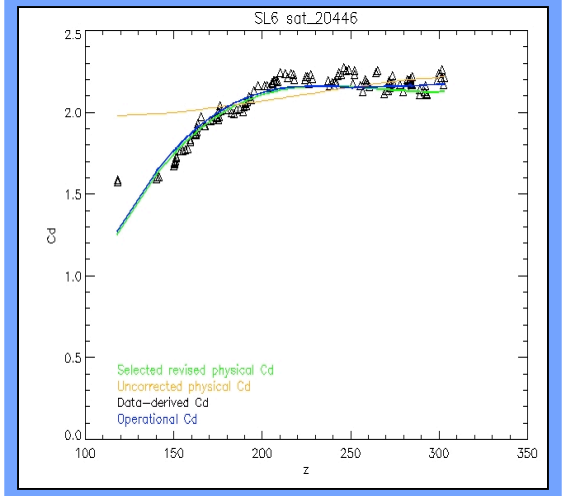
CAPS web site: http://terra1.spacenvironment.net/~ionops/

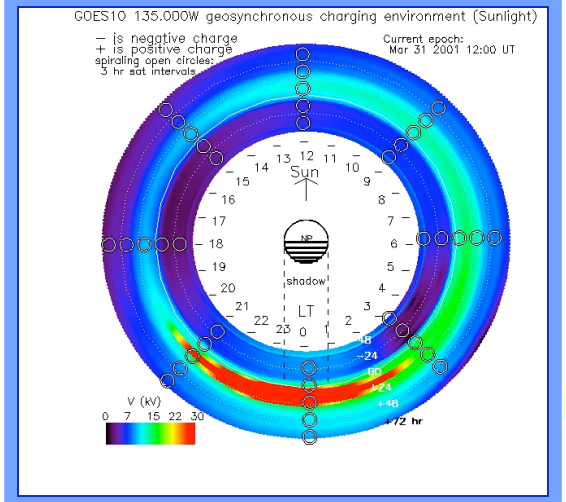


Solutions can be tailored for users

GAIM/IFM	JB2006/2008	GEOPOT08
HF & SATCOM availability	**Satellite reentry & drag**	**GEO spacecraft charging**







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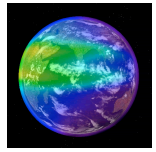


What are examples of solutions?

CAPS web site: http://terra1.spacenvironment.net/~ionops/

HF radio and satcom link capabilities are identified by CAPS

CAPS web site: http://terra1.spacenvironment.net/~ionops/

Space Environment Technologies

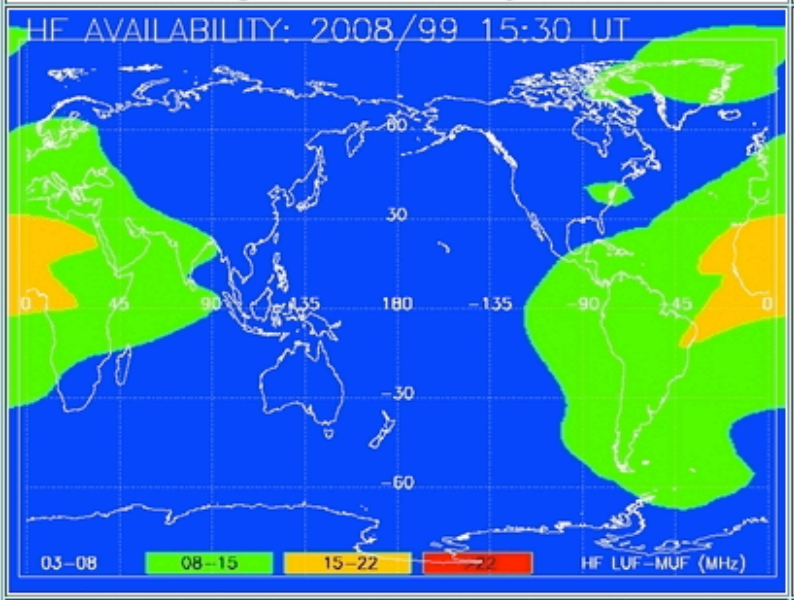
CAPS - *Current Global Communications*

SET proprietary site; SET and SEC proprietary data-not for use without written consent

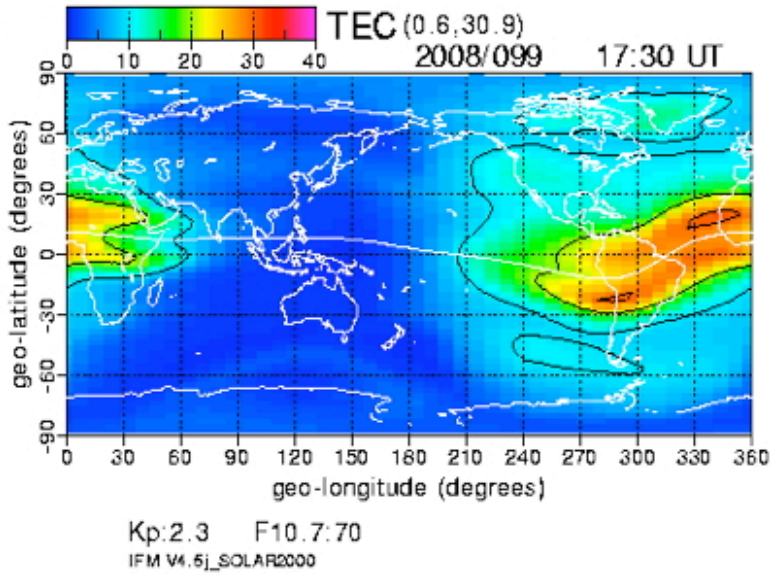
Space Environment Corporation

Home | Solar Geomag. Conditions | Global Comm. Status | Global MUF/foF2 Status | Global Scintillation Status | Data | Figures | About | Site Map

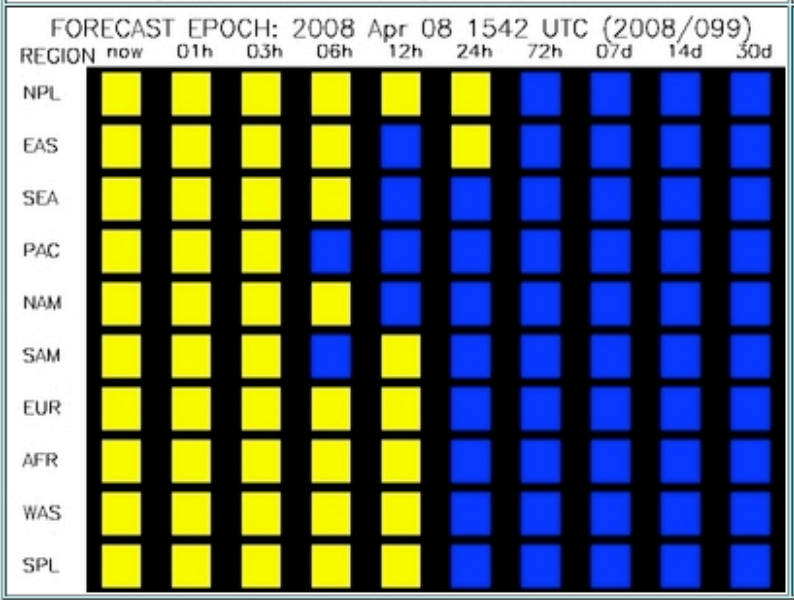
Current global radio availability conditions



Current global IFM Total Electron Content



Regional radio availability forecast conditions



(Click regions for Detailed Conditions)

- Current and predicted communications conditions
  - Red - high frequencies (HF) are unavailable (>22 MHz)
  - Yellow - lowest usable frequency (LUF) and maximum usable frequency (MUF) range is 15-22 MHz
  - Green - LUF-MUF range is 8-15 MHz
  - Blue - LUF-MUF range is 3-8 MHz

If a communication link is not working at these frequencies, there is a higher probability of malfunctioning equipment and/or jamming as a cause for outage.

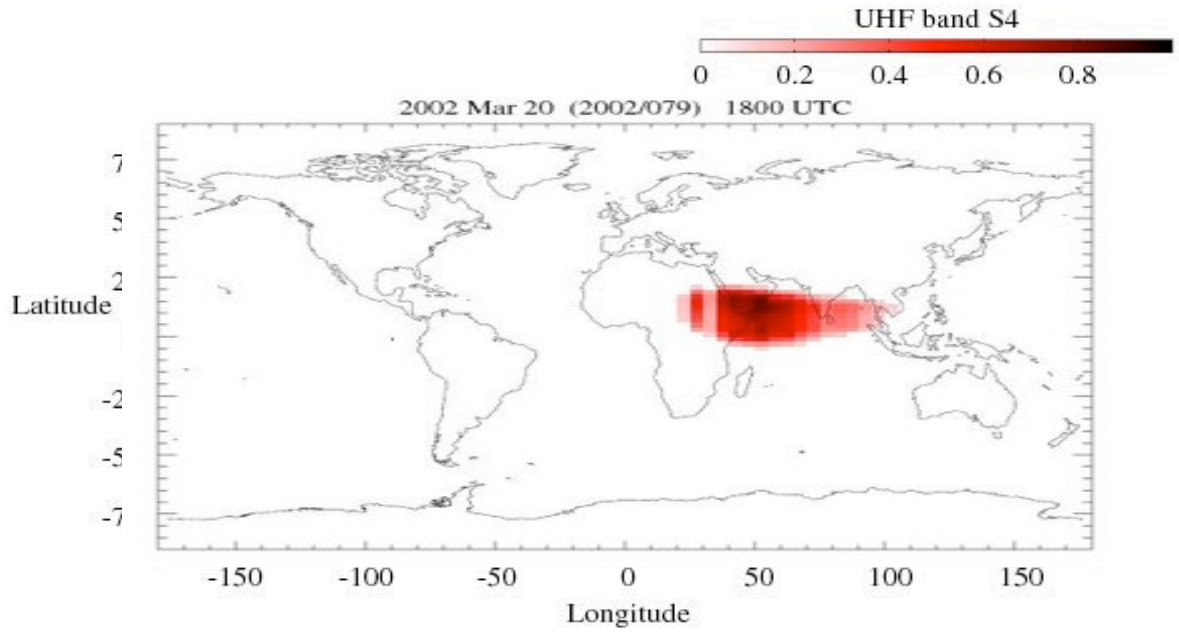
PBMOD UHF Scintillation Forecast

Today's forecast from first-principle models

for modified Julian day 54564, UT 12

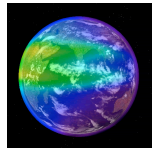
(day of year 099 2008, dmy 8 4 2008)

Issue time: Tue Apr 8 11:50:55 GMT 2008 (Tue Apr 8 11:50:55 GMT 2008)



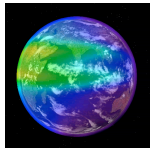
start stop <<first <prev next> last>>

Slideshow frame interval: 0.1 sec 0.3 sec 1 sec 3 sec 10 sec

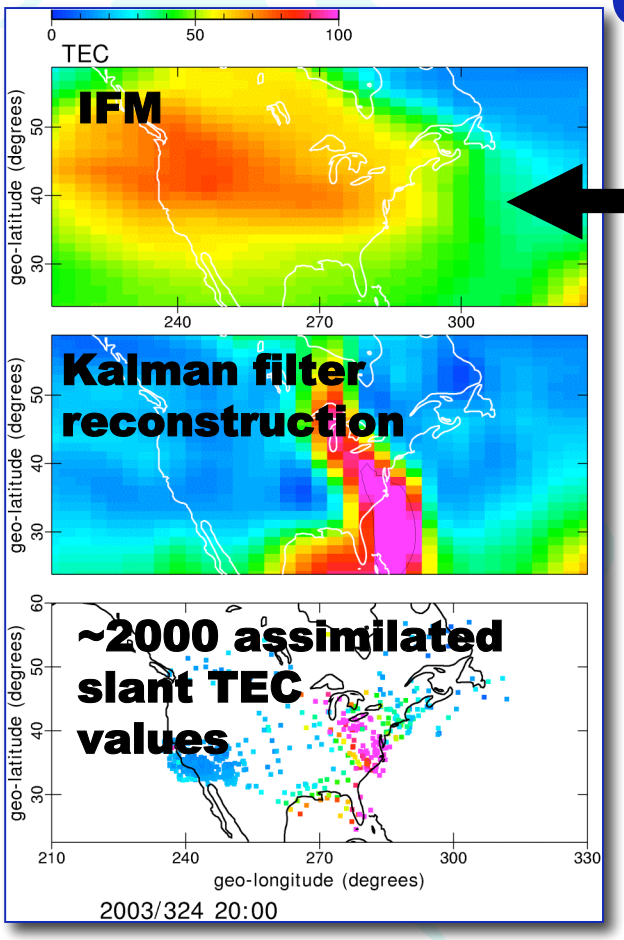


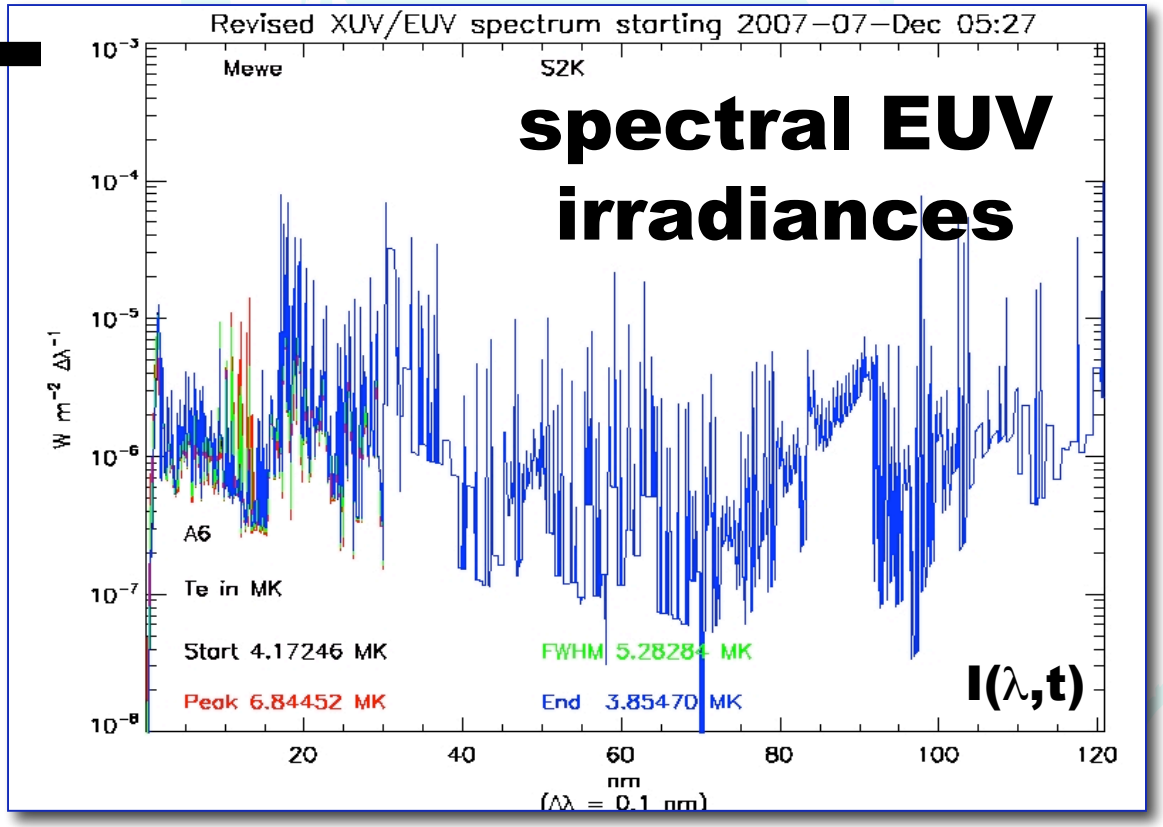
How is CAPS implemented?

CAPS web site: http://terra1.spacenvironment.net/~ionops/



Physics-based IFM model at the core of GAIM is driven by real-time solar irradiances





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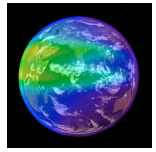
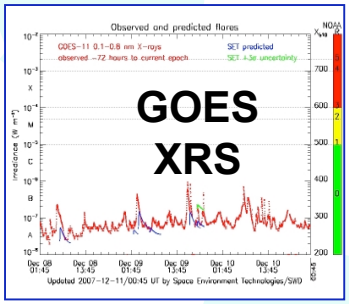


EUV and XUV spectral irradiances are generated with 1-minute and 0.1 nm resolution every 4 minutes

2008



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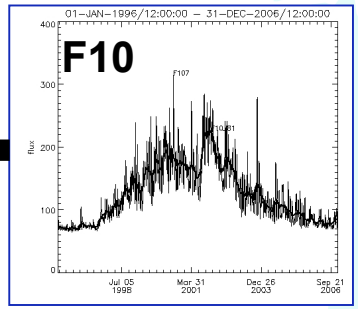

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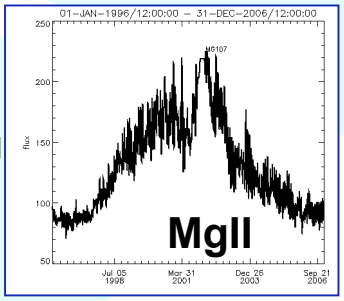

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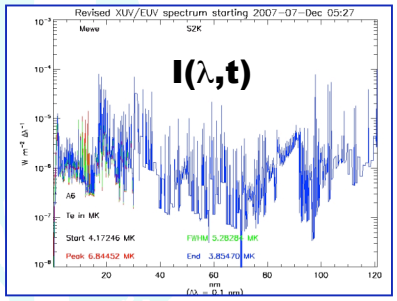
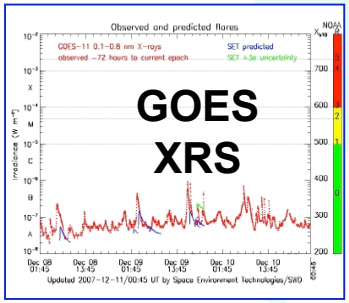


SFLR ——— **S2K** ———

2009



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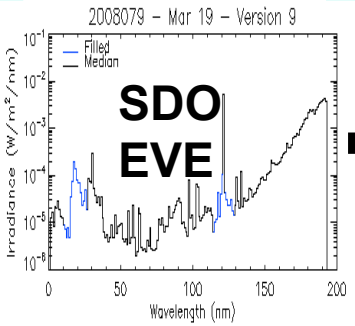

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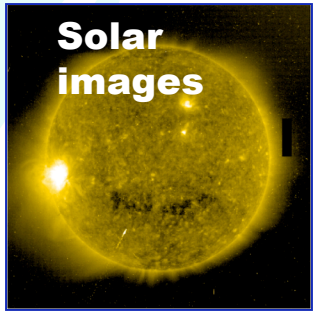

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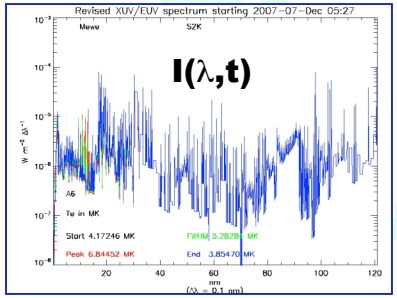
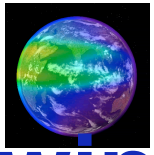
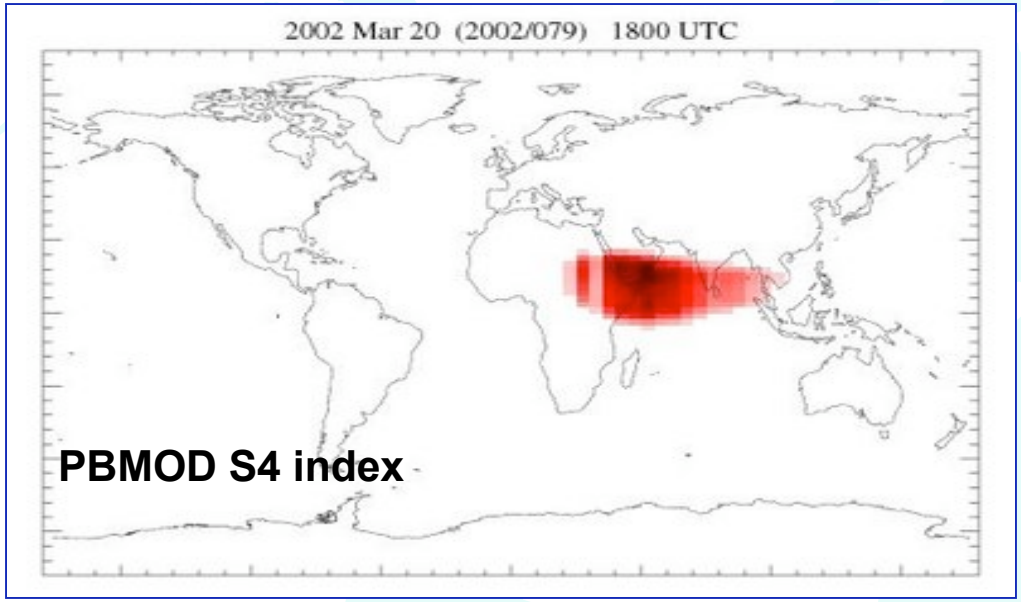


CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*



Real-time solar flux, solar wind, and geomagnetic indices are used to generate the PBMOD S4 index



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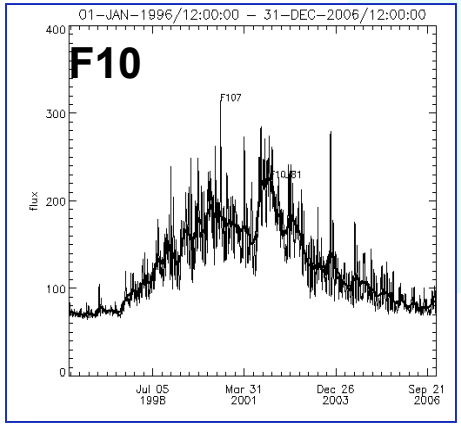

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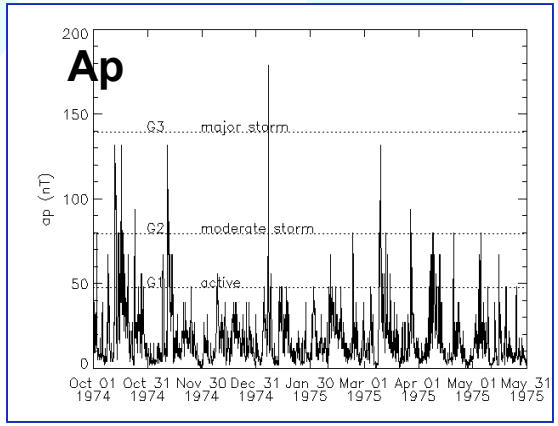

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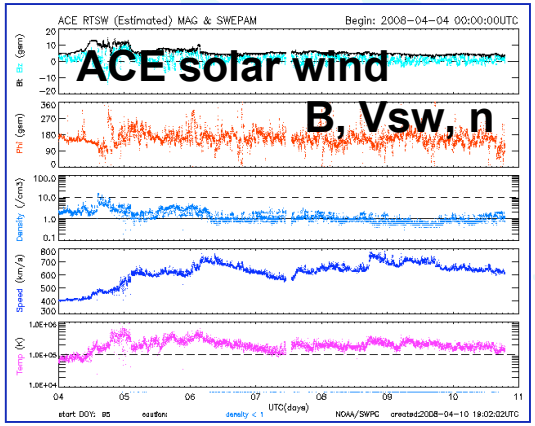
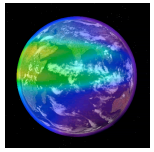


CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*

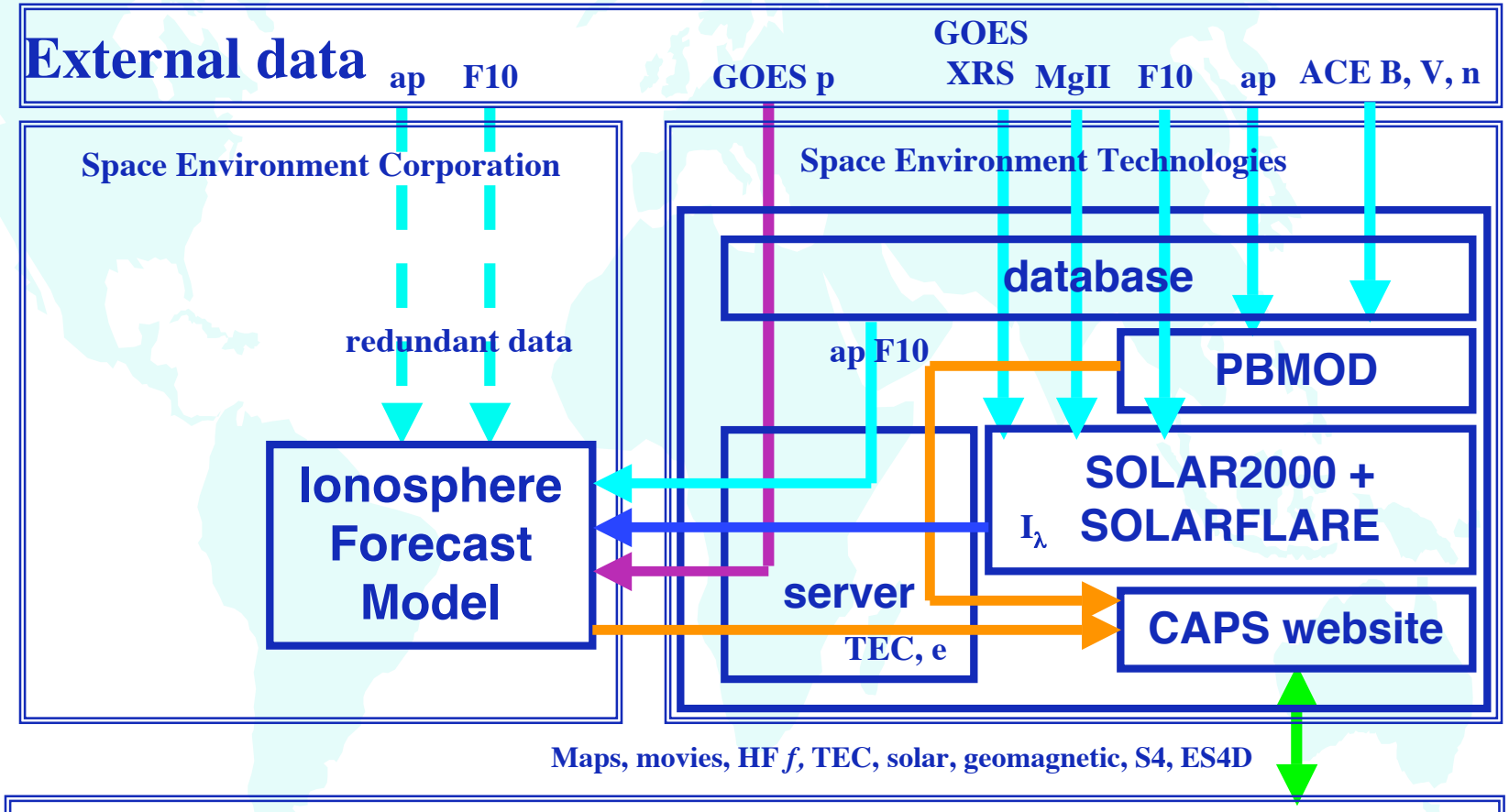


6-hr warnings: NOAA R scale & flares

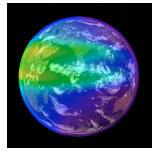
```
:Title: COMMUNICATION ALERT AND PLANNING SYSTEM STATUS (SOLAR/GEOMAG)
:Message ID: CAP1/A0/2454565.23333
:Issue Time: 2008 Apr 08 1828 UTC (2008/099)
#Prepared by Space Environment Technologies Space Weather Division (SET/
SWD)
#Contact spacenvironment@spacenvironment.net
#
COMM STATUS: Event duration - no unexpected effects; Event peak - no
significant effects
FLARE ALERT: A0 is near peak
FLARE STATUS: Quiet at Apr 08 2008/18:25 UT
FLARE FEATURES:      Flare start       peak          FWHM            end
-------------------------------------------------------------------------
Calendar Date        08-Apr 17:35  08-Apr 17:44  08-Apr 18:36  08-Apr 20:24
NOAA Radio Blackout       R0            R0            R0            R0
Flare class                             A0
```

CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS operational implementation

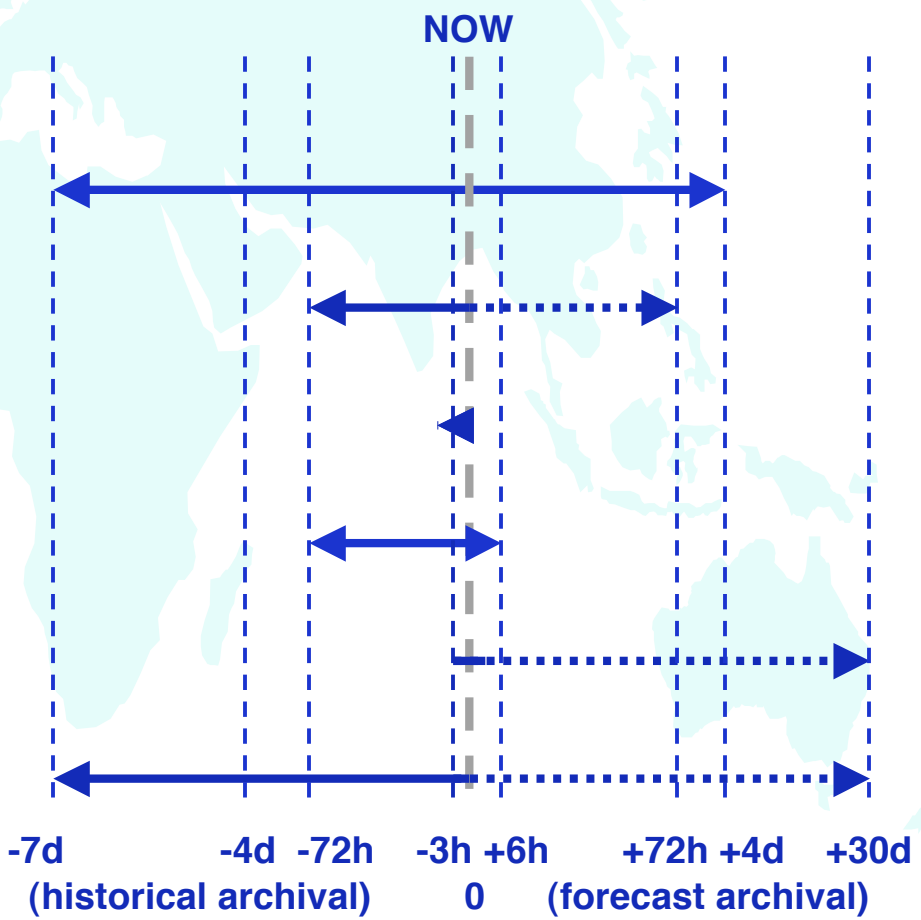


CAPS web site: http://terra1.spacenvironment.net/~ionops/

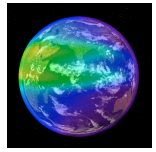


CAPS IFM/S2K/SFLR cadences, granularities, latencies, epochs

parameter	cadence	granularity	max latency
EUV	1 hr	1 day	12 hours
ap	1 hr	3 hours	1 hour
protons	4 min	5 minutes	10 minutes
flares	4 min	1 minute	8 minutes
TEC, e	15 min	15 minutes	15 minutes
HF maps	15 min	15 minutes	15 minutes



CAPS web site: http://terra1.spacenvironment.net/~ionops/



CAPS cost-basis for TRL 7.9 to TRL 9.0 transition

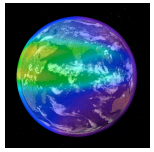
TRL 7.9 – System prototyping demonstrated in an operational environment - *COMPLETED APRIL 2007*

TRL 8.9 – Actual system completed and "mission qualified" through test and demonstration in an operational environment - *COMPLETED APRIL 2008*

TRL 9.0 – Actual system "mission proven" through commercial mission operations - ***START MAY 2008***

CAPS cost-basis = 1 FTE-year per TRL level for system-level integration of mature components

CAPS web site: http://terra1.spacenvironment.net/~ionops/



CAPS customers

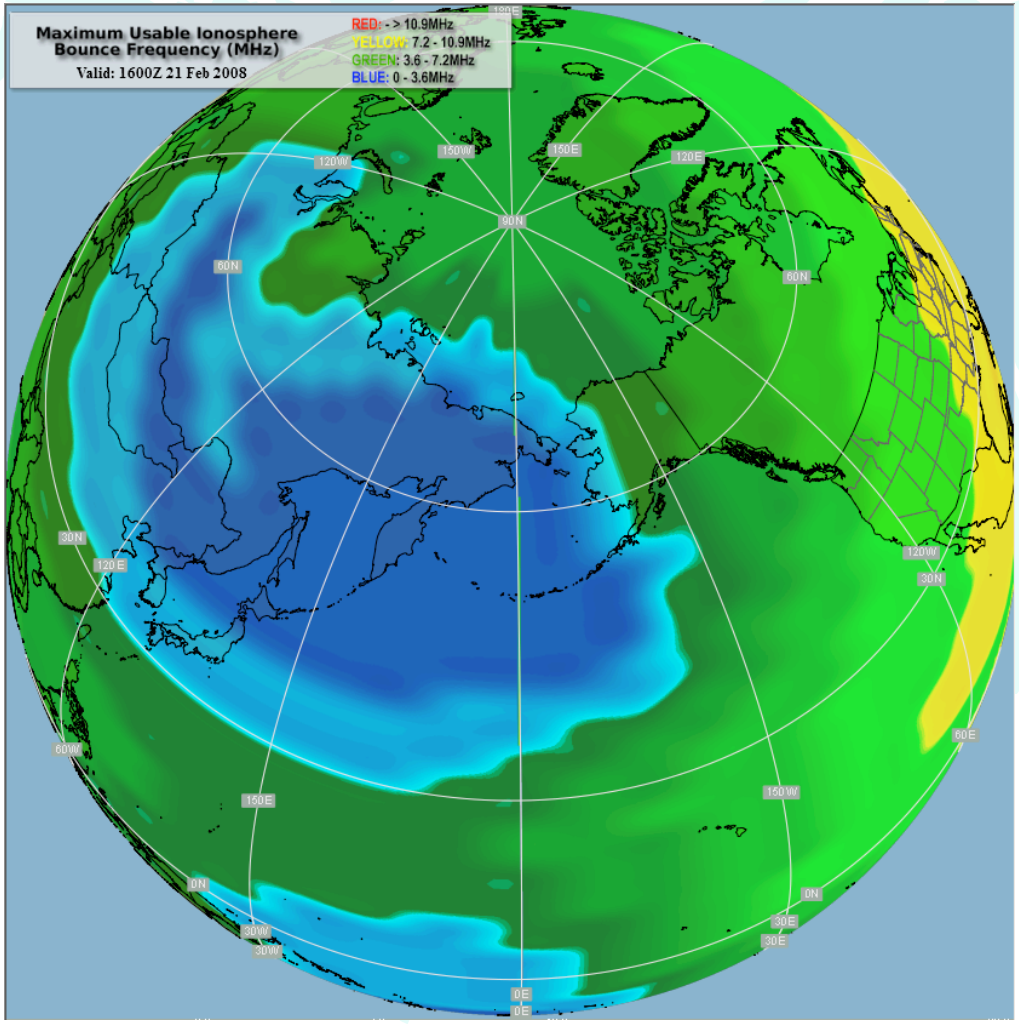
CAPS provides operational planning efficiency, increases safety, and reduces costs by providing current epoch specification and 1 minute to 72 hour forecast of HF frequency availability for:

- Commercial aviation (IPS MeteoStar)
- Department of Defense organizations

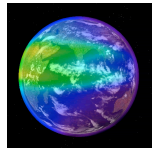
CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*

IPS MeteoStar LEADS provides aviation customers with tailored services using CAPS

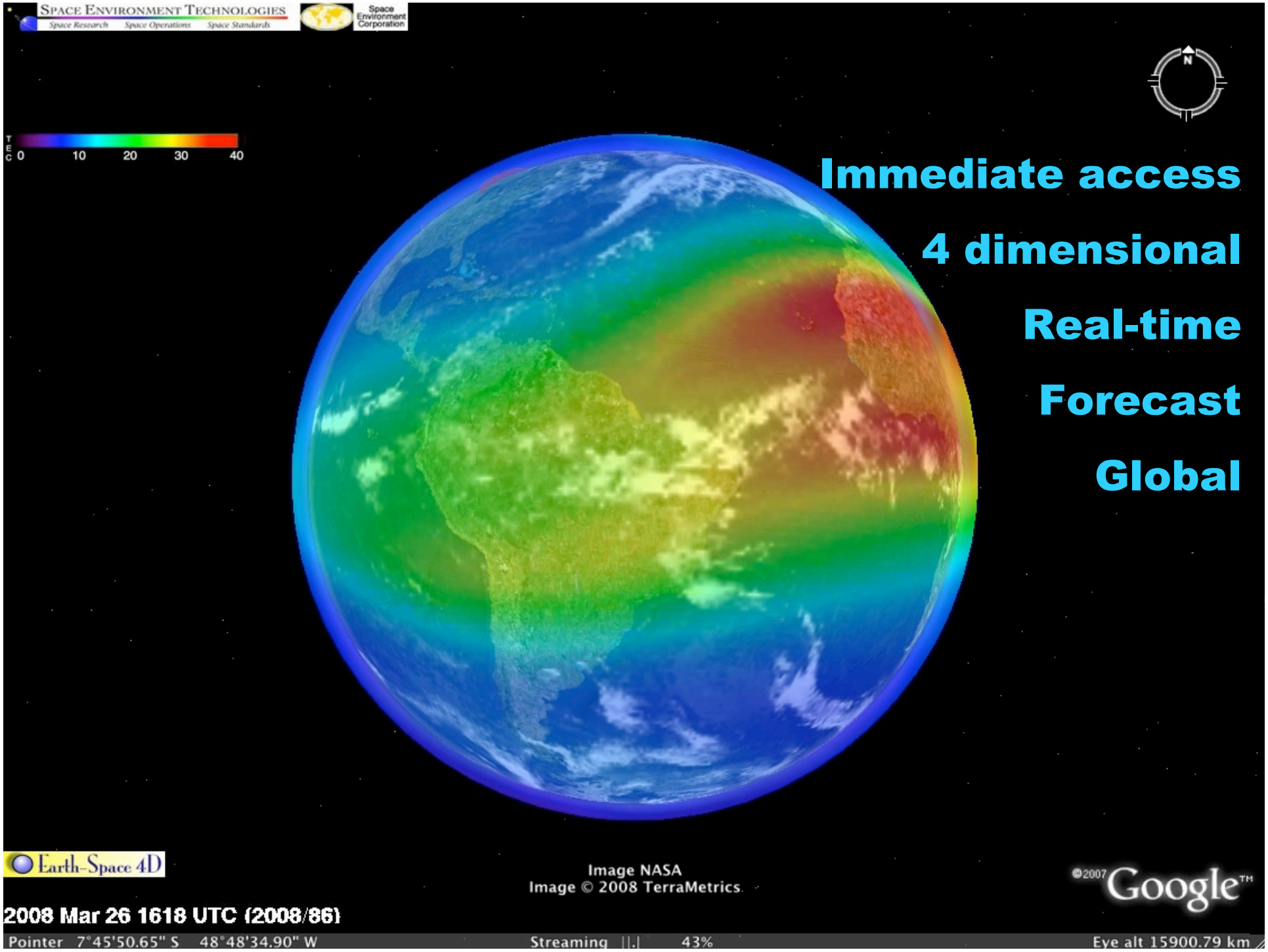


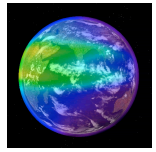
CAPS web site: http://terra1.spacenvironment.net/~ionops/



The future of space weather …

CAPS web site: http://terra1.spacenvironment.net/~ionops/

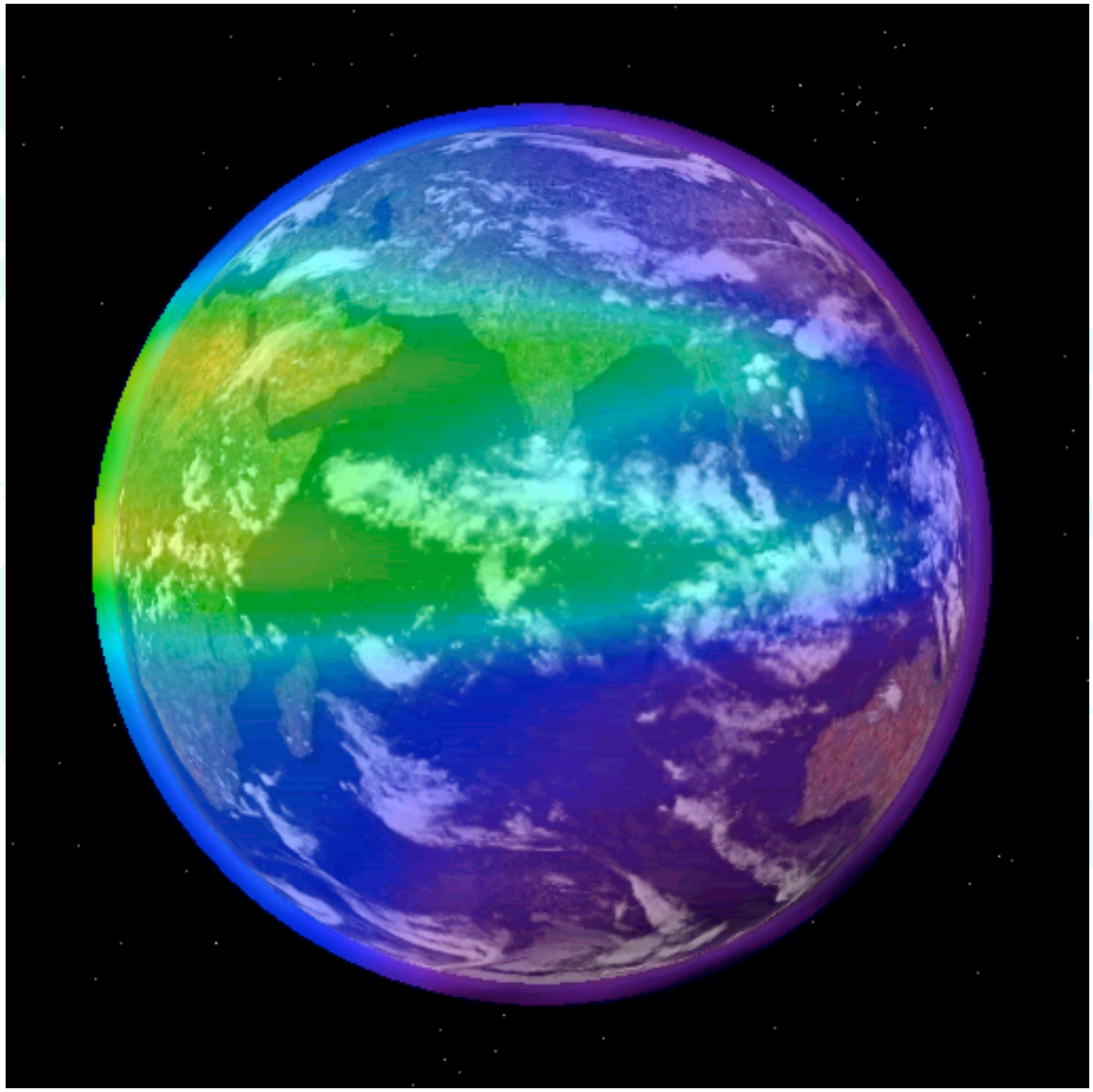

Space Environment Technologies
Space Research Space Operations Space Standards
Space Environment Corporation
TEC 0 10 20 30 40
N
Immediate access
4 dimensional
Real-time
Forecast
Global
Earth-Space 4D
Image NASA
Image © 2008 TerraMetrics
©2007 Google™
2008 Mar 26 1618 UTC (2008/86)
Pointer 7°45'50.65" S 48°48'34.90" W
Streaming 43%
Eye alt 15900.79 km



Backup slides

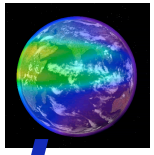
CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*



CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*



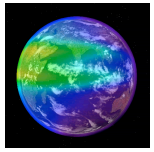
Our Mantra: *solve operational problems faced by identified customers*

Space Environment Technologies (SET) and its partners identify, develop, and provide solutions for problems that stem from space weather and that affect space- and ground-based operational systems.

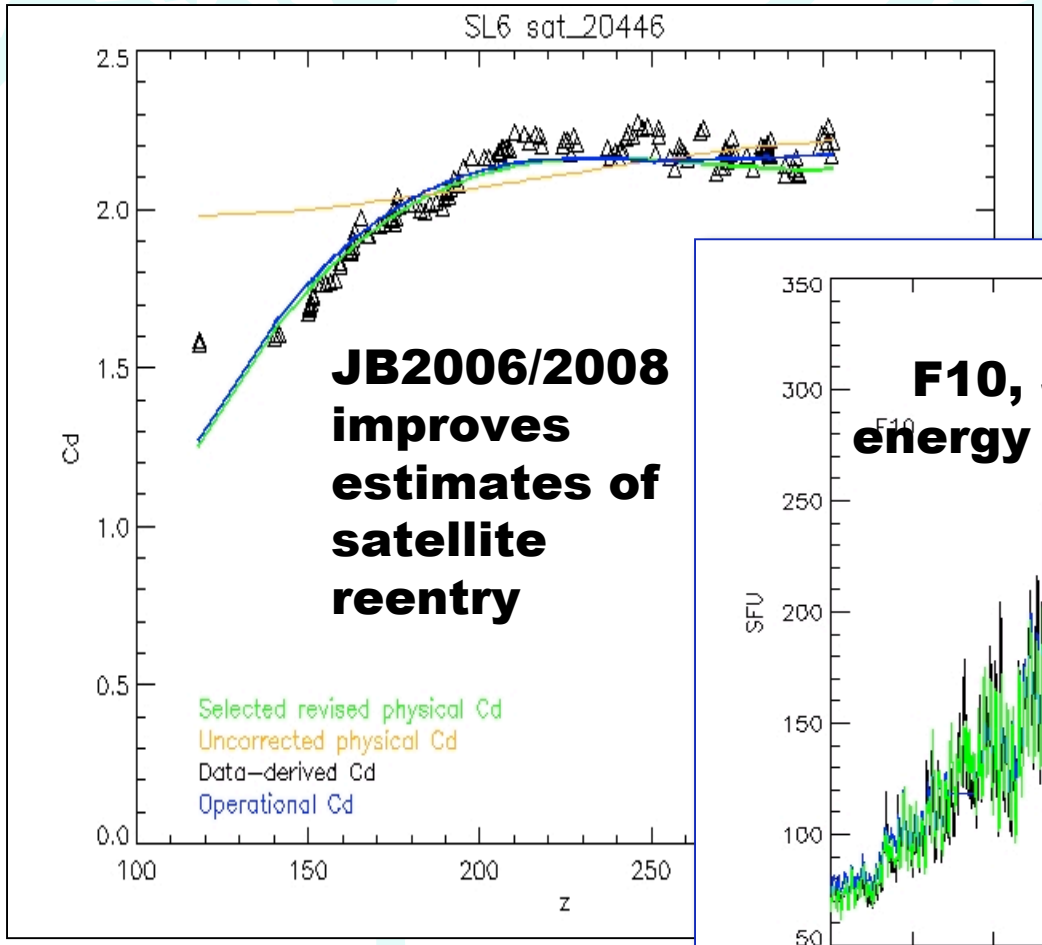
These systems include precision satellite orbit determination, constellation station-keeping, debris avoidance, reentry timing, satellite charging management, and communication link enhancement.

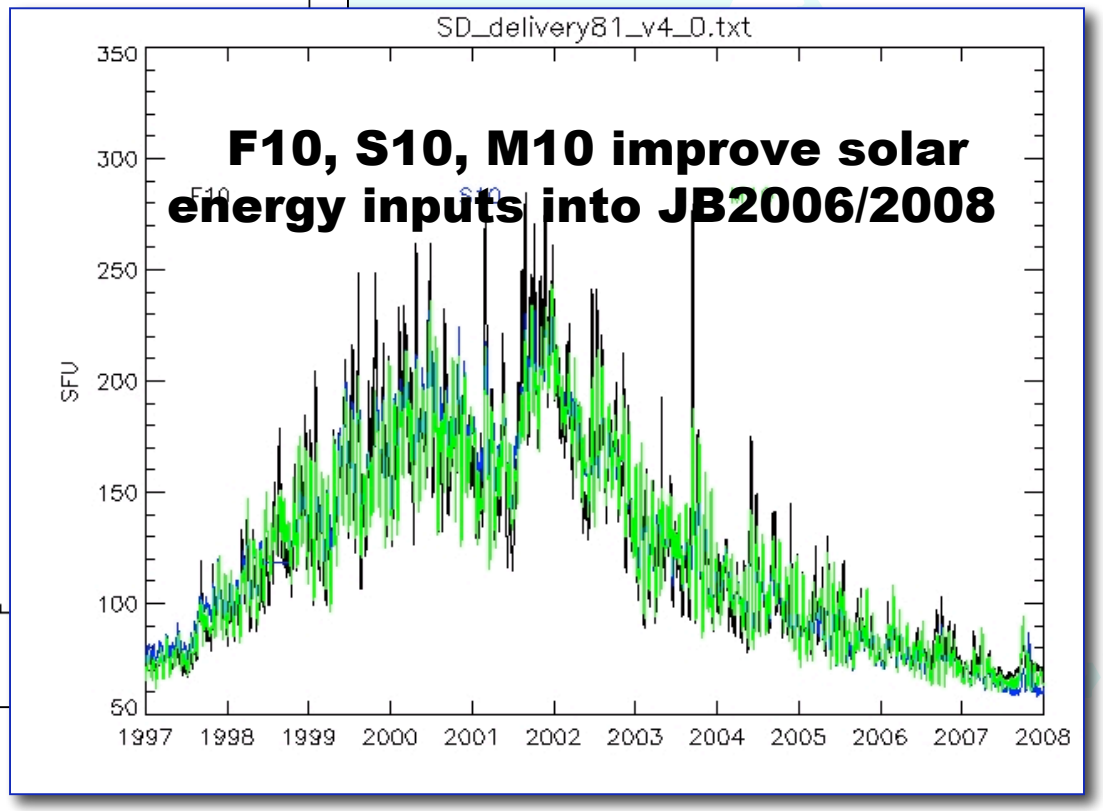
Our applications use real-time solar and geomagnetic data as inputs into space physics models to create historical, current epoch, and forecast solutions.

CAPS web site: http://terra1.spacenvironment.net/~ionops/



Satellite reentry and drag estimation are improved by JB2006/2008





JB2006 web site: http://sol.spacenvironment.net/~jb2006/

JB2006

Jacchia-Bowman Thermospheric Density Model

Space Environment Technologies

Introduction	Publications	Indices	Fortran Source Code	Contacts	Figures	SET SpaceWx.com

Dear Colleague,

Welcome to the JB2006 empirical thermospheric density model website. Please provide your name and email address if you desire to be notified about updates to the JB2006 model.

[click here to register for updates] *

Please note that cookies must be enabled in your Browsers Preferences to register. Your local installation may have firewall implementations that prevent cookies or Java servlet protocols, in which case you should email spacenvironment@spacenvironment.net with "JB2006" in the subject line to receive updates.

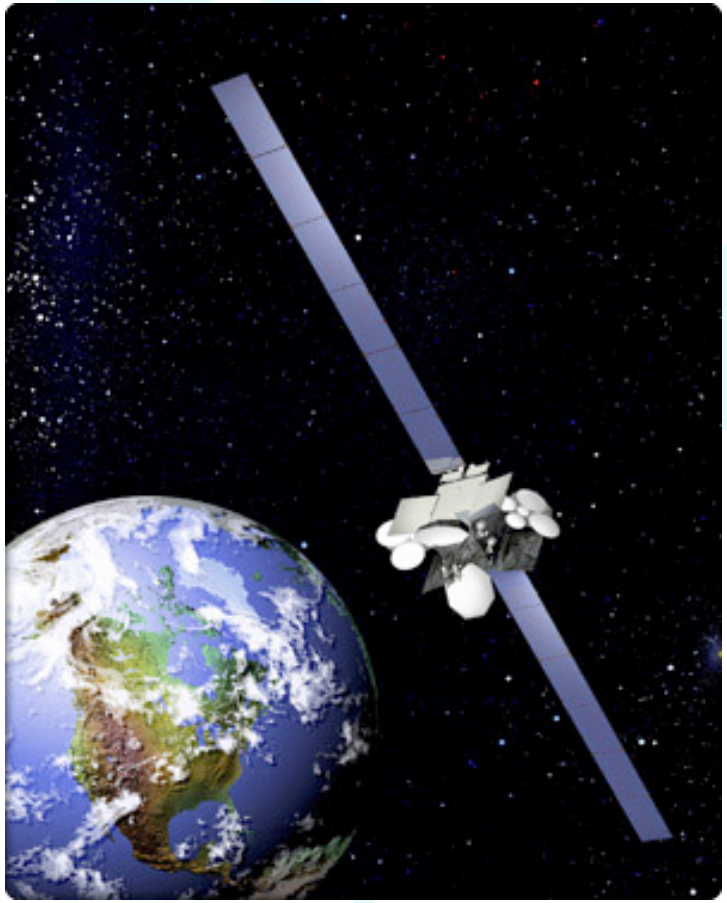
Thank you,

Space Environment Technologies

Last Website Update 28 Dec 07 (indices updated daily)

JB2006 web site: http://sol.spacenvironment.net/~jb2006/

Charging on Anik E-2 in 1998 at GEO caused TV losses



The Hamilton Spectator

Established 1846 • Mon-Fri 47¢ + 3¢ GST

P-ANIK!

High-tech chaos as satellites spin out of control

Plug pulled on phones, TV, radio, papers

OTTAWA — Telesat Canada was facing some tough questions today as it tries to explain how its two main communication satellites tumbled out of control, interrupting TV, radio, newspaper and telephone signals across the country.

After struggling for more than eight hours to bring the wobbly Anik E-1 under control, Telesat technicians thought they had the problem licked late yesterday.

The were only half right.

Shortly after 9 p.m. EST, as Anik E-1 settled back into position, Telesat's primary broadcasting satellite, Anik E-2, also got a bad case of the shakes.

CBC Newsworld and other national specialty cable channels, including MuchMusic, TSN, Vision and the Weather Channel, were knocked off the air. Partial service, with signals carried by fibre-optic cable, was later restored in some major centres, including Toronto.

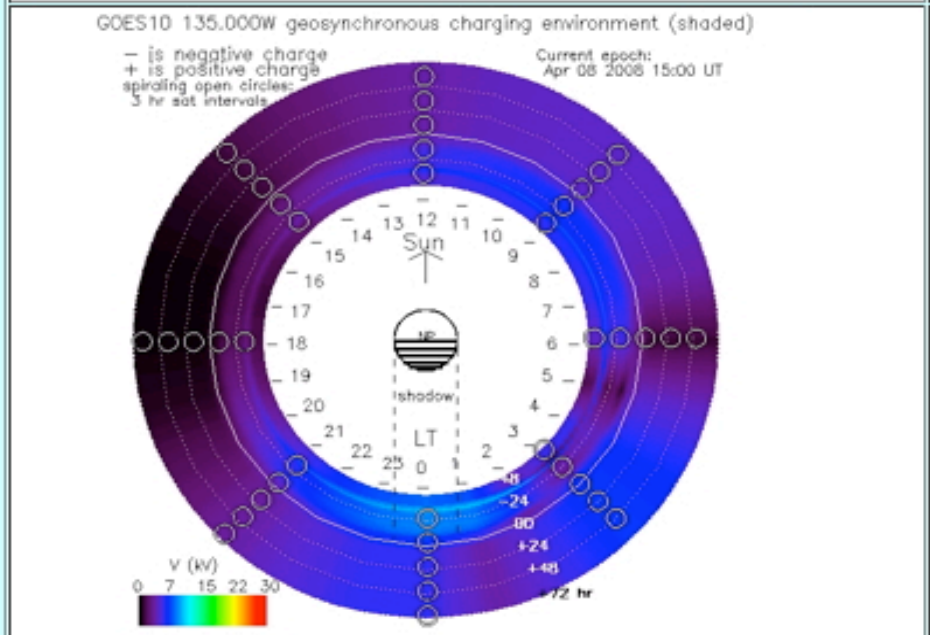
In Hamilton local cable companies and police communications were unaffected. The Mt. Hope weather office had minor disruptions.

"We don't know how it was brought about," said Chris Frank, Telesat's director of public affairs.

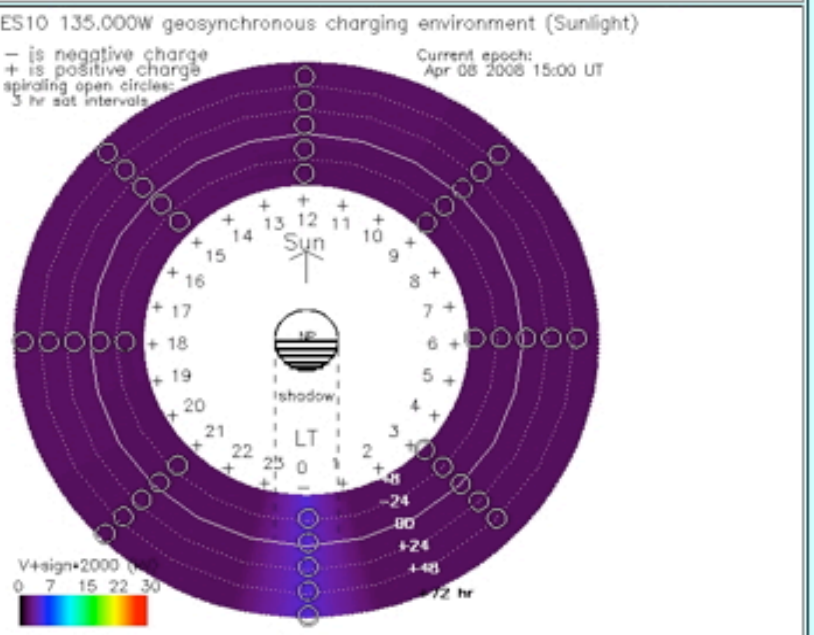
GAPS web site: http://terra1.spacenvironment.net/~gapops/

Geosynchronous Spacecraft Charging, GOES10 135.000W

Geosynchronous charging environment (shaded)



Geosynchronous charging environment (sunlight)



Geosynchronous Charging Conditions

Issue Time	Apr 08 2008 15:00 UT
Storm Alert	G0 Quiet geomagnetic activity at Apr 07 2008 03:00
Charging Alert (shade)	none
Charging Alert (sunlight)	none

GOES10 135.000W

- Geosynchronous Plasma Environment Model (GEOPOT08)
  - Shaded environment on nonlit surfaces of spacecraft
  - Sunlight environment on lit surfaces of spacecraft assuming photoemission on Aluminum

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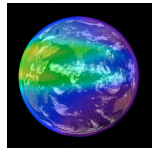
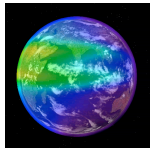


30-day global communications outlook

```
:Title: COMMUNICATION ALERT AND PREDICTION SYSTEM STATUS (COMM OUTLOOK)
:Message ID: CAP2/A0/2454565.25972
:Issue Time: 2008 Apr 08 1825 UTC (2008/099)
#Prepared by Space Environment Technologies Space Weather Division (SET/
SWD)
#Contact spacenvironment@spacenvironment.net
#
COMMUNICATION ALERT: HF/VHF radio blackouts
SOLAR FLARE EFFECTS: none
GEOMAG STORM EFFECTS: none
OUTLOOK: current 01-hr 03-hr 06-hr 12-hr 24-hr 72-hr 07-dy 14-dy 30-dy
-----------------------------------------------------------------------
N POLE      RED   RED   RED   RED   RED   RED   BLU   BLU   BLU   BLU
E ASIA      RED   RED   RED   RED   BLU   RED   BLU   BLU   BLU   BLU
SE ASIA/AU  RED   RED   RED   RED   BLU   BLU   BLU   BLU   BLU   BLU
PACIFIC     RED   RED   RED   BLU   BLU   BLU   BLU   BLU   BLU   BLU
NO AMERICA  RED   RED   RED   RED   BLU   BLU   BLU   BLU   BLU   BLU
SO AMERICA  RED   RED   RED   BLU   RED   BLU   BLU   BLU   BLU   BLU
EUROPE      RED   RED   RED   RED   RED   BLU   BLU   BLU   BLU   BLU
AFRICA      RED   RED   RED   RED   RED   BLU   BLU   BLU   BLU   BLU
W ASIA      RED   RED   RED   RED   RED   BLU   BLU   BLU   BLU   BLU
S POLE      RED   RED   RED   RED   RED   BLU   BLU   BLU   BLU   BLU
```

CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*

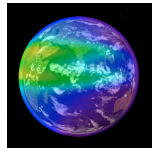


Future systems will use SDO data

Ops problem	Ops system	Solar inputs	Input source data system	Primary data sources	Secondary data sources	Cadence goal	Granularity goal	Latency goal
Comm links	GAIM vX	I(λ,t)	SETOPS S2K SETOPS S2K SETOPS SFLR SETOPS IDAR	Penticton NOAA SBUV GOES XRS SOHO EIT	TIMED SEE SORCE SOL **SDO EVE** **SDO AIA**	4 min	1 min	2 min
LEO sat reentry	JB2008	F10 S10 M10 Y10	SETOPS APEX SETOPS IDAR SETOPS SETOPS SETOPS	Penticton SOHO SEM SOHO EIT NOAA SBUV GOES XRS NOAA SBUV	TIMED SEE **SDO EVE** **SDO AIA** **SDO AIA** **SDO EVE** GOES EUV	1 hour	1 hour	1 hour
LEO sat collision	JB2008	F10 S10 M10 Y10	SETOPS APEX SETOPS IDAR SETOPS SETOPS SETOPS	Penticton SOHO SEM SOHO EIT NOAA SBUV GOES XRS NOAA SBUV	TIMED SEE **SDO EVE** **SDO AIA** **SDO AIA** **SDO EVE** GOES EUV	1 hour	1 hour	1 hour
GEO sat charging	GEOPOT vX	S10	APEX SETOPS IDAR	SOHO SEM SOHO EIT	GOES EUV **SDO AIA** **SDO EVE**	4 min	1 min	2 min

CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*

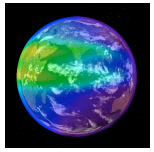


Ground/Aviation & space weather

Challenges	Solutions	Unmet needs
degraded geolocation & navigation	identify and reduce TEC uncertainty	1-6 hour forecasts of evolving flare and geomagnetic conditions
Communication outages Satcom outages Radar outages	identify f_o for each geographic region Identify scintillation Identify scintillation	1-12 hour forecasts of evolving flares, magnetic field, charged particles, and electric fields
radiation effects on aircrew	specify dose rates as function of time and location	1-6 hour forecasts of evolving solar energetic particle events

CAPS web site: http://terra1.spacenvironment.net/~ionops/

CAPS - *Communication Alert and Prediction System*



Spaceflight and space weather

Challenges	Solutions	Unmet needs
satellite surface/internal charging	identify charging conditions	1-3 hour forecasts of substorm 1-50 keV electron densities
precision satellite orbit determination, constellation station-keeping, debris avoidance, reentry timing	identify 3D densities	1-7 day forecasts of evolving solar flux and geomagnetic conditions
radiation effects on materials	specify dose rates as function of time and location	1-6 hour forecasts of evolving solar energetic particle events
precision geolocation and navigation	identify and reduce TEC uncertainty	1-6 hour forecasts of evolving flare and geomagnetic conditions

CAPS web site: http://terra1.spacenvironment.net/~ionops/