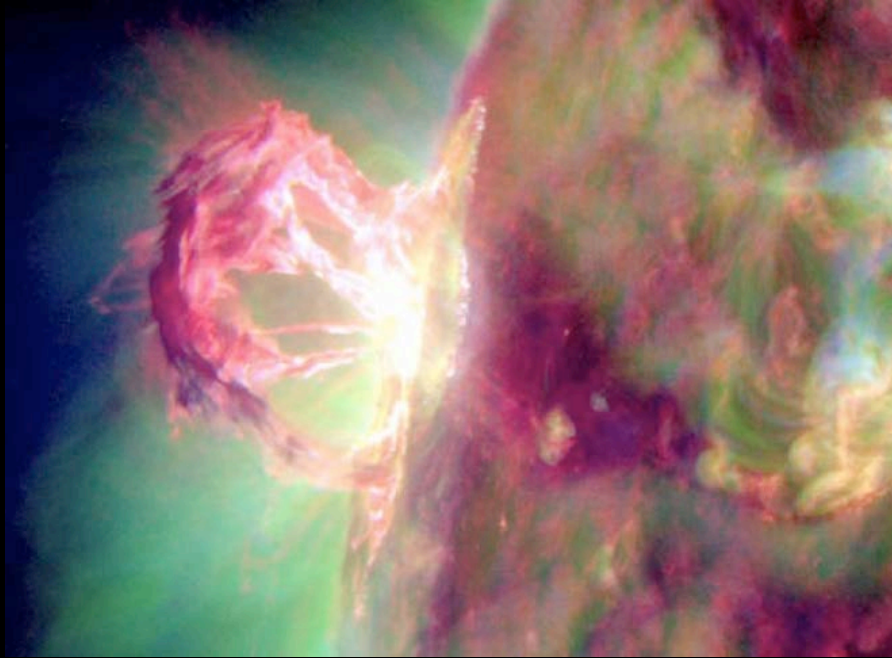


Space Weather and Aviation



NASA SDO



S. Solomon

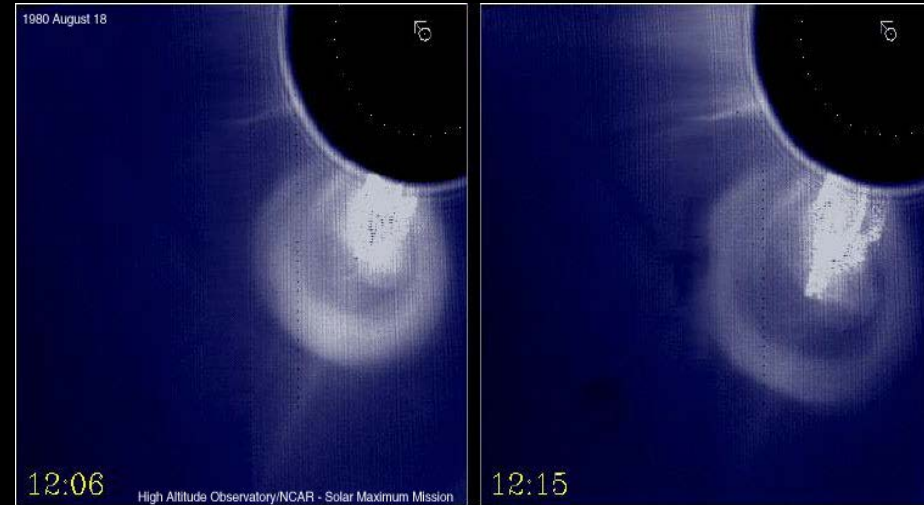
M. Wiltberger
NCAR/HAO

Outline

- Space Weather Background
 - Overview of Sun-Earth System
 - Storms, substorms, and other phenomena
- Aviation Connections
 - GPS System Issues
 - Polar Operations
 - Radiation Issues

Space Weather

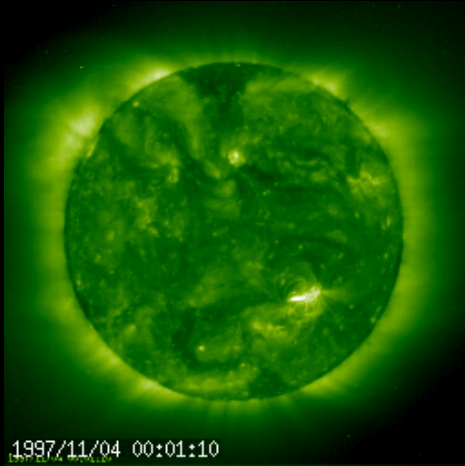
- Space weather describes events in space that effect the Earth and our technology
- Severe solar eruptions can cause disturbances which dramatically effect both the ionosphere and magnetosphere



- Coronal mass ejections send upwards of a billion tons of hot ionized gas propagating towards Earth arriving in 2-4 days
- The magnetosphere is formed by interaction between the Earth's magnetic field and the super sonic solar wind

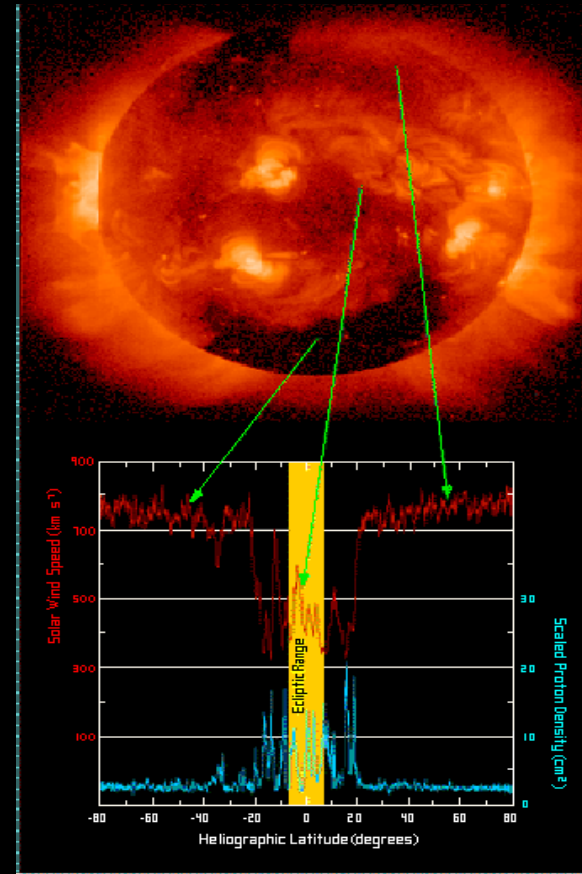


Solar Origins



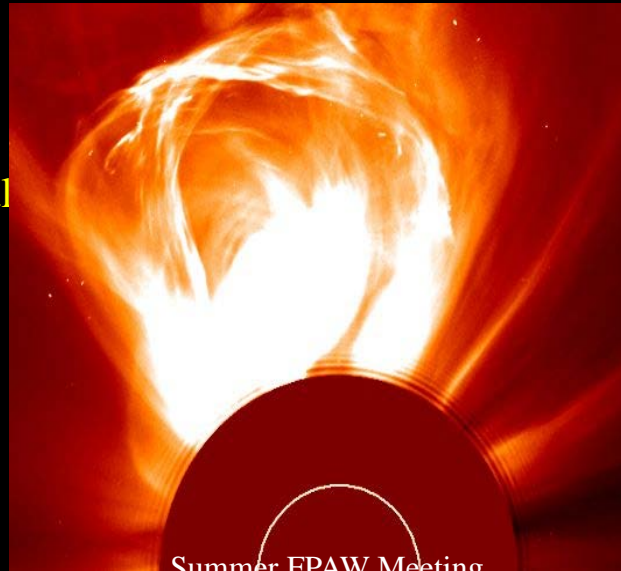
Solar Flares - abrupt release of energy

- localized solar region
- mainly radiation (UV, X-rays, γ -rays)
- occur near complex sunspot configurations



Coronal Mass Ejections (CMEs)

- Releases of massive amounts of solar material
- Usually with higher speeds and greater magnetic fields than surrounding solar wind
- Usually cause shocks in solar wind



Summer FPAW Meeting

Solar Wind

- Steady ionized gas outflow with average velocity 400 km/s
- Magnetic field direction variable
- Exact properties depend upon solar origins

Earth's Magnetosphere

The magnetosphere is region near the Earth where it's magnetic field forms a protective bubble which impedes the transfer of energy and momentum from the solar wind plasma

A variety of different phenomenon

Substorms

impulsive energy release over hours

Storms

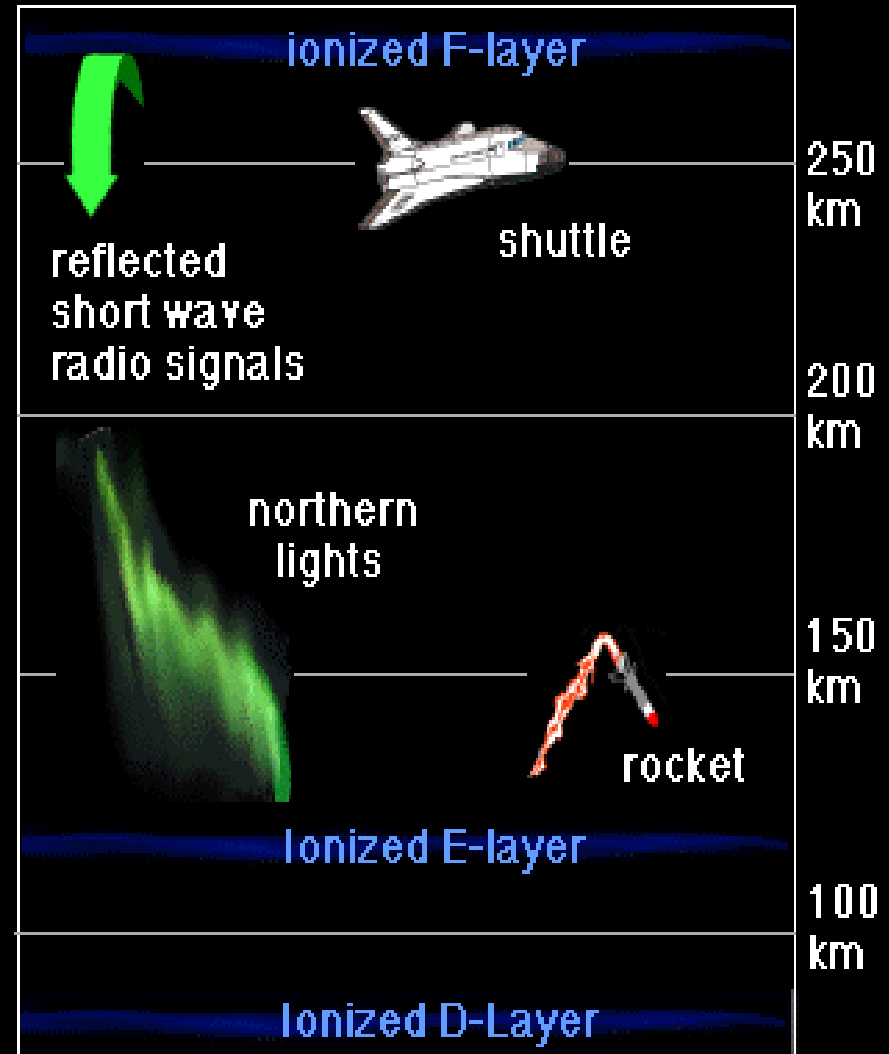
globally enhanced activity over days

Radiation belts

trapped particles which are omnipresent

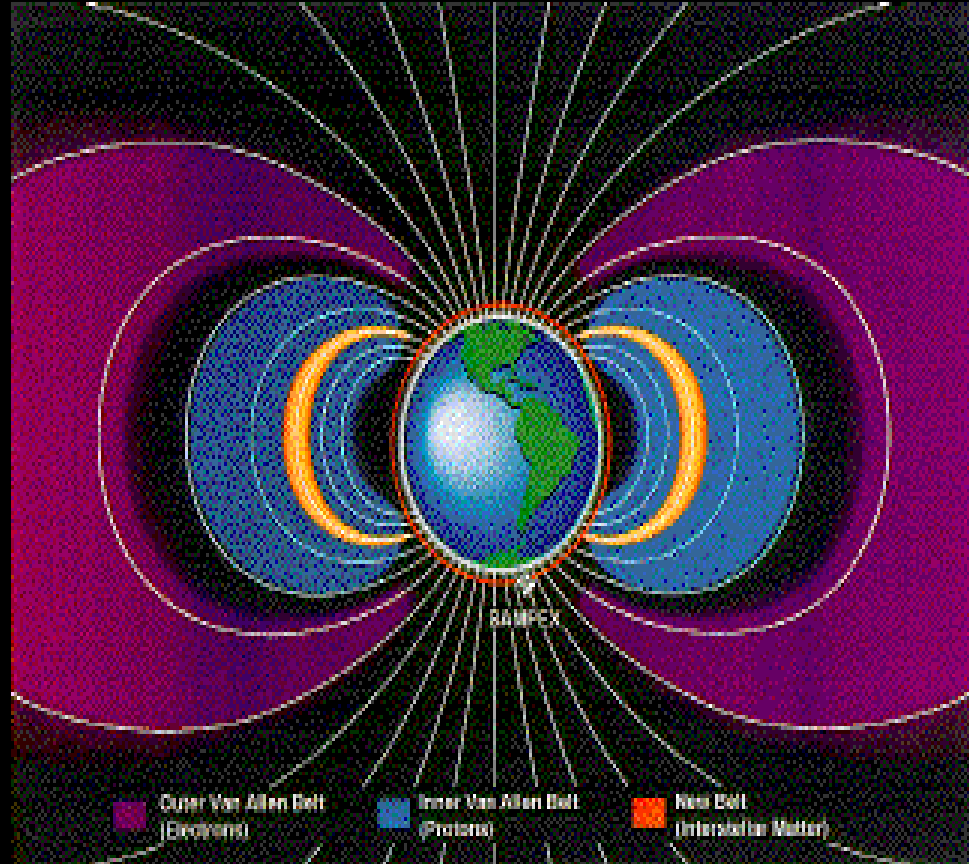
The Earth's Ionosphere

- Upper layer of the atmosphere that is partially ionized by solar x-rays and UV radiation
- Only 0.1% of the atmosphere is contained here, but it's extremely important
- D & E reflect AM radio, but TV is too short so it requires satellites
- Current systems from the magnetosphere close here
- Aurora caused by trapped electrons which are accelerated into the ionosphere during magnetospheric activity



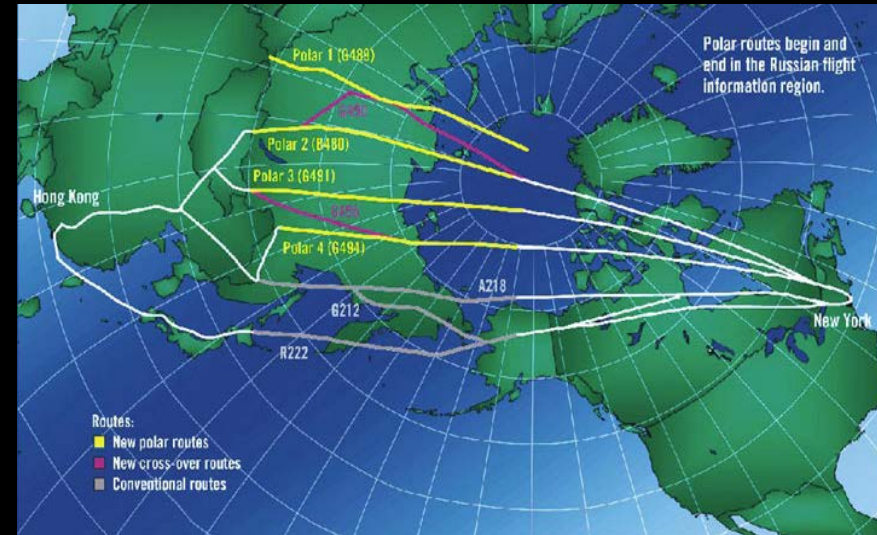
Radiation Belts

- Omnipresent energetic electrons and protons trapped in the Earth's magnetic field
- First discovered in 1959 by the Explorer 1 satellite, called the Van Allen Belts, consisting of an inner zone of protons and electrons and a more variable outer zone of electrons
- This static view has recently been modified based upon measurements beginning at the last maximum in solar sunspot activity

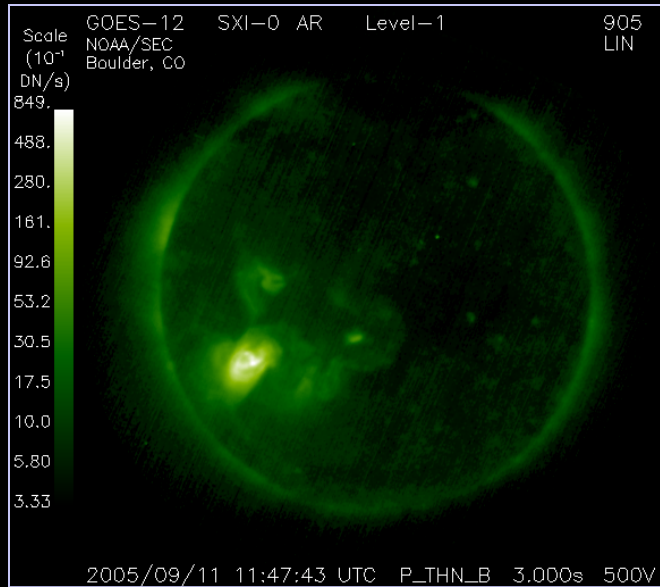


Aviation and SpWx

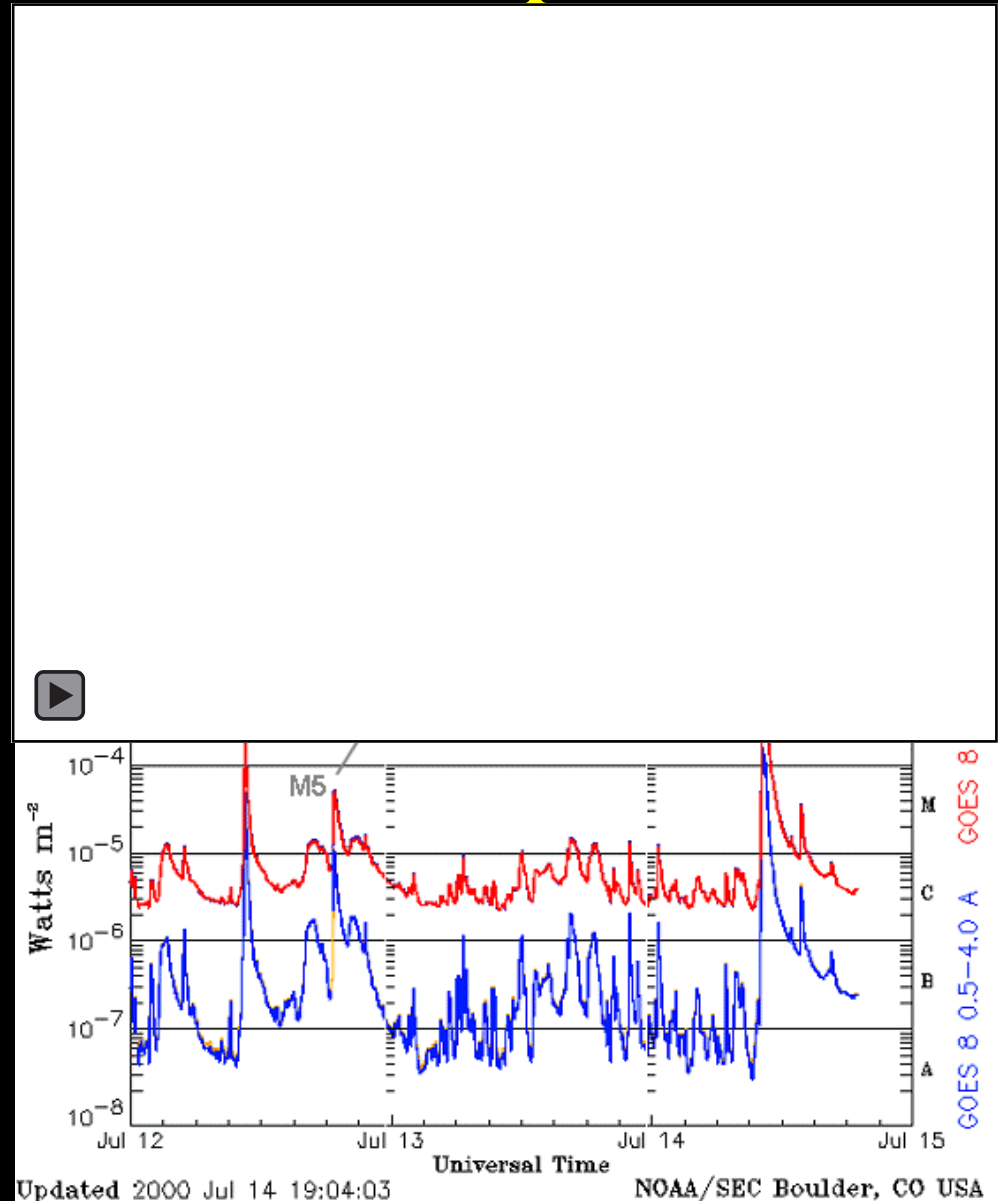
- Impacts & Risks of SpWx
 - Loss of HF communications
 - GPS errors
 - Effects of radiation on humans and avionics



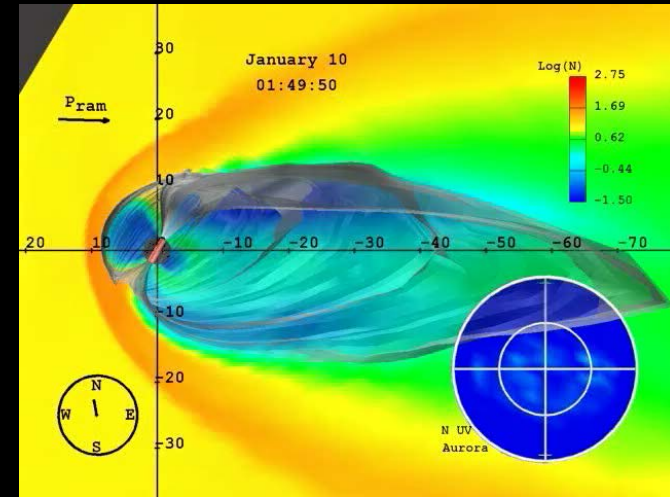
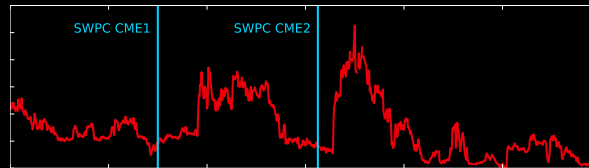
HF Communication Impacts



- Arrival: 8 minutes, photons
- Duration: Minutes to 3 hours
- Daylight-side impacts
- Probabilistic 1, 2, 3-day forecasts only
 - No existing capability to do physics based forecasts



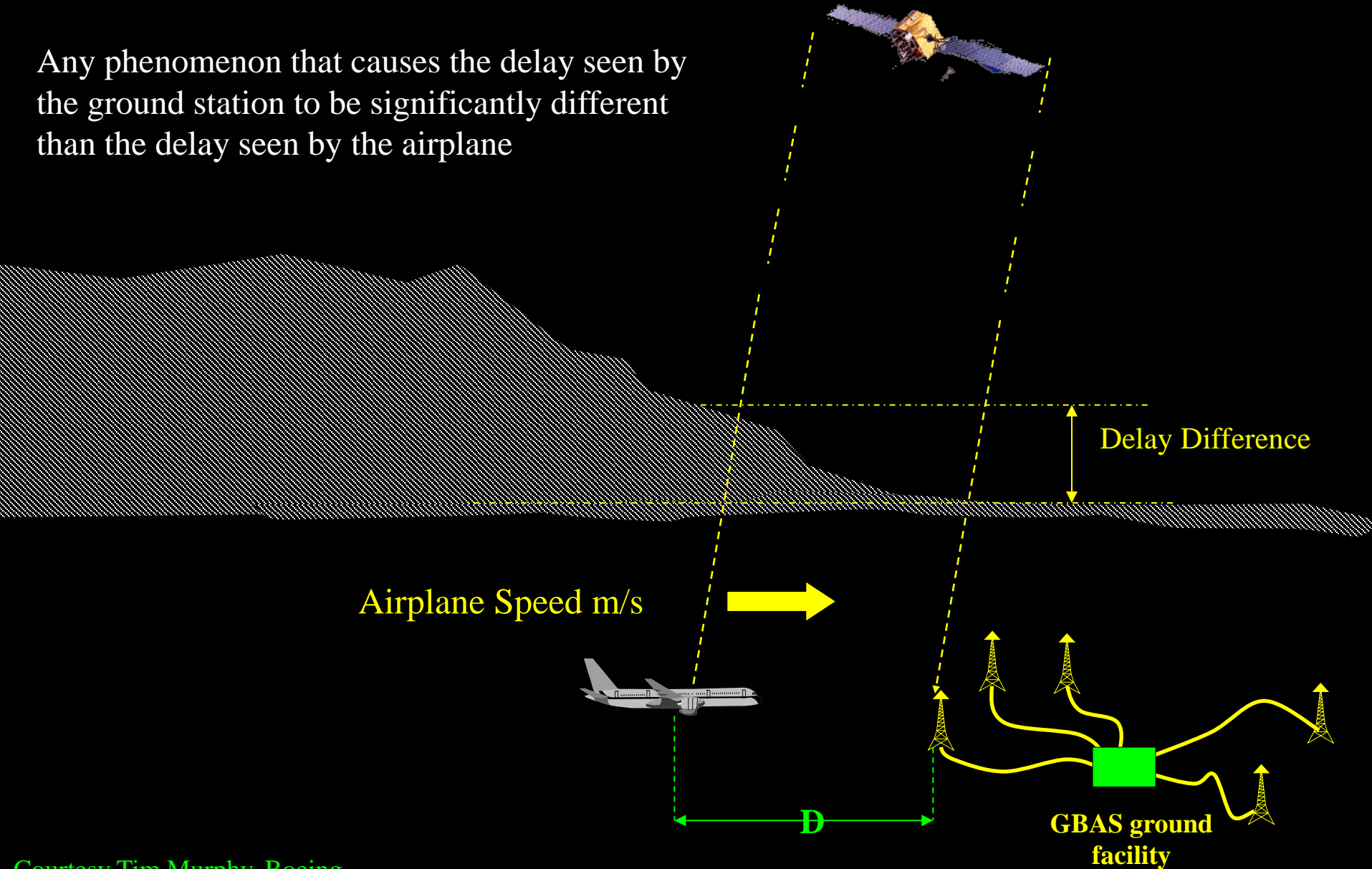
Geomagnetic Storms



- Arrival: 18-96 hours after CME
- Duration: Several hours to days
- Impacts: Ionosphere TEC enhancements, geomagnetic induced currents, aurora
- CME arrival time forecast 1-2 based upon modeling
- IMF direction remains unknown until measured by upstream monitor – 15-45 minute warning

Ionospheric Impacts on GPS

Any phenomenon that causes the delay seen by the ground station to be significantly different than the delay seen by the airplane



WAAS VPL Service Availability

October 30, 2003

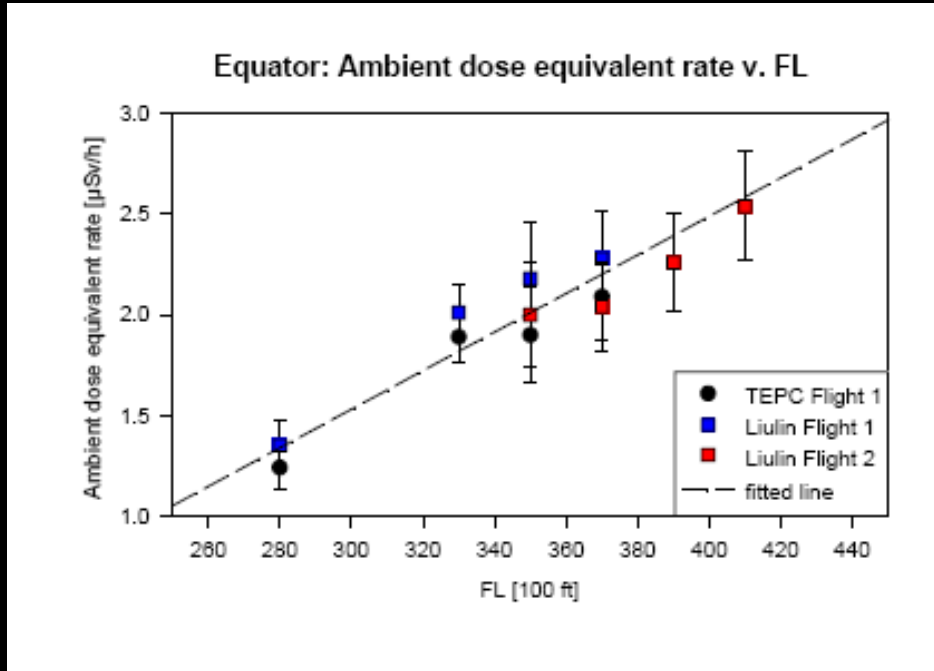


← Vertical
Navigation
Capability



(Animation Courtesy of FAA NSTB)

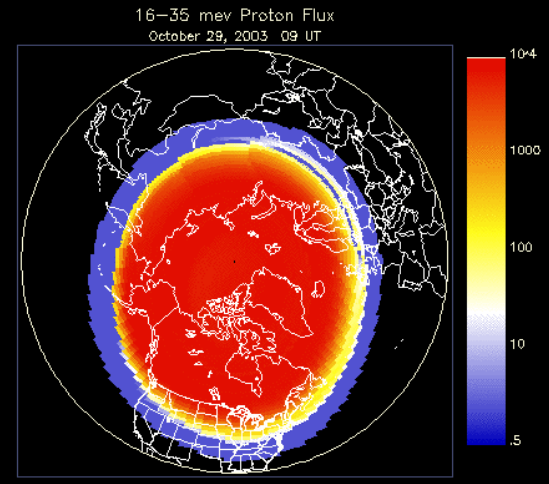
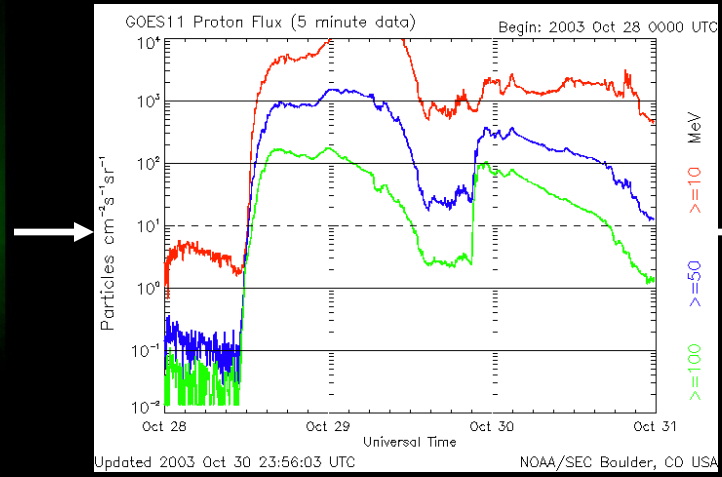
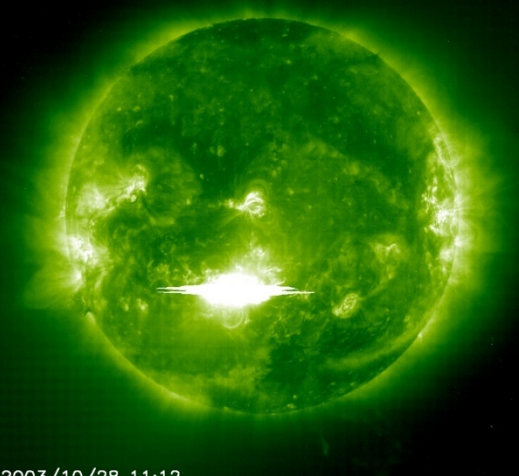
Dose Rates at Aviation Altitudes



- **FL 280: 1.3 $\mu\text{Sv/h}$**
- **FL 350: 2.0 $\mu\text{Sv/h}$**
- **FL 410: 2.6 $\mu\text{Sv/h}$**
- Rule of thumb: altitude \uparrow 1000 ft.
 \Rightarrow ambient dose equivalent rate
 \uparrow 0.1 $\mu\text{Sv/h}$

- German Aerospace center in cooperation with Luftsana and LTU Airlines studied exposure rates during flights from German to Africa during geomagnetically quiet conditions
- Even if someone spent the whole year at FL350 in the equatorial region their radiation exposure would not exceed the internationally accepted annual dose limit (17.5 mSv < 20 mSv).

Solar Energetic Particles

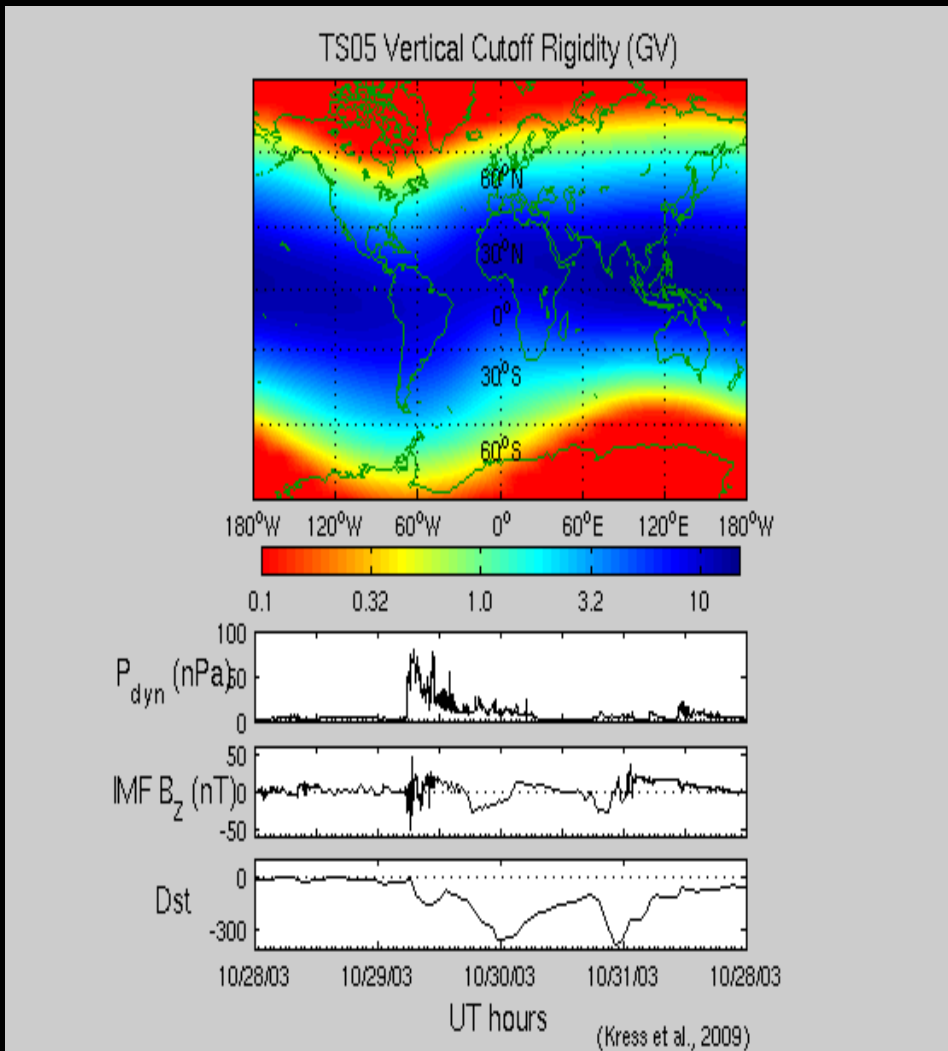


2003/10/28 11:12

- Arrival: 10's of minutes to days
- Duration: hours to days
- Short term forecasting capabilities
- Access is impacted by current geomagnetic activity



Geomagnetic Shielding



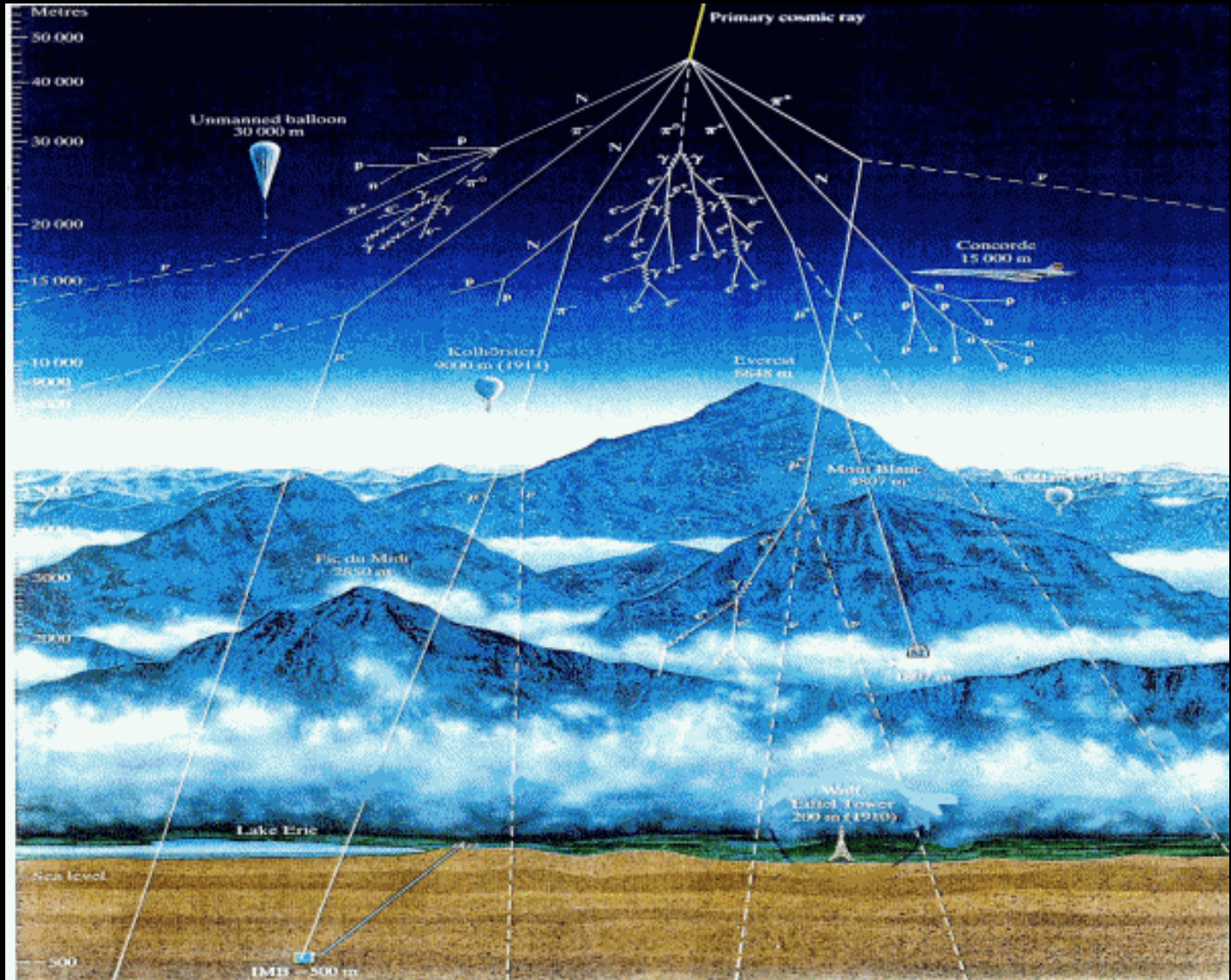
- Severe geomagnetic storms suppresses geomagnetic shielding allowing SEPs access mid- latitudes.
 - Due primarily to a build up of the ring current
 - Shock arrival can also be significant
- Particles with rigidities below the a cutoff value cannot access that point in space
 - We compute these using the TS05 storm magnetic field model and a particle tracing codes
 - During the Halloween storms we find 1 and 0.5 GV suppression during main phase and shock arrival

Conclusions

- Space Weather is a manageable risk in aviation operations
 - High altitude and high latitude operations increase this risk
 - Radiation is only a part of this risk
- Information is available from a variety of official and unofficial sources on the internet
- Feel free to contact me directly
wiltbemj@ucar.edu

Backups

Cosmic Ray Interactions



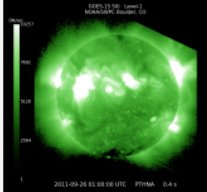
Space Weather Prediction Center

NOAA / Space Weather Prediction Center

Space Weather Now

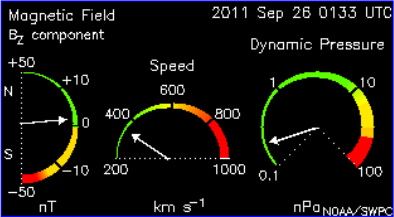
2011 Sep 26 01:36 UTC (Sep 25 19:36 MDT)

Latest GOES Solar X-ray Image



Alerts / Bulletins
 Latest Alert: Sep 25 1700 UTC ALERT: Type IV Radio Emission
 Last Advisory Bulletin: None in last 7 days.

ACE Real-Time Solar Wind Pages



Average over last 15 minutes
 10 frames/sec

Space Weather User Groups

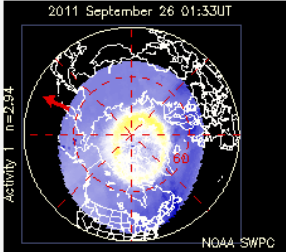
- [Navigation](#)
- [Radio](#)
- [Electric Power](#)
- [Satellite Operators](#)
- [Aurora](#)
- [News Media](#)

NOAA Scales Activity

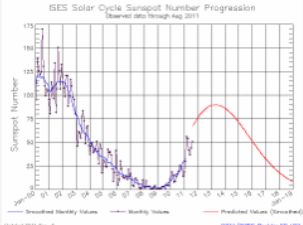
Range 1 (minor) to 5 (extreme)

NOAA Scale	Past 24 hrs	Current
Geomagnetic Storms	none	none
Solar Radiation Storms	S1	S1
Radio Blackouts	R2	none

Auroral Map



Solar Cycle Progression

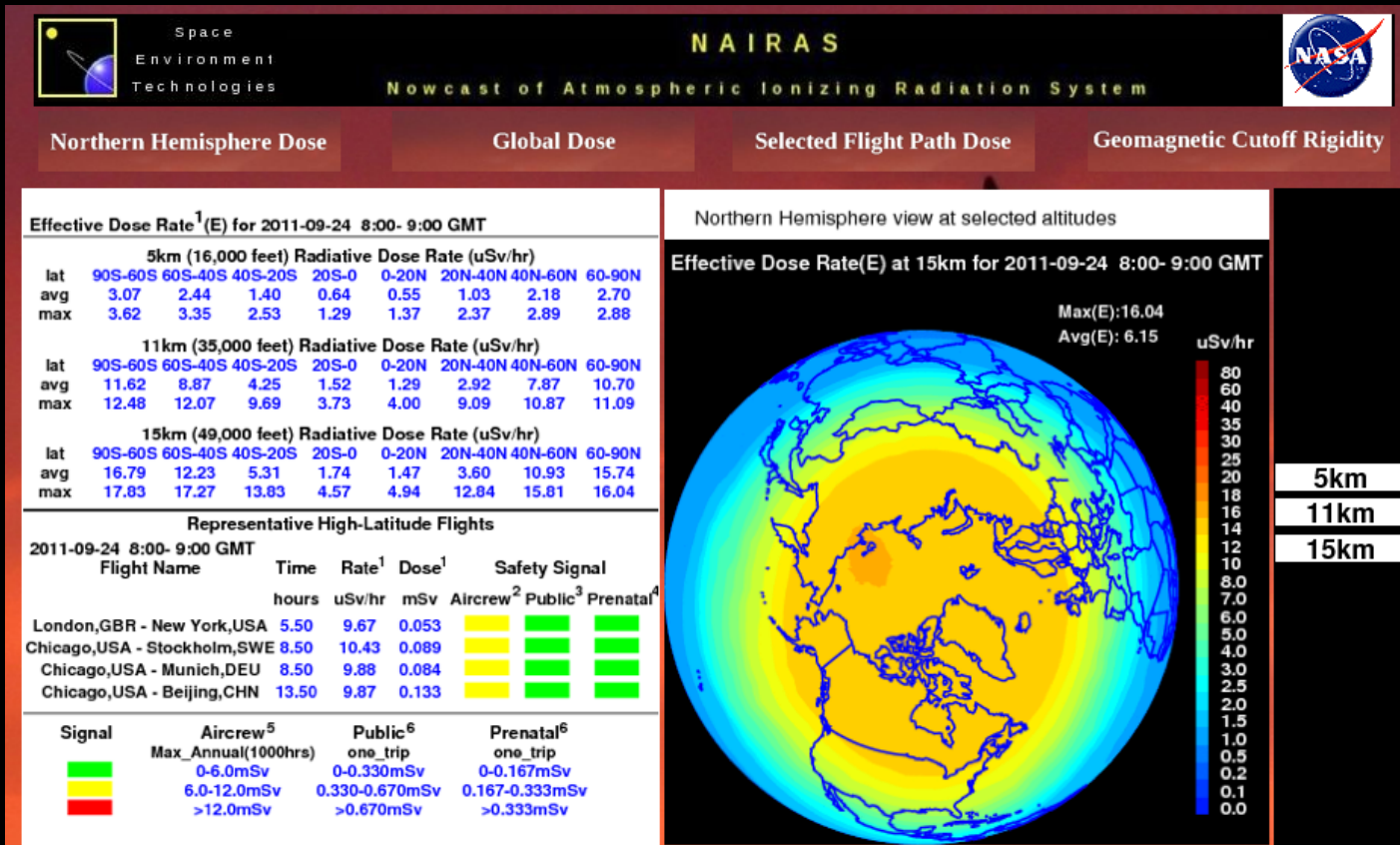


Related pages

- [Today's Space Weather](#)
- [SW for Aviation Service Providers](#)

- <http://www.swpc.noaa.gov/SWN/>

NARIAS Website



- http://terra2.spacenvironment.net/~raps_ops/current_files/index.html

SpaceWeather.com

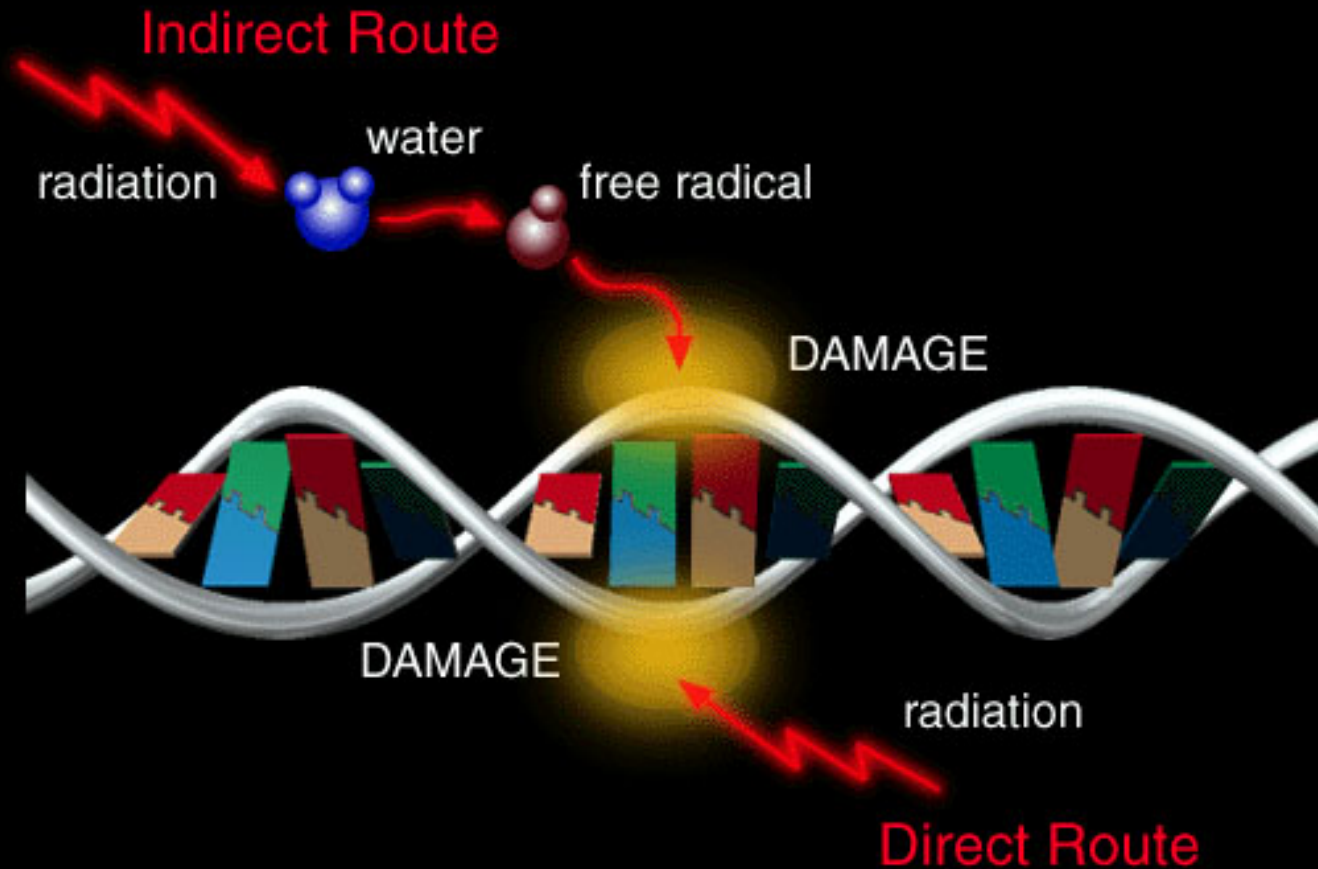
The screenshot shows the SpaceWeather.com website. At the top left is the logo featuring an astronaut with an umbrella and the text "spaceweather.com News and information about the Sun-Earth environment". To the right is a "Subscribe to Spaceweath" button. Below the header is a red navigation bar with links: "AURORA ALERTS", "SUBMIT YOUR PHOTOS!", "3D SUN", "CONTACT US", "SUBSCRIBE", and "FLYBYS".

The main content area is divided into two columns. The left column is titled "Current Conditions" and includes sections for "Solar wind" (speed: 336.0 km/sec, density: 0.9 protons/cm³), "X-ray Solar Flares" (6-hr max: C8 2219 UT Sep25, 24-hr: M7 0450 UT Sep25), and "Daily Sun: 25 Sep 11". Below this is a circular image of the sun with sunspots labeled 1302, 1301, 1295, and 1303. A caption below the image states: "Sunspot 1302 poses a continued threat for X-class solar flares. Credit: SDO/HMI".

The right column is titled "What's up in space" and includes a date "Monday, Sep. 26, 2011". It features a sub-section "Are we alone? Your iPhone has the answer. Download the all-new Drake Equation app to calculate the population of the Milky Way." with a small image of a galaxy. Below this is a "GEOMAGNETIC STORM WARNING" section, followed by a "STRONG SOLAR ACTIVITY" section, and a paragraph about Marko Posavec photographing sunspot 1302. At the bottom of the right column is a large image of the sun's surface.

- <http://spaceweather.com/>

Ways to damage DNA



Radiation Exposure Quantities Overview

- **Unit of absorbed dose from particle R (D_R):**

- **Unit: 1 Gray == 1 J/kg**

- **Equivalent Dose in Tissue (H_T):**

- **Unit: Sievert = Gray x w_R**

- **w_R : radiation weighting factor**

$$H_T = \sum_R w_R \cdot D_R$$

- **Effective Dose (E):**

- **Unit: Sievert: Sievert X w_T**

- **w_T : tissue weighting factor**

$$E = \sum_T w_T \cdot H_T$$

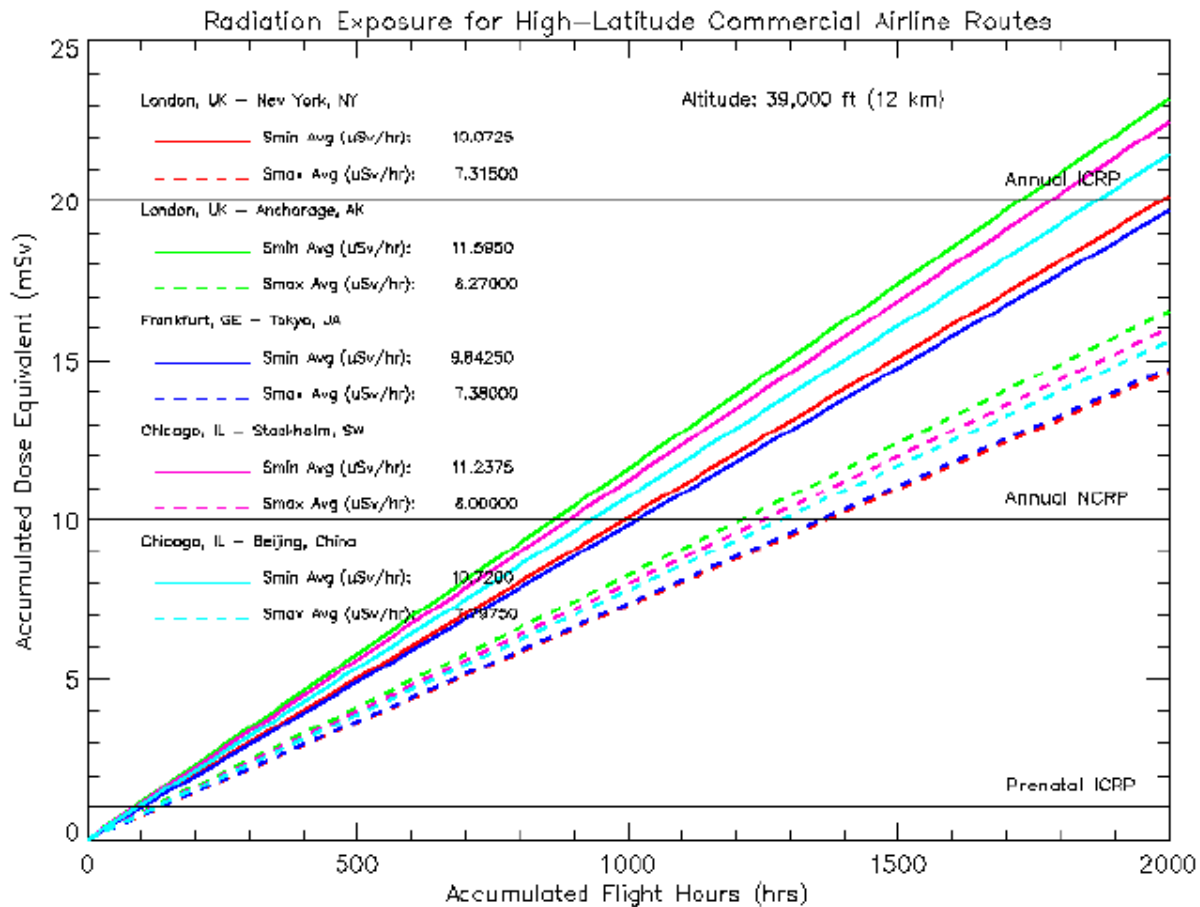
- **ICRP estimate:**

- **1 in 20,000 risk of fatal cancer per 1mSv dose (lifetime)**

Radiation Exposure of Aircrews

- ICRP recommendations for aircrews of jet aircraft
 - 5-year mean effective dose of 20 mSv per year, with no more than 50 mSv in a single year
 - After pregnancy reported: equivalent dose to conceptus should not exceed 1 mSv
- Additional FAA recommendations
 - ICRP limits apply to jet and non-jet aircraft
 - Pregnancy: equivalent dose to conceptus should not exceed 0.5 mSv in any month

GCR Exposure



ACREM Measurements during GLE60 on 15. April 2001 10 h 25 min

