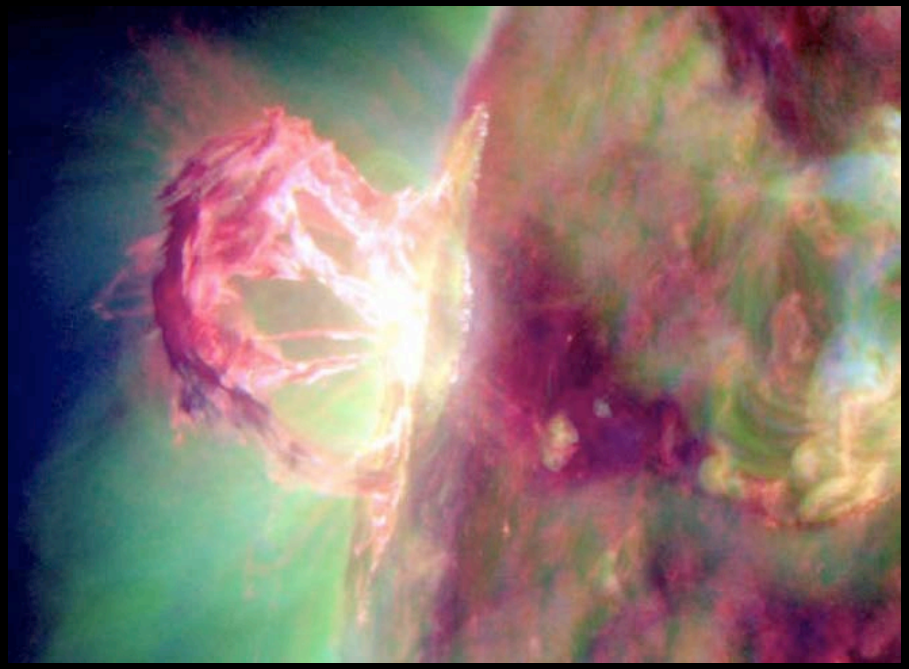
Space Weather and Aviation



NASA SDO

S. Solomon

M. Wiltberger

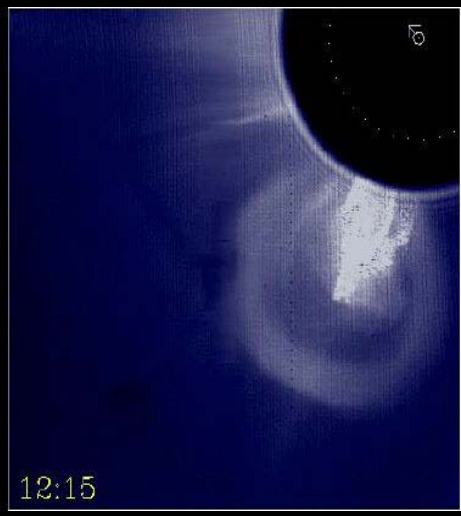
NCAR/HAO

Outline

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

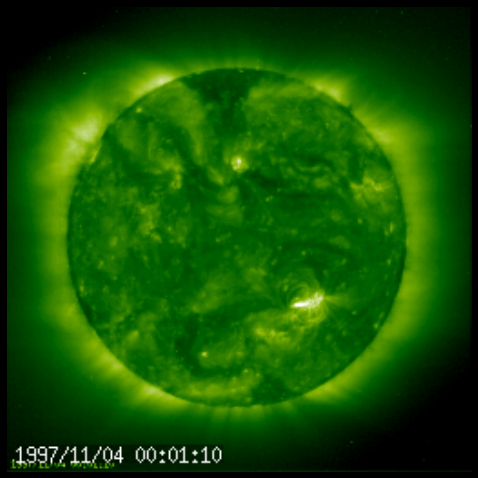
Space Weather

- 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



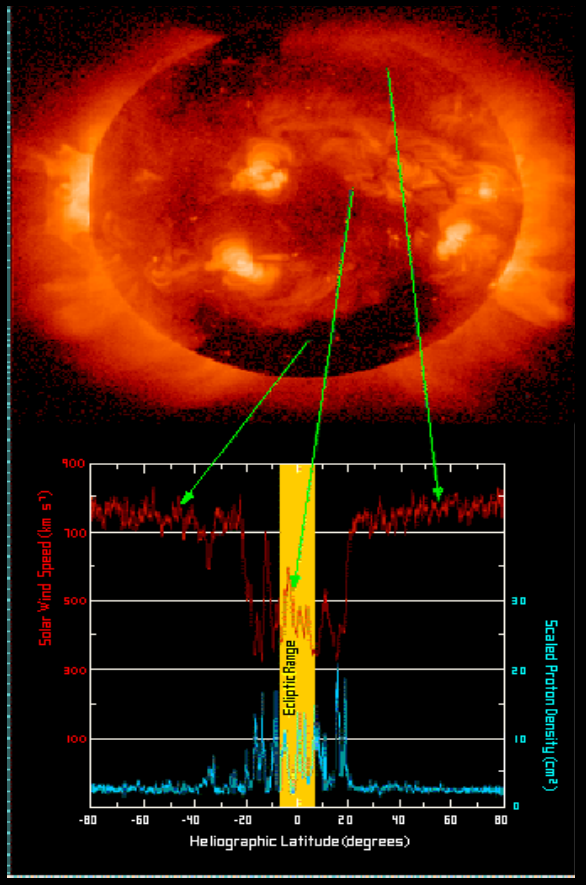
- Coronal mass ejections send upwards of a billion tons of hot ionized gas propagating towards Earth arriving in 2-4 days
- The magnetosphere is formed by interaction between the Earth's magnetic field and the super sonic solar wind

Solar Origins



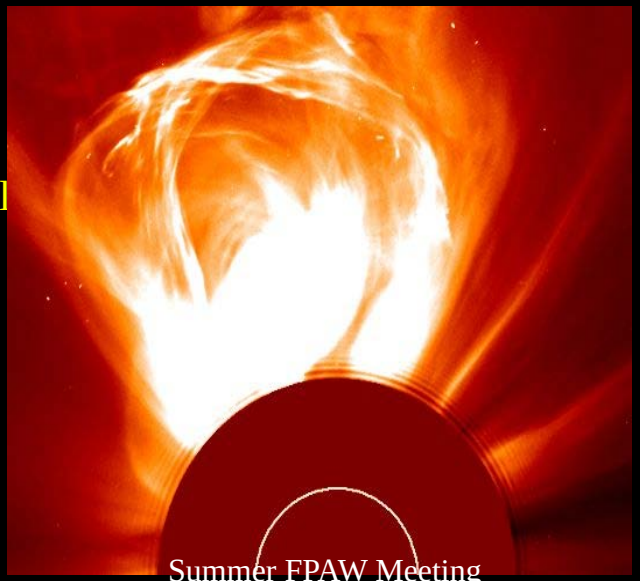
Solar Flares - abrupt release of energy

- 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



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

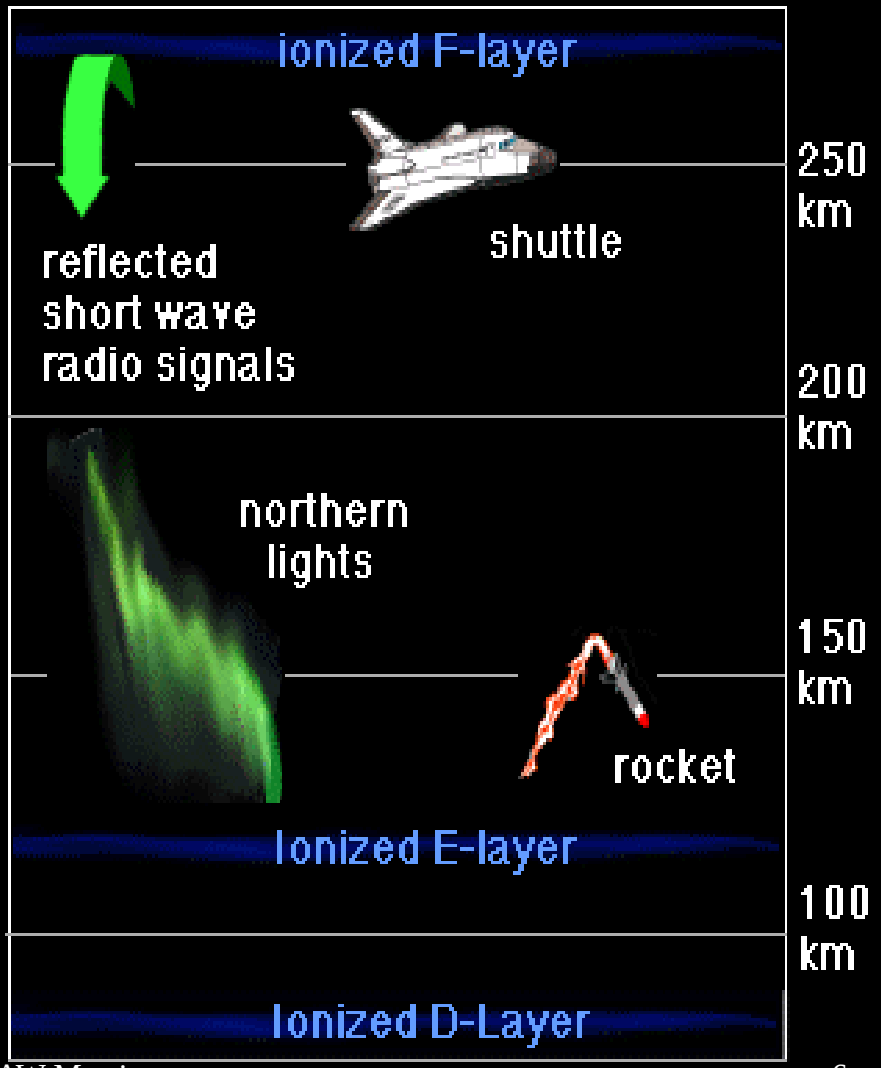
The magnetosphere is region near the Earth where it's magnetic field forms a protective bubble which impedes the transfer of energy and momentum from the solar wind plasma

A variety of different phenomenon

- Substorms
  - impulsive energy release over hours
- Storms
  - globally enhanced activity over days
- Radiation belts
  - trapped particles which are omnipresent

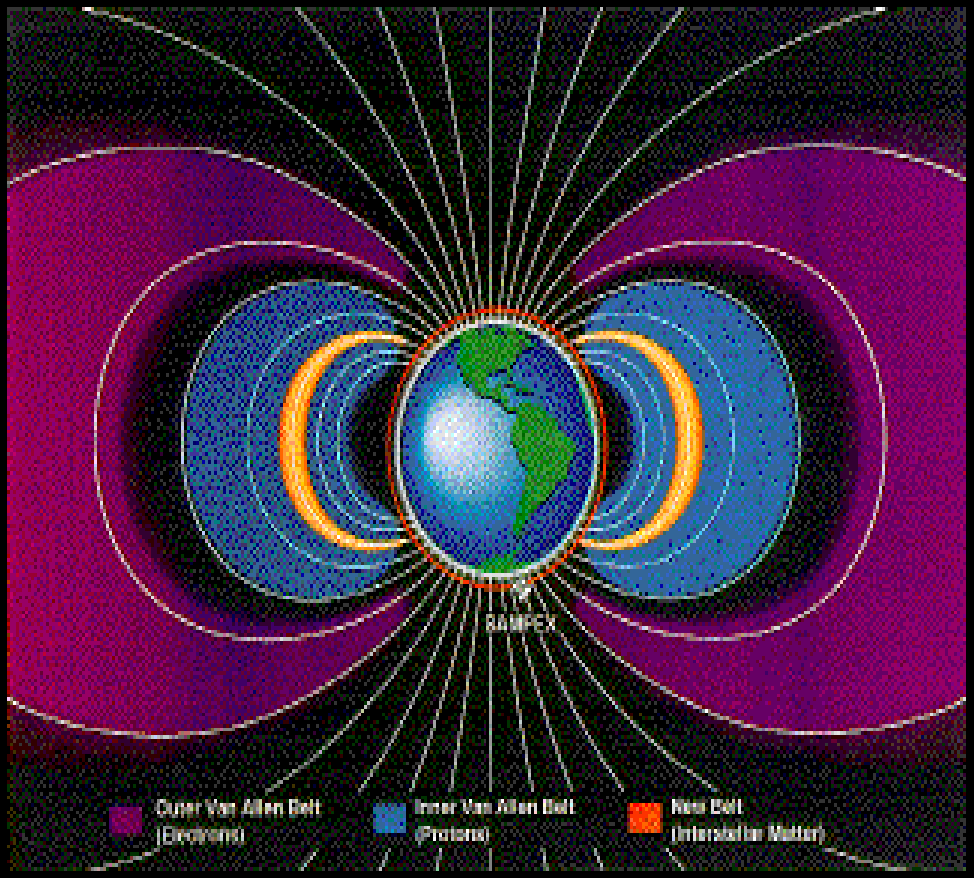
The Earth's Ionosphere

- Upper layer of the atmosphere that is partially ionized by solar x-rays and UV radiation
- Only 0.1% of the atmosphere is contain here, but its 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 ionosphere during magnetospheric activity



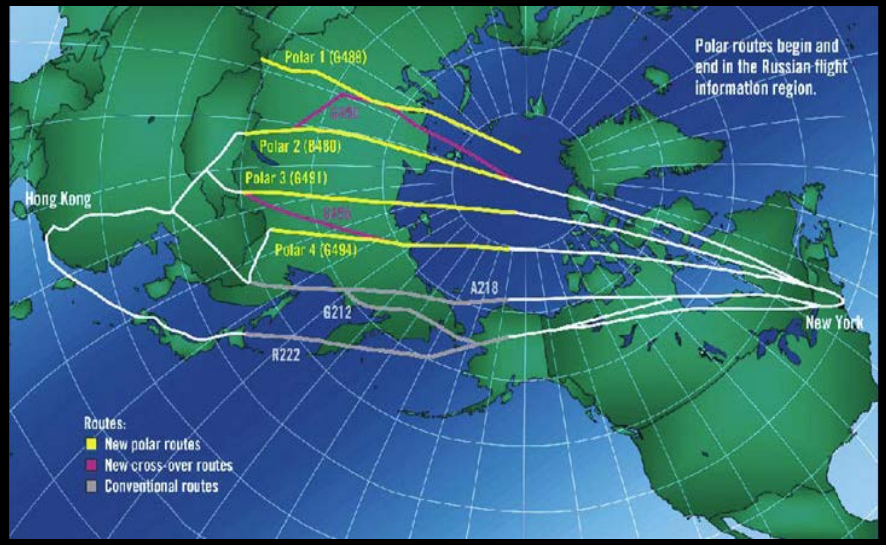
Radiation Belts

- 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

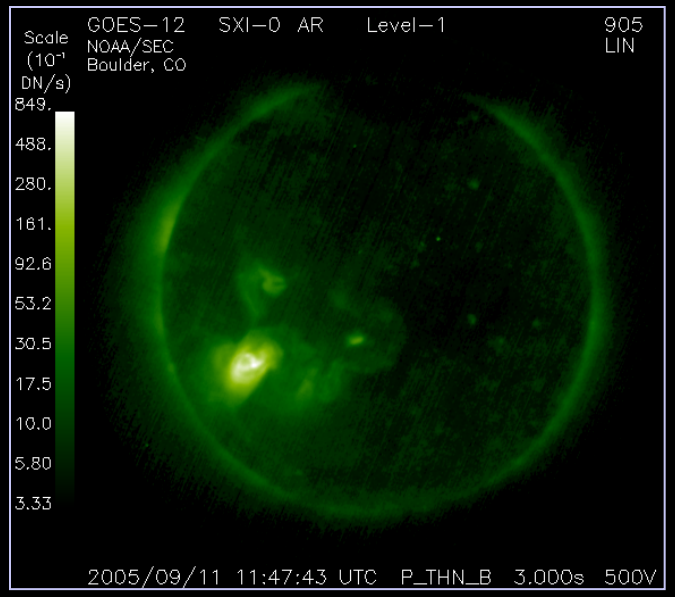


Aviation and SpWx

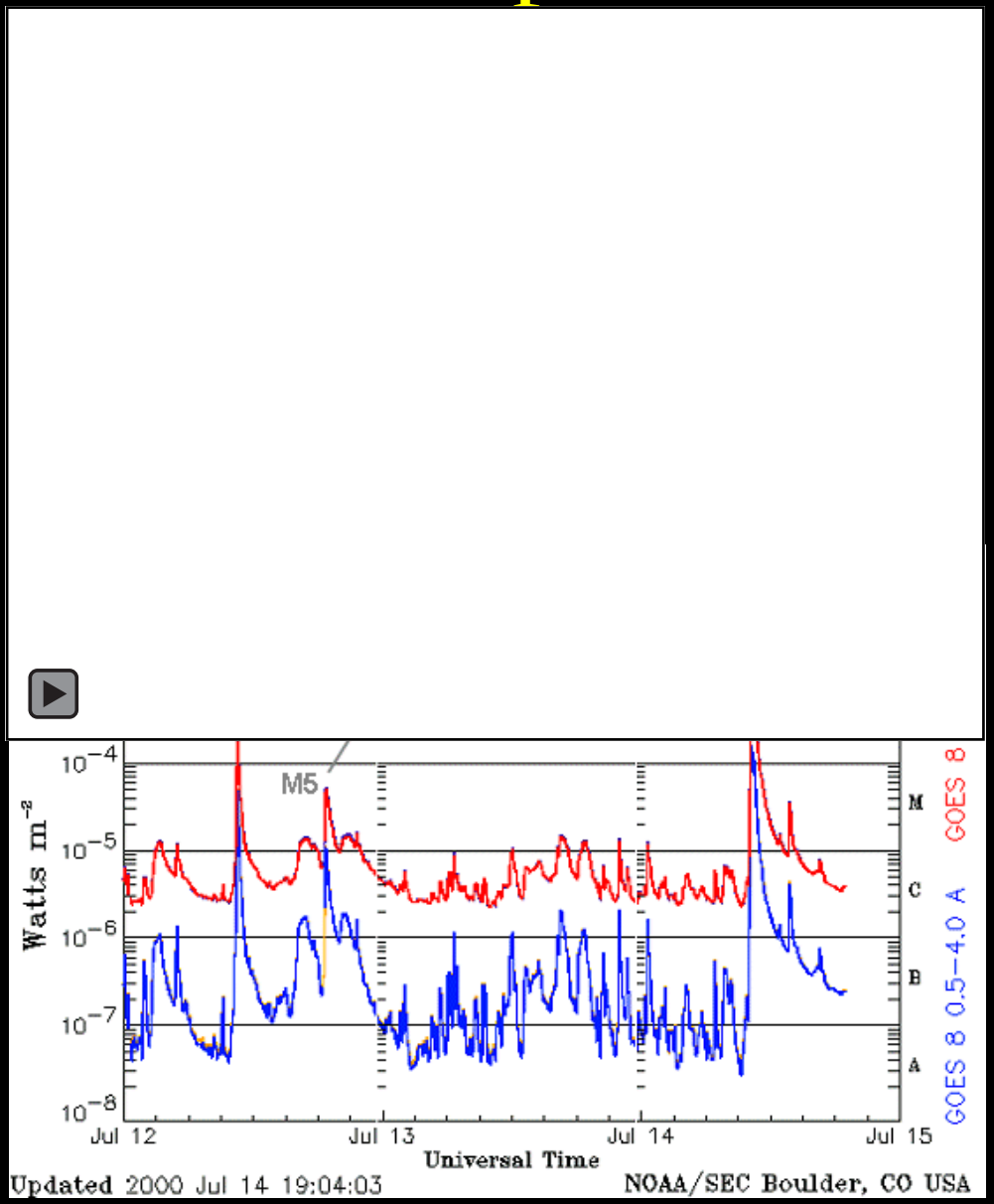
- Impacts & Risks of SpWx
  - Loss of HF communications
  - GPS errors
  - Effects of radiation on humans and avonics



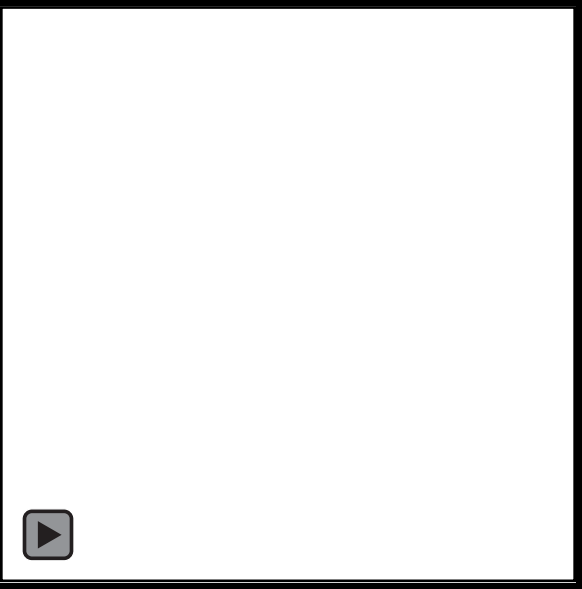
HF Communication Impacts

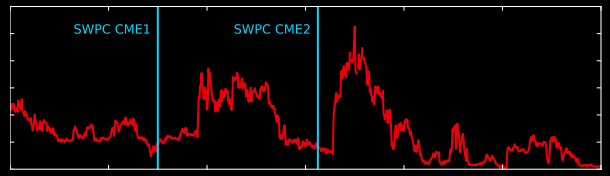


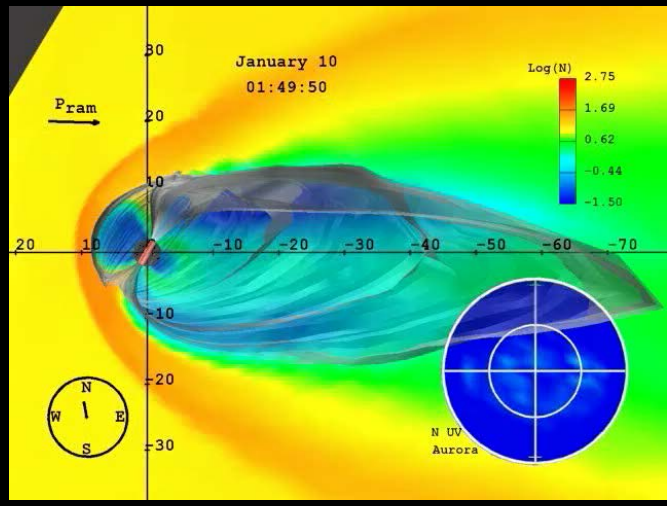
- Arrival: 8 minutes, photons
- Duration: Minutes to 3 hours
- Daylight-side impacts
- Probabilistic 1, 2, 3-day forecasts only
  - No existing capability to do physics based forecasts



Geomagnetic Storms



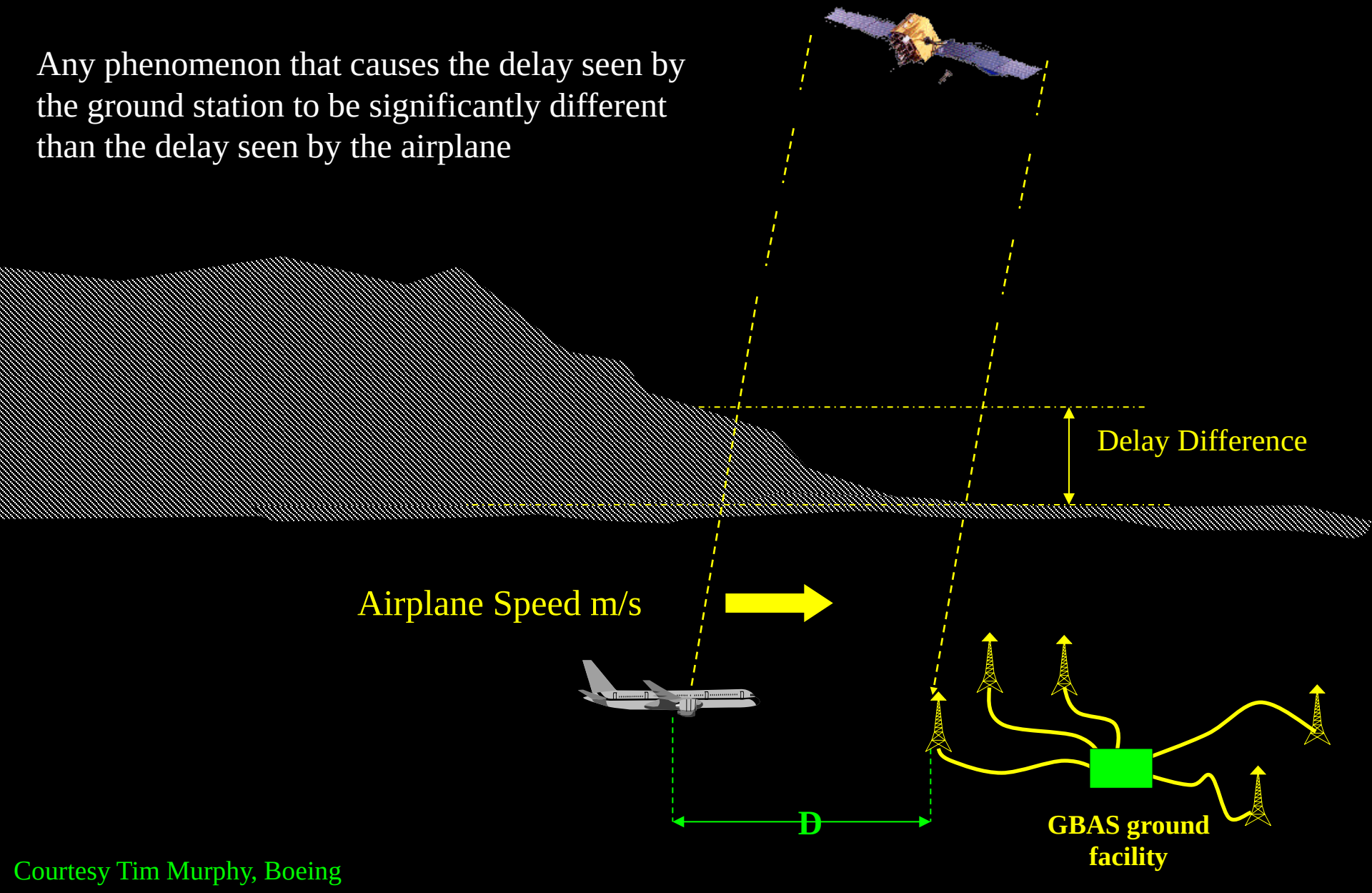




- Arrival: 18-96 hours after CME
- Duration: Several hours to days
- Impacts: Ionosphere TEC enhancements, geomagnetic induced currents, aurora
- CME arrival time forecast 1-2 based upon modeling
- IMF direction remains unknown until measured by upstream monitor – 15-45 minute warning

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



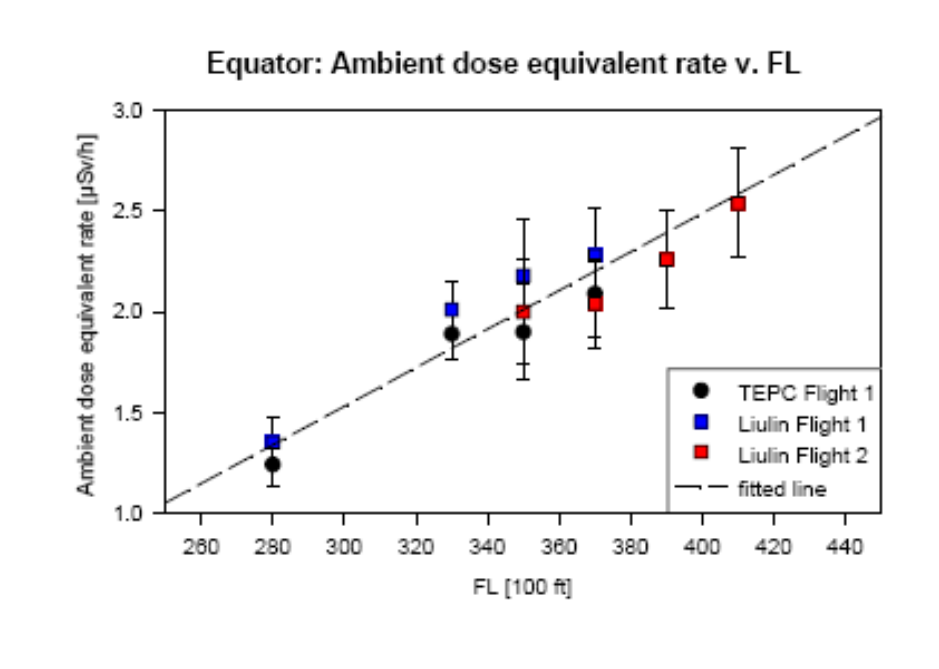
Courtesy Tim Murphy, Boeing

WAAS VPL Service Availability
October 30, 2003

Vertical Navigation Capability

(Animation Courtesy of FAA NSTB)

Dose Rates at Aviation Altitutdes

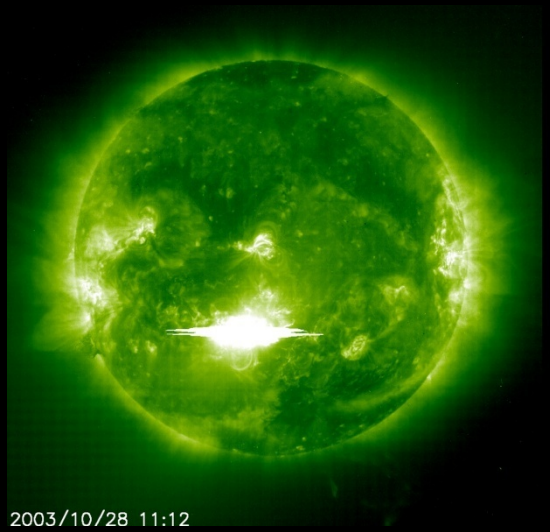


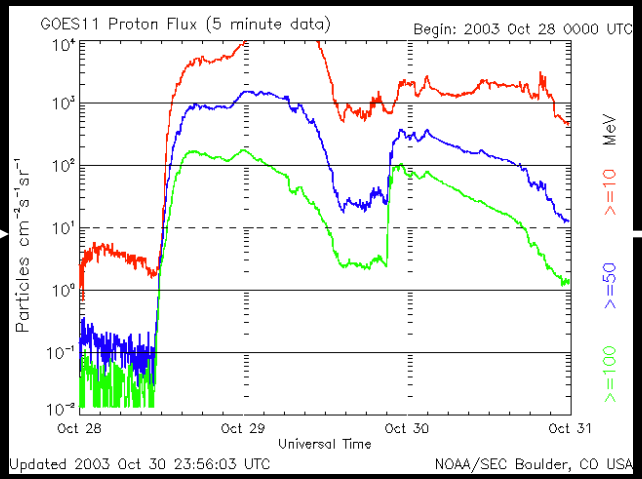
- **FL 280: 1.3 µSv/h**
- **FL 350: 2.0 µSv/h**
- **FL 410: 2.6 µSv/h**
- Rule of thumb: altitude ↑ 1000 ft. => ambient dose equivalent rate ↑ 0.1 µSv/h

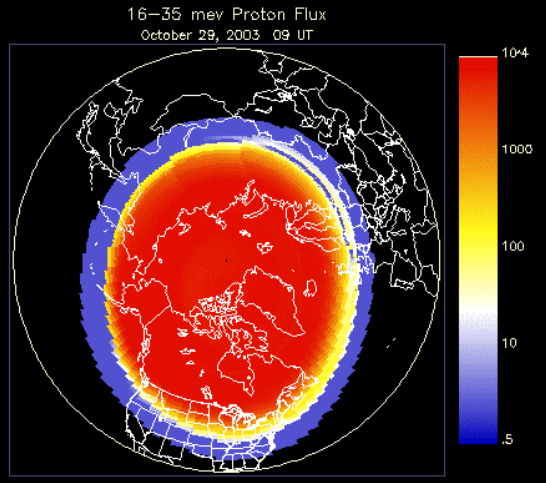
- German Aerospace center in cooperation with Luftsana and LTU Airlines studied exposure rates during flights from German to Africa during geomagnetically quiet conditions
- Even if someone spent the whole year at FL350 in the equatorial region their radiation exposure would not exceed the internationally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

From M. Meier

Solar Energetic Particles

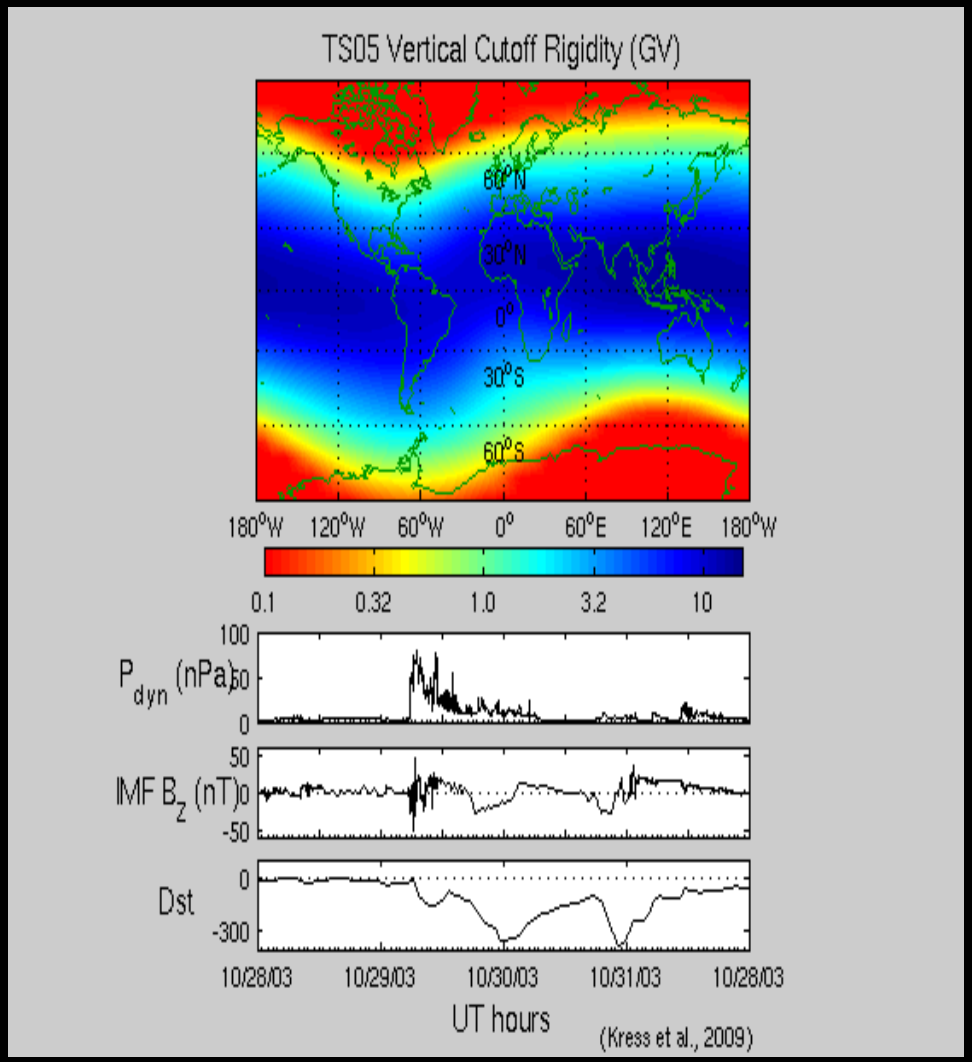






- Arrival: 10's of minutes to days
- Duration: hours to days
- Short term forecasting capabilities
- Access is impacted by current geomangetic activity

Geomagnetic Shielding



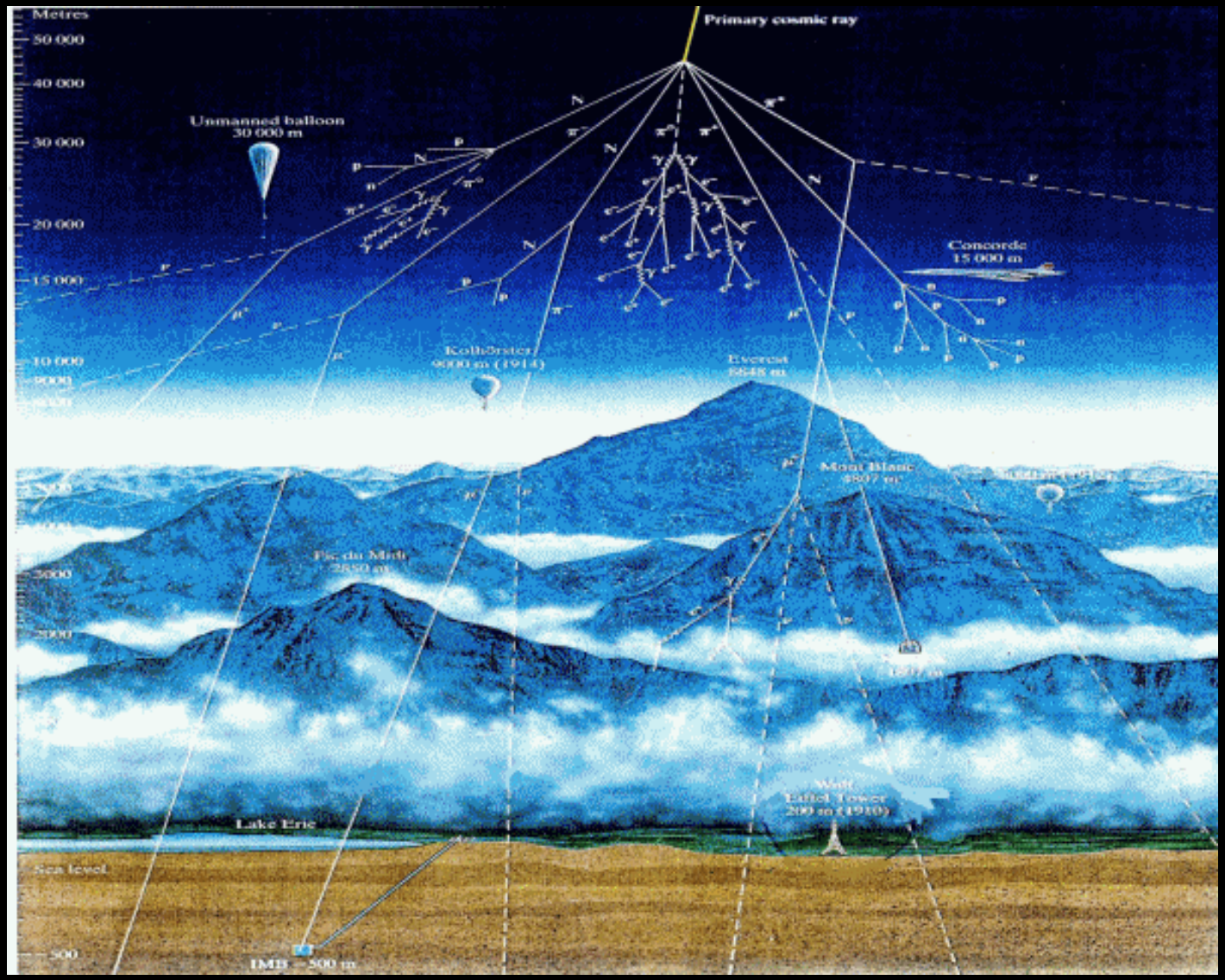
- Severe geomagnetic storms suppresses geomagnetic shielding allowing SEPs access mid- latitudes.
  - Due primarily to a build up of the ring current
  - Shock arrival can also be significant
- Particles with rigidities below the a cutoff value cannot access that point in space
  - We compute these using 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

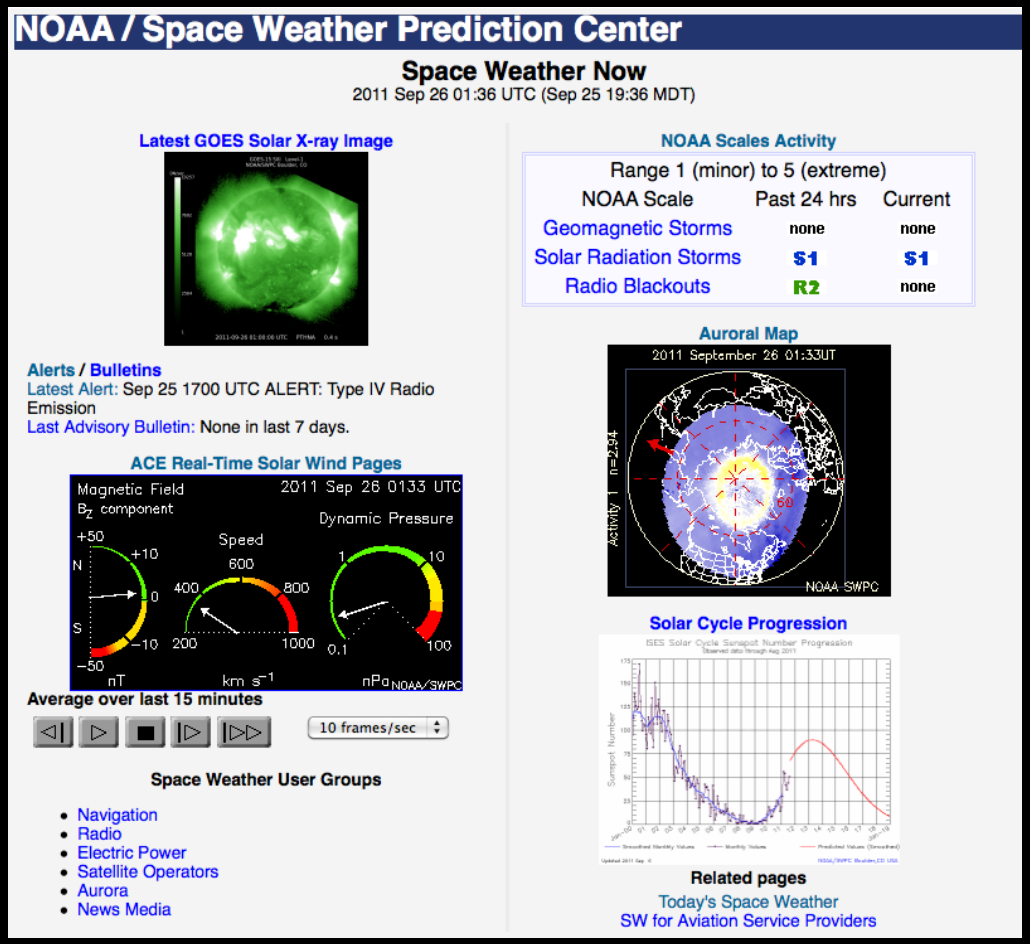
- Space Weather is a manageable risk in aviation operations
  - High altitude and high latitude operations increase this risk
  - Radiation is only a part of this risk
- Information is available from a variety of official and unofficial sources on the internet
- Feel free to contact me directly wiltbemj@ucar.eud

Backups

Cosmic Ray Interactions

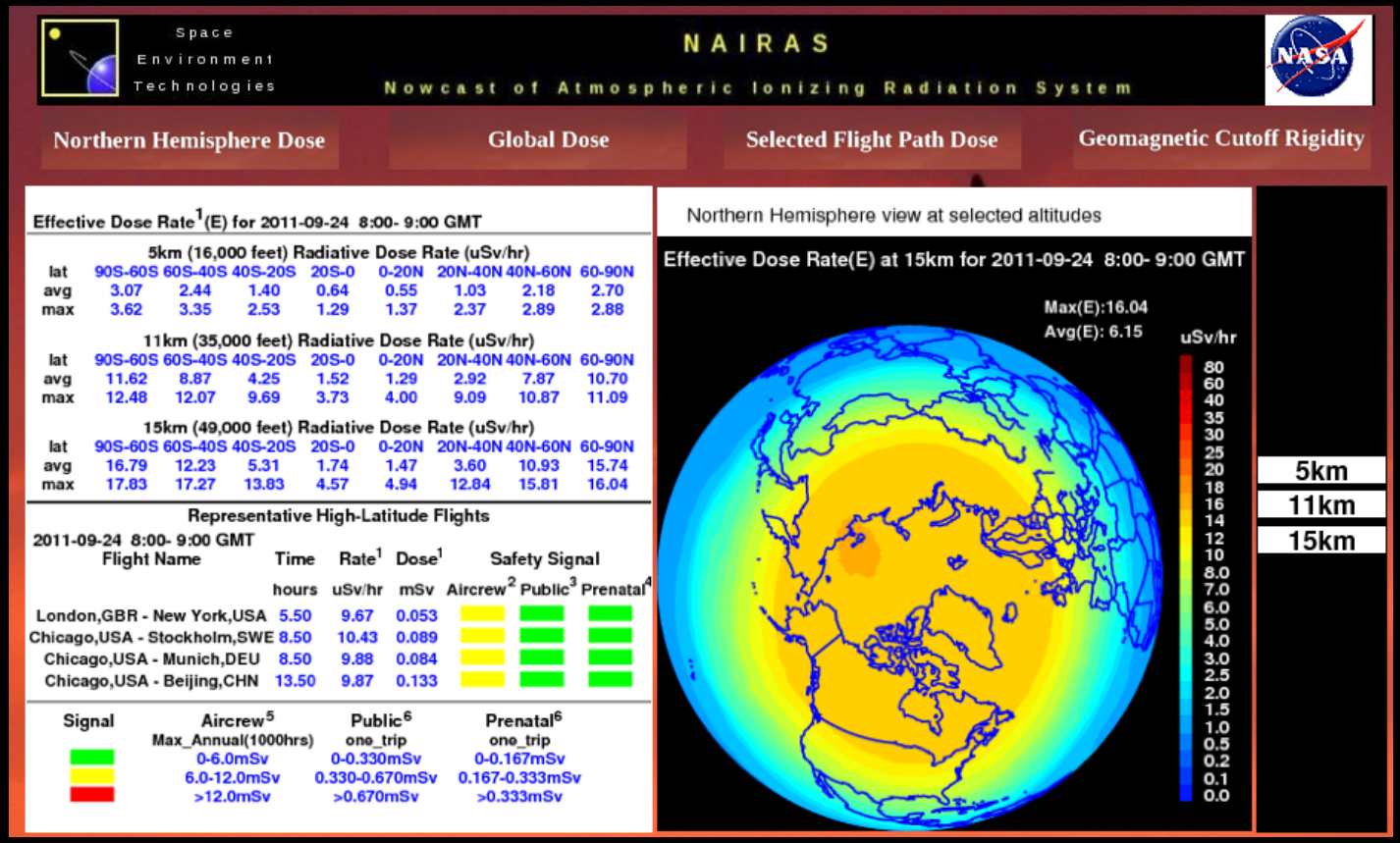


Space Weather Prediction Center



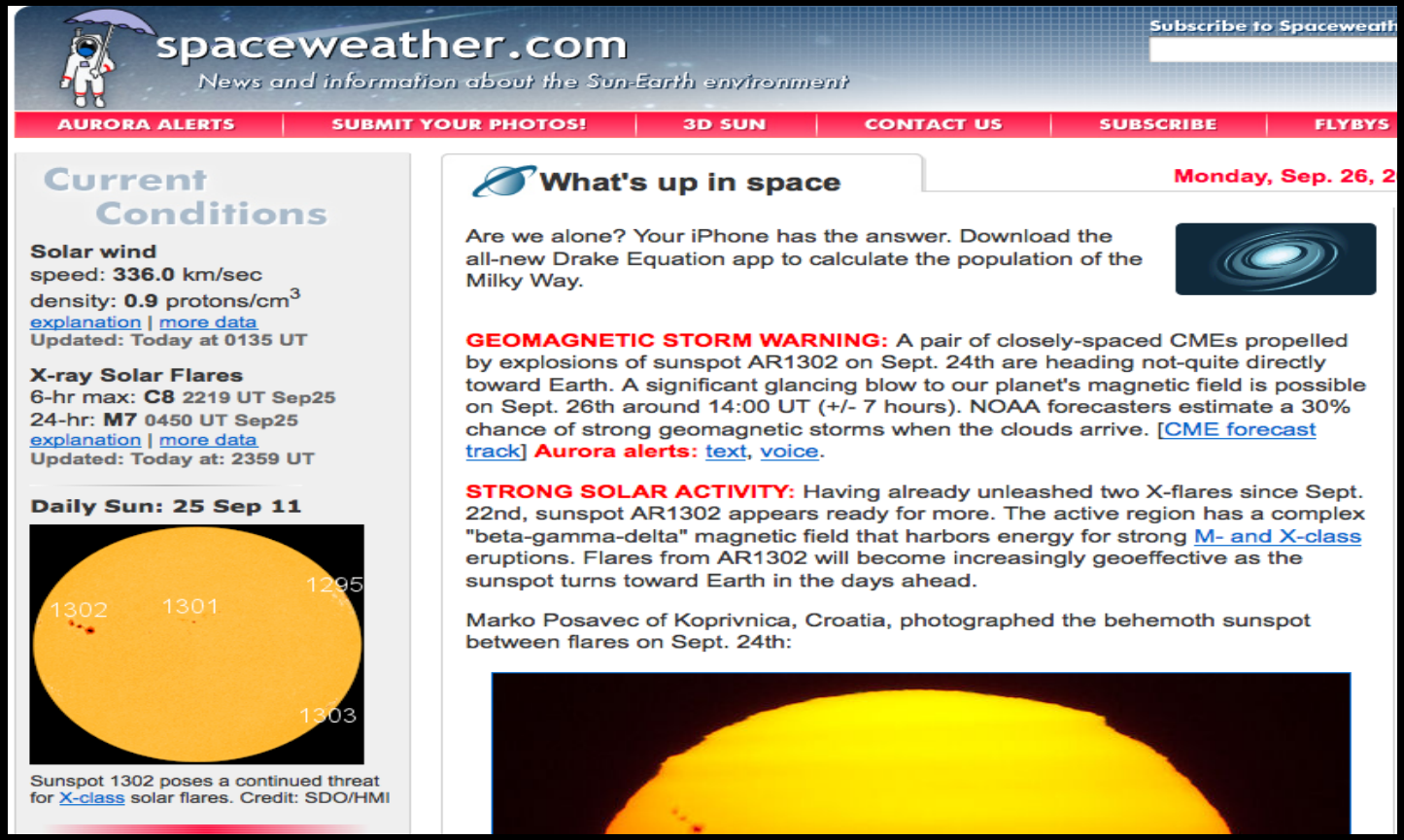
- http://www.swpc.noaa.gov/SWN/

NARIAS Website



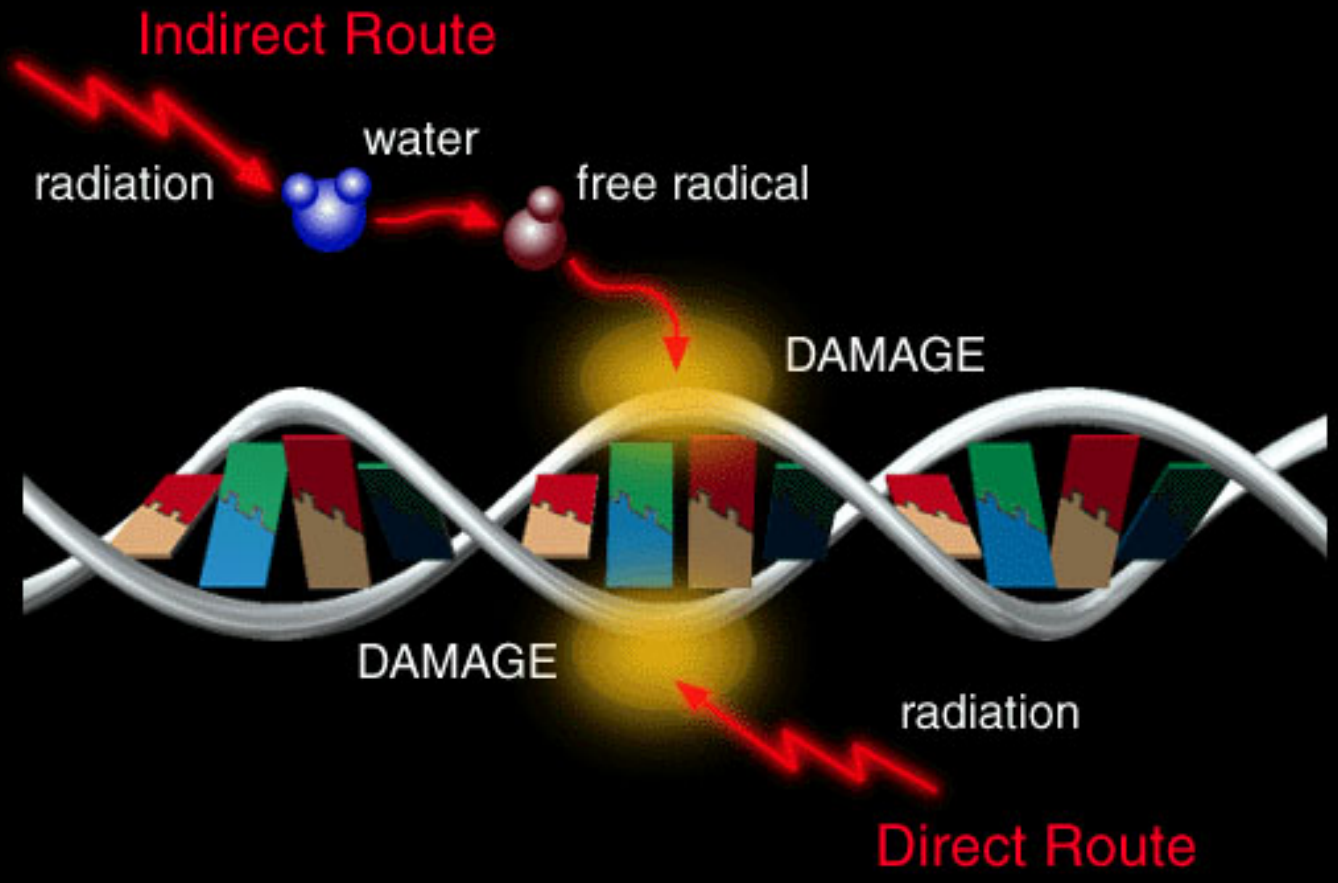
- http://terra2.spacenvironment.net/~raps_ops/current_files/index.html

SpaceWeather.com



- 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**

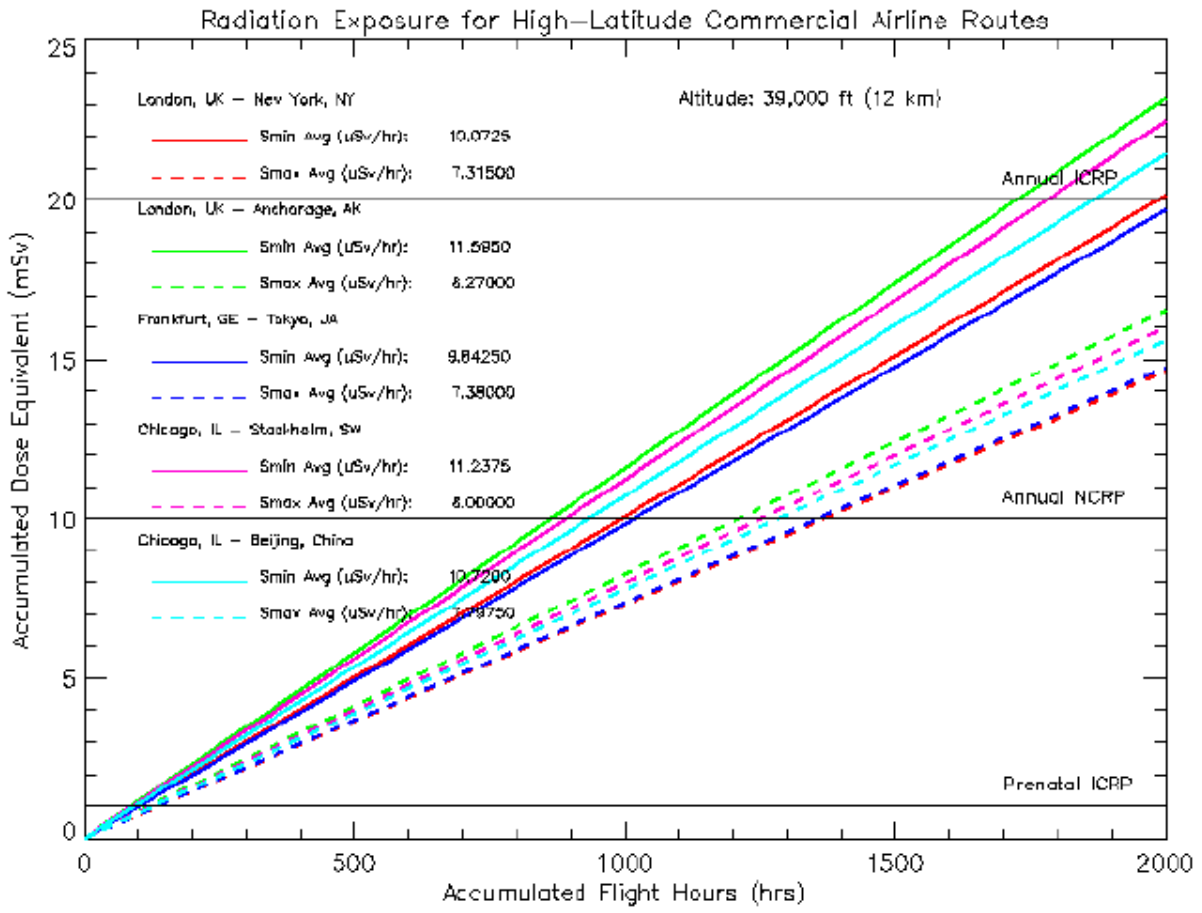
$$E = \sum_T w_T \cdot H_T$$

- **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



FRA to DFW flight