NASA Applied Sciences Program Public Health Review

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) Model

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NASA (Aviation) Weather Applications Program and the Advanced Satellite Aviation-weather Products (ASAP) Project

NASA Applied Sciences Aviation Applications Program and ASAP Project

NASA Applied Sciences Aviation Program

ASAP: Weather Program Implementation and Transition to Operations

- Oceanic Weather
  - Volcanic Ash
  - Convection
  - Turbulence
  - FL Winds
- In-Flight Icing
- Convective Weather
- Turbulence
- Space Weather
- Environmental Impacts

Typical Product Development Processes

- In-Flight Icing
  - Research
  - Validation
  - Integration
- Field Campaigns
  - Planning
  - Execution
  - Reporting

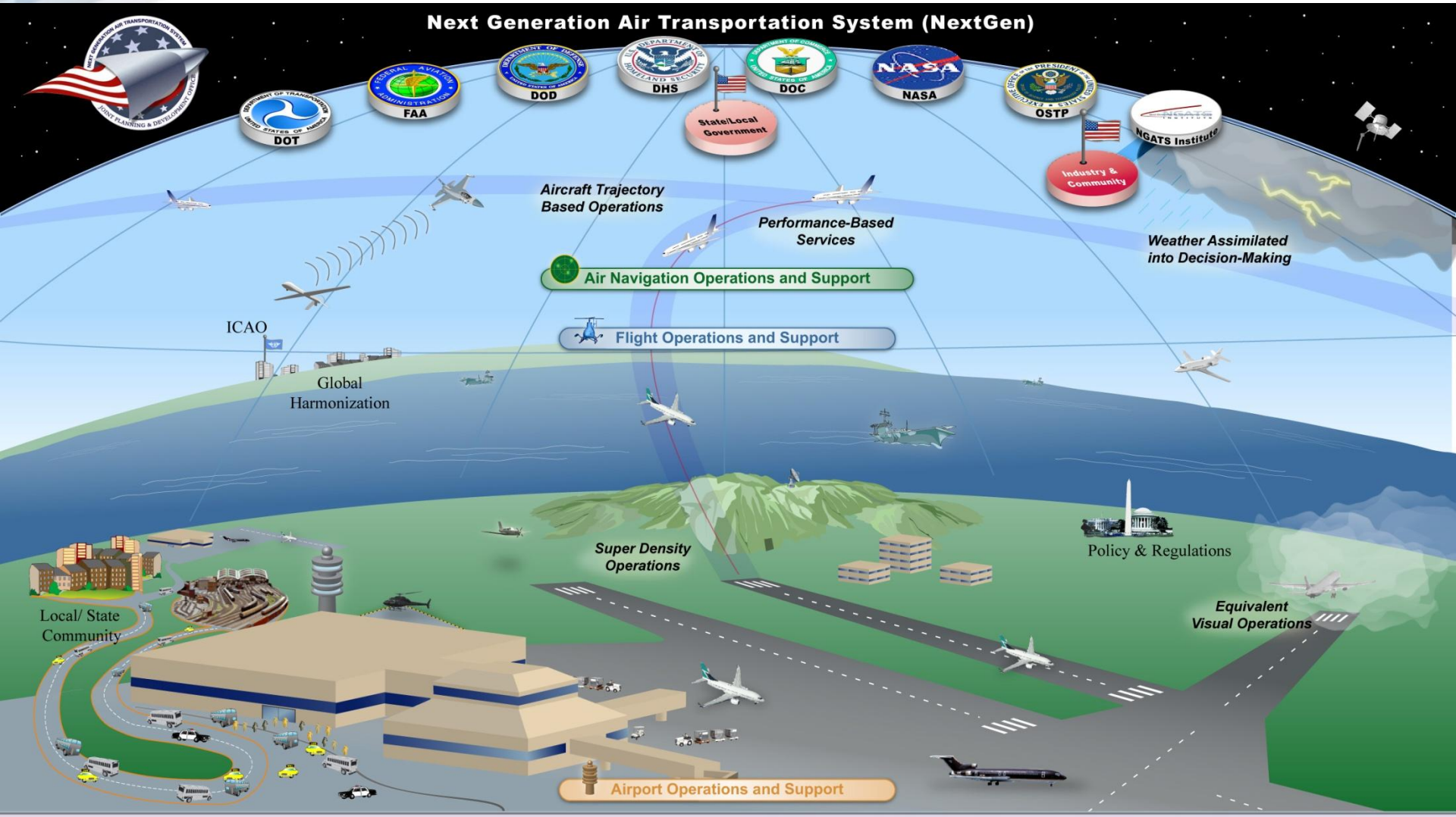
JPDO WxWG EI Team, FAA & NOAA NWS AvSB

FAA Aviation Weather Research Program Product Development Teams

- In-Flight Icing
- Convective Weather
- Turbulence
- Oceanic Weather
- National Ceiling and Visibility
- Terminal Ceiling and Visibility
- Winter Weather
- Model Development and Enhancement
- Aviation Forecasts
- Quality Assessments
- NEXRAD Algorithms

Aviation Applications Focal Point

Next Generation Air Transportation System
Joint Planning and Development Office



Questions/Comments:
Jay Merkle
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Updated 04/06/07, Version 1.1b

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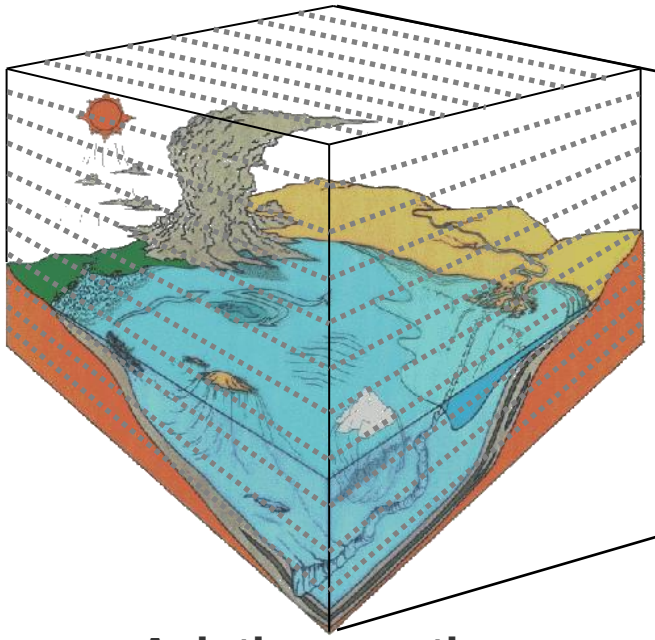
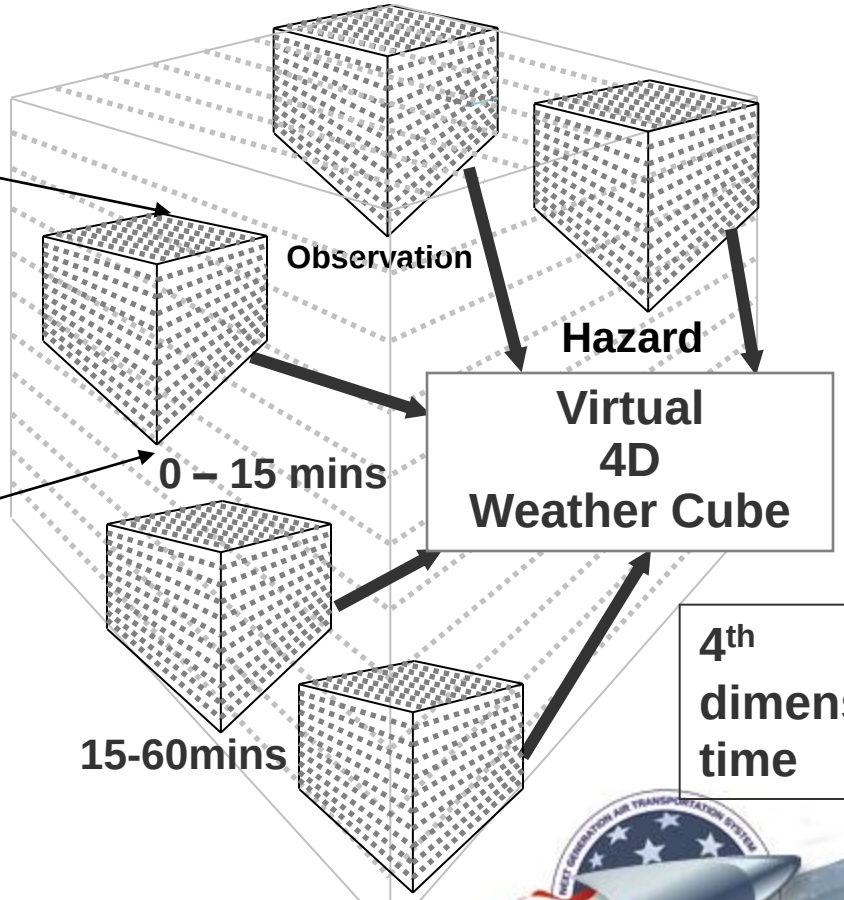
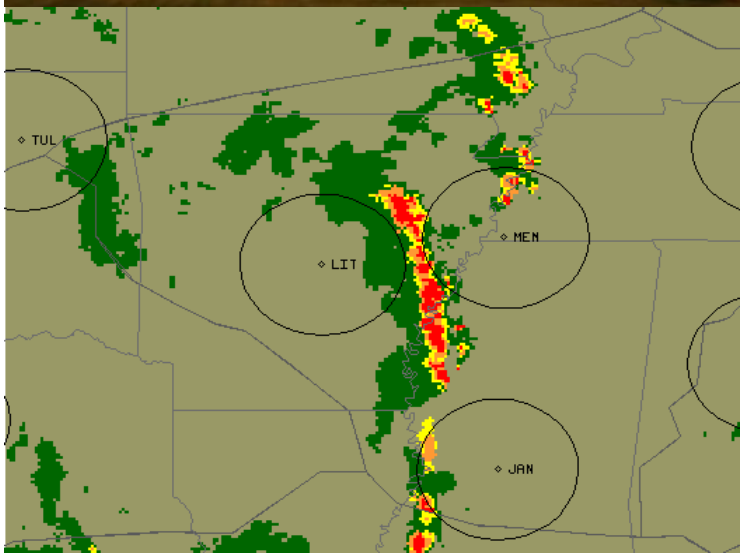


Aviation weather
information
in 3 dimensions
(latitude/longitude/height)



NextGen Priority #1: Convective Weather

NASA Applied Sciences Aviation Applications Program and ASAP Project



Aviation Summertime Delays

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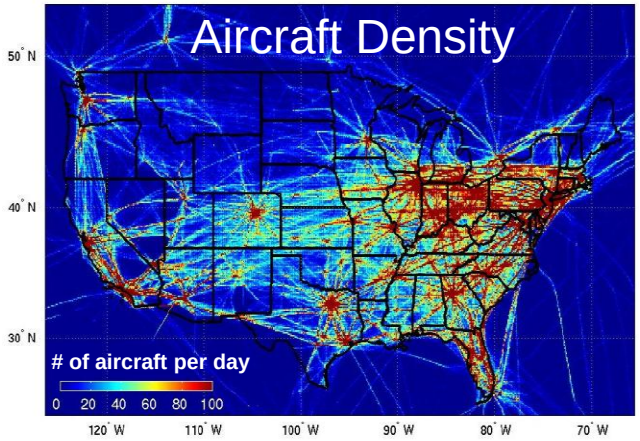
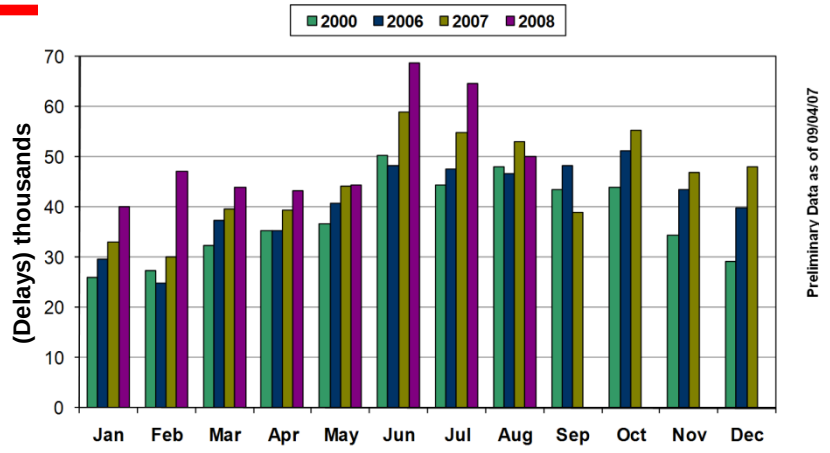
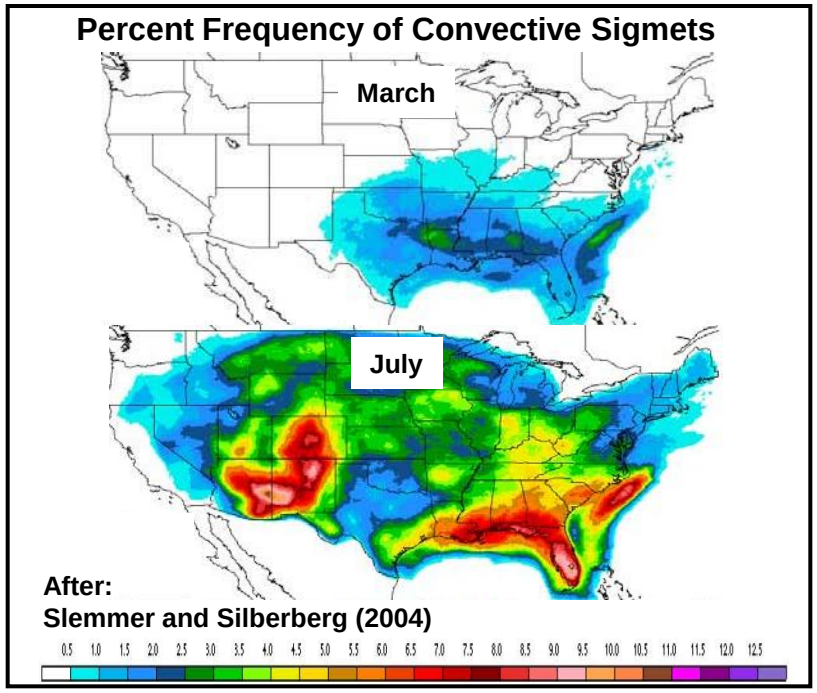
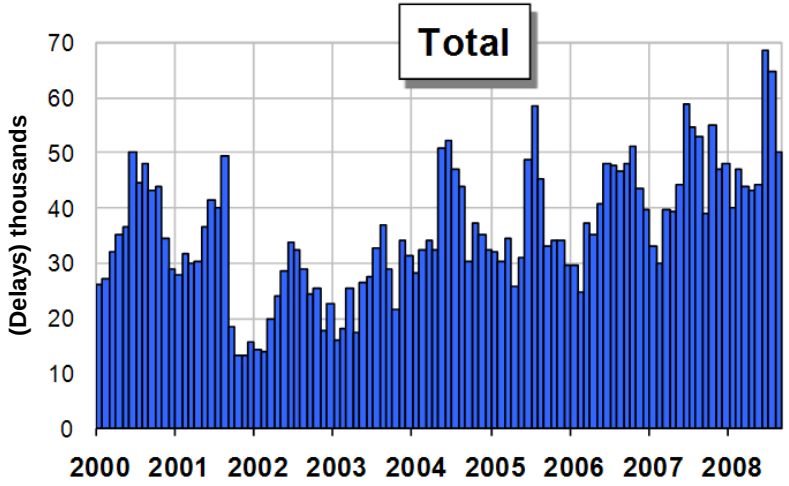


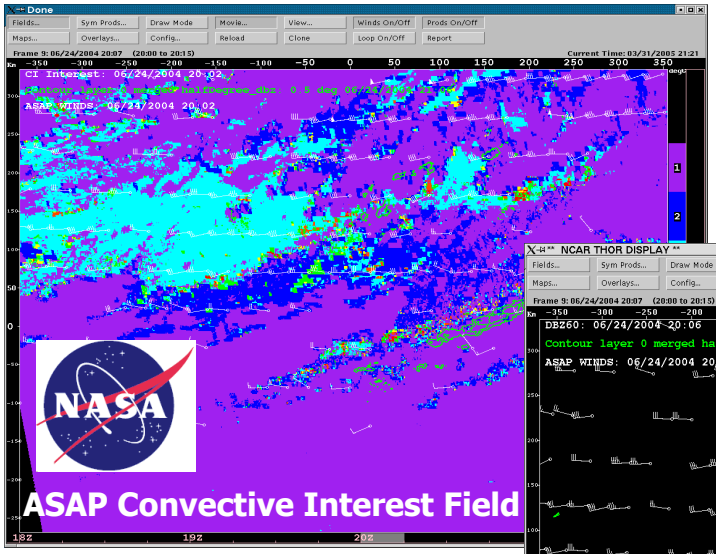




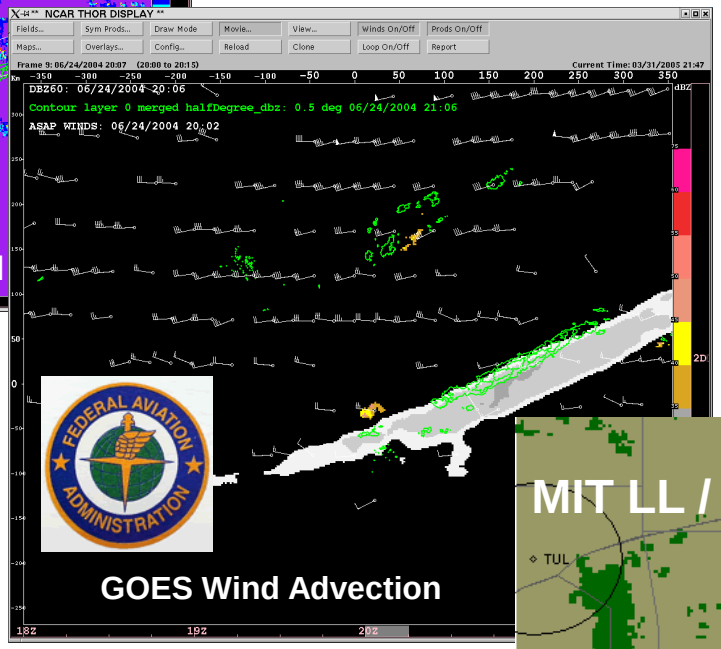


Courtesy: MITRE Corp.

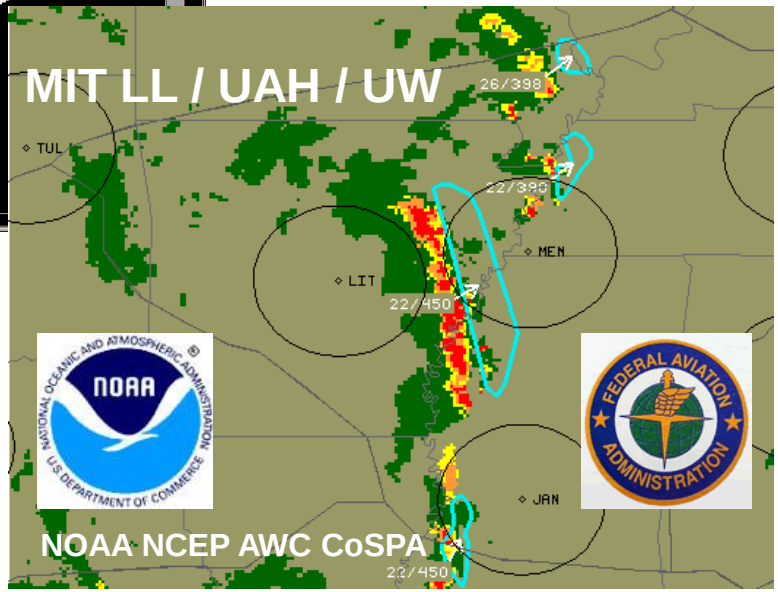
ASAP Convective Weather Algorithms: Integration of Satellite-derived Radar Nowcasts into FAA/NOAA AWC Consolidated Storm Prediction Algorithm



UAH



UW



Transition

from

research

to

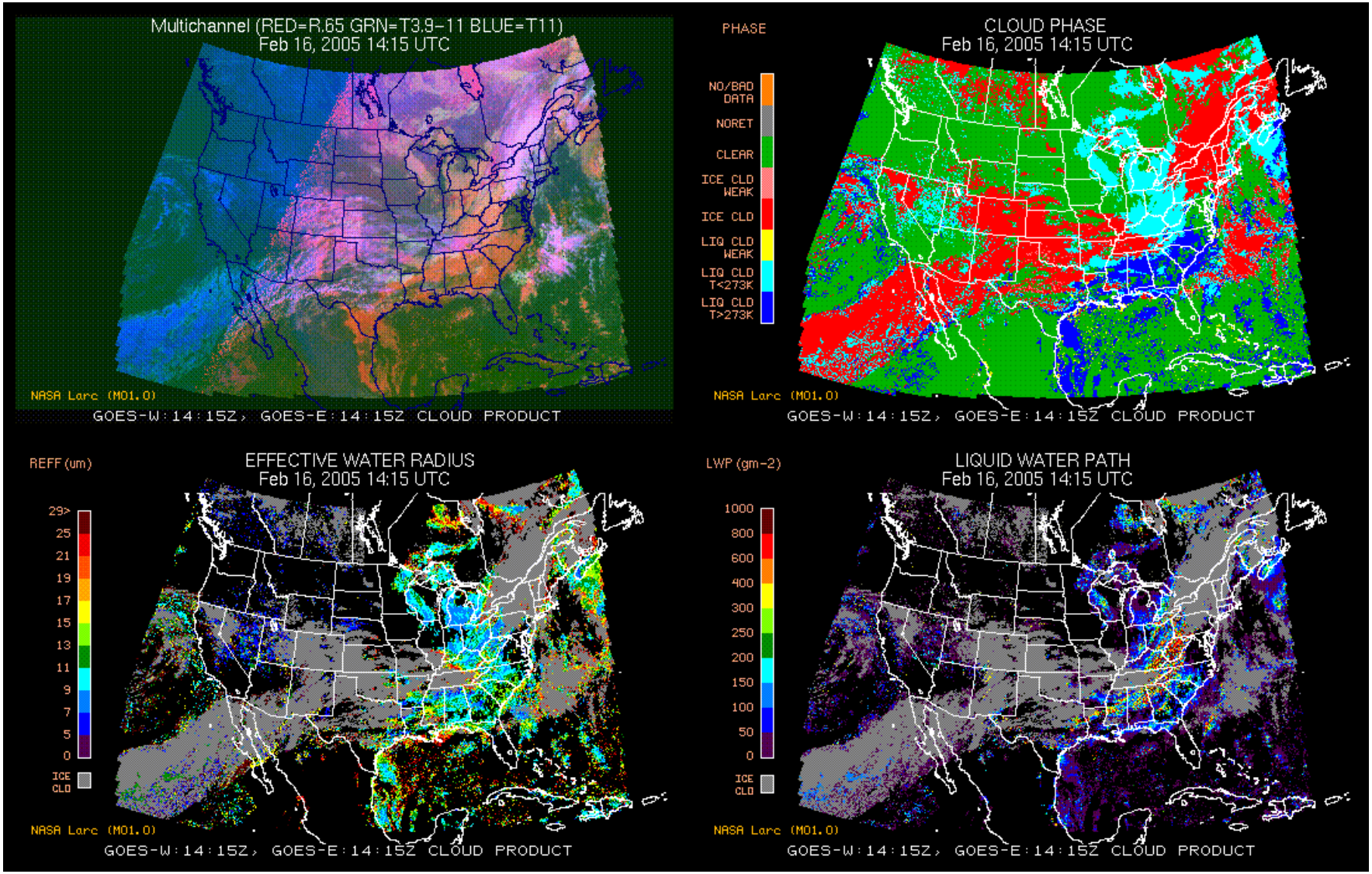
operations

Volcanic Ash Detection, Characterization, Tracking and Dispersion

- Characterization with AURA (OMI) and CALIPSO
- Aerosol and SO_2 dispersion
- Aviation impact studies

RUC Model Assimilation of NASA Cloud Properties

NASA Applied Sciences Aviation Applications Program and ASAP Project



In-flight Icing and Ice/Water Ingestion

Ceiling and Visibility

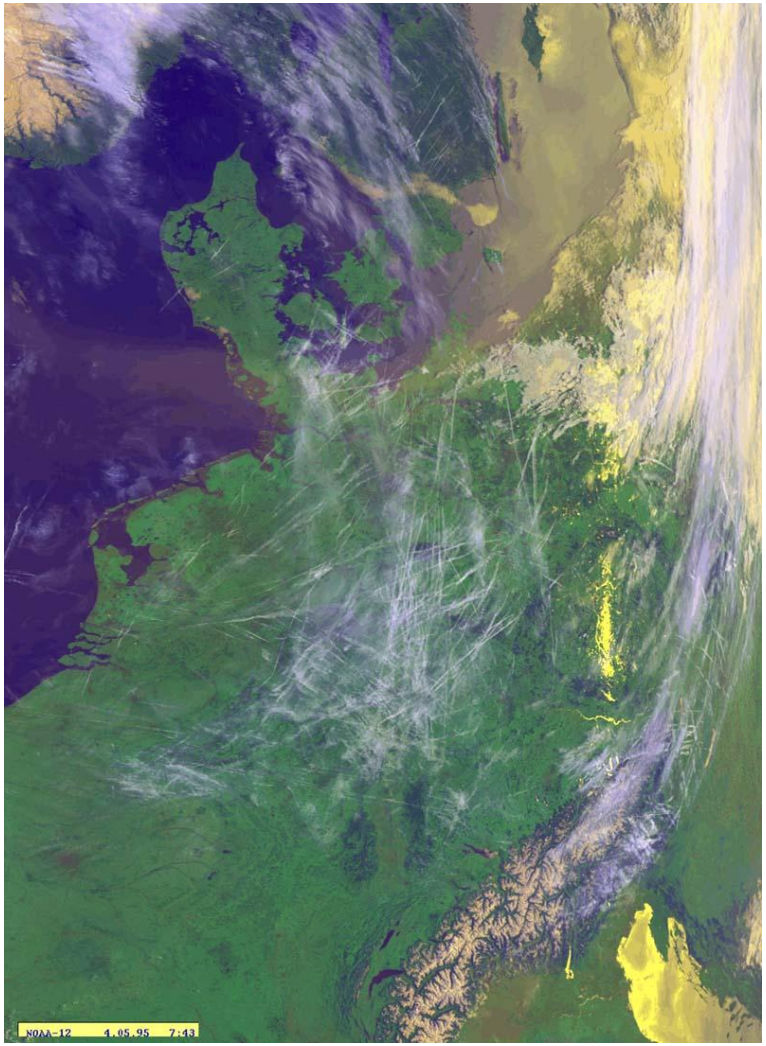
Low ceilings and multi-layer clouds: Unintended flight into IFR conditions continues to be a serious cause of weather mishaps for VFR pilots.

Supporting new funding of Minnis contractors for C&V and AERI research.

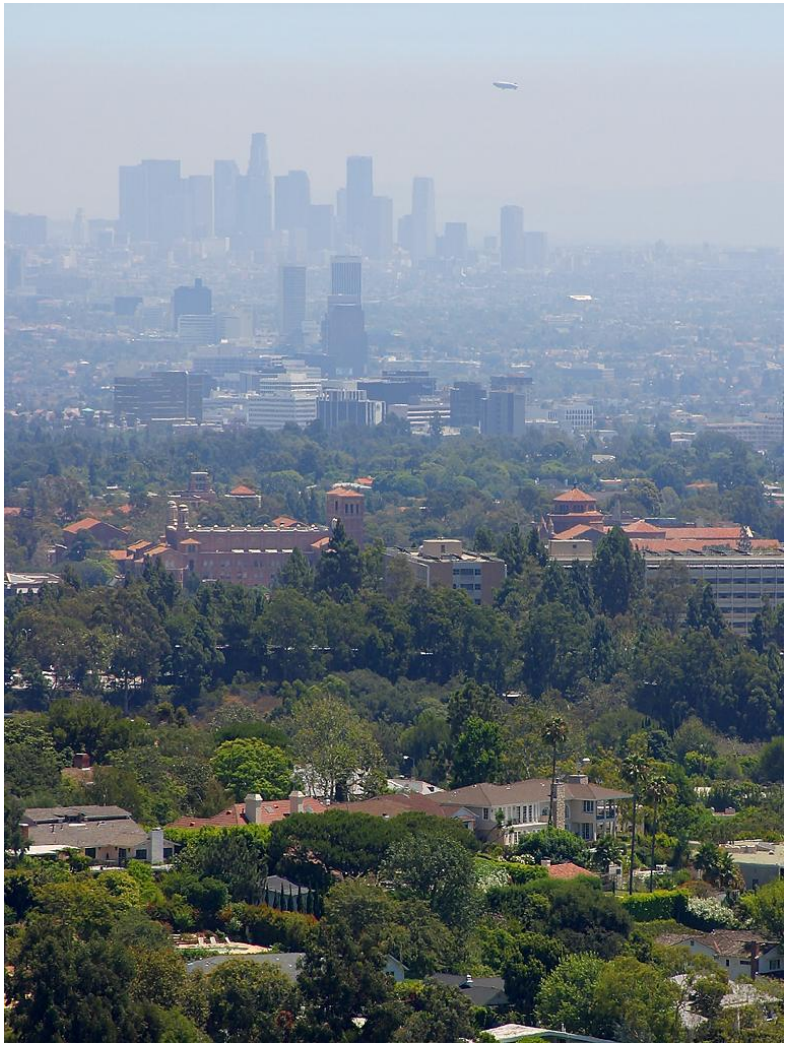

The Environment affects aviation,
and vice-versa…

Climate and Air Quality

NASA Applied Sciences Aviation Applications Program and ASAP Project



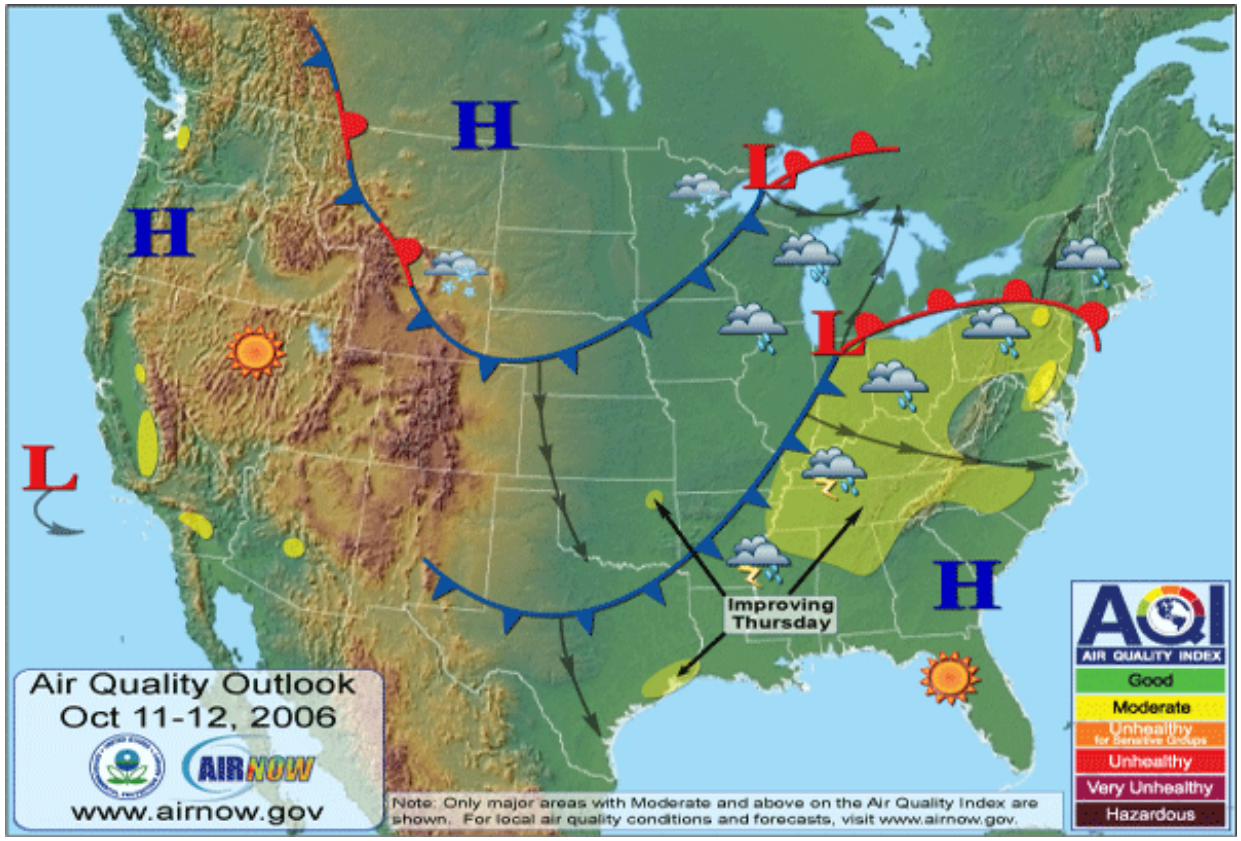
Aviation accounts for about 1% of global climate impact but may be substantially higher regionally.



If left unchecked, environmental constraints on the airspace system will exceed weather impacts

Air Quality Impacts

NASA Applied Sciences Aviation Applications Program and ASAP Project



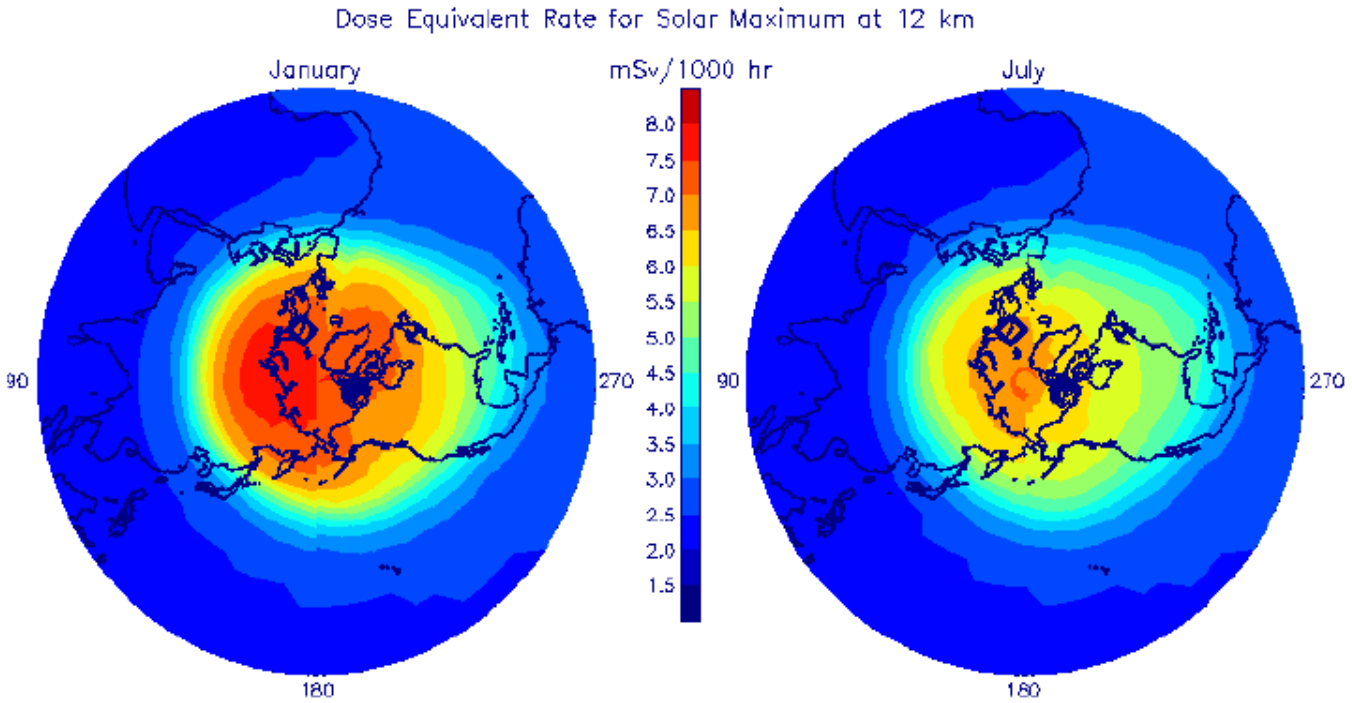
Goal: Assess Local, Regional and Global Impact of Aviation on Air Quality to provide the JPDO environmental constraint guidance for airport capacity and growth planning for NexGen

Space Weather Hazards

NASA Langley AIR model and HZE (High Charge and Energy) transport code

NASA Applied Sciences Aviation Applications Program and ASAP Project

The NASA Nowcasting of Atmospheric Ionizing Radation for Aviation Safety (NAIRAS) Model is under development to address the need for a model to correctly calculate human exposure/dosage



NAIRAS Overview

NASA Applied Sciences Aviation Applications Program and ASAP Project

- **Introduction and Motivation**
- **NAIRAS Model Concept**
- **Halloween 2003 Storm Case Study**
- **Current Developments**
- **Summary and Conclusions**

NAIRAS Team

NASA Applied Sciences Aviation Applications Program and ASAP Project

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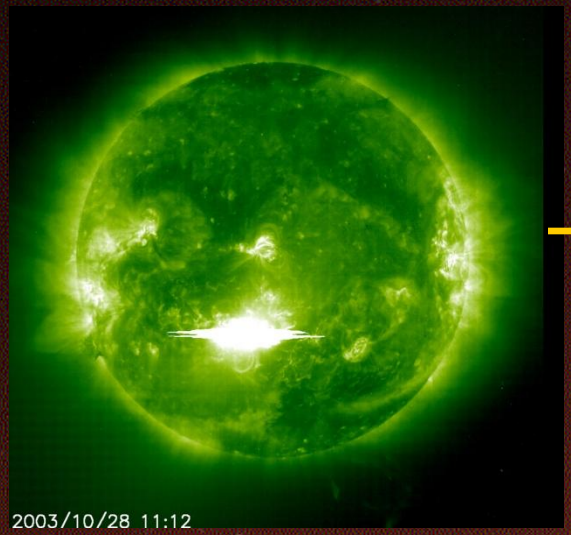
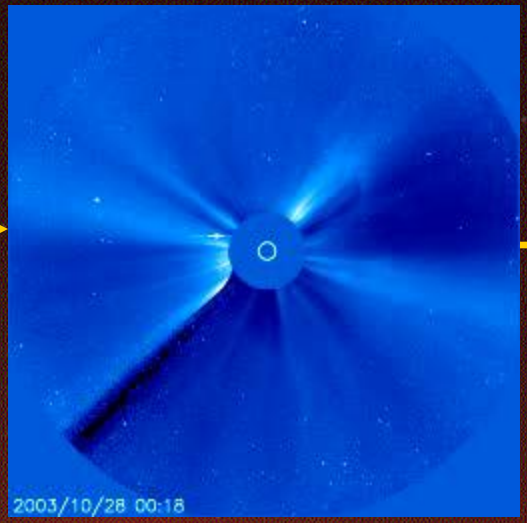
- Joe Kunches (Collaborator), NOAA Space Weather Prediction Center, Boulder, CO
- Barbara Grajewski (Collaborator), CDC/NIOSH, Cincinnati, OH
- Steve Blattnig (Collaborator), NASA Langley Research Center, Hampton, VA
- Xiaojing Xu (Collaborator), SSAI, Inc., Hampton, VA
- John J. Murray (Collaborator), NASA Langley Research Center, Hampton, VA

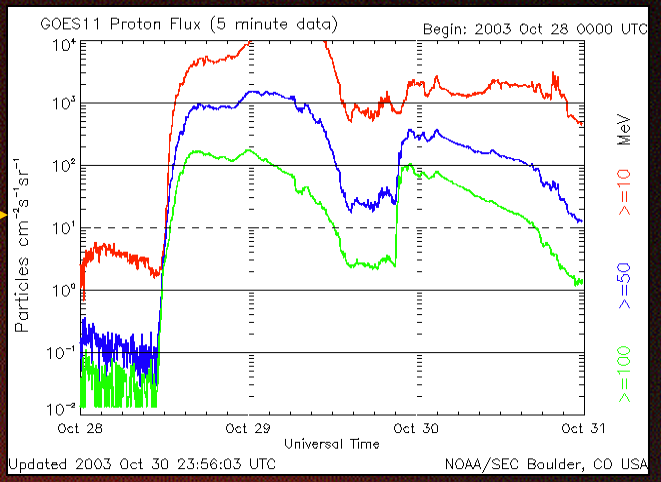
Sources of Atmospheric Ionizing Radiation

- **Galactic Cosmic Rays (GCR)**
  - Origins outside the solar system
  - Maximum GCR levels occur during minimum in 11 year solar cycle
  - Cumulative, long term, exposure hazard
- **Solar Energetic Particles (SEP)**
  - Origins from solar storm activity
  - Maximum SEP levels occur more often during maximum in solar cycle
  - Episodic, high dosage hazard

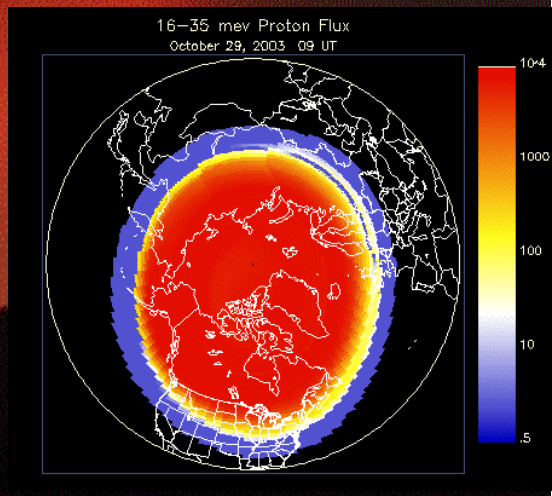
Solar Radiation Storms







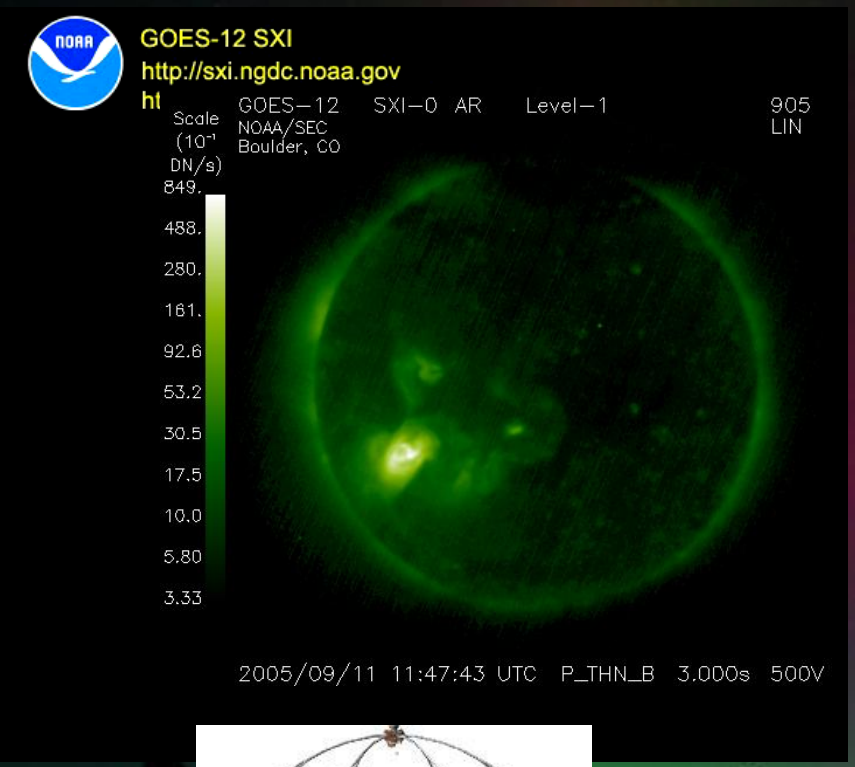
Radiation storm onset typically 30 mins to several hours after the eruption on the Sun



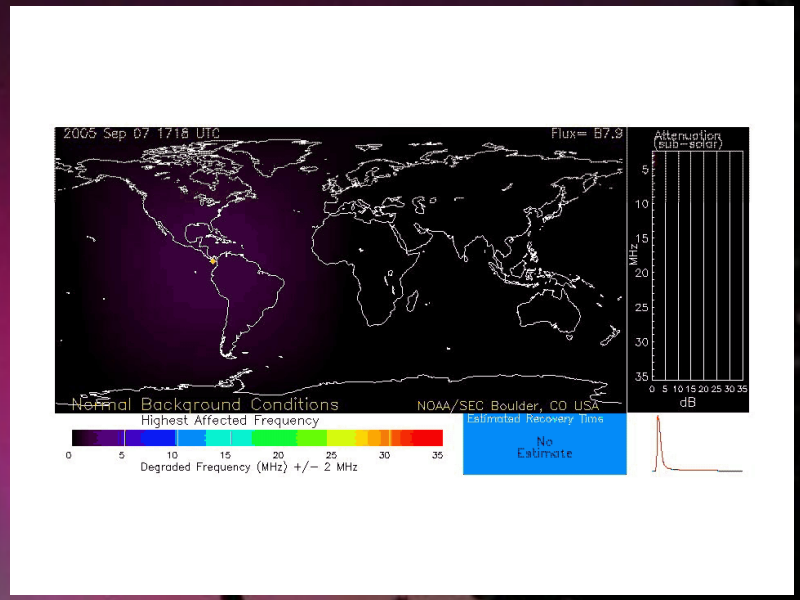
Impacts…

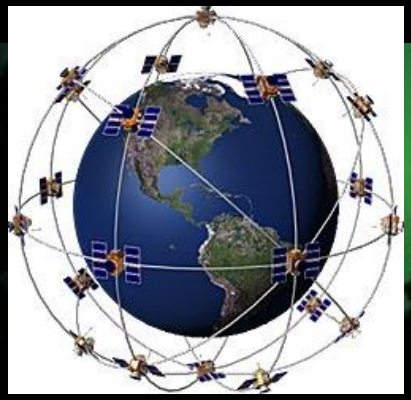
- High latitude HF communications
- Satellite Operations
- Spacecraft launch operations
- Aviation
  - Increased exposure to radiation at high latitudes
  - HF, VHF, and SATCOM

Solar Flares



- *A violent* explosion in the Sun's atmosphere with an energy equivalent of a hundred million hydrogen bombs.

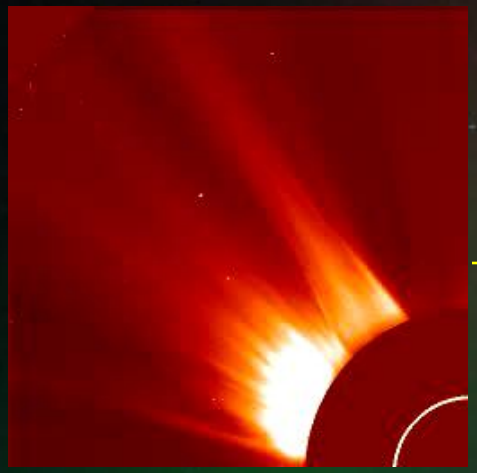


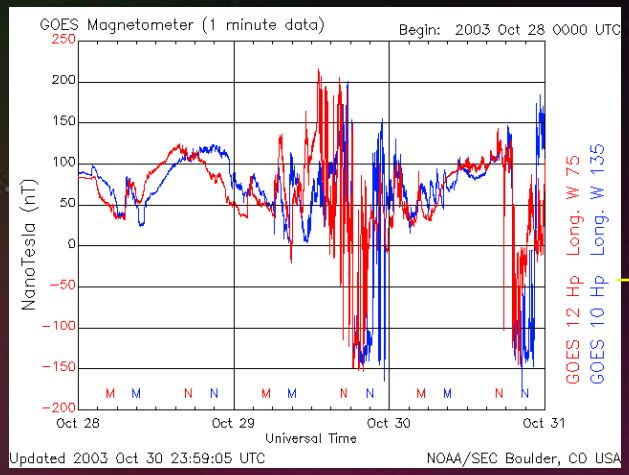


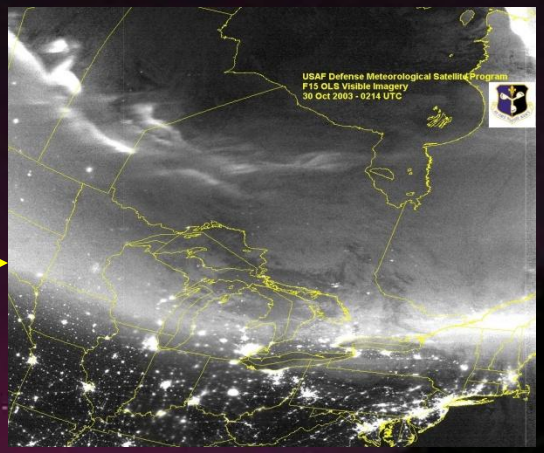
GPS Network

Aircraft Operations

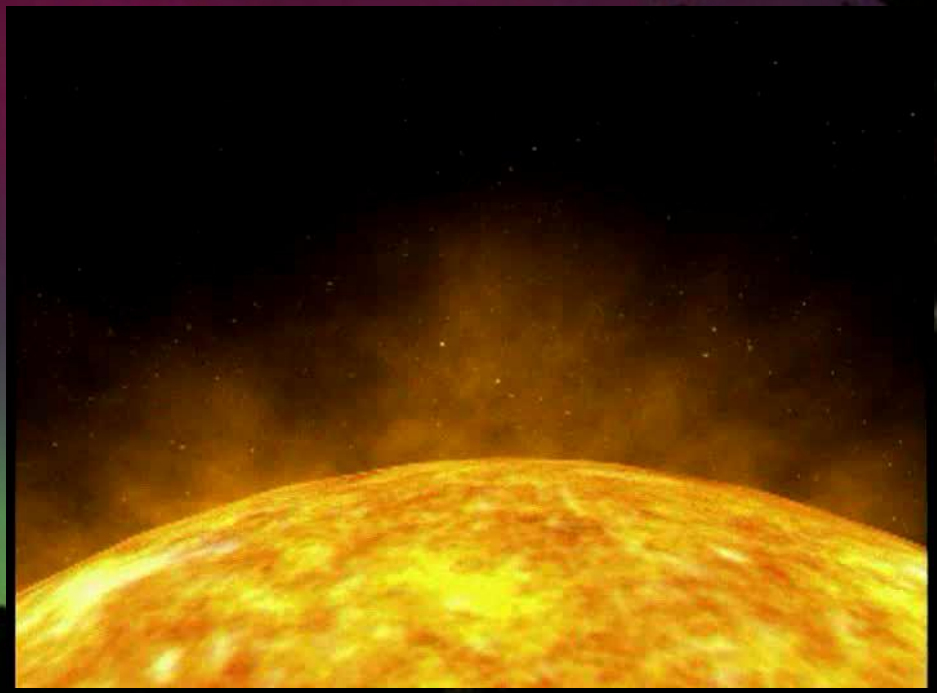
Geomagnetic Storms







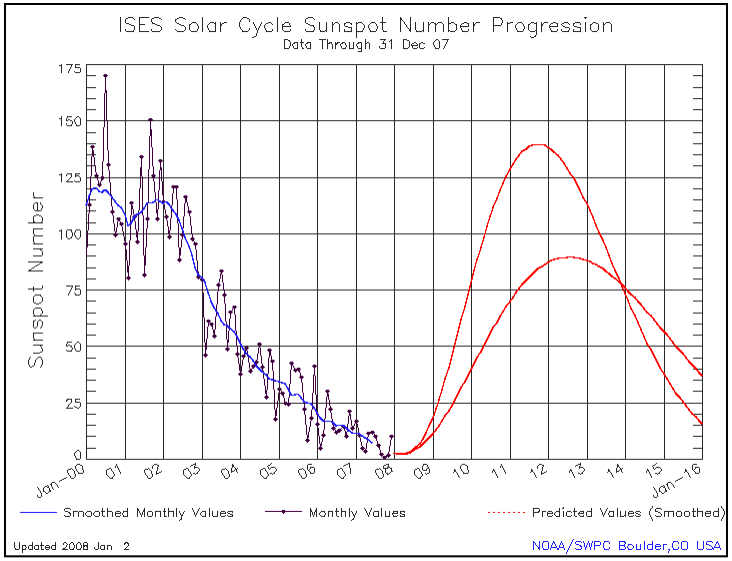
- Coronal Mass Ejections propagate through space at 2-3 million mph
- Impact Earth in 20 - 90 hours
- Have you seen Nicholas Cage's latest film "Knowing"

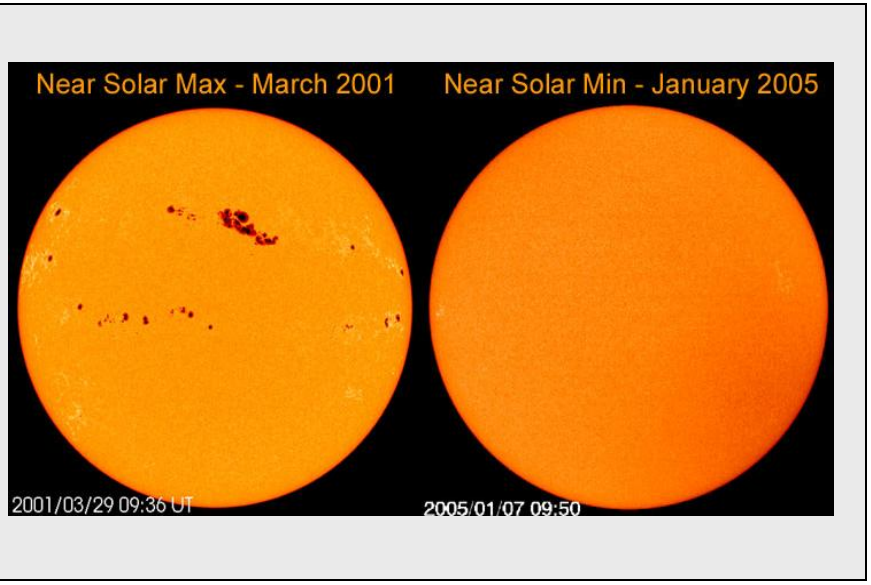


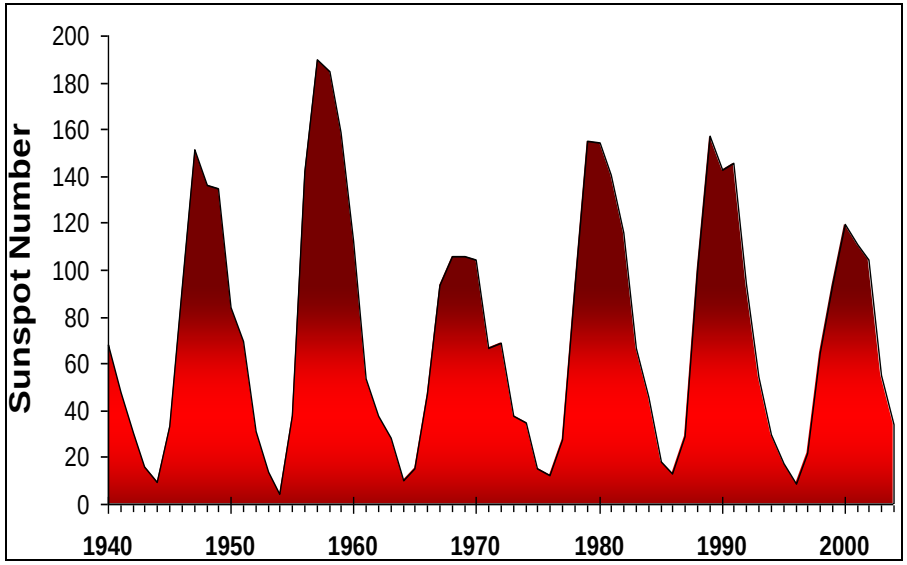
Solar Cycle 23

NASA Applied Sciences Aviation Applications Program and ASAP Project

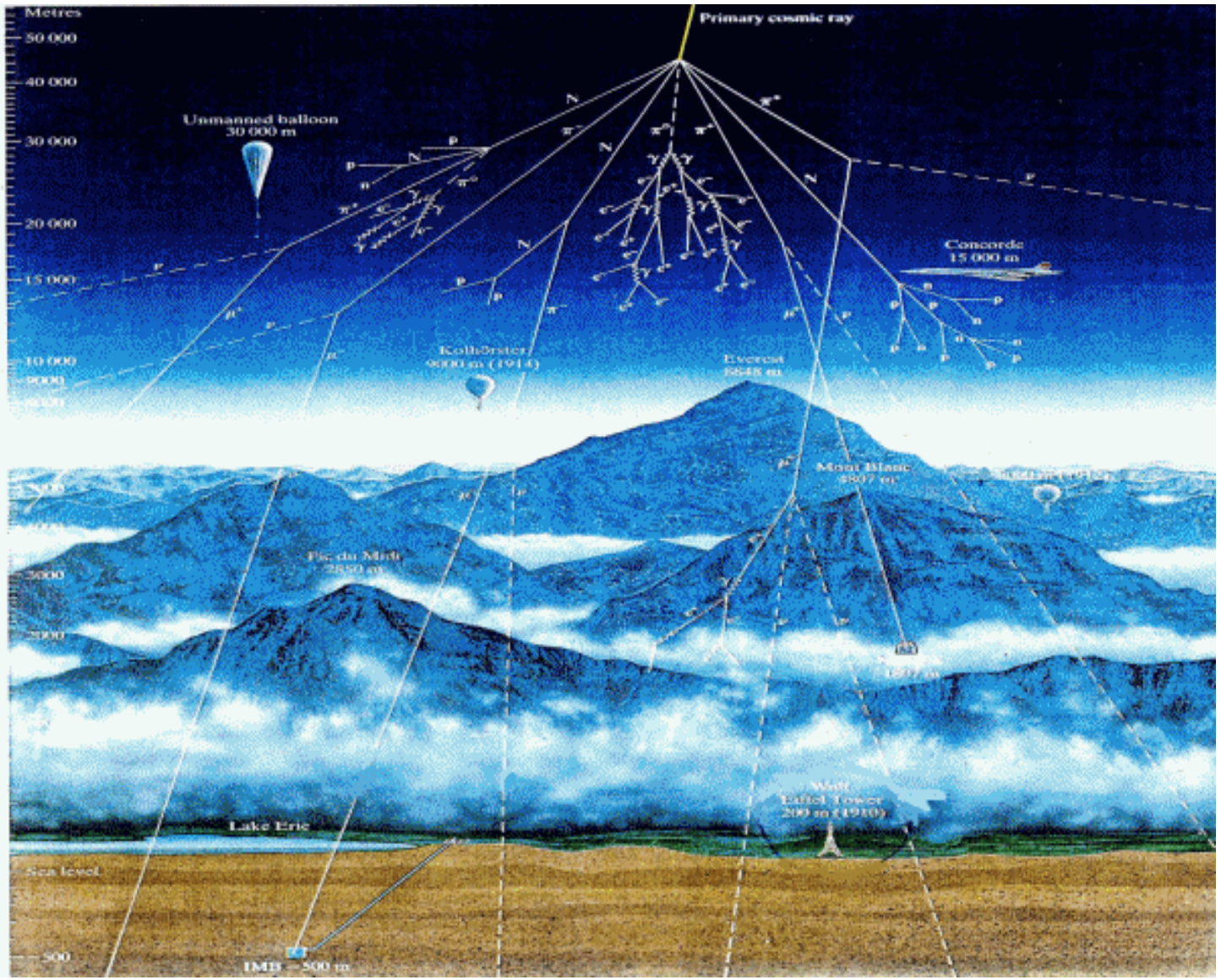
- Currently in solar minimum
- Solar Cycle 23 peaked in April 2000
- Minimum in 2008
- Next maximum in 2011 - 2012



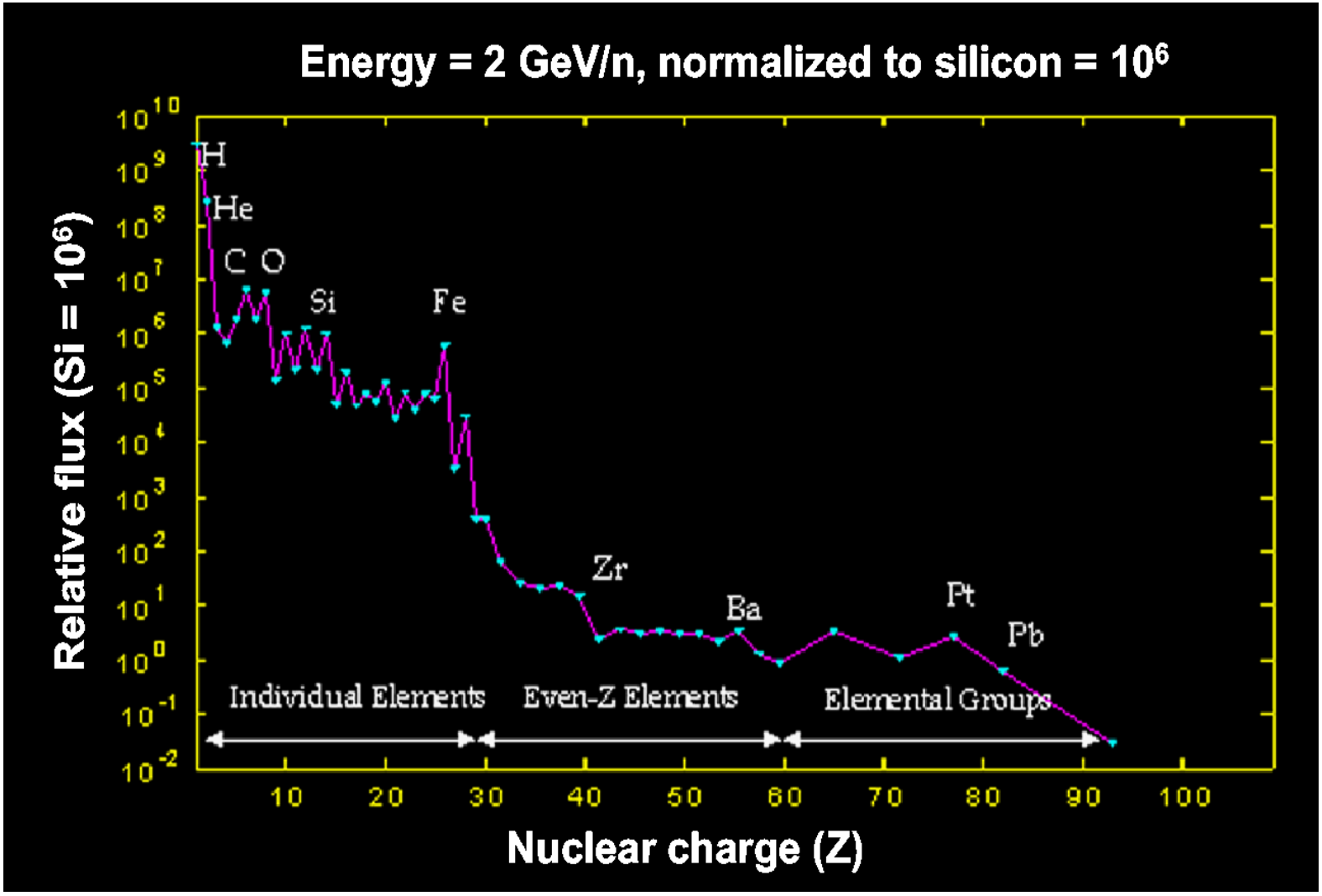




Cosmic Ray Interactions



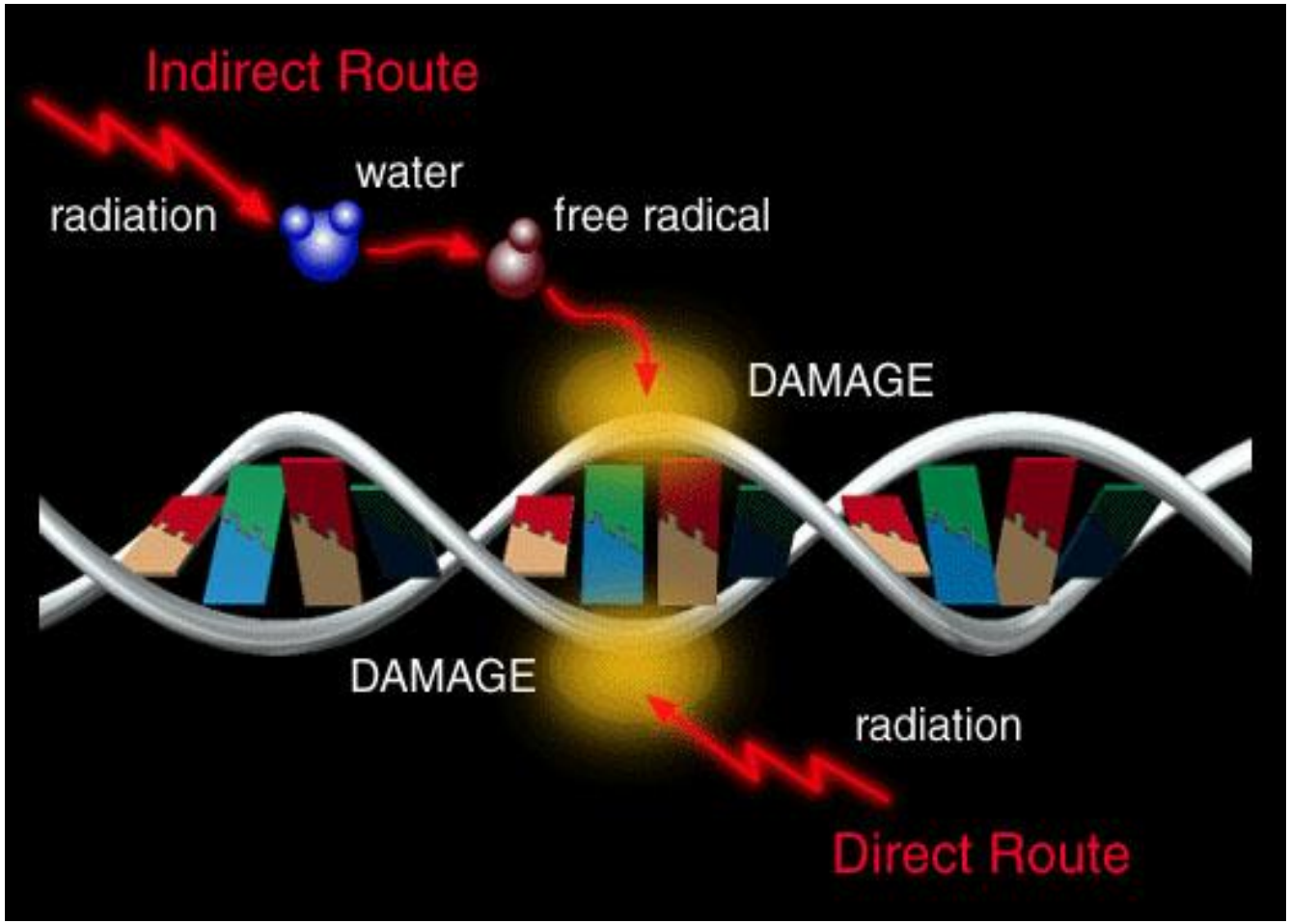
Particle Cascade Distribution



Human Exposure to Atmospheric Ionizing Radiation

- Primary source of human exposure to radiation with high-LET (linear energy transfer)
- High-LET radiation is effective at inflicting biological damage to human tissue leading to adverse health effects
  - Direct break of DNA strands → can lead to cancer
  - Produce chemically active radicals in biological tissues that alter the cell function or result in cell death → can lead to cancer
  - Reproductive disorders (prenatal injuries, spontaneous abortions)

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 Weighting Factors (ICRP publ. 60)

Radiation		w_R
x- & γ-rays, all energies		1
electrons, muons, all energies		1
Neutrons	< 10 keV	5
	10-100 keV	10
	100keV to 2MeV	20
	2 - 20 MeV	10
	> 20 MeV	5
Protons	> 2MeV	5
α, fission fragments, heavy ions		20-40

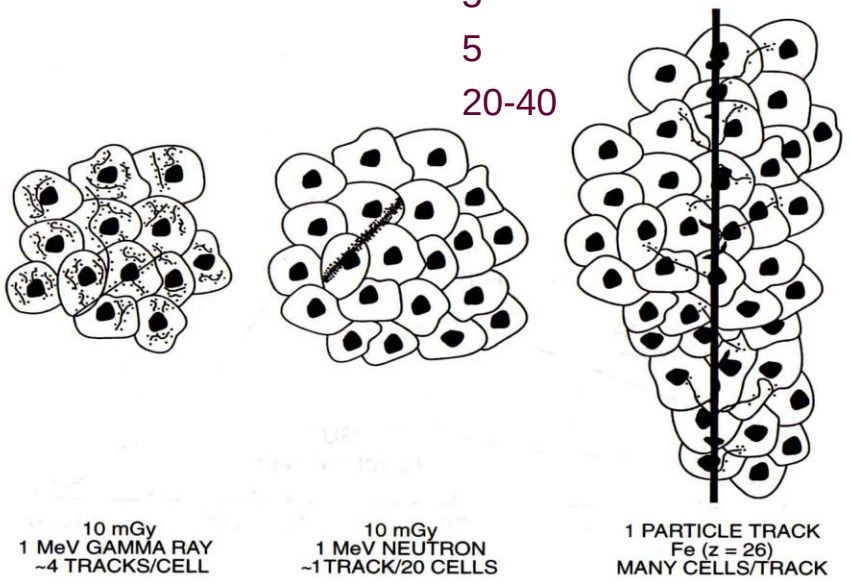
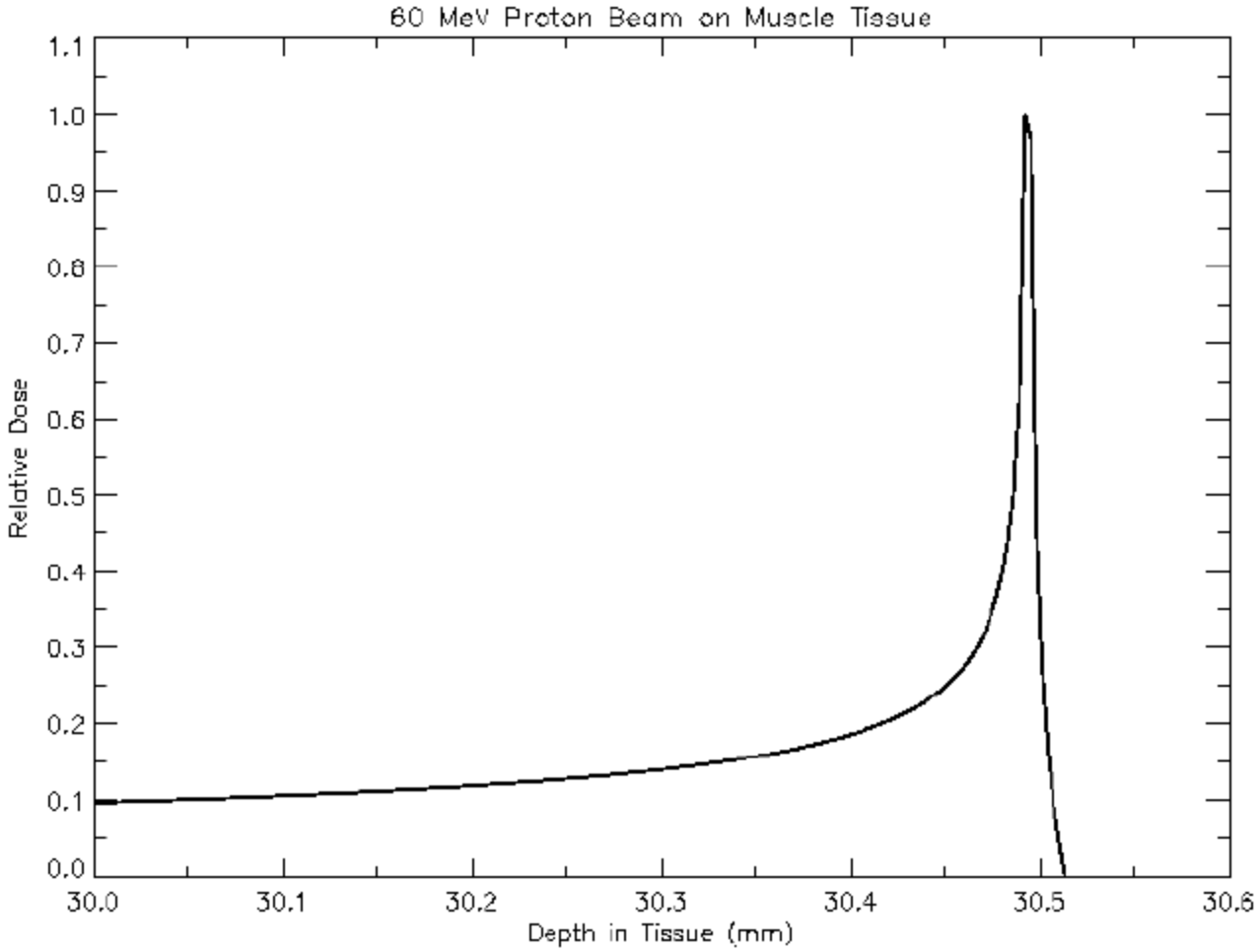


Fig. 6. Schematic to illustrate the difference in the deposition of energy at the tissue level between a low dose of low-LET radiation and two types of high-LET radiation, 1 MeV neutron, and an iron particle.


60 MeV Proton Beam on Muscle Tissue
Relative Dose
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
30.0
30.1
30.2
30.3
30.4
30.5
30.6
Depth in Tissue (mm)

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety NAIRAS Model

NASA Applied Sciences Aviation Applications Program and ASAP Project

- **Develop prototype operational aircraft radiation exposure model (adopt meteorological weather prediction paradigm)**
  - **Global**
  - **Real-Time**
  - **Data-Driven**
  - **Solar Wind-Magnetospheric Influences on Geomagnetic Shielding**
  - **Physics-Based Radiation Transport and Dosimetry**

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS)

Earth System Models

Radiation Dose Rates:

AIR (parametric)

HZETRN (physics-based)

Near-Earth Space Environment

•Badhwar/O'Neill GCR Model

•Empirical Cutoff Rigidity

(IGRF+T05)

•Physics-based Cutoff Rigidity

(LFM/CMIT+SEP-trajectory)

Earth Observations

Near-Earth Space Environment

NASA/ACE

NASA/HEAO-3

NOAA/GOES

Assimilated Atmospheric

Atmospheric Depth (NCEP/GFS)

Ground-Based

Neutron Count Monitors

Predictions/Forecasts

Ionizing Radiation Nowcast

3-D Effective Dose

3-D Differential Flux

NAIRAS Distributed Network System

High-Performance Computer Systems

Server Interface

Operational and Archival Databases

Differential Particle Flux

HZE Particles (A=5-56)

Light-Ions (A=1-4)

Neutrons

Pions and Muons

Electromagnetic Cascasde Particles

Observations, Parameters & Products

Decision Support Systems, Assessments, Management Actions

NAIRAS decision support tool for NOAA/SEC space weather forecasts, warnings, and advisories

NAIRAS available at NOAA/ADD experimental aviation-related weather forecasts, observations, and analysis

Specific analyses to support the decision making

Predict real-time radiation exposure at commercial airline altitudes (includes background GCR and SEP events)

Provide accumulated radiation exposures for representative set of domestic, international, and polar routes

Specific Decisions / Actions

Limit aircrew flight hours to within recommended annual and career limits

Alter route and/or altitude during SEP events

Value & Benefits to Society

Improvements in the decision-making, decisions, and actions

First-ever, data-driven, real-time prediction of biologically harmful radiation exposure levels at commercial airline altitudes

Quantitative and qualitative benefits from the improved decisions

Comprehensive database of radiation dose rates to formulate recommended annual and career limits to ionizing radiation exposure

Comprehensive database of radiation dose rates for airlines to assess cost/risk of polar routes

Real-time prediction of radiation exposure levels to enable optimal balance between airline cost and air traveler health risk during solar storm (SEP) events

Improve understanding of biological effects of atmospheric ionizing radiation on aircrew and passengers through collaboration of epidemiological studies by NIOSH

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety
NAIRAS Unique Features

NASA Applied Sciences Aviation Applications Program and ASAP Project

- Global
  - Geographic coverage: pole-to-pole
  - Altitude converge: Surface to 100 km
- Real-time
  - 1 hr SEP
  - 3 hr GCR
- Data-Driven
  - Solar-Cycle GCR Modulation: Ground-based neutron monitors
  - SEP spectra: NASA/ACE + NOAA/GOES
  - Geomagnetic Shielding (Internal+solar wind-magnetosphere coupling): NASA/ACE solar wind measurements
  - Atmospheric density: NCEP Global Forecasting System (GFS) (8x daily)
- Geomagnetic Shielding (solar wind-magnetosphere coupling)
  - Internal Field: IGRF
  - Magnetospheric magnetic field
    - Tsyganenko T05 (semi-empirical)
    - LFM MHD (physics-based)
  - Cutoff rigidities: Dartmouth-CISM (physics-based)
- Physics-based transport and dosimetry
  - High Charge and Energy Transport (HZETRN) Model

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety
Step 1 in NAIRAS Transition to Operations

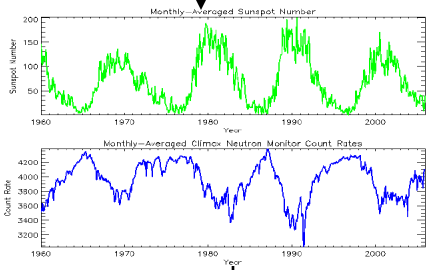
- **Experimental Data Products for Community Evaluation**
  - **4-D Effective Dose (netcdf)**
  - **Global Effective Dose Graphics**
  - **Routine Flight Planning tools**
  - **Browsers and Google Earth**
- **Data Availability**
  - **NOAA Aviation Digital Data Service (ADDS) experimental data products web interface**
    - **Commitment from NOAA NWS Aviation Services Branch**
  - **Space Environment Technologies (SET)**

Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS)

Real-time Neutron Monitor Data (e.g., IZMIRAN and LOMICKY)

↓

Fit to Climax NMC



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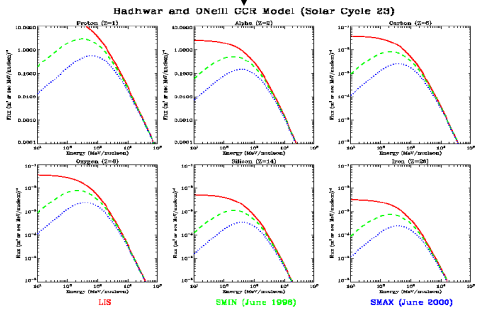
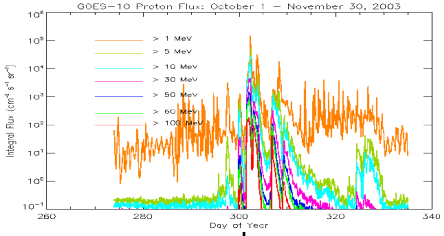
Badhwar+O'Neill GCR Model



NOAA GOES Data



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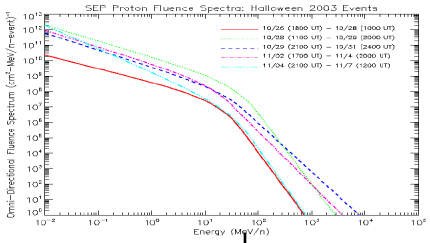
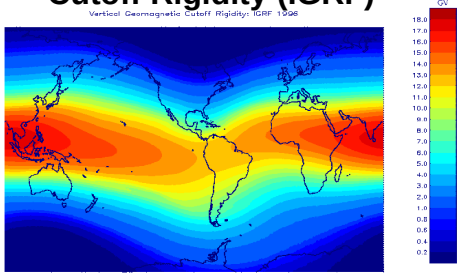
Spectral Fitting



Cutoff Rigidity (IGRF)



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Magnetospheric Magnetic Field (e.g., T05) Effects on Cutoff Rigidity

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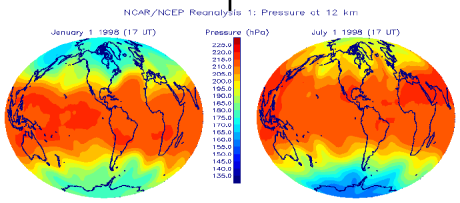
NASA/ACE Solar Wind and IMF Data

HZETRN + Dosimetry

↑

Atmospheric Density



NCEP/GFS

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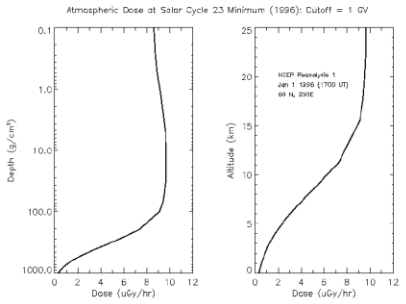
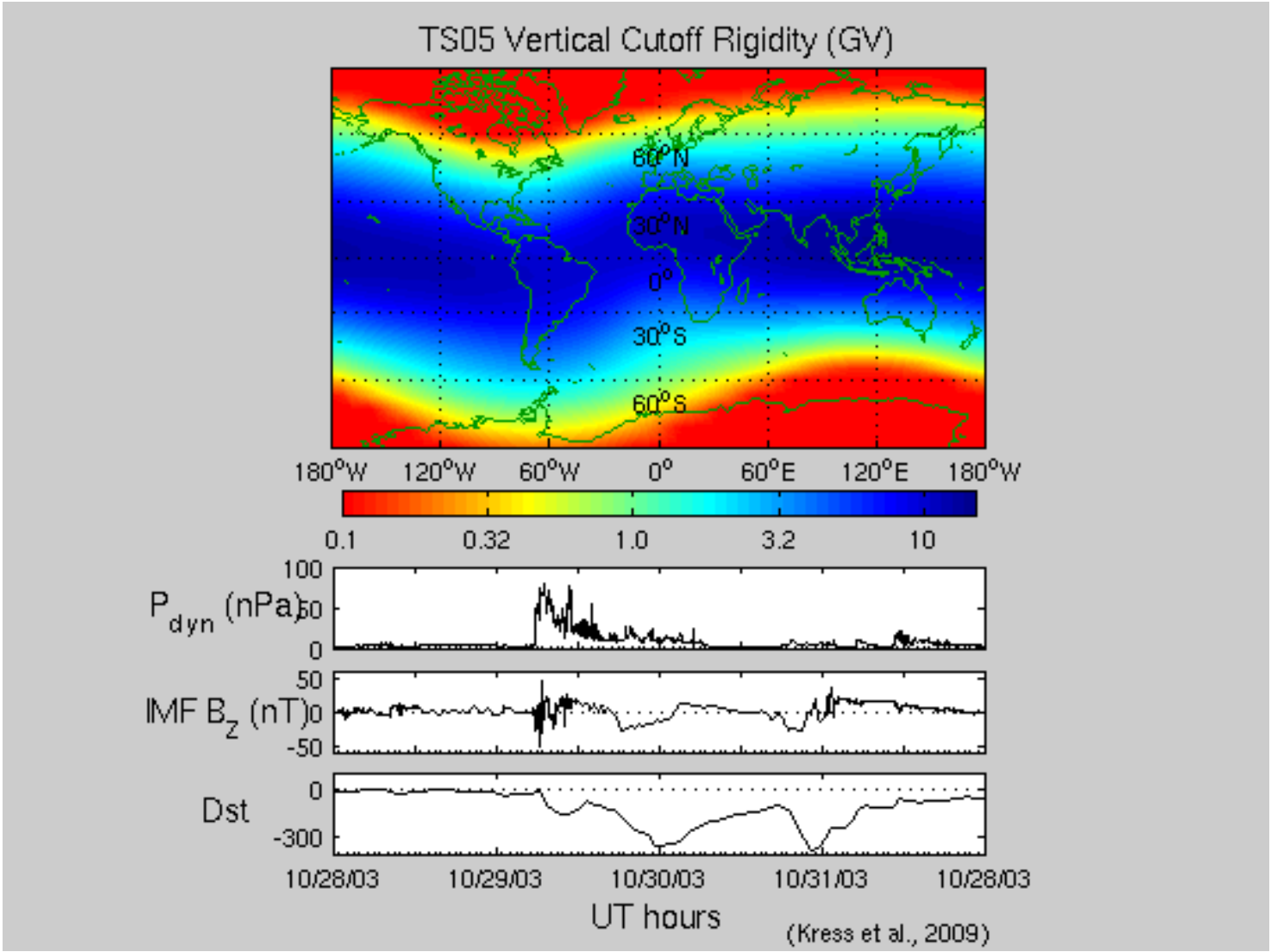


Atmospheric Dose and Dose Equivalent


TS05 Vertical Cutoff Rigidity (GV)
60°N
30°N
0°
30°S
60°S
180°W
120°W
60°W
0°
60°E
120°E
180°W
0.1
0.32
1.0
3.2
10
P dyn (nPa)
100
50
0
IMF B z (nT)
50
0
-50
Dst
0
-300
10/28/03
10/29/03
10/30/03
10/31/03
10/28/03
UT hours
(Kress et al., 2009)

NAIRAS Summary (1)

- **Programmatic**
  - NAIRAS adopted terrestrial weather prediction paradigm to space weather generated radiation field
    - Completed Year 1
  - Prototype model completion anticipated mid-2011
- **Halloween 2003 SEP Case Study Results**
  - Atmospheric radiation exposure during Halloween 2003 SEP event may have reached 22% of recommended ICRP prenatal limit (1 mSv) for typical polar route.
  - Neglecting time-dependent geomagnetic storm influences on cutoff rigidity during SEP events significantly underestimates radiation exposure by ~ 40% to ~ factor of 3
  - IGRF field can result in underestimation of high-latitude radiation exposure by ~ 30% for SEP events without accompanying geomagnetic storm

NAIRAS Summary (2)

- **GCR Component (initial)**
  - The real-time GCR model is accurate, on average, to within 25% for solar minimum and to within 50% for solar maximum
    - The larger model errors during solar maximum could be due to the long ACE sampling intervals
  - "Smoothed" neutron data generally improved fit
  - Separating neutron data according to solar polar field polarity significantly improved fit
  - Recommend using average heliospheric potential computed from all real-time neutron monitor measurements