MIT
HAYSTACK
OBSERVATORY

Space Weather Resources Available Through MIT Haystack's Madrigal Database

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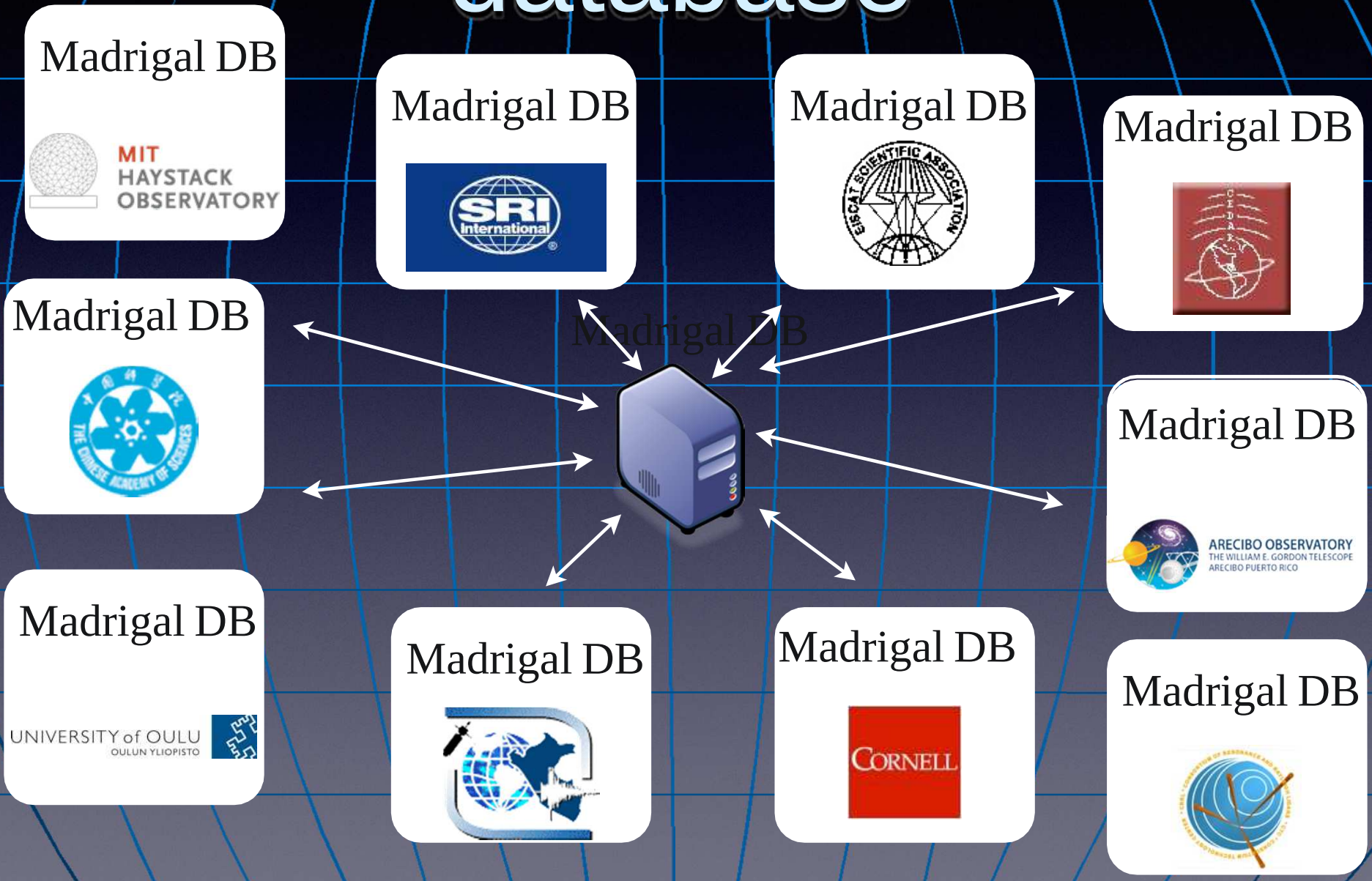
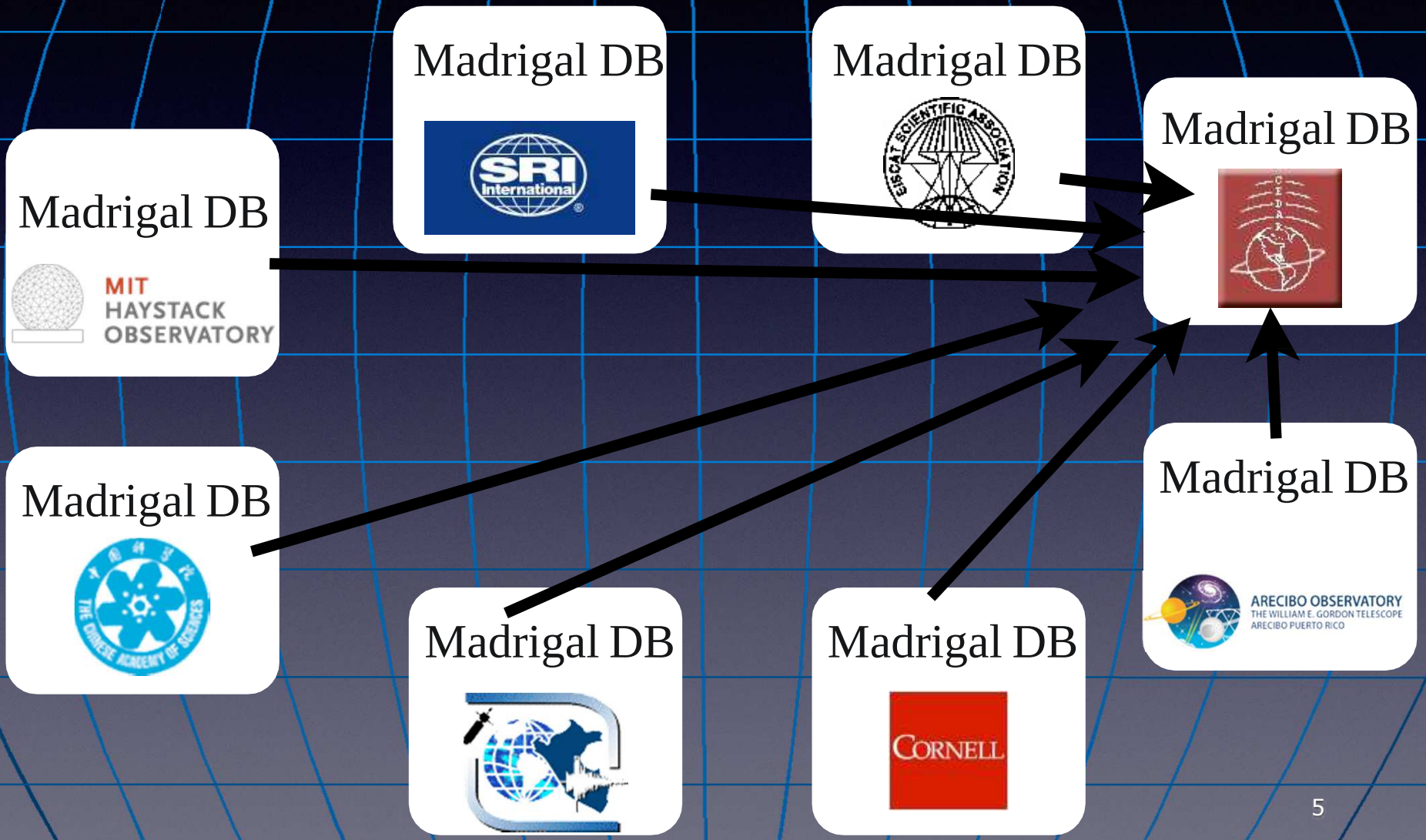
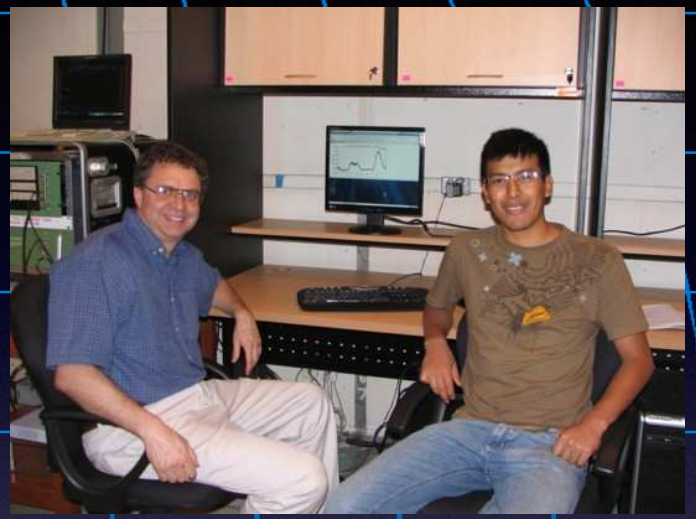
Madrigal is a distributed database

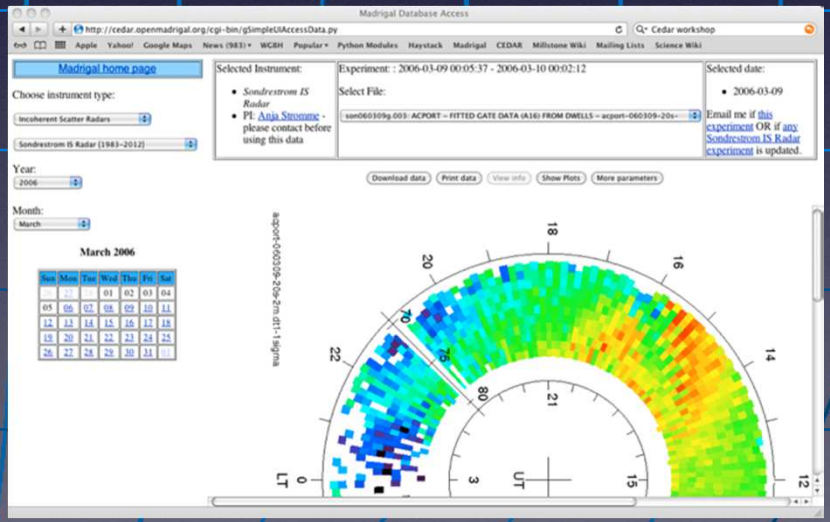


Cedar Madrigal archive imports all data weekly



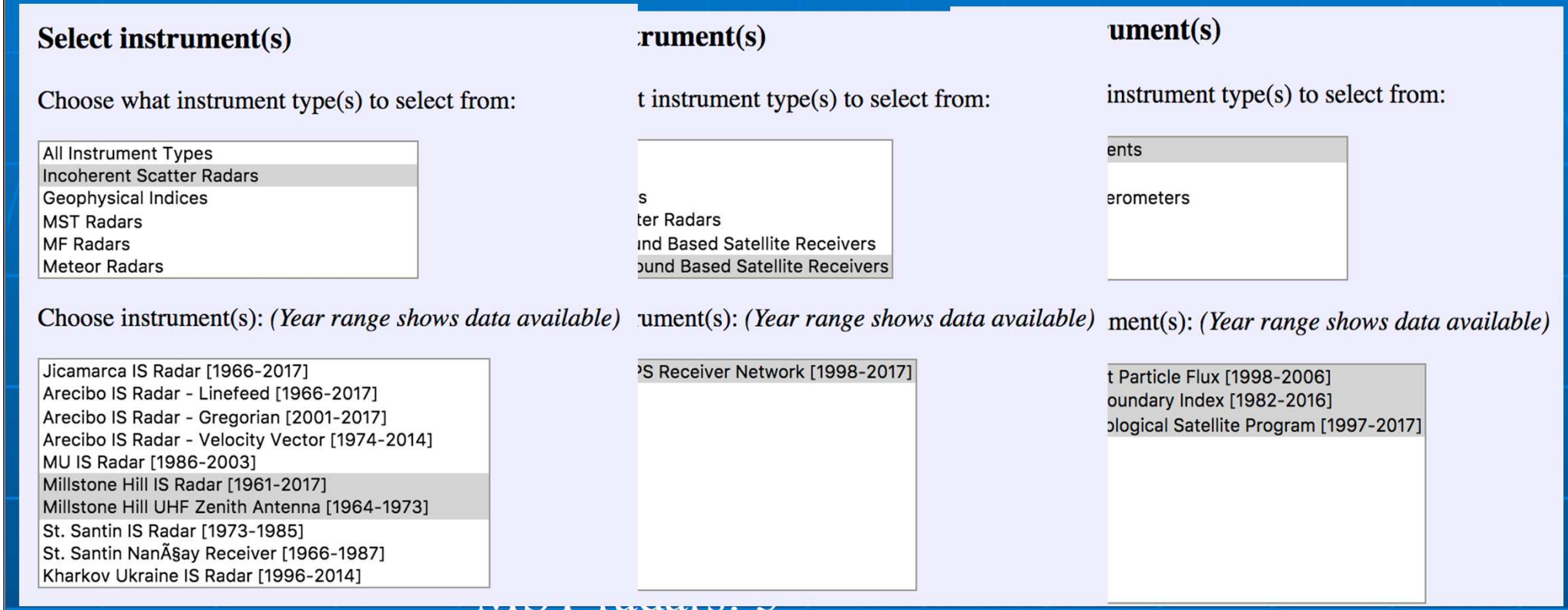
Madrigal is open-source





www.openmadrigal.org

The Madrigal database stores data from a wide variety of upper atmosphere research instruments

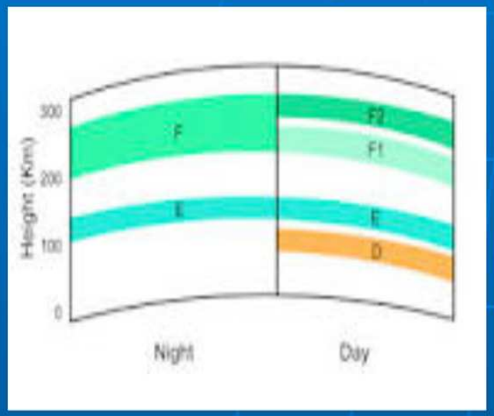


- MF radars: 16
- Meteor radars: 7
- FPI: 23
- Michelson Interferometers: 6
- Lidars: 4
- Photometers: 4

Incoherent Scatter Radars

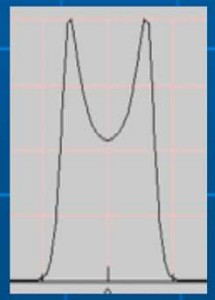
- Global Network of High Power Radars
- Measure Physical Properties of the Space Environment
  - Electron density, electron temperature, ion temperature, plasma velocity, and more...

ISR Measured and Inferred Parameters



Inferred Parameters

Electric Field strength
Conductivity and current
Neutral air temperature
Wind speed

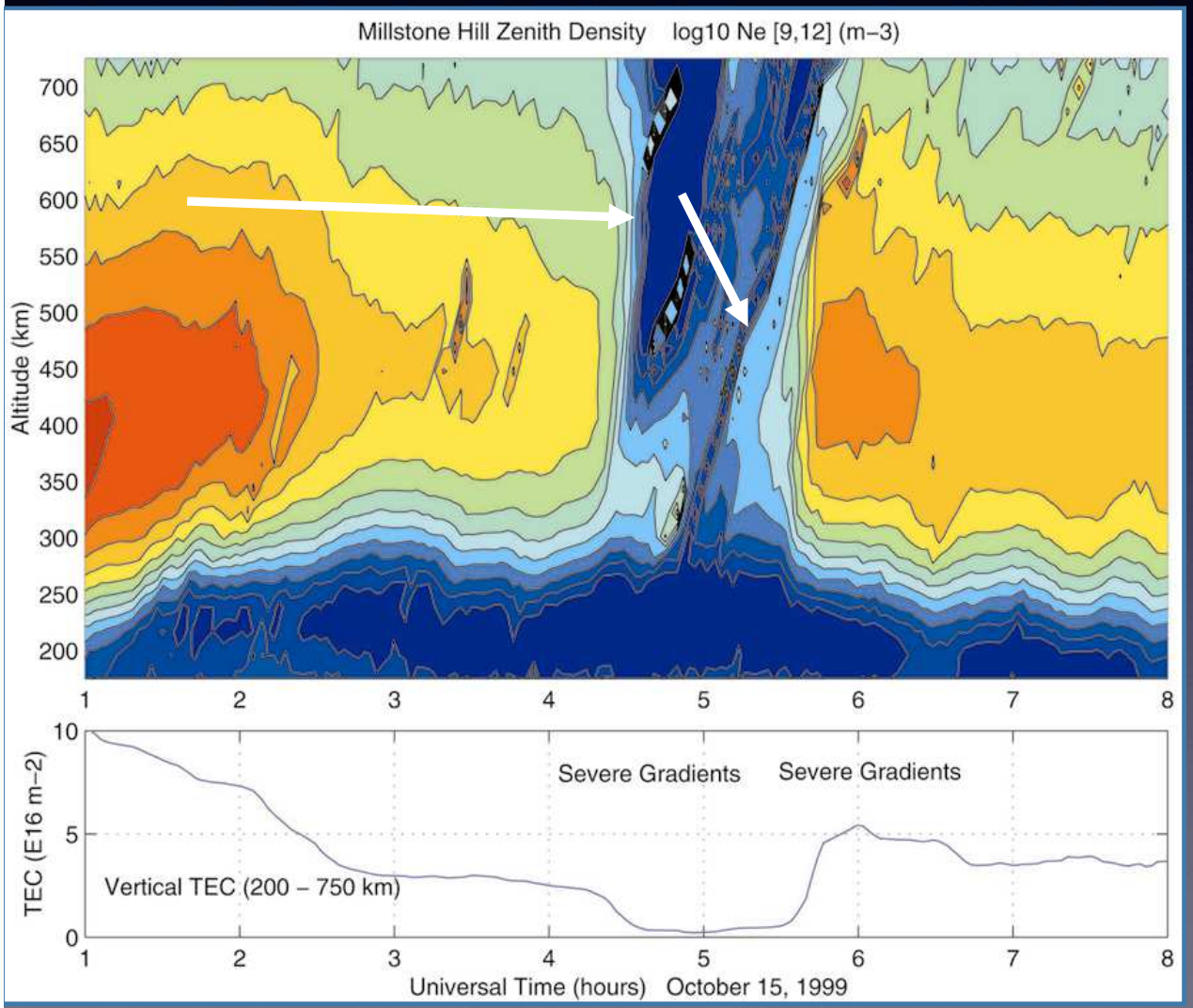


Quality of measurement

- Error bar on each parameter
- Spatial resolution
- Time resolution
- Spatial coverage

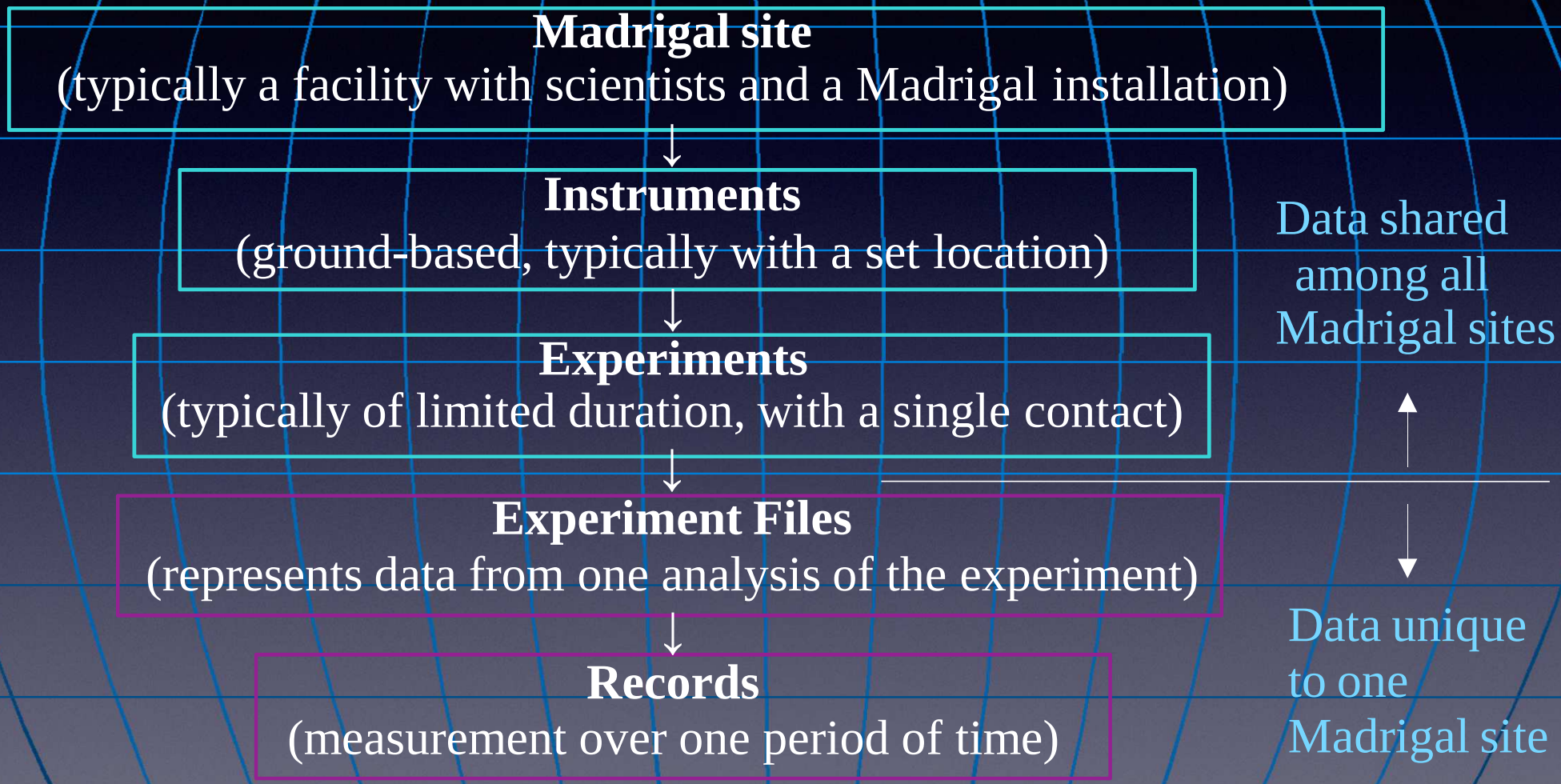
Space Weather Effects

Storms can adversely affect GPS, pagers and cell phones.



Millstone Hill Radar

Madrigal Data Model



Madrigal Derivation Engine

- Derived parameters appear to be in file
- Engine determines all parameters that can be derived
- Easy to add new derived parameters using code written in C or Fortran

Classes of derived parameters

- Space, time
  - Examples: Local time, shadow height
- Geophysical
  - Examples: Kp, Dst, Imf, F10.7
- Magnetic
  - Examples: Bmag, Mag conjugate lat and long, Tsyganenko magnetic equatorial plane intercept
- Models
  - Examples: MSIS, IRI

Examples of Space Weather Analysis using Data from Madrigal

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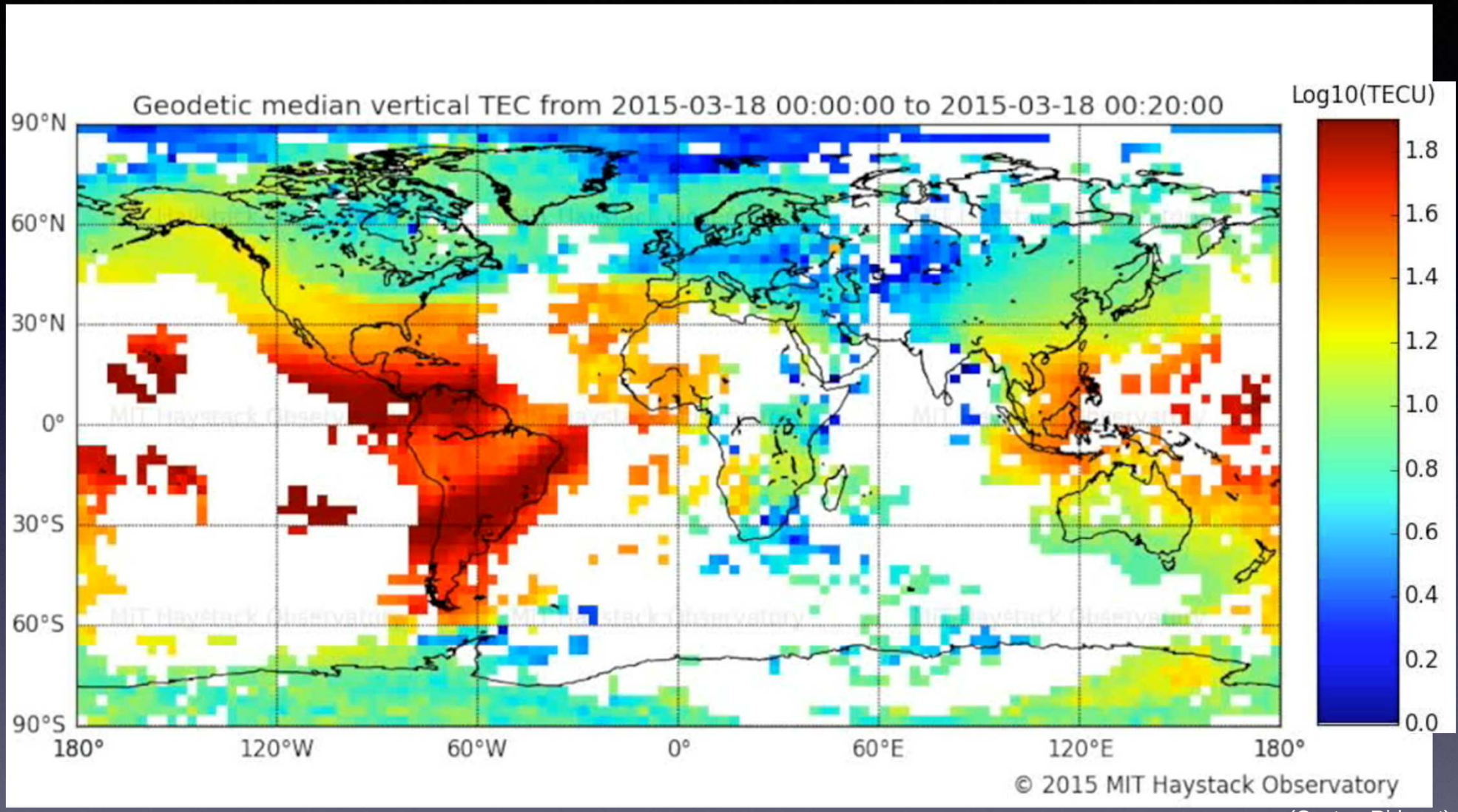
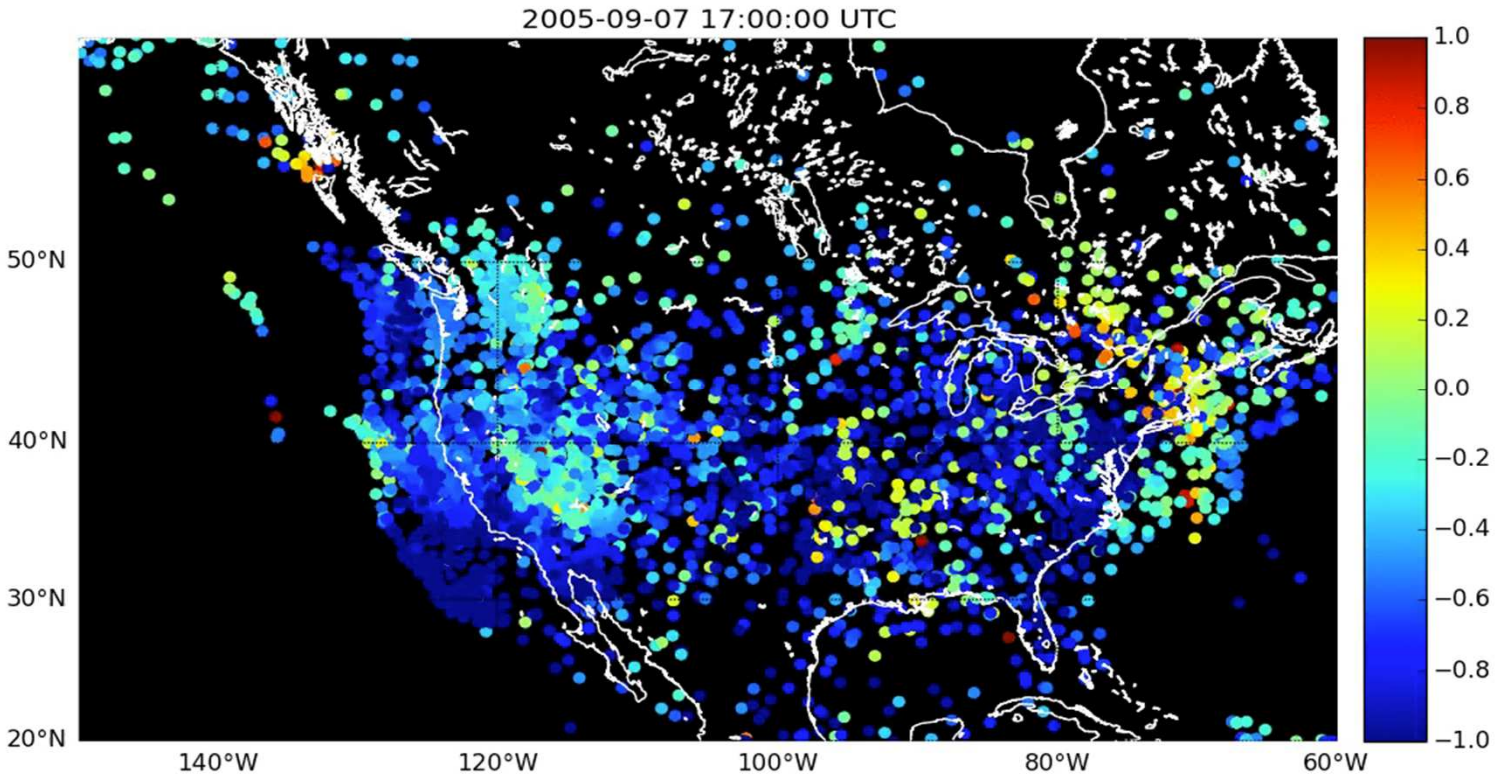
Total Electron Content from GNSS Data: Global Ionospheric Space Weather



(Coster, Rideout)

4000+ GNSS geodetic receivers from many sources (e.g. UNAVCO, Scripps Orbit and Permanent Array Center)
Processed by MIT Haystack to extract ionospheric delay information
Data provides large scale picture of global ionospheric space weather variations
Available to space science community through NSF supported Madrigal distributed database

Solar Flare Effects from Sept 7, 2005 Solar Flare



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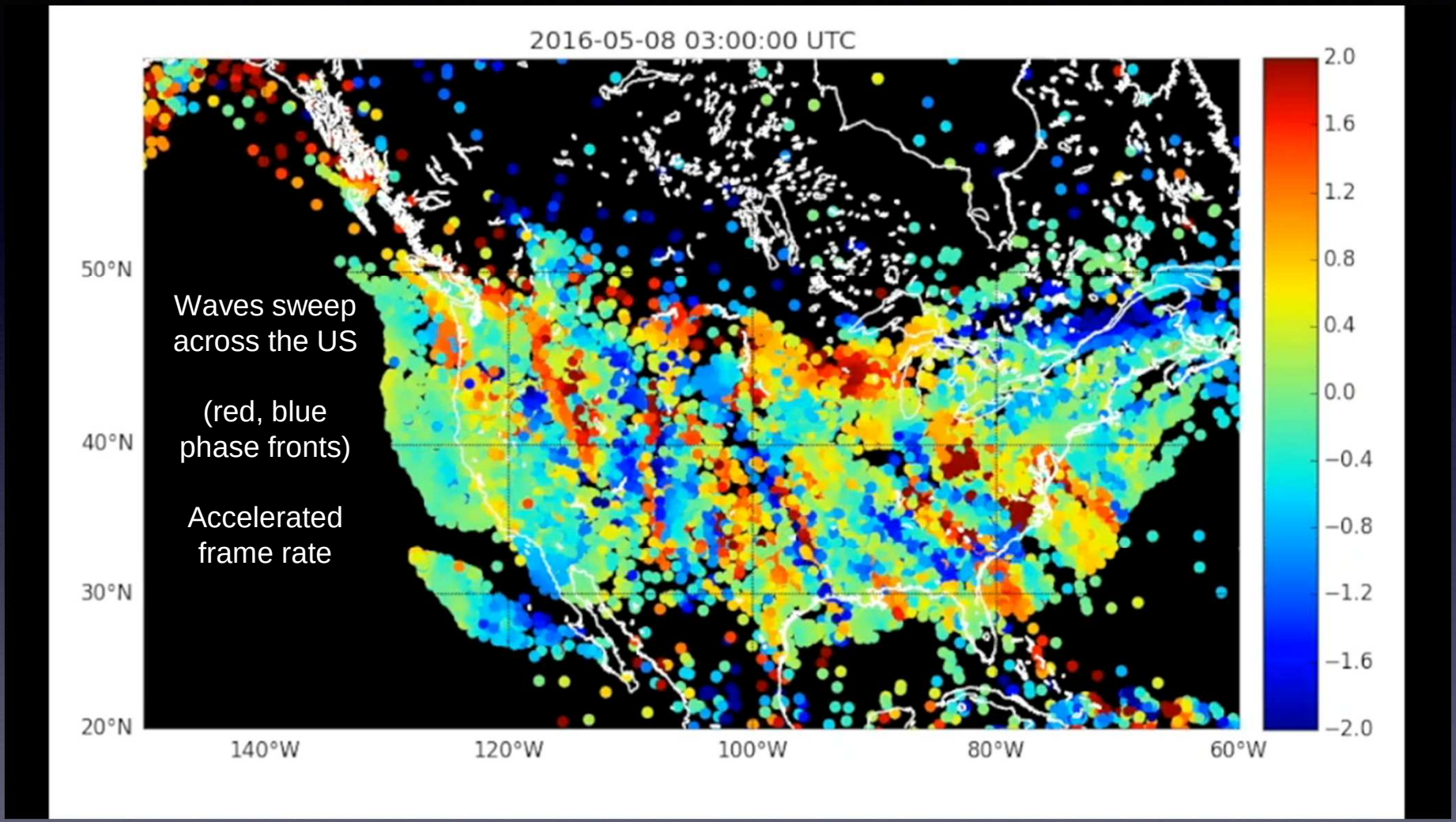
Traveling Ionospheric Disturbances: Space Weather over the US Mainland

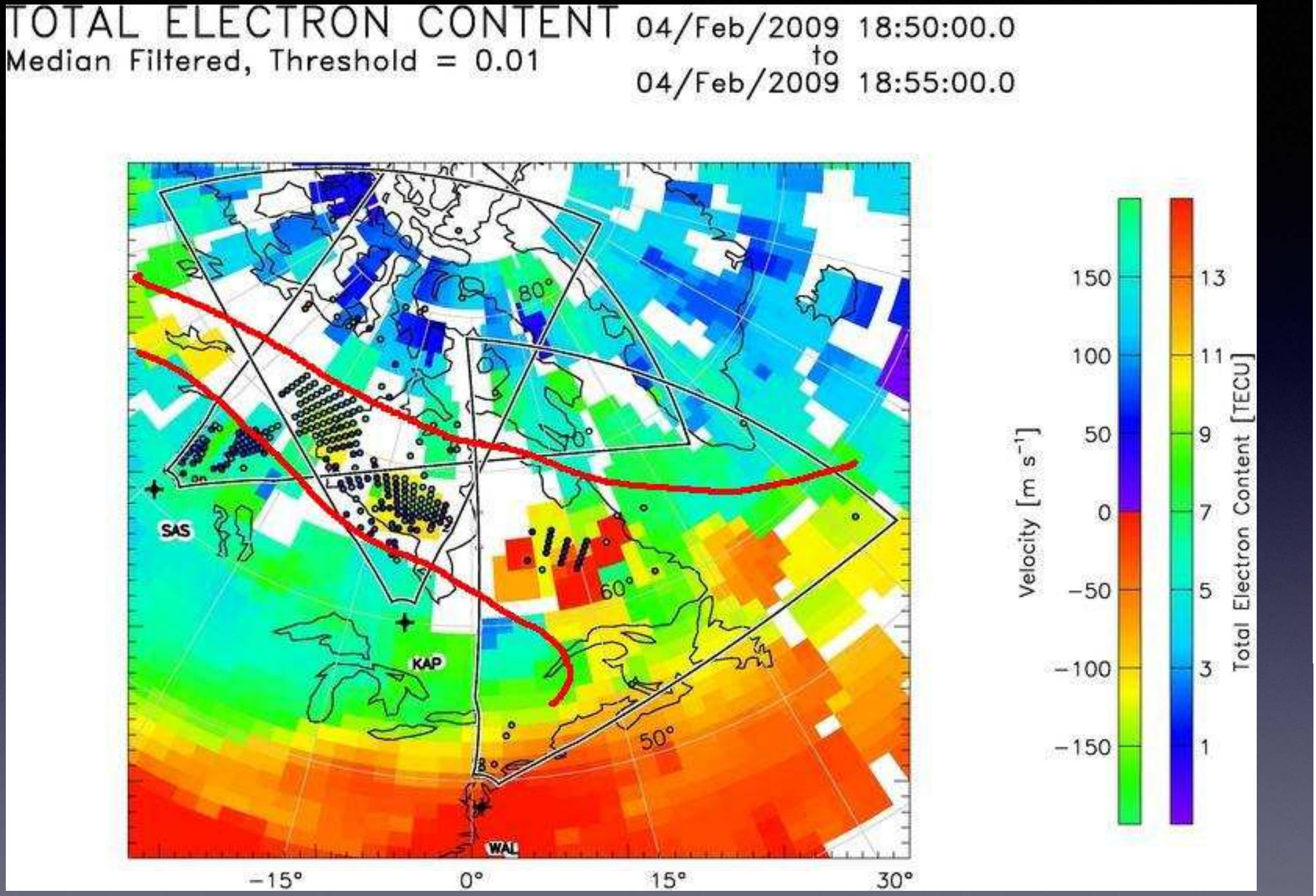


(Coster, Rideout, Vierinen)

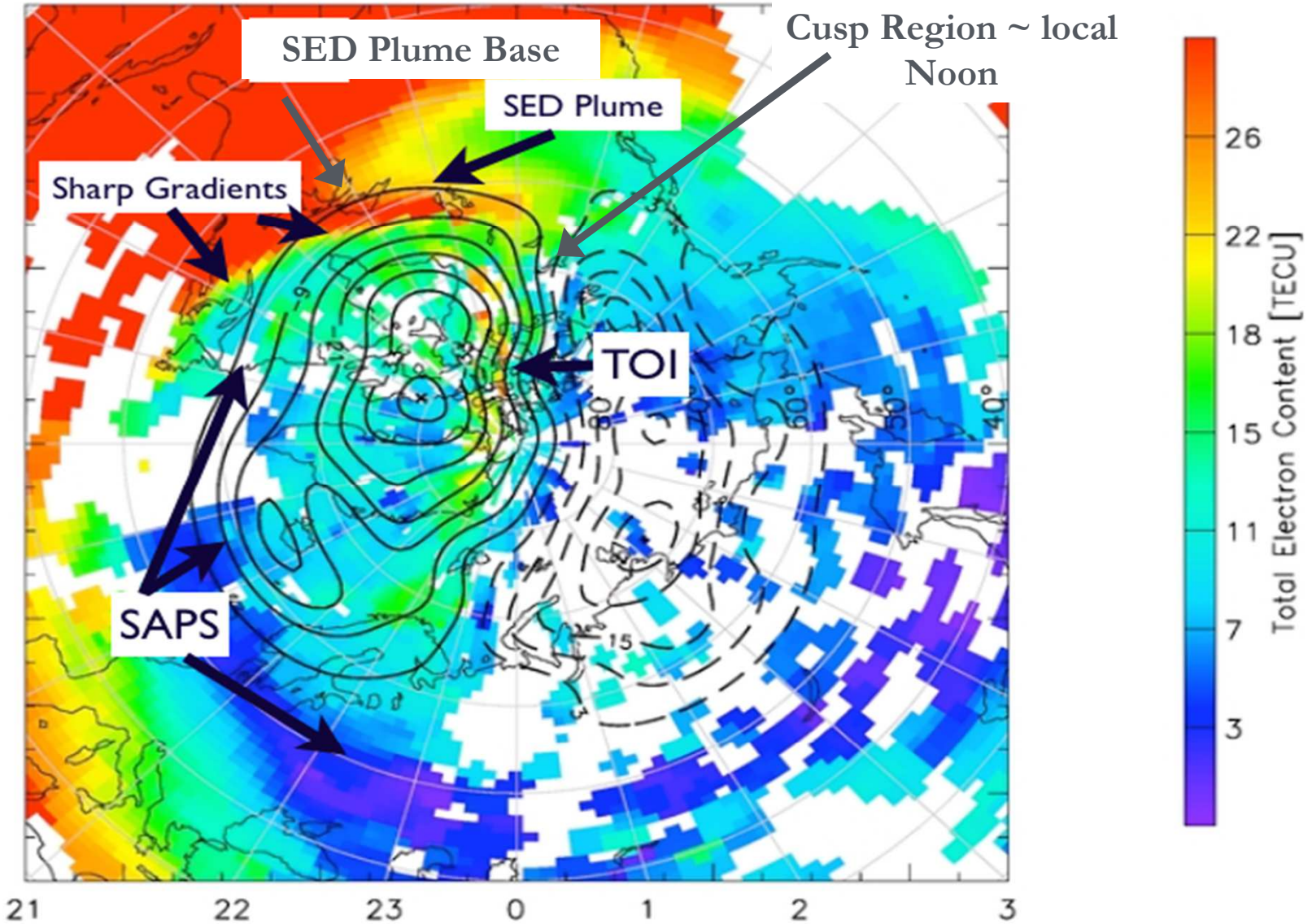
Subtracting background density reveals traveling ionospheric disturbances

Launched by neutral atmospheric processes, geomagnetic storms

Causes significant space weather variations; active research topic


TOTAL ELECTRON CONTENT
Median Filtered, Threshold = 0.01
04/Feb/2009 18:50:00.0
to
04/Feb/2009 18:55:00.0
80°
70°
60°
50°
SAS
KAP
WAL
−15°
0°
15°
30°
Velocity [m s^{-1}]
150
100
50
0
−50
−100
−150
Total Electron Content [TECU]
13
11
9
7
5
3
1

Common Features observed in TEC during geomagnetically disturbed conditions



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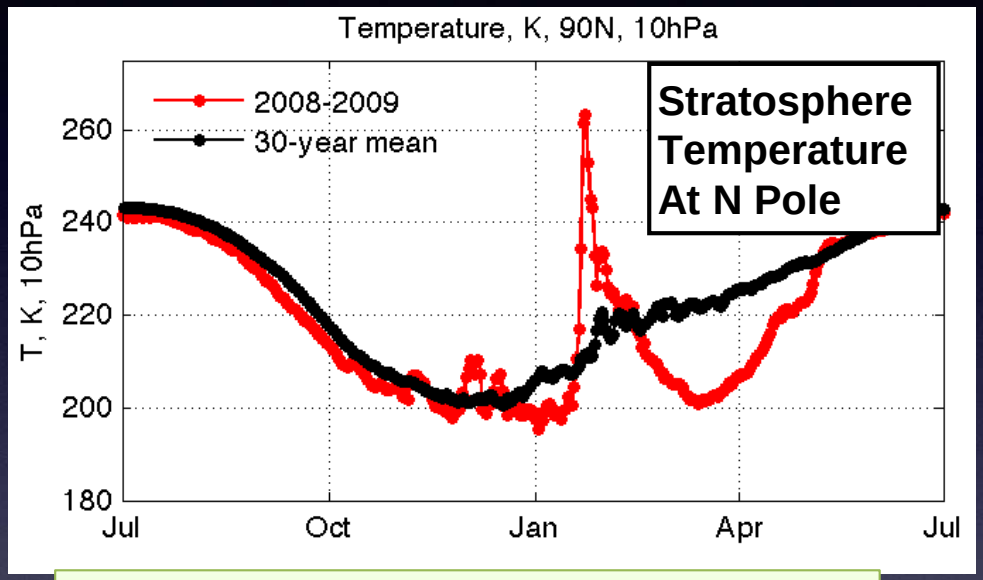
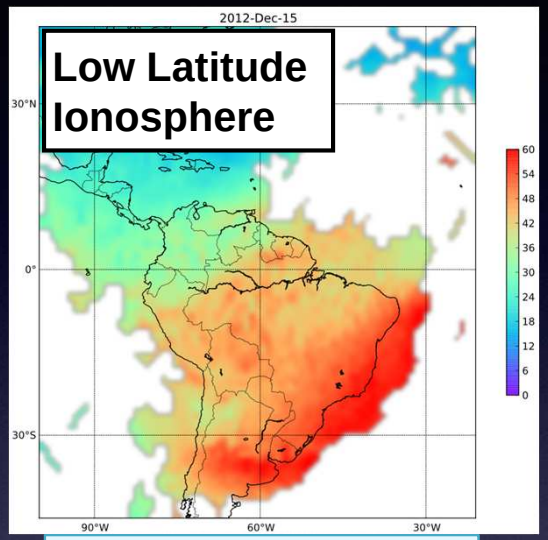
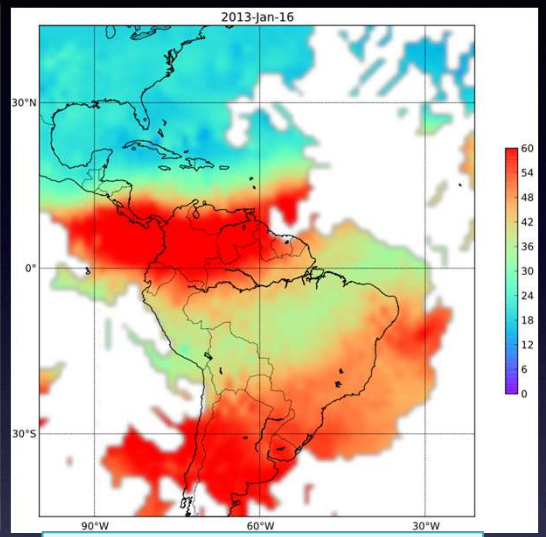
Whole Atmosphere Coupling: Space Weather From Below



Stratospheric temperature over Arctic rapidly increases during warming events…



TEC before SSW



TEC during SSW

…and low-latitude ionosphere is strongly disturbed a few days later

(Goncharenko et al)

Goal: Advance our understanding of mechanisms connecting atmospheric regions as a fundamental space weather driver

Stratospheric Sudden Warming (SSW) is a large disturbance highlighting these connections

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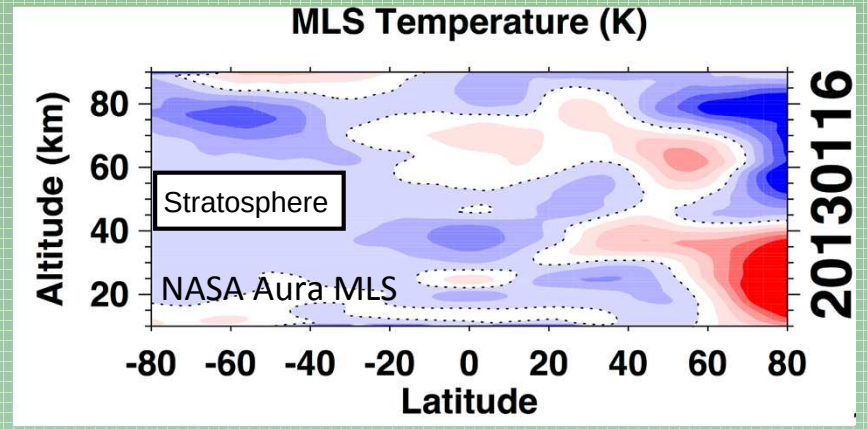
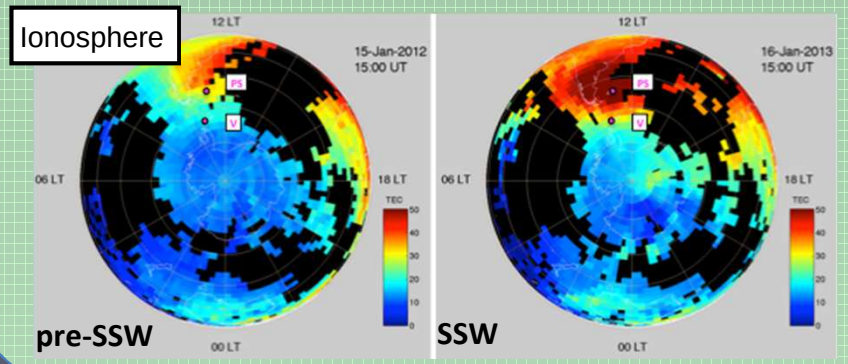
Modeling and Observing Space Weather Effects of Whole Atmosphere Coupling

NSF

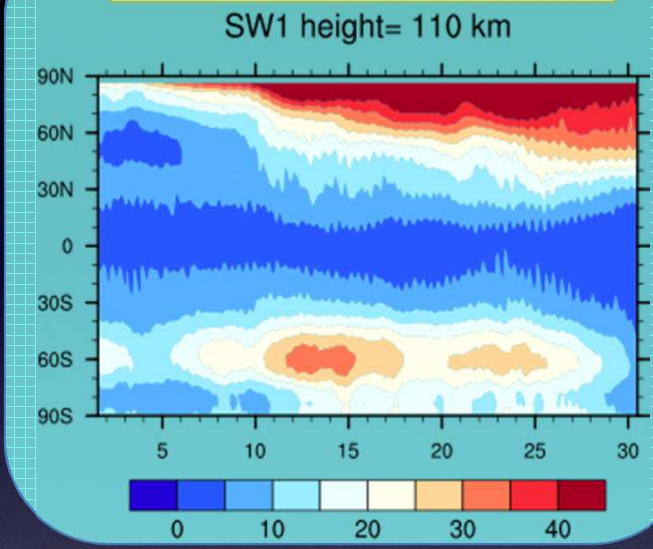
***Observations**: global coupling, pole to pole, stratosphere to ionosphere*



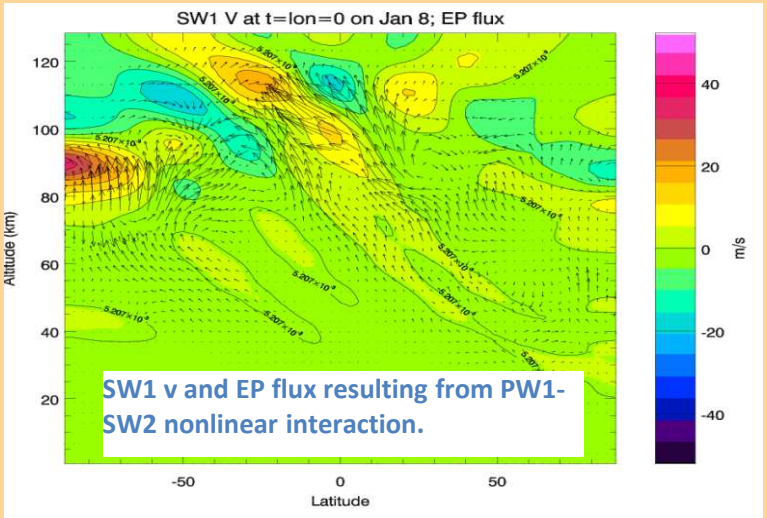
GPS TEC over Antarctica



TIMEGCM simulations

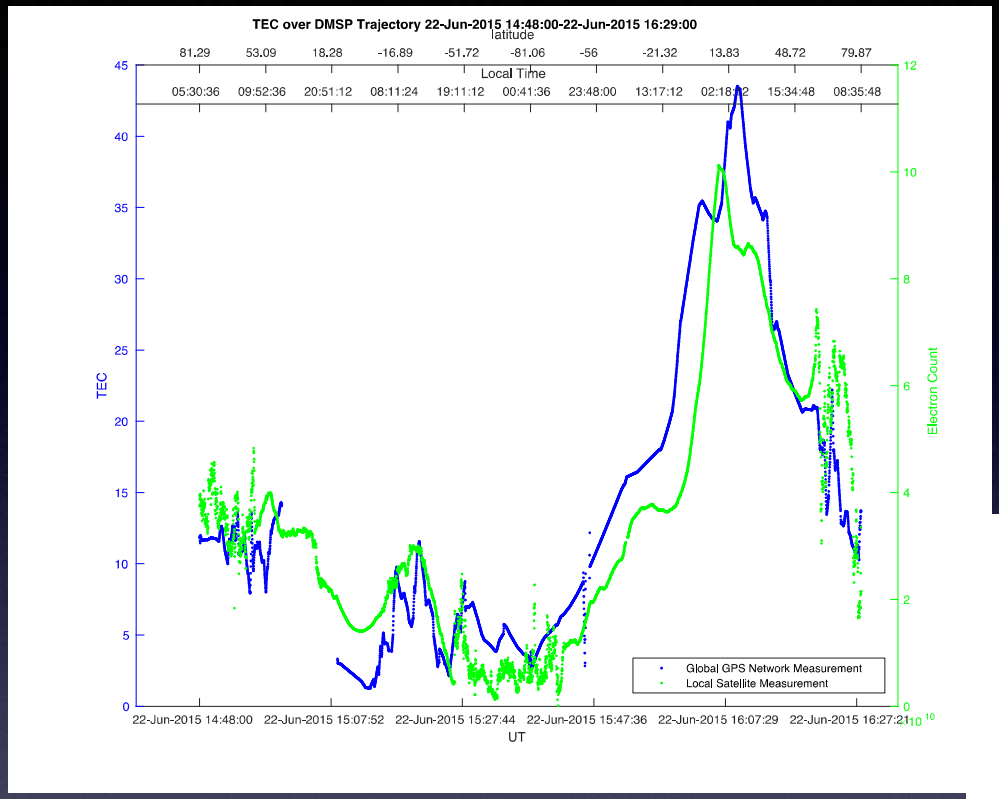


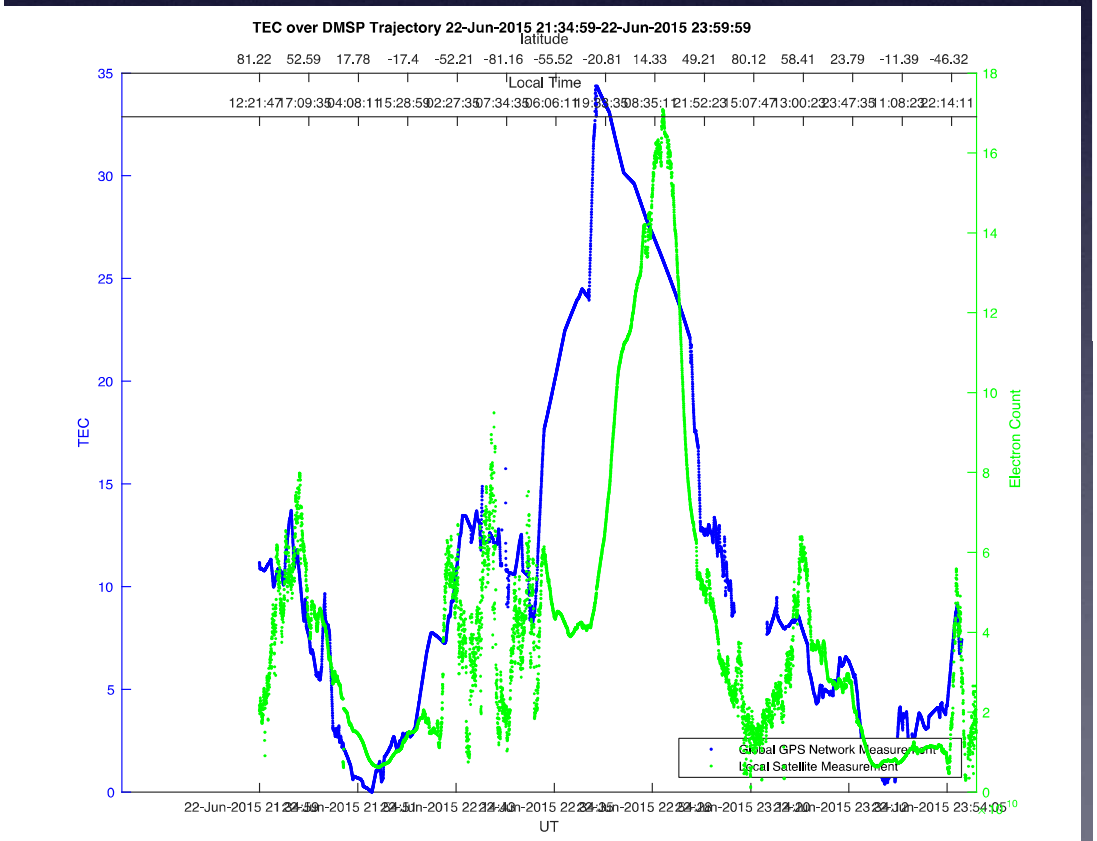
***Theory**: nonlinear interaction of planetary waves and tides*



(Goncharenko et al)

Comparison of DMSP Electron Density and GPS TEC before and during 22 Jun 2015 storm





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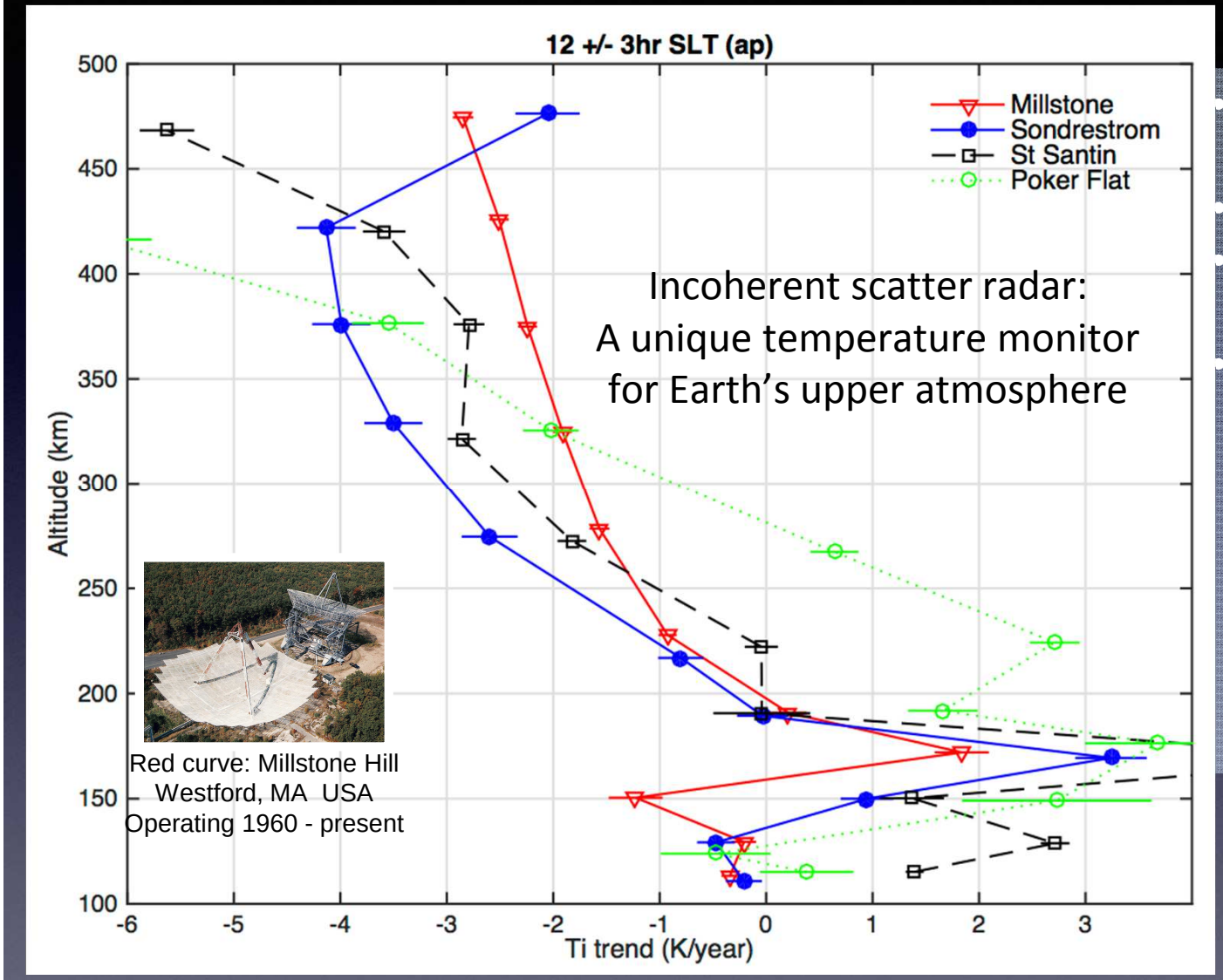
Long Term Ionospheric Climatology: Setting the Baseline for Space Weather



- Substantial upper atmosphere cooling
- Height & time dependent
- Affects space debris lifetime (for example)
- Causes under study:
  - Not just CO_2 increase
  - Atmospheric gravity wave activity?

NSF Madrigal upper atmosphere database and capabilities were essential to these studies

(Zhang, Holt)

Ionospheric cooling (dayside) measured with multiple ionospheric radars:
Similar intensity and height dependence across different locations
30+ - 50+ years of NSF supported upper atmosphere radar observations

Summary

The Madrigal open-source database provides easy access to ground-based and space-based space weather data products

Data products in Madrigal directly address:

Improve Space Weather Services through Advancing Understanding and Forecasting

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