



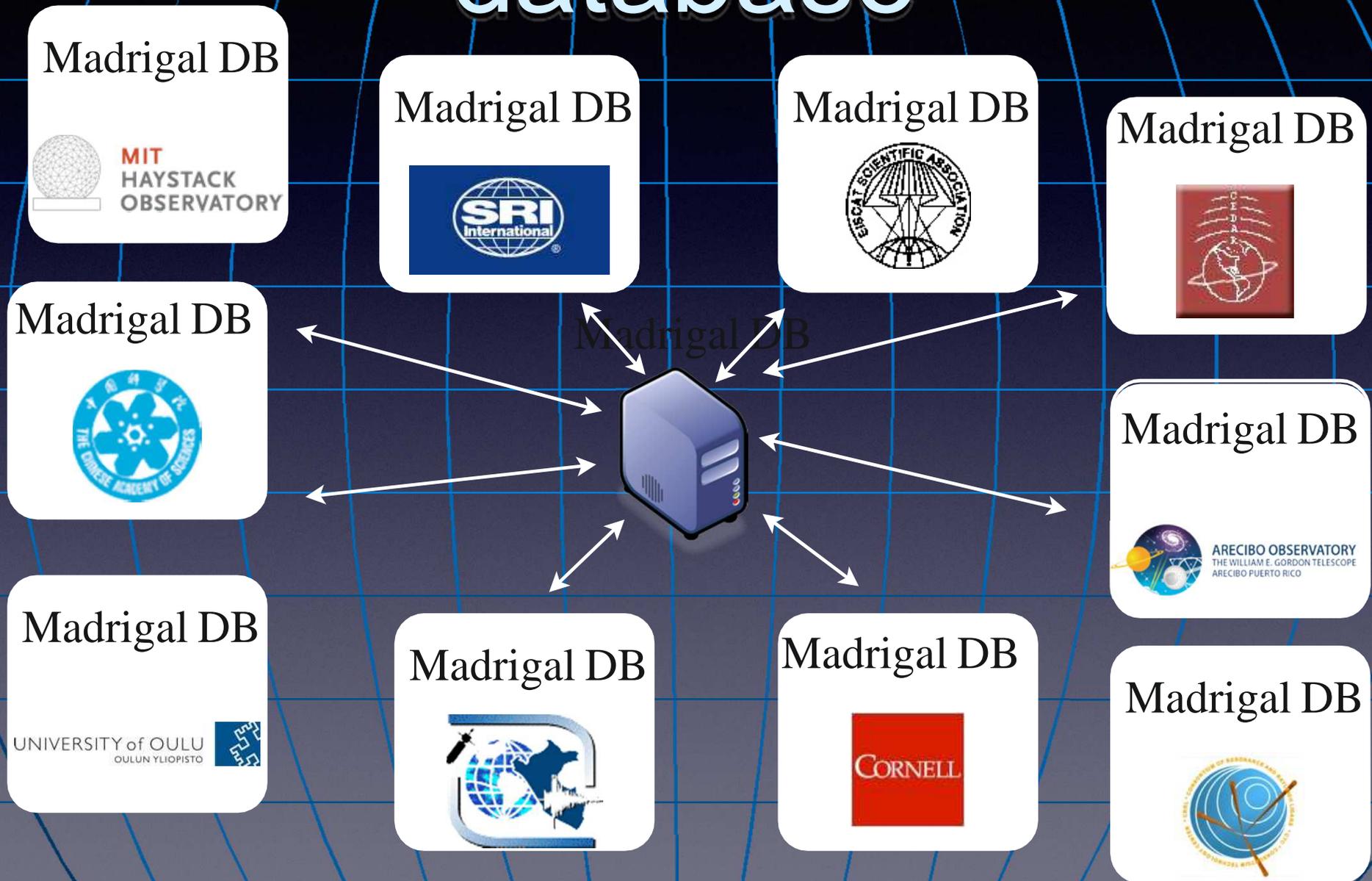
MIT
HAYSTACK
OBSERVATORY



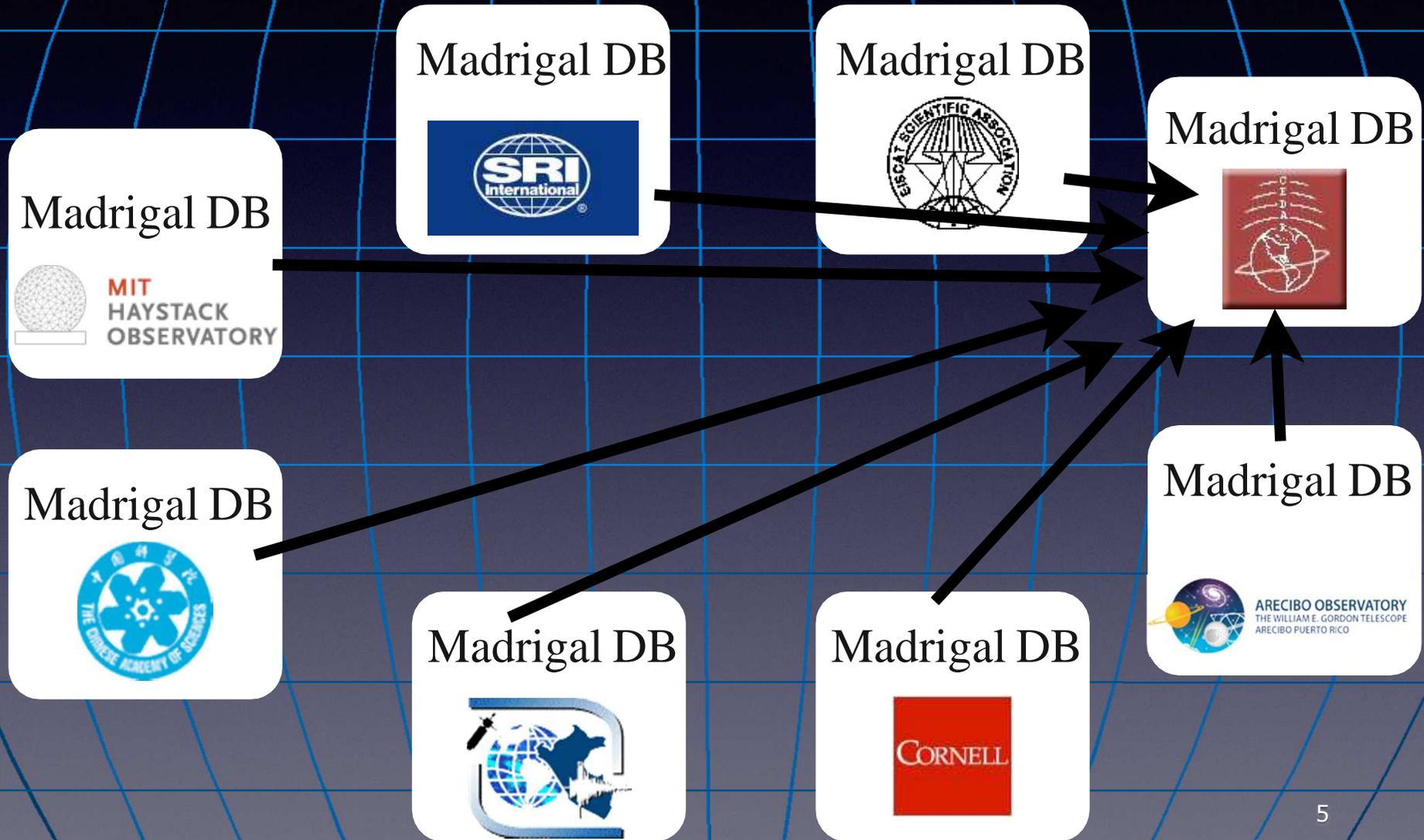
Space Weather Resources Available Through MIT Haystack's Madrigal Database

Anthea J. Coster,
William Rideout, Philip Erickson, Larisa
Goncharenko, Shunrong Zhang
MIT Haystack Observatory

Madrigal is a distributed database



Cedar Madrigal archive imports all data weekly



Madrigal is open-source

Madrigal Database

http://www.openmadrigal.org/

The Open Madrigal Initiative

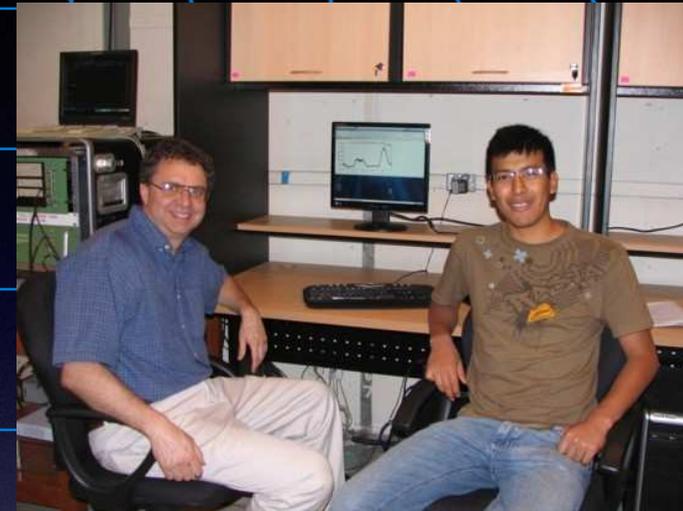
- [What is Madrigal?](#)
- [Download/update Madrigal](#) - includes Madrigal server and client APIs
- [Documentation](#)
 - [Web access](#)
 - [Script access](#)
- [Empirical Ionospheric Models](#)
- [Subversion Source Control](#)
- [Mailing Lists](#)
- [Administering OpenMadrigal](#)

The OpenMadrigal project seeks to develop and support an on-line database for geospace data. The project has been led by [MIT Haystack Observatory](#) since 1980, but now has active support from [Icamarca Observatory](#) and other community members. Madrigal is a robust, World Wide Web based system capable of managing and serving archival and real-time data, in a variety of formats, from a wide range of ground-based instruments. Madrigal is installed at a number of sites around the world. Data at each Madrigal site is locally controlled and can be updated at any time, but shared metadata between Madrigal sites allow searching of all Madrigal sites at once from any Madrigal site.

Madrigal is a robust, World Wide Web based system capable of managing and serving archival and real-time data, in a variety of formats, from a wide range of instruments. Data can be accessed from the Madrigal sites at [Millstone Hill, USA](#), [EISCAT, Norway](#), [SRI International, USA](#), [Arecibo, Puerto Rico](#), [Cornell University, USA](#), [Icamarca, Peru](#), the [Institute of Geology and Geophysics](#), the Chinese Academy of Sciences, and the [CEDAR Madrigal archive](#) using standard Web browsers; and directly, using APIs which are available for python, Matlab, and IDL.



Suggestions and comments should be directed to madrigal@haystack



Madrigal Database Access

http://cedar.openmadrigal.org/cgi-bin/simpleAccessData.py

Madrigal home page

Choose instrument type:
Incoherent Scatter Radars
Sondrestrom IS Radar (1983-2012)

Selected Instrument:
Sondrestrom IS Radar
Pl. Anka Sromatic - please contact before using this data

Experiment: 2006-03-09 00:05:37 - 2006-03-10 00:02:12

Select File:
san060309g003-ACPORT-FITTED GATE DATA (A16) FROM DMELLS - acport-060309-20s-

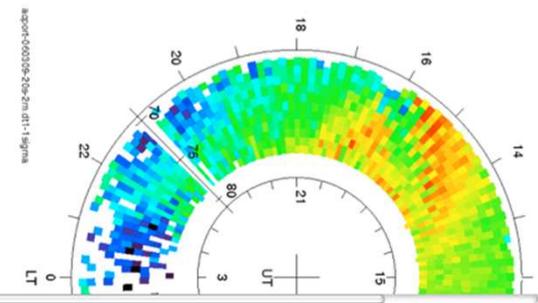
Selected date:
2006-03-09

Year: 2006
Month: March

Download data | Print data | View info | Show Plots | More parameters

March 2006

Sun	Mon	Tue	Wed	Thu	Fri	Sat
..	01	02	03	04	05	06
07	08	09	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31



www.openmadrigal.org

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

Select instrument(s)

Choose what instrument type(s) to select from:

All Instrument Types
 Incoherent Scatter Radars
 Geophysical Indices
 MST Radars
 MF Radars
 Meteor Radars

Choose instrument(s): *(Year range shows data available)*

Jicamarca IS Radar [1966-2017]
 Arecibo IS Radar - Linefeed [1966-2017]
 Arecibo IS Radar - Gregorian [2001-2017]
 Arecibo IS Radar - Velocity Vector [1974-2014]
 MU IS Radar [1986-2003]
 Millstone Hill IS Radar [1961-2017]
 Millstone Hill UHF Zenith Antenna [1964-1973]
 St. Santin IS Radar [1973-1985]
 St. Santin NanÅşay Receiver [1966-1987]
 Kharkov Ukraine IS Radar [1996-2014]

Instrument(s)

Choose instrument type(s) to select from:

Incoherent Scatter Radars
 Ground Based Satellite Receivers
 Ground Based Satellite Receivers

Choose instrument(s): *(Year range shows data available)*

GPS Receiver Network [1998-2017]

Instrument(s)

Choose instrument type(s) to select from:

Interferometers
 Interferometers

Choose instrument(s): *(Year range shows data available)*

Interferometer Particle Flux [1998-2006]
 Interferometer Boundary Index [1982-2016]
 Interferometer Biological Satellite Program [1997-2017]

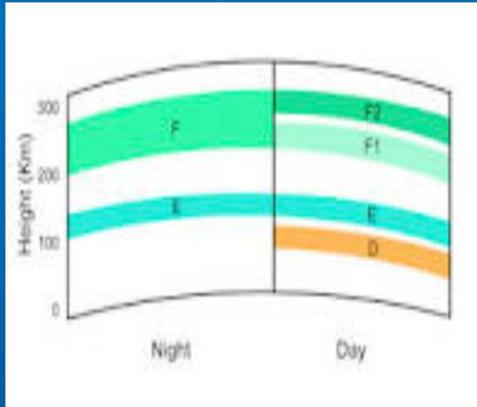
- MF radars: 16
- Meteor radars: 7
- FPI: 23
- Michelson Interferometers: 6
- Lidars: 4
- Photometers: 4

Incoherent Scatter Radars



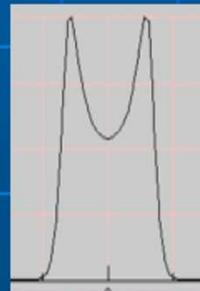
- Global Network of High Power Radars
- Measure Physical Properties of the Space Environment
 - Electron density, electron temperature, ion temperature, plasma velocity, and more...

ISR Measured and Inferred Parameters



Inferred Parameters

Electric Field strength
Conductivity and current
Neutral air temperature
Wind speed



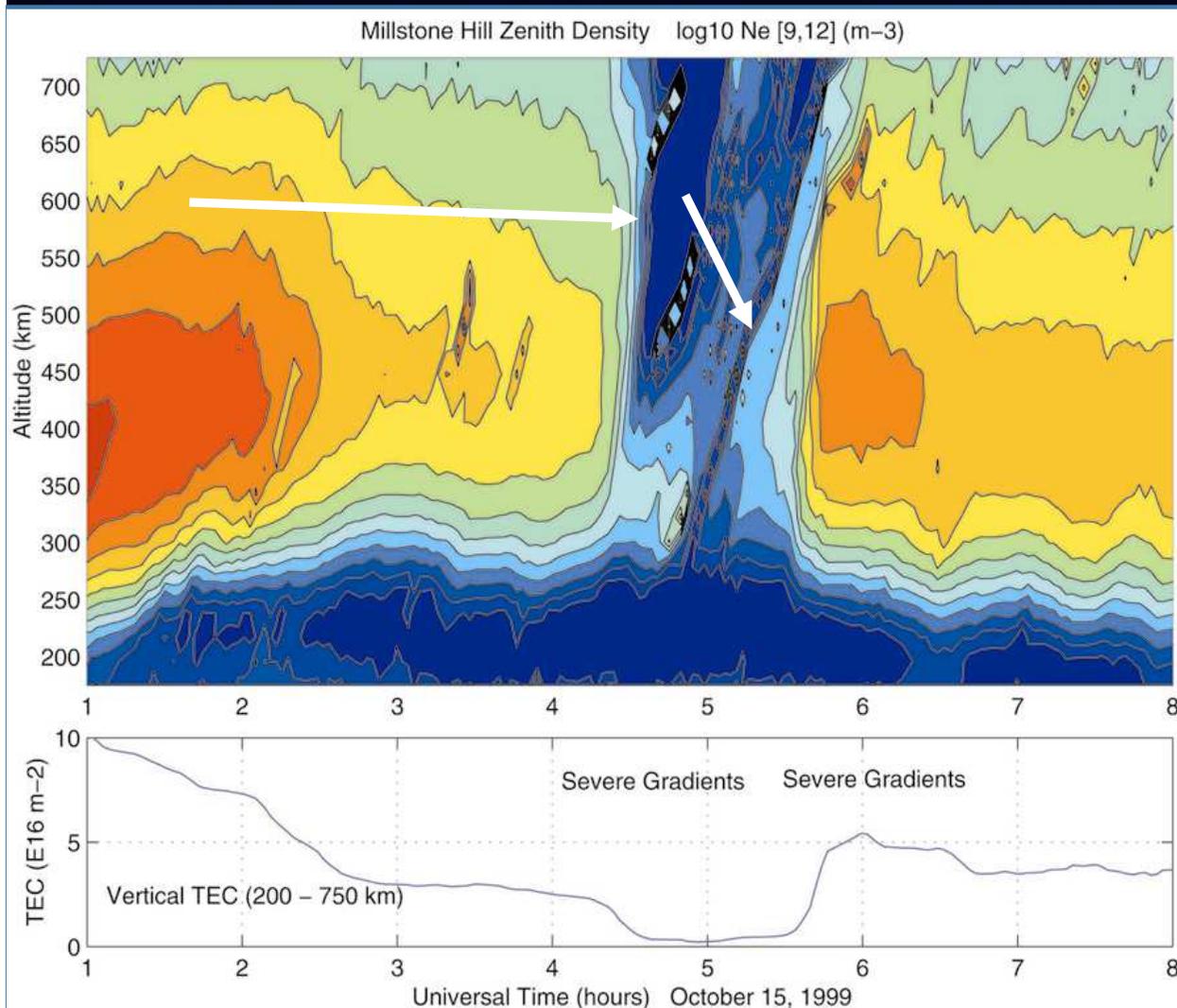
Quality of measurement

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



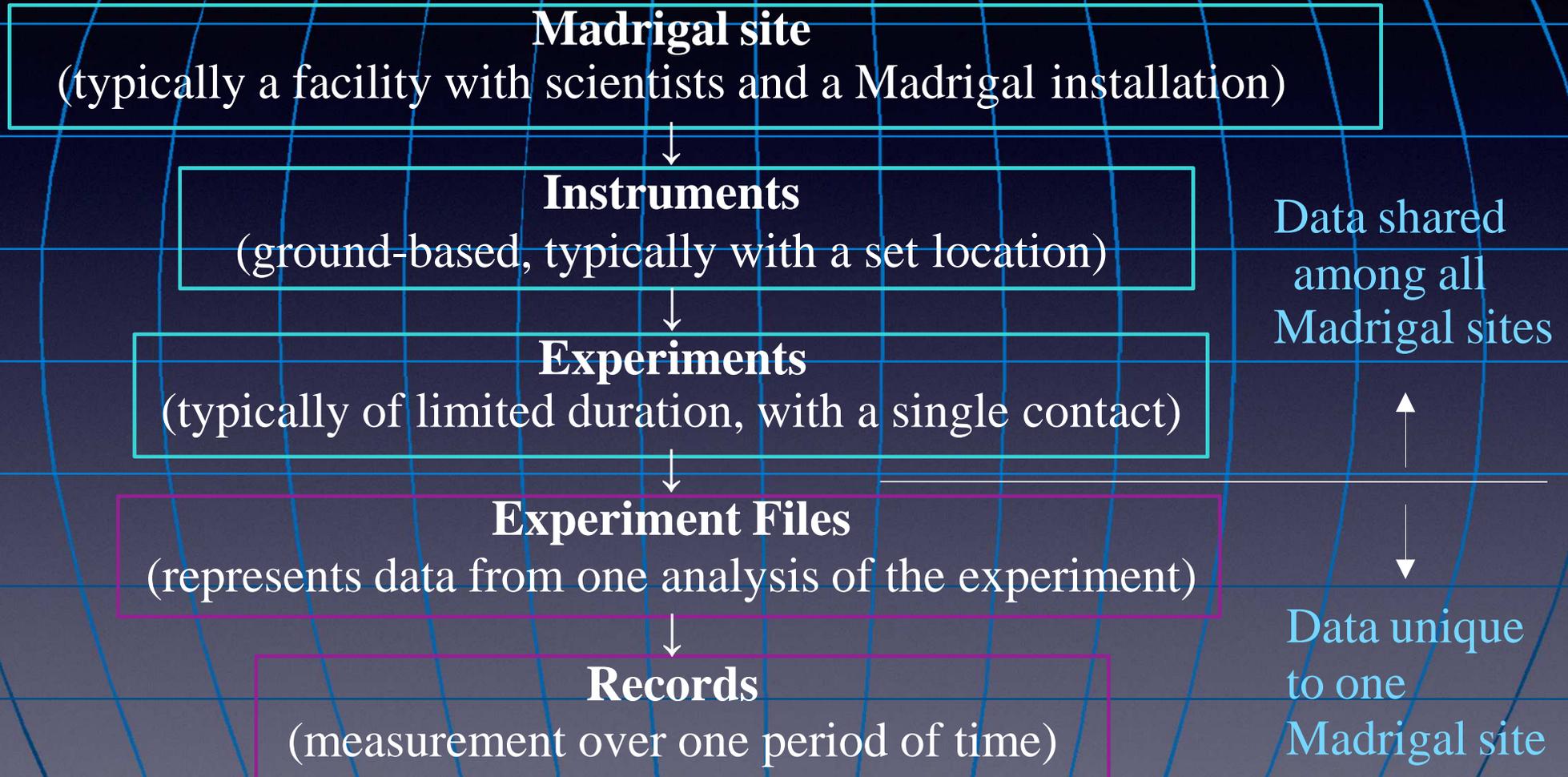
Space Weather Effects

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

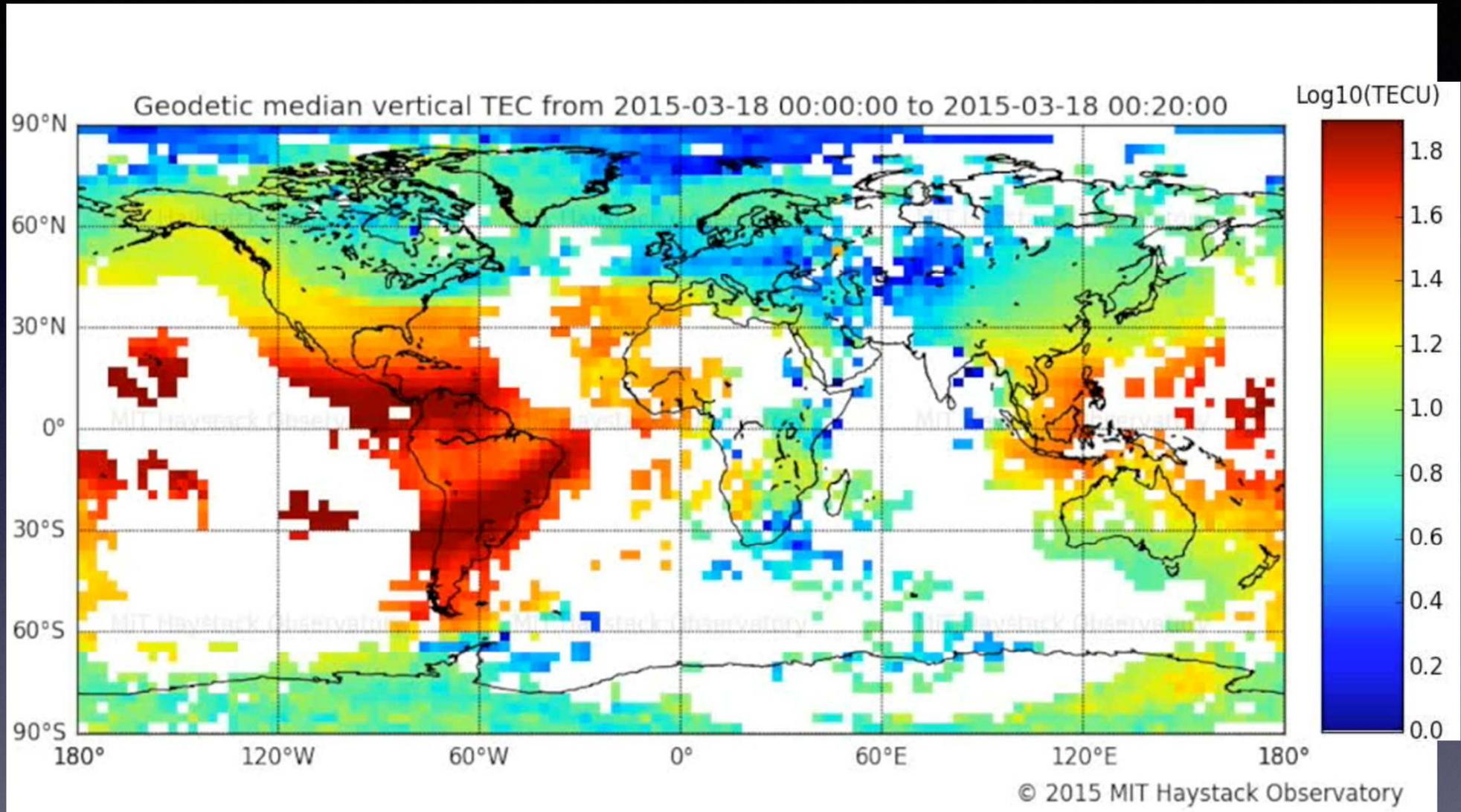
Classes of derived parameters

- 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



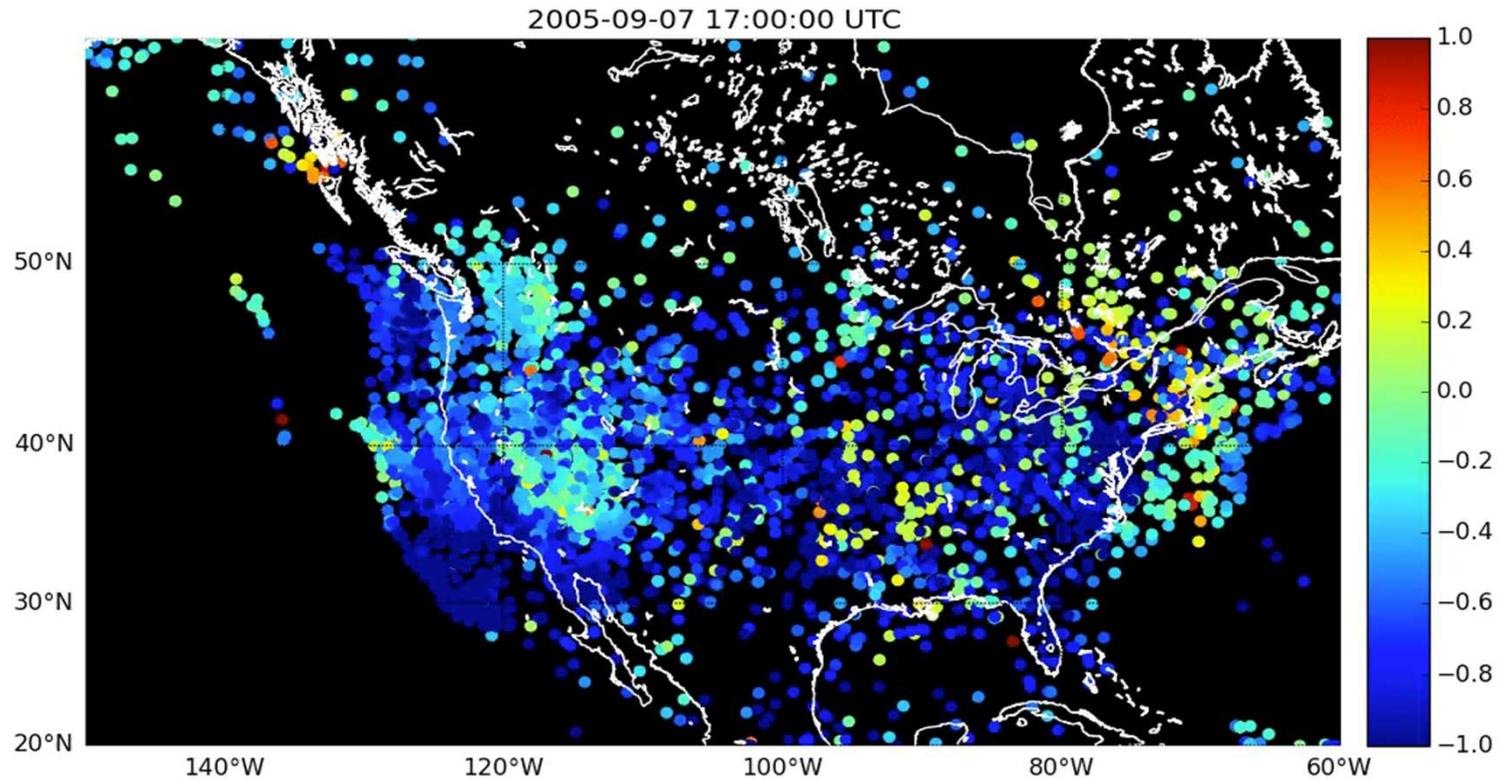
Total Electron Content from GNSS Data: Global Ionospheric Space Weather



(Coster, Rideout)

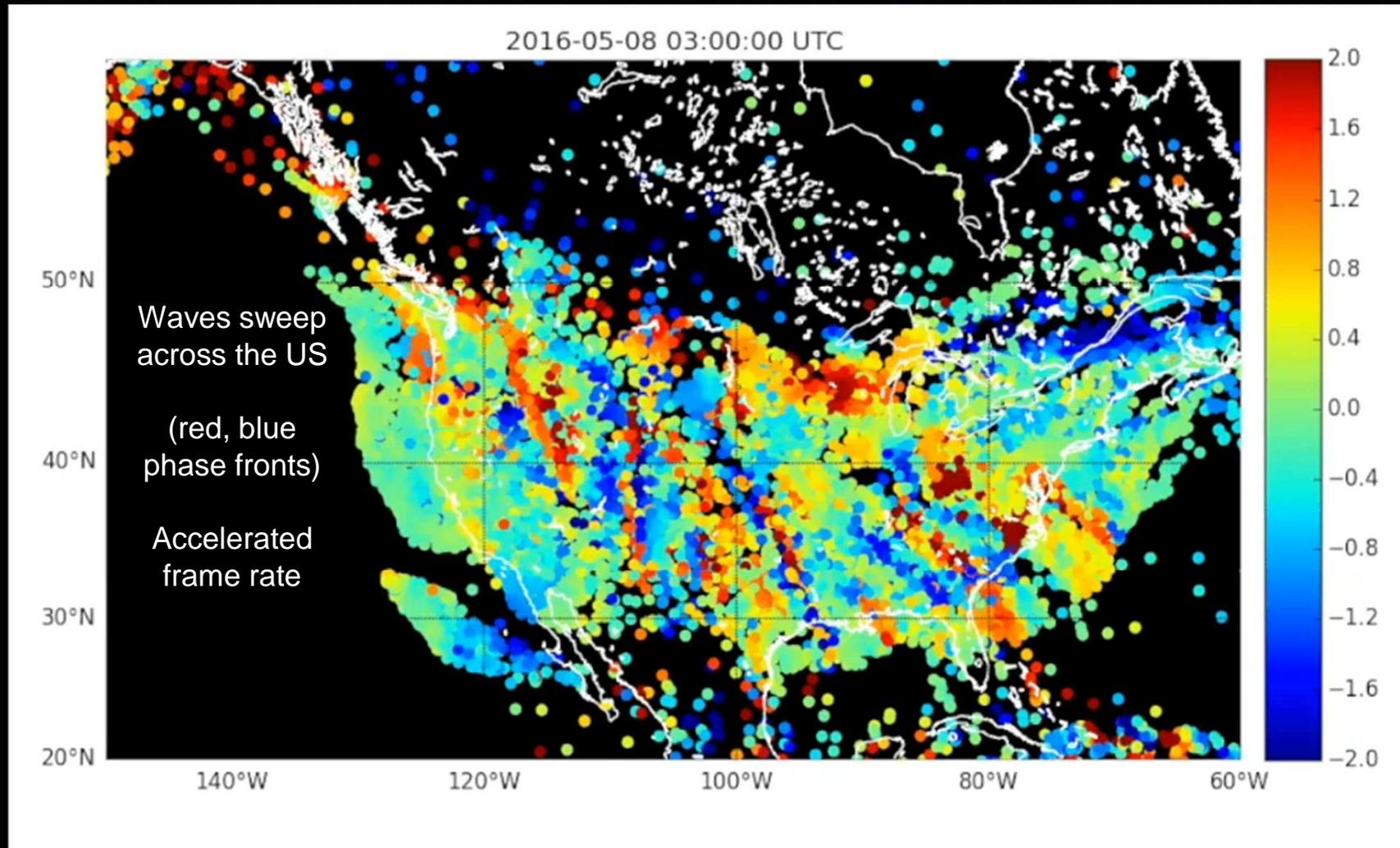
4000+ GNSS geodetic receivers from many sources (e.g. UNAVCO, Scripps Orbit and Permanent Array Center)
Processed by MIT Haystack to extract ionospheric delay information
Data provides large scale picture of global ionospheric space weather variations
Available to space science community through NSF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

Solar Flare Effects from Sept 7, 2005 Solar Flare





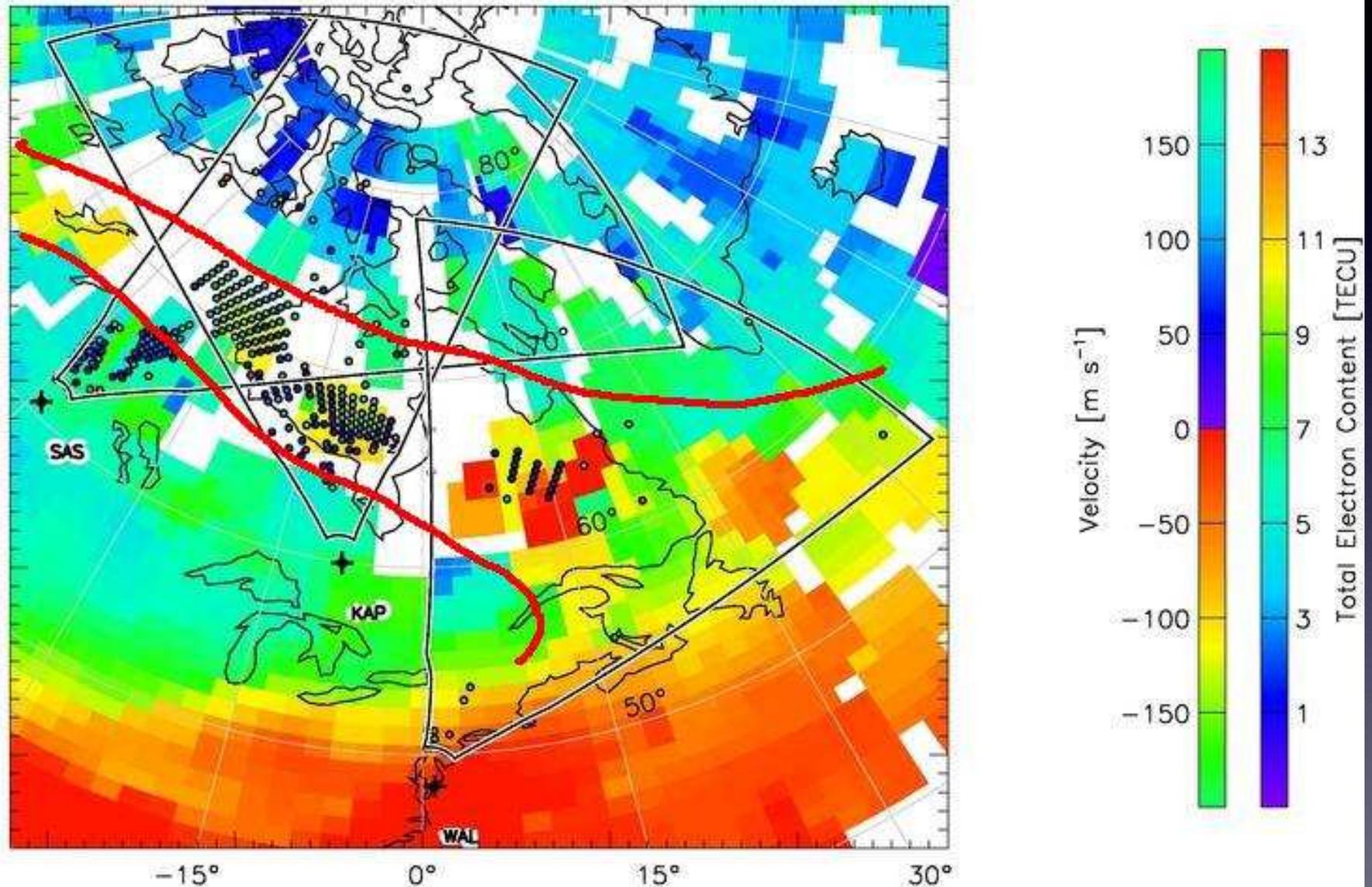
Traveling Ionospheric Disturbances: Space Weather over the US Mainland



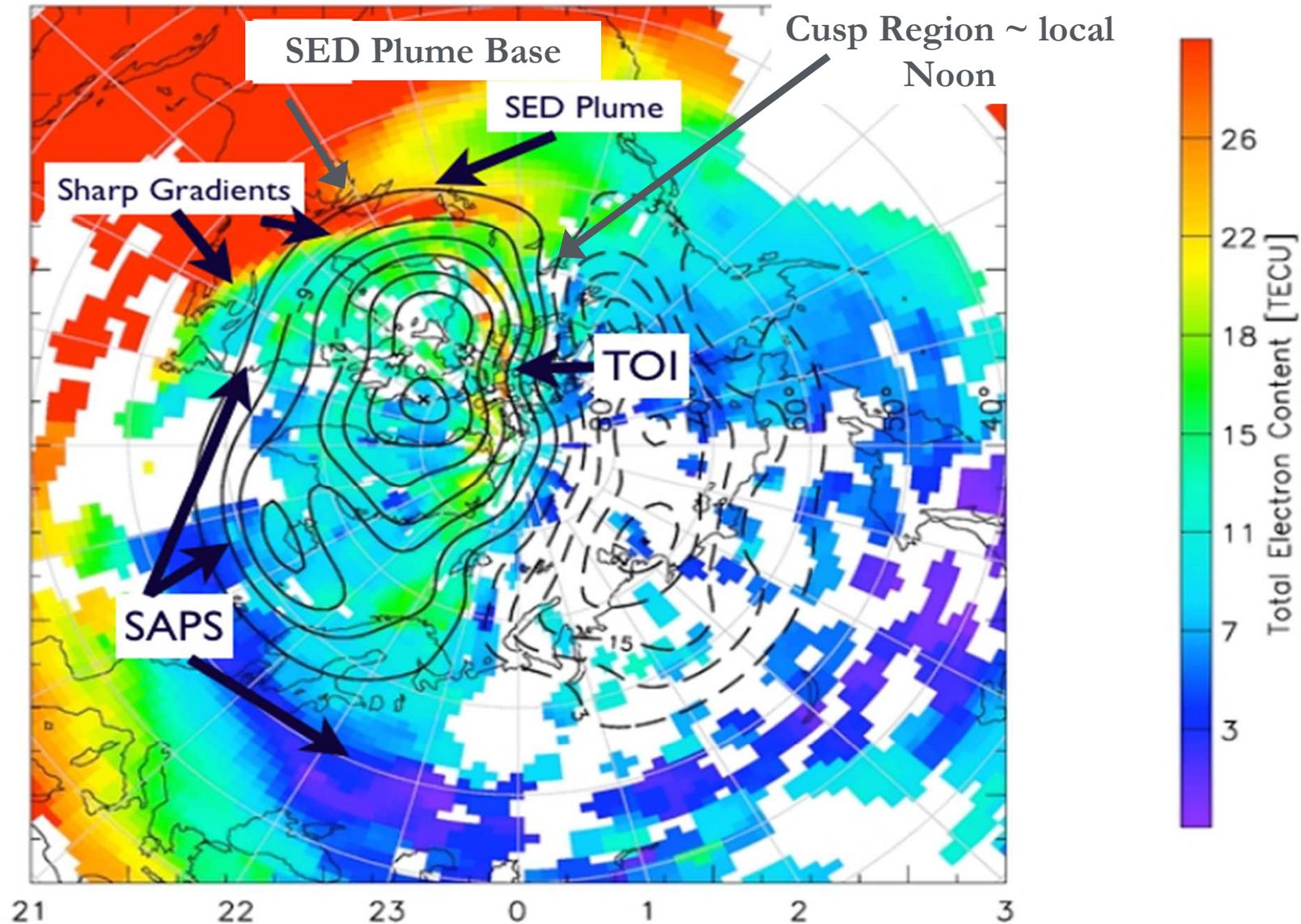
(Coster, Rideout, Vierinen)

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 04/Feb/2009 18:50:00.0
Median Filtered, Threshold = 0.01 to
04/Feb/2009 18:55:00.0

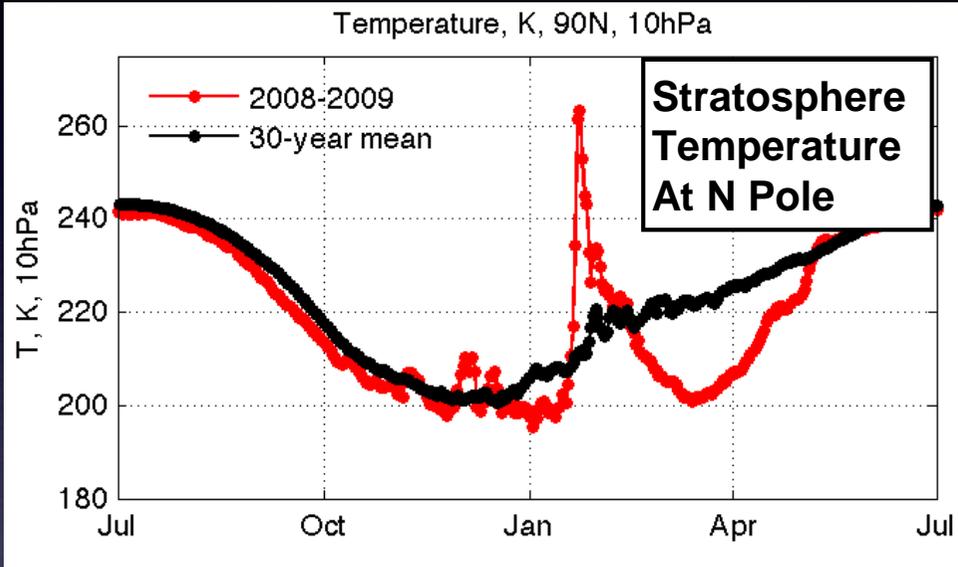


Common Features observed in TEC during geomagnetically disturbed conditions

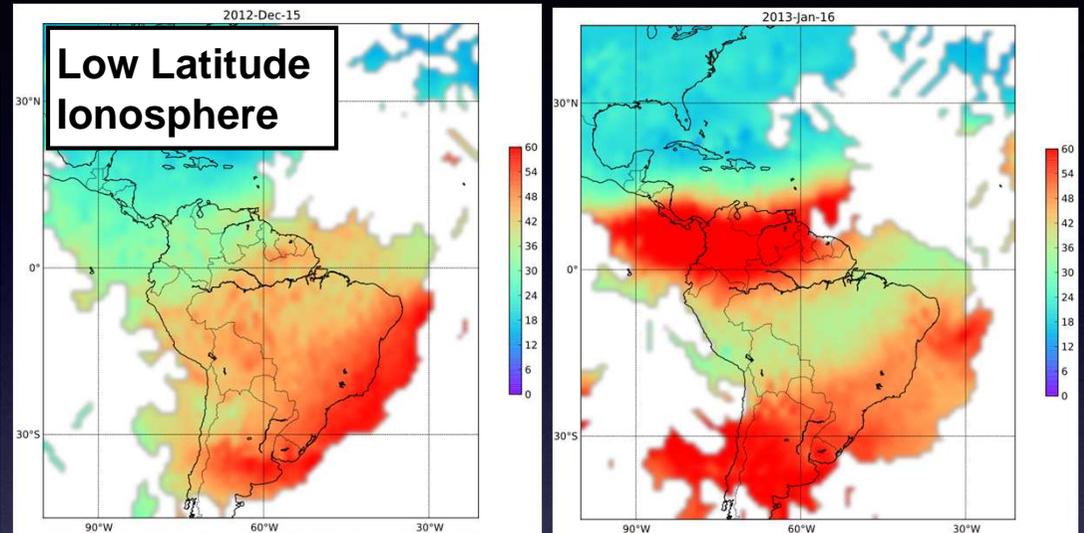




Whole Atmosphere Coupling: Space Weather From Below



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

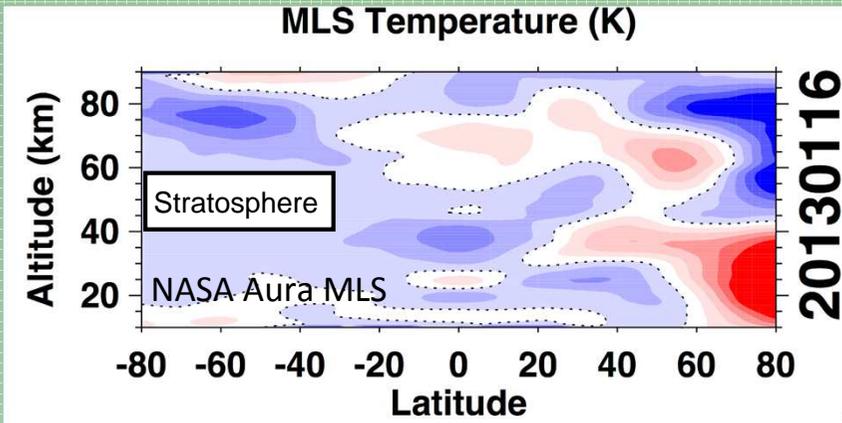
(Goncharenko et al)

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

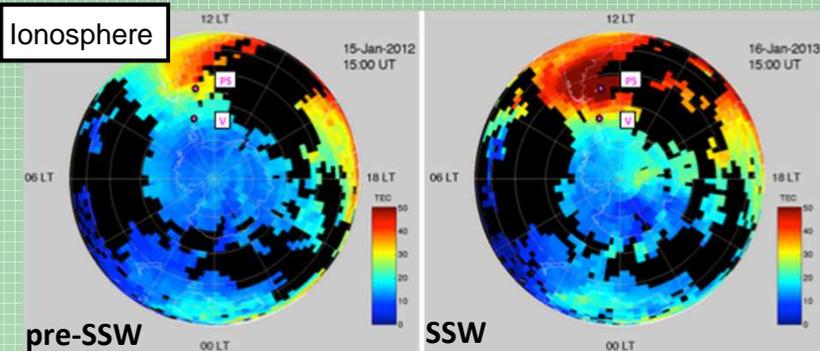
Stratospheric Sudden Warming (SSW) is a large disturbance highlighting these connections



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

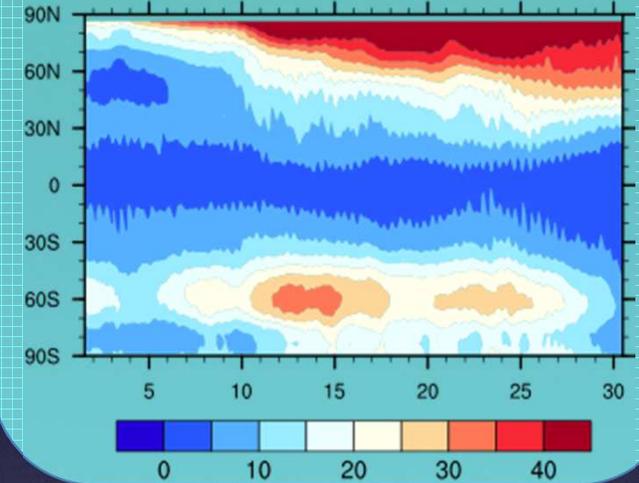


GPS TEC over Antarctica

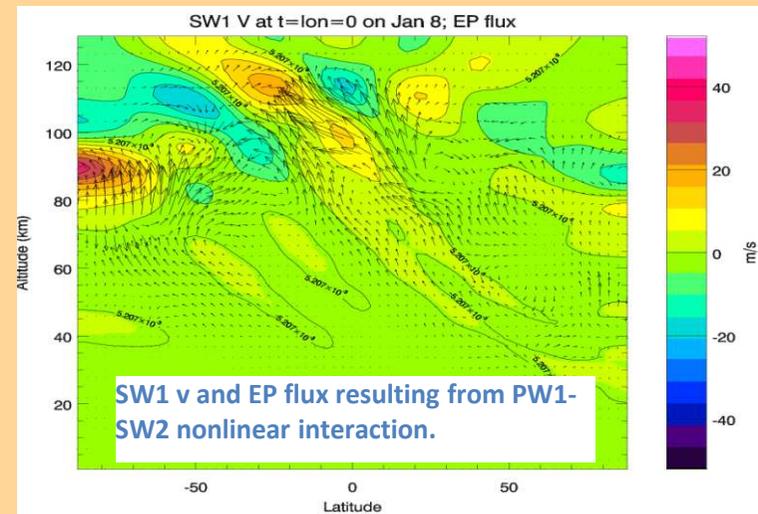


TIMEGCM simulations

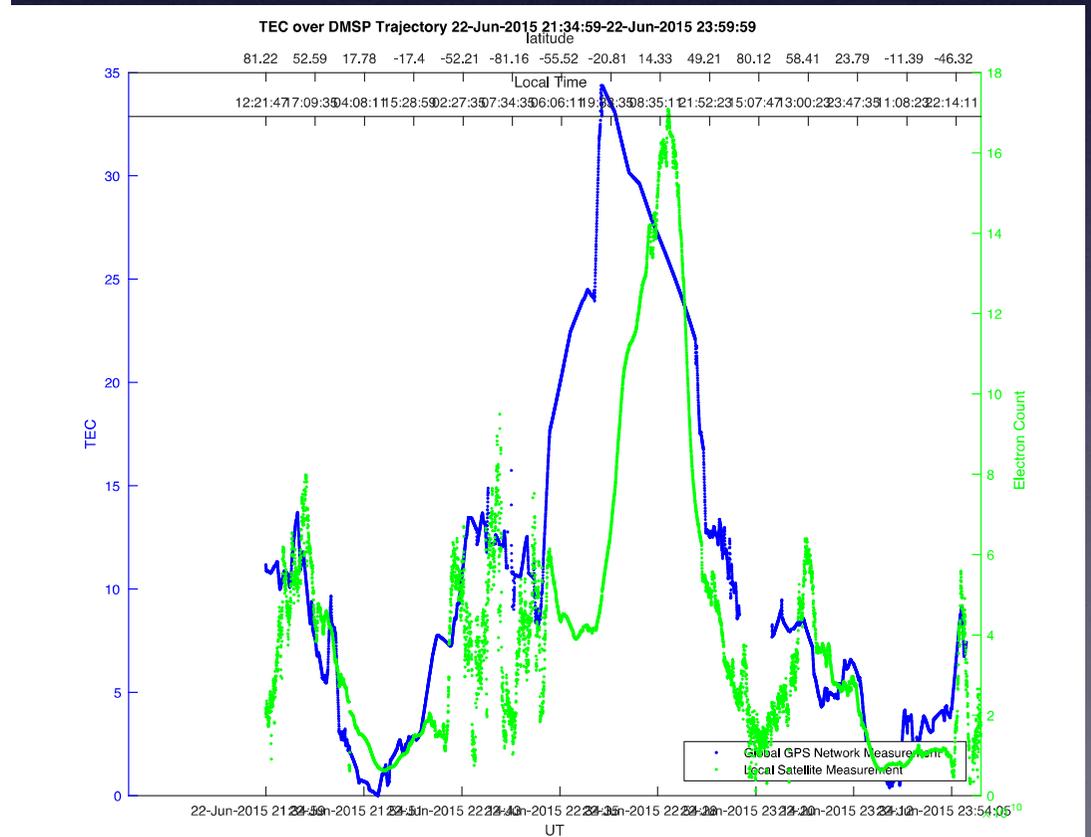
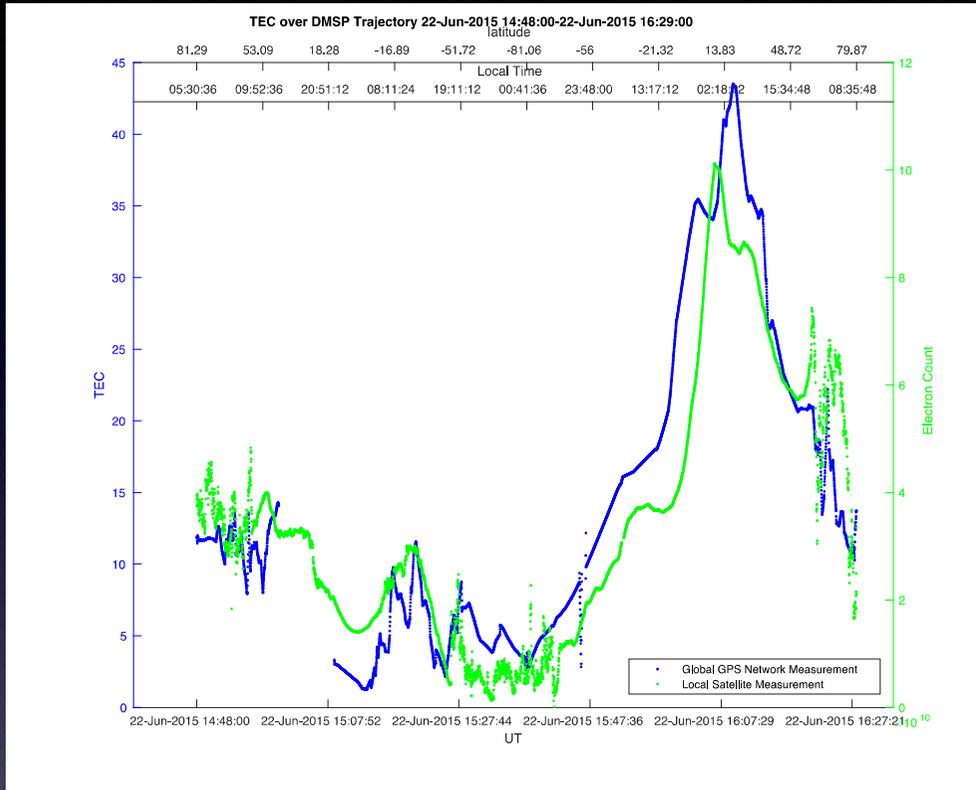
SW1 height= 110 km



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

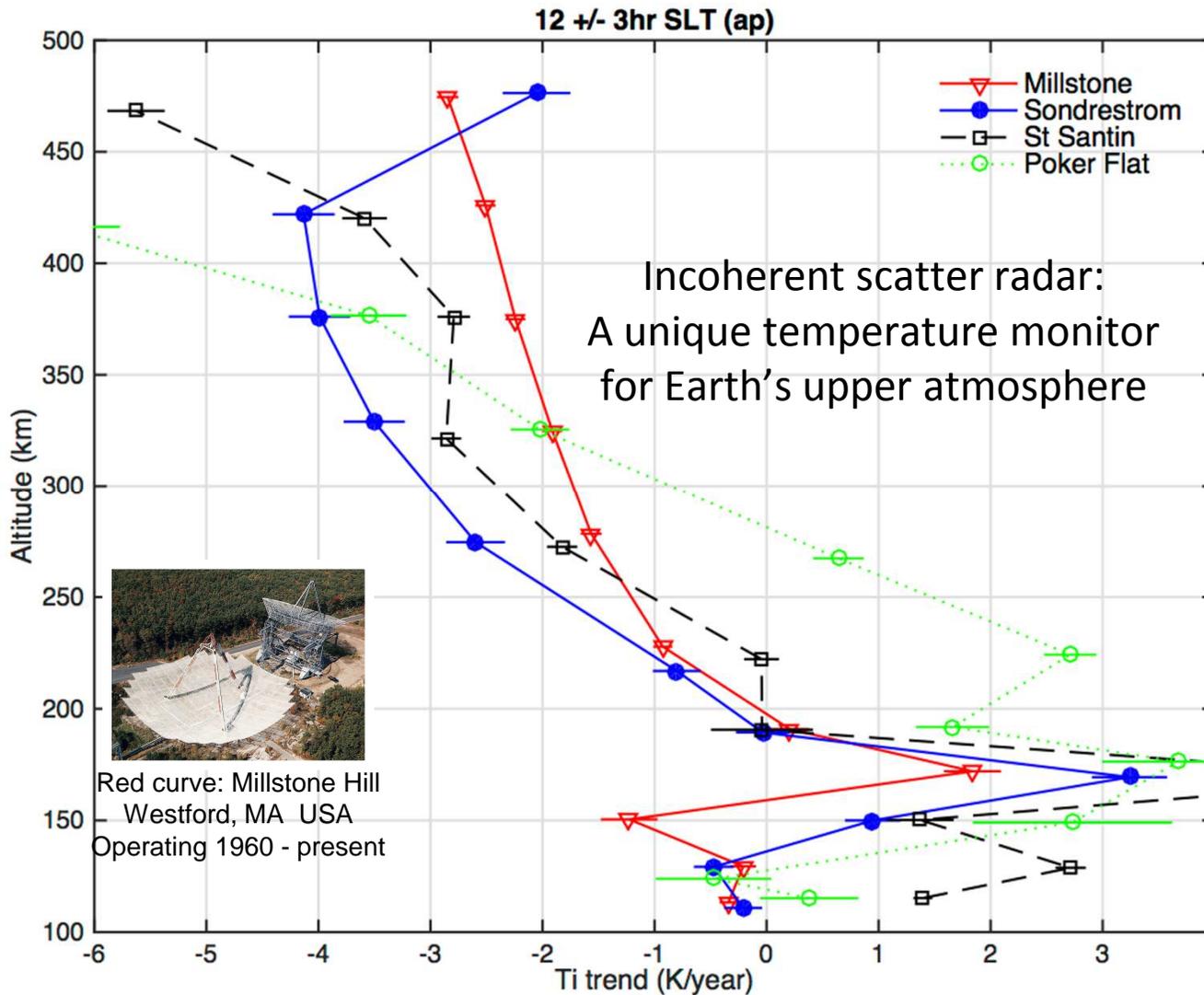


Comparison of DMSP Electron Density and GPS TEC before and during 22 Jun 2015 storm





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 CO₂ 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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