Space Weather Resources Available Through MIT Haystack’s Madrigal Database

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MIT Haystack Observatory
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.

- Incoherent Scatter Radars: 22
- MST Radars: 3
- MF Radars: 16
- Meteor radars: 7
- FPI: 23
- Michelson Interferometers: 6
- Lidars: 4
- Photometers: 4
Incoherent Scatter Radars

- PFISR
- RISR
- Sondrestrom
- EISCAT
- Svalbard
- Kharkov
- Irkutsk
- Millstone Hill
- Jicamarca
- Arecibo
- MU

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 site
(typically a facility with scientists and a Madrigal installation)

↓

Instruments
(ground-based, typically with a set location)

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Experiments
(typically of limited duration, with a single contact)

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Experiment Files
(represent data from one analysis of the experiment)

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Records
(measurement over one period of time)

Data shared among all Madrigal sites

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Data unique to one Madrigal site
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
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

Subtracting background density reveals traveling ionospheric disturbances launched by neutral atmospheric processes, geomagnetic storms cause significant space weather variations; active research topic.
Traveling Ionospheric Disturbances: Space Weather over the US Mainland

Subtracting background density reveals traveling ionospheric disturbances(Launched by neutral atmospheric processes, geomagnetic storms Causes significant space weather variations; active research topic

Waves sweep across the US (red, blue phase fronts)

Accelerated frame rate

(Coster, Rideout, Vierinen)
TOTAL ELECTRON CONTENT
Median Filtered, Threshold = 0.01
04/Feb/2009 18:50:00.0 to 04/Feb/2009 18:55:00.0
Common Features observed in TEC during geomagnetically disturbed conditions

- SED Plume Base
- Cusp Region ~ local Noon
- Sharp Gradients
- SED Plume
- TOI
- SAPS
Whole Atmosphere Coupling: Space Weather From Below

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

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

Stratospheric temperature over Arctic rapidly increases during warming events...

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

(Goncharenko et al)

(TEC before SSW)

(TEC during SSW)

温度, K, 90N, 10hPa

Stratosphere Temperature At N Pole

Low Latitude Ionosphere

(Goncharenko et al)
**Observations:** global coupling, pole to pole, stratosphere to ionosphere

**TimeGCM simulations**

MLS Temperature (K)

GPS TEC over Antarctica

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

SW1 v and EP flux resulting from PW1-SW2 nonlinear interaction.

(Goncharenko et al)
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

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

Incoherent scatter radar: A unique temperature monitor for Earth’s upper atmosphere

(Zhang, Holt)
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.