The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

**2333-23**

**Workshop on Science Applications of GNSS in Developing Countries (11-27 April), followed by the: Seminar on Development and Use of the Ionospheric NeQuick Model (30 April-1 May)**

*11 April - 1 May, 2012*

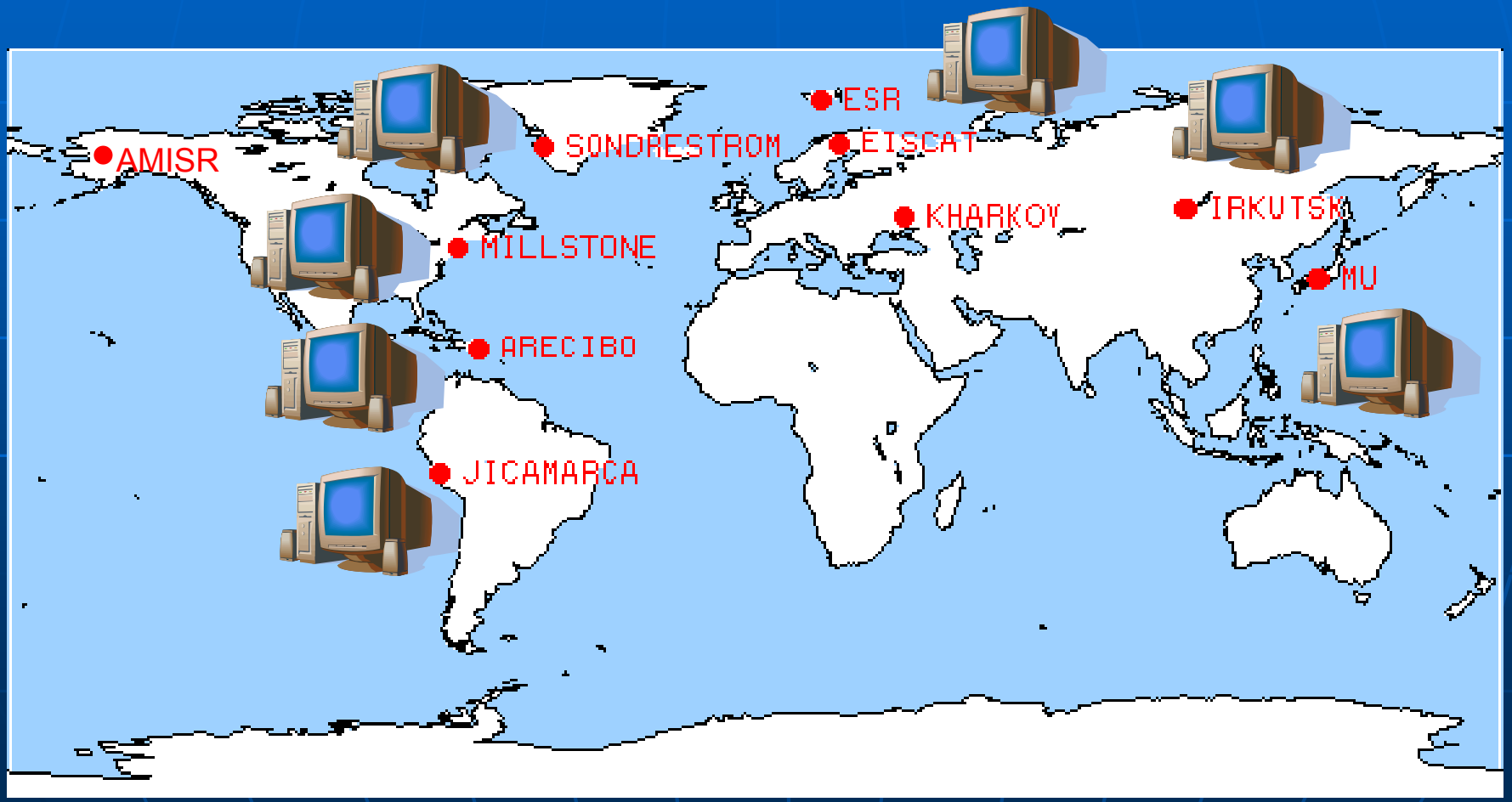
# What is Madrigal?

DELAY Susan

*Institute for Scientific Research, Boston College*
*St. Clement's Hall, 140 Commonwealth Avenue*
*CHESTNUT HILL MA 02467-3862*
*Massachusetts*
*U.S.A.*

# What is Madrigal?

Distributed, open-source, standards-based local databases that share metadata and have VO-features built in




**http://madrigal.haystack.mit.edu/madrigal**

# MIT Haystack Educational outreach materials

http://www.haystack.mit.edu/edu/index.html

**Lesson plans:**

http://www.haystack.mit.edu/edu/pcr/resources/lessonplans.html

**Details of museum exhibit: Solar Storms to Radio Waves**

**http://www.haystack.mit.edu/edu/poa/museum/index.html**

Space Weather Podcasts:

http://www.haystack.mit.edu/swfx

Notes from AMISR summer school:

http://www.haystack.mit.edu/cgi-bin/asg_science/science.cgi/Summer_School

# The Madrigal database stores data from a wide variety of upper atmosphere research instruments in the Cedar database format.

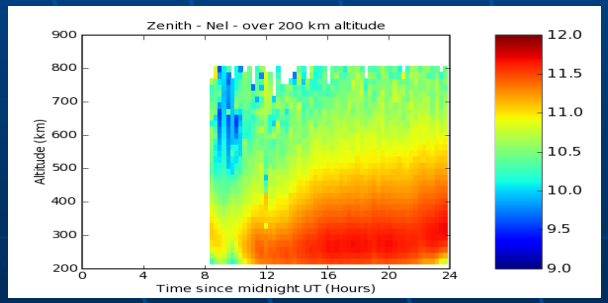
Incoherent Scatter Radar

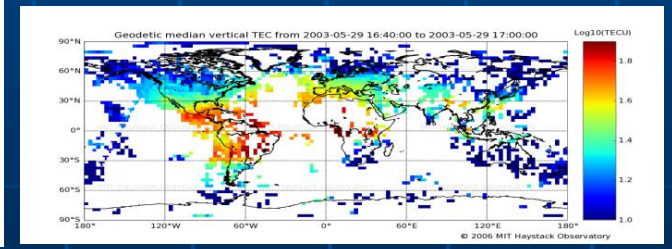
TEC via GPS

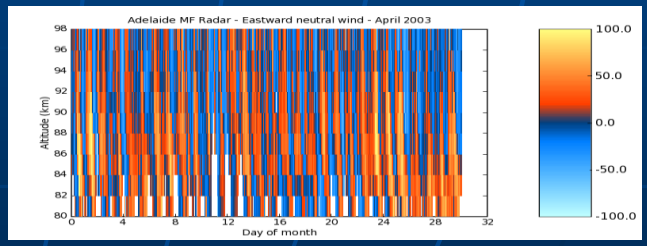
MF Radar

Cedar database format

Loading programs can be written in Python, C, or Tcl



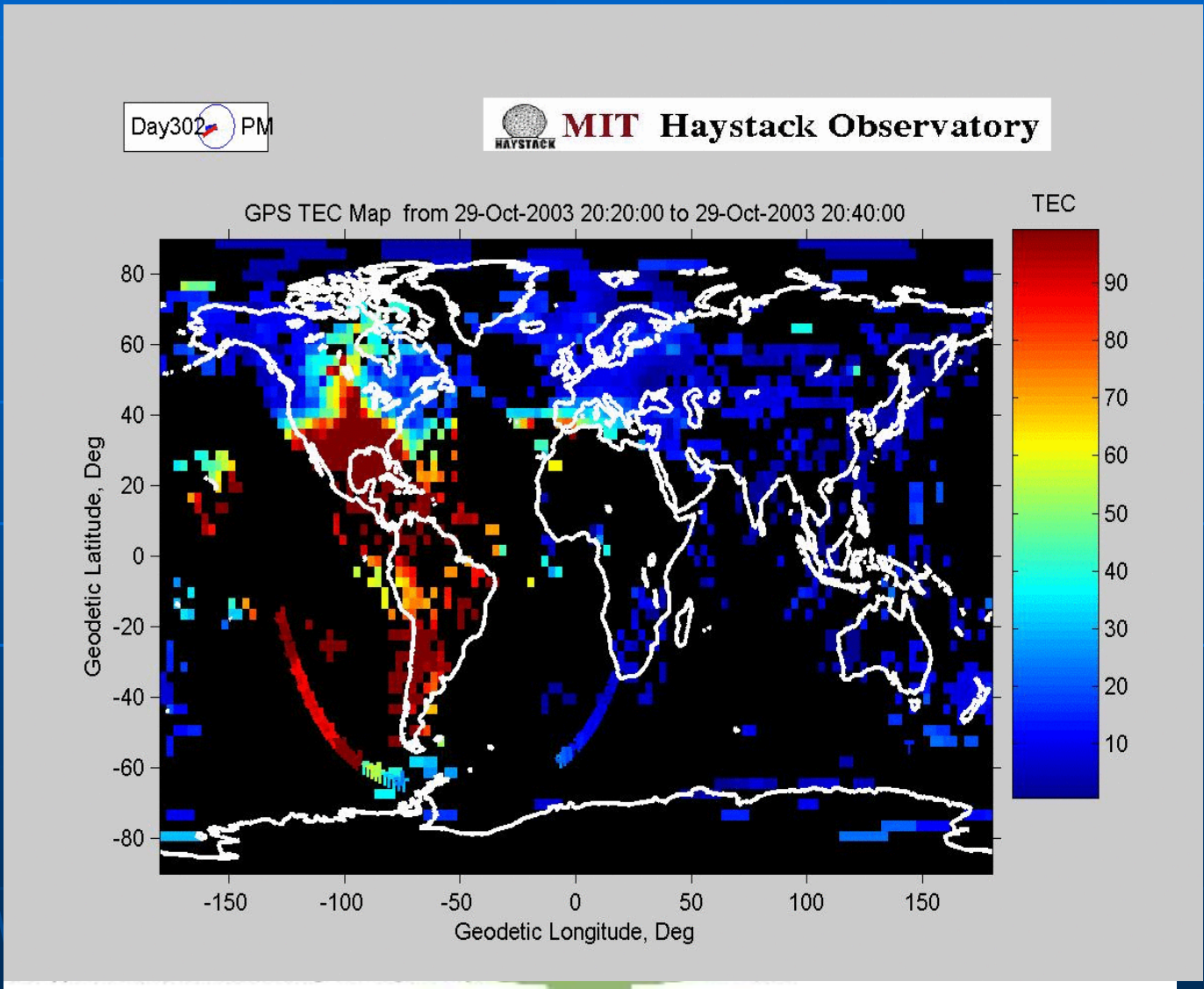




Other instrument types in Madrigal: Meteor radar, Digisonde, Fabry-Perot, Geophysical indices

# Wide Area Distribution of 'Raw' Information

Distributed networks of sensors yield global physics unattainable with single-point measurements

Example :
Global GPS-derived ionospheric mapping during geomagnetic disturbances




[Coster et al, 2003]

# How can the Madrigal database be accessed?

User


Web interface

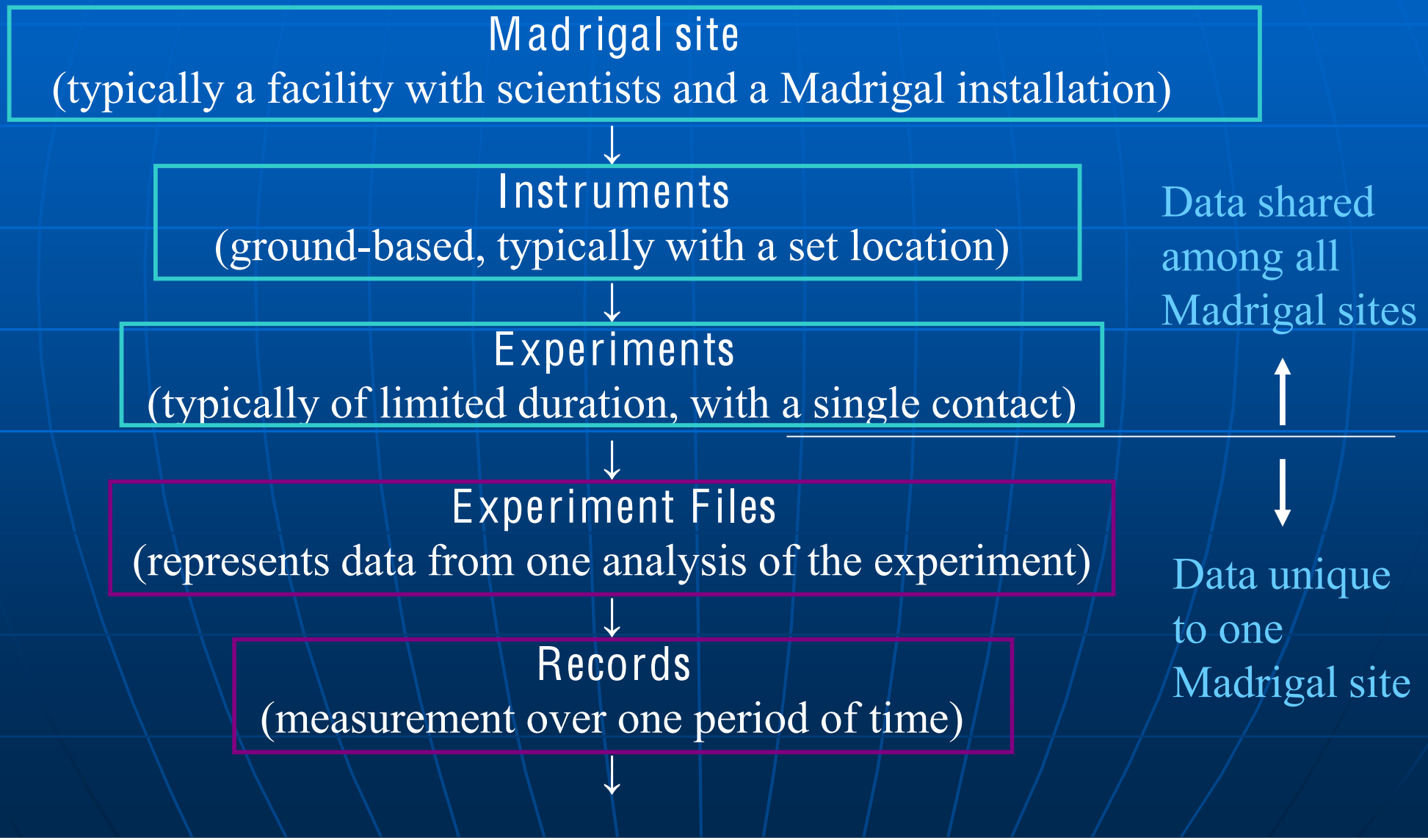
## Web services API

- From anywhere on internet
- Python API
- Matlab API
- Allows for easy VO access
  - AstroGrid has links

Database standard – Cedar file format
- allows easy import into Cedar

Real-time and historical data

# Madrigal Data Model



# Cedar/Madrigal Database

- All parameters in file defined
  - http://cedarweb.hao.ucar.edu/documents/parameters_list.txt
- Ranges of parameters for each instrument
- Data stored in one or two 16 bit ints
  - Additional increment parameters
- Error parameters always available
- File format defined in
  - http://cedarweb.hao.ucar.edu/cgi-bin/cedar_file_access.pl?filename=documents/cedar_fmt.pdf

# 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

- Tutorial
- Access Data
- Run Models
- Documentation
- Open Madrigal
- Space Science Resources
- Real-time Data Sources

# Welcome to the Madrigal Database at Haystack Observatory

*Try the new Simple Madrigal Data Access link on the Access Data page.*

Madrigal is an upper atmospheric science database used by groups throughout the world. 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 upper atmospheric science instruments. The basic data format is the same as that used by the National Science Foundation supported Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) program, which maintains a CEDAR Database at the National Center for Atmospheric Research (NCAR). Data files are easily exchanged between the two sites, but Madrigal has a significantly different emphasis. 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.

Data can be accessed from the Madrigal sites at Millstone Hill, USA, Arecibo, Puerto Rico, EISCAT, Norway, SRI International, USA, Cornell University, USA, Jicamarca, Peru, The Institute of Solar-Terrestrial Physics, Russia, and Wuhan Ionospheric Observatory, the Chinese Academy of Sciences. and directly, using APIs which are available for several popular programming languages. A CVS archive of all Madrigal software and documentation is available from the Open Madrigal Web site. The latest version of Madrigal may also be downloaded from there.


http://madrigal.haystack.mit.edu/madrigal/

# Madrigal web tutorial - Table of contents



Madrigal web tutorial - Table of contents | Doc home | Madrigal home

**Previous:** Madrigal user's guide **Up:** Madrigal user's guide **Next:** What is Madrigal?

# Access Madrigal Data

There are four ways to access Madrigal data. Choosing *Simple Madrigal Data Access* will allow you to print and plot Madrigal data via an easy to use interface. However, this interface does not allow you to see derived parameters or to filter data. To look at the data from a particular Madrigal experiment using the full-featured Madrigal interface, choose *Browse for Individual Madrigal Experiments*. To get data in ascii format from a group of Madrigal experiments all at once, choose *Global Madrigal Database Report*. To plot data from one or more instruments and/or experiments, choose *Plot Data from Instruments*.

---

## Simple Madrigal Data Access

The simple madrigal data access link allows new users of Madrigal to print and plot data easily. In order to make it easy to use, a number of Madrigal's capabilities are not available, including the ability to choose which parameters to print, the ability to display derived parameters, and the ability to filter data. Use the other three Madrigal interfaces below to access these more powerful capabilities. Click here for a tutorial on this way to access Madrigal data.

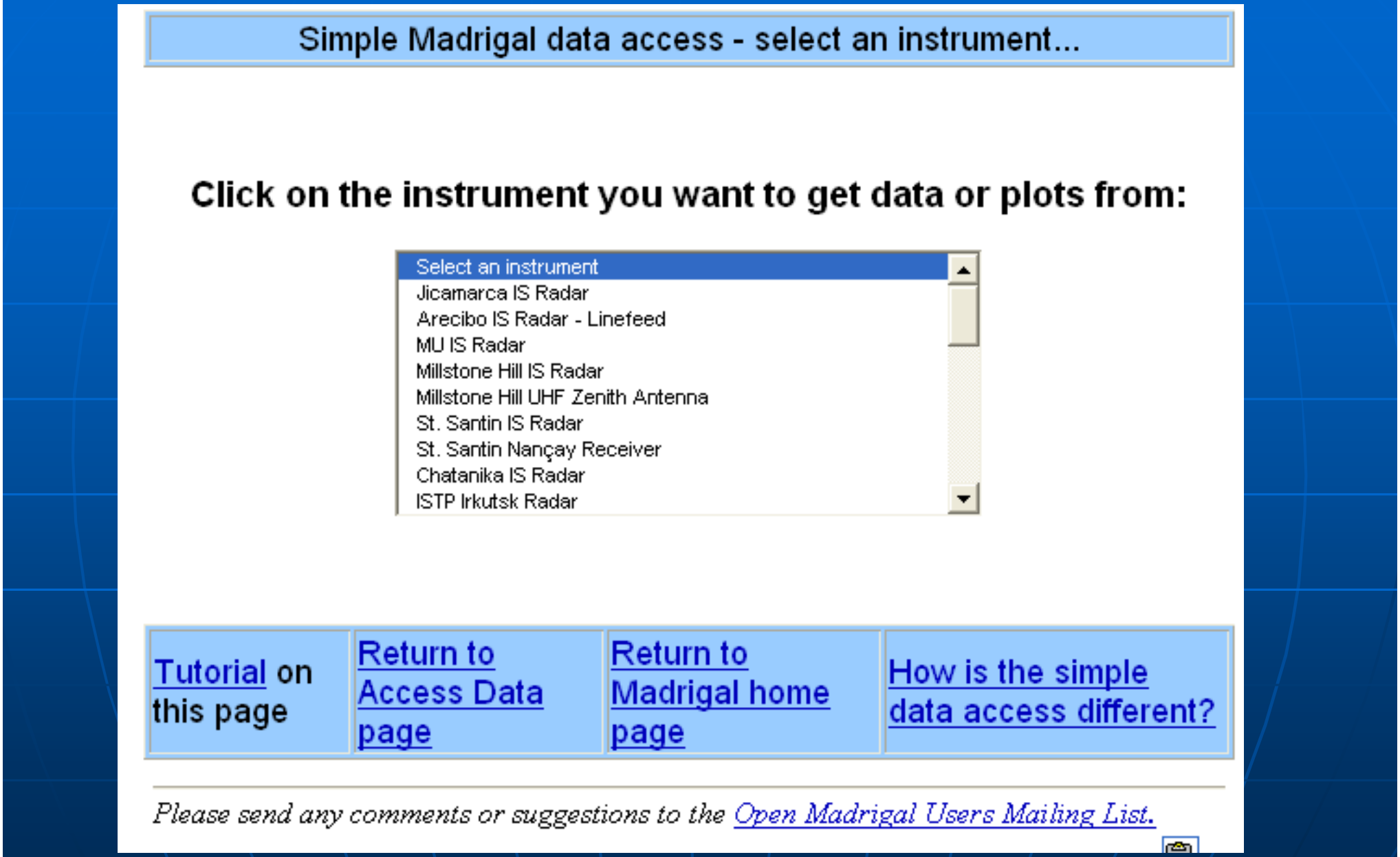
## Browse for Individual Madrigal Experiments

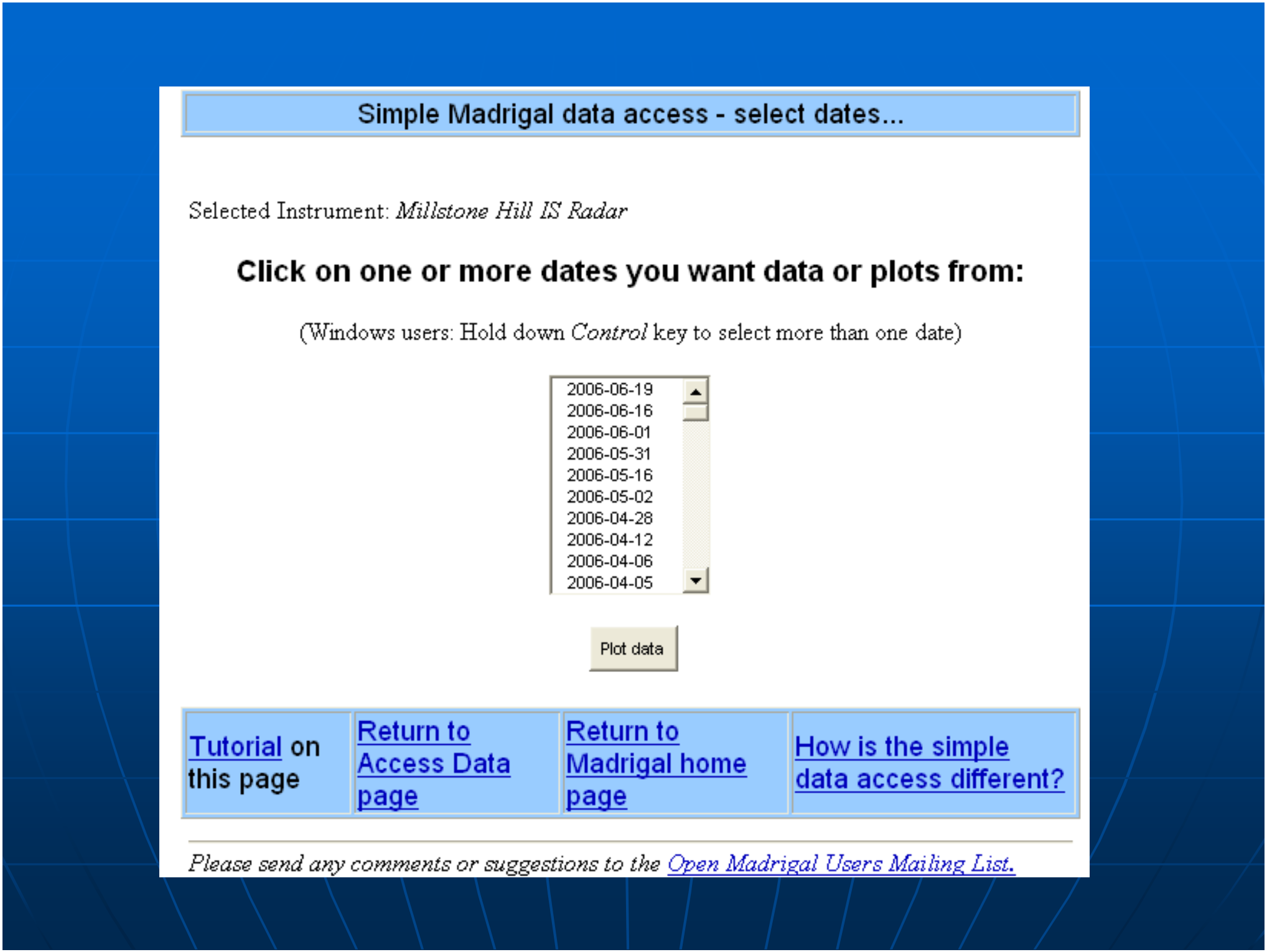
Browse for individual Madrigal experiments displays a list of available experiments, subject to user-specified filters. One of the filters specifies the instruments you want to see. For several of the incoherent scatter radars, for example Millstone and EISCAT, there are several options corresponding to different antennas. As a rule, select the first option, which displays all data from that instrument. In addition to the filters, a number of options may be selected on the form. For example, it is possible to display a combined listing of experiments at all Madrigal sites, or only the experiments at the current site. Click here for a tutorial on this way to access Madrigal data.

## Global Madrigal Database Report

This form allows you to generate a report on multiple experiments at once. Experiments can be filtered by instrument, kind of data, and date range or season. The data within any given experiment can be filtered using any parameter, measured or derived. Data from all experiments located in the local Madrigal database matching your criteria will be returned in a single report. Click here for a tutorial on this way to access Madrigal data

## Plot Data from Instruments


Simple Madrigal data access - select an instrument...
Click on the instrument you want to get data or plots from:
Select an instrument
Jicamarca IS Radar
Arecibo IS Radar - Linefeed
MU IS Radar
Millstone Hill IS Radar
Millstone Hill UHF Zenith Antenna
St. Santin IS Radar
St. Santin Nançay Receiver
Chatanika IS Radar
ISTP Irkutsk Radar
Tutorial on this page
Return to Access Data page
Return to Madrigal home page
How is the simple data access different?
Please send any comments or suggestions to the Open Madrigal Users Mailing List.

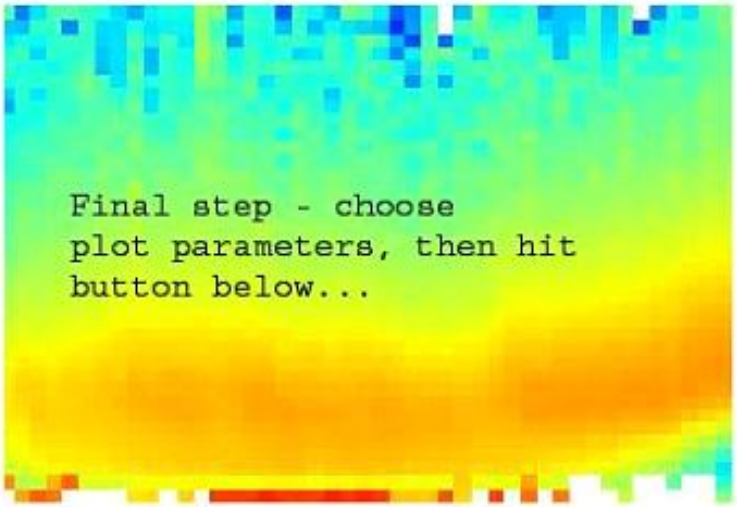

Simple Madrigal data access - select dates...
Selected Instrument: *Millstone Hill IS Radar*
**Click on one or more dates you want data or plots from:**
(Windows users: Hold down *Control* key to select more than one date)
2006-06-19
2006-06-16
2006-06-01
2006-05-31
2006-05-16
2006-05-02
2006-04-28
2006-04-12
2006-04-06
2006-04-05
Plot data
Tutorial on this page
Return to Access Data page
Return to Madrigal home page
How is the simple data access different?
*Please send any comments or suggestions to the Open Madrigal Users Mailing List.*

## Simple Madrigal data access - select parameter and y axis for plotting...

| Selected Instrument: | Selected dates: |
| --- | --- |
| • *Millstone Hill IS Radar* | • 2005-09-10 |

### Create a new plot...

**Choose parameter to plot:** Log10(uncorrected electron density)




Time

**Select y axis:** Altitude

### or, view existing plots and descriptions:

- 2005-09-10
  - INSCAL Analysis notes for mlh 1142298092
  - Electron density summary plots
  - Electron temperature summary plots
  - Ion temperature summary plots
  - Ion velocity summary plots

# Electron density summary plots for Millstone Hill Radar

# Sep. 10, 2005

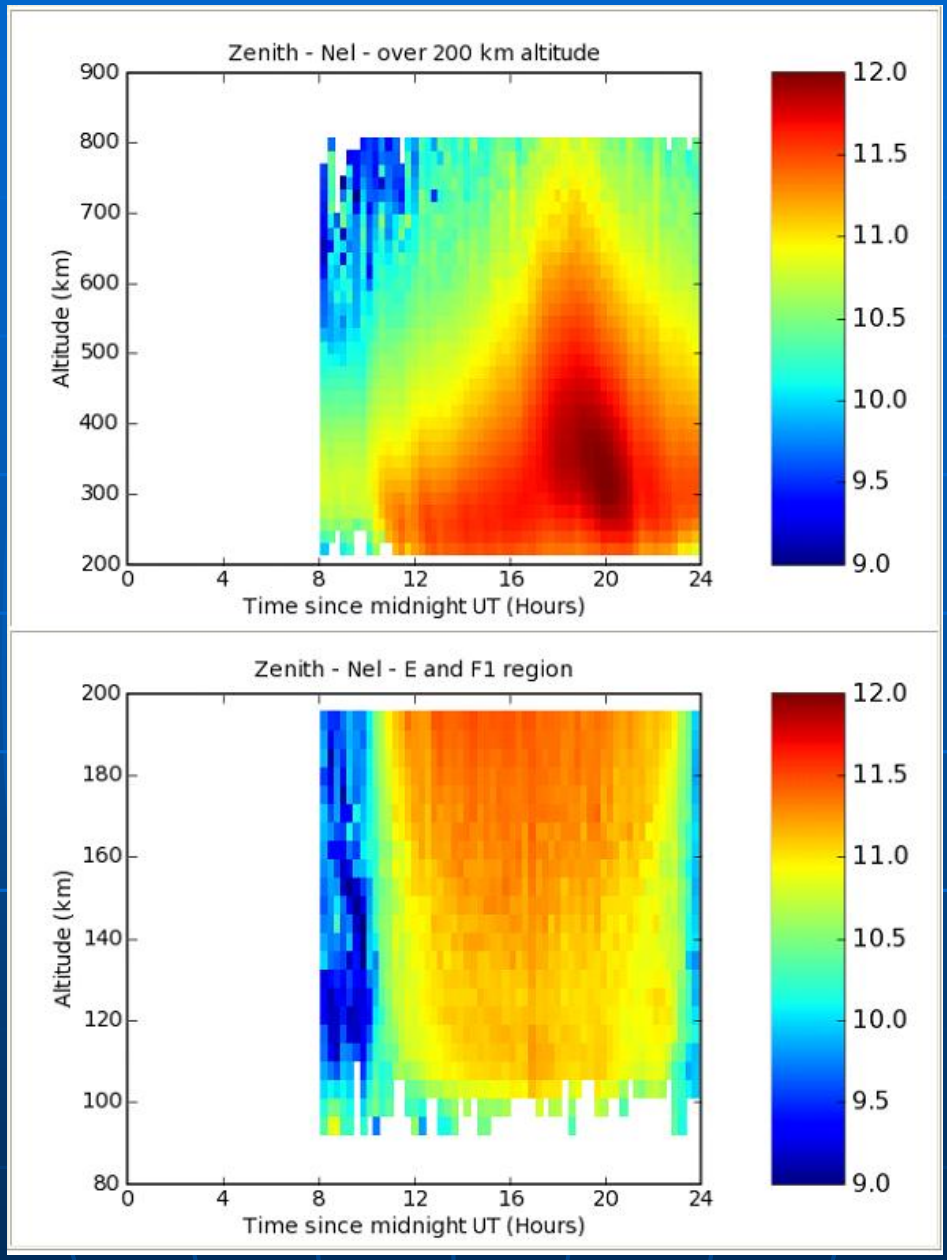
| Electron temperature summary plots | Ion temperature summary plots | Ion velocity summary plots |
|---|---|---|

## Rapid LTCS Experiment

*This is an experiment designed to provide rapid time coverage of the E-region and F-region ionosphere. This experiment is useful for providing high altitude resolution in the E-region and F-region along with sufficient pointing directions using MISA to provide electric field measurements. The dwell time in a given position is 8 minutes to provide the possibility of a long integration if needed. The overall cycle time of the experiment is 65 minutes with a measurement triplet every 32 minutes.*

This page has the following summary plots of electron density:

1. Zenith antenna - altitudes above 200 km versus time using single pulse measurements
2. Zenith antenna - E and F1-region altitudes versus time using alternating code measurements
3. Misa antenna - Azimuth=0°(North), Elevation=45°, altitudes above 200 km versus time using single pulse measurements
4. Misa antenna - Azimuth=0°(North), Elevation=45°, E and F1-region altitudes versus time using alternating code measurements
5. Misa antenna - Azimuth=-90°(West), Elevation=45°, altitudes above 200 km versus time using single pulse measurements
6. Misa antenna - Azimuth=-90°(West), Elevation=45°, E and F1-region altitudes versus time using alternating code measurements


Zenith - Nel - over 200 km altitude
Altitude (km)
900
800
700
600
500
400
300
200
0
4
8
12
16
20
24
Time since midnight UT (Hours)
12.0
11.5
11.0
10.5
10.0
9.5
9.0
Zenith - Nel - E and F1 region
Altitude (km)
200
180
160
140
120
100
80
0
4
8
12
16
20
24
Time since midnight UT (Hours)
12.0
11.5
11.0
10.5
10.0
9.5
9.0

# Access Madrigal Data

There are four ways to access Madrigal data. Choosing *Simple Madrigal Data Access* will allow you to print and plot Madrigal data via an easy to use interface. However, this interface does not allow you to see derived parameters or to filter data. To look at the data from a particular Madrigal experiment using the full-featured Madrigal interface, choose *Browse for Individual Madrigal Experiments*. To get data in ascii format from a group of Madrigal experiments all at once, choose *Global Madrigal Database Report*. To plot data from one or more instruments and/or experiments, choose *Plot Data from Instruments*.

---

## Simple Madrigal Data Access

The simple madrigal data access link allows new users of Madrigal to print and plot data easily. In order to make it easy to use, a number of Madrigal's capabilities are not available, including the ability to choose which parameters to print, the ability to display derived parameters, and the ability to filter data. Use the other three Madrigal interfaces below to access these more powerful capabilities. Click here for a tutorial on this way to access Madrigal data.

## Browse for Individual Madrigal Experiments

Browse for individual Madrigal experiments displays a list of available experiments, subject to user-specified filters. One of the filters specifies the instruments you want to see. For several of the incoherent scatter radars, for example Millstone and EISCAT, there are several options corresponding to different antennas. As a rule, select the first option, which displays all data from that instrument. In addition to the filters, a number of options may be selected on the form. For example, it is possible to display a combined listing of experiments at all Madrigal sites, or only the experiments at the current site. Click here for a tutorial on this way to access Madrigal data.

## Global Madrigal Database Report

This form allows you to generate a report on multiple experiments at once. Experiments can be filtered by instrument, kind of data, and date range or season. The data within any given experiment can be filtered using any parameter, measured or derived. Data from all experiments located in the local Madrigal database matching your criteria will be returned in a single report. Click here for a tutorial on this way to access Madrigal data

## Plot Data from Instruments

# Madrigal Experiment Selector

| Return to Madrigal homepage | Tutorial on this page | Return to access data page |
|---|---|---|

## Select instrument(s)

College Fabry-Perot
Sondre Stromfjord and Thule Fabry-Perots
Thule Fabry-Perot
Stockholm IR Michelson
CEDAR lidar
USU CCD Imager
CEDAR Imager
MIO
All-sky cameras at Qaanaaq
World-wide GPS Receiver Network

## Select date range

1 | 1 | 1950 Start Day, Month, Year

31 | 12 | 2006 End Day, Month, Year

## Select list format

- [ ] Experiment ID
- [x] Madrigal Site
- [x] Start Date
- [x] Start Time
- [x] End Date
- [x] End Time
- [ ] Instrument Code
- [x] Instrument Mnemonic
- [ ] Instrument Name
- [x] Experiment Name

## Options

| Sort Order | Date Order | Date Format | File Selection | Show Experiments at |
|---|---|---|---|---|
| (•) Date | (•) Earliest first | (•) 03/21/1999 | (•) Show Latest Files | (•) All Madrigal Sites |
| ( ) Instument | ( ) Latest First | ( ) 21.03.1999 | ( ) Show History Files | ( ) This Madrigal Site |

List selected data

# Madrigal Experiment Listing

| Return to Madrigal homepage | Tutorial on this page | Return to access data page |
|---|---|---|

| Site | Start Date | S Tm | End Date | E Tm | Inst | Experiment Name |
|---|---|---|---|---|---|---|
| GO Mills | 09/10/2005 | 0000 | 09/10/2005 | 2355 | gps | World-wide Vertical Total Electron Content |
| GO Mills | 09/11/2005 | 0000 | 09/11/2005 | 2355 | gps | World-wide Vertical Total Electron Content |

# World-wide GPS Receiver Network

## World-wide Vertical Total Electron Content

| | | |
|---|---|---|
| Return to Madrigal homepage | Tutorial on this page | Return to access data page |

**Start Time: 09/10/2005 00:00:00 End Time: 09/10/2005 23:55:00**

**CEDAR Format Datasets:**

- gps050910g.001 - default file for Minimum Scallop TEC Processing - status: final
  - View description from the catalog and/or header records
  - File Summary - Record summary, list of parameters in file, etc.
  - Data Browser (isprint) - Flat-file listing of a user-selected portion of the file
  - Download file - Download gps050910g.001 in selected format

**Additional information:**

- TEC Maps

**Notes**

Add to these notes

# ISPrint Database Browser

## Experiment: World-wide Vertical Total Electron Content

| Return to experiment list | Return to Madrigal homepage | A tutorial on how to use this page | Return to access data page |
|---|---|---|---|

Sat Sep 10 00:00:00 2005 - Sat Sep 10 23:55:00 2005 : World-wide GPS Receiver Network

**Available Filters - Using default or manually entered selections**

**Set data filters manually, or ...**

- Data will be listed only if it falls within the range of the filter
- For azimuth and elevation, two separate ranges can now be used
- Explanation of Filters

| | | | | | |
|---|---|---|---|---|---|
| Start date: | Sep | 10 | 2005 | | |
| Start time: | H: 0 | M: 0 | S: 0 | | |
| End date: | Sep | 10 | 2005 | | |
| End time: | H: 23 | M: 55 | S: 0 | | |

*Optional free-form filters using any parameter mnemonic on this page*

**...use a saved filter and parameter selection:**

Public Directories: jfoster:jfoster

Public filters: coherent1

You are not logged in.

## Available Parameters (Comprehensive)

- Description of parameters
- ISPrint(Short form)

*(parameters with regular typeface are derived)*

### Time Related Parameter

| | | | | |
|---|---|---|---|---|
| BDAY | BEG_UT | BHHMMSS | BHM | BMONTH |
| B_UTH | DAY | DAYNO | DUT21 | EHHMMSS |
| FYEAR | HOUR | JDAYNO | MD | MIN |
| MONTH | RECNO | SEC | SLT | UT |
| UT1 | UT2 | UTH | YEAR | |

### Geographic Coordinate

| | | | | |
|---|---|---|---|---|
| GDLAT | GLON | SDWHT | SZEN | |

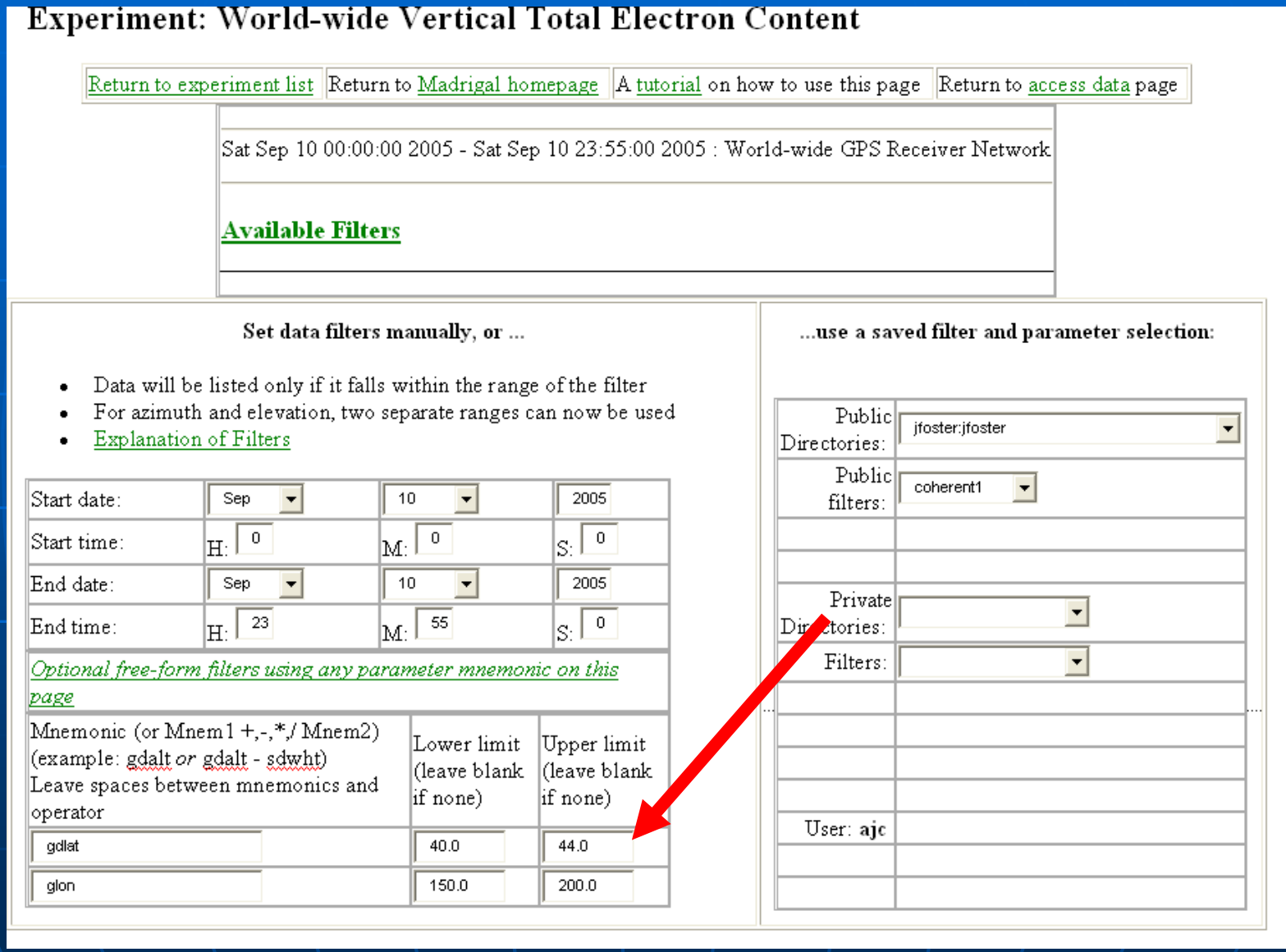
### Geophysical Index

| | | | | |
|---|---|---|---|---|
| AP | AP3 | DST | F10.7 | FBAR |
| KP | | | | |

### Interplanetary Magnetic Field

| | | | | |
|---|---|---|---|---|
| BIMF | BXGSE | BXGSM | BYGSE | BYGSM |
| BZGSE | BZGSM | SWDEN | SWQ | SWSPD |
| | | | | |

### I. S. Radar Basic Parameter


Experiment: World-wide Vertical Total Electron Content
Return to experiment list
Return to Madrigal homepage
A tutorial on how to use this page
Return to access data page
Sat Sep 10 00:00:00 2005 - Sat Sep 10 23:55:00 2005 : World-wide GPS Receiver Network
Available Filters
Set data filters manually, or ...
Data will be listed only if it falls within the range of the filter
For azimuth and elevation, two separate ranges can now be used
Explanation of Filters
Start date: Sep 10 2005
Start time: H: 0 M: 0 S: 0
End date: Sep 10 2005
End time: H: 23 M: 55 S: 0
Optional free-form filters using any parameter mnemonic on this page
Mnemonic (or Mnem1 +,-,*,/ Mnem2) (example: gdalt or gdalt - sdwht) Leave spaces between mnemonics and operator
Lower limit (leave blank if none)
Upper limit (leave blank if none)
gdlat 40.0 44.0
glon 150.0 200.0
...use a saved filter and parameter selection:
Public Directories: jfoster:jfoster
Public filters: coherent1
Private Directories:
Filters:
User: ajc

*(parameters with regular typeface are derived)*

**Time Related Parameter**

| | | | | |
|---|---|---|---|---|
| ☐ BDAY | ☐ BEG_UT | ☐ BHHMMSS | ☐ BHM | ☐ BMONTH |
| ☐ B_UTH | ☐ DAY | ☐ DAYNO | ☐ DUT21 | ☑ EHHMMSS |
| ☐ FYEAR | ☐ HOUR | ☐ JDAYNO | ☐ MD | ☐ MIN |
| ☐ MONTH | ☐ RECNO | ☐ SEC | ☐ SLT | ☐ UT |
| ☐ UT1 | ☐ UT2 | ☐ UTH | ☐ YEAR | |

**Geographic Coordinate**

| | | | | |
|---|---|---|---|---|
| ☑ GDLAT | ☑ GLON | ☐ SDWHT | ☐ SZEN | |

**Geophysical Index**

| | | | | |
|---|---|---|---|---|
| ☐ AP | ☐ AP3 | ☐ DST | ☐ F10.7 | ☐ FBAR |
| ☐ KP | | | | |

**Interplanetary Magnetic Field**

| | | | | |
|---|---|---|---|---|
| ☐ BIMF | ☐ BXGSE | ☐ BXGSM | ☐ BYGSE | ☐ BYGSM |
| ☐ BZGSE | ☐ BZGSM | ☐ SWDEN | ☐ SWQ | ☐ SWSPD |
| | | | | |

**I. S. Radar Basic Parameter**

| | | | | |
|---|---|---|---|---|
| ☑ TEC | | | | |

**I. S. Radar Operation Parameter**

| | | | | |
|---|---|---|---|---|
| ☐ FOF2 | | | | |

# Live demo of Madrigal web page

- Start at any Madrigal server (e.g., http://www.haystack.mit.edu/madrigal)

# Remote Access to Madrigal Data

- Built on web services
- Like the web, available from anywhere on any platform
- Complete Matlab and Python API written
- More APIs available on request or via contribution

# Madrigal Web Services

- Simple delimited output via CGI scripts
- Not based on SOAP or XmlRpc since no support in languages such as Matlab
- CGI arguments and output fully documented at http://www.haystack.edu/madrigal/remoteAPIs.html

# Simple Python example

```
# create the main object to get all needed info from Madrigal
madrigalUrl = 'http://www.haystack.mit.edu/madrigal'
testData = madrigalWeb.madrigalWeb.MadrigalData(madrigalUrl)

# get all MLH experiments in 1998
expList = testData.getExperiments(30, 1998,1,1,0,0,0,1998,12,31,23,59,59)
for exp in expList:
    # print out all experiments
    print exp

# print list of all files in first experiment
fileList = testData.getExperimentFiles(expList[0].id)
    for thisfile in fileList:
        print thisfile
```

# Python Remote API

- Can run on any platform with python (PC, Unix, Mac, etc)
- Fully documented with examples
- See http://madrigal.haystack.edu/madrigal/remotePythonAPI.html for documentation, more examples, and source

# Live Python API demo

- See /home/brideout/examples/demoMadrigalWebServices.py

To run the python demo:

/opt/madrigal/bin/python /opt/madrigal/bin/demo/demoMadrigalWebServices.py

# Matlab Remote API

- Methods
  - getInstrumentsWeb
  - getExperimentsWeb
  - getExperimentFilesWeb
  - getParametersWeb
  - isprintWeb
  - madCalculatorWeb
- Methods match Madrigal model

# Simple Matlab example

```
filename = '/usr/local/madroot/experiments
                /2003/tro/05jun03/NCAR_2003-06-05_tau2pl_60_uhf.bin';

eiscat_cgi_url = 'http://www.eiscat.se/madrigal/cgi-bin/';

% download the following parameters from the above file: ut, gdalt, ti

parms = 'ut,gdalt,ti';

filterStr = 'filter=gdalt,200,600 filter=ti,0,5000';

% returns a three dimensional array of double with the dimensions:
%
%   [Number of rows, number of parameters requested, number of records]
%
%  If error or no data returned, will return error explanation string instead.
data = isprintWeb(eiscat_cgi_url, filename, parms, filterStr);
```

**Matlab Madrigal API call**

# Simple Matlab example, continued

- See http://madrigal.haystack.edu/madrigal/remoteMatlabAPI.html for complete documentation and more examples

# Live Matlab API demo

- See /home/brideout/examples/demoMadrigalWebServices.m

To run the Matlab demo:

1. cd /opt/madrigal/bin/demo
2. Start matlab
3. From the command window, run "demoMadrigalWebServices".

# Extending/contributing to Madrigal

- Madrigal is completely open source
- See www.openmadrigal.org for CVS
- All new code is C/Python, with some Tcl.  Derivation methods sometimes in Fortran.

# DEMOS

- DEMO GPS TEC MAPS

**http://madrigal.haystack.mit.edu/cgi-bin/madrigal/simpleChooseInstrument.py**

- DEMO CONVERSION TO GEOMAGNETIC COORDINATES

**http://madrigal.haystack.mit.edu/cgi-bin/madrigal/madInvent.cgi**

- DEMO DST FILTER (WITH EXPLANATION)
- DEMO MATLAB PROGRAMS TO LOOK AT GPS TEC