Preparing vertical TEC Data for model validation

Anthea Coster
MIT Haystack Observatory

Outline

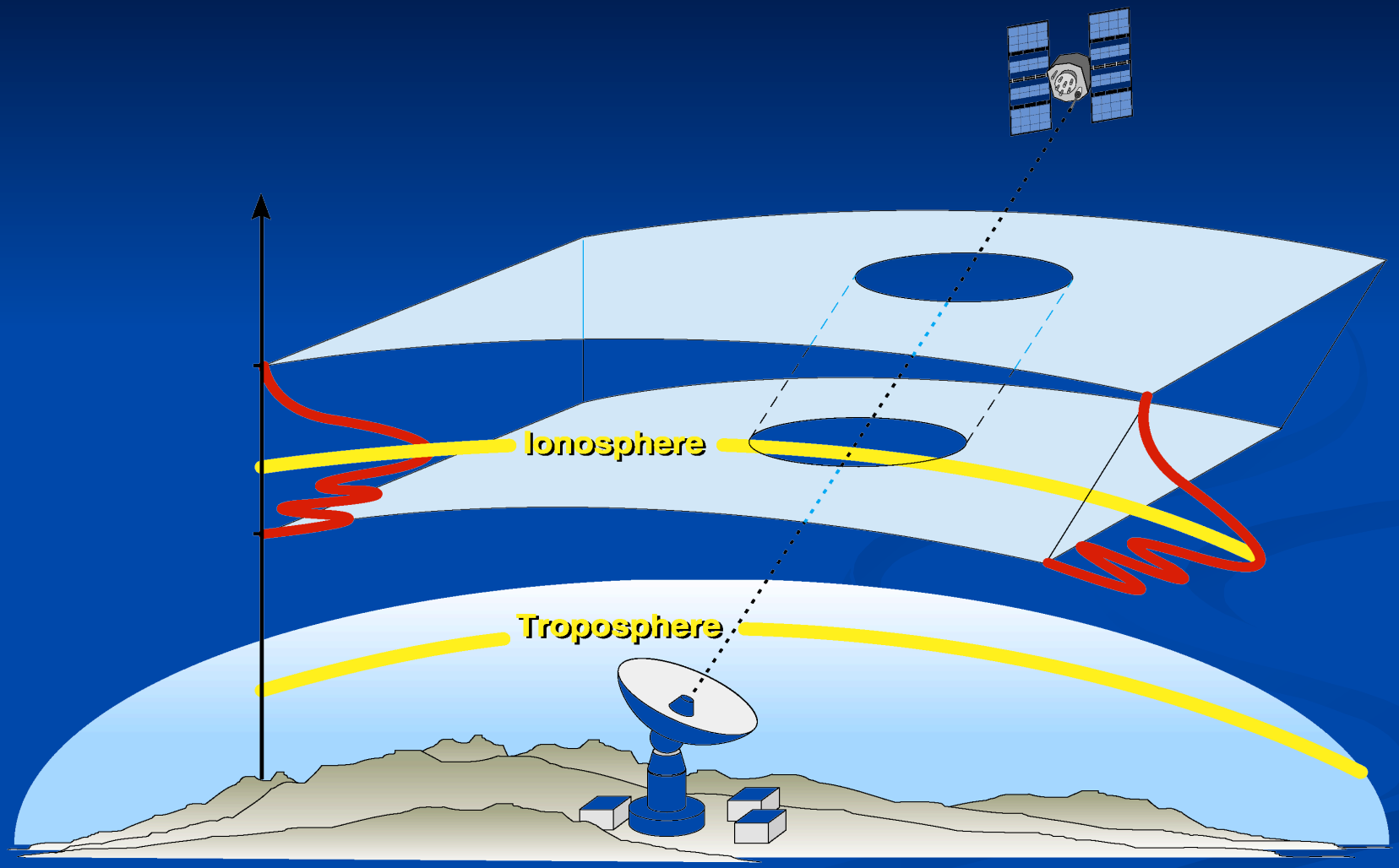
What is now available through CEDAR Madrigal Web

What are errors in TEC

Remind everyone that what is needed for model –data validation depends on problem at hand

9th CCMC Community Workshop
23 April - 27 April 2018

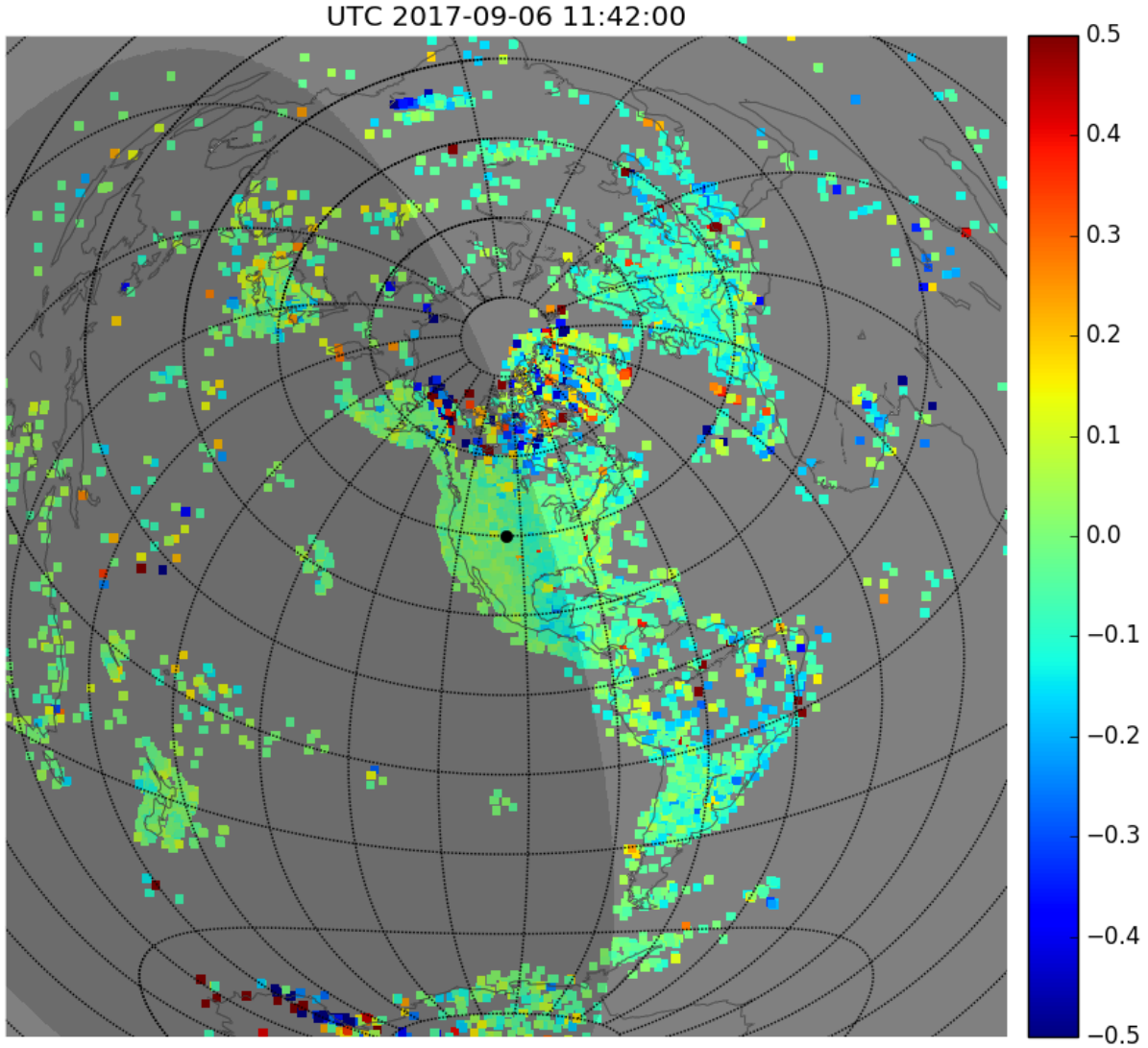
Atmospheric Propagation



From Attila Komjathy, JPL

Definition:

TEC = Total Electron Content
(10^{16} x el/$m^{2)}$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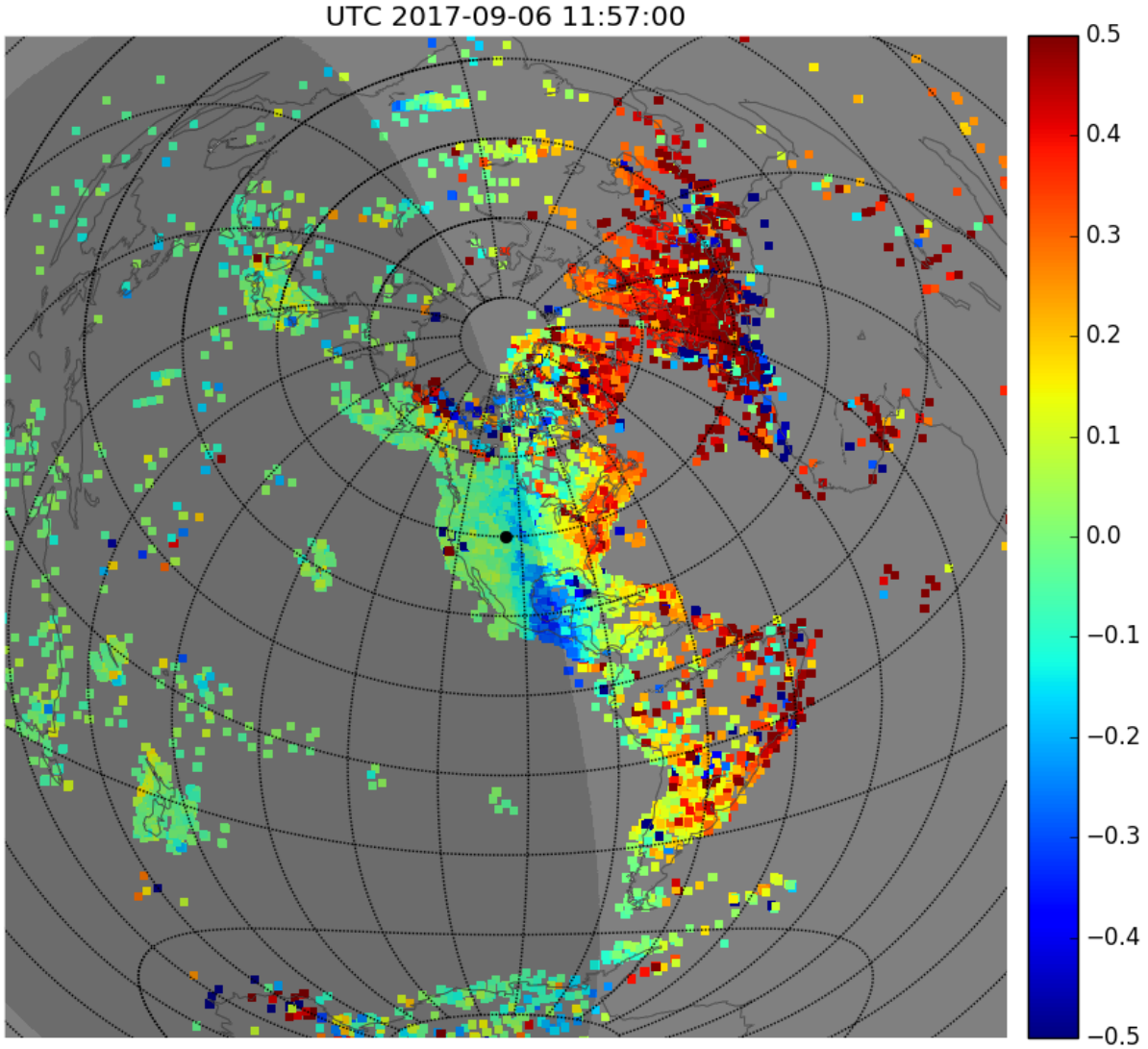
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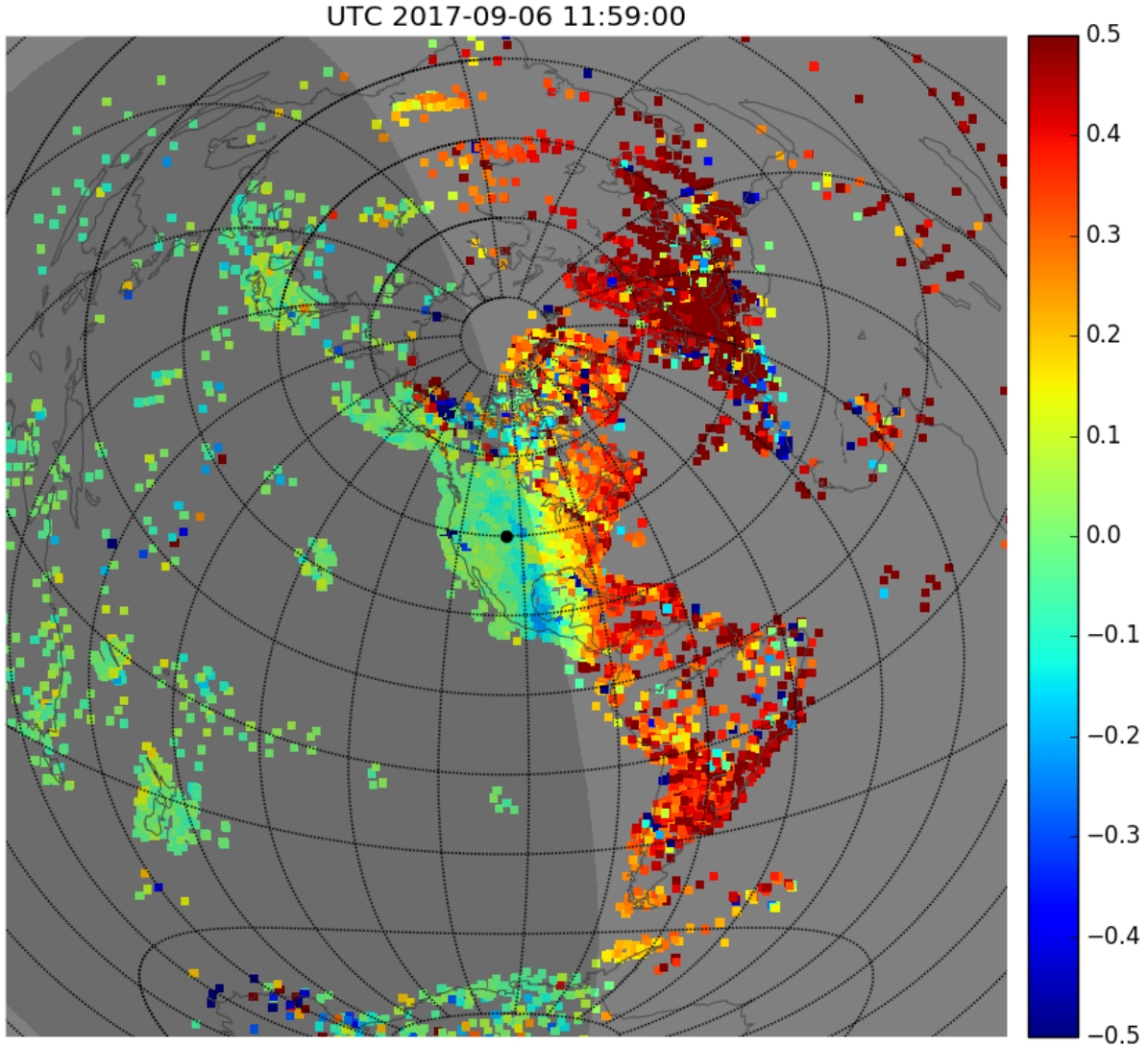
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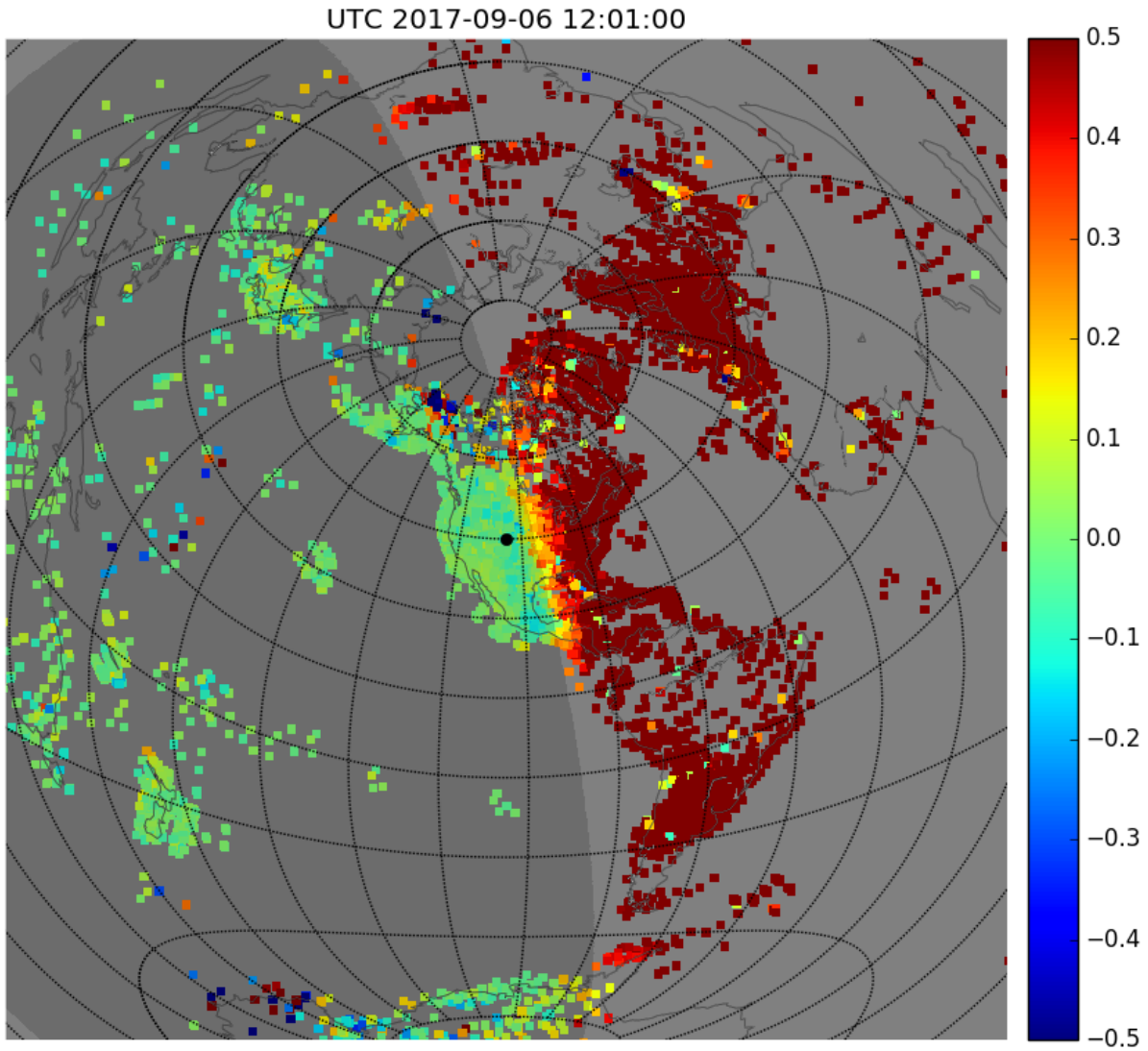
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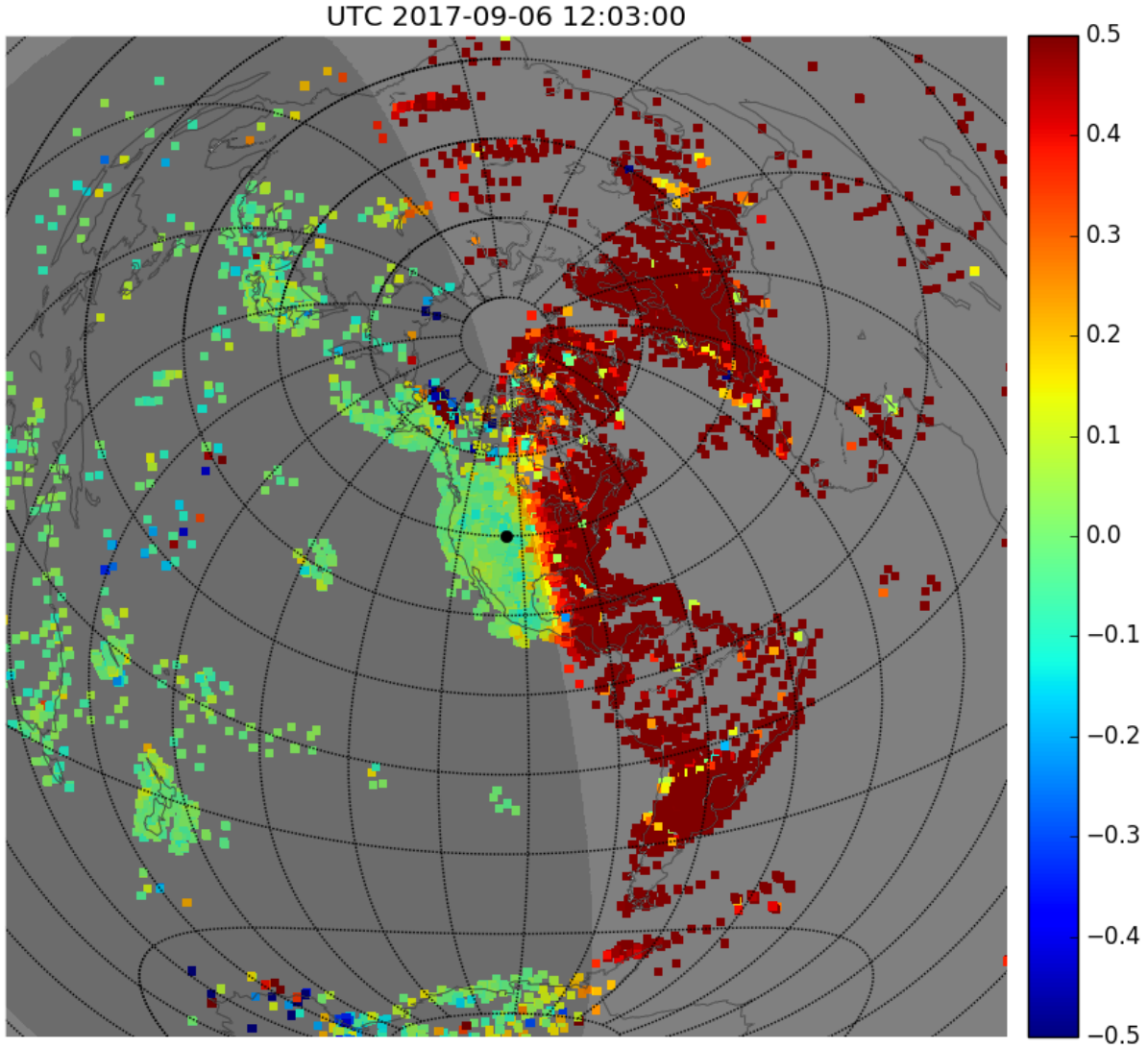
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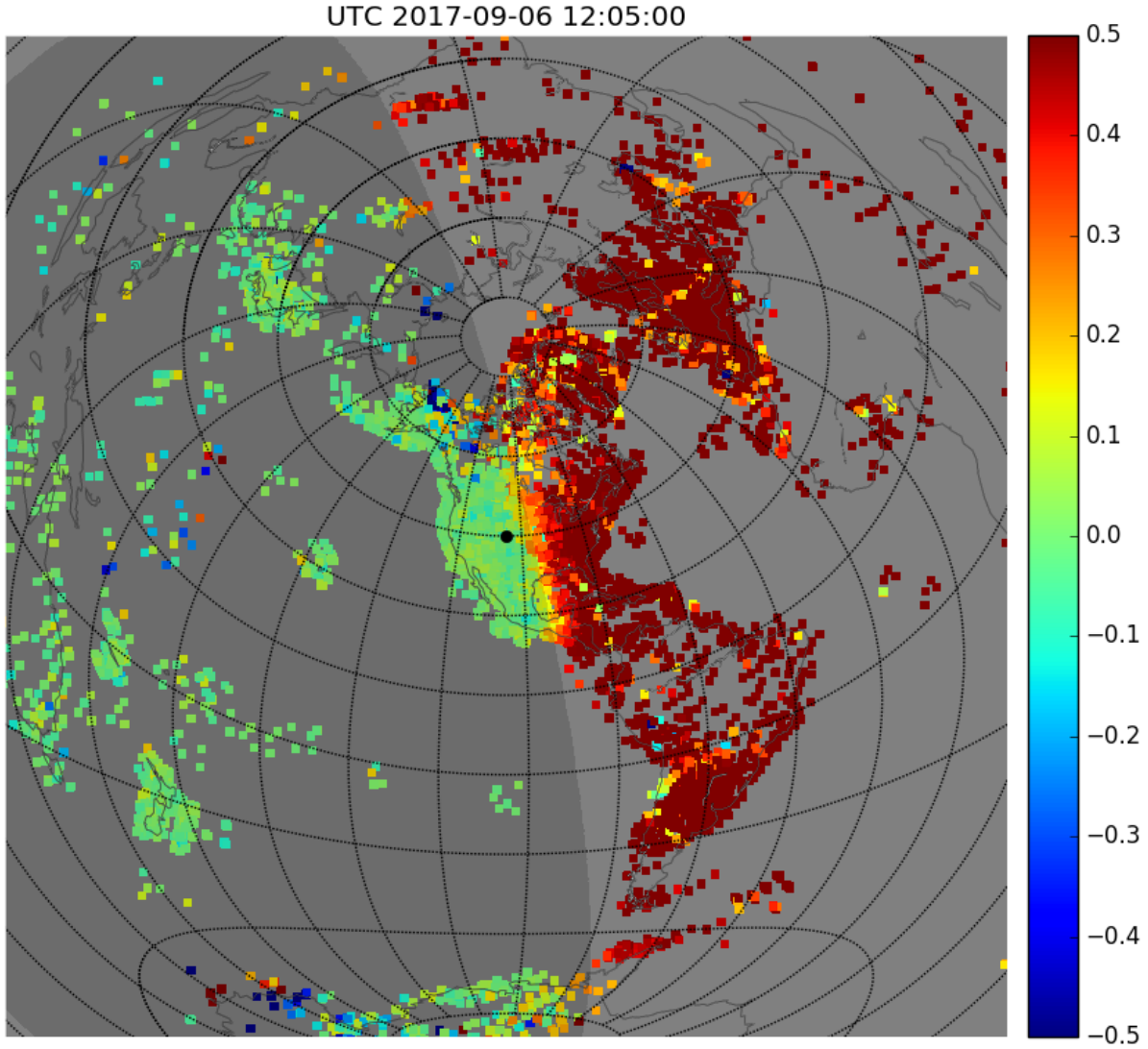
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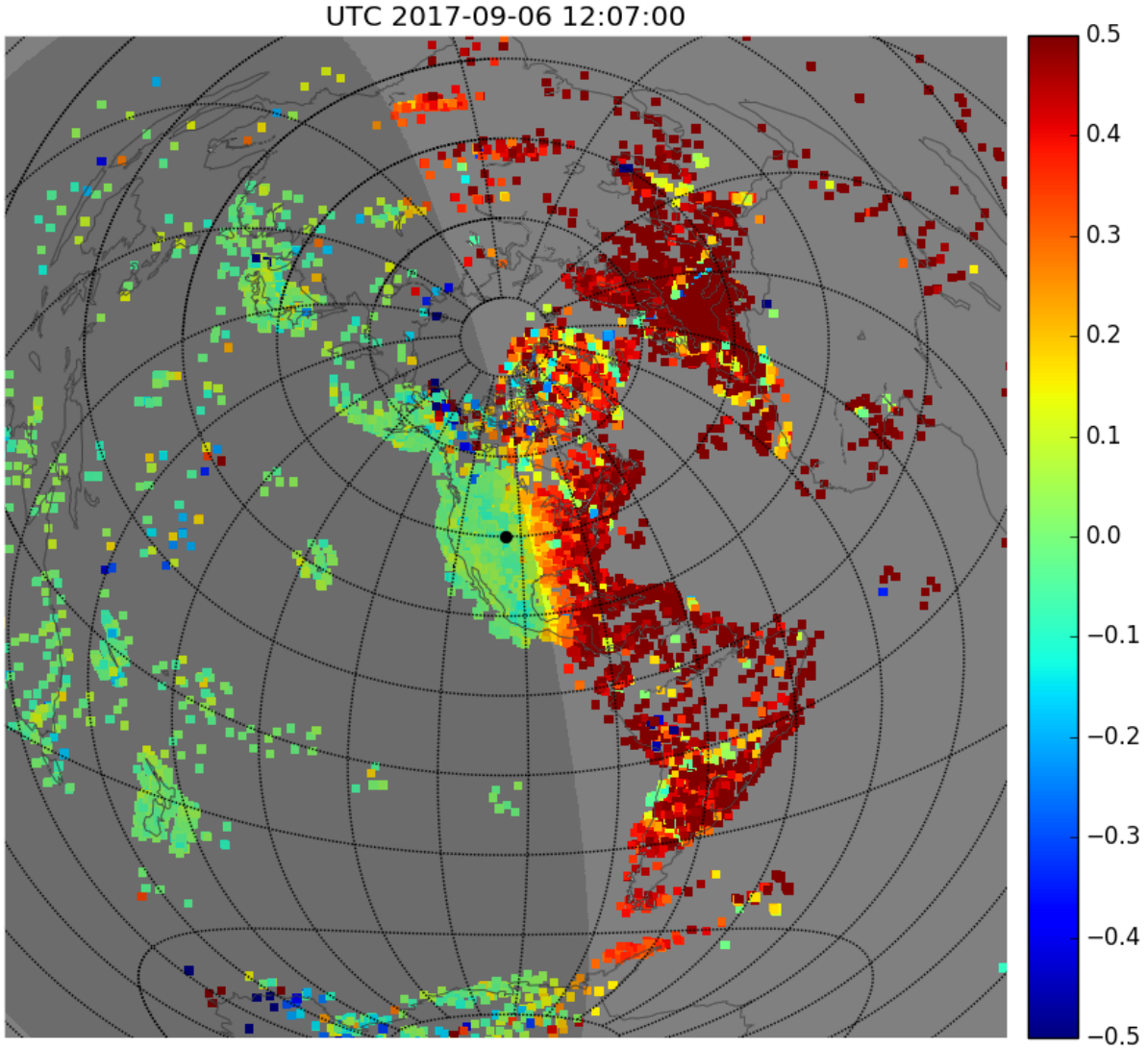
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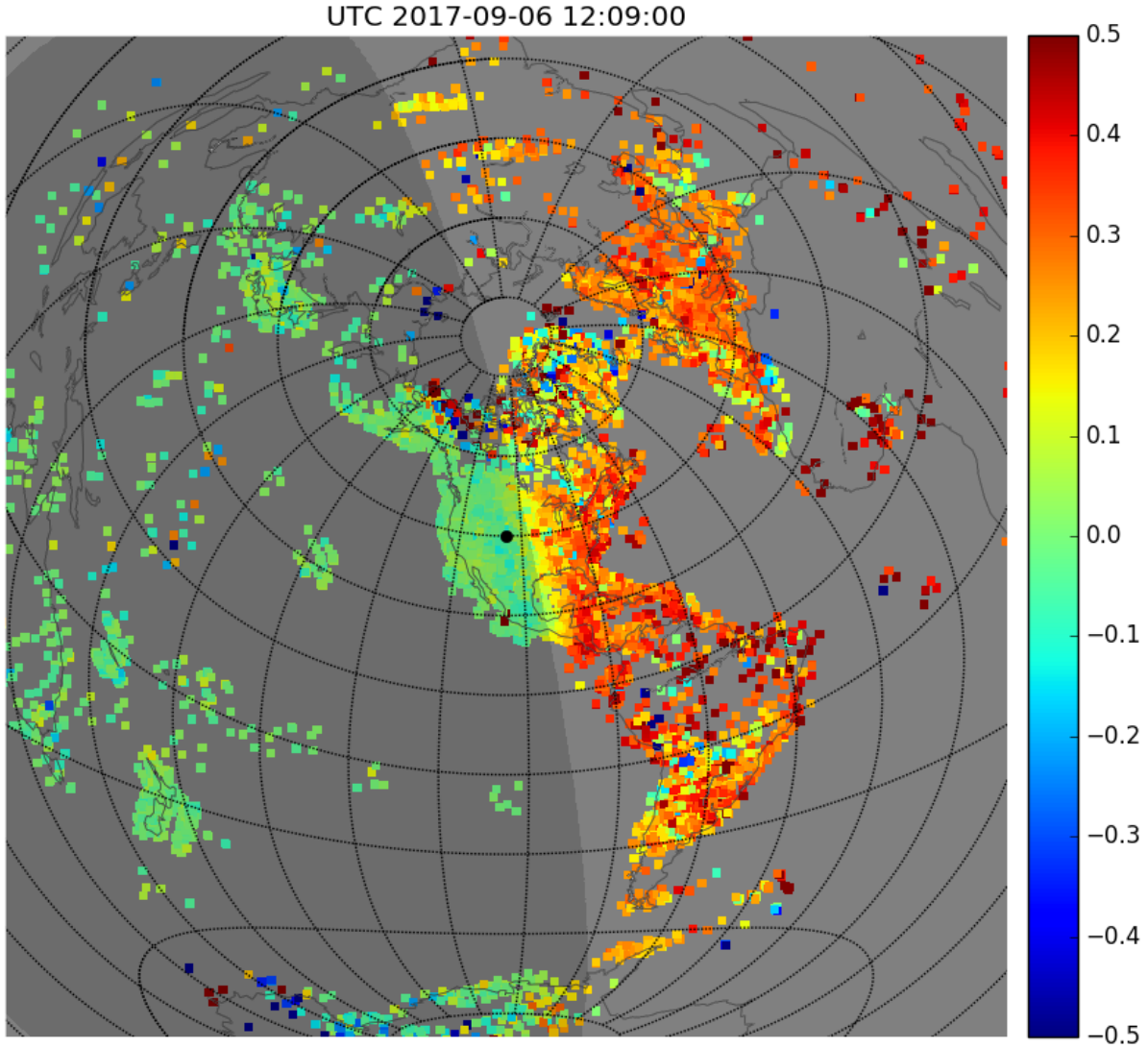
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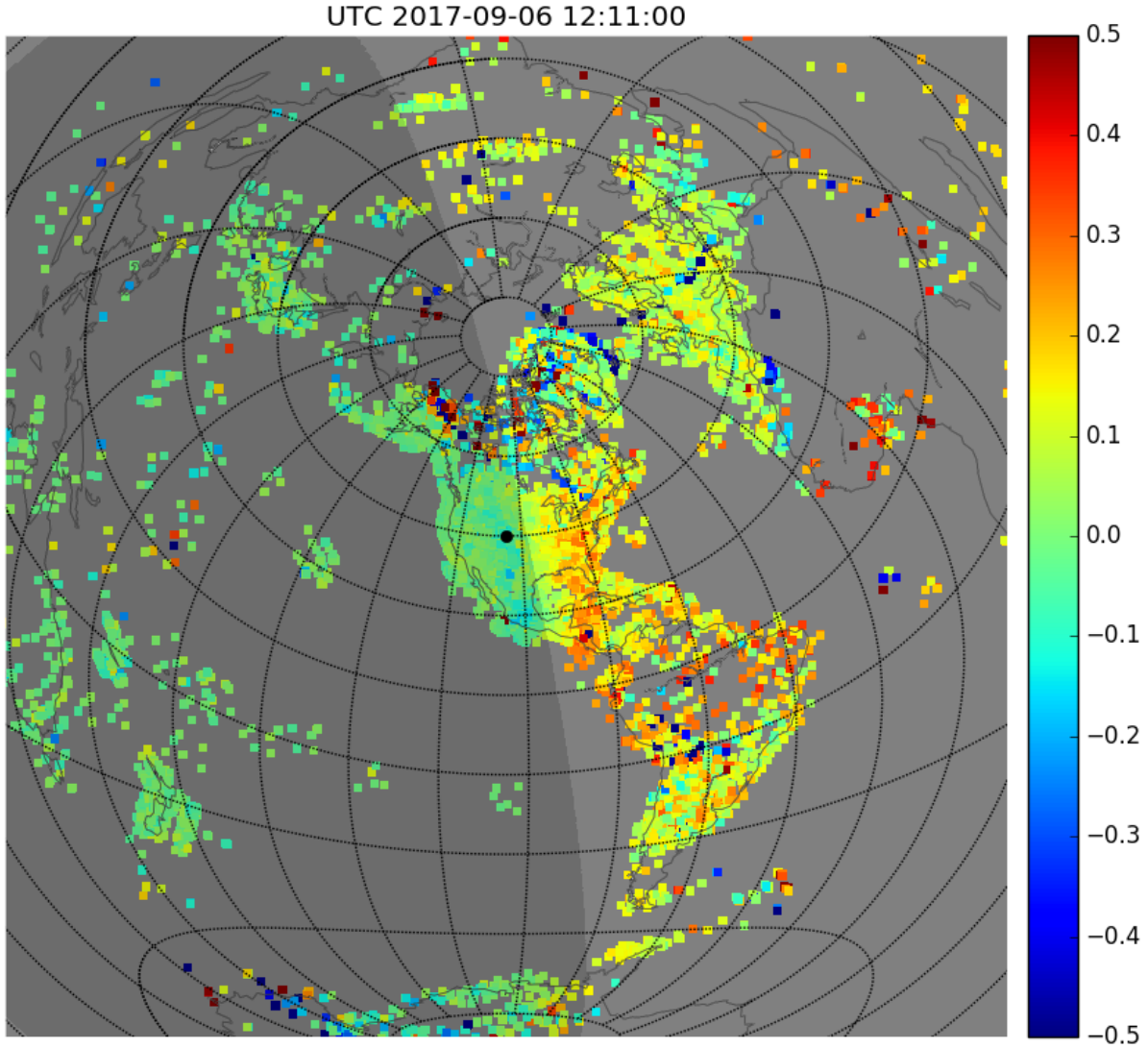
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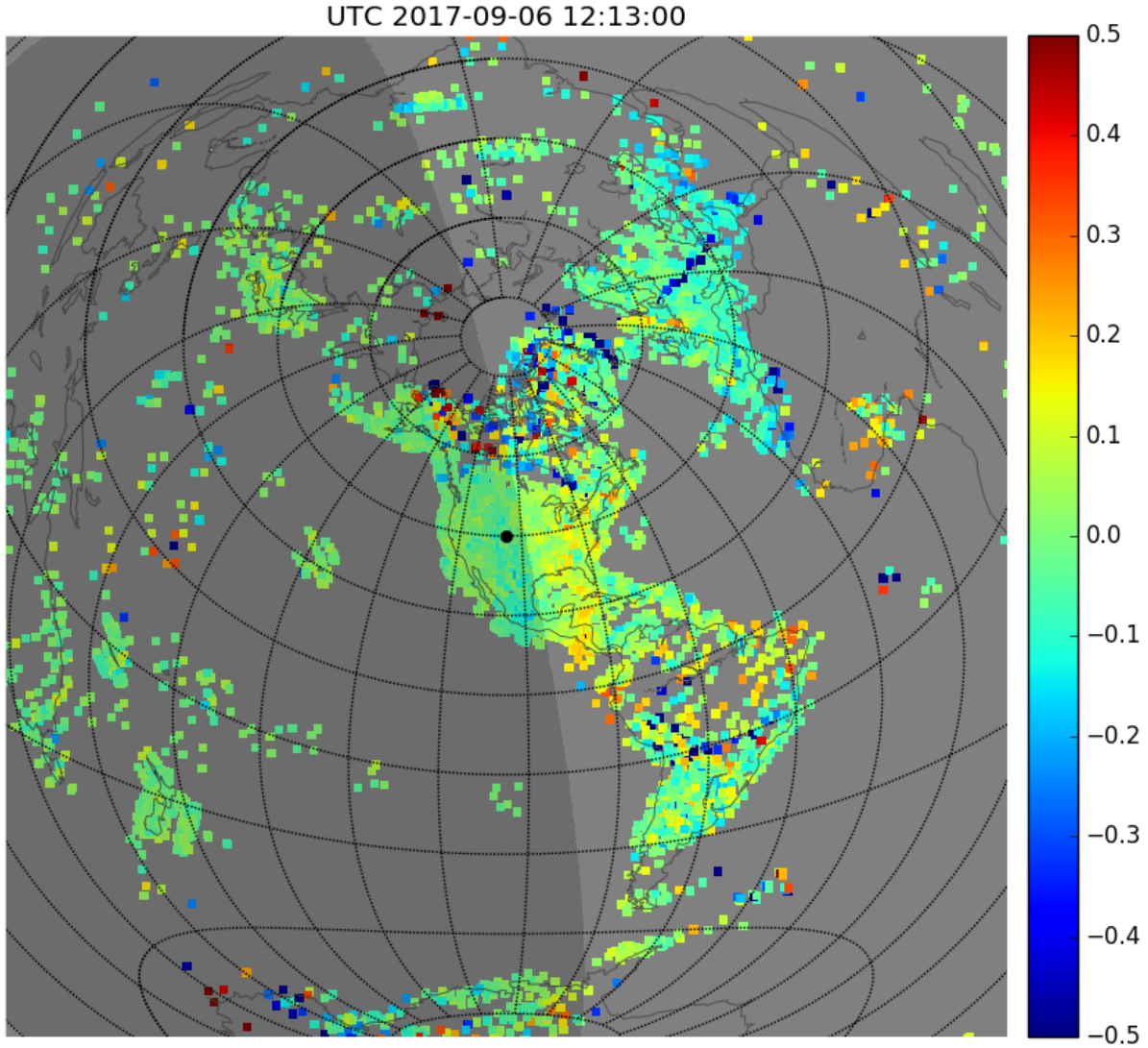
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Outline

What is now available through CEDAR Madrigal Web

What are errors in TEC

Remind everyone that what is needed for model –data validation depends on problem at hand

Welcome to the Madrigal3 CEDAR Database

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. 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.

To see a list of all Madrigal sites, use the *Other Madrigal sites* pull down menu. Data can also be accessed directly, using APIs which are available for several popular programming languages (Matlab, python, and IDL). A Subversion archive of all Madrigal software and documentation is available from the Open Madrigal Web site. The latest version of Madrigal and the remote API's may also be downloaded from there.

If you want to use the old Madrigal 2 version of the CEDAR Madrigal databse, it is still temporarily available at http://madrigal.haystack.mit.edu. If you are using the old version because of a problem with Madrigal3, please contact brideout@haystack.mit.edu to describe the issue.

Choose kind of data for World-wide GPS Receiver Network, year 2017:

Minimum Scallop TEC Processing

Line of sight TEC data

Standard TEC Data in Madrigal

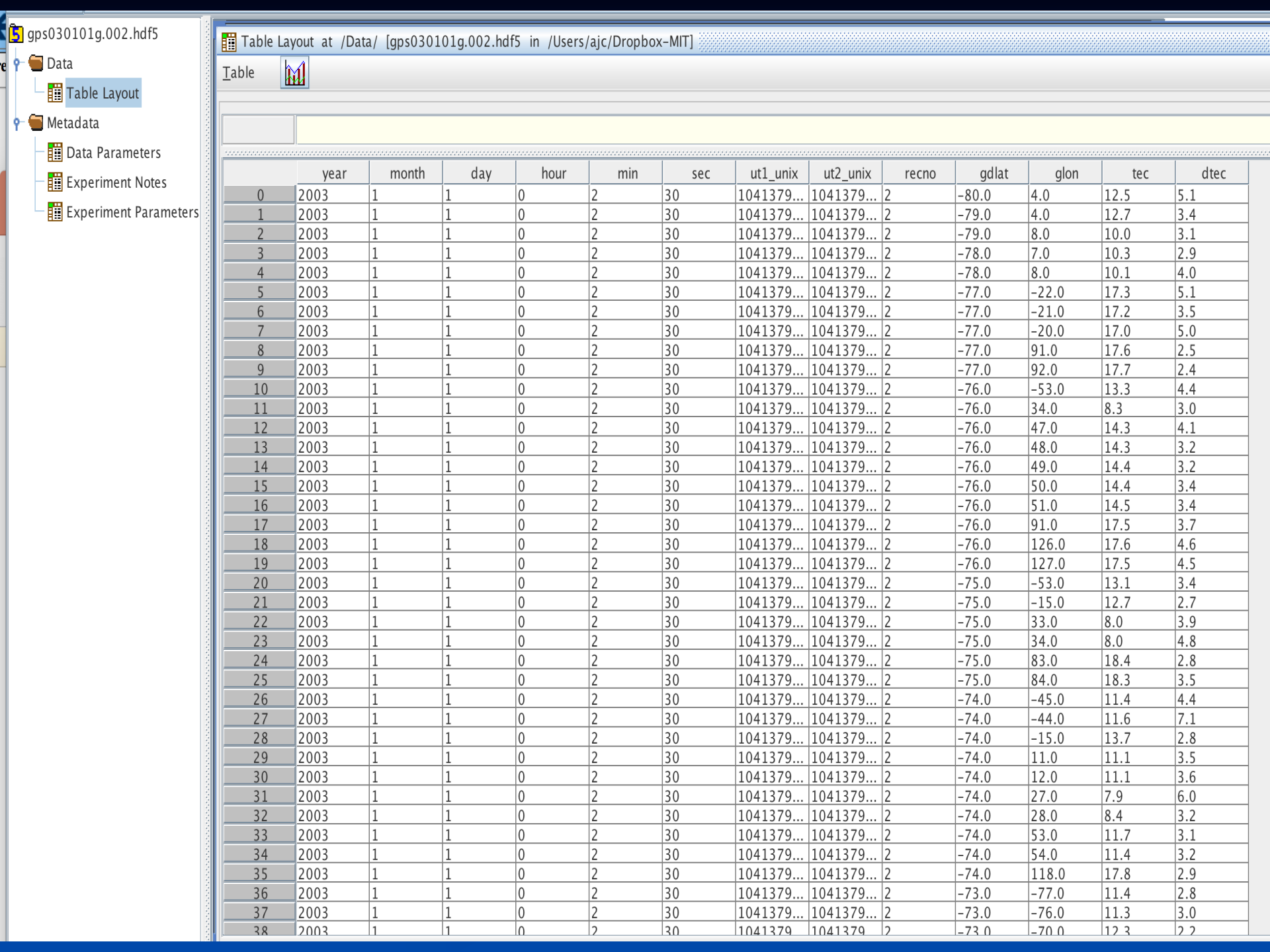
1. Provided in 1 degree by 1 degree bins
2. Provided every 5 minutes
3. Vertical TEC data estimates and Errors on these estimates
4. Geographic Lat and Long
5. Only provides data where observations are available. Does not attempt to model TEC where data is not available. Uses all GNSS data available.
6. New TEC products are on the horizon …i.e. GLONASS observations

What is in HDF5 file of TEC - Using HDFView

Data Parameters at /Metadata/ [gps030101g.002.hdf5 in /Users/ajc/Dropbox-MIT]

Table

	mnemonic	description	isError	units	category
0	YEAR	Year (universal time)	0	y	Time Related Parameter
1	MONTH	Month (universal time)	0	m	Time Related Parameter
2	DAY	Day (universal time)	0	d	Time Related Parameter
3	HOUR	Hour (universal time)	0	h	Time Related Parameter
4	MIN	Minute (universal time)	0	m	Time Related Parameter
5	SEC	Second (universal time)	0	s	Time Related Parameter
6	UT1_UNIX	Unix seconds (1/1/1970) at start	0	s	Time Related Parameter
7	UT2_UNIX	Unix seconds (1/1/1970) at end	0	s	Time Related Parameter
8	RECNO	Logical Record Number	0	N/A	Time Related Parameter
9	GDLAT	Geodetic latitude of measurement	0	deg	Geographic Coordinate
10	GLON	Geodetic longitude of measurement	0	deg	Geographic Coordinate
11	TEC	Vertically integrated electron density	0	tec	I. S. Radar Basic Parameter
12	DTEC	Error in Vertically integrated electron density	1	tec	I. S. Radar Basic Parameter



	year	month	day	hour	min	sec	ut1_unix	ut2_unix	recno	gdlat	glon	tec	dtec
0	2003	1	1	0	2	30	1041379...	1041379...	2	-80.0	4.0	12.5	5.1
1	2003	1	1	0	2	30	1041379...	1041379...	2	-79.0	4.0	12.7	3.4
2	2003	1	1	0	2	30	1041379...	1041379...	2	-79.0	8.0	10.0	3.1
3	2003	1	1	0	2	30	1041379...	1041379...	2	-78.0	7.0	10.3	2.9
4	2003	1	1	0	2	30	1041379...	1041379...	2	-78.0	8.0	10.1	4.0
5	2003	1	1	0	2	30	1041379...	1041379...	2	-77.0	-22.0	17.3	5.1
6	2003	1	1	0	2	30	1041379...	1041379...	2	-77.0	-21.0	17.2	3.5
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8	2003	1	1	0	2	30	1041379...	1041379...	2	-77.0	91.0	17.6	2.5
9	2003	1	1	0	2	30	1041379...	1041379...	2	-77.0	92.0	17.7	2.4
10	2003	1	1	0	2	30	1041379...	1041379...	2	-76.0	-53.0	13.3	4.4
11	2003	1	1	0	2	30	1041379...	1041379...	2	-76.0	34.0	8.3	3.0
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22	2003	1	1	0	2	30	1041379...	1041379...	2	-75.0	33.0	8.0	3.9
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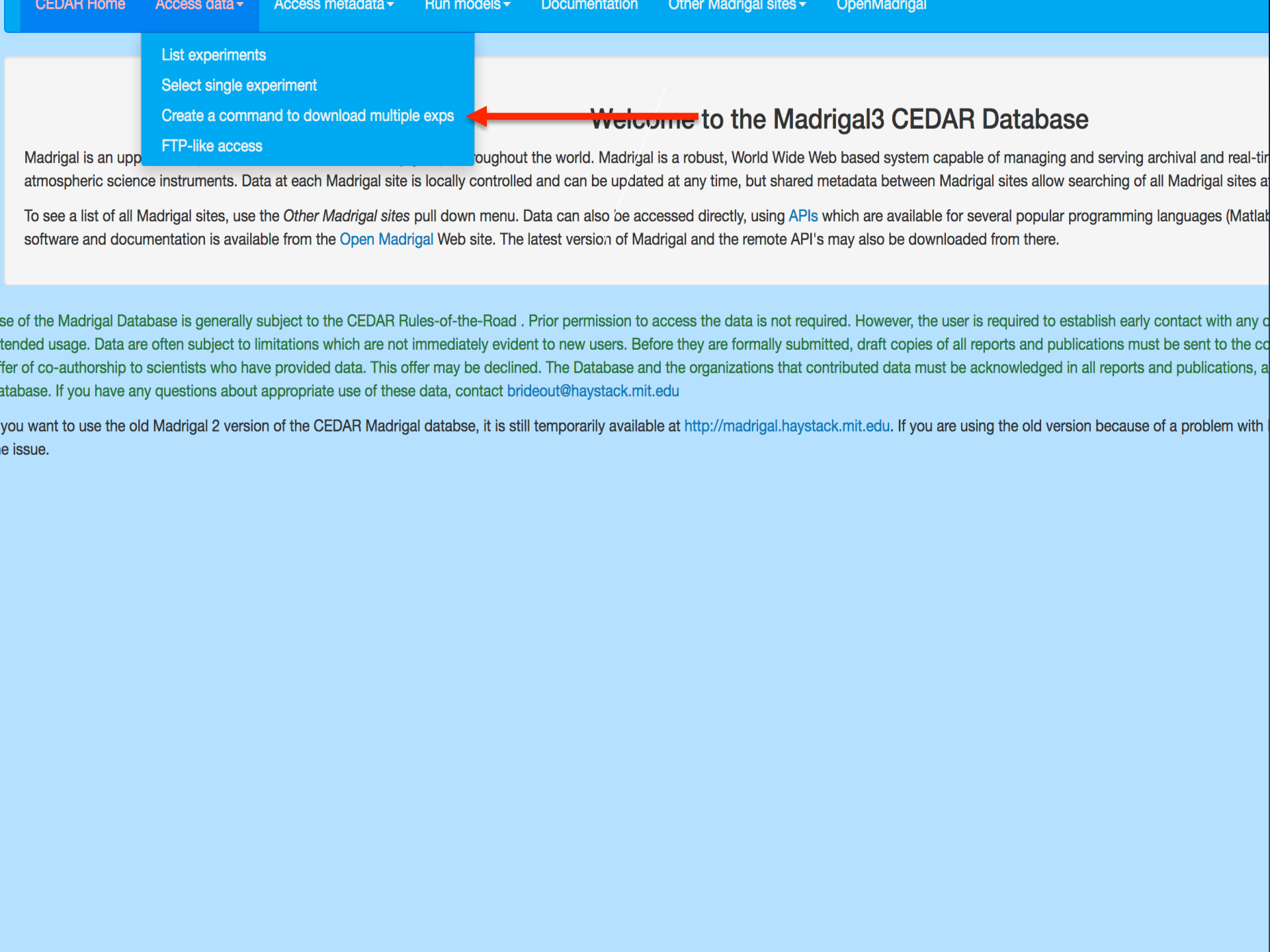
29	2003	1	1	0	2	30	1041379...	1041379...	2	-74.0	11.0	11.1	3.5
30	2003	1	1	0	2	30	1041379...	1041379...	2	-74.0	12.0	11.1	3.6
31	2003	1	1	0	2	30	1041379...	1041379...	2	-74.0	27.0	7.9	6.0
32	2003	1	1	0	2	30	1041379...	1041379...	2	-74.0	28.0	8.4	3.2
33	2003	1	1	0	2	30	1041379...	1041379...	2	-74.0	53.0	11.7	3.1
34	2003	1	1	0	2	30	1041379...	1041379...	2	-74.0	54.0	11.4	3.2
35	2003	1	1	0	2	30	1041379...	1041379...	2	-74.0	118.0	17.8	2.9
36	2003	1	1	0	2	30	1041379...	1041379...	2	-73.0	-77.0	11.4	2.8
37	2003	1	1	0	2	30	1041379...	1041379...	2	-73.0	-76.0	11.3	3.0
38	2003	1	1	0	2	30	1041379...	1041379...	2	-73.0	-70.0	12.3	2.2

Line of Site TEC Data in Madrigal (only 2 years as of today)

1. Provided for every receiver
2. Provided every 30 seconds (time)
3. Receiver ID
4. Satellite ID
5. Receiver Lat and Long
6. Pierce Point altitude, Lat and Long
7. Azimuth and Elevation to Satellite
8. HDF5 format


CEDAR Home
Access data
Access metadata
Run models
Documentation
Other Madrigal sites
OpenMadrigal
List experiments
Select single experiment
Create a command to download multiple exps
FTP-like access
Welcome to the Madrigal3 CEDAR Database
Madrigal is an upp
roughout the world. Madrigal is a robust, World Wide Web based system capable of managing and serving archival and real-tir
atmospheric science instruments. 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 a
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software and documentation is available from the Open Madrigal Web site. The latest version of Madrigal and the remote API's may also be downloaded from there.
se of the Madrigal Database is generally subject to the CEDAR Rules-of-the-Road . Prior permission to access the data is not required. However, the user is required to establish early contact with any c
tended usage. Data are often subject to limitations which are not immediately evident to new users. Before they are formally submitted, draft copies of all reports and publications must be sent to the co
ffer of co-authorship to scientists who have provided data. This offer may be declined. The Database and the organizations that contributed data must be acknowledged in all reports and publications, a
atabase. If you have any questions about appropriate use of these data, contact brideout@haystack.mit.edu
you want to use the old Madrigal 2 version of the CEDAR Madrigal databse, it is still temporarily available at http://madrigal.haystack.mit.edu. If you are using the old version because of a problem with
e issue.

My recommendation (and Bill Rideout's)

Use globalDownload command to obtain multiple days (even years) of our TEC product. The globalDownload command is available in python, matlab, and IDL scripts.

TEC data can be provided in HDF5 or ascii format. HDF5 is faster.

Succesful Example of running globalDownload.py

```
globalDownload.py
--url=http://madrigal.haystack.mit.edu/madrigal
--outputDir=/Users/ajc/Dropbox-MIT
--user_fullname="anthea_coster"
--user_email=costera@mit.edu
--user_affiliation=MIT
--startDate=01/01/2003
--endDate=01/03/2003
--format=hdf5
--inst=8000
```

Outline

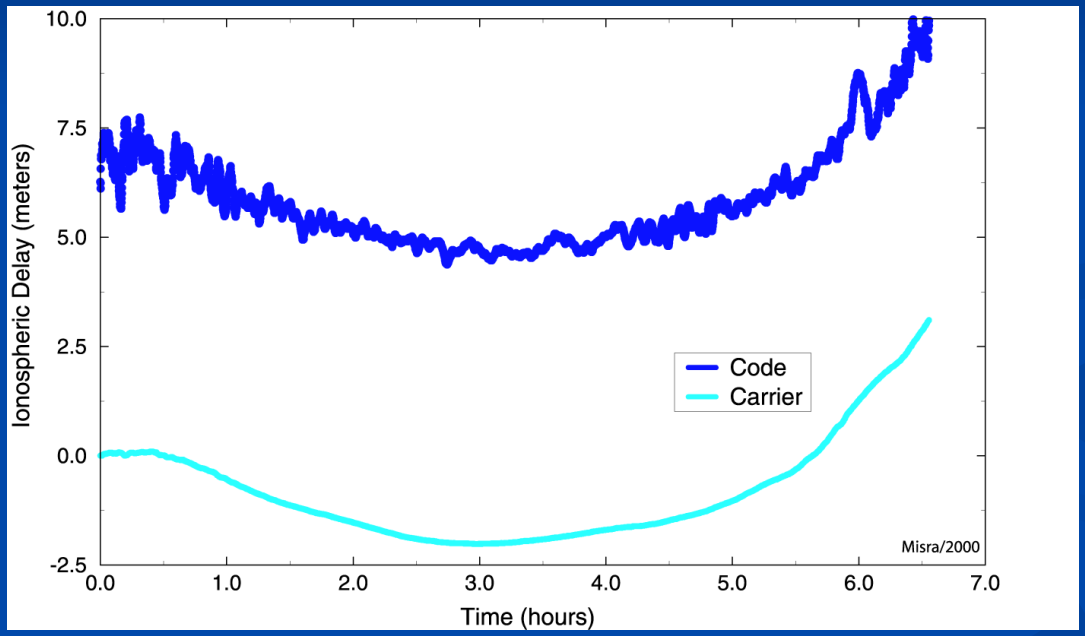
What is now available through CEDAR Madrigal Web

What are errors in TEC

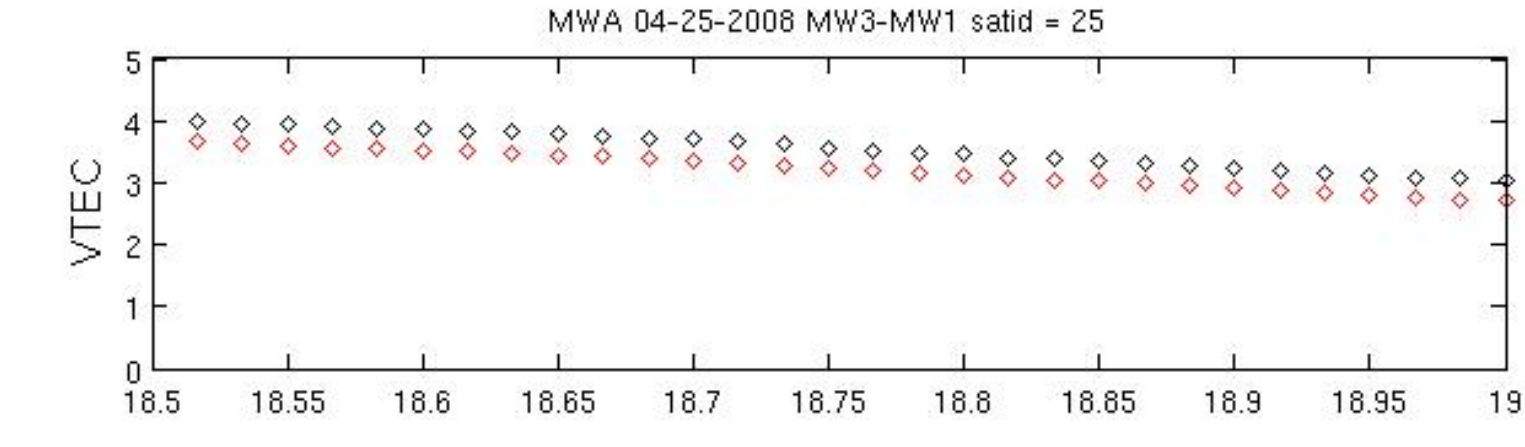
Remind everyone that what is needed for model –data validation depends on problem at hand

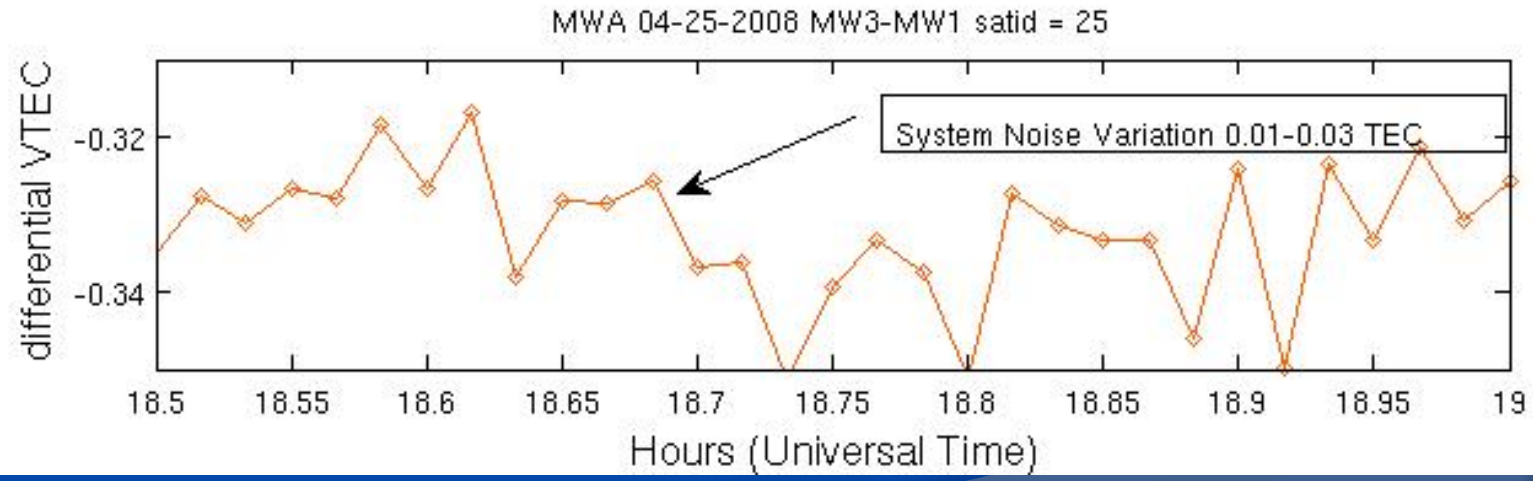
Total Electron Content (TEC) Estimation

Dual-Frequency Measurements



GPS Phase Noise ~ 0.01-0.03 TEC MW3-MW1

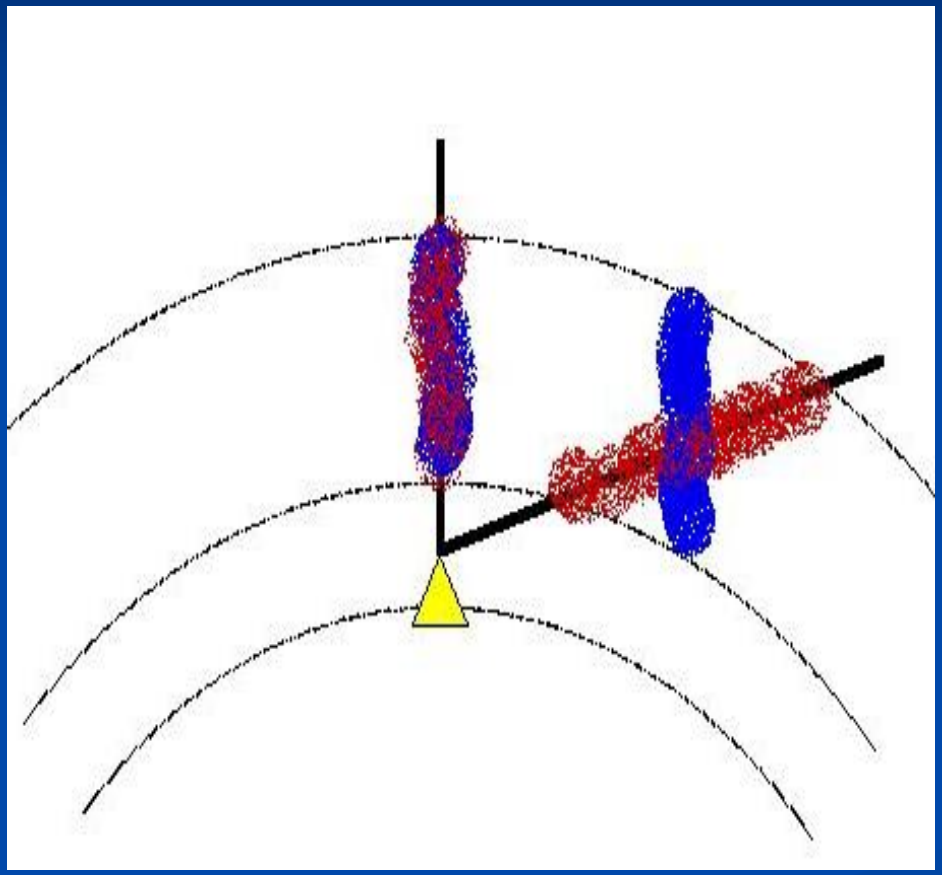




Problem 1: GPS Biases

- GPS delay difference between two frequencies provides TEC
- Delay differences are also introduced by the satellite and receiver
- Satellite biases are determined by IGS community and are fairly stable
- Receiver biases are determined by individual user and most users estimate one bias over a 24 - hour period.

Problem 2: Mapping Function



- Mapping function used to map TEC (line of sight) to Vertical TEC
- Assigns V-TEC to pierce point
- Function of Elevation Range:

$1 < Z < 3$

Importance of Bias Estimation

- L1-L2 Biases
  - Sources: SV and RCVR hardware
  - Variable changes possible
  - Up to 6 TECu (for SV); 30 TECu (for RCVR

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Model Data Comparisons

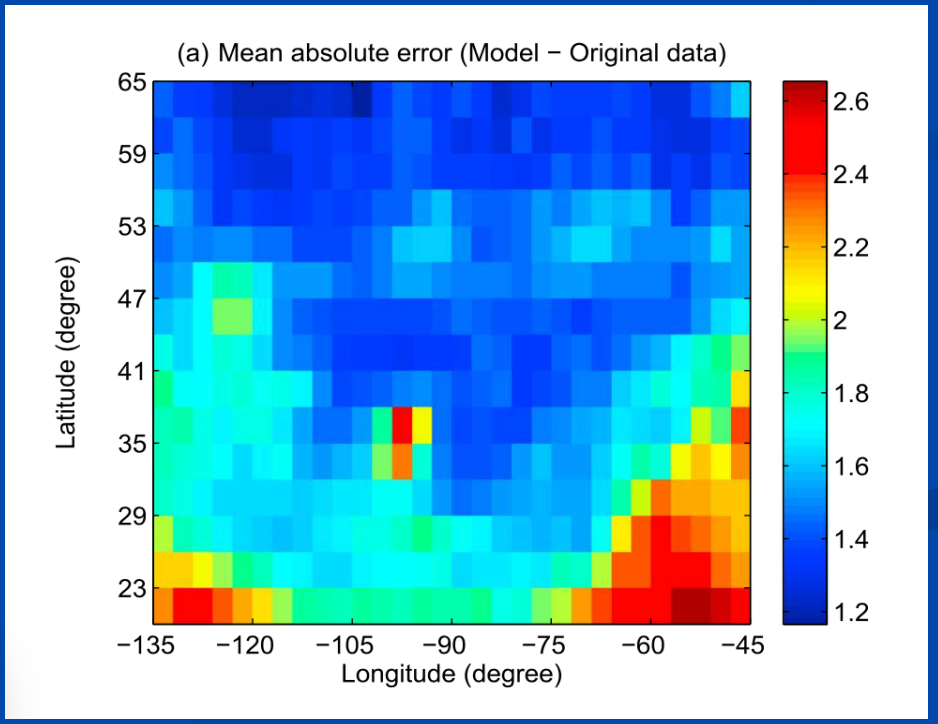
- Questions to ask:
  - Monthly Means or Medians?
  - Change bin sizes? 5 degrees by 5 degrees?
  - Change time averages? 15 minutes? 1 hour averge?
  - Pre-screen data for outliers, for geomagnetic activity?
  - Use GPS TEC model for daily comparison?

EOF analysis and modeling of GPS TEC climatology over North America

Accounts for diurnal, seasonal, solar cycle, and spatial variations in TEC over NA.

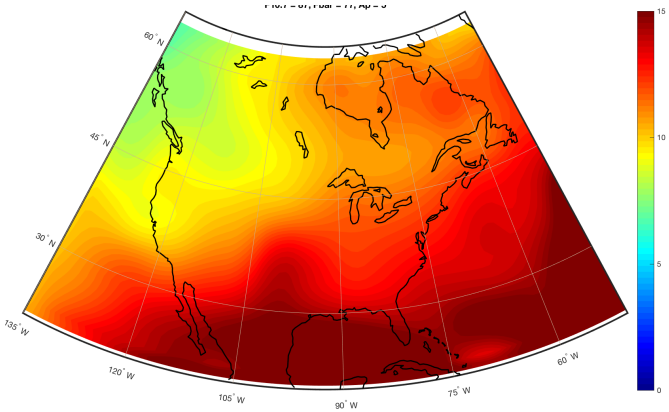
Average error of NA is 1.2 to 2.6 TECu.

Chen, Z., S.-R. Zhang, A. J. Coster, and G. Fang (2015), EOF analysis and modeling of GPS TEC climatology over North America, *J. Geophys. Res. Space Physics*, *120*, 3118–3129, doi:10.1002/2014JA020837.



NATEC model, Aug 30, F10.7 = 87; Ap = 5; Fbar=77

16:30



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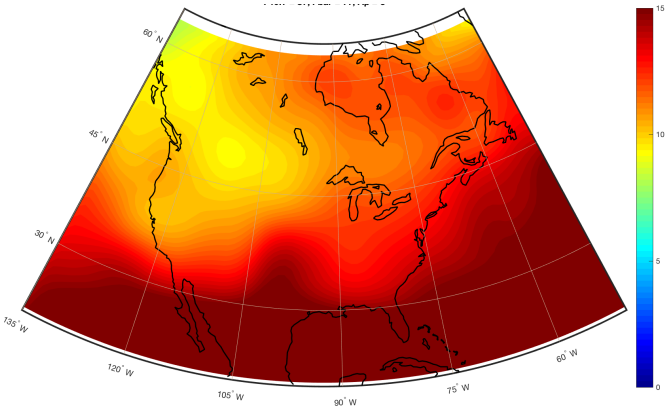
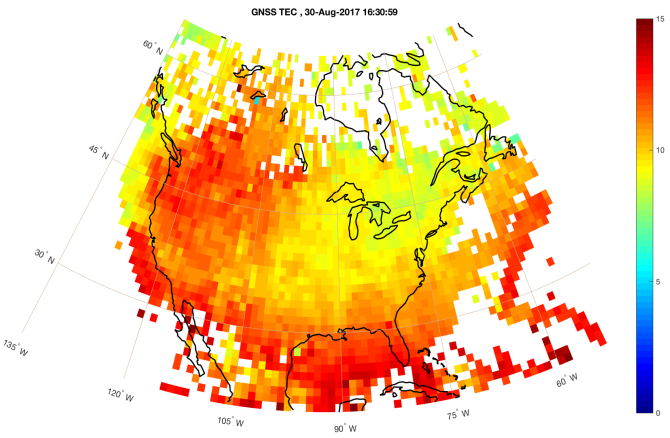


GPS TEC data, Aug 30, 2017, F10.7 = 87; Ap = 5

16:30



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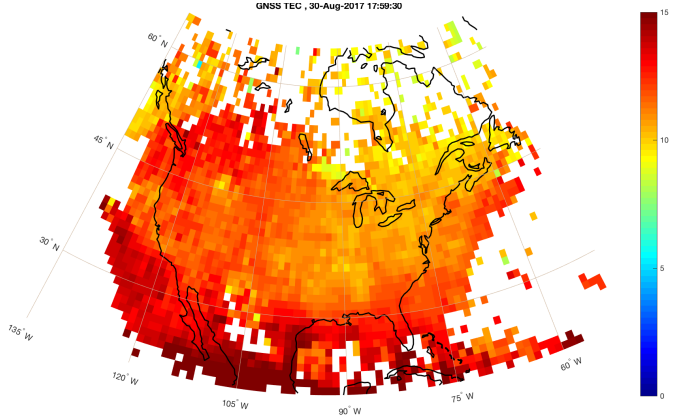

Questions with Madrigal

- Start with Bill Rideout
  brideout@haystack.mit.edu