G L O B A L I O N O S P H E R E R A D I O O B S E R V A T O R Y

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USER GUIDE

GAMBIT Version: 1.0
September 4, 2020

Contents

ABBREVIATIONS

GAMBIT	Global Assimilative Model of Bottomside Ionosphere Timeline
GIRO	Global Ionosphere Radio Observatory
IRI	International Reference Ionosphere
IRTAM	IRI-based Real-Time Assimilative Model
LGDC	Lowell GIRO Data Center
VTEC	Vertical Total Electron Content

SCOPE

This document is a User Guide for the *GAMBIT Explorer 1.0* (Gambit-X, or GX) User Application software.

GAMBIT Explorer is a tool for accessing, visualizing, and analysis of data acquired over the Internet from

1) GAMBIT Database at University of Massachusetts Lowell holding global maps computed by IRTAM 3D model:
   - ✓ f_oF2, O-wave critical frequency of F2 layer, and N_mF2, peak electron density of F2 layer, derived from f_oF2
   - ✓ h_mF2, peak height of the F2 layer
   - ✓ *B0* and *B1*, standard vertical profile shape parameters of International Reference Ionosphere (IRI)
2) CEDAR Madrigal database at MIT Haystack Observatory
   - ✓ Vertical Total Electron Content (VTEC) measurement data
3) Database at University of Warmia and Mazury in Olsztyn
   - ✓ Global 30-day average VTEC maps

1. BACKGROUND

IRTAM (http://giro.uml.edu/IRTAM)

IRTAM is a global empirical assimilative model of the subpeak 3D ionospheric plasma density that computes its weather nowcast by smoothly transforming the underlying International Reference Ionosphere (IRI) climatology model into the optimal match with the measurements provided by

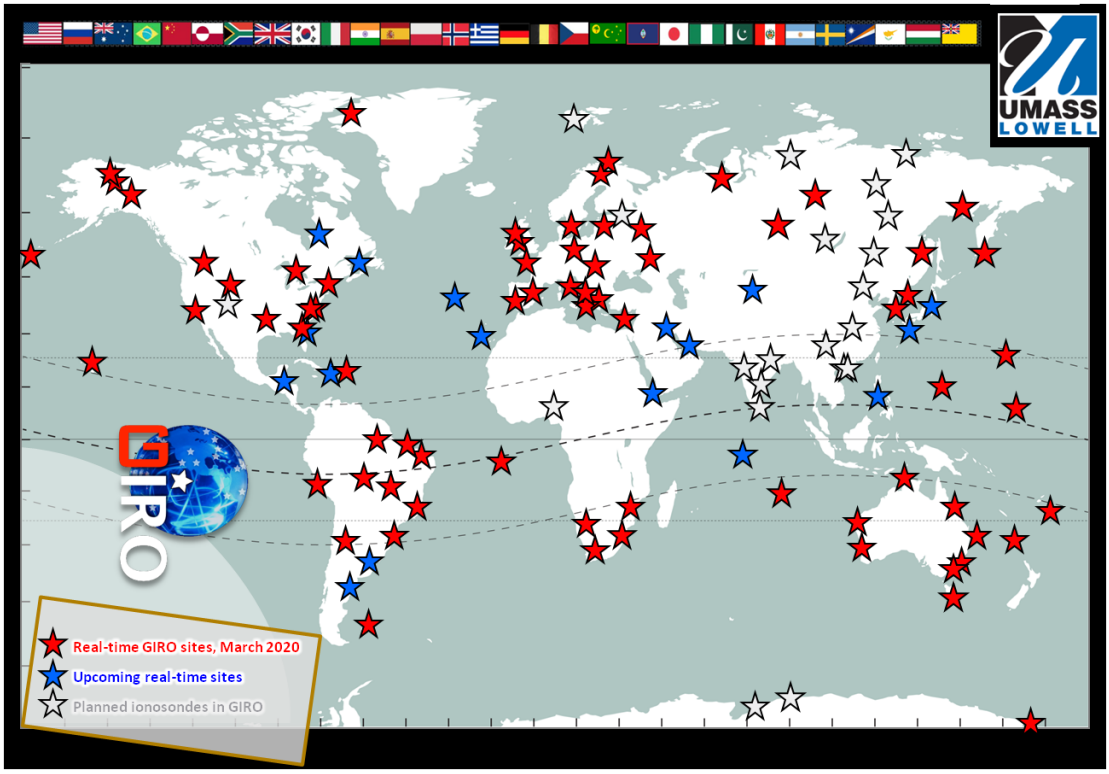
Global Ionosphere Radio Observatory (GIRO). Every 15 minutes, IRTAM computes its updated specification, submits the outcome to Lowell GAMBIT database, releases 24-hour animated weather timelines at http://giro.uml.edu/IRTAM, and distributes IRTAM model coefficients to the weather service subscribers.

GAMBIT (http://giro.uml.edu/GAMBIT)

GAMBIT Database and Explorer are used to store and disseminate IRTAM results

GIRO (http:/giro.uml.edu)

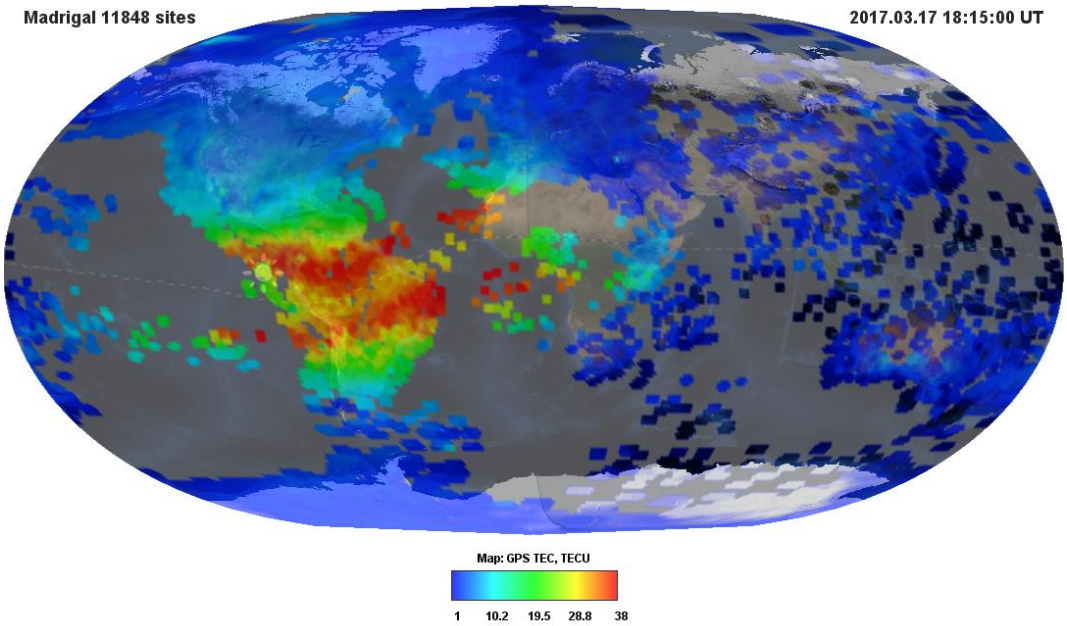
Global Ionosphere Radio Observatory manages data from a network of 120+ ionosondes, of which about 60 stations report measurements to Lowell GIRO Data Center in near real-time.



GIRO Network of Ionosondes

CEDAR Madrigal (http://cedar.openmadrigal.org)

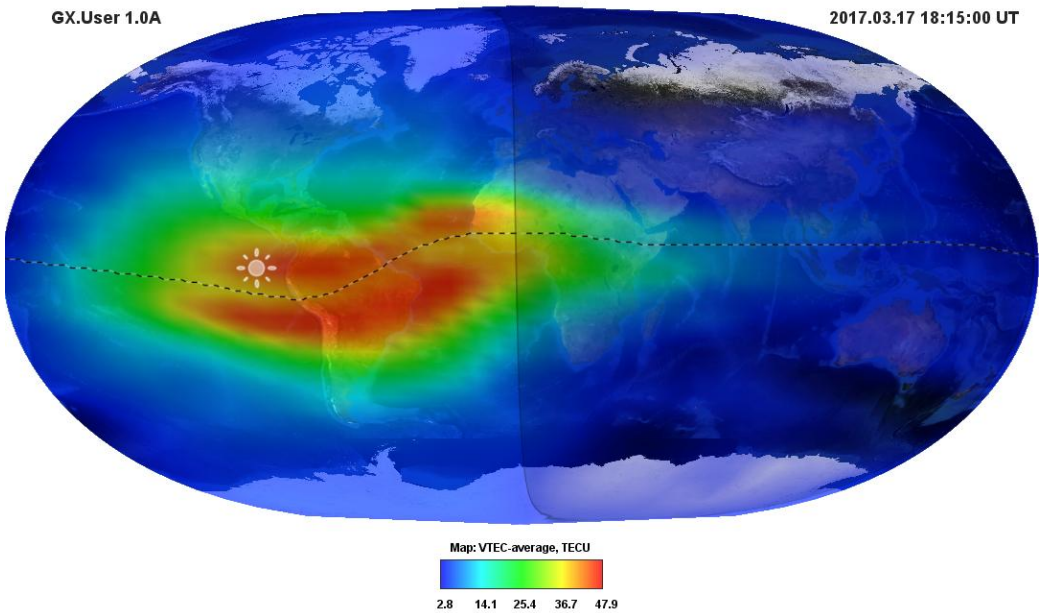
Madrigal database is a distributed geospace data sharing infrastructure with 10 nodes is 5 countries and extensive data holdings in 20 categories, including world-wide GNSS receiver network.



VTEC from Madrigal GNSS Network; each color pixel corresponds to a receiver site

Climate VTEC Repository at UWM (https://igsiono.uwm.edu.pl)

Based on the "rapid" VTEC maps released by UQRG service of Polytechnic University of Catalonia (UPC) in Spain, the global climate VTEC maps are 30-days moving average for each epoch and coordinates.



Global 30-day average VTEC from Climate VTEC repository at UWM, Poland

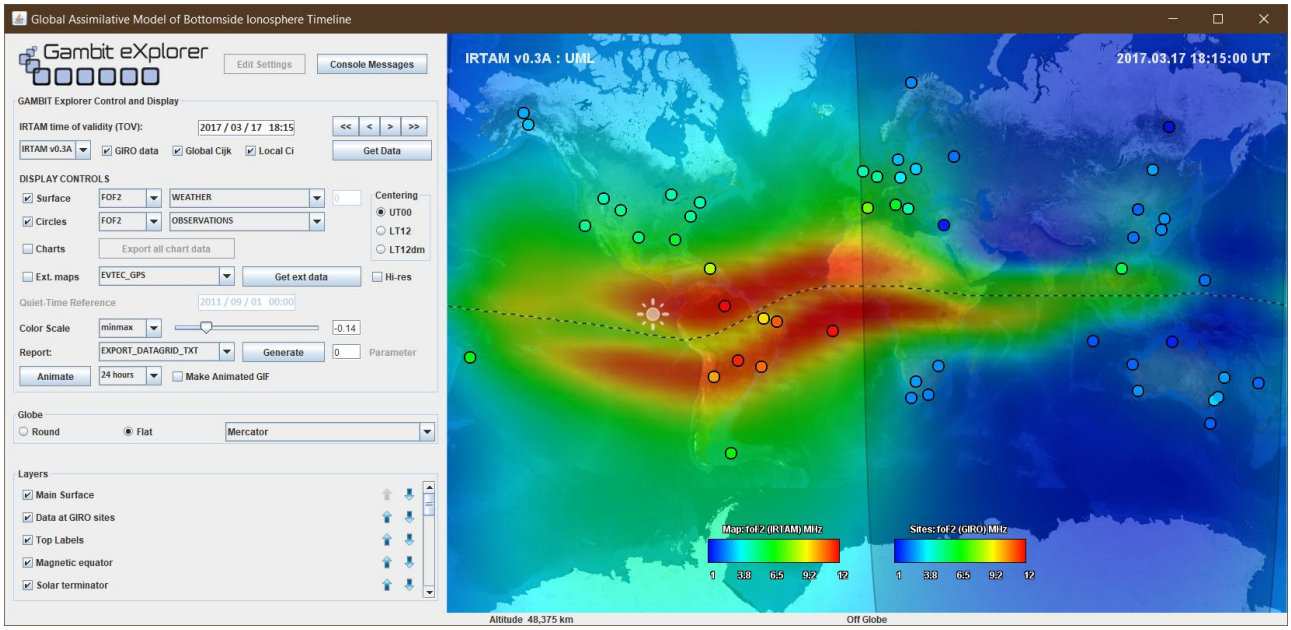
2. INSTALLATION

Installation instructions are provided in a separate document on http://giro.uml.edu/GAMBIT.

Important: user account information must be provided in files user/gambit_info.txt and user/guest_info.txt before starting GAMBIT Explorer. If gambit_info.txt is left empty, connections to GAMBIT database are made in the guest role.

3. MAIN SCREEN OPERATIONS

GAMBIT is a single frame application with all controls available on the main panel:



Main panel of GAMBIT Explorer showing IRTAM (color map) and GIRO (circles) foF2 data

3.1. Data Display Selections

GAMBIT operates with four different groups of data that can be selected for download and visualization:

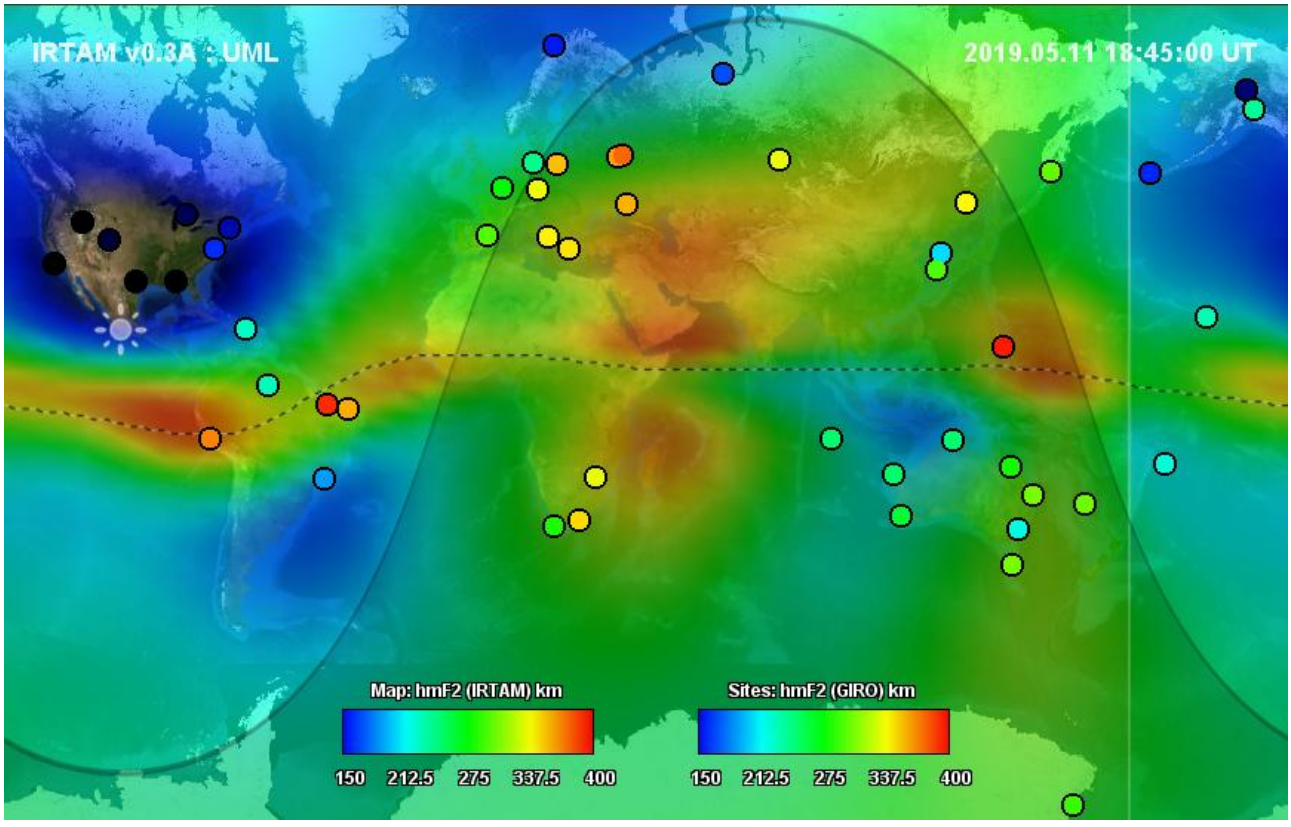
Data	Ionospheric Properties	Display types	Download server
IRI climate map	foF2 (NmF2), hmF2, B0, B1	Surface, Chart	None
IRTAM weather map			GAMBIT Database, Lowell
GIRO observations		Color Circle, Chart	
VTEC climate map	VTEC	Surface	UWM, Poland
VTEC observations	VTEC	External Map	Madrigal Database

3.2. Display Types

Four different types of display are available:

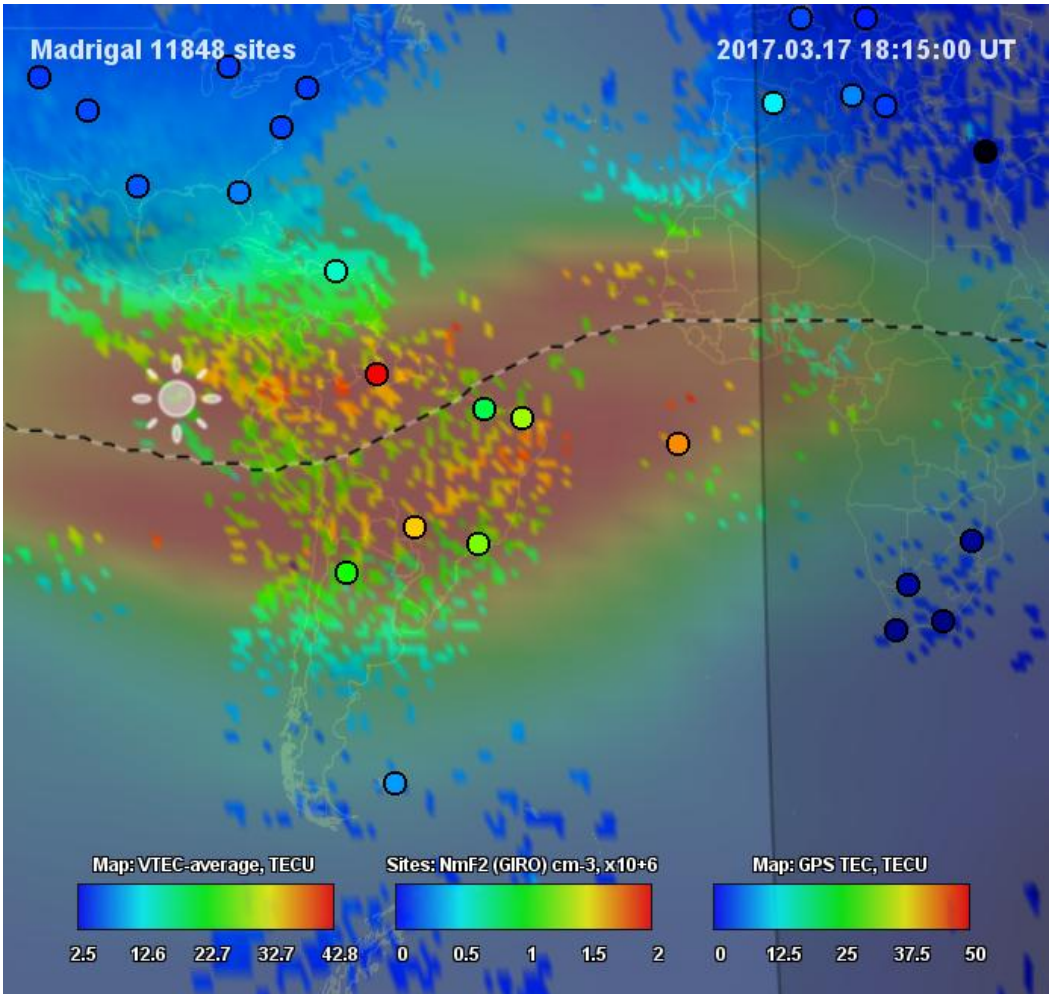
1) SURFACE
2) CIRCLES
3) CHARTS
4) EXTERNAL MAP

Common GX visualization combines *Surface* and *Circles*. For example, IRTAM weather h_mF2 as *Surface* and GIRO h_mF2 measurements as *Circles*:



Typical GX display that combines IRTAM weather h_mF2 *as* Surface *and GIRO* h_mF2 *measurements as* Circles*:*

Combination of *Sufrace* and *External Map* is usually impractical as two color surfaces blend into each other. Here's an example that combines *Surface*, *Circles*, and *External Map* in one display:



Example combination of Surface (Climate VTEC), circles (NmF2), and external map (VTEC)

3.3. Data Selection for Download

To select data for download, start with typing in the "target" time (also known as Time of Validity, TOV):

Do not use Delete or Backspace buttons, just type over existing numbers

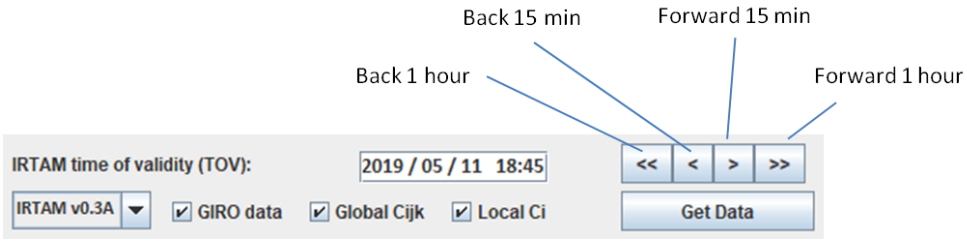
In most cases, all three checkboxes will be selected to download full content from GAMBIT database, including (left to right) (1) GIRO measurements that were used for IRTAM computations, (2) IRTAM coefficients for the global weather map, and (3) IRTAM coefficients for the local weather timelines at each GIRO station. For slow Internet connections to GAMBIT database in Lowell, it may be helpful to disable downloads of local weather coefficients or GIRO data.

The average VTEC maps are downloaded from UWM automatically, and VTEC measurements from Madrigal database are downloaded by request.

Date/time entry into the TOV textbox is subject to immediate check for validity at a single press of a key. This feature may require a trick to avoid the autocheck blocking the new value. For example, changing March "03" to October "10" will not work if 0 is attempted to be changed to 1, because "13" is invalid. Changing "3" to "0" will not work, either, because "00" is invalid. One possibility is to replace 3 with 2, 0 with 1, and 2 with 0.

3.4. Data Download

- IRI climate display does not require data download.
- IRTAM data and VTEC climate are downloaded by request by pushing "Get Data" button:



Once data are downloaded, it is possible to further navigate in time using arrows above the "Get Data" button.

- Madrigal VTEC download is initiated by a separate button:

Madrigal VTEC will use the same time as IRTAM TOV.

Daily Climate-VTEC and Madrigal-VTEC data files are stored locally so that there is no need to download them again for the same day. They are stored in <home>/input folder of the Gambit-X.

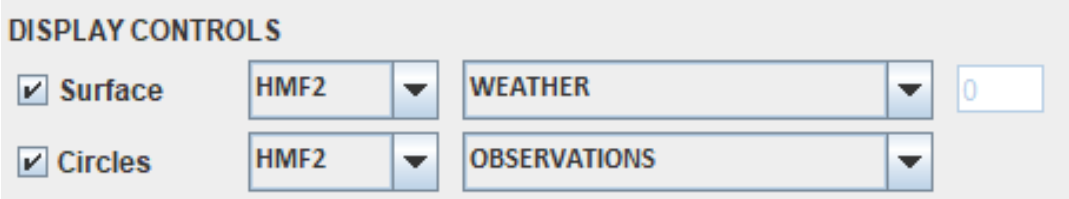
3.4. Typical User Action Sequence

1. Specify time
2. Click "Get Data"
3. Click "Get ext data" if VTEC measurements are needed.
4. Select characteristic from the list

   foF2, NmF2, hmF2, B0, B1, VTEC, Tau

5. Select data type for *Surface*

   CLIMATE, WEATHER, DELTA, and DELTA PERCENT



6. Data type for the *Circles* is selected automatically to match the selection for *Surface:*

   OBSERVATIONS, OBSERVATIONS_CLIMATE, and OBSERVATIONS_WEATHER

If you would like to combine different characteristics or data types for *Surface* and *Circles,* then select *Surface* first and *Circles* second.

Only Climate VTEC is available for *Surface* at this time. Selection of VTEC or Tau as characteristics for display requires CLIMATE selection for the data type. Provision of near-real-time weather VTEC maps is under development.

3.5. Color scale optimization

Adjust the color scale used for the display using two controls: Algorithm selection and Adjustment Factor slide bar:

Algorithm selection can be one of three:

- Minmax: use minimum and maximum value to map the color scale
- 1sigma: reduce min and max values by 1 sigma of the distribution (will saturate)
- Custom: use user-defined values given in the settings file Gambit_UserApp.ini

3.6. Moving around the map display

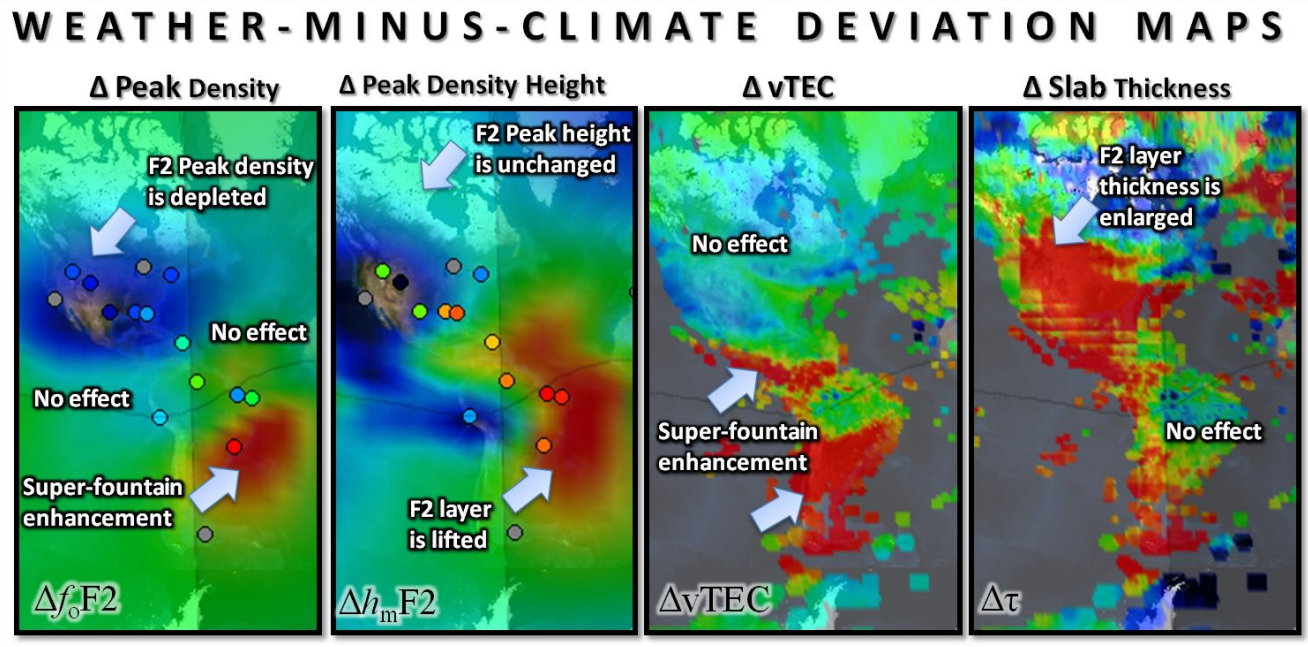
Several mouse and keyboard commands are available to move the map display.

- **To pan around the Earth** while keeping the same view distance, left-drag-click and move the mouse. Single-left-clicking and letting go moves to new point on the Earth.
- **To rotate**, use right-drag-clicking and moving the mouse. This will spin the perspective around. (You can use the W, A, S, D keys on the keyboard instead of a mouse)
- **To zoom in and out**, use the mouse wheel to scroll up and down. If you don't have a mouse wheel, hold both left & right mouse buttons down at the same time, then move up or down on the mouse. (You can use the Insert and End keys on the keyboard instead of a mouse)

3.7. Weather-Minus-Climate maps

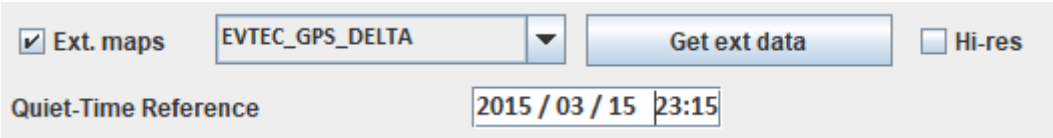
Weather-minus-climate maps plot deviations of the weather from the climatology; they are a useful tool for rapid evaluation how different is the ionospheric conditions from their expected quiet-time behavior. GAMBIT Explorer uses a symmetric color scale for deviations with zero in the middle, so that the quiet ionosphere (small deviations around zero) is presented on the globe with green shades and then red shades are for the positive deviations and blue shares for the negative ones. Therefore, blue and red color areas on the weather-minus-climate maps correspond to disturbed conditions.

Select characteristic for the Surface and pick "DELTA" for the data type. For example, here's a manually annotated figure that combines zoomed-in sections of various weather-minus-climate maps for analysis of the ionospheric dynamics during St Patrick geostorm of 2015:

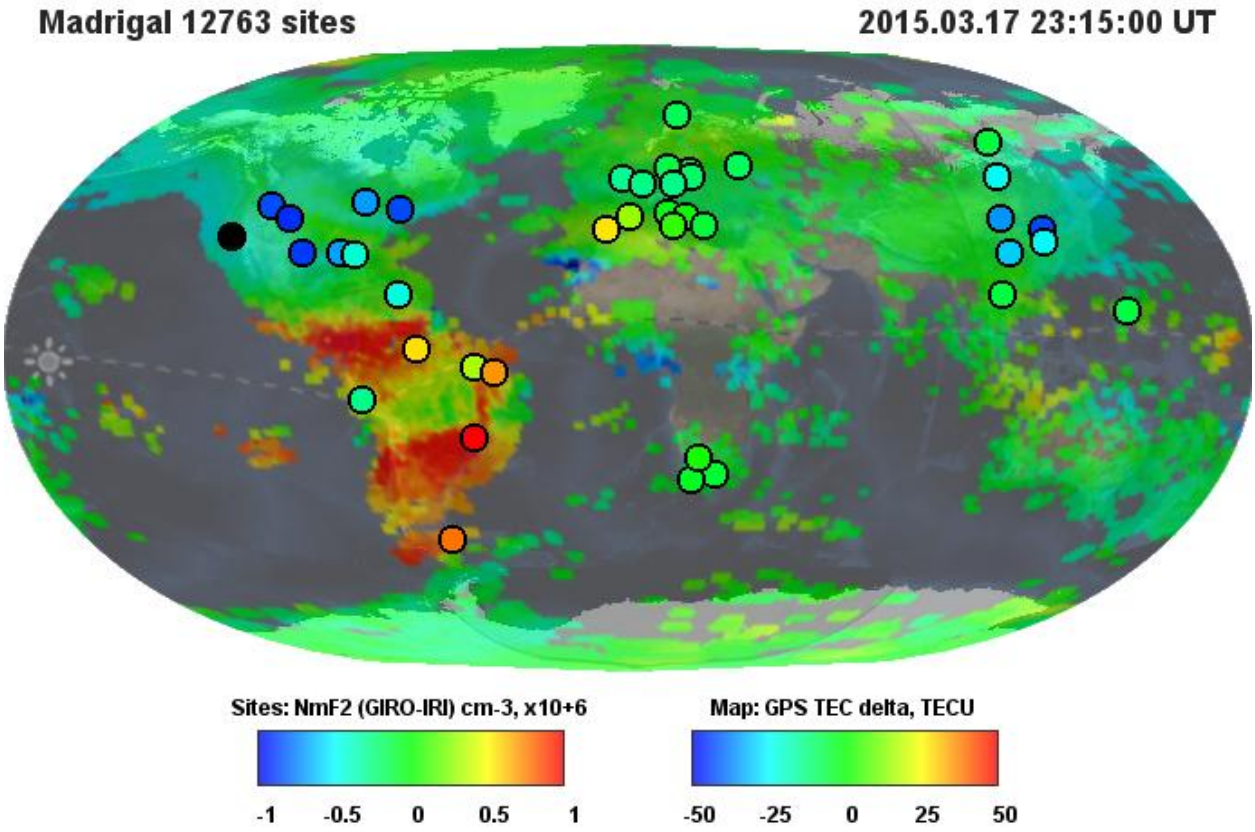


Example weather-minus-climate composite map made using GAMBIT resources (2015 St. Patrick storm)

Weather-minus-climate maps of Madrigal VTEC and associated slab thickness can be computed using a quiet-time reference day:



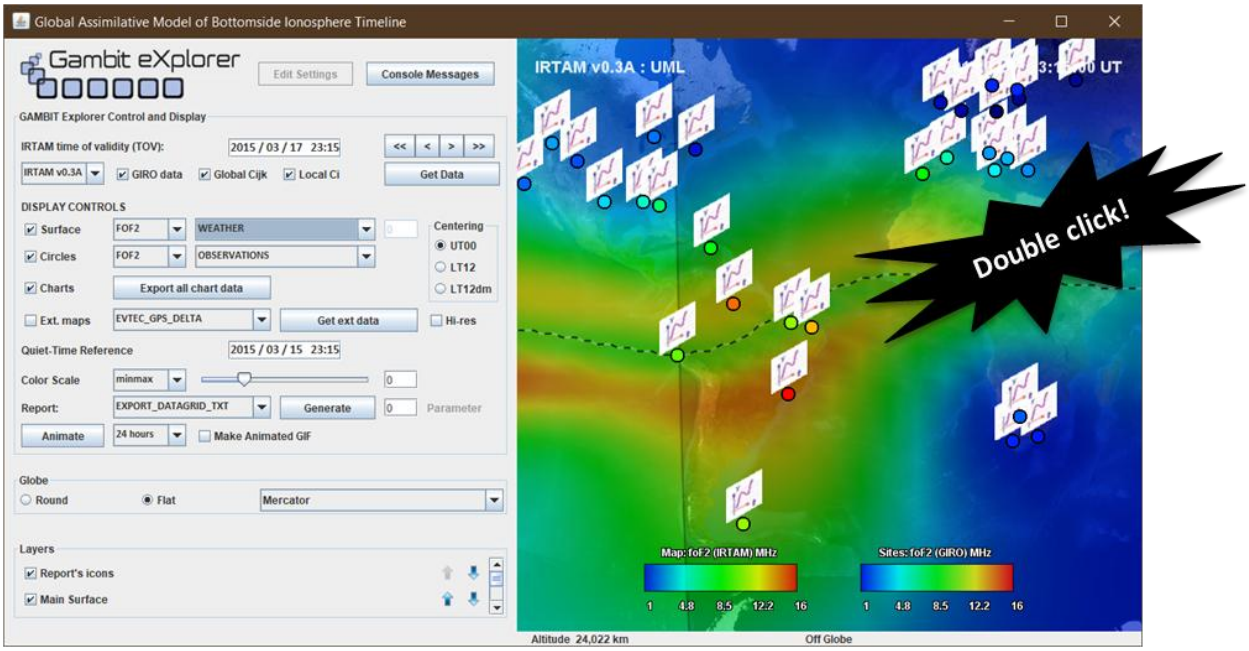
These WmC maps can be contrasted to GIRO observations, for example:



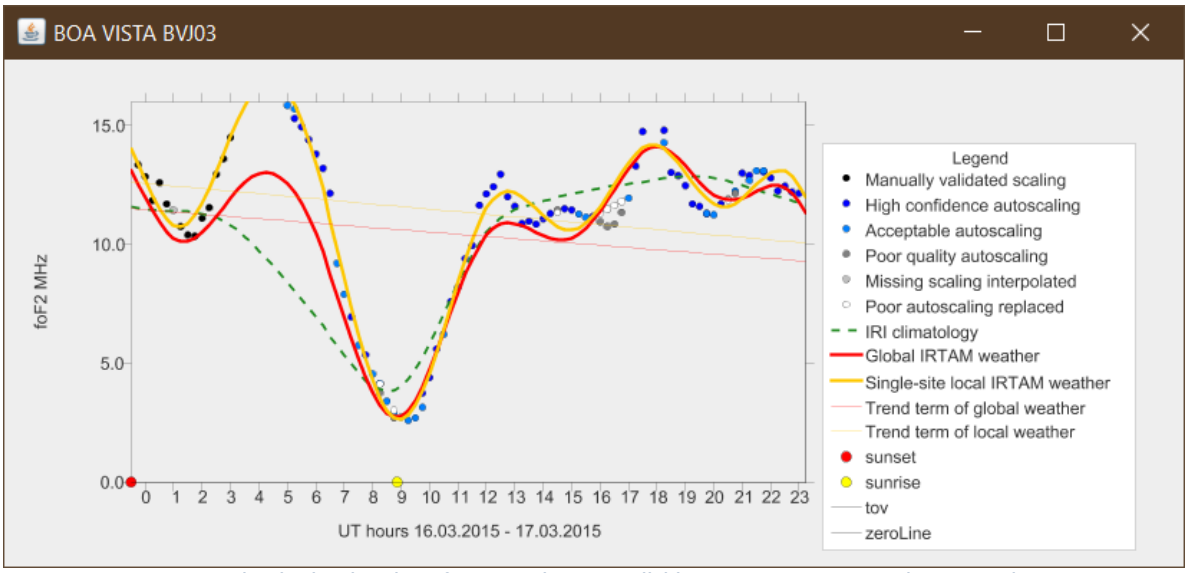
Example weather-minus-climate map combining deviations of Madrigal VTEC and GIRO peak density NmF2 (VTEC data courtesy Anthea Coster, MIT Haystack Observatory)

3.7. Single-site Charts

Select the Chart checkbox; GX will respond by placing an icon next to each GIRO site on the globe:



Double click on the chart icon of interest to bring up its detailed Chart window:



Example single-site chart for Boa Vista, Brazil (data courtesy Inez Batista, INPE)

- Observed f_oF2 values are shown as dots
- Black dots are values from manually scaled ionograms
- Dots of the blue and gray shades are ionogram autoscaling results of different quality levels
- Red curve is global weather timeline restored from IRTAM coefficients
- Yellow curve is "local" IRTAM weather valid for Cachoeira Paulista location only
- Green dashed curve is IRI climate

4. IMAGE ANIMATIONS

Animations are 2D (map+sites) + 1D (time) data presentations. Use animation controls to initiate display over given past time interval from current TOV. Check "Make Animated GIF" checkbox to produce an animated GIF file to include in Powerpoint presentations.

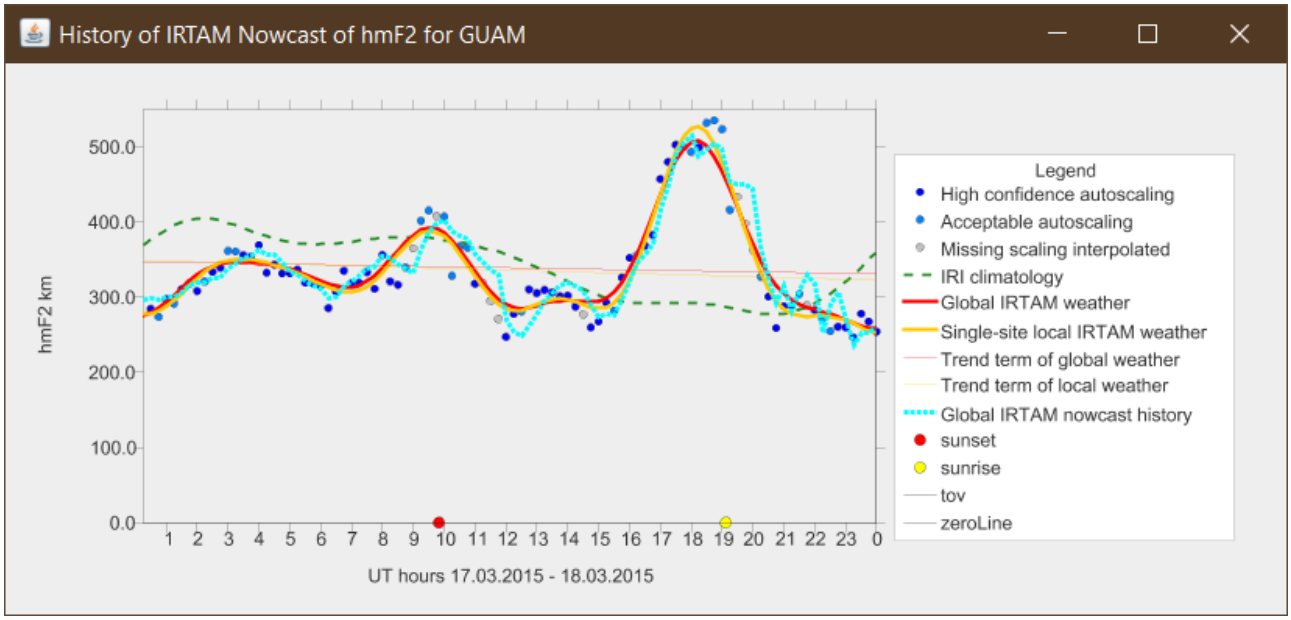
All output files, including text and images, are created in subfolders of the <home>/output folder.

5. DATA EXPORT

Use Report drop-down menu to produce text and graphics export for incorporation of GAMBIT data in other data analysis environments. Selection of the Report types includes:

REPORT	CONTENT	PARAMETERS
EXPORT_DATAGRID_TXT	Data grid of currently selected map in plain text	Specify output file name
EXPORT_DATAGRID_IONEX	Data grid of currently selected map in IONEX format	Specify output file name
EXPORT_ALL_SITES	Site-specific timelines of data items in columnar format	Specify start and stop time of the interval
OUTPUT_COEFFICIENTS	Output IRTAM coefficients for all characteristic in GAMBIT database	Specify start and stop time of the interval
GIRO_NETWORK	List of all GIRO stations contributed to this IRTAM computation	Default output file: giro_stations.txt
GIRO_INTERSITE_DISTANCES	Ground distances between GIRO sites	Select GIRO stations from the list
NOWCAST_TIMELINE	Collects history of nowcast values over last 24 hours to compare it to the current nowcast and 24 hours of backcast	Select only one station in the list. Default output file:

Example report of the NOWCAST_TIMELINE:



Cyan dotted curve is history of hmF2 nowcast (96 IRTAM computations for "now" time collected over 24 hour period). As before, red curve is one IRTAM computation for the TOV of 2015.03.18 00UT that covers previous 24 hours in the backcast mode. From this comparison, it is clear that nowcast computation is prone to data noise.

For optimal results, research projects that use IRTAM as the "ground truth" reference should use one IRTAM computation in the nowcast mode covering previous 24 hours of time. If period of interest is more than 24 hours, single runs can be stitched together with minimal overlap.

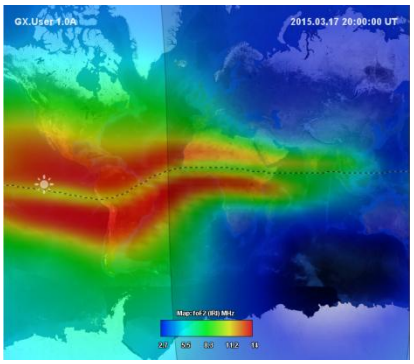
For optimal results, operational space weather systems that use IRTAM as background model for RF signal's Doppler frequency computation within a time window, shall use single IRTAM nowcast computation rather than the timeline of IRTAM computations to avoid artifacts of jitter.

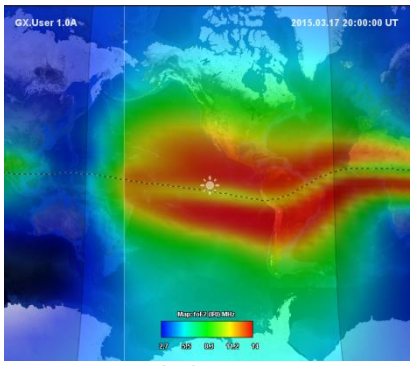
6. GX.USER ADVANCED TECHNIQUES

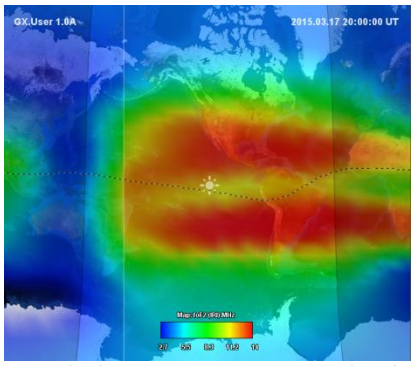
6.1 Three options of map display centering

Maps can be centered on screen using three options:

D I S P L A Y C E N T E R I N G O P T I O N S


Universal Time Midnight

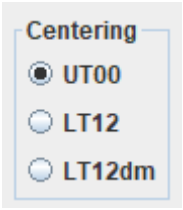

Local Time Noon


Local Time Noon, Demagnetized

- **UT Midnight** places Grinwich meridian at the center of the map: this is Earth co-rotating frame
- **LT Noon** places sub-solar point at the center of the map: this is Sun-Centric frame
- **LT Noon Demagnetized** uses LT Noon centering but transforms the map to remove the effects of the geomagnetic field precession around geographic axis (using same-modip angle transposition)

Differences between three map centering options are clearly seen in animations

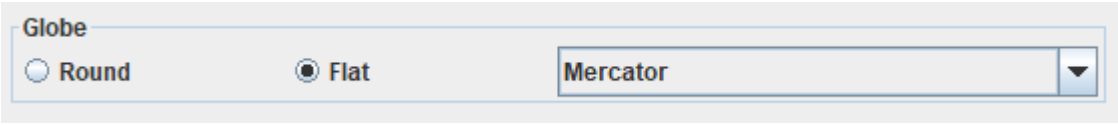
Centnerting controls:



= UT Midnight
= Local Time Noon
= Local Time Noon Demagnetized

6.2 Globe projection options

Several options of transforming globe data on 2D flat display are available as listed in the Globe section



6.3 Selecting data items for Charts display

Contents of Charts can be modified by manually editing selections in <home>/user/Gambit_UserApp.ini configuration file in [Main Chart Selections] section.

Each entry adds one data entry for display in the charts. Each entry is format to include

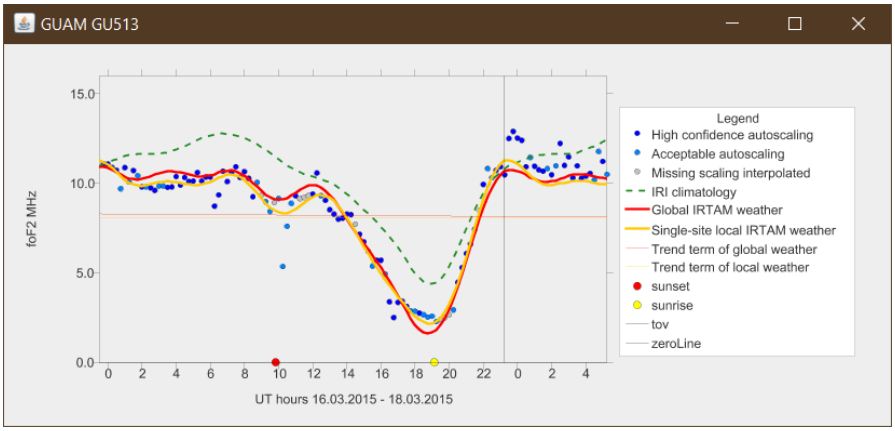
DATA_ITEM = R, G, B, Strength, GraphicElement

R, G, B are integers of RGB definition of the color
Strength can be 0 (bold), 1 (thin), 2 (faint), 3 (dashed), or 4 (dotted)
GraphicElement can be 0 (bar), 1 (line), or 2 (circles)
DATA_ITEM can be selected from the following list:

```
ALL_OBSERVED_RAW              All observations as observed
ALL_OBSERVED_PROCESSED        All observations as conditioned by the quality control
OBSERVED_MANUAL_ONLY          Manually validated scaling
OBSERVED_HIGHCONF_ONLY        High confidence autoscaling
OBSERVED_GOODCONF_ONLY        Acceptable autoscaling
OBSERVED_LOWCONF_ONLY         Poor quality autoscaling
OBSERVED_UNKNOWN_CONF         Unknown quality autoscaling
OBSERVED_GAP_FILLED           Missing scaling interpolated
OBSERVED_LOWC_REPLACED        Poor autoscaling replaced
OBSERVED_EXTRAPOLATED         Observation forecast
OBSERVED_DAYBOUNDARY_DIXED    Day boundary fixed scaling
TIMEGRID_MISMATCH_PERCENT     Deviation of measurement time from time grid
CONFIDENCE_SCORE              Autoscaling Confidence Score
FLAG                          Observation status flag
CLIMATE                       IRI climatology
LOCAL_WEATHER                 Single-site local IRTAM weather
GLOBAL_WEATHER                Global IRTAM weather
LOCAL_NOWCAST_HISTORY         Local IRTAM nowcast history
GLOBAL_NOWCAST_HISTORY        Global IRTAM nowcast history
O2C_DIFFERENCE                Observations-minus-climate
O2LW_DIFFERENCE               Observations-minus-localWeather
O2GW_DIFFERENCE               Observations-minus-globalWeather
O2LWH_DIFFERENCE              Observations-minus-localNowcastHistory
O2GWH_DIFFERENCE              Observations-minus-globalNowcastHistory
LW2C_DIFFERENCE               Local weather correction to climate
GW2C_DIFFERENCE               Global weather correction to climate
LW2GW_DIFFERENCE              Difference between local and global weather"),
LOCAL_TREND                   Trend term of local weather
GLOBAL_TREND                  Trend term of global weather
```

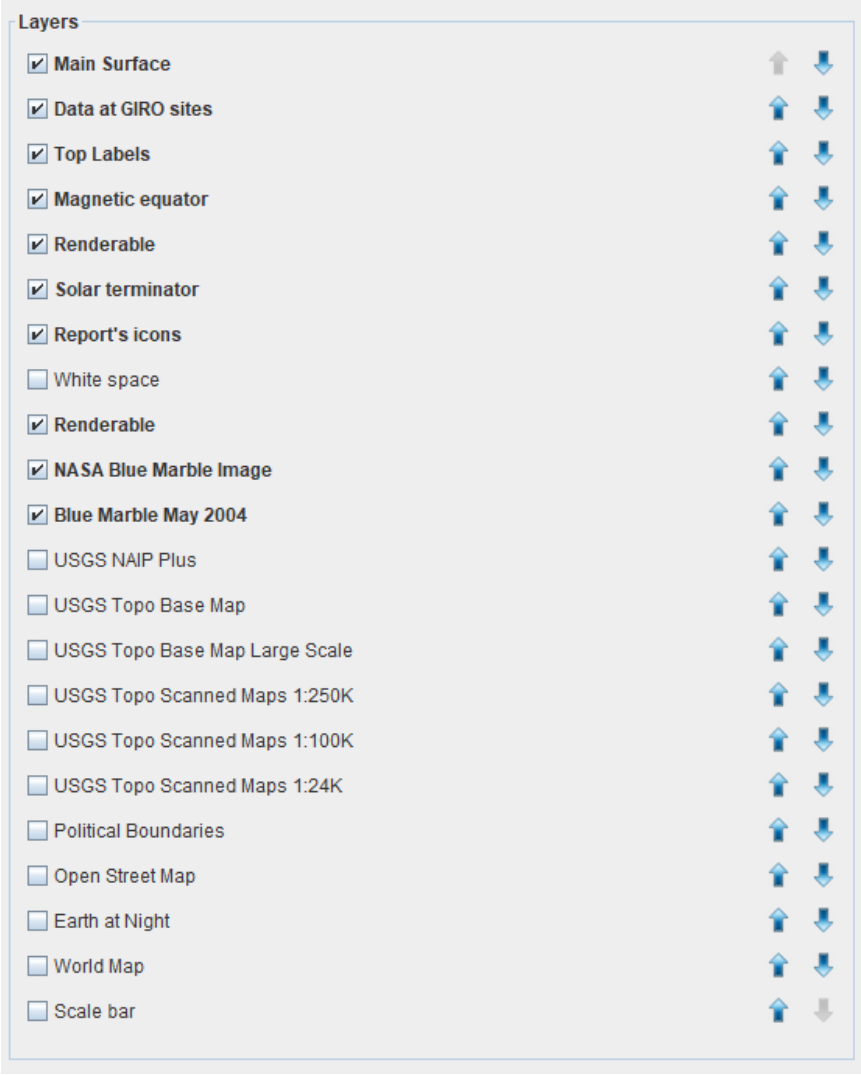
6.4 IRTAM in Short-Term Forecast mode

Charts can be configured to display data past TOV (i.e., in the forecast mode) by setting parameter ForecastPeriod_min in Gambit_UserApp.ini file. The observations past TOV are not available in GX.User version. In order to evaluate quality of IRTAM forecast against observations, it is necessary to upgrade to GX.Master application that has access to DIDBase.



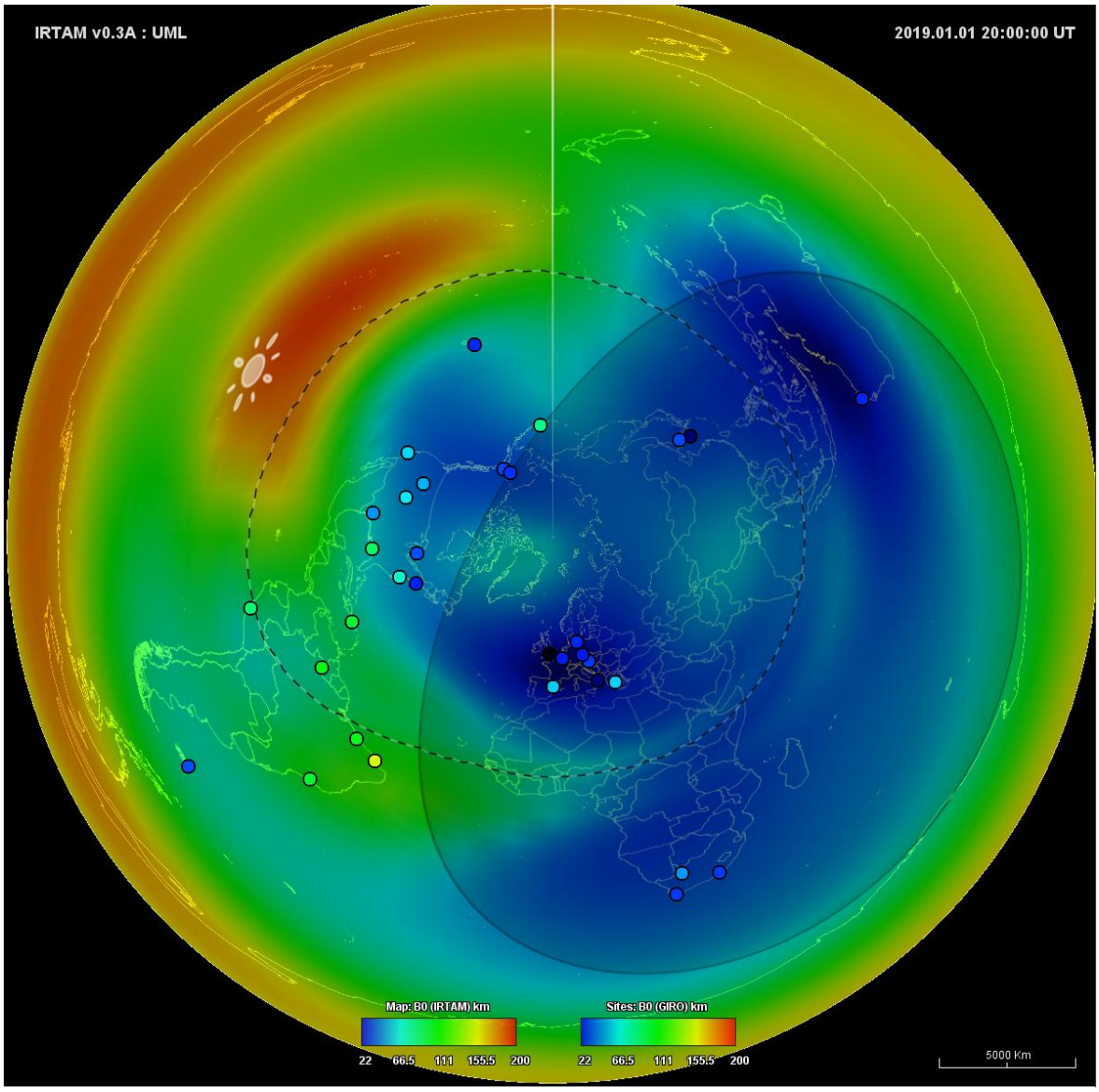
GAMBIT Explorer MasterApp for IRTAM short-term forecast evaluation (Guam data courtesy Mark Leahy, NEXION)

6.5 Manipulating individual layers



Some of the useful layer manipulations:

- Disable Blue Marble images and enable Political Boundaries
- Use White space for white background displays
- Add/remove solar terminator and day/night shading



Display of the bottomside half-thickness B0 with political boundaries instead of NASA Blue Marble image (North Polar projection of the bloge)

7. GX.MASTER VERSION

Expert registration is required to obtain Gambit Explorer MasterApp version, please apply to Ivan_Galkin@uml.edu

GX.Master includes IRTAM computation code and extended list of reports, including a variety of statistical analyses. Primary objective of GX.Master version is to allow operators to manually correct specific autoscaling results in DIDBase for the time period of interest to then rerun the assimilation and submit updated IRTAM results to GAMBIT database.

ADDITIONAL READING

Galkin, I.A., B. W. Reinisch, A. M. Vesnin, D. Bilitza, S. Fridman, J. B. Habarulema, and O. Veliz (2020), Assimilation of Sparse Continuous Near-Earth Weather Measurements by NECTAR Model Morphing, *Space Weather*, doi:10.1029/2020SW002463.

Galkin, I.A. B.W. Reinisch, and D. Bilitza (2018), Realistic Ionosphere: real-time ionosonde service for ISWI, *Sun and Geosphere*, 13/2, 173-178, doi:10.31401/SunGeo.2018.02.09.

Galkin, I.A., Reinisch, B.W., Huang, X., and Bilitza, D. (2012), Assimilation of GIRO data into a real-time IRI. *Radio Sci.*, RS0L07. doi:10.1029/2011RS004952.