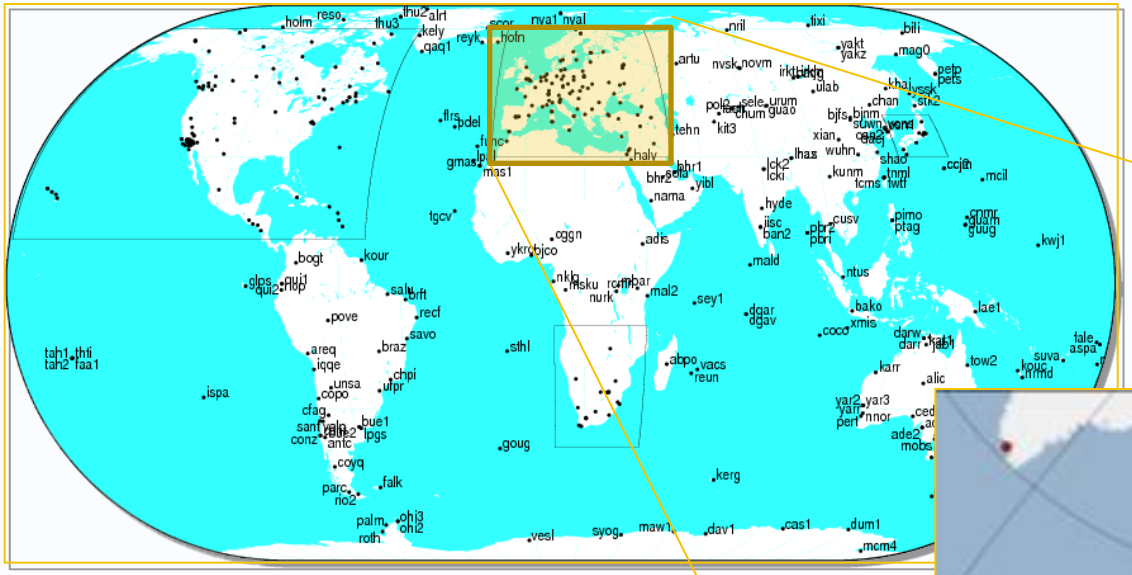
Real-time Water Vapor and TEC calculation using existing GNSS reference station infrastructure

Rana Charara

Trimble Infrastructure

GNSS Netwoks



IGS
International GNSS Service

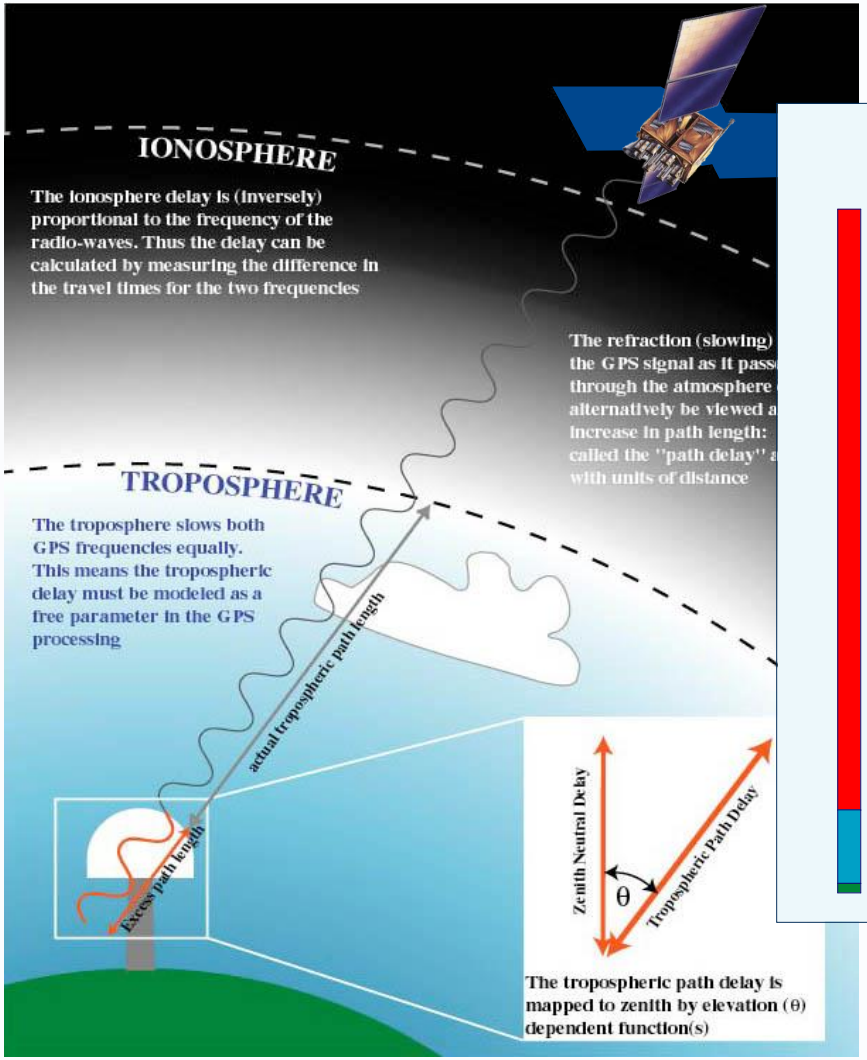
Puts high-quality GNSS data and data products online in near real time.

EUREF
European Permanent Network

European Terrestrial Reference System 89 (ETRS89) is used as the standard precise GPS coordinate system throughout Europe.

GNSS Netwoks users

Science Behind GPS Met



TOTAL ATMOSPHERIC DELAY

- **IONOSPHERIC DELAY**
  Estimate from dual frequency observations and known dispersion relations
- **NEUTRAL DELAY**
  Estimate during geodetic inversion
  - **HYDROSTATIC DELAY**
    Estimate from surface pressure measurement
  - **WET DELAY**
    Wet = neutral - hydrostatic

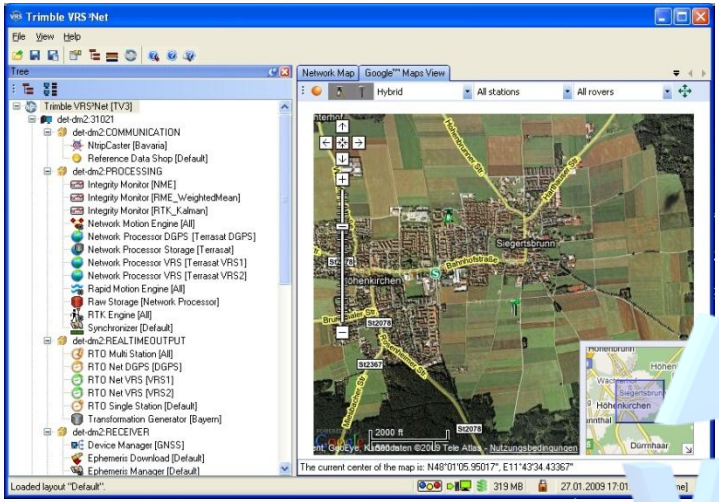
Wet delay is nearly proportional to PW

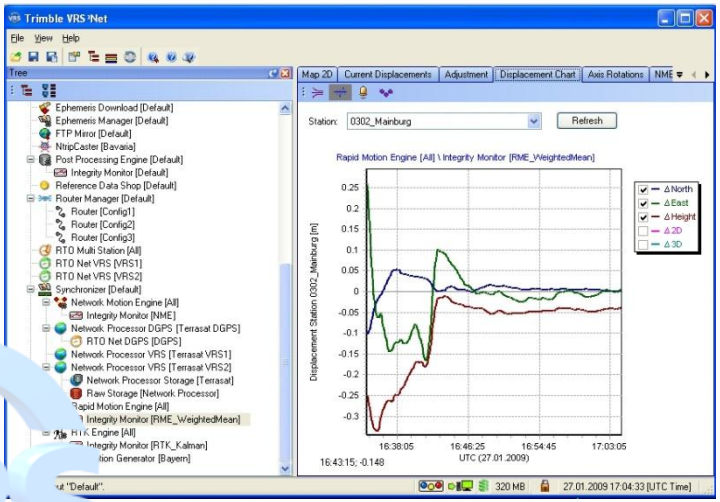
$PW = \Pi \cdot ZWD$

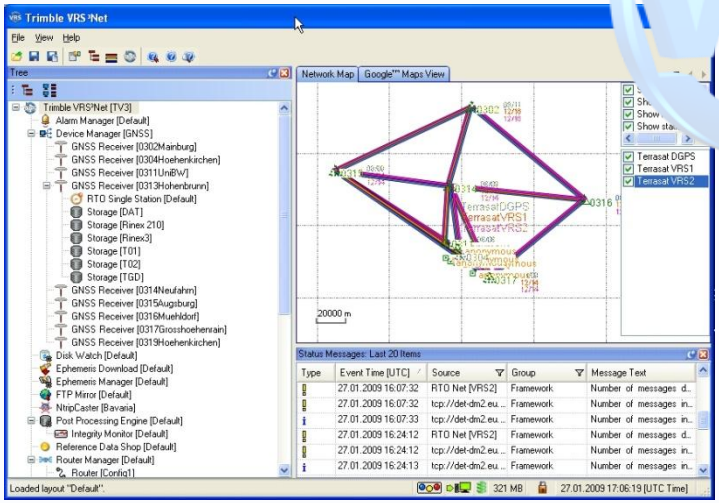
where $\Pi = f$ (physical constants T_m)

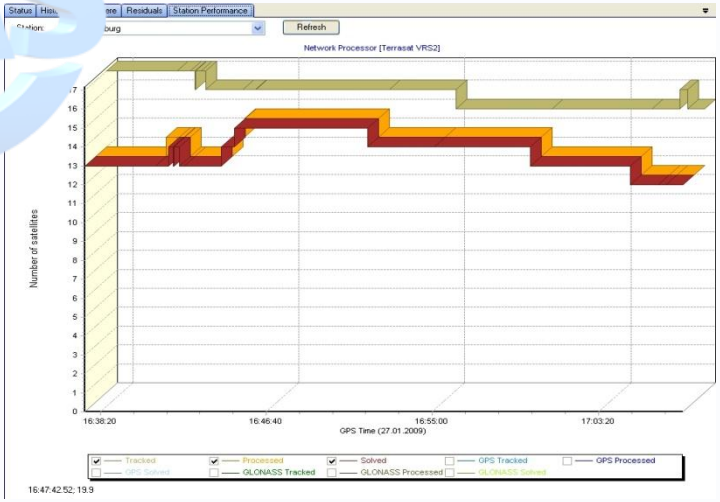
Courtesy of Seth Guttman, NOAA

Trimble® PIVOT™









GNSS and the Atmosphere

- Trimble Pivot Platform 
  - Atmo App 
  - Iono App 

Description

Atmo App (Troposphere)

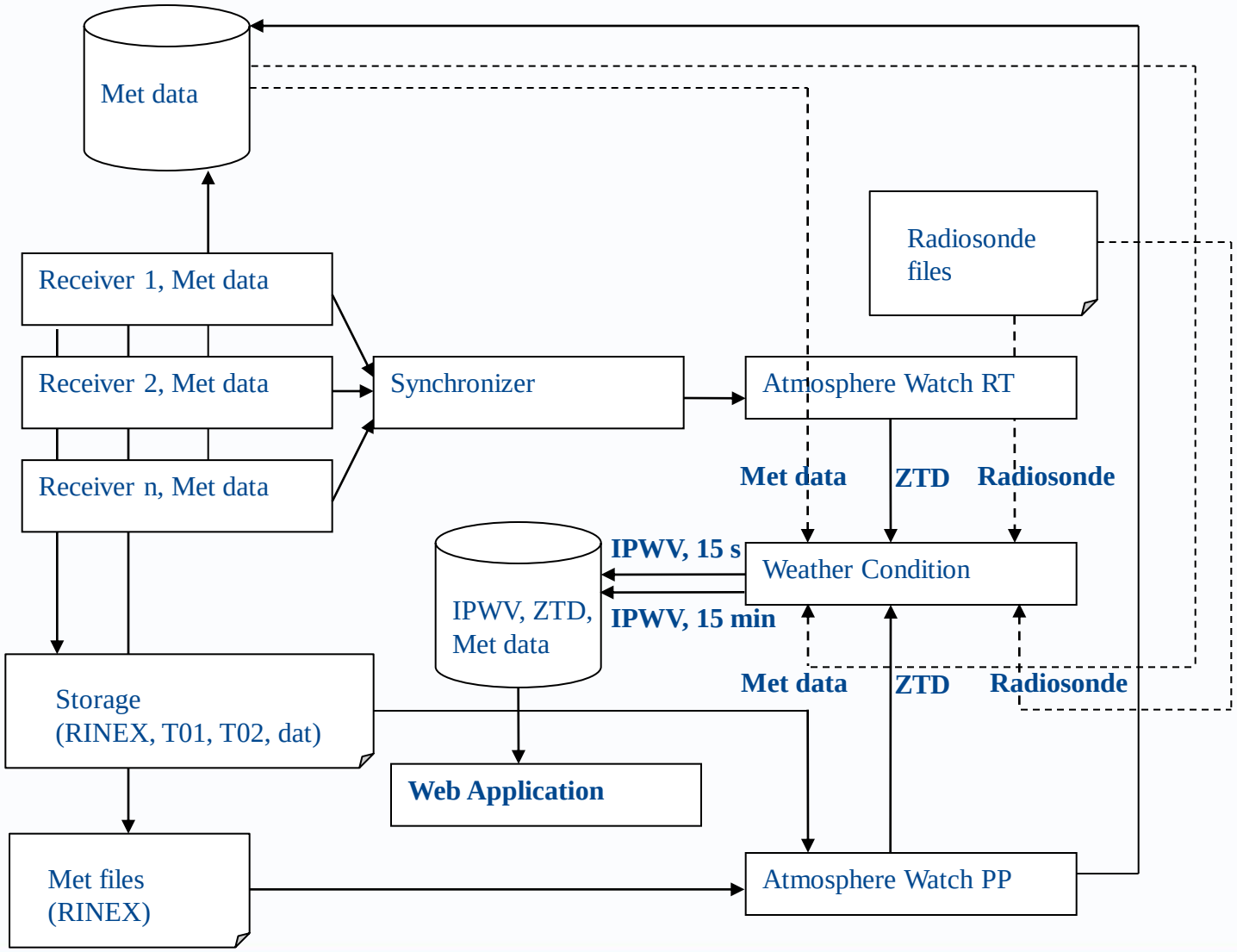
Atmosphere Watch

- Troposphere
  - Zenith Total Delay (ZTD)
  - Tropospheric Slant Delay

Weather Condition

- Integrated Precipitable Water Vapor (IPWV)
- Dry / Wet delays

Workflow in Atmosphere App (IPWV)



Output

	Station Name	Station Code	Tracked	Processed	Zenith Total Delay [m]
	FIN_Enon	Enon	19	18	2.300
	FIN_Haap	Haap	19	17	2.352
	FIN_Hauk	Hauk	19	17	2.375
	FIN_Iisa	Iisa	19	17	2.357
	FIN_Ival	Ival	18	18	2.359
	FIN_Kaam	Kaam	19	17	2.349
	FIN_Kaar	Kaar	19	18	2.277
	FIN_Kaja	Kaja	19	18	2.336
	FIN_Kala	Kala	19	17	2.388
	FIN_Kari	Kari	19	17	2.345
	FIN_Keit	Keit	19	17	2.350
	FIN_Kemi	Kemi	18	18	2.329
	FIN_Kilp	Kilp	17	15	2.222
	FIN_Kitt	Kitt	19	18	2.336
	FIN_Kokk	Kokk	20	17	2.386
	FIN_Kola	Kola	19	18	2.344
	FIN_Kuhm	Kuhm	19	18	2.314
	FIN_Kuus	Kuus	18	18	2.281
	FIN_Liek	Liek	19	18	2.347
	FIN_Melt	Melt	18	18	2.355
	FIN_Muon	Muon	19	18	2.323

ing Function]

Description

Atmo App (Troposphere)

Atmosphere Watch

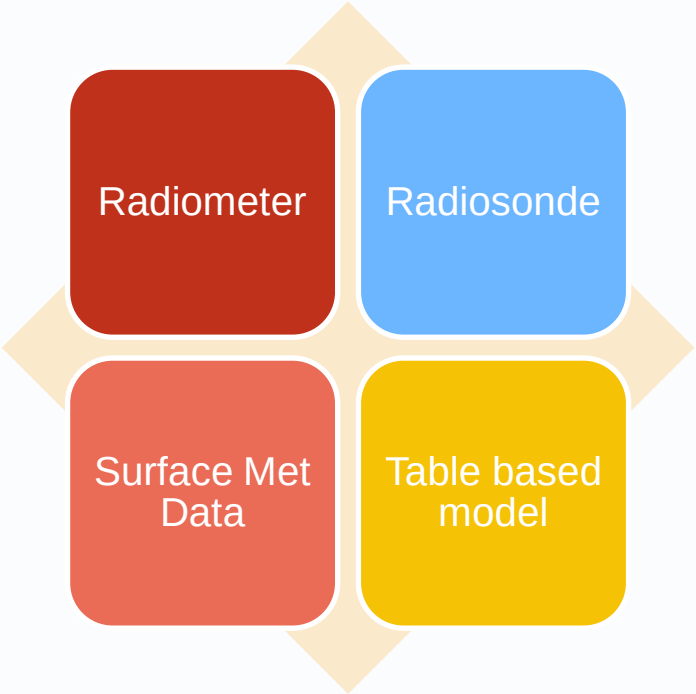
- Troposphere
  - Zenith Total Delay (ZTD)
  - Tropospheric Slant Delay

Weather Condition

- Integrated Precipitable Water Vapor (IPWV)
- Dry / Wet delays

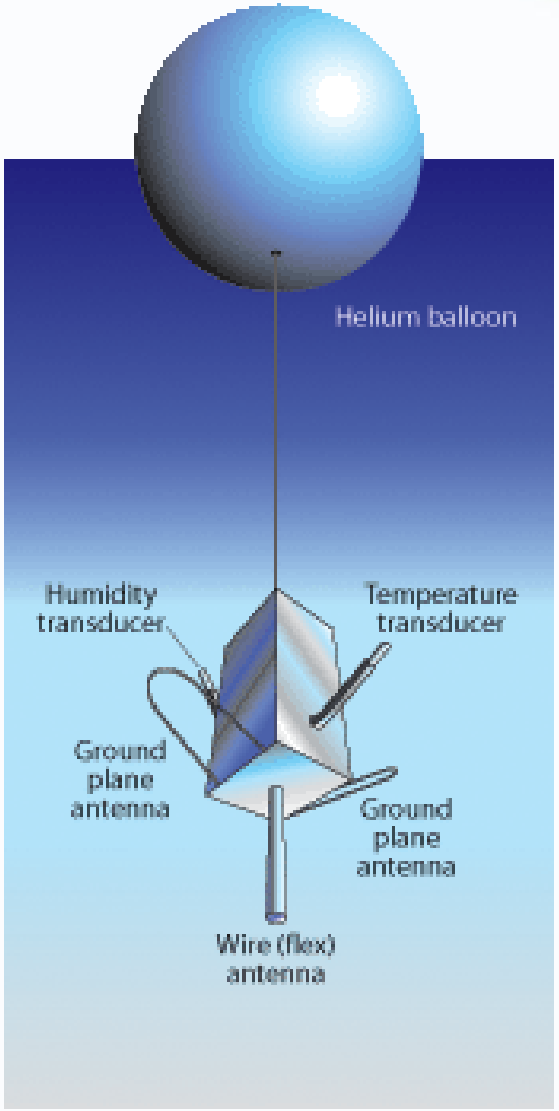
Weather Condition Module

- ZTD from Atmosphere Watch
- Temperature
- Pressure



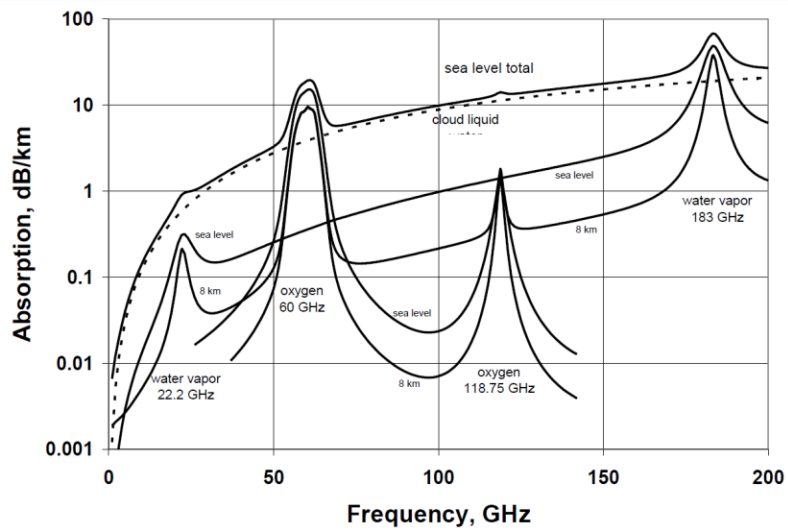
Input MET-Radiosonde

- Helium balloon
- Launched twice a day from airports
- Profiles troposphere
- Data can be downloaded
- http://esrl.noaa.gov/raobs/intl/GetRaobs.cgi



Input MET-Radiometer

- Performs tropospheric scans frequently
- Creates 360° x 180° degree scans
- Measures atmospheric radiation in the 20 to 60 GHz region
- www.radiometrics.com



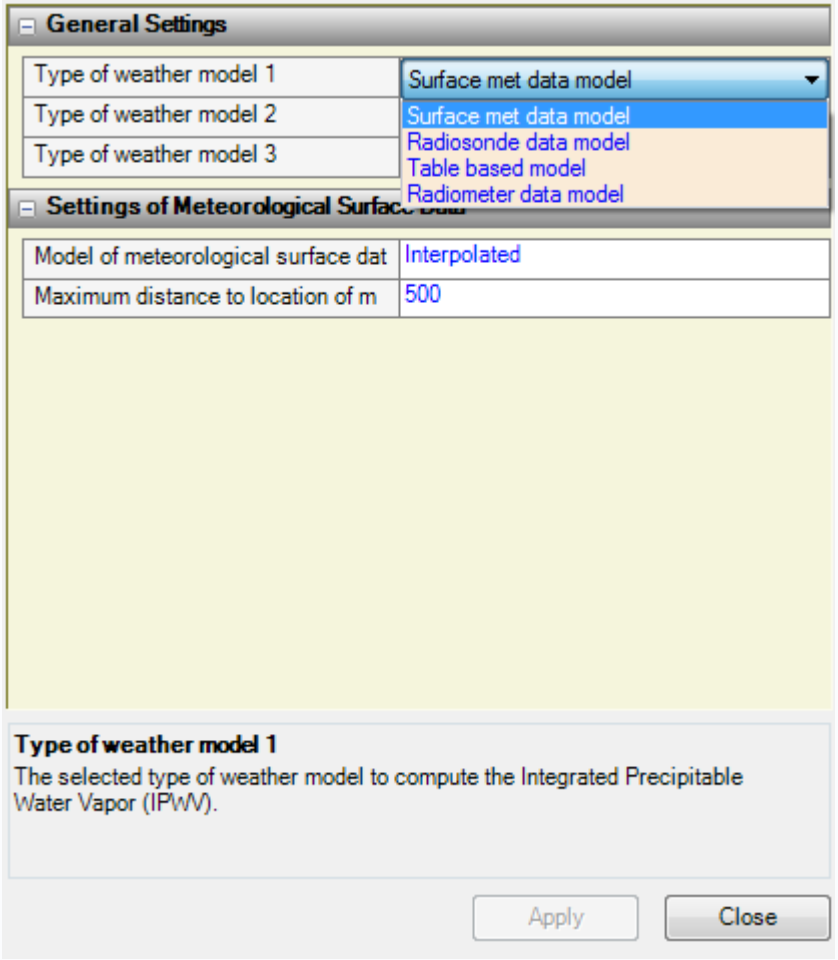
Input MET

- **Surface Met Data**
  - Temperature measured at GPS station location
  - Higher sampling rate compare to radiosonde
  - No need to interpolate

- **Table-based model**
  - More of a trend than an accurate model
  - Suitable for global networks

Weather Condition

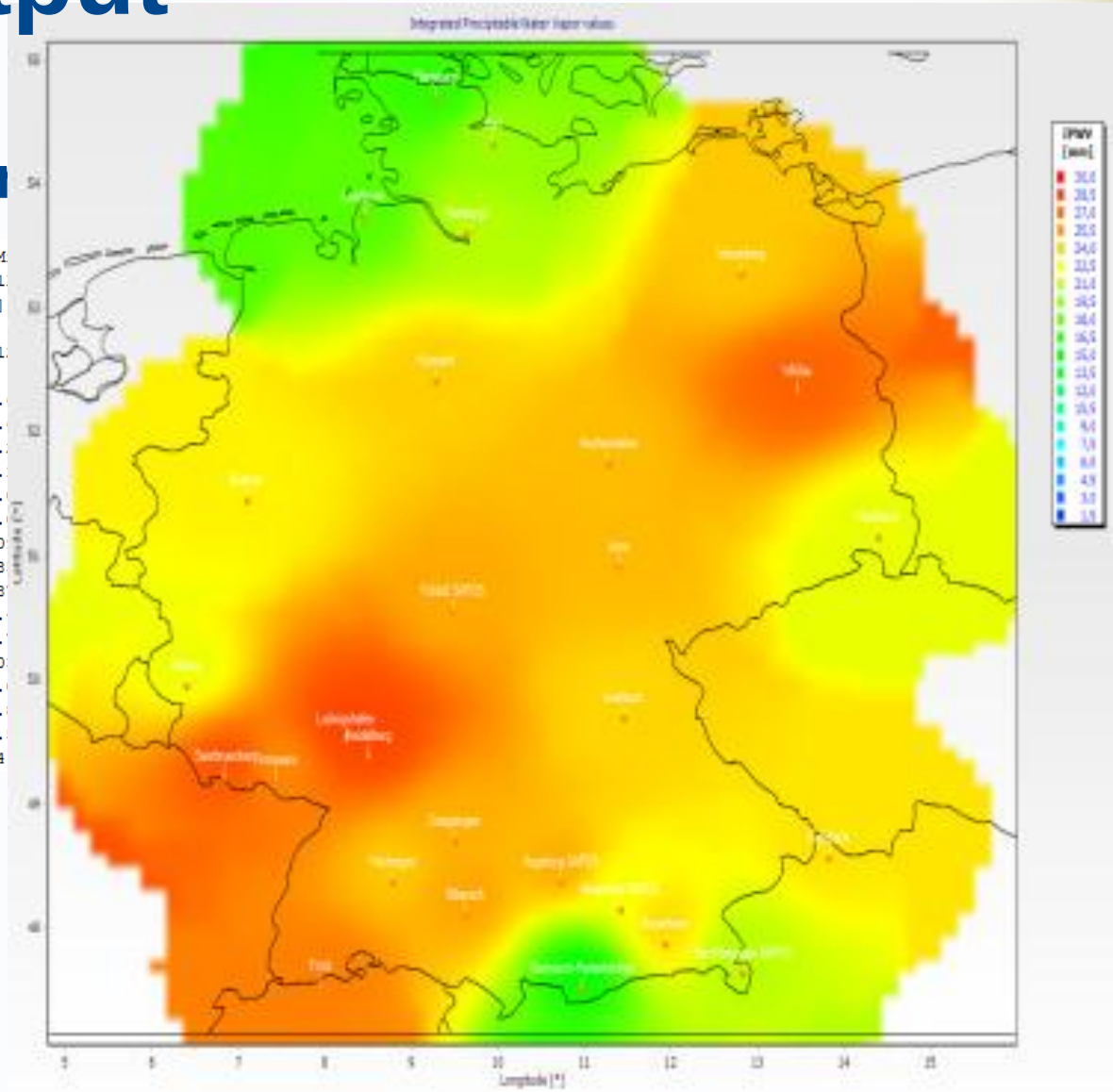
- **Setup**



Output

- Curren

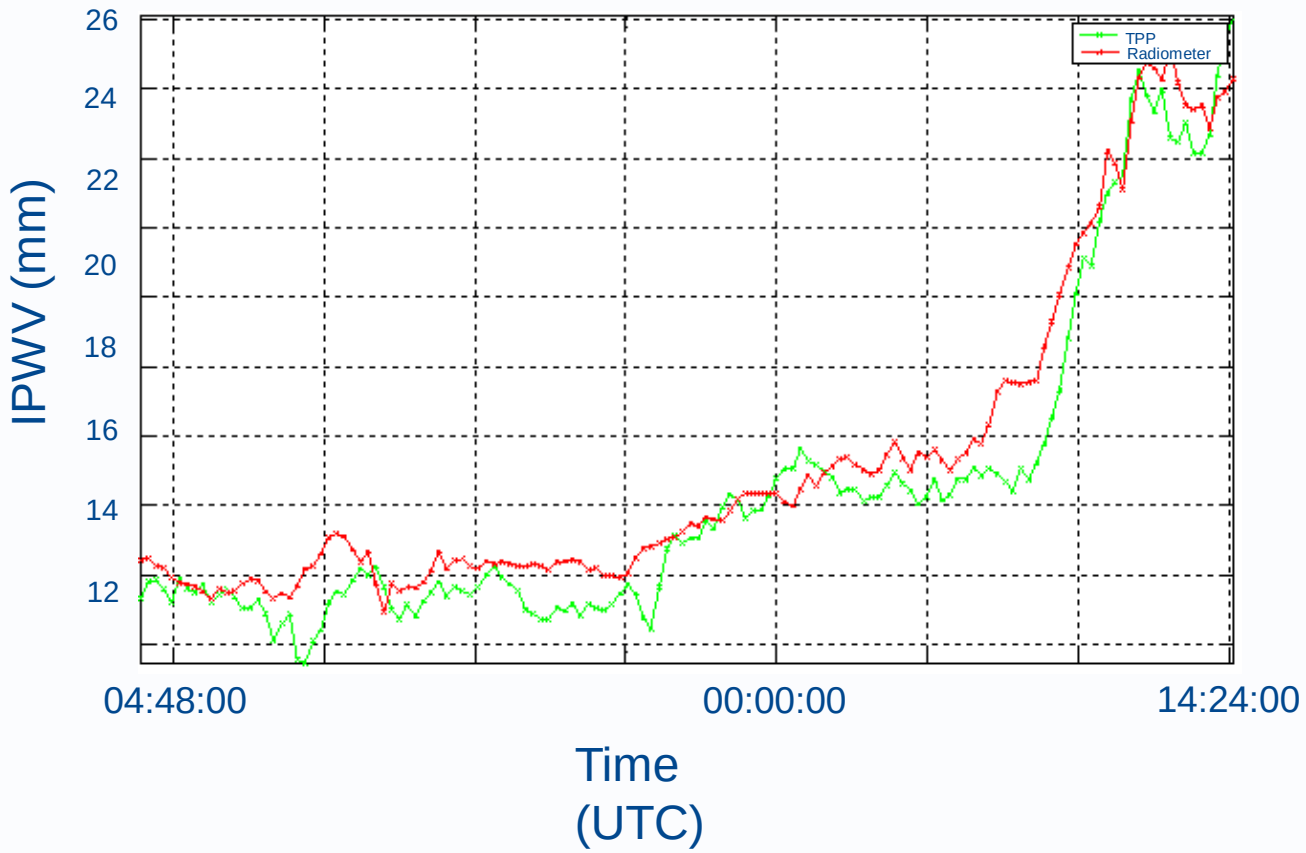
```
#[Year] [Month] [Day] [Hour] [M
[Station code] [Number of satel
[Satellite id];[Elevation[deg]]

#2012 09 15 00 00 00.0000000  1
0286 16 2.177 0.007
G02;42.69;311.81;3.497;0.057;1.
G04;40.17;246.15;3.685;0.035;1.
G05;19.98;338.43;6.971;0.216;3.
G07;70.67;185.45;2.430;0.048;1.
G08;32.14;216.94;4.488;0.127;2.
G10;81.82;318.57;2.269;0.040;1.
G13;73.98;62.12;2.371;0.031;1.0
G16;22.61;61.44;6.199;0.124;2.8
G23;35.78;82.42;4.071;0.029;1.8
R01;47.95;349.16;3.178;0.111;1.
R07;23.08;127.43;6.087;0.049;2.
R09;32.65;38.40;4.415;0.064;2.0
R10;77.63;109.40;2.318;0.070;1.
R11;37.07;204.42;3.950;0.177;1.
R17;17.71;365.20;7.806;0.240;3.
R24;13.42;306.32;10.154;0.102;4
```




```
];[Wet Slant Delay[m]];
```

Comparison IPWV: TPP / Radiometer

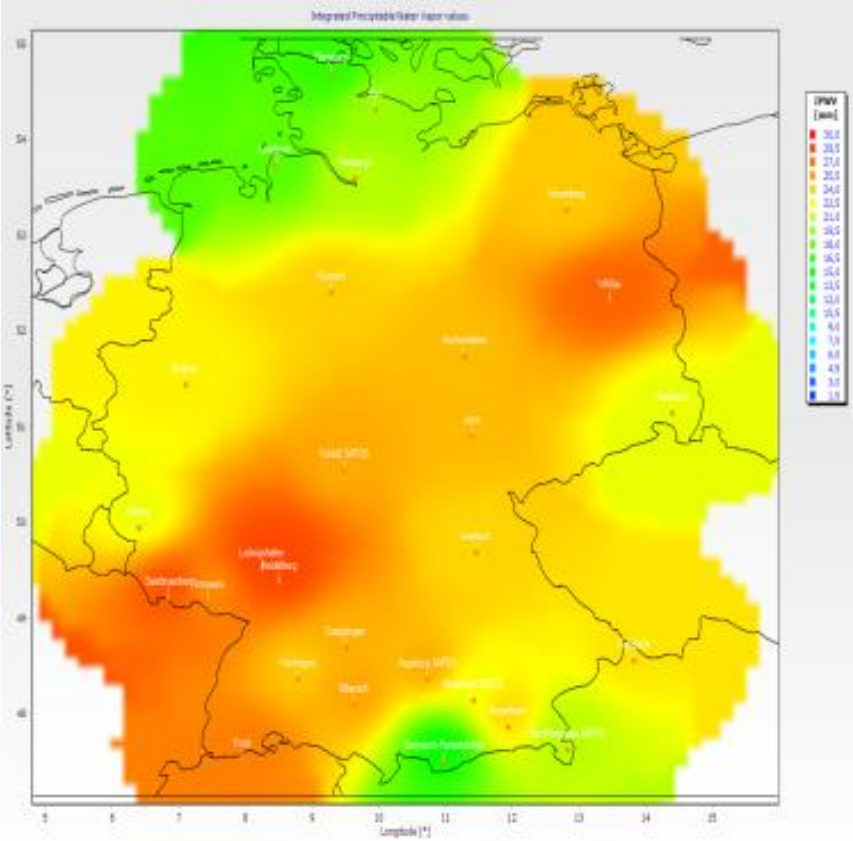
- Station IAWL (Waterloo / Iowa)
- Apr. 16, 2013

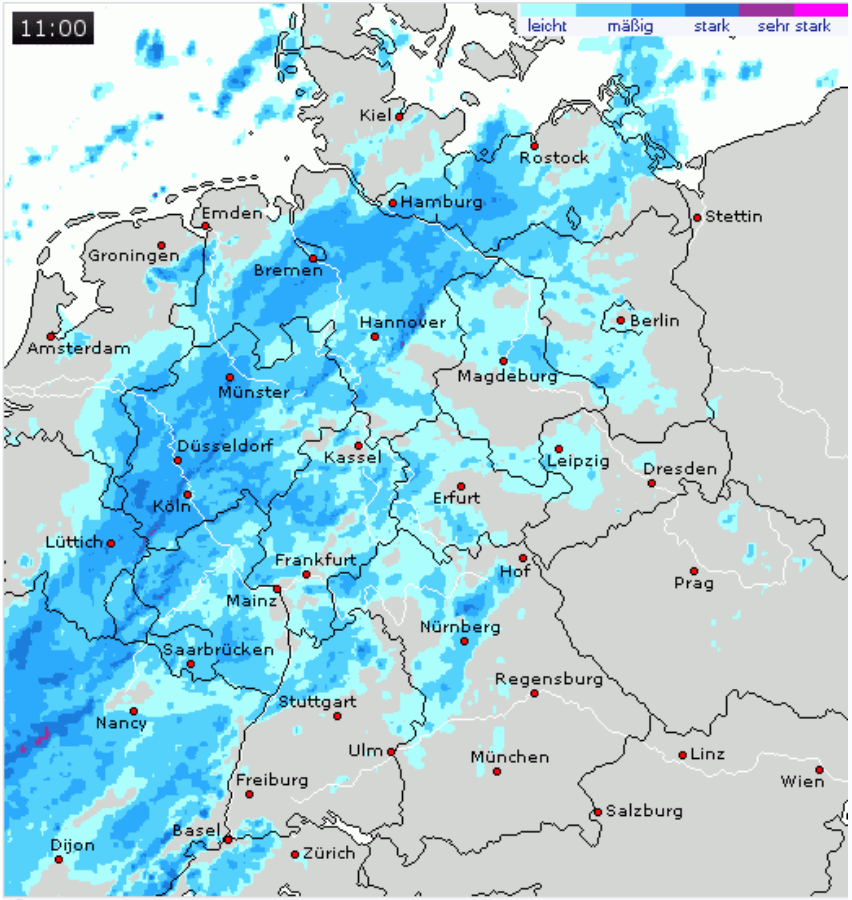


Comparison IPWV:

TPP / Weather Prediction

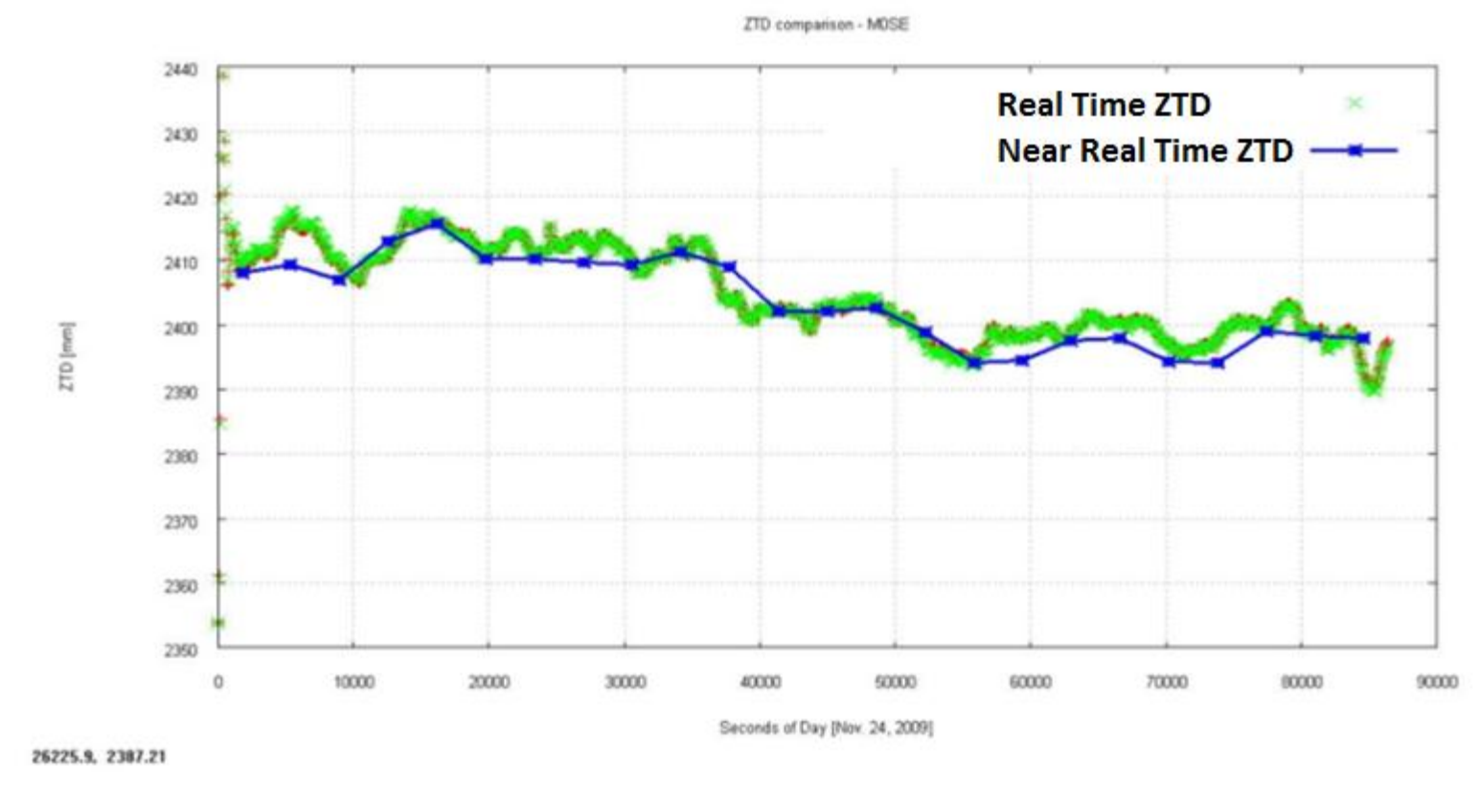
Oct. 5th, 2012





Comparison ZTD: TPP / BERNESE

Station MOSE-Swiss (November 24th, 2009)



Atmo App View

Trimble Atmosphere

Trimble Atmosphere calculates IPWV and TEC values from gathered GNSS data including weather information from various data sources.

Station 'FIN_Puda' does not provide data to the Atmosphere Watch module(s).

90 of 91 Stations providing data in realtime.
-- Stations providing data for post processing.

Atmosphere Watch	Used Tropo Mapping Function	Tropospheric Output Type +...	Processing Mode	Date of DCB Files	Min TEC Value	Max TEC Value	Last Update [GPS time]
Finland North	Modified Hopfield - Niell (dry and wet)	Zenith total delay (ZTD) - None	Real time	10.2012	6.9	21.8	04.10.2012 14:21:30
Finland South	Modified Hopfield - Niell (dry and wet)	Zenith total delay (ZTD) - None	Real time	10.2012	16.4	24.8	04.10.2012 14:21:30

Weather Condition	Used Weather Model(s)	Min IPWV Value [mm]	Max IPWV Value [mm]	Last Update [GPS Time]
Finland North	Radiosonde data model (Age: 8 hours)	9.2	19.4	04.10.2012 14:21:30
Finland South	Radiosonde data model (Age: 2 hours)	10.9	27.6	04.10.2012 14:21:30

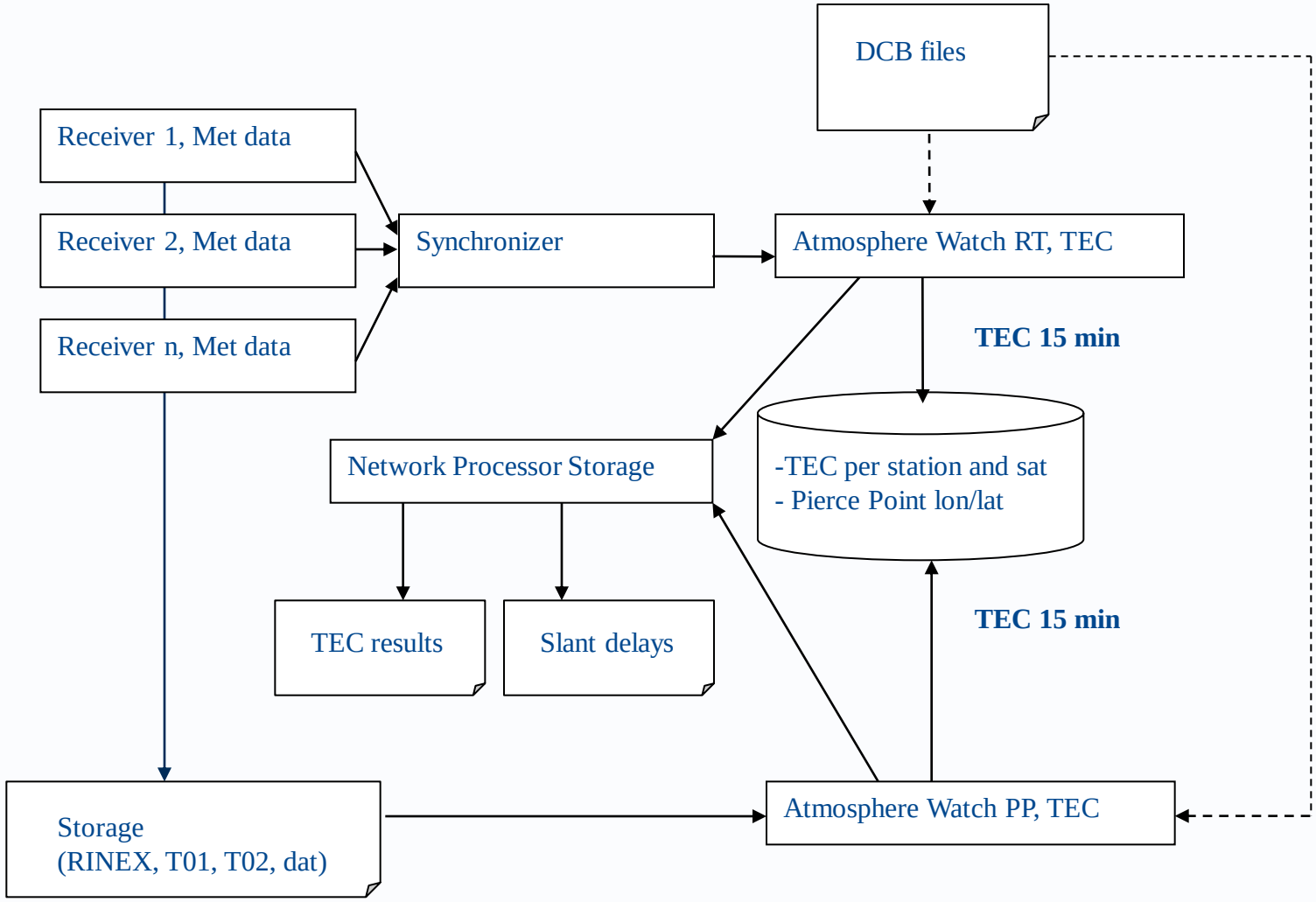
Description

Atmo App (Ionosphere)

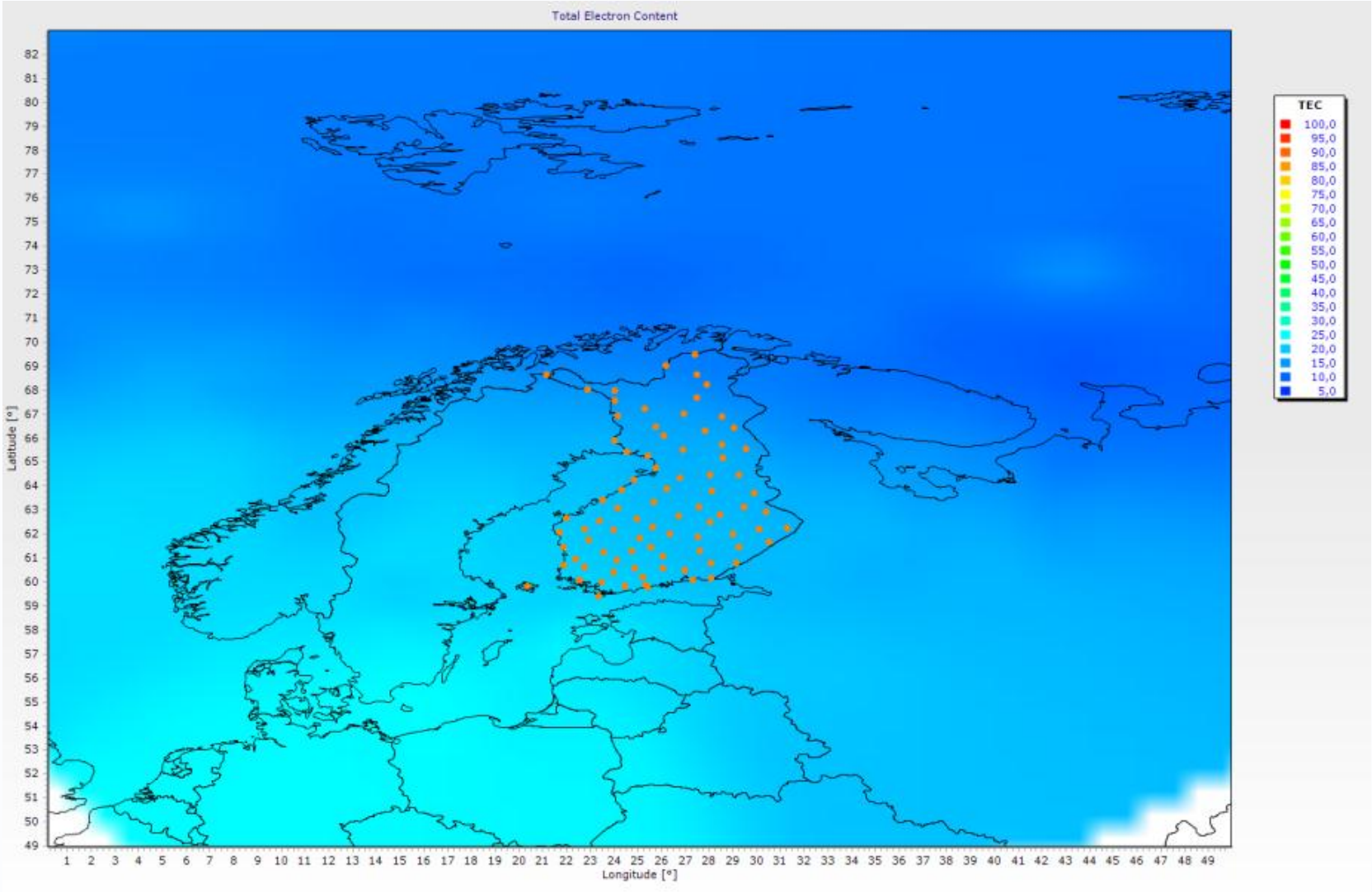
Atmosphere Watch

- Ionosphere
  - Total Electron Content (TEC)

Workflow in Atmosphere App (TEC)



Output


Total Electron Content
Latitude [°]
Longitude [°]
TEC
100,0
95,0
90,0
85,0
80,0
75,0
70,0
65,0
60,0
55,0
50,0
45,0
40,0
35,0
30,0
25,0
20,0
15,0
10,0
5,0

Description

Iono App

Receiver Module / Device Manager

- Quality check for each tracked satellite
- Overlay images with iono. activities

Iono Activity

- Iono Index
- Scintillation
- TEC Values
- IRIM
- GRIM
- I95

Description

Iono App

Receiver Module / Device Manager

- Quality check for each tracked satellite
- Overlay images with iono. activities

Iono Activity

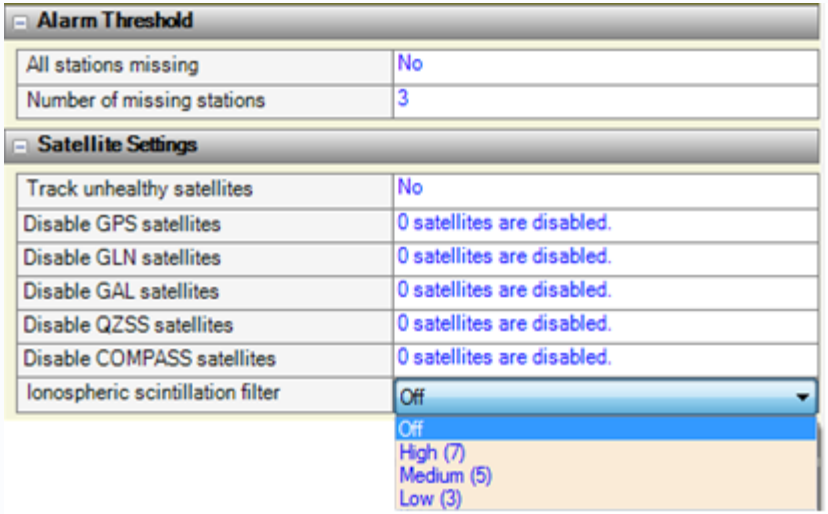
- Iono Index
- Scintillation
- TEC Values
- IRIM
- GRIM
- I95

Scintillation Data From Receiver

- Offset between the expected difference between L1 and L2 carrier phase measurement and the actual

Quality check

- Device Manager Properties



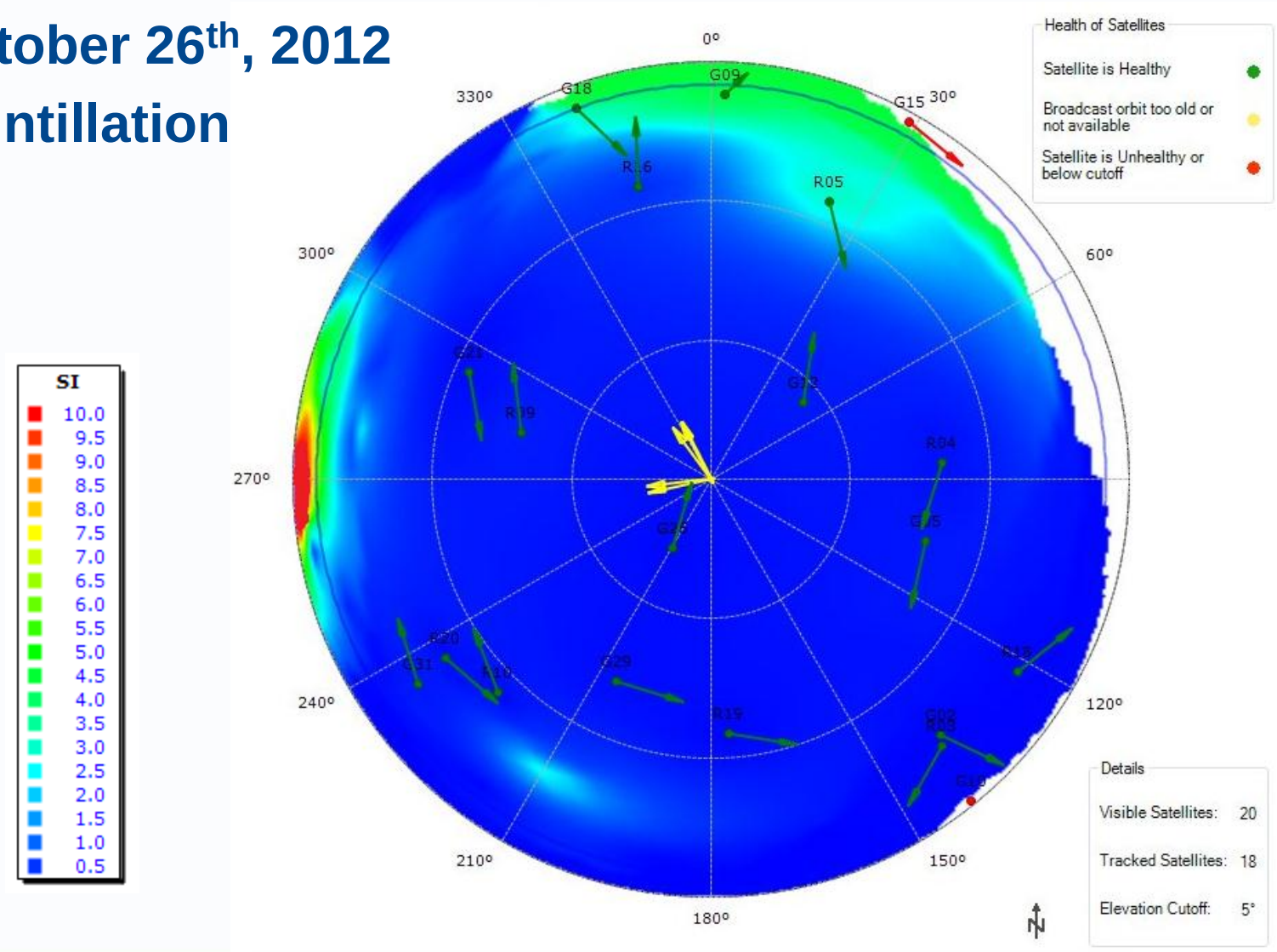
Alarm Threshold	
All stations missing	No
Number of missing stations	3

Satellite Settings	
Track unhealthy satellites	No
Disable GPS satellites	0 satellites are disabled.
Disable GLN satellites	0 satellites are disabled.
Disable GAL satellites	0 satellites are disabled.
Disable QZSS satellites	0 satellites are disabled.
Disable COMPASS satellites	0 satellites are disabled.
Ionospheric scintillation filter	Off

Off
High (7)
Medium (5)
Low (3)

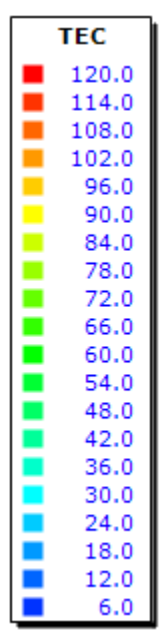
Overlay Images (Macaé / Brasilia)

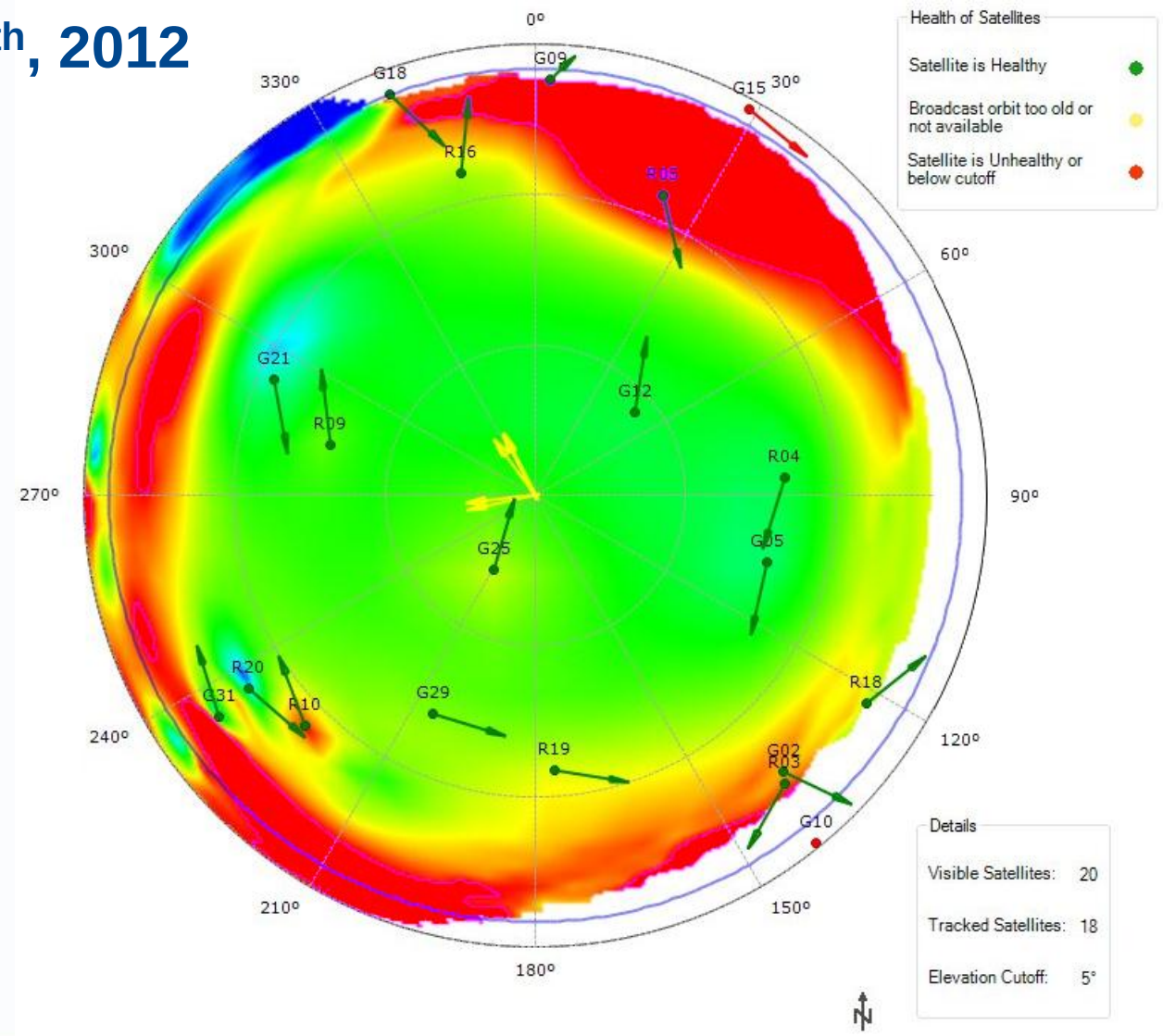
- October 26th, 2012
- Scintillation



Overlay Images (Macaé / Brasilia)

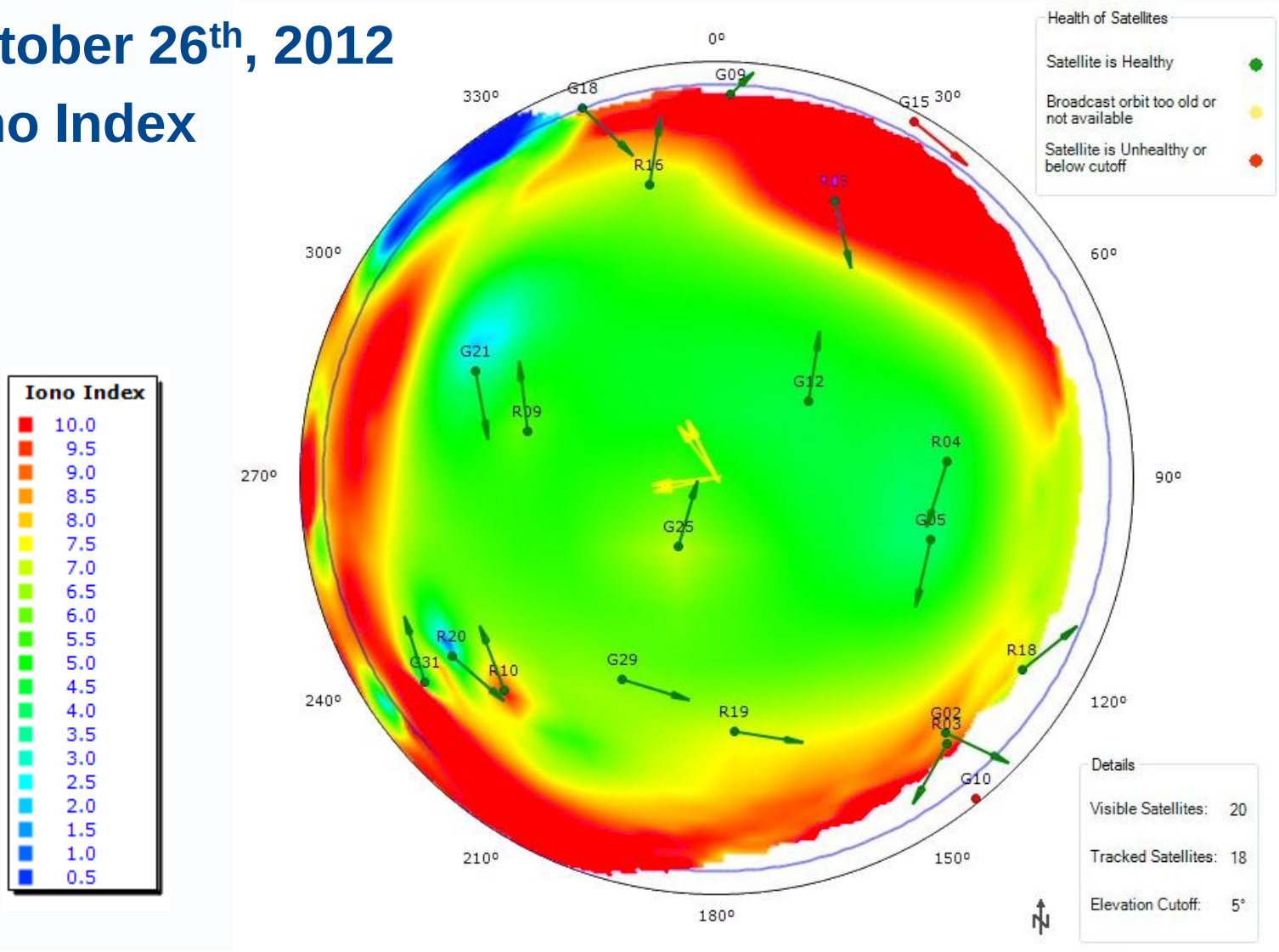
- October 26th, 2012
- TEC





Overlay Images (Macaé / Brasilia)

- October 26th, 2012
- Iono Index



Description

Iono App

Receiver Module / Device Manager

- Quality check for each tracked satellite
- Overlay images with iono. activities

Iono Activity

- Iono Index
- Scintillation
- TEC Values
- IRIM
- I95

Input

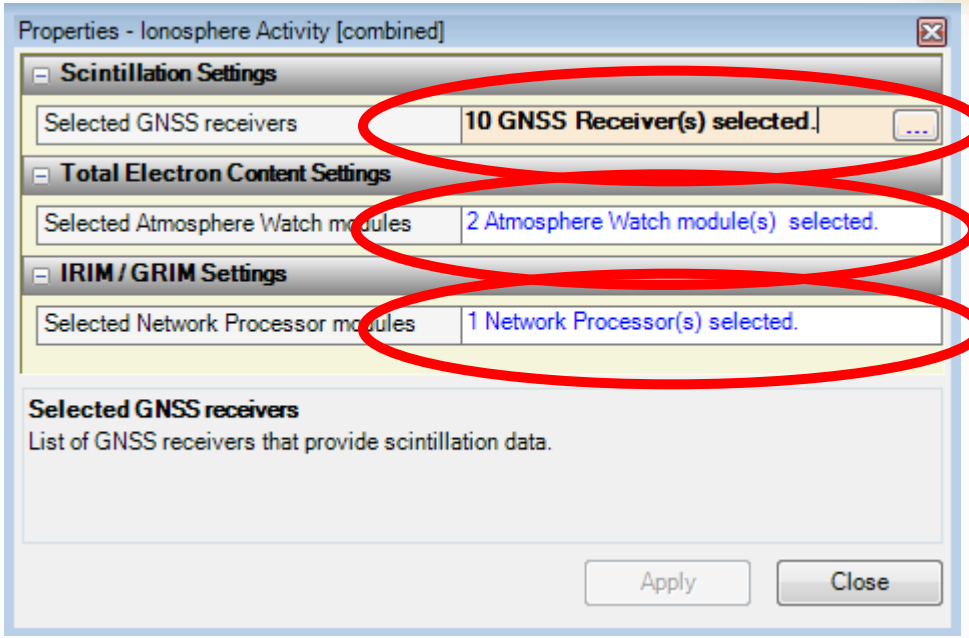
- TEC from Atmosphere Watch
- Scintillation Data from Receiver
- Iono results from Network Processor

Iono results from Network Processor

- I95 Index
- IRIM (Ionospheric Residual Integrity Monitoring)
- GRIM (Geometric Residual Integrity Monitoring)

Setup

- Select GNSS Receivers
- Select Atmosphere Watch Modules
- Select Network Processor Modules



Iono App View

Trimble Ionosphere

Trimble Ionosphere provides ionosphere activity and scintillation information for single CORS stations or GNSS networks.

The App is healthy.

0	Stations with a scintillation index > 5
0	Network Processors with I95 > 5
0	Stations with IRIM > 0.03 m
0	Stations with GRIM > 0.01 m
0	Stations with TEC > 30

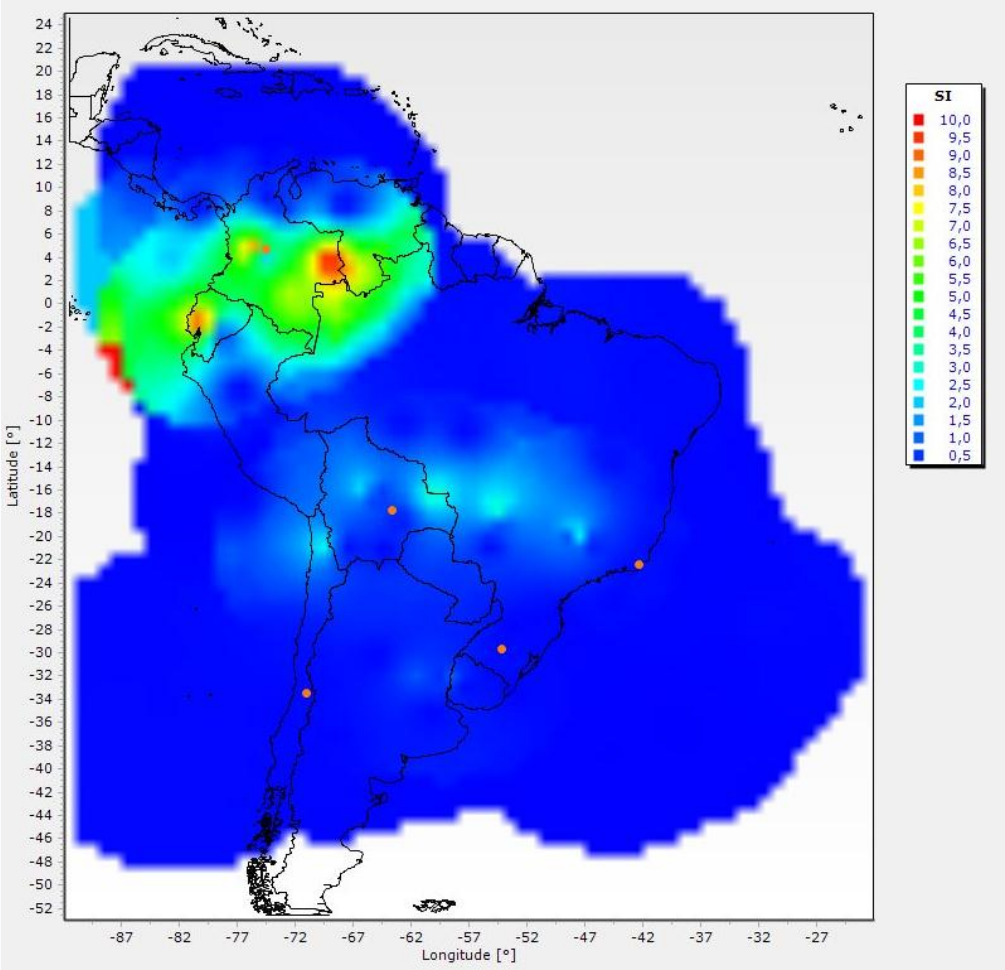
Combined Index View

Last Update [GPS time]: 09:30:22

Station Name	Scintillation Index	TEC	Iono Index	I95	IRIM
FIN_Suom	0,1	16,6	1,4	2,5	0,04
FIN_Hauk	0,1	16,3	1,4	2,5	0,02
FIN_Enon	0,1	16,5	1,4	2,5	0,03
FIN_Kala	0,1	16,4	1,4	2,5	0,01
FIN_Vete	0,1	16,6	1,4	2,5	0,02
FIN_lisa	0,1	16,6	1,4	2,5	0,01
FIN_Keit	0,1	17,1	1,4	2,5	0,02
FIN_Melt	0,1	16,3	1,4	2,5	0,02
FIN_Savu	0,1	17,2	1,4	2,5	0,03
FIN_Nils	0,1	17,1	1,4	2,5	0,02
FIN_Nurm	0,1	17,0	1,4	2,5	0,01
FIN_Kaam	0,1	16,4	1,4	2,5	0,03
FIN_Kaar	0,1	15,2	1,3	2,5	0,03
FIN_Utaj	0,1	16,4	1,4	2,5	0,02
FIN_Kaja	0,1	16,5	1,4	2,5	0,02
FIN_Kemi	0,1	17,1	1,4	2,5	0,02
FIN_Kokk	0,1	16,4	1,4	2,5	0,02
FIN_Kitt	0,1	16,2	1,4	2,5	0,02
FIN_Kilp	0,1	14,1	1,2	2,5	0,02
FIN_Kola	0,1	15,9	1,3	2,5	0,03
FIN_Puol	0,1	16,5	1,4	2,5	0,02
FIN_Raah	0,1	16,3	1,4	2,5	0,01

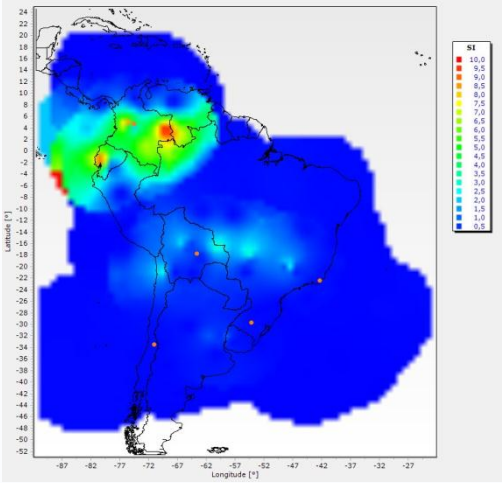
Scintillation View

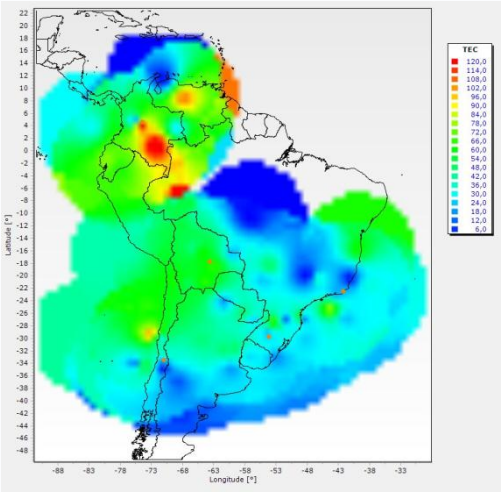
- **October 27th, 2012**

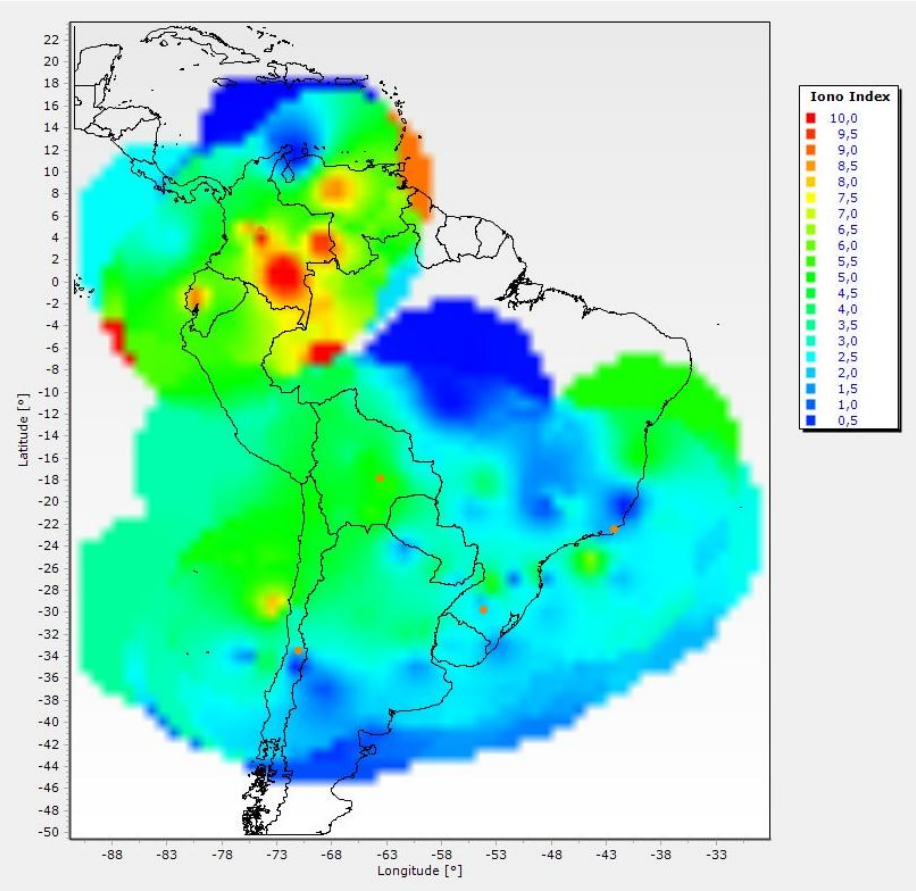


Iono Index View

- **October 27th, 2012**

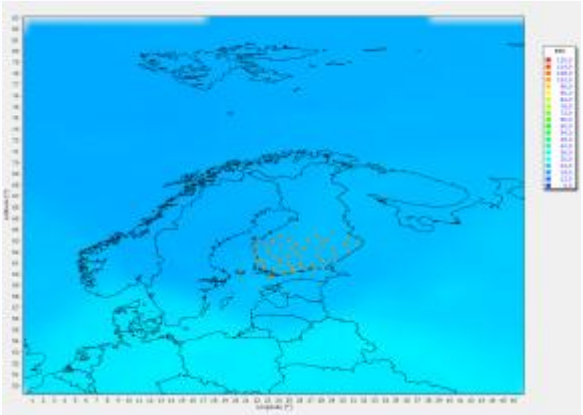


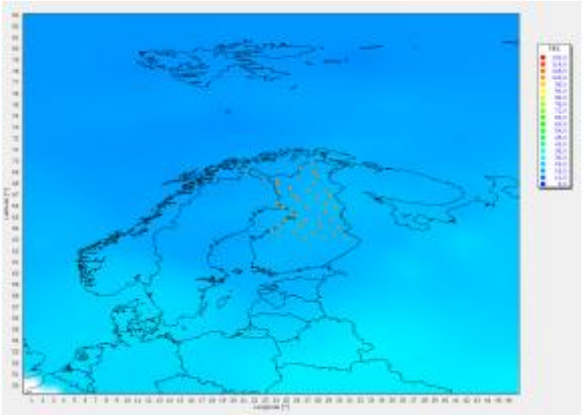


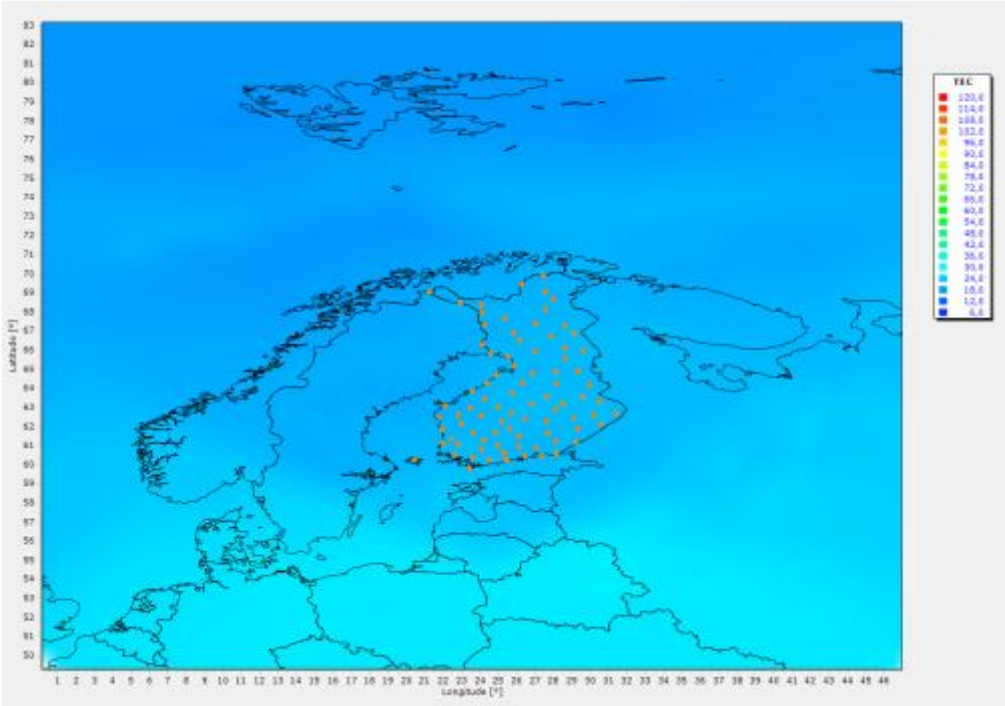


Single / Combined TEC view

- **October 5th, 2012**

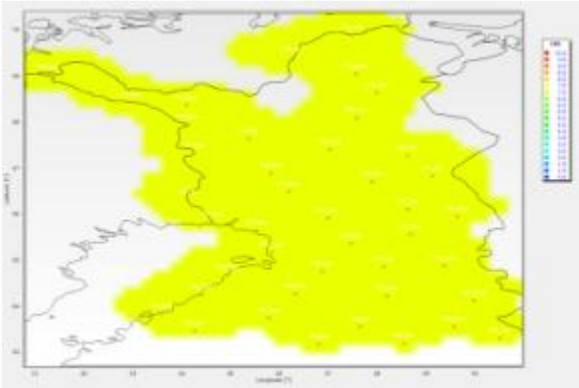


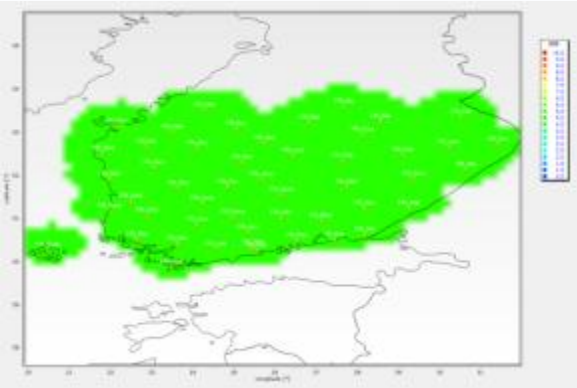


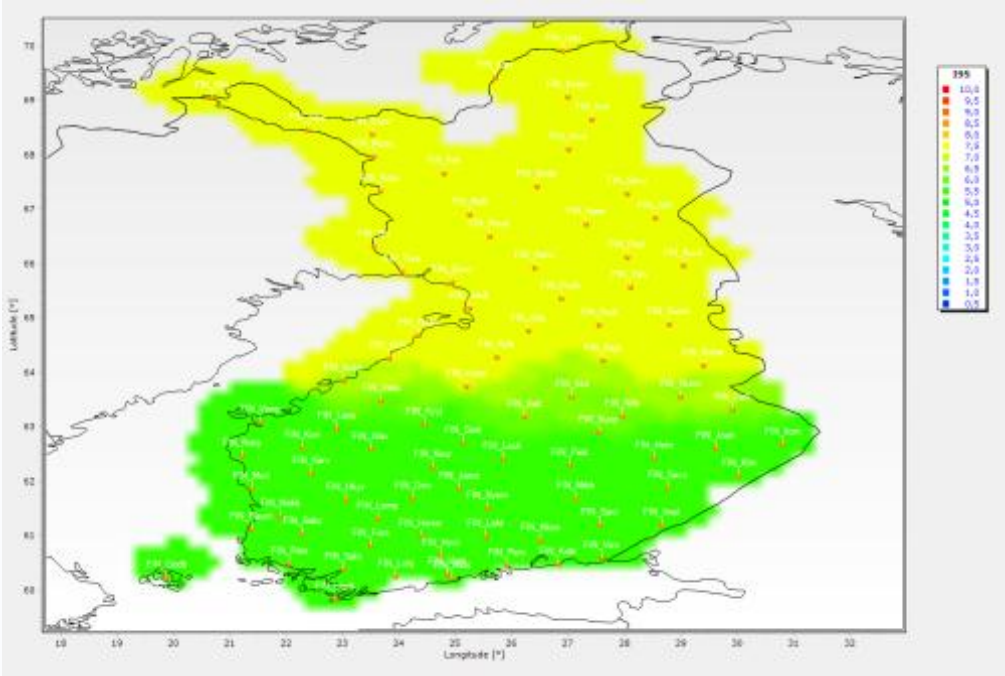


Single / Combined I95 view

- October 5th, 2012

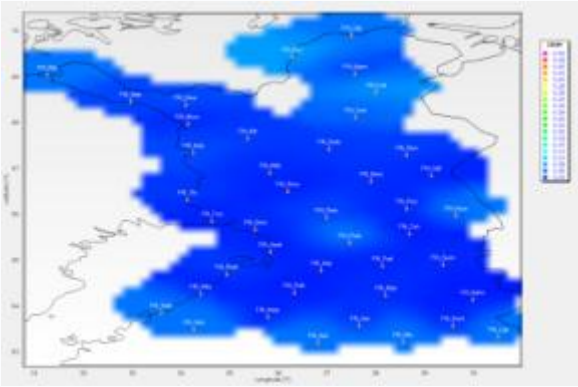


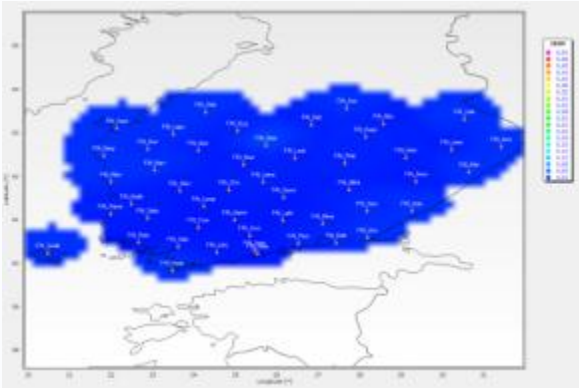


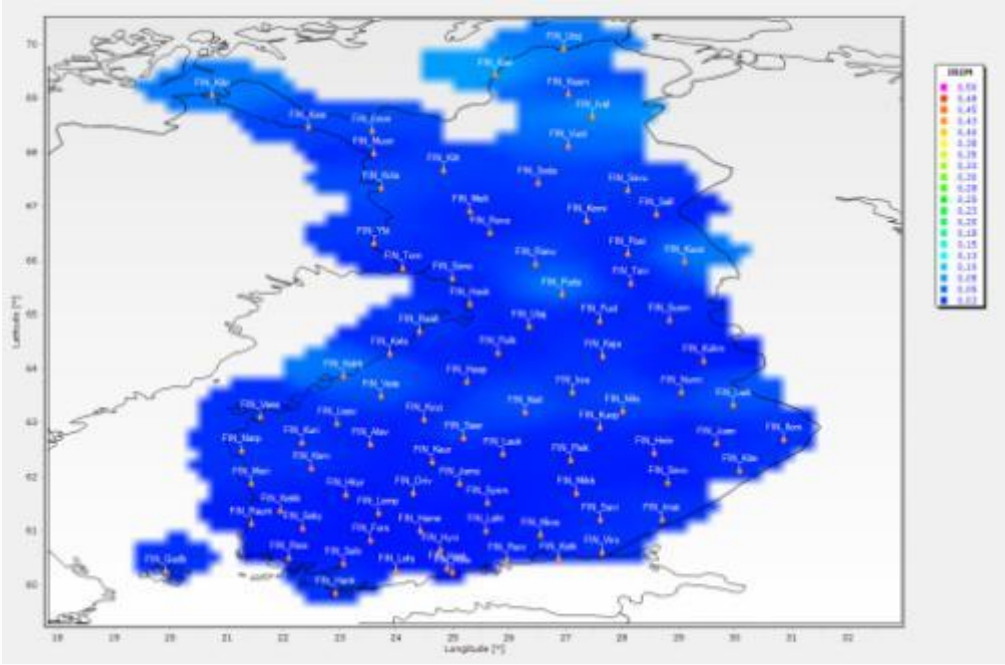


Single / Combined IRIM view

- **October 5th, 2012**







Mobile Applications

2 Apps available:

- Pivot Admin 
- Pivot Field 

Pivot Admin

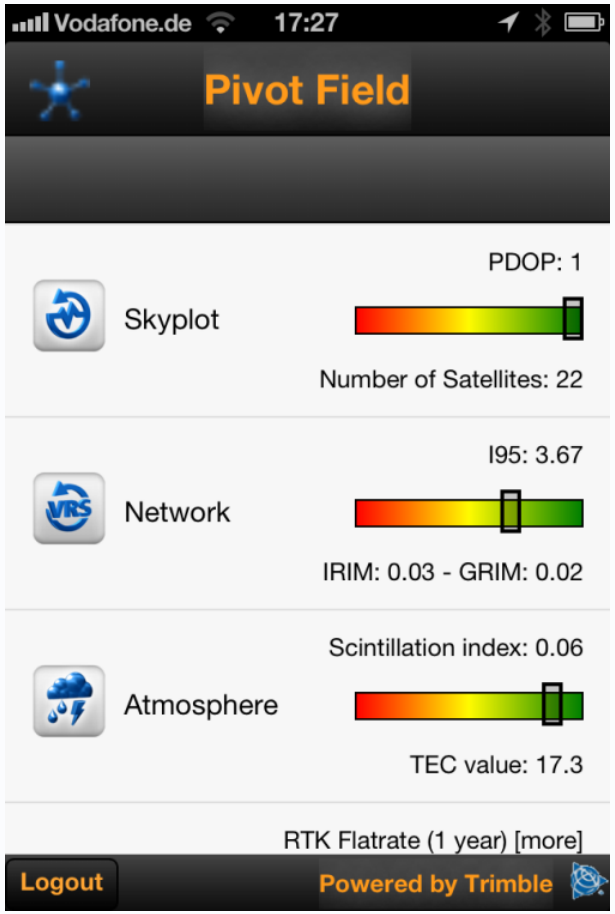
Gives an administrator information about the health status of his system.

Features:

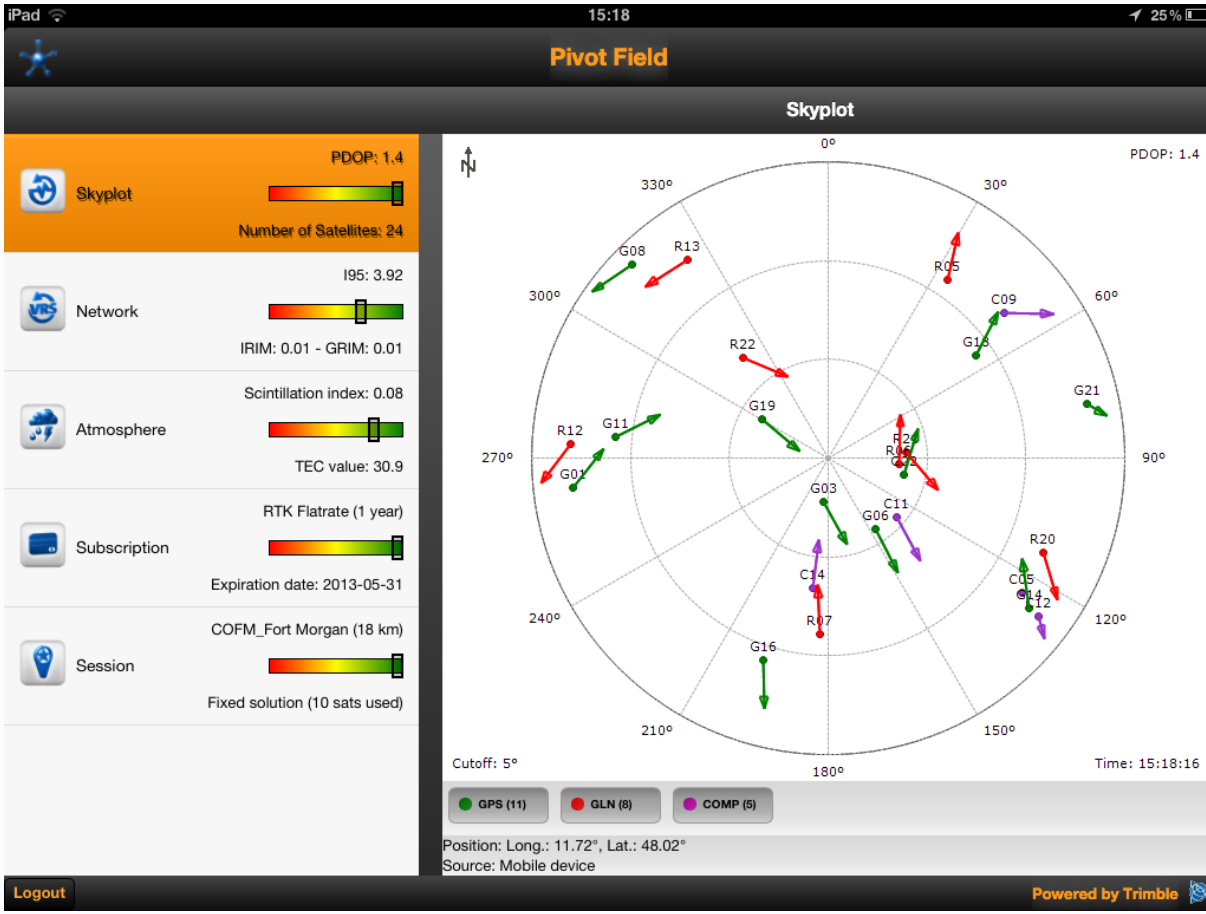
- **App health**
- **Computer health**
- **Favorites**

Pivot Field start screen

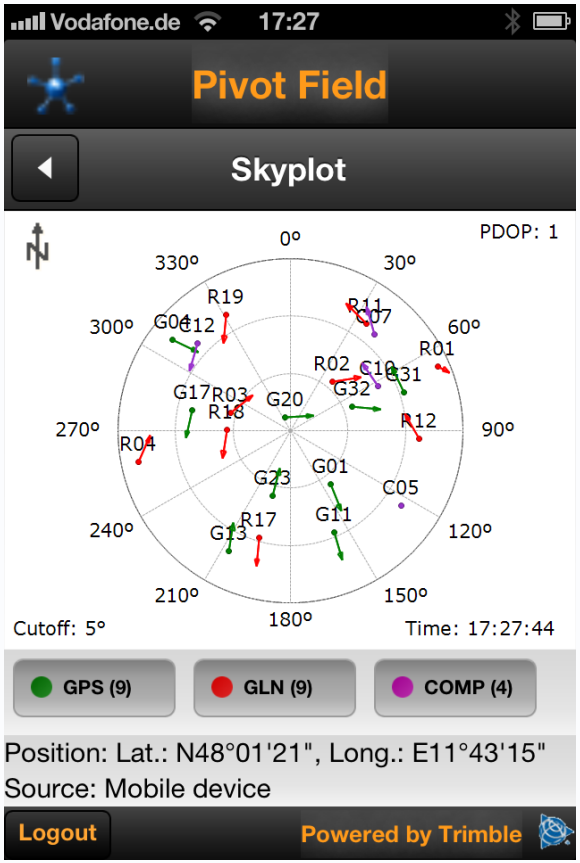
Phone



Tablet



Pivot Field - Skyplot

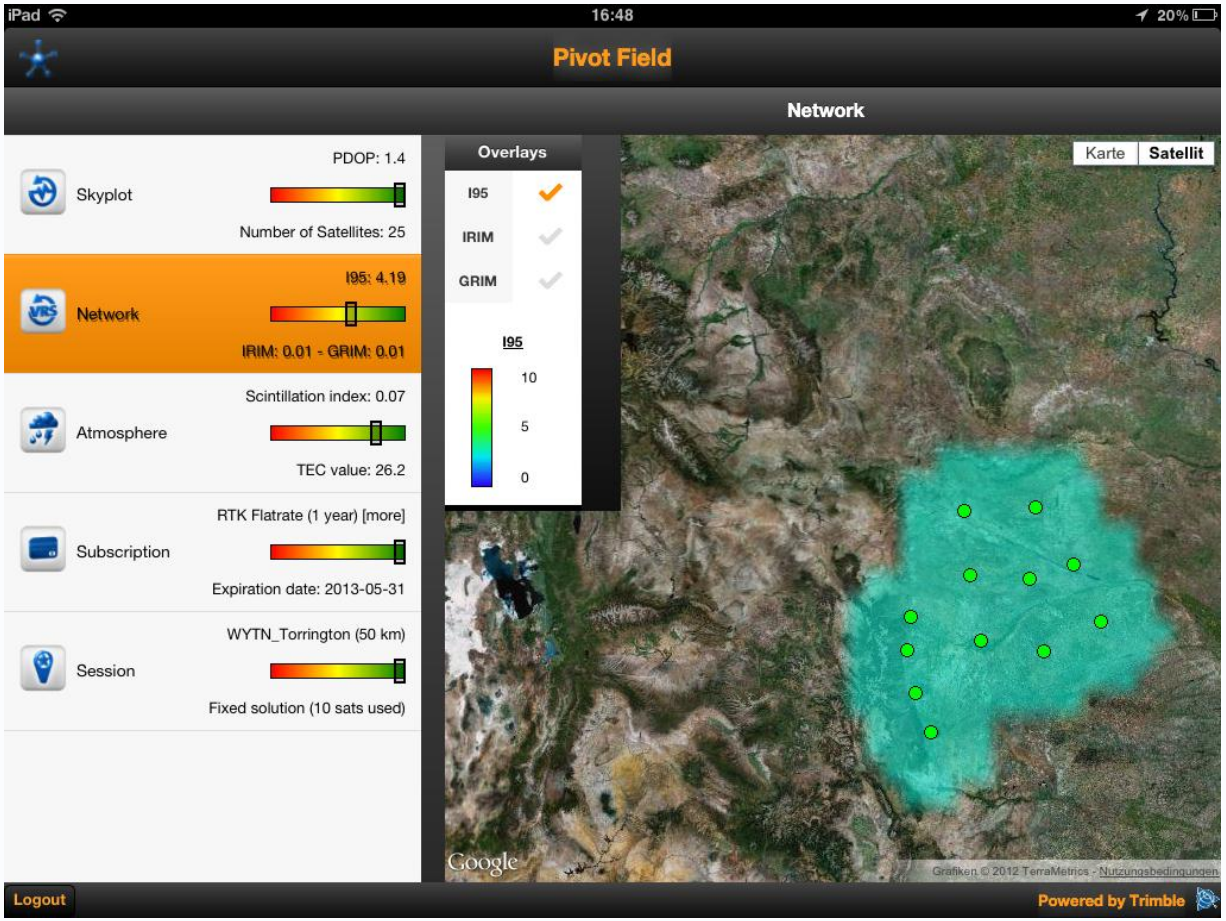


The information for the skyplot is coming from the Trimble Global system and not from an individual customer system.

Only buttons for satellite systems tracked for your location are shown

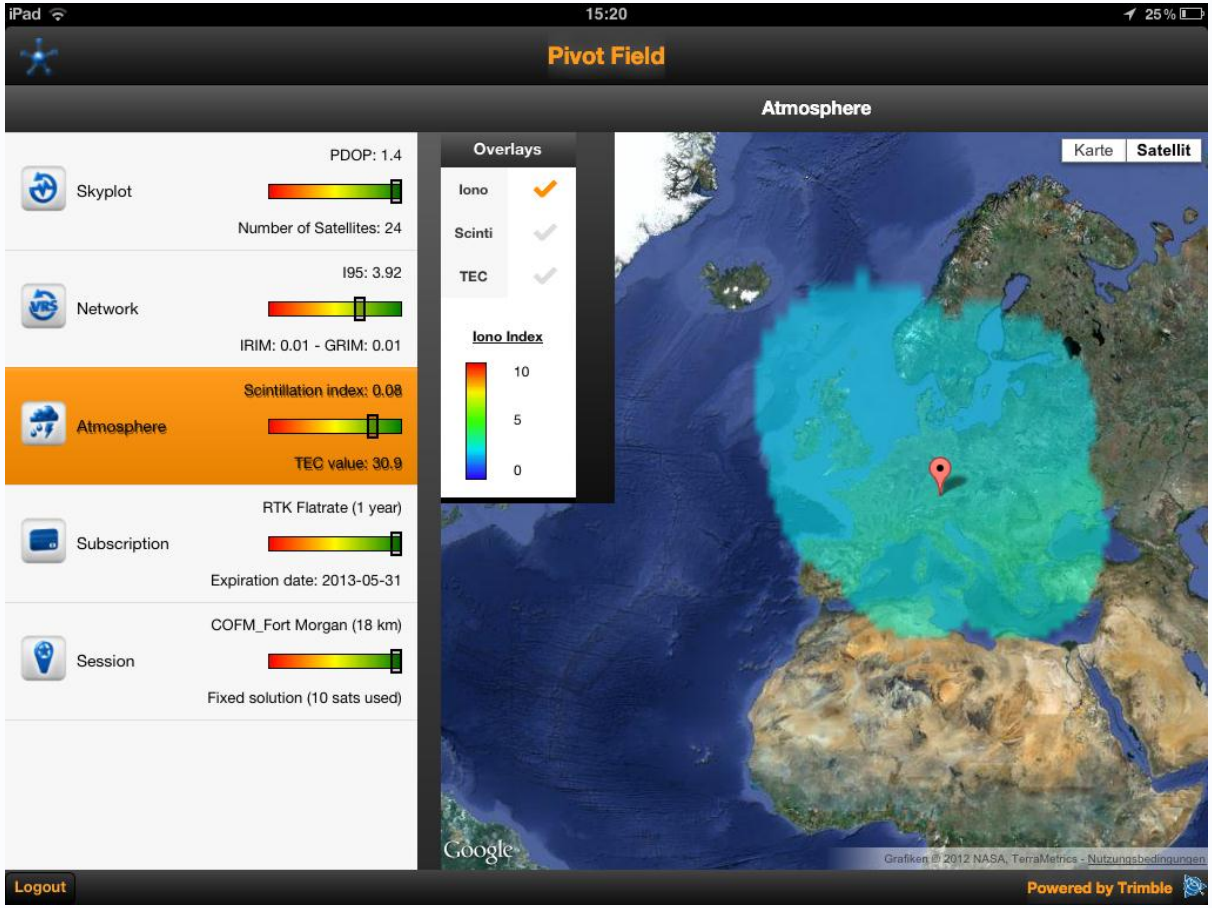
Pivot Field - Network

Network information based on the ionosphere activity module



Pivot Field - Atmosphere

Overlay is based on the atmosphere watch selected in the ionosphere activity module



Benefit

- IPWV is indicator of the water vapor
  - It gives an absolute value of water vapor
- IPWV, forecasting -> nowcasting
  - Animating it over time provides a short time prediction
- Delays, input to numerical weather models
  - GNSS-based tomography: spatial and temporal variation of water vapor
- TEC is indicator for RTK performance
  - The higher the TEC value is, the worse the RTK performance in terms of position quality and initialization time
- TEC is interesting for space weather research
  - LEO satellites may be influenced by high TEC values

Summary

- Atmosphere monitoring
- Easy understanding
- Troubleshooting
- System protection

Questions?

Contact

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