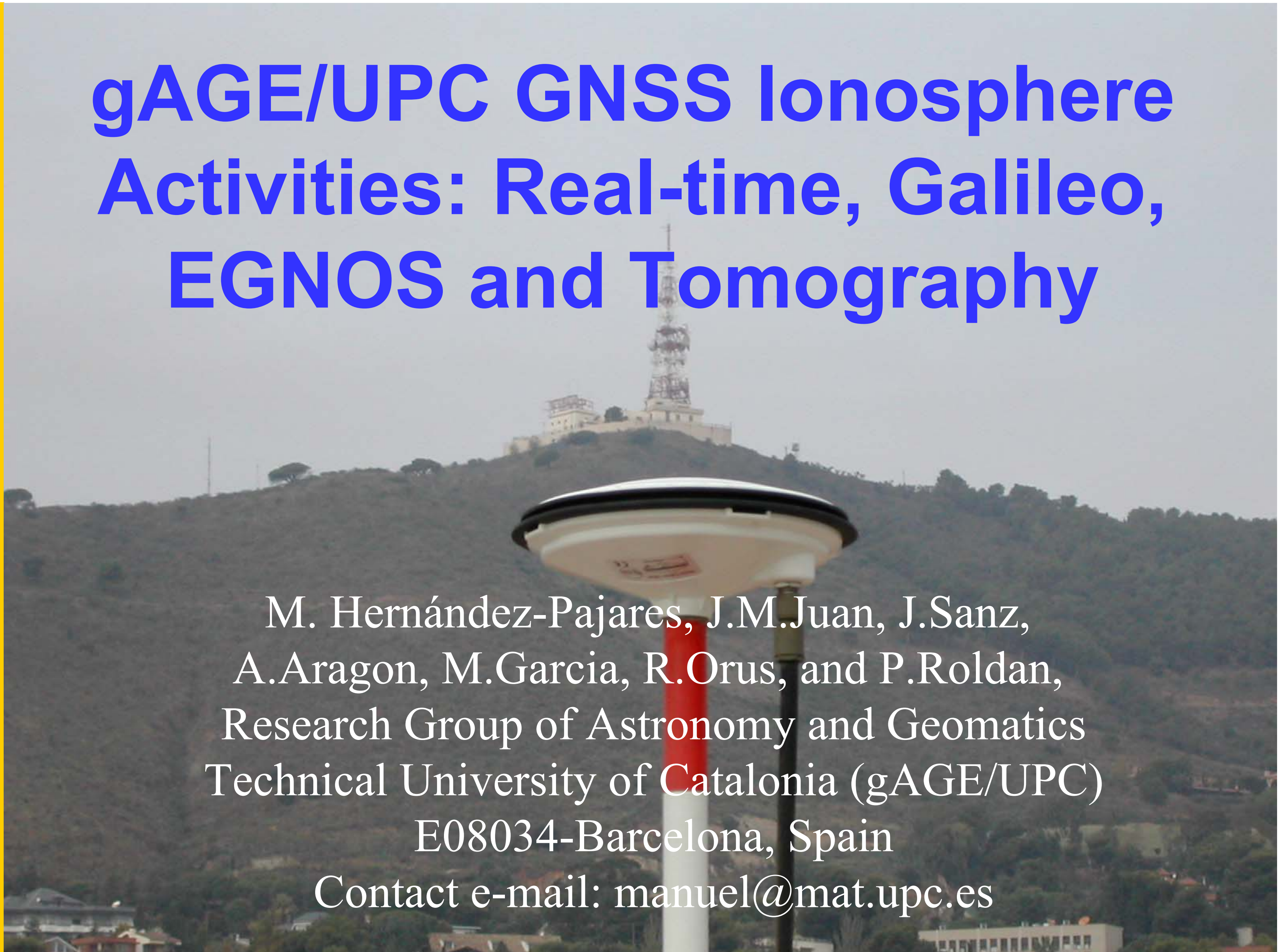

gAGE/UPC GNSS Ionosphere Activities: Real-time, Galileo, EGNOS and Tomography

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Outline

- Introduction.
- Accurate Wide Area RT ionospheric corrections, the key for:
  - With GPS: Wide Area RTK *(WARTK)*
  - With Galileo: Wide Area RTK with three-frequency systems *(WARTK-3).*
  - Accurate EGNOS real-time Ionospheric Monitoring.
- GPS ionospheric tomography.
- Conclusions

Introduction

The improvement of real-time GNSS ionospheric determination models makes now possible to fix ambiguities in real-time WADGPS networks (ref. stations separated by hundreds-thousand km).

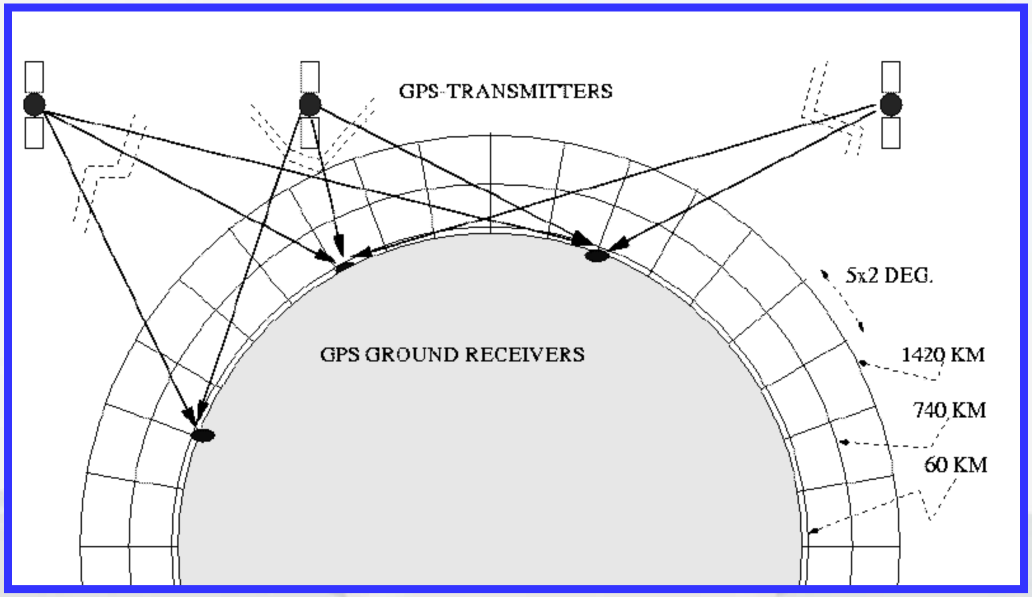
New applications arise in such WADGPS networks:

(1) cm-level real-time positioning, potentially in single-epoch with Galileo and Modernized GPS.

(2) real-time instantaneous tropospheric determination.

(3) real-time ionospheric integrity monitoring, i.e. for SBAS systems such as EGNOS.

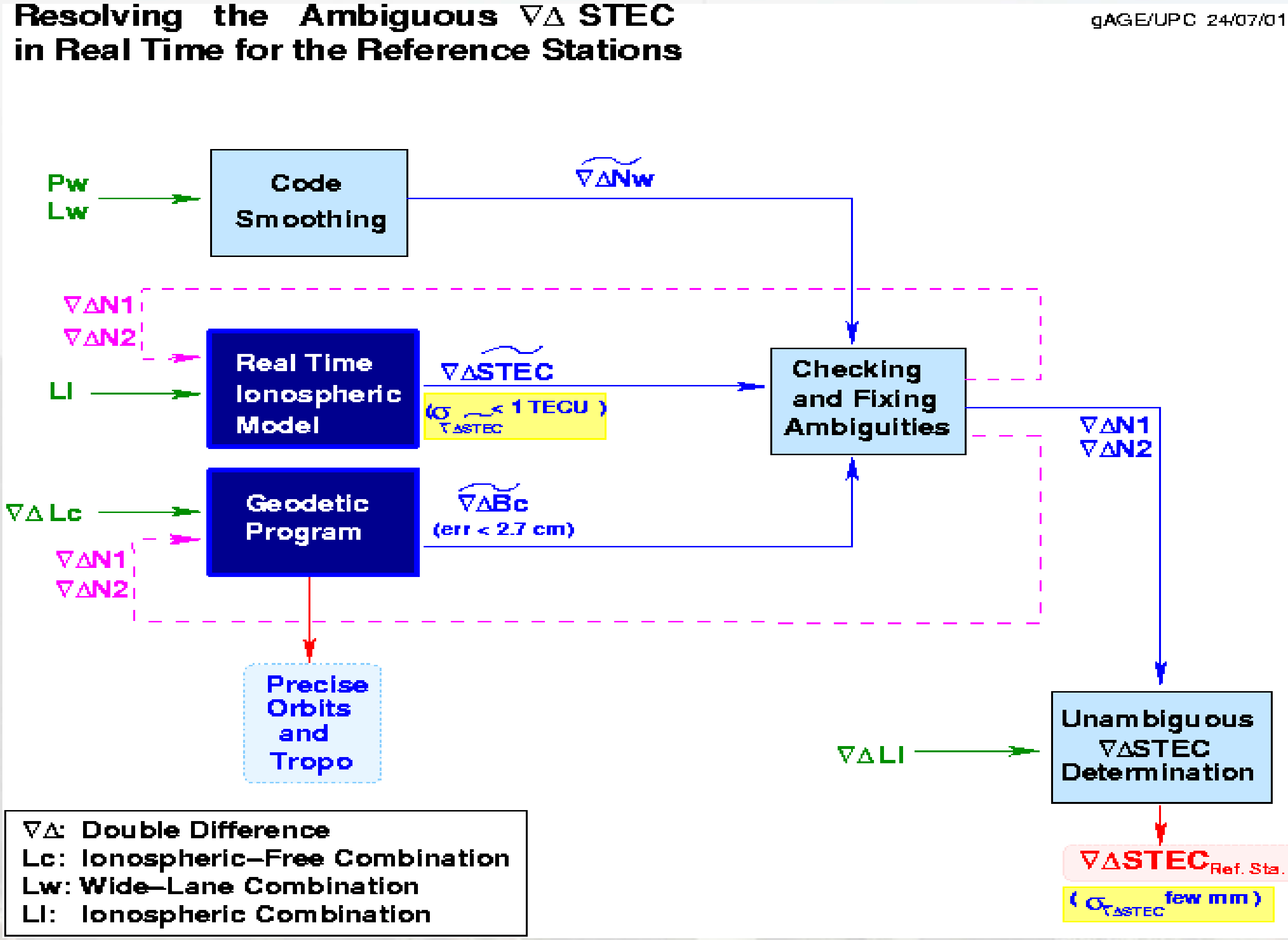
Real-time iono. model



- Only carrier phase data needed
- With tomographic description: more accurate
- DCB's no longer needed
- No affected by pseudorange multipath

$$L_I = STEC + B_I = \int_{REC}^{SAT} N_e dl + B_I = \sum_i \sum_j \sum_k (N_e)_{i,j,k} \Delta s_{i,j,k} + B_I$$

WARTK: Combining real-time Ionospheric & Geodetic models



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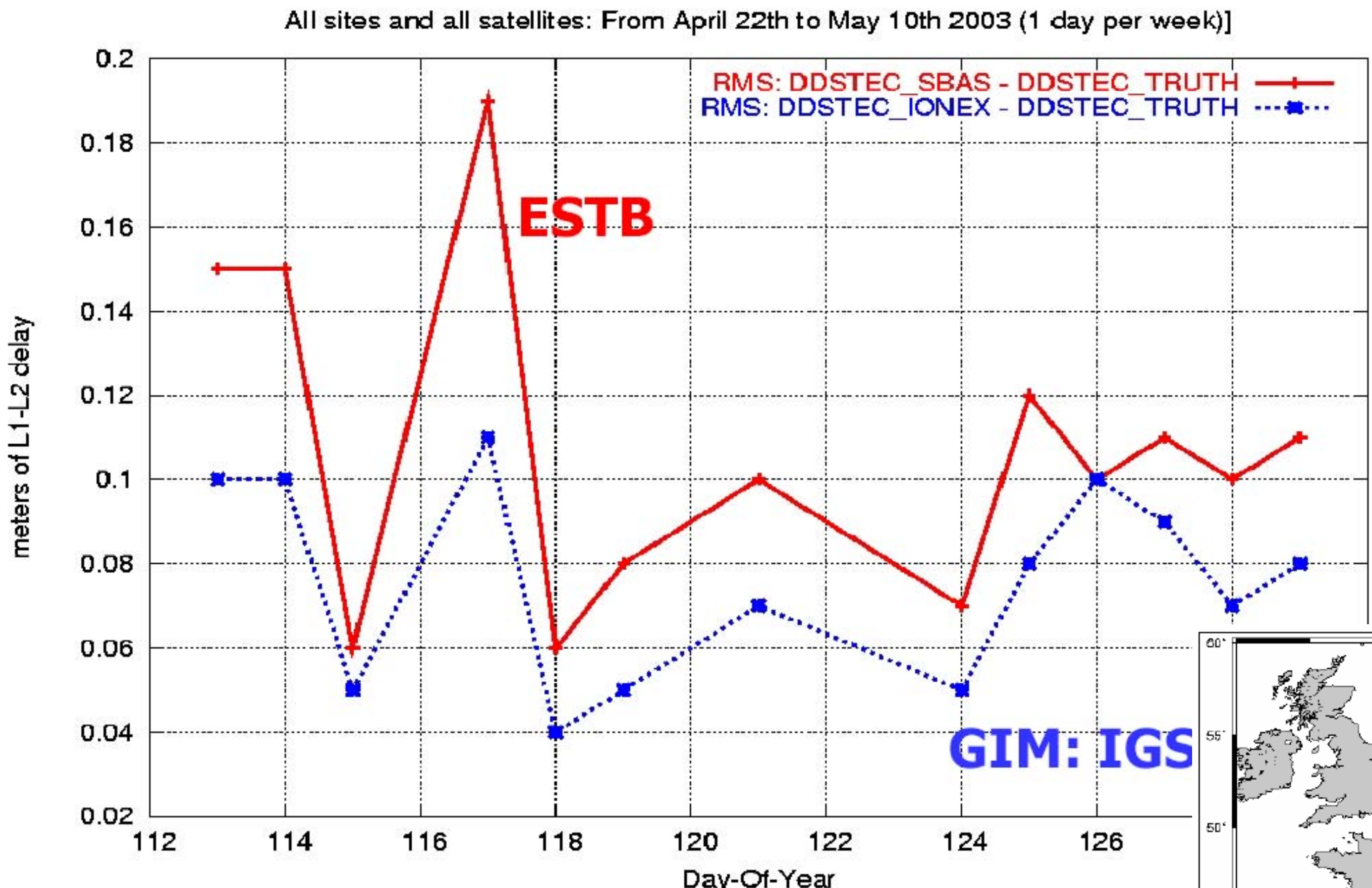
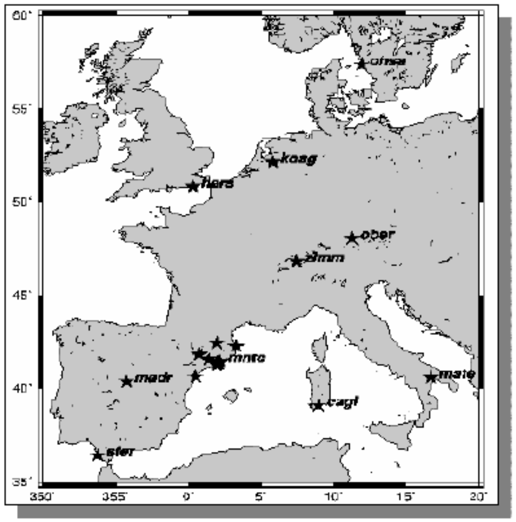
Example 1: EGNOS Test Bed vs IGS differential iono.

$$RMS\,(\nabla\Delta STEC_{XXX} - \nabla\Delta STEC_{TRUTH})$$





REAL CASE of use of very accurate DDSTEC reference values: During these days of April-May 2003, the double-differenced STEC values from the IGS TEC maps (time resolution of 2 hours) are about 40% better than the ESTB values (real-time, not final configuration).

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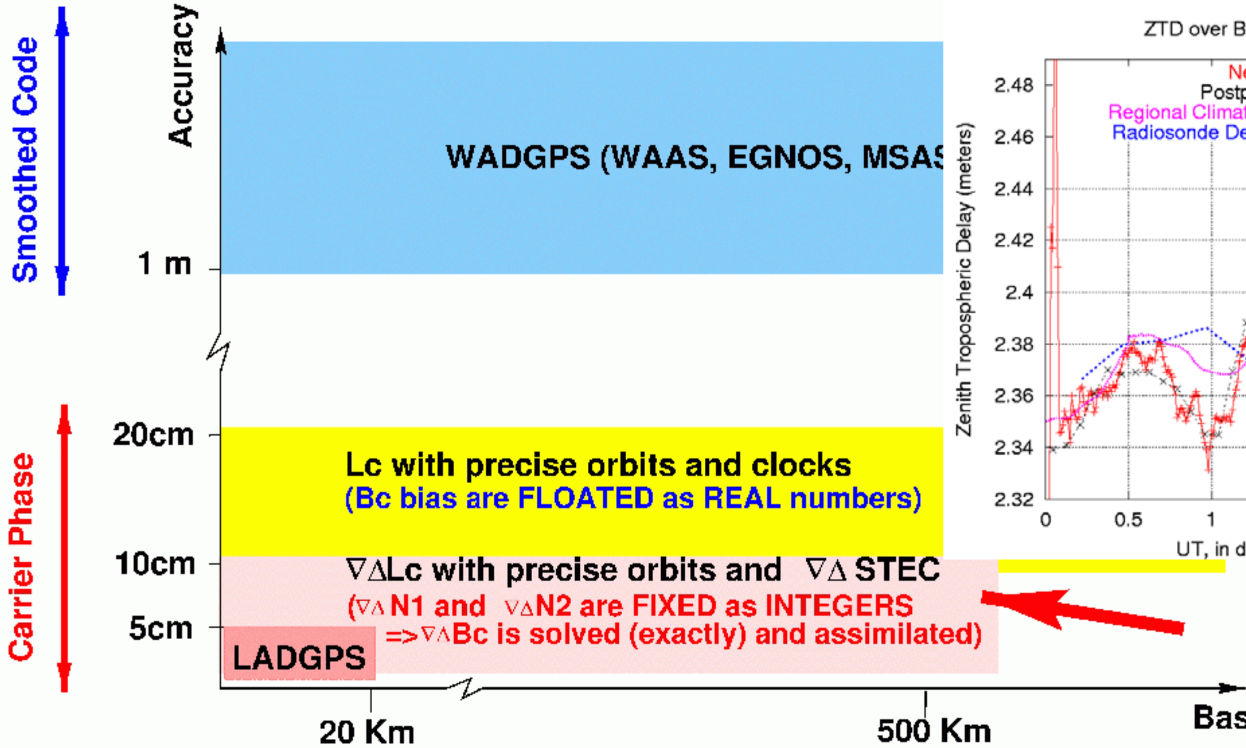
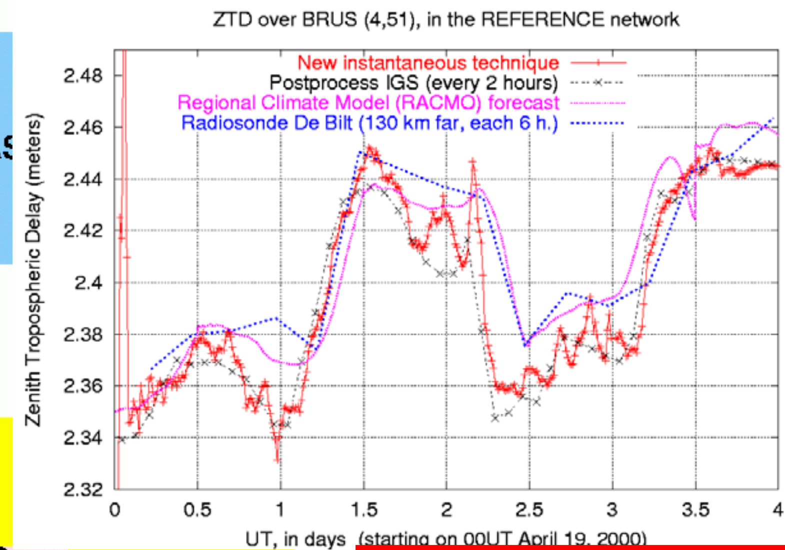
WARTK(GPS): cm-Navigation at hundreds km far

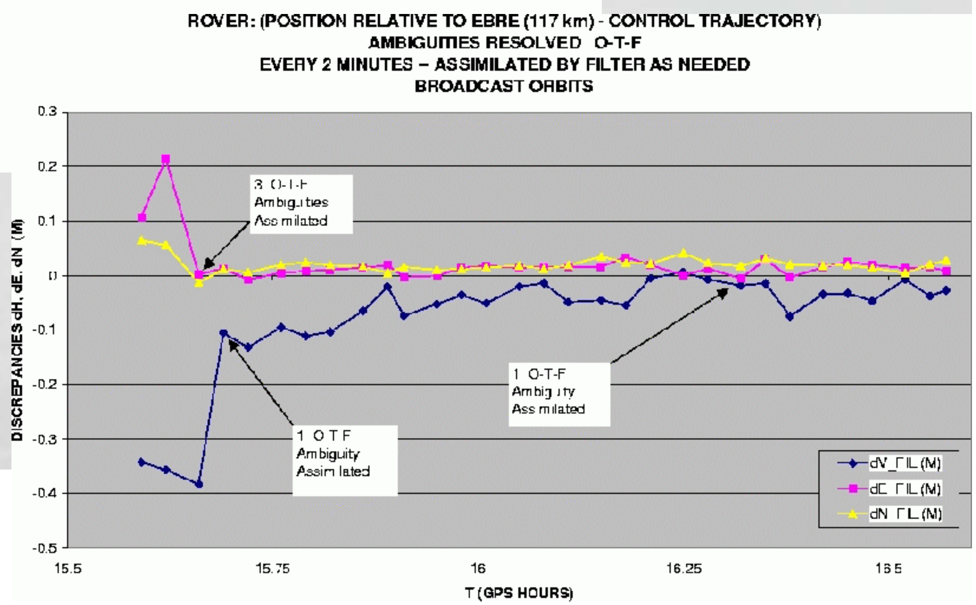




Instantaneous Zenith Tropospheric Delay in WADGPS networks

LC: Ionospheric-Free Combination

Sub-decimeter real-time positioning at more than 100 km far from the nearest GPS reference station.



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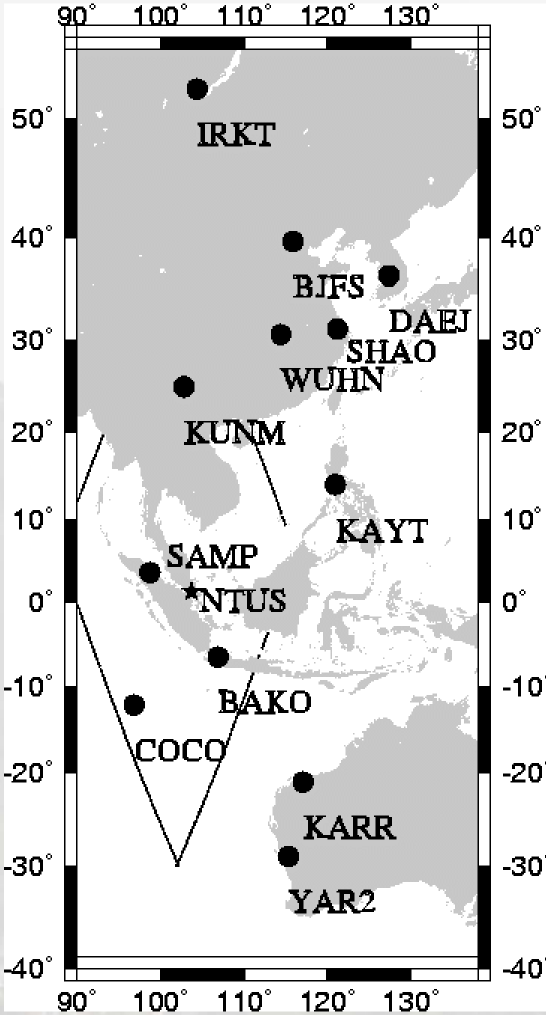
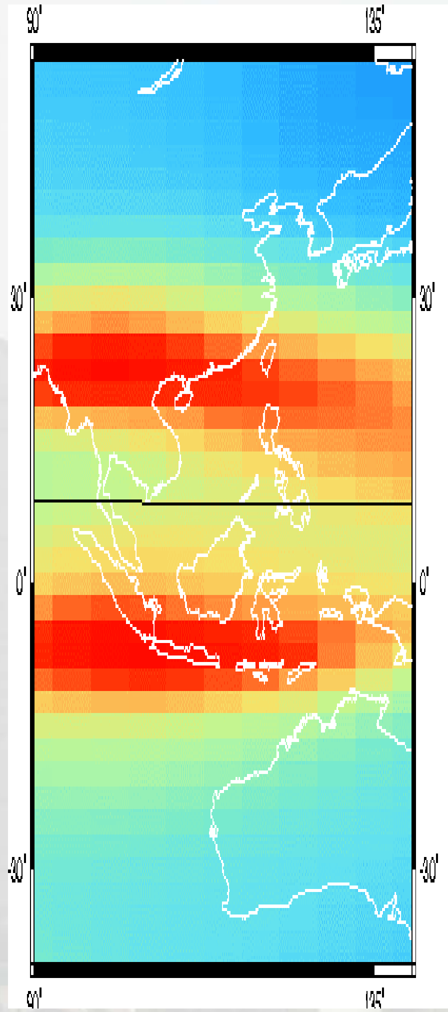
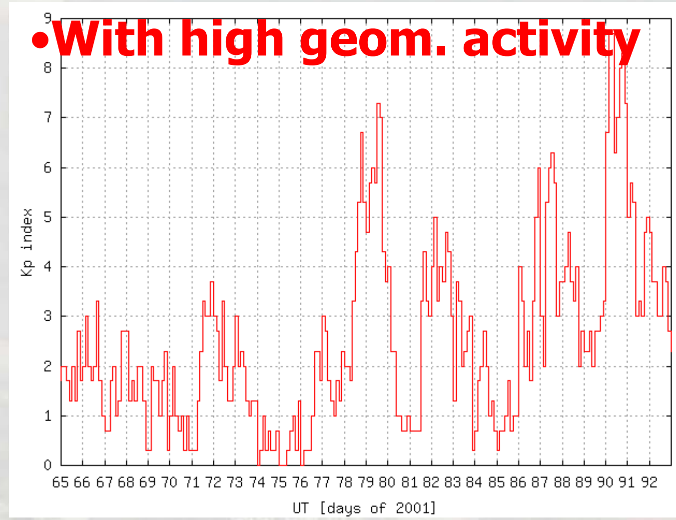
Accurate STEC from fixed GPS sites thousands km far



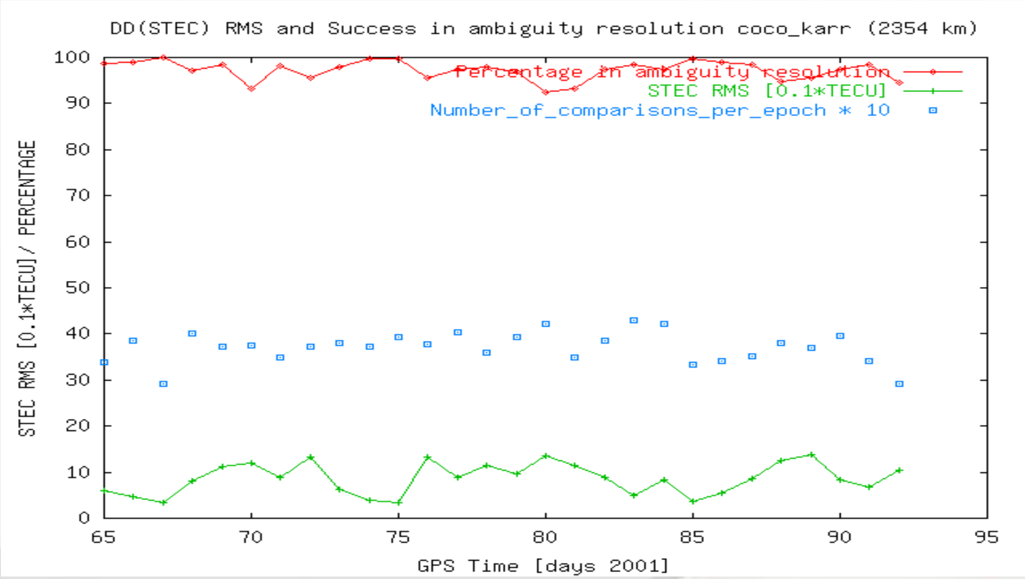


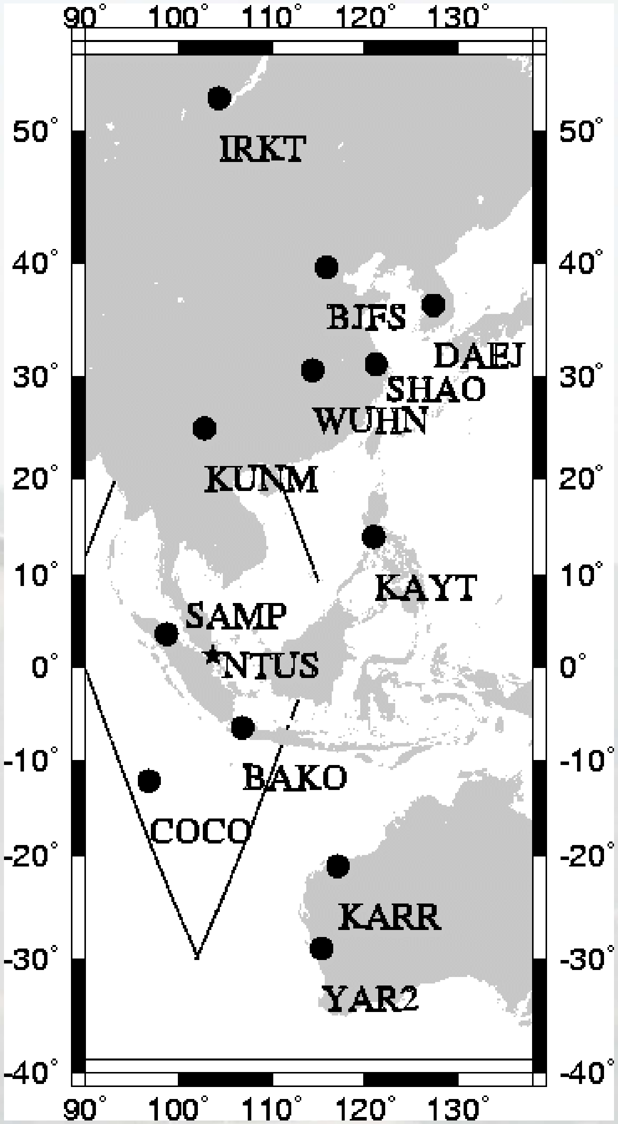
New Experiment:

- 13 IGS stations
- Distances: 1000-3000km
- Including equator, tropics
- 4 weeks 2001 65-92
- Solar Max. conditions
- Seasonal Max.
- With high geom. activity



Real-time DDSTEC vs. truth





Sta.	Ref.	Dist. (km)	% Succ.	RMS [TECU]	# Obs.
IRKT	DAEJ	2507	93	1.2	8329
BJFS	DAEJ	1067	91	1.4	8131
KUNM	DAEJ	2640	95	1.0	3900
WUHN	DAEJ	1369	92	1.4	6358
SAMP	KARR	3341	95	1.1	6441
COCO	KARR	2354	97	0.9	9963
BAKO	KARR	1939	90	1.5	6121
YAR2	KARR	909	97	0.8	12630

WARTK: experiments & results

Exp.	Ionos. Activity	Distances (km) Rover/Ref.	Ref. Succes	Rover Success	Kind Rover	Dates	Region	Reported in
BelKin99	Quiet	116/ 286	97%	80-100%	Car	March 23, 1999	Spain NE	Colombo et al. 1999
NWPacific (1)	Active Kp=6	400/ 900	90-100%	80%	IGS Site	May 3, 1998	Canada -USA NW	Hernández-P. et al. 2000a Colombo et al. 2000
NWPacific (2)	Irreg. Apr30	162/ 900	95-100%	80-90%	IGS Site	Apr28 to May 1, 1998	Canada -USA NW	Hernández-P. et al. 2000b
SolarMax (1)	Solar Max.	130/ 500	85-95%	80%	IGS Site	Apr 19 -22, 2000	Central Europe	Hernández-P. et al. 2001
SolarMax (2)	Very Active	130/ 500	50-95%	80%	IGS Site	Jul 12 -15, 2000	Central Europe	Hernández-P. et al. 2000b
Baltic99 (1)	TID's	144/ 285	97%	83%	Fixed Site	Aug 25, 1999	North Europe	This paper
Equator01	S.Max. Equat.	1000-3000	90%	-	IGS Site	Mar6 to Apr 2, 2001	Asia-Oceania	This paper
	Kp:0-9							

Prototype of the real-time ionospheric part running now in Catalonia, NE Spain, in testing mode (under contract of the Cartographical Institute of Catalonia, ICC).

More details in:

Hernandez-Pajares M., J. M. Juan, J. Sanz and O. L. Colombo, Improving the real-time ionospheric determination from GPS sites at very long distances over the equator, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 107, NO. A10, 1296, doi:10.1029/2001JA009203, 2002.

Hernandez-Pajares M., J. M. Juan, J. Sanz, O. L. Colombo and H. van der Marel, A new strategy for real-time integrated water vapor determination in WADGPS networks, GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 17, PAGES 3267-3270, 2001.

Hernandez-Pajares M., J. M. Juan, J. Sanz and O.L.Colombo, Application of ionospheric tomography to real-time GPS carrier-phase ambiguities resolution, at scales of 400-1000 km and with high geomagnetic activity, GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 13, PAGES 2009-2012, JULY 1, 2000.

WARTK-3 for Galileo and Modernized GPS (1)

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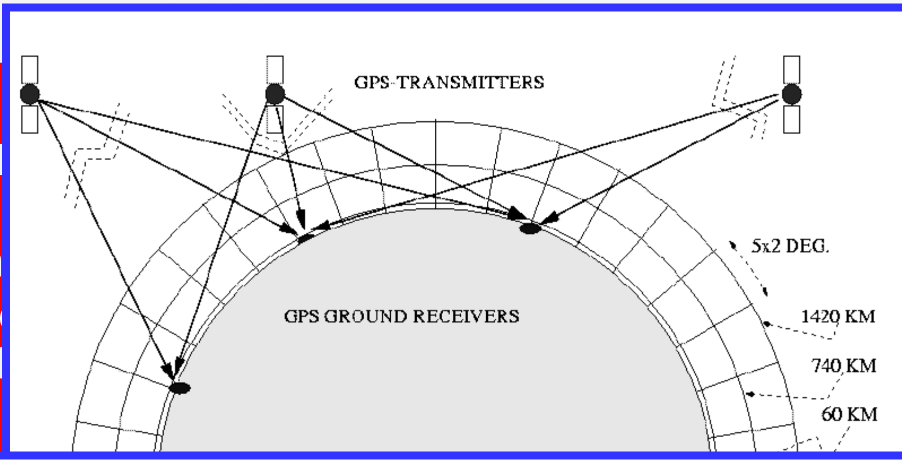
1.
lan
ps



WARTK-3

(ref.sites)

$$L_I = STEC + B_I = \int_{REC}^{SAT} N_e \, dl + B_I = \sum_i \sum_j \sum_k (N_e)_{i,j,k} \Delta s_{i,j,k} + B_I$$

3. The L1 phase ambiguity is derived from the difference between L1 and the unambiguous wide lane obtained previously

$$error(\nabla\Delta I) < 0.26 TECU$$

-1.95 cycles N1/TECU

$$\nabla\Delta\hat{N}_1 = \frac{1}{\lambda_1}\nabla\Delta\left(L_1 - L_w + \lambda_w N_w\right) = \nabla\Delta N_1 - \frac{1}{\lambda_1}\nabla\Delta(\varepsilon_w + m_w - m_1) + \frac{1}{\lambda_1}(\alpha_1 - \alpha_w)\nabla\Delta I$$

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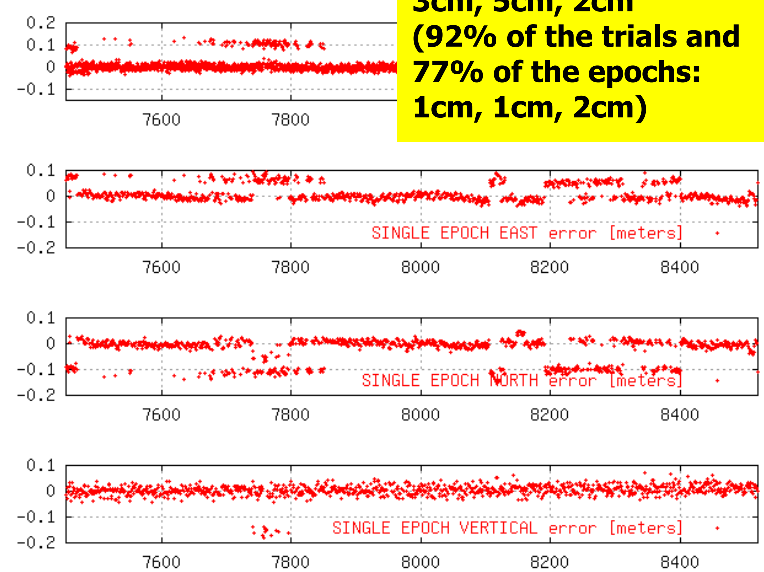
WARTK-3 for Galileo and Modernized GPS (2)

	PROS	CONS
TCAR	Low computational load.	Ionospheric error limiting seriously.
ITCAR	Improved results by integrating TCAR in a navigation filter.	The ionospheric delay still limits the 3rd ambiguity fixing.
WARTK	Accurate RT ionospheric modelling allowing precise navigation at hundreds of kilometers far from the reference sites.	Computation load: need of computing a first ionospheric free navigation solution for the roving user.
WARTK-3	Low computation load and accurate real-time ionospheric model providing single epoch precise navigation at more than hundred km far (the best of *both worlds*).	

East, Norh, Up RMS: 3cm, 5cm, 2cm (92% of the trials and 77% of the epochs: 1cm, 1cm, 2cm)



Thank you!

More details in: Hernandez-Pajares M., J. M. Juan, J. Sanz and O. L. Colombo, Impact of Real-Time Ionospheric Determination on Improving Precise Navigation with GALILEO and Next-Generation GPS, NAVIGATION, Vol. 50, No. 3, Fall 2003 (under international patent solicited by ESA).

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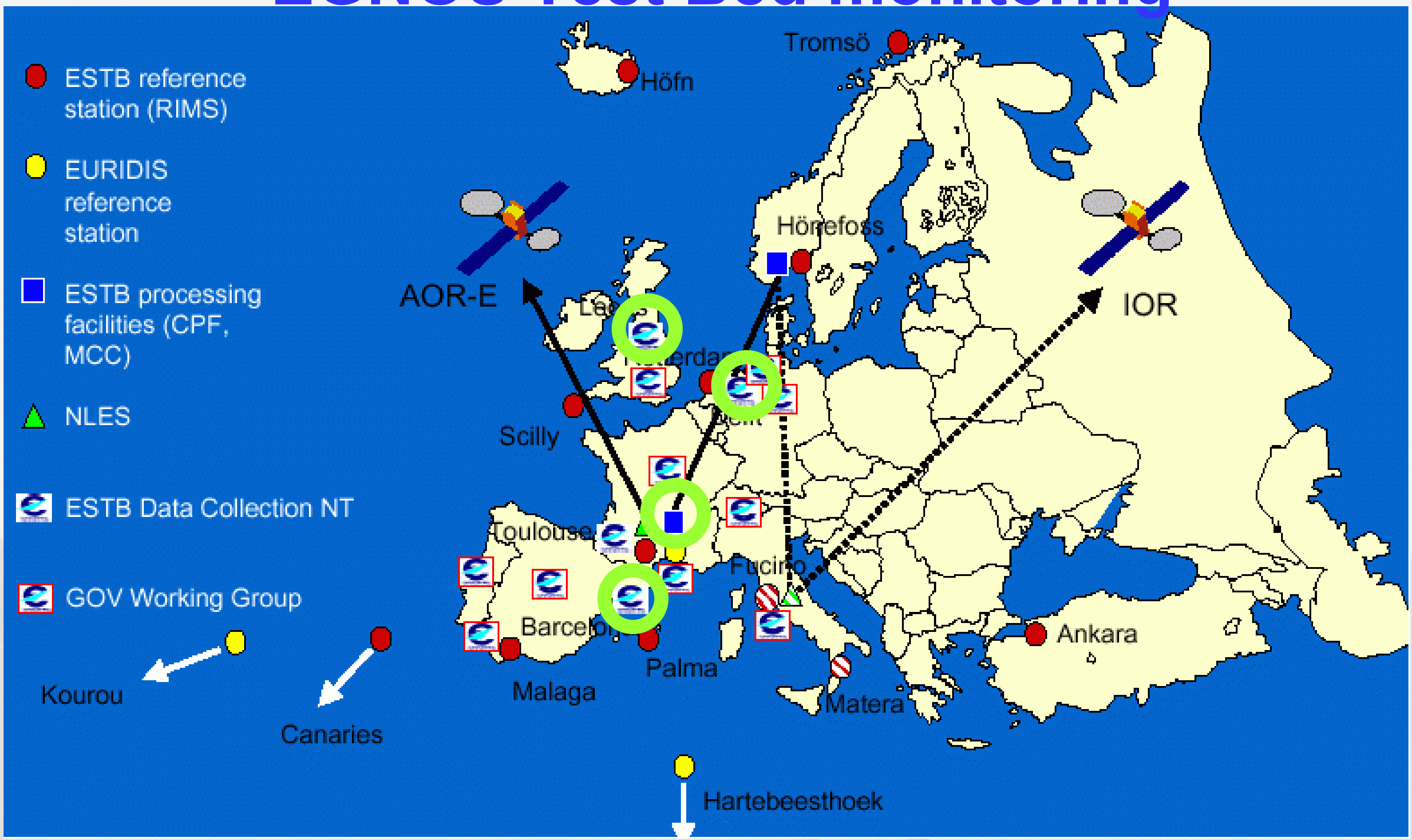
2. EGNOS Test Bed Monitoring activity

EGNOS Test Bed monitoring



Leeds, Delft, M3/ENAC, UPC1, UPC2	Receiver: NovAtel (OEM3)	Antenna: L1/L2 NovAtel 600 (Pinwheel)

Collecting 24h data (1Hz) every Thursday-Friday since January 10th 2002

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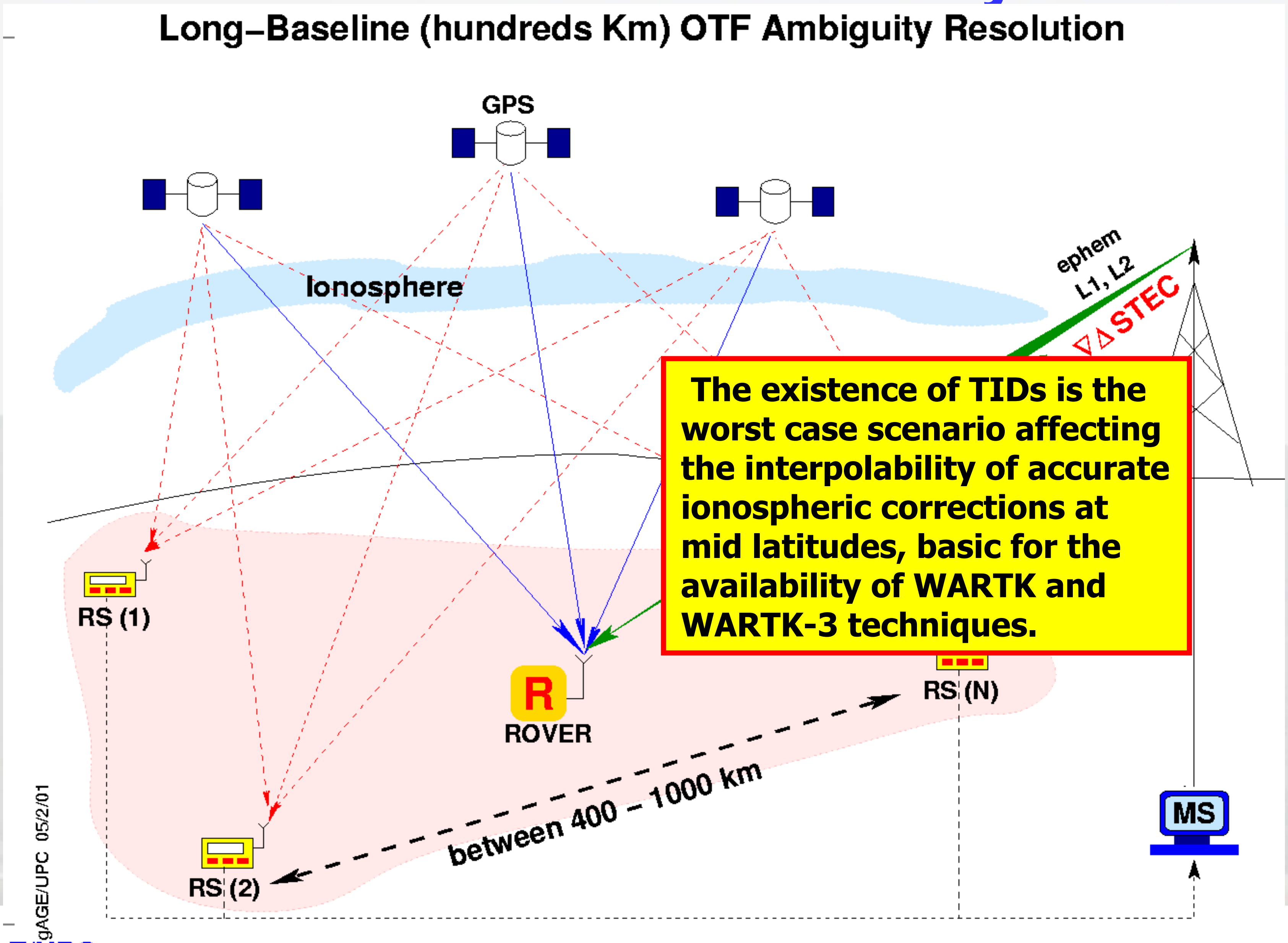
Wide Area RTK network layout



The existence of TIDs is the worst case scenario affecting the interpolability of accurate ionospheric corrections at mid latitudes, basic for the availability of WARTK and WARTK-3 techniques.

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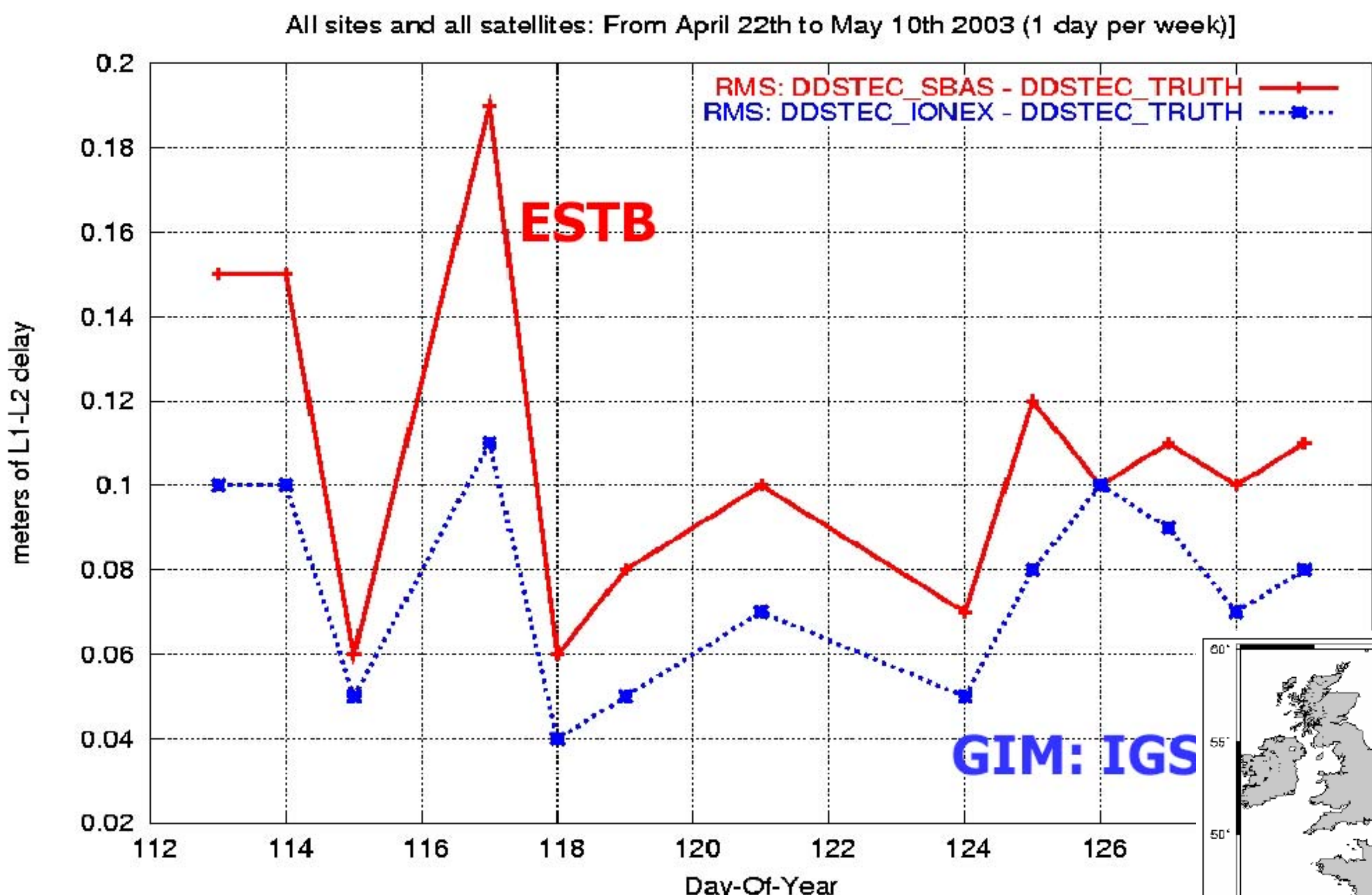
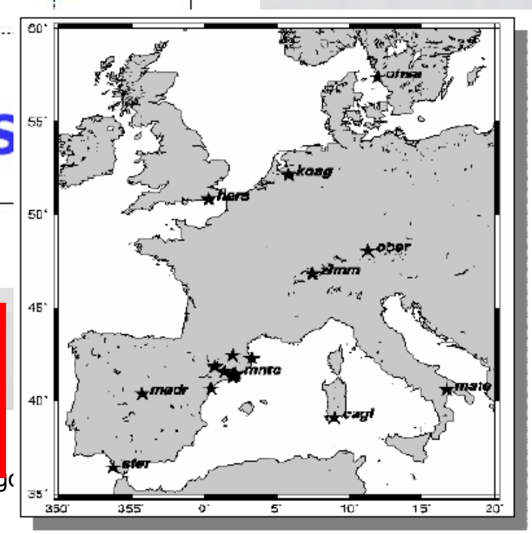
Example 1: ESTB vs IGS differential iono.

$$\text{RMS}\,(\nabla\Delta STEC_{XXX} - \nabla\Delta STEC_{TRUTH})$$





During these days of April-May 2003, the double-differenced STEC values from the IGS TEC maps (time resolution of 2 hours) are about 40% better than the ESTB values (real-time, not final configuration).

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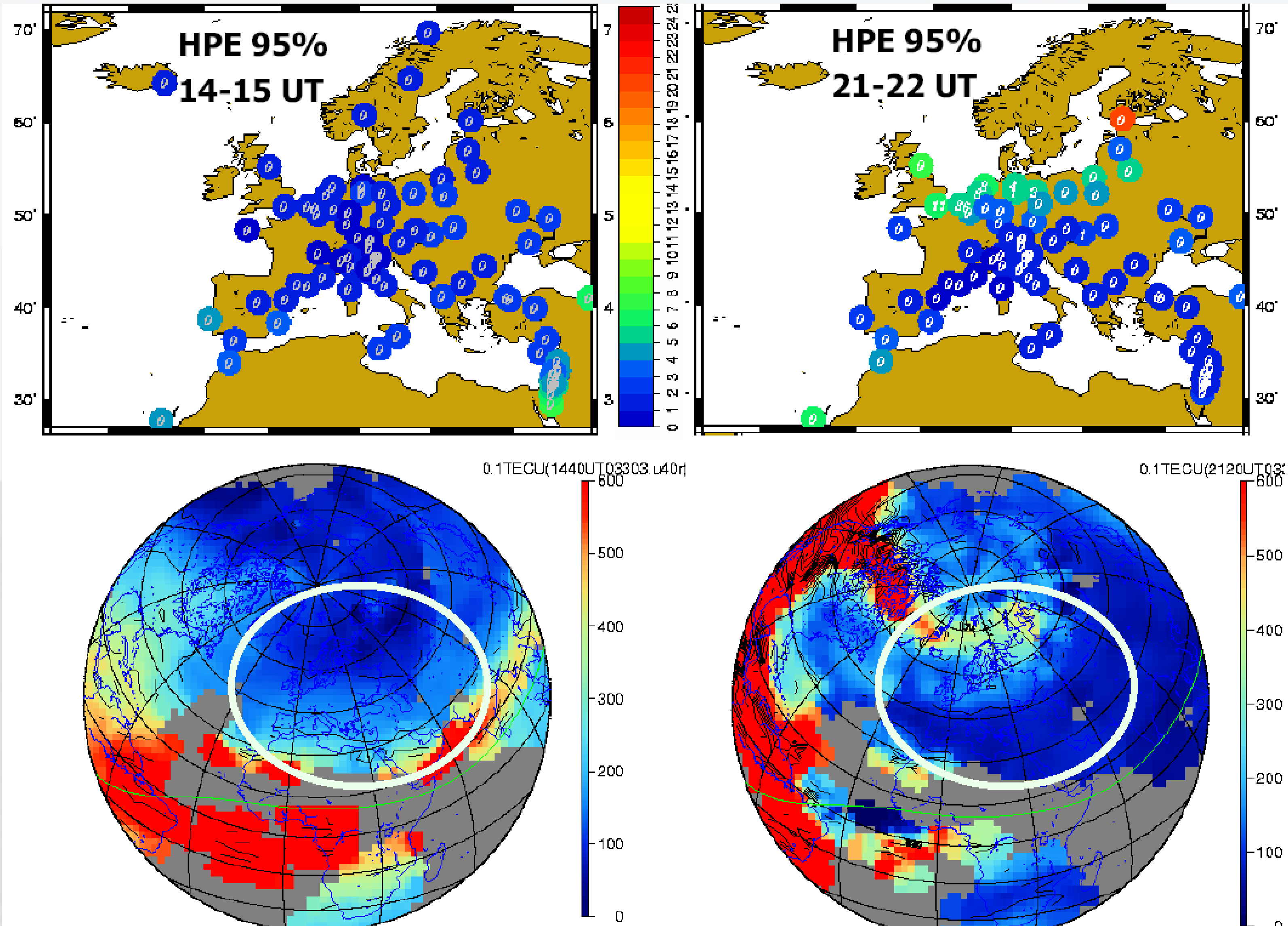
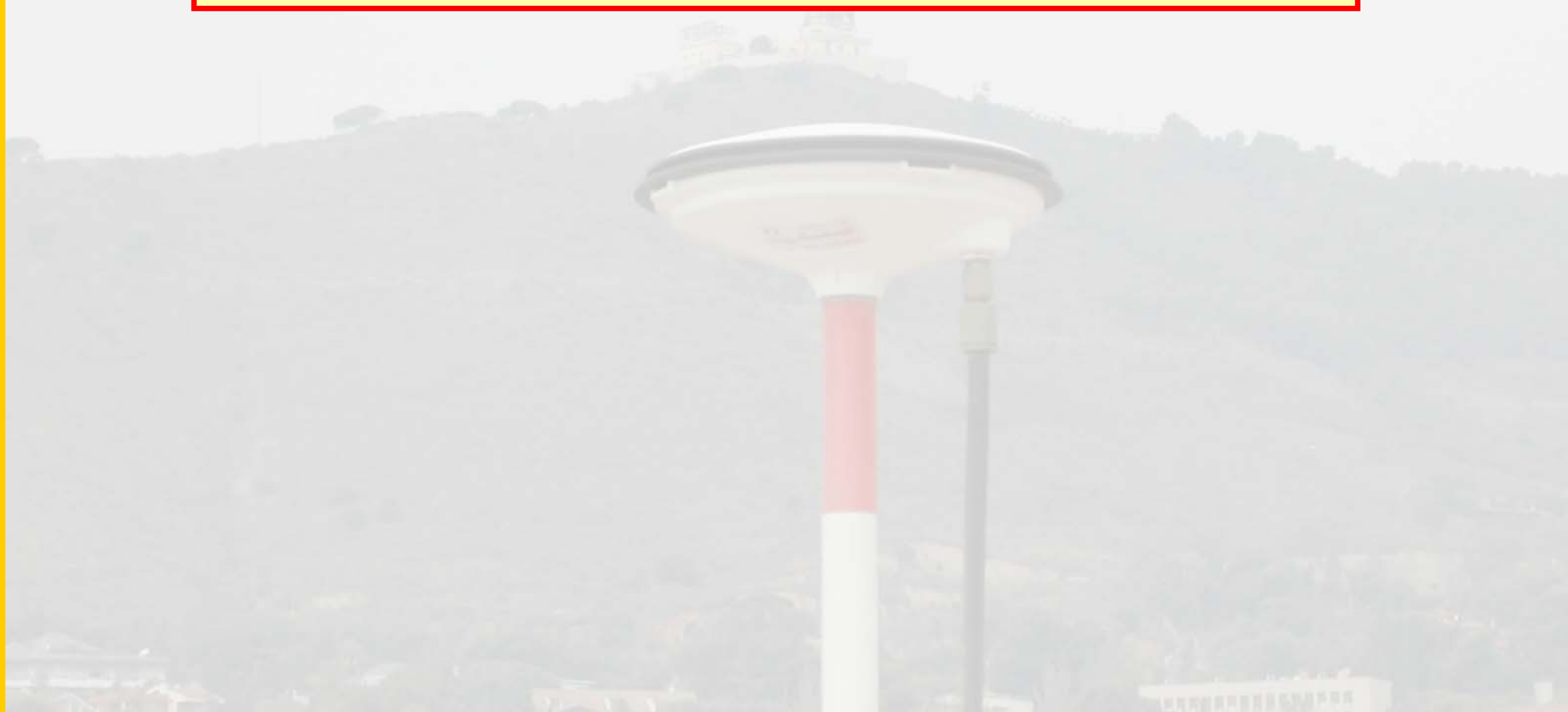
Example 2: ESTB during the Oct'03 Iono. Superstorm

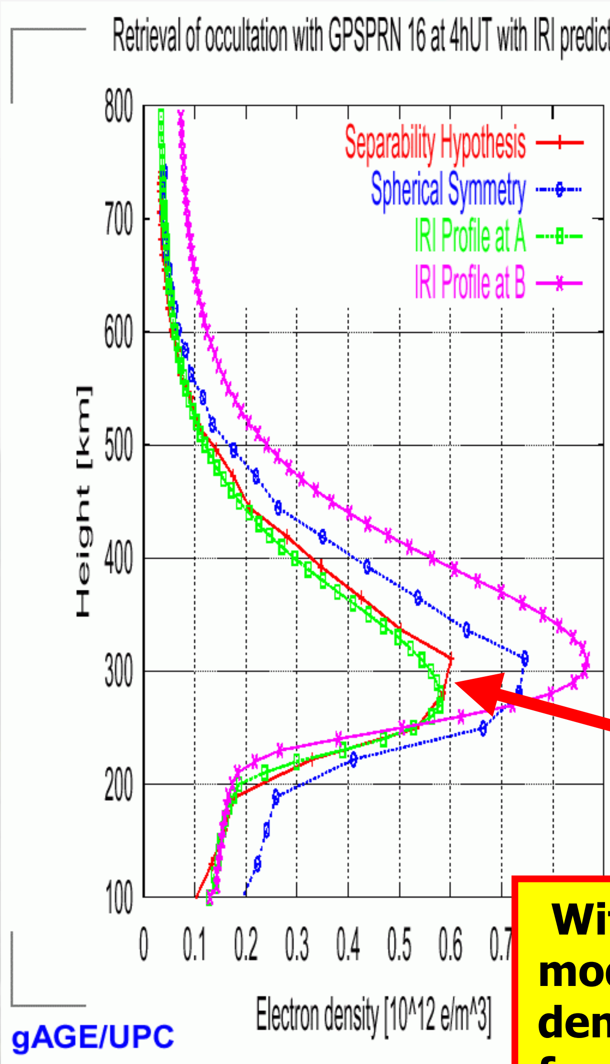


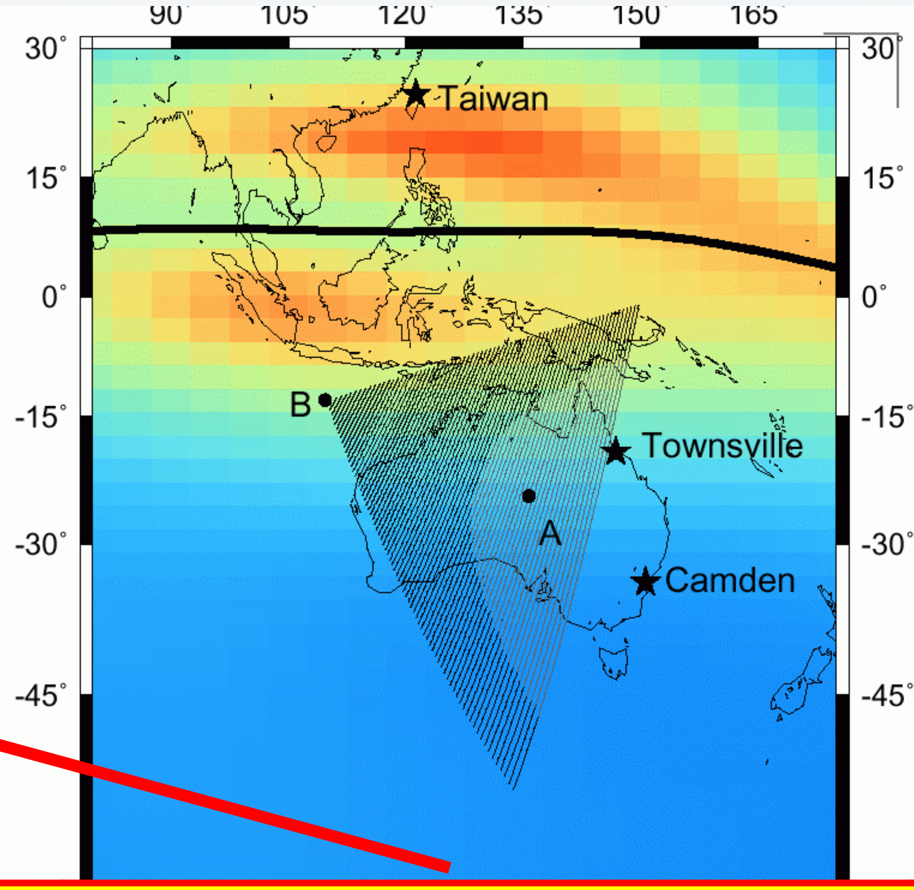
During the 30 October ionospheric superstorm a TEC enhancement reached North Europe producing Loss of Integrity event in the EGNOS Test Bed system.

2. GPS Ionospheric Tomographic activity



Benefits of separability hypothesis





With the TEC (computed from ground GPS data) modelling the horizontal variation, the electron density at tangent point A (green) is estimated from the GPS occultation data better (red) that assuming spherical symmetry (blue).

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Results with GPS/MET data during 11 days in 1995 (Solar Cycle minimum)

The improvement in f0F2 estimation is very clear using the improved Abel transform vs. the classical one: a reduction in the RMS of about 25% to 35%, at low and mid-high latitude (20% in disturbed ionosphere).

Results confirmed in the estimation of the f0E, and in datasets during Solar Maximum with SAC/C and CHAMP, being in this last case important the simultaneous topside electron content estimation by voxels.

Table 1. Table of foF2 Errors With Respect to Ionosonde Measurement[a]

		N.comp	Sep.Hyp. RMS: MHz [%]	Sph.Symm RMS: MHz [%]
		Quiet Ionosphere		
Low	Day	177	1.2 [16.2]	1.6 [21.4]
latitudes	D&D	10	0.5 [9.7]	0.8 [14.5]
0° ± 30°	Night	100	1.1 [27.6]	1.3 [31.7]
Middle and high	Day	2054	0.7 [11.6]	1.1 [17.8]
latitudes	D&D	908	0.8 [19.1]	1.1 [25.9]
±30° ± 90°	Night	1122	0.6 [17.6]	0.8 [23.9]
		Disturbed Ionosphere		
Europe	Day	105	0.9 [17.7]	1.6 [31.2]
	D&D	94	0.7 [18.2]	1.2 [30.8]
	Night	32	0.4 [16.1]	0.8 [34.9]

[a]The error is Absolute RMS in MHz and Percentual relative RMS difference in brackets. The number of comparisons is also given.

Recent results can be found in:
Garcia-Fernandez, M., M. Hernandez-Pajares, M. Juan, and J. Sanz, Improvement of ionospheric electron density estimation with GPSMET occultations using Abel inversion and VTEC information, *Journal of Geophysical Research*, Vol. 108, No. A9, 1338, doi:10.1029/2003JA009952, 2003.

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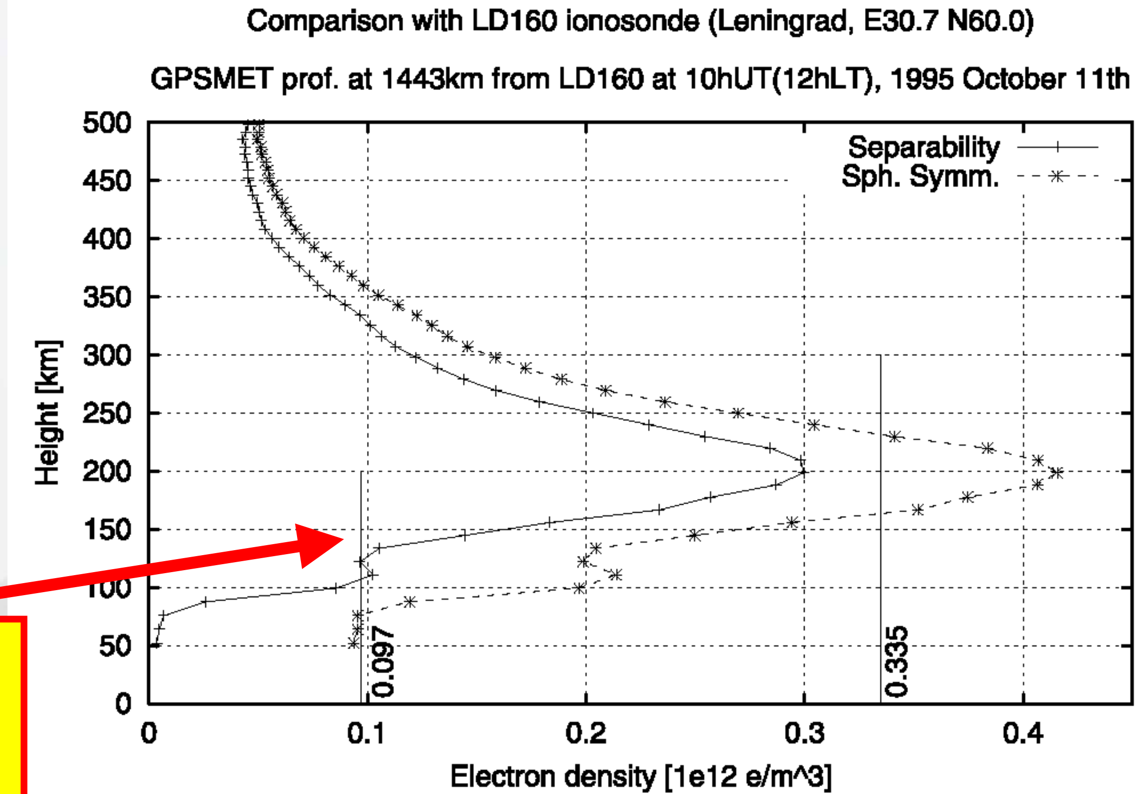
Separability: improvement in E layer estimation



The improved Abel can provide reliable estimates of the NmE value as well (not just NmF2 values).

Figure 6. Effect of accumulative errors on the computation of the E layer electron density. The errors in the estimation of the upper layers strongly affects the lowermost layers. This particular example corresponds to an occultation of the GPSMET with the PRN20 at 11 October 1995 (day of year 284), 1000 UT (1200 LT), at E43.3 N44.9, compared with the corresponding NmF2 and NmE values obtained with the Leningrad Ionosonde.

Performance for f0E

Table 2. Table of foE Errors With Respect to Ionosonde Value[a]

	N.comp	Sep. Hyp. RMS: MHz [%]	Sph. Symm. RMS: MHz [%]
E layer	135	0.4 [17.1]	0.7 [28.5]
Es layer	35	0.5 [16.2]	1.0 [30.4]

[a]The error is Absolute RMS in MHz and Percentual relative RMS difference in brackets.

The improvement in foE estimates reachs to a reduction of 40% in E layer and near 50% in Es layer

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Thank you!