SBAS-type ionospheric correction and integrity assessment experiment in the Central and South American regions

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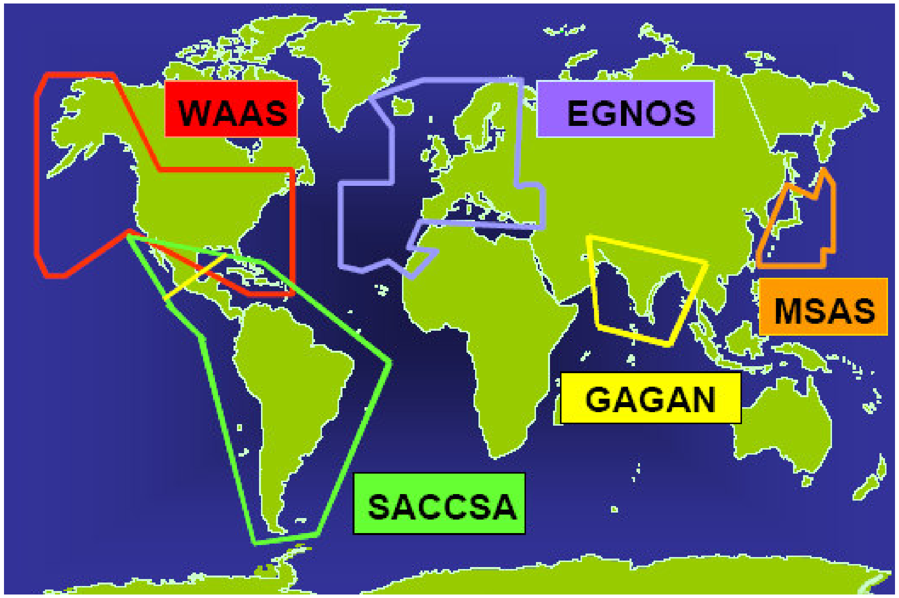
Satellite Based Augmentation Systems (SBAS)

- *SBAS are primarily designed to provide integrity for GNSS-based navigation (e.g.: for civil aviation).*
- *Integrity includes the ability to provide timely warnings to the user when the system should not be used for the intended operation.*
- *The probability of supplying so called 'hazardously misleading information' is required to remain extremely small (~10^{-7}).*
- *Integrity standards for civil aviation are defined by:*
  - ✓ *ICAO, International Standards and Recommended Practices (SARPS), Annex 10, Vol I, 5th Edition, Jul 1996.*
  - ✓ *RTCA, Minimum Operational Performance Standards for GPS/WAAS Airborne Equipment, SC159 Do-229C, Washington, D.C., Nov 2001.*

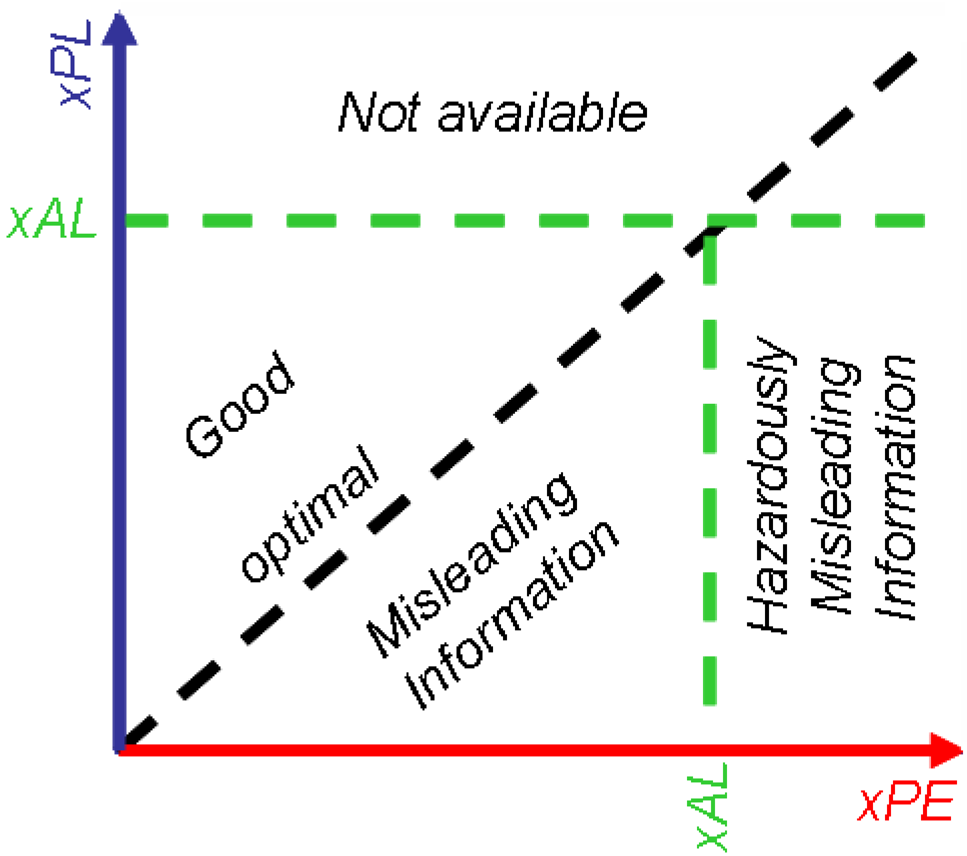
Satellite Based Augmentation Systems (SBAS)

- In addition to integrity, SBAS can provide corrections to improve the navigation accuracy.
- At present, the ionosphere is the main natural agent that deteriorates both, integrity and accuracy.
  - The CAR/SAM ionosphere presents an extremely challenging problem for SBAS developments.
  - ICAO promotes an SBAS project for the CAR/SAM regions: RLA/03/902 – SACCSA (Solución de Aumentación para el Caribe, Centro y Sur América).



SBAS integrity on Signal in Space according to ICAO

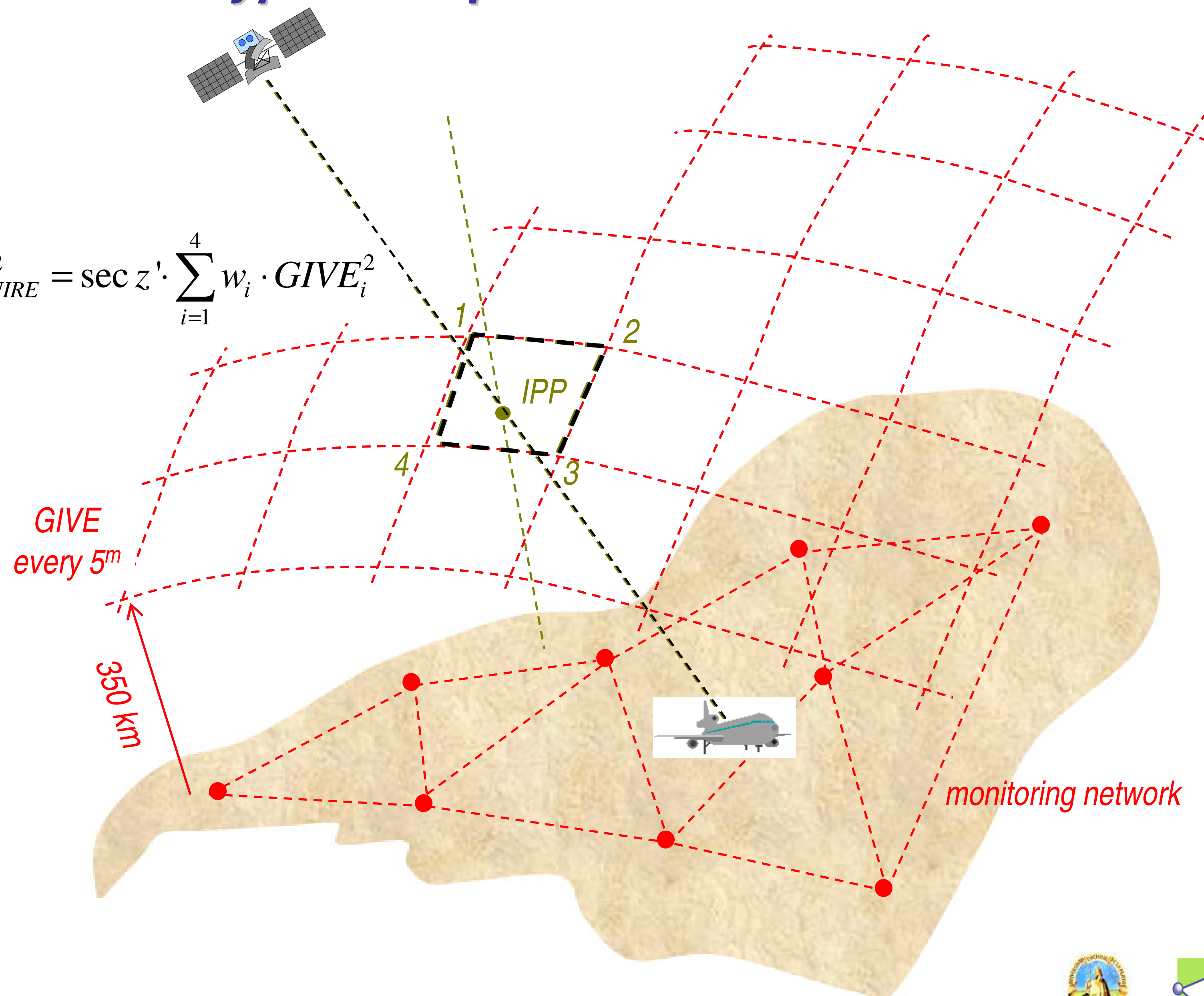
- Described in terms of:
  - ✓ position errors: HPE (horizontal) and VPE (vertical);
  - ✓ protection levels: HPL (horizontal) and VPL (vertical); and
  - ✓ alert limits: HAL (horizontal) and VAL (vertical).



Operation	HAL	VAL
NPA	0,3 NM	N/A
APV I	0,3 NM	50 m
APV II	40 m	20 m
CAT I	40 m	15 - 10 m

Roturier et al., 2001. The SBAS Integrity Concept Standardised by ICAO. Application to EGNOS. EGNOS navigation conference publications.

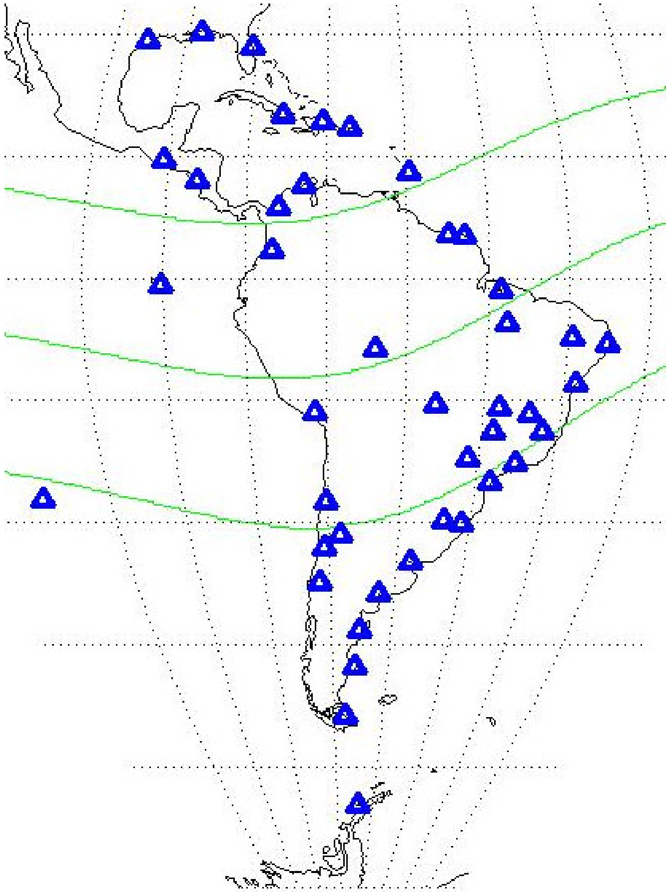
SBAS-type ionospheric correction and its error



$$\sigma^2_{UIRE} = \sec z' \cdot \sum_{i=1}^{4} w_i \cdot GIVE_i^2$$

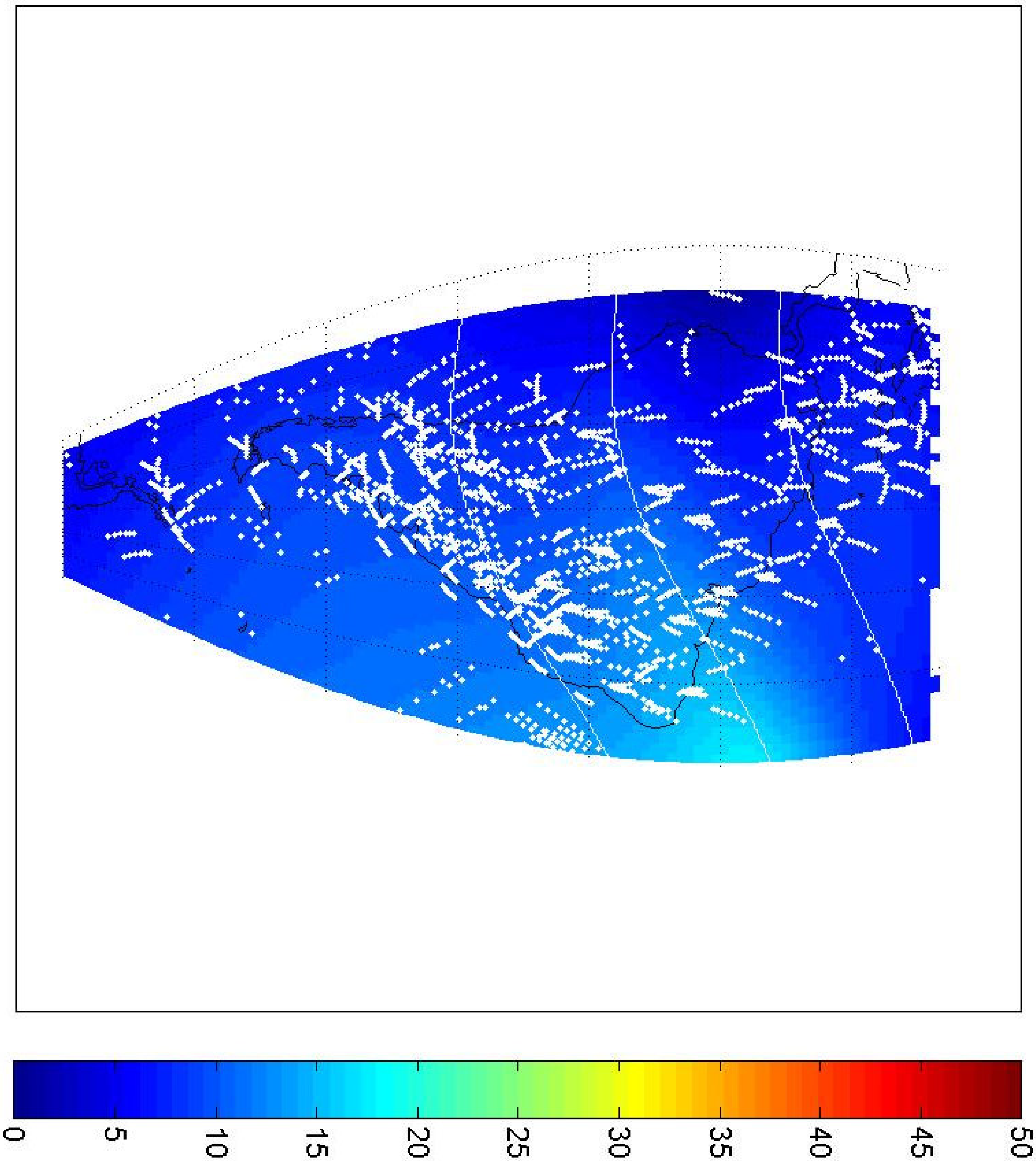
GIVD and GIVE computation

- Based on the use of the La Plata Ionospheric Model (LPIM).
  - ✓ Brunini et. al. South American regional ionospheric maps computed by GESA: a pilot service in the framework of SIRGAS, Advances in Space Research, doi 10.1016/j.asr.2007.08.041, 2008.
- Computation (now-cast and forecast) of 2.5ºx2.5º GIVD and GIVE every 5^m by means of an adaptative and robust Kalman filter specially tuned for the CAR/SAM regions.
- Data from 50 stations belonging to the SIRGAS-CON system (www.sirgas.org).



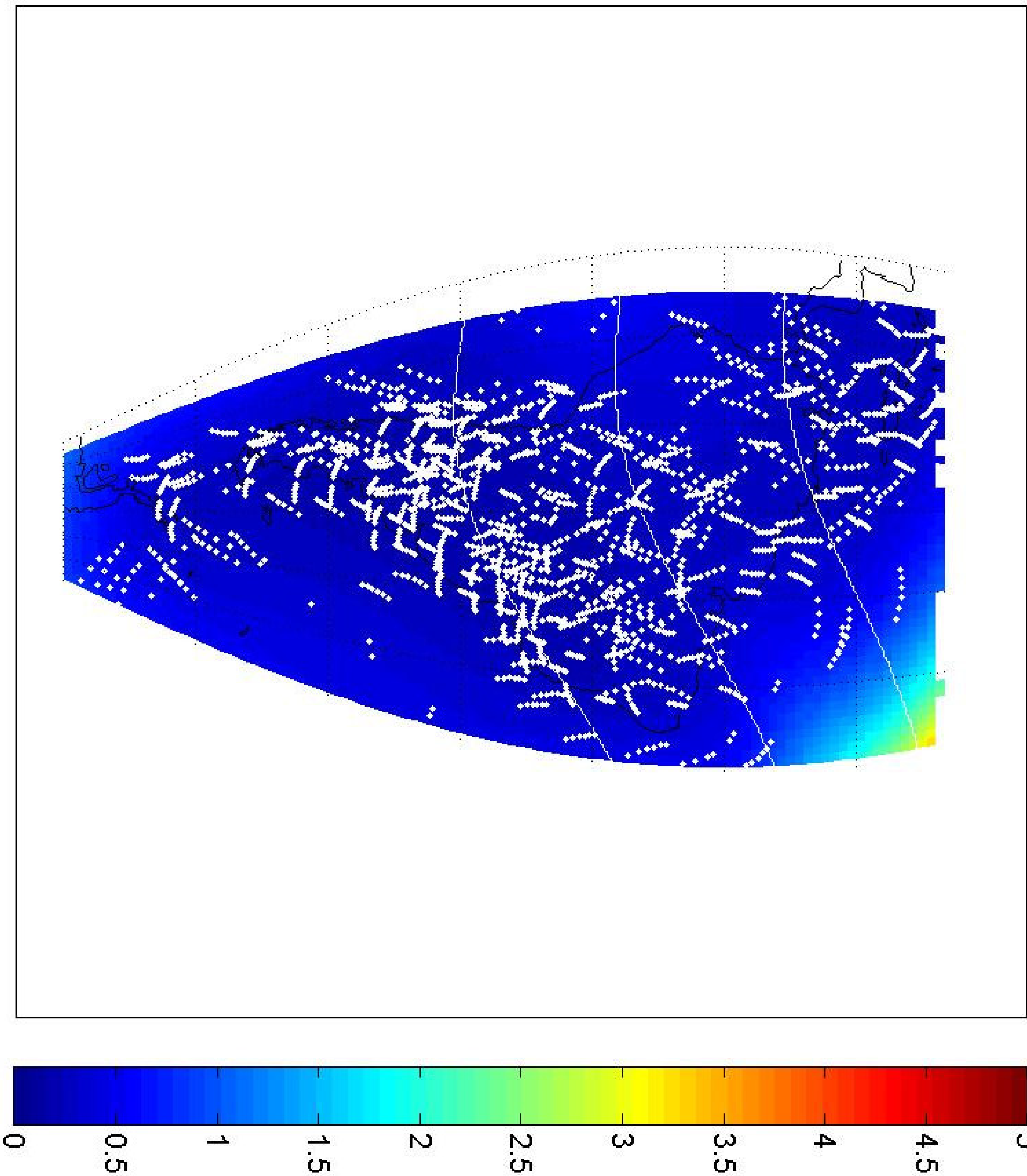
LPIM-GIVD

http://cplat.fcaglp.unlp.edu.ar



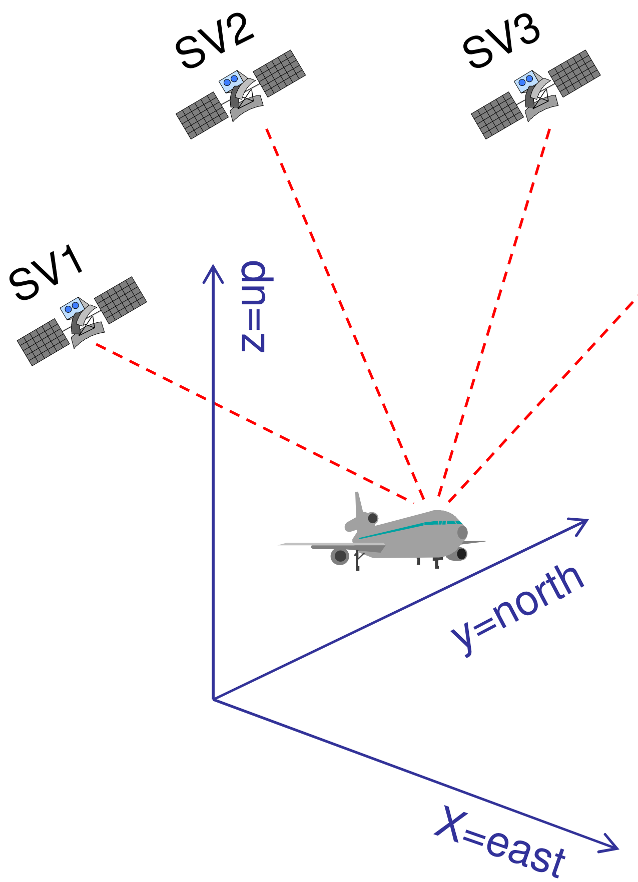
LPIM-GIVE

http://cplat.fcaglp.unlp.edu.ar



Computation of protection levels

- From range domain to position domain



$$\begin{vmatrix} x \\ y \\ z \\ t \end{vmatrix} = \begin{vmatrix} \cos E_1 \cdot \sin A_1 & \cos E_2 \cdot \cos A_1 & \sin E_1 & c \\ \cos E_2 \cdot \sin A_2 & \cos E_2 \cdot \cos A_2 & \sin E_2 & c \\ \vdots & \mathbf{A} \; \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \cos E_n \cdot \sin A_n & \cos E_2 \cdot \cos A_n & \sin E_n & c \end{vmatrix} \times \begin{vmatrix} \rho_1 \\ \rho_1 \\ \vdots \\ \vdots \\ \rho_1 \end{vmatrix}$$

- From σ^2_{UIRE} to HPL and VPL

$$\begin{vmatrix} \sigma_x^2 \\ \sigma_y^2 \\ \sigma_z^2 \\ \sigma_t^2 \end{vmatrix} = diag \left\{ \mathbf{A} \times \begin{vmatrix} \sigma^2_{UIRE,1} & 0 & \vdots & 0 \\ 0 & \sigma^2_{UIRE,2} & \vdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \vdots & \sigma^2_{UIRE,n} \end{vmatrix} \times \mathbf{A}^T \right\}$$

$$HPL = k \cdot \sqrt{\sigma_x^2 + \sigma_y^2} \qquad VPL = k \cdot \sigma_z$$

- The k-factor depends on the phase of flight.

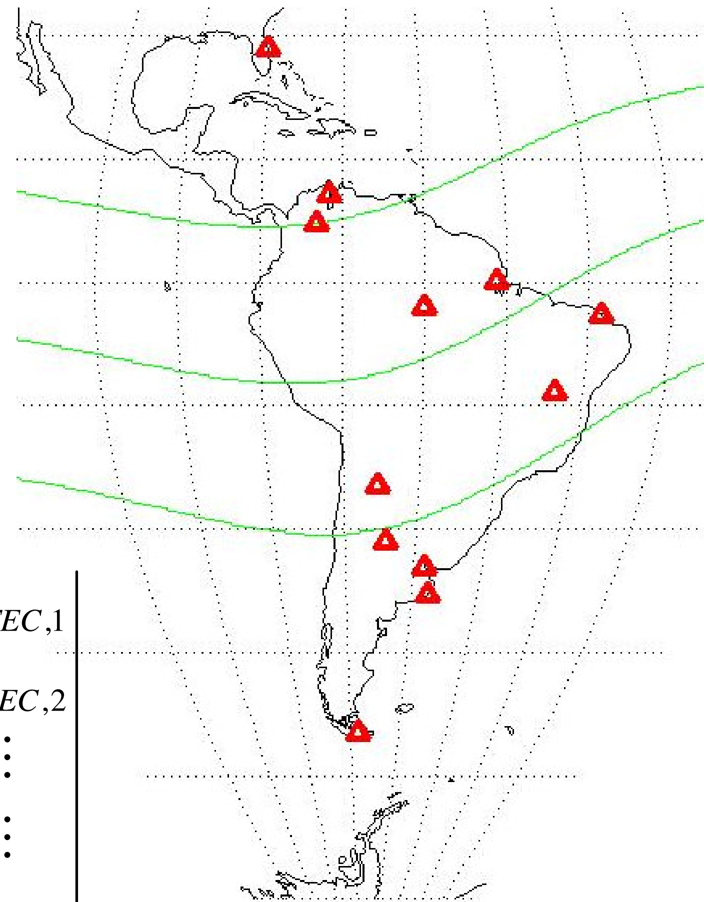
Computation of position errors

❑ 12 stations that did not participate in the GIVD and GIVE computation.

❑ *sTEC* computed from LPIM compared to the corresponding value computed from GIVD

$$e_{sTEC} = sTEC - \sec z' \cdot \sum_{i=1}^{4} w_i \cdot GIVD_i$$

❑ *sTEC* errors are propagated to position

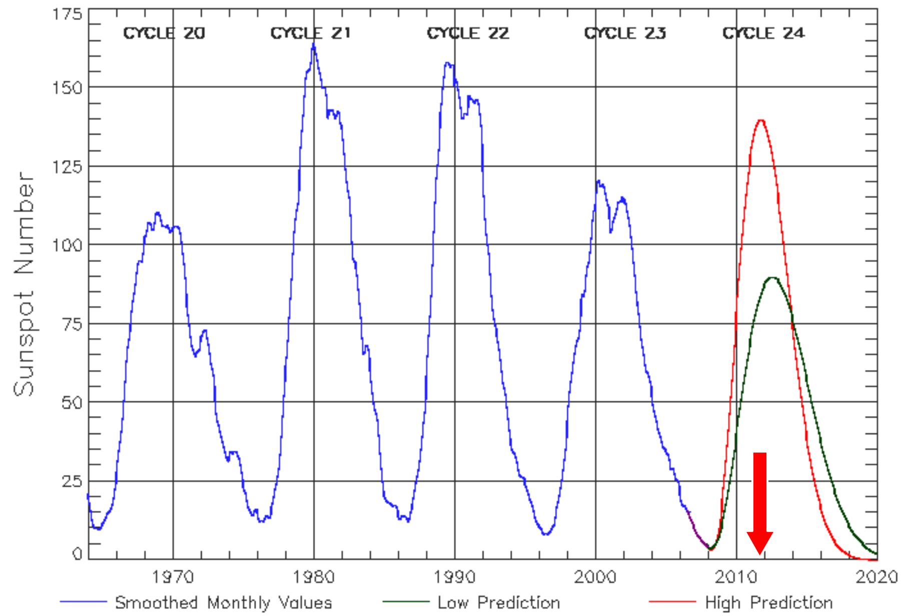


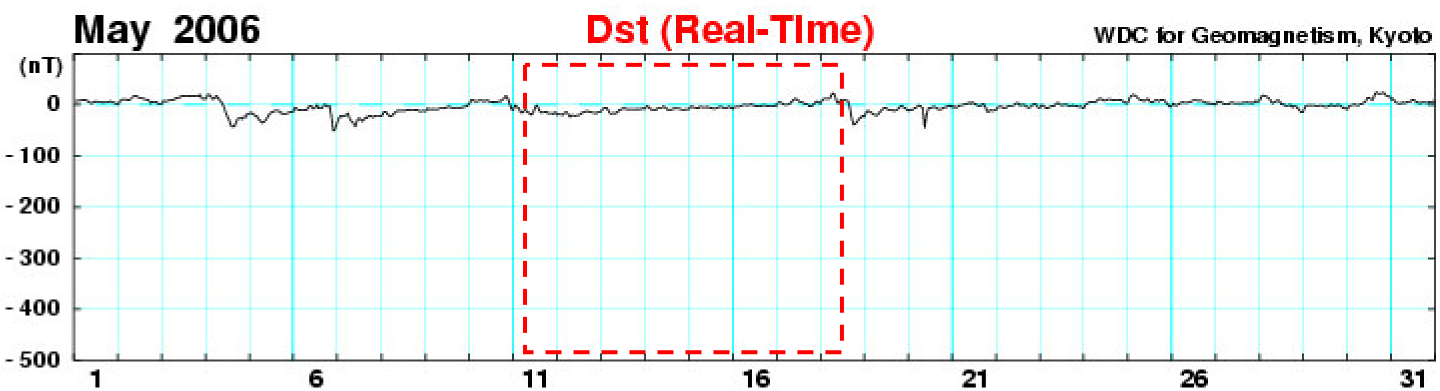
$$\begin{vmatrix} e_x \\ e_y \\ e_z \\ e_t \end{vmatrix} = \begin{vmatrix} \cos E_1 \cdot \sin A_1 & \cos E_2 \cdot \cos A_1 & \sin E_1 & c \\ \cos E_2 \cdot \sin A_2 & \cos E_2 \cdot \cos A_2 & \sin E_2 & c \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \cos E_n \cdot \sin A_n & \cos E_2 \cdot \cos A_n & \sin E_n & c \end{vmatrix} \times \begin{vmatrix} e_{sTEC,1} \\ e_{sTEC,2} \\ \vdots \\ \vdots \\ e_{sTEC,n} \end{vmatrix}$$

$$HPE = +\sqrt{e_x^2 + e_y^2} \qquad VPE = |e_z|$$

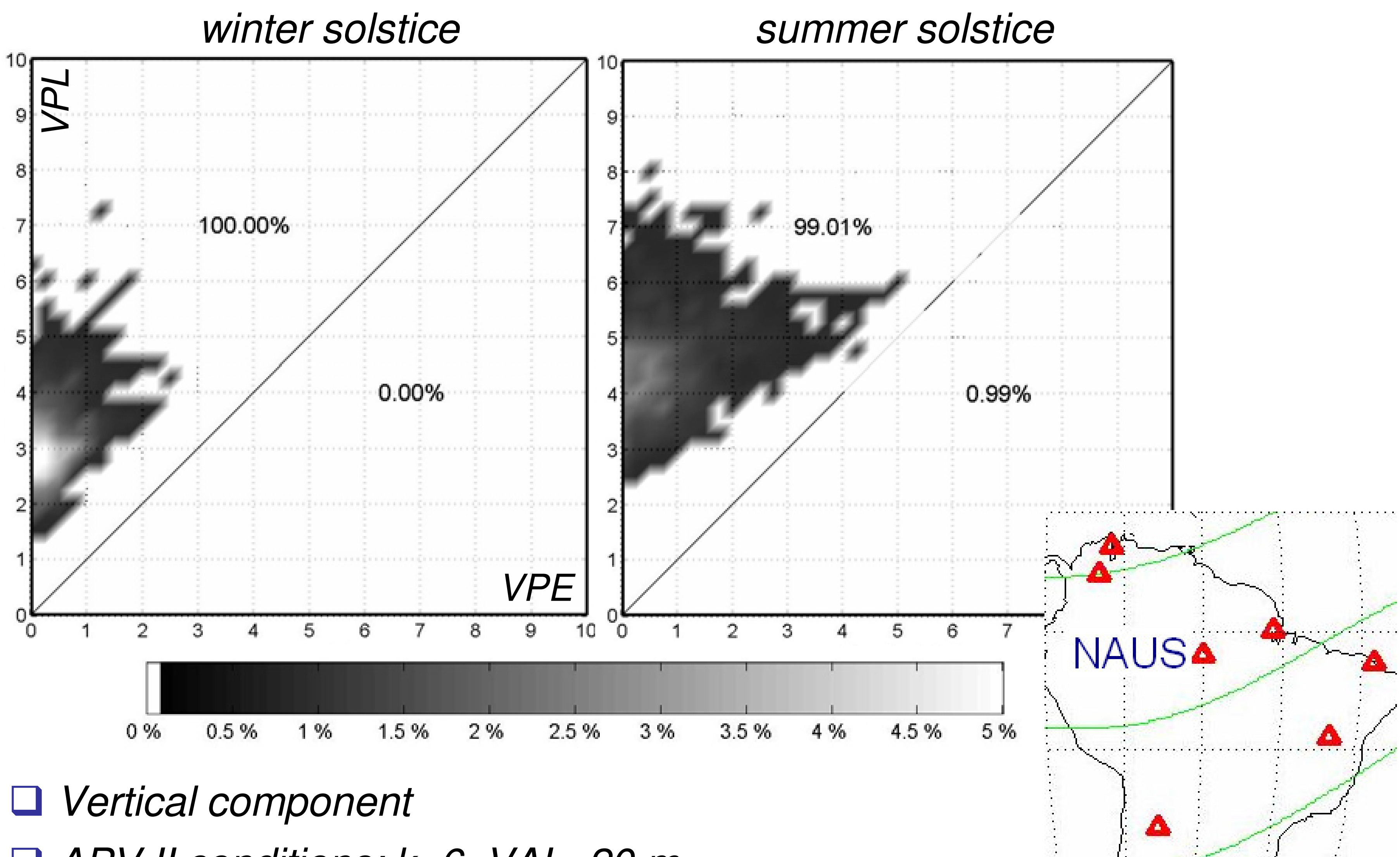
Database

- One week per month from May 2006 to May 2007 (82 complete days).
- Low solar activity.
- Quiet geomagnetic conditions (Dst > -50).



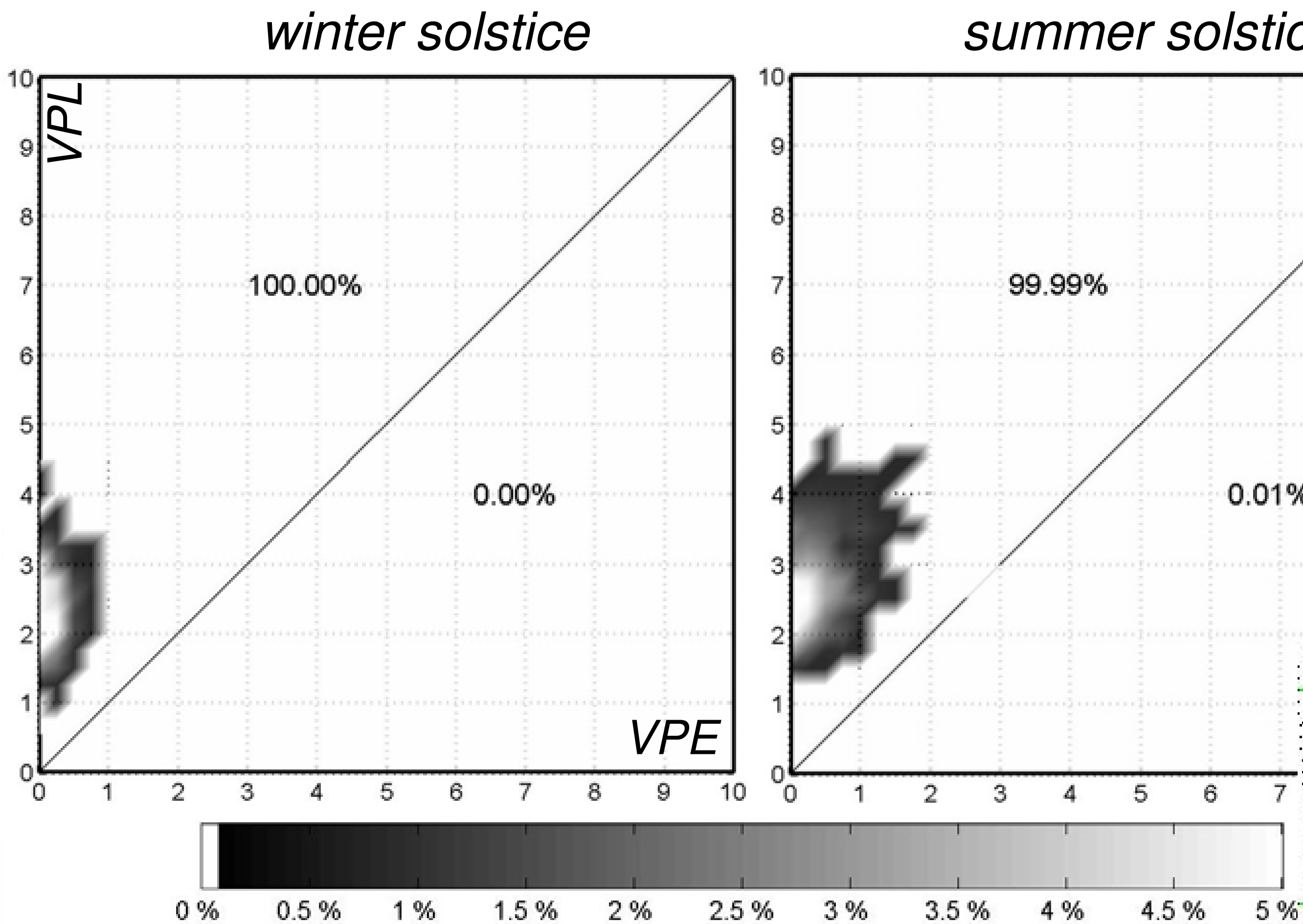


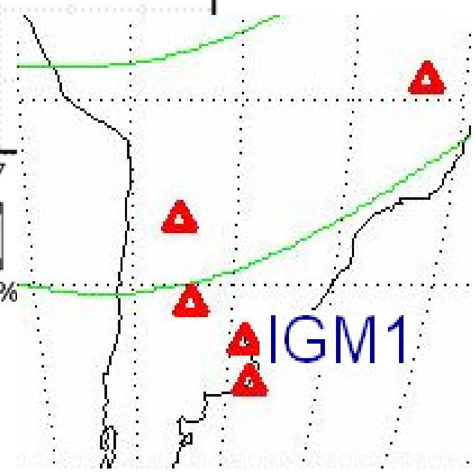
Results (equatorial station Manaus, Brazil)



- Vertical component
- APV II conditions: k=6, VAL=20 m

Results (mid-latitude station Buenos Aires, Argentina)

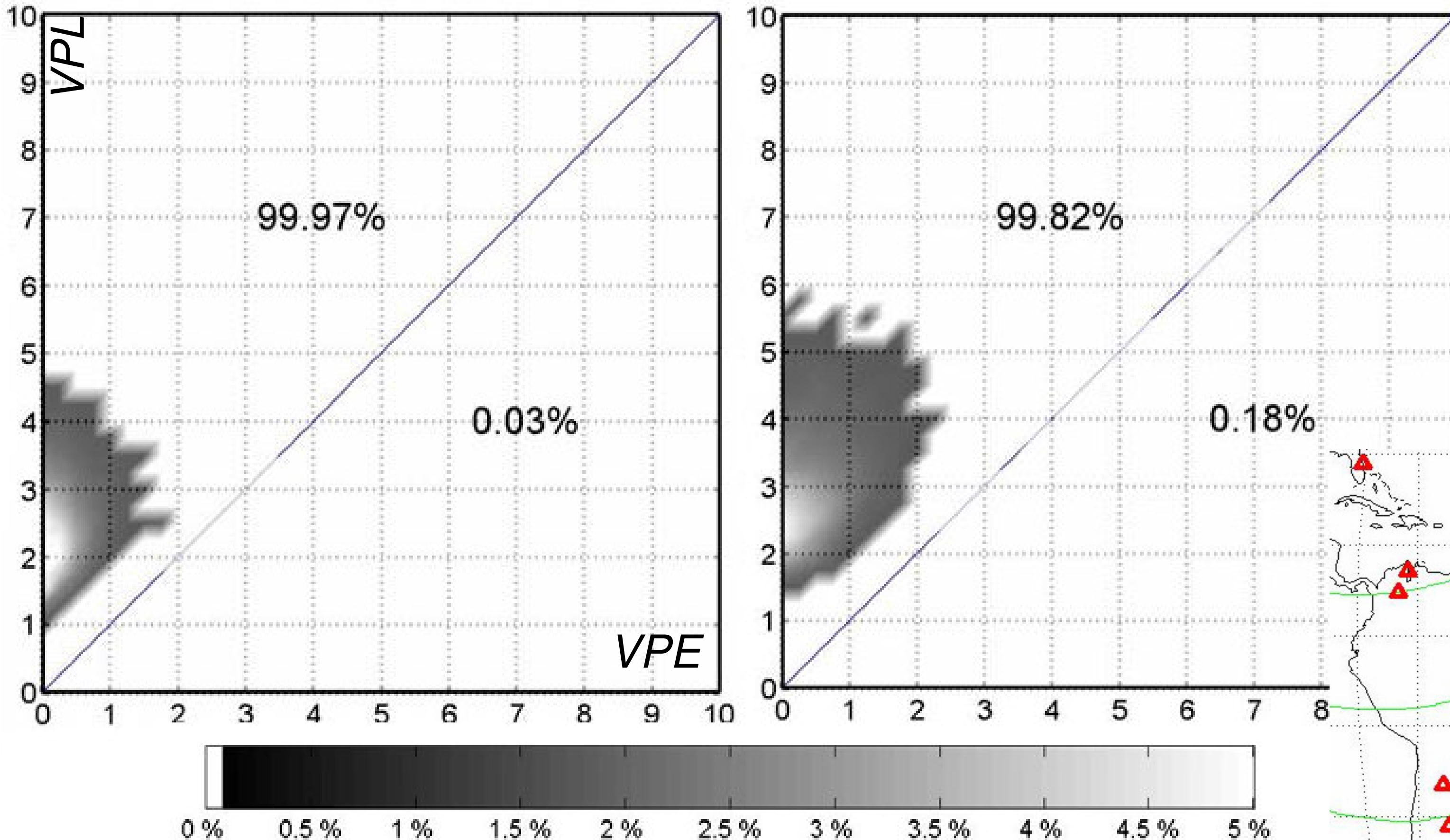


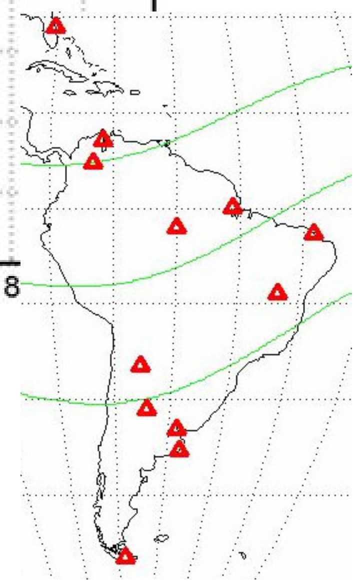


- Vertical component
- APV II conditions: k=6, VAL=20 m

Results (all evaluating stations)

winter solstice   summer solstice





- Vertical component
- APV II conditions: k=6, VAL=20 m

Conclusions

- *Results are encouraging:*
  - ✓ *horizontal and vertical position errors (HPE and VPE) are well below the corresponding alert limits for APV II (HAL=40 m and VAL=20 m);*
  - ✓ *samples never fall into the 'hazardously misleading information' nor the 'not available' regions;*
  - ✓ *the percentage of samples falling into the 'misleading information' region remains lower than 0.2%.*
- *Much more job must be done:*
  - ✓ *0.2% 'misleading information' samples is still far from 0.00002% required by ICAO standards! GIVE computation must be improved;*
  - ✓ *high solar activity and disturbed ionospheric conditions must be investigated.*

Many thanks for your attention

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