Tropospheric Products validation in the GNSS SIRGAS Network.

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SIRGAS, Sistema de Referencia Geocéntrico para las Américas

- Materialized by more than 400 permanent GNSS stations.
- Densification of the ITRF in Latin America and the Caribbean.
- Rigorously processed at weekly bases.

### Zenit Total Delay (ZTD) estimation

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| | igswwwwD.sp3  
| | igswwww7.erp |
| A-priori toposphere modeling and mapping function | Pre-processing |
| | GMF ([Böhm et al., 2007](#)) and VMF ([Böhm et al., 2006](#)) |
| Parameter estimation | VMF + Gridded VMF1 coefficients |
| Estimation of horizontal gradients | CHENHER: Model described in ([Chen and Herring, 1997](#)) (24 hours) |
| Parameter spacing | 1 or 2 hours |
The ACs ZTDs are the input data for the weekly SIRGAS combined tropospheric products.

**Redundancy**
Each station is processed by 3 ACs.

Internal precision of SIRGAS final ZTDs
Mean RMS = 1mm
(in the 90% of estimated values)

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ZTD\textsubscript{GNSS\_SIR} validation \textit{wrt} ZTD\textsubscript{IGS}

External precision analysis of the final SIRGAS ZTDs

60 GNSS\textsubscript{SIR} stations / IGS stations (distributed in different regions)
RESULTS

Mean Bias = 0.76 mm
(0.03 % of the mean value of ZTD)

Mean RMS = 6.6 mm
(0.29 % of the mean value of ZTD)
**ZTD\textsubscript{GNSS\_SIR} validation wrt Radiosonde data (RS)**

Radiosonde profiles were downloaded from Wyoming Weather Web
http://weather.uwyo.edu/upperair/sounding.
DATA: Precipitable water [mm] for entire sounding (PW o IWV\textsubscript{RS})

**Methodology**


1) PW\textsubscript{RS} (IWV), 00 and 12 h UTC
2) Temperature and dew-point from the profiles
3) Ph\textsubscript{RS}

**Input**

\[
\begin{align*}
ZWD &= \left(22,9744 + \frac{375463}{Tm} \right) \times 10^5 I W V \\
Tm &= \frac{\int_{H}^{\infty} e/T \, dz}{\int_{H}^{\infty} e/T^2 \, dz} \\
IZHD &= 0,002276738 \cdot \frac{P_{GNSS}}{1 - 0,00266. \cos (2\phi) - 0,28.10^{-6}.h_{GNSS}} \\
P_{GNSS} &= P_{RS} \left(1 - 0.0000226 \cdot (h_{\text{GNSS}} - h_{\text{RS}})^{5.225}\right)
\end{align*}
\]

Davis, 1985

**Output**

ZTD\textsubscript{RS} = ZHD+ZWD
00 and 12 h UTC

**Experience:**
42 GNSS\textsubscript{SIR} stations / radiosonde within 30 km

Askne and Nordius, 1986
Rüeger, 2002

Berg, 1948
**ZTD\textsubscript{GNSS\_SIR} validation wrt Radiosonde data (RS)**

42 GNSS\textsubscript{SIR} stations / radiosonde in different regions

**Ecuatorial**
Lat $-1^\circ$

**Subtropical**
Lat $-20^\circ$

**low latitudes, Lat $-53^\circ$**
ZTD\textsubscript{GNSS\_SIR} validation wrt Radiosonde data (RS)

42 GNSS\textsubscript{SIR} stations / radiosonde within 30 km

Results:
Mean Bias = - 8.6 mm (0.37 % of the mean ZTD)
Mean SD = ± 11.4 mm (0.49 % of the mean ZTD)
Mean correlation coefficient = 0.97
Availability of SIRGAS tropospheric products

http://www.sirgas.org/en/tropo-delays/

Where can they be downloaded?

Tropospheric delays

Within the weekly processing of the SIRGAS Continuously Operating Network (SIRGAS-CON), the SIRGAS Analysis Centres operationally estimate tropospheric Zenith Path Delays (ZPD) with an hourly sampling rate. These ZPD estimates are the input data for the generation of SIRGAS tropospheric products, which provide weekly combined troposphere estimates of high-reliability for each SIRGAS station. The station positions, as a necessary part of this analysis, are taken from the SIRGAS weekly combined solutions. Consequently, stations without estimated positions in the weekly combination are not included in the combined tropospheric solution.

The SIRGAS tropospheric products are computed by the SIRGAS Analysis Centre for the Neutral Atmosphere (CIMA), which is operated by the Facultad de Ingeniería of the Universidad Nacional de Cuyo (UNCuyo, Mendoza, Argentina) in cooperation with the Facultad de Ingeniería of the Universidad Juan Agustín Maza (Mendoza, Argentina) and with support of the Argentinean Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET).

The SIRGAS tropospheric products are weekly generated with a latency of 30 days. They are available with an hourly sampling rate in daily SINEX TRO files since January 2014 and they can be downloaded from


More details about the processing strategy can be found at


Whenever you use the SIRGAS tropospheric products, please include this publication as a citation.

IGS SINEX format

YEAR / DAY / SSSSddd0.yyzpd.gz
Integrated Water Vapor (IWV)

Calculation strategy

\[ \Pi = \frac{10^5}{(22,9744 + \frac{375463}{Tm}) \cdot 0.4614991785} \]

\[ ZHD = 0.002276738 \cdot \frac{P_{\text{GNSS}}}{1 - 0.00266 \cdot \cos(2\varphi) - 0.28 \cdot 10^{-6} \cdot h_{\text{GNSS}}} \]

\[ P_{\text{GNSS}} = P_{\text{ref}} \cdot (1 - 0.0000226 \cdot (h_{\text{GNSS}} - h_{\text{ref}}))^{5.225} \]

Input

Weighted combination

ZTD (GNSS) \( c/1h \), delay 21 days, Pmsl, 2mT (ERA5) \( c/1h \), delay 5 days

Output

IWV = \( \Pi \cdot ZWD \)

IWV

Each 1h, delay: 28 days

Units:

- ZTD, ZHD and ZWD [m];
- IWV [kg/m\(^2\)]; P [hPa]; h [m]; Tm and Ts [k]

"ERA5 hourly estimates of variables on single levels"
VALIDATION: IWV\textsubscript{GNSS\_SIR} wrt Radiosonde data (RS)

42 GNSS\textsubscript{SIR} stations / radiosonde in different regions

- Ecuatorial, Lat -1°
- Subtropical, Lat -20°
- Low latitudes, Lat -53°
Validation: $\text{IWV}_{\text{GNSS SIR}} - \text{IWV}_{\text{RS}}$

42 GNSS$_{\text{SIR}}$ stations / radiosonde within 30 km

Mean Bias = -1.08 kg/m$^2$
Mean SD = ±2.22 kg/m$^2$
Mean correlation coefficient 0.96
IWV_{GNSS,SIR} - IWV_{RS}

IWV_{sir}-IWV_{rs} [kg/m^2] . Period 2014 - 2020

Correlation IWV_{sir} vs IWV_{rs} . Station ABMF
Correlation Coef (r): 0.8773

Correlation IWV_{sir} vs IWV_{rs} . Station CALI
Correlation Coef (r): 0.92402

Correlation IWV_{sir} vs IWV_{rs} . Station PAST
Correlation Coef (r): 0.86534

Correlation IWV_{sir} vs IWV_{rs} . Station SAGA
Correlation Coef (r): 0.89858

Pearson correlation coefficient: IWV_{sir} vs IWV_{rs} . Period 2014 - 2020

Period: 7 years (2014-2020)
CONCLUSIONS

• The ZTD final SIRGAS products are available from 2014, with an hourly interval, with a latency of 28 days.

• The Internal precision of SIRGAS final ZTDs is 1mm.

• An External analysis could evaluate the accuracy of SIRGAS final ZTDs:
  
  * respect to ZTD$_{IGS}$
    
    Mean Bias = 0.76 mm (0.03 % of the mean value of ZTD)
    Mean RMS = 6.6 mm (0.29 % of the mean value of ZTD)
  
  * respect to RS
    
    Mean Bias = -8.6 mm (0.37 % of the mean value of ZTD)
    Mean SD = ± 11.4 mm (0.49 % of the mean value of ZTD)
    Mean correlation coefficient = 0.97

This results conclude that ZTD SIRGAS products are consistent over the entire region and provide a reliable time series of troposphere parameters, that could be used as a reference in further research.

• The ZTD final SIRGAS products are used to calculate IWV products, they are available from 2014, with an hourly interval, with a latency of 28 days.

• This indirect method allows the estimation of IWV with an accuracy of 2.22 kg/m$^2$ (mean SD), with a significant correlation with respect to the IWV$_{RS}$ (r > 0.96), in line with previous studies.

• Based on the validation results, it is confirmed that the method applied for the calculation of IWV, can be used for the analysis of water vapor content, with an unparalleled densification both spatially and temporally (hourly), complementing the radiosonde records on continental territory. Highlighting the capability of the GNSS stations to provide IWV$_{GNSS}$ estimates for a denser network.
Thank you for giving us the opportunity to share our progress!!!

Acknowledgements
To GNSS station operators
To data centers
To processing centers
To the SIRGAS community