Water Vapour assessment using GNSS and Radiosondes and long-term trends estimation over Polar Regions

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Outline:

- ❖ Importance of Water Vapour and its retrieval by GPS
- ❖ GPS and Radio Soundings data analysis at polar sites
- ❖ Long time series of Precipitable Water Vapour
- ❖ PW time series from ERA-Interim dataset for comparison and cross validation between series
- ❖ Long-term PW trends
- ❖ Summary & Outlook

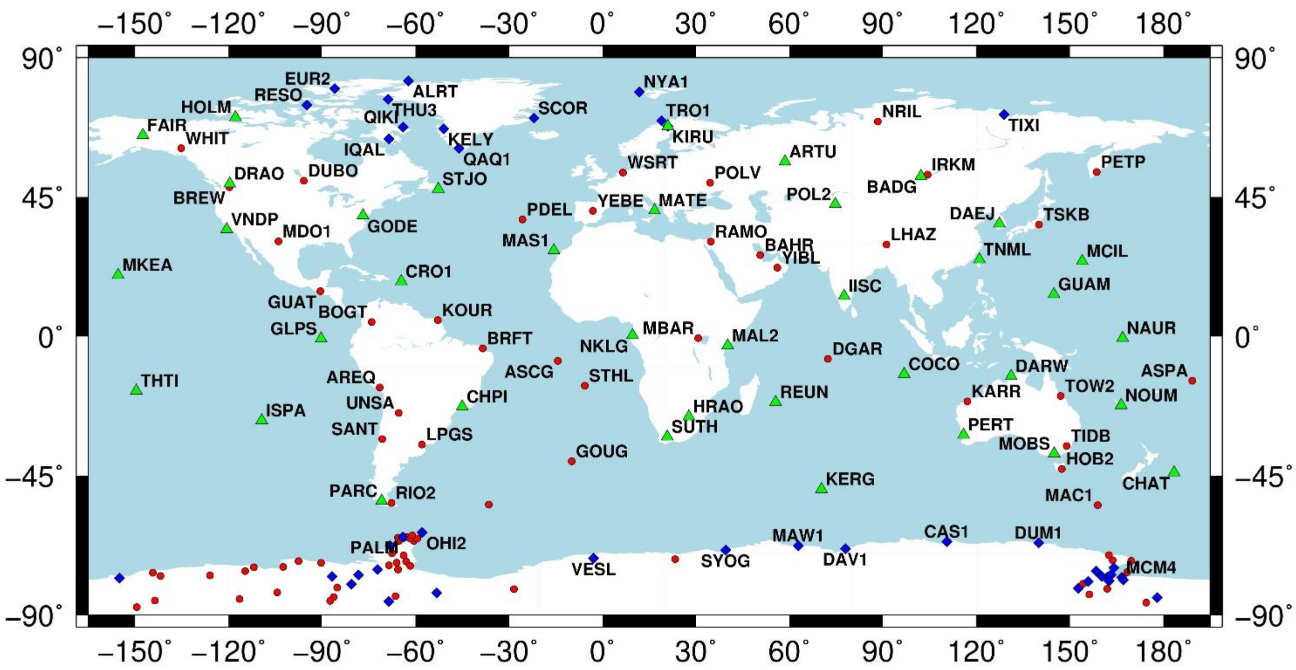
Atmospheric Water Vapour:

- Water vapour (WV) is the most abundant radiatively active gas, accounting for about 75% of the terrestrial greenhouse effect
- Polar Regions are important in the global budget of WV
- Atmospheric WV is an indicator of the Earth's climate state and evolution
- Accurate long time series of WV content are useful to understand the recent climate behavior and to assess the reliability of global climate models
- WV has been inserted in the list of Essential Climate Variables (ECV) contributing to the characterization of Earth' s climate, according to the definition by the Global Climate Observing System (GCOS)
- IAG Inter-Commission Committee on "Geodesy for Climate Research" (ICCC) has been established to enhance the use of geodetic observations for climate studies
- GPS has proven to give a strong contribution in the calculation of the amount of Precipitable WV (PW)

State-of-the-art data processing for PW retrieval

- **GPS**: Bernese GNSS Software v. 5.2
  - Homogeneous reprocessing of data
  - IGS14 products: orbits, PCV files, a priori positions/velocities
  - Refined models for hydrostatic component and mapping function: VMF1 (Boehm et al. 2006) and GPT2w (Boehm et al. 2015)

- **RS**: corrections for biases in Vaisala sensors
  - Temperature biases (Leurs and Eskridge 1995)
  - Humidity systematic errors (Miloshevich et al. 2006, 2009)



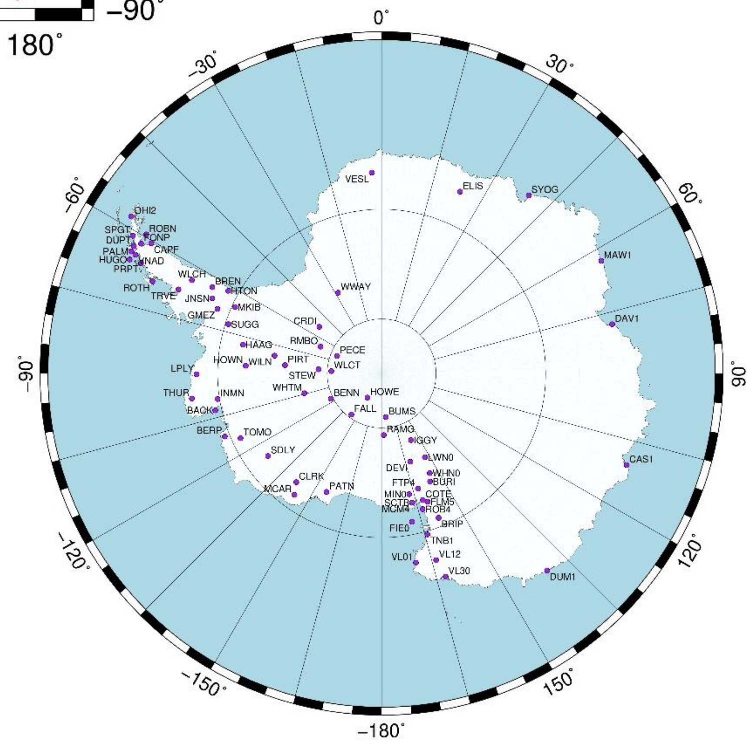
GNSS networks

IGS (ftp://igs.ign.fr/pub/igs/data/)

Victoria Land Network for Deformation control (VLNDEF) (ftp://ftp.ira.inaf.it/pub/igoa/obs/)

Polar Earth Observing Network (POLENET) (ftp://data-out.unavco.org/pub/rinex/obs/)

GNSS @national scientific bases



Details of GPS data processing:

A global network of more than 200 stations

20 years of continuous data (1 epoch/30 s)

Bernese GNSS Software

- IGS14 products and data
- VMF1 mapping function
- 1 ZHD/6 hours value from ECMWF + GPT2w
- 100 global sites + > 100 Antarctic GPS
- 16 GNSS stations co-located with RS

Details of GPS data processing (cont.):

Parameters and models used in the GPS data analysis

Solid Earth tide	IERS Conventions
Permanent tide	Conventional tide free system: IERS Conventions
Ocean Tides	FES2004 [(a)]
Pole Tides	Linear trend for mean pole offsets: IERS Conventions
Ocean Loading	FES2014b + TPXO8-Atlas including the CoM correction for the motion of the Earth due to the ocean tides [(b)]
Atmospheric Loading	Not applied
A priori information	IGS weekly ERP files (X-pole. Y-Pole, UT1-UTC) used with IGS Precise orbits IG2 [(c)] / IGS [(d)]
Subdaily EOP Model	IERS2010
Nutation	IAU2000R06
Hydrostatic delay	Computed from 6-hourly ECMWF grids [(e)]
Mapping functions	VMF1
Wet delay	Zero a priori model, 1 –h parameter estimated
Gradients	Zero a priori values, 24-h parameter estimated
Phase center model	igs14.atx [(e)]
Radome Calibrations	igs14.atx [(e)]
Antenna height	igs.snx [(e)]
Horizontal offsets	Applied
A priori radiation pressure	C061001
A priori ionosphere model	CODE GIMs [(f)]

[(a)] *https://www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes/description-fes2004.html*

[(b)] *http://holt.oso.chalmers.se/loading/*

[(c)] *ftp://igs.ensg.ign.fr/pub/igs/products/repro2/*

[(d)] *ftp://ftp.igs.org/pub/product/*

[(e))] *http://ggosatm.hg.tuwien.ac.at/DELAY/*

[(f)] *ftp://ftp.aiub.unibe.ch/CODE/*

Details of GPS data processing (cont.):

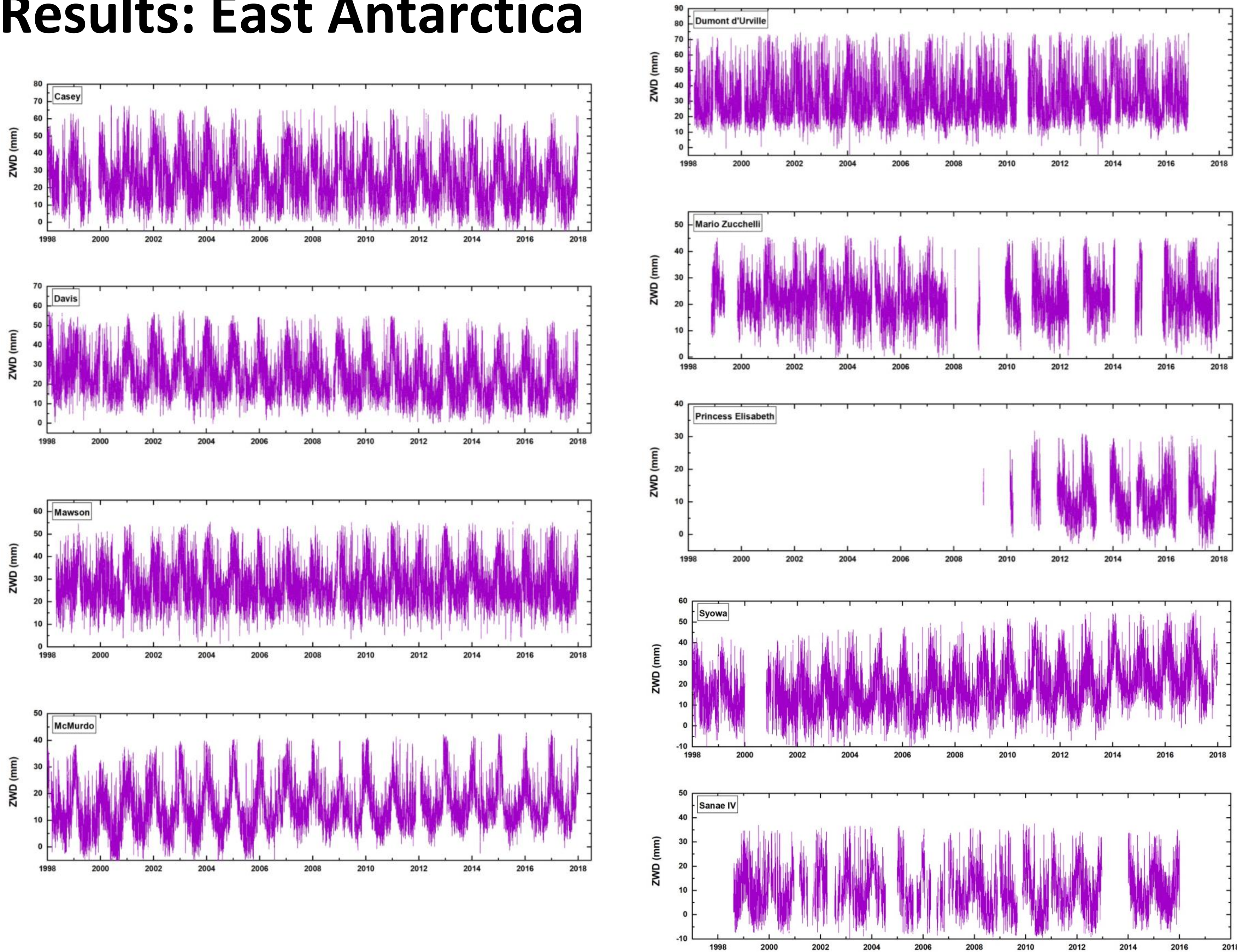
$$ZTD = ZHD + ZWD; \qquad ZHD = ZHD\,(\varphi, \lambda, t, h)$$

$$TD = mH_{VMF1} \cdot HD + mW_{VMF1} \cdot WD$$

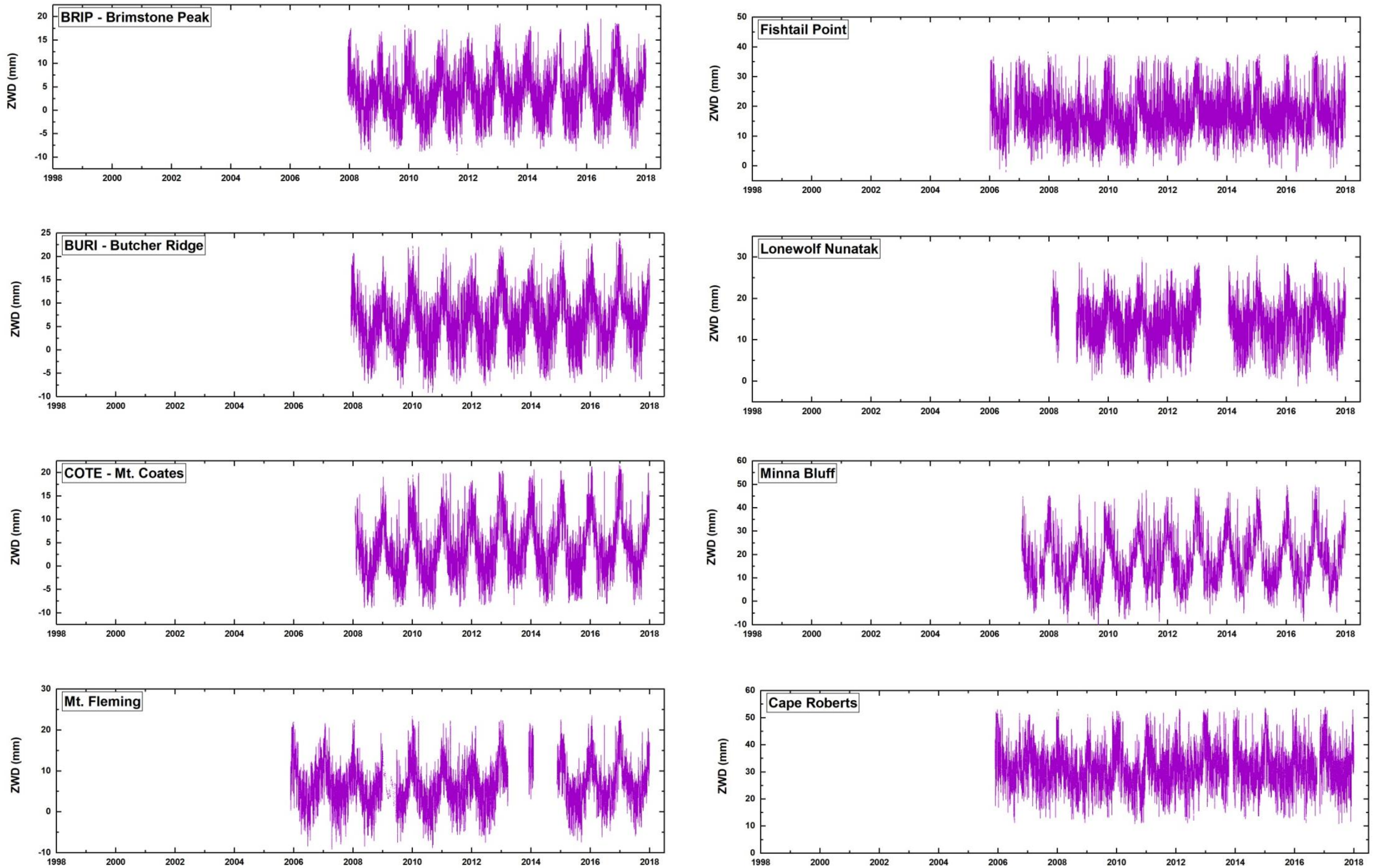
ZWD => *PW* using T_m derived by RS

$$T_m = \frac{\int (p_v / T)\, dz}{\int (p_v / T^2)\, dz} \qquad \Pi = \frac{10^6}{\rho R_v \left[(k_1 / T_m) + k_2^{'} \right]}$$

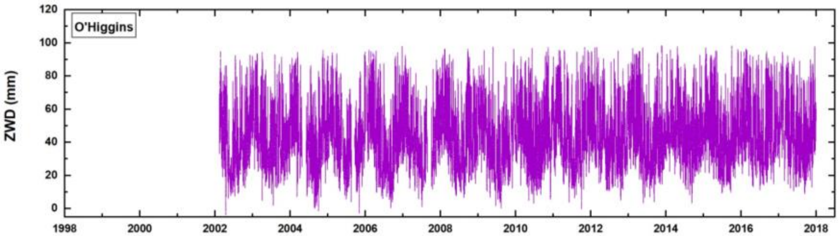
Results: East Antarctica

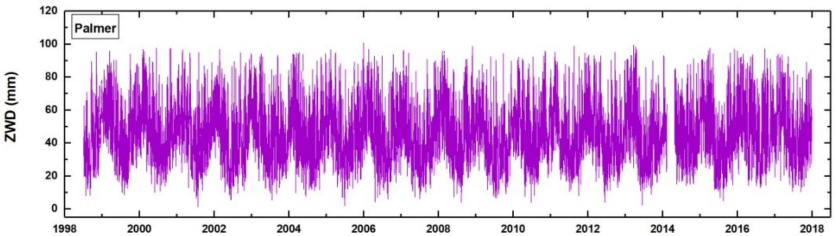


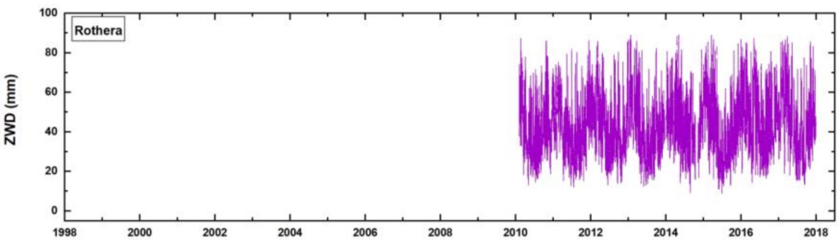
Results: TAMDEF

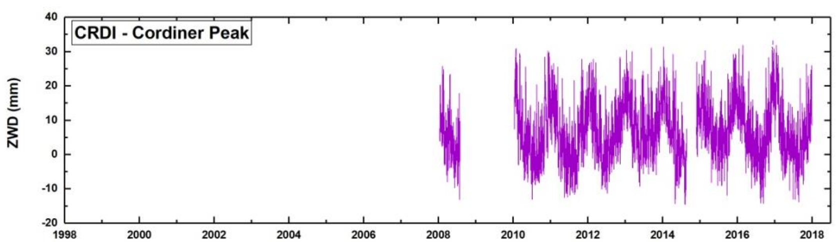


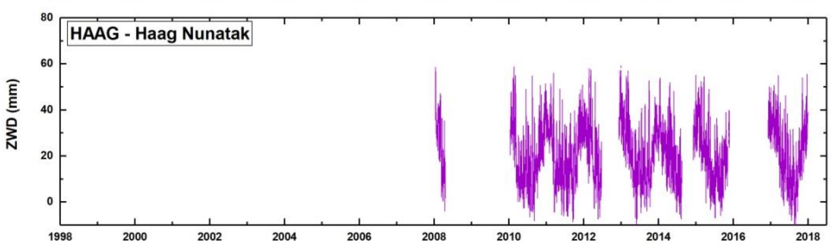
Results: West Antarctica

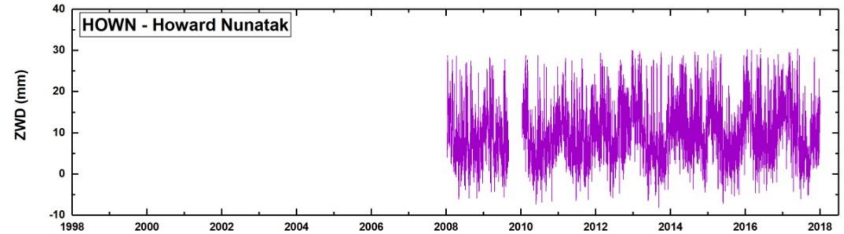


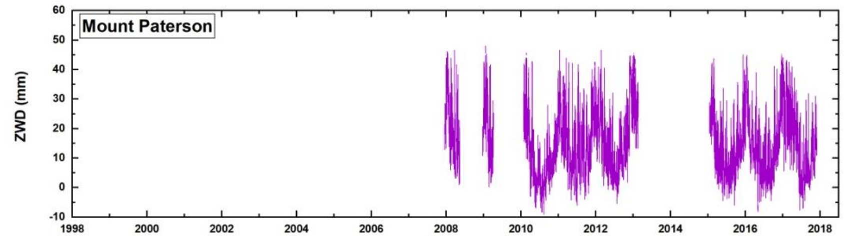


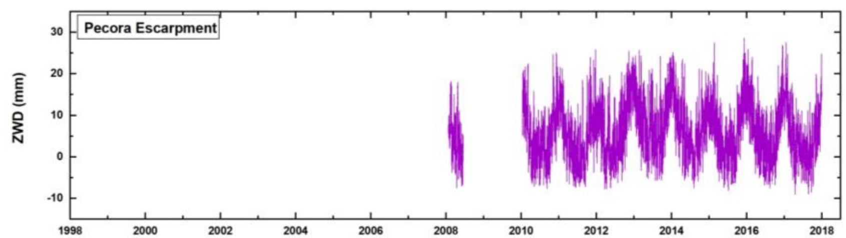


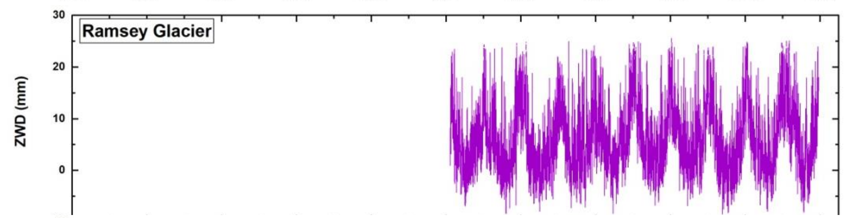


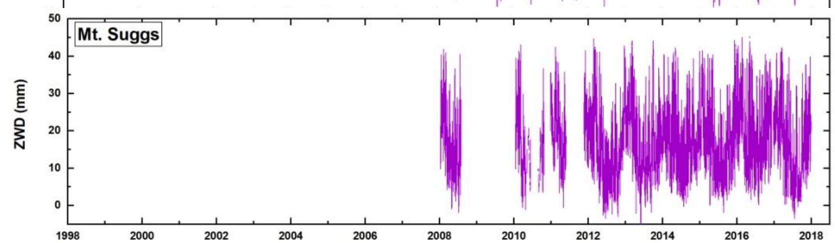


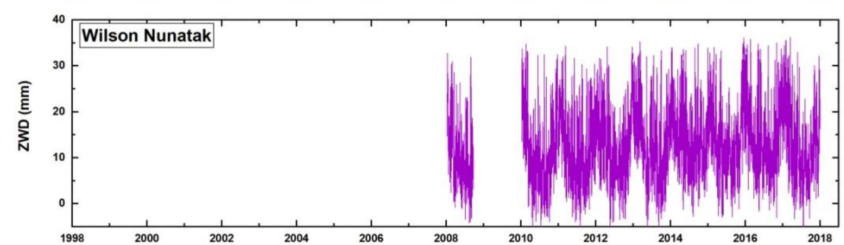




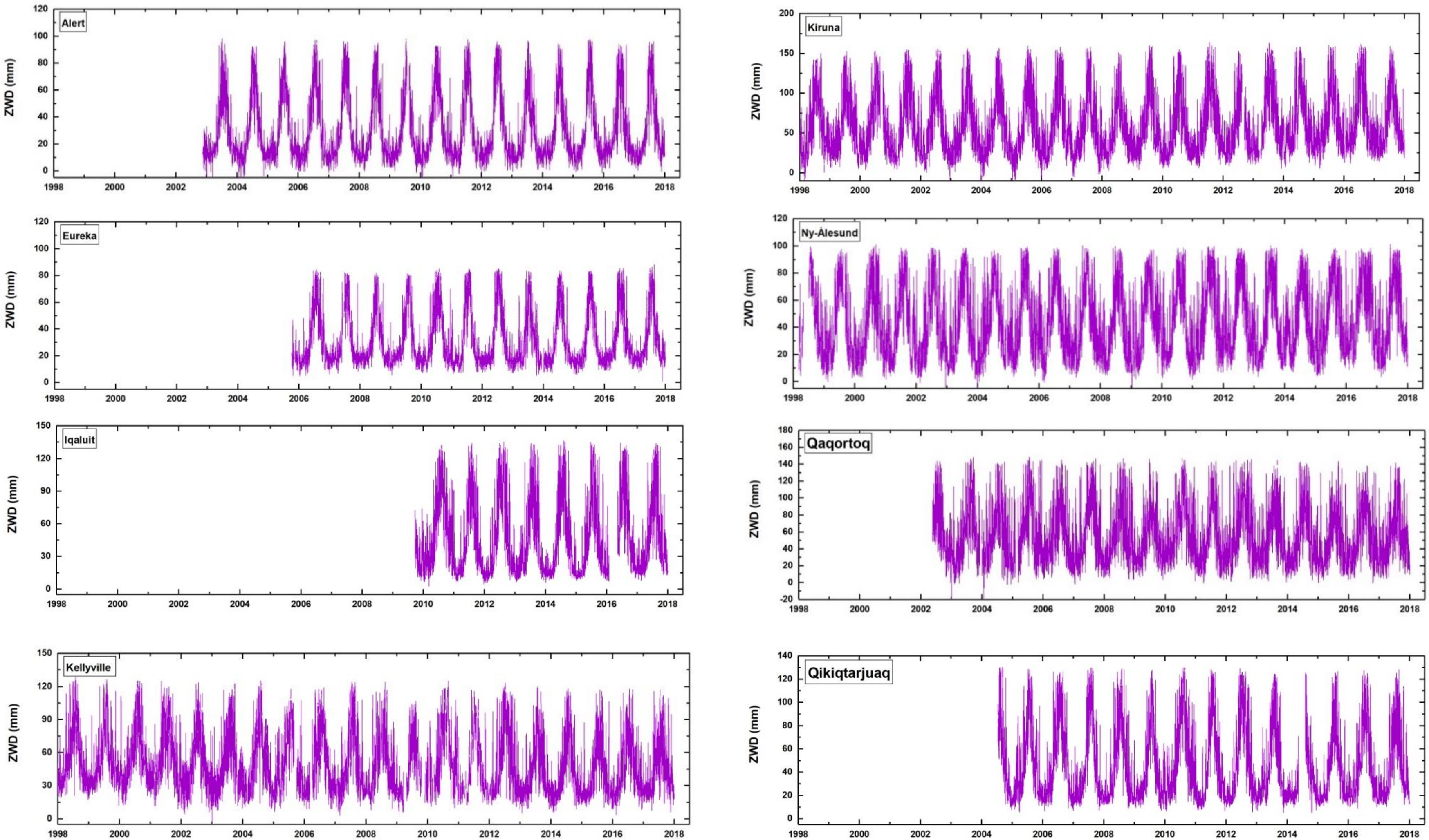




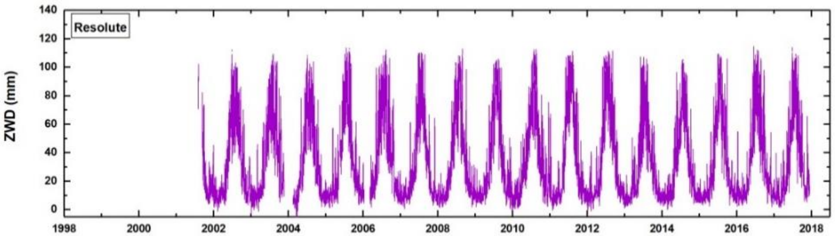


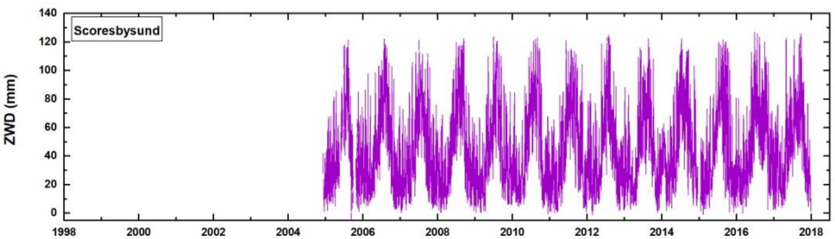


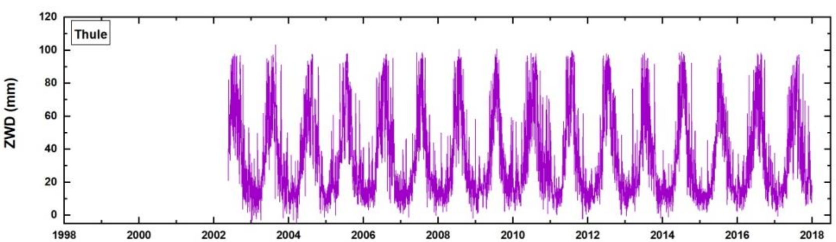
Results: Arctic

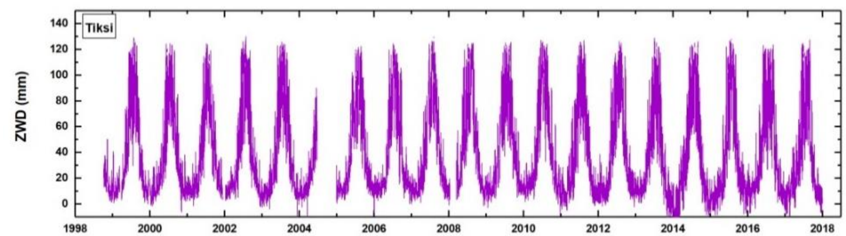


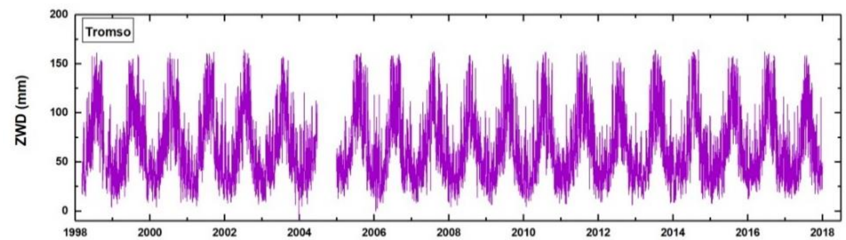
Results: Arctic (cont.)





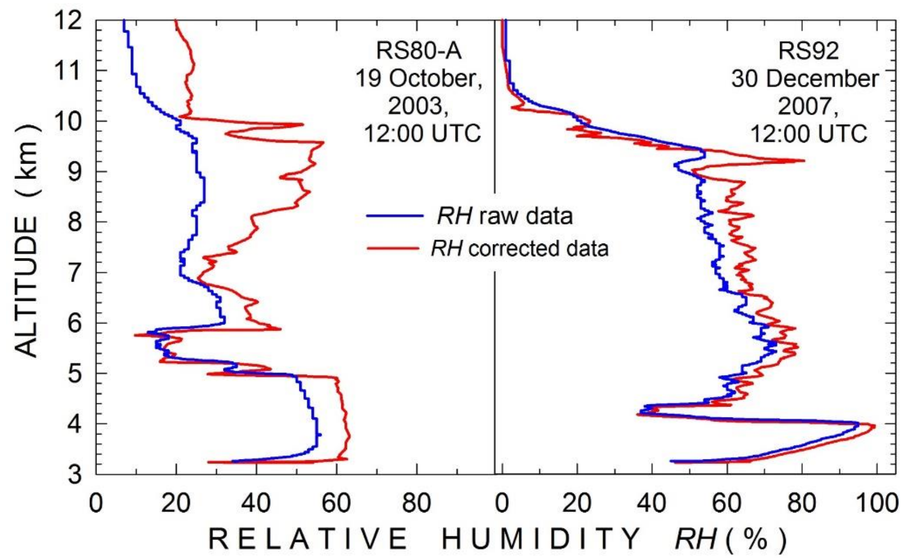






Details of RS data processing (cont.):

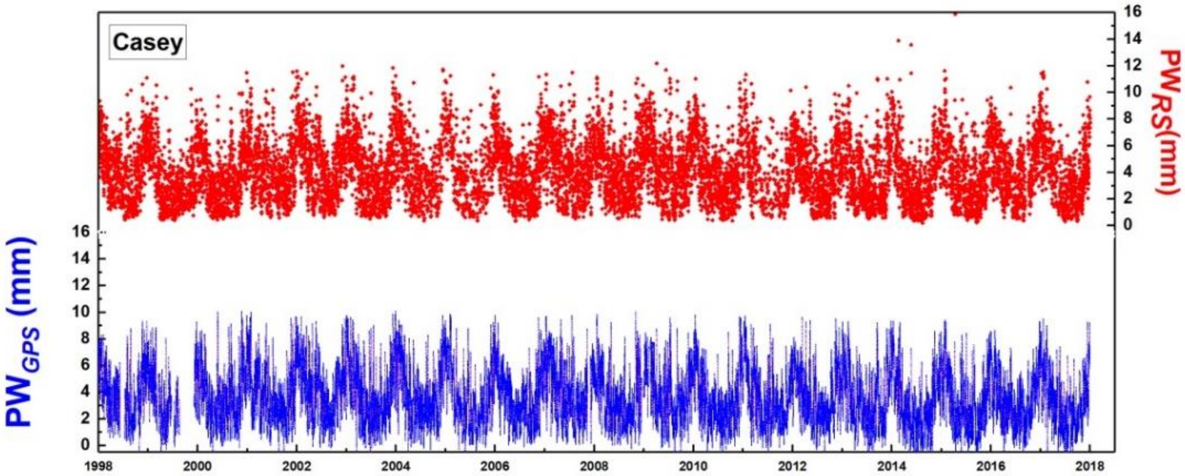
Tropospheric WV has been calculated, for each RS measurement, by integrating the vertical distribution curve of absolute humidity *q(z)* from the surface-level to 12 km altitude, using the vertical profiles of *T*(*z*) and *RH(z),* appropriately corrected for the main lags, instrumental errors and the various dry biases:

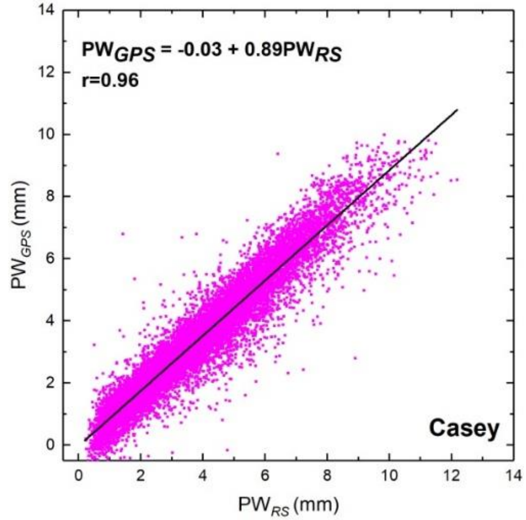


$$q(z) = e(z)/R_w\, T(z)$$

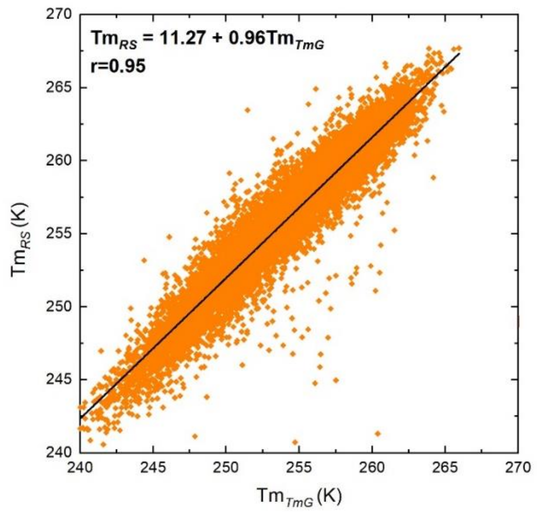
The total PW_{RS} is obtained by adding to this value the monthly average values of stratospheric WV content derived from Michaelson Interferometer for Passive Atmospheric Sounding (MIPAS)–Environmental Satellite (ENVISAT) observations

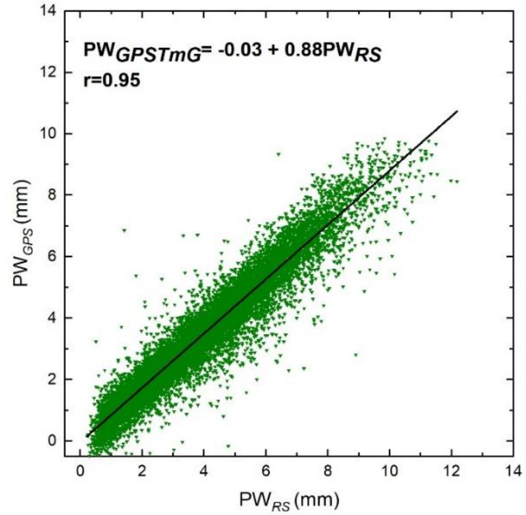
RS- and GPS-derived Precipitable Water:



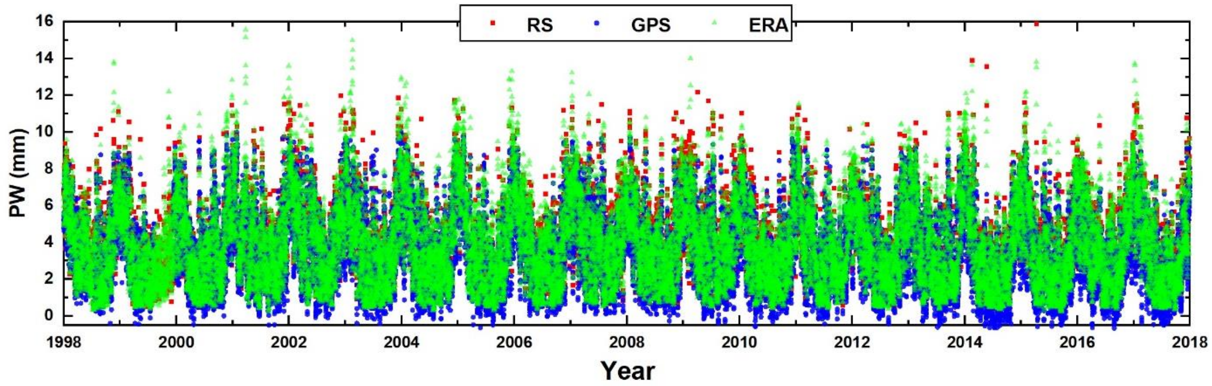


T_{mG} was estimated at GNSS sites every 6 hours by a bi-linear interpolation using T_m grid values provided by TU Wien
(https://vmf.geo.tuwien.ac.at/trop_products/GRID/2.5x2/VMF1/STD_OP)





PW time series from RS, GPS and ERA-Interim datasets



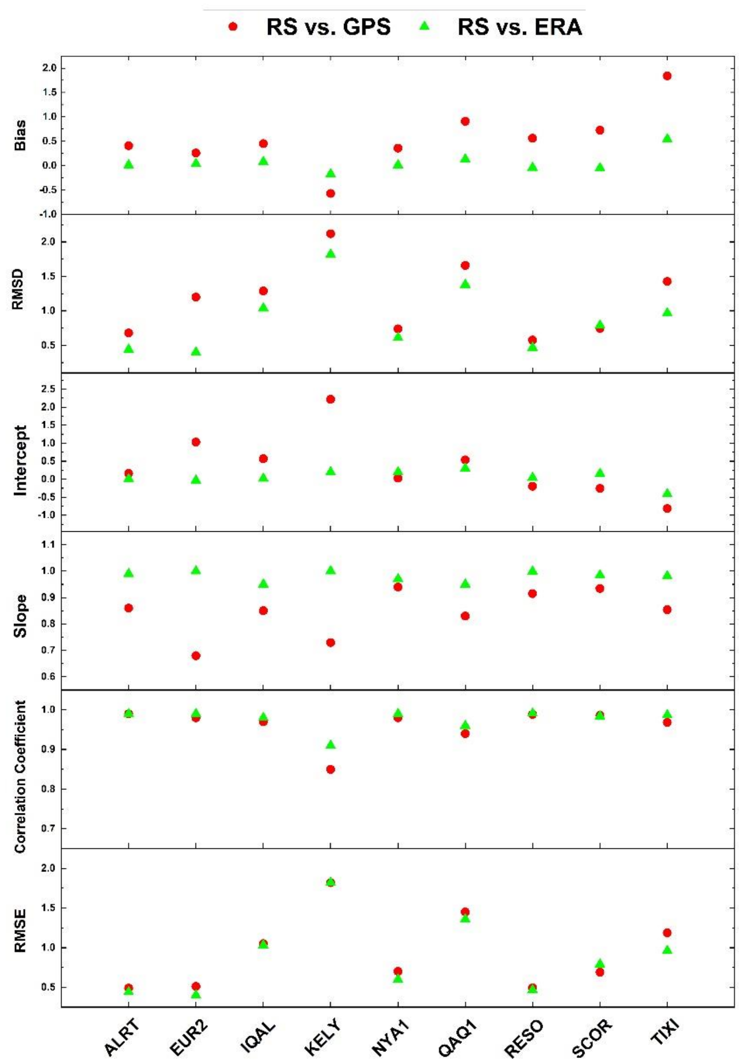
RS PW comparison with GPS and ERA at co-located sites

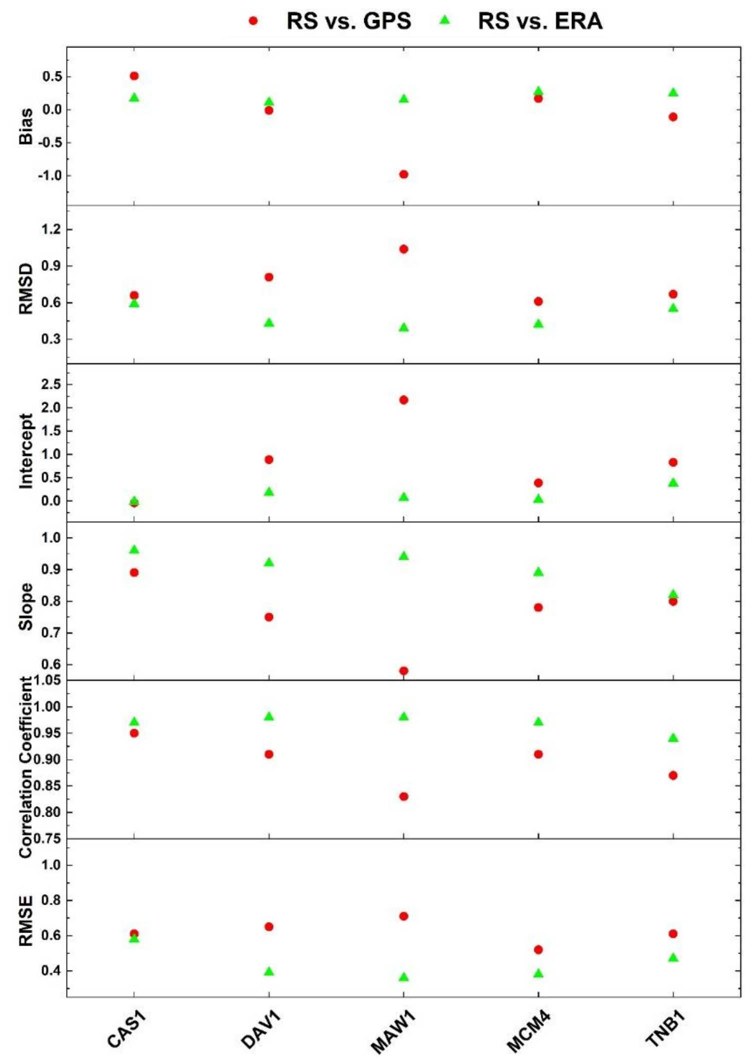
Scatter plots of PW values (RS vs GPS and RS vs ERA)

6 parameters have been estimated for each scatter plot:

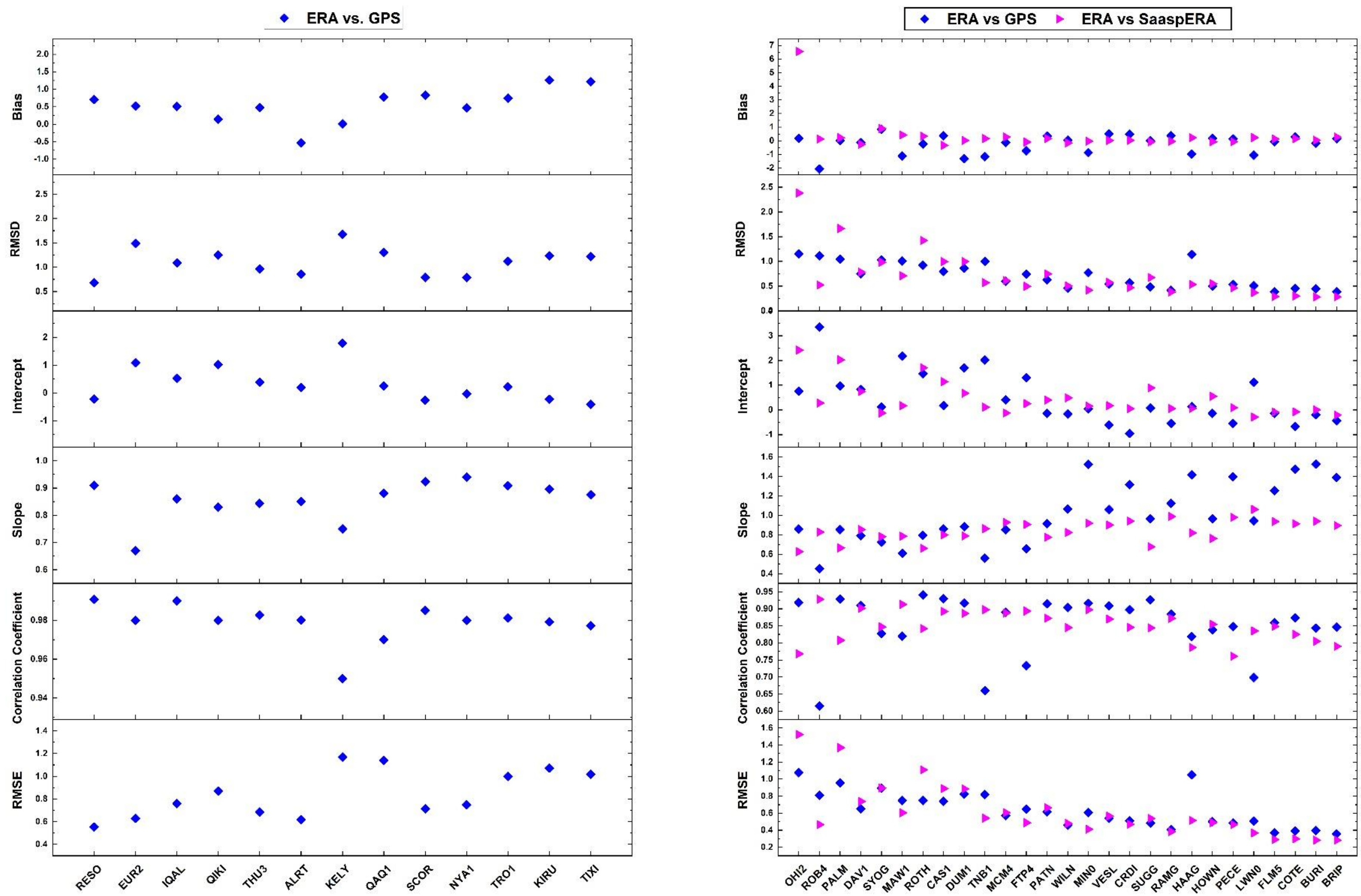
1) Bias
2) RMSD
3) Intercept of the linear regression
4) Slope of the linear regression
5) Pearson’s correlation coefficient
6) RMSE

RS PW comparison with GPS and ERA at co-located sites:



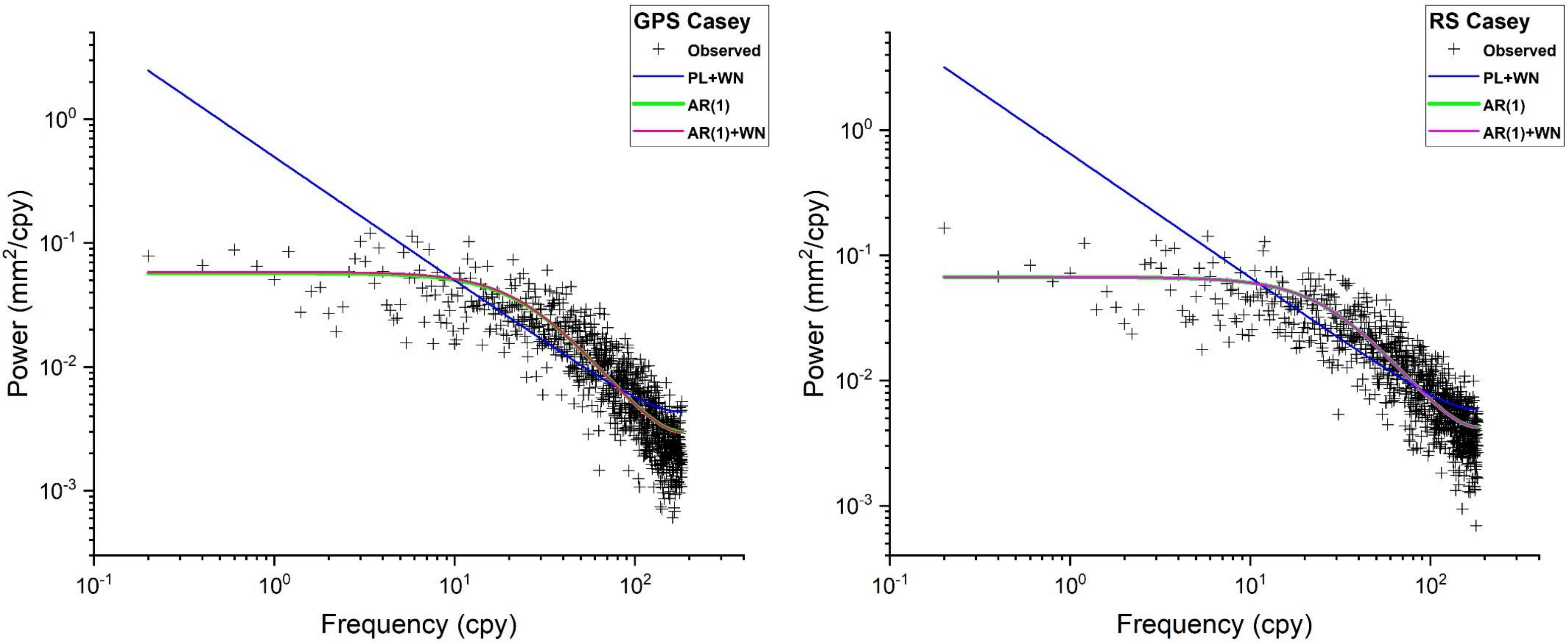


PW comparison between GPS and ERA:



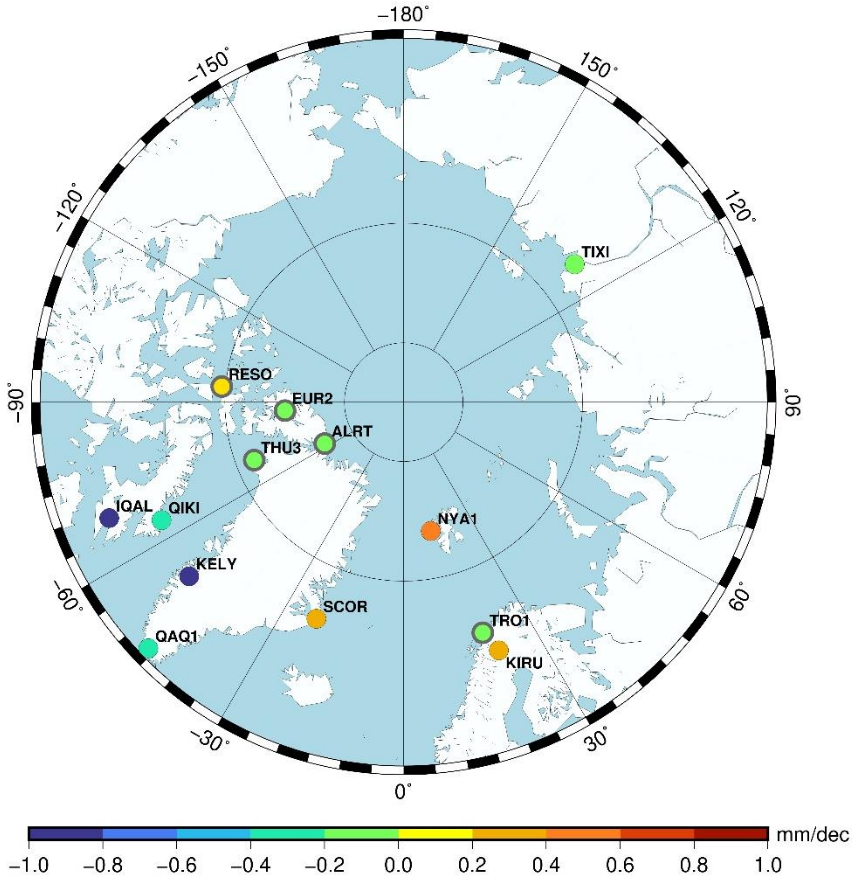
Model noise and PW trend estimation:

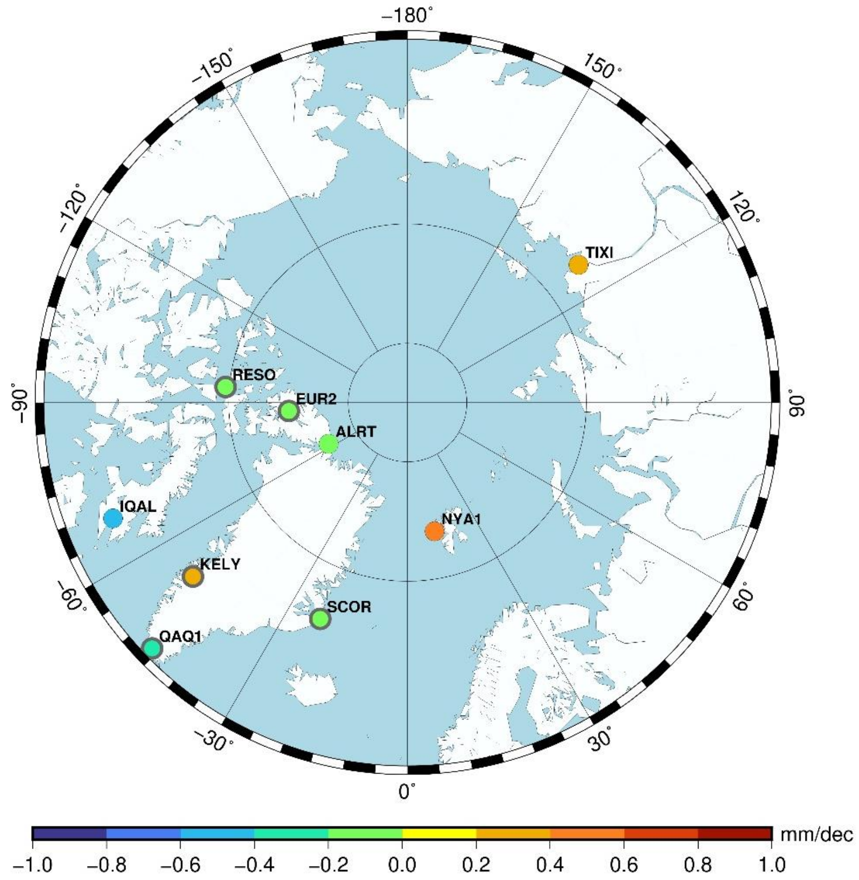
Hector software: function with a linear trend + annual signal + semiannual signal + different noise models



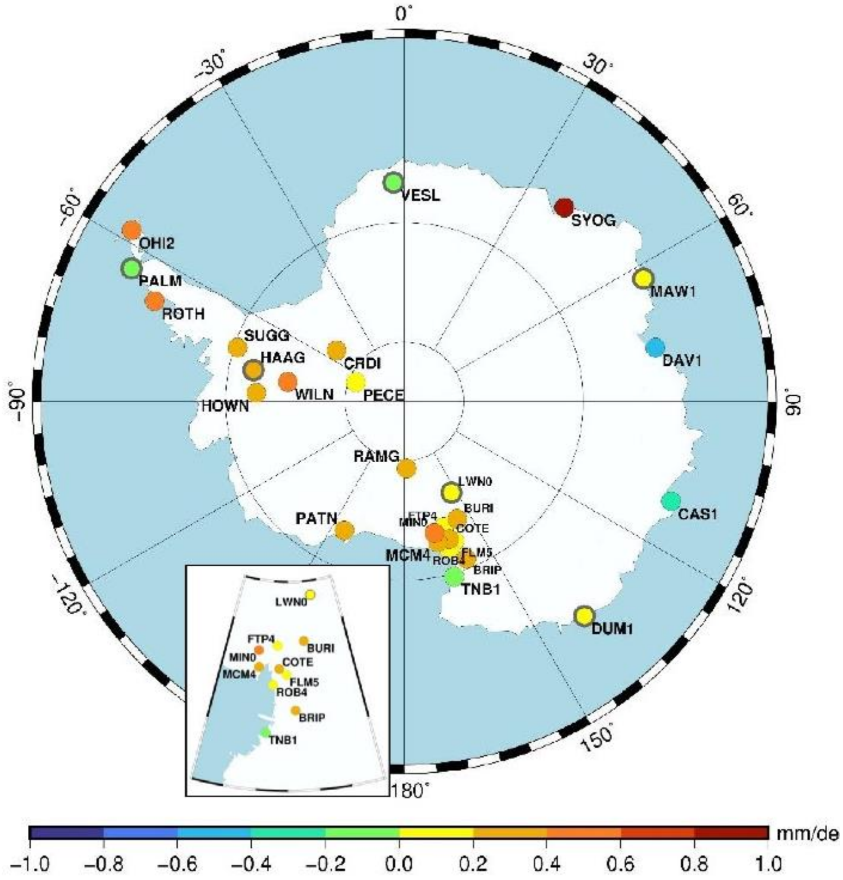
AR(1) noise model selected and linear trend, bias, annual and semiannual values estimated

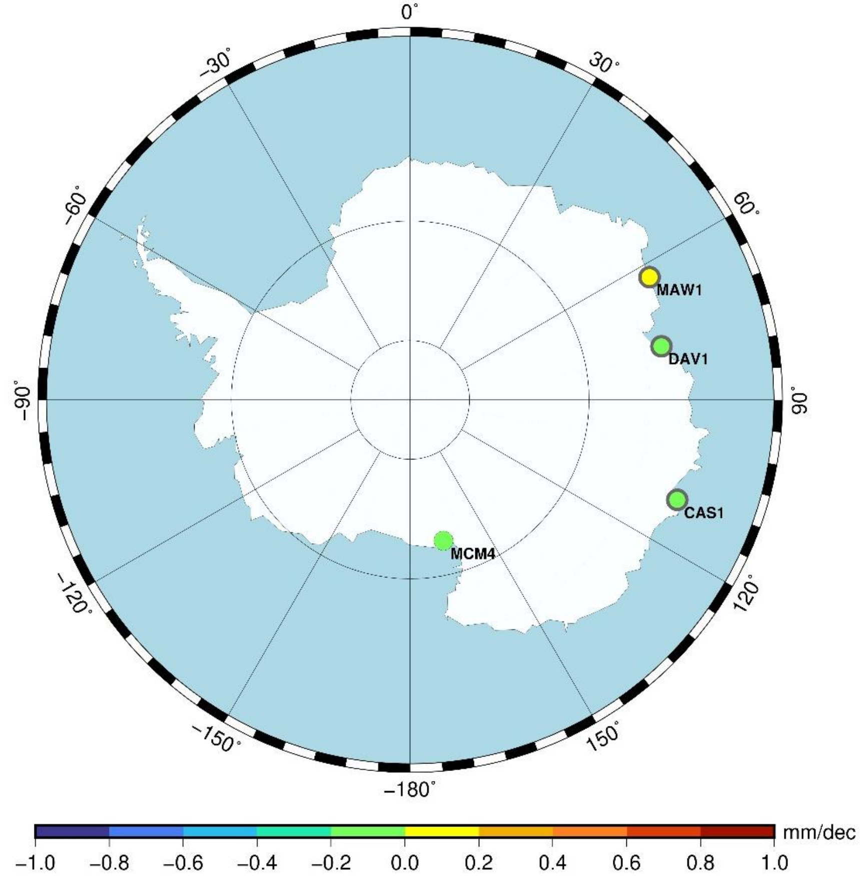
Arctic GPS and RS PW trends (mm/dec):





Antarctic GPS and RS PW trends (mm/dec):





Summary & Outlook

- In the homogenous GPS data reprocessing, *ad hoc* procedures have been implemented that allow to estimate reliable ZWD values without the need for local surface meteorological data
- A small dry bias of RS with respect to GPS has been found in the Arctic, while no clear behavior is present in Antarctica
- Still problems with negative ZWD values in inner Antarctica are present
- The GPS and RS PW seasonal variations are rather consistent, as confirmed by scatter plots and related correlation coefficients
- The PW trends are extremely small: long times series are necessary to give reliable values and also fitting methods are crucial
- Reprocessing is planned, with ITRF2020 and relevant IGS homogenous products, VMF3/GPT3, adding more stations and longer observation records
- The challenging topic of the atmospheric water budget forecast in Antarctica will be addressed via GPS PW, in a joint project with atmosphere physicists, considering the WMO efforts for the implementation of Antarctic Regional Climate Centres (RCCs)

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- British Antarctic Survey for Rothera data set
- PNRA (Italian Antarctic Research Programme) and the Meteo-climatological Observatory (http://www.climantartide.it/) for Mario Zucchelli Station radio soundings and meteorological data
- Royal Observatory of Belgium for providing Princess Elisabeth Station GNSS data.

INAF IRA

remote sensing

Article

Water Vapour Assessment Using GNSS and Radiosondes over Polar Regions and Estimation of Climatological Trends from Long-Term Time Series Analysis

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Abstract: The atmospheric humidity in the Polar Regions is an important factor for the global budget of water vapour, which is a significant indicator of Earth's climate state and evolution. The Global Navigation Satellite System (GNSS) can make a valuable contribution in the calculation of the amount of Precipitable Water Vapour (PW). The PW values retrieved from Global Positioning System (GPS), hereafter PW_{GPS}, refer to 20-year observations acquired by more than 40 GNSS geodetic stations located in the polar regions. For GNSS stations co-located with radio-sounding stations (R

Thank you for your attention!

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