Atmospheric Water Vapour Observations

AT ROB AND RMI FOR WEATHER AND CLIMATE MONITORING

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Observing the Atmospheric Water Vapour

Forewords

Workshop

What this presentation IS NOT about?

- Detailed scientific results on a specific activity.
- Not especially focused on polar regions but applicable to polar regions.

What this presentation IS about?

- Overview of different ongoing activities.
- Try to link to polar regions, whenever possible.
- Goal: to bridge and identify potential synergies.
- 'Slightly' Focus-Biased on GNSS

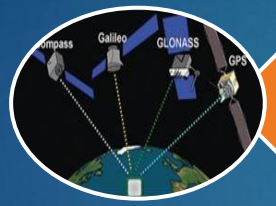
Observing the Atmospheric Water Vapour

HOW & WHY ? CONTEXT AND MAIN APPLICATIONS

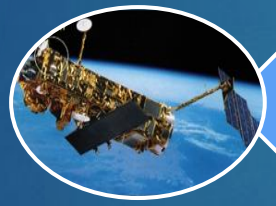
Observing the Atmospheric Water Vapour

Which are our datasets?

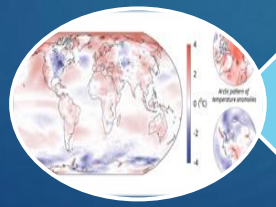
In-situ Observations
- Surface observations, Radiosonde



Ground-based Remote Sensing Observations
- GNSS



Satellite-based Remote Sensing Observations
- GOME, SCHIAMACHY, GOME-2, AIRS



NWP, Re-analysis and Climate Models
- ERA-Interim and ALARO

Observing the Atmospheric Water Vapour

For which main Research / Application Fields ?

Observing the Atmospheric Water Vapour

FOR WEATHER FORECAST AND METEOROLOGY

GNSS-Meteorology

GNSS-Meteorology is today a quite mature field of research/applications and is applied operationally

Applications

- Non-Numerical Nowcasting
- Numerical Nowcasting
- Numerical Weather Prediction

Product Latency Requirements

Real-Time (<= 5min Updates) → 15-Min Updates → Hourly Updates

GNSS for improving Weather Forecasting

The EUMETNET EIG GNSS Water Vapour Program (E-GVAP, 2005-today)

ROB's Legacy Contribution to E-GVAP :

- Support European NWP models
- Operate an analysis centre (24x7x365)
- 500-600 GNSS stations
- To provide tropospheric products - Hourly updates – Latency < 30min
- For Data assimilation in NWP models, Water Vapour Maps…

GNSS for improving Weather Forecasting

The EUMETNET EIG GNSS Water Vapour Program (E-GVAP, 2005-today)

More Recently, we added two more contributions:

- To support rapid-update cycle NWP models
- To support global NWP models (Météo France, UK Met Office, ECMWF) and support NWP outside Europe (e.g. USA and Env. Canada)
- ~300 GNSS stations that includes polar region stations (more can be added in the future, POLENET?).

Observing the Atmospheric Water Vapour

FOR STUDYING THE CLIMATE

Using GNSS to Study the Climate System

Foreword: From Meteorology to Climate

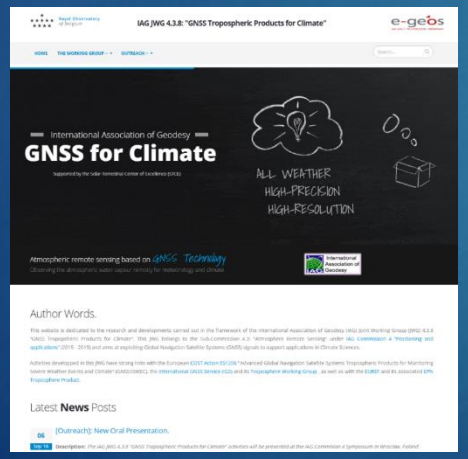
GNSS-Meteorology is today a quite mature field of research/application and is applied operationally

In contrast, the use of GNSS in climate sciences has been widely advertised, but remain almost untouched until…

Using GNSS to Study the Climate System

From Meteorology to Climate

Revived thanks to the European COST Action (ES1206) "GNSS4SWEC": "Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate" (2013-2017). *http://www.cost.eu/COST_Actions/essem/ES1206*



Work continued in the framework of the IAG WG 4.3.8 "GNSS Tropospheric Products for Climate" (2015-2019), Chaired by Rosa Pacione (e-geos/ASI) and Eric Pottiaux (ROB). *http://iag-gnssclimate.oma.be*

Using GNSS to Study the Climate System

The COST Action ES1206 – GNSS4SWEC

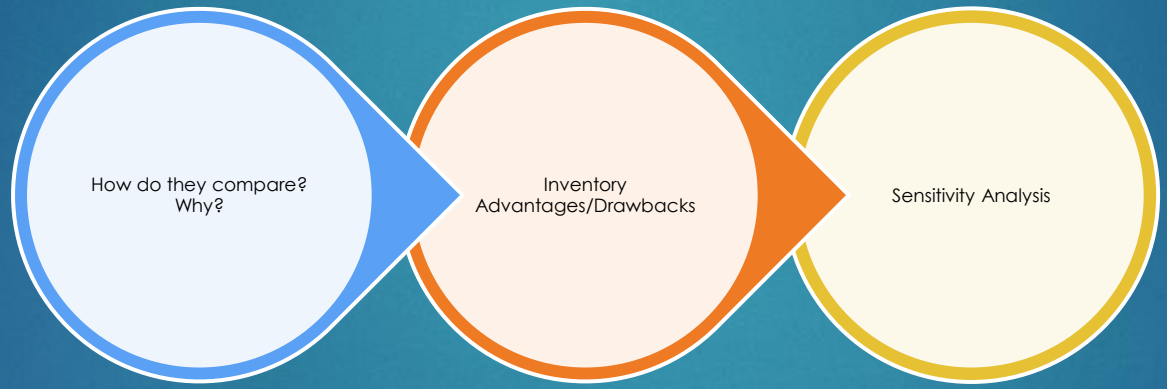
WG3 "Use of GNSS tropospheric products for climate monitoring"

- Inter-Technique Comparison
- Climate Model Assessment and Validation
- Diurnal, Seasonal, Intra-Seasonal, Inter-Seasonal Variability, Trend…
- Detect and mitigate discontinuities in the IWV time series (homogenization)
- Establish a GNSS climate data record based on existing and reprocessed and homogenized tropospheric products (ZTD and IWV)

Using GNSS to Study the Climate System

Inter-Technique Comparison

First natural step prior using any dataset for any further study of the climate system !

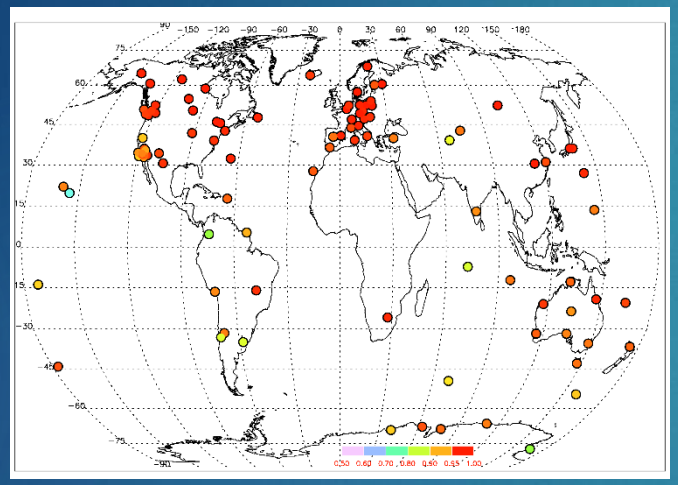


Van Malderen, R. et al.: A multi-site intercomparison of integrated water vapour observations for climate change analysis, Atmos. Meas. Tech., 7, 2487-2512, https://doi.org/10.5194/amt-7-2487-2014, 2014.

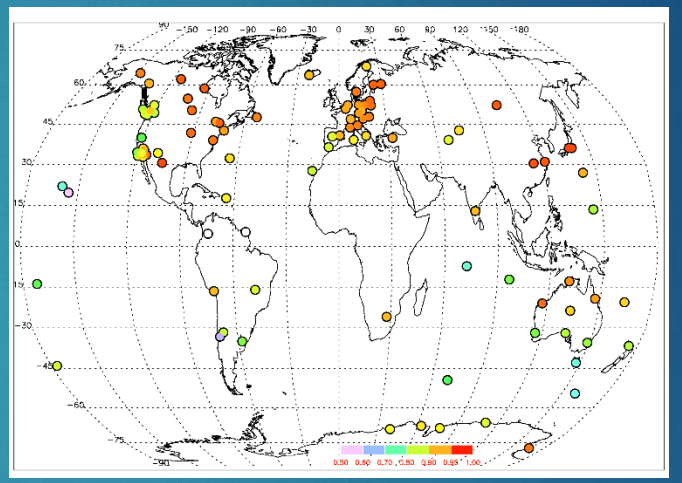
Using GNSS to Study the Climate System

Inter-Technique Comparison

R^2 between GNSS and ERAinterim



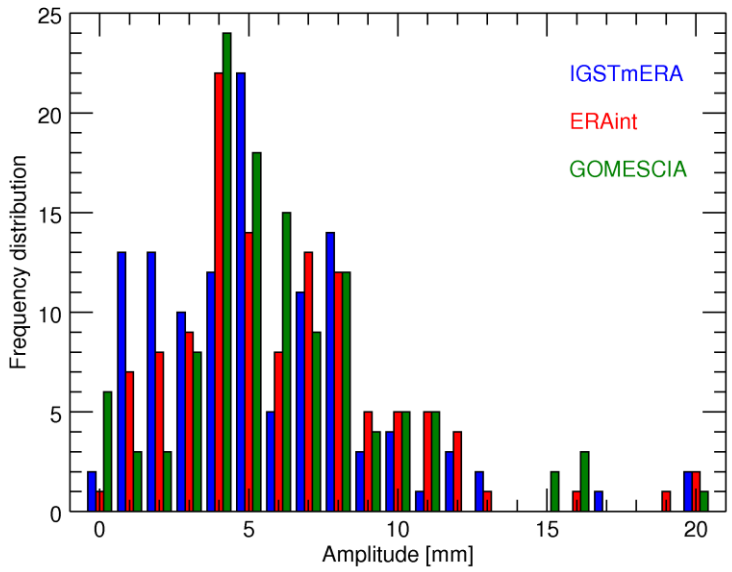
R^2 between GOMESCIA and ERAinterim

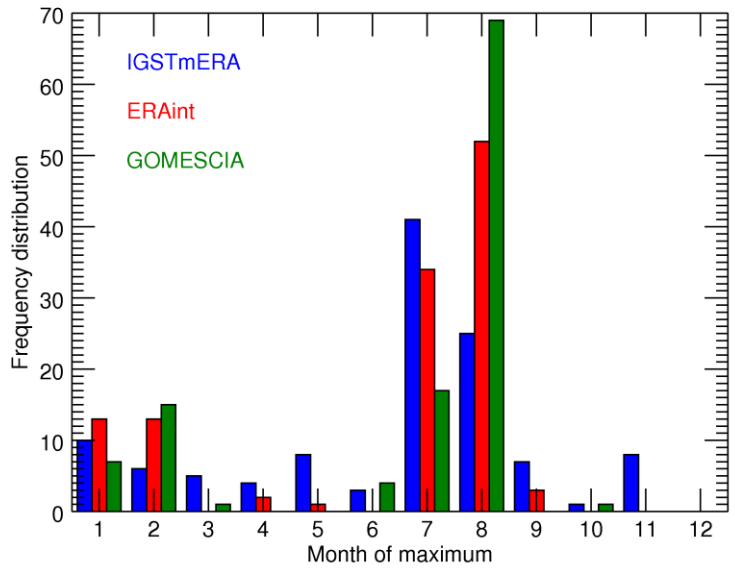


- Very high correlation between ERA-interim and GNSS, except at some island and coastal sites (➔ bad spatial representation by ERA-interim?)
- Lower correlation coefficients between ERA-interim and GOMESCIA, and dry bias of GOMESCIA w.r.t. ERA-interim
- Discrepancies between observation datasets and ERA-interim higher in Antarctica?

Using GNSS to Study the Climate System

Diurnal, Seasonal, Intra-Seasonal, Inter-Seasonal Variability, Trend…





- **GOMESCIA** and **GNSS** deviate in their representation of the lowest amplitudes (IWV ≤ 5 mm).
- The phase of the maximum peaks one month later in the NH in **GOMESCIA** w.r.t. **GNSS.**

Van Malderen et al., Manuscript in preparation, to be submitted to GNSS4SWEC S.I. (ACP/AMT/ANGEO)

Using GNSS to Study the Climate System

Main Drivers of the Seasonal Variability

- **What** are the **main drivers** of the seasonal variability and long-term time behaviour of the IWV time series?

- **How** can this scientific question be assessed?

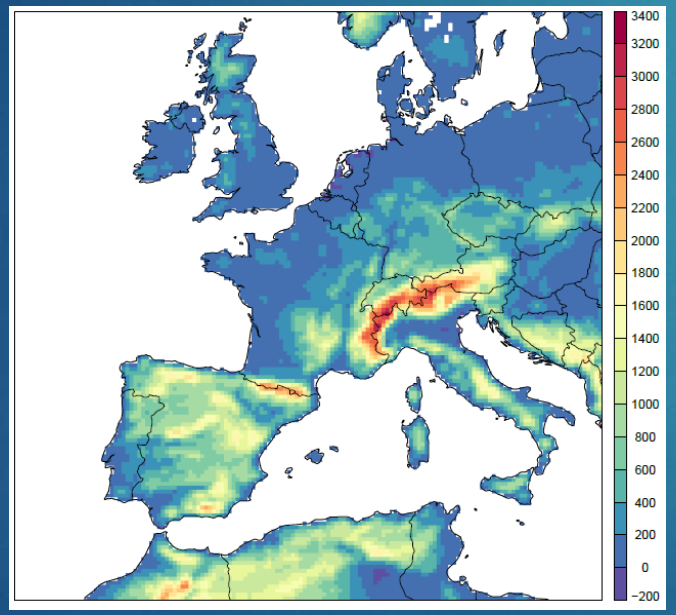
  - Running climate models and study the underlying processes (e.g. validation of climate models with GNSS IWV retrievals) ← → Climate Model Assessments

Using GNSS to Study the Climate System

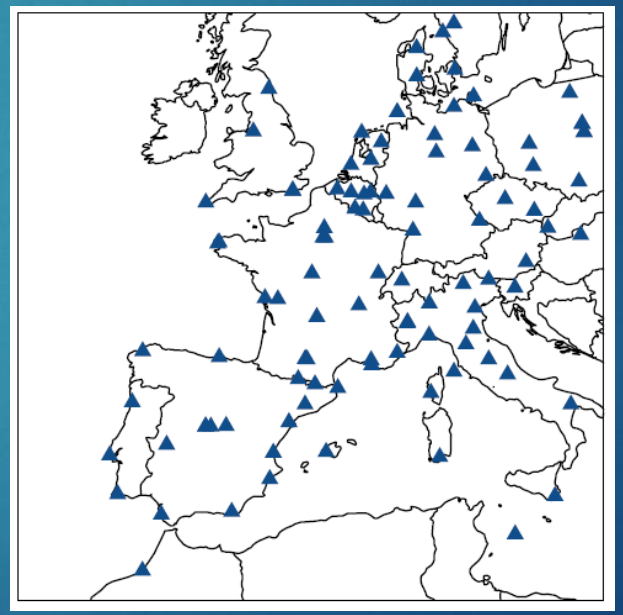
Climate Model Assessments

GNSS-based (EPN repro2 + IGS repro 1) Validation of the IWV in ALARO-0 coupled to SURFEXv5 for the 19-yr period 1996-2014 over western Europe

ALARO Domain - Model



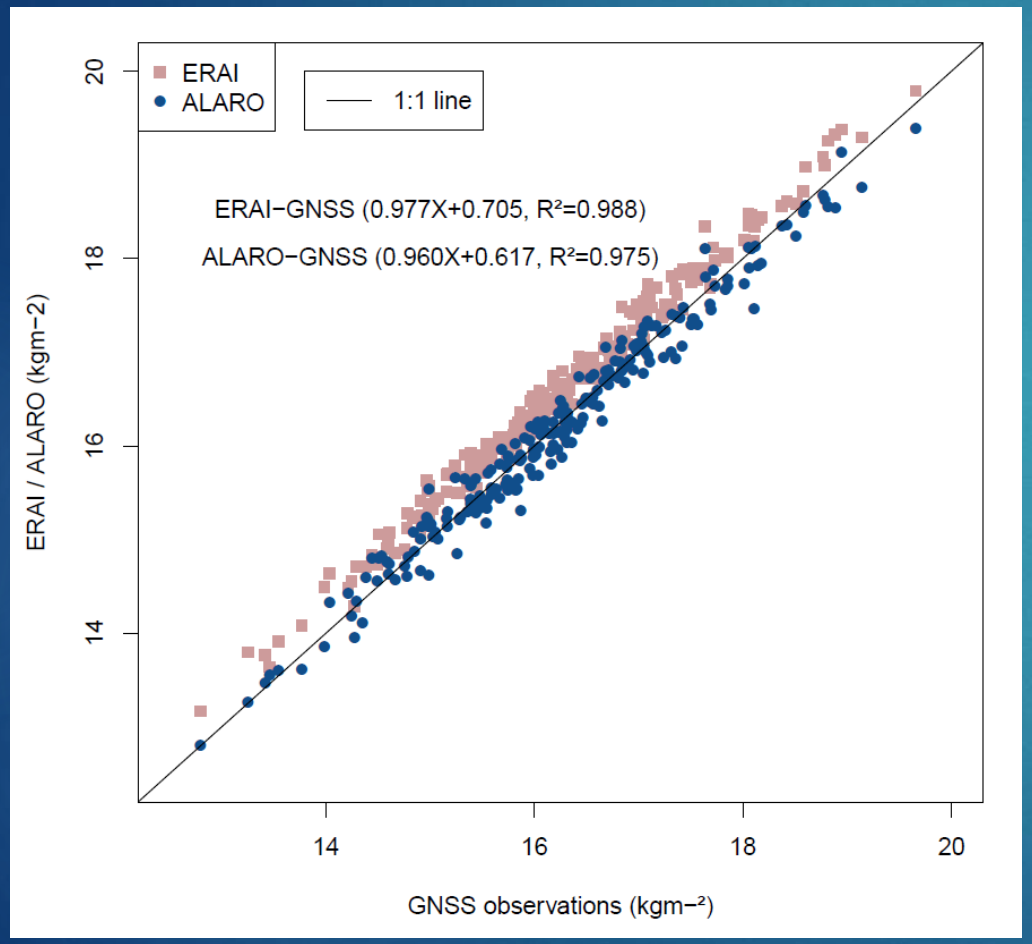
GNSS Station - Observations

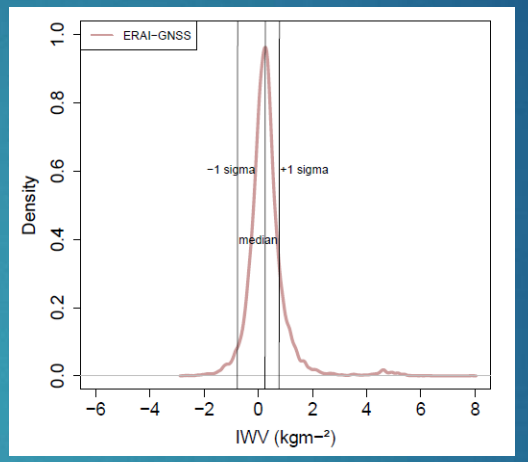


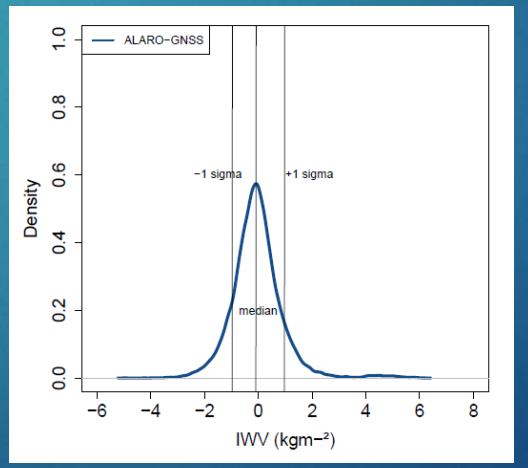
Berckmans et al., Manuscript in preparation, to be submitted to ACP.

Using GNSS to Study the Climate System

Climate Model Assessments

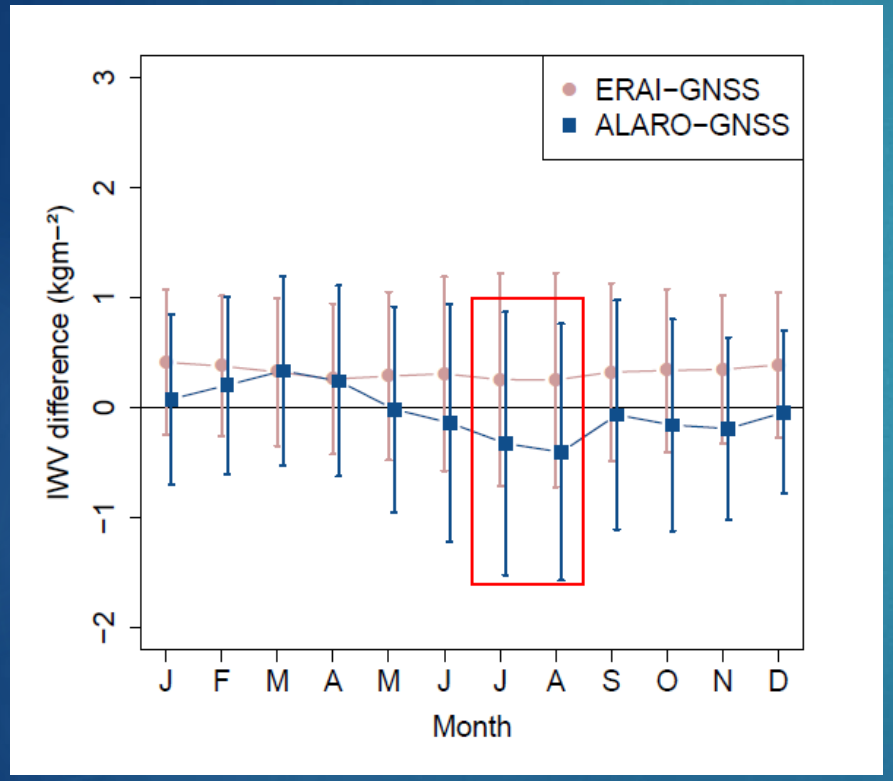


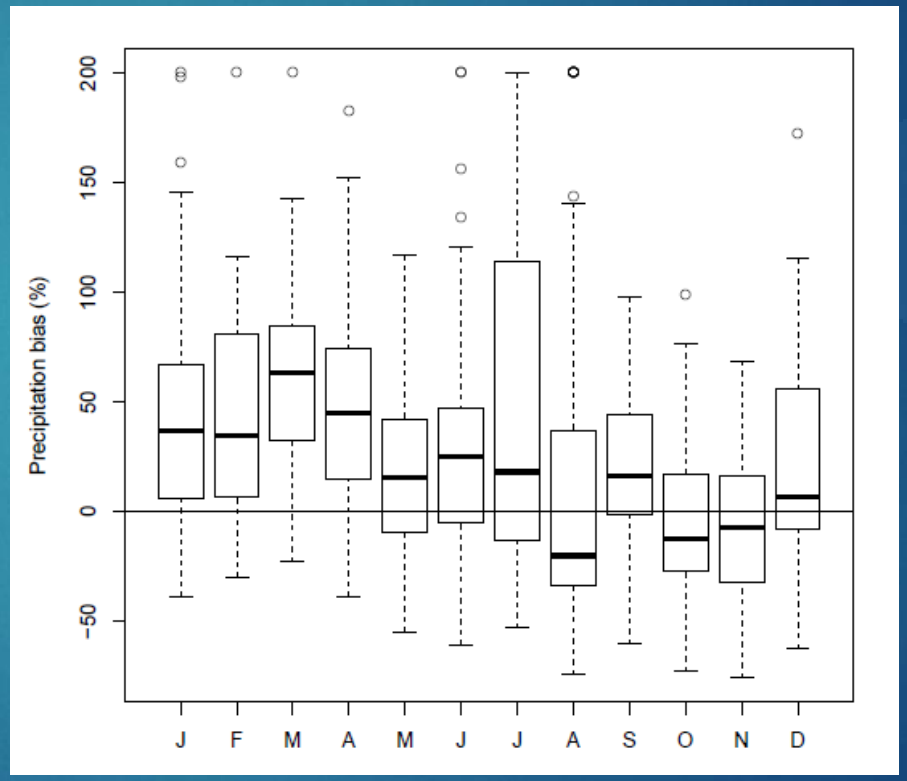




Using GNSS to Study the Climate System

Climate Model Assessments – Seasonal Variability





Using GNSS to Study the Climate System

Main Drivers of the Seasonal Variability

- What are the main drivers of the seasonal variability and long-term time behaviour of the IWV time series?

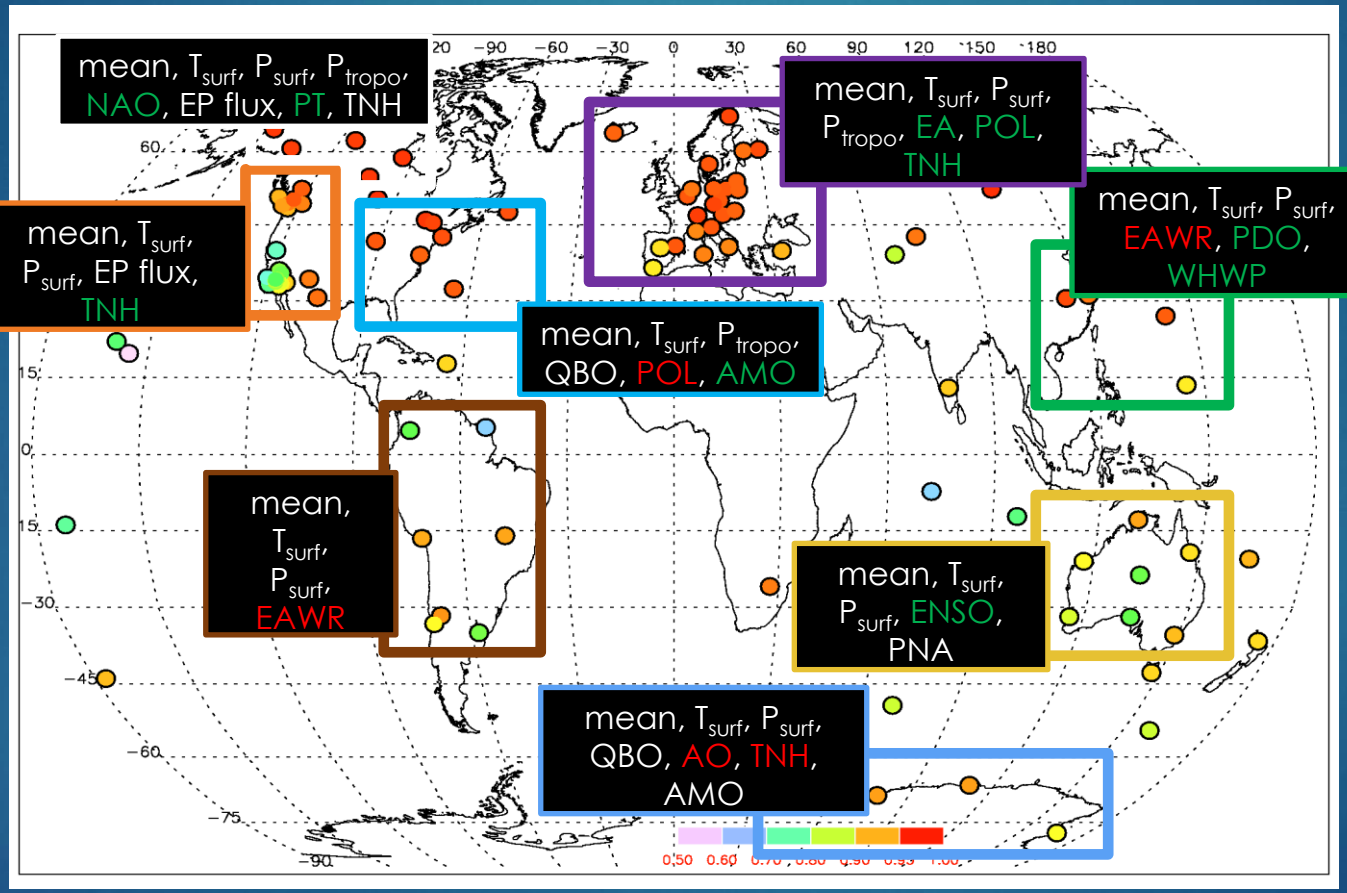
- How can this scientific question be assessed?

  - Running climate models and study the underlying processes (e.g. validation of climate models with GNSS IWV retrievals)

  - Running stepwise multiple linear regression, with representations (=time series, in particular monthly means) of circulation patterns (e.g. ENSO) and lower-atmospheric oscillations (e.g. NAO): means (or harmonics), T_{surf}, P_{surf}, P_{tropo}, all teleconnection patterns (with lead times)

Using GNSS to Study the Climate System

Main Drivers of the Seasonal Variability



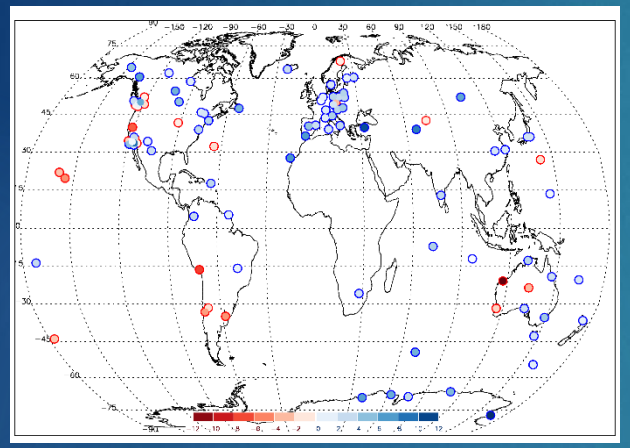
Van Malderen et al., Manuscript in preparation, to be submitted to GNSS4SWEC S.I. (ACP/AMT/ANGEO)

Using GNSS to Study the Climate System

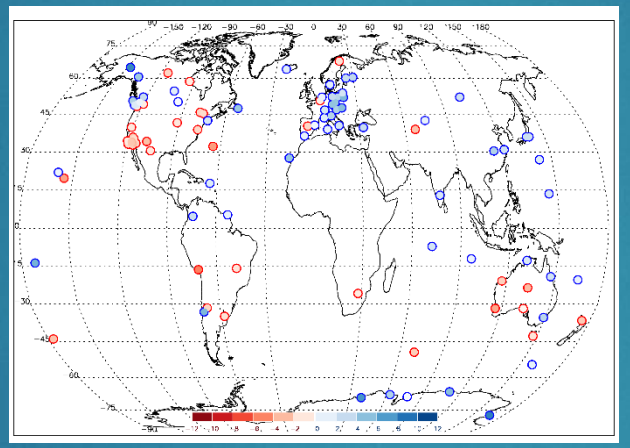
Diurnal, Seasonal, Intra-Seasonal, Inter-Seasonal Variability, Trend…

Surface warming affects the capacity of the atmosphere to hold water vapour (Clausius-Clapeyron)

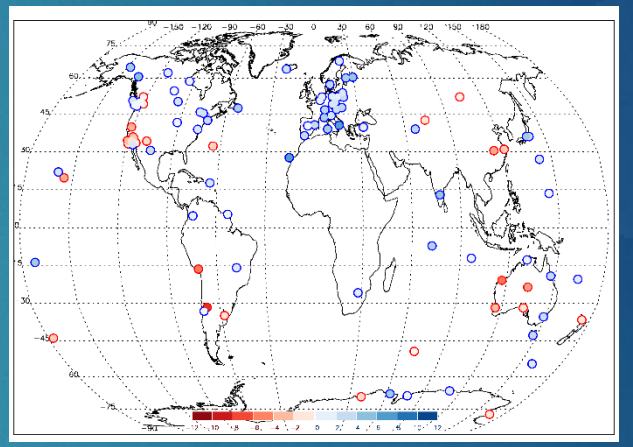
GNSS



GOMESCIA



ERAinterim



Figures: IWV trends [%/dec] (January 1996-Dec 2010)

- IWV is increasing over Europe, decreasing over West Australia
- Some location / regions have fairly good agreement between the datasets
- In other regions: picture less clear among the different datasets (→ inhomogeneities?)

Using GNSS to Study the Climate System

Homogenisation of Time Series

- Even after a careful reprocessing of historical GNSS observations to produce climate-quality time series of IWV, these time series can emphasize "artifical" (i.e. non climatic) breaks (e.g. due to undocumented or mis-modelled equipment changes).

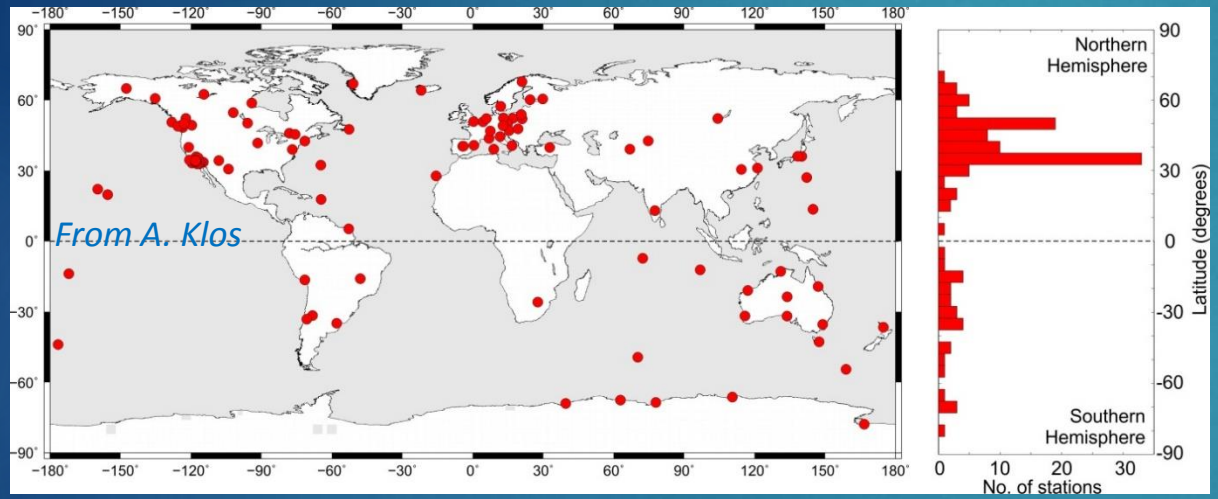
- These breaks can significantly influence what we are studying with these time series (e.g. climate trends) and consequently prevent us of using them properly for climate science.

- There is thus a clear need for homogenizing these time series.

Using GNSS to Study the Climate System

Homogenisation of Time Series - Status

Activity started within GNSS4SWEC, team of about 10 people and continued today within the IAG 4.3.8 "GNSS Tropospheric Products for Climate" with few new players.



Starting Dataset:

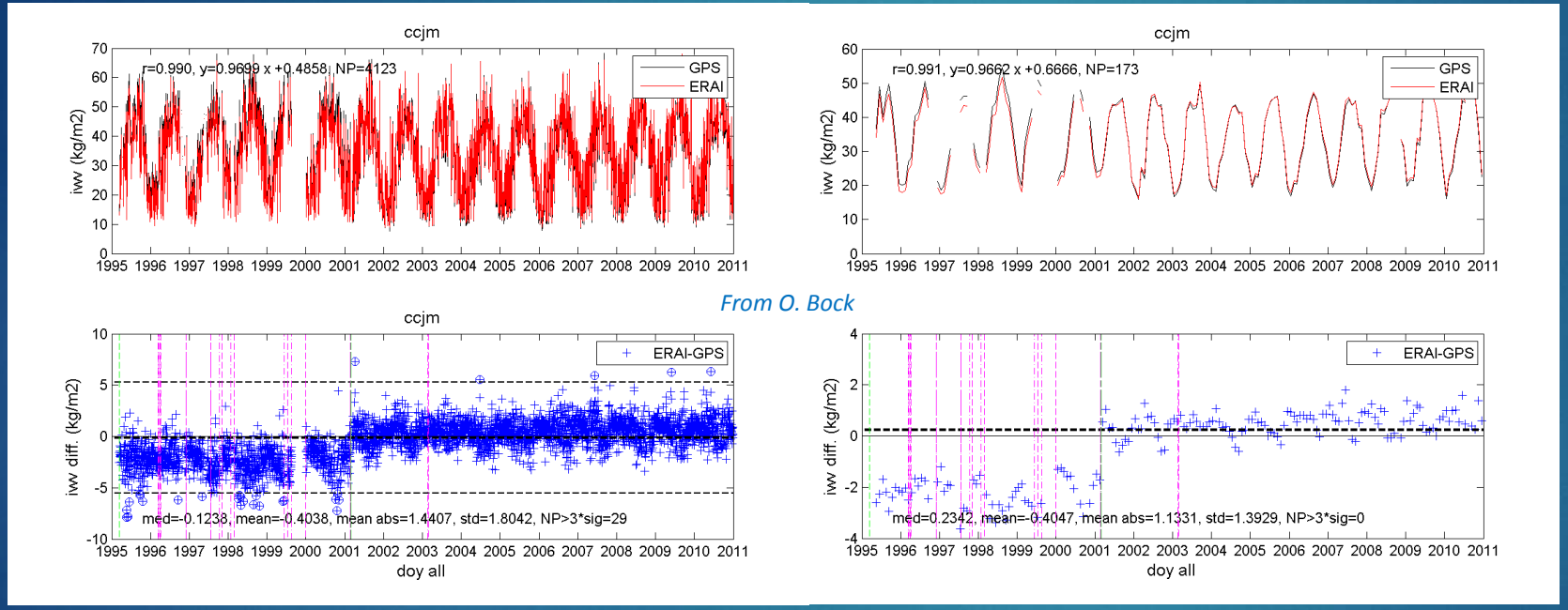
- *120 sites worldwide, with homogeneous reprocessing from 1995 – 2010*
- *IGS repro 1: International GNSS Service, first reprocessing*
- *Screened, outlier removed, and ZTD converted to IWV by O. Bock*

Series of Manuscripts in preparation, to be submitted to GNSS4SWEC S.I. (ACP/AMT/ANGEO)

Using GNSS to Study the Climate System

Homogenisation of Time Series - Approach

Use of a reference IWV dataset (ERA-interim)



From O. Bock

This sounds 'quite easy' but the activity is actually quite challenging ! → we started a benchmarking activity on synthetic datasets to assess the performances of different (automatic) homogenization tools.

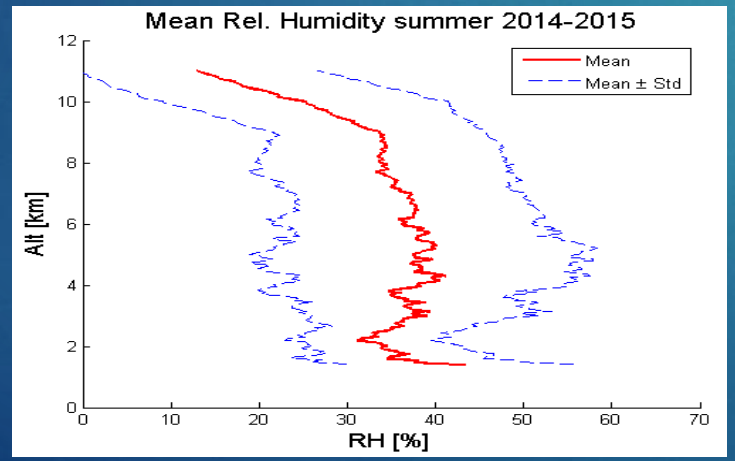
Observing the Atmospheric Water Vapour

IN ANTARCTICA

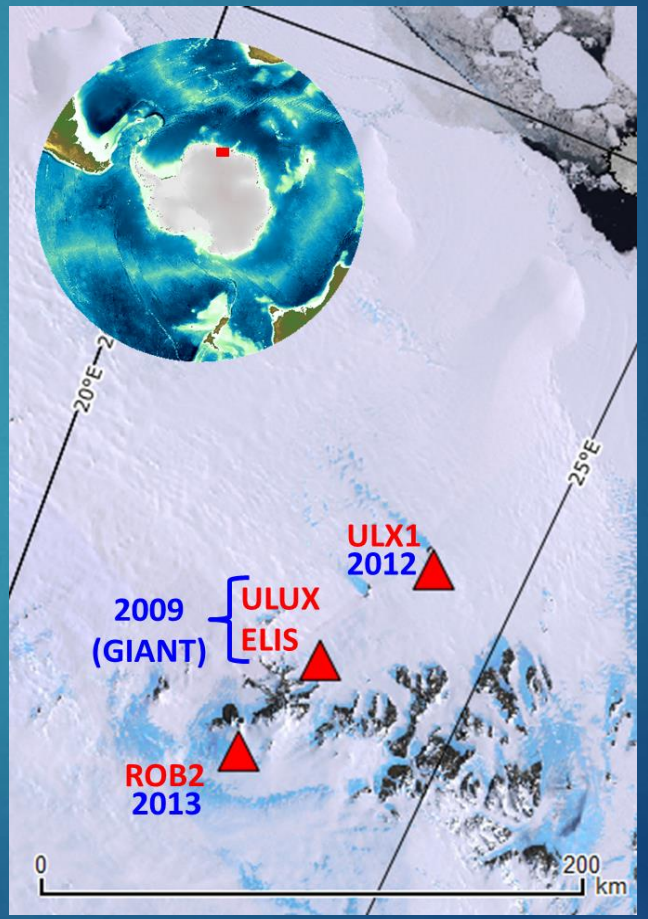
Water Vapour Measurements @ / Around PE Station

1 Radiosonde Launch Site
4 Geodetic GNSS Stations + 1 on Ice Sheet (Unmounted, 2016)

Radiosonde Launches @ PE Sation



Geodetic GNSS Receivers



Conclusions

We observe the atmospheric water vapor with different techniques for… including at polar sites.

- Non-Numerical Nowcasting
- Numerical Nowcasting
- Numerical Weather Prediction
- Climate Variability
- Climate Trends
- Instruments Inter-Comparison
- Sensitivity Analysis
- Model Assessment and Validation
- Time Series Homogenization
- Studying Extremes

Thank you for your attention