ETH zürich

Sensing small-scale structures in the troposphere with tomographic principles

Gregor Moeller, Chi Ao, Zohreh Adavi, Hugues Brenot, André Sá, George Hajj, Natalia Hanna, Chaiyaporn Kitpracha, Eric Pottiaux, Witold Rohm, Endrit Shehaj, Estera Trzcina, Kuo-Nung Wang, Karina Wilgan, and Kefei Zhang

Working group of the International Association of Geodesy

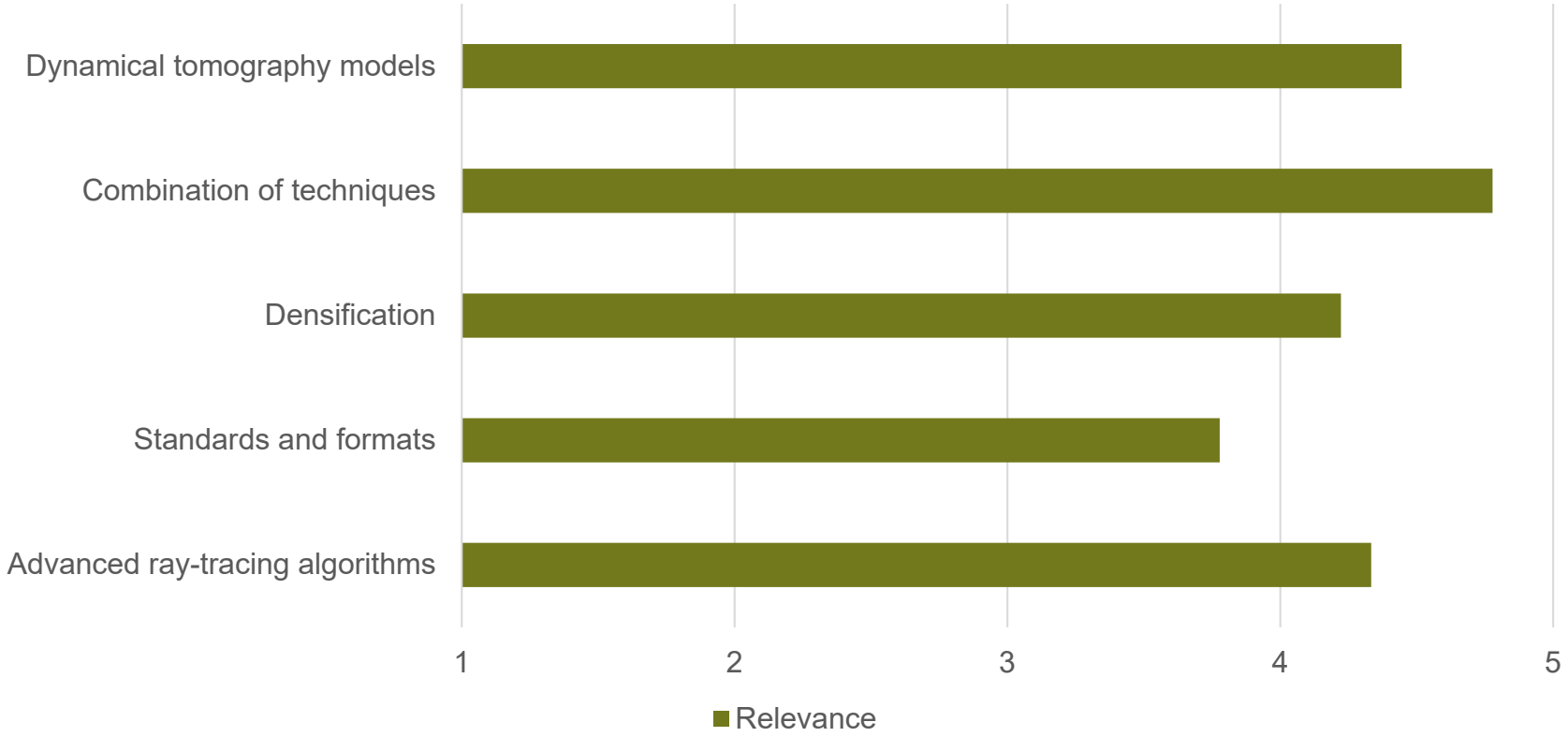
Contents

- Initial survey
- Objectives of the working group
- Ongoing activities
- Summary

Initial survey

What are the objectives you would like to see addressed in the next 4 years of the tomography working group?

List of top 5



Initial survey

What are the objectives you would like to see addressed in the next 4 years of the tomography working group?

Further suggestions

- Comparisons with other methods alternative to tomography (e.g. collocation)
- Real-time processing
- Reconstruction of wet refractivity gradients
- Explore use of geostationary imagers and sounders
- Detection of storms using GNSS tomography
- Practical/science applications of tomography
- Tomography assimilation

Objectives of the working group

- Combination of techniques
  Ground-based GNSS, radio occultation, InSAR, radiometer, …
- Advanced processing strategies
  Dynamic models, dense networks, atmospheric bending, …
- Promote tomography applications

Ongoing activities @ BIRA

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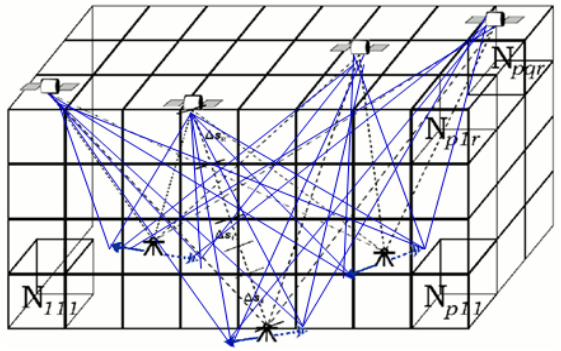
Illustration of additional **pseudo-slant observations** in GPS tomography.



Recommendation of improving the geometrical matrix of tomography retrievals with pseudo-slant observations.

remote sensing
Open Access Article

Cross-Comparison and Methodological Improvement in GPS Tomography

by Hugues Brenot[1,*], Witold Rohm[2], Michal Kačmařík[3], Gregor Möller[4], André Sá[5], Damian Tondaś[2], Lukas Rapant[6], Riccardo Biondi[7], Toby Manning[8] and Cédric Champollion[9]

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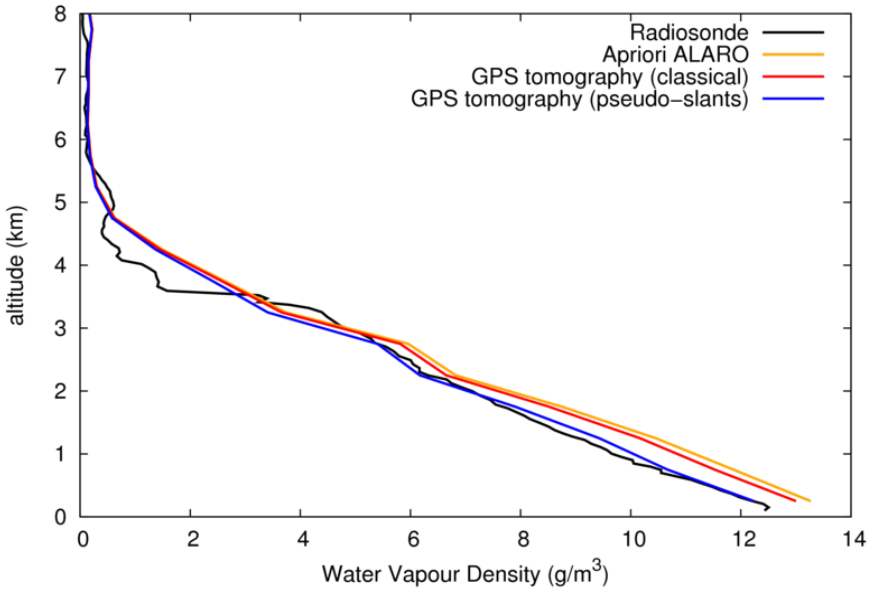


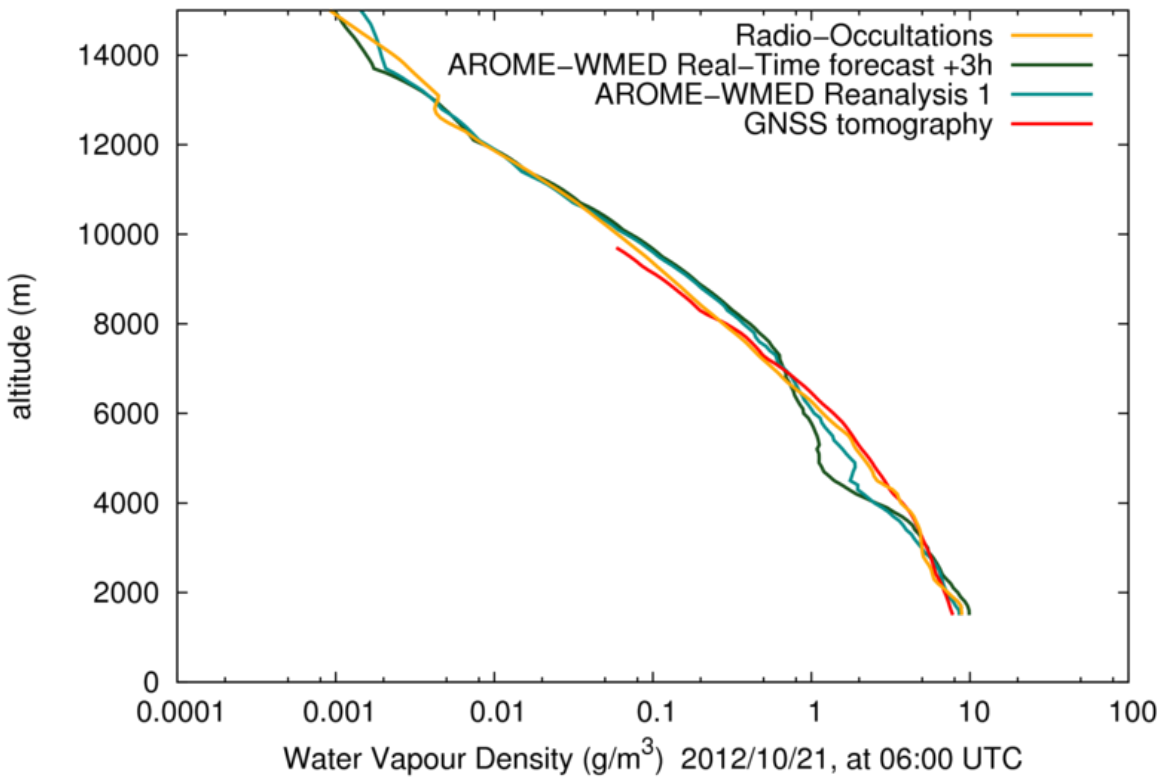
Application to the Belgian **dense network** (baselines from 5 to 30 km) during the pouring rains of 15-17 August 2010 (weather depression called Yvette by German meteorologists).

www.stce.be
Solar Terrestrial Centre of Excellence (STCE)

Ongoing activities @ BIRA

This work focusses on IOP15b (21-22 October), investigating the interest of GNSS tomography for **nowcasting** (retrievals of water vapor density, wet and total refractivity, with a **resolution of 10 km horizontally and 0.5 km vertically**).

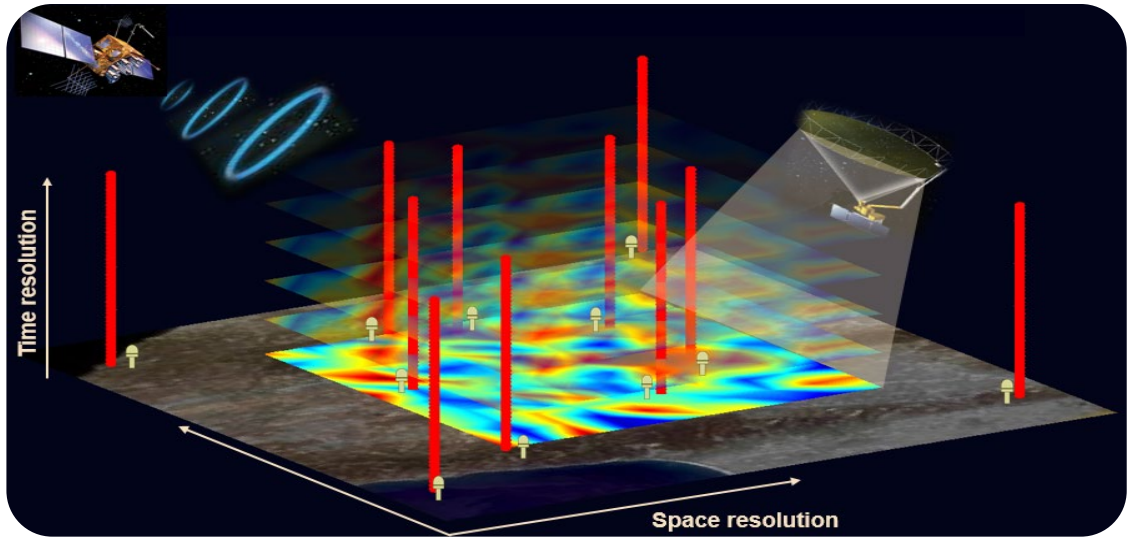
The sensitivity to a priori (initialisation of the GNSS tomography), has been investigated by considering both very-short-term forecasts (e.g. **real-time forecasts +3h**) and analyses (and e.g. **reanalysis**) from a high resolution numerical weather prediction system (NWP); i.e. AROME-WMED with a domain covering the western Mediterranean area. Pseudo slant observations have been considered in GNSS tomography to improve the geometrical distribution considered in retrievals (see Brenot et al., 2013, 2014, 2020).



HyMeX

https://www.hymex.org

Ongoing activities @ ETH Zürich



GNSS/InSAR combination

GNSS - ZTDs

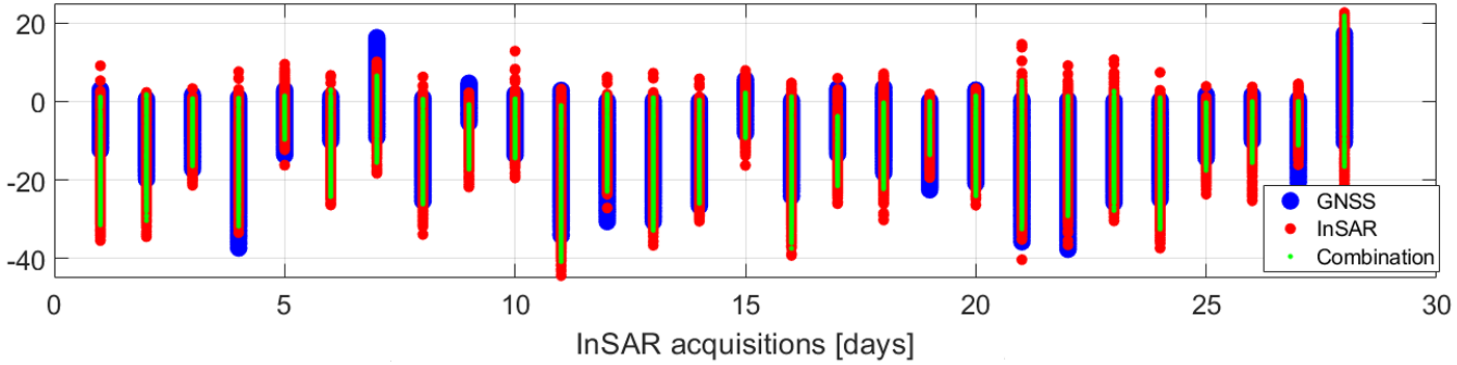
- Absolute measurements
- High temporal resolution
- Low spatial density

InSAR - ddSTDs

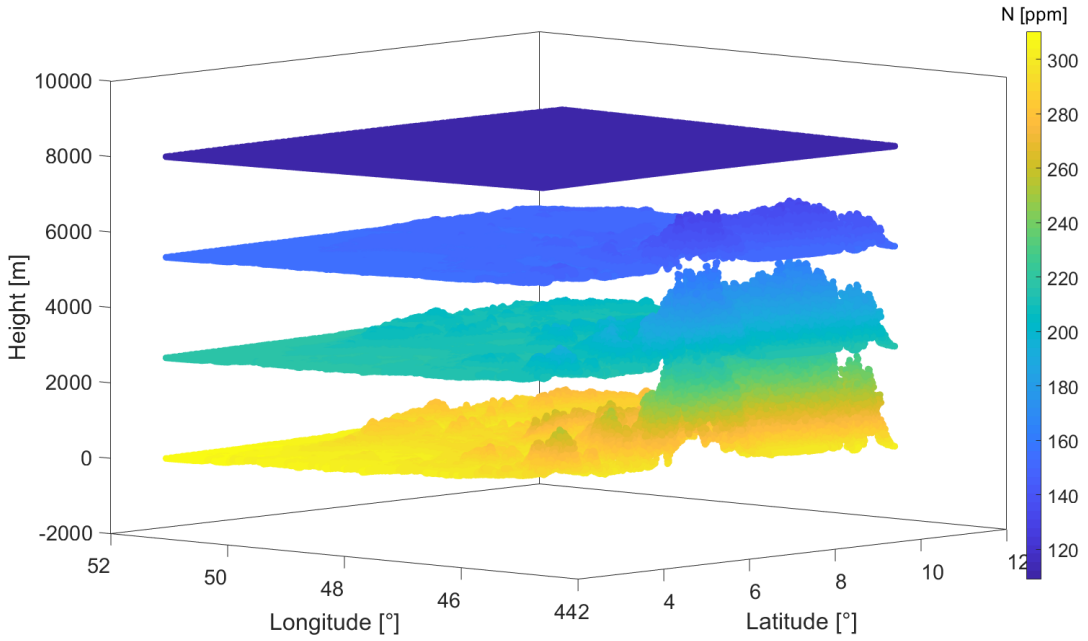
- Relative measurements
- High spatial density
- Low temporal resolution

COMEDIE: Collocation of Meteorological Data for Interpretation and Estimation of tropospheric path delays: 1) model of ZTDs, ddSTDs and 2) model of ZTD and ddSTD correlations

ddSTDs: Combination is more congruent with InSAR



Ongoing activities @ ETH Zürich



Refractivity fields from COMEDIE

ZTD	$(ZTD_0 + a_{ZTD}(x - x_0) + b_{ZTD}(y - y_0) + c_{ZTD}(t - t_0))e^{-\frac{z}{H_{ZTD}}}$
N_{tot}	$\frac{1}{H_{ZTD}}(ZTD_0 + a_{ZTD}(x - x_0) + b_{ZTD}(y - y_0) + c_{ZTD}(t - t_0))e^{-\frac{z}{H_{ZTD}}}$
$ddSTD$	$MF_1 \times ZTD(x, y, z, t_1) - MF_2 \times ZTD(x, y, z, t_2)$
$C_{ss}(N, ZTD)$	$\frac{\sigma_0^2}{q^2}\left[\frac{2 \cdot (-z_{ZTD} + z_N)}{(\Delta z_0)^2} \cdot e^{-\frac{z_N + z_{ZTD}}{2z_0}} + \frac{1 - q}{2z_0}\right]$
$C_{ss}(ddSTD_{p1}, N_{p2}^{t1})$	$MF_{p1}^{t1} \times C_{ss}(ZTD_{p1}^{t1}, N_{p2}^{t1}) - MF_{p_{ref}}^{t1} \times C_{ss}(ZTD_{pref}^{t1}, N_{p2}^{t1})$

- Input: ZTDs (InSAR ddSTDs)
- Output: Refractivity at any point
- Fast computation of N
- Accuracy dependent on models

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Ongoing activities @ GFZ

TUB/GFZ new project: Advanced MUlti-GNSS Array for Monitoring Severe Weather Events (AMUSE)

The goals of AMUSE are:

- developments to provide **multi-GNSS STDs** instead of GPS-only
- developments to provide **high-quality slant tropospheric delays** instead of only zenith delays
- developments to provide **ultra-rapid** tropospheric information
- **monitoring and assimilation of the tropospheric products** by the German Weather Service

For more details: see poster D1828 EGU2020-9669

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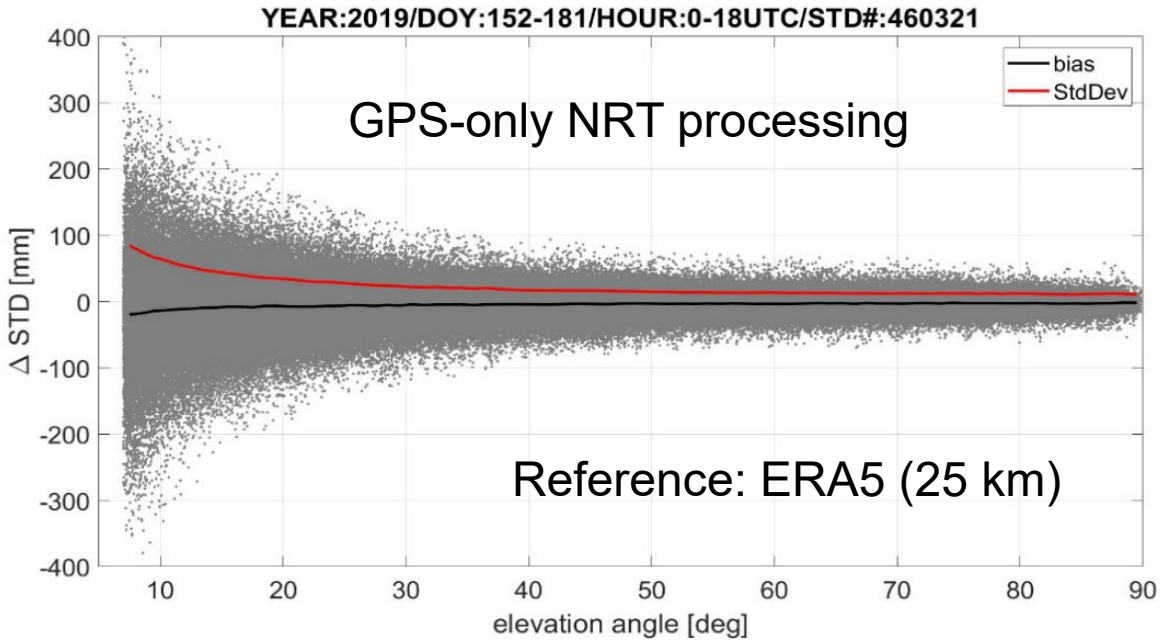
Ongoing activities @ GFZ

One important aspect of the project **AMUSE** is monitoring the quality of the GNSS-based products (e.g. by comparing with NWM)



Working on local tropospheric model for generating tropospheric ties

- based on data from IGS stations and Wettzell‘s footprint network (GNSS stations around Wettzell)
- using simple grid techniques and tomography
- compare with ray-tracing technique

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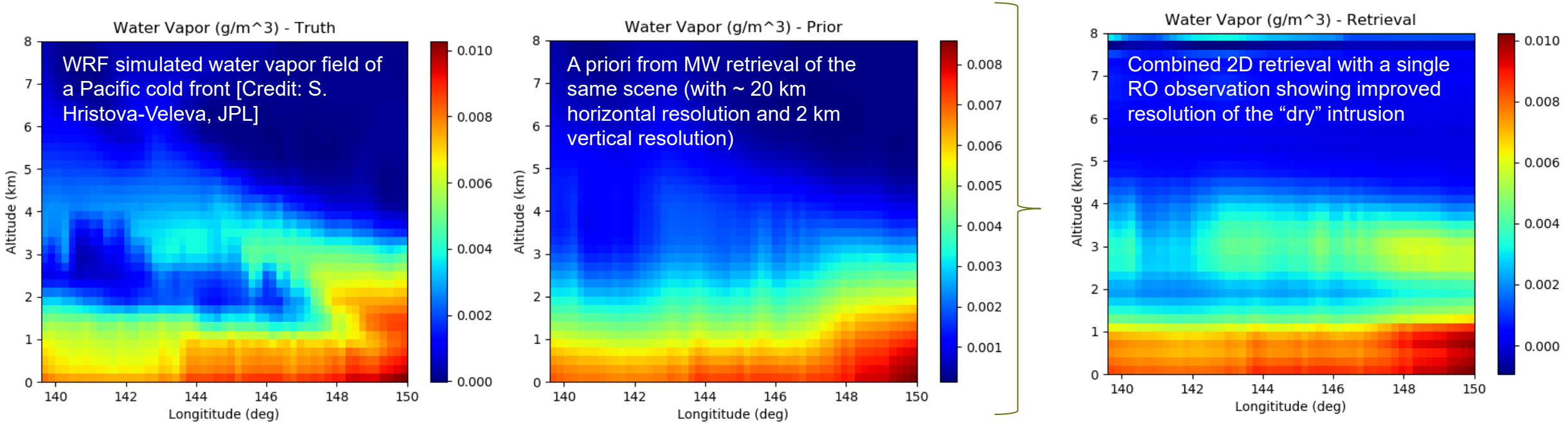
Ongoing activities @ JPL

Progress on Water Vapor Tomography from Combined GNSS-RO and Passive MW Measurements

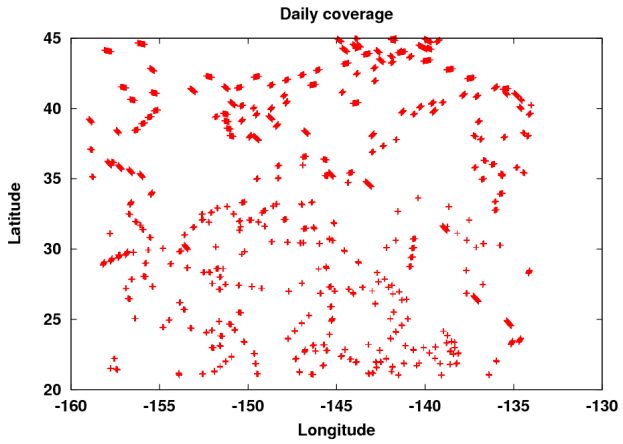
Chi O. Ao, George Hajj, and Kuo-Nung Wang

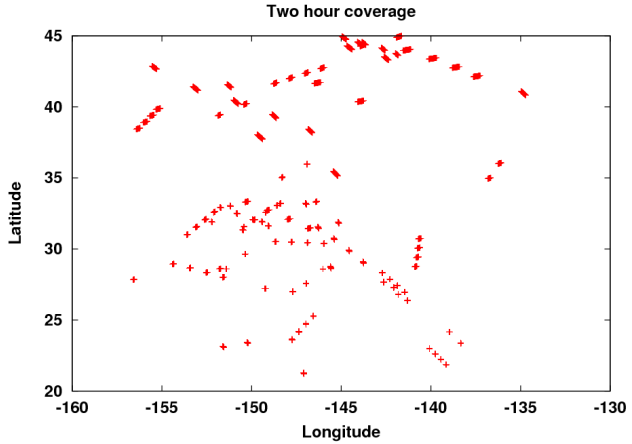
2D GNSS-RO retrieval with horizontal gradient from MW as a priori

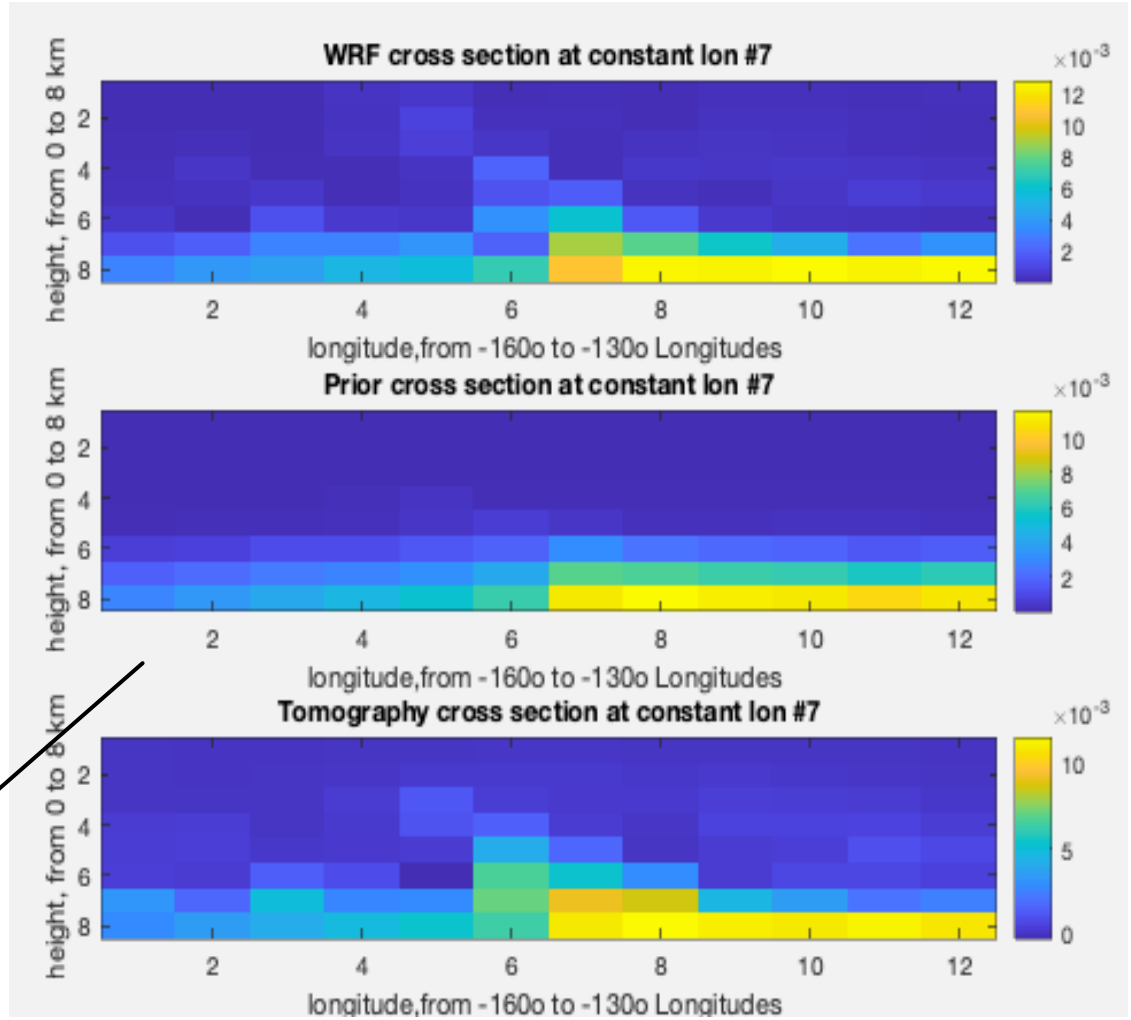


Ongoing activities @ JPL

Tomographic reconstruction from a constellation of 8 GNSS-RO receivers







Top: “Truth” at low-resolution

Middle: Prior at low-resolution

Bottom: Tomographic Reconstruction

Ongoing activities @ TU Wien, UPWr, UBI and partners

Assimilation of GNSS tomography wet refractivity fields

- Building the TOMOREF operator in the WRF DA system;
- EGU presentation: https://doi.org/10.5194/egusphere-egu2020-5339

ISSWIND: Improve wind speed and directon forecasts using GNSS tomography outputs

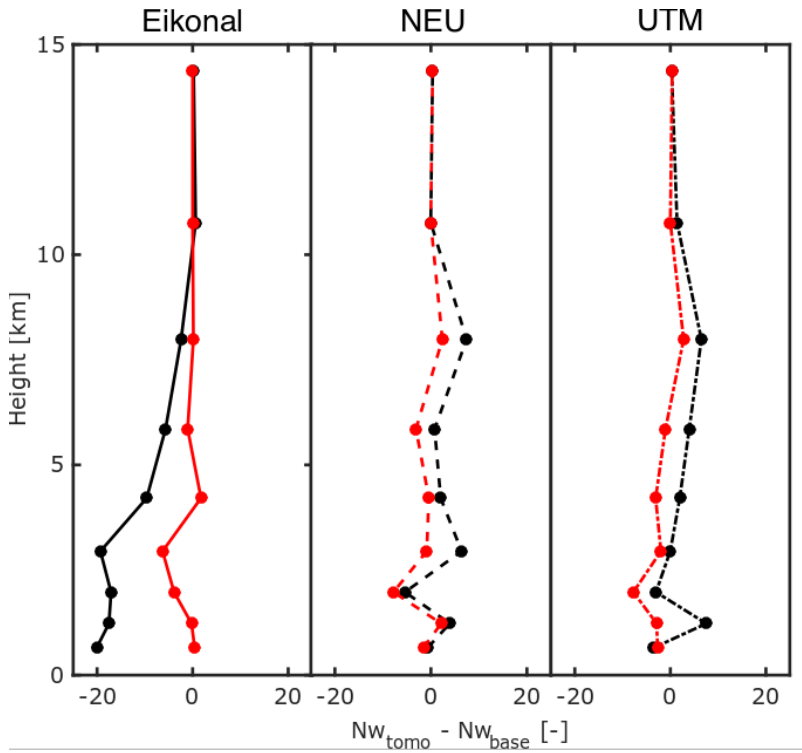
- Finding the most suitable tomographic model settings;
- Preparation of the tomographic outputs in the required format for assimilation;

Analysis of GOES-R as a Constraint in GNSS Tropospheric Tomography

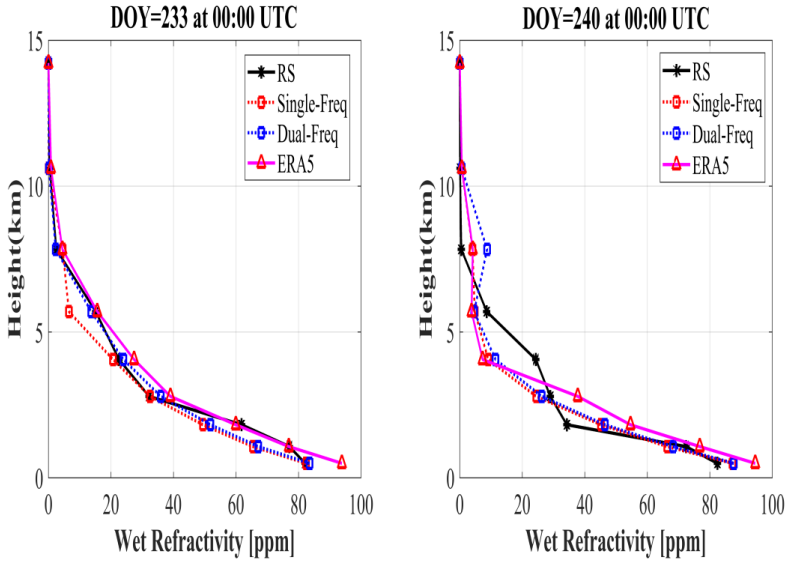
- The combination of wet refractivity maps computed from Geostationary Operational Environmental Satellite (GOES) sounder and refractivity fields obtained by GNSS tomography;
- EGU presentation: https://doi.org/10.5194/egusphere-egu2020-14965

Ongoing activities @ TU Wien, UPWr, UBI and partners

Analysing different parameterisation methods in GNSS tomography using the COST benchmark dataset



Assessment of single-frequency observations in GNSS Tropospheric Tomography



Ongoing PhD theses:

- **Combination of GNSS radio occultation profiles and GNSS tomography** (Natalia Hanna, natalia.hanna@geo.tuwien.ac.at)
- **Defining the temporal resolution of tomography based on ZTD gradients** (Zohreh Adavi, zohreh.adavi@geo.tuwien.ac.at)

Summary

- IAG working group on GNSS tomography
- Study period: 2019 – 2023
- Why tomography?
  - Assimilation of wet refractivities in numerical weather prediction models
  - Improve understanding of severe weather events
  - Wet refractivity fields for the correction of other space-geodetic techniques (like VLBI)
  - Space-based tomography on dense cubesat constellations

Interested in the activities of the working group?

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