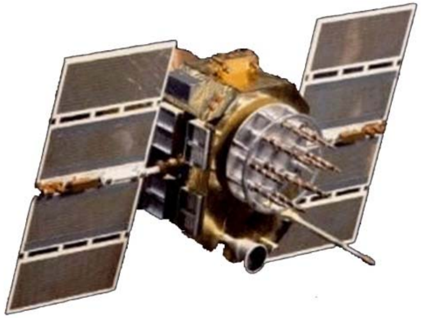
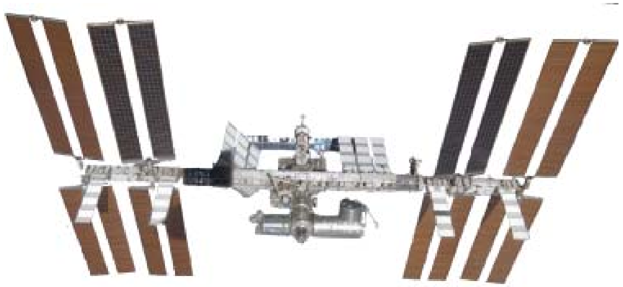
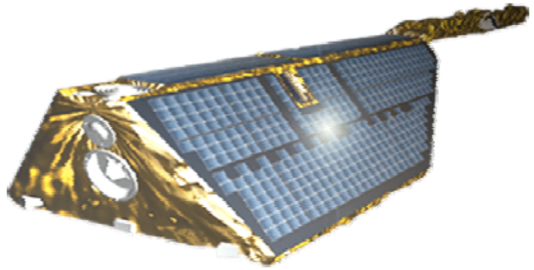
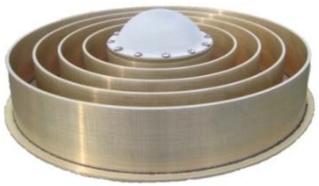




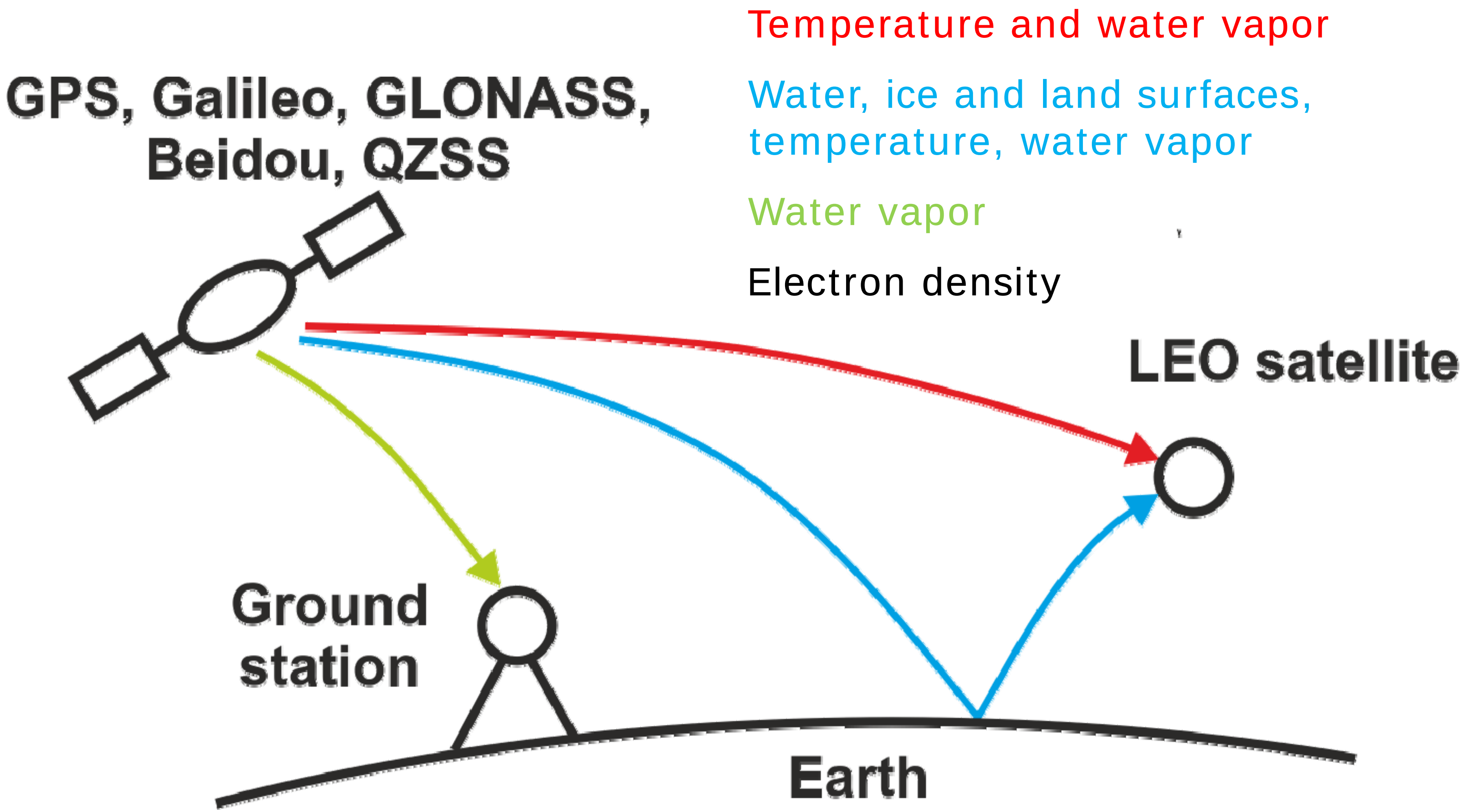
GNSS Atmosphere Sounding at GFZ: Overview and Recent Results

J. Wickert

F. AlShawaf, C. Arras, Z. Deng, G. Dick, M. Fritsche, S. Heise, X. Li, C. Lu, M. Ramatschi, T. Schmidt, M. Semmling, T. Simeonov, S. Vey, F. Zus, H. Schuh

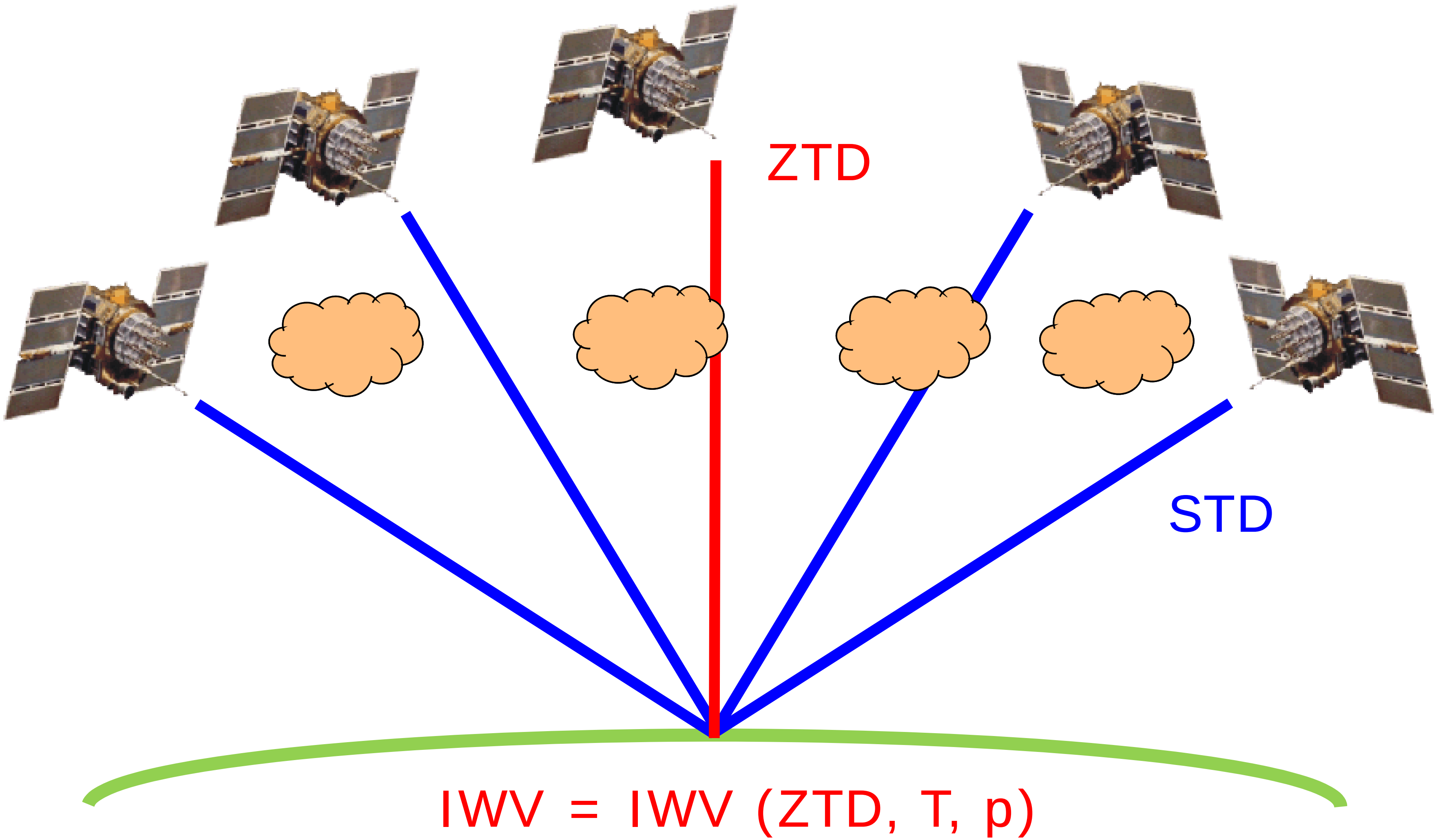



GNSS propagation errors and remote sensing

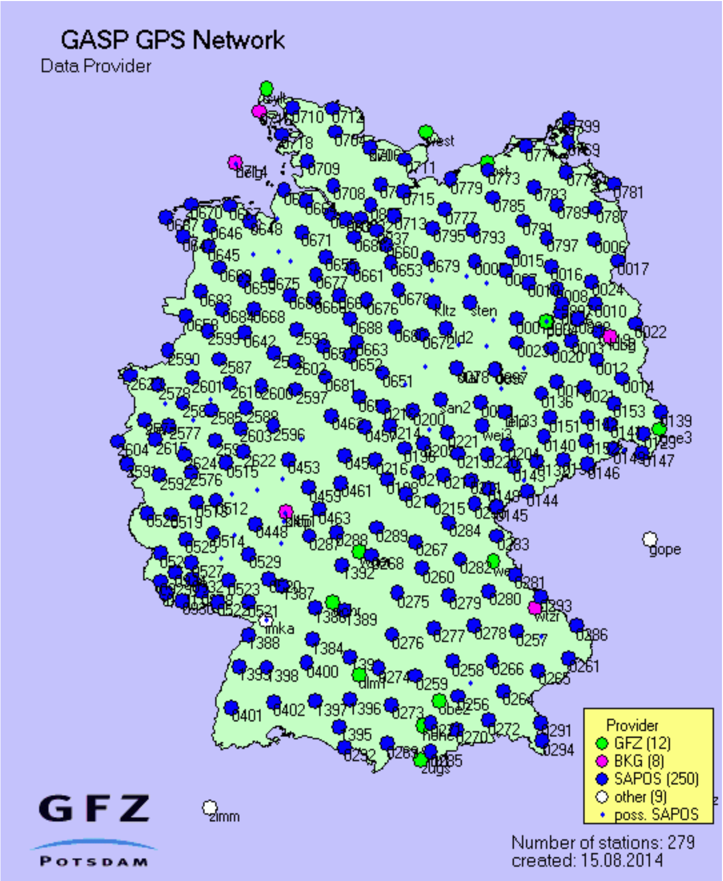


Atmosphere Sounding:
An established technique

Zenith/Slant Total Delay (ZTD, STD), and Integrated Water Vapor (IWV)

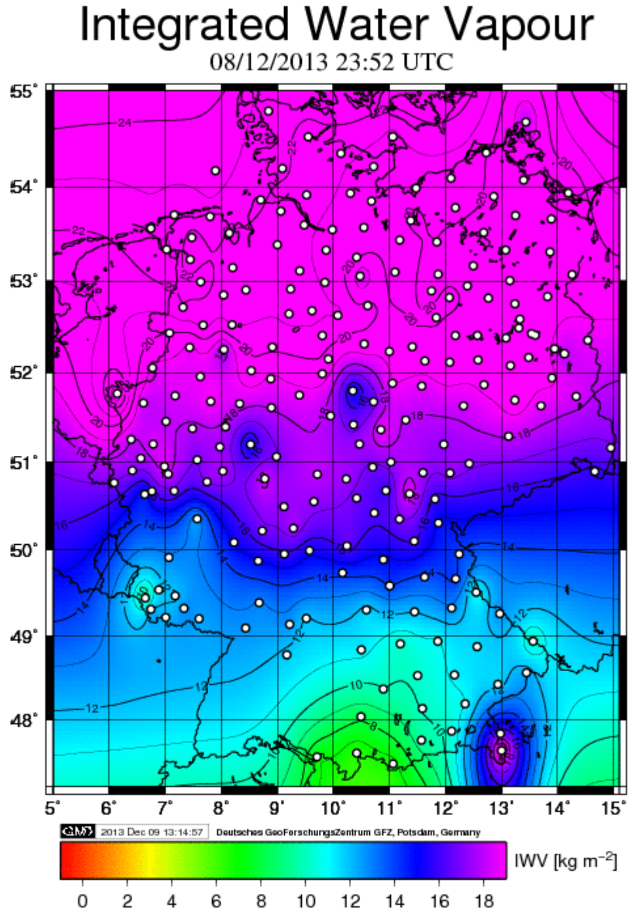


Operational ZTD/IWV/STD Monitoring



Zenith Total Delay,
Integrated Water Vapor,
Slant Total Delay

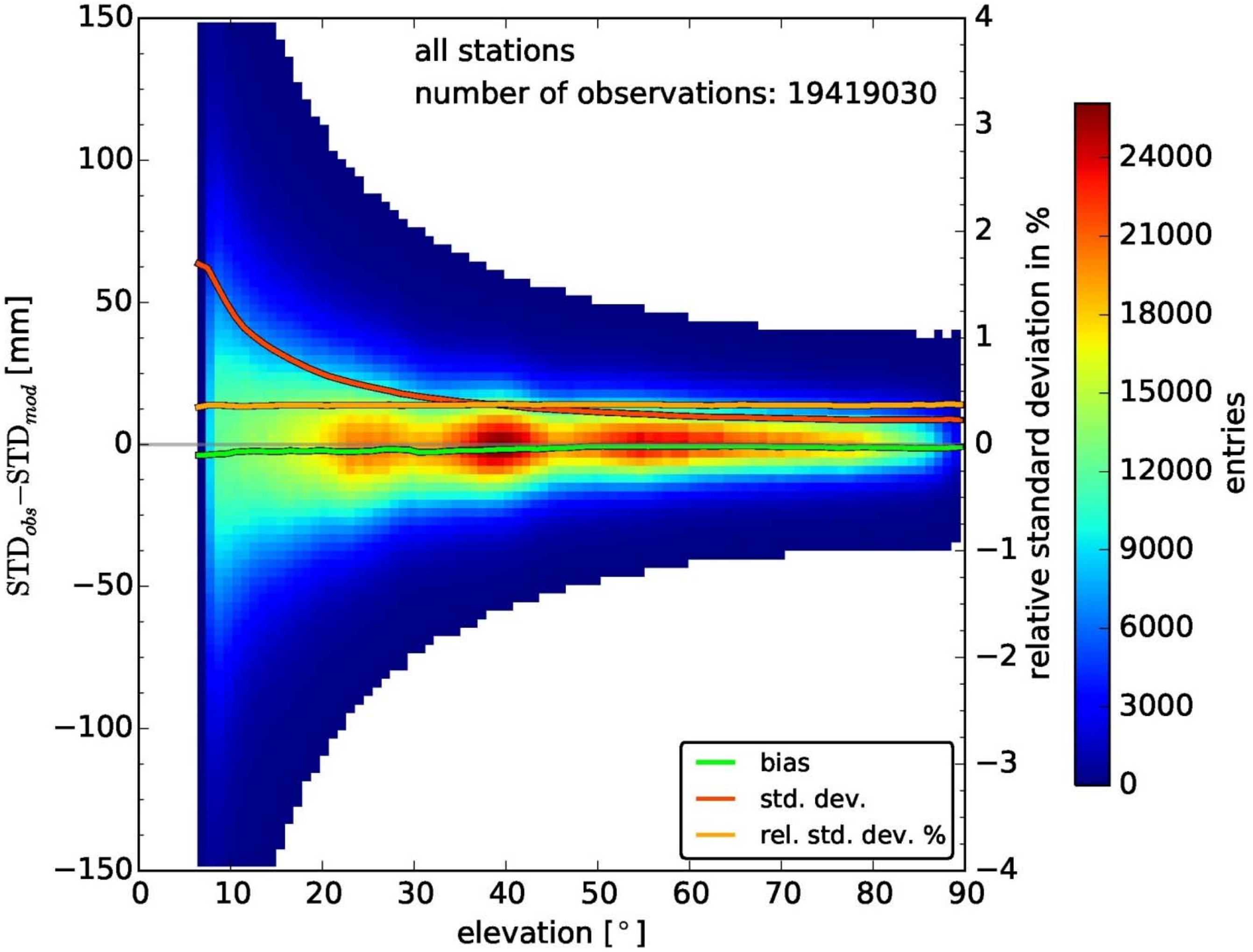
in Near-Real Time



Hurricane Xaver December 8, 2013
Severe weather warning for Hamburg

- Average delay 1 h from observation
- Operational use by several European Weather Services
- German Weather Service close to operational use (slant data, STD)

Validation „Slant operator“ with COSMO-DE

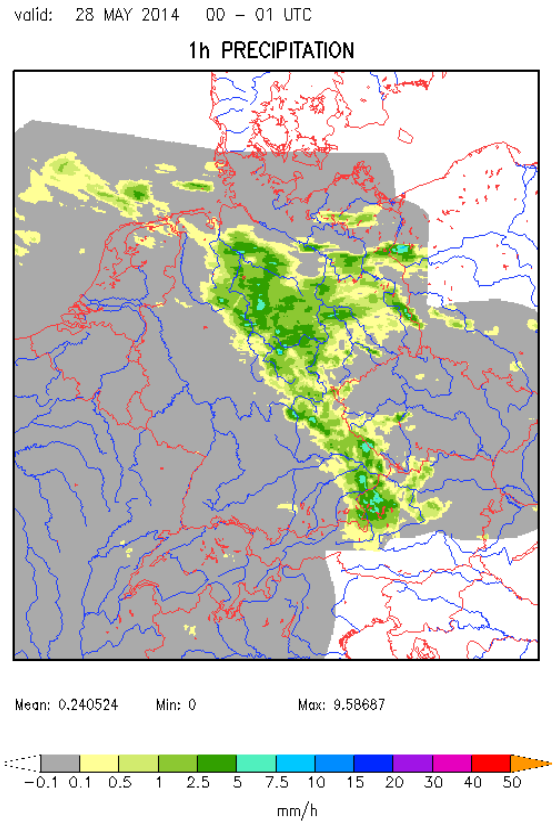


Statistics March 2015 (M. Bender, DWD)

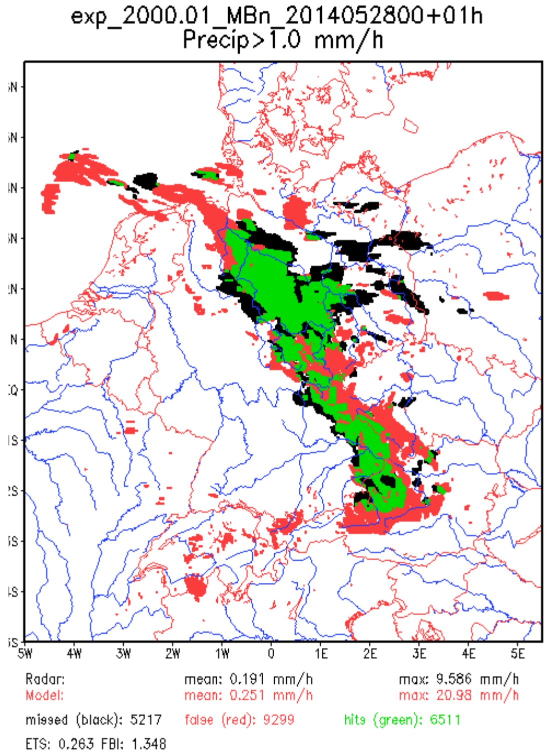
Precipitation forecast (DWD)

28.5.2014, 1:00 UTC, 0:00 UTC forecast, 1 mm/h threshold

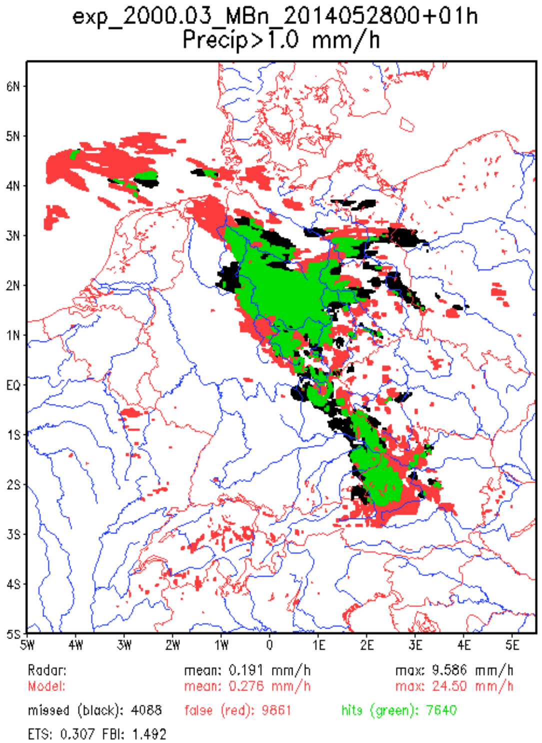
Radar observations



control experiment



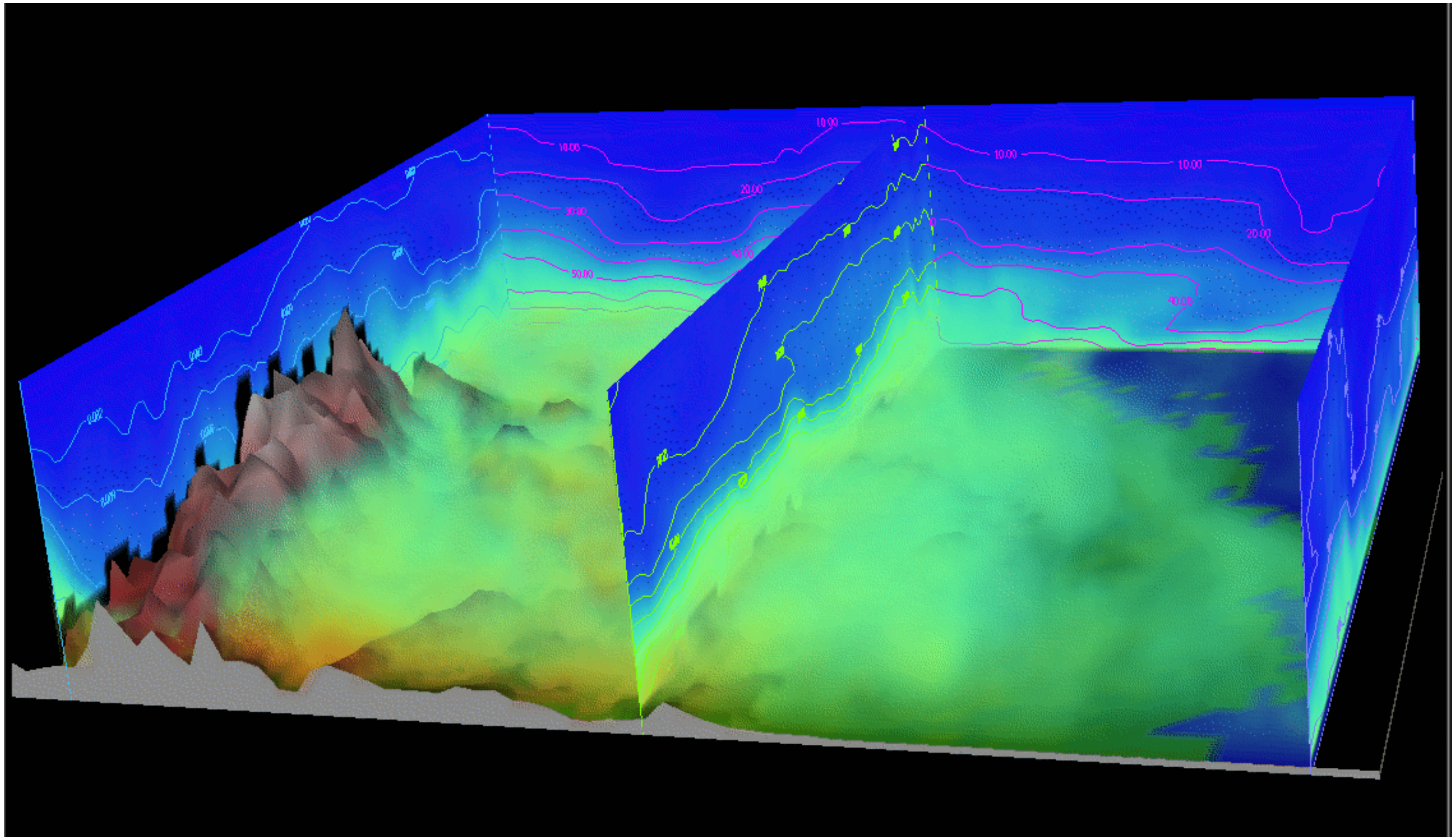
STD assimilation



	hit	miss	false	ETS
control experiment	6511	5217	9299	0.283
STD assimilation	7640	4088	9861	0.307

(M. Bender, DWD)

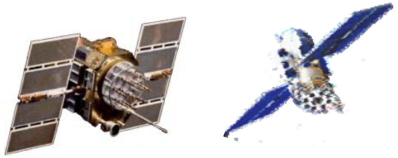
3D water vapor above Germany



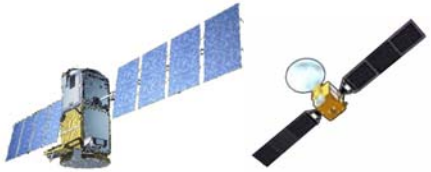
January 18, 2007, low pressure Kyrill
Tomography developed at GFZ (DFG project)

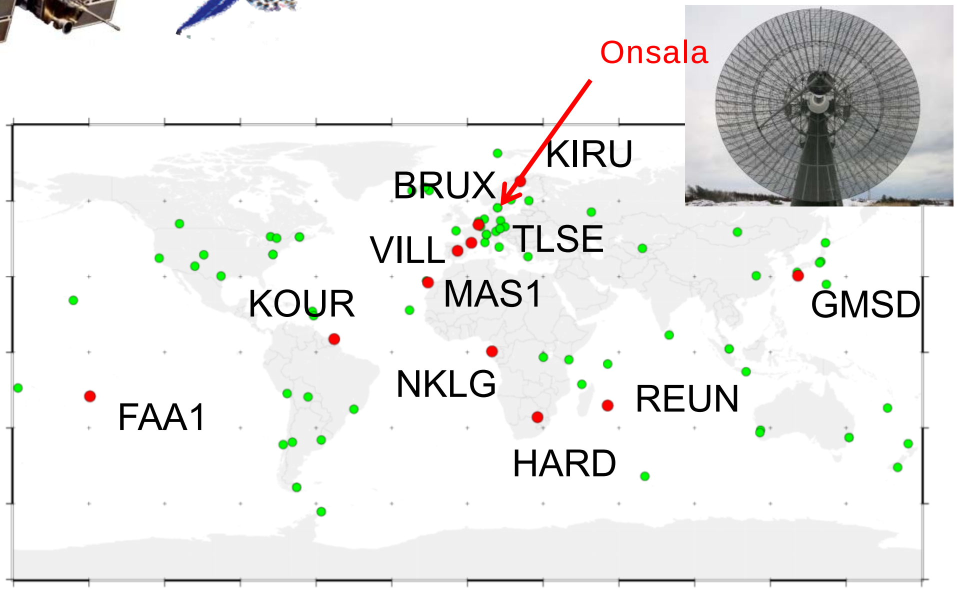
Bender et al., 2011

Multi-GNSS
activities
(only one example)



Initial Multi-GNSS Results

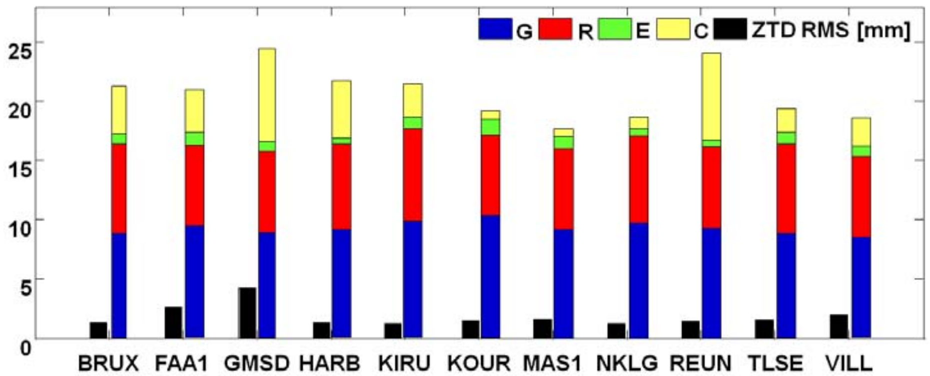


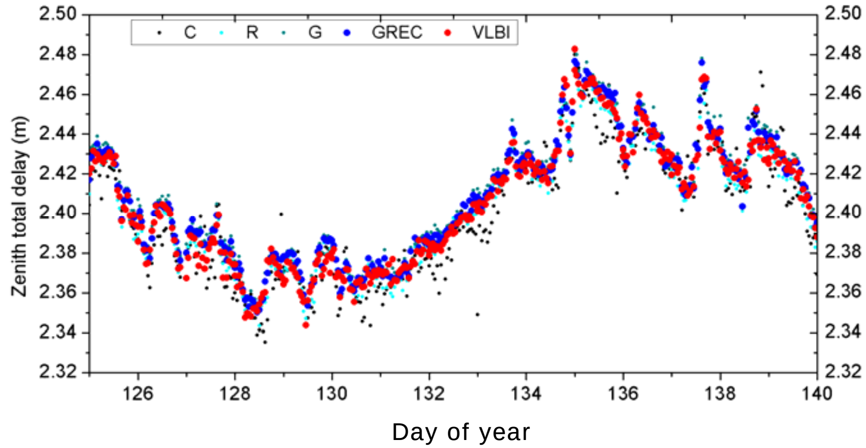


11 stations are processed in Multi-GNSS mode since 2014
~20 satellites for each station

More slants,
more stable ZTD and gradients

Additional ZTD comparison with VLBI at Onsala, Sweden
(RMS ~7 mm)

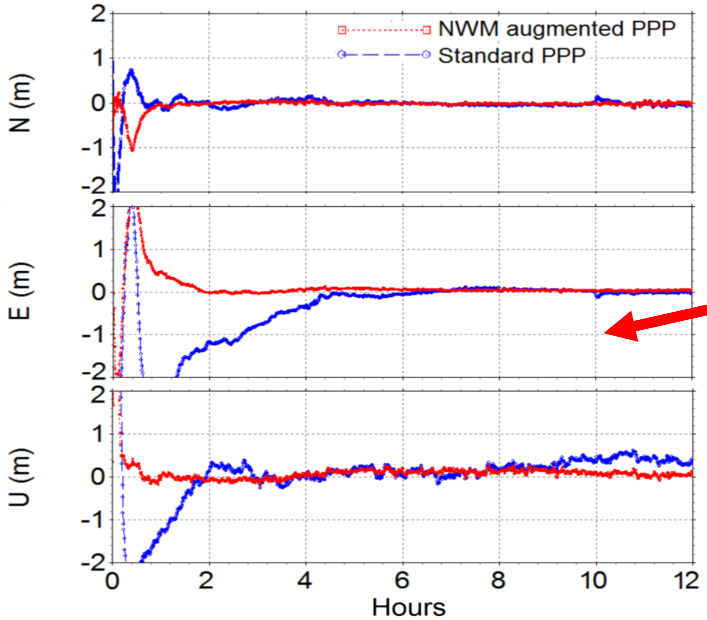




Thanks: VLBI group GFZ

Use of
Numerical Weather models
for
Precise Point Positioning

Weather models for Real-Time PPP



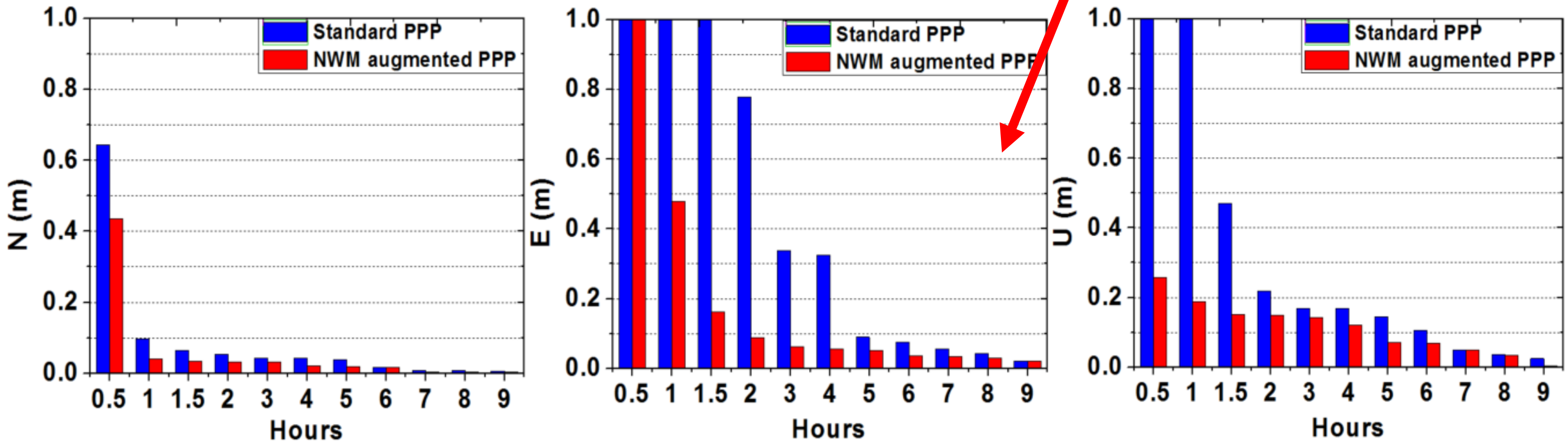
Numerous investigations, ISI published (Li et al., Lu et. al) here: BeiDou

RT-PPP for station at Japan (GMSD)

Convergence time

E: 4.5 h-standard PPP,
1.5 h-NWM PPP, 66.7%;
U: 2 h vs. 0.5 h, improve 75.0%.

Positioning results



Atmospheric models for GNSS processing (Neutral gas and Ionosphere)

* ray-trace sw by F. Zus (GFZ)

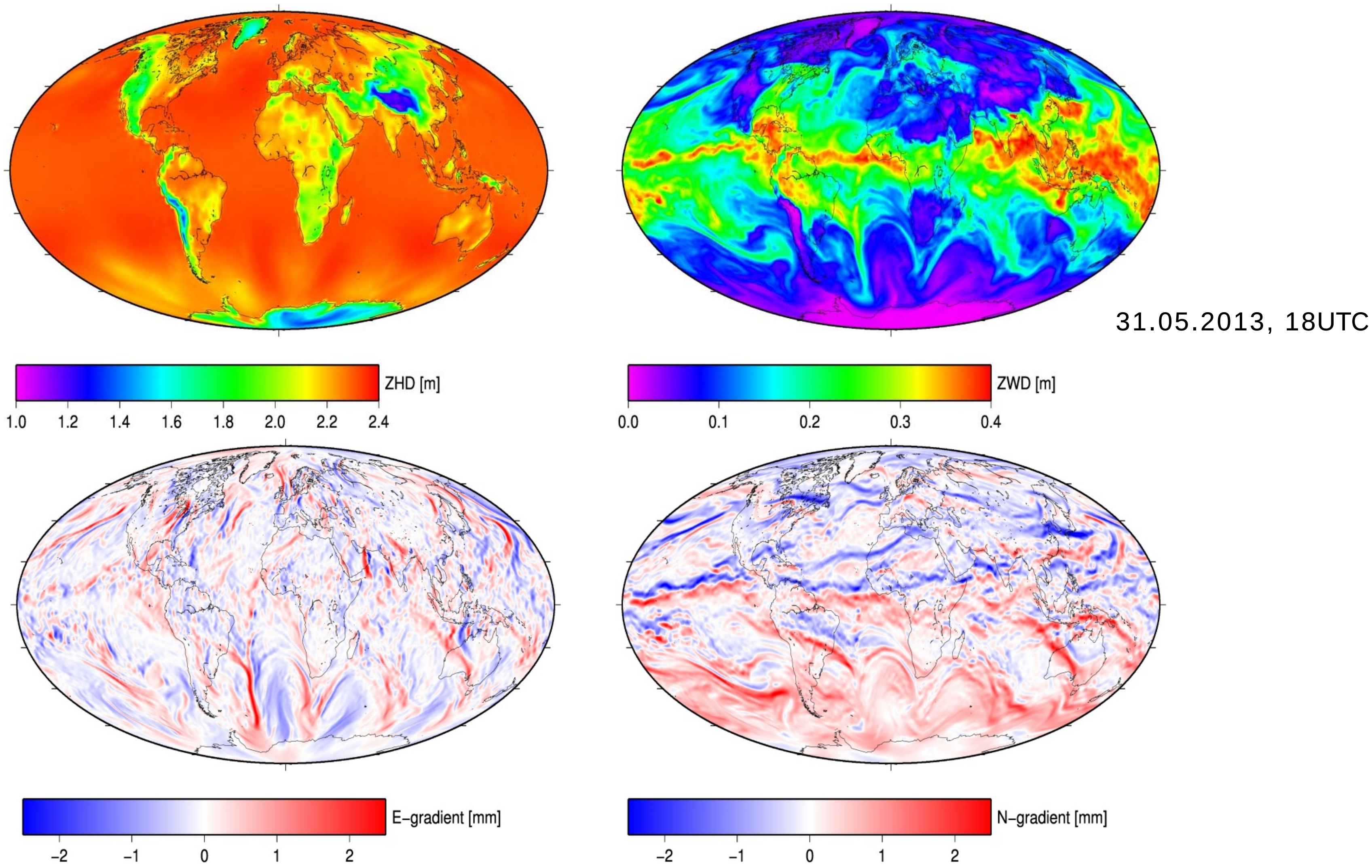
* Refractivity field: NCEP's GFS short range forecasts

* Electron density field: IRI-2016

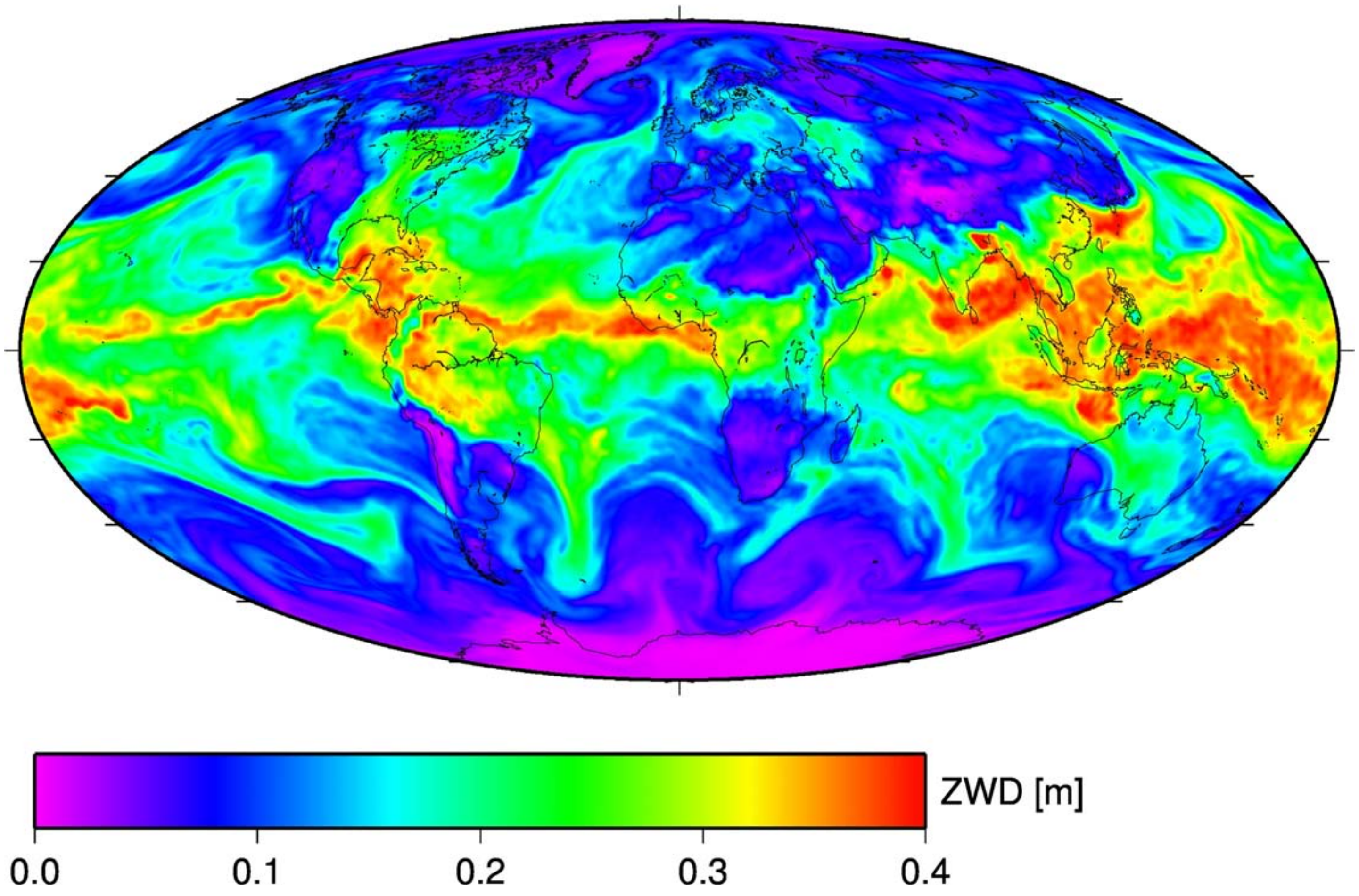
* Earth's magnetic field: IGRF12

* available every 3h with no latency for all IGS stations (on request zusflo@gfz-potsdam.de)

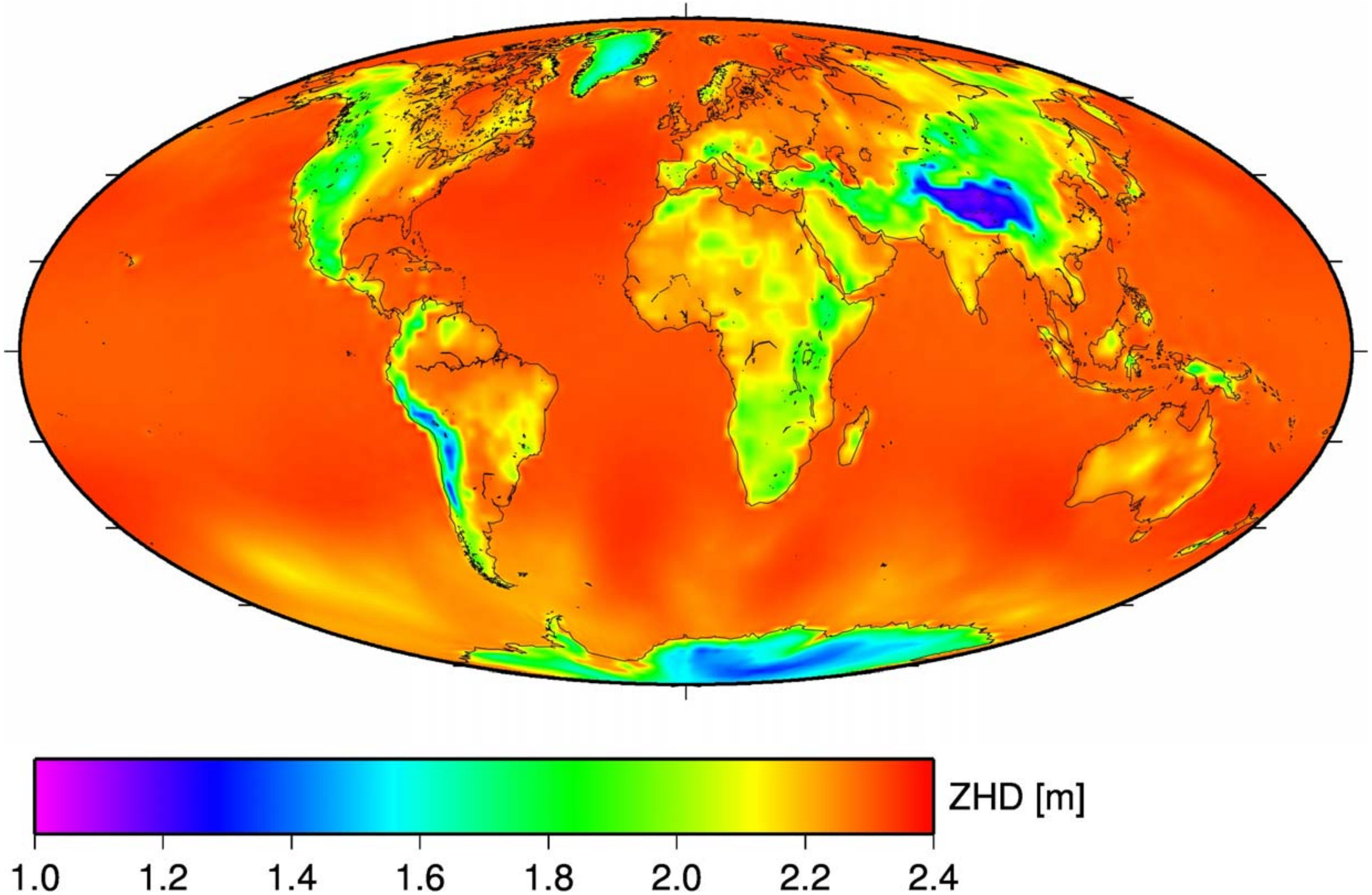
Tropospheric parameters:
MF, zenith delays & horizontal gradients



Variation of global **Z**enith **W**et **D**elay



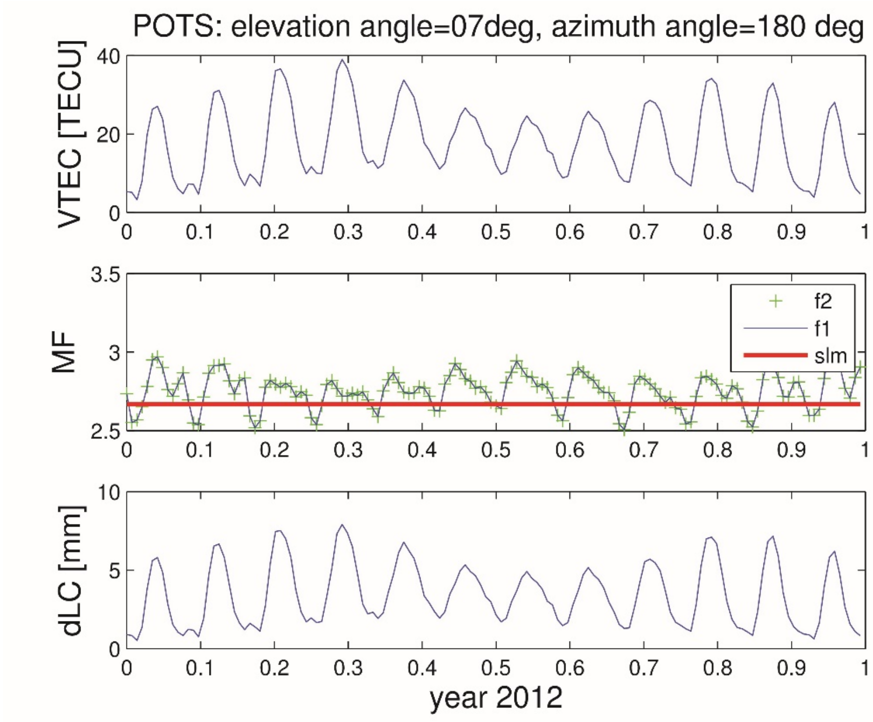
Variation of global Zenith Hydrostatic Delay



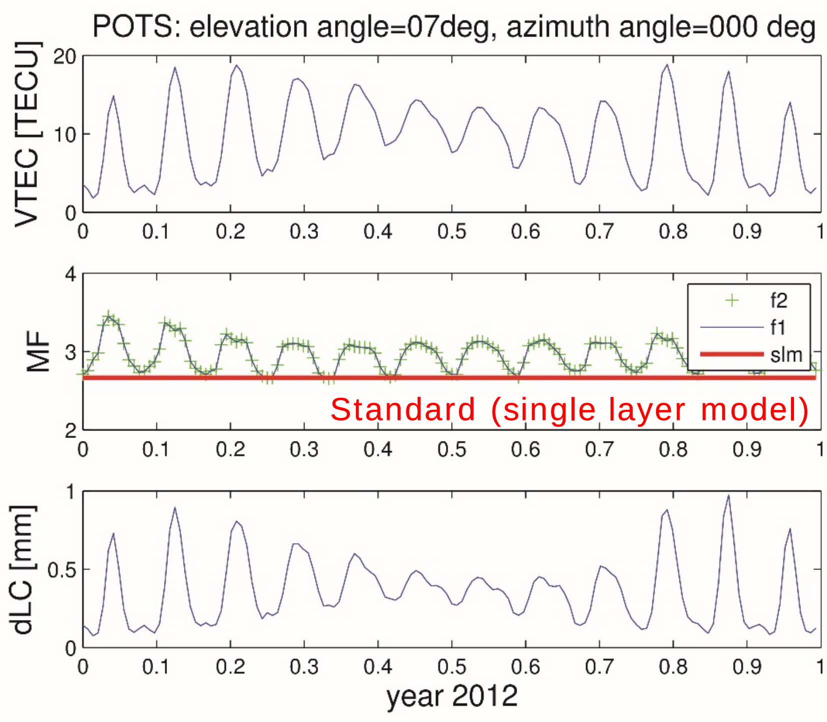
Ionospheric parameters: iMF & VTEC

Example: Station POTSdam

South view



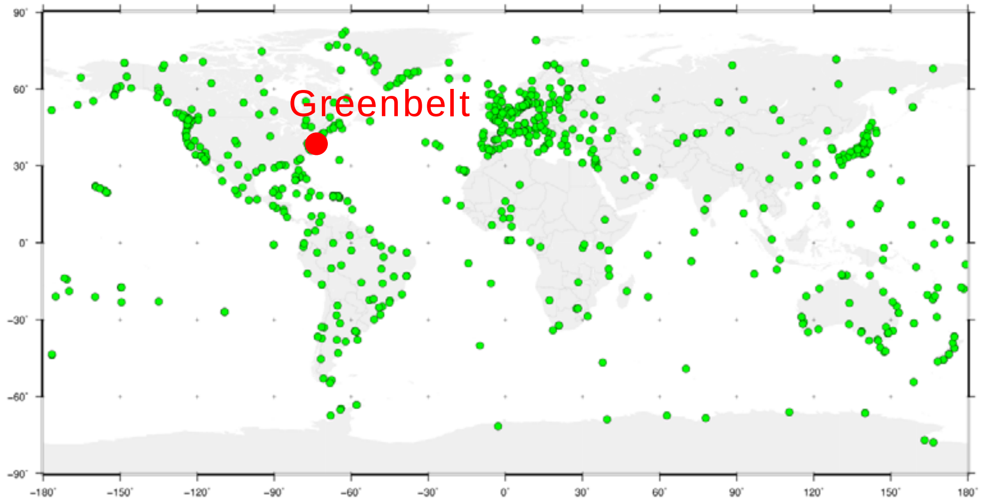
North View

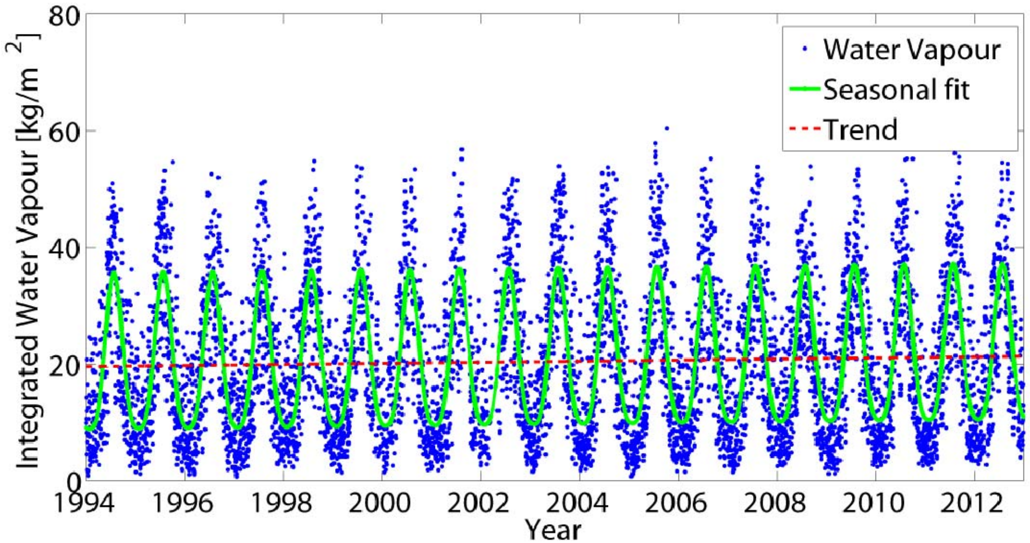


*each month consists of one day only (the respective 15th)

Atmosphere Sounding: Water vapor and climate

Long term water vapor trends





- Recent consistent reprocessing
- ~800 stations
- 19 years of data (1994 - 2013)

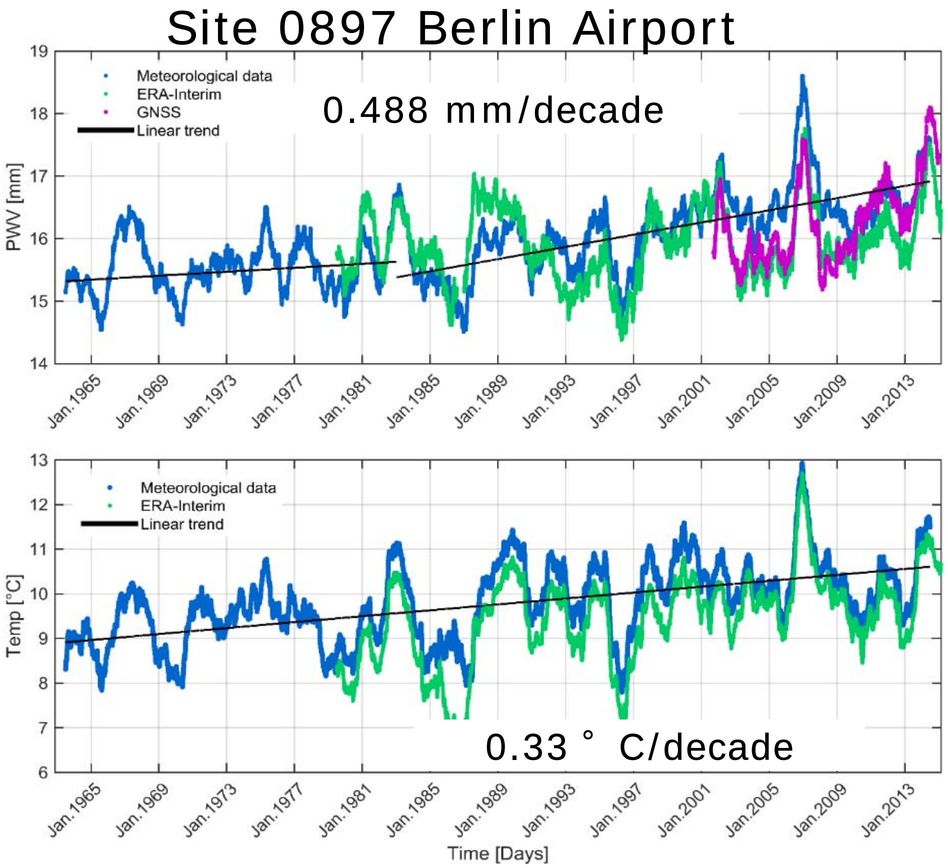
- Example:

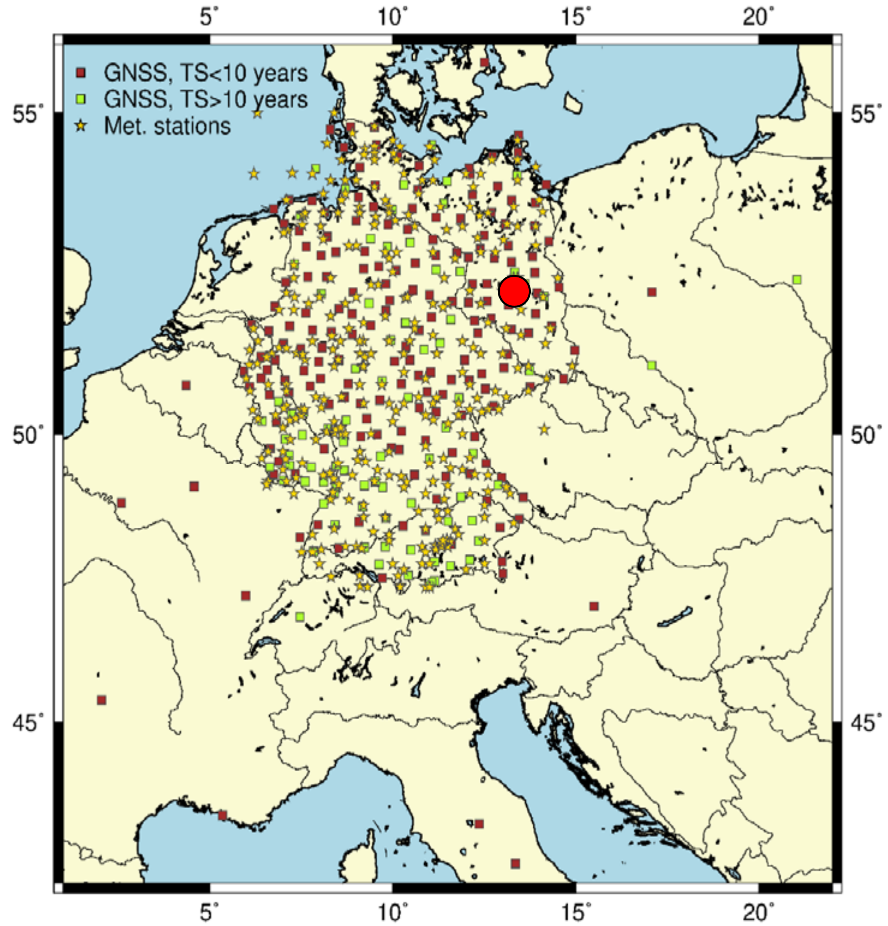
  Greenbelt (+0.94 mm/decade)
- Quality of the entire data set currently evaluated

Ning et al., J. of Climate, 2016

Water vapor trends

Monitoring of Temperature/Water vapor from GNSS (IWV) /SYNOP/ Model

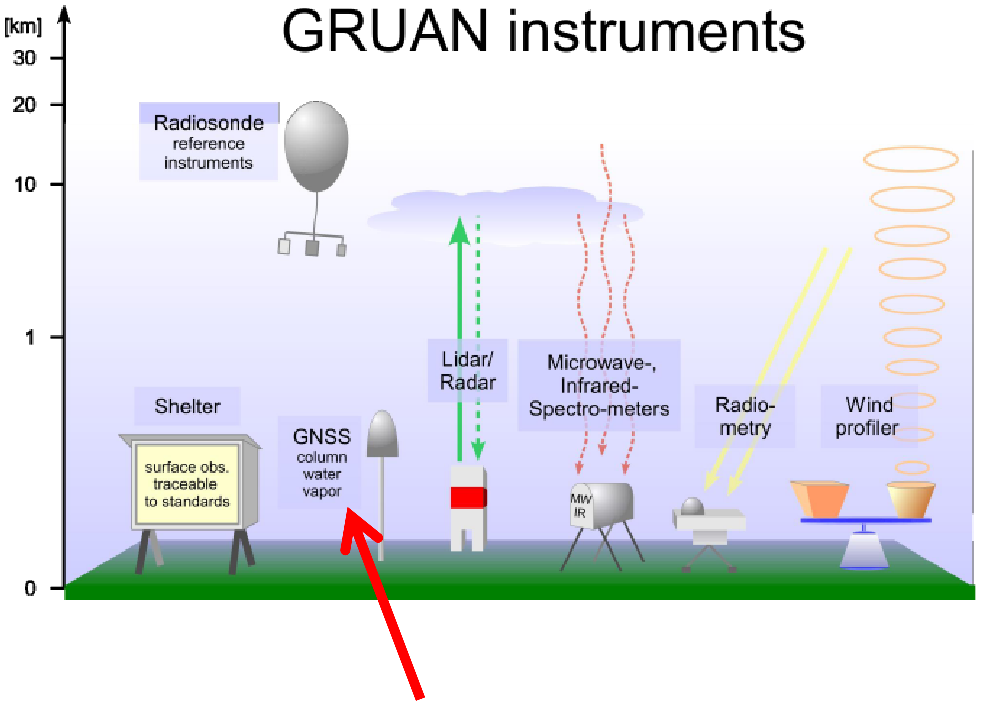




AlShawaf et al., AMT, 2016

GNSS for Global Climate Observing System (WMO)

GCOS Reference Upper Air Network (GRUAN, 16 stations)



GFZ GNSS stations
Ny Alesund, Lindenberg

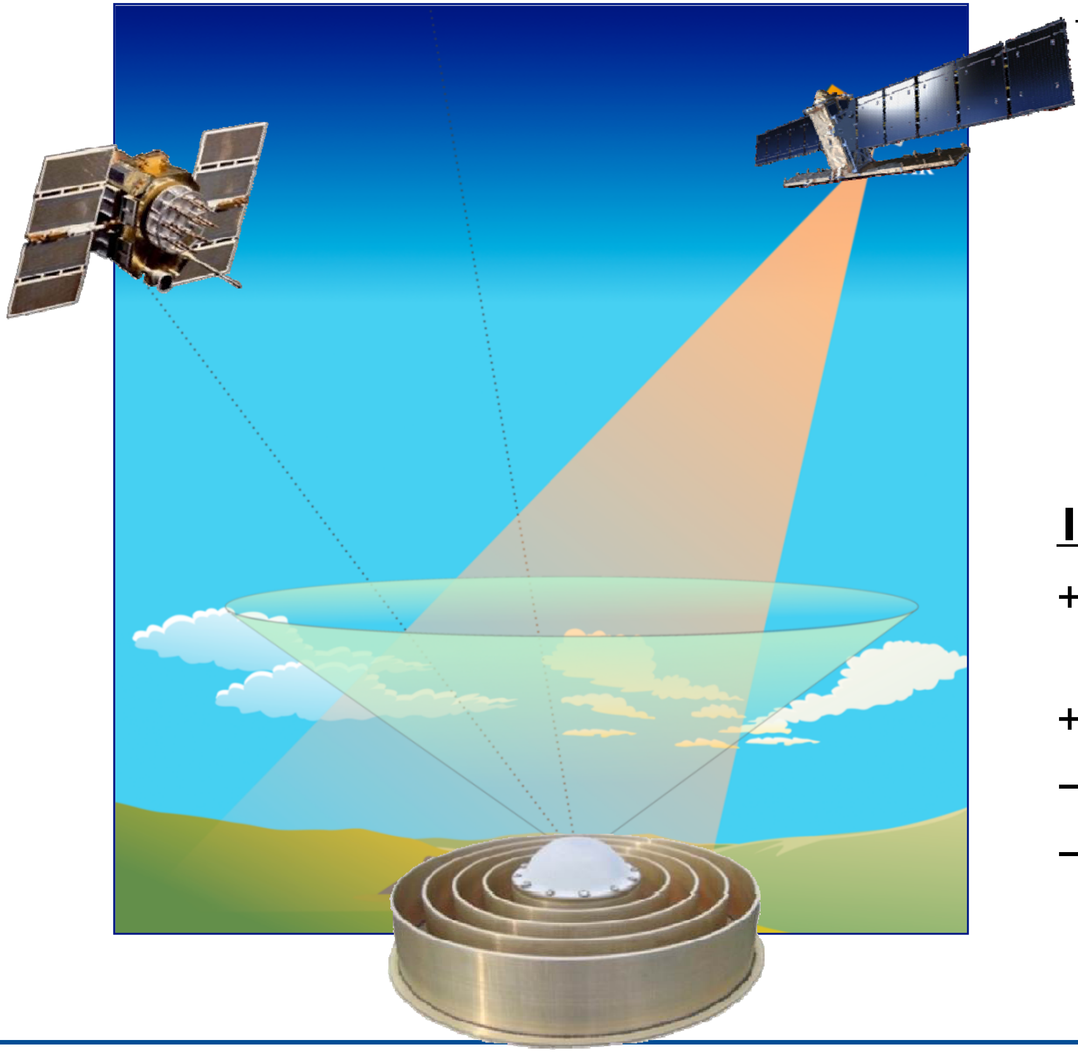
GNSS is standard technique for climate monitoring
GRUAN processing center at GFZ

GRUAN polar GNSS station

Sensor Combination:

GPS and SAR

Combination of WV from GNSS and InSAR



GNSS

+ Total water vapor content
+ High temporal resolution
− Pointwise measurements
− Spatial averaging

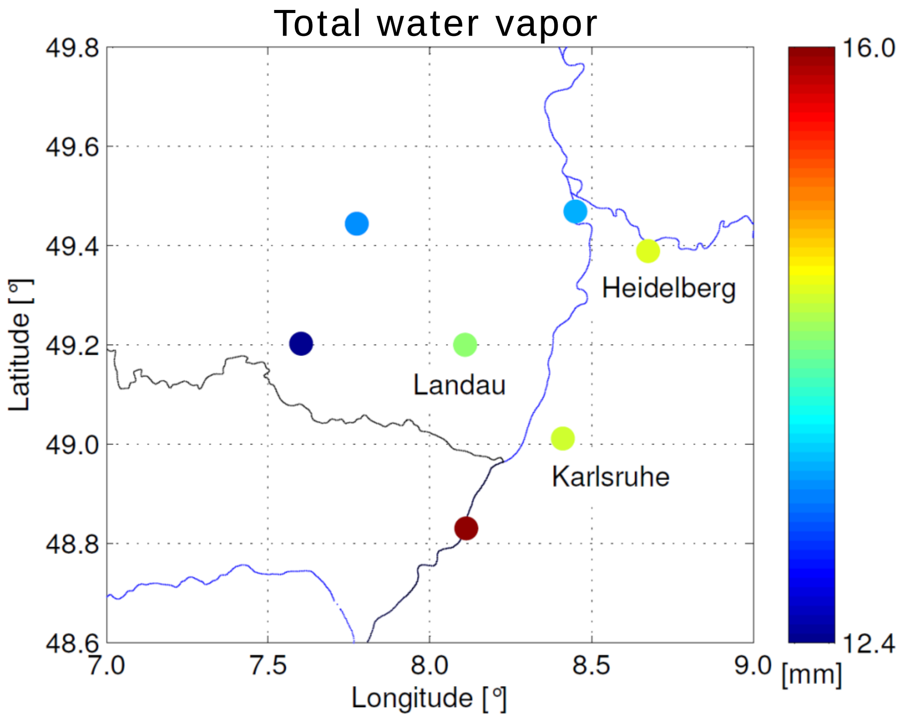
InSAR

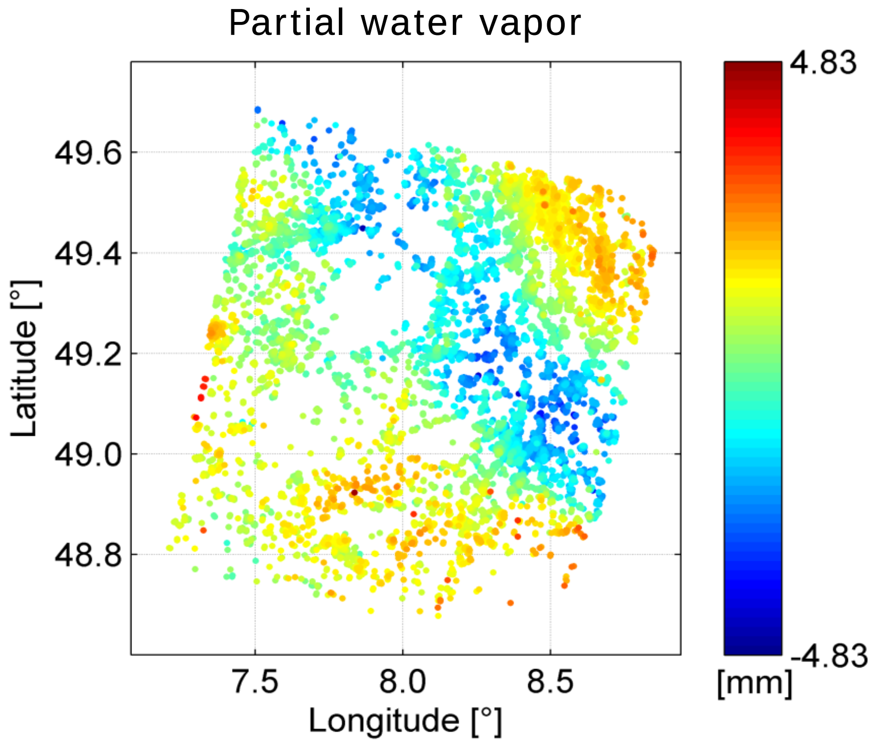
+Large coverage (e.g., 250 km for Sentinel)
+High spatial resolution
−Relative measurements
−Low temporal resolution

AlShawaf et al., JGR, 2015

IWV from GNSS and PWV from InSAR

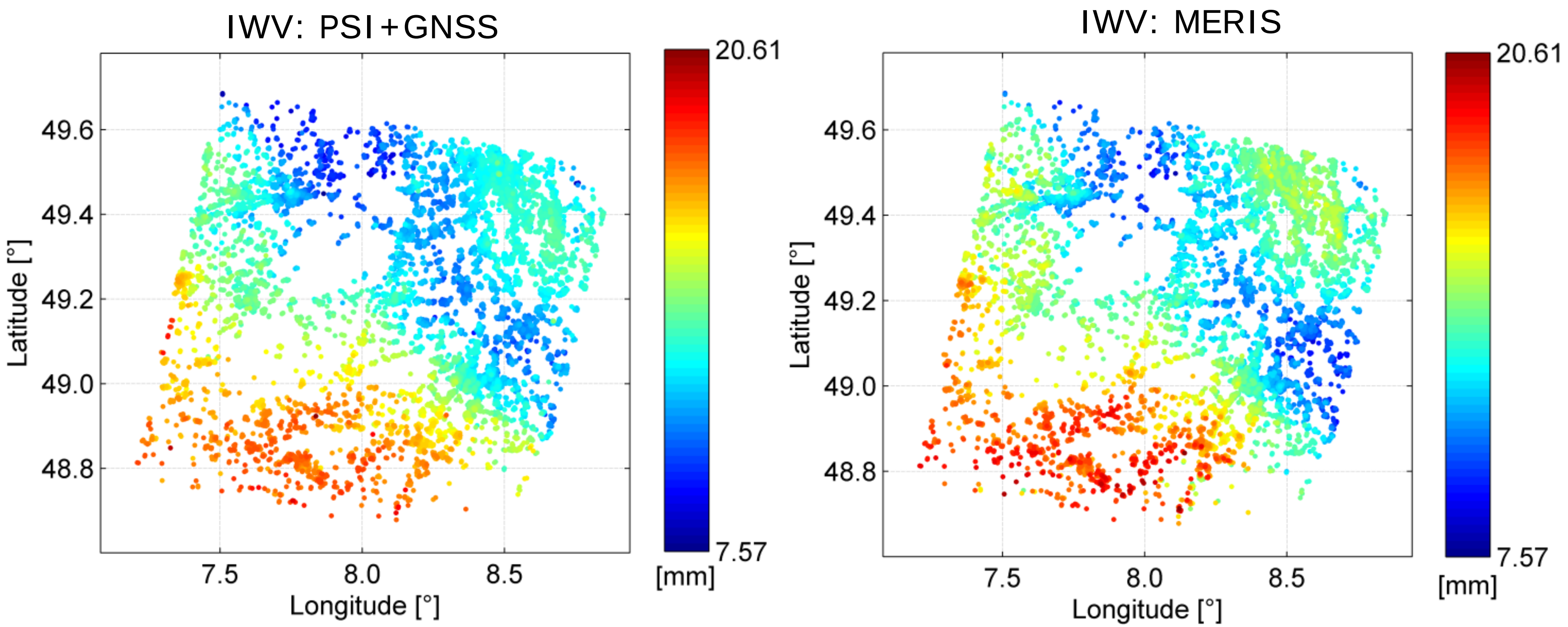
April 27, 2007





IWV from GNSS and PWV from InSAR

April 27, 2007

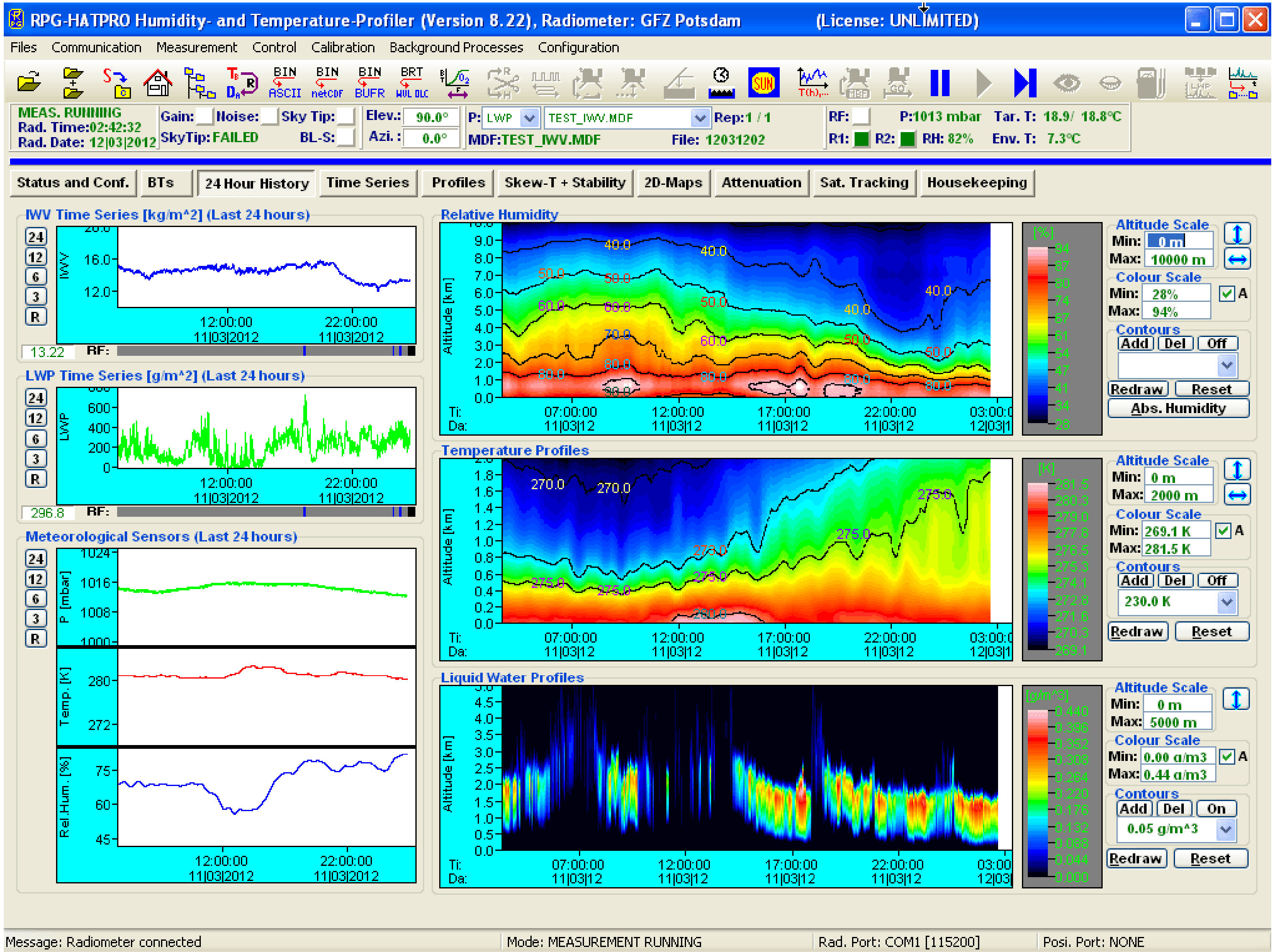


Corr. coefficient	**0.92**
Mean [mm]	-0.43
Standard Deviation [mm]	0.84

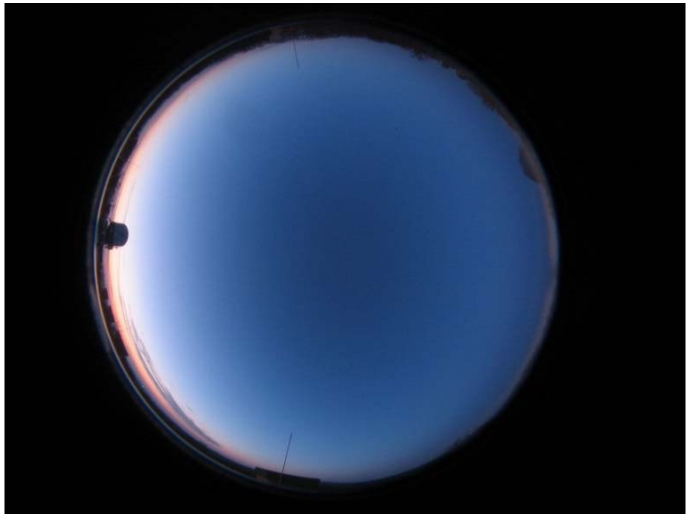
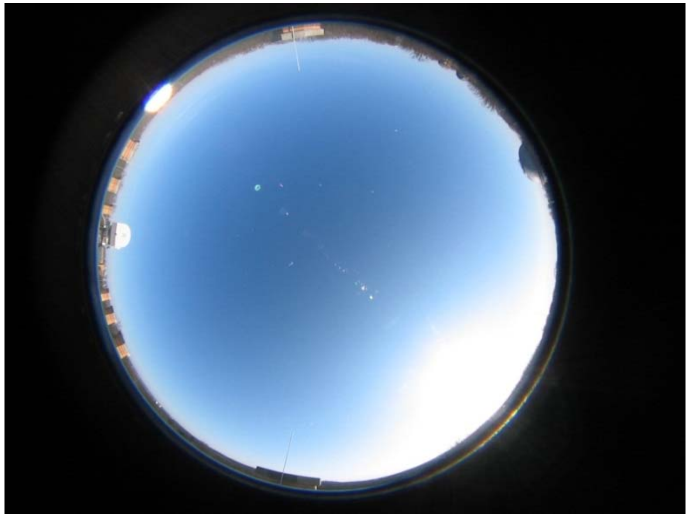
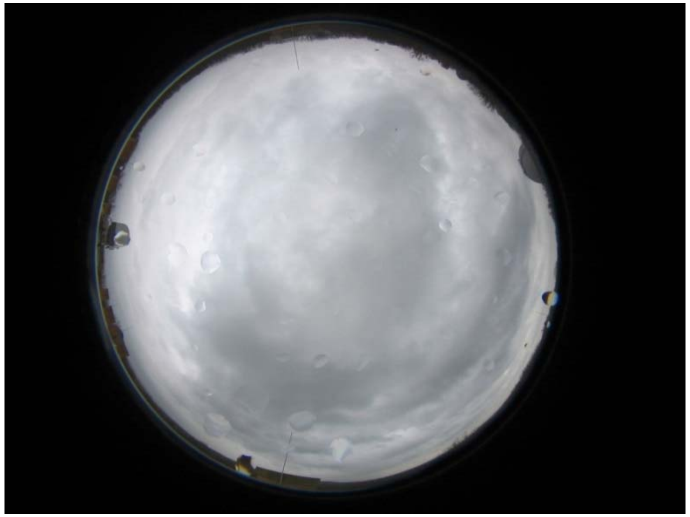
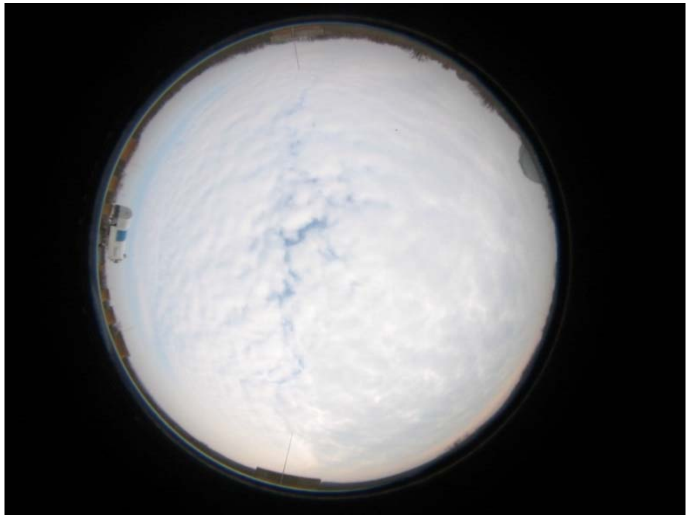
Independent measurements at GFZ: Water vapor radiometer

GFZ water vapor radiometer

GFZ water vapor radiometer



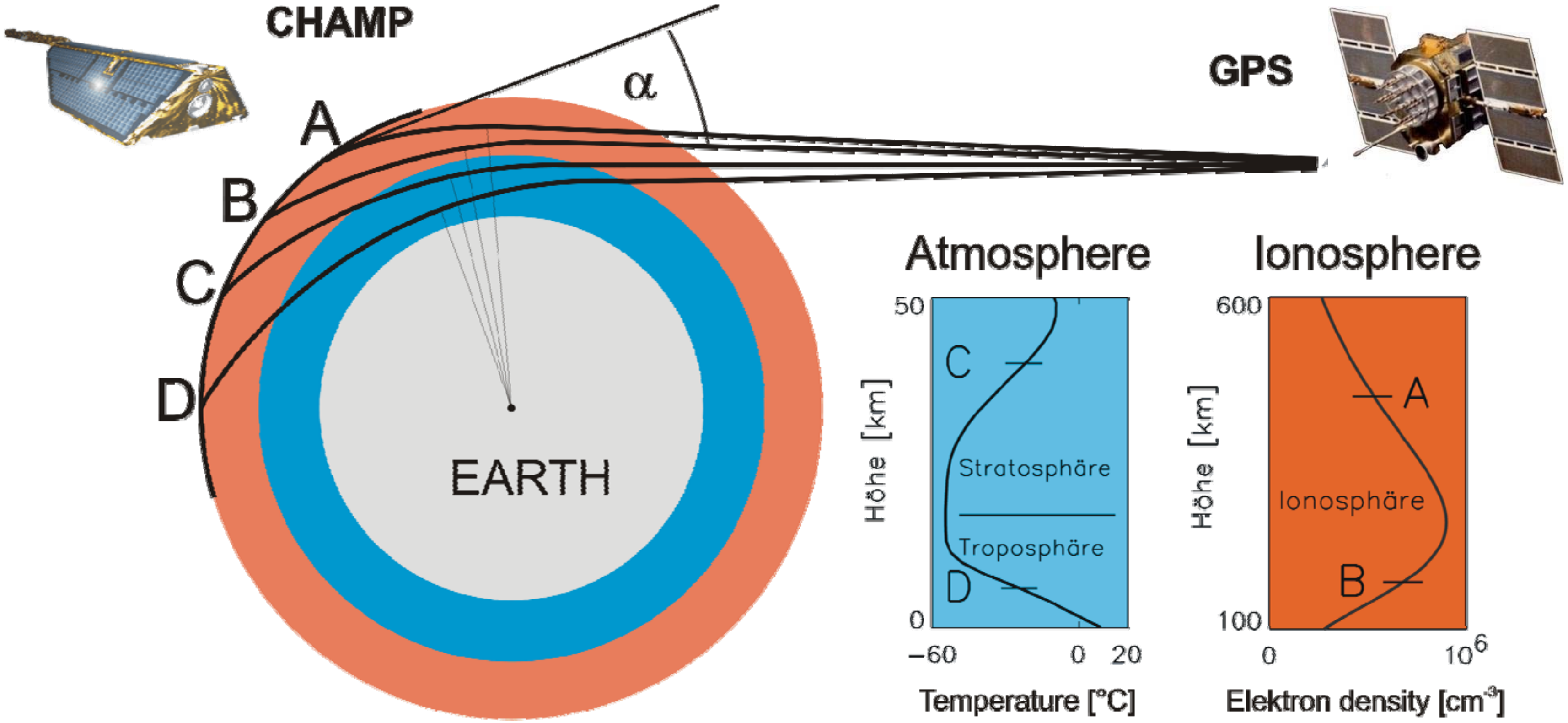
GFZ cloud cam at A17 building

Space based atmosphere sounding:

GNSS Radio Occultation

GNSS radio occultation

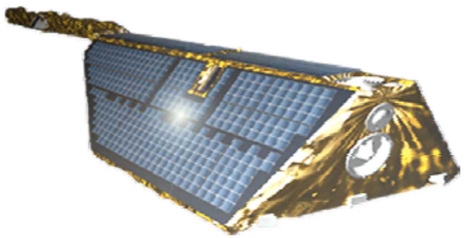


Wickert , 2002

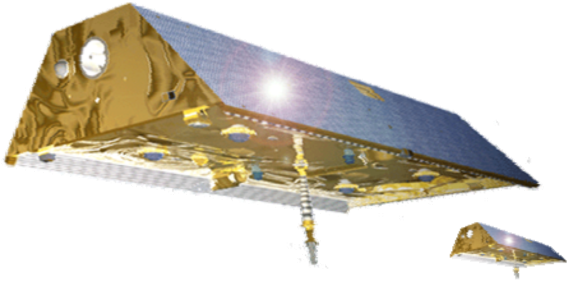
Key properties: global coverage, all-weather, calibration free, very precise, high vertical resolution

Very attractive for weather forecast, climate and atmospheric research

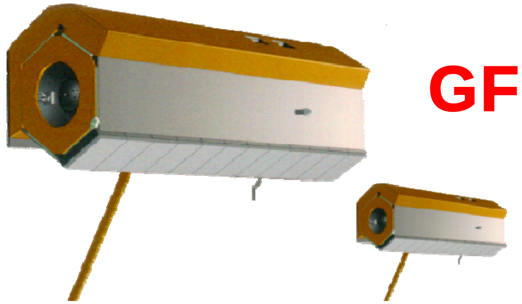
Satellites with GNSS radio occultation



CHAMP (2000-2010)

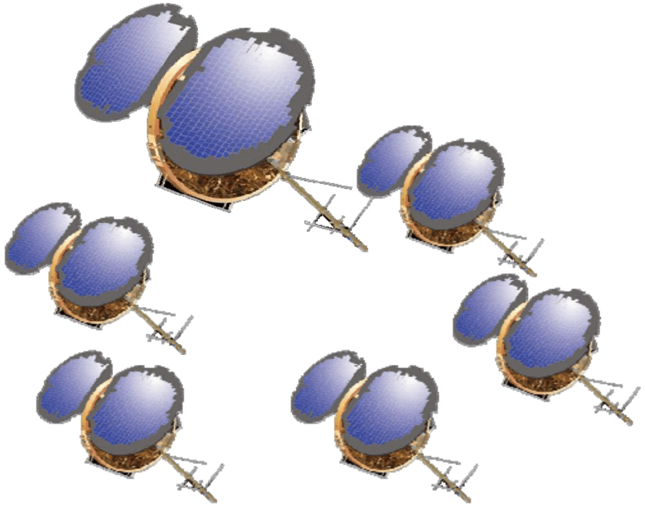


GRACE (since 2002)

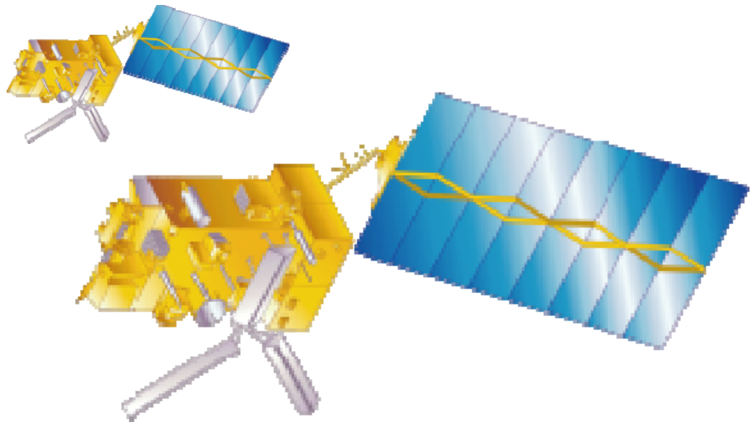


GFZ

TerraSAR/TanDEM-X
since 2007/2010
unique data

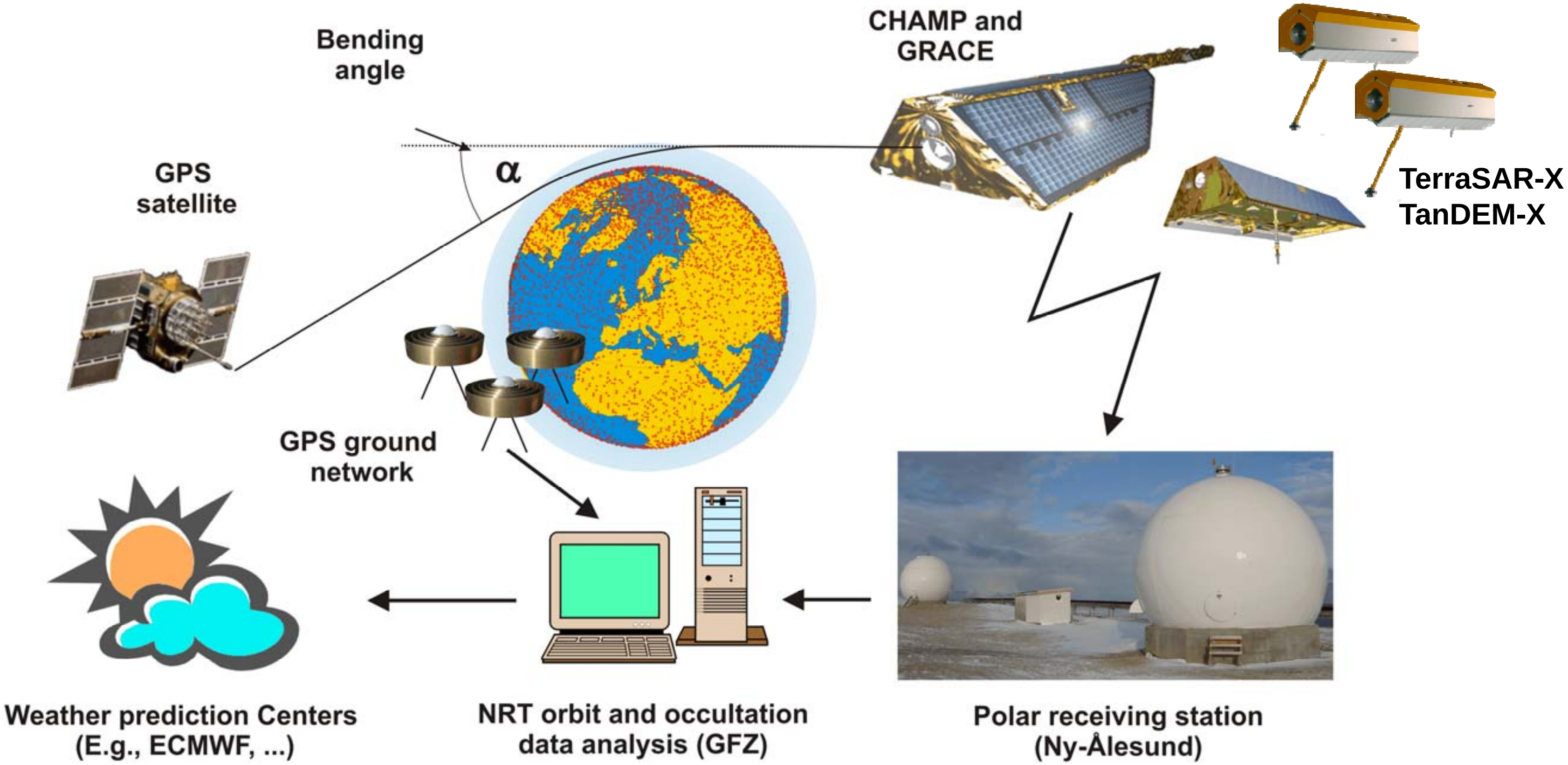


FORMOSAT-3/COSMIC
(6; since 2006, follow-on in prep.)



Metop-A/B (since 2006/2012,
two satellites)

Operational GPS weather data for world-wide leading forecast centers



Precondition: Development and Operation of complex Infrastructure inclusive of dedicated scientific analysis software

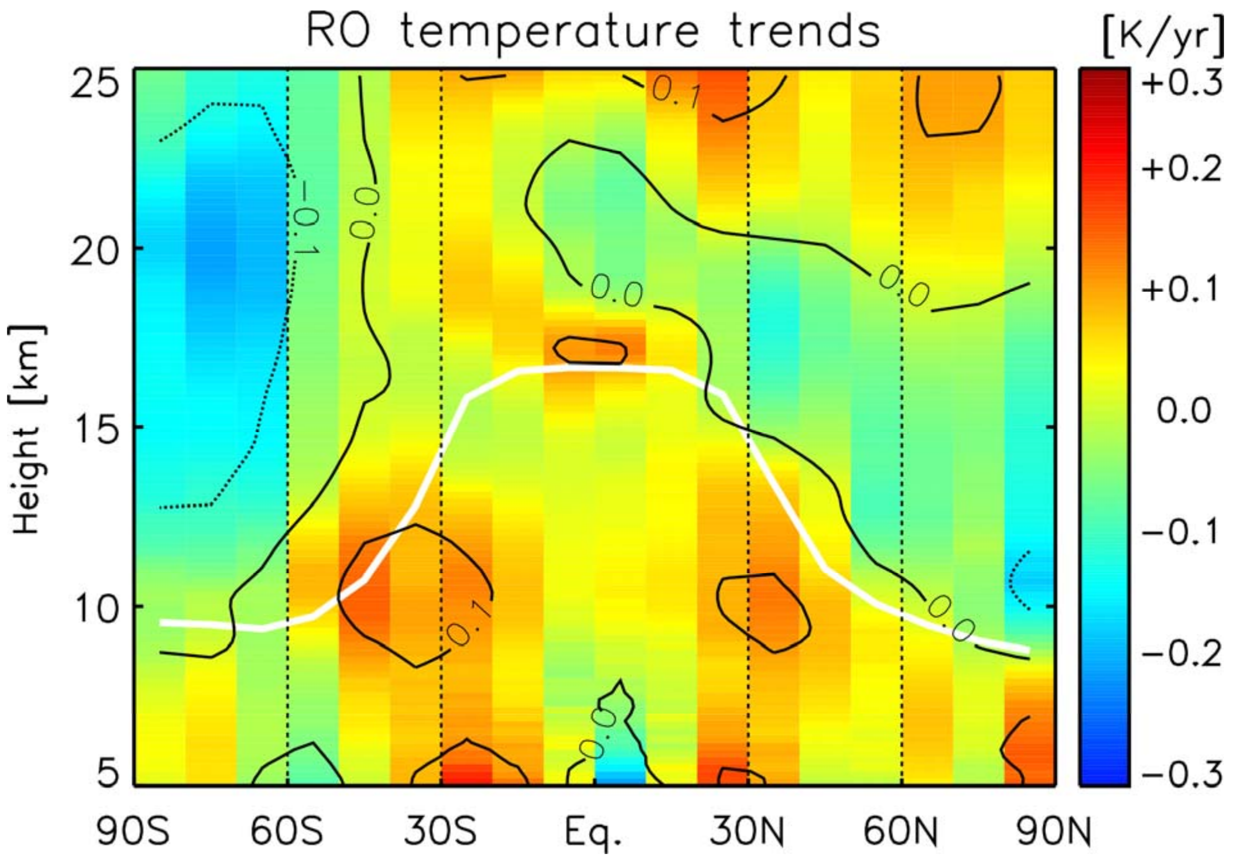
New: June 30, 2014 - Initial NRT data TanDEM-X

Operational use of GPS-RO for weather forecast

- 2006: Initial operational CHAMP/GRACE and COSMIC data use by MetOffice and ECMWF
- Currently used in addition by weather centers at Germany, U.S., France, Canada, Japan, Taiwan
- Relatively small number of observations has big impact: Why?

*Superior vertical resolution compared to other satellite sounders
*Assimiliation without bias correction

Climate: Global Temperature Change from CHAMP/GRACE GPS-RO data

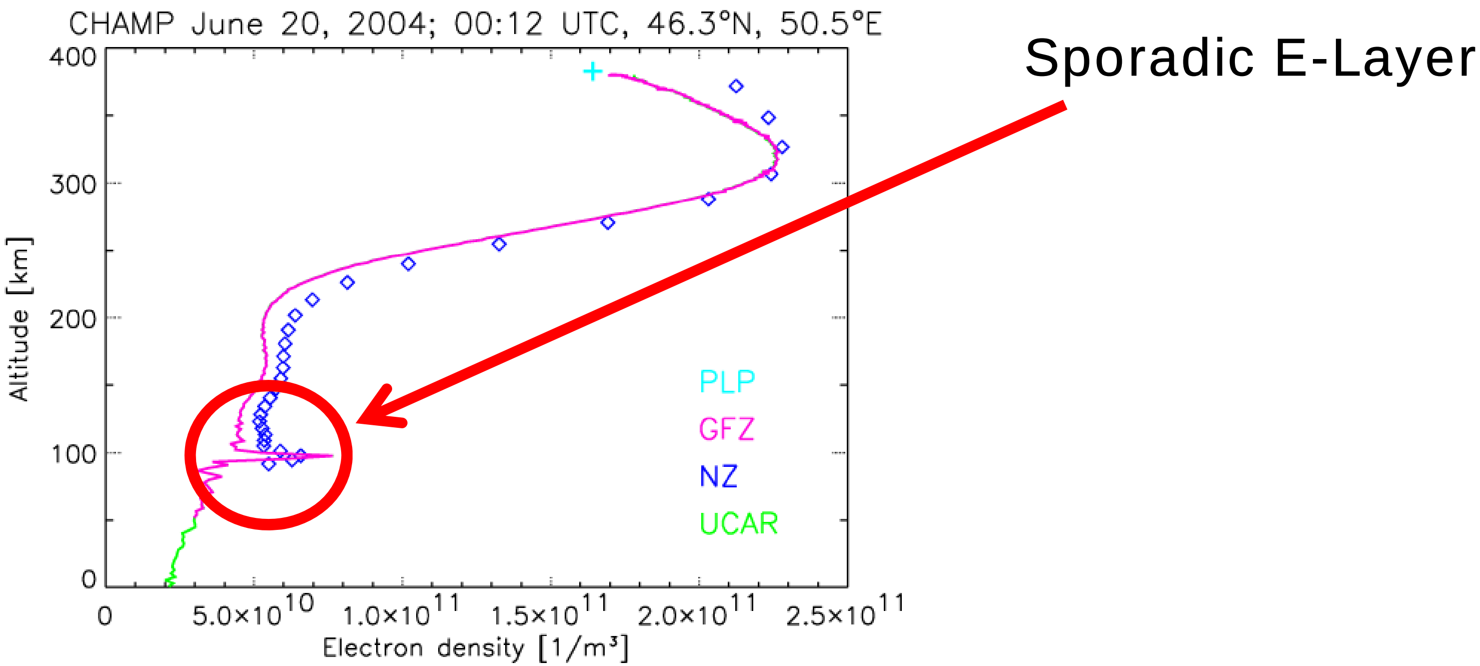


Schmidt et al., 2010

RO-Applications:

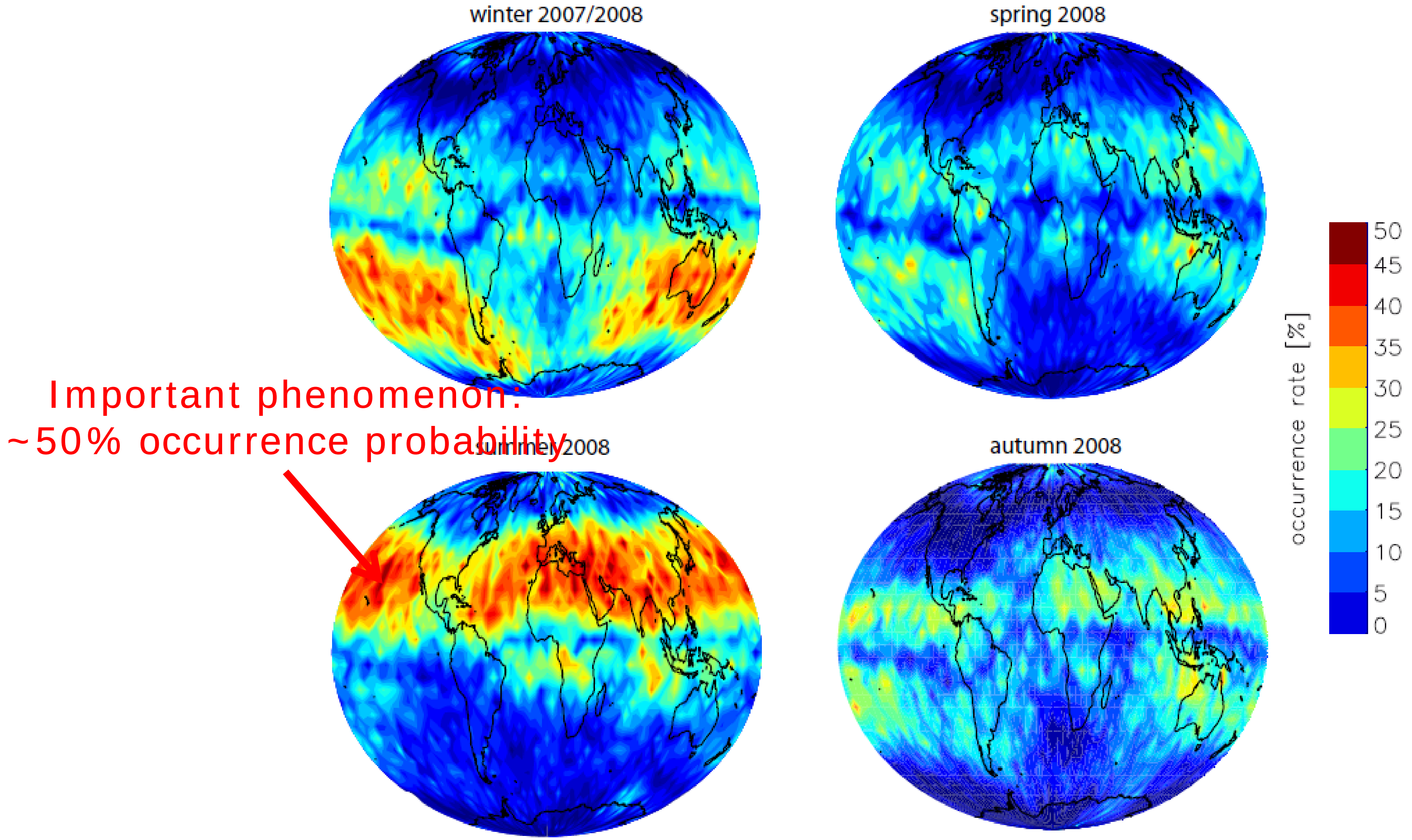
Ionosphere monitoring

Ionosphere: Vertical electron density profiles and detection of disturbances



Relevant for navigation, communication,
Studies of atmospheric coupling processes
Characterization of space weather

Global ionosphere monitoring mit GPS-RO



Sporadic-E Results from CHAMP, GRACE, FormoSAT-3/COSMIC 2007/2008

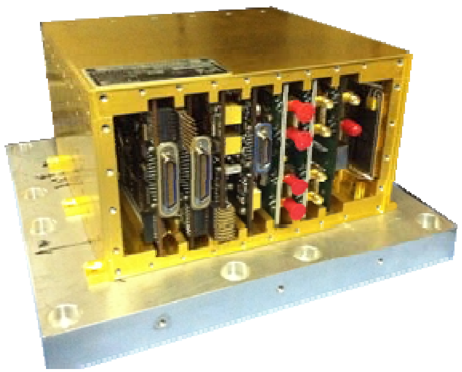
PhD work C. Arras, GFZ

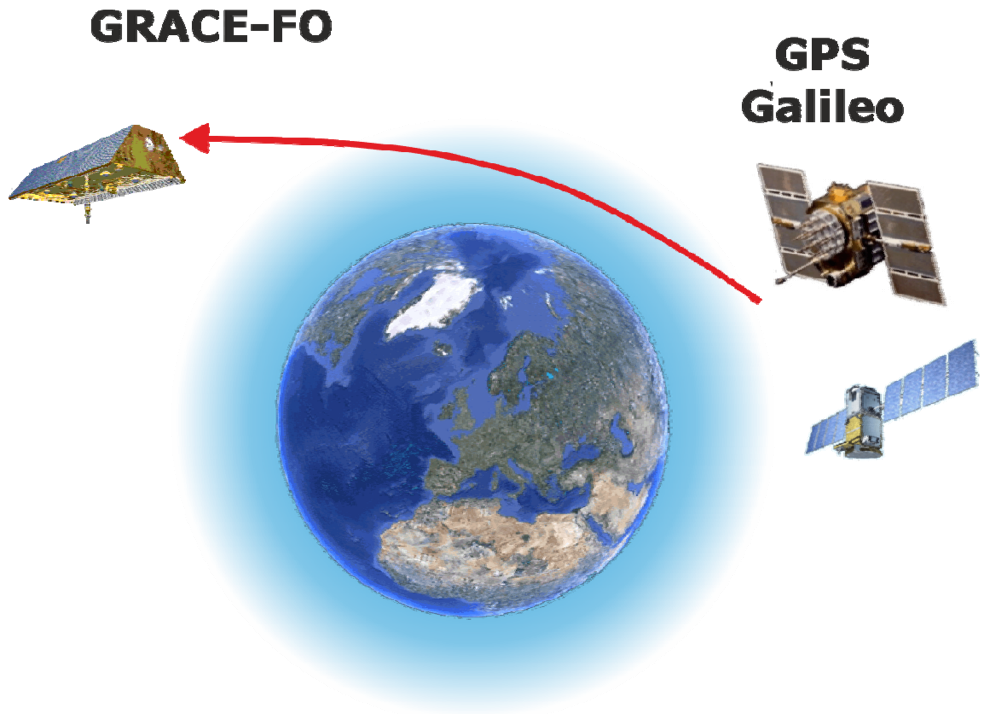
GNSS atmosphere sounding with GRACE-FO

GRACE-FO: Launch planned in 2017 (August 4)

New and improved GNSS receiver compared to GRACE: TriG ?

Initial application of Galileo for operational GNSS radio occultation





Complementary Add-on:

GNSS-Reflectometry

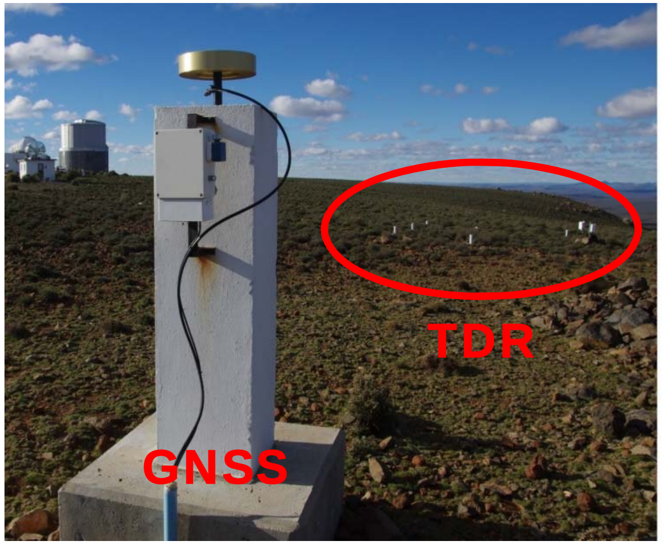
Potential applications of GNSS Reflectometry

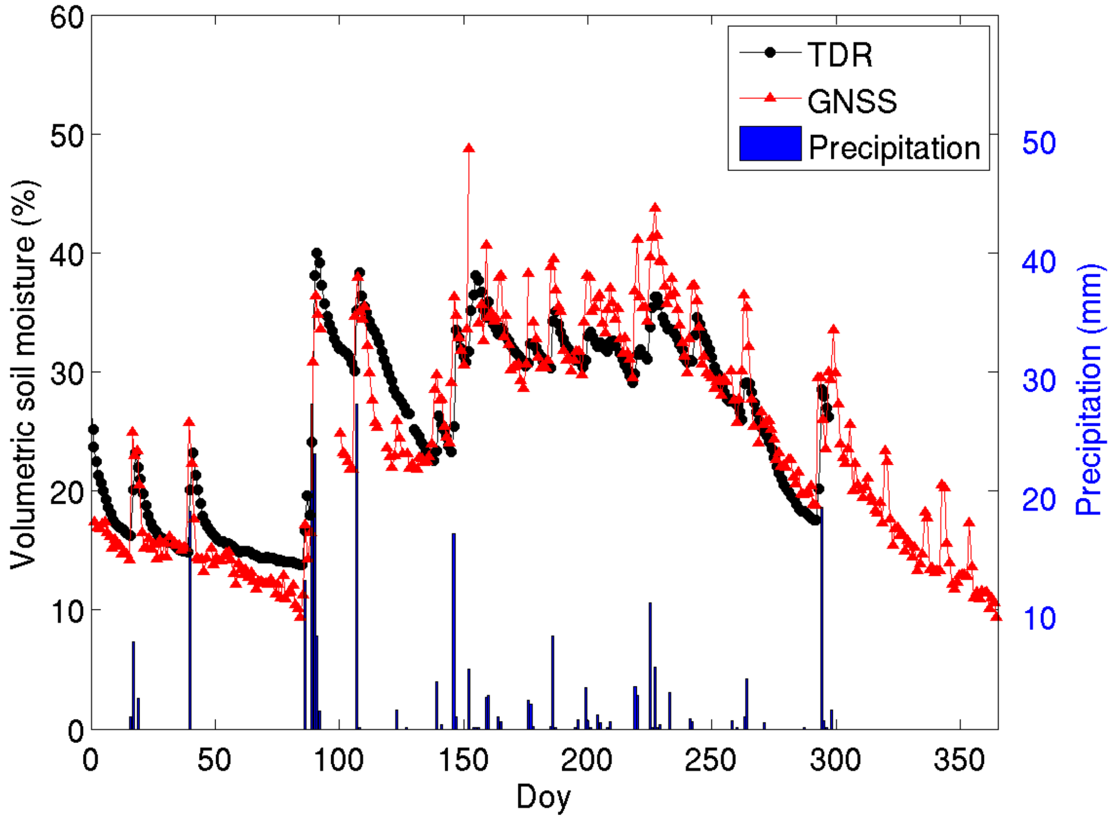
- Weather: wind direction/velocity, specific humidity
- Climate: sea level, sea ice coverage, ice shelf altitude, salinity
- Ionosphere and Space Weather: electron density
- Disasters: tsunami early warning, flood monitoring
- Land surfaces: soil moisture, biomass, snow cover and depth, humidity content of snow

Wickert et al., EU-project report GfG², 2012

Land surface monitoring using GNSS-Reflectometry

Soil moisture at Sutherland, South Africa





- Very good representation of precipitation events and evapotranspiration
- Outlook: Snow height, snow water equivalent, vegetation, tide gauge with data from existing GNSS networks

GFZ GNSS stations for regional remote sensing

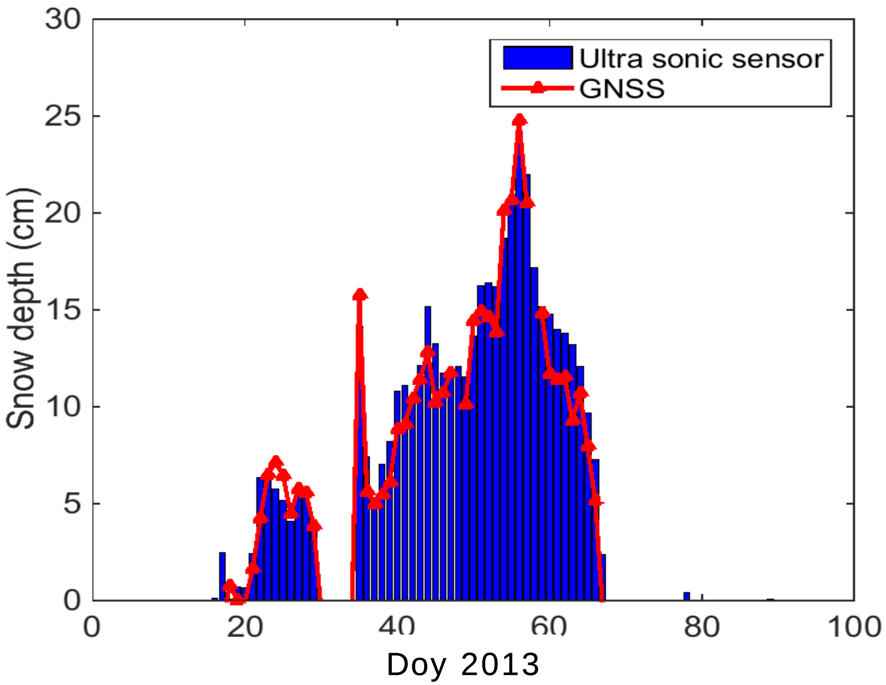
Dead Sea (DESERVE project)
sea surface, water vapor, soil moisture,
inSAR cooperation with KIT (KIT-cube)
(Photo selected for GFZ calender 2015)

Midelt, Morocco
(PMARS project)
soil moisture,
water vapor
water reservoir
monitoring

Snow depth

Methodic study at Wettzell

GNSS derived snow depths correspond very well to in-situ observations by an ultra sonic sensor (RMSE 1.7 cm)



IAG/GGOS joint working group 4.3.9 on GNSS reflectometry (see poster tomorrow Nievinski et al.)

Current Status and Future Activities of the IAG/GGOS Joint Working Group 4.3.9 on GNSS reflectometry

F. Nievinski[1], T. Hobiger[2], E. Cardellach[3], R. Haas[2], K. Heki[4], Y. Kitazawa[5], K. Larson[6], M. Martín-Neira[7], M. Ribot[8], N. Roussel[9], M. Semmling[10], J. Strandberg[2], S. Vey[10], K. Yu[11], W. Wan[12], J. Wickert[10], S. Williams[13].

(1) Federal Univ. of Rio Grande do Sul, Brazil; (2) Chalmers Univ. of Technology, Sweden; (3) Institut de Ciències de l'Espai (ICE-CSIC/IEEC), Spain; (4) Hokkaido Univ., Japan; (5) IHI Corporation, Japan; (6) Univ. of Colorado, USA; (7) ESA, Europe; (8) École Polytechnique Fédérale de Lausanne, Switzerland; (9) Université de Toulouse, France; (10) GFZ Potsdam, Germany; (11) Wuhan Univ., China; (12) Tsinghua Univ., China; (13) National Oceanography Centre, UK.

felipe.nievinski@ufrgs.br and thomas.hobiger@chalmers.se

Introduction

Global Navigation Satellite Systems (GNSS) have revolutionized positioning, navigation, and timing. In recent years, the usage of

Goals

We succeeded in establishing liaisons with neighboring organizations, such as the Permanent Service for Mean Sea