GNSS-Meteorology and GNSS-Climate Activities at ROB

CONTRIBUTION TO NATIONAL PROJECTS, E-GVAP AND COST ACTION ES1206 (GNSS4SWEC)

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Royal Observatory of Belgium

Solar-Terrestrial Centre of Excellence

ROB's Contribution to E-GVAP

STATUS SINCE LAST MEETING

Announced last year

New developments, with major focus:

- Upgrading to the Bernese GNSS software v. 5.2.
- Upgrading to a new I.T. infrastructure and new OS.
- Preparing for a multi-GNSS (GPS+GLONASS) processing.
- Preparing new operational solutions (sub-hourly and global).

Work Plan and Solutions Nomenclature

	Name	Geographical Scope	Update Cycle	Targeted Application	To E-GVAP?
1	ROBP	World-Wide	1-day	CRD + Validation	No
4	ROBH	Europe	1-hour	European NWP D.A.	Yes
2	ROBT	Europe	1-hour	Test for ROBH	Yes
3	ROBG	World-wide	1-hour	Global NWP D.A.	Yes
3	ROBQ	Benelux/Europe	15-min	Rapid-Cycle Hi-Res. NWP D.A.	Yes
	ROBR	World-Wide	Real-time	Nowcasting	No

Work plan priority

What Happened in 2016?

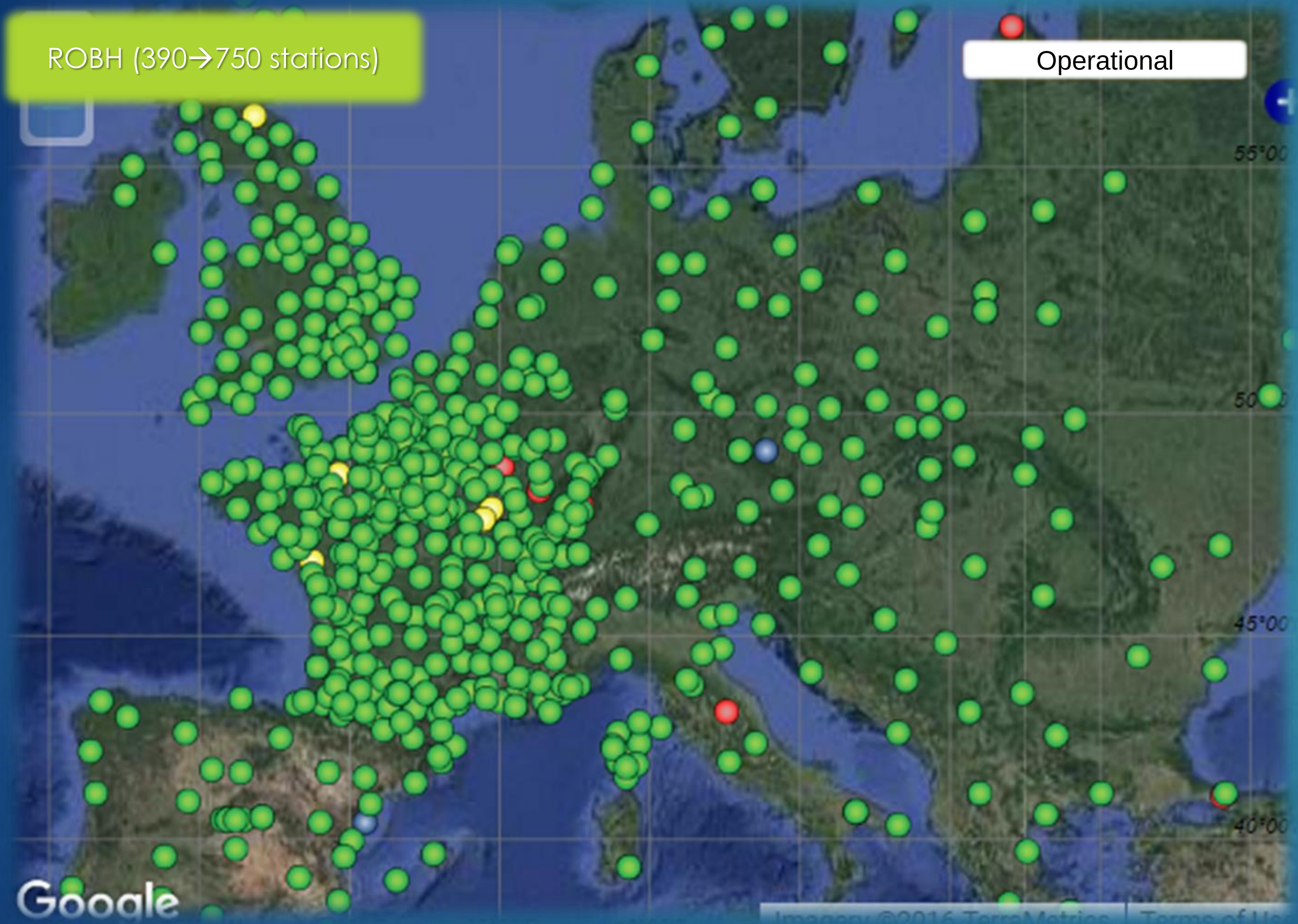
	Before 29 Nov 2016			After 29 Nov 2016		
	Software	*GNSS*	*Status*	*Software*	*GNSS*	*Status*
ROBH	BSW 5.0	GPS only	Operational	BSW 5.2	GPS+GLO	Operational
ROBT	BSW 5.2	GPS+GLO	Test	BSW 5.2	GPS+GLO	Test ⚠
ROBG	BSW 5.2	GPS+GLO	Test	BSW 5.2	GPS+GLO	Operational
ROBQ	BSW 5.2	GPS+GLO	Test	BSW 5.2	GPS+GLO	Operational

Switch

General Processing Parameters

- Bernese GNSS Software v 5.2.
- IERS standards 2010.
- Troposphere Model: GMF dry as a priori / Estimation of the GMF wet.
- Atmospheric Tidal Loading (ATL) applied.
- GPS + GLONASS observations.
- IGV Ultra-rapid orbits and ERPs (fall back to IGU and/or CODE possible).
- Updated FES2004 coefficients for the Ocean Tide Loading (OTL).
- Products in COST-716 Format 2.2a and new file naming convention.

ROBH for European NWP Models D.A.



Status: 1 December 2016 (Several stations are located outside the represented domain).

Targeted Application: regional NWP

- European Network
- ~750 GNSS Stations
- GPS+GLO, 2 HRS arc + Stacking

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- ZTD-Only
- 15-min Sampled ZTD
- Hourly Update Cycle
- Comp. ~20-25 min - Latency ~ 45 min
- Uploaded to E-GVAP

ROBT for tuning ROBH and Test D.A. Purposes

Status: 1 December 2016 (Several stations are located outside the represented domain).

Targeted Applications:
Global NWP D.A.

- Mainly EPN + National Network stations
- ~760 GNSS Stations
- GPS + GLONASS, 2 HRS arc + NEQ Stacking

- ZTD-Only
- 15-min Sampled ZTD
- 1-Hour Update Cycle
- Computation ~30 min - Max. Latency ~ 47 min
- COST Format 2.2a
- Uploaded to E-GVAP

ROBG for Global NWP Models D.A.

Status: 1 December 2016 (Several stations are located outside the represented domain).

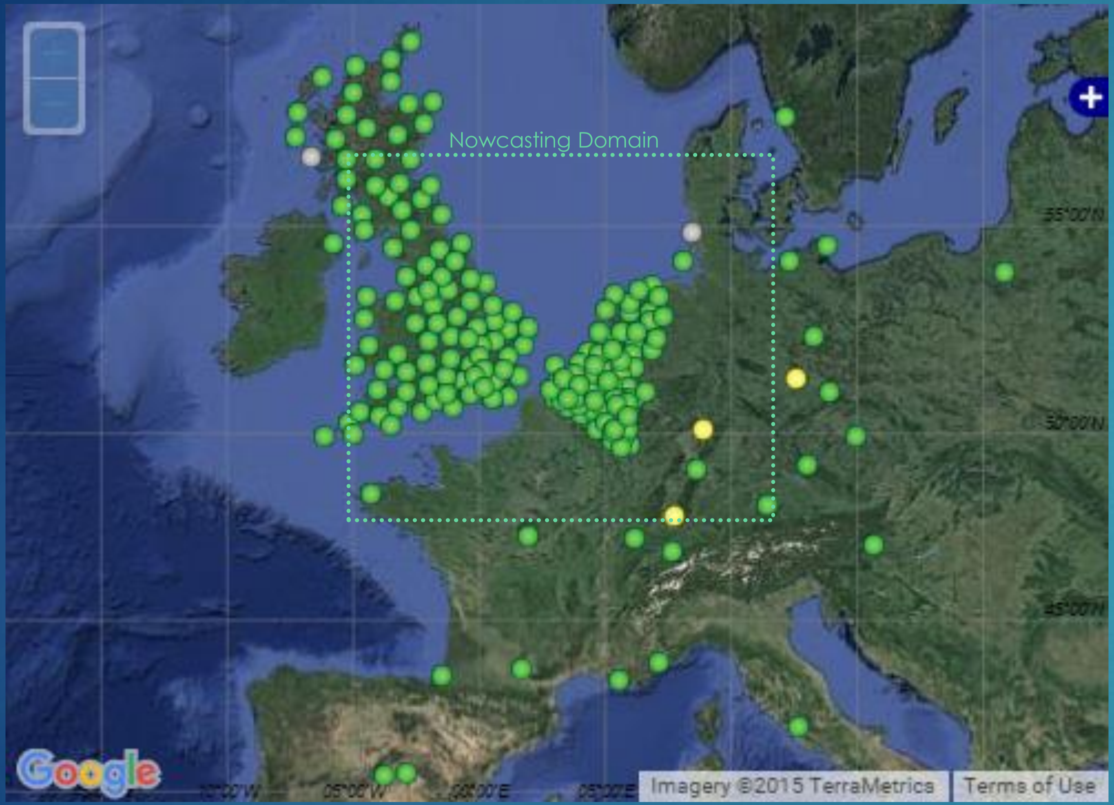
Targeted Applications:
Global NWP D.A.

- Mainly IGS stations
- ~300 GNSS Stations
- GPS + GLONASS, 4 HRS arc, no Stacking

- ZTD-Only
- 15-min Sampled ZTD
- 1-Hour Update Cycle
- Comp. ~10-14 min - Max. Latency ~ 45-50 min
- COST Format 2.2a
- Uploaded to E-GVAP

Three contributions to global NWP D.A.: GOPG (operational), METG (test?) and ROBG (operational) → combination / quality checks possible (ASIC).

ROBQ for (NWP) Nowcasting (D.A.)



Status: 1 December 2016 (Several stations are located outside the represented domain).

Additional real-time/highrate GNSS observations from Luxembourg, north of France, Germany, Denmark can be useful.

Targeted Applications:
rapid-update NWP and nowcasting

National Networks + EPN stations

~230 GNSS Stations

GPS + GLONASS, 4 HRS arc, no Stacking

ZTD-Only

15-min Sampled ZTD

15-Min Update Cycle

Comp. ~8-13 min - Max. Latency < 15min

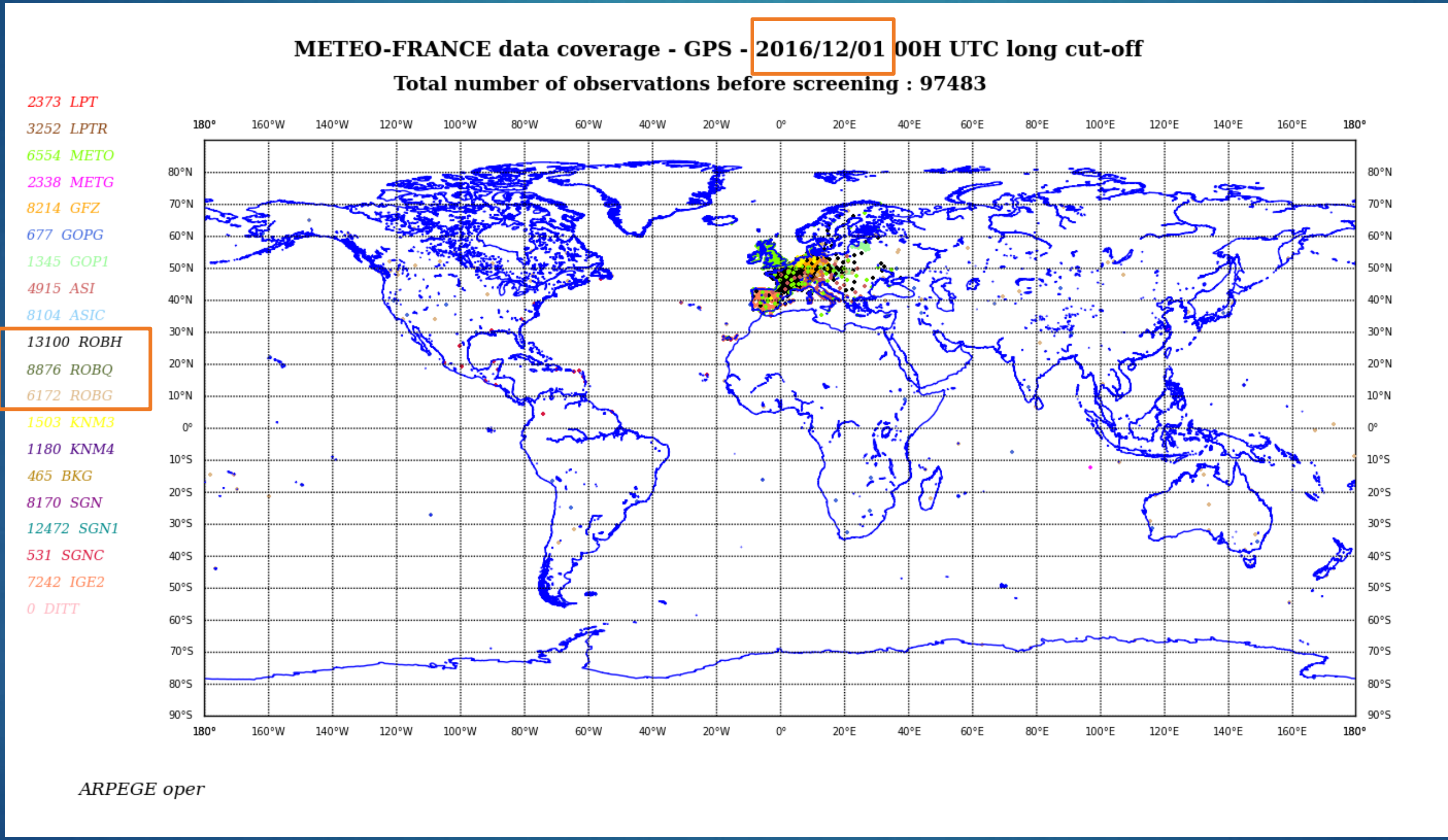
COST Format 2.2a

Uploaded to E-GVAP

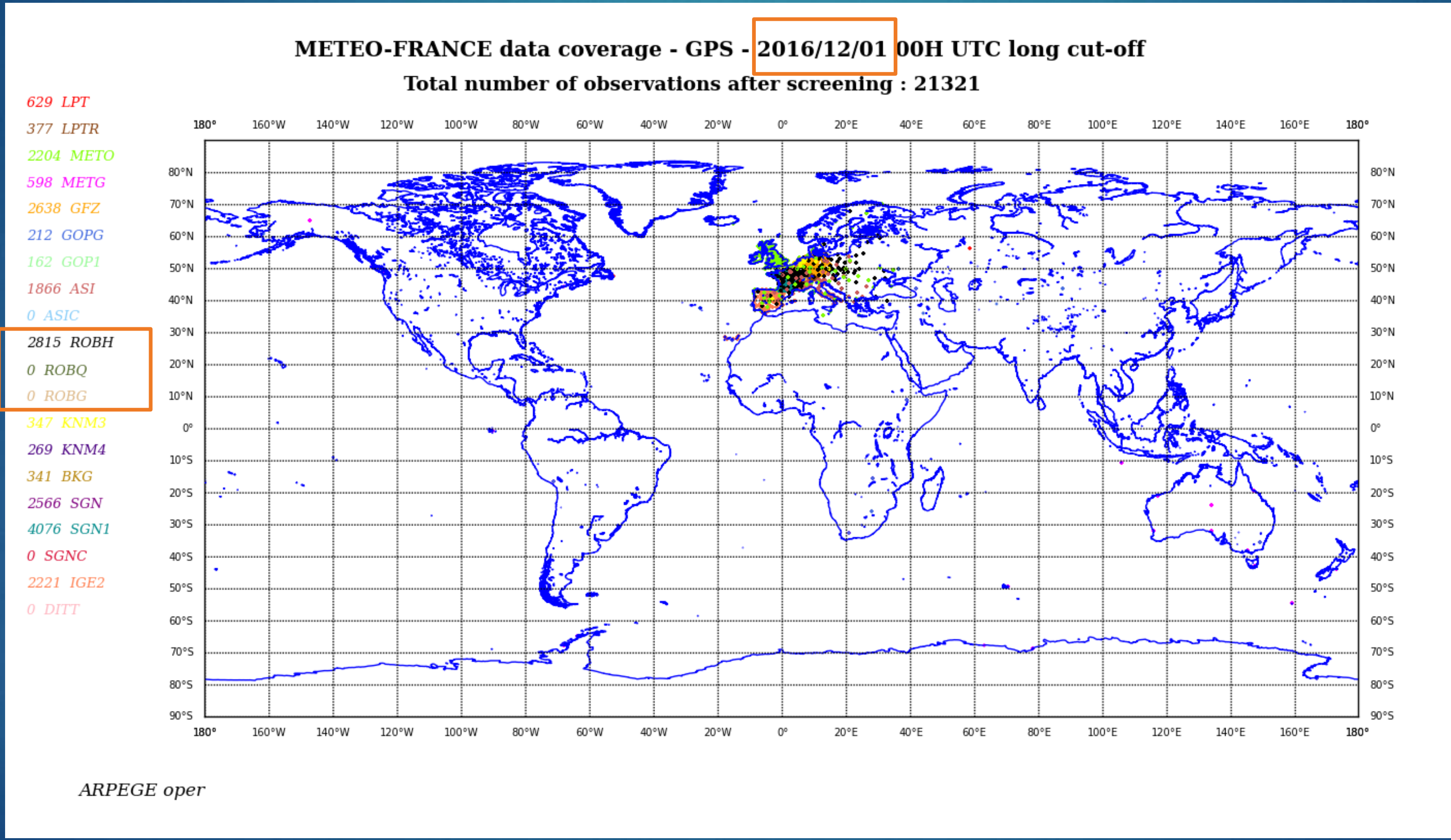
Only the last 15 minutes !!!

ROB's Contribution to E-GVAP

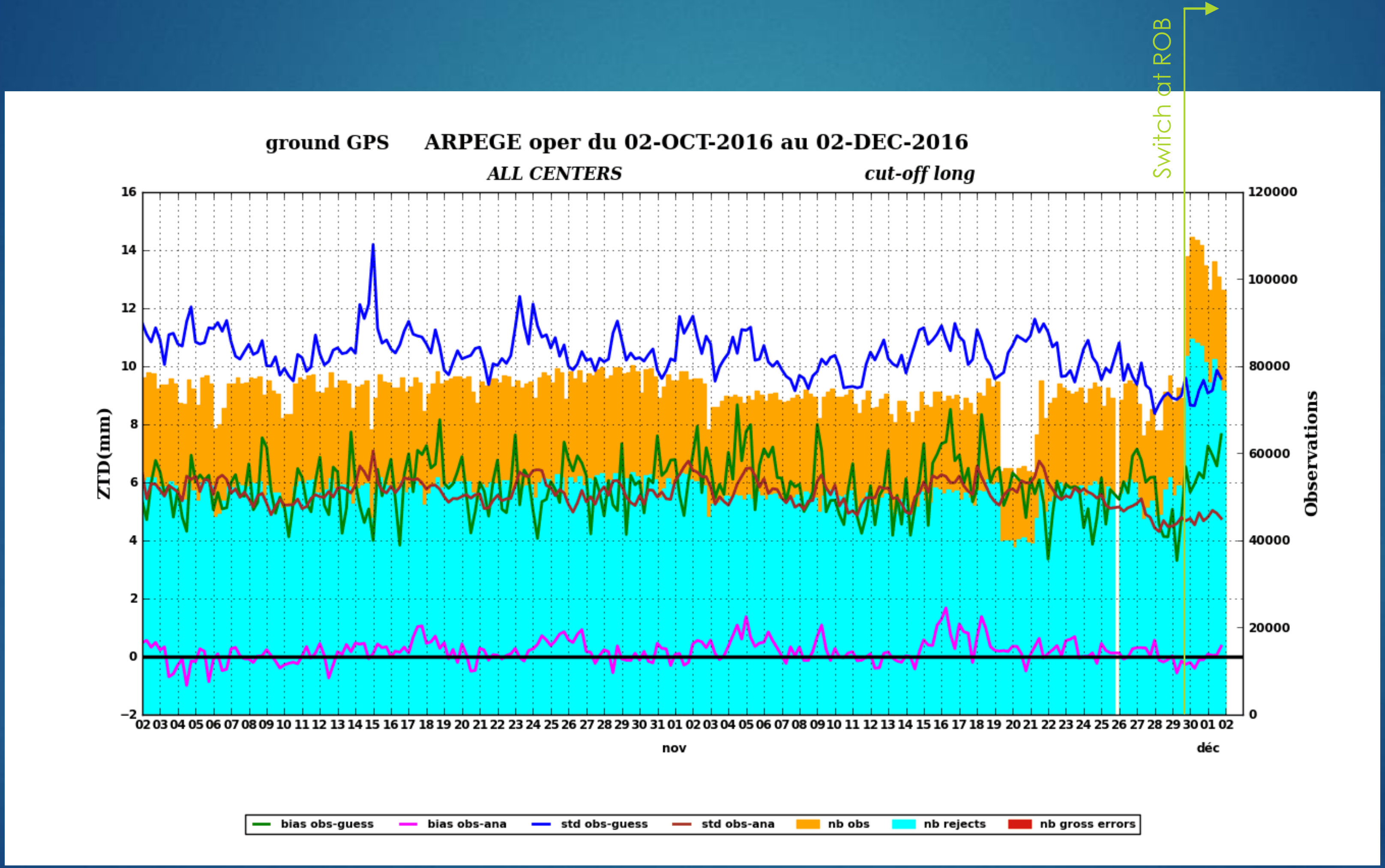
Example of what Happened on Nov. 29: Météo France



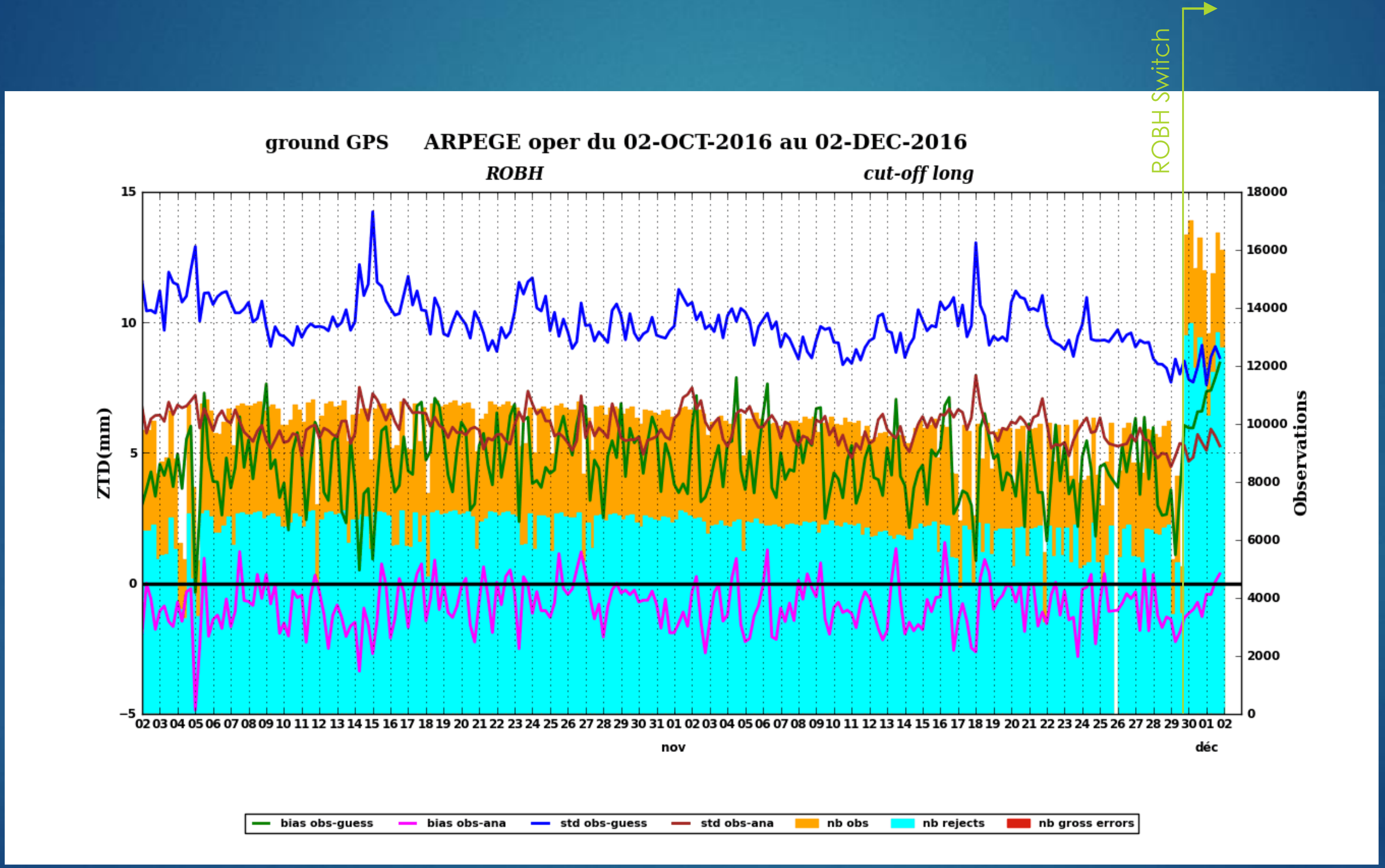
Example of what Happened on Nov. 29: Météo France



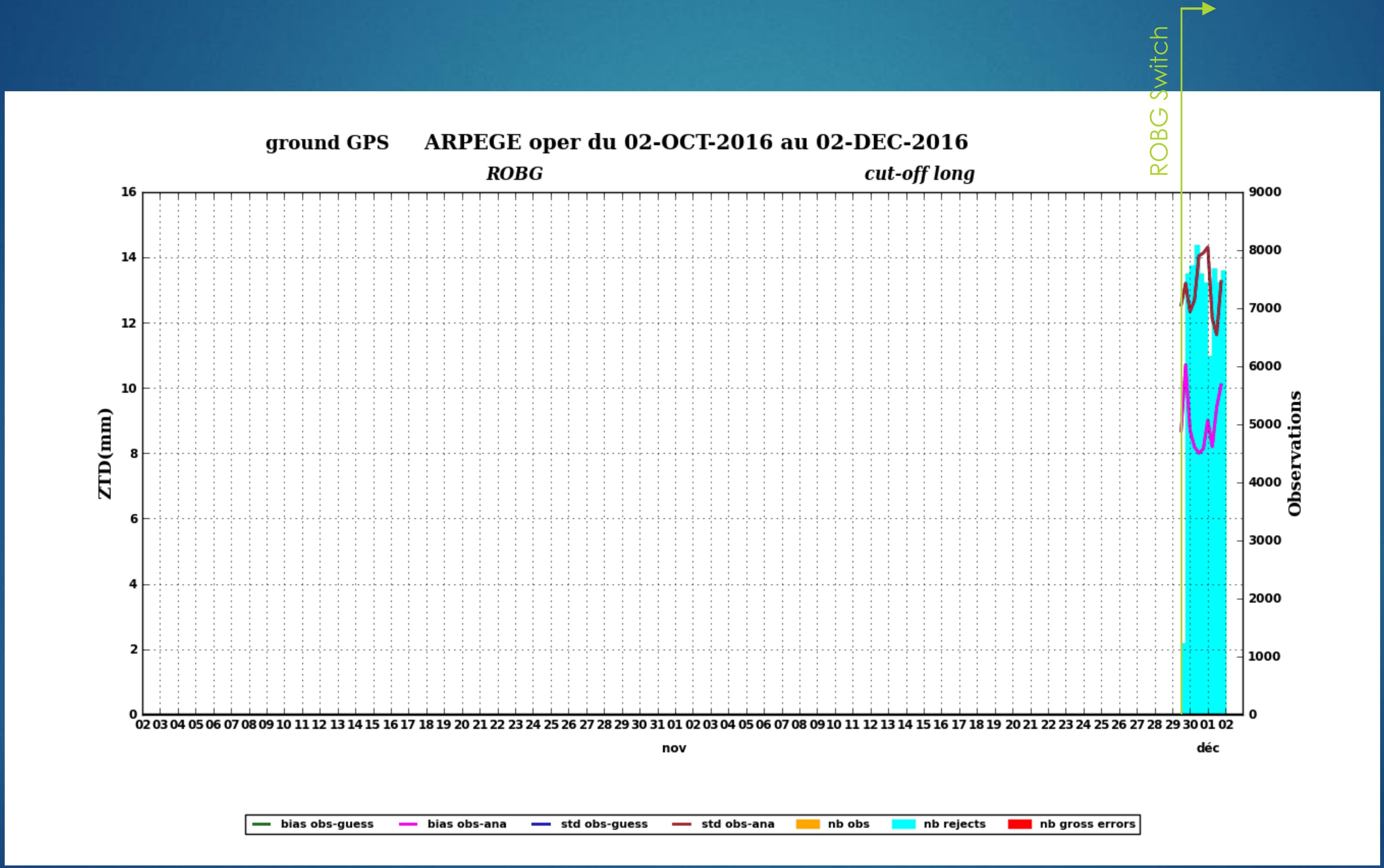
Example of what Happened on Nov. 29: Météo France



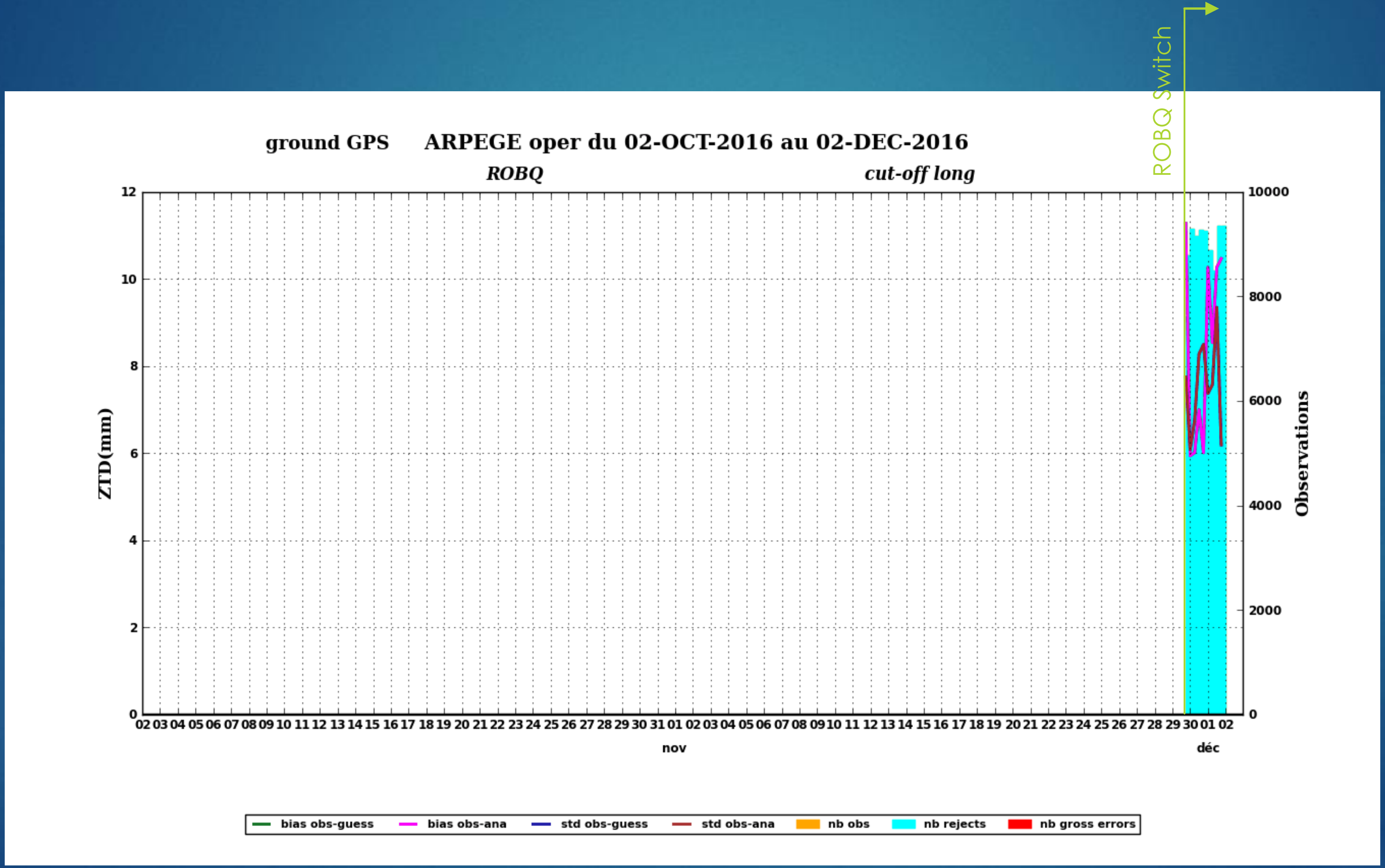
Example of what Happened on Nov. 29: Météo France



Example of what Happened on the D.A. side : Météo France



Example of what Happened on Nov. 29: Météo France



ROB's Contribution to GNSS4SWEC

RECENT ACTIVITIES

AMT Paper on State-of-the-Art in S.I.

Atmos. Meas. Tech., 9, 5385–5406, 2016
www.atmos-meas-tech.net/9/5385/2016/
doi:10.5194/amt-9-5385-2016

Atmospheric Measurement Techniques
Open Access
EGU

Review of the state of the art and future prospects of the ground-based GNSS meteorology in Europe

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Abstract. Global navigation satellite systems (GNSSs) have revolutionised positioning, navigation, and timing, becoming a common part of our everyday life. Aside from these well-known civilian and commercial applications, GNSS is now an established atmospheric observing system, which can accurately sense water vapour, the most abundant greenhouse gas, accounting for 60–70 % of atmospheric warming. In Europe, the application of GNSS in meteorology started roughly two decades ago, and today it is a well-established field in both research and operation. This review covers the state of the art in GNSS meteorology in Europe. The advances in GNSS processing for derivation of tropospheric products, application of GNSS tropospheric products in operational weather prediction and application of GNSS tropospheric products for climate monitoring are discussed. The GNSS processing techniques and tropospheric products are reviewed. A summary of the use of the products for validation and impact studies with operational numerical weather prediction (NWP) models as well as very short weather prediction (nowcasting) case studies is given. Climate research with GNSSs is an emerging field of research, but the studies so far have been limited to comparison with climate models and derivation of trends.

More than 15 years of GNSS meteorology in Europe has already achieved outstanding cooperation between the atmospheric and geodetic communities. It is now feasible to develop next-generation GNSS tropospheric products and applications that can enhance the quality of weather forecasts and climate monitoring. This work is carried out within COST Action ES1206 advanced global navigation satellite systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC, http://gnss4swec.knmi.nl).

1 Introduction

Atmospheric water vapour has a complex life cycle in the troposphere, including vertical and horizontal transport, mixing, condensation, precipitation, and evaporation. Due to its high temporal variation (more than 50 % within a few hours, Johansson et al., 1998) and its complex distribution, linked to its relationship with atmospheric dynamics and the role

Published by Copernicus Publications on behalf of the European Geosciences Union.

http://www.atmos-meas-tech.net/9/5385/2016/amt-9-5385-2016-relations.html

Main Recent Contributions

- RT PPP activities: processing GNSS observations in (true) real-time in support to rapid-cycle NWP and nowcasting applications.

- Producing (precise) Slant Tropospheric Delays (STD) based on the Bernese GNSS Software 5.2 and a double-difference approach.

- Producing and homogenizing long-term tropospheric time series for climate model validation, and climate trend and time variability studies.
  → *See also Roeland's presentation + CORDEX.Be hereafter*

ROBR: Real-Time Tropospheric Products

GOP-ROB Collaboration: Using Tefnut to generate real-time tropospheric products including asymmetry information and to contribute to the Real-time Demonstration Campaign.

Targeted Applications:
rapid-update NWP and nowcasting

- National Networks + EPN + IGS stations
- 185 GNSS Stations
- GPS and GPS + GLONASS mode

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- ZTD and Gradients (GRD)
- 30-sec Sampled ZTD+GRD
- RT Update Cycle
- Latency < 100 sec
- COST Format 2.2a
- Not uploaded to E-GVAP

➤ ROB's Contribution to COST Action ES1206 (GNSS4SWEC)

ROBR: Real-Time Tropospheric Products

- Real-time demonstration campaign : continuous production which also assess ‘operation’ production, such as we did in COST-716.

- Real-time benchmark campaign : producing various flavor of real-time products based on the benchmark data in order to assess, fine-tune and optimize the real-time tropospheric products.

- These activities will continue after GNSS4SWEC in the framework of the IAG 4.3.7 working group “Real-time GNSS tropospheric products” chaired by Jan Dousa. (+ link to E-GVAP)

Production of Slant Delays with BSW52

Inter-technique validation of tropospheric slant total delays

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Abstract. An extensive validation of line-of-sight tropospheric Slant Total Delays (STD) from Global Navigation Satellite Systems (GNSS), ray-tracing in Numerical Weather Prediction Models (NWM) fields and microwave Water Vapour Radiometer (WVR) is presented. Ten GNSS reference stations and almost two months of data from 2013, including severe weather events, entered the comparison. Seven institutions delivered their STDs based on GNSS observations processed using five software and eleven strategies. STDs from NWM ray-tracing came from three institutions using three different NWM models. Results show generally a very good mutual agreement among all solutions from all the techniques. The mean bias (over all stations) between the GNSS solution selected as reference, which did not use post-fit residuals in STDs, and all other GNSS solutions without post-fit residuals is -0.6 mm for STDs scaled in the zenith direction, and the corresponding mean standard deviation is 3.7 mm. Standard deviations of comparisons between GNSS a NWM ray-tracing solutions are typically 10 mm +/- 2 mm (scaled in the zenith direction), depending on the NWM model and the particular station considered. When comparing GNSS versus WVR STDs, standard deviations reached 12 mm +/- 2 mm, as scaled in zenith direction. Moreover, the influence of adding raw GNSS post-fit residuals, as well as residuals screened out of systematic effects, to STDs was studied. It was found that adding raw post-fit residuals always led to lower quality of GNSS STDs while the situation was not that straightforward after the post-fit residuals cleaning.

1 Introduction

Tropospheric Slant Total Delay (STD) represents the total delay that undergoes the GNSS radio-signal due to the neutral atmosphere along his path from a satellite to a ground receiver antenna. This total delay can be separated into the hydrostatic part, caused by the atmospheric constituents, and the wet part caused specifically by water vapour. By quantifying the total delay, and by separating the hydrostatic and wet parts, it is possible to retrieve the amount of water vapour in the atmosphere along the path followed by the GNSS signal.

1

- Based on the original work done by Van der Marel et al. 2005 (TOUGH Program).
- Multipath and slant delay algorithms and programs originally upgraded to work on BSW 5.2.
- Using the Benchmark campaign data of GNSS4SWEC.

Paper submitted to AMT (GNSS4SWEC Special Issue), should appear soon in the discussion area.

Production of Slant Delays with BSW52

- This work will be continued:
  - I already completed the processing of the full benchmark dataset.
  - I plan to produce longer time series of STD of a subset of stations (EPN?).
  - I plan to produce Slant Tropospheric Delays for one or several specific case studies, exploiting dense networks such as the Belgian one so that D.A. of slant delays can be evaluated and optimized.

ROB's Contribution to GNSS-Climate

STATUS SINCE LAST MEETING

ROB's Post-Processing Solution

Goals:

- Provide the very precise station positions needed for ROBH, ROBQ, ROBG, ROBT tropospheric Products.
- Provide very precise troposphere products for operational tropospheric product validation.
- Is the basis for preparing long-term re-processing activity (e.g. High-resolution climate model assessment and validation).

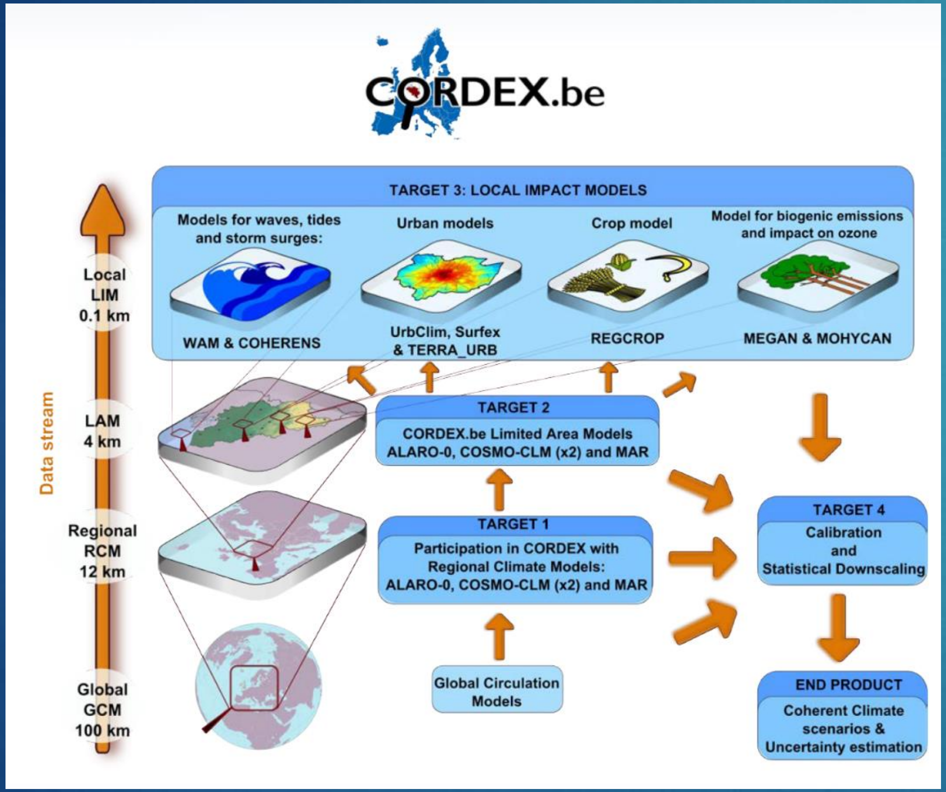
ROBP for NWP/Climate Re-Analysis

Targeted Applications:
NWP re-analysis and Climate Models

- National Networks + EPN + IGS stations
- ~1200 GNSS Stations
- GPS + GLONASS, daily RINEX, Possible 3-day Stacking

- ZTD-Only (but GRD possible)
- 1-hrs Sampled ZTD
- Daily Update Cycle
- Comp. time: ~ 16-20 hours - Latency ~ 6 days
- COST Format 2.2a
- Not uploaded to E-GVAP

CORDEX.be: COmbining Regional climate Downscaling EXpertise in Belgium



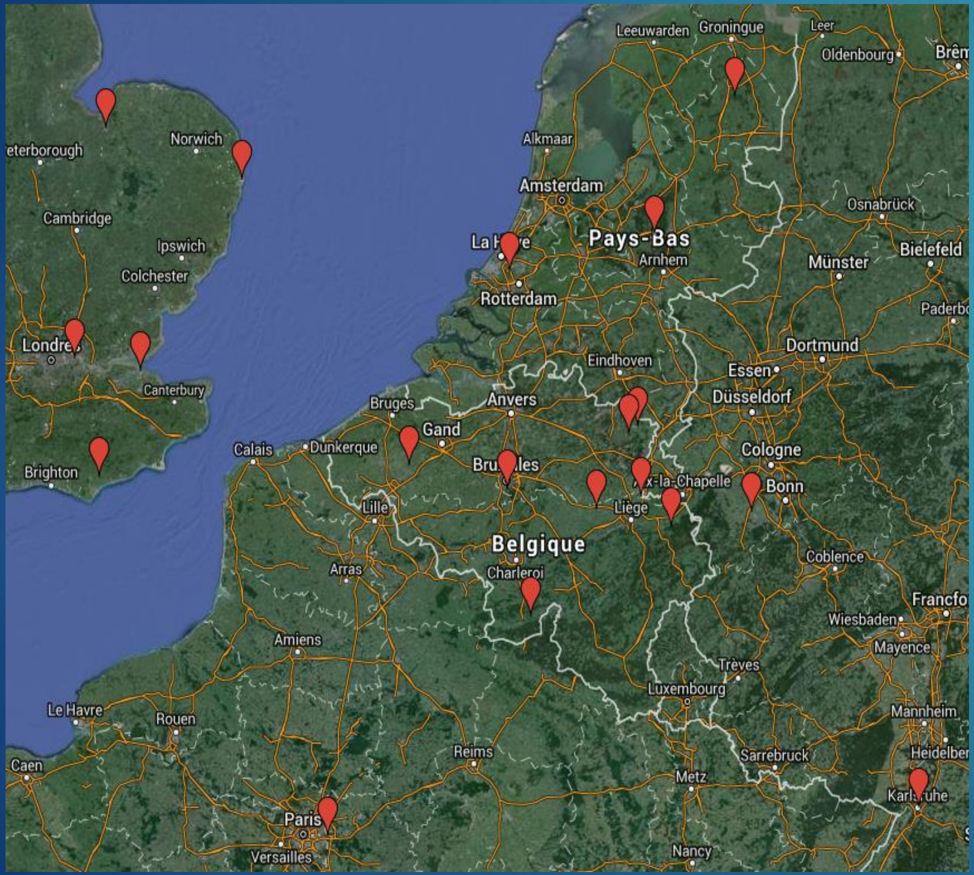
Objectives:

- Contribution to the CORDEX project.
- Beyond CORDEX: high resolution runs.
- Beyond CORDEX: local impact models.
- Inferring the climate uncertainties to the Belgian level (4 high-res models + CORDEX ensembles).

ROB Involvement in CORDEX.be

- ROB leads the WP "High-Resolution Climate model runs verification in Belgium" (ALARO, COSMO-CLM and MAR).
- ROBP, albeit a different GNSS network, was used to provide the tropospheric products in COST-716 Format 2.2.
- ZTD2IWV conversion and choice of climate variable to compare (ECV) for the verification.

GNSS Stations Used in the CORDEX.be Re-Analyse (Within the high resolution domain only)



- Selection Criteria:
  - Location: max within the high-resolution domain + world-wide.
  - Length : Permanently observing (2000-2010), very few gaps.
  - Quality: High-quality observations
  - Providing accurate Meta-data.
- World-wide: ~150 (in 2000) and 300 (in 2010) GNSS stations
- High-Resolution Domain: between 15 (in 2000) and 22 (in 2010) GNSS Stations

Conclusions and Plans

FOR 2017-2018

Conclusions and Plans

- The porting to the new I.T. infrastructure + Bernese GNSS software v 5.2 (GPS+GLONASS) has been fully completed (29 Nov. 2016)
  - ROBH has been upgraded to BSW 5.2
  - The new global solution ROBG and the sub-hourly (15min) ROBQ are now provided as operational solutions.
  - ROBT remains for for testing, fine-tuning & assessments (even if uploaded to the E-GVAP hub).

- Shorter-term plans: space for improvements and optimisations remains and will be investigated.

- Long-term plans: investigate the production of horizontal gradients and slant delays in hourly analysis + real-time production?

Some Open Questions & Discussions

- Fall-back mechanisms for orbit products is possible when these products are delayed. Should we implement such fall-back procedures? Impact on D.A. ? (e.g. O-B statistics).
- Latency versus quality & quantity ? → see also requirement review.
- Parameter constraints: currently over-constraints? (Link to variational bias correction, impact studies…)
- Feedback (e.g. O-B graphs such as Météo France) can be very usefull, particularly if these are station per station! (See recent case with UK Met Office) → should be generalised?
- Authenticating users of our products becomes more and more essential to sustain our activities as analysis centre! (e.g. we need to justify the running cost of such service) → how to achieve that?

Nomenclature of the ROB solutions

ROB has 5 processing systems and provides solutions from 4 of them to E-GVAP:

System	Input	Update cycle	Purpose	Status	Stations	Proc. time	Software
ROBH	Hourly RINEX files	Hourly	European NWP data assimilation	Operational	~ 750 stations	20-25 min.	BSW 5.2 GPS+GLO
ROBQ	Real-time GNSS observations (NTRIP)	Sub-hourly – every 15 Minutes	Nowcasting + rapid-cycle NWP data assimilation	Operational	~ 230 stations	~ 8-13 min.	BSW 5.2 GPS+GLO
ROBT	Hourly RINEX files	Hourly	Tests + prepare next ROBH	Tests (for R&D)	~ 770 stations	~ 30 min.	BSW 5.2 GPS+GLO
ROBG	Hourly RINEX files	Hourly	Global NWP data assimilation	Operational	~ 300 stations	~ 10-14 min.	BSW 5.2 GPS+GLO
ROBP	Daily RINEX files	Daily (latency of 6 days)	CRD + validation + prepare for re-analysis	Internal only	~ 1200 stations	16-20 hours	BSW 5.2 GPS+GLO