P3.4

Met Office

E-GVAP: EIG EUMETNET GNSS Water Vapour Programme

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Introduction

Water vapour is not only a potent greenhouse gas accounting for 60-70% of global warming, but also around half of all atmospheric energy results from the condensation of water vapour. Observations are traditionally scarce, however as Global Navigation Satellite System (GNSS) signals are sensitive to atmospheric water vapour - a noise term for the positioning community, they may be used to provide humidity information to the Numerical Weather Prediction (NWP) models. The main purpose of E-GVAP is to provide ground-based GNSS ZTD estimates for use in operational meteorology in near real time (NRT), and to further the use of such data in both NWP and weather forecasting. E-GVAP is based on a close collaboration between geodesy and meteorology with 23 national meteorological services collaborating with 24 GNSS Analysis Centres (ACs), responsible for collecting and processing GNSS data. The majority of the ACs are geodetic institutes with few being national met services. Each AC collaborates with the GNSS site and data owners to access the raw GNSS data (RINEX) used for delay estimation.

Zenith Total Delay (ZTD)

Refractivity, N, is responsible for slowing and bending of radio waves and is related to the properties of the troposphere and stratosphere (see e.g. Bevis et. al, Jour. Appl. Met, vol 33, p. 379, 1994).

$$N \;=\; R_d k_1 \rho_d + R_w \rho_w (k_2 + k_3/T) \;=\; \frac{p}{T}\,\frac{1}{1+q(1/\epsilon-1)}(k_1 + \frac{q}{\epsilon}(k_2 - k_1/\epsilon + \frac{k_3}{T})),$$

Where ρ is density, subscript d and w refer to dry air and water vapour respectively, R is the gas constant. The k's are constants determined empirically, p is pressure, T is temperature, q is specific humidity, and e is the ratio of the molecular weight of water vapour to that of dry air. The first form shows refractivity is strongly related to the density of the molecules, the second that refractivity is directly related to the variables pressure, specific humidity and temperature. The GNSS data processing provides an estimate of the Zenith Total Delay (ZTD). In an NWP model it corresponds to the integral of refractivity over height in the vertical, in GNSS data processing it can be considered a particular type of weighted average of atmospheric delay towards the GNSS satellites mapped to Zenith. The ZTD can be split into two parts;

$$ZTD = ZHD{+}ZWD, \quad ZHD \approx 2.276810^{-5}\frac{p_a}{c(\theta_a,h_a)}[m/hPa], \quad ZWD = \frac{R_d}{\epsilon g_s(\theta)}\sum_{i=1}^{N} q_i(k'{+}\frac{k_3}{T_i})\Delta p_i$$

The zenith hydrostatic delay, ZHD, is closely approximated by the 'Saastamoinen formula', in which it depends solely on the pressure at the GNSS antenna (Pa) and a function (c) close to unity, which varies slowly with latitude and altitude. The summation is done over the many layers of an NWP model. g_s is the local gravitational acceleration, $k' = k_2 - k_1/e$. Typical values of ZHD near MSL is in the order 2 meters, whereas ZWD varies between 0 and 0.5 m. NWP models are much superior in predicting ZHD relative to ZWD, hence the ZTD mainly provides humidity information to NWP.

E-GVAP (http://egvap.dmi.dk)

The current E-GVAP data coverage is shown in figure 1. There is a focus on Europe, but also obtaining global data, because of members running global NWP models.

Current E-GVAP members are National meteorological services of Austria, Belgium, Croatia, Cyprus, Denmark, Finland, Frathence, Germany, Hungary, Iceland, Ireland, Latvia, Luxemburg, Netherlands, Norway, Portugal, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

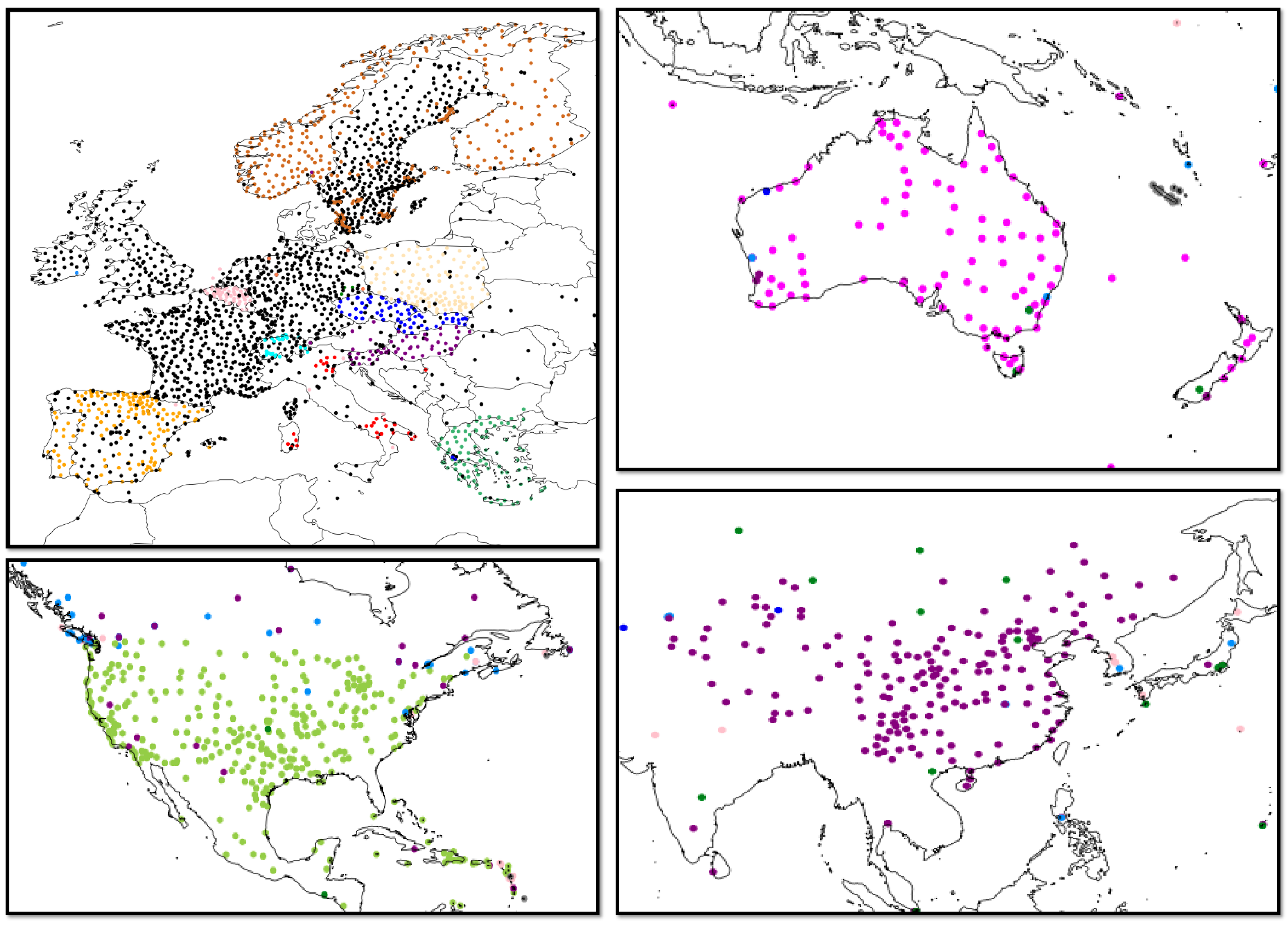

Fig 1. Regional maps of GNSS stations contributing data to E-GVAP.

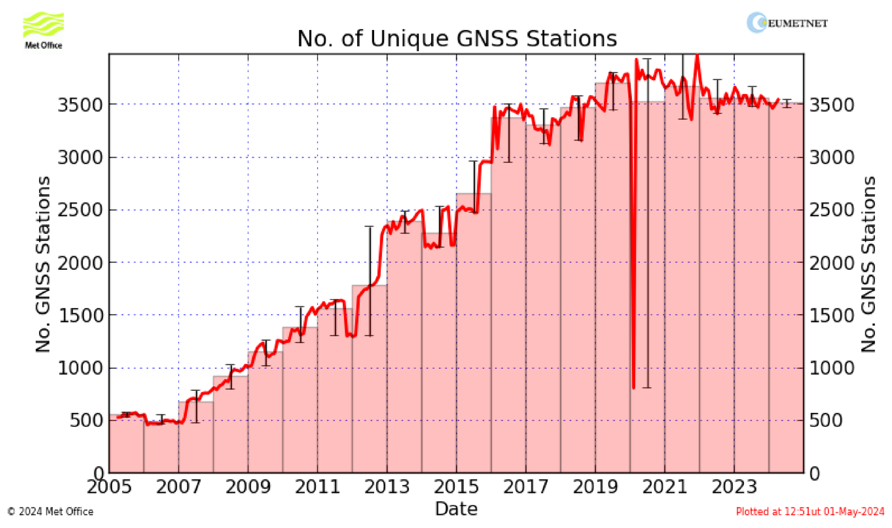

Fig 2. Number of unique GNSS sites versus time.

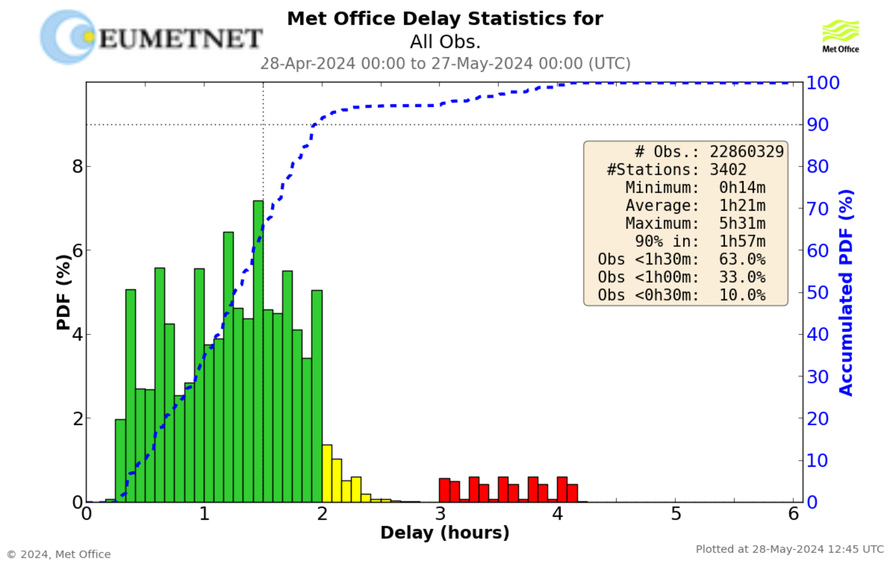

Fig 3. E-GVAP timeliness in 30 min. bins.

ZTD is now routinely assimilated in operational NWP at many national met services. In combination with auxiliary information, ZWD can be determined and used to obtain an estimate of Integrated Water Vapour (IWV), animated sequences of which can be used to assist forecasters, especially for now-casting severe weather events.

The number of contributing GNSS sites in E-GVAP is gradually increasing and we are constantly interested in adding additional sites. Regarding high resolution NWP, we are nowhere near saturation: the current goal for NWP is data being available within 90 min, but future high resolution NWP models require faster access to data due to reduced cut-off times. Some ACs are already running close to real-time processing, with delays in the order 5 to 15 minutes.

bias [mm]	std. dev. [mm]	#site	AC	bias [mm]	std. dev. [mm]	#site	AC
1.6	9.7	506	ASIC	2.4	10.7	271	ROBG
1.7	6.7	206	ASI_	-0.8	11.1	654	ROBH
5.7	10.8	104	AUT1	-4.2	11.4	211	ROBQ
1.1	7.6	93	BKGA	-0.9	13.7	816	ROBT
-1.0	10.0	391	CONH	5.5	15.0	221	SGN1
3.2	24.6	134	GA01	7.8	16.7	221	SGN2
-0.3	7.6	579	GF1G	7.2	14.1	189	SGN3
-0.3	7.5	542	GF1R	0.5	15.1	189	SGN4
0.2	10.0	43	GOPG	1.8	19.0	35	SGNC
2.5	12.0	296	IGE2	13.7	71.5	14	SGNN
1.5	11.1	142	IGER	8.0	34.2	21	SGNR
4.9	15.3	57	JMA	3.2	13.7	378	SGN_
2.1	14.8	42	LPTX	-25.7	31.6	48	-SGO1
-2.3	10.9	200	LPT_	3.4	19.5	7	TUWN
1.0	9.8	277	MTGH	-1.2	8.7	147	WUEL
-0.1	9.3	279	MTRH	-1.4	14.8	323	WUHM
-2.2	10.9	249	MTRS	-1.6	17.0	299	WUHN
-1.9	9.9	735	NGA1				
-1.9	8.8	379	NGA2				

Fig 4. GNSS ZTD versus NWP ZTD per analysis centre & solution for a month

The table in figure 4 provides an example of validation, where GNSS ZTDs are compared to NWP ZTDs from the UK Met Office global model. In this type of comparison, the goal is that the standard deviation should be <15 mm. GNSS data are highly useful for climate monitoring purposes. However, the quality of the estimates can improve with time, near real-time data ZTD data should not be used for climate monitoring. Several reprocessing campaigns are currently being made to deliver climate-quality ZTD estimates such as EUREF Repro3 campaign.

Next Generation GNSS meteorology

ZTD is a single value, however as GNSS receivers observe many satellites, potentially much more detailed atmospheric information could potentially be derived. Some E-GVAP ACs are now routinely delivering (North-South and East-West) tropospheric gradients. Furthermore, Slant Total Delays (STDs), i.e. the atmospheric delay between the receiver and individual satellites, may be provided, delivering an order of magnitude more data than from a single ZTD estimate. It is difficult however to derive high-quality STDs in near real-time. Recently though, the German national research centre for Earth Sciences, GeoForschungsZentrum (GFZ) has started providing STDs estimates to E-GVAP for quality assessment. On the NWP side, software for assimilating tropospheric gradients and/or STDs is being developed at many NWP centres..

Also, EIG EUMETNET is engaged in a new EIG EUMETNET Observation System Experiment (OSE) to assess the impact of assimilating tropospheric gradients and/or STDs in NWP schemes. The objectives of the study are to provide:

1. Evidence of the model forecast impact of combining the assimilation of tropospheric gradients and ZTD (as a proxy to STD) vs. assimilation of STD only vs. assimilation of ZTD only by carrying out the following NWP scenarios:

- Scenario 1: Baseline: no assimilation of any ground based GNSS derived products
- Scenario 2: Control: assimilation of ZTD only.
- Scenario 3: Assimilation of STD where STD data exists – assimilation of ZTD elsewhere.
- Scenario 4: Assimilation of ZTD + gradients where gradients exist – assim. of ZTD elsewhere.

2. Recommendations on the most impactful use of GNSS products provided by E-GVAP (e.g., if recommendation is to use STDs then what should be the coverage/density/frequency etc).

E-GVAP 2024-2029

The next phase of E-GVAP runs from 2024 to 2029 with a continued focus on extending the network coverage and improving timeliness through sub-hourly data processing to facilitate rapid update, high resolution NWP. In addition, there will be enhanced focus on the provision of STDs, as well as on ZTDs from moving platforms. A general modernisation of the software and platforms used to handle E-GVAP data will also be implemented, including alignment with new standards for data exchange and presentation of metadata required by the WMO.

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