Assimilation experiments with ground-based GPS observations in the Environment Canada Global and Regional Deterministic Prediction Systems

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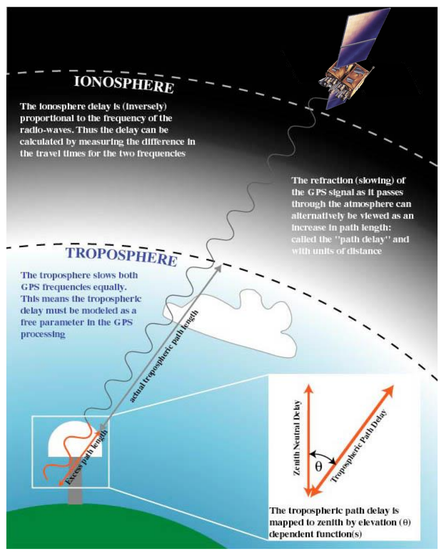


1. Introduction

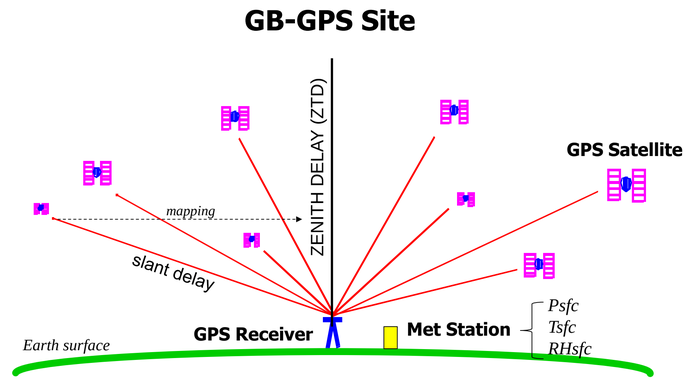
❑ **Ground-based GPS** (GB-GPS) is an established observing system which can accurately sense integrated atmospheric quantities through the delay the atmosphere induces in GPS satellite microwave signal reception at the earth's surface. Complements GPS-RO (occultation)

❑ **Atmospheric refractivity** along signal paths causes the delay. Refractivity in the troposphere is related to air pressure, temperature and water vapour content.

❑ Individual **slant delays** detected by ground-based receivers are mapped to the zenith to provide estimates of the **Zenith Tropospheric Delay (ZTD)**, expressed in units of excess signal path length (metres or millimetres). ZTD ranges from 2200-2700 mm at sea level .

❑ ZTDs are obtained in the processing of GPS signal data from geodetic quality GPS receivers with specialized software designed to provide highly accurate (mm level) station coordinates.

❑ A knowledge of surface pressure (Psfc) at a GPS site allows precipitable water (PW) to be retrieved from the ZTD observations with an accuracy comparable to radiosonde PW.

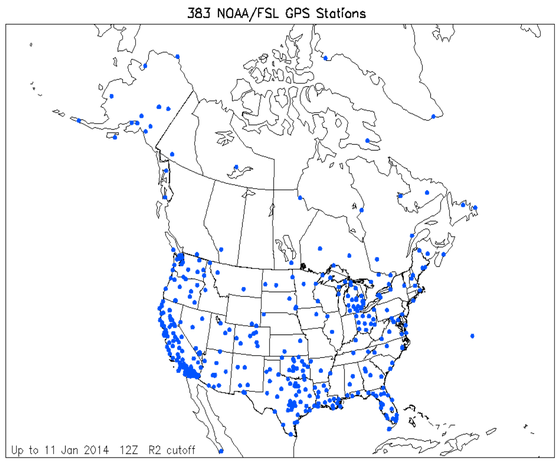


$$ZTD = k P_{sfc} + 10^{-6} \int_{sfc}^{\infty} \left((k_2 - \varepsilon k_1) \frac{Pq}{\varepsilon T} + k_3 \frac{Pq}{\varepsilon T^2} \right) dz$$

$$ZTD = ZHD(Psfc) + ZWD(PW)$$

hydrostatic (dry) delay | wet delay

2. The NOAA GB-GPS Network Observations

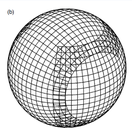


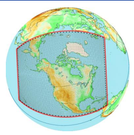
❑ Near real time ZTD and PW observations are available every 30 minutes from over 380 sites of the NOAA GB-GPS Network. A ZTD "formal error" is included. Data are monitored at EC since 2003.

❑ Measurements of surface pressure (Ps) temperature (Ts) and relative humidity (RHs) from collocated or nearby automatic weather stations (e.g. METAR stations) are included at most sites.

❑ We choose to assimilate ZTD rather than PW. We also assimilate Ps with ZTD to better constrain analysis increments.

3. Analysis and Prediction Systems Used





Global System (GDPS)

❑ New **EnVar** upper-air analysis (hybrid **En**semble Kalman Filter and **Var**iational)
❑ GEM-4 **global** NWP model with 15 km Yin-Yang grid, 80 levels (top = 0.1 hPa)
❑ 6h assimilation cycle (00,06,12,18Z)
❑ 5-day forecasts issued at 00 and 12Z

Regional System (RDPS)

❑ New **EnVar** upper-air analysis
❑ Operational 4D-Var GDPS analyses at T-6h initialize the trial forecasts
❑ GEM **Limited Area Model** (LAM 10 km, 80 levels) piloted by GEM global model
❑ 00 and 12Z runs with 2-day forecasts

NOTES: These are **experimental versions** of the systems expected to become operational in late 2014. **EnVar** analysis = Variational assimilation with global EnKF system trial forecasts (192 ensemble members) providing time-dependent 4D background (B) error covariances for B matrix over the 6h assimilation window. A 50%/50% mix of EnKF and standard static "NMC method" covariances are used below 10 hPa becoming 100% NMC (or 3D-Var only) above 6 hPa.

4. Assimilation Experiments (2011 Periods)

	GDPS Summer	GDPS Winter	RDPS Summer	RDPS Winter
Period in 2011	1 July to 31 August	1 Feb to 3 March	1 July to 28 August	1 Feb to 31 March
Number (& length) of forecasts	124 (5-day / 120h)	62 (5-day / 120h)	116 (2-day / 48h)	117 (2-day / 48h)
GB-GPS data assimilated	ZTD, Ps	ZTD, Ps	ZTD, Ps, Ts, RHs	ZTD, Ps, Ts, RHs
Notes			GPS in LAM analysis only (not in global)	GPS in LAM analysis only (not in global)

Other observation types assimilated include surface (SYNOP, BUOY), 4D radiosonde, aircraft, satellite AMVs (sat winds), GPS radio occultation (GPS-RO), NOAA Wind Profiler Network winds, METOP-A scatterometer winds and satellite radiances from AMSU-A, AMSU-B/MHS, SSMIS, AIRS, IASI, GOES and MeteoSat. The new 4D radiosonde (RS) data are RS observations placed at correct locations and times using the observed winds to transport the balloon horizontally as it ascends.

5. Data Assimilation & QC: Key Points

❑ Assimilation of ZTD observations has most impact on analysis water vapour below the 400 hPa level (and hence on analysis PW).

❑ Impact of ZTD assimilation is much less for analysis surface pressure, except in extremely dry conditions. Impact on temperature is minimal.

❑ ZTD is not assimilated in very dry conditions (background PW < 2 mm) or if difference between observed and background Ps is very large.

❑ Observations (O) are rejected that fail standard background (B) O-B difference check. ZTD observations with "formal errors" over 15 mm are also rejected.

❑ Data for sites are blacklisted based on monitoring O-B statistics (means and Standard Deviations).

❑ ZTD data are not assimilated if difference between model surface and GPS antenna height exceeds 1000 m. Height difference limits for Ps, Ts and RHs are 800 m, 800 m and 50 m respectively.

❑ GPS surface met data (Ps, Ts, RHs) are not assimilated if GPS site is within 50 km of reporting synoptic or upper-air station.

❑ GPS observations are assimilated every 2 hours (giving 3 observations per site per 6h assimilation window) and spatially thinned to 50 km.

❑ Data are not bias corrected but sites where ZTD bias (mean O-B) from monitoring is significant (> 10 mm) are blacklisted.

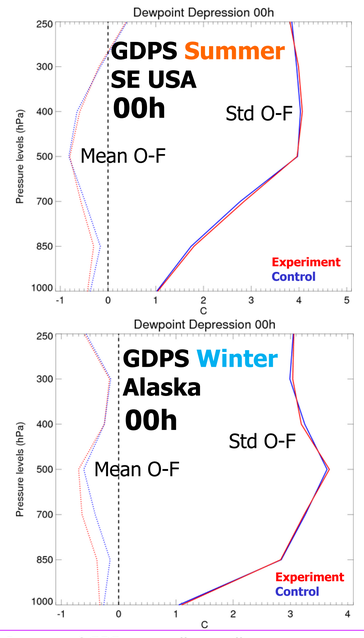
❑ ZTD observation errors are dynamic and increase with increasing observed wet delay (PW). The ZTD errors range from 4 mm (low PW) to 30 mm (high PW).

❑ The GPS ZTD observation operator provides ZTD at GPS antenna height from model profiles of pressure, temperature and water vapour.

6. Impact of GPS Data on the GDPS and RDPS

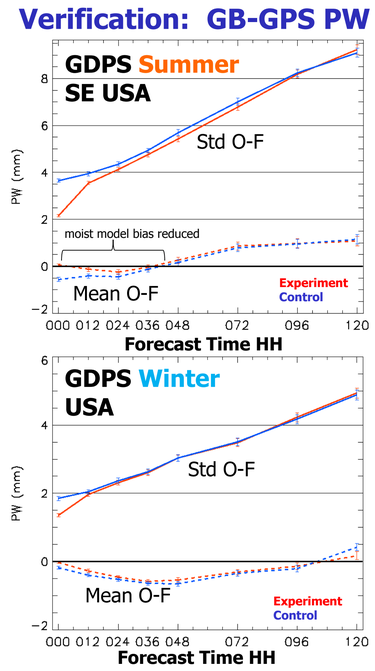
Impact of the GB-GPS observations is evaluated by comparing forecast (F) verification results from the 4 GPS assimilation **experiments** with those from the corresponding **controls** (without GB-GPS data). Shown are some key results of O-F verifications against North American observations (O) from **radiosondes**, **GB-GPS network (PW)** and USA **SHEF rain gauge network (1200 UTC 24h precipitation accumulations)**. In general, results for the GDPS and RDPS experiments are similar over the common 2-day (00-48h) period.

Verification: Radiosondes



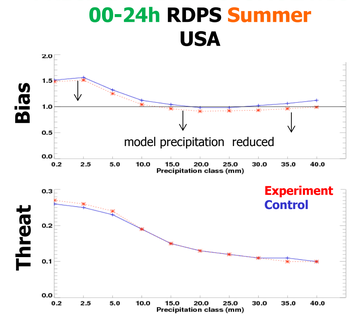
➢ Impact of GPS generally small
➢ Biggest impacts are on mean analysis (00h) **dewpoint depression** (moisture) over Southeast USA (summer) and Alaska (winter) where **analysis with GPS is drier than control**

Verification: GB-GPS PW



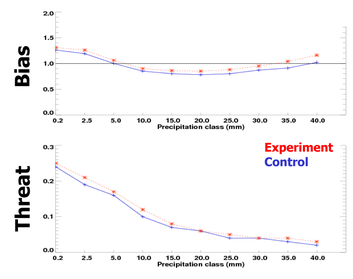
➢ **Positive impact** of GB-GPS observations; impact visible to **day 4** (96h) in Summer
➢ GPS reduces PW O-F differences
➢ GPS impact is smaller and shorter-lived in (drier) winter

PRECIPITATION ACCUMULATION
00-24h RDPS Summer
USA



➢ **Positive impact** of GPS on lower class (< 10 mm) bias and threat scores for 0-24h accum

12-36h RDPS Summer
Central USA



➢ GPS increases precip accums, **improves threat score** (Central Region)

7. Summary and Future Plans

❑ Ground-based GPS Zenith Tropospheric Delay (ZTD) observations from the NOAA GB-GPS network are assimilated in new experimental versions of the EC global (GDPS) and regional (RDPS) deterministic prediction systems. Some collocated GB-GPS surface met data are also assimilated. Impact of the GB-GPS data is evaluated using verifications of forecasts against observations.

❑ Results of both summer and winter assimilation experiments show overall positive impact of the GB-GPS observations on analysis and forecast humidity (PW), especially in verification of forecasts against GB-GPS PW observations. Impact on precipitation forecasts is less obvious but notably positive for some regions and lead times.

❑ Future plans include addition of GB-GPS ZTD observations from the E-GVAP (Europe) and IGS (global) networks to the GDPS with investigation into more Canadian sites.

REFERENCE: Macpherson, S. R., G. Deblonde, J. M. Aparicio, B. Casati, 2008: Impact of NOAA Ground-Based GPS Observations on the Canadian Regional Analysis and Forecast System. *Mon. Wea. Rev.*, **136**, 2727–2746.