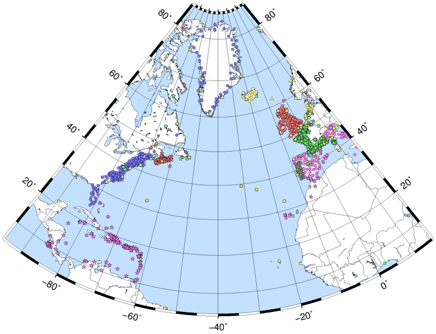


GPS contribution to the DIP-NAWDEX project

Pierre Bosser[1] and Olivier Bock[2]

[1] ENSTA Bretagne - Lab-STICC, Brest, France

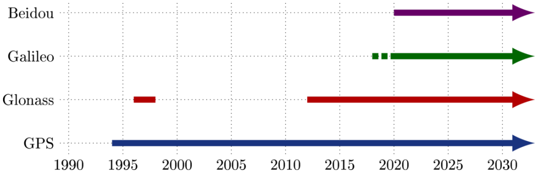
[2] IGN - Lareg, Paris, France

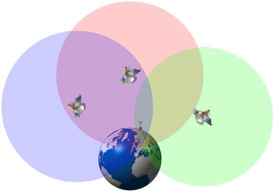
Outlines

Outlines

1. Meteorology / Climatology using GNSS
   - Precise positioning with GNSS
   - Troposphere modeling on GNSS signal propagation
   - Use of GNSS for meteorological / climatological studies
2. Nawdex GPS datasets
3. Preliminary results
4. Conclusion

Global Navigation Satellite System





- Four independent systems: GPS, Glonass, Galileo, Beidou
- Orbital altitude of GNSS satellites around 20,000 km above Earth.
- Positioning using time propagation measurements of a radio wave, from satellites to receiver.

GNSS positioning

From a few meters down to the level of millimeters:

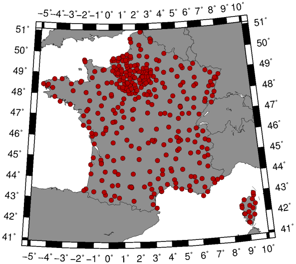
- Standard positioning is used for m-accuracy positioning.
- Using **carrier phase measurements**, it is possible to get **cm to mm-accuracy** positioning.

Different methods for **high accuracy positioning**:

- Relative / absolute
  - **Relative** to a ”fixed” continuously operating reference station
    - ☺ Easier to get an accurate position
    - ☹ Less practical for scientific applications
  - **Absolute** to satellite orbits
    - ☺ Ready for scientific applications
    - ☹ Accurate positioning could be achieved... need of good modeling
- Real-time or post-processed

GNSS permanent stations

Networks of **continuously operating reference station** are set up for three dimensional positioning, meteorology, space weather, and geophysical applications throughout the world.



Troposphere impact on GNSS

GNSS signals travel through the Earth's atmosphere. Two different layers alter the propagation:

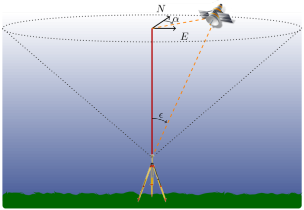
- The **ionosphere**,
- The electrically neutral atmosphere, mainly its lower part, the **troposphere**.

➥ The latter one's impact is modeled as **troposphere propagation delay**; it varies from 2,4 m at zenith up to $\sim$24 m at 5° elevation angle.

This delay is expressed as the sum of two contributions:

- The **hydrostatic delay**, which depends only on the total density of the air.
- A non hydrostatic part called **wet delay**, related to temperature and water vapor density.

Troposphere modeling



$$\Delta L_{\text{tropo}}(\alpha,\epsilon) = \Delta L_h^z \cdot mf_h(\epsilon) + \Delta L_w^z \cdot mf_w(\epsilon) + m_\alpha(\epsilon)[\Gamma_{ns}\cos\alpha + \Gamma_{ew}\sin\alpha]$$

- α, ϵ: azimuth, elevation of GNSS satellite
- ΔL_{tropo}: tropospheric delay for a given direction
- ΔL_h^z: Zenith Hydrostatic Delay (**ZHD**) retrieved from ground pressure measurements.
- ΔL_w^z: Zenith Wet Delay (**ZWD**) estimated during the processing.
- Γ_{ns}, Γ_{ew}: horizontal gradients
- mf_h, mf_w, m_α: mapping functions for delays and gradients.

ZWD and IWV

ZWD is closely linked to IWV:

$$IWV = k(T_m) \times \Delta L_w^z$$

T_m is the mean temperature of the wet column, $k \approx 150$ kg·m^{-1} (retrieved from NWP models) [Bevis et al., 1994, JGR].

ZWD are commonly used for meteorological / climatological studies, e.g.:

- 4D-Var Assimilation in NWP models [Poli et a., 2007, JGR]
- HyMeX Program [Bock et al., 2016, QJRMS]
- Radiosonde quality assessment [Wang et al., 2008, JoC]

Outlines

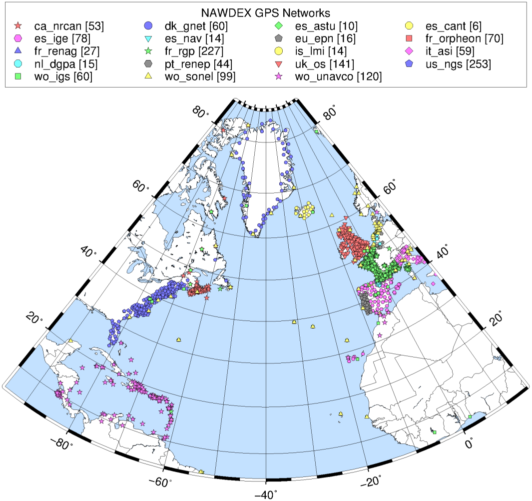
1. Meteorology / Climatology using GNSS
2. Nawdex GPS datasets
   - GPS network
   - GPS processing strategy
3. Preliminary results
4. Conclusion

Providers

Use of more than **1,200 COR stations** around the North Atlantic area.

- 19 data providers (free or private data)
  ➥ Specific request to some providers (Nottingham Geospatial Institute, DTU Space, LMI, Direção-Geral do Território).
- Period of interest: day-of-year 240 to 310 (August 27 to November 5)

Networks


NAWDEX GPS Networks
ca_nrcan [53]
dk_gnet [60]
es_astu [10]
es_cant [6]
es_ige [78]
es_nav [14]
eu_epn [16]
fr_orpheon [70]
fr_renag [27]
fr_rgp [227]
is_lmi [14]
it_asi [59]
nl_dgpa [15]
pt_renep [44]
uk_os [141]
us_ngs [253]
wo_igs [60]
wo_sonel [99]
wo_unavco [120]
80°
80°
60°
60°
40°
40°
20°
20°
−80°
−60°
−40°
−20°
0°

Precise Point Positioning

GPS processing using **PPP** strategy:

- **Absolute** and **post-processed** positioning using **GPS carrier phase measurements**.
- Use of **Gipsy-Oasis II 6.4** (JPL / NASA)
- Further details:
  - SRIF for filtering / estimation
  - PPP with fixed ambiguities
  - 30h session around midday
  - Use of IERS 2010 standard
  - One position per sessions
  - troposphere parameters modeled as random walk processes.
- $\sim$ 7 days for whole processing.

Troposphere modeling

Use of ECMWF-based data (VMFgrid):

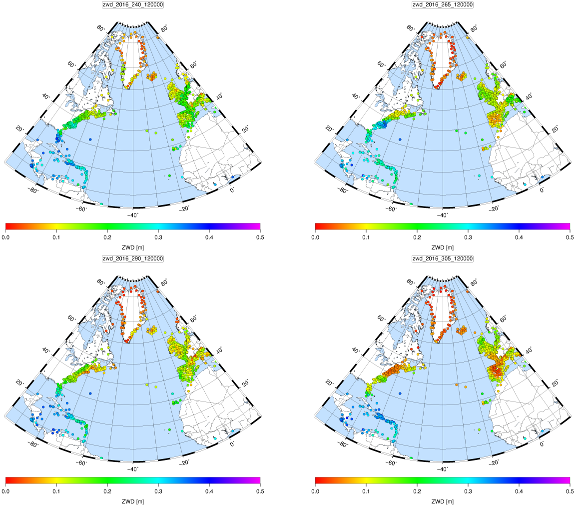
- Values for ZHD
- A priori values for ZWD
- Mapping function, for hydrostatic and wet delays, horizontal gradients

Estimation as random walk process:

- ZWD, 5 mm$\cdot$h$^{-1/2}$
- Horizontal gradients, 0.5 mm$\cdot$h$^{-1/2}$
- @ 5 min. resolution

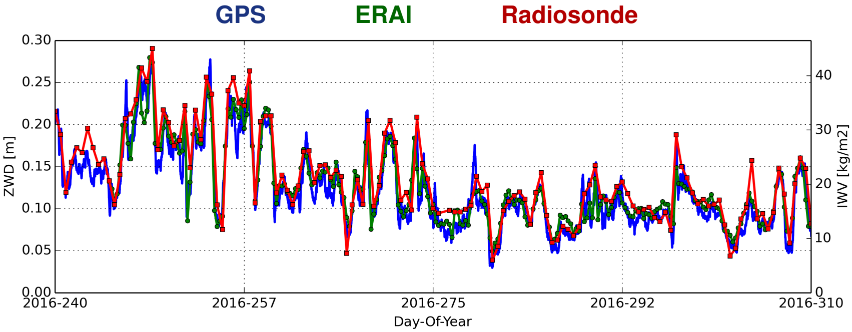
Outlines

ZWD estimates for the global network



Brest (Guipavas)

Raw comparisons between GPS solution and ERAI, Radiosonde (from UWYO)



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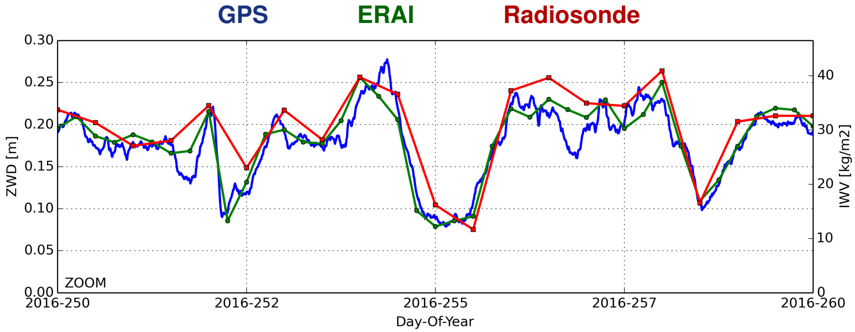

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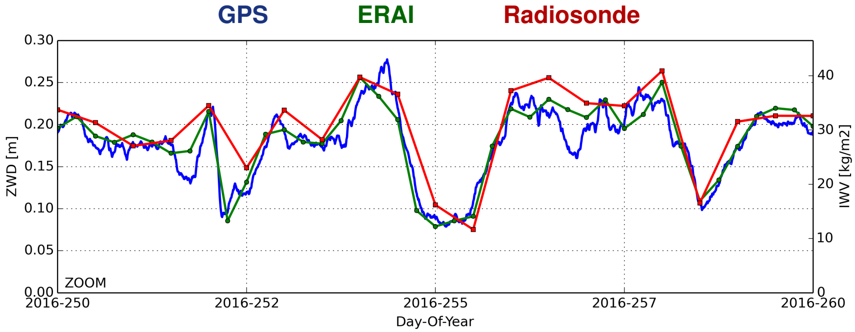

wrt GPS	Δ ZWD [mm]	Δ IWV [kg·m^{-2}]
ERAI	4.9 ± 13.7	0.76 ± 2.12
RS_UWYO	12.6 ± 12.7	1.96 ± 1.97

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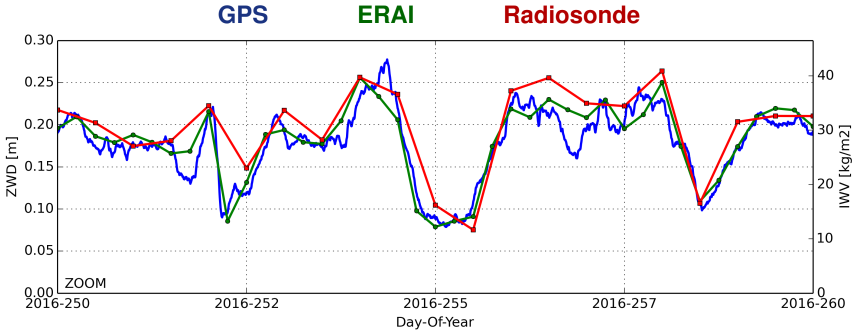

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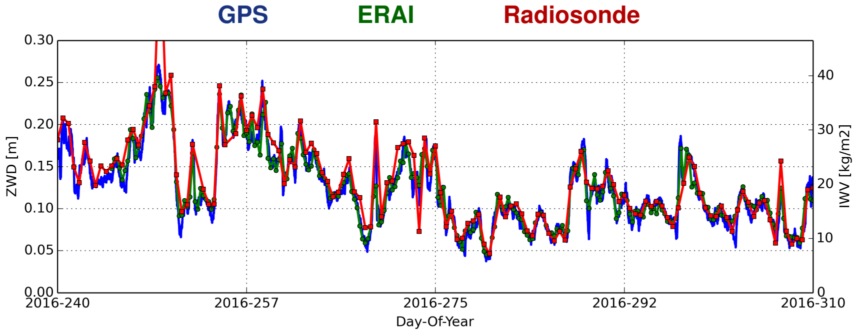
- High temporal resolution
- Good agreement with other techniques

SIRTA (Trappes)

Raw comparisons between GPS solution and ERAI, Radiosonde (from UWYO)



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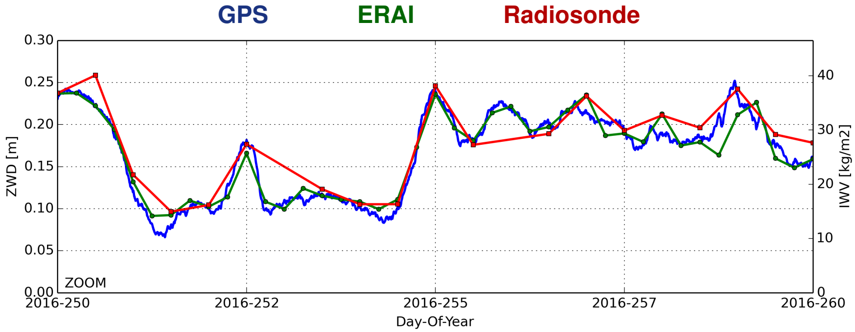
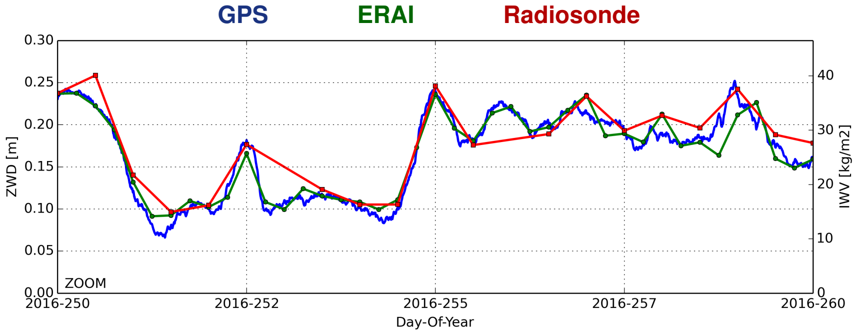


SIRTA (Trappes)

Raw comparisons between GPS solution and ERAI, Radiosonde (from UWYO)

ENSTA Bretagne



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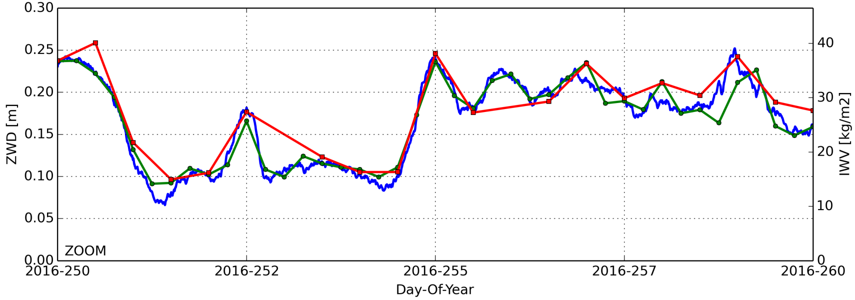

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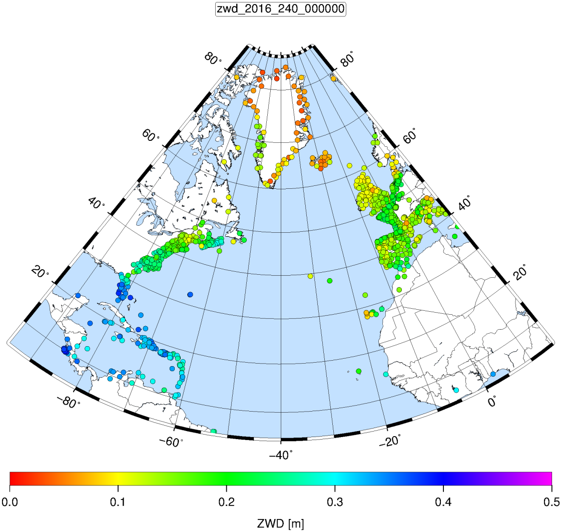
Outlines

Summary

- A ground based GPS dataset was produced for the NAWDEX campaign.
- ZTD are estimated for more than **1200 ground based GPS stations** from Aug. 28 to Nov. 5 at **5 min. time resolution**.
  ☹ Dataset limited to inshore area...
- IWV can be retrieved from this dataset using NWP models.
- A first assessment of the dataset is lead on two French stations using ERAI and RS data.
  ➥ **Pretty good agreement** (consistent with scientific literature)
- This dataset is intended to be used for the documentation of IOPs.

Outlook

- Internship that starts today !
- GPS processing:
  - Screening / quality control of the datasets
  - Extension of the datasets over some areas (Sweden, Finland ?)
  - Methodological tests (random walk, data weighting)
- Validation of the whole GPS dataset using external products:
  - Radiosoundings (NAWDEX launch, higher resolution / better quality check)
  - Humidity products from satellites
  - NWP models
  - Use of horizontal gradients ?
- Case studies
- ...


zwd_2016_240_000000
80°
80°
60°
60°
40°
40°
20°
20°
-80°
-60°
-40°
-20°
0°
0.0
0.1
0.2
0.3
0.4
0.5
ZWD [m]