Water vapour monitoring over France using the low-cost GNSS collaborative network Centipede

Supplementary material

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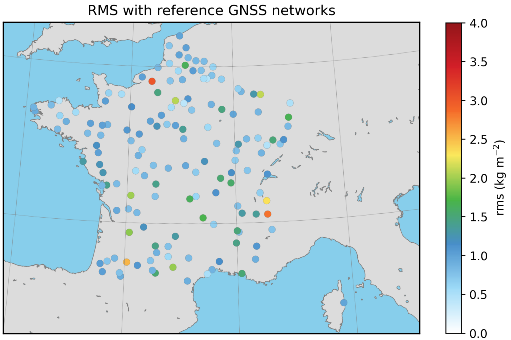
Pierre Bosser[(1)], Julien Ancelin[(2)] Marianne Métois[(3)], Lucie Rolland[(4)], Maurin Vidal[(4)]

(1) ENSTA Bretagne, Lab-STICC, Brest, France
(2) INRAe DSLP, Saint-Laurent-de-la-Prée, France
(3) Université de Lyon, UCBL, ENSL, UJM, CNRS, LGL-TPE, Villeurbanne, France
(4) Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, IRD, Laboratoire Géoazur, Valbonne, France



The Centipede Network

- https://centipede.fr/

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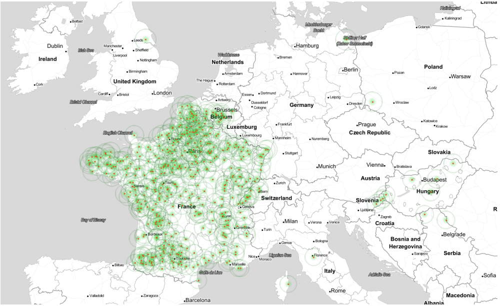


The Centipede network

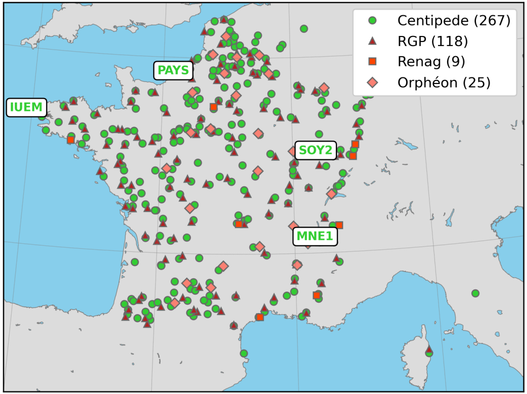
- Founded in 2019.
- Collaborative permanent GNSS network that aims to offer free real-time centimeter positioning.
- Consists of more than 330 low-cost reference stations mainly located in France.
- Nearly 500 regular users.

→ Since July 2022, the raw GNSS data acquired have been archived by the Réseau National GNSS (Rénag) scientific network data center.

→ **Is the Centipede network suitable for geoscience applications?**

Dataset

▶ GNSS networks



We consider stations from three reference GNSS networks surrounding Centipede stations with a radius inferior to 20 km and a difference in height inferior to 100 m:

- 267 stations from Centipede network during the whole period.
- 118 stations from RGP, 9 from Rénag, 25 from Orphéon.

We are interested in the period from 1 August to 31 December 2022.

Processing

▶ GipsyX PPP-AR processing

GNSS raw data are analyzed with GipsyX in PPP-AR mode [Ber+20]:

- Final JPL orbits & clocks (30 s).
- Only GPS observations are processed, using a 30 h window centered on each day.
- Cut-off angle of 7deg; uniform weighting of carrier phase observations (1 cm).
- The troposphere is modeled thanks to VMF1 model (a priori and mapping. functions); ZTD and horizontal gradients are estimated every 5 min as random walk processes.

Methodology

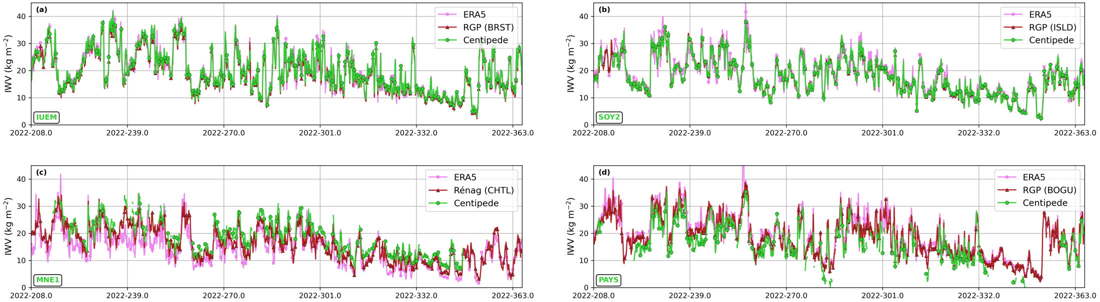
▶ IWV retrieval

GNSS troposphere delays are converted into IWV using ERA5 surface pressure fields (0.25 deg$\times$1 h) [Her+20] for ZHD computation and T_m values from TU-Vienna [Boe+06].

We also used TCWV product from ERA5 to extract IWV at each GNSS location. The methodology is the same as used in [Bos+21].

In the following, IWV from Centipede are compared to ERA5 and reference GNSS IWV.

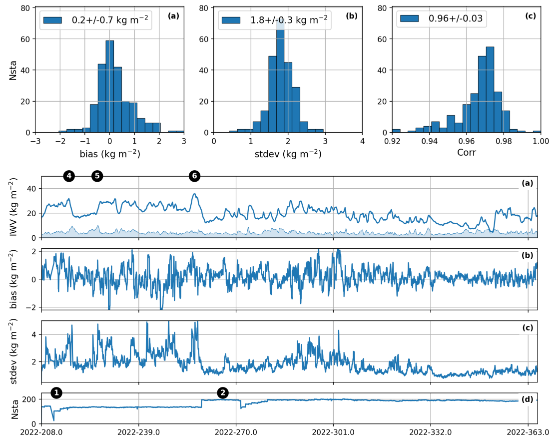
IWV time series



- The IWV time series are in very good agreement for a large majority of stations.
- However, a small number of stations show more significant differences.

ERA5 – Centipede

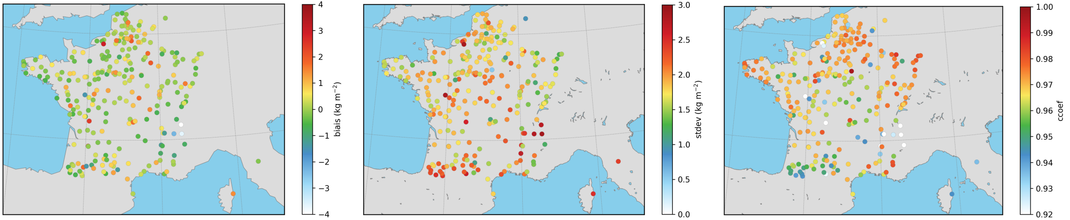
▶ Statistics of differences for 267 Centipede stations



- The number of Centipede stations varies over the period, due to a server outage (❶) and a change in the data retrieval mode (❷).
- The bias with ERA5 is small and stable over time.
- The standard deviation of the difference shows a higher variability over time; the highest values seem to correspond to periods of high spatial variability of IWV and/or high IWV values (❹, ❺, ❻) and to the decreasing number of Centipede stations available.
- These statistics of the differences with ERA5 are in line with the results obtained in previous studies using geodetic stations [Bos+21; Din+23].

ERA5 – Centipede

▶ Geographical distribution of differences for 267 Centipede stations

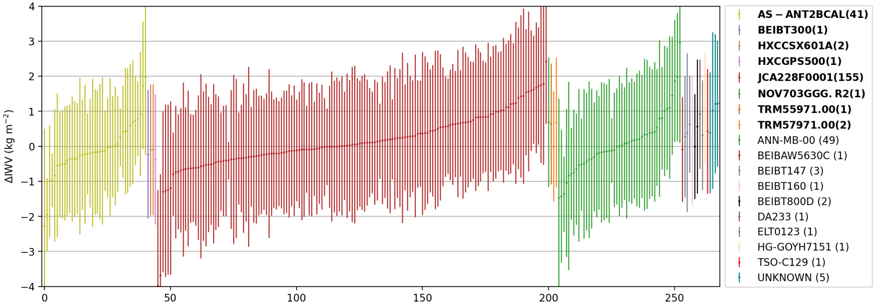


bias (←) ; stdev (–) ; correlation (→)

- Biases and standard deviations are higher in mountainous areas.
- The correlation coefficient is lower in mountainous areas.
- In the lowlands, the differences are smaller, although some stations show significant differences.

ERA5 – Centipede

▶ Impact of antenna model on the differences: bias ± stdev

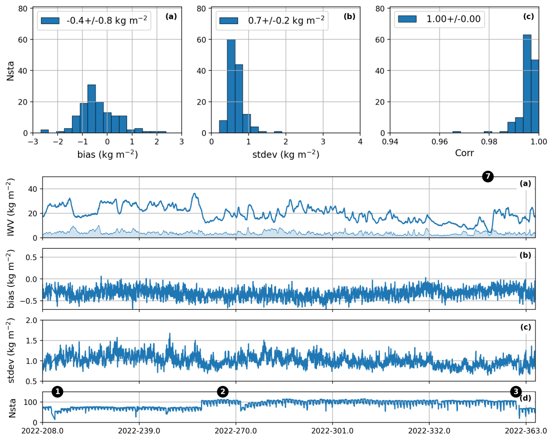


Antennas for which a calibration is available are shown in bold in the legend

- There is no clear relationship between antenna type and deviations.
- The effect of using calibrated / documented antennas is not apparent.

Reference GNSS stations – Centipede

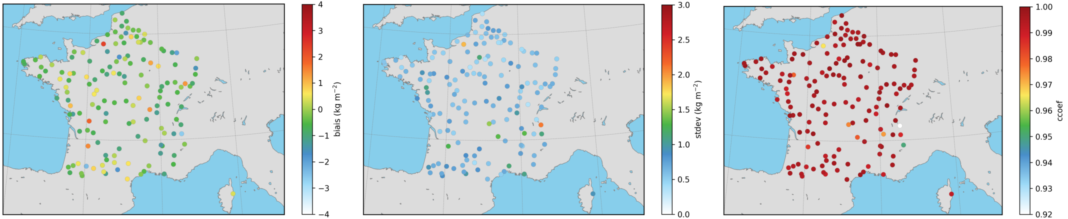
▶ Statistics of differences for 152 Centipede stations



- The number of Centipede stations varies over the period, due to a server outage (❶) and a change in the data retrieval mode (❷). The number of reference stations decreased at the end of the year due to a server outage of a sub-network of the RGP (❸).
- The histogram of differences calculated by station shows a small but statistically significant bias (Centipede wetter than reference networks).
- As the IWV decreases, a slight reduction in this bias is observed (❼). The standard deviation of the differences is small and stable over time;
- The correlation coefficients are close to 1, with 90% of the stations above 0.99.

Reference GNSS stations – Centipede

▶ Geographical distribution of differences for 152 Centipede stations

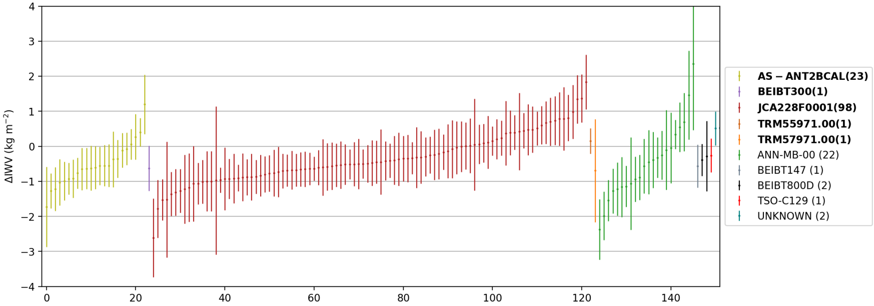


bias (←) ; stdev (–) ; correlation (→)

- The geographical distribution of the differences is homogeneous.
- Some stations show larger differences; a possible reason for these differences will be explained later.

Reference GNSS stations –Centipede

▶ Impact of antenna model on the differences: bias ± stdev



Antennas for which a calibration is available are shown in bold in the legend

- As previously, there is no clear relationship between antenna type and deviations.
- The effect of using calibrated / documented antennas is still not apparent.

ERA5 & Reference GNSS stations – Centipede

▶ Influence of low elevation observations

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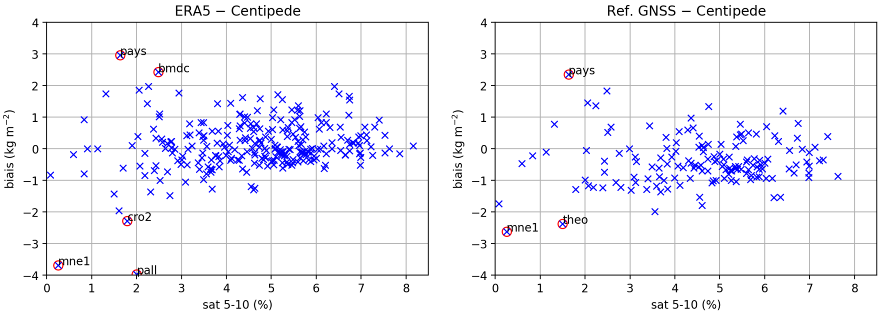
- For each stations, we compute the rate of observations between 5 and 10 deg.
- The satellites with the highest biases (> 2 kg·m^{-2}) systematically have a small rate of low elevation observations.

→ The observation configuration of some stations is not optimal due to the presence of masks. This affects the quality of the analysis.



Conclusion

Despite a possible wet bias, Centipede data show good agreement with ERA5 and GNSS reference network data, with mean deviations consistent with the literature.

These results confirm the high potential of low-cost GNSS networks.

- The development of such network is a real opportunity for geoscience applications, particularly in poorly instrumented areas.
- In such areas, their contribution could be especially significant for meteorology or climatology for which the monitoring of water vapour by GNSS is widely used.

https://centipede.fr/

https://renag.resif.fr/

ORPHEON GNSS data were provided to the authors for a scientific use in the framework of the GEODATA-INSU-CNRS convention up to be signed

Références

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