



# Near real-time water vapour monitoring with shipborne GNSS for numerical weather prediction

Pierre Bosser, Pierre Tulet

## ► To cite this version:

Pierre Bosser, Pierre Tulet. Near real-time water vapour monitoring with shipborne GNSS for numerical weather prediction. EGU General Assembly 2024, Apr 2024, Vienna, Austria. 2024, 10.5194/egusphere-egu24-8726 . hal-04554587

**HAL Id: hal-04554587**

**<https://hal.science/hal-04554587>**

Submitted on 22 Apr 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.





# Near real-time water vapour monitoring with shipborne GNSS for numerical weather prediction

Pierre Bosser<sup>(1)</sup>, Pierre Tulet<sup>(2)</sup>

(1) Lab-STICC/M3 UMR 6285 CNRS, ENSTA Bretagne, Brest, France ; (2) LAERO UMR 5560 CNRS, UT3, IRD, Toulouse, France

## Context & Objectives

MAP-IO (Marion Dufresne Atmospheric Program Indian Ocean) is a research project that aims to collect long-term atmospheric, biological and oceanic observations to document the under-instrumented areas of the Indian and Southern Oceans. To this end, the French research vessel (R/V) Marion-Dufresne, based on the island of Réunion in the Indian Ocean, has been equipped with about twenty autonomous instruments to take measurements along its route. [Tul+24].

Among the instruments deployed on this R/V, a GNSS antenna is in operation since autumn 2020, providing unique and continuous measurements of atmospheric water vapor in this part of the world.



The R/V Marion Dufresne © N. Gravier (left) and the GNSS antenna (right)

## Routine processing strategies

The data were initially transmitted daily to shore for **Ultra** (day +1) and **Rapid** (day +3) routine analysis in PPP-AR using Gipsy-Oasis 6.4 [Zum+97].

Strategy	Latency	Orbits & Clocks	Sampling	Troposphere	GNSS
<b>Ultra</b>	Day + 1	JPL ultra	300 s	GPT / GMF	G
<b>Rapid</b>	Day + 3	JPL rapid	30 s	GPT / GMF	G

The troposphere effect on GNSS signal propagation is modeled by time-varying Zenith Hydrostatic Delays (ZHD), Zenith Wet Delays (ZWD) and horizontal gradients. The ZHD is corrected a priori using the GPT model. The ZWD is estimated during the processing as a stochastic parameter modeled by a random walk of  $5 \text{ mm h}^{-1/2}$ .

The GNSS Zenith Troposphere Delays (ZTD) is finally obtained by summing ZHD and ZWD. The Integrated Water Vapor (IWV) content is also derived from ZTD estimates using ship-borne temperature and pressure measurements using standard methods [Bev+92; Bos+07].

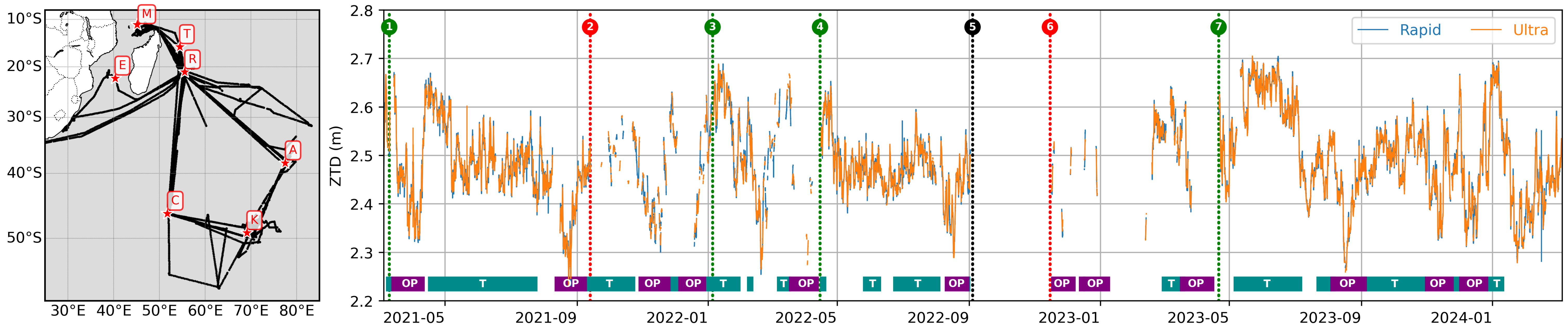


The quality of the retrieved IWV was assessed in a multi-technique intercomparison study [Bos+22].

The data are continuously made available to the scientific community via the AERIS atmosphere Data and Services Centre.



## ZTD measurements over the period 2021 - 2024



The R/V operates 4 annual rotations (**OP**) from Reunion Island (**R**) among the French Austral Islands: Crozet Archipelago (**C**), Kerguelen Islands (**K**), Saint-Paul and Amsterdam Islands (**A**). The rest of its mission consists of conducting oceanographic and geophysical campaigns in the open sea or near French islands as Mayotte (**M**), Îles Éparses (**E**) and Tromelin (**T**).

The time series of ZTD produced by the 2 routine analyses cover almost 70% of the period. Periods of interruption are associated with ship maintenance (5) and instrument issues (antenna, 2 and cable, 6). Changing the antenna location on the ship (1 and 3) and the equipment (4 and 7) solved these problems.

Over the whole period, the ZTD from the two analysis are highly consistent with differences of  $0.1 \pm 7.1 \text{ mm}$ .

The space and time variations of the ZTD reflect the different climatic regions crossed by the R/V.

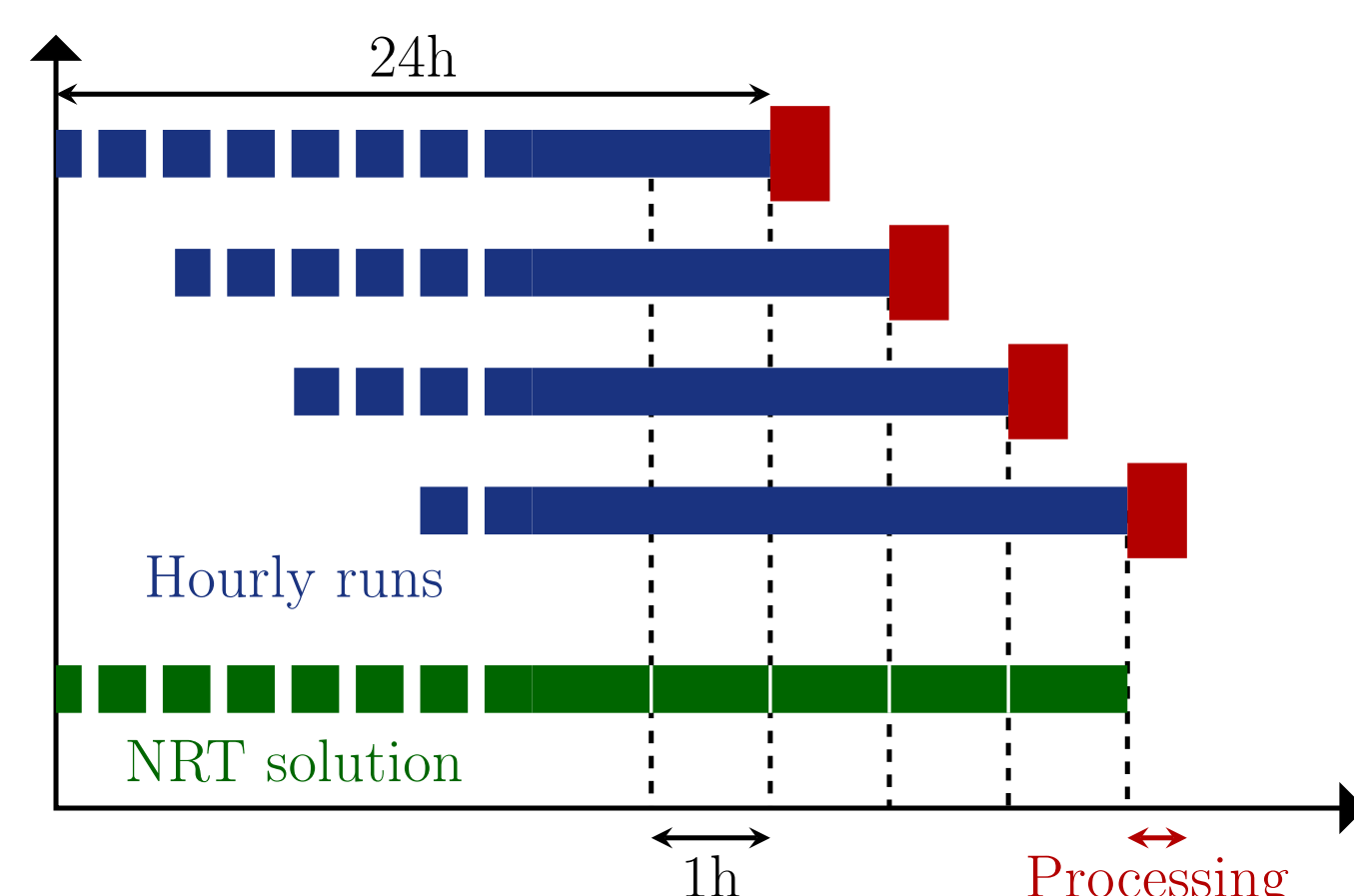
- More southerly passages during rotations (**OP**) are systematically accompanied by lower ZTD, mainly due to lower water vapor contents.
- On the other hand, during campaigns, mostly in tropical regions (**T**), ZTD reach higher values because the atmosphere may contain more water vapor due to higher temperatures.

## Near Real-Time processing strategy

With improved transmission facilities, raw GNSS measurements are now transmitted hourly since early 2023 and can be analyzed with a latency of less than 30 minutes. An initial assessment of the Near Real Time (**NRT**) processing was conducted based on GNSS raw data collected in August 2023 during a rotation of the R/V Marion-Dufresne in the French Austral Islands (**OP**).

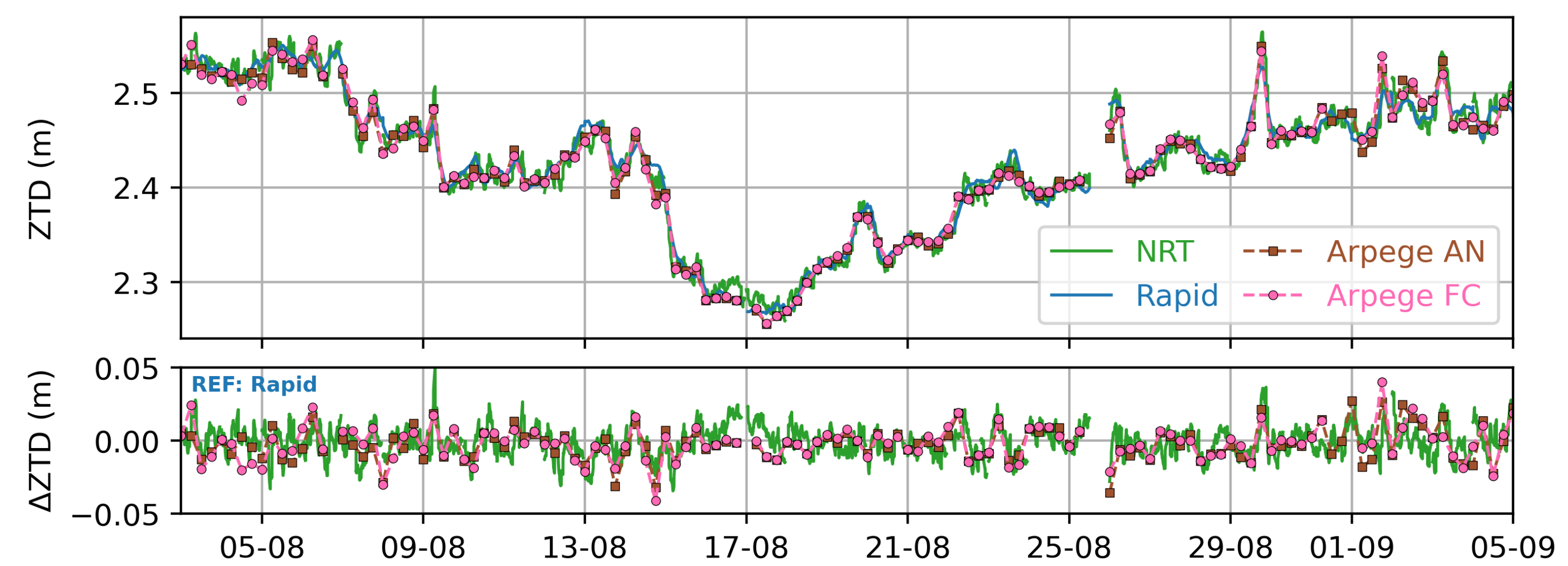
Strategy	Latency	Orbits and Clocks	Sampling	Troposphere	GNSS
<b>NRT</b>	h + 20 min	JPL / GDGPS	30 s	GPT / GMF	GRE

The processing is done with GipsyX 2.0 in PPP mode [Ber+20]. The analysis is run every hour over a 24-hour window, using the raw hourly data transmitted by the R/V and the cumulative real-time ephemerides and clocks provided by JPL / GDGPS. Only the last hour of each analysis is then considered. The rest of the parameterization of this analysis is similar to the routine analyses.



The solutions of the **NRT** processing are compared with the ZTD computed from the mean sea level pressure and IWV fields of the Arpege Numerical Weather Prediction (NWP) model [Dég+94]. Two outputs from the model are used, the analysis (**Arpege AN**) and the 6h-forecast (**Arpege FC**).

## Near Real-Time processing assessment



There is good overall agreement between the different time series. The time series from the **NRT** calculation is slightly noisier, but accurately reproduces the overall evolution of the ZTD.

From a more quantitative point of view, the **NRT** calculation shows an RMS of differences of about 10 mm compared to the **Rapid** processing, with a low bias.

(mm)	wrt <b>Rapid</b>	wrt <b>NRT</b>
<b>NRT</b>	$-0.7 \pm 10.2$	—
<b>Arpege AN</b>	$-2.3 \pm 11.4$	$-2.3 \pm 11.0$
<b>Arpege FC</b>	$-1.8 \pm 11.7$	$-1.9 \pm 11.5$

The Arpege **analysis** and **forecast** shows an RMS of differences about 11 mm with **NRT** and **Rapid** solutions, with a bias of about 2 mm (GNSS wetter than Arpege).

## References

- [Ber+20] W. Bertiger et al. "GipsyX/RTGx, a new tool set for space geodetic operations and research". In: *Advances in Space Research* 66.3 (Aug. 2020), pp. 469–489. DOI: 10.1016/j.asr.2020.04.015.
- [Bev+92] M. Bevis et al. "GPS Meteorology: Remote Sensing of Atmospheric Water Vapor Using the Global Positioning System". In: *Journal of Geophysical Research: Atmospheres* 97 (1992), pp. 15787–15801. DOI: 10.1029/92JD01517.
- [Bos+07] P. Bosser et al. "An improved mean gravity model for GPS hydrostatic delay calibration". In: *Geoscience and Remote Sensing Letters* 4 (2007), pp. 3–7. DOI: 10.1109/LGRS.2006.881725.
- [Bos+22] P. Bosser et al. "Routine Measurement of Water Vapour Using GNSS in the Framework of the Map-Io Project". In: *Atmosphere* 13.6 (2022), p. 903. DOI: 10.3390/atmos13060903.
- [Dég+94] M. Déqué et al. "The ARPEGE/IFS atmosphere model: a contribution to the French community climate modelling". In: *Climate Dynamics* 10.4–5 (1994), pp. 249–266. DOI: 10.1007/bf00208992.
- [Tul+24] P. Tulet et al. "MAP-IO, an atmospheric and marine observatory program onboard Marion Dufresne over the Southern Ocean". In: *Earth System Science Data Discussions* 2024 (2024), pp. 1–43. DOI: 10.5194/essd-2023-531.
- [Zum+97] J. F. Zumberge et al. "Precise point positioning for the efficient and robust analysis of GPS data from large networks". In: *Journal of Geophysical Research* 102 (1997), pp. 5005–5017. DOI: 10.1029/96JB03860.

## Conclusion & Perspectives

GNSS data collected aboard the R/V Marion Dufresne as part of the MAP-IO program are being used to monitor the spatio-temporal distribution of atmospheric water vapor in the Southern and Indian Oceans.

- The ZTD/IWV measurements routinely retrieved in this framework are intended to be used for long-term studies, as is common for ground-based antennas.
- The NRT calculation appears to be of sufficient quality for use in NWP (Cal/Val or assimilation).
- The next stage of this work will be to establish an operational procedure for the assimilation of these NRT GNSS troposphere solutions into NWP models. This also includes a possible adaptation of the COST format to moving antennas.