IWV retrieval from ship-borne GNSS receiver in the framework of the MAP-IO project

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Foreword: GNSS IWV (1)

- **Accurate GNSS positioning** ($<$ a few mms) required the estimation of **zenith troposphere propagation delay** (*ZTD*):

$$ZTD = ZHD + ZWD \qquad [\mathrm{m}]$$

  - *ZHD*: zenith hydrostatic delay ($\propto P_{sfc}$)
  - *ZWD*: zenith wet delay
- **Integrated water vapour** (*IWV*) could be retrieved from zenith wet delay:

$$IWV = Q(Tm)ZWD \qquad [\mathrm{kg\,m^{-2}}]$$

T_m: weighted mean temperature of the wet atmospheric column

➥ Accuracy: 1–2 $\mathrm{kg\,m^{-2}}$ IWV ($\sim$ 6–12 mm ZTD) for ground reference GNSS antennas [Boc+13; Nin+16]

Foreword: GNSS IWV (2)

Numerous advantages of the GNSS technique:

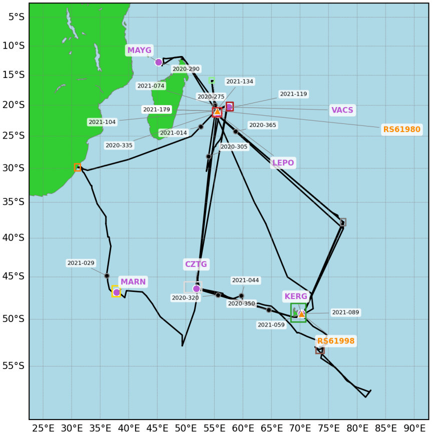
- the instrumentation is low-cost and power-efficient;
- the measurements are obtained in all weather conditions and do not require instrumental calibrations.

GNSS products from ground reference antennas are now commonly used for climatology and meteorology studies:

- **Agreement** with more conventional meteorological instrumentation;
  [Bev+92; Haa+03; Bos+10; Boc+13]
- Common use in **climatology**;
  [Boc+16; Had+18]
- **Assimilation** in numerical weather prediction models.
  [Pol+07; Gue+16]

Context

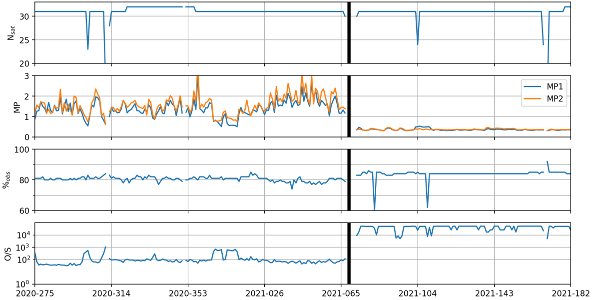
- Studies highlight the **performance of IWV retrieval from ship-borne GNSS antenna**, with RMS with respect to classical techniques in the range 1-3 $kg\,m^{-2}$ [Wan+19; Bos+21; Män+21]
- The challenge lies in the **simultaneous estimation of kinematic position and *ZTD***.
- **Marion Dufresne Atmospheric Program – Indian Ocean** (MAP-IO): collection of long-term marine biology and atmospheric observations in Indian & Austral Oceans
- Installation of a GNSS receiver on the RV **Marion Dufresne** in October 2020 to describe and monitor global moisture in the atmosphere.
- GNSS raw data are recorded continuously and used to retrieve **integrated water vapor** contents (IWV) along the RV route.



GNSS raw data quality check

First step: raw data quality check with TEQC [Est+99]

- N_{sat}: **Number of satellites** by 24h sessions
- MP: **Multipath** on L1 and L2 carriers
  Interference induced by antenna environment.
  (Lowest value expected)
- $\%_{obs}$: **Percentage of used observations**
  Percentage of complete to possible observations
- O/S: **Observations / Slips**
  Ratio between complete observations and the number of slips from GNSS raw data.
  (Highest value expected)



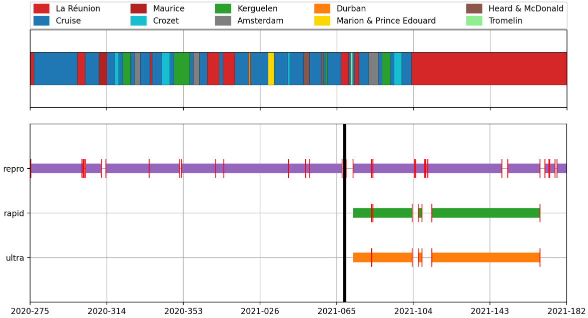
A change in GNSS antenna location occurs in Mar. 2021 (**bold vertical line**) in order to improve *MP* and O/S values.

➥ This change is shown to improve both these indicators.

GNSS raw data are processed in PPP mode with Gipsy-Oasis II 6.4 over the period Oct. 2020 - Jun. 2021 following 3 strategies:

	Latency	Rate	Trop. Mod.	IWV conv. *ZHD* / T_m
ultra	day + 1 h	300 s	GMF/GPT	PTU / PTU
rapid	day + 72 h	30 s	VMF1	PTU / VMF1
repro	every 2 mths	30 s	VMF1	ERA5 / VMF1

ZWD is estimated as random-walk process with process parameter of 5 $\mathrm{mm\,h^{-1/2}}$.

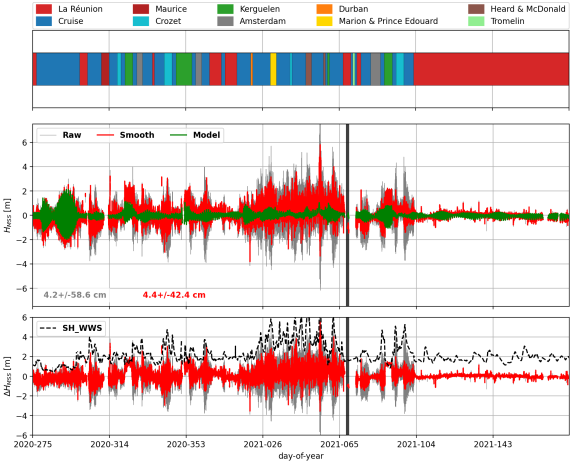


See also [Bos+21] for a more complete description of the processing strategies and IWV retrieval.

First assessment: GNSS height estimates from **repro** solution

- Geoid height values from **raw** and **smoothed** GNSS ellipsoid height estimates.
- **Modeled geoid height** derived from mean sea surface model CNES_CLS_2015 [Puj+18] and oceanographic tide FES2014b [Lya+16]
- **Significant height of combined wind waves and swell** product from ERA5

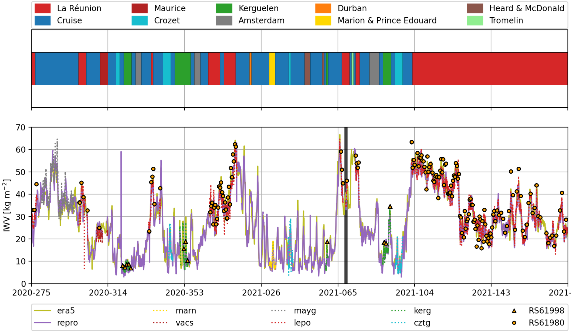
- Decrease of variability of differences in height after antenna location change.
- Large variability explained by wind waves, swell
- Low variability at the end of the period when docked.
- Systematic positive offset in Kerguelen area: models deficiency ?



Assessment of repro IWVs with nearby IWV retrievals

- Ground GNSS stations: **Crozet**, **Kerguelen**, **Marion & Prince Edouard**, **La Réunion**, **Mayotte**, **Maurice**.
- Ground-launched radiosondes: **La Réunion** (●), **Kerguelen** (▲).
- **ERA5** extraction.

- **Overall agreement between all the techniques**; radiosondes from La Réunion tend to overestimate IWV.
- Different characteristics of IWV values:
  - Southern areas: $\sim$ 15 $\mathrm{kg\,m^{-2}}$ [5 $\rightarrow$ 30 $\mathrm{kg\,m^{-2}}$]
  - Northern areas: $\sim$ 30 $\mathrm{kg\,m^{-2}}$ [20 $\rightarrow$ 65 $\mathrm{kg\,m^{-2}}$]
- Sensing of severe Weather events as Danilo (2021-12) and Iman (2021-65) tropical cyclones.



Assessment of repro IWVs with nearby IWV retrievals

- RMS with **ground GNSS** range from 2.2 to 3.1 $kg\,m^{-2}$
  Causes for large differences:
  - High differences in height between antennas
  - Lower quality of ship-borne IWV before the change of location of the GNSS antenna.
- Large deviations with **radiosondes** (also observed as comparing to ground GNSS); the kind of radiosonde (M10) may be in cause [Boc+13; Dup+20; Lee+20].
- Differences with **ERA5** extraction are consistent with recent studies [Bos+21; Män+21]
- Differences are shown to be reduced after the change of the location of the antenna (*).

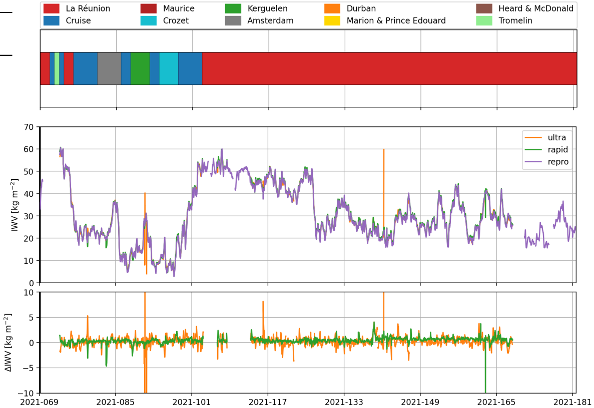
	N_{pts}	$b \pm \sigma$ [$kg\,m^{-2}$]	RMS [$kg\,m^{-2}$]	ρ
cztg	1803	$+0.13 \pm 2.65$	2.65	+0.91
cztg*	926	$+0.12 \pm 2.75$	2.75	+0.72
kerg	3194	-1.10 ± 2.45	2.69	+0.92
kerg*	1059	-0.30 ± 1.57	1.60	+0.97
marn	468	-2.69 ± 2.49	3.67	+0.80
lepo	26912	-0.48 ± 2.18	2.23	+0.98
lepo*	20549	-0.59 ± 1.74	1.84	+0.99
mayg	3959	-0.35 ± 3.49	3.51	+0.88
vacs	574	$+2.30 \pm 2.10$	3.11	+0.29
RS61980 (●)	152	-2.57 ± 3.44	4.30	+0.96
RS61980* (●)	115	-2.32 ± 3.29	4.02	+0.97
RS61998 (▲)	11	-2.36 ± 2.70	3.59	+0.94
ERA5	6126	$+0.20 \pm 2.84$	2.85	+0.98
ERA5*	2498	$+0.44 \pm 2.45$	2.49	+0.98

* : After changing the location of the antenna location.

Assessment of ultra and rapid IWVs with repro IWVs

	N_{pts}	$b \pm \sigma$ [kg m^{-2}]	RMS [kg m^{-2}]	ρ
ultra	24120	+0.25 ± 1.12	1.15	+1.00
rapid	250181	+0.43 ± 0.59	0.73	+1.00

- Interruptions in PTU acquisitions when the ship is docked prevent to compute IWV over the whole period for **ultra** and **rapid**.
- Differences are quasi equally due to differences in ZTD retrieval and conversion from ZTD to IWV.
- Good agreement between **rapid** and **repro**.
- Agreement between **ultra** and **repro** is also quite conclusive and highlight the potential use of ship-borne GNSS IWV for NWP purposes.



Summary & Outlook

- Crucial role of the GNSS antenna location on ship in GNSS raw data and estimates quality.
- Validation of the quality of ship-borne derived IWV from Marion Dufresne GNSS antenna at the 1-3 $\mathrm{kg\,m^{-2}}$ level.
- Large differences with other techniques may be explained by instrumental issues (location of the GNSS antenna on ship, kind of radiosonde).

- Extension of this dataset for long term study of water vapor distribution in the Indian and Austral Oceans.
- Use of ultra solution with 1–2 h delay for NWP purposes could be expected.

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