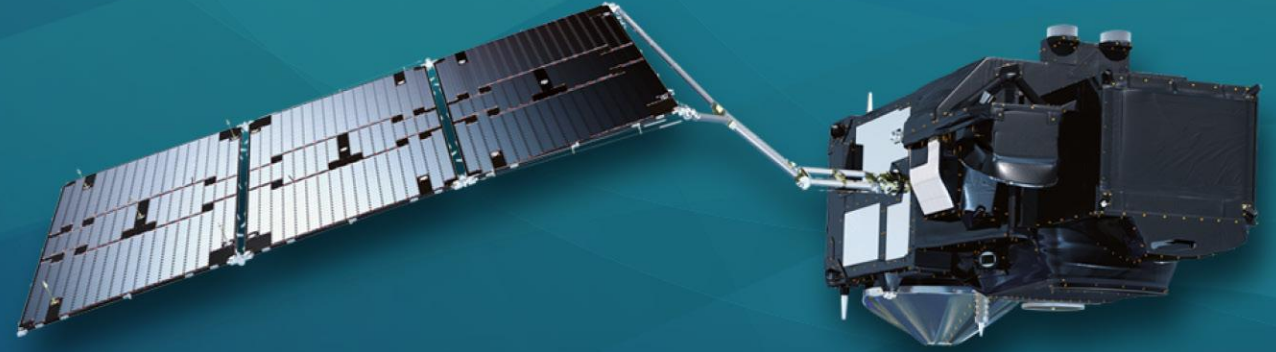




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# 9<sup>th</sup> Sentinel-3 Validation Team meeting 2026

30 March–01 April 2026 | ESA–ESRIN | Frascati (Rome), Italy

## Sentinel-3 MWR stability assessment using comparisons to radiosonde and GNSS in-situ measurements of wet tropospheric correction

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<sup>(1)</sup> CLS, <sup>(2)</sup> EUMETSAT



## ○ Long-term monitoring of the microwave radiometer (MWR) within the COPAS project

- Focus on open ocean surfaces
- Complementary to long-term diagnostics already presented in a previous presentation: *“Sentinel-3 microwave radiometers over ocean surfaces: long-term monitoring and performance assessment within the COPAS project”* (See also public [quarterly and annual reports on EUMETSAT website](#))
- Importance of ensuring the stability of wet tropospheric correction:
  - **Health of the instrument**
  - **WTC => major contributor to altimeter range uncertainties**



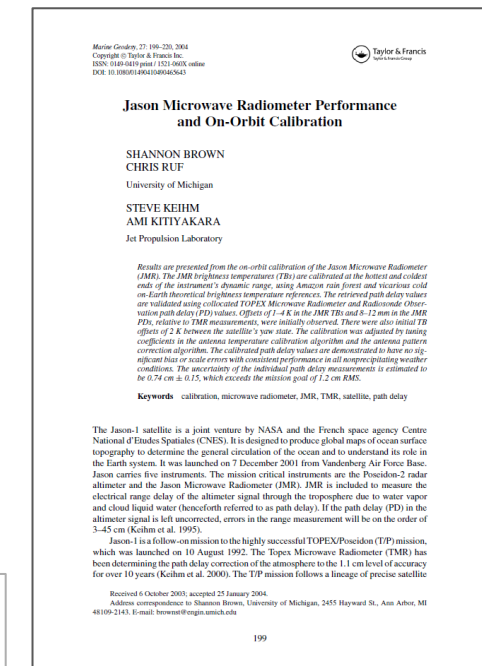
## ○ Objective

Comparison of WTC with in-situ sources (radiosondes & GNSS stations) to evaluate MWR stability and try to estimate MWR WTC uncertainty

## ○ Method

- Inherited from comparisons made for Jason-1 microwave radiometer with radiosonde data (Brown et al. (2004))

S. Brown, C. Ruf, S. Keihm, and A. Kitiyakara. Jason microwave radiometer performance and on-orbit calibration. Marine Geodesy, 27, 2004. ISSN 01490419. doi: 10.1080/01490410490465643.



# Comparison to radiosonde observations



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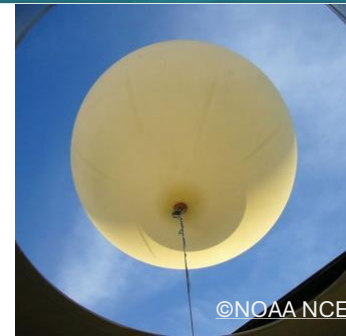


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## ○ Integrated Global Radiosonde Archive (IGRA)

- Global network of radiosonde stations
- Temperature and humidity profiles **every 12 hours**
- ~12 km altitude per hour, up to ~30km
- Affected by wind



## ○ One WTC value derived by integrating the profile:

$$WTC = - \left( 1.116 \times 10^{-3} \int_{P_{sat}}^{P_{surf}} q \, dP + 17.665 \int_{P_{sat}}^{P_{surf}} \frac{q}{T} \, dP \right) \times (1 + 0.0026 \cos(2\phi))$$

## ○ Station selection:

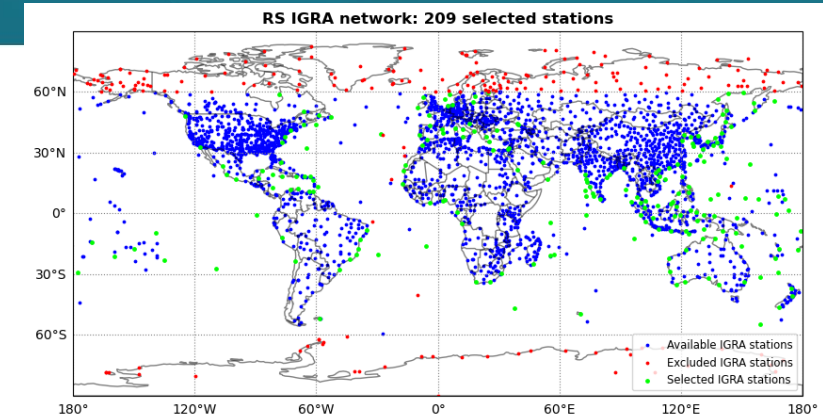
- Avoiding land contamination (station-coast distance < 50 km)
- Avoiding ice contamination ( $|\text{lat}| < 60^\circ$ )

## ○ Valid records selection:

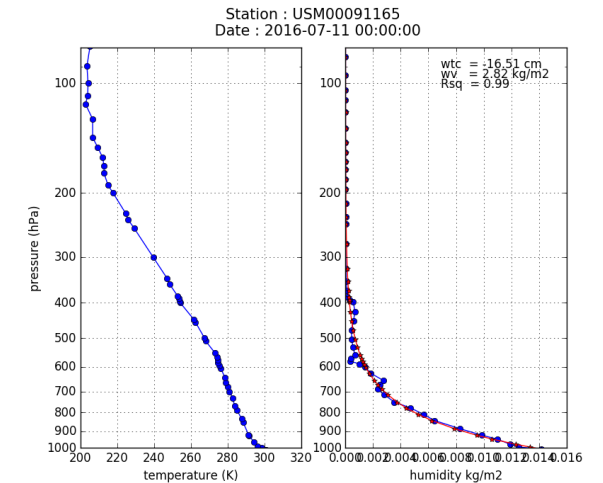
- Sufficient altitude ( $H > 10\text{km}$ )
- Profile unaffected by clouds (good fit with standard humidity profile,  $R^2 > 0.8$ )
- Mean monthly WTC bias < 8cm (empirical threshold)

## ○ Colocation criteria:

- Valid MWR measurements close in space and time (315km; 6h)



*Left:* Illustration of a radiosonde  
*Right:* IGRA archive coverage in 2024. The green points represent the 209 stations selected for the comparison with MWR.



Example of measured temperature (blue, left) and humidity (blue, right) profiles of USM00091165 station, with fitted standard humidity profile (red). ( $R^2=0.99$ )

# Comparison to radiosonde observations



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## Overall analysis of differences

**Good agreement** of MWR WTC with WTC measured by IGRA radiosonde data.

Satellite	Spatial (km)	Temporal (hrs)	Mean (cm)	Std (cm)	Samples
S3A	<315	<6	<b>0.72</b>	<b>2.74</b>	95,875
		<0,5	<b>0.99</b>	<b>2.67</b>	6,760
S3B	<315	<6	<b>0.69</b>	<b>2.75</b>	80,266
		<0,5	<b>0.95</b>	<b>2.56</b>	5,531

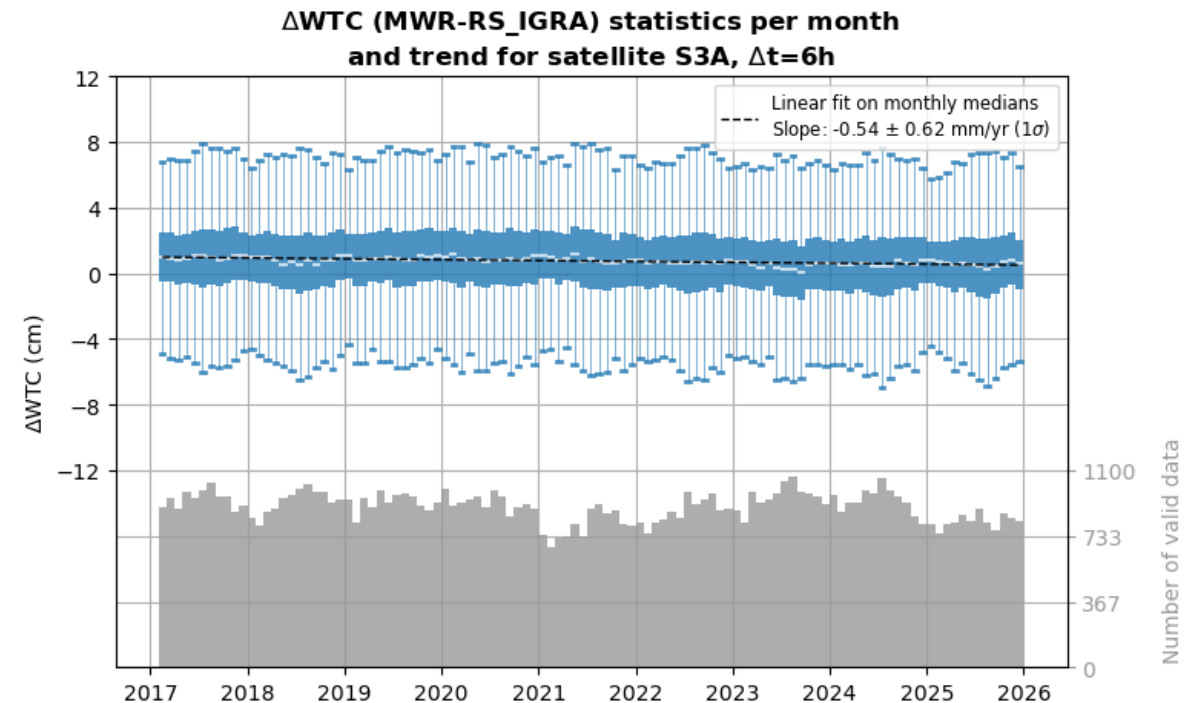
Table of statistics of WTC differences (MWR - IGRA), for both satellites and over the course of each mission.

## Stability

Linear fit on monthly medians shows no significant deviation:  $-0.54 \pm 0.62$ mm/yr (S3A) and  $-0.53 \pm 0.79$ mm/yr (S3B)

**MWR WTC exhibits very good stability wrt IGRA**

Timeseries of WTC differences (MWR - IGRA), for S3A over the course of the mission. For each month, a boxplot (blue) indicates the distribution of the data. A linear fit (black dashed line) is made on the monthly medians (white). The number of valid samples for each month are indicated in the gray histogram.



# Comparison to GNSS observations



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## ○ SuomiNet network:

- University-based GPS-only network, mostly US-based
- Estimations of total Zenith Path Delay (ZPD) **every 30 min**
- **Discontinued in 2024**

## ○ IGS network:

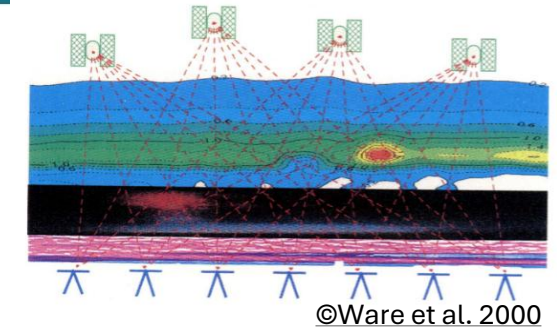
- Global multi-GNSS network
- ZPD values **every 5 minutes**, data very consistent with SuomiNet

## ○ ECMWF model dry tropospheric correction (DTC) is subtracted from ZPD to obtain WTC values:

$$WTC = ZPD - DTC$$

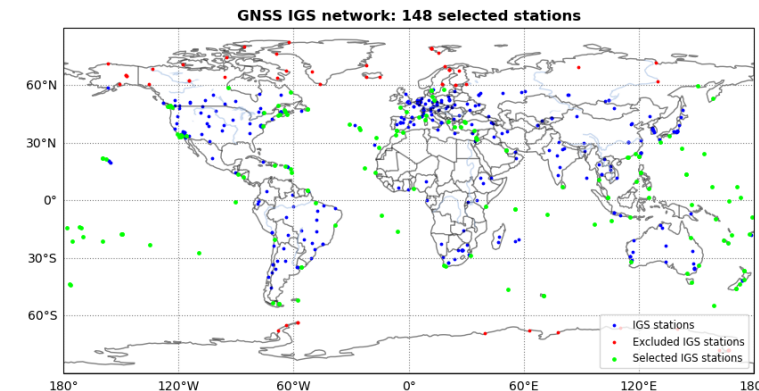
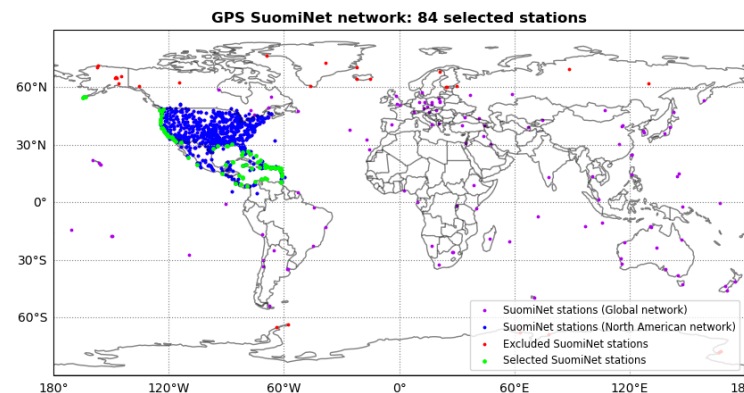
## ○ Similar station and record selection as previously

## ○ Colocation criteria: Valid MWR measurements close in space and time (315km; 30min)



*Left:* GNSS ground station (here ABMF00GUA/ABMF in Guadeloupe)  
*Right:* Measuring principle of the atmosphere by GNSS stations/satellites

*Left:* SuomiNet network coverage in 2024. The green points represent the 84 stations selected for the comparison with MWR.  
*Right:* IGS network coverage in 2024. The green points represent the 148 stations selected for the comparison with MWR.



# Side note: comparison of IGS and SuomiNet



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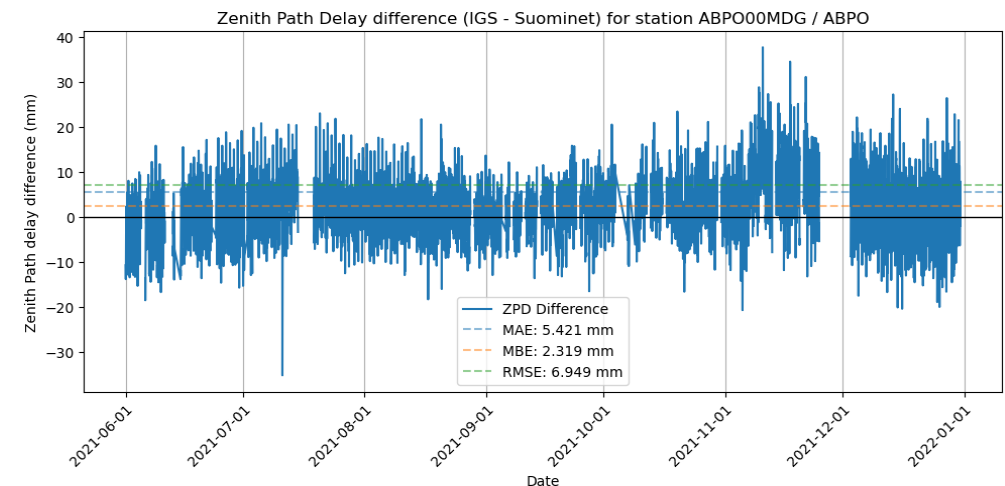
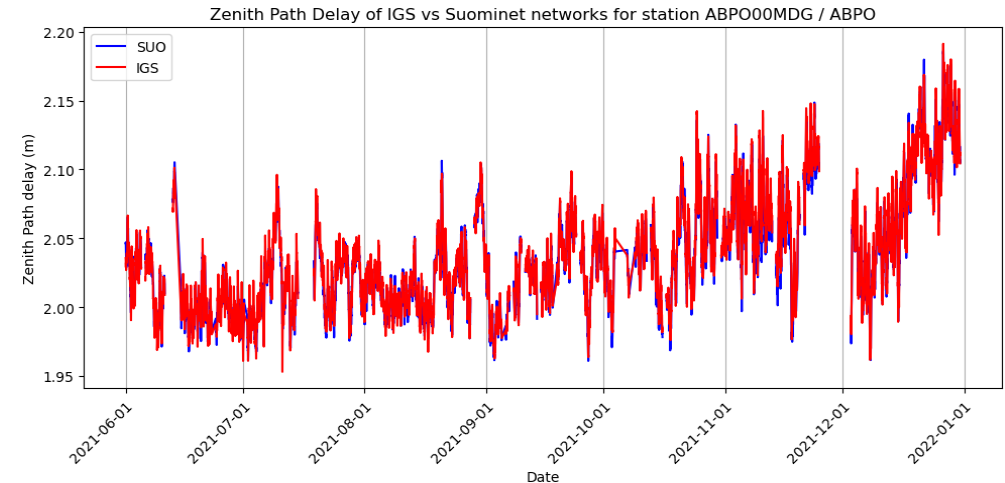
## Common stations in both networks

SuomiNet network part	Comparison start date	Comparison end date	Common stations
Global network	2021-06-01	2021-12-31	68
North American network	2024-01-01	2024-05-31	18

## Comparison of ZPD values

- **Very good agreement**
- **Mean bias = 0.29mm (global) and 1.72mm (NA)** over ~2m typical values
- Maximum bias ~10mm for certain stations
- Differences probably due to:
  - Multi-GNSS vs GPS
  - IGS = combination of multiple solutions of Analysis Centers
  - Daily variation could also be linked to daily tropospheric parameters processing runs

## Conclusion : IGS seems a very good alternative to SuomiNet



ZPD values for IGS and SuomiNet networks (top) and their difference (bottom) for the station couple ABPO00MDG/ABPO from June 1<sup>st</sup> to 31<sup>st</sup> December 2021

# Comparison to GNSS observations



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## Overall analysis of differences

**Good agreement** of MWR WTC with WTC measured by SuomiNet GPS data, slightly better than IGRA. (IGRA mean= $\sim 0.7$  for 6h and  $\sim 0.9$  for 30min)

Satellite	Spatial (km)	Temporal (hrs)	Mean (cm)	Std (cm)	Samples
S3A	<315	<6	<b>0.65</b>	<b>2.70</b>	924,938
		<0,5	<b>0.57</b>	<b>2.61</b>	209,589
S3B	<315	<6	<b>0.62</b>	<b>2.68</b>	777,036
		<0,5	<b>0.54</b>	<b>2.61</b>	65,756

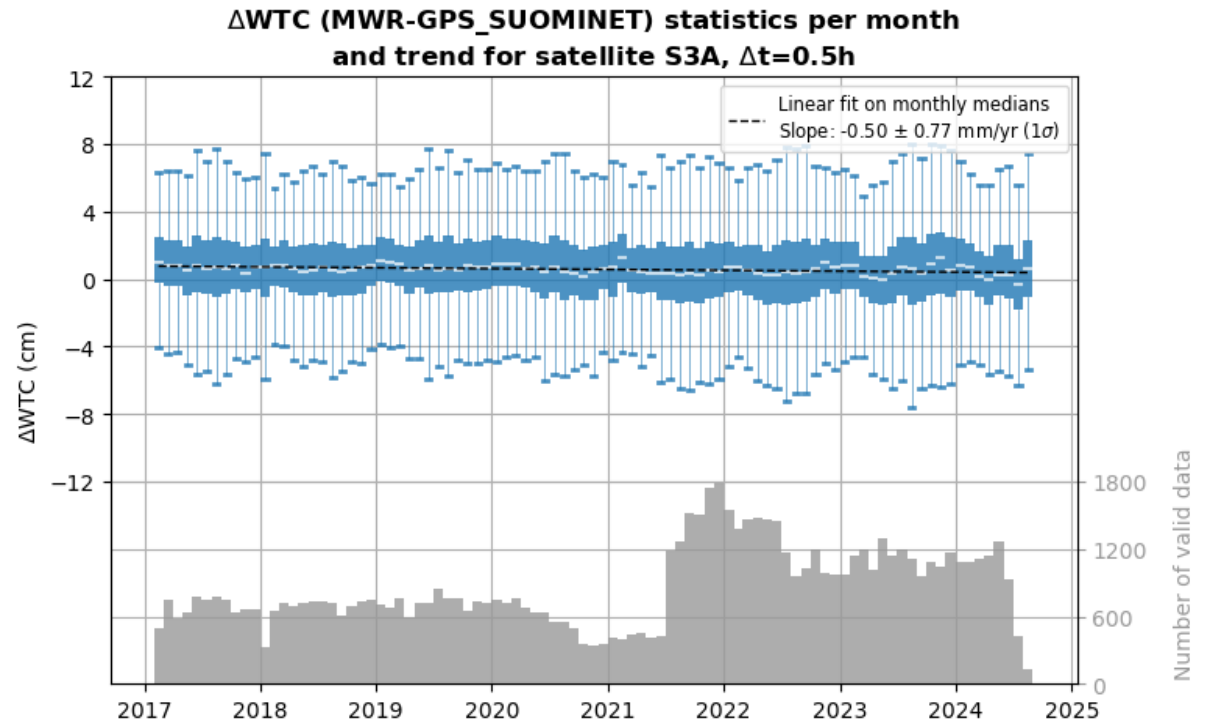
Table of statistics of WTC differences (MWR - SuomiNet), for both satellites and over the course of each mission.

## Stability

Linear fit on monthly medians shows no significant deviation:  $-0.50 \pm 0.77$ mm/yr (S3A) and  $-0.16 \pm 1.03$ mm/yr (S3B)

**MWR WTC exhibits very good stability wrt SuomiNet**

Timeseries of WTC differences (MWR - SuomiNet), for S3A over the course of the mission. For each month, a boxplot (blue) indicates the distribution of the data. A linear fit (black dashed line) is made on the monthly medians (white). The number of valid samples for each month are indicated in the gray histogram.



# Comparison to GNSS observations



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## Overall analysis of differences

**Very good agreement** of MWR WTC with WTC measured by IGS multi-GNSS data, better than SuomiNet and IGRA (IGRA mean= $\sim 0.7\text{cm}$  for 6h and  $\sim 0.9\text{cm}$  for 30min SuomiNet mean= $\sim 0.6\text{cm}$  for 6h and  $\sim 0.5\text{cm}$  for 30min)

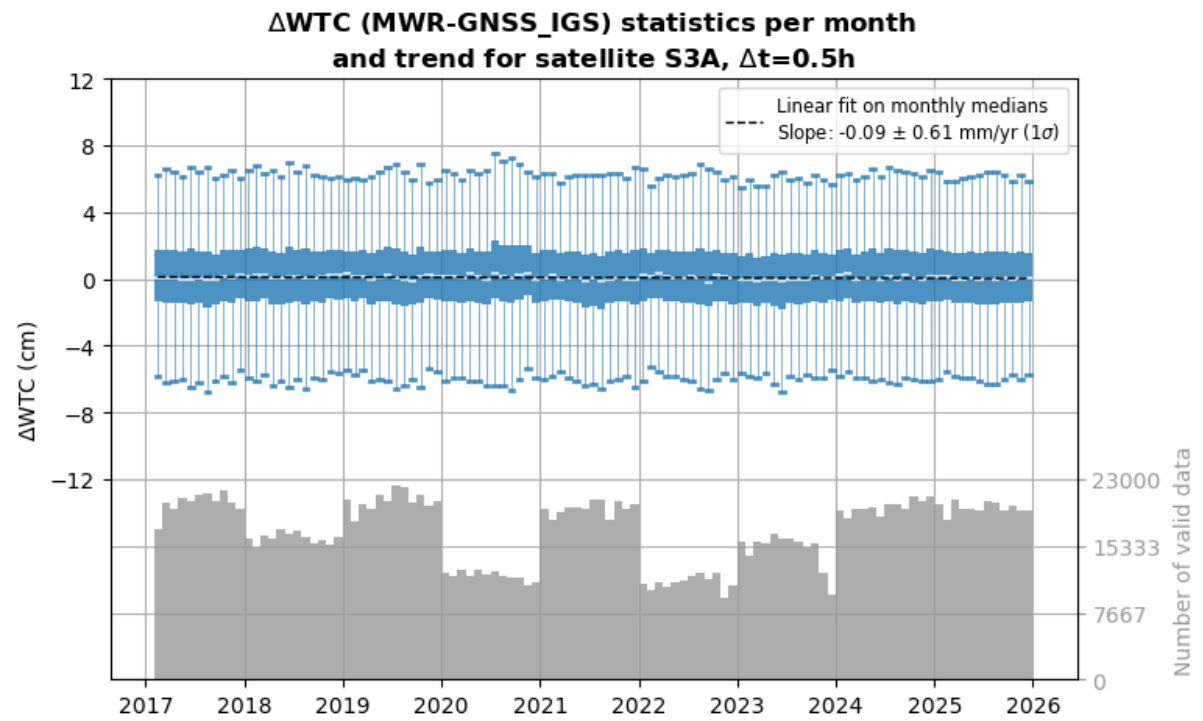
Satellite	Spatial (km)	Temporal (hrs)	Mean (cm)	Std (cm)	Samples
S3A	<315	<6	0.13	2.70	21,716,350
		<0,5	0.16	2.61	1,829,970
S3B	<315	<6	0.09	2.69	17,854,767
		<0,5	0.12	2.59	1,504,947

Table of statistics of WTC differences (MWR-IGS), for both satellites and over the course of each mission.

## Stability

Linear fit on monthly medians shows no significant deviation:  $-0.09 \pm 0.61\text{mm/yr}$  (S3A) and  $-0.08 \pm 0.77\text{mm/yr}$  (S3B)

**MWR WTC exhibits very good stability wrt IGS**



Timeseries of WTC differences (MWR - IGS), for S3A over the course of the mission. For each month, a boxplot (blue) indicates the distribution of the data. A linear fit (black dashed line) is made on the monthly medians (white). The number of valid samples for each month are indicated in the gray histogram.



## ○ Rationale (Brown et al. (2004))

- Filtering the dataset :
  - Minimal time difference ( $\Delta t < 45\text{min}$ ),
  - No clouds ( $\text{CLWC} < 0,1\text{kg/m}^2$ )
- Calculating RMS with **cumulative approach**
- **Self-decorrelation** MWR-MWR fitted with exponential

$$\text{RMS}_{\Delta\text{WTC}(\text{MWR}-\text{MWR})}(x) = -a_0 \cdot e^{-\frac{x}{m_0}} + b_0 \cong \Delta\text{Spatial}(x)$$

- Best offset to fit MWR-InSitu data

$$\text{RMS}_{\Delta\text{WTC}(\text{MWR}-\text{InSitu})}(x, t) = \sqrt{\Delta\text{InSitu}^2 + \Delta\text{MWR}^2 + \Delta\text{Spatial}(x)^2 + \Delta\text{Temporal}(t)^2}$$

$$\text{RMS}_{\Delta\text{WTC}(\text{MWR}-\text{InSitu})}(x) = -a_0 \cdot e^{-\frac{x}{m_0}} + b_1$$

- Difference at 0km spatial separation => **estimation of radiometer WTC uncertainty.**

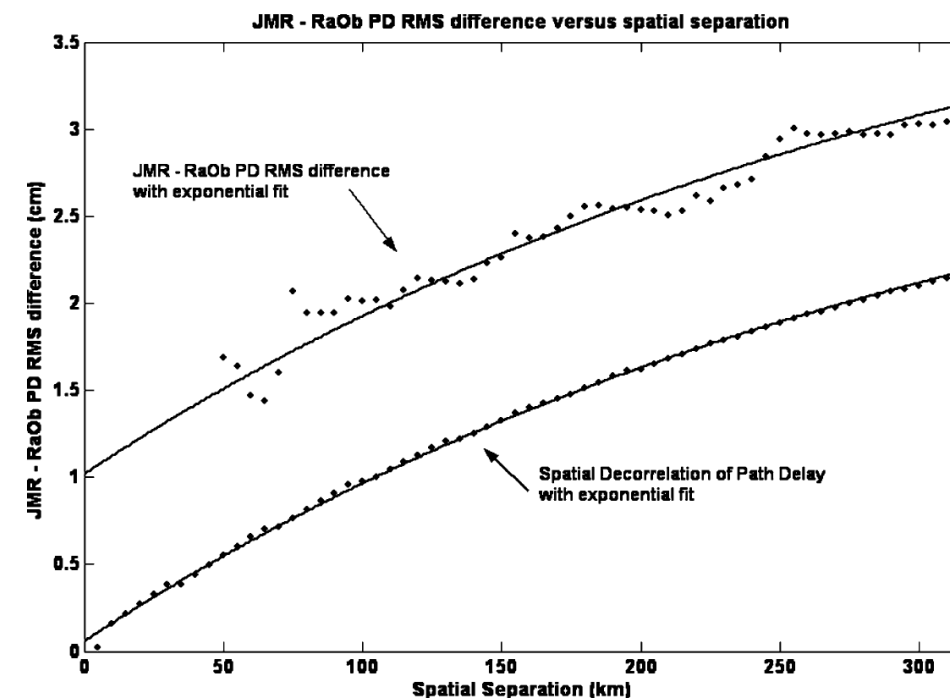
$$\text{RMS}_{\Delta\text{WTC}(\text{MWR}-\text{InSitu})}(0, t) = \sqrt{\Delta\text{InSitu}^2 + \Delta\text{MWR}^2} = b_1 - a_0$$

$$\Rightarrow \Delta\text{MWR} = \sqrt{\text{RMS}_{\Delta\text{WTC}(\text{MWR}-\text{InSitu})}(0, t)^2 - \Delta\text{InSitu}^2}$$

- For Jason-1 and radiosondes:

$$\Delta\text{InSitu} = 0.7\text{cm} \quad (\text{optimistic, Alishouse et al. (1990)})$$

$$\Rightarrow \Delta\text{MWR} = \mathbf{0.74\text{cm} \pm 0.15\text{cm}} \quad (< 1.2\text{cm mission requirement})$$

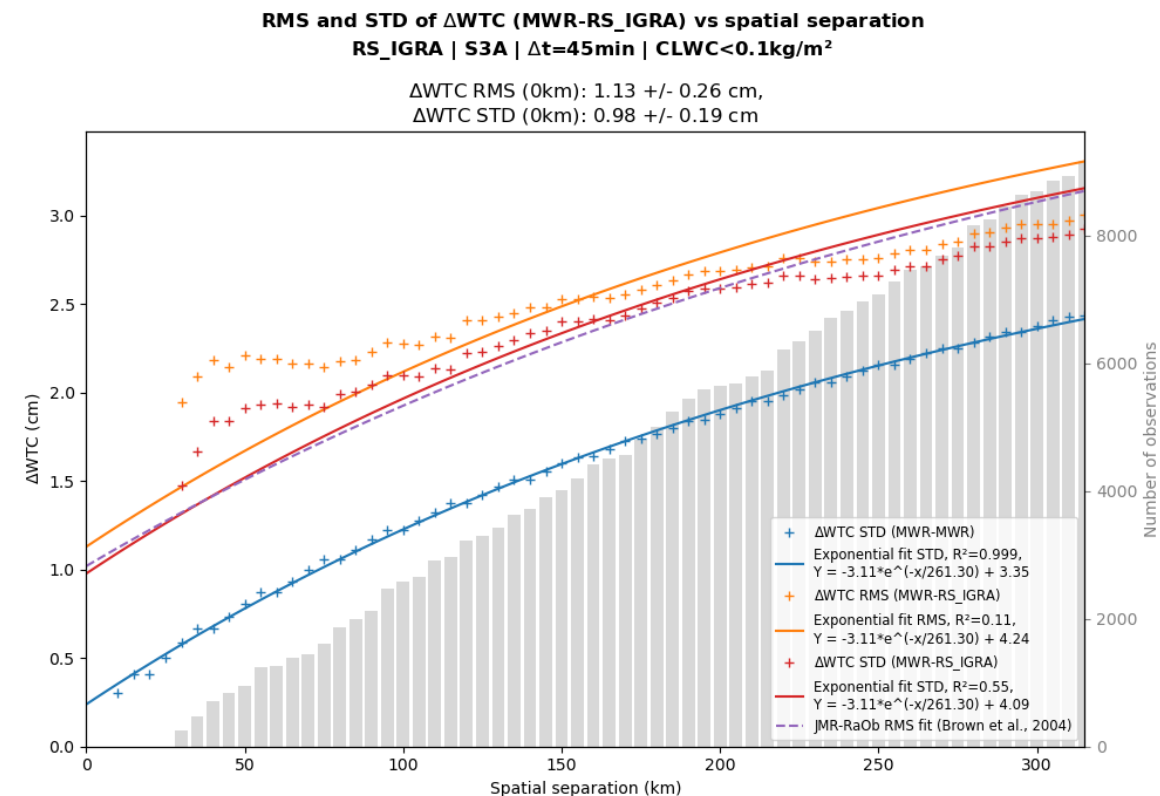


Analysis of spatial decorrelation of the WTC led by Brown et al. (2004) for Jason-1 radiometer and radiosondes

J. C. Alishouse, S. A. Snyder, J. Vongsathorn and R. R. Ferraro, Determination of oceanic total precipitable water from the SSM/I, in IEEE Transactions on Geoscience and Remote Sensing, vol. 28, no. 5, pp. 811-816, Sept. 1990, doi: 10.1109/36.58967

## ○ Results for S3

- Self-decorrelation yields promising results with a very good fit  
=> **instrumental stochastic noise**
- High intercept value ~0.25 cm (blue curve)  
=> **instrumental stochastic noise**
- For radiosondes, RMS intercept of MWR – in-situ fit is  $1.13\text{cm} \pm 0.26\text{cm}$  for S3A and  $1.05\text{cm} \pm 0.26\text{cm}$   
=>  $\Delta MWR = 0.89\text{cm} \pm 0.33\text{cm}$  for S3A  
 $\Delta MWR = 0.78\text{cm} \pm 0.35\text{cm}$  for S3B
- However, fit of MWR - radiosonde data is not very good. GNSS sources show even less satisfying fits.
- **Further analysis needed before concluding** (non-cumulative approaches, other statistics, restricting/widening the dataset...), verify Brown et al. assumptions (take a shorter temporal time separation)



Analysis of spatial decorrelation of the WTC of the S3 radiometer vs IGRA radiosondes

The self-decorrelation is plotted in blue, the RMS and STD of the WTC differences (MWR-InSitu) are respectively plotted in orange and red. The continuous lines correspond to each exponential fit. The fit obtained by Brown et al. (2004) is indicated with the purple dashed line

- **Comparison to WTC in-situ sources**
  - **Good agreement** of MWR WTC with in-situ sources.
  - IGS GNSS network exhibits the least differences compared to SuomiNet and IGRA.
  - **No significant drift ( $1\sigma$ ) of Sentinel-3A or Sentinel-3B WTC** can be detected with respect to in-situ observations. Both satellites remain very stable over the course of each mission.
- **Spatial decorrelation**
  - Self-decorrelation results are coherent with previous results for JMR
  - Despite interesting first results, need to **lead further investigations and verify some assumptions** of the method to conclude as to the MWR uncertainty
- **Perspectives**
  - Pursue spatial decorrelation study.
  - Include new in-situ sources : other radiosonde/GNSS networks, shipborne GNSS, DORIS?
  - Use in-situ comparisons during S3C commissioning phase

**Thank you for your attention !**