On The Retrieval of IWV From Microwave Attenuation Measurements: Experimental Results

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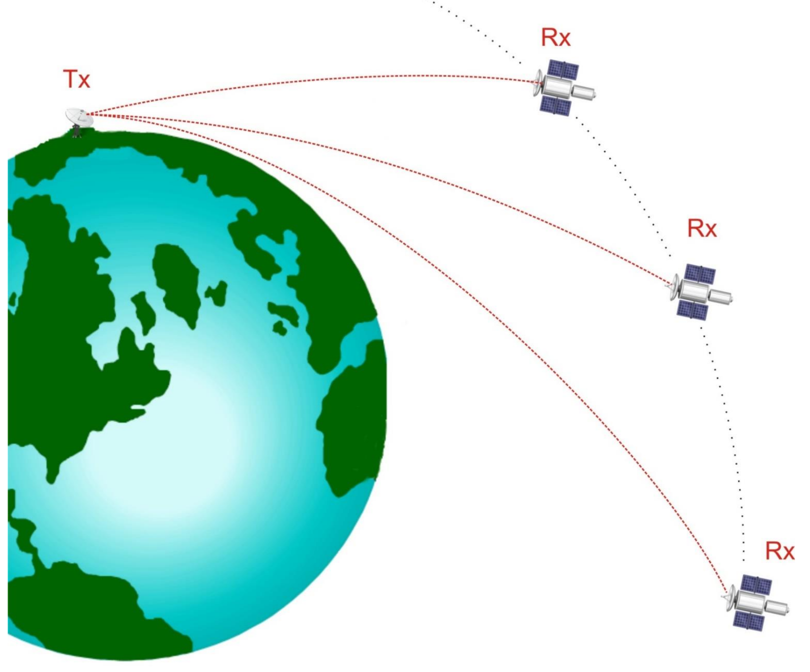
SUMMARY

The measure of water vapor (WV) in the lowest part of the troposphere is a critical issue which, up to now, cannot be measured from space with sufficient accuracy. A novel technique, which is based on a microwave radio link and the measure of differential attenuation of two signals transmitted at closely spaced frequencies in the Ku-K band, has been recently proposed. In order to prove the potential of this technique a new low-cost microwave link has been designed and the first measurements will be performed by means of a ground-to-ground link. Instrument design and characteristics, as well as experimental results are presented here.

1. THE NDSA CONCEPT

- NDSA is a method to estimate the Integrated Water Vapor (IWV) along a microwave link in the troposphere.
- It is based on the indirect measurement of the *spectral sensitivity S* related to the differential attenuation undergone by a pair of tone signals at two slightly separated frequencies f_1 and f_2.



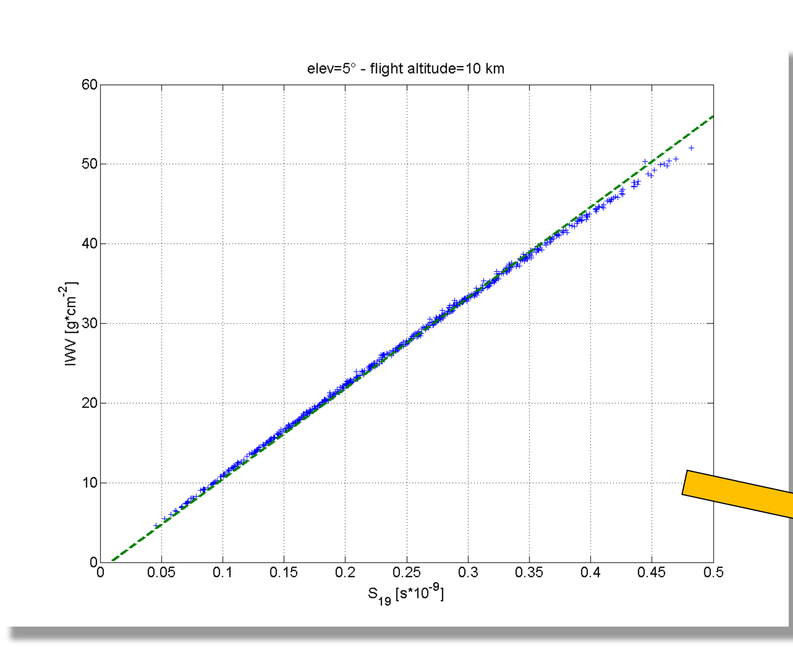
$$S_{fc} = \frac{A(f_1) - A(f_2)}{(f_2 - f_1)A(f_1)} = \frac{1}{\Delta f}\left(1 - \frac{P_1}{P_2}\right) \quad \text{(Eq. 1)}$$

- $P_{1,2}$: received powers of the two tones at $f_{1,2}$
- $\Delta f = (f_2 - f_1)$: frequency separation
- $f_c = (f_2 + f_1)/2$: center frequency

- *S* is strongly correlated to IWV → it can be directly converted into IWV and the regression is independent of the elevation angle

$$IWV = a_1 S_{fc} + a_0 \quad \text{(Eq. 2)}$$

Example of ground-LEO configuration



Simulation of IWV vs. S at 19 GHz for a receiver placed on a platform at 10 km altitude. Each point in the scatter plot refers to a spherically symmetric atmosphere generated through real radiosonde observations

- Proposed measurement configuration

- f_1 = 18.8 GHz - f_2 = 19.2 GHz
- Δf = 400 MHz
- f_c = 19 GHz

✓ f_c = 19 GHz is the optimal frequency for an Earth-satellite link that includes the lowest tropospheric shells. The same concept is applicable to aerial platforms such as HAPS or stratospheric baloons

TABLE 1: Coefficients of the IWV-S_{19} linear regression

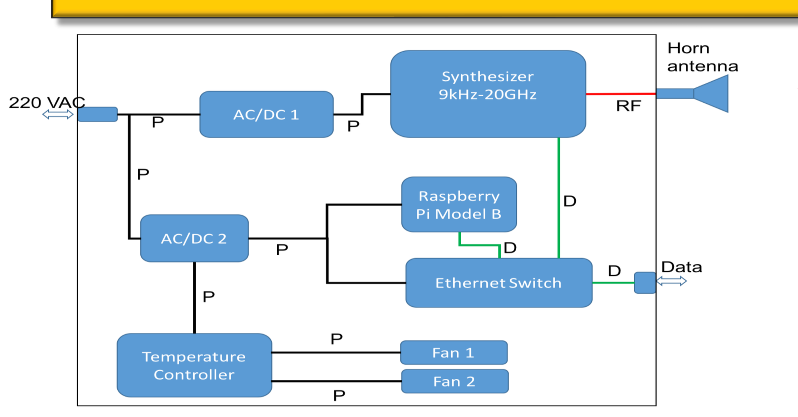
a_1 [s^{-1}·g·cm^{-2}] ·10^{-9}	a_o [g·cm^{-2}]	Relative error [%]
114	0.58	3.0

- F. Cuccoli, L. Facheris: "Normalized Differential Spectral Attenuation (NDSA): a novel approach to estimate atmospheric water vapor along a LEO – LEO satellite link in the Ku/K bands", *IEEE Trans. Geosc. Rem. Sensing*, Vol. 44, June 2006, pp. 1493-1503

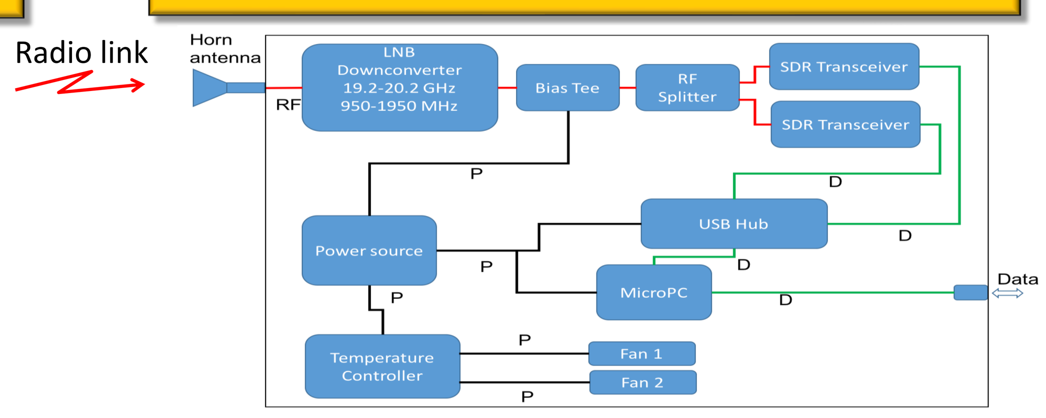
2. THE INSTRUMENT

- A low-cost instrument prototype able to perform the first NDSA measurements in ground-ground configuration has been designed and realized.
- It consists of a synthesized microwave transmitter and a software defined radio microwave receiver operating from 18.2 to 19.2 GHz.
- Two tones separated by 400 MHz are transmitted and sampled at the receiver with a frequency of 61 MS/second at the receiver.

Ground-based radio transmitter

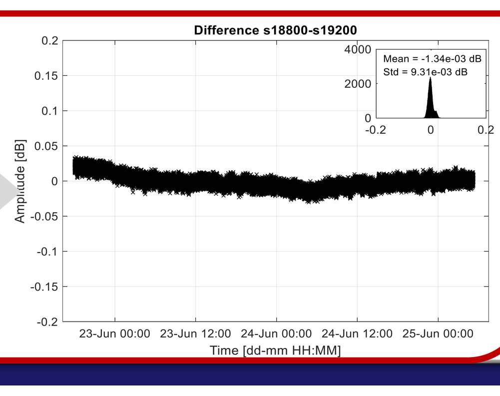


Radio receiver



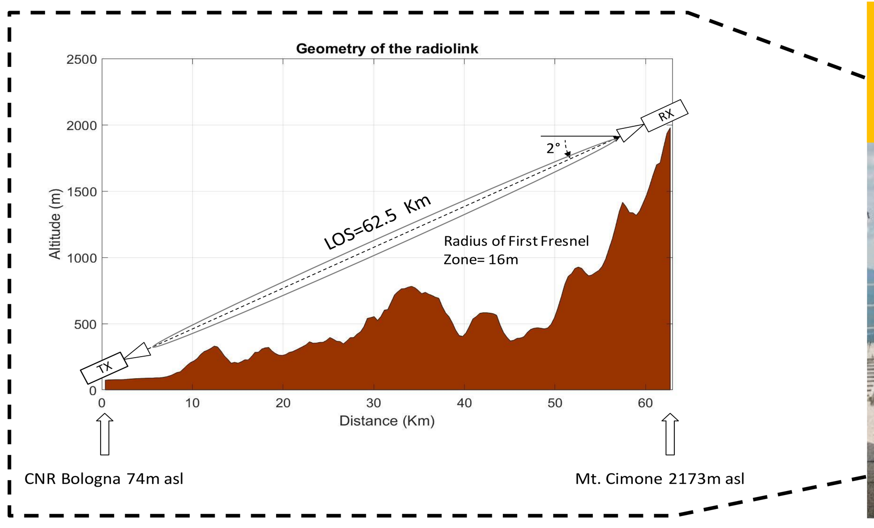
Transmitter characteristics		Receiver characteristics	
TX-Antenna	Corrugated Circular Horn	RX-Antenna	Corrugated Circular Horn
Antenna Gain	21.6 dBi	Antenna Gain	21.6 dBi
Antenna Polarization	Circular	Antenna Polarization	Circular
Antenna HPBW	15.8°	Antenna HPBW	15.8°
Tx frequency range	9Khz-20GHz	LNB-band (RF)	18.2-19.2 GHz
Tx frequency resolution	0.001 Hz	LNB-Noise Figure	1.6 dB
Tx output power (Max))	20 dBm	LNB IF	1.55 - 1.95 GHz
TX Output Frequencies	18.8 ; 19.2 GHz	ADC RF Bandwidth	75MHz-6GHz
		ADC Sample Rate (max)	61.44 MS/s (12 bit)

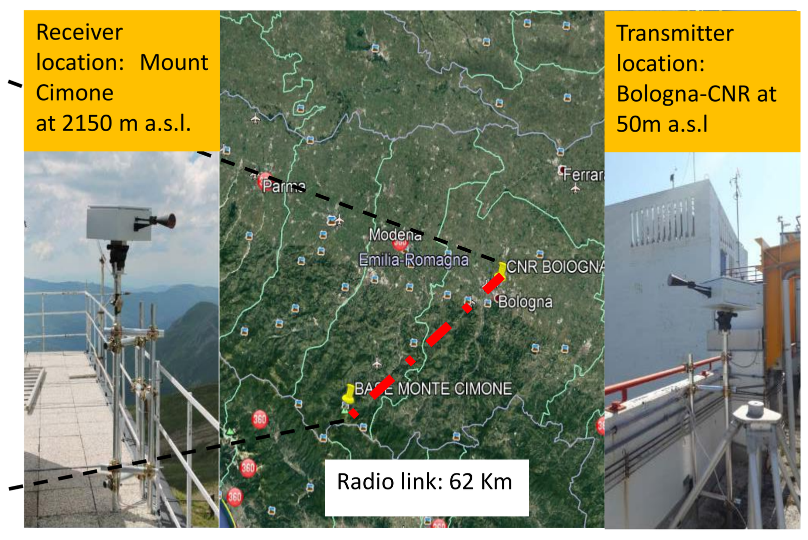
Test in anechoic chamber:
-good stability
-incertitude
$\Delta A<0.1$ dB



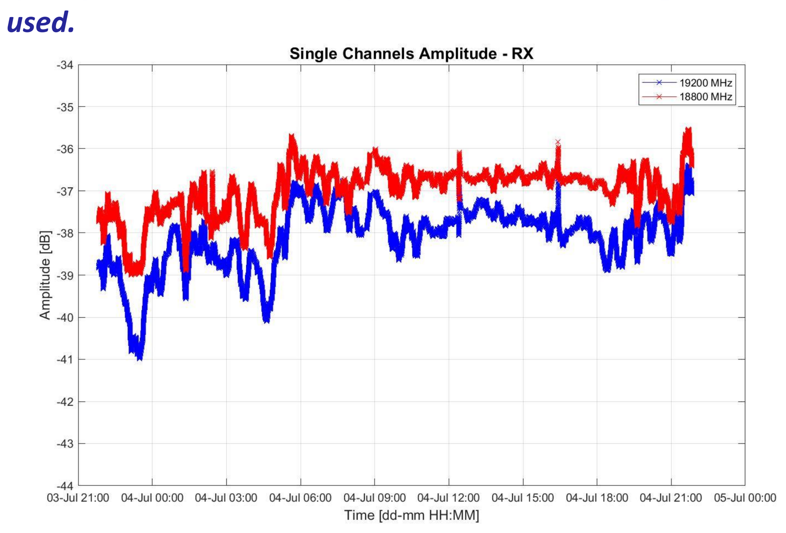
3. GROUND TO GROUND EXPERIMENT

- A first ground-to-ground experiment from June to August has been performed, to test the instrument and technique performances.
- The transmitter has been installed at sea level and the receiver on the top of a mountain (around 2000 m a.s.l.) thus obtaining a transect in the troposphere of tens of Km.

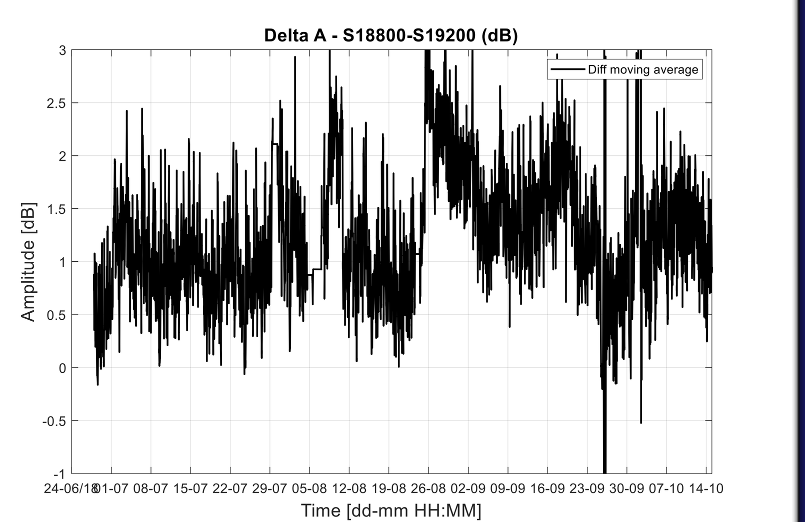




Example of received tones amplitudes measured along 4/7/2018. A moving average filter with an integration time of 10 minutes was used.



1 Received tones at 18.8 and 19.2 GHz (one day)



2 Difference between received tones ΔA= S18800-S19200 (4 months)

4. RESULTS

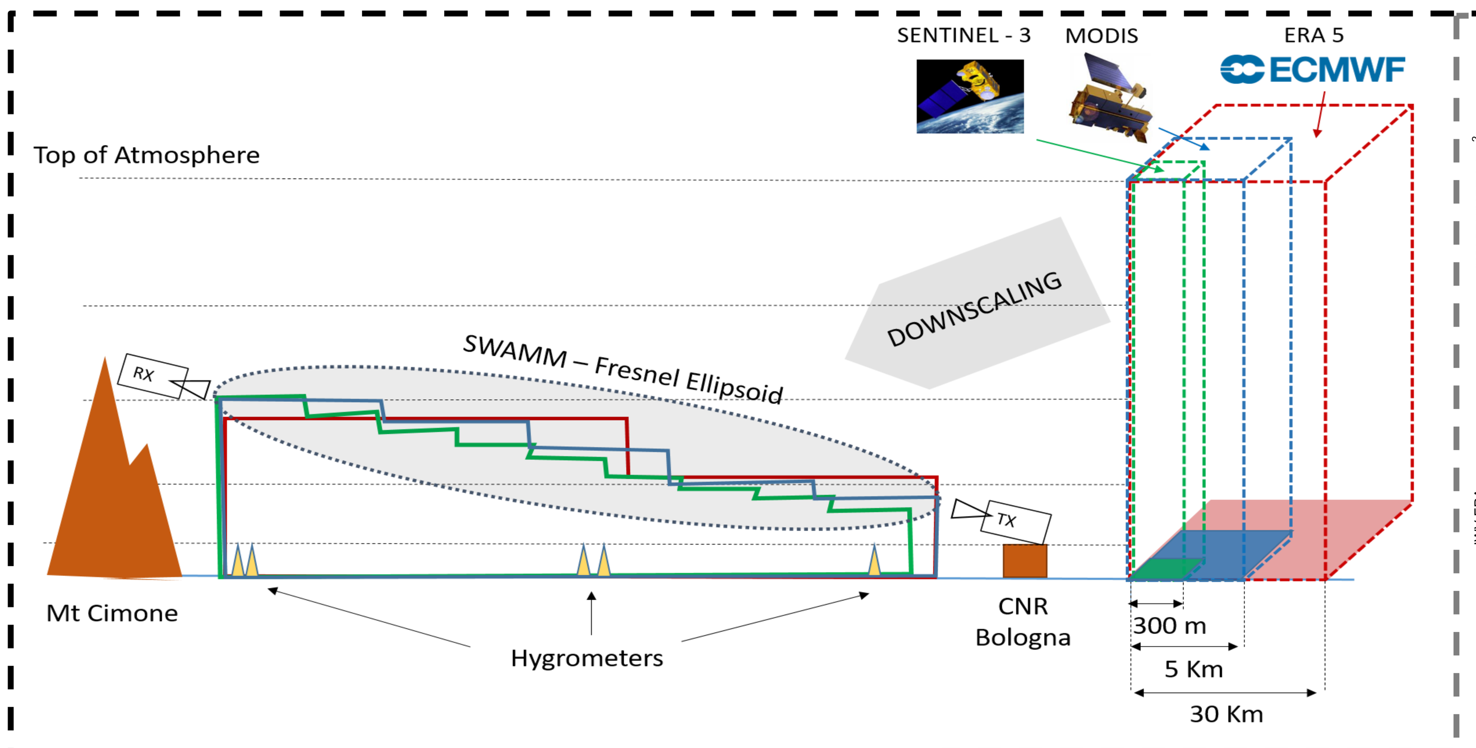
4.1 - FROM ΔA TO IWV

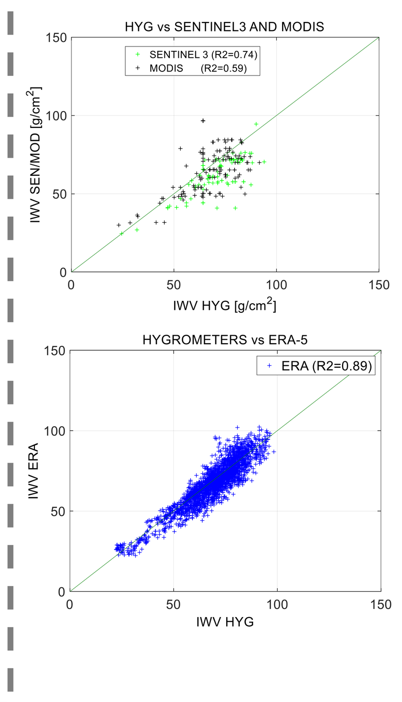
Using the differential attenuation ΔA aquired on the ground to ground link as input to equations 1) and 2) with the semiempirical coefficient summarized in Table 1, we derive the multitemporal IWV along the Bologna-Cimone transect (FIGURE 3).

4.2 – COMPARISON BETWEEN IWV- SWAMM AND IWV FROM OTHER SENSORS

In order to validate the NDSA estimation of IWV on the Cimone-Bologna link with a compatible spatial/temporal resolutions we exploit available IWV from different datasets:

✓ Ground stations : Radiosounding data estimates (RDS), Hygrometers estimate (HYG)
✓ Remote sensing (TOA) : Sentinel-3 OLCI-IWV at 300m resolution, Modis (Terra+Aqua) at 5Km
✓ Model Reanalysis (TOA) : ECMWF ERA-5 at 30 Km, but every 1hour





1) Satellites + ERA-5 provide a total columnar IWV, i.e. calculated from Top of the Atmosphere to the ground. To be compared with SWAMM, IWV have been downscaled to the radio path height (assuming 1st Fresnel ellipsoid) using an exponential relationship then reintegrated over the path:

- $Wk(z) = W0k * exp(-H * (z - z0k))$

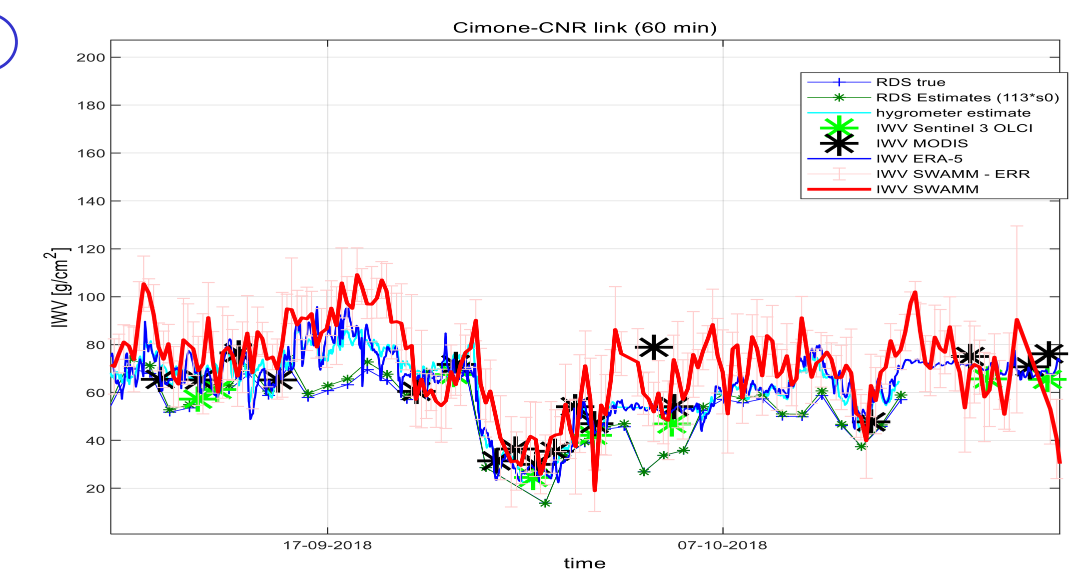
2) Rescaled IWV are first compared with IWV from hygrometers of distributed meteo stations along the link.

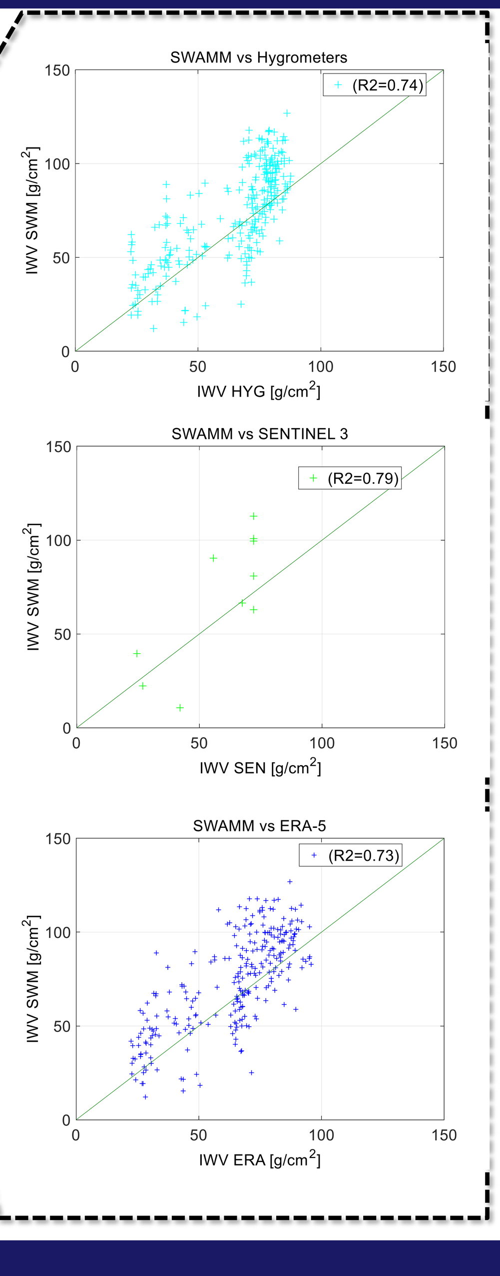
✓ A very good agreement is obtained. This prove the consistency of the downscaling method.

3) Afterwards, IWV is compared with SWAMM.

✓ The temporal trend of IWV (fig. below) of SWAMM and other sensors estimates and their scatter plots are shown in figures (below) and (right side) respectively.

3





✓ The measured difference values are aligned with what expected
✓ The values seem to be correlated to the averaged IWV, at least in the general trend.
✓ Some discrepancies are still under investigations.
✓ Sensitivity with the absolute IWV need to be assessed!