RETRIEVING ATMOSPHERIC WATER VAPOR CONTENT USING GRAZING ANGLE GNSS-R MEASUREMENTS

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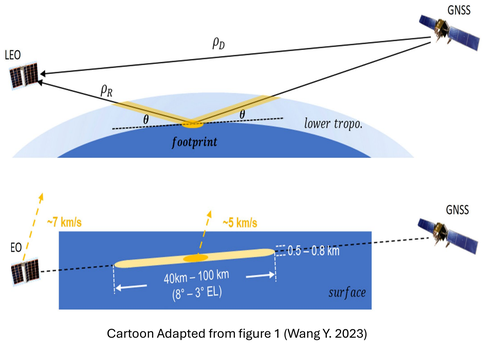
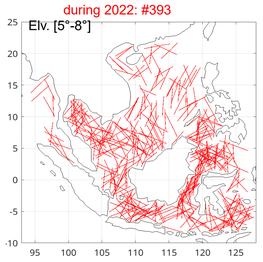
Abstract: This poster presents the performance of the water vapor content (IWV) retrieval from phase-based, 50-Hz GNSS-R data collected by Spire Global grazing-angle satellites over the Ocean in the Southeast Asia region during 2022. The GNSS-R water vapor retrievals are compared quantitatively with the ones from two Numerical Weather Models VMF3 and ECMFW ERA5 reanalysis. It also presents qualitatively one case study with real observations using collocated IWV measurements from sentinel-6 Microwave Radiometer. This study demonstrates that the grazing angle GNSS-R data and the retrieval technique can provide reliable observations of IWV in critically important region such as over the oceans and polar regions



Cartoon Adapted from figure 1 (Wang Y. 2023)

Grazing angle-GNSS-R data with Specular Point Elevation in [5°-8]: :The tropospheric error phase delay becomes large especially from the variable water vapor, relative to errors in the surface heights.

Coherent tracks > 80s during 2022: #393



GNSS-R IWV Processing Flowchart

Spire GNSS-R grazing angle
L1B grzRfl
Reflection signal Carrier phase (50-Hz)

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Coherency Detection
Phase-rate circular length
Calm ocean/ Sea ice

↓

Cycle Slip removal
SCANF

↓

$\Phi_{reflect} = \Phi_{geom} + \Phi_{tropo} + \Phi_{iono} + \Phi_{clk} + \varepsilon$

↓

Ionosphere: dual-frequency

Clock biases GNSS: IGS
SPIRE POD

Geometric
Orbit GNSS: IGS
SPIRE POD

Surface Heights Model
Ocean Surface Heights Model
DTU18 MSS+TPX08 + grid SLA

→

Atmospheric Slant Delay
$\Phi_{tropo} = ZHD.MF_H + ZWD.MF_w$

↓

Zenith Wet Delay
$\Phi_{wet} = \Phi_{tropo} - (ZHD.MF_H)_{vmf3}$
$\mathrm{ZWD} = \Phi_{wet}/(MF_w)_{vmf3}$

↓

Integrated Water Vapor
$TCWV = IWV = \Pi \times \mathrm{ZWD}$
$where\ \Pi \approx function(Tsurface)$

Reference (Wang Y. 2023)

Spire-IWV is a relative measurement- due to phase ambiguity

DATASETS AND MODELS

- *GNSS-R:* Spire Grazing-Angle GNSS-R data for 2022:
  L1B grzRfl , 50Hz, GPS L1 and L2, SP Elevation Angle in [5°-8].
  Coherent regions: Calm ocean and Sea Ice
- Model: *ECMWF Reanalysis v5 : on a hourly 0.25°x0.25° grid :*
  two parameters: TCWV and $T_{surface}$
- Model: *Troposphere Delay Model: VMF3 on a 6-hourly 1°x1° grid*
- *Real Observations: Sentinel-6: Microwave Radiometer TCWV*

COMPARISON with MODELS VMF3 and ERA5 IWV

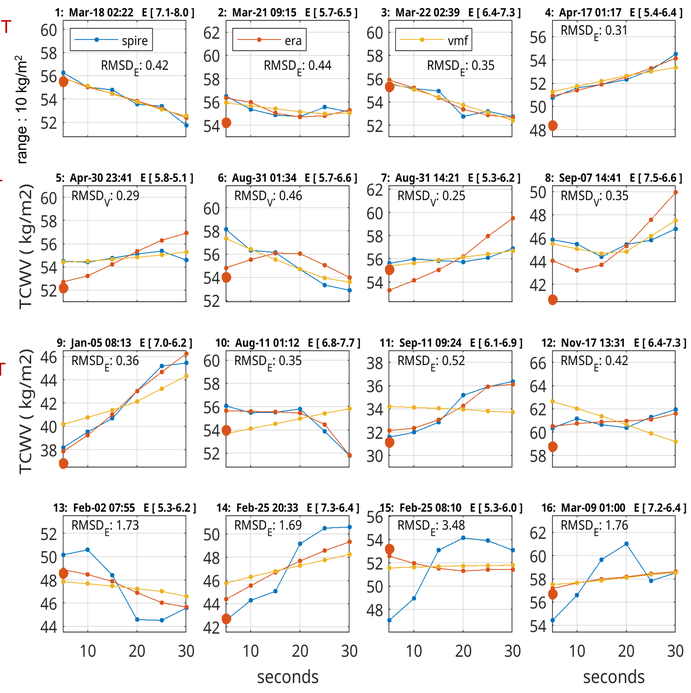
GNSS-R 30s segments (~ 150km)
6913 segments

BOTH FIT
Spire = ERA5 = VMF3

VMF3 FIT & Spire ≠ ERA5

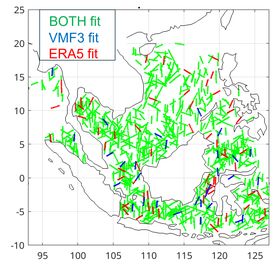
ERA5 FIT & Spire ≠ VMF3

NO FIT
Spire ≠ ERA5
Spire ≠ VMF3

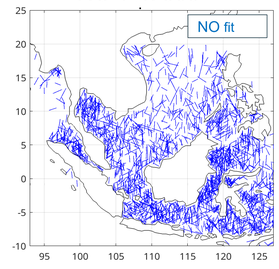


GNSS-R tracks during 2022
Elevation range [5°-8°]
5s (~25km) time series

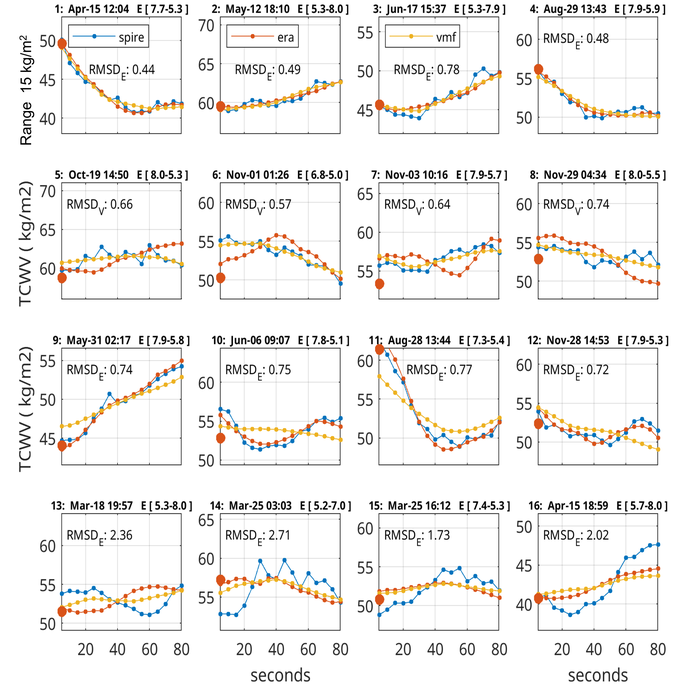
FIT: 30s



NO FIT: 30s

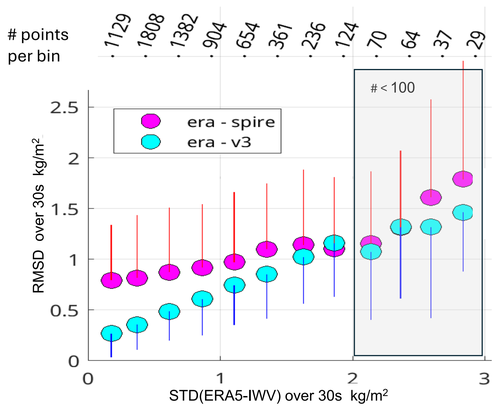


GNSS-R 80s segments (~400km)
366 segments during 2022



- Spire-IWV is a relative measurement-> Spire-IWV & ERA5-IWV leveled relative to VMF3-IWV over the segment duration (i.e..30s or 80s)
- Red dot at t_0: true ERA5-IWV starting value.

- $\mathrm{RMSD_E}$= RMSD(spire,ERA5)
- $\mathrm{RMSD_V}$= RMSD(Spire, VMF3) in kg/m^2



duration	30s	60s	80s
Spire = VMF3 = ERA5	458 (7%)	109 (6%)	18 (5%)
Spire =VMF3 ≠ ERA5	345 (5%)	30 (1.5%)	17 (5%)
Spire = ERA5 ≠ VMF3	236 (3.5%)	47 (2.5%)	13 (3.5%)
Spire NO FIT	2512 (36%)	860 (44%)	178 (48%)
Total #segments	6913	1924	366

Values for 30s: Spire = ERA5 , if $\mathrm{RMDS_E} < 0.55$ Spire = VMF3 , if $\mathrm{RMDS_V} < 0.55$ kg/m^2
Spire ≠ ERA5, if $\mathrm{RMDS_E} > 0.85$ Spire ≠ VMF3, if $\mathrm{RMDS_V} > 0.85$ kg/m^2

STATISTICS

The RMSD(Spire, ERA5) statistics, Mean and STD, increase slowly.in contrast to the ones for RMSD(VMF3, ERA5) as a function of the fluctuations in the ERA5 model.

Spire-IWV performance is consistent and stable regardless of the level of variations in the ERA5-IWV.

The SPIRE-IWV can be clustered into three main categories:

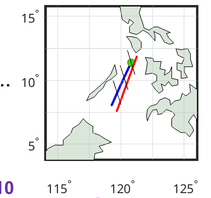
- ~ 15% close to a model
- (BOTH, VMF3 or ERA FITs)
- ~ 40% NO FIT
- ~ 45% in between, i.e. bounded

regardless of the segment duration..

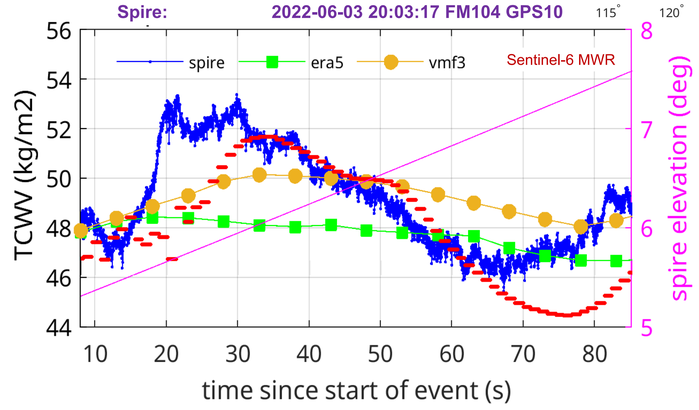
There are clear cases when SPIRE-IWV either fits ERA5-IWV or VMF3-IWV. This indicates that SPIRE-IWV can provide reliable IWV observations.

FUTURE WORK

- Comparison with collocated real measurements. to check the performance of the NO FIT Spire IWV sets...
- Application to the highly coherent polar regions.



MWR sentinel 6a: 2022-06-03 20:36 C057 P0203
Spire: 2022-06-03 20:03:17 FM104 GPS10



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Reference: Y. Wang, "*Troposphere Sensing Using Grazing-Angle GNSS-R Measurement from LEO Satellites*", 2023, doi:10.1029/2023GL106249.