



WROCLAW UNIVERSITY  
OF ENVIRONMENTAL  
AND LIFE SCIENCES

# A Comparison Between Raytraced GFS/WRF/ERA and GNSS Slant Path Delays in Tropical Cyclone Meranti

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# Motivation

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- Tropical Cyclones as natural destructive phenomena,
- limited knowledge about TC structure and dynamics,
- Global Navigation Satellite System (GNSS) technique enables to retrieve the state of the troposphere with a high accuracy in all weather conditions,
- previous GNSS-based studies during TCs have been limited to analysis of PWV alone,
- concept of STD GNSS and STD raytracing as a tool for verifying the quality of weather models.

# Determining refractivity from meteorological variables

Gaseous refractivity can be computed from fundamental meteorological variables: temperature  $T$  (K) and partial pressures of dry air  $p_d$  and water vapor  $p_v$  (in hPa):

$$N = k_1 \frac{p_d}{T} + k_2 \frac{p_v}{T} + k_3 \frac{p_v}{T^2} = N_h + N_w,$$

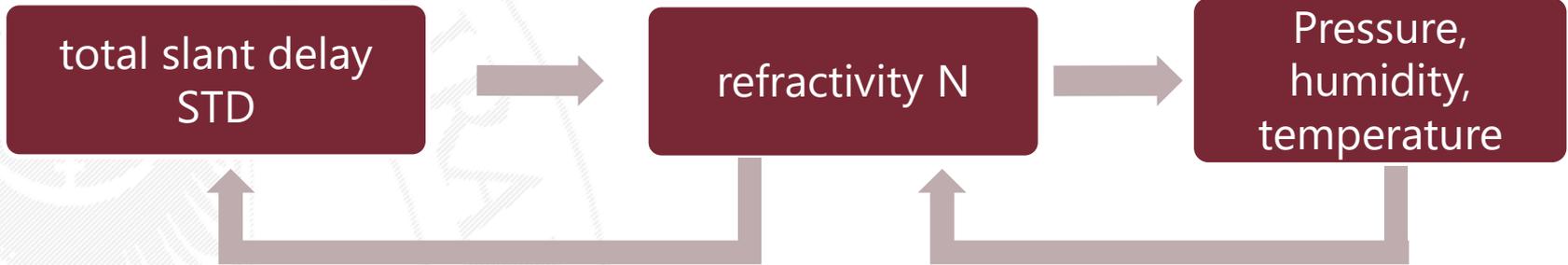
where according to Rüeger (2002) „best available“:  $k_1 = 77.695$  (K hPa<sup>-1</sup>),  $k_2 = 71.97$  (K hPa<sup>-1</sup>) and  $k_3 = 3.75406 \cdot 10^5$  (K<sup>2</sup> hPa<sup>-1</sup>).

Hydrometeors refractivity is equal to integrated refractivities induced by liquid and ice water:

$$N_{Hm} = N_{lw} + N_{ice} \approx 1.45 \cdot M_{lw} + 0.69 \cdot M_{ice},$$

where  $M_{lw}$  and  $M_{ice}$  are liquid water and ice water contents (g cm<sup>-3</sup>), respectively.

# GNSS signal delay due to atmosphere

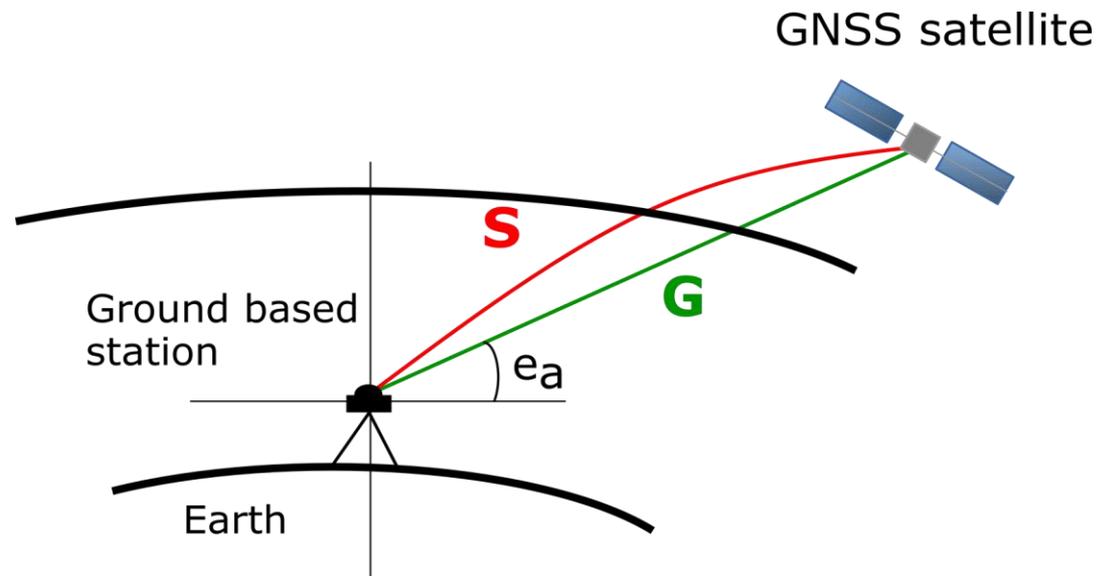


NWP models/ reanalysis

$$STD = L - G = \int_s n(s) ds - G$$

$$= 10^{-6} \int_s N(s) ds + S - G$$

$$STD = SHD + SWD + SHmD$$



# Raytracing

Slant total delays can be assessed from GNSS phase measurements by a ground based receiver. Another way to estimate signals tropospheric delays employs numerical weather prediction models (NWP) which provide meteorological parameters on several vertical layers.

Assuming geometric optics approximation, we used 2D piecewise-linear raytracing approach where ray is a curved line, does not leave the plane of a constant azimuth and horizontal gradients are neglected.

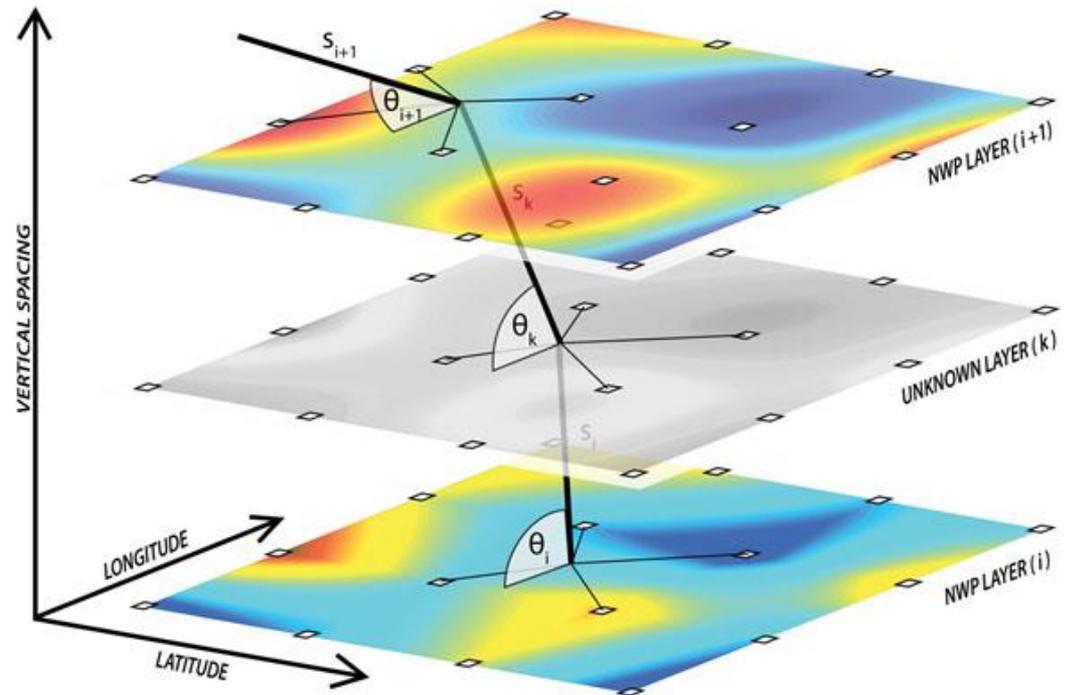
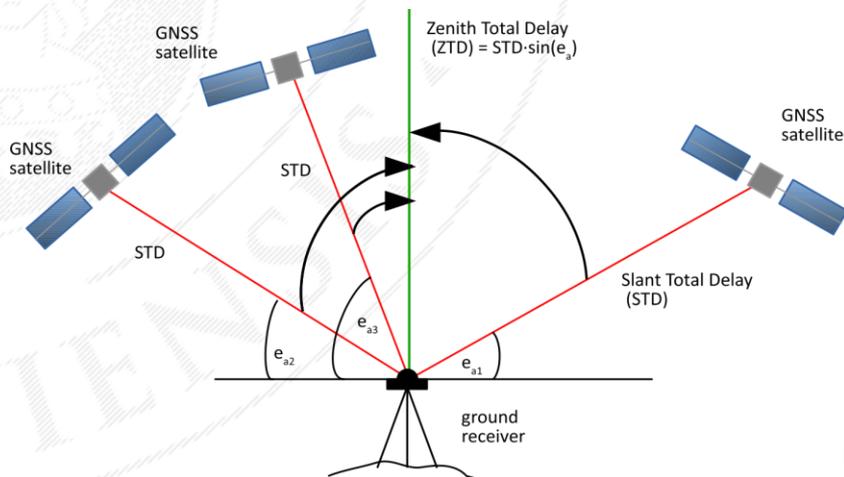
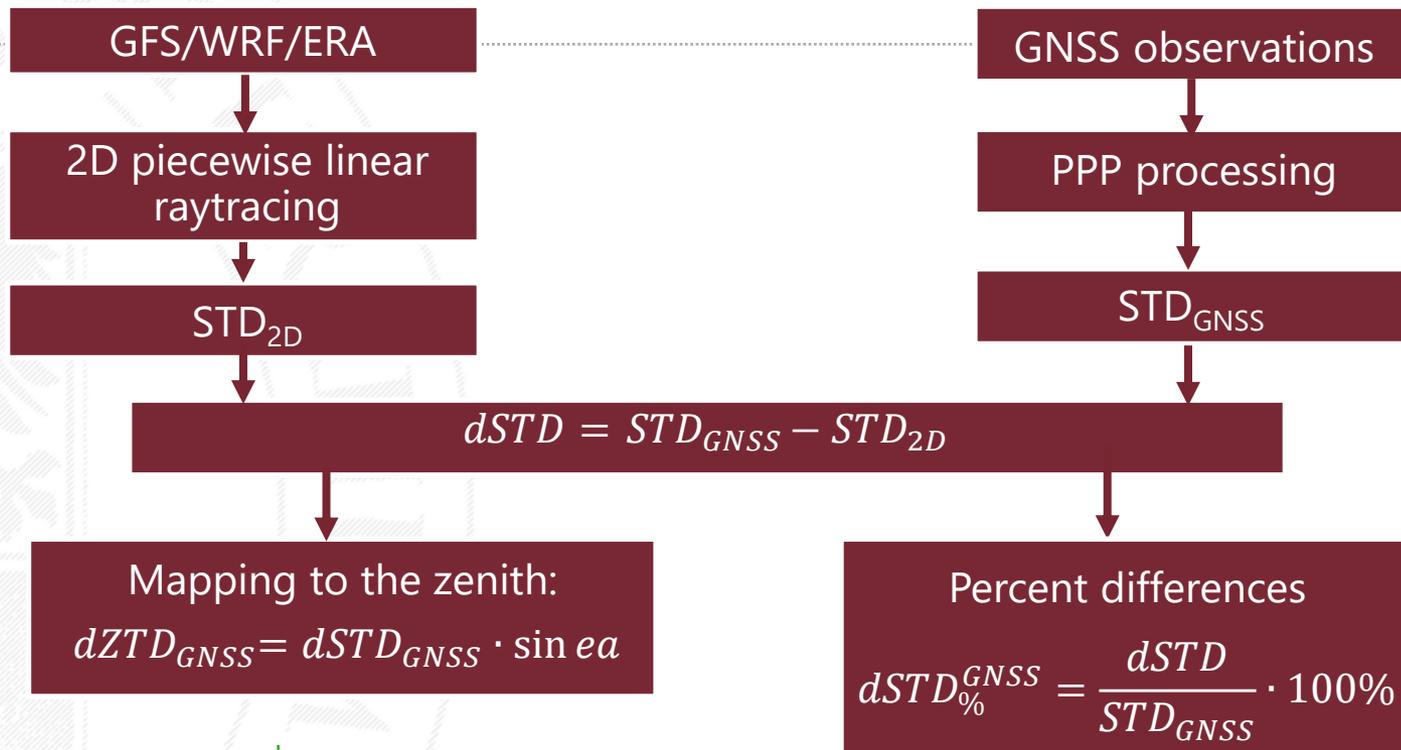


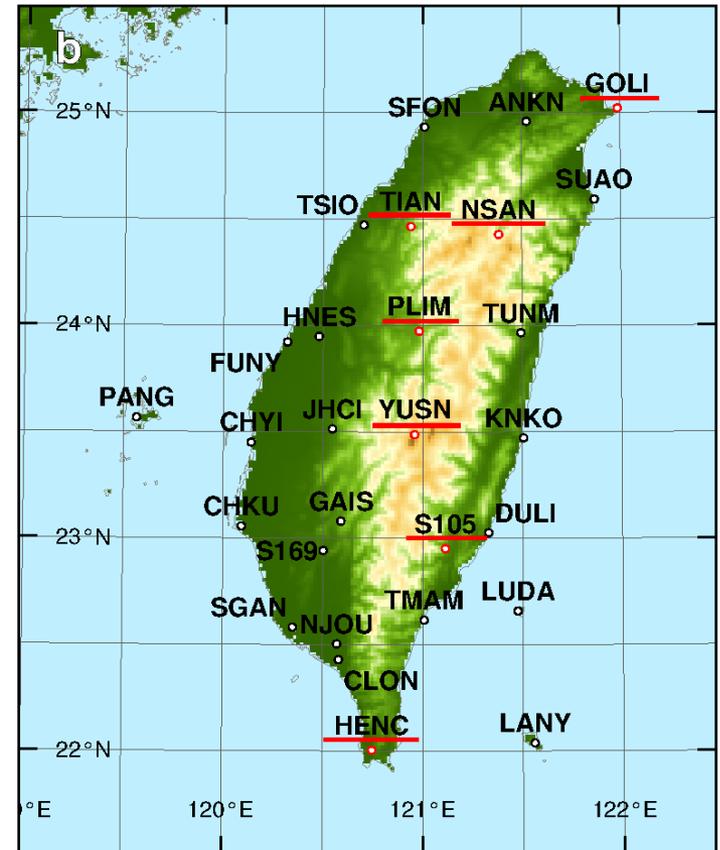
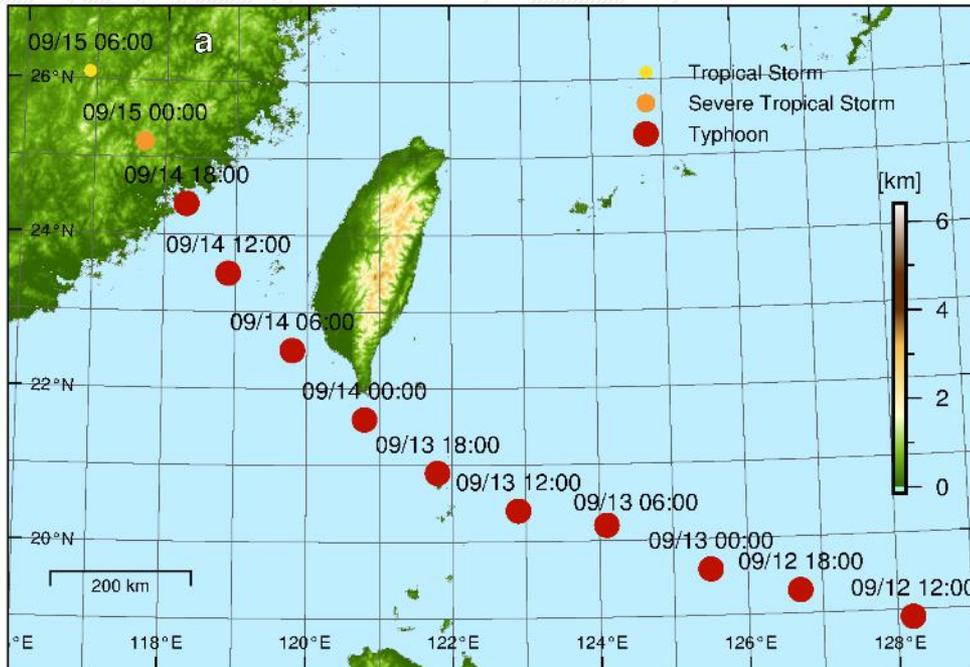
Figure taken from <http://www.igg.up.wroc.pl/igg/>

# Methodology



# Data

- 28 GNSS stations in Taiwan, further inspection of HENC, GOLI, PLIM (south, north, mountains range)
- Tropical cyclone Meranti – analysis period: 12.09 12:00 to 15.09 12:00
- STD calculated from weather models:
  - Global Forecast System,
  - ERA-Interim,
  - Weather Research and Forecasting.



# STD comparison

## WRF (mean±std)

$$dZTD_{HM} = -0.5 \pm 29.4 \text{ mm}$$

$$dZTD = 2.3 \pm 28.0 \text{ mm}$$

## ERA (mean±std)

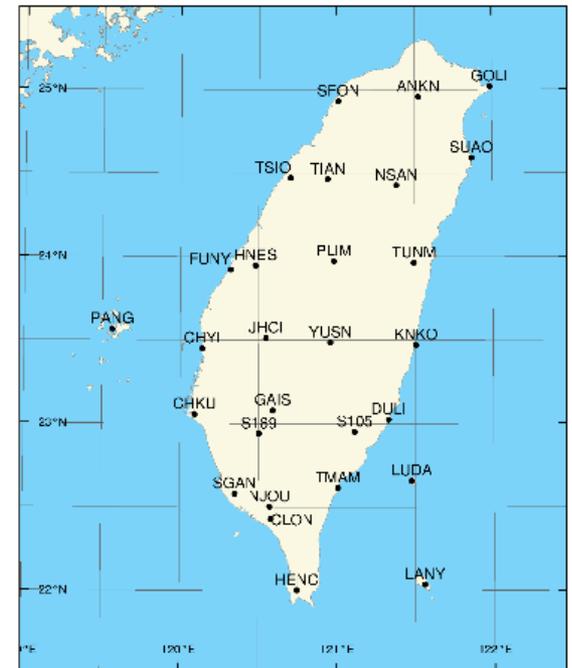
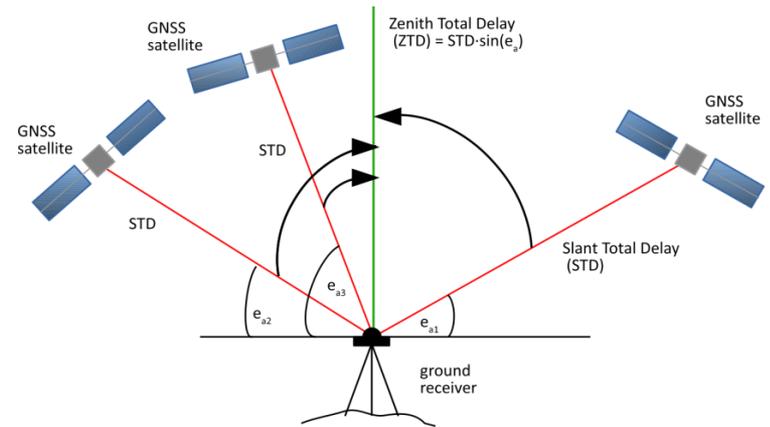
$$dZTD_{HM} = -16.5 \pm 35.2 \text{ mm}$$

$$dZTD = -16.1 \pm 35.0 \text{ mm}$$

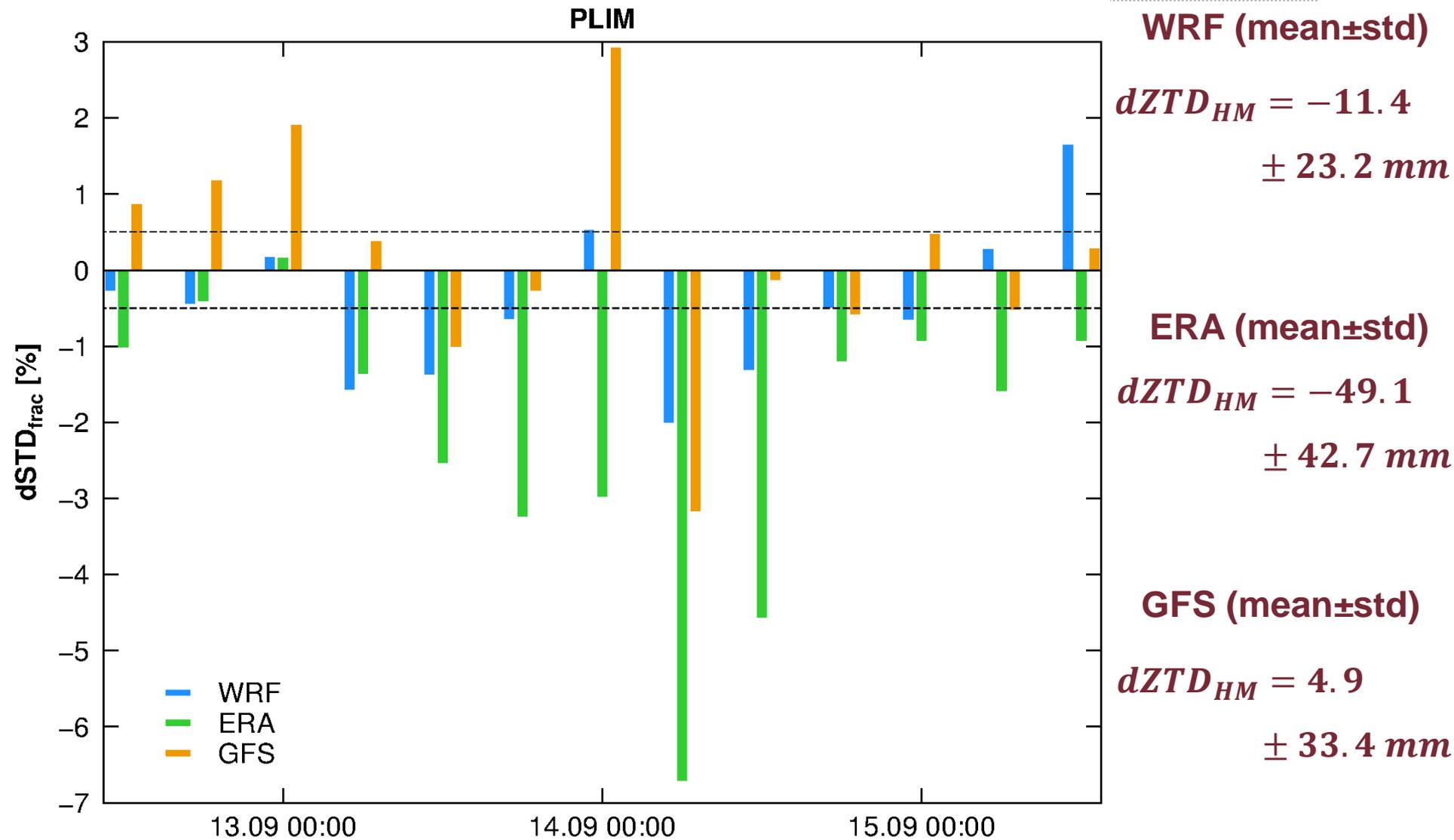
## GFS (mean±std)

$$dZTD_{HM} = 3.4 \pm 27.0 \text{ mm}$$

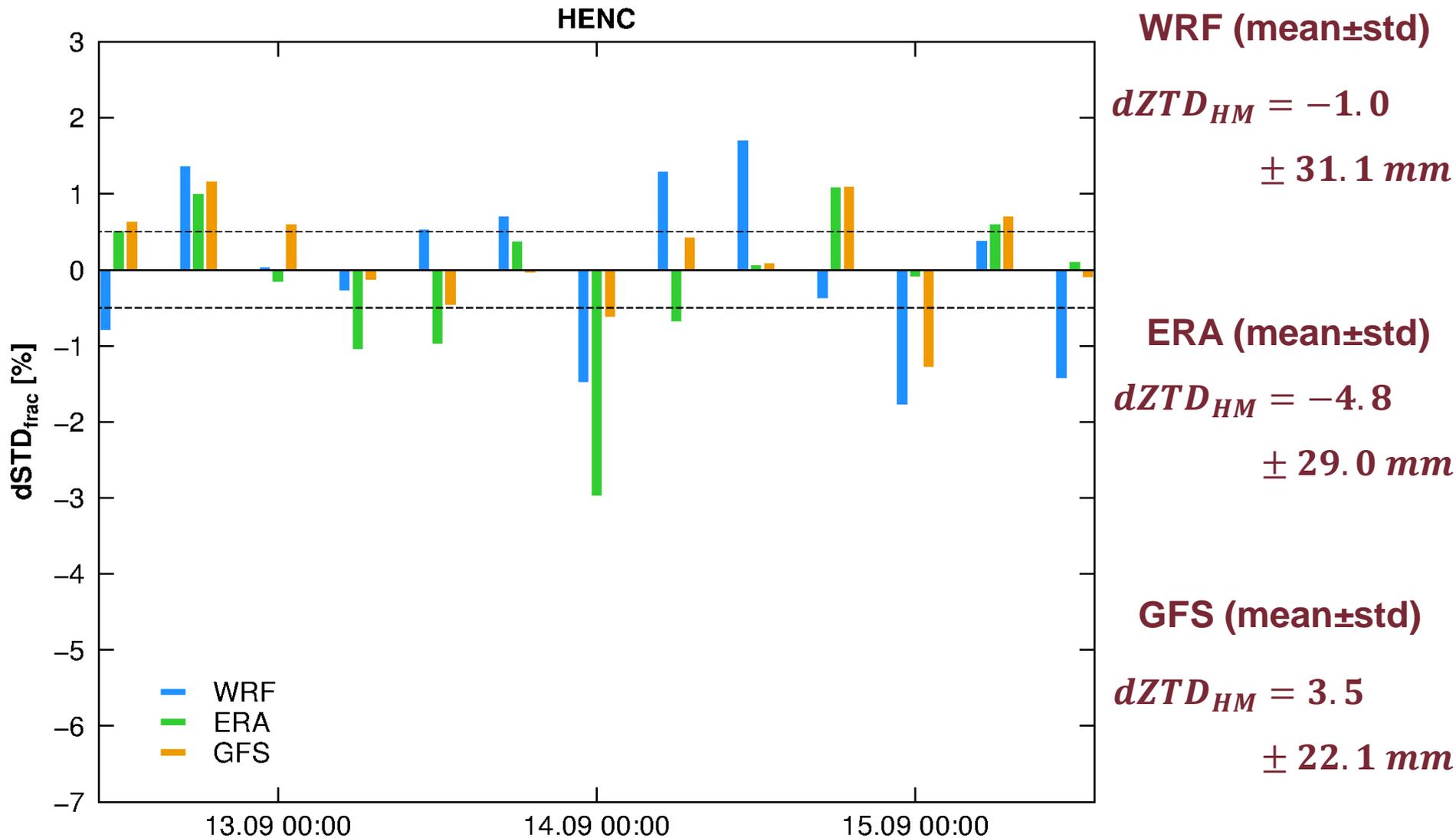
$$dZTD = 4.1 \pm 27.2 \text{ mm}$$



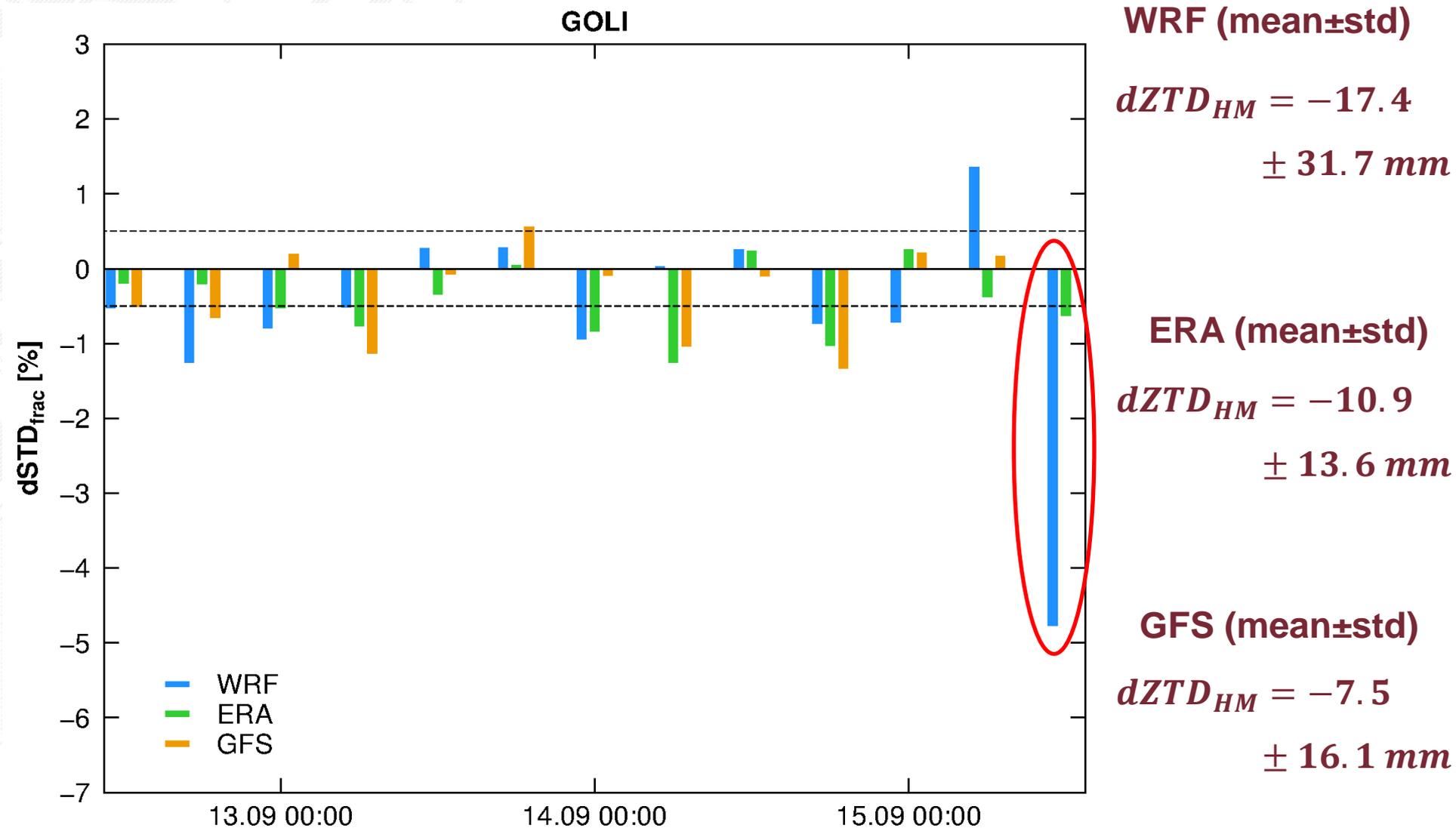
# Mountain station - PLIM 558 m asl



# HENC – south station

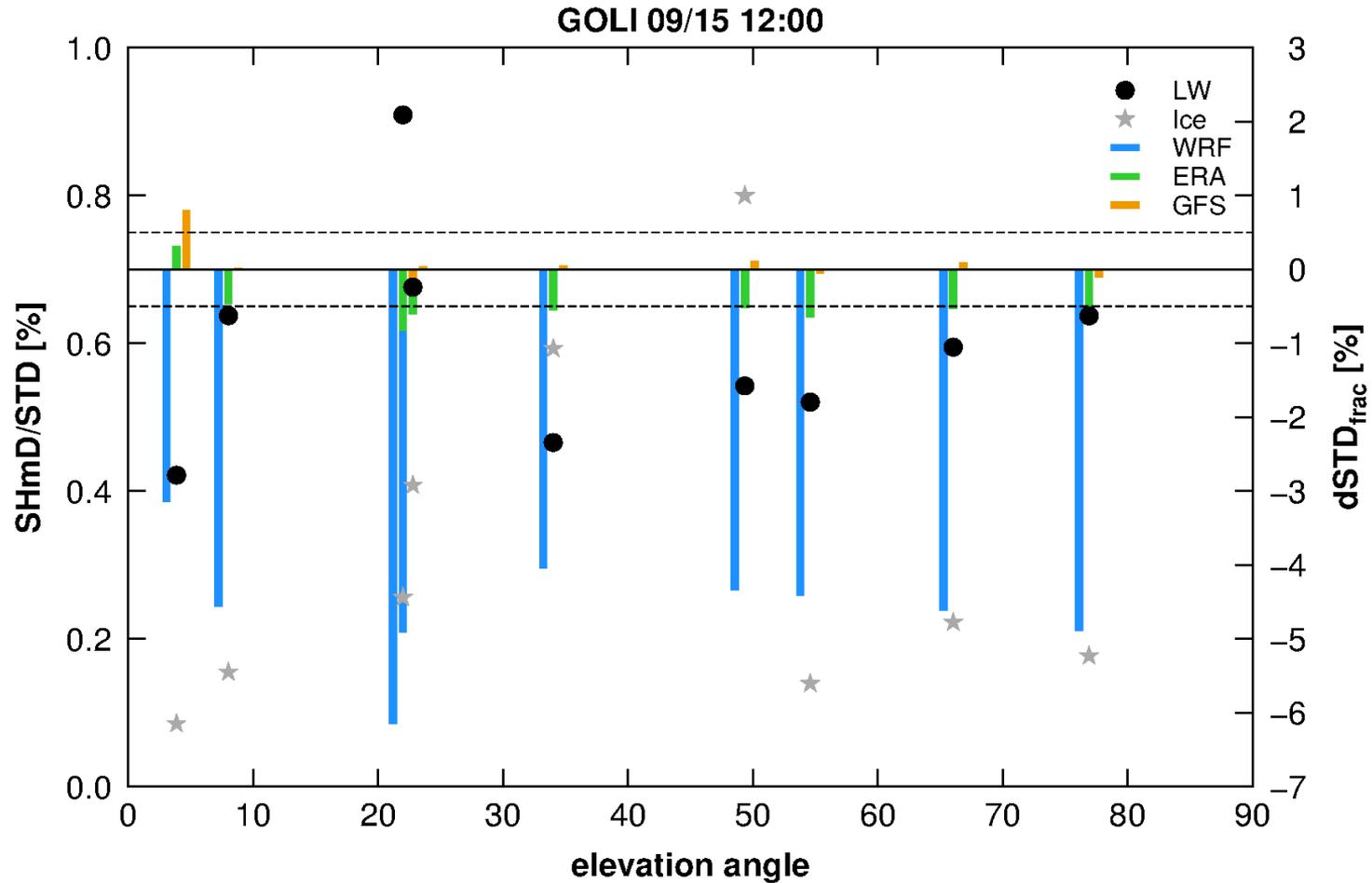


# GOLI – north station

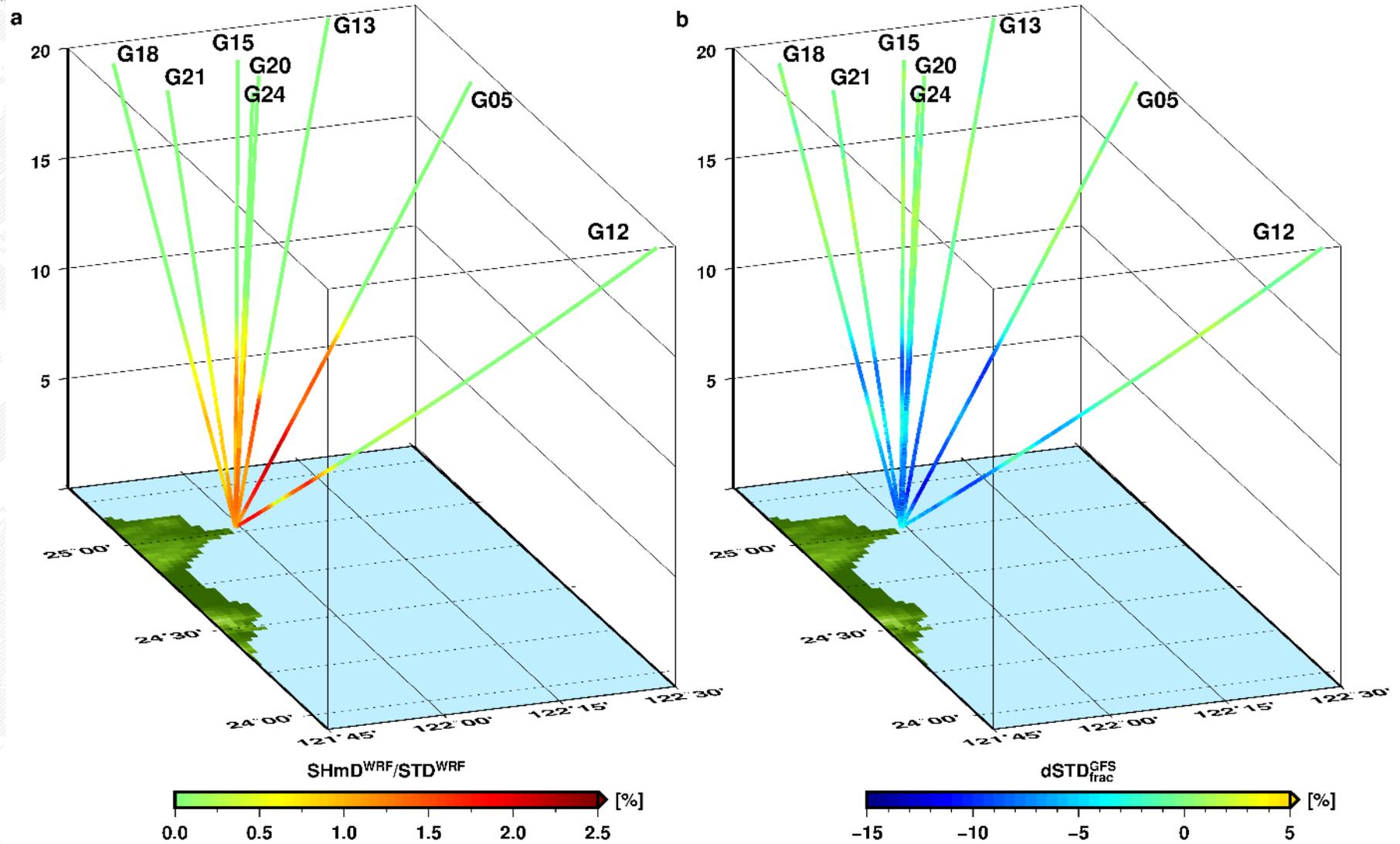


# Slant-by-slant verification

GOLI station: 15 September 2016, 12 UTC



# Slant by slant verification: 15 September 2016, 12 UTC



# Conclusions

- validation of multi-model data set (GFS/WRF/ERA) using GNSS slant total delays during the passage of TC Meranti for 28 stations in Taiwan,
- best resemblance for WRF with a mean of -0.5 mm and standard deviation equal to 29.4 mm,
- mean hydrometeors contribution is significant for WRF and reaches up to 2.8 mm, while for GFS and ERA are equal to 0.7 and 0.4 mm, respectively,
- absolute fractional differences are on average below 0.5% for GOLI station while for HENC the differences are within 0.8% due to closer location to passing Meranti,
- the largest errors of almost -7% and over -3% for ERA and GFS, respectively, are detected at 06 UTC on 14 September for PLIM station,
- slant by slant verification at 12 UTC on 15 September for GOLI station showed the discrepancy up to 15% between WRF and GFS below 10 km height.

# References

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Lasota, E., Rohm, W., Guerova, G., & Liu, C. Y.(2019). A Comparison Between Raytraced GFS/WRF/ERA and GNSS Slant Path Delays in Tropical Cyclone Meranti. *IEEE Transactions on Geoscience and Remote Sensing*, doi: 10.1109/TGRS.2019.2936785

Thank you for your attention!



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