

GCOS Reference Upper Air Network (GRUAN) GNSS Precipitable Water Product

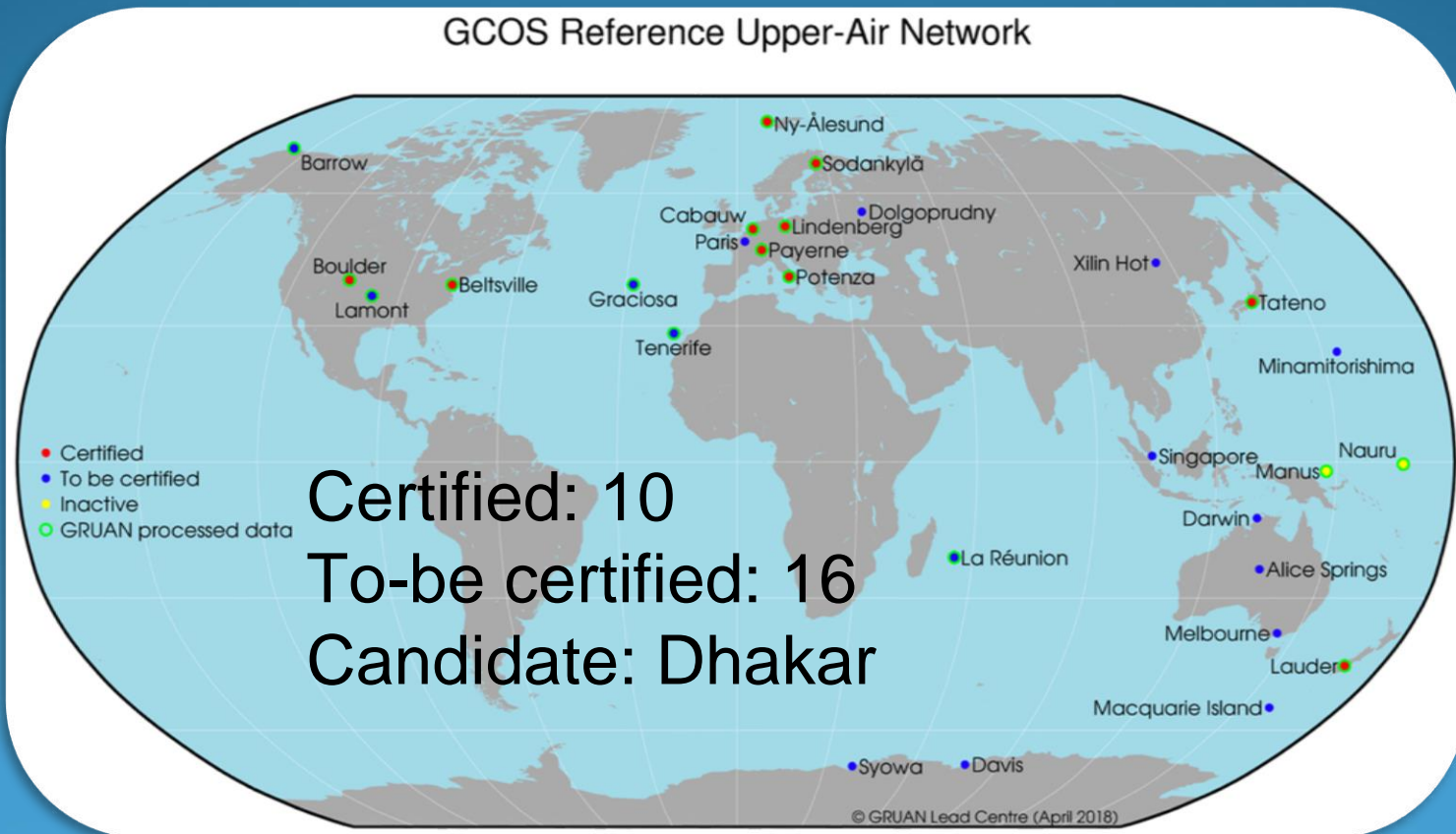
- GRUAN
- GRUAN GNSS-PW Task Team
- GRUAN GNSS-PW Data product
- Applications of GNSS-PW GDP

*Junhong (June) Wang, Jonathan Jones,
Galina Dick, Kalev Rannat & GNSS-PW TT*

Theme: Multi-GNSS through Global Collaboration

What is GRUAN?

- Global Climate Observing System (GCOS) Reference Upper Air Network
- Network for ground-based reference observations for climate in the free atmosphere in the frame of GCOS
- Currently 27 stations, envisaged to be a network of 30-40 sites across the globe

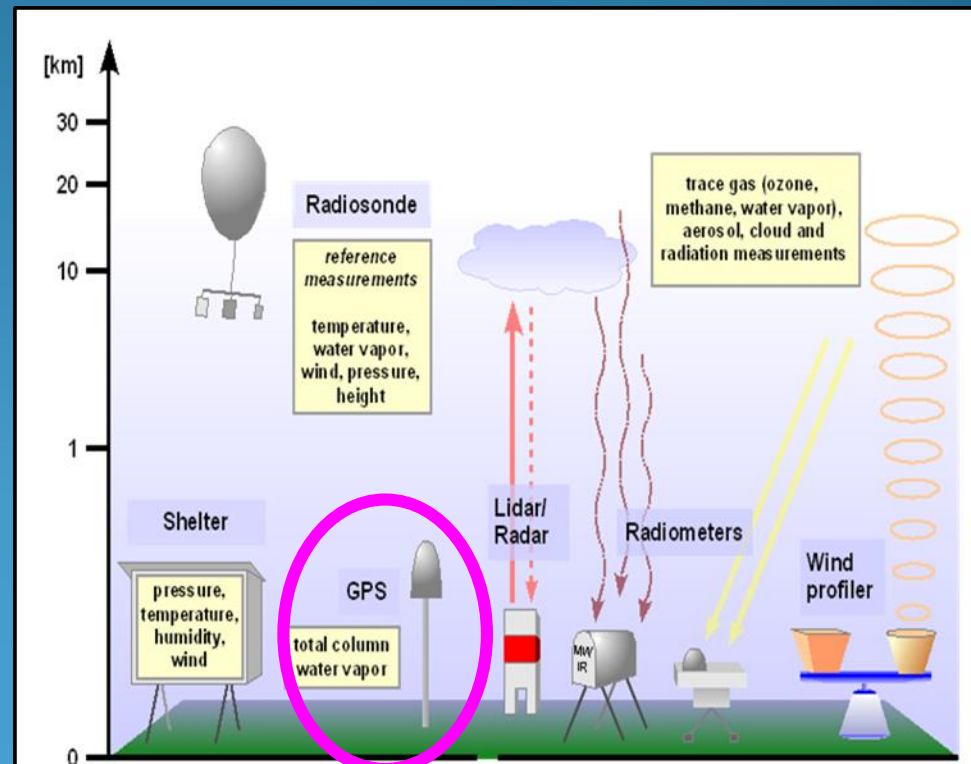


GRUAN Measurements and “DNAs”

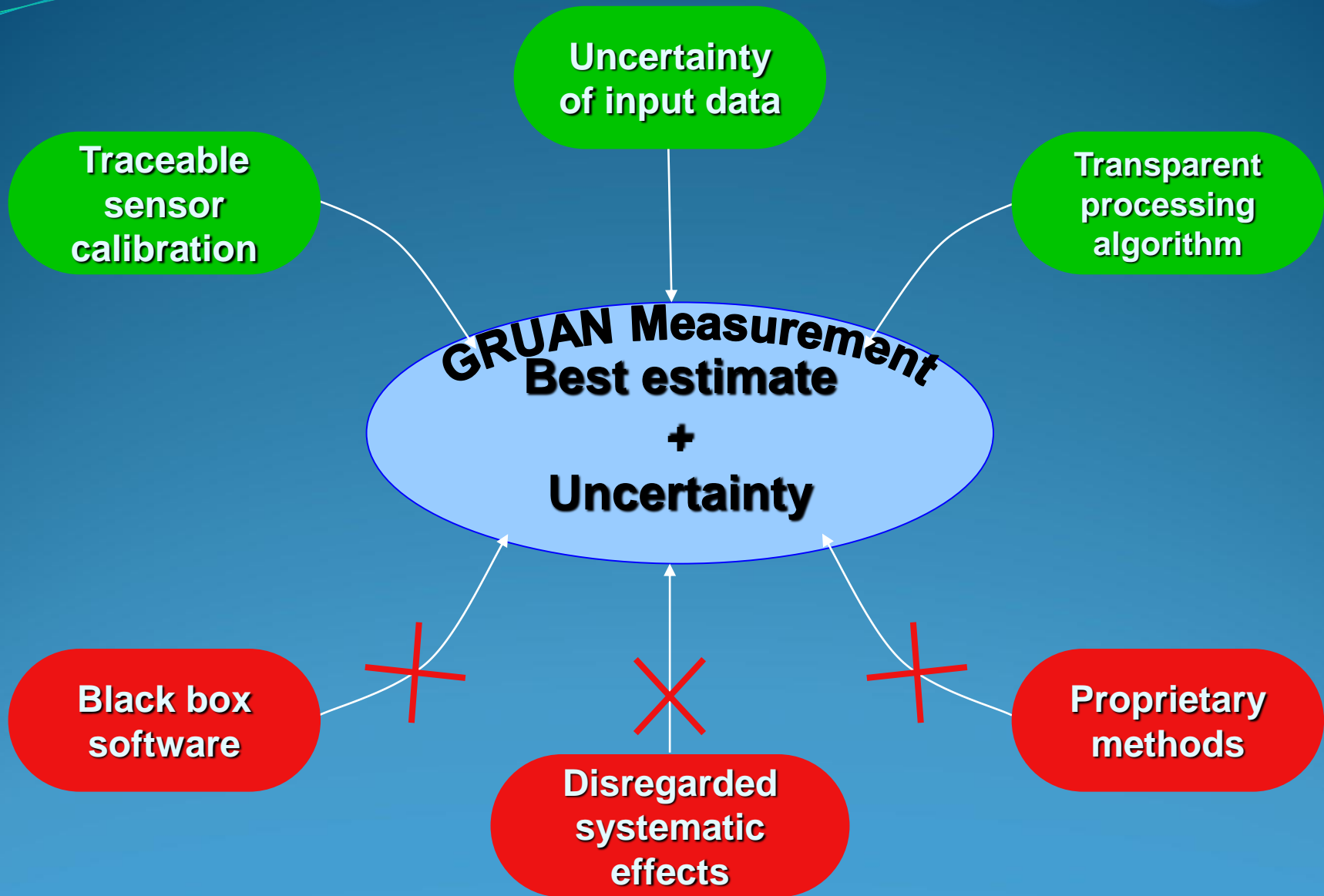
- ✓ Traceability
- ✓ Uncertainty estimate
- ✓ Management of change
- ✓ Long-term stability
- ✓ Redundancy

Priority 1: Temperature, pressure, water vapour

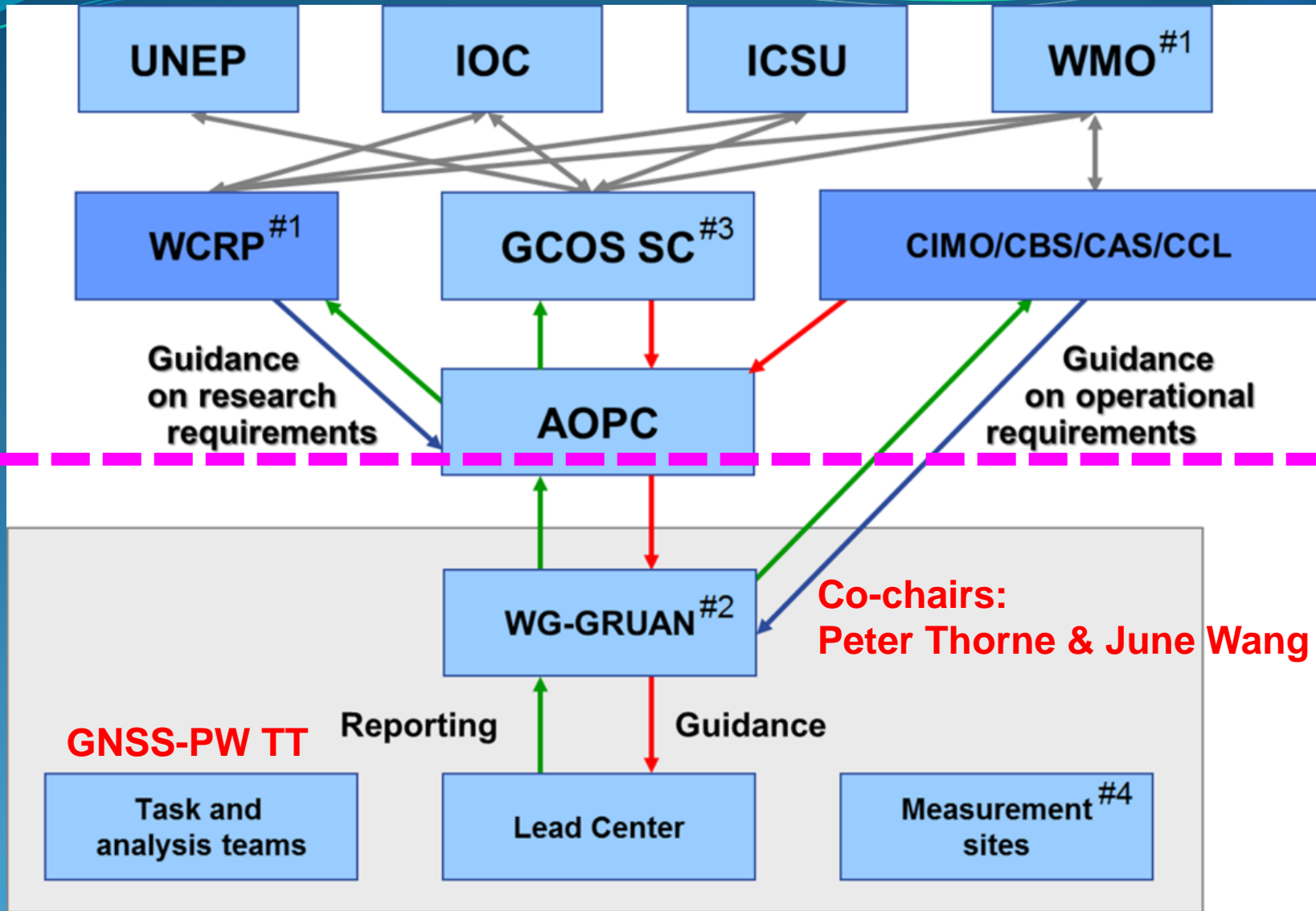
Priority 2: Ozone, methane ...



Establishing reference quality



GRUAN Structure



GRUAN GNSS-PW TT

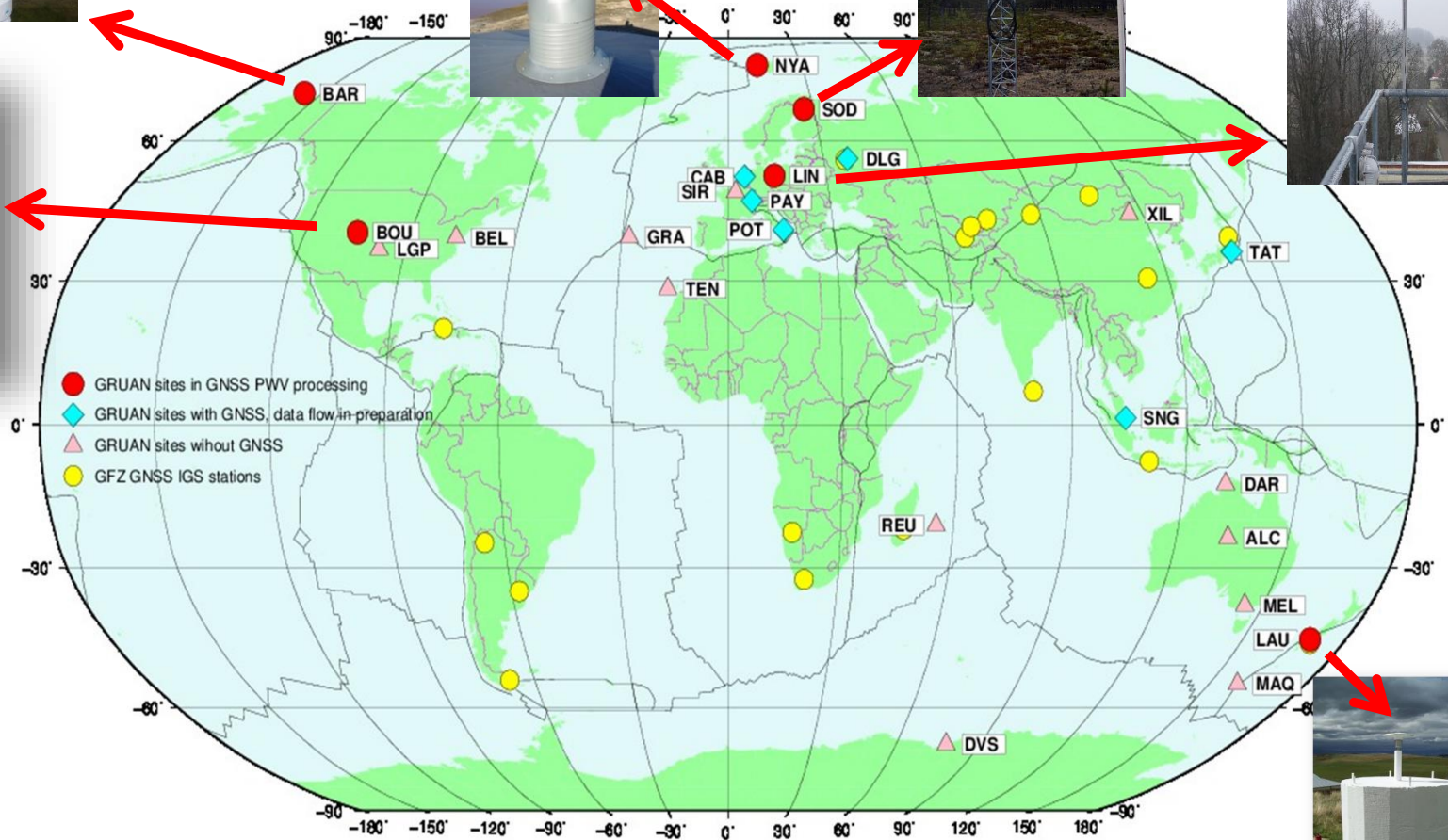
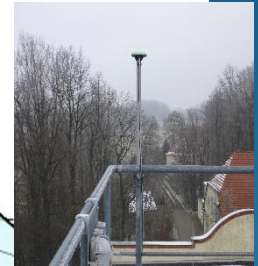


Goal: To develop explicit guidance on hardware, software and data management practices to obtain GNSS PW measurements of consistent quality at all GRUAN sites.

Leverage from IGS resources!

Jonathan Jones	Met Office, UK	co-chair
Kalev Rannat	Tallinn University of Technology, EE	co-chair
John Braun	UCAR, USA	
Galina Dick	GeoForschungsZentrum Potsdam, DE	GFZ
Gunnar Elgered	Chalmers University, SE	
Yoshinori Shoji	Meteorological Research Institute, JP	
Jens Wickert	GeoForschungsZentrum Potsdam, DE	GFZ
George Liu	Hong Kong Polytechnic University, HK	
Tong Ning	Lantmäteriet (Swedish Mapping, Cadastre and Land Registration Authority), Sweden	Developed uncertainty estimate algorithm
Rosa Pacione	e-GEOS S.p.A., Matera Space Center, Italy	
Junhong (June) Wang	State University of New York at Albany, USA	retired co-chair/WG co-chair

GRUAN GNSS Network



Courtesy of Galina Dick, Wuhan

www.gruan.org



GNSS-PW Uncertainty Estimate

$$\begin{aligned}ZWD &= ZTD - ZHD \\ZHD &= f(P_s) \\PW &= \Pi * ZWD \quad \Pi = f(T_m)\end{aligned}$$

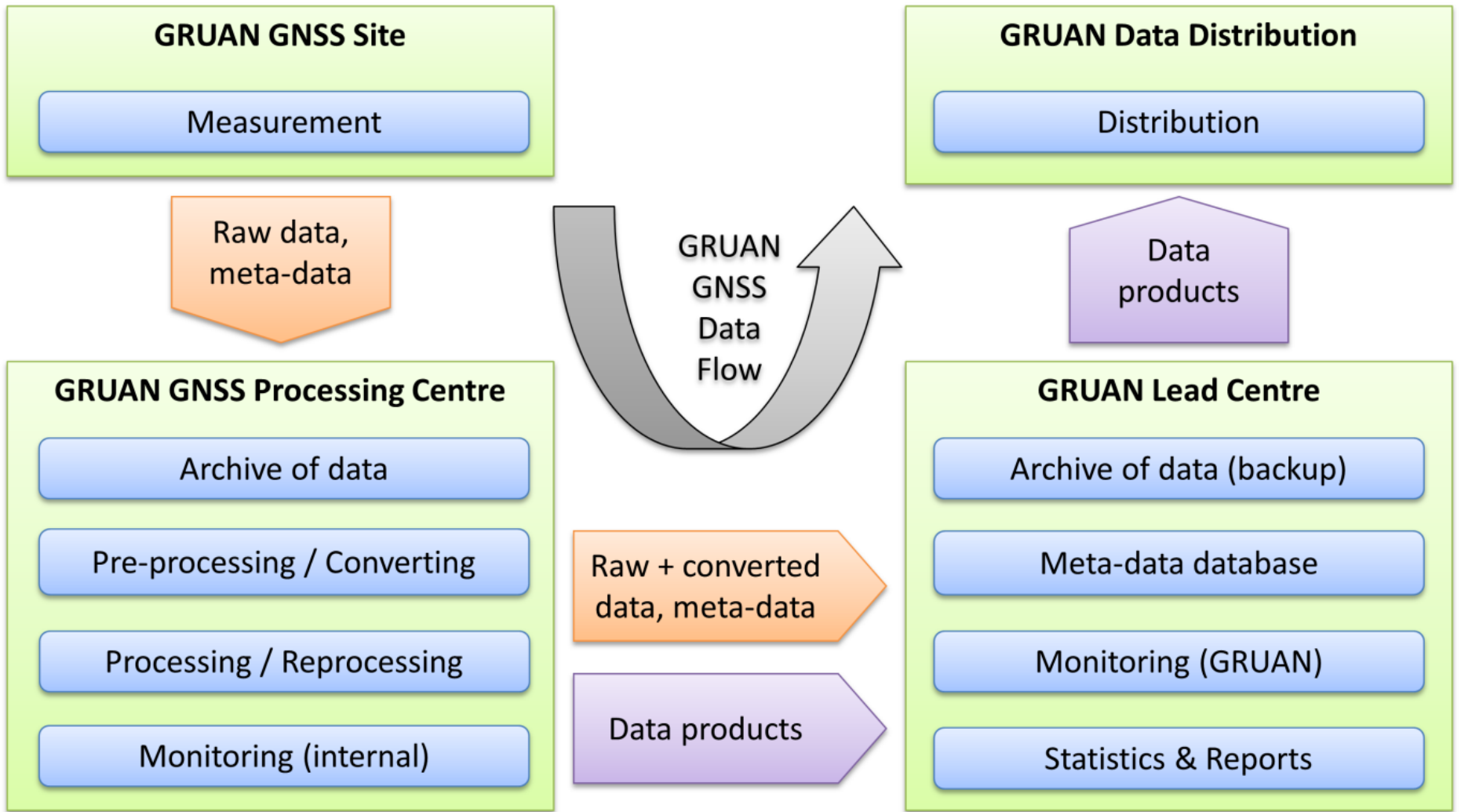
Ning, T., Wang, J., Elgered, G., Dick, G., Wickert, J., Bradke, M., Sommer, M., Querel, R., and Smale, D.: The uncertainty of the atmospheric integrated water vapour estimated from GNSS observations, *Atmos. Meas. Tech.*, 9, 79-92, doi:10.5194/amt-9-79-2016

$$\delta q = \sqrt{\left(\frac{\partial q}{\partial x} \delta x\right)^2 + \dots + \left(\frac{\partial q}{\partial z} \delta z\right)^2}$$

$$\sigma_{PW} = \sqrt{\left(\frac{\sigma_{ZTD}}{\Pi}\right)^2 + \left(\frac{2.2767\sigma_{P_0}}{f(\lambda, H)\Pi}\right)^2 + \left(\frac{P_0\sigma_c}{f(\lambda, H)\Pi}\right)^2 + \left(PW\frac{\sigma_{\Pi}}{\Pi}\right)^2}$$

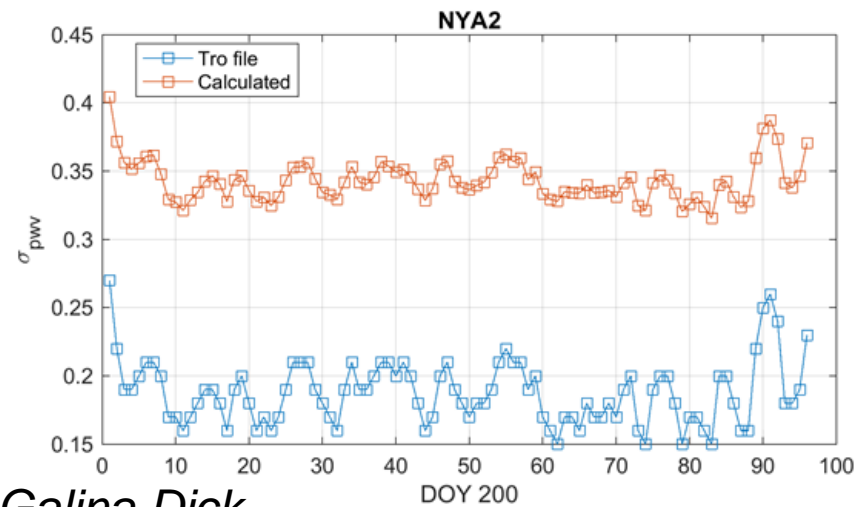
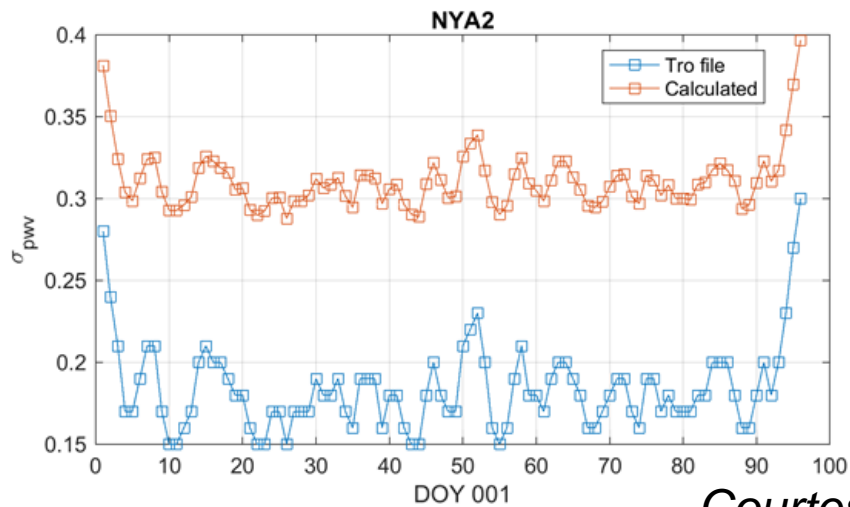
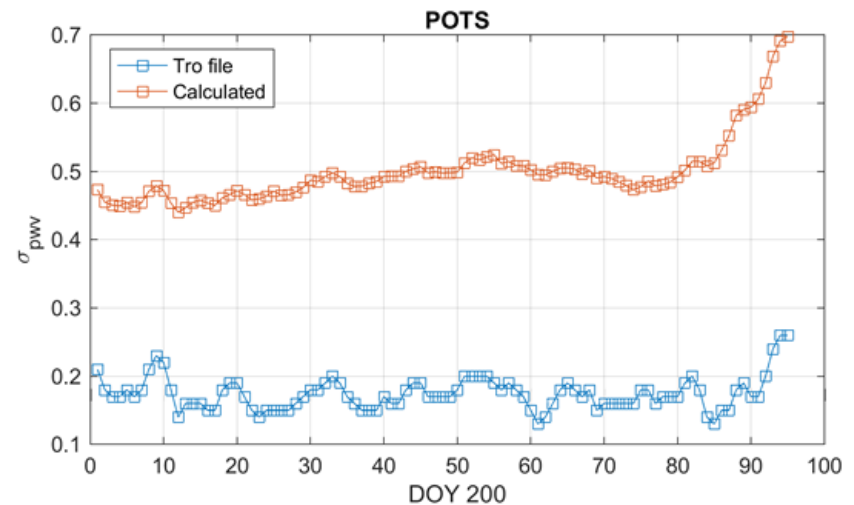
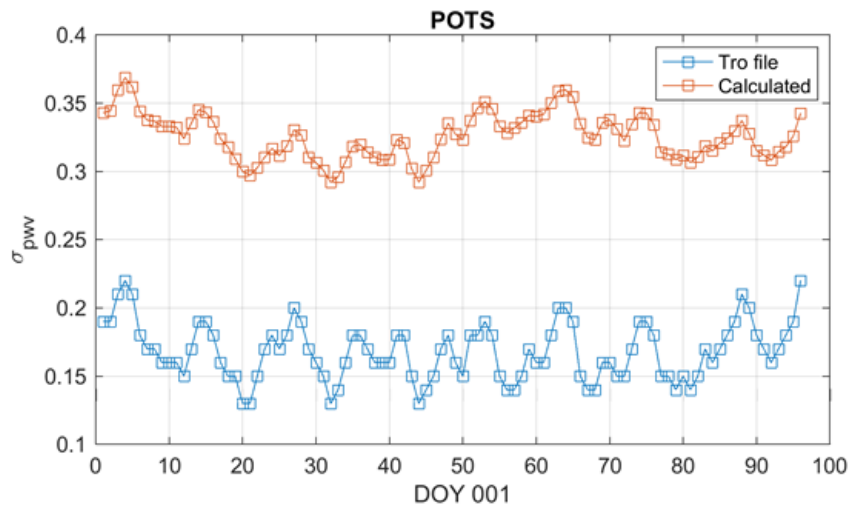
$$\sigma_{ZTD} (>75\%); \quad \sigma_c (10-20\%); \quad \sigma_{T_m} (2-4\%)$$

GFZ: GRUAN GNSS Data Product



Courtesy: M. Sommer, K. Rannat, Galina Dick

GNSS PW Uncertainty Estimation



Courtesy of Galina Dick

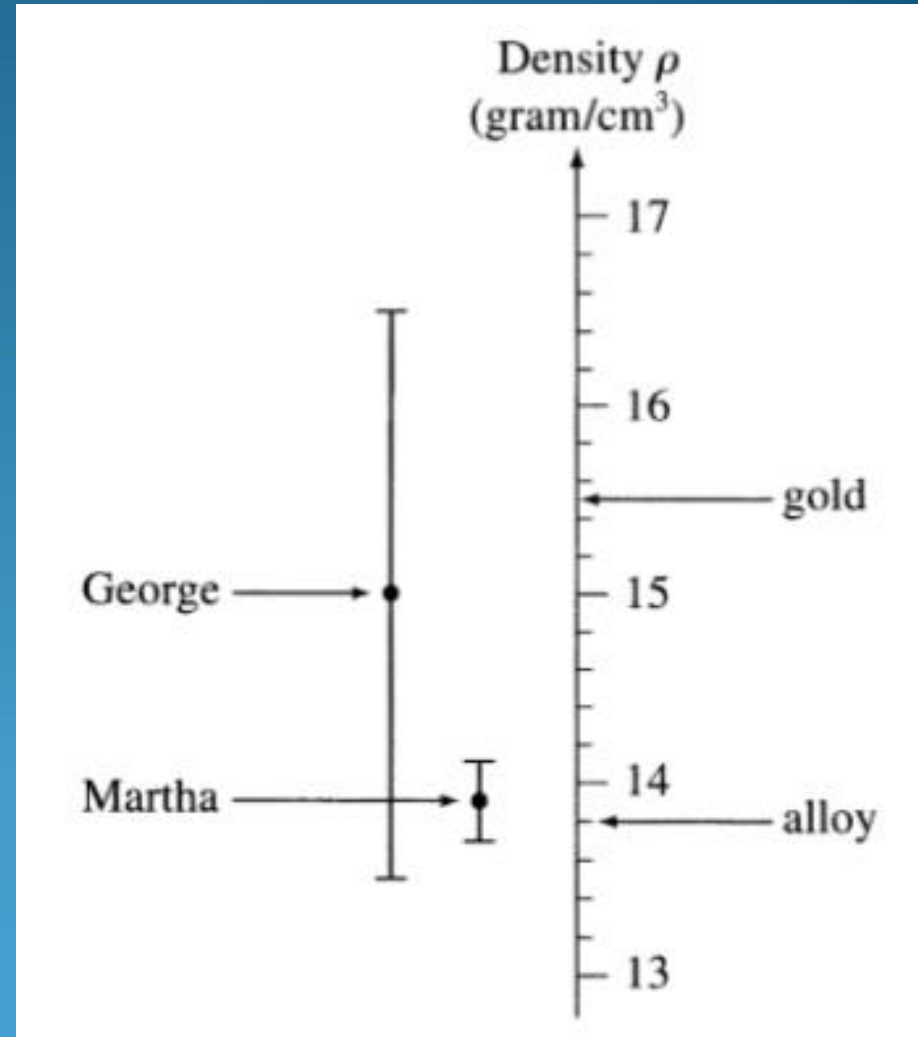
Importance of Knowing the uncertainties

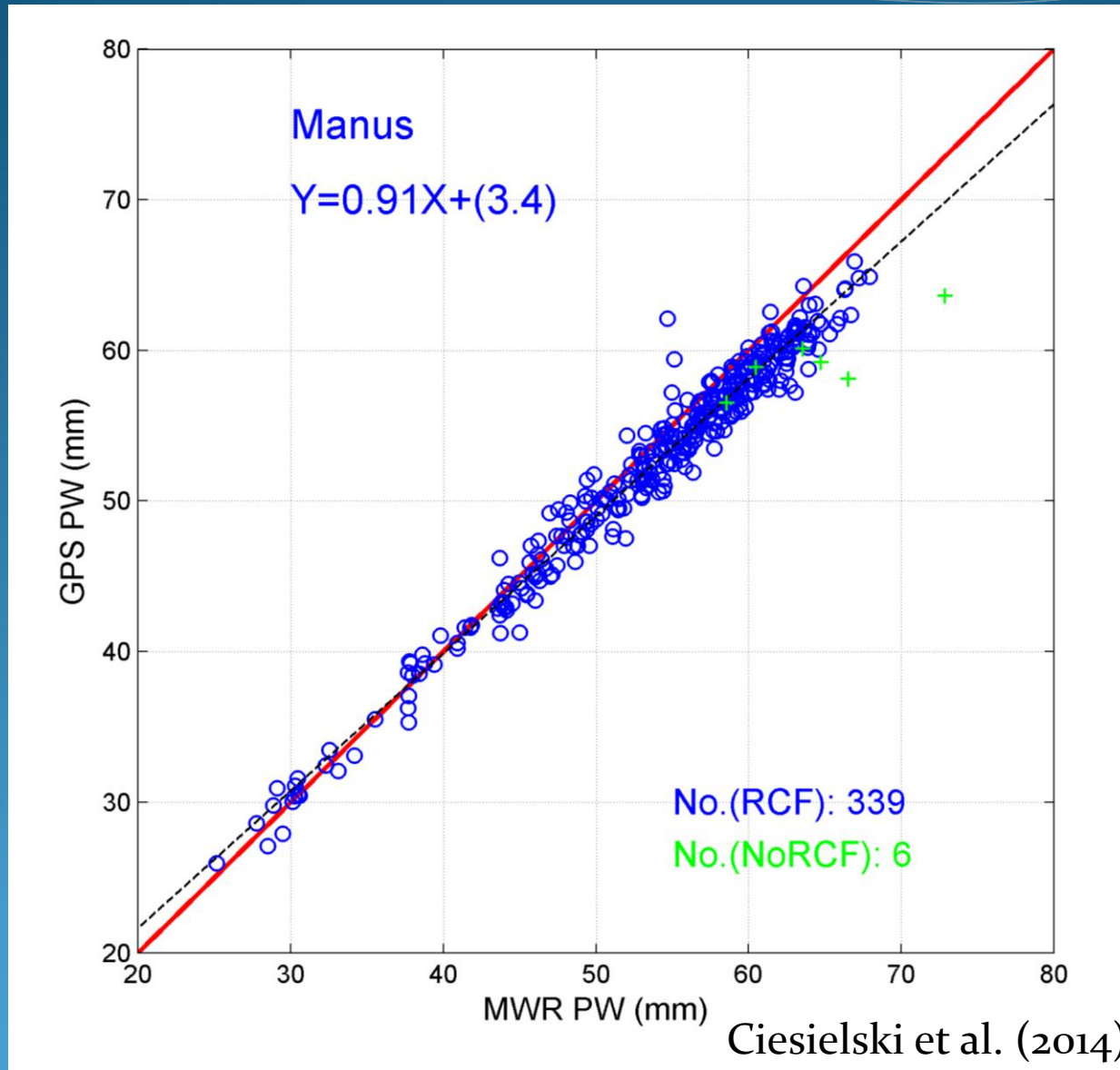
➤ Is a crown made of 18-karat gold or a cheaper alloy?

➤ Fact:

$$\rho_{\text{gold}} = 19.3 \text{ gram/cm}^3$$

$$\rho_{\text{alloy}} = 13.8 \text{ gram/cm}^3.$$





Uncertainty, Redundancy and Consistency

- GRUAN stations should provide *redundant* measurements
- Redundant measurements should be consistent:
 - ✓ No meaningful consistency analysis possible without uncertainties
 - ✓ if m_2 has no uncertainties use $u_2 = 0$ (“agreement within errorbars”)

$ m_1 - m_2 < k \sqrt{u_1^2 + u_2^2}$	TRUE	FALSE	significance level
k=1	consistent	suspicious	32%
k=2	in agreement	significantly different	4.5%
k=3	-	inconsistent	0.27%

Immeler, F. J.; Dykema, J.; Gardiner, T.; Whiteman, D. N.; Thorne, P. W. and Vömel, H., Reference Quality Upper-Air Measurements: guidance for developing GRUAN data products. *Atmospheric Measurement Techniques*, 2010, 3, 1217–1231.

Application: Closely co-located receivers **GRUAN**



2. Statistical Analysis

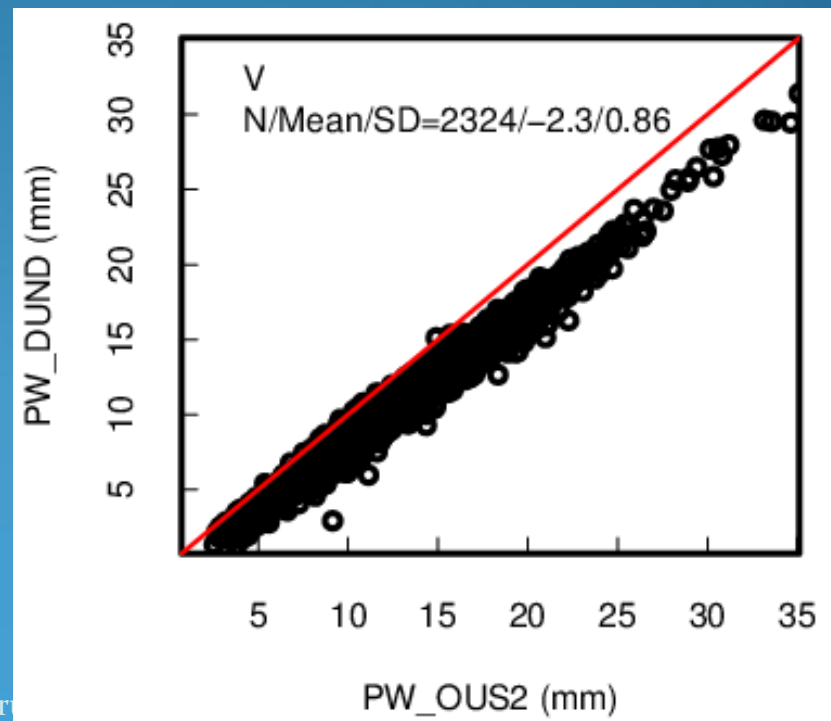
$$S_{A-B} \approx \sqrt{E_A^2 + E_B^2}$$

$$E_A = E_B = \text{S.D.}/\sqrt{2} \\ = 0.86/\sqrt{2} = 0.61 \text{ mm}$$

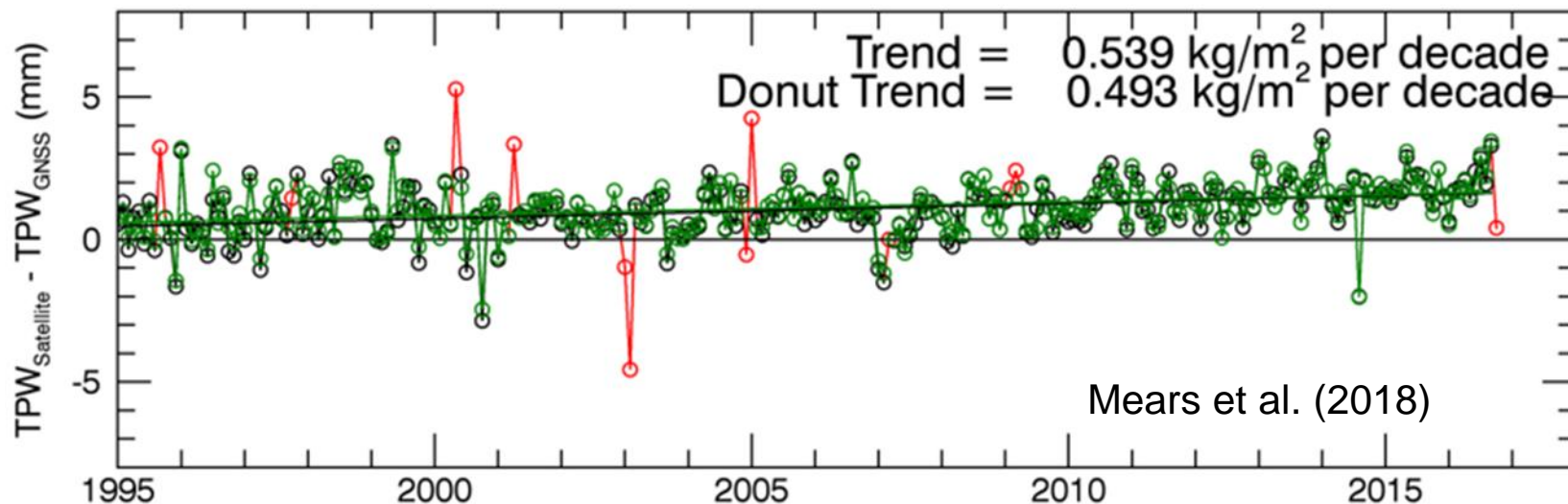
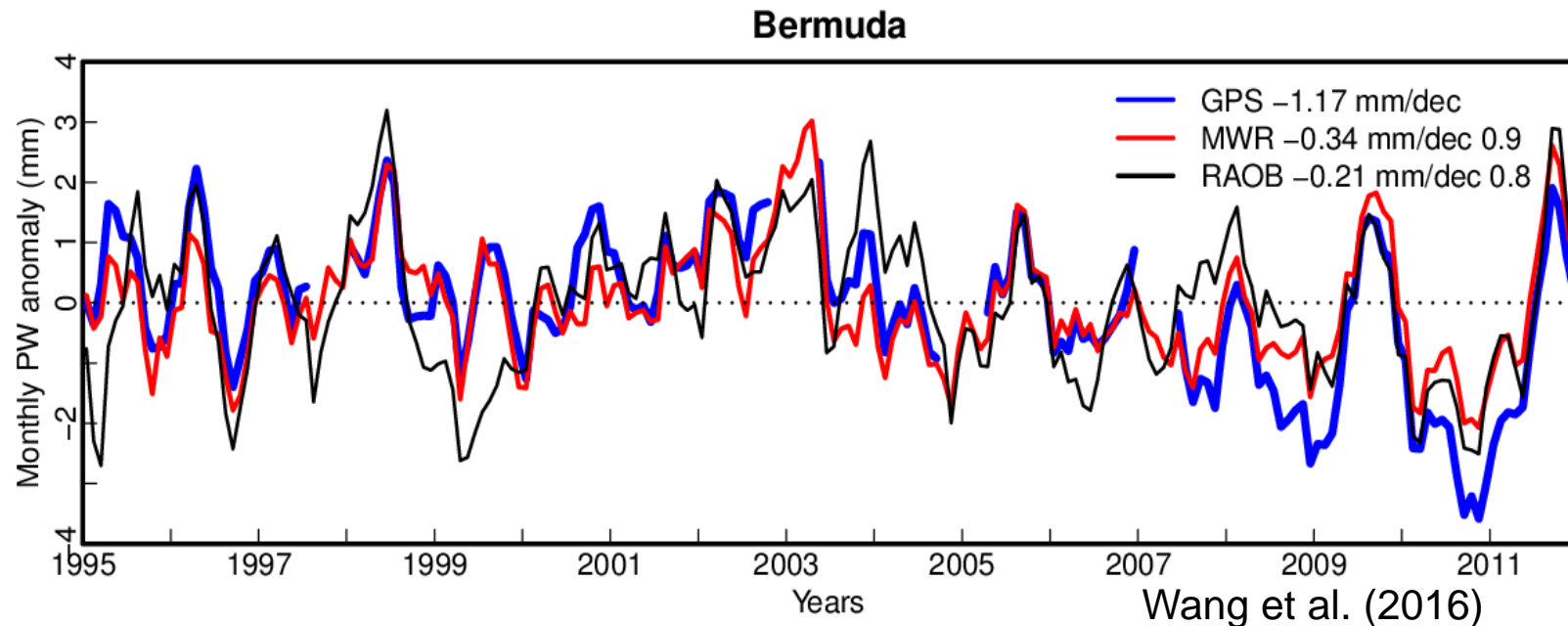
Theoretical analysis:

0.56/0.64/0.66 mm

(Tong et al. 2016)



Application: Long term Trends



Summary

1. Strong collaborations between GRUAN and IGS! Thank you!!!
2. Looking for potential GRUAN sites at IGS or other GNSS sites!
3. Looking for collaborations on better ZTD uncertainty estimates!
4. Looking for users for GRUAN GNSS PW and other products!

GCOS Reference Upper-Air Network

