A book by GRUAN

Reference Climate Measurements and Instrumentation

1. Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements, (2nd Ed.), John R. Taylor
2. Meteorological measurements and instrumentation, R.Giles Harrison
3. Meteorological Measurement Systems, Fred V. Brock and Scott J. Richardson

GRUAN Technical Document 2

GNSS-PW Technical Document

Junhong (June) Wang

Department of Atmospheric & Environmental Sciences
New York State Mesonet
SUNY Albany, NY

KALEV RANNANT, MATT HANSON, YOSHINORI SHOJI, JOHN BRAUN, GALINA DICK, GUNNAR ELGERED, SETH GUTMAN, JENS WICKERT , TONG NING, MARKUS BRADKE, MICHAEL SOMMER, RICHARD QUEREL, DAN SMALE , JONATHAN JONES, GEORGE LIU, ROSA PACIONE ANYONE ELSE?

Structure of GRUAN Technical Document

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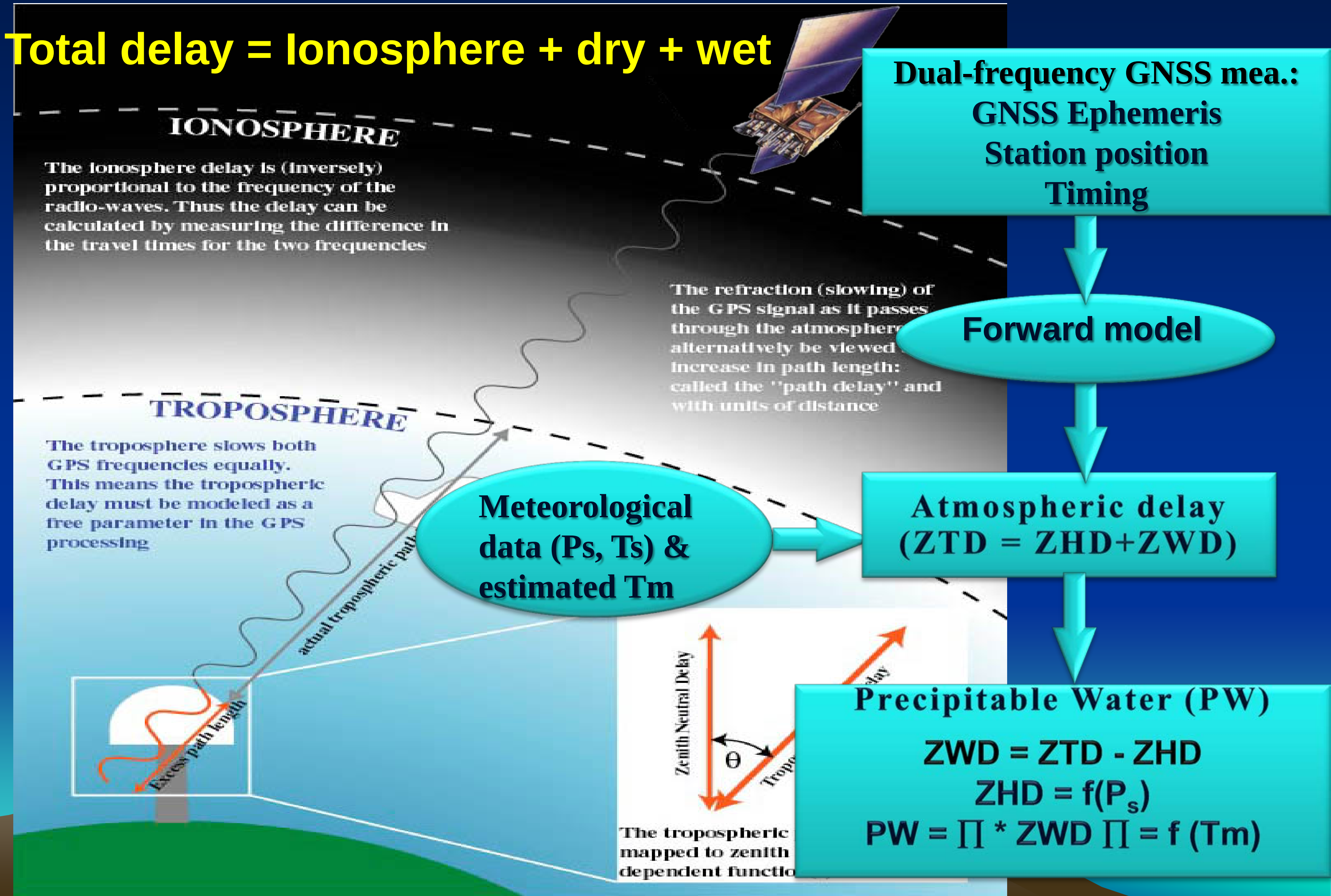
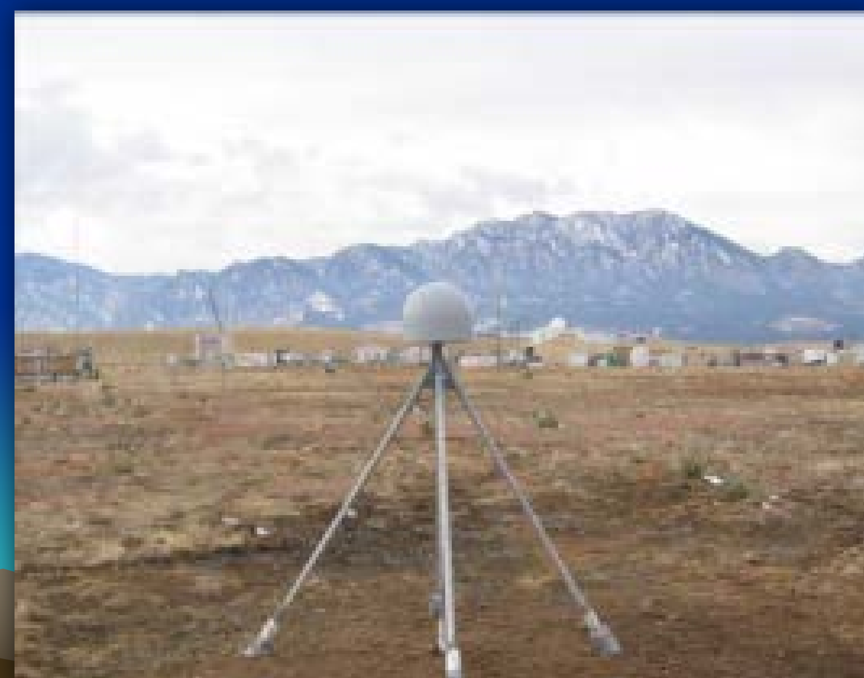
How does GNSS estimate precipitable water?



Instruments



1.1 To what extent does this measurement system fulfil the WMO rolling review of requirements?

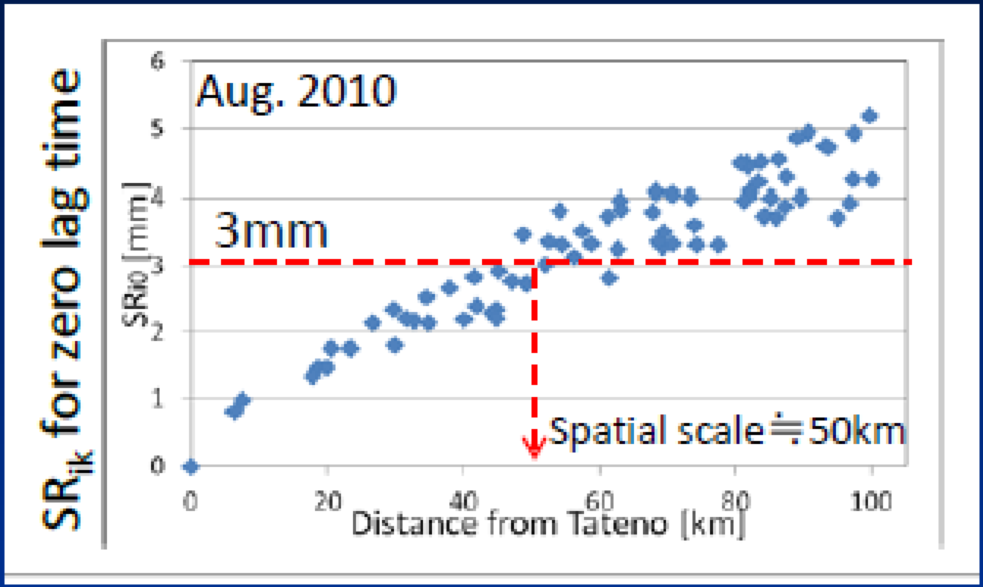
Application Area	Uncertainty	Horizontal Resolution	Observation Cycle	Timeliness	Coverage
GNSS-PW Final: NRT:	< 1mm <2 mm	Point	5 min 5 min	<1 month 2-3h	Global*
Climate-AOPC	1 mm 1.4 mm 3 mm	50 km 100 km 200 km	3 h 4 h 6 h	7 d 14 d 60 d	Global
Global NWP	1 mm 2 mm 5 mm	15 km 50 km 250 km	60 min 6 h 12 h	6 min 30 min 6 h	Global
High Res NWP	1 mm 2 mm 5 mm	0.5 km 5 km 20 km	15 min 60 min 6 h	15 min 30 min 2 h	Global
Nowcasting / VSRF	1 mm 2 mm 5 mm	5 km 10 km 50 km	15 min 30 min 60 min	5 min 10 min 30 min	Global

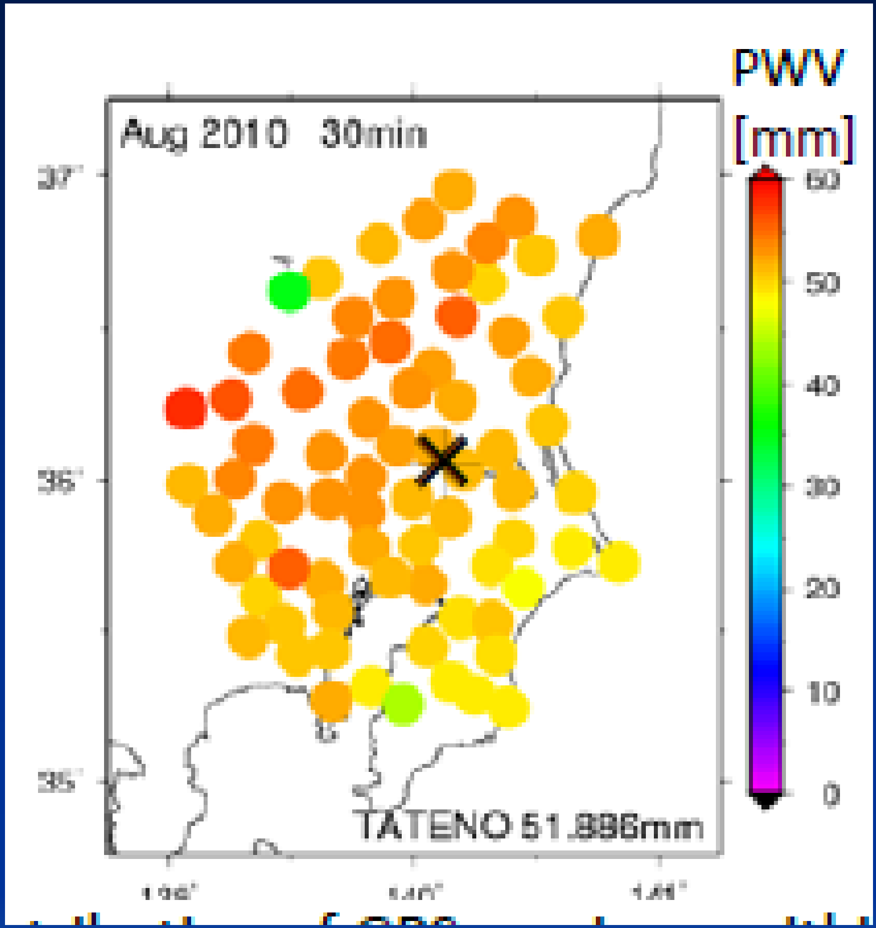
1.7 Finances (~27-48K Euros)

Equipment	Costs (EURO)
GPS Receiver/Antenna	15,000-20,000
Surface Observations	700-1,600
Station Monumentation	700-13,000
Installation	5000
Communication (Internet)	Variable
Total	**21,400-39,600**

Maintenance	Average Costs (EURO)
2 Site Visits per year (1 maintenance & 1 emergency)	3000
Spares	2500
Rent Costs	Variable
Local Archiving	500-2000
Total	**6000-7500**

2.5 Instrument Co-location





Yokota et al. 2014 (ICM4)

4 . Measurement Uncertainty

ZWD = ZTD – ZHD

ZHD = f(P_s)

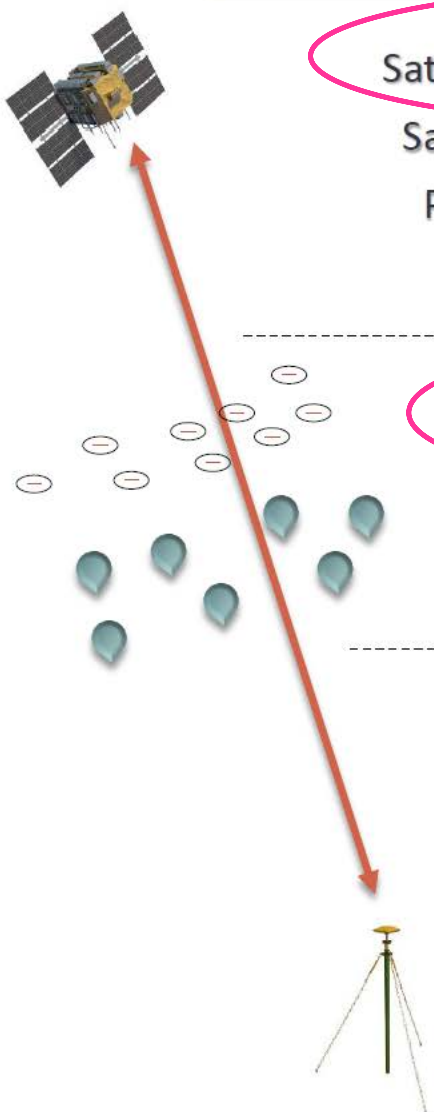
PW = ∏ * ZWD ∏ = f (Tm)

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

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

σ_{ZTD} (>75%); σ_c (10-20%); σ_{Tm} (2-4%)

Error sources and effects



Satellite orbit and clock products

Satellite antenna models

Phase wind-up correction

Satellite hardware delays

Satellite-specific effects

Ionosphere delay

Troposphere delay

Atmospheric effects

Multipath effect

Receiver clock corrections

Receiver antenna models

Receiver hardware delays

Site-specific effects

- Site displacement effects
  - Solid Earth tides
  - Ocean loading
  - Atmospheric pressure loading
  - Deformation due to polar motion

Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný (GOP)

From Jan Dousa

9. Site Assessment and Certification
(“Strictly required” & “Optional but desired”)

Equipment	Requirement
GPS Receiver/Antenna	Geodetic quality dual frequency carrier phase observations are needed for any GRUAN site.
Surface Observations (pressure and temp.)	Pressure accurate to <0.5 hPa to remove hydrostatic delay. A 0.5 hPa error in surface pressure ~0.2 mm error in PW.
Station Monumentation	GPS antenna should be installed in a manner that conforms to IGS standards.
Installation	
Communication (Internet)	Data need to be provided to analysis center(s) in timely manner to ensure that are included in routine processing.

Momumentation

Good top surface of pillar narrower than antenna

Problem: no orienting & leveling device

Good orienting & leveling devices

Good rooftop with orienting & leveling device