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Spatio-temporal distributed water vapor retrieved from GNSS observations and its usage in monitoring a rainfall process in Hong Kong

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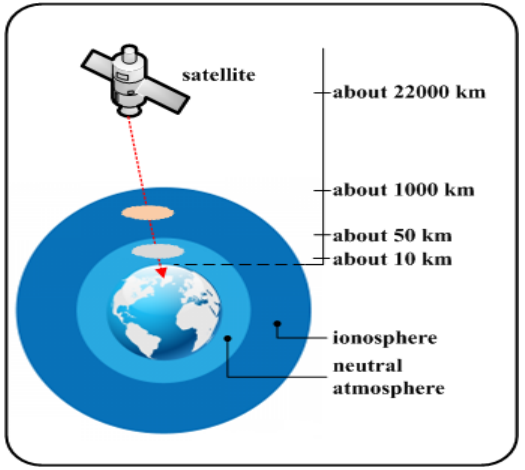
Outline

- Backgrounds
- Water vapor retrieved from GNSS observations
  - Precipitable water vapor (PWV)
  - Spatio-temporal distributed water vapor
- Monitoring a rainfall process in Hong Kong
- Conclusions

Backgrounds

- Tropospheric atmosphere
  - the lowest layer of Earth's atmosphere
  - extends upward to about 10 km above sea level
  - **almost all** weather occurs within this layer
  - **the wettest** layer of the atmosphere by far



- GNSS
  - tropospheric **refraction**
  - line-of-sight delay **error**, i.e., tropospheric delay errors
  - calibration of observations

Delay error → Useful information

Calibration → Retrieval

- Meteorology
  - water vapor is a necessary information
  - **GNSS Meteorology**
  - water vapor **retrieval**

Water vapor retrieval：precipitable water vapor

- The total amount of water vapor above a particular location is highly variable
- **PWV**: the depth of liquid water (in mm) that would result if all the water vapor in the atmospheric column is condensed and precipitated
- Zenith wet delay $\Delta\rho_{r,wet}^{Z}$ and PWV

$$\Delta\rho_{r,wet}^{Z} = 10^{-6}\int\left[k_2'\left(\frac{e}{T}\right)+k_3\left(\frac{e}{T^2}\right)\right]Z_W^{-1}dz$$

$$PWV = \frac{1}{\rho_l}\int\rho_w dz$$

$$\mathrm{PWV} = \Pi\cdot\Delta\rho_{r,wet}^{Z}$$

$$\mathrm{PWV} = 10^6\left[R_w\cdot\rho_w\cdot\left(\frac{k_3}{T_m}+k_2'\right)\right]^{-1}\cdot\Delta\rho_{r,wet}^{Z}$$

$$T_m = \frac{\int(e/T)Z_W^{-1}dz}{\int(e/T^2)Z_W^{-1}dz}$$

A particular station

→ GNSS observations

→ zenith wet delay $\Delta\rho_{r,wet}^{Z}$

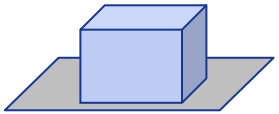
→ PWV

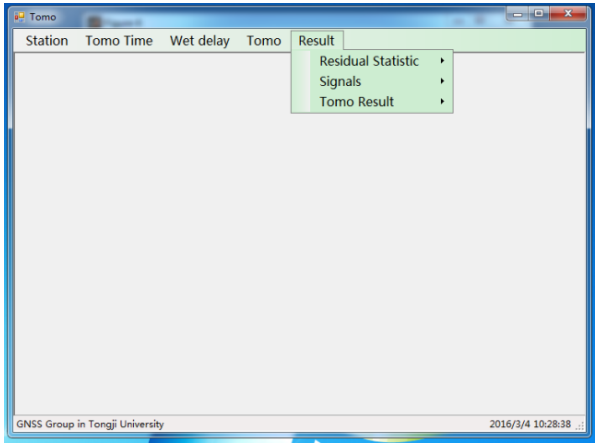
Water vapor retrieval: spatio-temporal water vapor

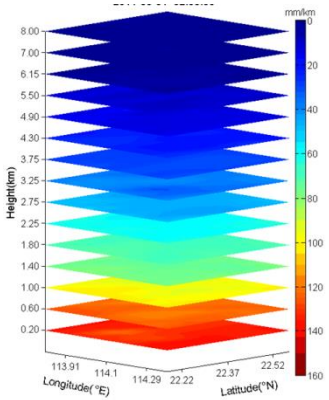
- two-dimensional
- integral water vapor
- PWV

Tomography

- three- or four-dimensional
- spatio-temporal distributed water vapor
- TWV







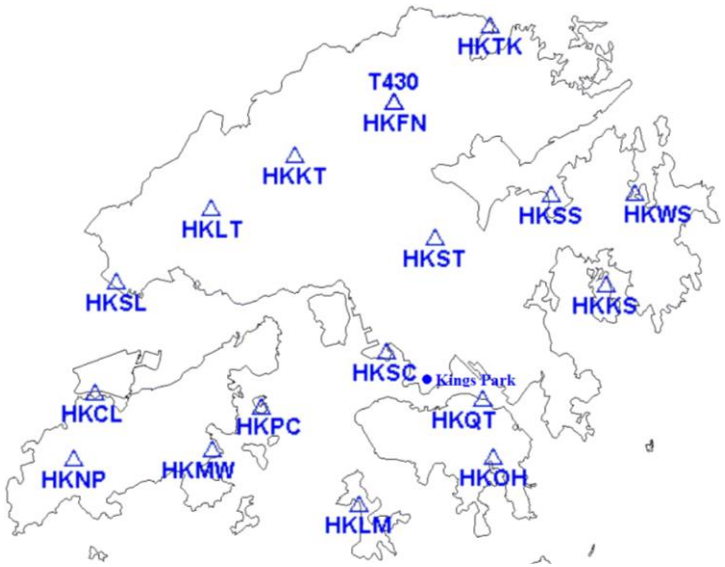
A certain amount of stations

→ GNSS observations

→ water vapor in line-of-sight (SWV)

→ TWV

Monitoring a rainfall process in Hong Kong



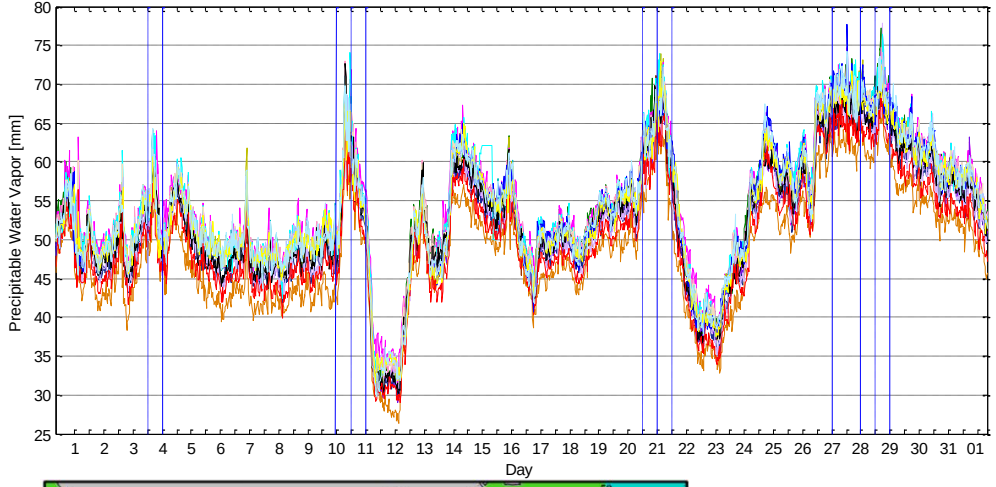
Hong Kong Satellite Positioning Reference Station Network(SatRef), and a radiosonde station Kings Park https://www.geodetic.gov.hk/sc/index.htm

Rainstorm Warning Signals in May 2016

Colour	Beginning Time Month/Day Hour:Minute	Ending Time Month/Day Hour:Minute	Duration Hour:Minute
Amber	05/03 18:10	05/03 20:55	02:45
Amber	05/10 06:00	05/10 07:35	01: 35
Red	05/10 07:35	05/10 09:35	02: 00
Amber	05/10 09:35	05/10 11:20	01: 45
Red	05/10 11:20	05/10 13:45	02: 25
Amber	05/10 13:45	05/10 14:45	01: 00
Amber	05/21 01:55	05/21 06:15	04 :20
Amber	05/28 16:35	05/28 18:40	02: 05

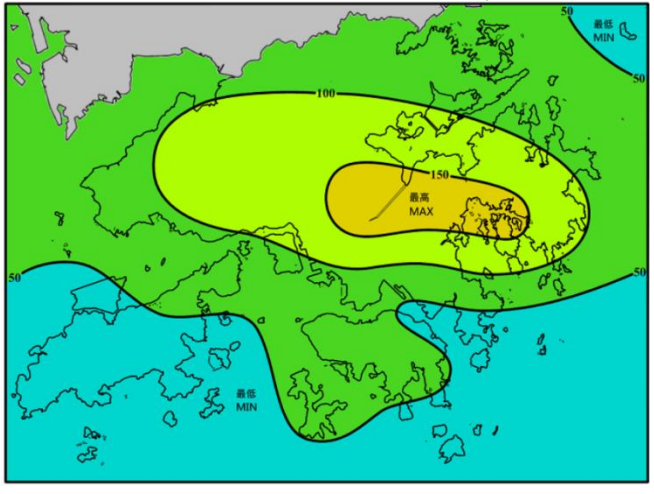
https://www.hko.gov.hk/sc/wxinfo/pastwx/mws2016/mws201605.htm

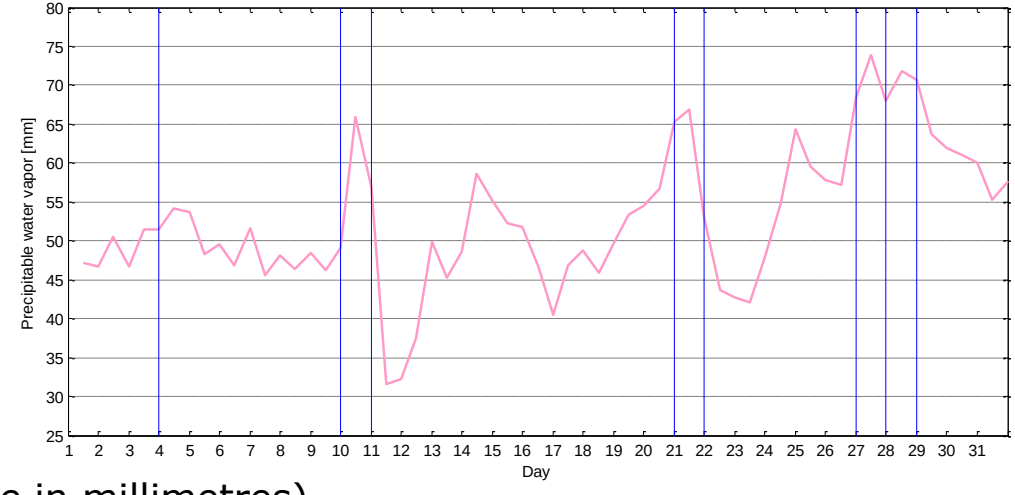
Monitoring a rainfall process in Hong Kong



GNSS **PWV**

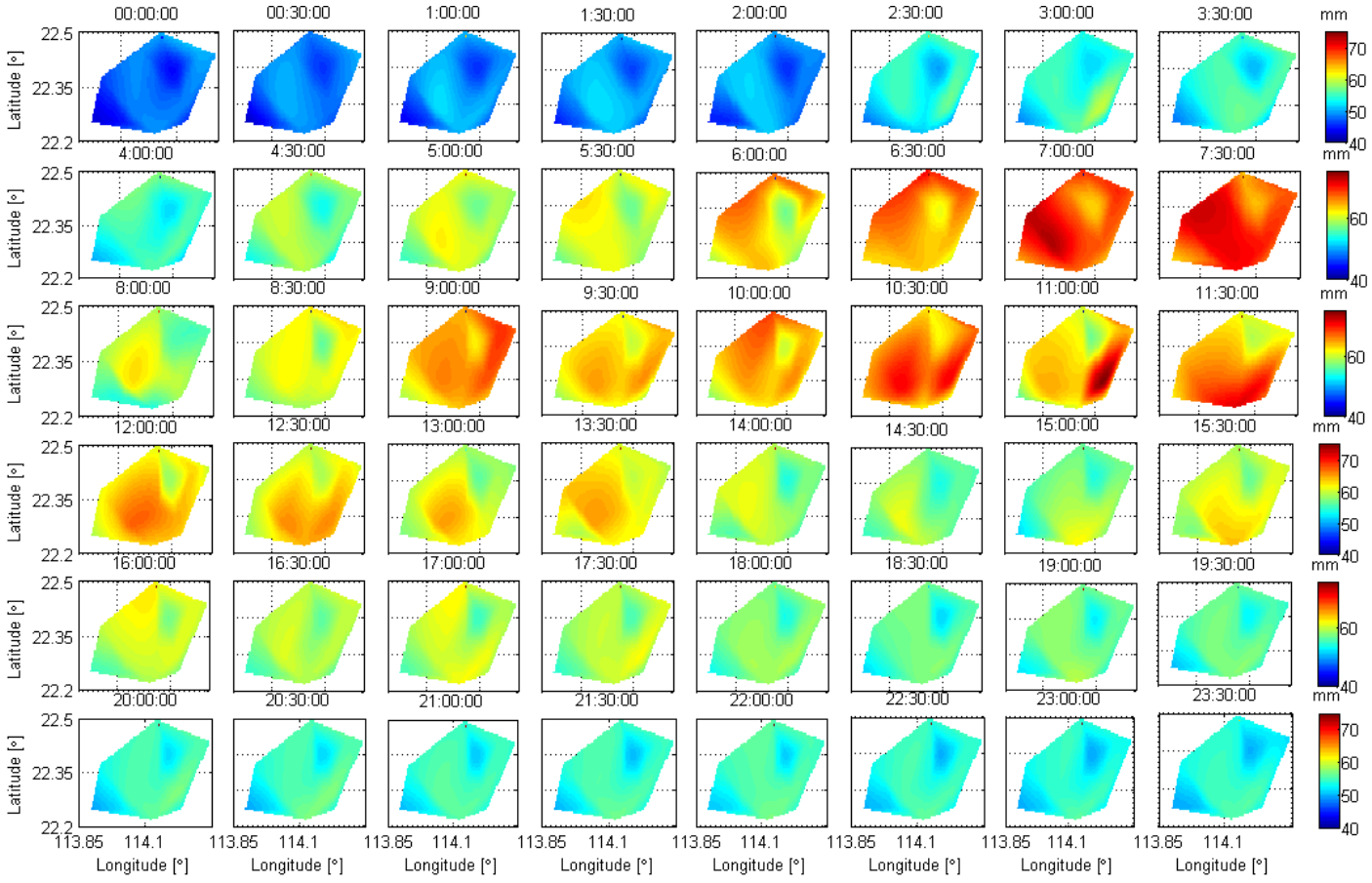
Rainfall Map | Radiosonde **PWV**





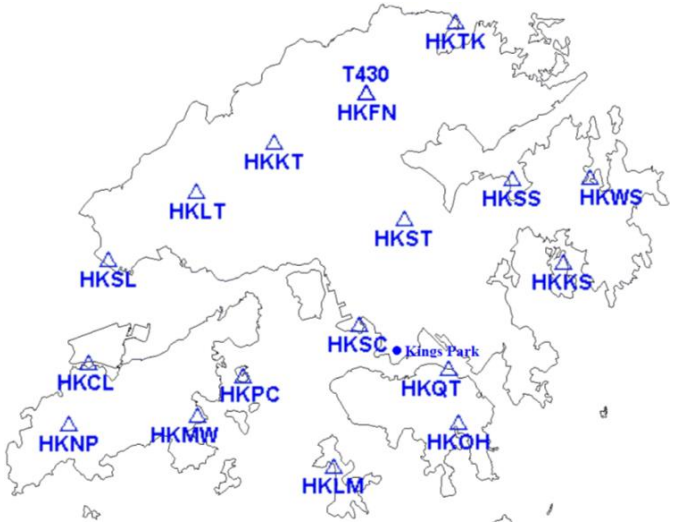
Rainfall Map for 10 May 2016 (isohyets are in millimetres)

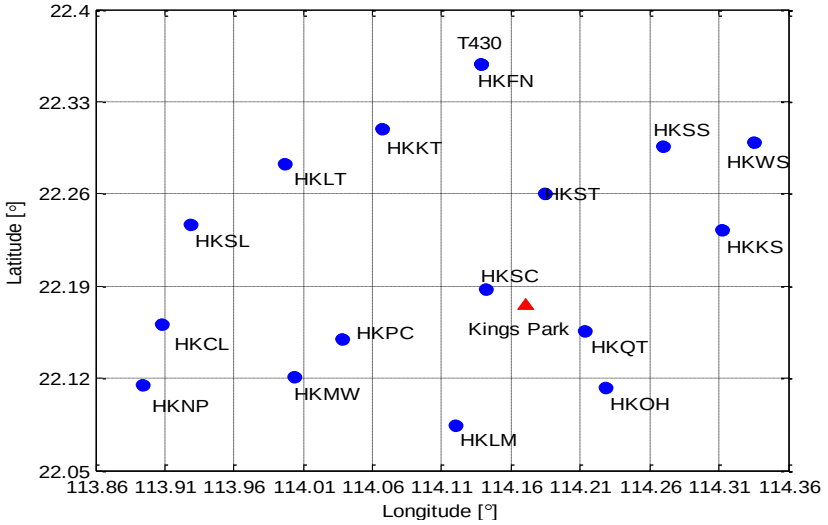
Monitoring a rainfall process in Hong Kong



Hong Kong Regional **PWVs** in 10th May, 2016

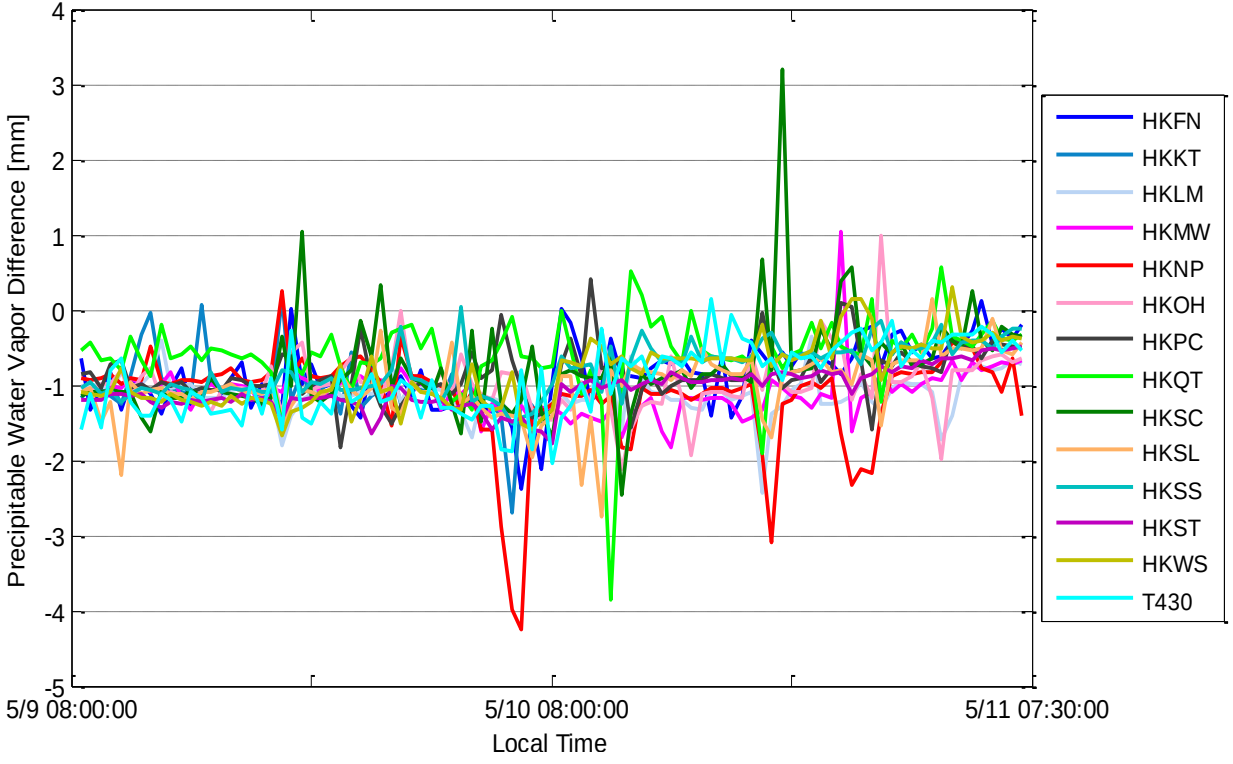
Monitoring a rainfall process in Hong Kong





- **TWV** : spatio-temporal water vapor with tomography technique
- **Longitude**: 113.86~114.36°E, resolution of 0.05°
- **Latitude** : 22.05~22.40°N, resolution of 0.07°
- **Height** : 400, 800, 1200, 1600, 2000, 2500, 3000, 3500, 4000, 4600, 5200, 5800, 6500, 7500 and 8500 m，in total 15 layers
- **Time** : resolution of 30 min

Monitoring a rainfall process in Hong Kong

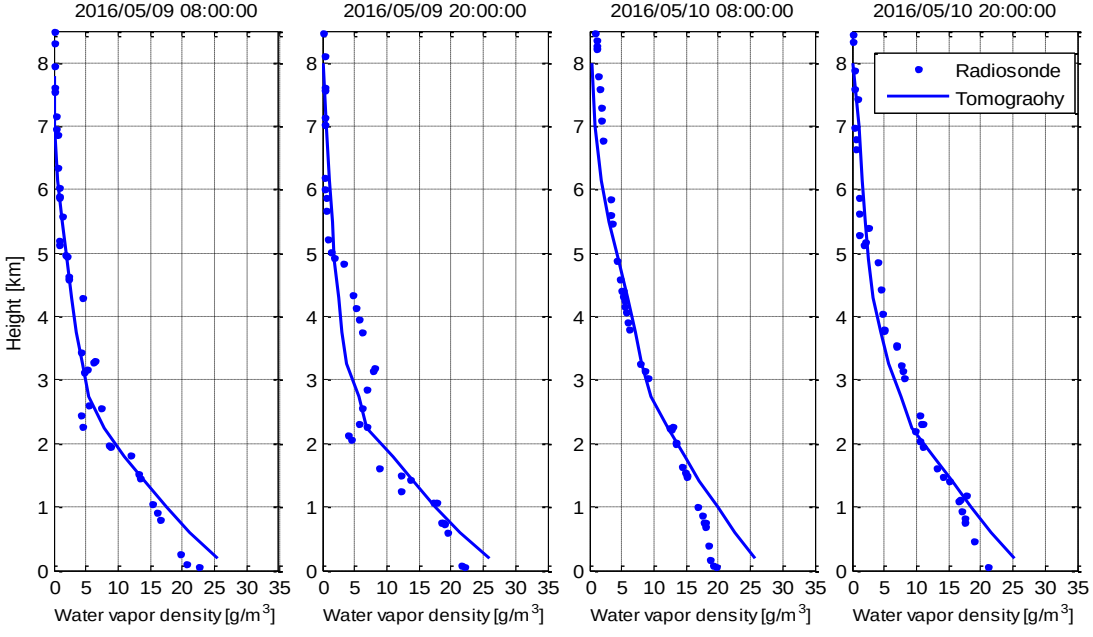


The difference between GNSS **PWVs** and TWV re-calculated **PWVs**

Monitoring a rainfall process in Hong Kong

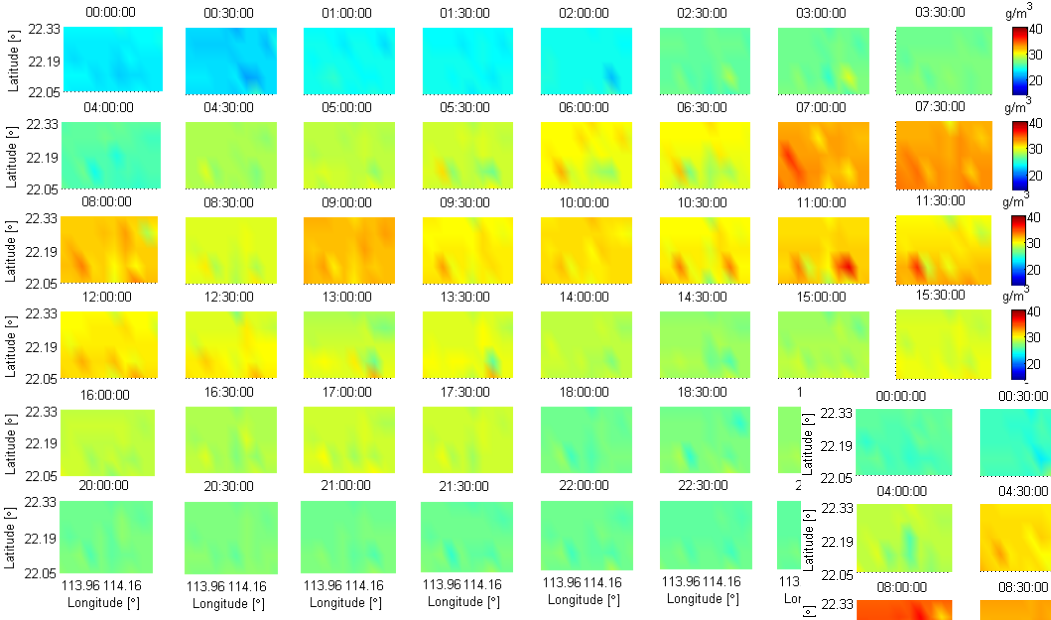
The **PWVs** above the radiosonde station Kings Park [mm]

	05/09 08:00:00	05/09 20:00:00	05/10 08:00:00	05/10 20:00:00
TWV re-calculated	47.95	48.15	66.21	55.30
Radiosonde	46.25	49.16	65.86	56.87



The water vapor profile above Kings Park

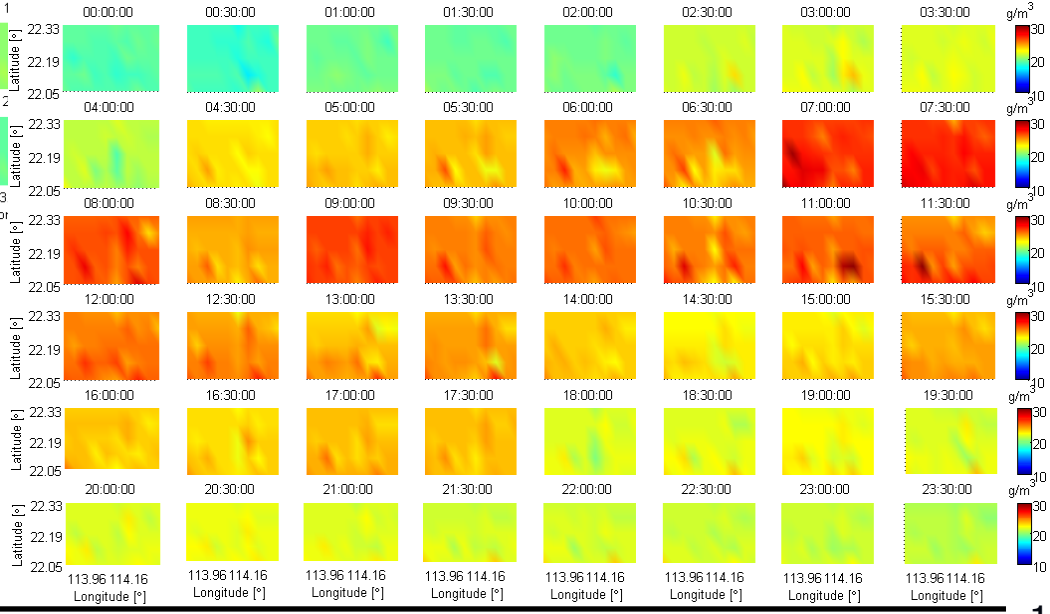
Monitoring a rainfall process in Hong Kong



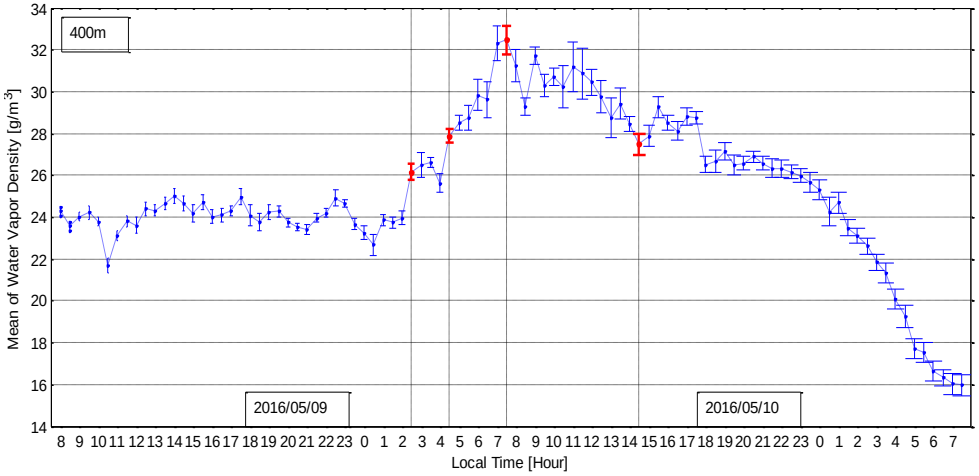
spatio-temporal water vapor density in 10th May, 2016

below 400 m

between 400 and 800 m

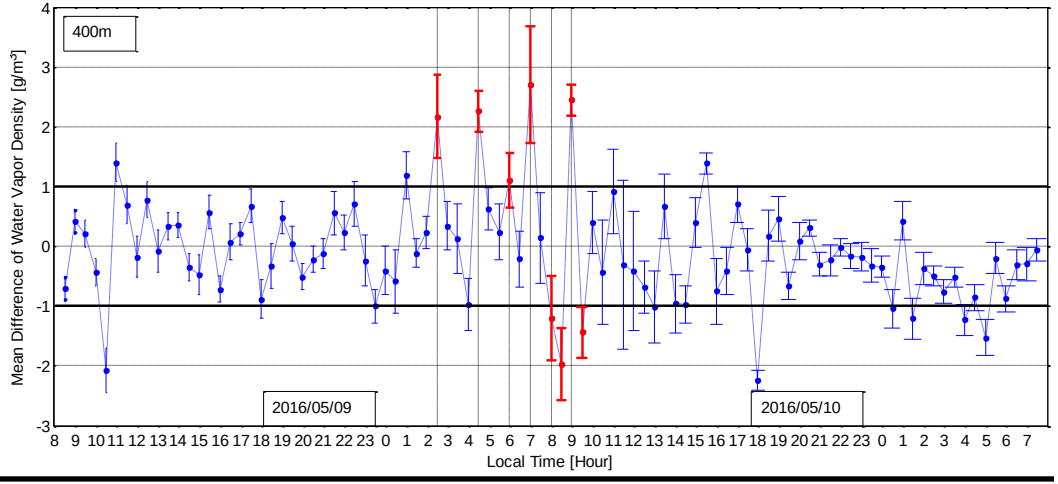


Monitoring a rainfall process in Hong Kong

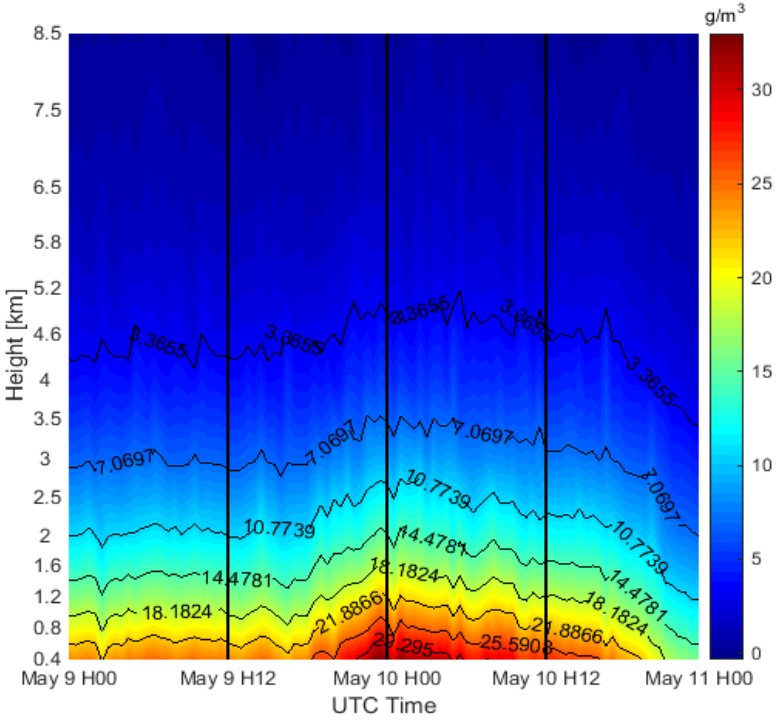


The mean value of water vapor density below 400 m

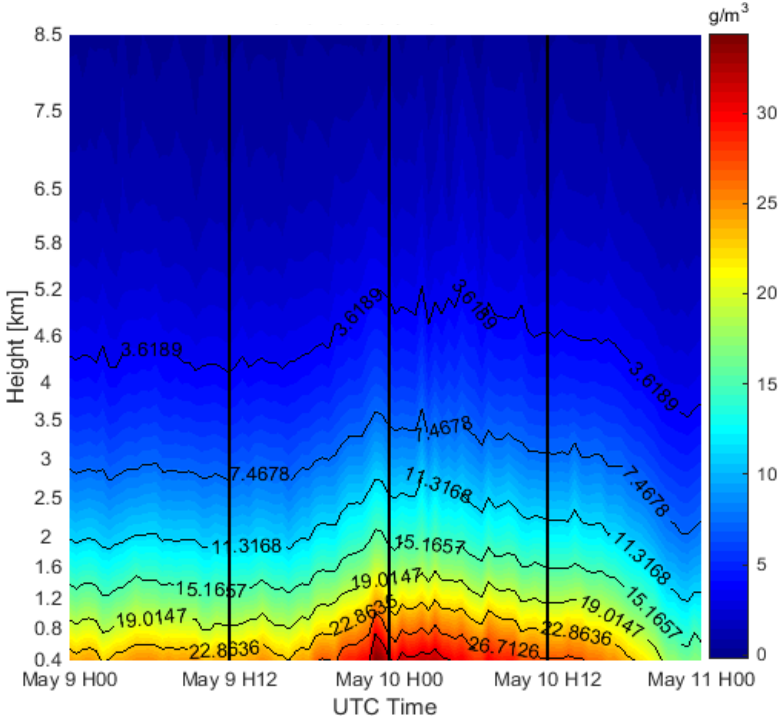
the variations



Monitoring a rainfall process in Hong Kong



The time-varying water vapor profile above HKST



The time-varying water vapor profile above HKNP

Conclusions

- Hong Kong Satellite Positioning Reference Station Network (SatRef)
- GNSS retrieved tropospheric delay ($\Delta\rho^{Z}_{r,wet}$, etc.)
- GNSS retrieved spatio-temporal distributed water vapor (PWV, TWV, etc.)
- Initial results about monitoring a rainfall process with GNSS water vapor

- GNSS retrieved PWVs and radiosonde PWVs are in good agreement
- Internal and external (radiosonde) check of TWVs are of good performance
- Spatio-temporal PWVs and TWVs are useful to monitor a rainfall process
- There's **still** a lot of work to be done in a lot of places

Thanks for your attention!

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