GNSS+ Tropospheric Sounding for Weather and Climate – An Australian Perspective

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Introduction

GNSS atmospheric sounding is an international hotspot primarily due to the rapid development of critical geospatial infrastructure (both ground-based and space-borne), and relevant algorithms and new methodologies. The fusion/integration of sensors and systems including those space-/air-/ground-based has heralded a new era of GNSS innovation.

This contribution introduces our 10-years effort and major achievements in the area of GNSS tropospheric sounding in a retrospective manner. The first Australian near real-time water vapour processing platform is established and various tests, in particular, monitoring and forecasting of severe weather and nowcasting using multi-sensor technologies are carried out which can be effectively used for investigating the spatio-temporal variability of the troposphere.

As a result of our research collaboration with the Australian Bureau of Meteorology (BoM), the radio occultation technique has been officially used in the operational Australian weather forecasting model since late 2011 and 10 hours improvement in the predictability of weather has been achieved.

Our current effort and future plan in the area of GNSS+ for weather and climate through water vapour detection is outlined. This includes the technologies, the algorithmic development and innovation.

The Australian Case Study

The March 2010 storm was used as a case study in our research. The following radar images show the development of storms whose characteristics are: (1) 10 severe multicell storm events over a period of 9 hours; (2) $500m damage in lost properties reported; (3) ~100 GNSS stations were operational in Victoria at the time which produced 1h resolution ZTD and IWV values.

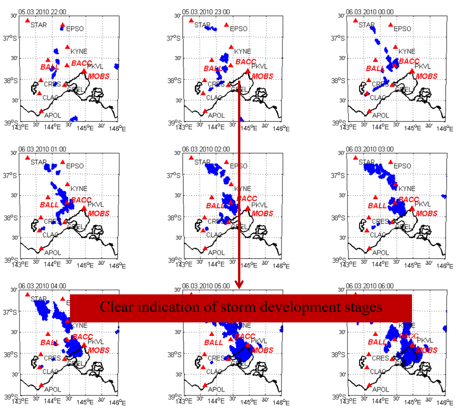


Fig 1. 9 hours storm activity in the Melbourne area, red triangles GNSS stations, blue colour marking outline of the radar image (Melbourne Airport, BALL, BACC, MOBS stations selected)

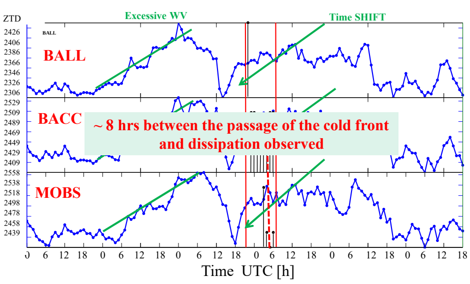


Fig 2. ZTD observed by CORS stations during the Melbourne storm, the storm occurred at 4am (UTC) on 6 March (2pm Melbourne time), and ~ 8 hrs between the passage of the cold front and dissipation observed

Figure 2 presents the changes of the ZTD prior to, during and post the severe Melbourne storms. An 8-hour gap between the passage of the cold front and dissipation was clearly shown. The correlation between the GPS-derived PWV and the rainfall measurements is shown in Figure 3 below (Choy et al, 2015).

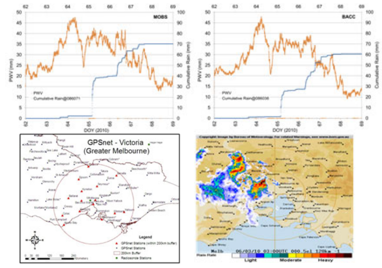


Fig 3. Correlation between the GPS-derived precipitable WV and the rainfall recorded (Choy et al, 2013)

GNSS RO for Australian NWP

Radio Occultation (RO) has been intensively studies and was successfully incorporated into the Australian operational weather forecasting services by BoM as a new data source in 2011 – via the Australian Community Climate and Earth-System Simulator (ACCESS) Numerical Weather Prediction (NWP) mode. Ten hours improvement has been demonstrated and as a result the team was awarded the Excellence in Innovation for Australia 2012 and the finalist of the Australian innovation challenge award. The figure below shows a simplified GNSS RO data processing scheme.

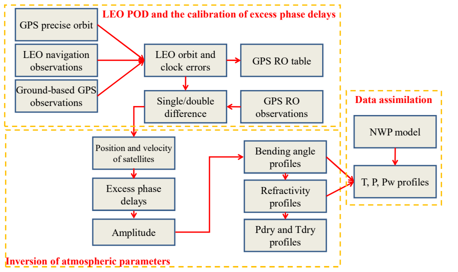
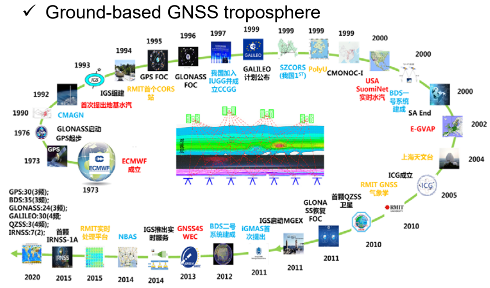


Fig 4. A simplified RO data processing system and assimilated into the Australian ACCESS NWP model

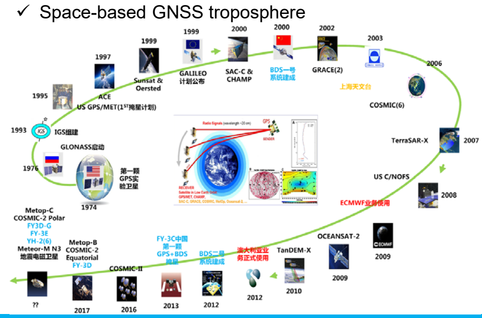
Major Milestones for GNSS Troposphere

The following two figures present major milestone achievements of both ground-based and space-borne GNSS tropospheric sounding technology.

✓ Ground-based GNSS troposphere



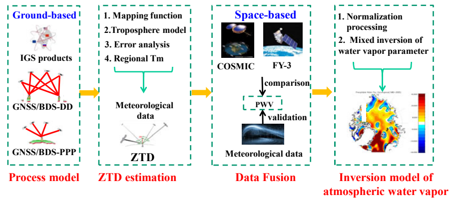
✓ Space-based GNSS troposphere



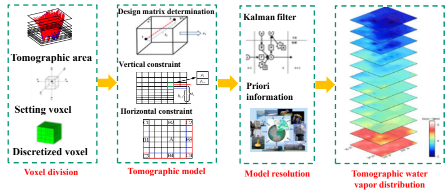
Prospective

Recognising the unprecedented interest of the GNSS atmospheric sounding and the need to data mine the important information in the long-term GNSS data accumulated. The following is schematic aims of our future research effort, in particular, applying artificial intelligence and machine learning in the data analysis and mining.

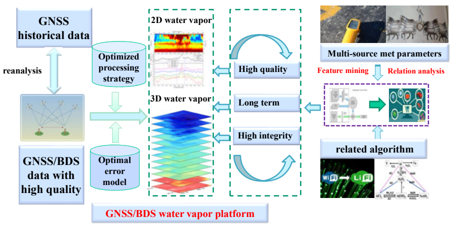
- GNSS+ multi-source water vapor co-detection and inversion theory (single- to multi-GNSS, space-/air-/ground-based data, post-processed to real time, …)



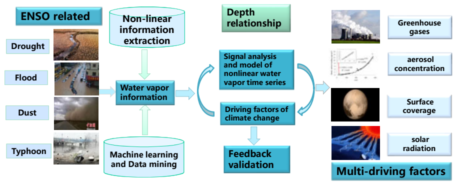
- Real time four-dimensional reconstruction of atmospheric water vapor information (data fusion and tomography techniques)



- Relationship between WV variation and extreme weather events (mechanism, characteristics, relationship etc)



- Reanalysis of long term data, feature extraction, data mining/ data analytics, artificial intelligence (AI), determination and prediction of climate change



Summary

GNSS atmospheric sounding has been our focus of research since the early 2000s which involves a large range of ground-based, air-/space-borne platforms and multiple sensors. The research incudes both GNSS troposphere and ionosphere as well as GNSS reflectometry. Some major contributions of our research in this regards in the past ten years can be summarised as follows:

- The first Australian near real-time ZTD/PWV platform has been developed at RMIT SPACE in collaboration with the Australian Bureau of Meteorology. It has operated since 2015 with ~156 GNSS CORS stations and provided much better results than the threshold requirements of EGVAP definition (0.06mm, 6.3mm) and better than 1 kg/m^2 IWV accuracy achieved;
- The atmospheric modelling research was initially for improving positioning/tracking as a primary goal and extended into a range atmospheric research;
- Exciting research in GNSS RO led to the operational usages in Australian weather forecasting (ACCESS model) and ~10 hrs improvement was achieved;
- The effort was later on extended into atmospheric density modeling for space tracking and LEO satellite orbit determination (+ space weather studies);
- Our current effort is to further extend the above work and moving into both atmospheric for severe weather and climate change (e.g. ENSO) and atmospheric for space weather, scintillation and ionosphere irregularities.

Our research outcomes have been reported in various journal publications (RSE, GRL, JGR, ASR, GPS Solutions, J of Geodesy etc.)