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Recent quest for GNSS severe weather and NWP using the state of the art Australian national GNSS positioning infrastructure

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4. *The University of Melbourne, Australia*

2010 Severe storm Melbourne

5-6 March 2010 storms

Heavy rains

Flash flooding
Large hails

>$500m damage
>250 homes inundated

Disruption to transport services

Horse race and footy match cancelled

Docklands Stadium roof collapsed

Motivation (1)

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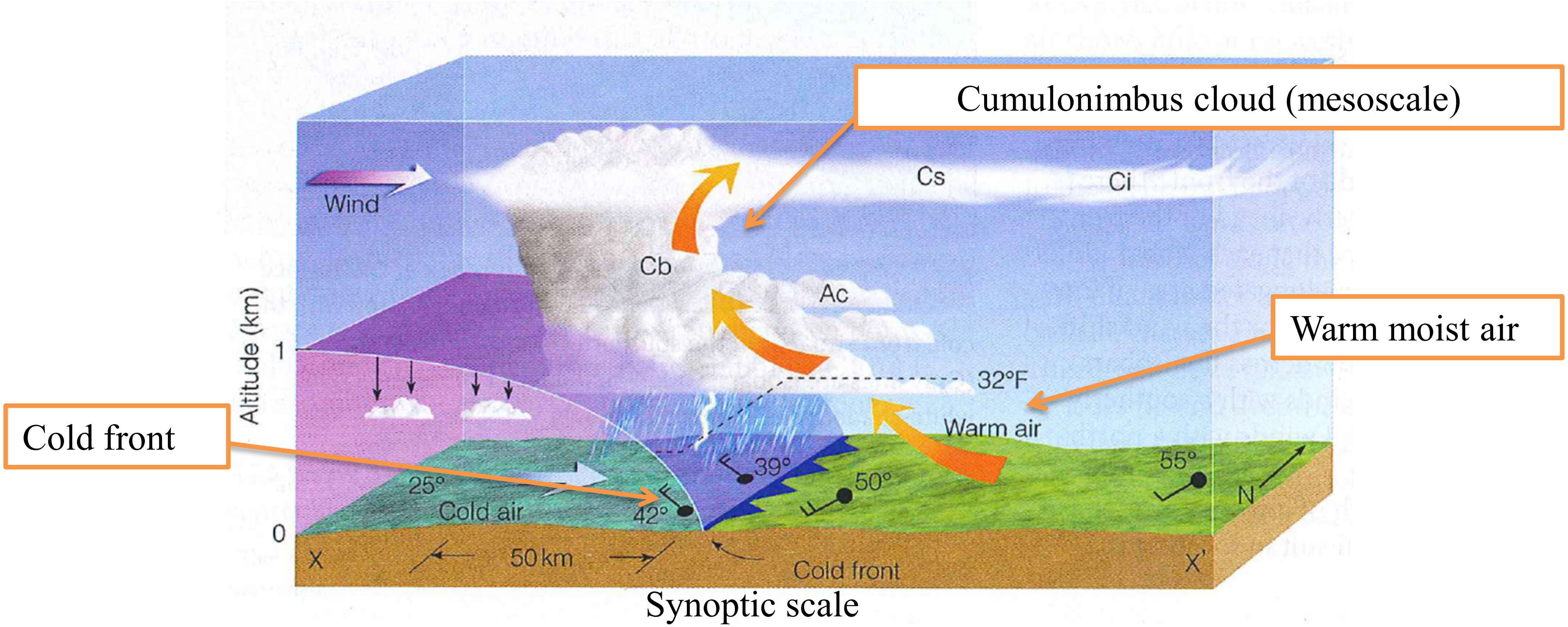
- Severe weather events (SWE) are closely linked with water vapour (WV) contents and troposphere conditions
- The amount of WV is a key factor in the formation of severe storms
- The structure and dynamics of the SWE phenomena should be "sensed/detected" by GNSS signals



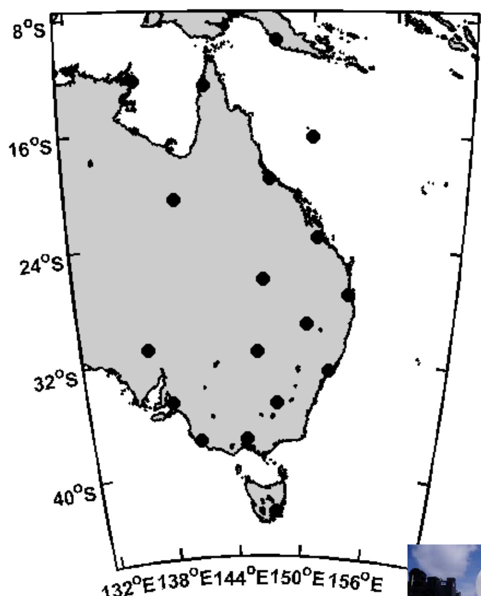
Synoptic scale

Formation of storms on the edge of cold front (Ahrens and Samson, 2011)

Motivation (2)

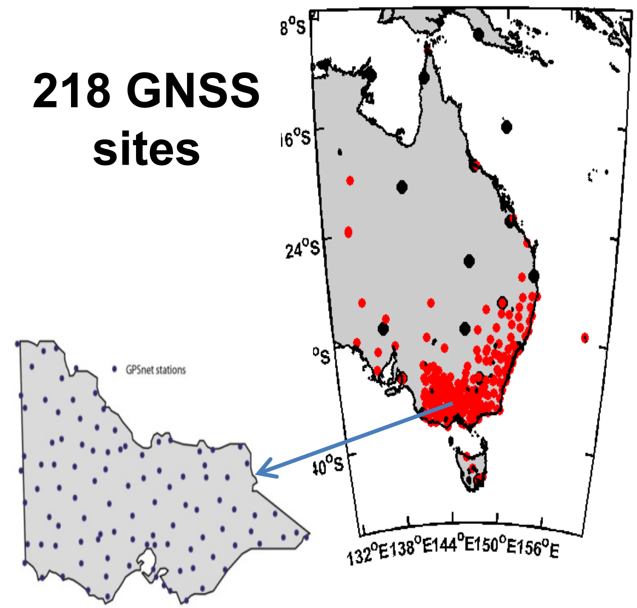
- **Existing meteorolical technologies - limited number of reliable meteorological WV sensors**

14 Radiosondes



WV radiometer

218 GNSS sites



- **A large number of reliable, high frequency and high density WV GNSS NPI observations ->ZTD or IWV**

Australian Positioning Infrastructure (NPI)

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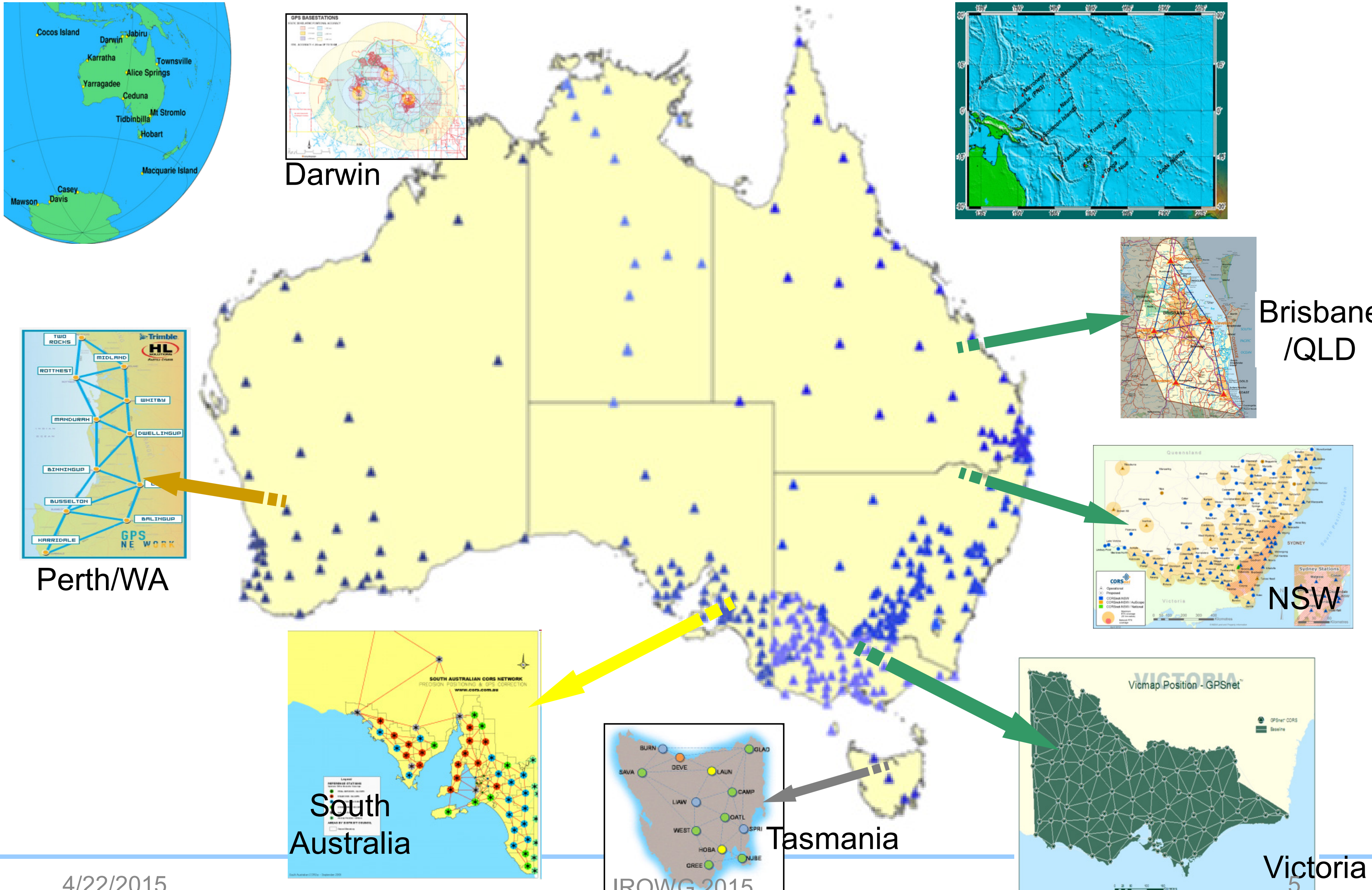

Multi-GNSS – Australia is in the “hot spot”

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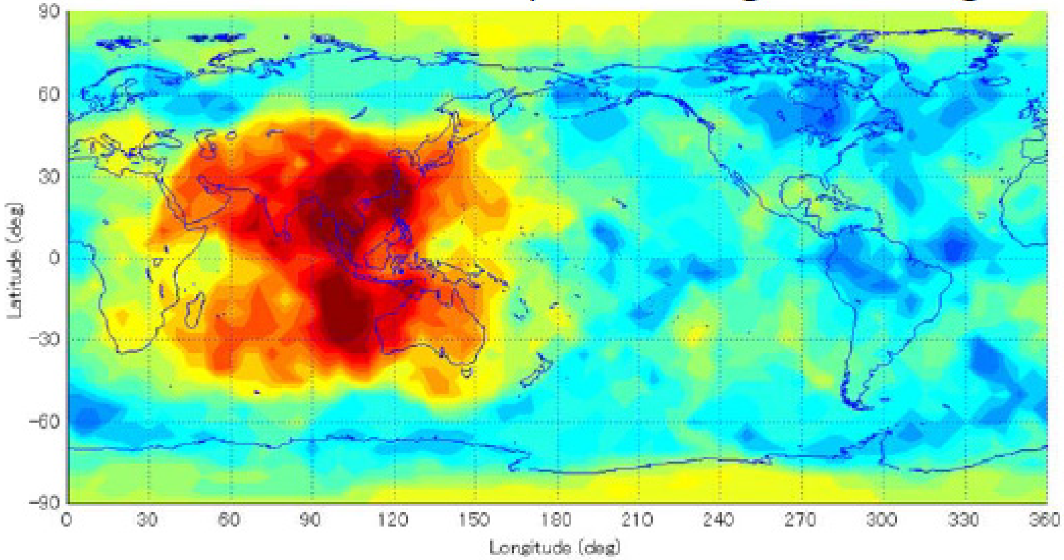
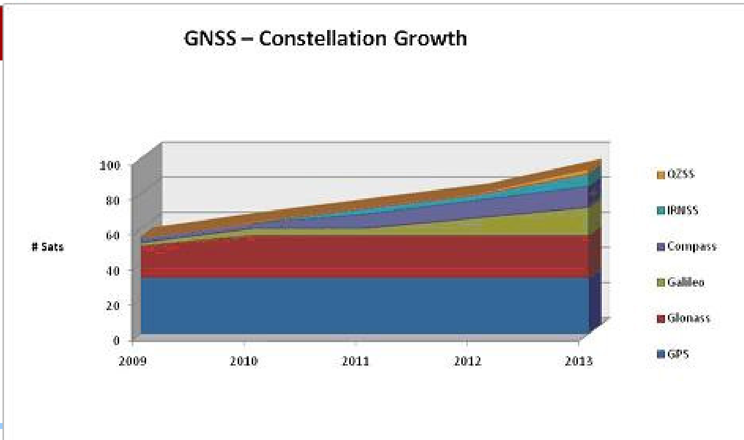
Visible satellite number (mask angle 30 degrees)



By 2020, Australia is projected to be in the GNSS “**hot-spot**” with access to **35** GNSS satellites and **7+** constellations at any time

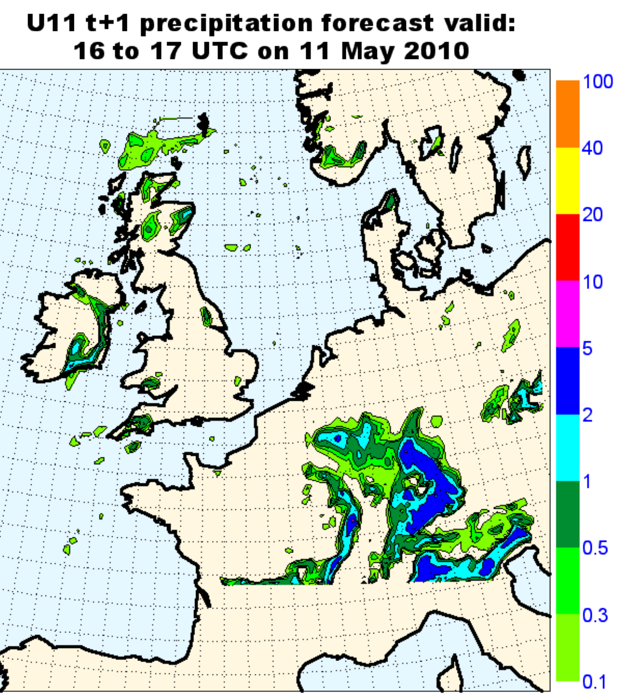
GPS(27)+Glonass(24)+Galileo(30)+COMPASS(35)+IRNSS(7)+QZSS(3)+SBAS(7)



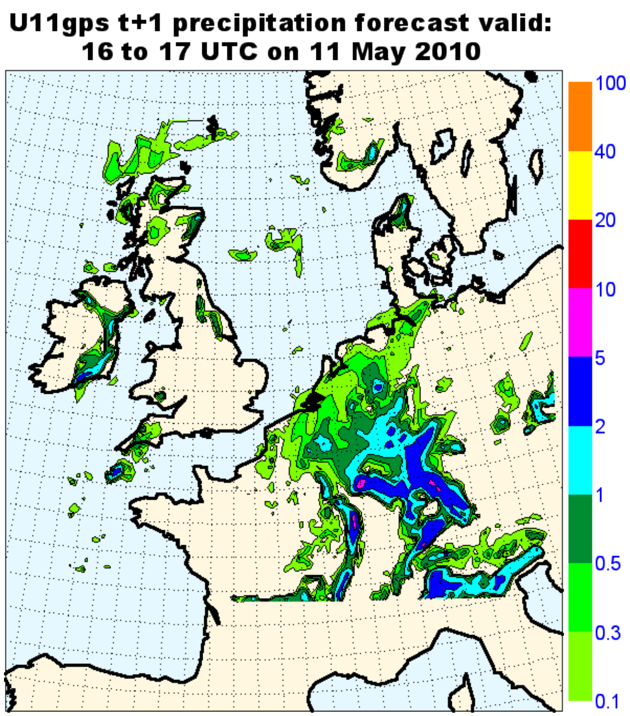
Source: Australian Space Policy Unit

Assimilation in NWP Models

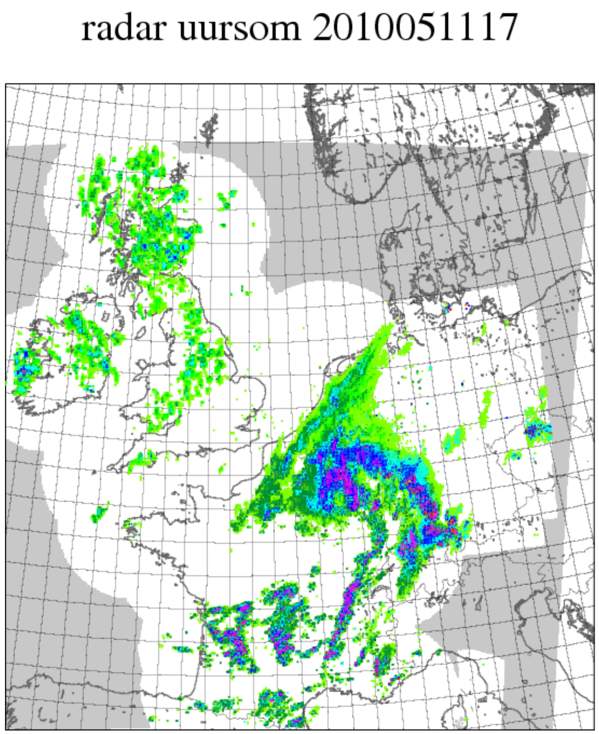
- Dense CORS networks processed in Near Real Time (~45 min latency)
- Stable, high quality ZTD (zenith total delay) and integrated WV (IWV)
- Reported to improve the rainfall and humidity prediction
- Used operationally in Meteo France, KNMI, tested at MetOffice



Forecasting without GPS



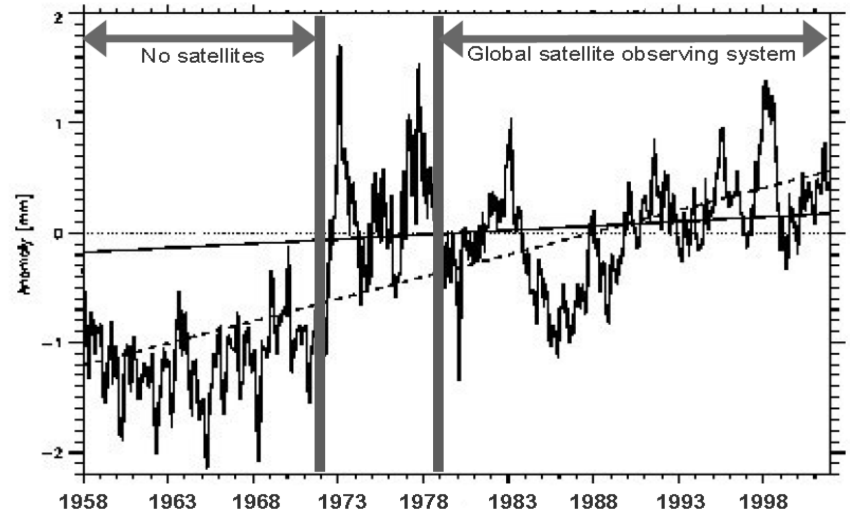
Forecasting with GPS
(courtesy Siebren de Haan KNMI)



Radar composite

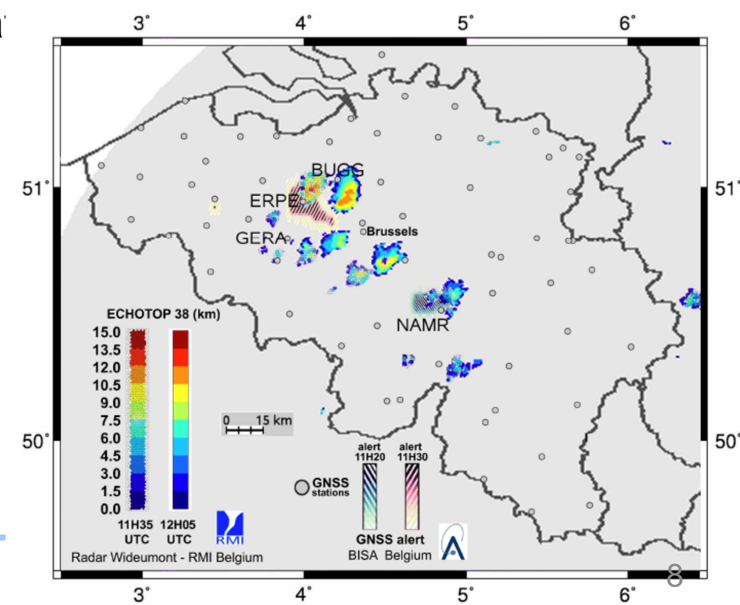
Ground-based GNSS

✓**Climate change monitoring**
- Instrumental bias free, self-calibration, long-term stability,
- observation characteristics are consistent across geographical regions and at all times,
- All-weather conditions



Stendel (2006), Monitoring Climate Variability and Change by Means of GNSS Da

✓**Nowcasting**
- Current and 0-6 hours ahead weather forecast



Brenot et al.(2012), Preliminary signs of the initiation of deep convection by GNSS

The NDRG project

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- **NDRG – Natural Disaster Resilience Grant**
  - Funded by the Commonwealth Attorney-General's Department under the Australian National Partnership Agreement on Natural Disaster Resilience signed by Prime Minister and state Premier of Victoria.
  - Under the Agreement, Victoria develops an Implementation Plan, for approval by the Commonwealth Minister for Justice.
- **Partnership**
  - RMIT University, Bureau of Meteorology, Department of Environment and Primary Industries (DEPI), Univ of Melbourne, CRC-SI, Met Office/UK
  - Valued at ~$590k for ~2 years
- **Aims/objectives**
  - Develop a smart GPS-based WV estimation system for disaster management users to reduce the risks/impact of natural weather disaster events
  - Assimilated to the Australian Community Climate and Earth-System Simulator (ACCESS) model.
- **Complementary to the EU COST Action project**
  - Advanced GNSS tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)

GNSS ZTD processing strategies (1)

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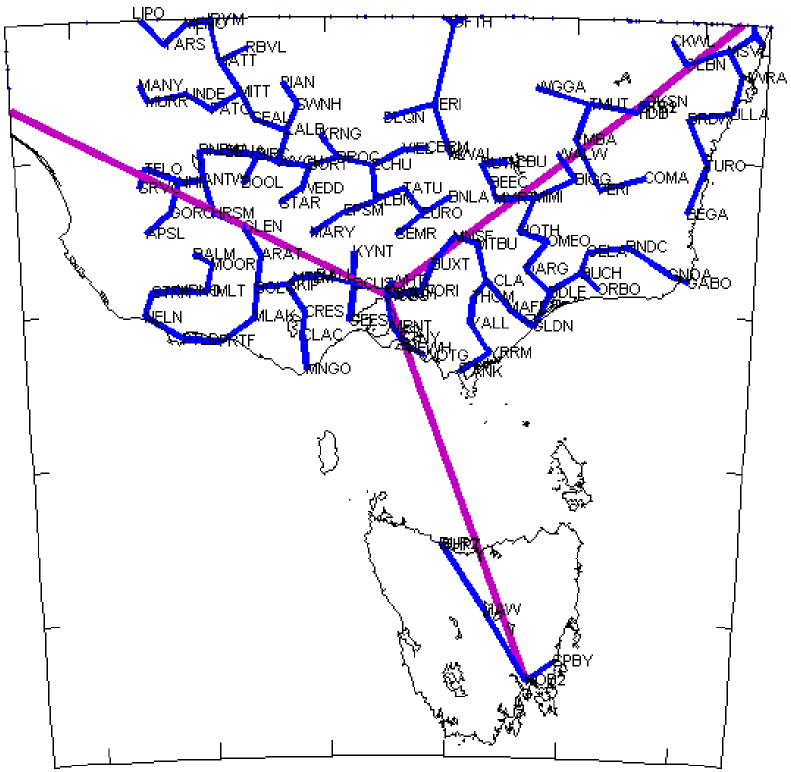
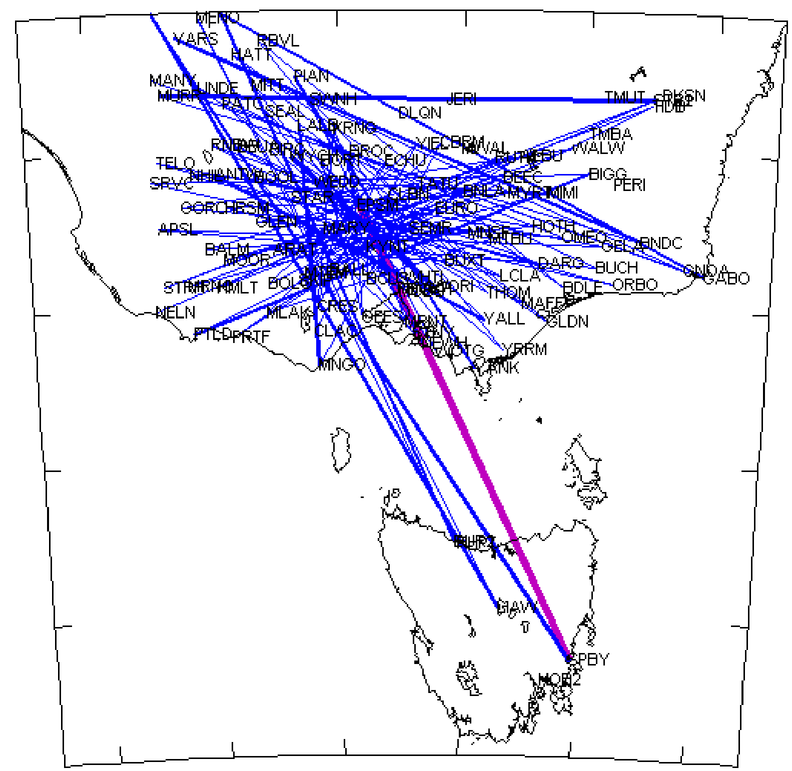
1. NETWORK SOLUTION SHORTEST

2. NETWORK SOLUTION LONGEST



Shortest BLN solution



longest BLN solution

GNSS ZTD processing strategies (2)

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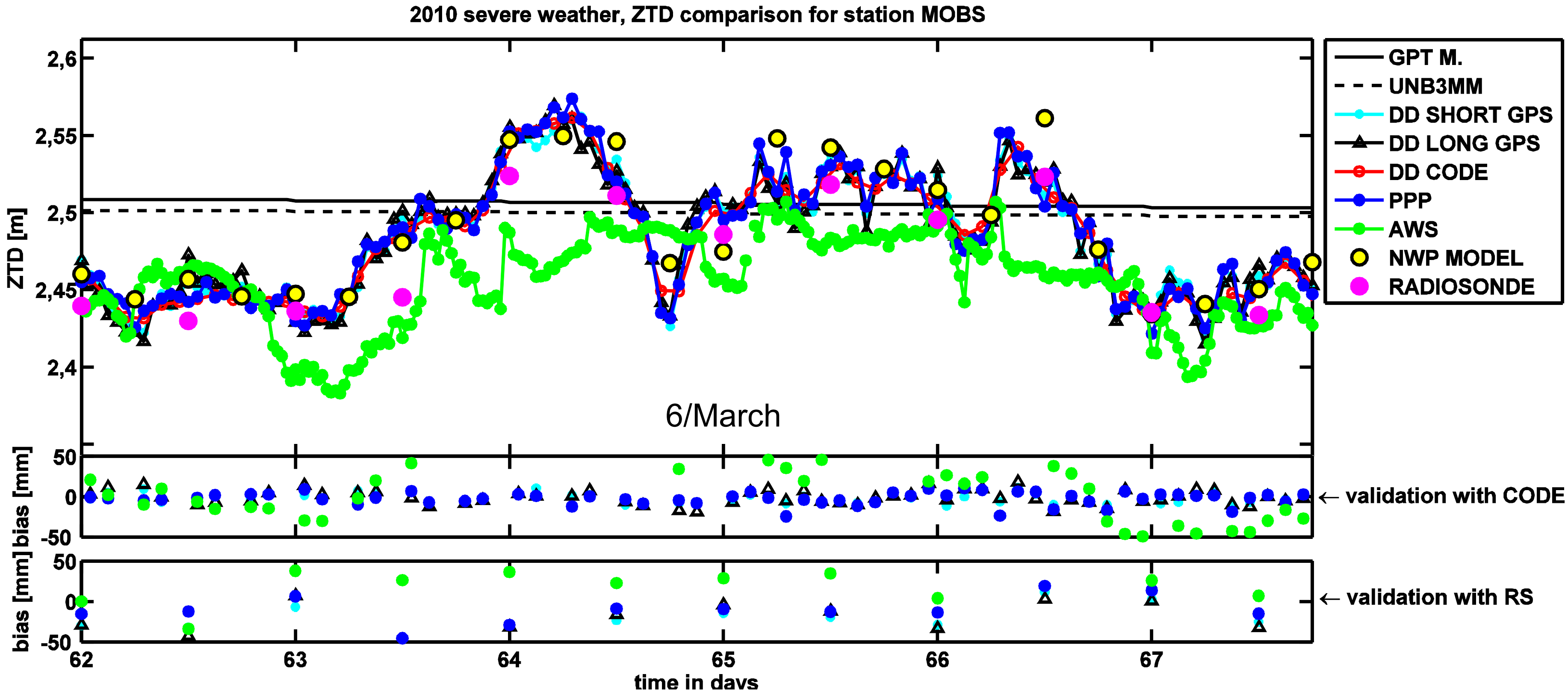

Scenario	Compared with CODE Final TRP solutions based on precise and predicted IGS products (mm)				Compared with radiosonde	
	Bias	Std	Bias	Std	Bias	std
SHORT	-0.6	9.0	-1.1	8.5	-15.2	9.1
LONG	-3.3	7.8	0.8	13.3	-12.2	12.2
PPP	-1.7	10.9	-3.5	15.4	-10.2	7.2

6 days radiosonde data used

Bias mostly due to the radiosonde dry bias

Yuan, Zhang et al (2014), JGR

Storm passage vs GNSS CORS

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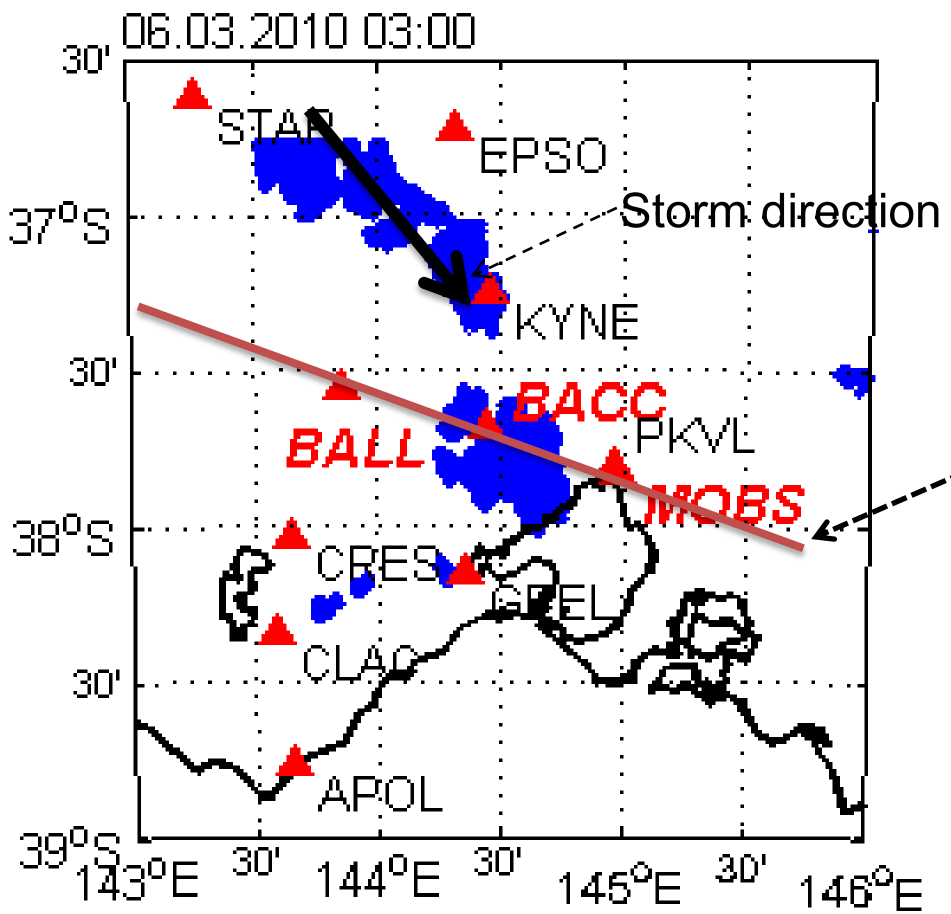
Storm passage from radar image over Victorian GPSnet CORS stations



Selected cross section

GNSS and storm passage detection

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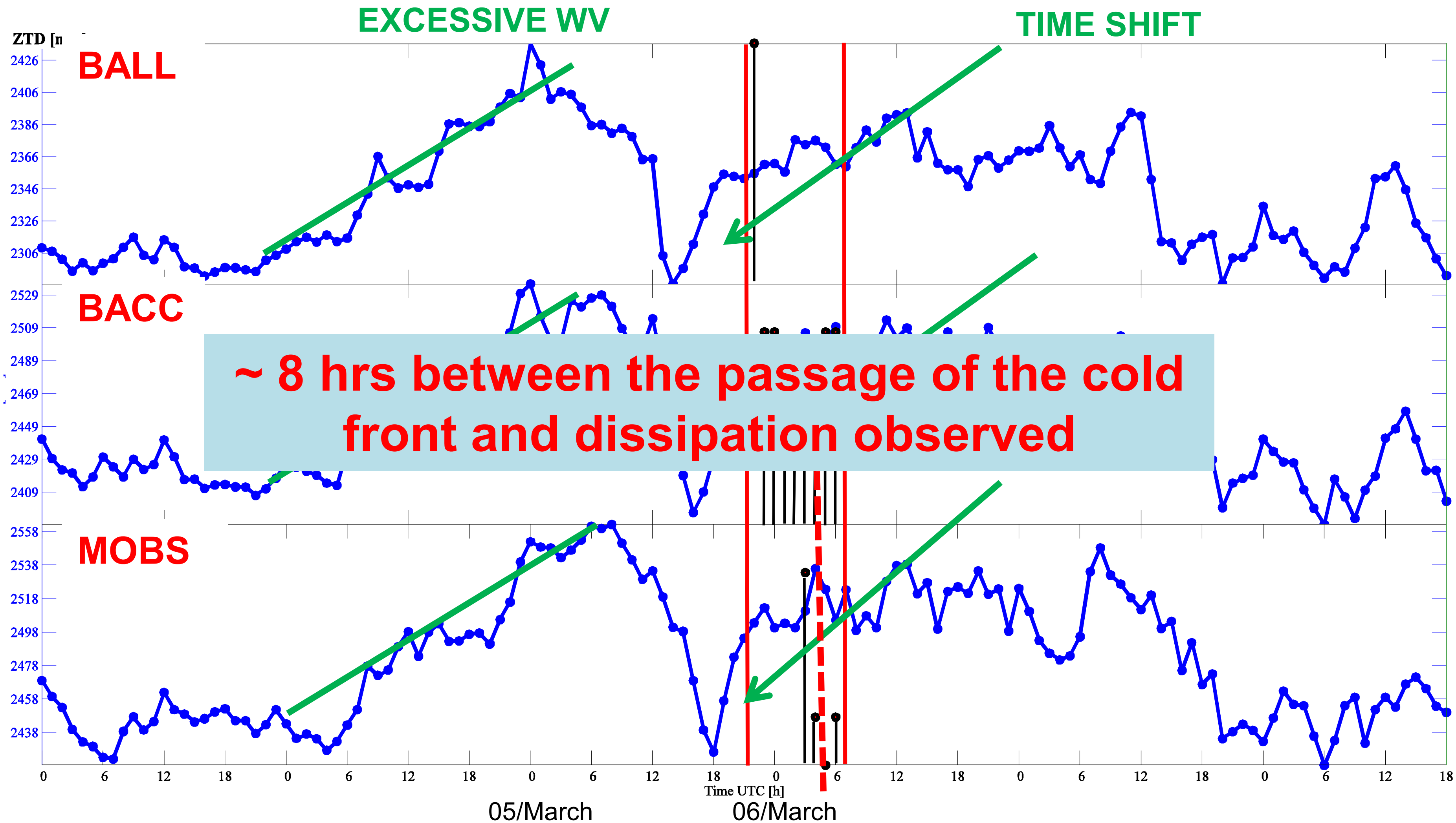
ZTD observed by CORS stations over Melbourne storm in 2010



The storm occurred at **4am** (UTC) on 6 March (2pm Melbourne time)

Correlation between PWV and rainfall

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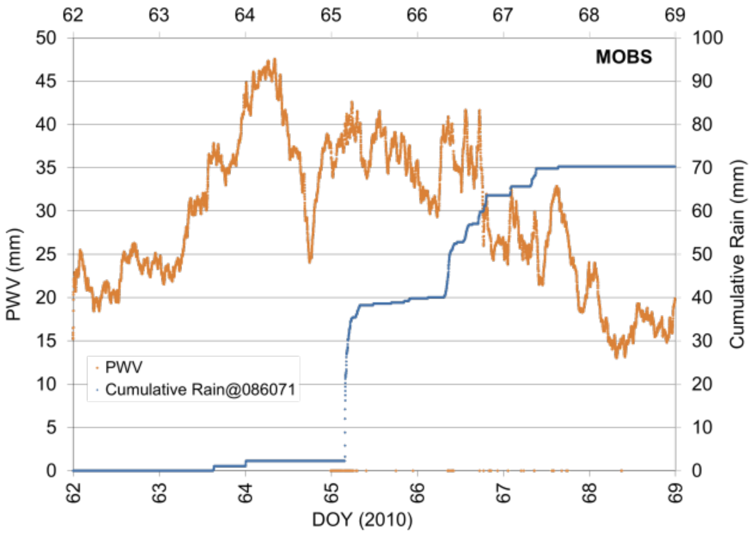
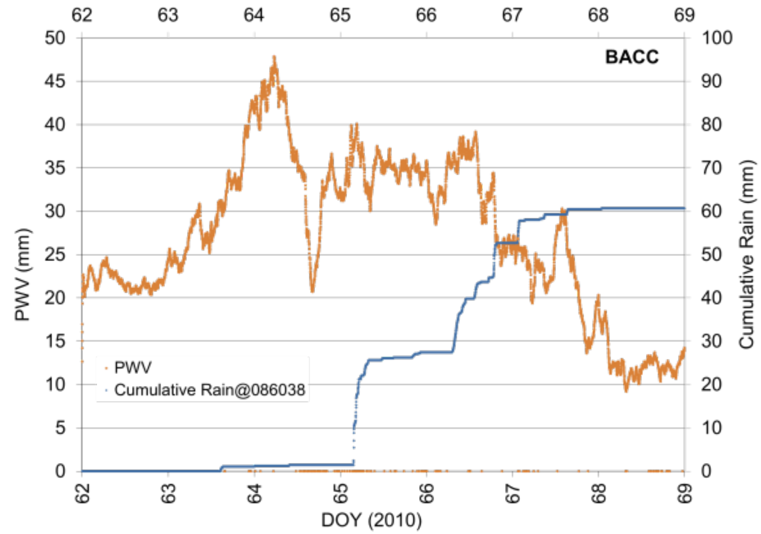
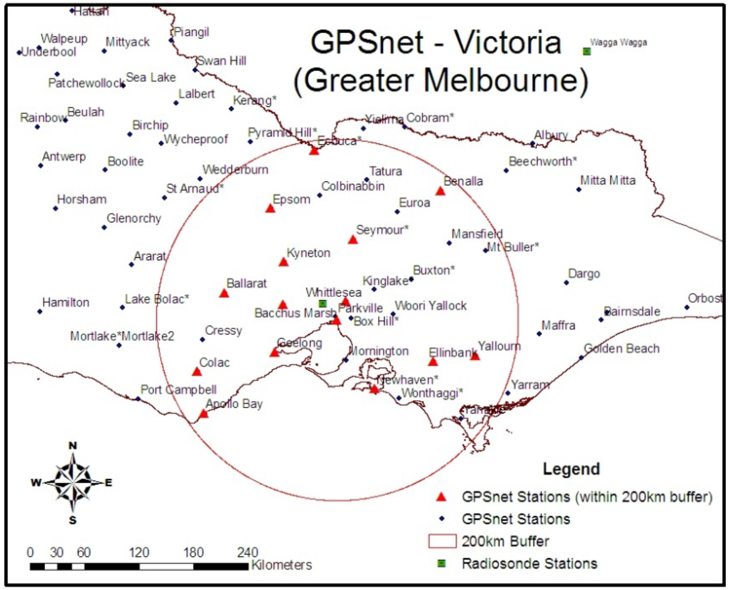
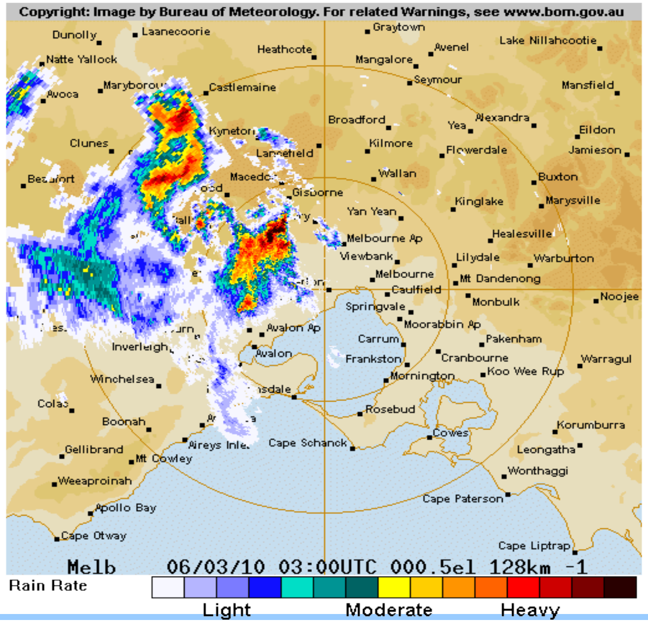




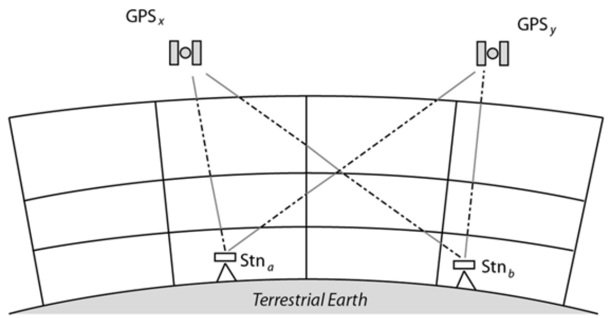


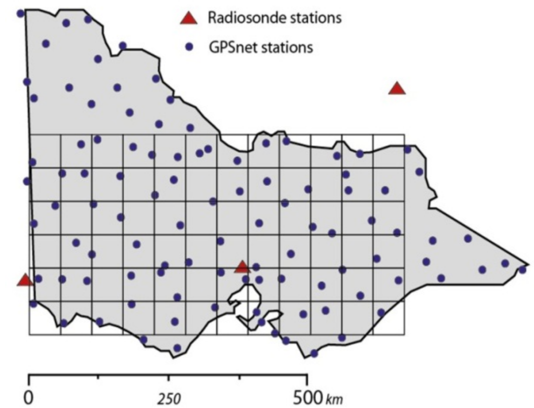


GNSS tomography technique

GNSS tomography (3D)

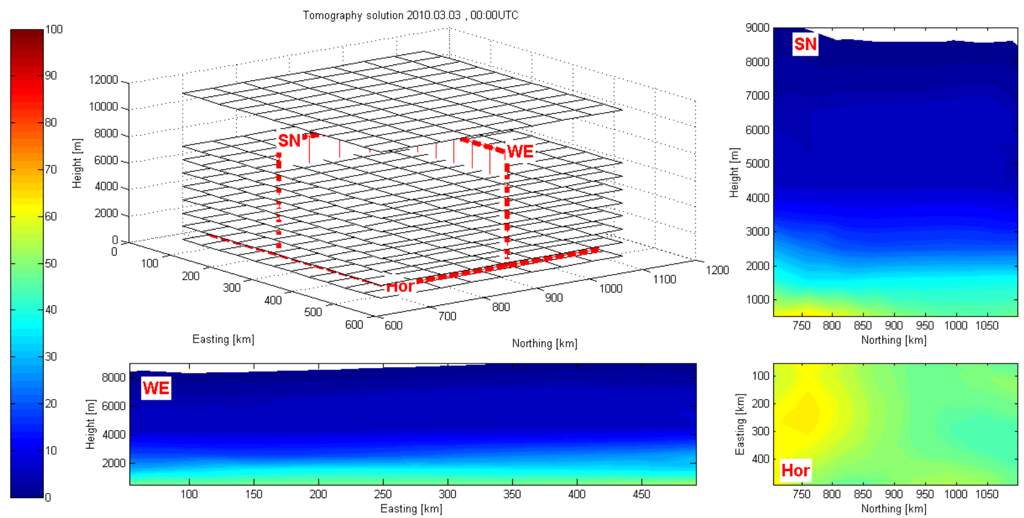
- Reconstruct dynamically changing 3D variability of troposphere
- Observations from difference aspects and orientations
- Related to wet refractivity ($\boldsymbol{N_{wet}}$) using:
- $\Delta^{SWD} = 10^{-6}\int_a^x N_{wet}\Delta s$
- Kalman filter for the forward processing





Matrix equation system

$$\begin{pmatrix} \Delta^{2,PD}{}^{x,y}_{a,b} \\ ZTD_p \\ N_{(\lambda,\phi,h)} \\ 0_i \end{pmatrix} = H \cdot \begin{pmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \\ \dots \end{pmatrix}$$



Signature of storms using GNSS tomo

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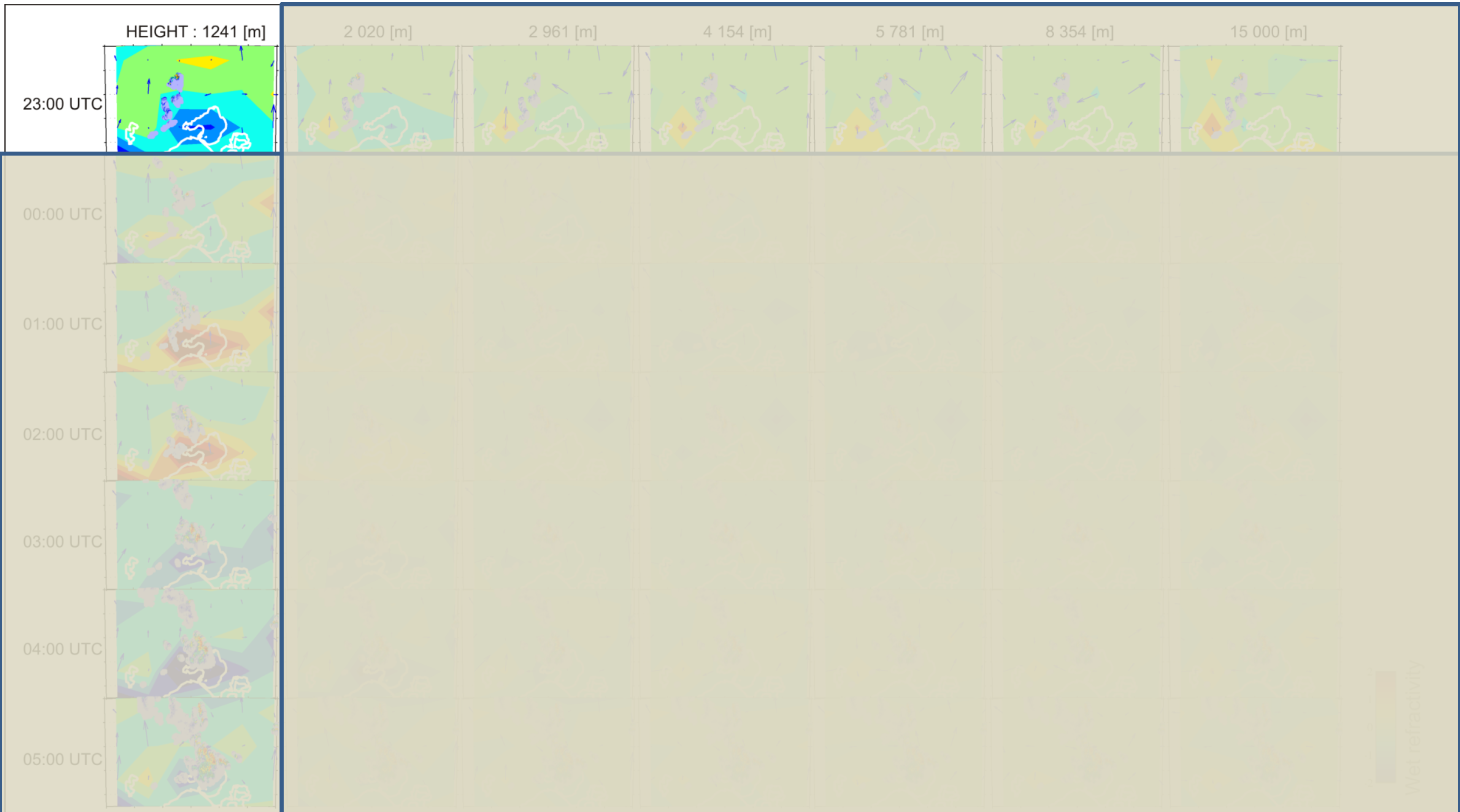

Tomography can capture the dynamics of the storm in horizontal and vertical direction

Multi-observational GPS tomography

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Case study: January 2011 Melbourne storms

✓ Additions to the observation model

		Additional observations		
Campaign 1	DD SWD			
Campaign 2	DD SWD	RS		
Campaign 3	DD SWD	Synoptic		
Campaign 4	DD SWD	GPS RO		
Campaign 5	DD SWD	RS	Synoptic	GPS RO

Multi-observational GPS Tomography

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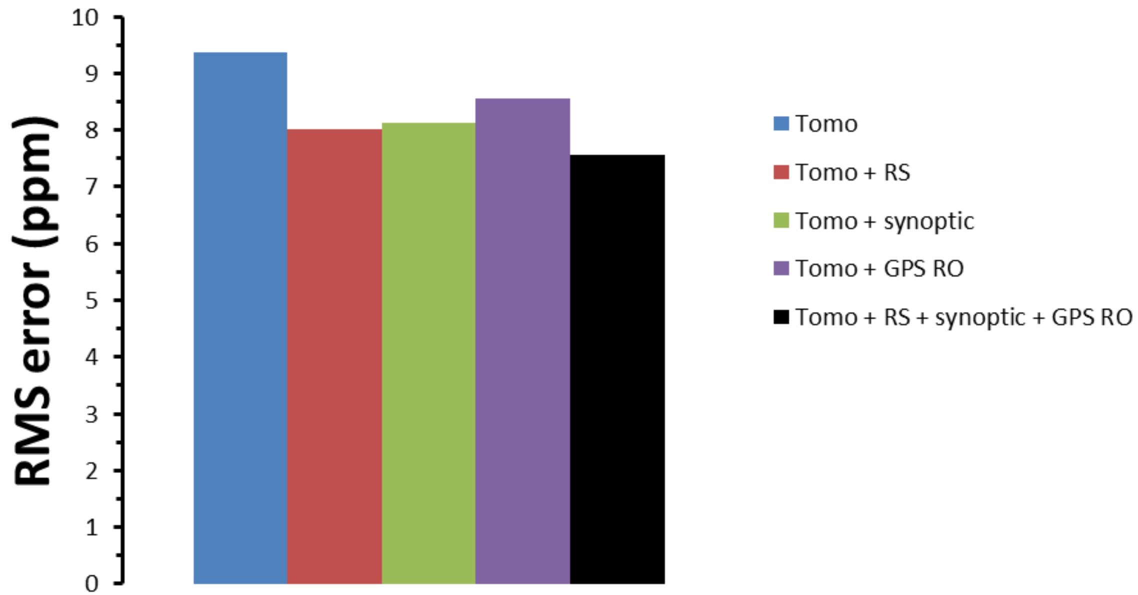
Preliminary results

✓ Overall RMS



✓ RMS prior and during storm

	Campaign	**RMS (ppm)** *Prior to storm* *1-8 Jan. 2011*	**RMS (ppm)** *Storm period* *9-15 Jan. 2011*
1.	Tomo	*10.319*	*8.470*
2.	Tomo + RS	*7.984*	*8.062*
3.	Tomo + Synoptic	*8.232*	*8.048*
4.	Tomo + GPS RO	*7.861*	*9.214*
5.	Tomo + RS + Synoptic + GPS RO	*7.960*	*7.206*

Manning T (2014), Zhang et al (IEEE JSTAR, 2015)

Current RMIT NRT system (1)

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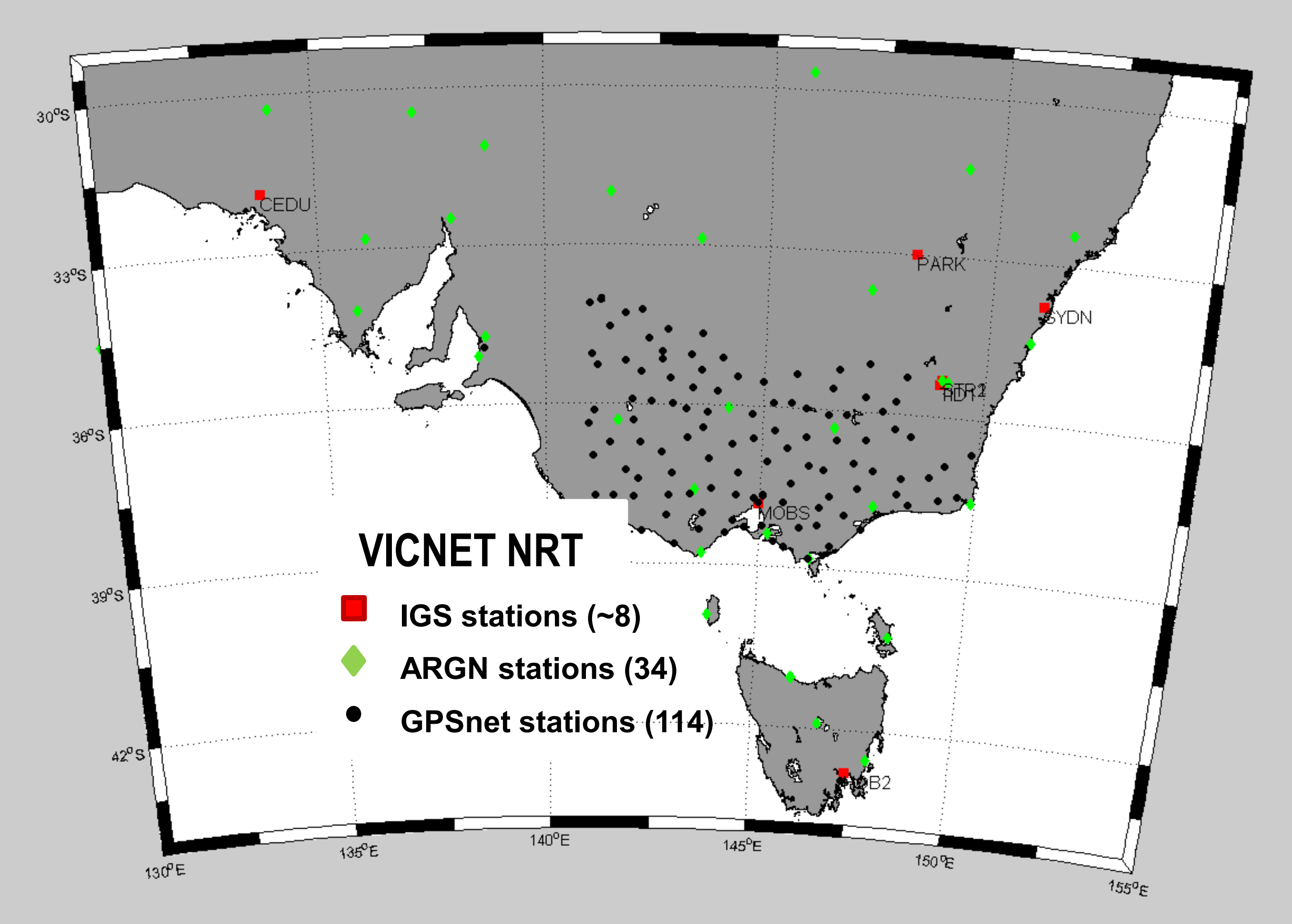

Real-time/near realtime data stream, upto 1Hz observations

Current NRT platform (2)

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- **Network DD Fixed solution**
  - Operational since 10/03/2015,
  - Estimation in 30 min interval,
  - Window length 6 hours,
  - Stacking strategy from 7 last processing windows
- **PPP (Precise Point Positioning)**
  - Operational since 22/03/2015,
  - Estimation in 15 min interval,
  - Window length 6 hours,
  - Final results come from 1 window.
- **Network Float DD solution**
  - operational since 27/03/2015,
  - processing window/interval as is in the DD Fixed solution

Preliminary quality assessment (CODE Final/Rapid ZTD)

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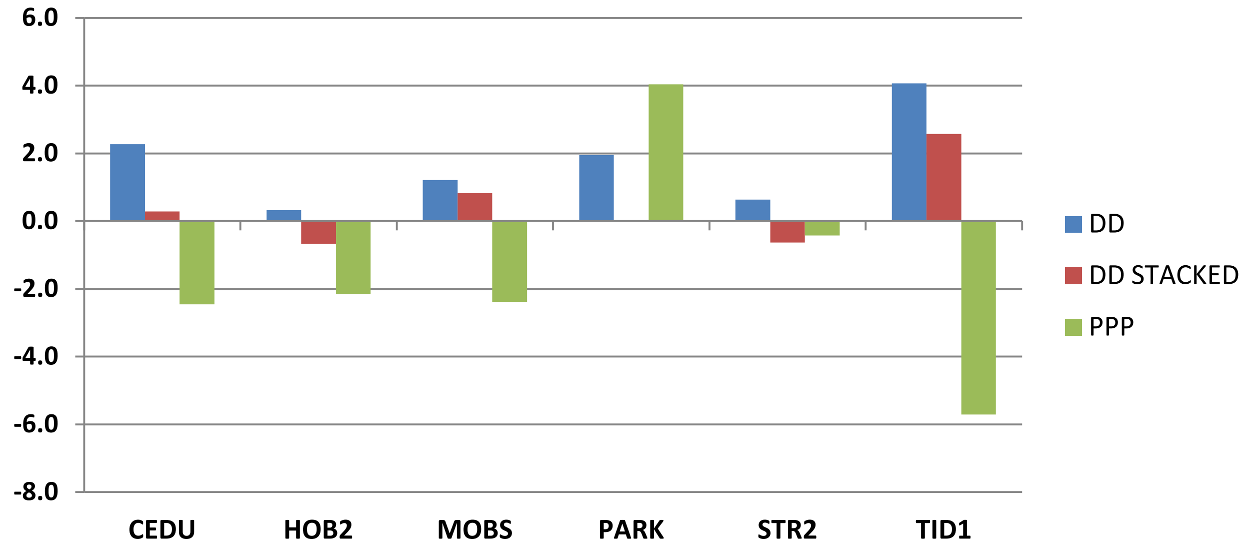
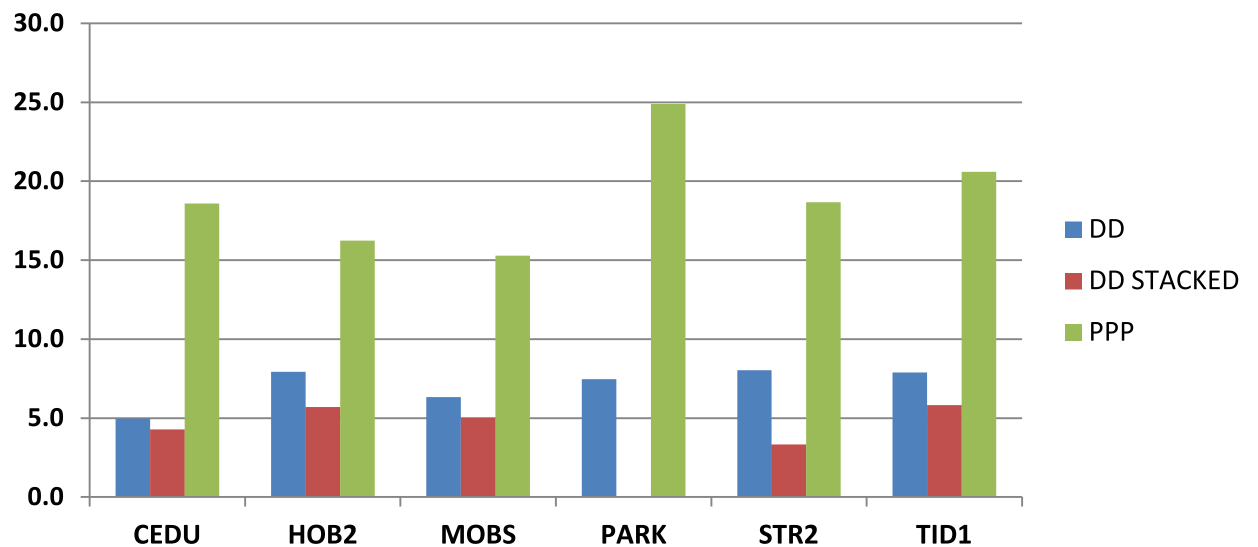
- **ZTD bias [mm]**



- **ZTD STD [mm]**



Preliminary quality assessment (CODE Rapid ZTD)

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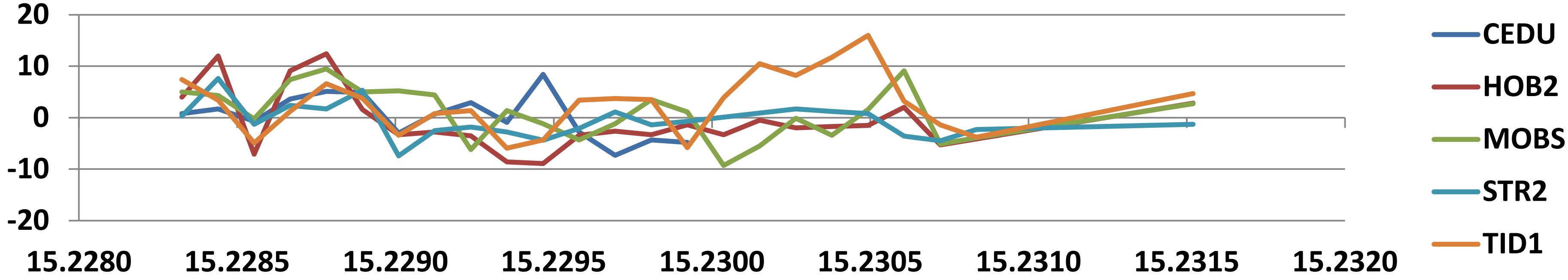
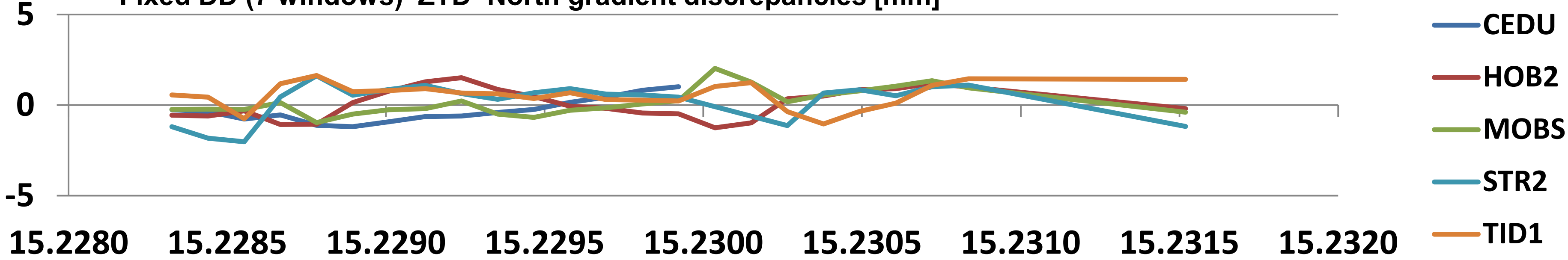
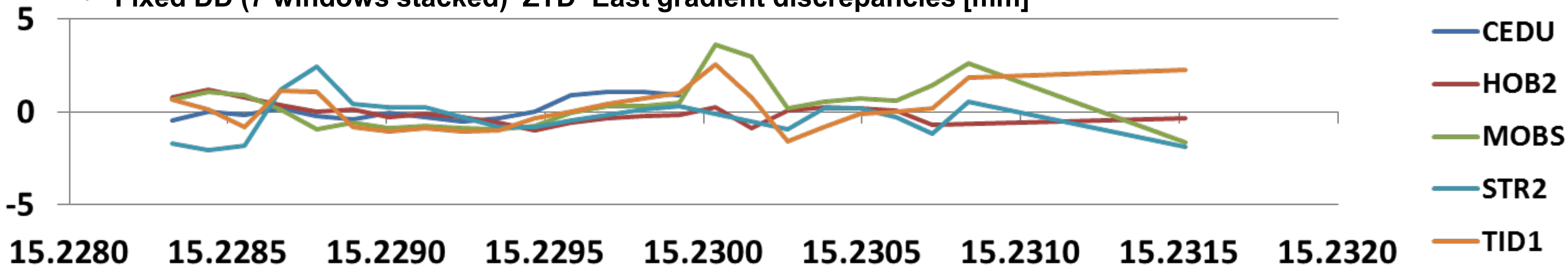
- **Fixed DD (7 windows stacked) ZTD discrepancies [mm]**



- **Fixed DD (7 windows) ZTD North gradient discrepancies [mm]**



- **Fixed DD (7 windows stacked) ZTD East gradient discrepancies [mm]**



Summary

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- **Significant development over Australian NPI through NCRIS**
- **Signatures of severe weather investigated following our successful operational use of GPS RO since 2012**
- **RT/NRT ground-based ZTD platform based on NPI has been developed and the data assimilation trials are under way**
- **GNSS atmosphere sounding represents a milestone improvement in environmental sensing technology**
  - Continuous & accurate measurements of atmospheric <u>parameters</u> with good <u>spatial & temporal resolutions</u> are important for NWP & climate analysis
  - It opens **new avenues** for atmospheric info acquisition
  - Good potential for severe weather events (ground-/space-based)
- **Of particular importance to data void regions (e.g. Australia)**
  - Its large area and relatively less dense radiosonde observations
  - Long coastal zones + large ocean areas

Thank you

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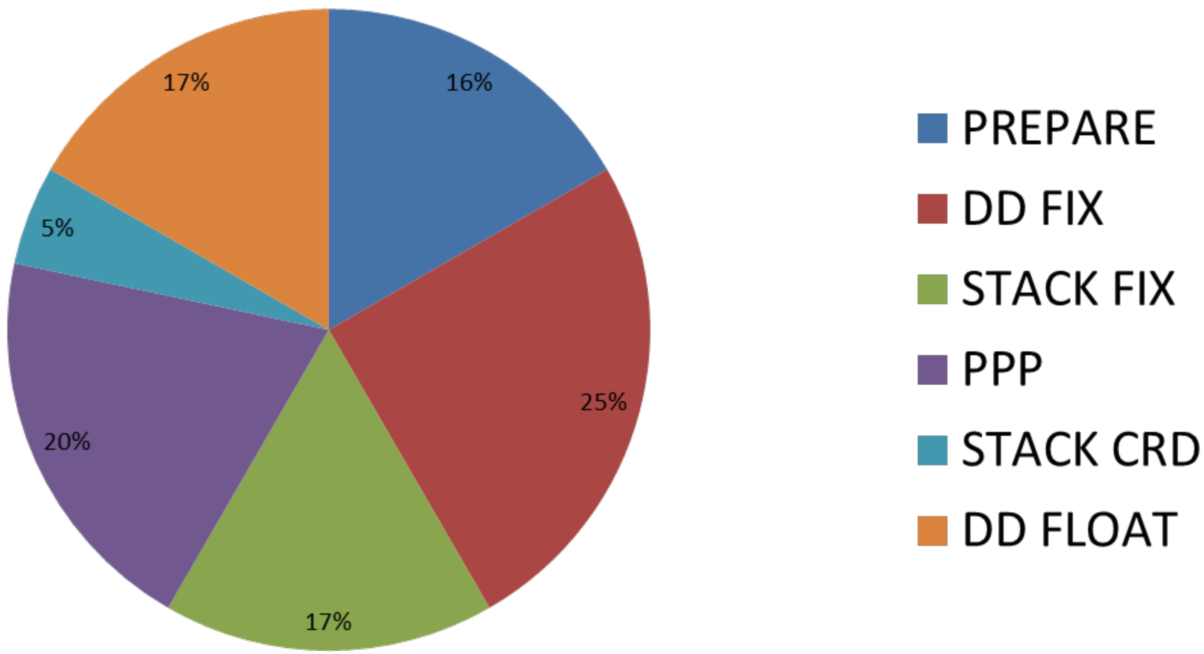
Computation schedule

"space3" RMIT server computation loading:

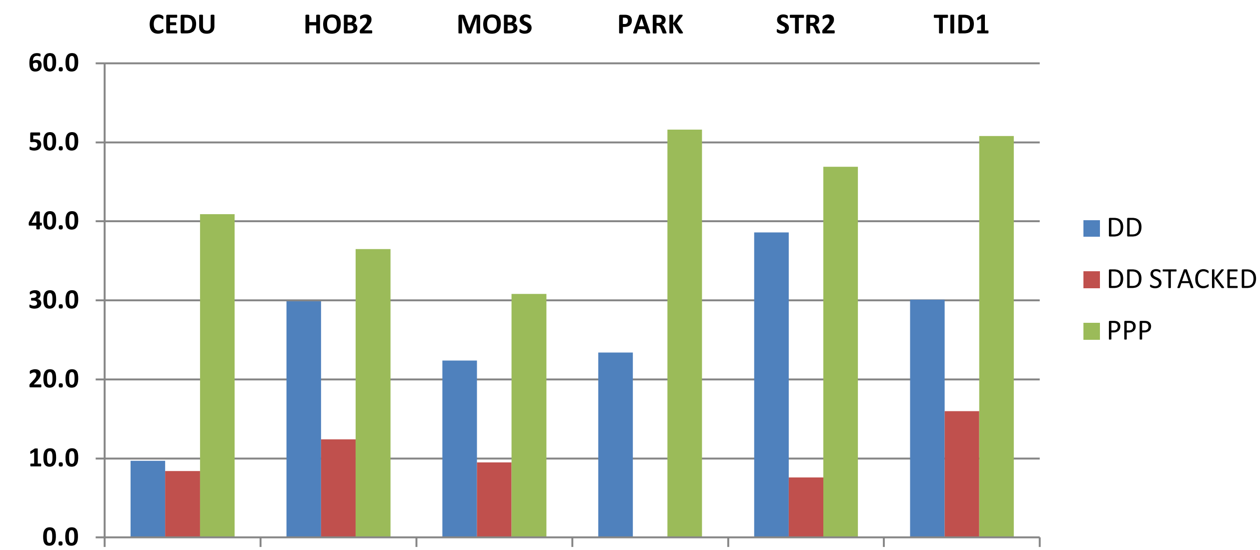
- <u>4 CPUs available with 4GB of RAM</u>, (8 CPUs and 8GB for tests)
- DD estimation ~ 12 min (all possible stages are parallelized),
- PPP ~ 13 min (all possible stages are parallelized),
- Float DD ~ 10 min (all possible stages are parallelized),
- Stack TRO (DD Fix/Float) ~ 12 min (uses one CPU only).



This represents the time taken by these processors within an hour

Quality assesment w.r.t. CODE Final/Rapid ZTD

- **ZTD max bias [mm]**



- **ZTD min bias [mm]**