Sensing the 4D Structure of Severe Weather Using GPS Tomography in the Australian Region

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Outline

- **The GNSS meteorology concept**
- **Space/ground GNSS infrastructure**
- **GNSS applications in meteorology**
  - Climate
  - NWP
  - Nowcasting
- **Tomography and 4D retrievals**
- **Summary**

GNSS Meteorology

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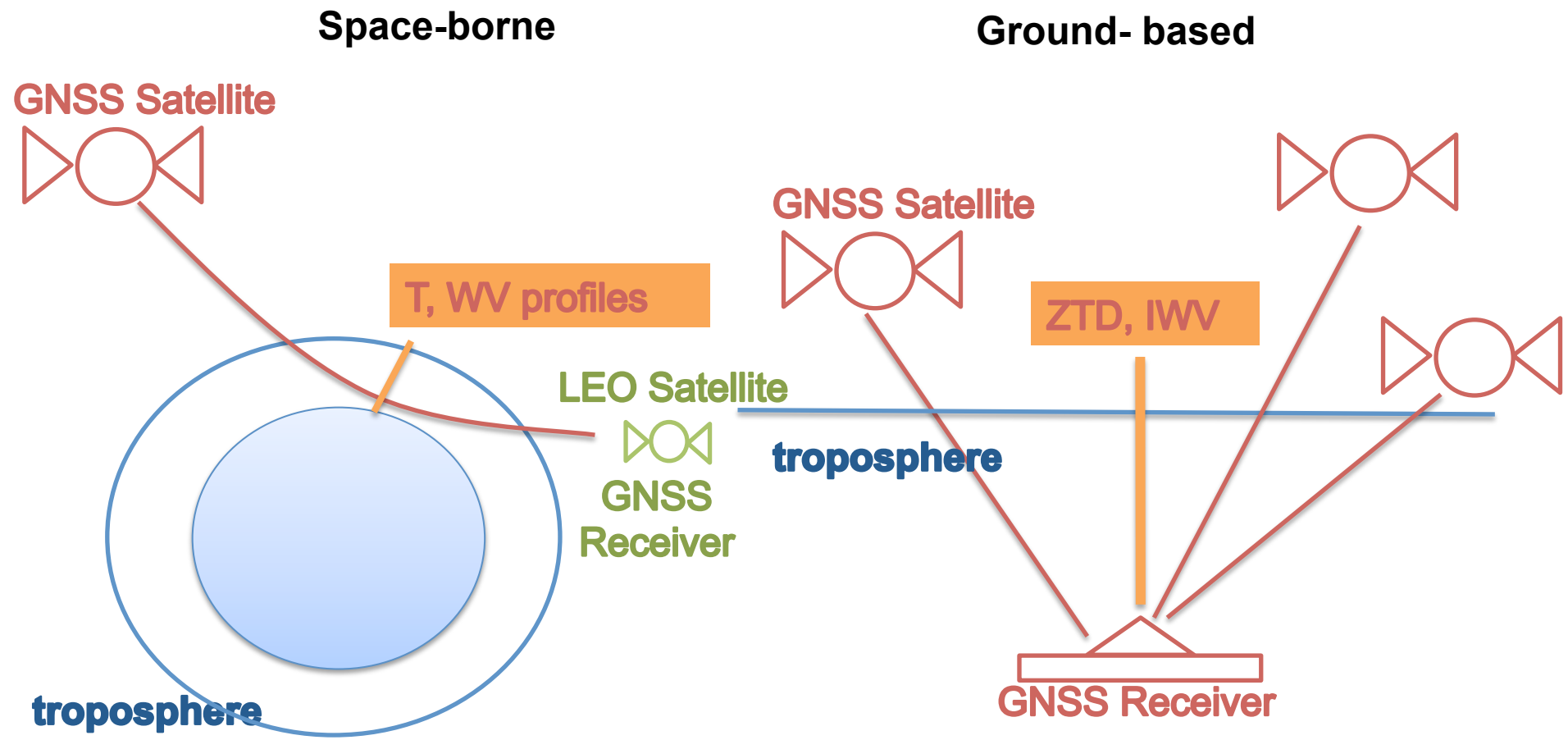

Kursinski, E. R., Hajj, G. A., Schofield, J. T., Linfield, R. P., & Hardy, K. R. (1997). Observing Earth's atmosphere with radio occultation measurements using the Global Positioning System. *Journal of Geophysical Research*, *102*(D19), 23429-23465.

Rocken, C., Ware, R., Van Hove, T., Solheim, F., Alber, C., Johnson, J., ... & Businger, S. (1993). Sensing atmospheric water vapor with the Global Positioning System. Geophysical Research Letters, 20(23), 2631-2634.

Space Infrastructure

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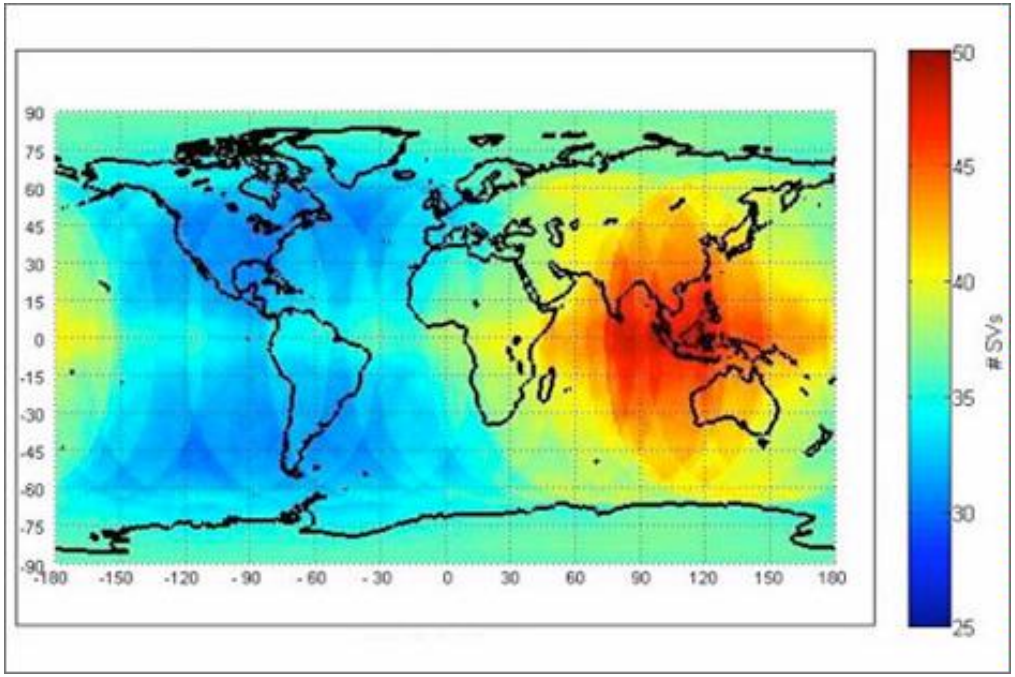

Global Navigation Satellite System (GNSS)

- Global Navigation Satellite Systems (GPS + Glonass + Galileo + Beidou + QZSS + …)
- ~60 satellites available, ~130 SVs by 2020
- Australia – Oceania GNSS "hotspot"

Ground Infrastructure – CORS/NPI

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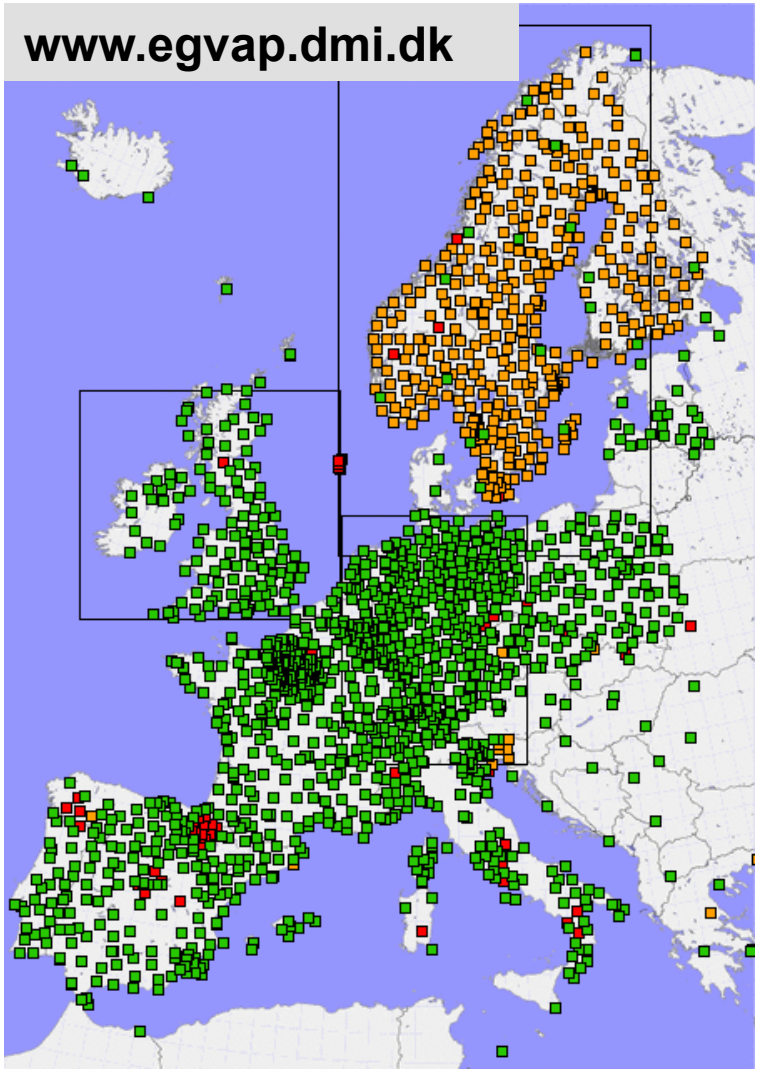
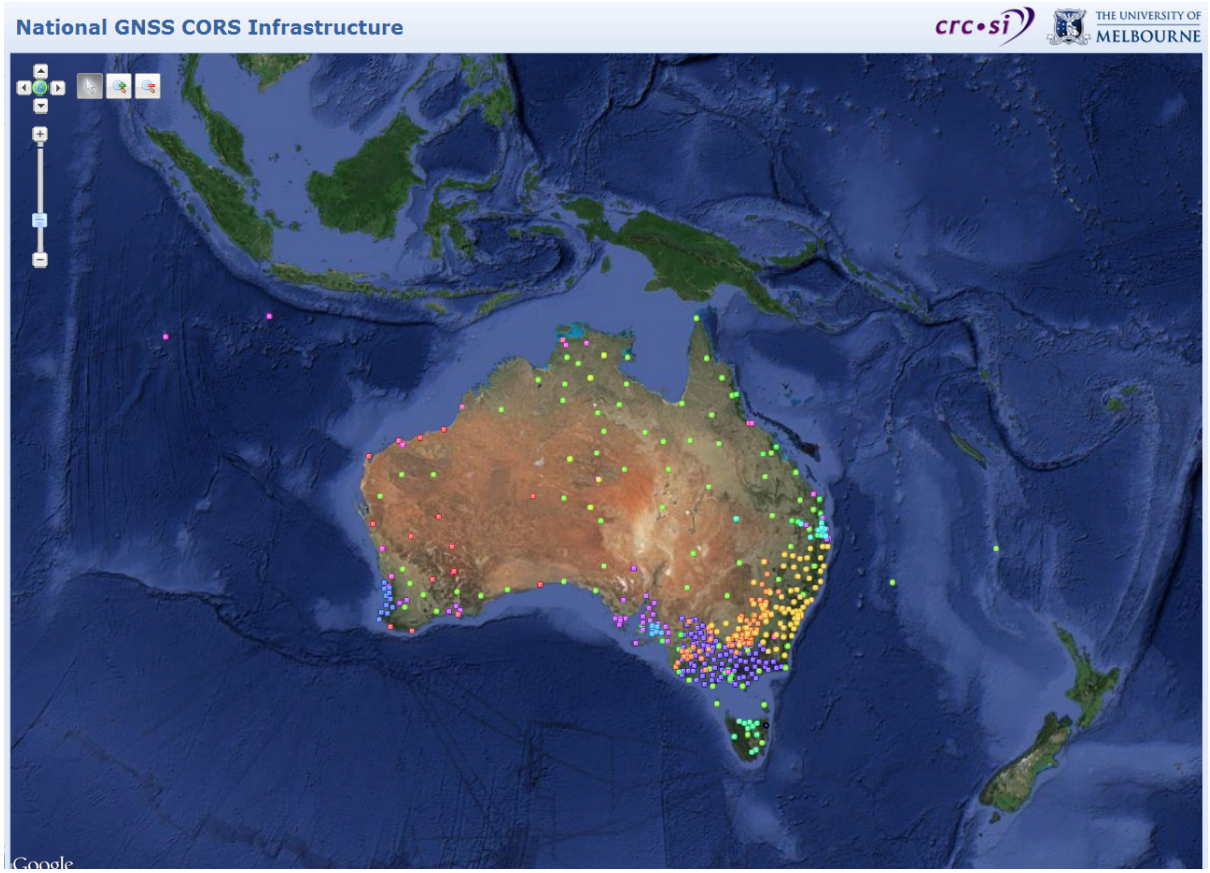


- E-GVAP (~1800 GNSS stns) and SuomiNET dedicated GNSS networks for weather monitoring and positioning
- Unique nature of collaboration between geodesy and meteorology
- NRT processing with quality control
- BUFR format for EUMETNET meteorological agencies

Australian NPI



http://feynman.thinkspatial.com.au/natgnss/

- "Spatially Enabling Australia"
- ~400 stations across Australia
- Geoscience Australia driven project
- Mixed private/public ownership
- 25 different data providers
- East coast with dense network
- Stations at the Pacific and Indian Ocean islands

Meteorological applications

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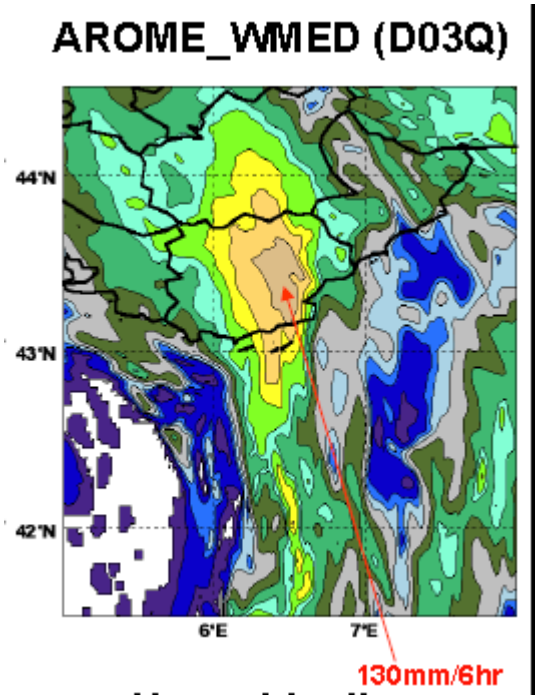
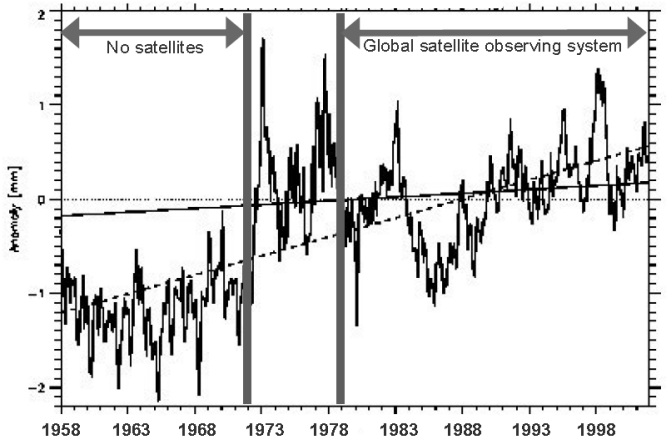
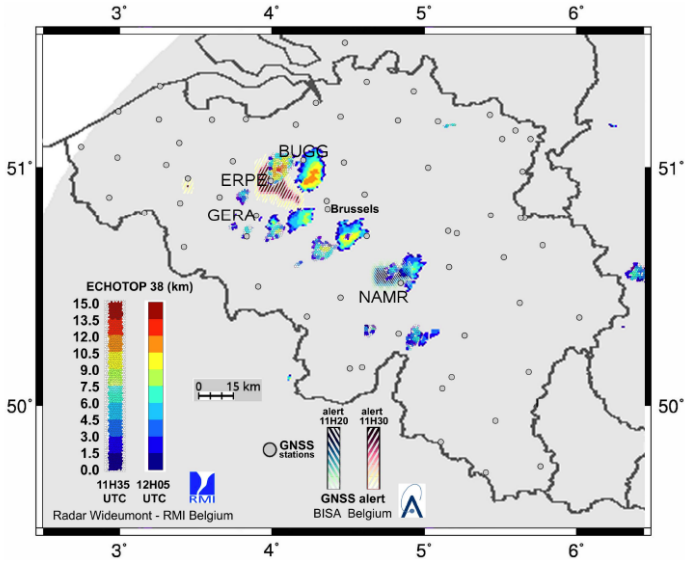
- **Climate change monitoring**
- **Assimilation in NWP models**
- **Nowcasting**



Courtesy Jonathan Jones MetOffice



M. Stendel (2006), Monitoring Climate Variability and Change by Means of GNSS Data,



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

Climate change monitoring

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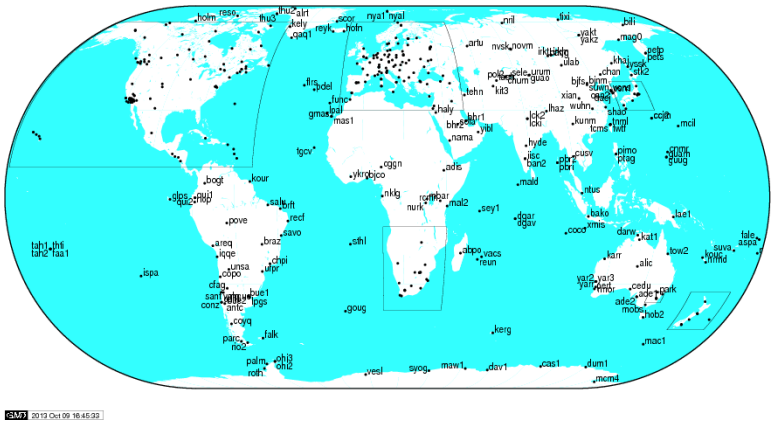
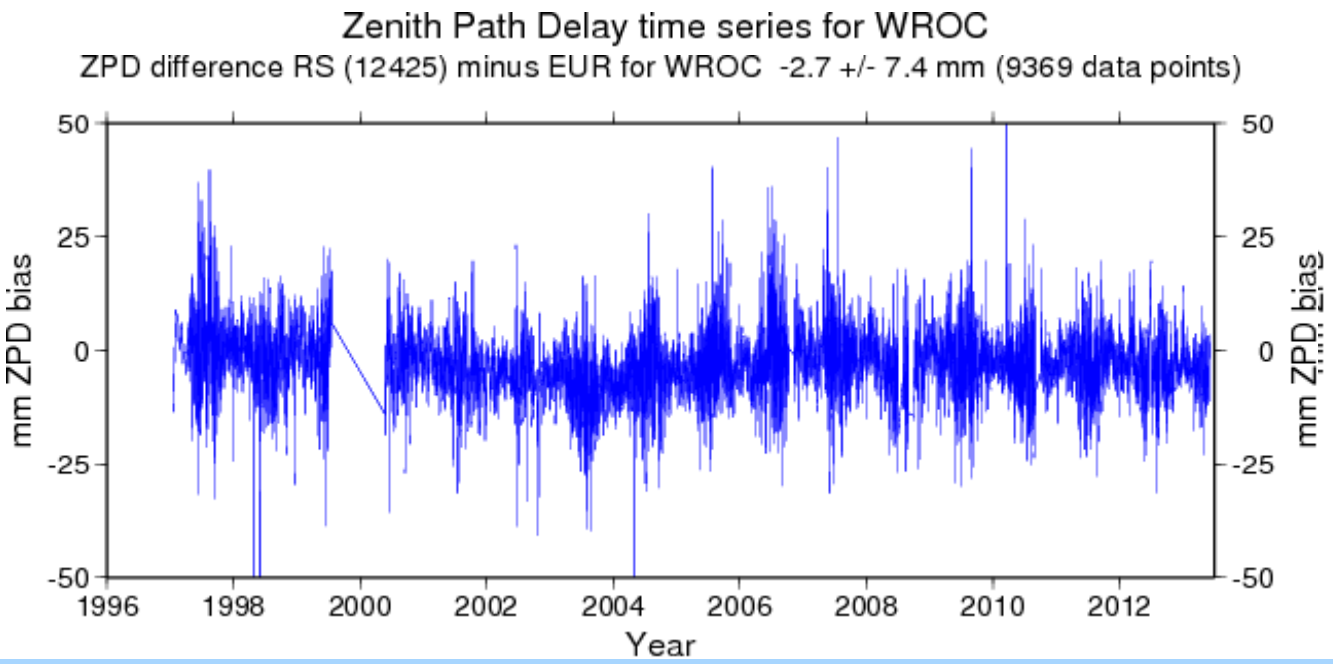
- Instrumental bias free
- Self-calibration
- Long-term stability
- All-weather conditions
- Observational characteristics are consistent across geographical regions and at all times.





Assimilation in NWP models (1)

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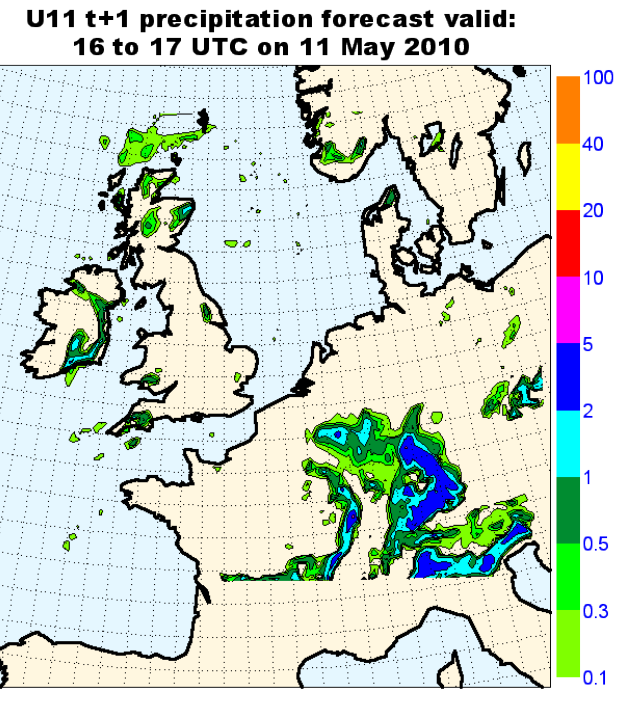
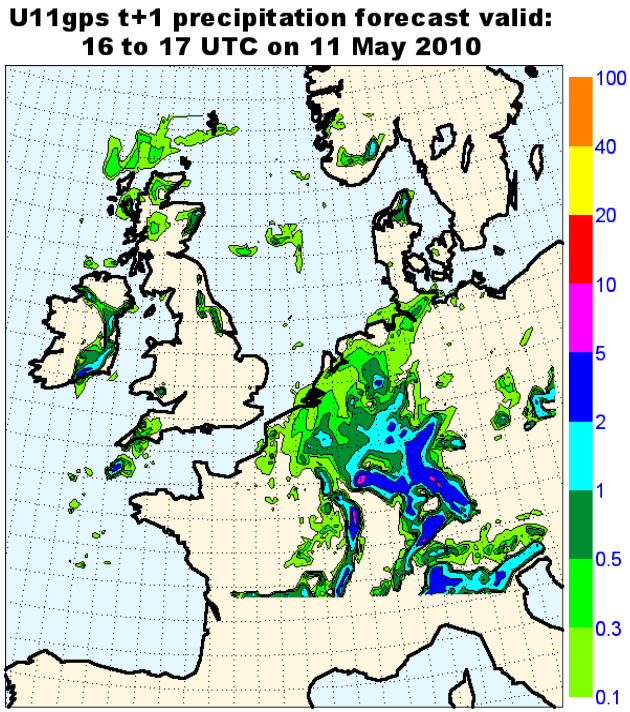
- dense CORS networks processed in Near Real Time (~45 minutes latency)
- stable high quality ZTD and IWV
- E-GVAP part of EUMETNET provides data in BUFR format
- Reported to improve the rainfall and humidity prediction
- Used operationally in Meteo France, KNMI, tested at MetOffice

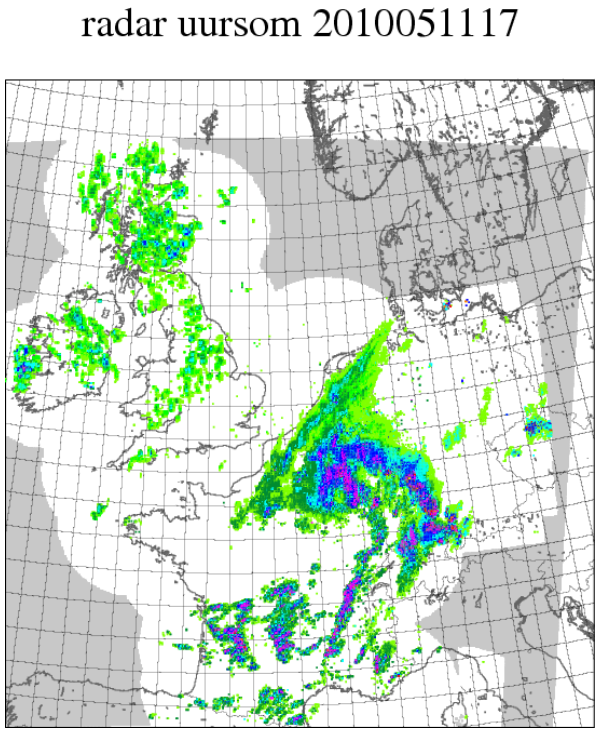


Forecasting without GPS



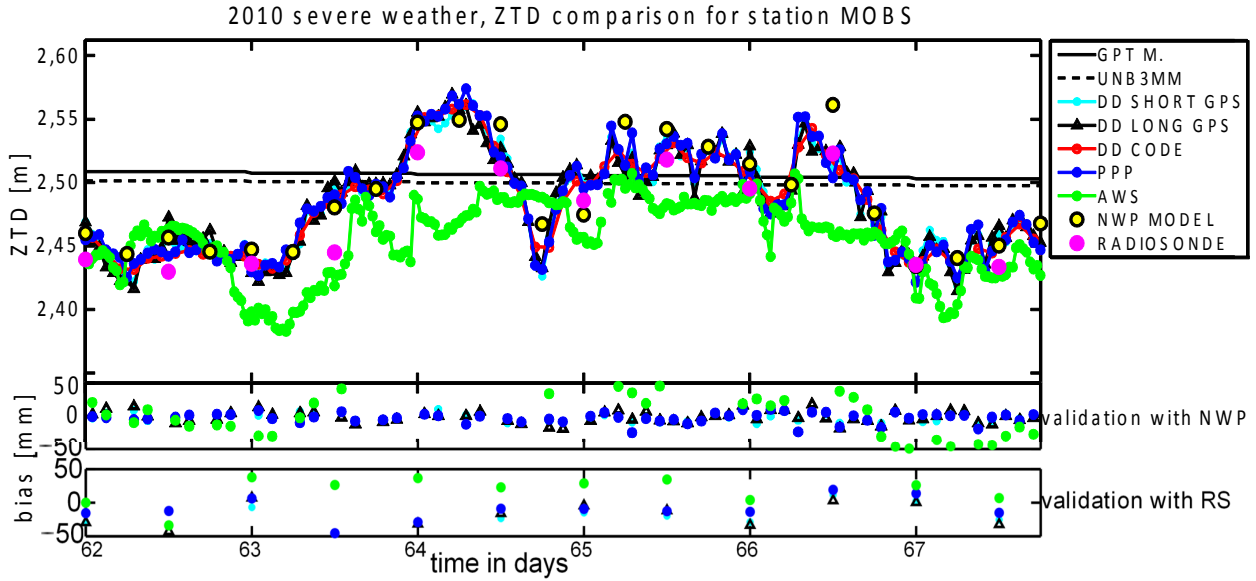
Forecasting with GPS

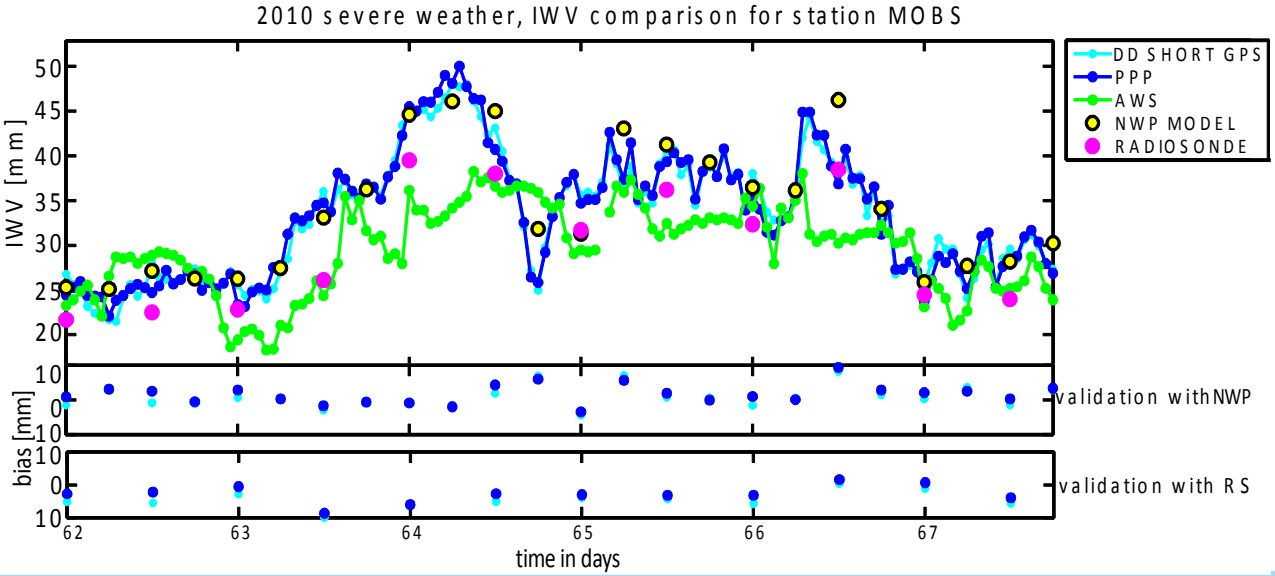
(courtesy Siebren de Haan KNMI)



Radar composite

Assimilation in NWP models (2)





- **3 severe weather case studies**
  - ✓ 218 station processed
  - ✓ 6 Mar 2010 severe weather storm in Melbourne
  - ✓ 7-12 Jan 2011, flash flooding in Victoria
  - ✓ 25 Feb - 2 Mar 2012, flooding in Victoria
- High consistency and quality of data in all-weather conditions (bias=0mm, std <10mm)
- Assimilation into ACCESS under way

Supporting Nowcasting (1)

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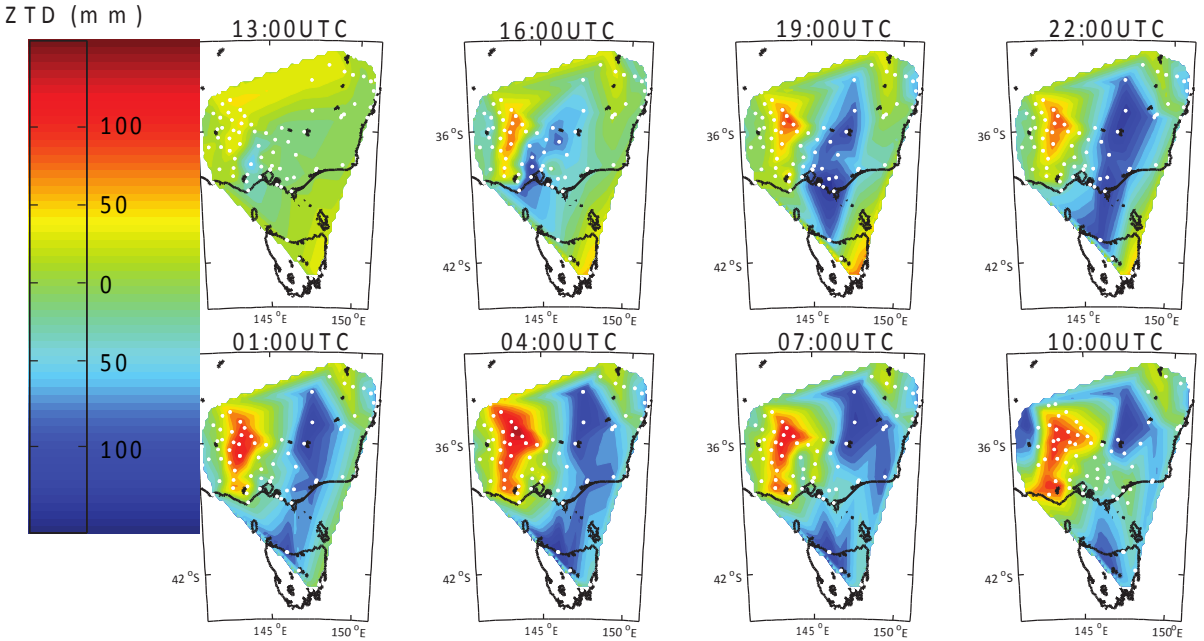
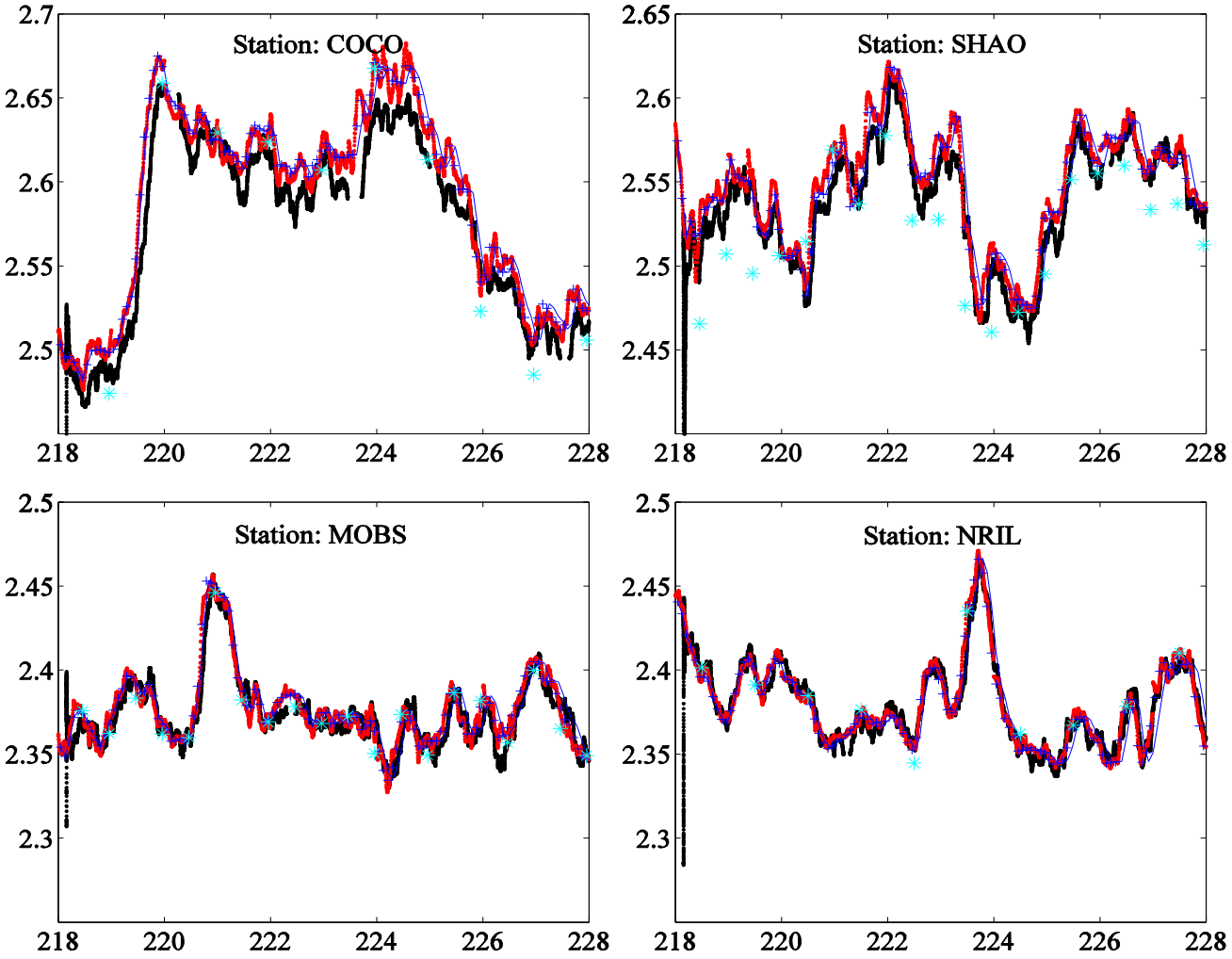


- Near Real Time (NRT) 45 minutes delay and Real Time (RT) (0 minutes delay) processing
- In-situ ZTD and IWV observations
- 2D ZTD and IWV maps showing passage of cold/warm or dry/moist air
- 30 minutes resolution

Supporting Nowcasting (2)



- 21 stations global coverage with diff altitudes
- Single station real-time solution (PPP)
- Output every second
- High consistency with radiosonde and post-processed IGS products **(bias = 2 mm std < 15 mm)**
- In-situ ZTD and IWV observations

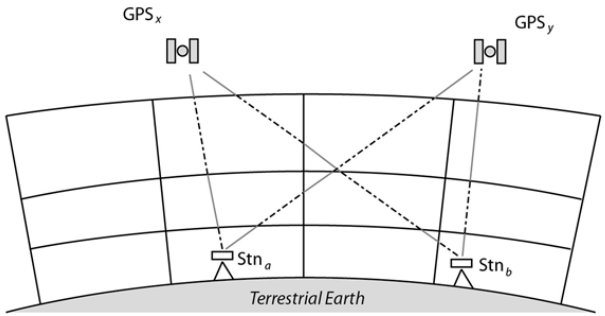
GNSS tomography

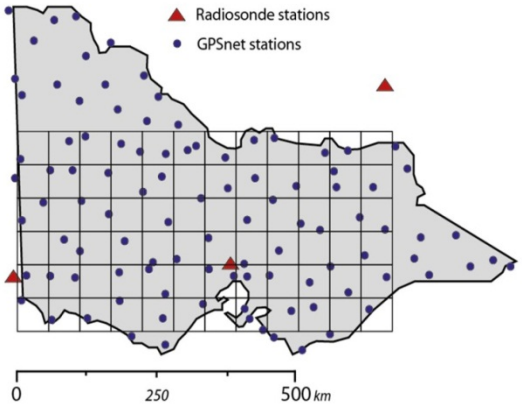
GNSS tomography (3D)

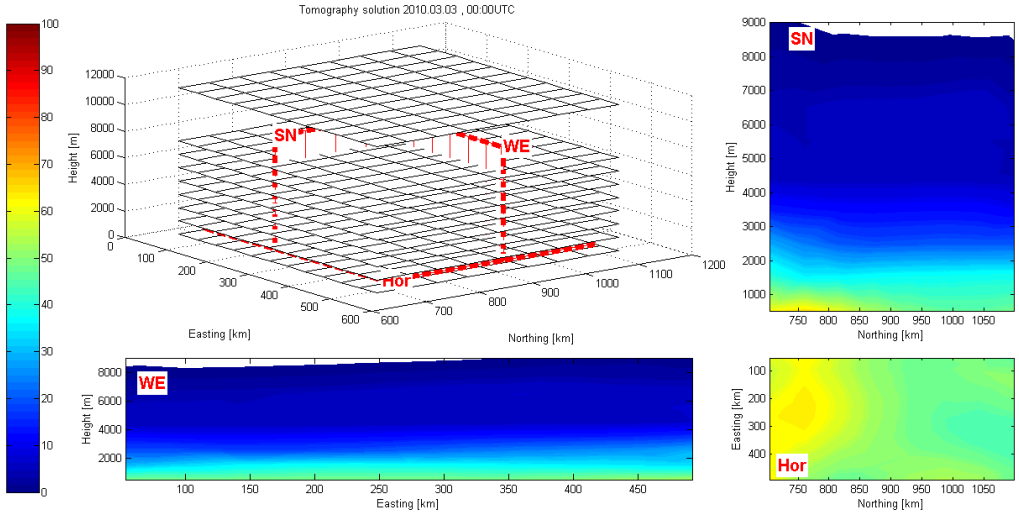
- Reconstruct dynamically changing 3D variability of troposphere
- Observations from difference aspects and orientations
- Related to wet refractivity (N_{wet}) using:
- $\Delta_{SWD} = 10^{-6} \int a_x N_{wet} \Delta s$
- Kalman filter for the forward processing

Matrix equation system

$$\begin{pmatrix} \blacksquare & \blacksquare & A/2 & PD_{lat} & PD_{lon} & h_x & h_y & @ \\ ZTD_p & @N_{(\lambda,\phi,h)} & @ \\ 0_i \end{pmatrix} = H \cdot \begin{pmatrix} \blacksquare N_1 & @N_2 & @\blacksquare N_3 & @N_4 & @\blacksquare N_5 & @N_6 & @\cdots \end{pmatrix}$$

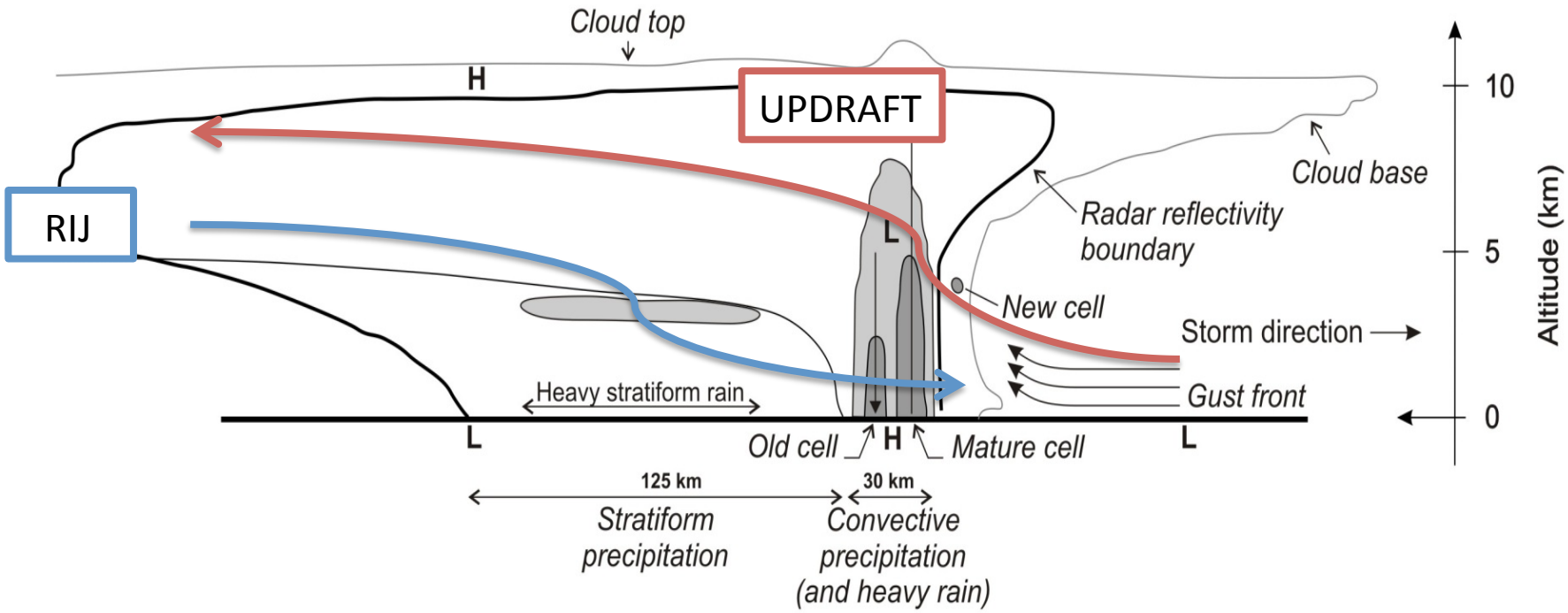






GNSS tomography for severe weather

Vertical cross-section of tomography model along the severe storm propagation



(Houze, 2004) Vertical cross-section of multicell storm

GNSS and MCS(3D)

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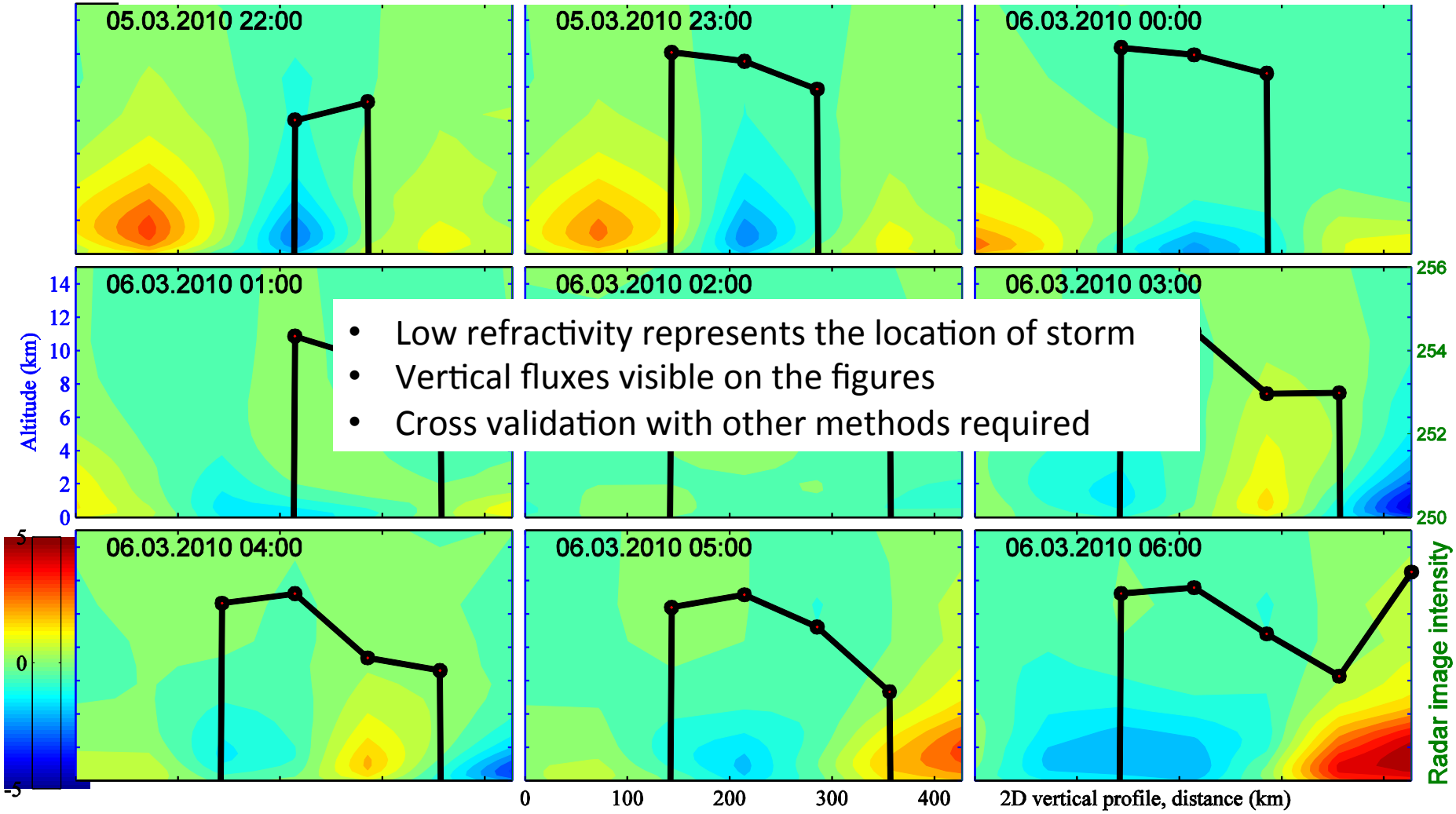
Vertical cross-section of tomography model along the severe storm propagation



- Low refractivity represents the location of storm
- Vertical fluxes visible on the figures
- Cross validation with other methods required

GNSS tomography for severe weather

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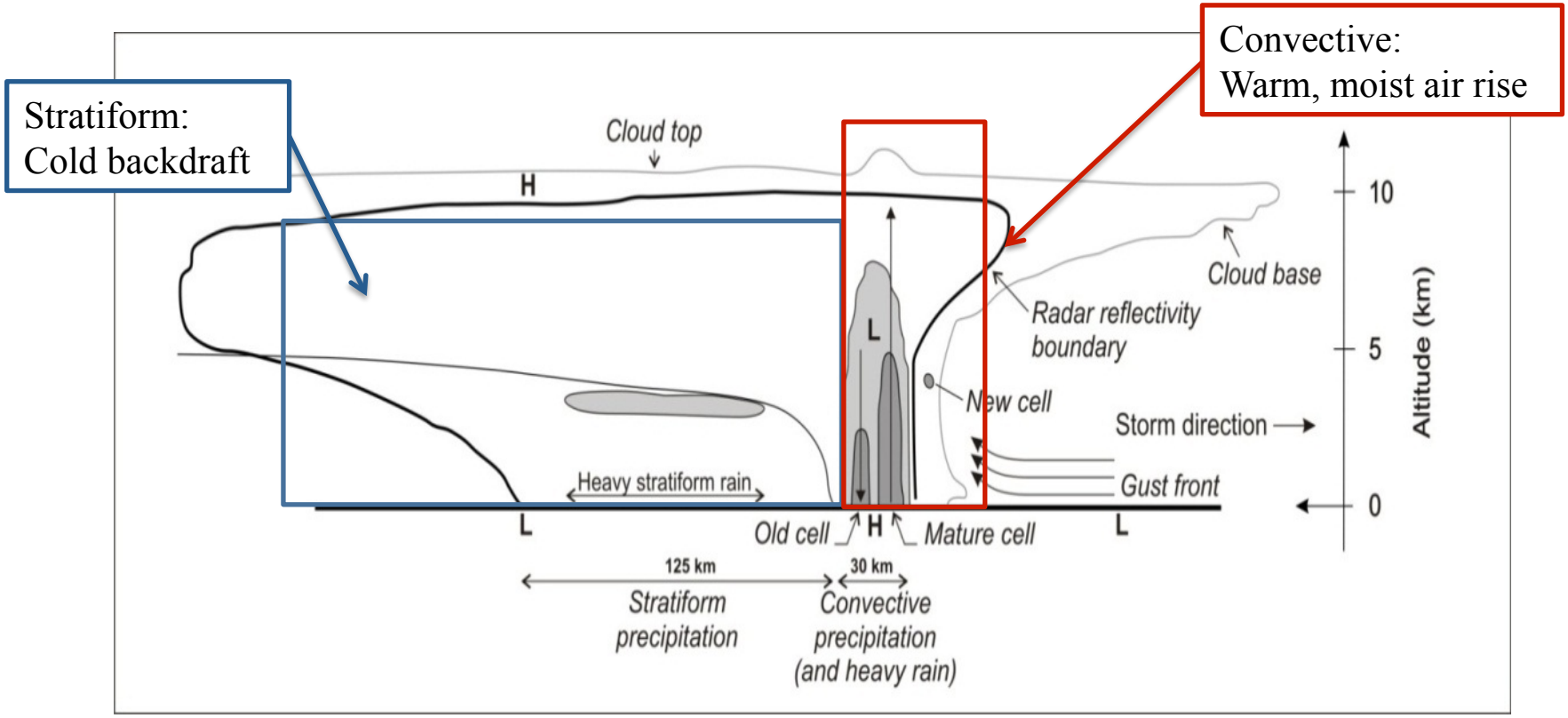
Horizontal tomography slices of the investigated area



(Houze, 2004) Vertical cross-section of multicell storm

Case Study 1: March 2010

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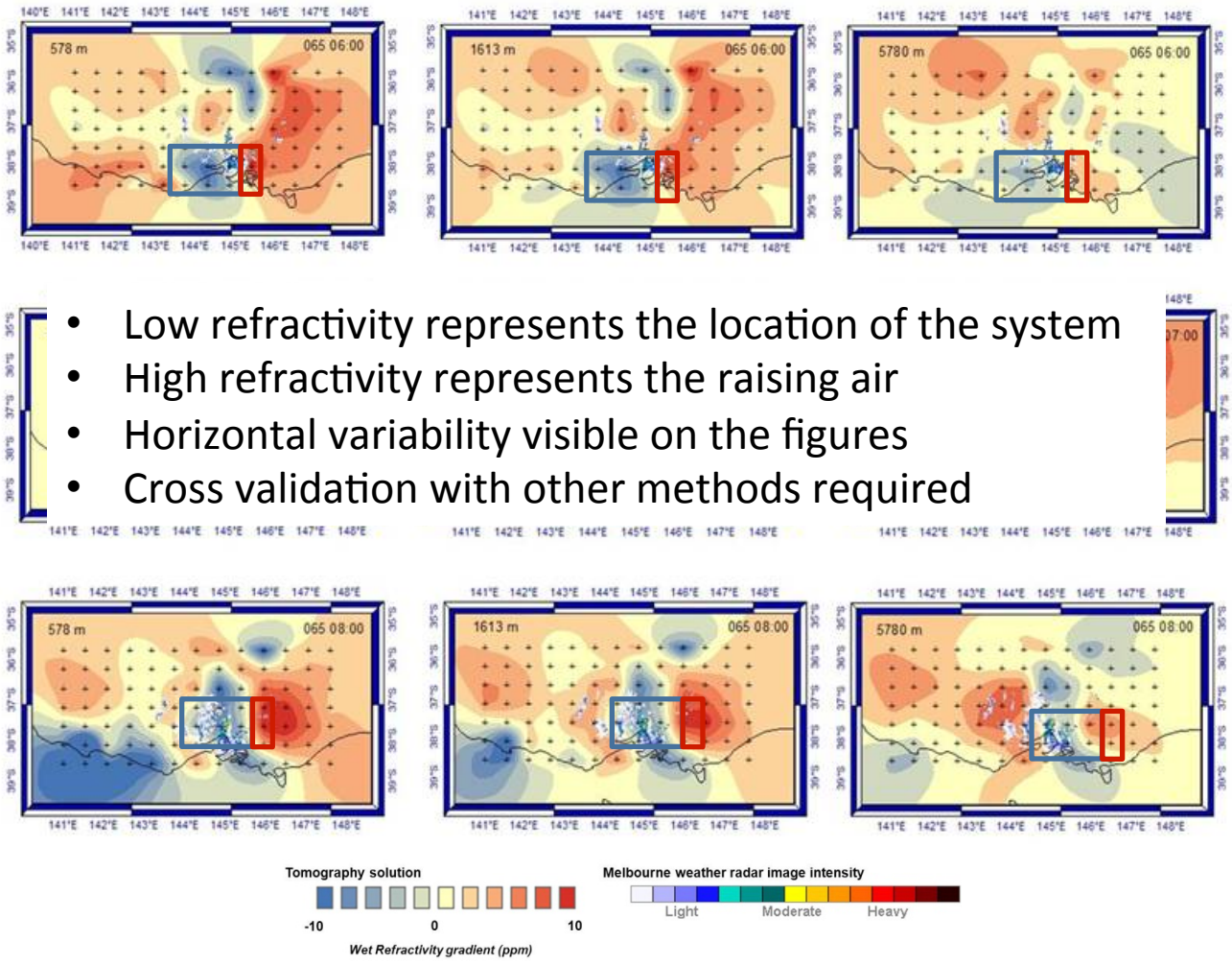
Horizontal tomography slices of the investigated area



- Low refractivity represents the location of the system
- High refractivity represents the raising air
- Horizontal variability visible on the figures
- Cross validation with other methods required

Conclusions

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- Rapid and significant GNSS development in both space and ground geodetic infrasctructure
- GNSS are a new and important tool for climate, weather prediction and nowcasting
- The SPACE Research Centre and BoM are working together to provide NRT and RT GNSS troposphere products for Australia
- In addition to our successful operational usage of GPS radio occultation for ACCESS
- 3D SW structures can be detected via GNSS tomography
- Future – high frequency, RT line of sight observations, will open up exciting new opportunities for meteorology and climate studies

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Thank you

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