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Radars and Rainfall Extremes

How can we make use of long-term radar observations and modelling to better characterize and understand rainfall extremes in Australia ?

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Measuring Rainfall …

- Point measurement : rain gauge, disdrometers. Typical resolution 1 to 10 minutes, generally aggregated to 1 hour or 1 day
  - Pro : accurate (but not perfect !) measurement
  - Con : cannot capture spatial variability of rainfall (unless you are very rich)

- Convective scale and mesoscale (300*300 km) : weather radars. Typical resolution of radar products ~ 1 km (horizontal) x 0.5 km (vertical) , 1 obs every 5-10 minutes at each point. New opportunistic observations : microwave links from phone companies (not exploited yet in Australia)
  - Pro : spatial coverage, large range of rainfall values (light to extreme)
  - Con : accuracy → geometry, beam blocking, rain/hail mixture, clutter, insects, birds, fire, chaff, UFOs, …

- Regional (1000s kms) and global scale : polar-orbiting and geostationary satellites using a combination of microwave, vis, IR, and radar sensors. To some extent, denser parts of operational radar networks for some regions.
  - Pro : only way to get rainfall at those scales
  - Con : accuracy (esp. land), temporal resolution (at least 3h)

Characterizing Rainfall Extremes with Radar!

- General consensus for city-scale / small region studies of rainfall extremes:

  Radars assisted with rain gauge data. Mesoscale coverage + time resolution needed for process studies
  Microwave link retrievals should one day be added to that list.
  Bureau solution (single-pol radars): **Rainfields** (blended radar – rain gauge)

- Reasons :

  Regions where people live in Australia are well covered by decent radars
  Dual-polarization radars are coming (but no historical data)
  Dense rain gauge networks where people live (+ a lot of microwave links)
  → Accuracy of radar-derived rainfall estimations is at its highest

  WCRP Core indices for sub-daily precipitation and longer time scales can all be estimated using radar reflectivities converted to rainfall rate.

Weather Radars

- Radars provide quantitative information on convective clouds in a ~ 300 km x 300 km and over the whole troposphere. The same point is measured every 5-10 mins

- Volumetric sampling : azimuthal scans for about 15 elevation angles
- Typical resolution of radar products ~ 1 km (horizontal) x 0.5 km (vertical)

- Primary measurement is **reflectivity**, which relates to the intensity of convection (**rainfall rate** close to the ground, ice water content aloft) and important convection properties (CTH, CAF, etc …)

- **Doppler** radars provide additional information on convective dynamics (3D winds, mesocyclone detection) inside convection and also clear-air at close range (<20-30 km)

- **Dual-polarization** radars provide better estimates of high rainfall rates, hail identification and size, rainfall rate in rain/hail mixture, in partial beam blocking situations (orography) - *no long-term record yet in Australia except CPOL (Darwin)*

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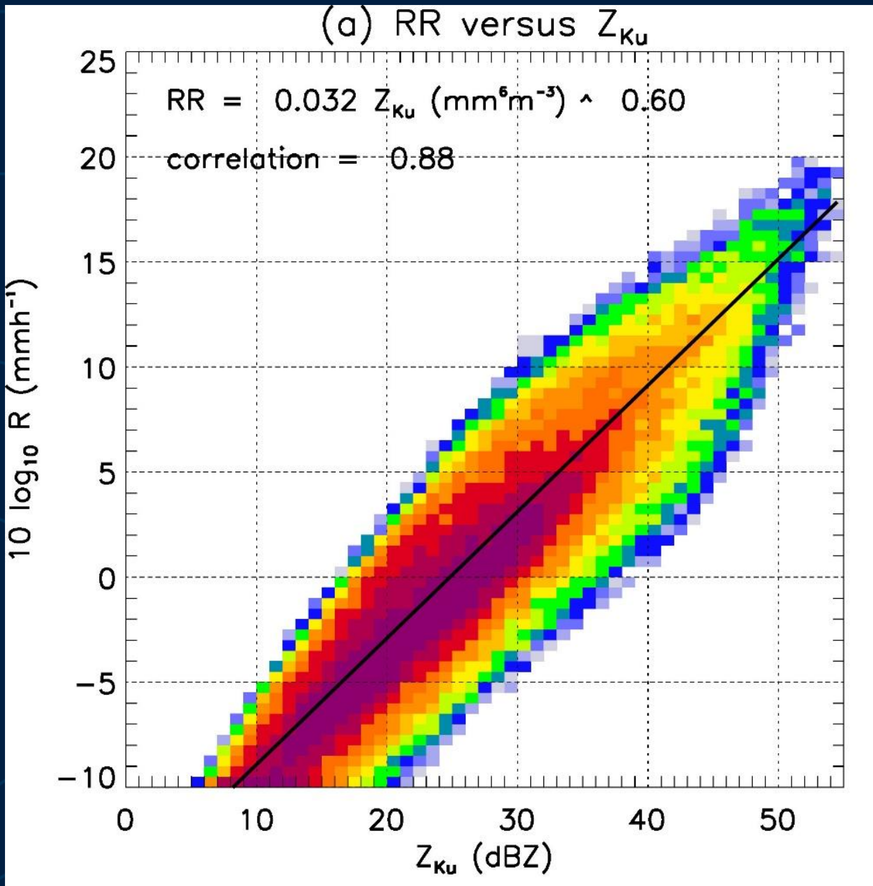
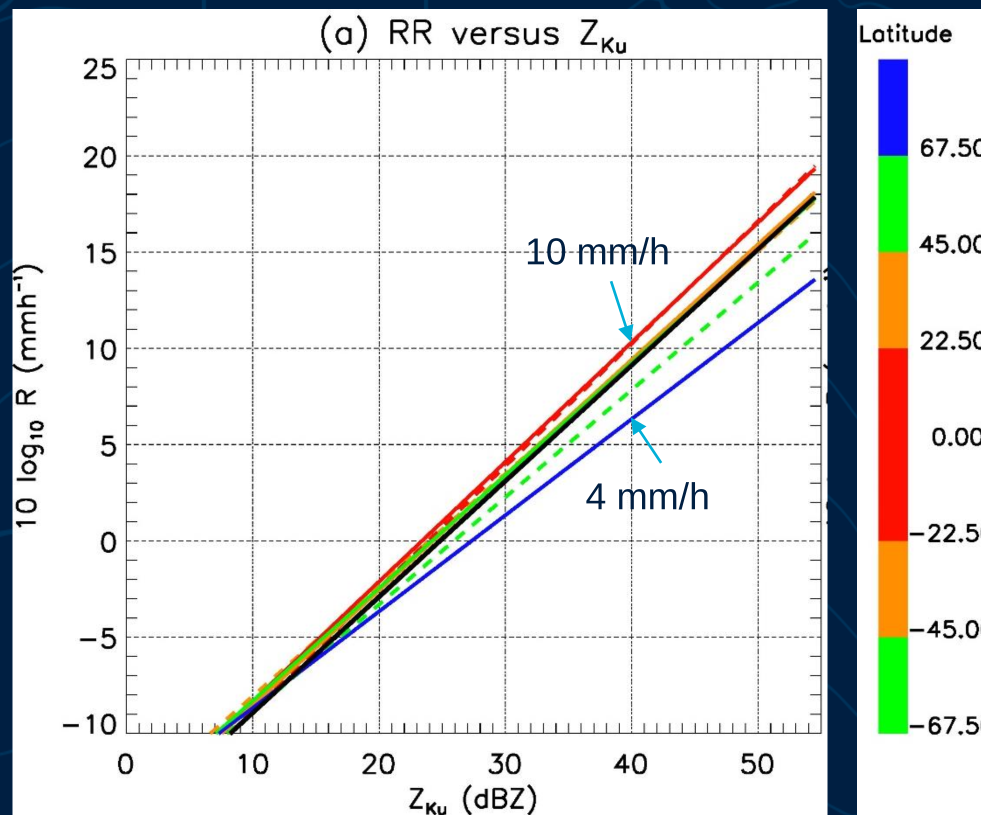
The bread and butter : the Z – R relationship



Latitudinal variability
of Z – R relationship

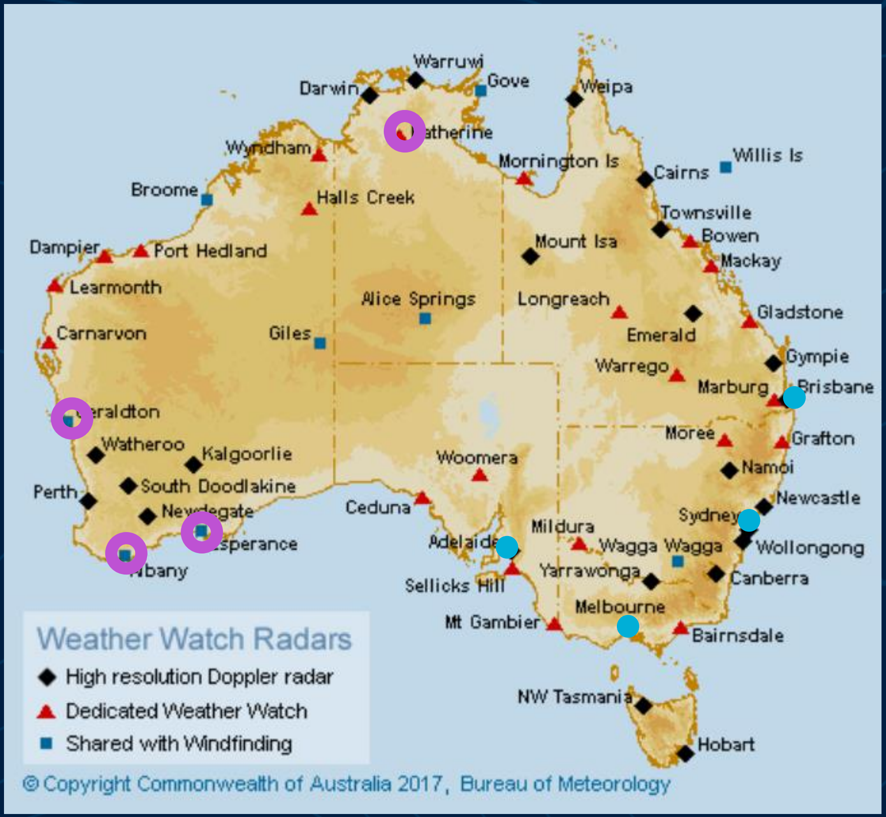


Weather Radars
… Are … NOT … perfect ?

Protat et al. 2019, in prep.

The Australian Operational Radar Network

- Four capital city operational radars upgraded to dual-pol (yay !)



● Dual-pol Upgrade
May – September 2017

- Buckland Park (Adelaide)
- Mt Stapylton (Brisbane)
- Terrey Hills (Sydney)
- Laverton (Melbourne)

○ Next ones ordered (FY18-19):

- Esperance, Albany, Geraldton (WA)
- Tindal (NT)

- New 10 yr + radar contract signed (new radars = dual-pol !)

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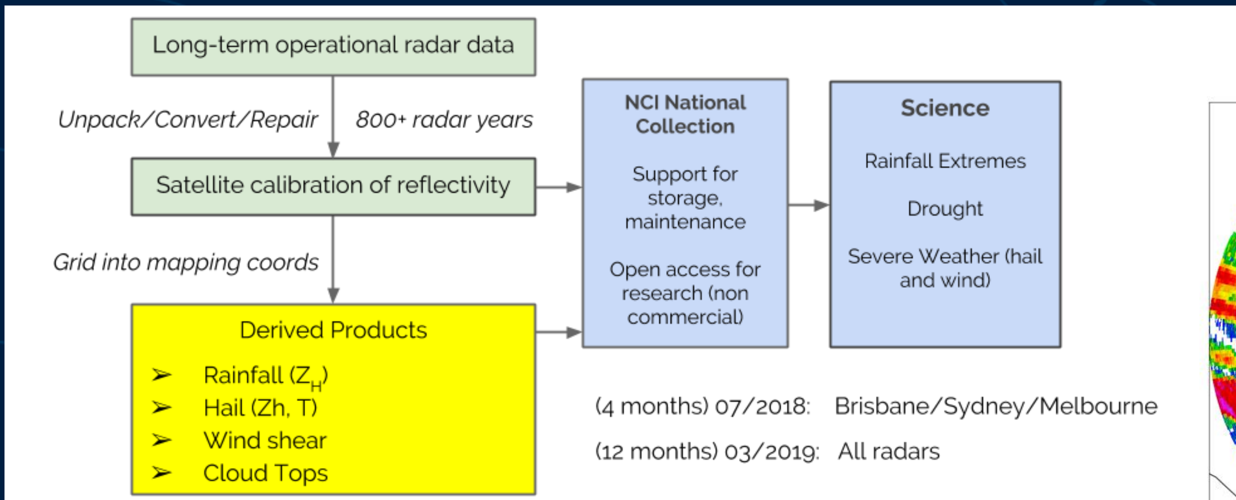
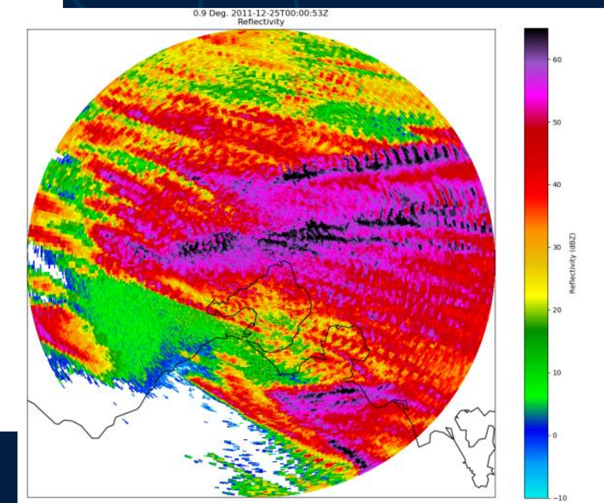
Building a National Operational Radar Archive (Joshua Soderholm)



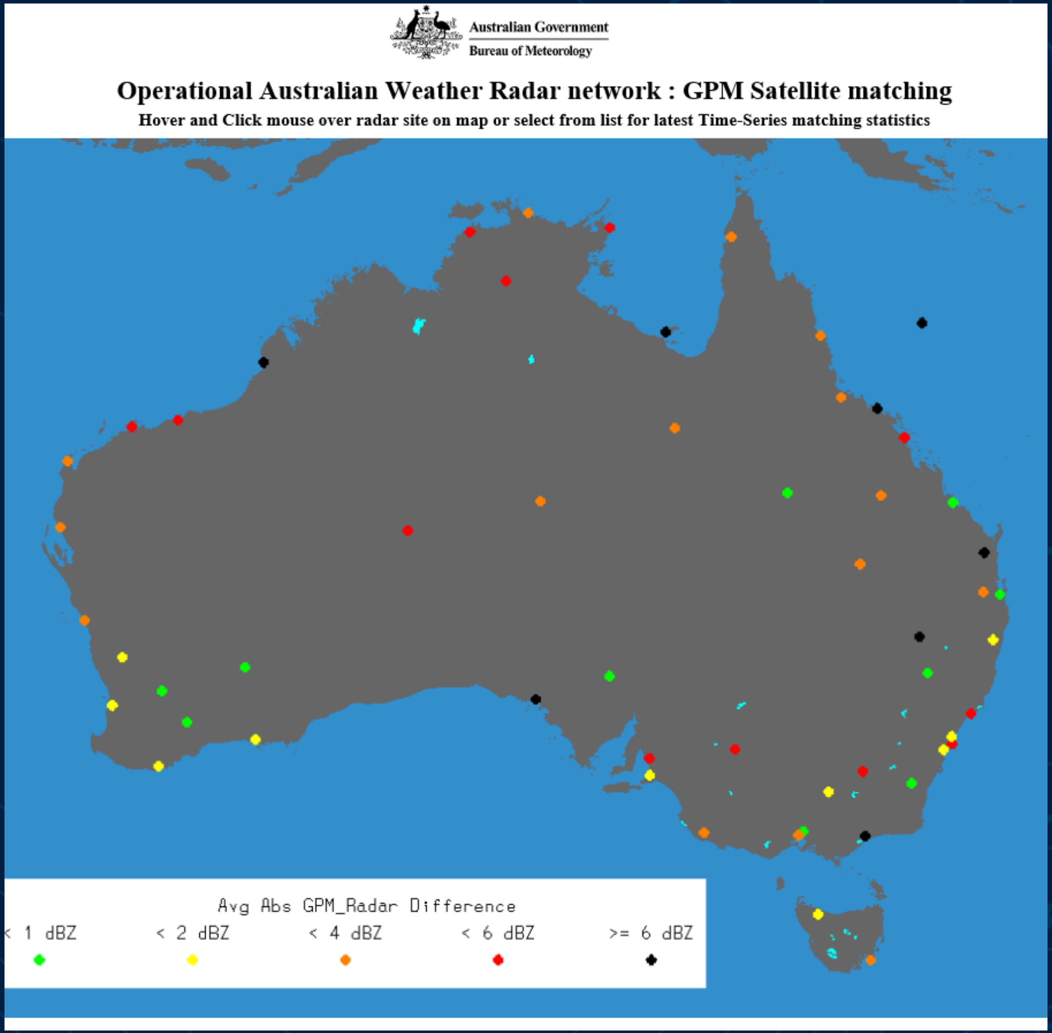


Status :
Completed for all radars: **Collation** (from 4 archives, daily files, naming convention), **Recovery** (15-20% corrupted, repaired), **Conversion** (HDF5 Odim + daily image of max ref), **Calibration** (TRMM/GPM+clutter)

Prototype **gridded rainfall**, hail size and azimuthal shear available for the Brisbane, Melbourne and Sydney radars (18-20 yrs)

Next steps : CTH, clutter, attenuation, better rainfall, other radars, training

Building a National Operational Radar Archive: Radar data quality control underpins everything !



Fantastic work from R. Warren, V. Louf, M. Whimpey, J. Soderholm

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Radar sources of uncertainties for rainfall

- Removal of non-meteorological echoes : major problem is **ground clutter**. High reflectivity = artificially high rain rates near ground !
    - Mitigation for the Open Radar Archive: additional corrections, looking for permanent echoes with high reflectivities / low Doppler.

- **Regional variability of the Z – R relationship**
    - Mitigation for the Open Radar Archive: local relationships are derived from ~matched rainfall from gauges and radar reflectivity above rain gauge
    - Convective and stratiform relationships will be derived and used.

- Partial or complete **beam blocking** in orographic areas = artificially low rain rates
    - Mitigation for the Open Radar Archive: identify + correct cases that can be

- **Rain / hail mixture** = artificially high rain rates
    - Mitigation for the Open Radar Archive: not much we can do about that for single-pol radars. Some threshold on Z will be applied (~55 dBZ). This could have effects for extremes (to be investigated, probably with dual-pol data)

Characterizing Rainfall Extremes …

- A heavy rainfall case will be labelled "extreme" because of its impact.
  - Should we study different types of extremes : producing flash floods, floods due to high accumulation, high total rainfall regionally producing basin-scale issues, longer timescale accumulations of rain ?
  - If we have to, should the indice(s) used to characterize extremes be tailored to the actual type of extreme: high percentile of rainfall PDF, threshold on instantaneous rainfall rate, on accumulated rainfall rate, etc …
  - If this is a proper framework, next we need to characterize :
    - The morphology of heavy rainfall cases : what do they look like ?
    - The large-scale "conditions" or "forcing" or "environment" conducive to each type of extremes, using these tailored indices
- Is the same sort of discussion also relevant to heat extremes ?

Should we discuss the use of collaborative tools ? (LS forcing ?)

Characterizing Rainfall Extremes with Radar

- With a high-quality database of radar rainfall extreme cases, we need to study:
  - The **morphology** of extreme cases and associated **processes**: their internal structure, mesoscale organization, distribution of convective properties, the relative importance of warm versus cold rain processes, presence of hail, mesocyclones, etc …
  - The **composite analysis** of these cases to understand physical processes: group all cases to investigate their life cycle, their diurnal cycle, statistically.
  - The **large-scale environment** conducive to these extremes : either using reanalyses (maybe OK for the midlatitudes ?) or the so-called variational analysis (recommended for the sub-tropics and tropics)
- **High-resolution model** evaluation / improvement → simulations can then be used to extend the radar process studies with what radars can't measure
- **Global models' cumulus parameterization** improved using statistical radar analyses → how will rainfall extremes change in a changing climate?

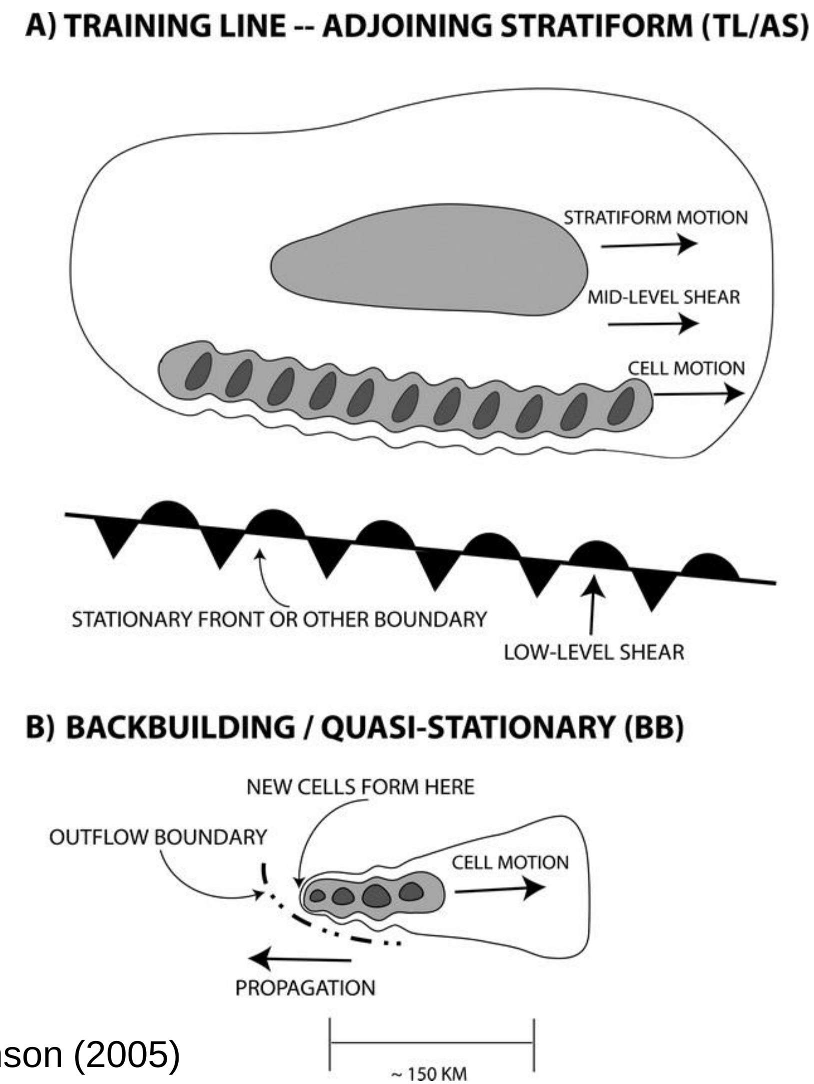
Mesoscale convective systems (MCSs)

Schumacher and Johnson (2006):

- Of all extreme (50-yr) 24-h rain events in the eastern CONUS during 1999–2003, over 66 % were associated with MCSs
- Of these, >33 % were training line / adjoining stratiform (TL/AS) systems and ~20 % were back-building (BB) systems

Stevenson and Schumacher (2014):

- Of all extreme (100-yr) 24-h rain events in the eastern CONUS during 2002–2011, over 63 % were associated with MCSs
- Two of the top ten events were associated with TL/AS MCSs (the rest were synoptic or tropical systems)

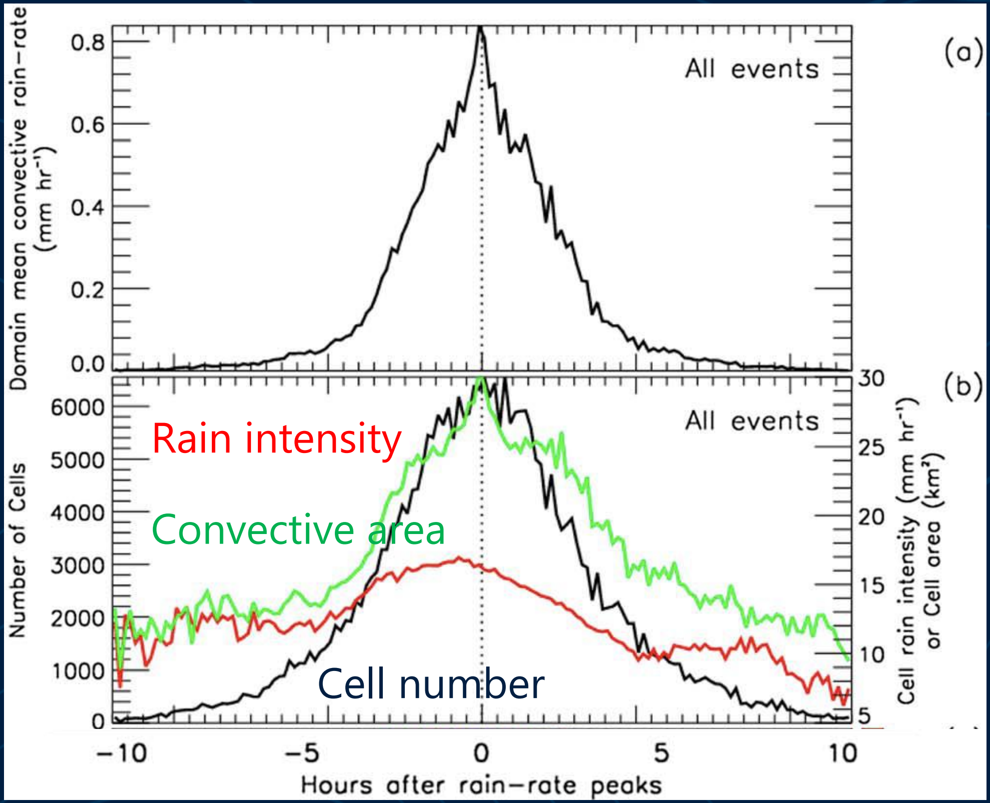


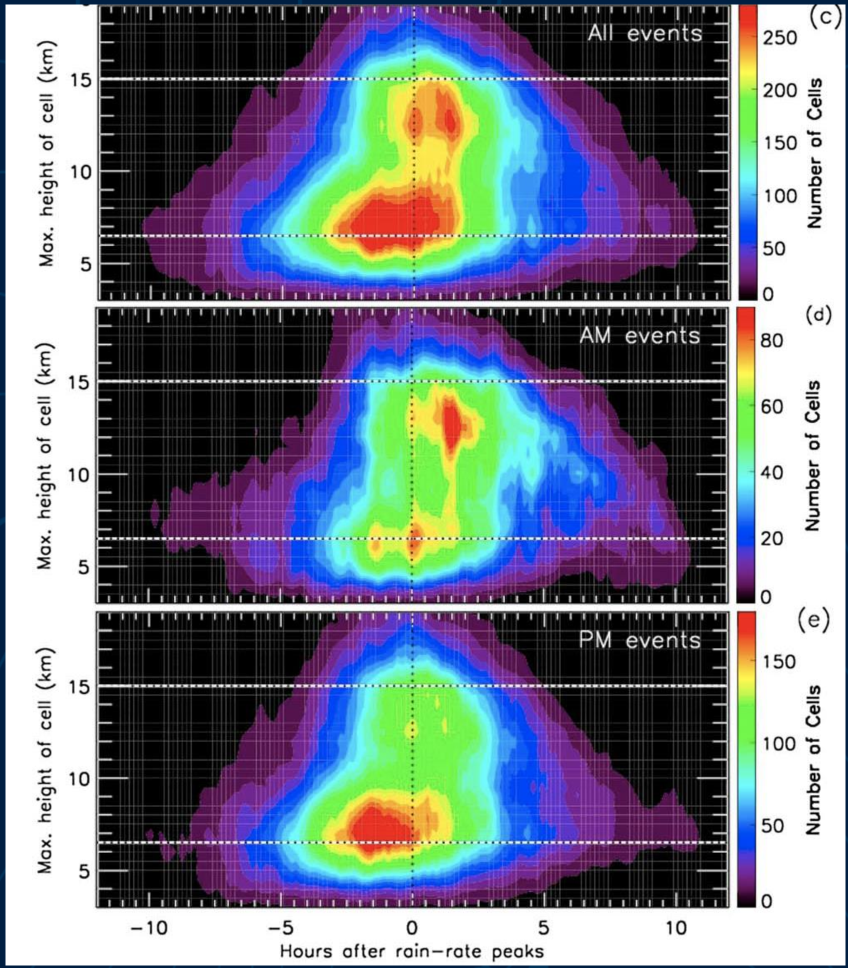
Schumacher and Johnson (2005)

Stolen from Rob Warren ☺

Composite life cycle of 144 heavy tropical rain cases

- The composite time evolution confirms dominant role of area fraction. Gradual growth of cloud depth from congestus to deep, but they also coexist.





Kumar et al., 2013, JGR

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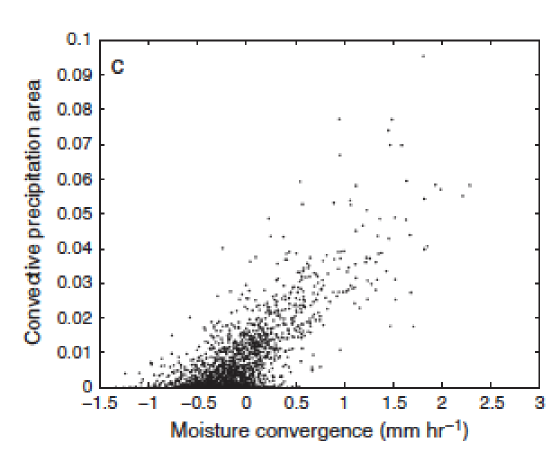
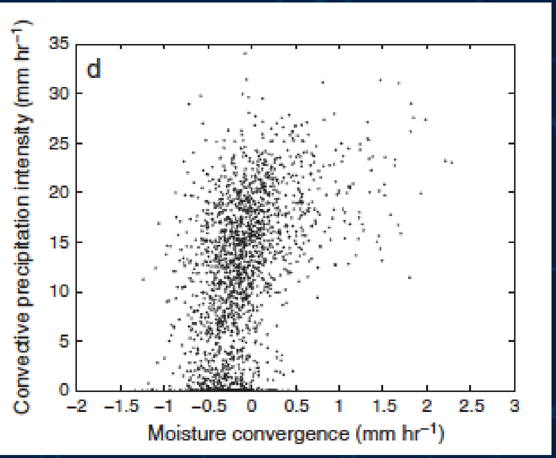
What drives convective area fraction ?

- Convective area fraction is strongly related to convergence (vertical motion, moisture), not to CAPE – most parameterizations use CAPE

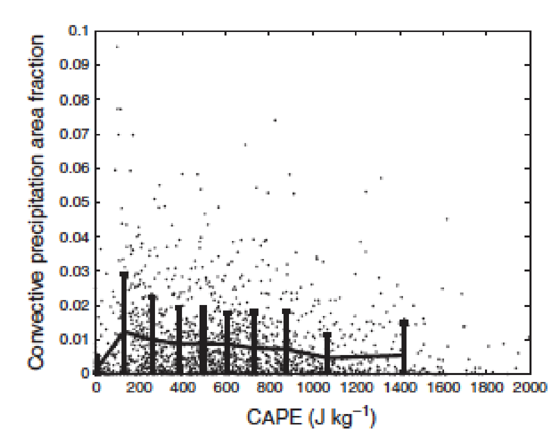
Convergence

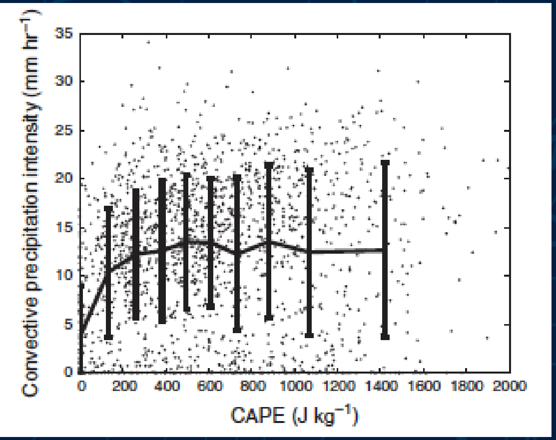




Davies et al., 2013, JGR

CAPE



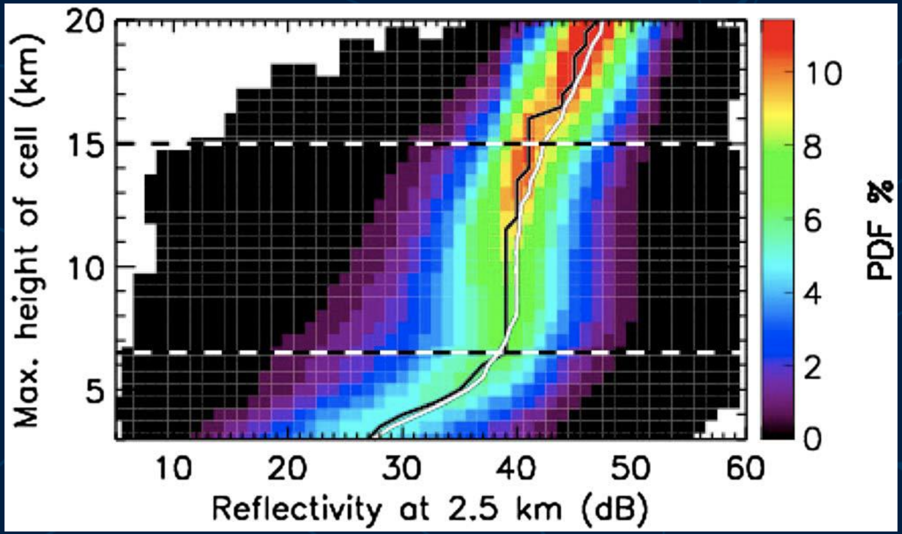


Convective area fraction

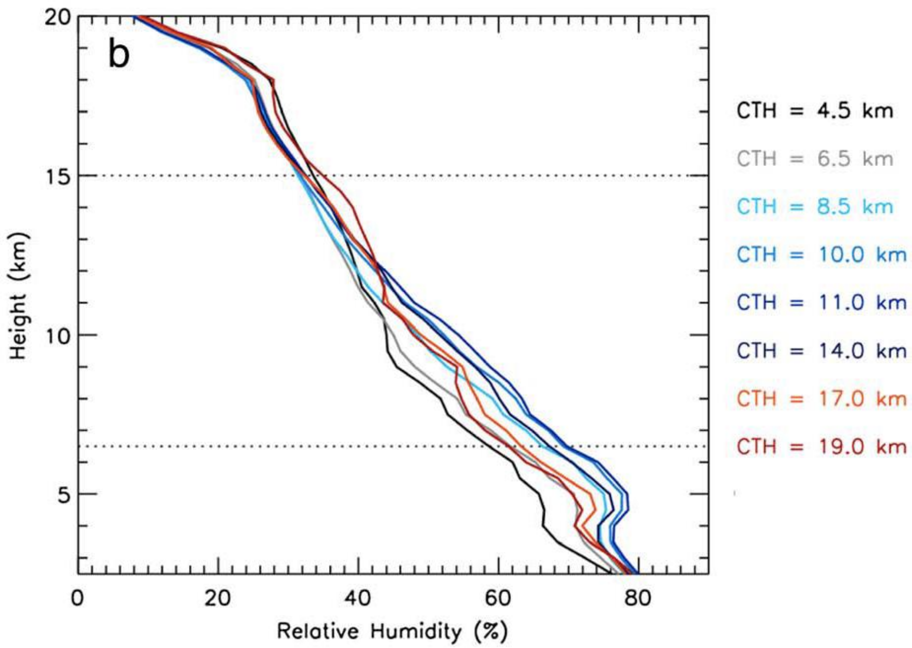
Rainfall intensity

Convective types and associated rain

- Using CPOL radar echo top height, we identify 3 types of precipitating convection (not including shallow convection). The most extreme rainfall (at 10-mn timescale) originates in overshooting convection, which itself occurs in a relatively dry environment.



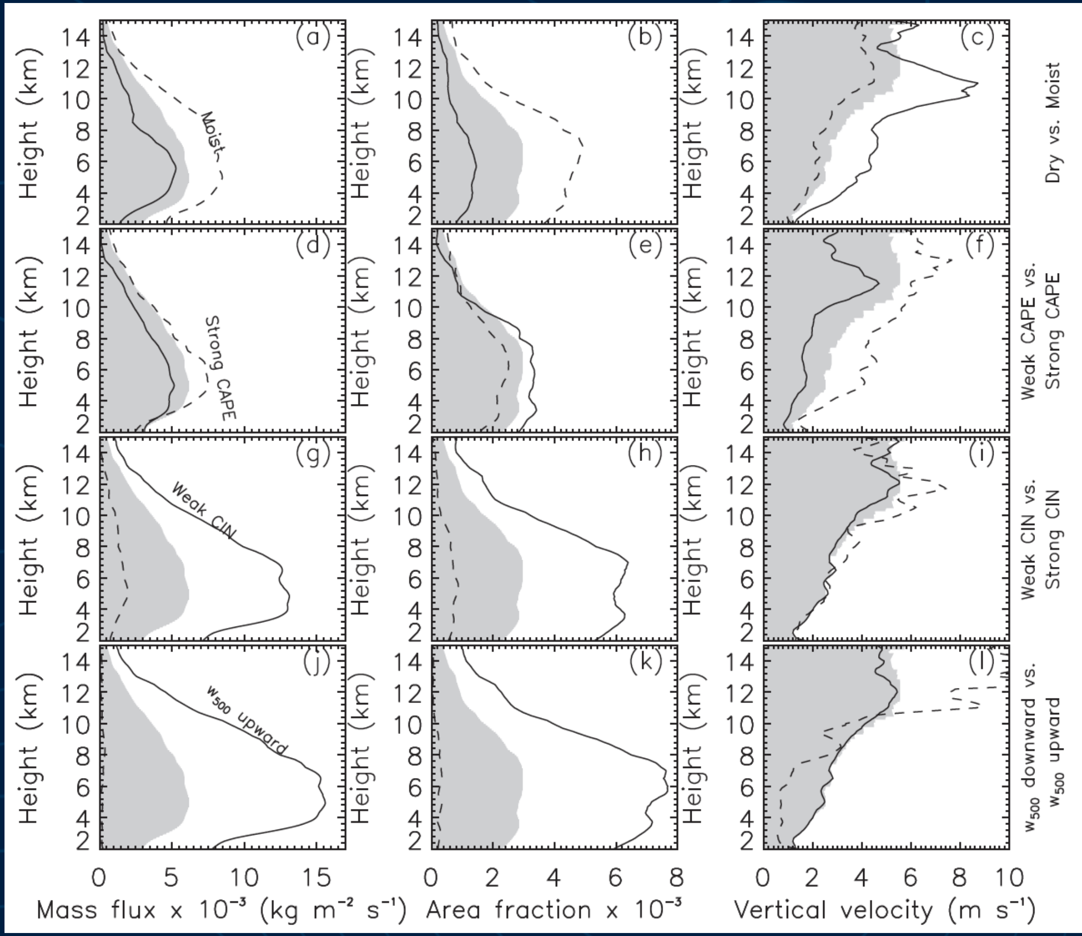
CPOL 2.5 km Z as a function of ETH



Kumar et al., 2013, JGR

Large-scale controls of convection

- Moisture strongly affects area fraction and velocity in opposing ways, CAPE mostly affects velocity and CIN and w_{500} control the existence of convection.



Moisture

CAPE

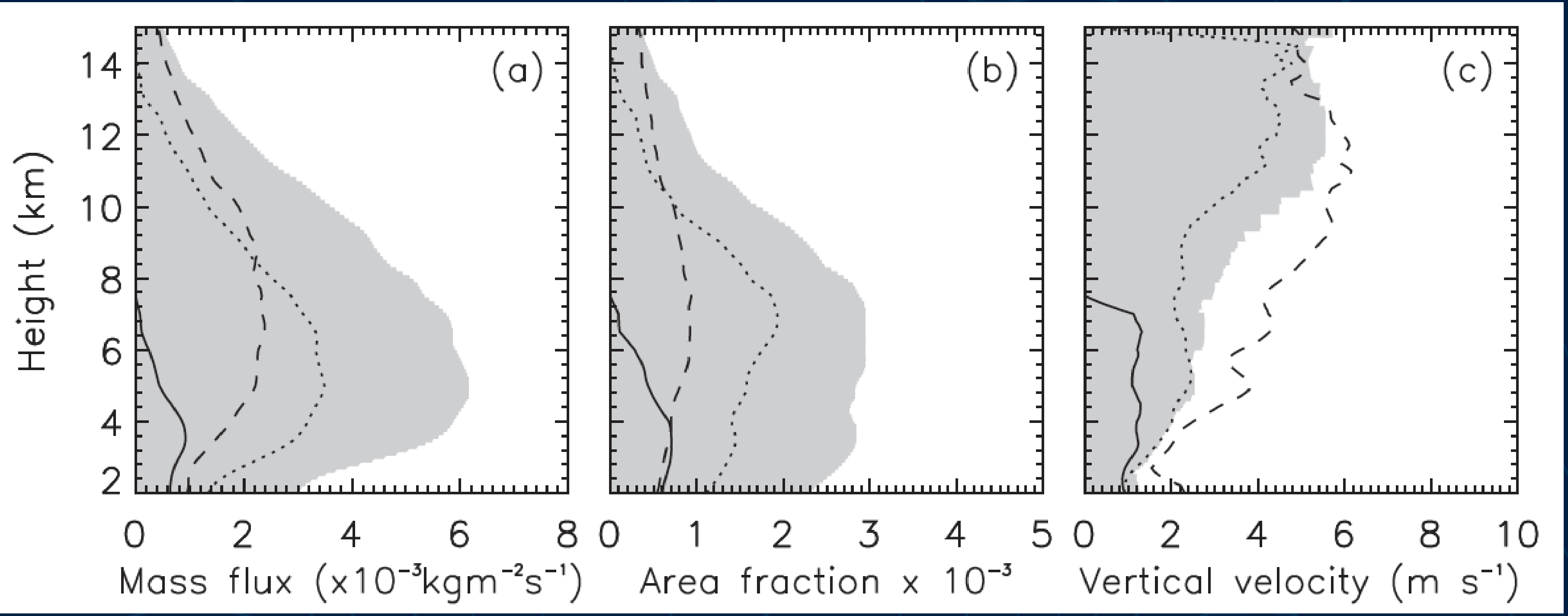
CIN

w_{500}

Kumar et al., 2015, JAS

Contribution of convective populations to total convective mass flux

- The three convection types contribute to total mass flux in unique ways, with different vertical distribution.



Kumar et al., 2015, JAS

Conclusions

- Radars are awesome but not perfect !
- Radars can be used to understand the mesoscale organization of extremes
- The National Open Radar Archive will be an invaluable resource
- Radars and a description of the largescale environment can be used to understand what large-scale conditions are conducive to extremes
- Radars can be used to evaluate and improve high-resolution models and global model parameterization of convection

- Big questions :
  - What are the spatial and temporal distributions of storms producing rainfall extremes in Australia?
  - What are the large-scale and mesoscale processes involved in Australia?
  - What are the primary organisational modes of convection?
  - How predictable are Australian storms producing rainfall extremes given current and soon-to-be operational forecast systems?
  - How is climate change likely to influence storms producing rainfall extremes in Australia?

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Thanks

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