

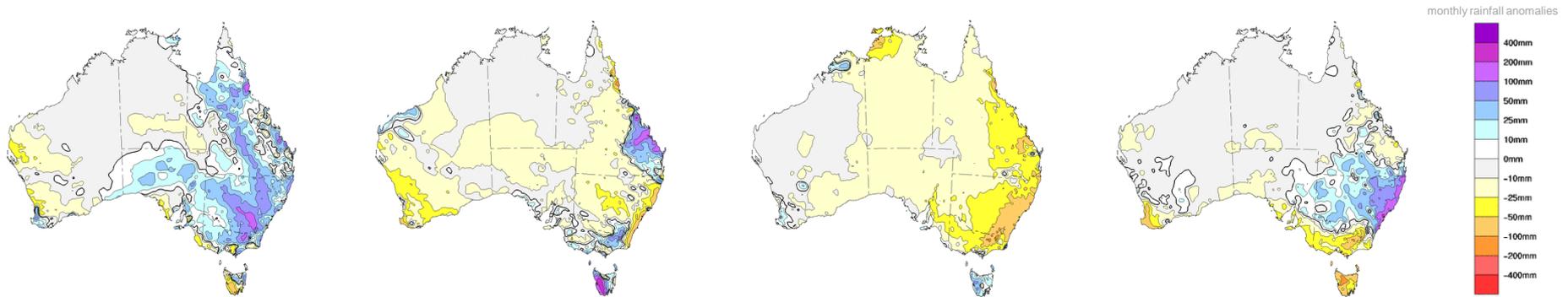
A weather system perspective on winter-spring rainfall variability in southeastern Australia during El Niño

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Rainfall variability in southeastern Australia

Large-scale drivers

- El Niño Southern Oscillation
- Madden-Julian Oscillation
- Indian Ocean Dipole
- Southern Annular Mode
- Atmospheric Blocking

Synoptic-scale drivers

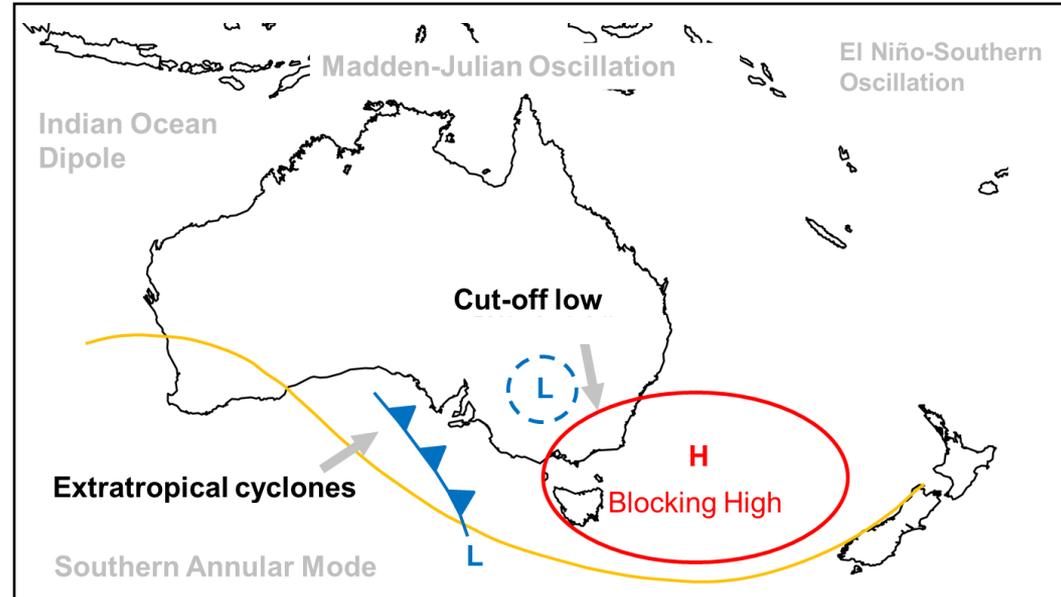
- (Extratropical) cyclones
- Cut-off lows

Contributions to rainfall in the austral winter-spring season:

Extratropical cyclones/frontal rain	33 - 45%
Cut-off lows	~ 50%

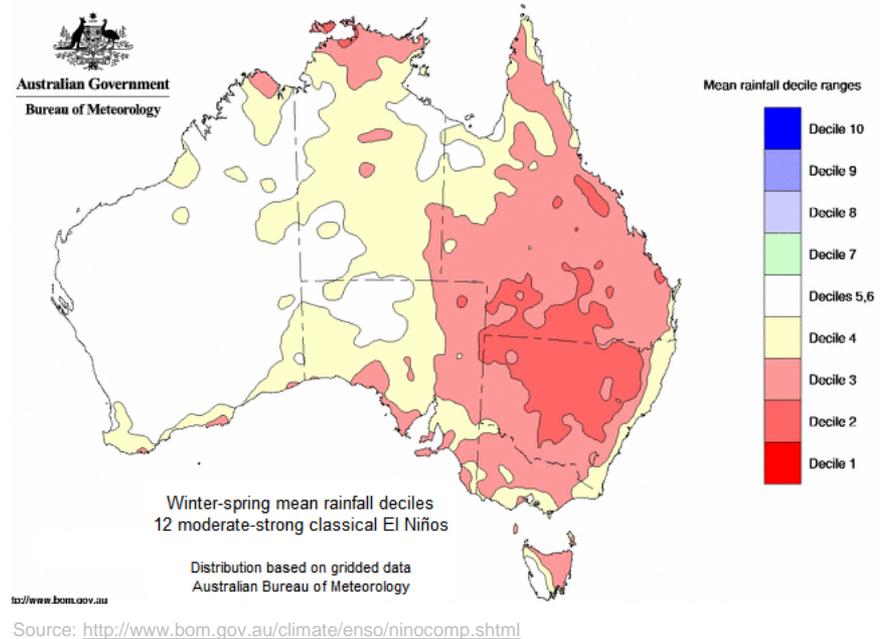
Cut-off low rainfall much more variable than frontal rainfall!

(e.g., Wright, 1989; Pook et al., 2006; Pook et al., 2014)



Average impact of El Niño on rainfall in Australia

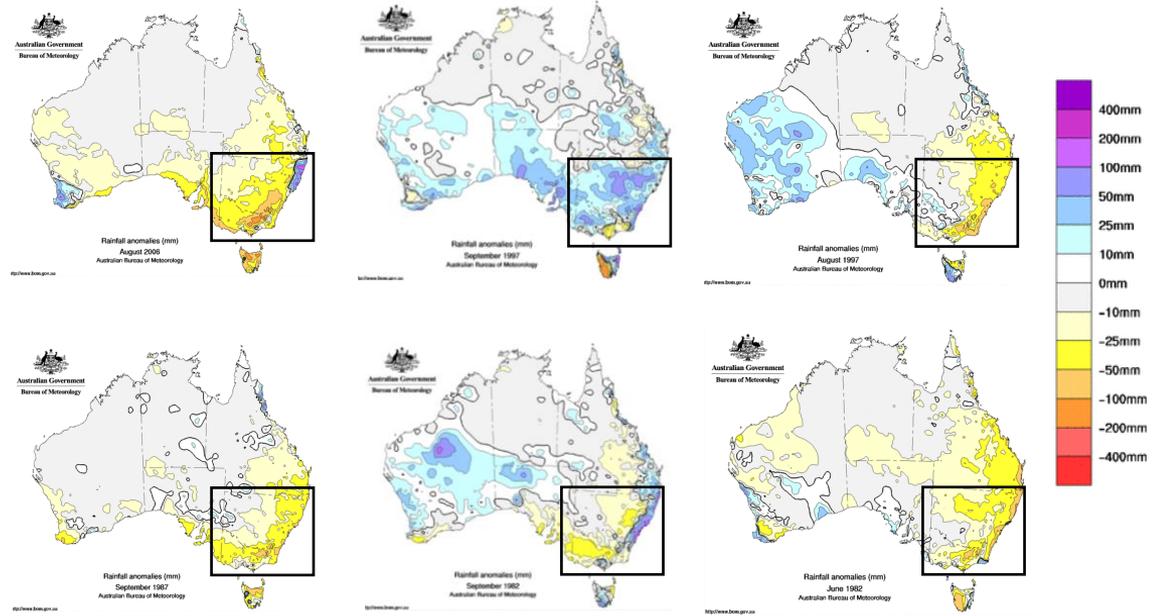
- Rainfall usually **reduced** in the eastern and extreme southern parts of Australia during the winter-spring season (Risbey et al., 2009)



Average impact of El Niño on rainfall in Australia

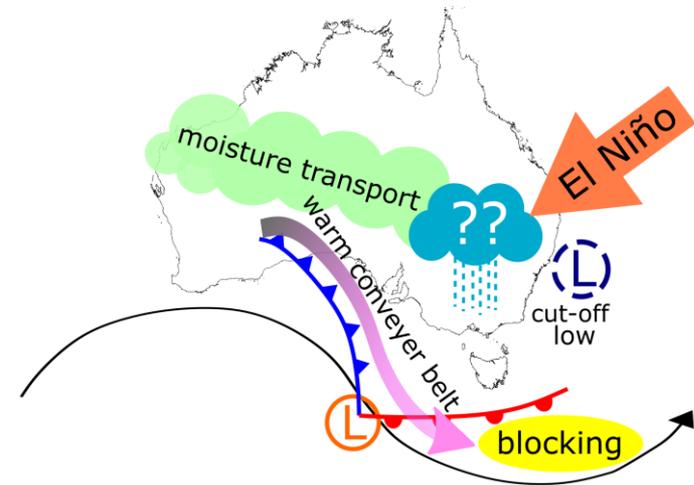
- **BUT**, large case-to-case variability, especially on subseasonal time scales!

Randomly selected months of Australian winter-spring season during an El Niño year



Questions of interest

- 1 What are the monthly rainfall anomaly patterns during the winter-spring season in southeastern Australia and how does the occurrence of these patterns change during El Niño events?
- 2 How do weather system frequencies over Australia change during El Niño?
- 3 How are weather systems related to observed rainfall anomaly patterns and which weather systems produce rainfall in southeastern Australia during El Niño?
- 4 Where is the origin of air masses during rainfall?

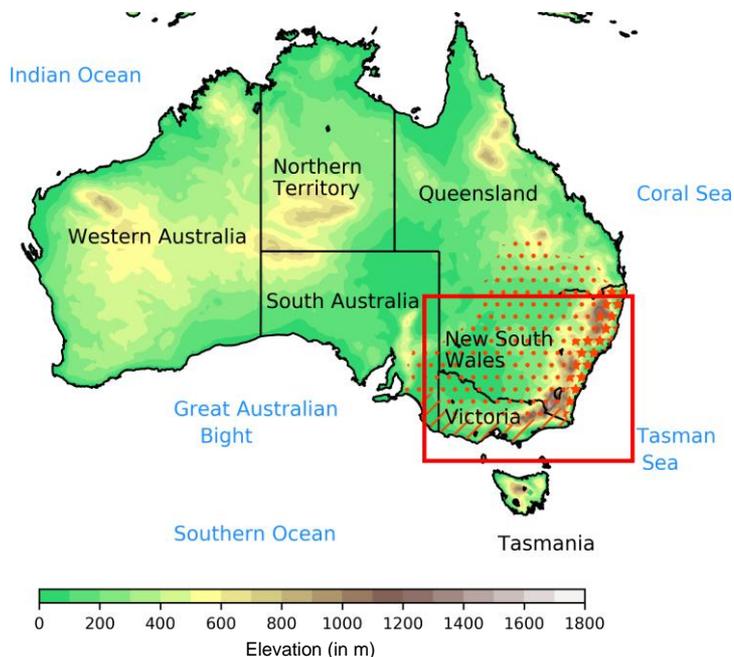


1

What are the monthly rainfall anomaly patterns during the winter-spring season in southeastern Australia and how does the occurrence of these patterns change during El Niño events?

Monthly rainfall anomaly patterns

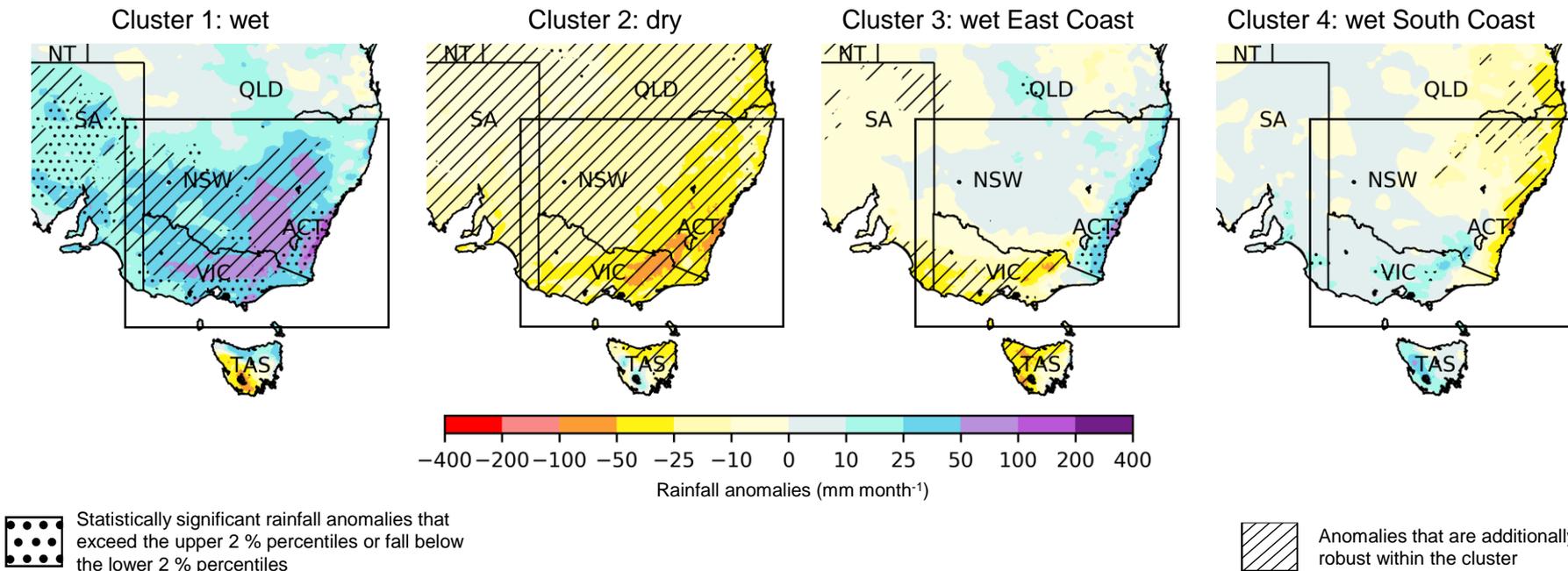
Derive patterns by K-means clustering



- K-means clustering (Hartigan et al., 1979; Clark et al., 2018)
- monthly rainfall anomalies (BoM, $\Delta x = 0.05^\circ$) based on 1961-1990 climatology over southeastern Australia (red box) in the winter-spring season 1979-2015
- Silhouette Score is used to find the physically most sensible number of clusters \rightarrow 4 clusters
- With focus on El Niño: Subset of clusters that only consists of months in an El Niño year (1982, 1987, 1991, 1993, 1994, 1997, 2002, 2006, 2009, 2015)

Monthly rainfall anomaly patterns during El Niño

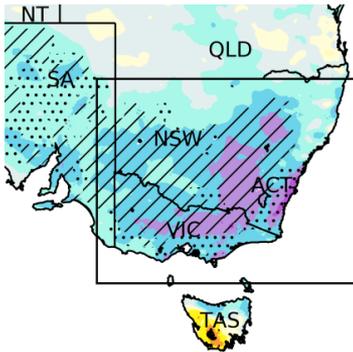
Cluster-mean rainfall anomalies



Monthly rainfall anomaly patterns during El Niño

Cluster characterization

Cluster 1: wet

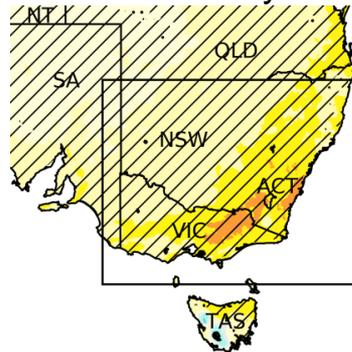


8.3%

Less months

This is the most unusual case during El Niño

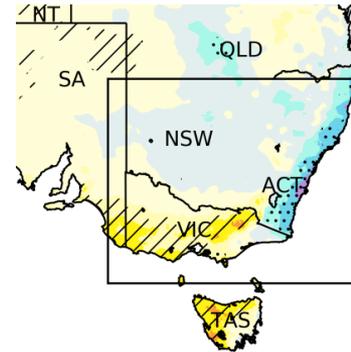
Cluster 2: dry



48.3%

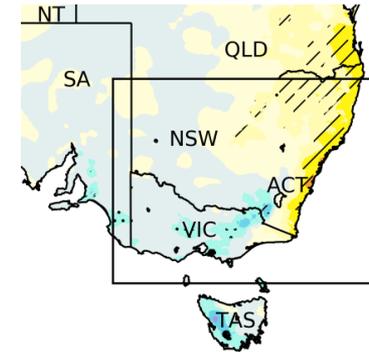
Confirms the observation of below-average rainfall during El Niño in southeastern Australia (e.g., Risbey et al. (2009))

Cluster 3: wet East Coast



20.0%

Cluster 4: wet South Coast



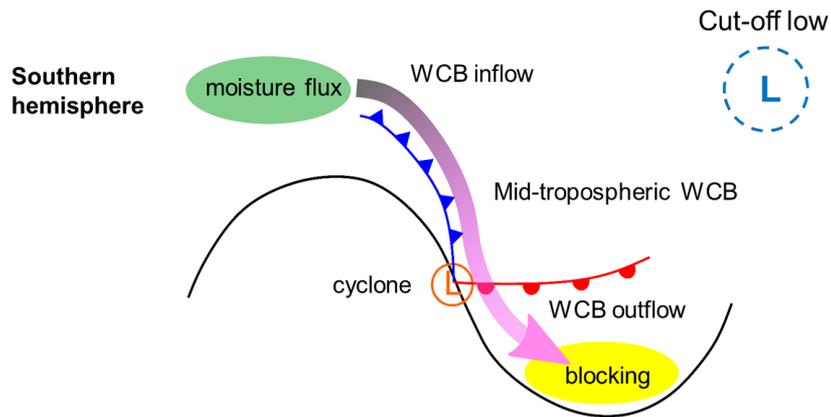
23.2%

2

How do weather system frequencies over Australia change during El Niño?

Weather systems during El Niño

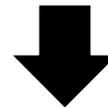
Objectively identified weather systems by Sprenger et al. (2017)



- Identified as occurrence frequency (binary fields) based on ERA-Interim data (6 hourly, 1° resolution)
- Eulerian fields: cut-off lows, atmospheric blocking, moisture flux, cyclones
- Lagrangian fields: warm conveyor belts (WCBs)



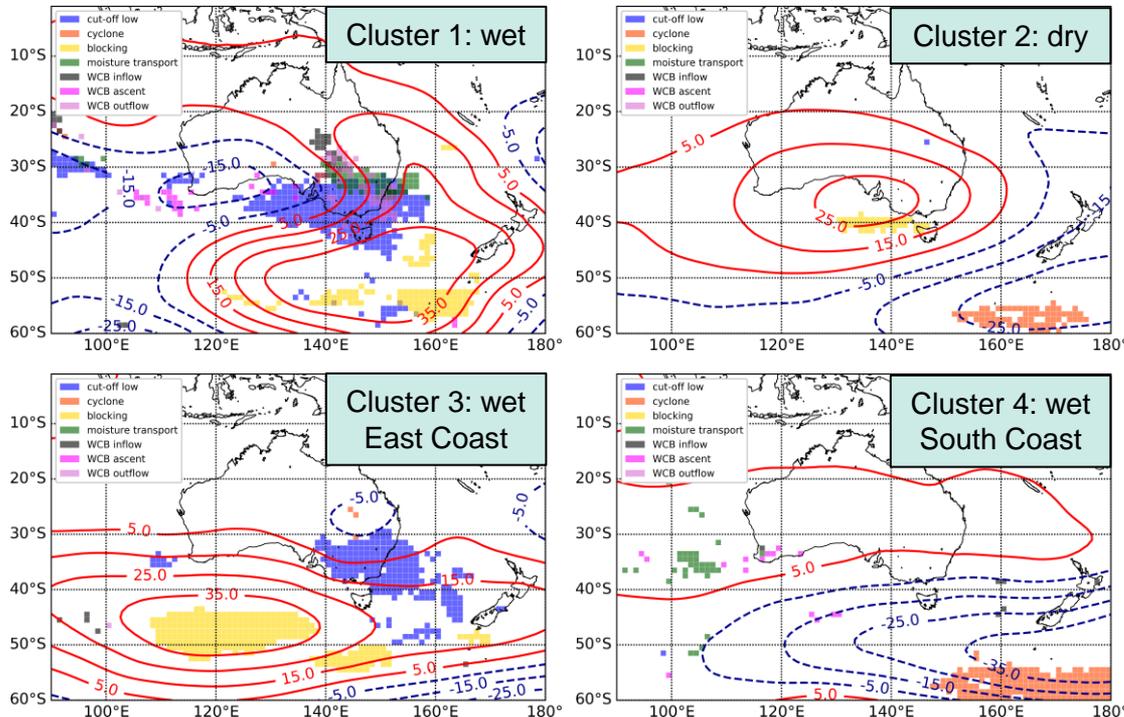
For each rainfall anomaly cluster:
average monthly frequency anomalies of weather systems



Statistical significance: Monte-Carlo

Weather systems during El Niño

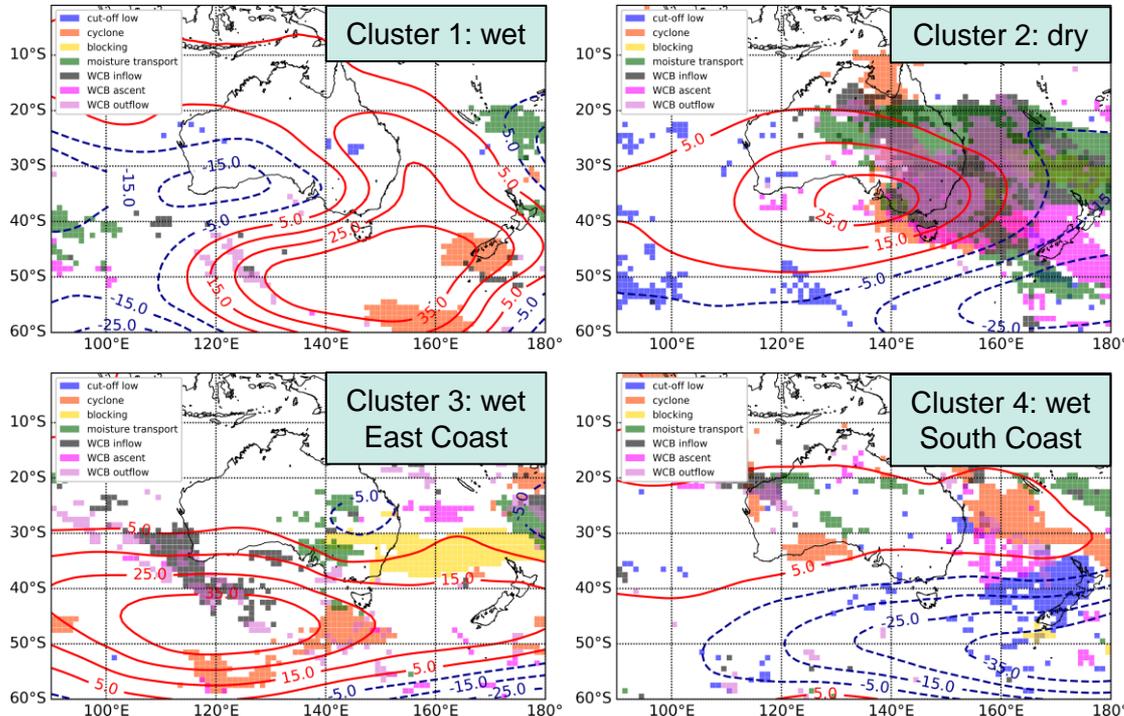
Cluster-mean significant and robust **positive** anomalies of weather system frequency



- Increased frequency of cut-off lows, WCBs and moisture transport over southeastern Australia in wet Cluster 1
- Anticyclone centered over Australia and more frequent blocking in dry Cluster 2
- Enhanced blocking southwest of Australia and enhanced frequency of cut-off lows in wet East Coast Cluster 3
- Equatorward storm track shift in wet South Coast Cluster 4

Weather systems during El Niño

Cluster-mean significant and robust **negative** anomalies of weather system frequency



— positive geopotential anomalies
 - - - negative geopotential anomalies

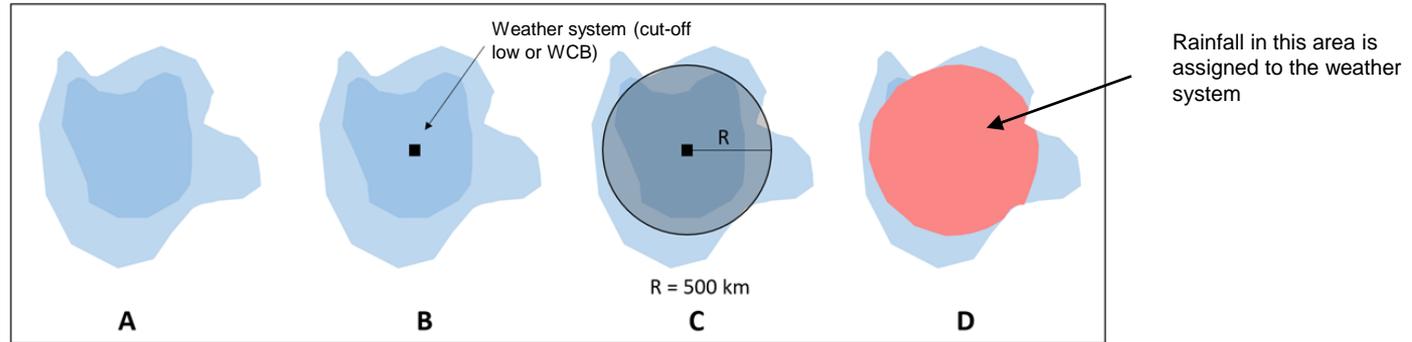
- Less frequent occurrence of cyclones, cut-off lows (hard to see), WCBs and moisture transport over and east of southeastern Australia in dry Cluster 2
- Blocking over Tasman Sea, extratropical cyclones south of and moisture transport over southeastern Australia less often observed in wet East Coast Cluster 3
- Below-average occurrence of cut-off lows, extratropical cyclones and associated WCB activity over Tasman Sea in wet South Coast Cluster 4

3

How are weather systems related to observed rainfall anomaly patterns and which weather systems produce rainfall in southeastern Australia during El Niño?

Contribution of weather systems to rainfall

Matching of daily rainfall with cut-off lows and WCB ascent (as proxy for frontal rainfall)



yields 4 possible cases

Rainfall assigned to cut-off low

Rainfall assigned to WCB

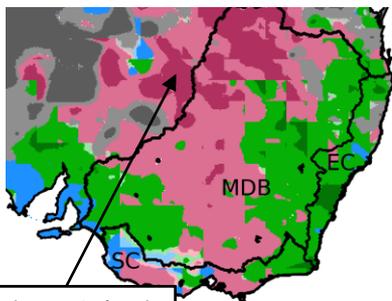
Rainfall assigned to both (overlap WCB and cut-off low mask)

Rainfall assigned to none of both

Contribution of weather systems to rainfall

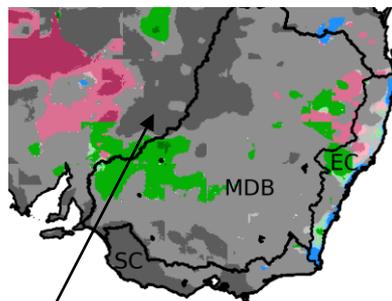
Dominant contributor to rainfall

Cluster 1: wet



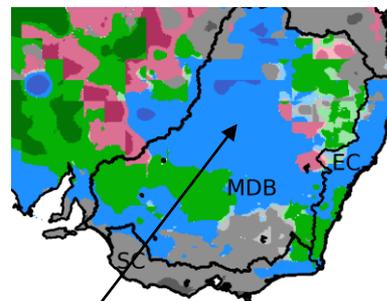
More than 50% of total rainfall is matched with a WCB which is the dominant contributor in Cluster 1 (especially inland)

Cluster 2: dry



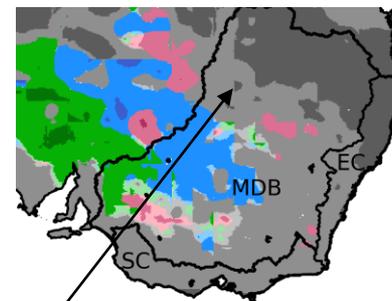
A large part of rainfall in Cluster 2 cannot be explained by cut-off lows or WCBs

Cluster 3: wet East Coast

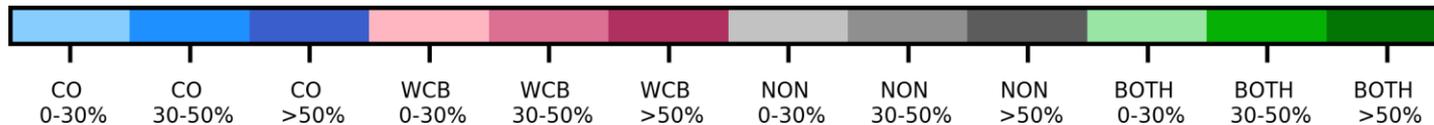


Cut-off lows play a dominant role as contributors to rainfall in Cluster 3

Cluster 4: wet South Coast



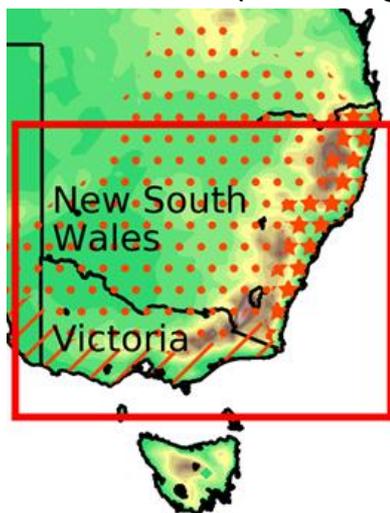
In multiple regions, rainfall seems not to be related to cut-off lows of WCBs



percentage amount of the total rainfall within a cluster that is explained by the dominant contributor

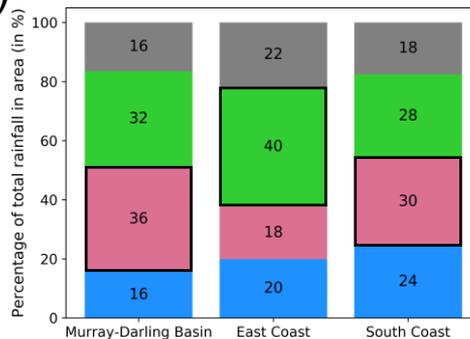
Contribution of weather systems to rainfall

Area sum (drainage divisions)

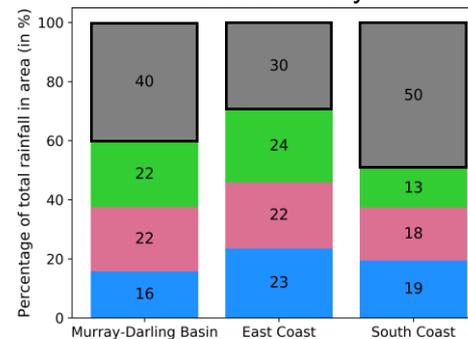


-  Murray-Darling Basin
-  South Coast Basin (Victoria)
-  East Coast Basin (New South Wales)

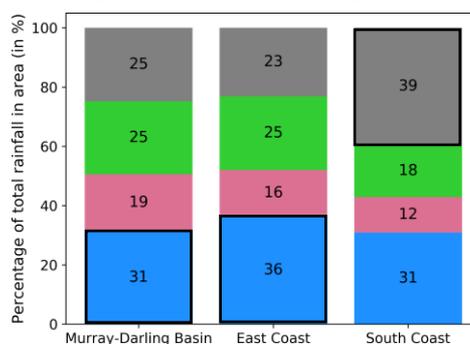
Cluster 1: wet



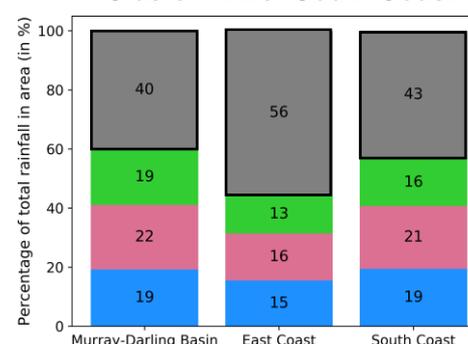
Cluster 2: dry



Cluster 3: wet East Coast



Cluster 4: wet South Coast



-  WCB
-  Cut-off low
-  Both
-  Non

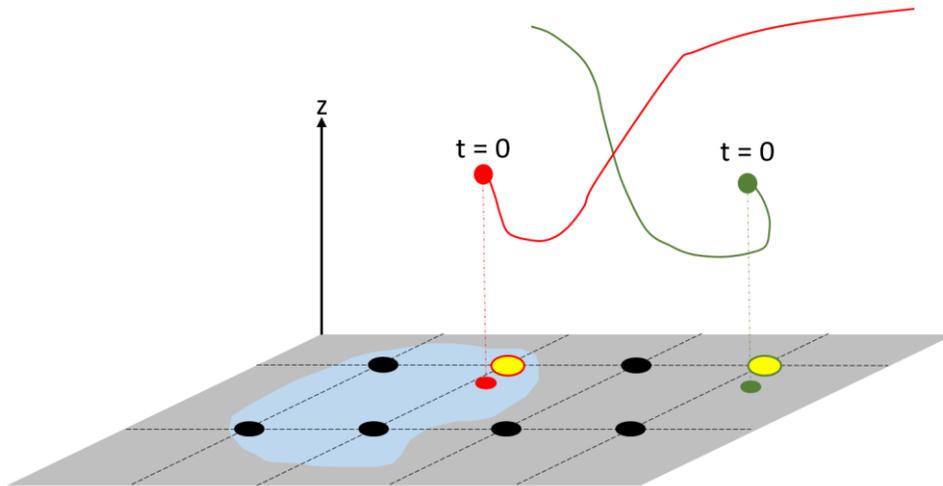


4

Where is the origin of air masses during rainfall?

Origin of air masses during rainfall

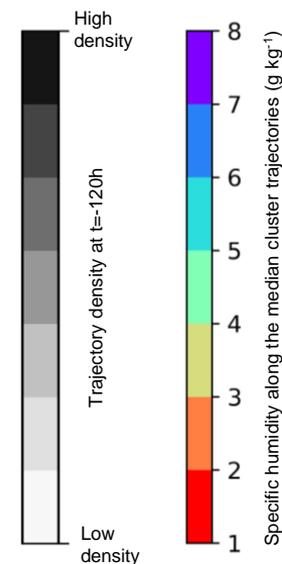
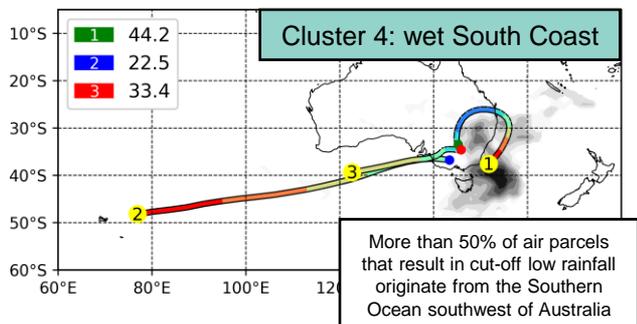
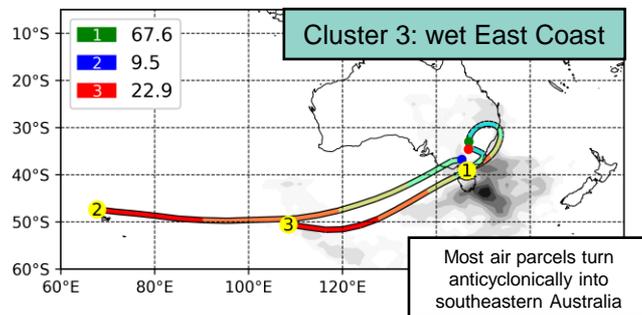
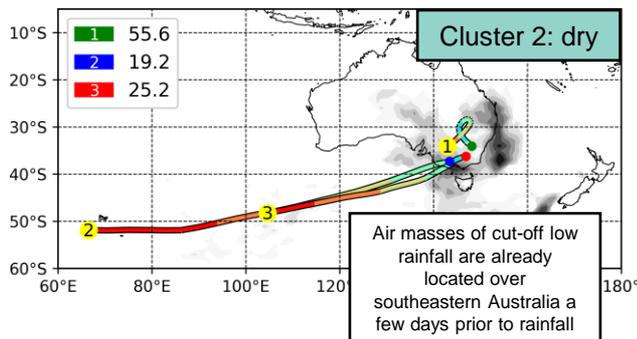
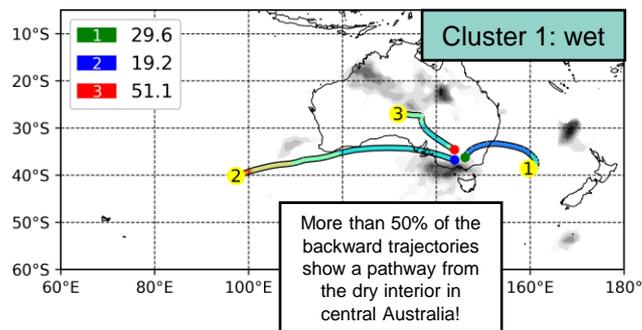
Calculate 10-day backward trajectories of rainfall ($\Delta x = 60\text{km}$) over southeastern Australia with LAGRANTO (Sprenger and Wernli, 2015)



- Check at each grid point, if daily rain amount > 0.1 mm; if yes, calculate backward trajectories at each pressure level between 490 and 970 hPa ($\Delta p = 30$ hPa) when relative humidity exceeds 80% (Sodemann et al., 2008)
- Assign backward trajectories to matching cases (Slide 15)
- Clustering of backward trajectories (Hart et al., 2015) reveals 3 trajectory cluster for each matching case
- Only focus on rare cut-off low and WCB rainfall (2 out of 4 matching cases)

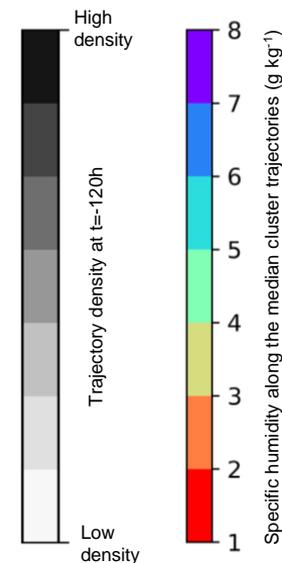
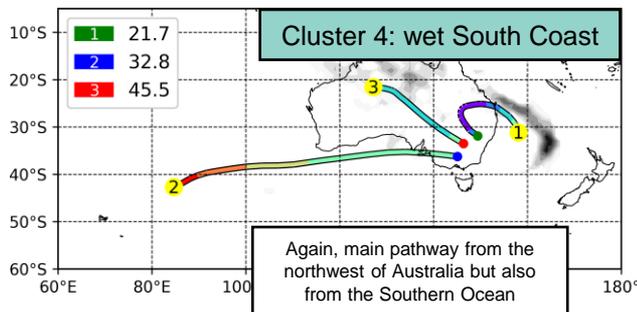
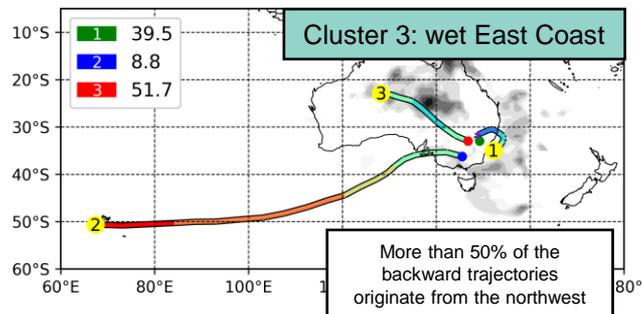
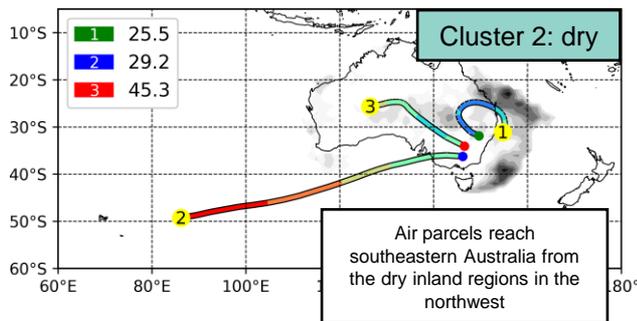
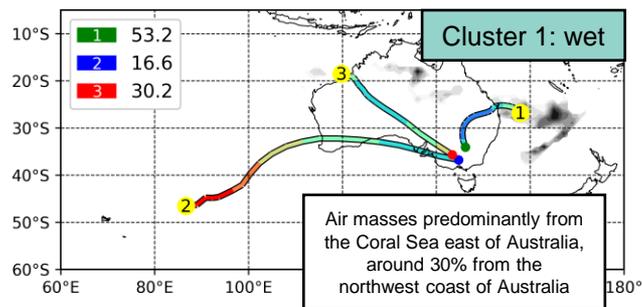
Origin of air masses during rainfall

Air masses that result in **cut-off low rainfall** over southeastern Australia



Origin of air masses during rainfall

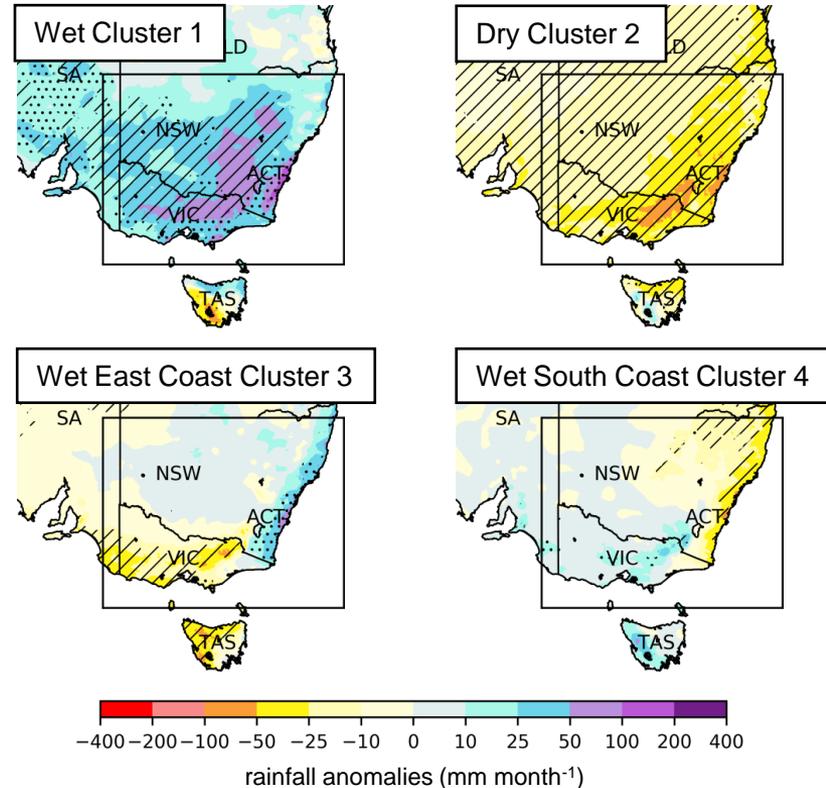
Air masses that result in **WCB rainfall** over southeastern Australia



Conclusions

- Four different spatial rainfall anomaly patterns dominate the rainfall variability in the winter-spring season and separate roughly
 - Wet
 - Dry
 - East Coast wet and South Coast wet months in southeastern Australia

- During El Niño, around 48% of winter-spring months show below-average rainfall over the region (Cluster 2) and only 8% are associated with unusual wet conditions (Cluster 1)



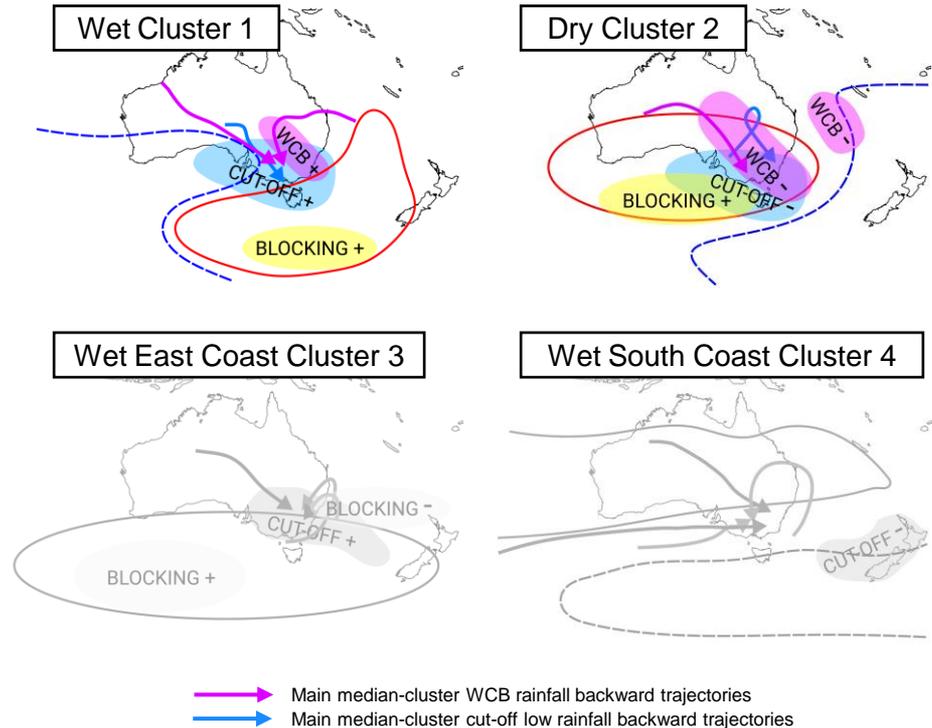
Conclusions

Wet Cluster 1

- Above-average blocking southeast of Australia and enhanced weather system activity (WCBs, cut-off lows, moisture transport)
- High contribution of WCBs to rainfall, especially inland of southeastern Australia
- Air masses of WCB (cut-off low) rainfall from Coral Sea and the northwest coast of Australia (dry interior of central Australia)

Dry Cluster 2

- Unusual often blocking over central Australia that co-occurs with a lack of weather system activity
- High proportion of rainfall is not matched with cut-off lows or WCBs
- Air masses of WCB (cut-off low) rainfall from the dry interior of central Australia (local southeastern Australia)



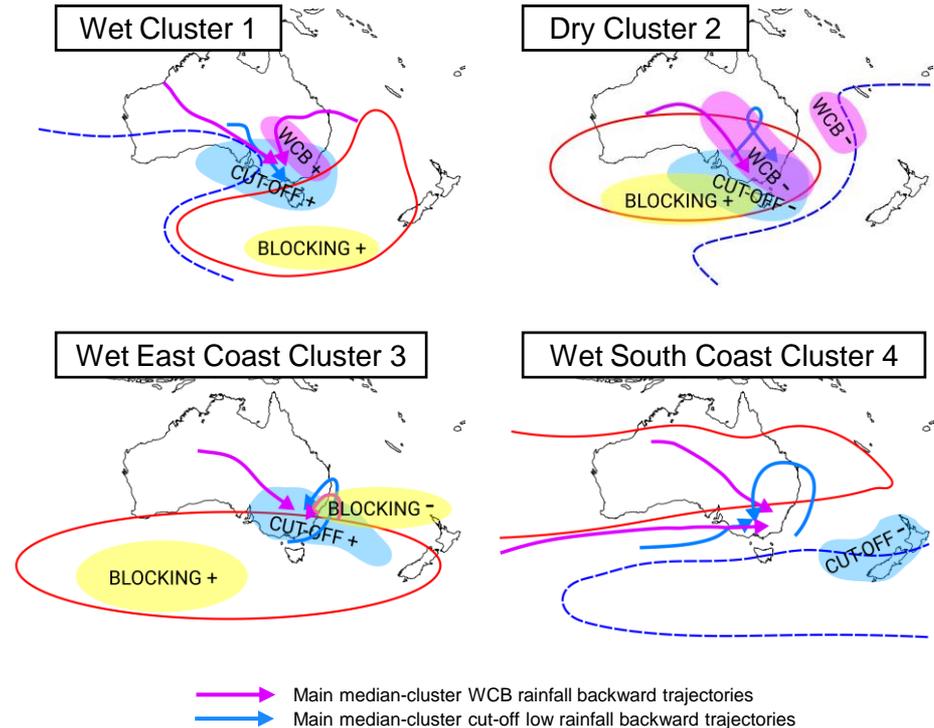
Conclusions

Wet East Coast Cluster 3

- More frequent blocking south of Western Australia vs. less frequent blocking over Tasman Sea → enhanced frequency of cut-off lows
- Dominant contribution of cut-off lows to rainfall
- Air masses of WCB (cut-off low) rainfall from dry interior of central Australia (Southern Ocean/Tasman Sea)

Wet South Coast Cluster 4

- Enhanced zone of negative geopotential anomalies, less frequent cut-off lows over Tasman Sea
- High proportion of rainfall is not matched with cut-off lows or WCBs
- Air masses of WCB (cut-off low) rainfall from the dry interior of central Australia and the Southern Ocean (Tasman Sea/Southern Ocean)



Thank you for your attention!

Paper accepted in Quarterly Journal of Royal Meteorological Society

Hauser, S., C. M. Grams, M. J. Reeder, S. McGregor, A. H. Fink, J. F. Quinting (2020) A weather system perspective on winter-spring rainfall variability in southeastern Australia during El Niño. *QJRMS*. doi: 10.1002/qj.3808. *Accepted*.

Cited publications in presentation

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