

Heat Waves in the Australian Region

Michael Reeder

School of Earth, Atmosphere and Environment
Monash University, Australia

Australian Natural Hazards

Table 5 – Comparison of fatality totals with other Australian natural hazards (from PerilAUS).

Natural hazard	Deaths 1900–2011	% total natural hazard deaths 1900–2011
Extreme heat	4,555	55.2
Flood	1,221	14.8
Tropical cyclone	1,285	15.6
Bush/grassfire	866	10.5
Lightning	85	1
Landslide	88	1.1
Wind storm	68	0.8
Tornado	42	0.5
Hail storm	16	0.2
Earthquake	16	0.2
Rain storm	14	0.2

Coates L., Haynes K., O'Brien J., McAneney J., and De Oliveira F. D. 2014. Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844–2010. *Environ. Sci. Policy*, 42, 33–44.

What is a Heat Wave?

Table 3

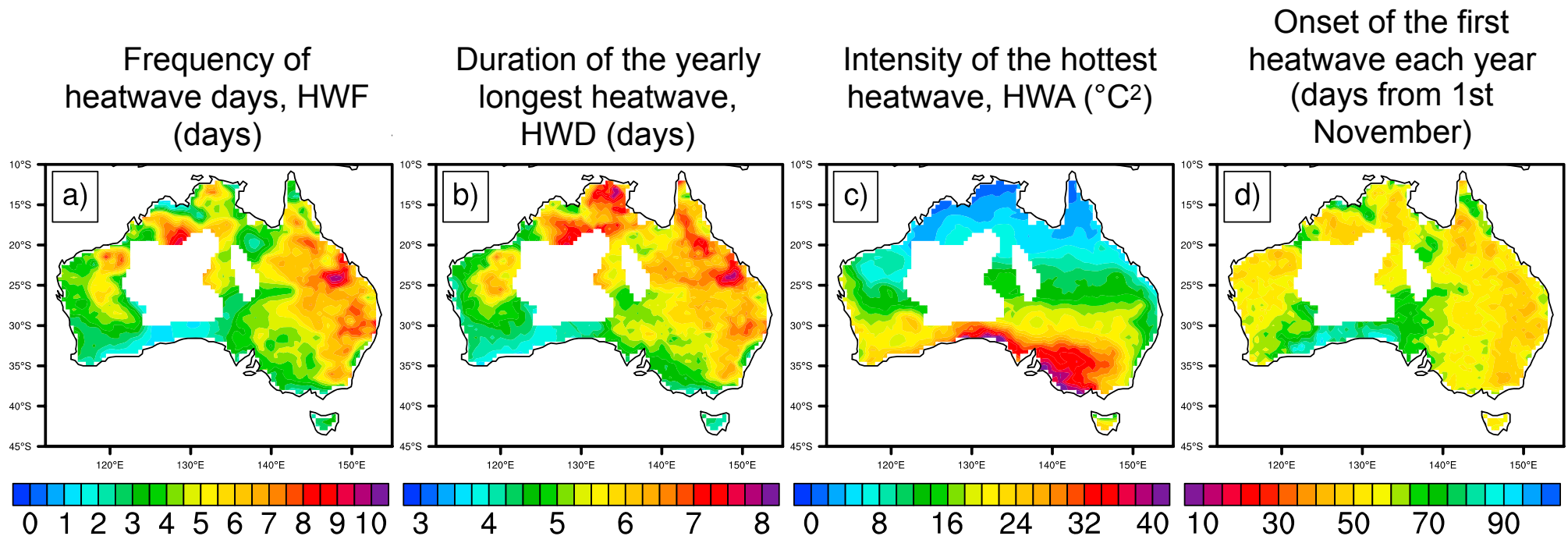
Examples of more recent specific heatwave indices proposed in the climate science literature. While there are some commonalities between the indices, no two studies have used the same index. This can make it very difficult to compare changes in heatwaves at regional scales, particularly when interested in a number of characteristics.

Study	Index description	Heatwave characteristic measured
Meehl and Tebaldi (2004)	“Worst” 3-day event:—the hottest 3 consecutive nights per year	Intensity
Meehl and Tebaldi (2004)	Exceedance index—longest period where maximum temperature is above the 97.5th percentile for at least 3 days; average daily maximum temperature across the event is over the 97.5th percentile; all days are above the 81st percentile.	Duration
Fischer and Schär (2010)	AT105F—number of days where apparent temperature (relative humidity and temperature combined) exceeds 40.6 °C	Frequency, intensity
Fischer and Schär (2010)	Multi-measurement index—periods of at least 6 days where maximum temperature exceeds the calendar day 90th percentile (15 day calendar window). Per summer, the total number of events; the hottest day of the hottest event; the length of the longest event; and the sum of all heatwave days are calculated	Frequency, intensity, duration
Fischer and Schär (2010)	CHT—combined hot days and tropical nights (see Table 1)	Frequency, intensity
Vautard et al. (2013)	Periods of various length where daily mean temperature is above the 90th percentile	Frequency, intensity, duration and persistence
Schoetter et al. (2014)	At least 3 days above the 98th percentile of maximum temperature	Cumulative intensity (calculated via mean intensity and extent, as well as duration)
Stefanon et al. (2013)	Exceedance of the calendar-day (21-days) 90th percentile of maximum temperature	Spatial extent, duration
Nairn and Fawcett (2013)	At least 3 consecutive days where temperature (the average of the maximum and minimum) exceeds the climatological 95th percentile, and is anomalously warm compared to the prior month	Intensity, duration, spatial extent

Perkins, S. E. 2015. A review on the scientific understanding of heatwaves - Their measurement, driving mechanisms, and changes at the global scale. *Atmos. Res.*, 164-65, 242-267.

Heat Wave Statistics

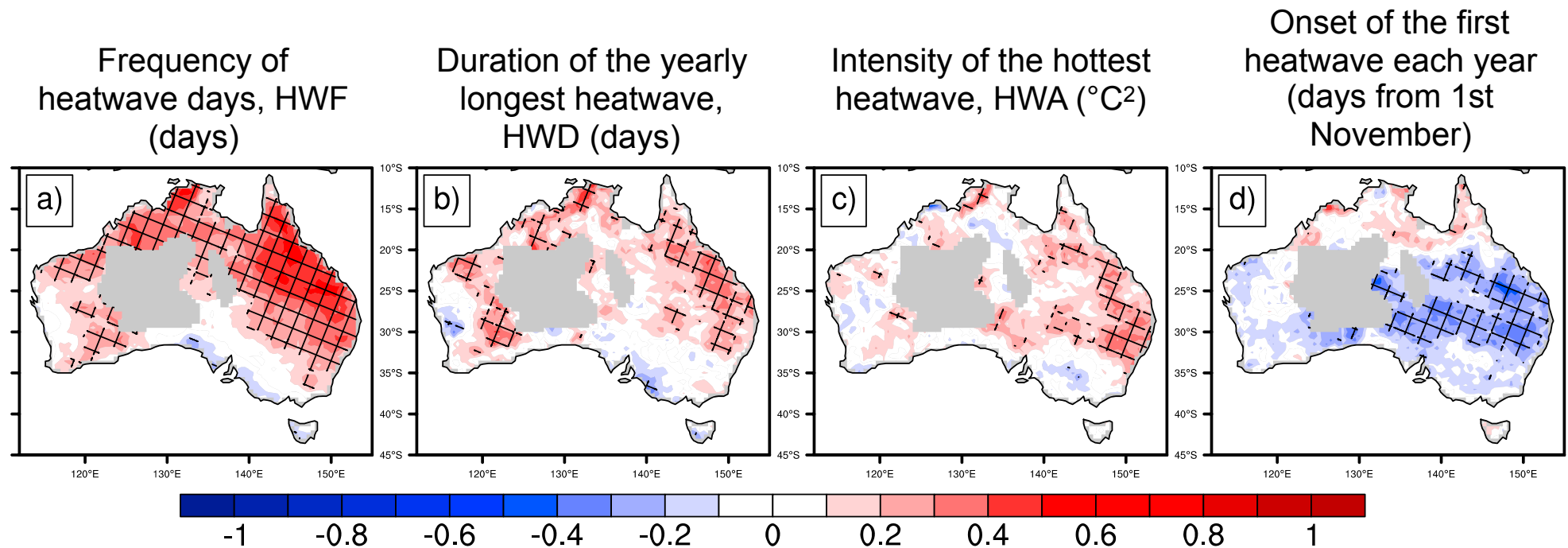
Climatology of Australian heatwave characteristics using AWAP data set over 102 (commencing in years 1911–2012) extended summers (November to March).



Perkins, S. E., D. Argüeso, and C. J. White. 2015. Relationships between climate variability, soil moisture, and Australian heatwaves. *J. Geophys. Res.*, 120, 8144 - 6164.

ENSO

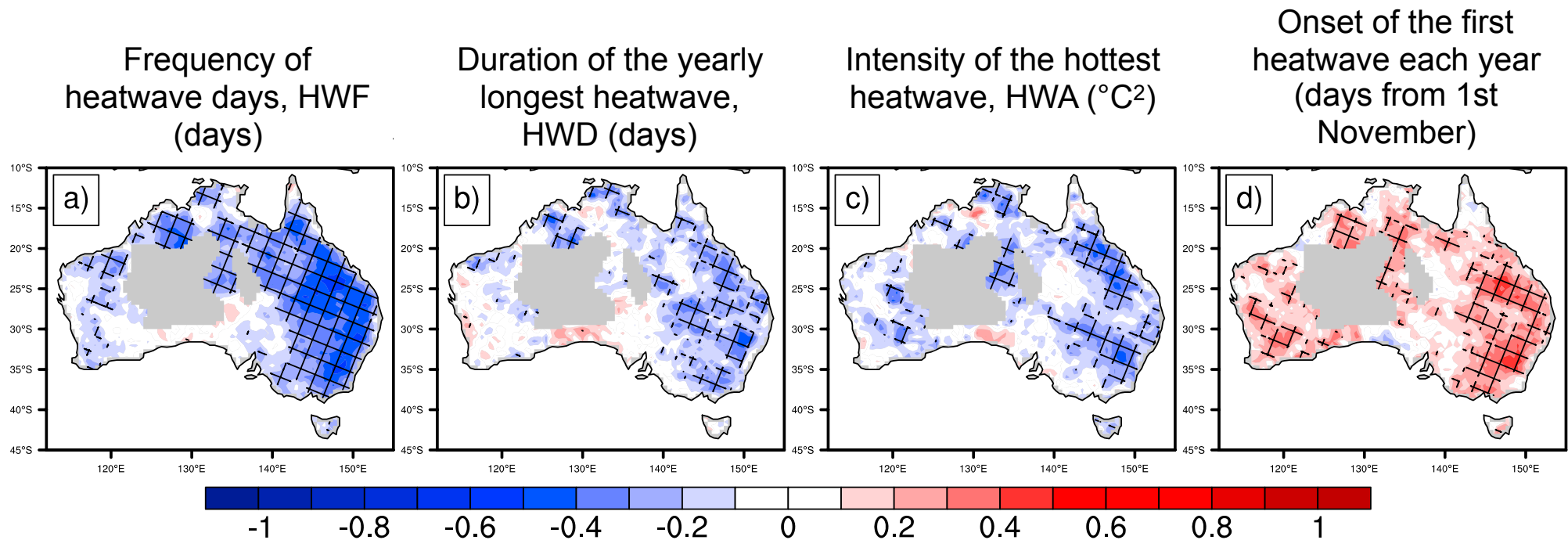
Correlations between ENSO and HWF, HWD, HWA, and HWT, respectively, with hatching indicating statistical significance.



Perkins, S. E., D. Argüeso, and C. J. White. 2015. Relationships between climate variability, soil moisture, and Australian heatwaves. *J. Geophys. Res.*, 120, 8144 - 6164.

Surface Sensible Heating

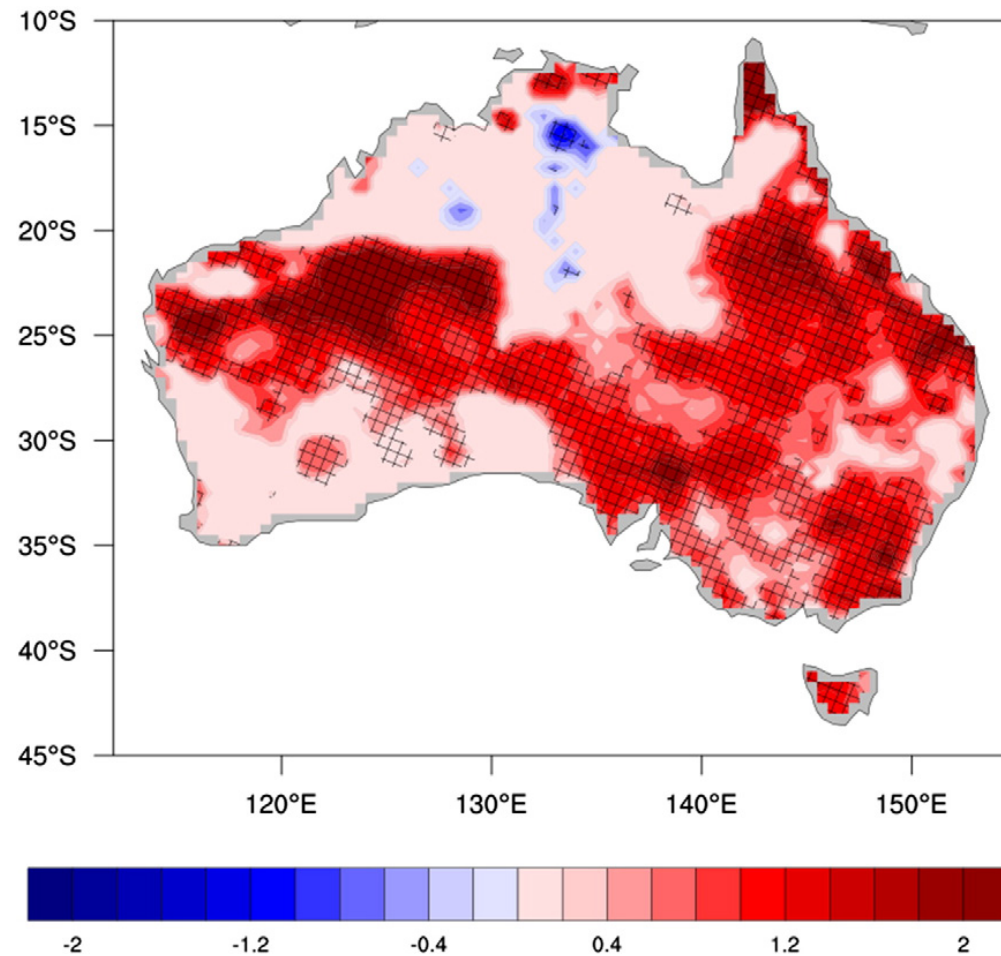
Correlations between antecedent soil moisture with HWF, HWD, HWA, and HWT, respectively, with hatching indicating statistical significance.



Perkins, S. E., D. Argüeso, and C. J. White. 2015. Relationships between climate variability, soil moisture, and Australian heatwaves. *J. Geophys. Res.*, 120, 8144 - 6164.

Recent Heat Wave Trends

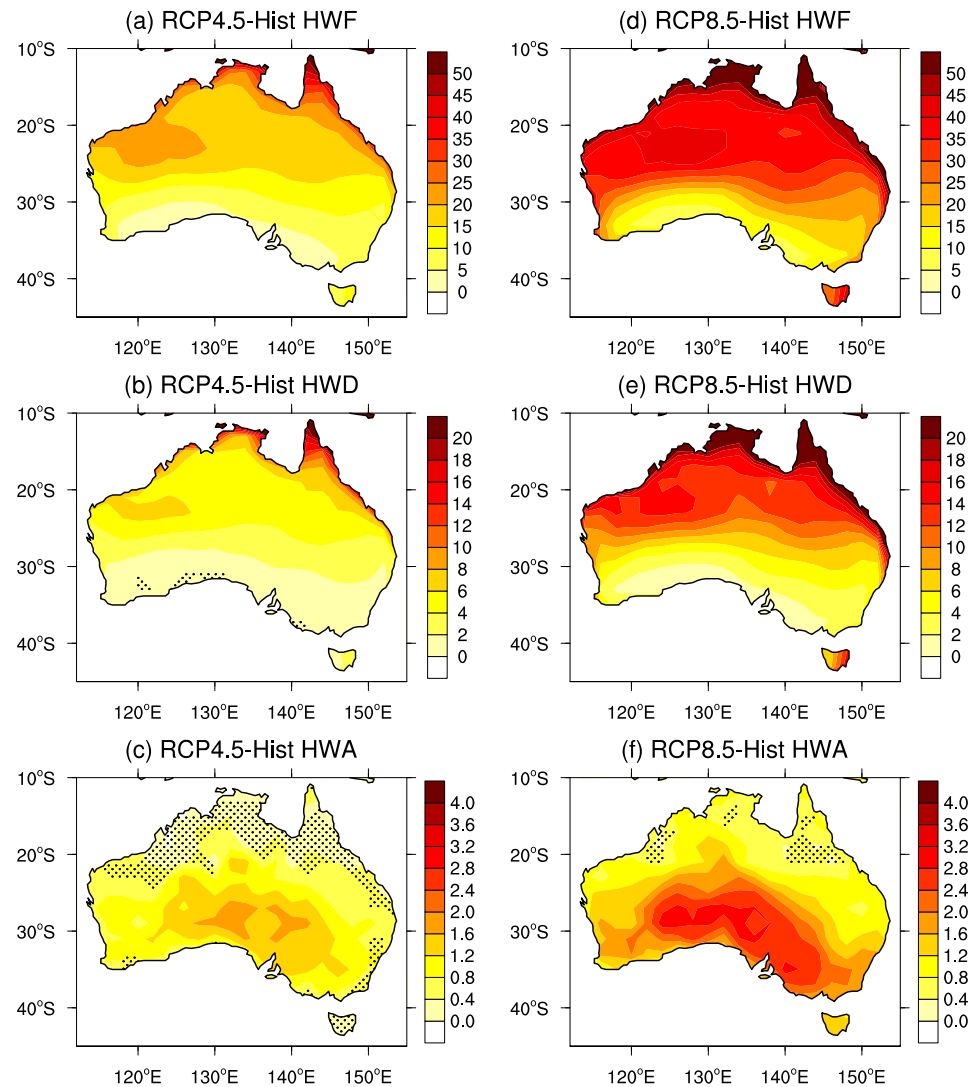
Trends in the number of heat wave days (November–March) between 1950 – 2013.
Units are in days/decade, hatching indicates significance at the 5% level.



Perkins, S. E. and L. V. Alexander. 2013. On the measurement of heat waves. J. Clim., 26, 4500 – 4517.

Future Changes

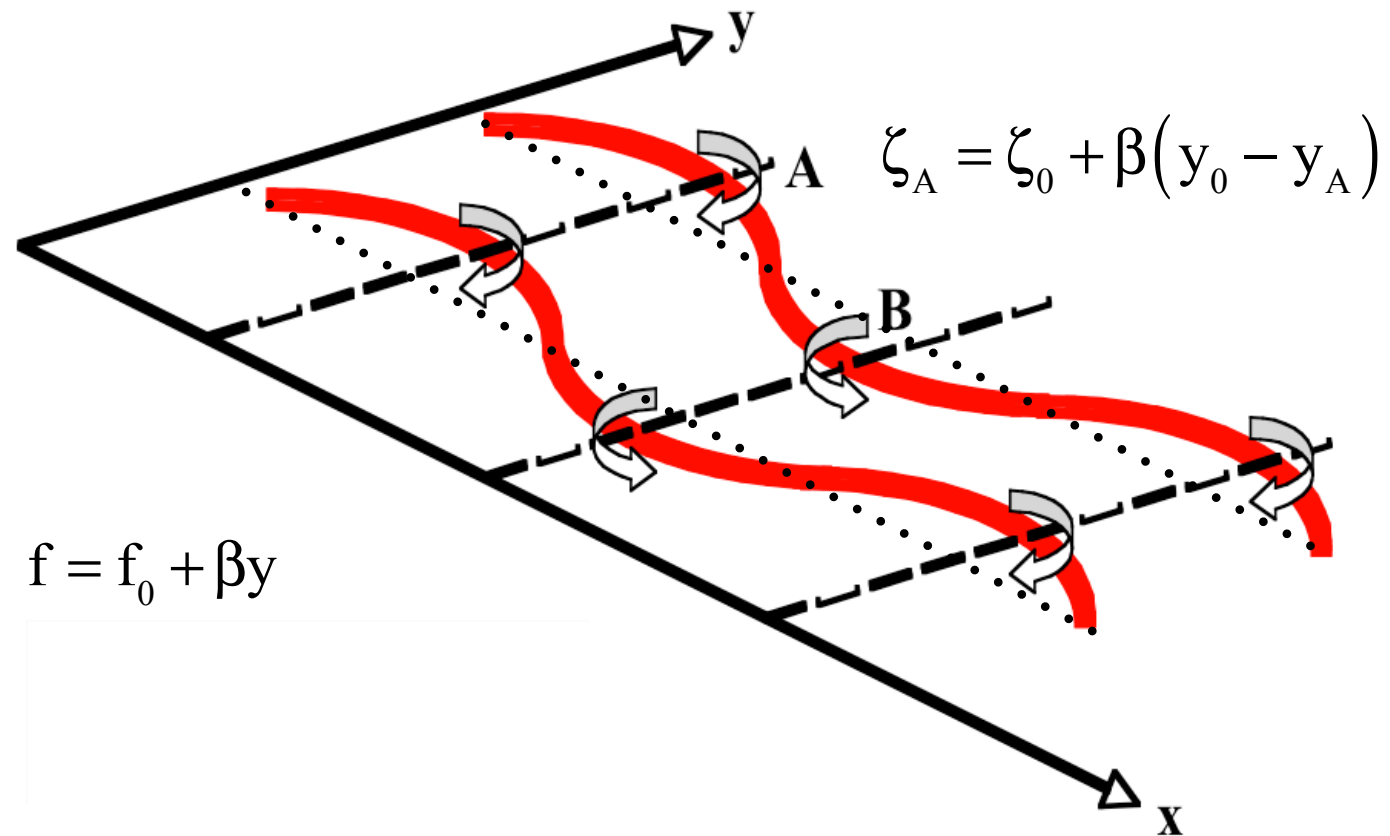
RCP minus historical MMM HW climatology: 2081-2100



Cowan et al. 2014. More frequent, longer, and hotter heat waves for Australia in the Twenty-First century. *J. Clim.*, 27, 5851 - 5871.

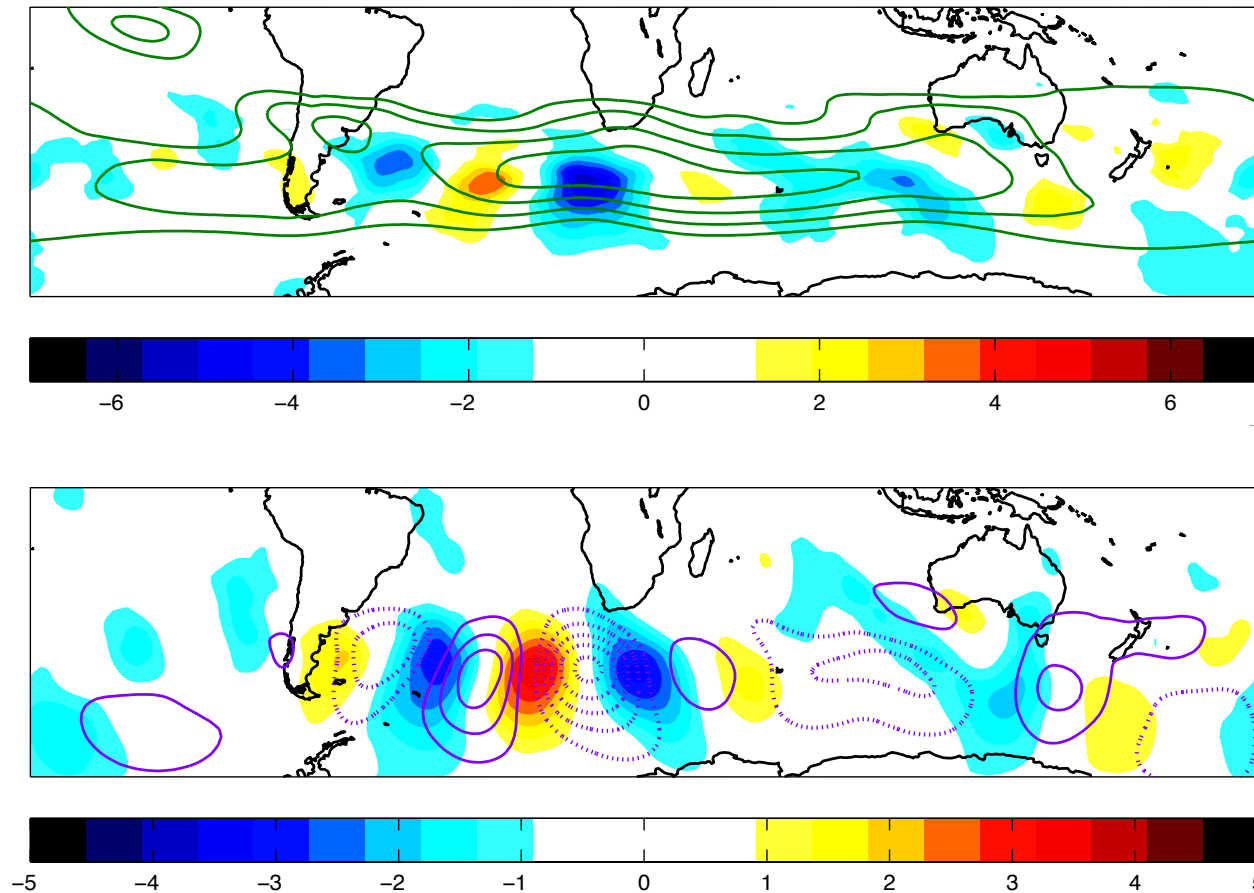
Southern Hemisphere Rossby Waves

$$\frac{D}{Dt}(f + \zeta) = 0 \quad \Rightarrow \quad f_0 + \beta y_A + \zeta_A = f_0 + \beta y_0 + \zeta_0$$



DJF Midlatitude Rossby Wave Packets

Day -4

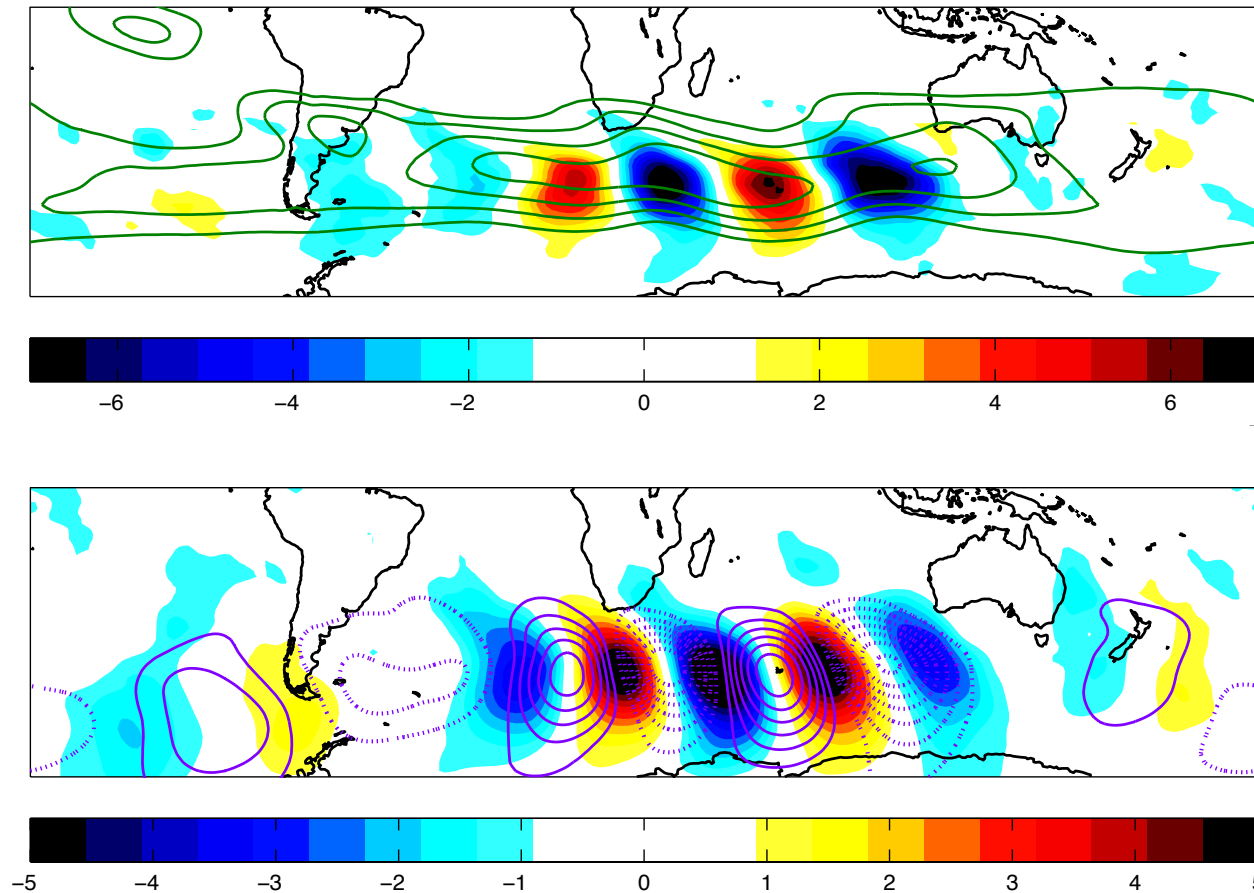


Time lagged composite on 350 K. (a) pv anomalies (PVU) (shaded). (b) meridional wind anomalies (ms^{-1}) (shaded), 200 mb geopotential height anomalies (purple contours).
Composite jet [20, 30, 40] ms^{-1} (green contours)

O'Brien, L., and M. J. Reeder. 2017. Southern Hemisphere summertime Rossby waves and weather in the Australian region. *Quart. J. Roy. Meteor. Soc.*, 143, 2374 – 238.

DJF Midlatitude Rossby Wave Packets

Day -2

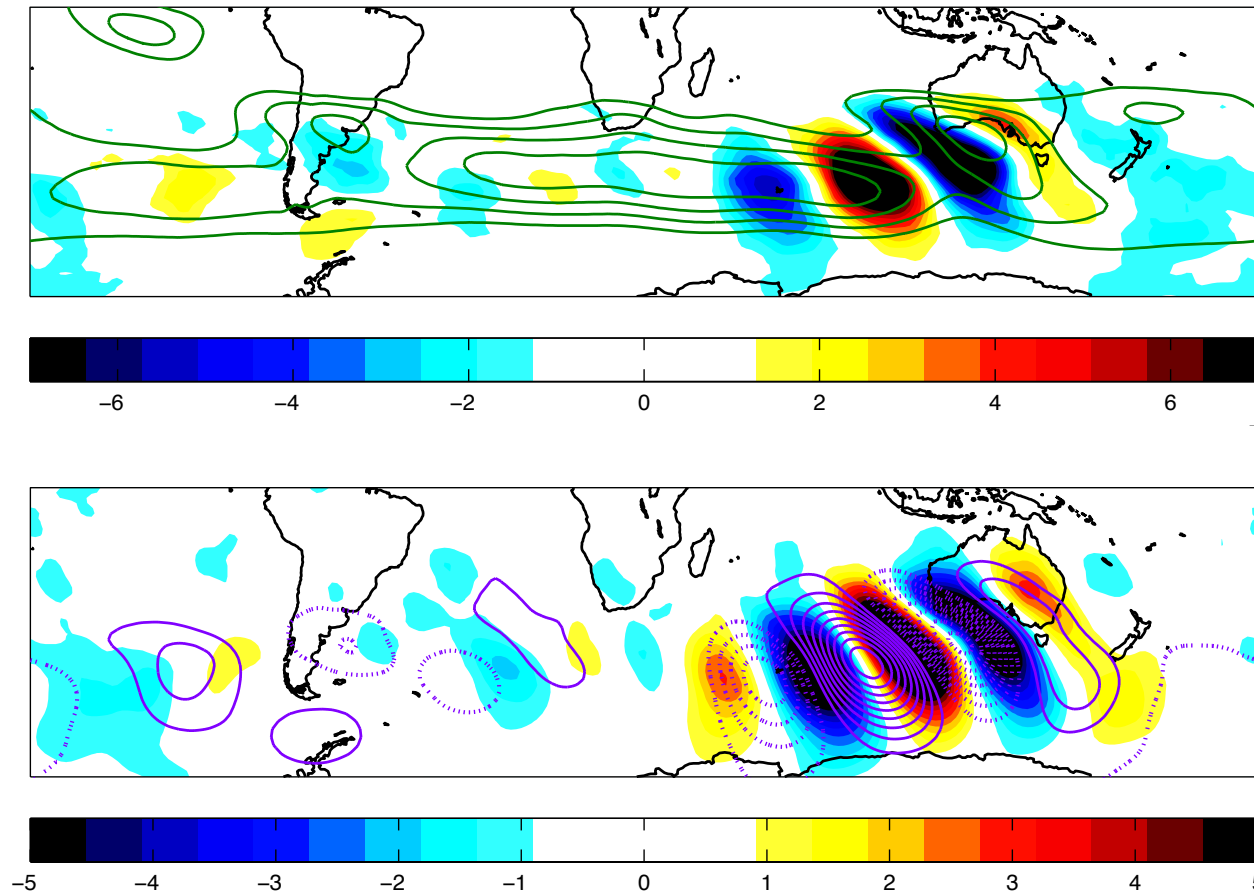


Time lagged composite on 350 K. (a) pv anomalies (PVU) (shaded). (b) meridional wind anomalies (ms^{-1}) (shaded), 200 mb geopotential height anomalies (purple contours).
Composite jet [20, 30, 40] ms^{-1} (green contours)

O'Brien, L., and M. J. Reeder. 2017. Southern Hemisphere summertime Rossby waves and weather in the Australian region. *Quart. J. Roy. Meteor. Soc.*, 143, 2374 – 238.

DJF Midlatitude Rossby Wave Packets

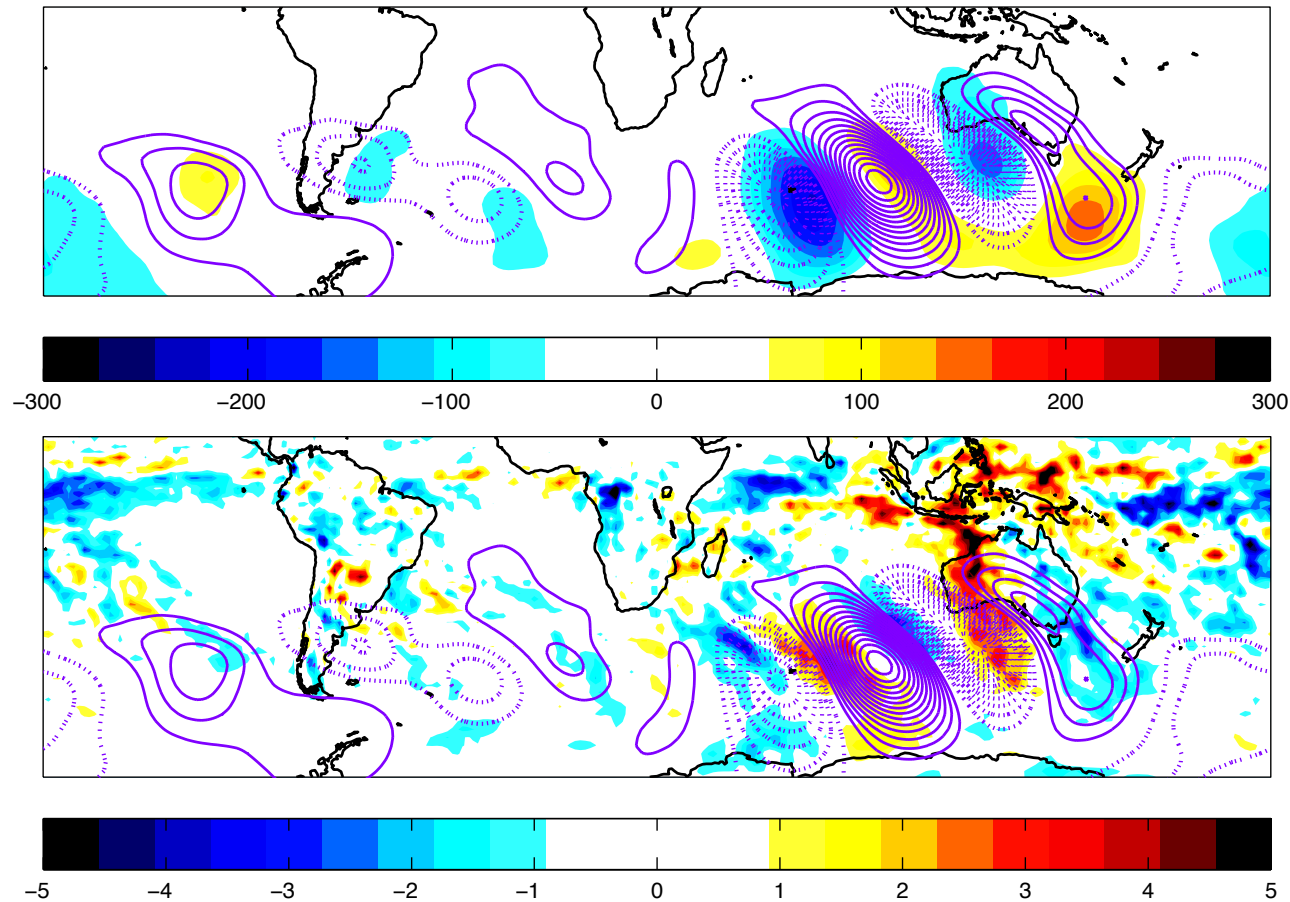
Day 0



Time lagged composite on 350 K. (a) pv anomalies (PVU) (shaded). (b) meridional wind anomalies (ms⁻¹) (shaded), 200 mb geopotential height anomalies (purple contours).
Composite jet [20, 30, 40] ms⁻¹ (green contours)

O'Brien, L., and M. J. Reeder. 2017. Southern Hemisphere summertime Rossby waves and weather in the Australian region. *Quart. J. Roy. Meteor. Soc.*, 143, 2374 – 238.

DJF Midlatitude Rossby Wave Packets

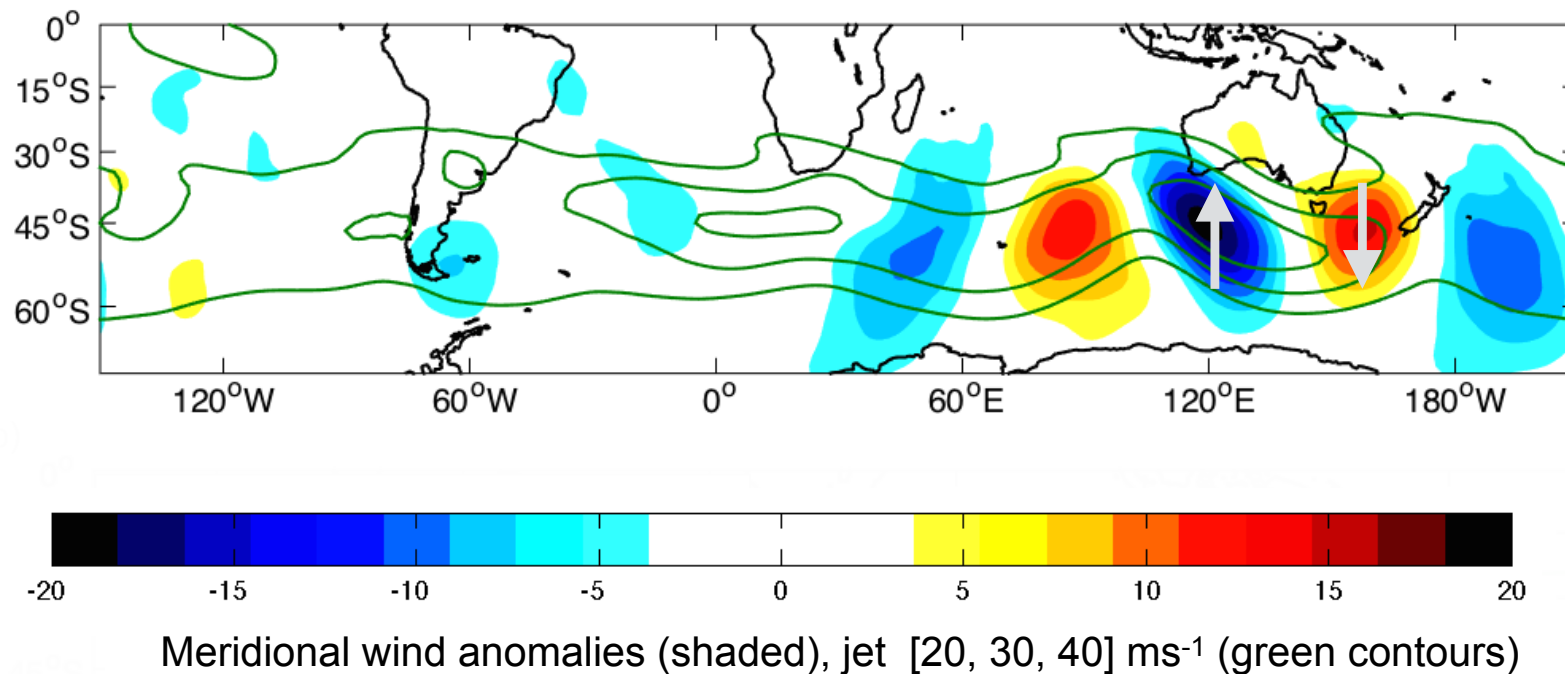


Time lagged composite on 350 K. (a) 850 mb geopotential height anomalies (shaded), 200 mb geopotential height anomalies (purple contours). (b) Depth averaged diabatic heating.

O'Brien, L., and M. J. Reeder. 2017. Southern Hemisphere summertime Rossby waves and weather in the Australian region. *Quart. J. Roy. Meteor. Soc.*, 143, 2374 – 238.

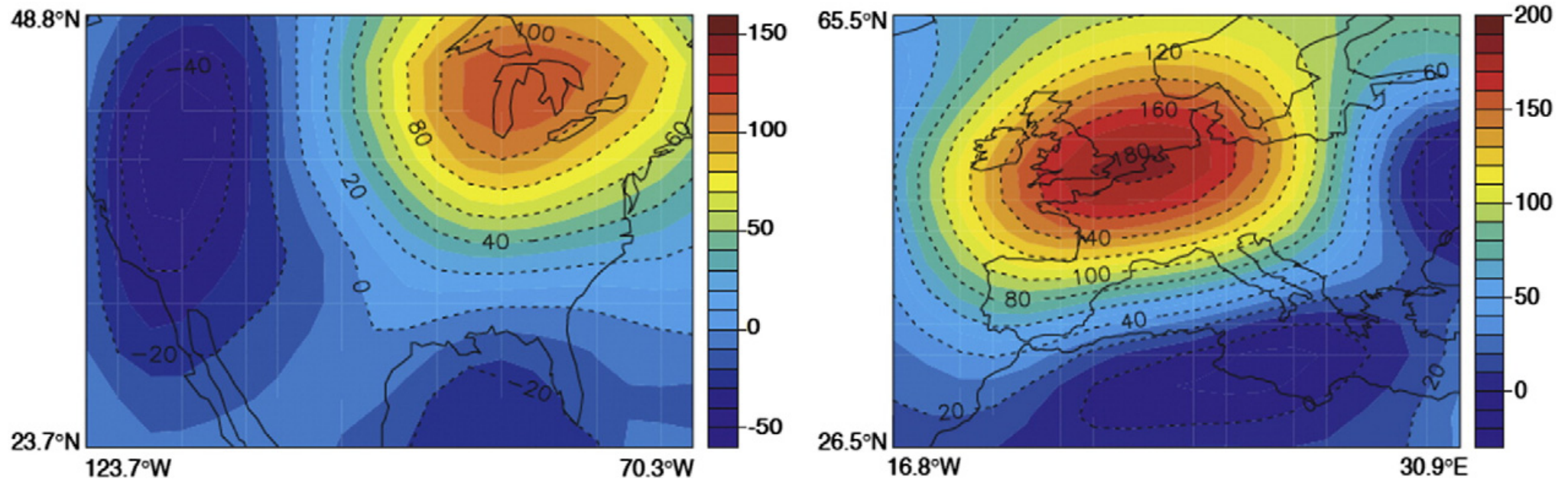
1 Day Prior to a SE Australian Heat Wave

Heat waves are characterised by upper-level anticyclonic anomalies, which evolve from propagating Rossby wave packets generated upstream several days earlier.



O'Brien, L., and M. J. Reeder. 2017. Southern Hemisphere summertime Rossby waves and weather in the Australian region. *Quart. J. Roy. Meteor. Soc.*, 143, 2374 – 238.

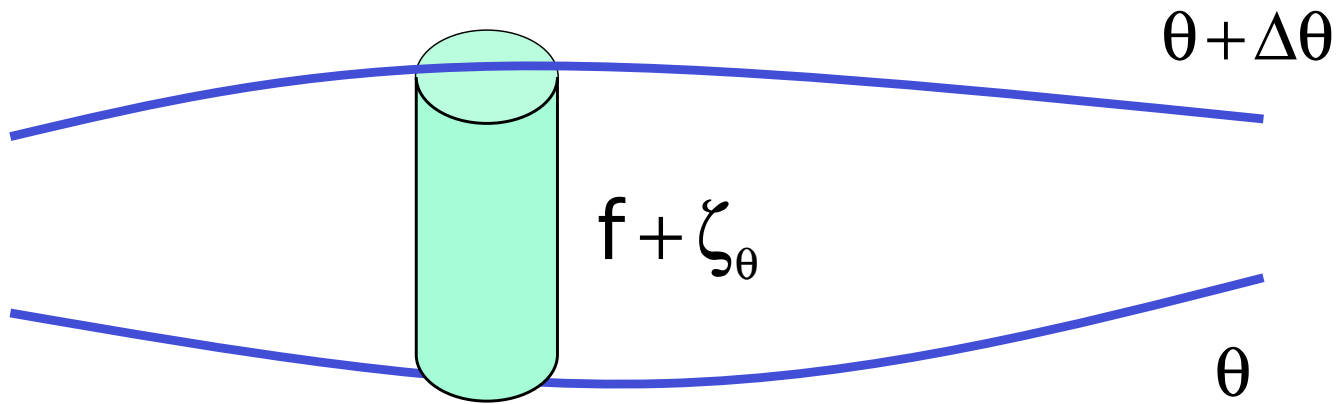
Heat Waves Are Characterised by Upper-Level Anticyclones



500 hPa height anomalies for heat waves in (left) Chicago 1995 and (right) Europe 2003.

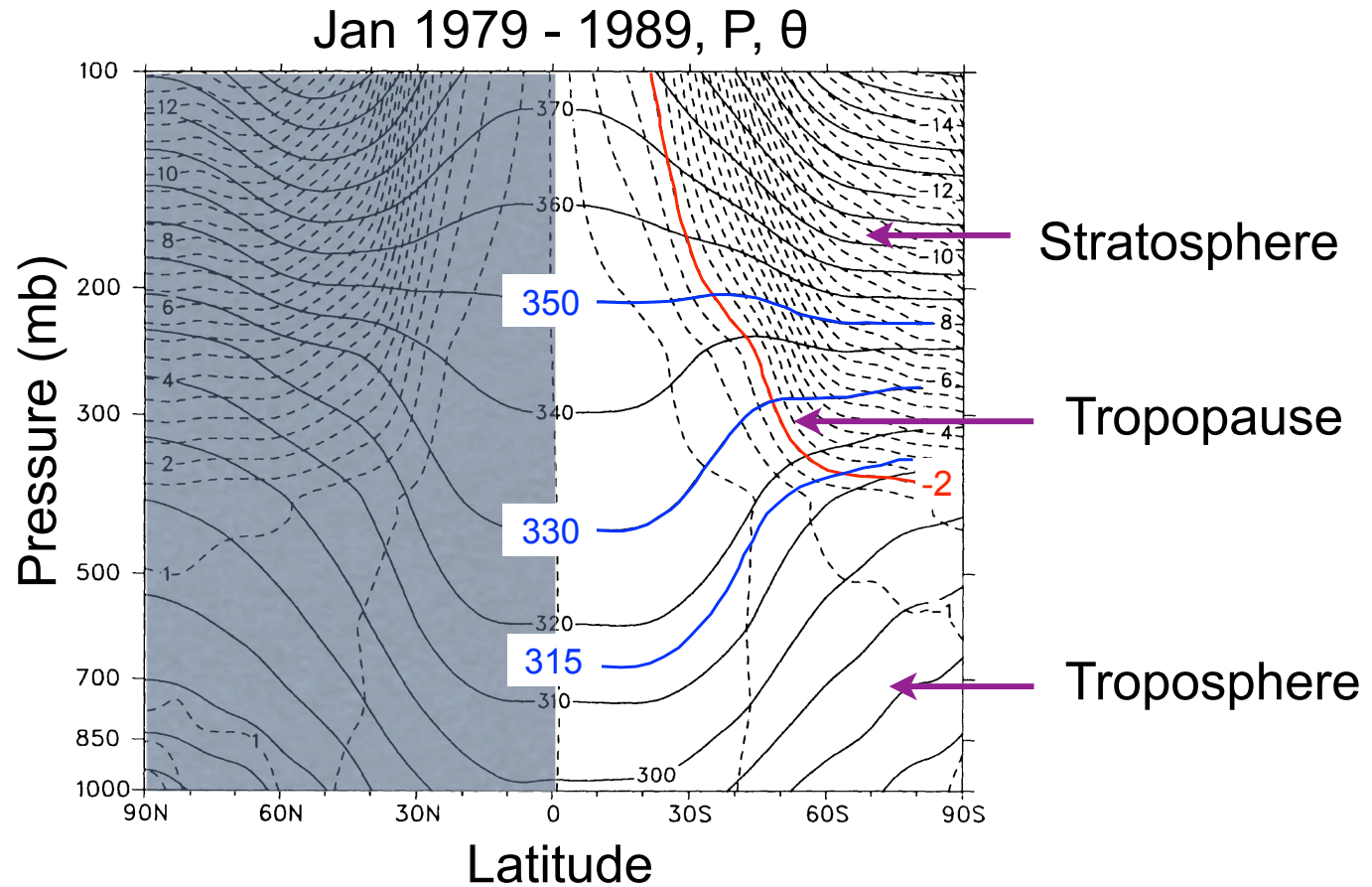
Meehl, G.A., Tebaldi, C., 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. *Science* 305 (5686), 994–997.

Potential Vorticity



$$\frac{DP}{Dt} = 0 \qquad P = \frac{f + \zeta_\theta}{\left(-g \frac{\partial p}{\partial \theta} \right)}$$

Potential Vorticity Climatology

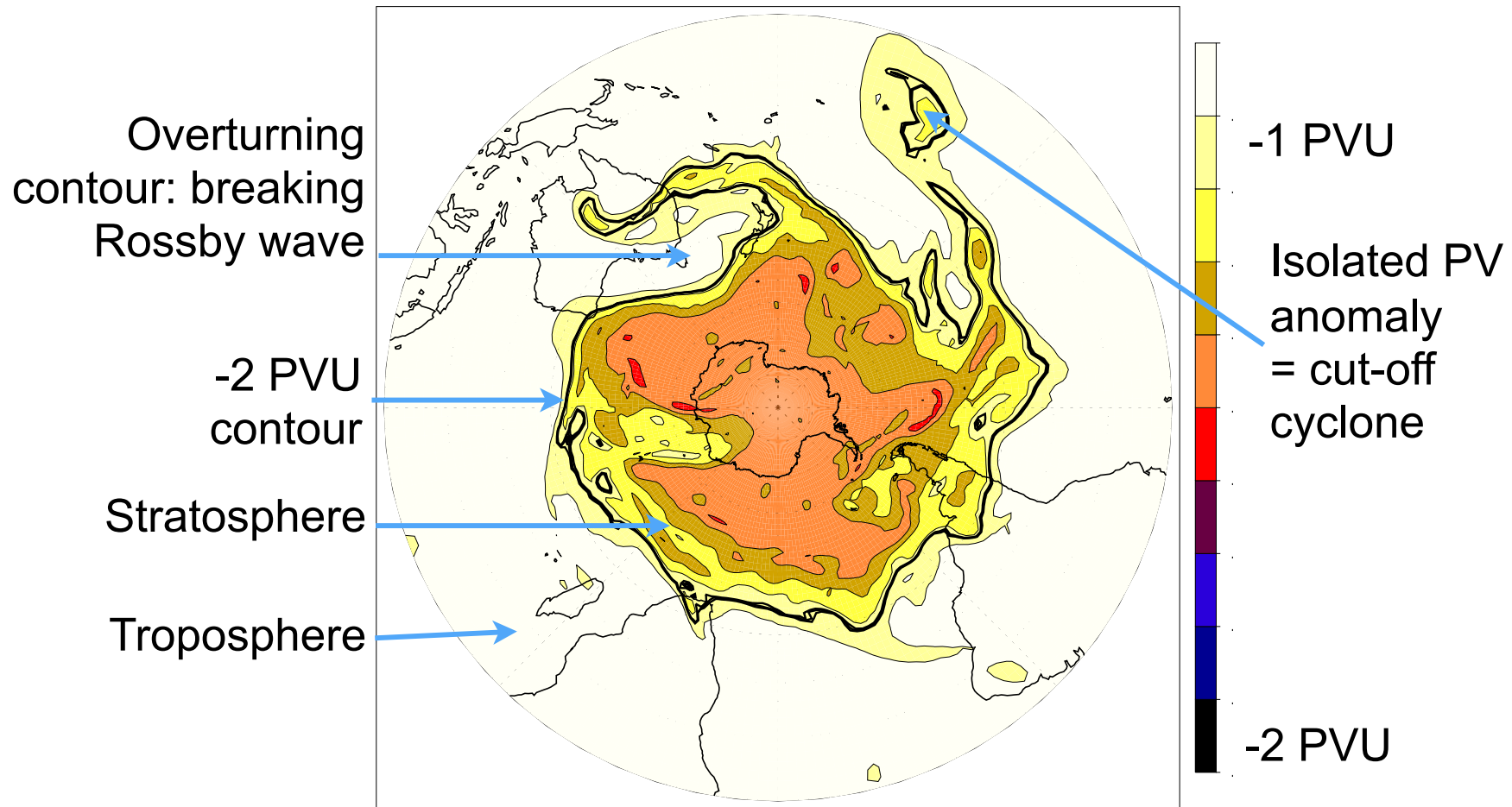


Bluestein, H. B., 1992. Principles of Kinematics and Dynamics. Vol. I, Synoptic - Dynamic Meteorology in Midlatitudes. Oxford University Press, 431 pp.

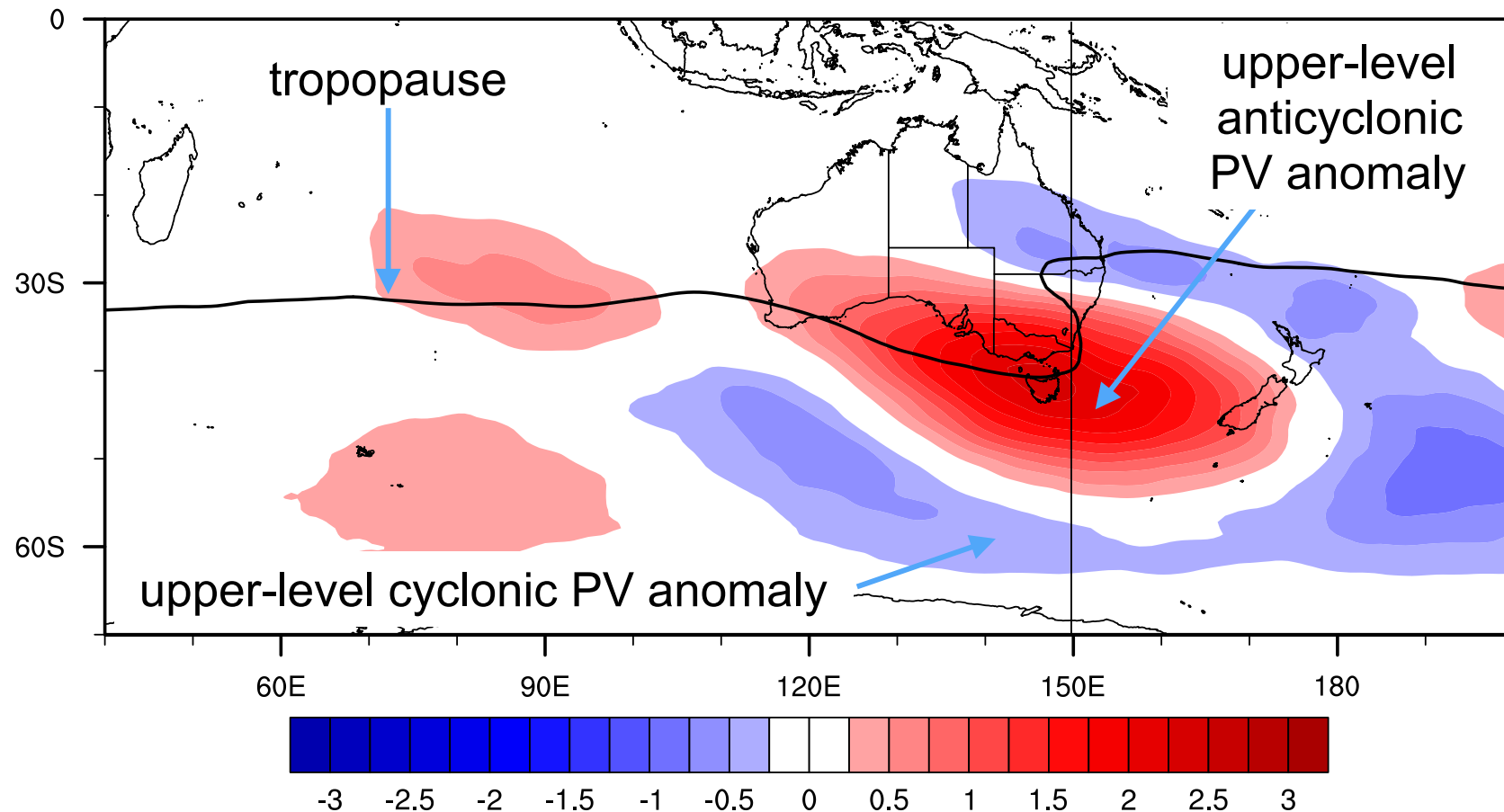
Rossby Waves are Potential Vorticity Gradient Waves

Pre-Black Saturday Heat Wave

PV 350 K 0600 UTC 29 Jan 2009

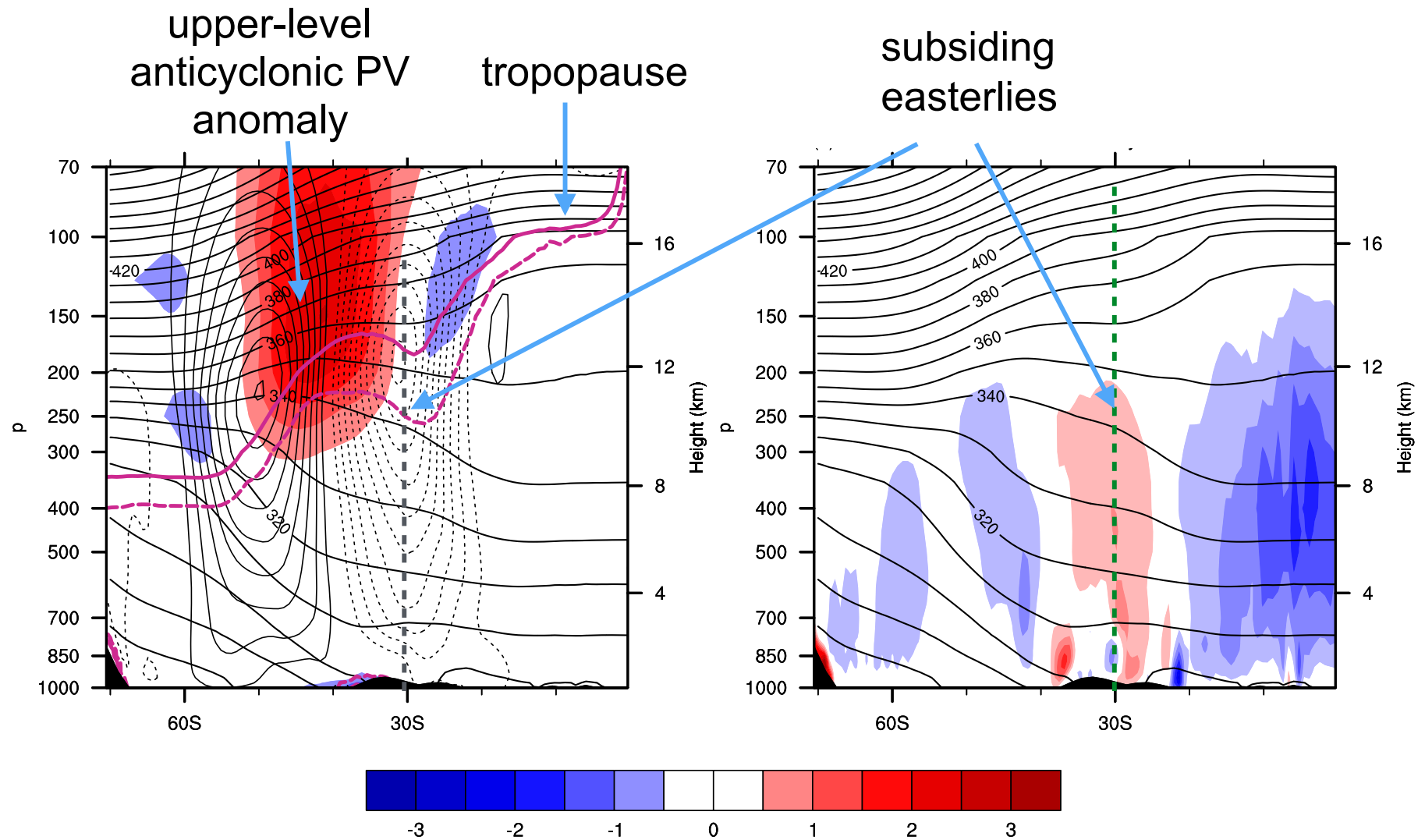


Composite Mean PV Anomaly on 350 K



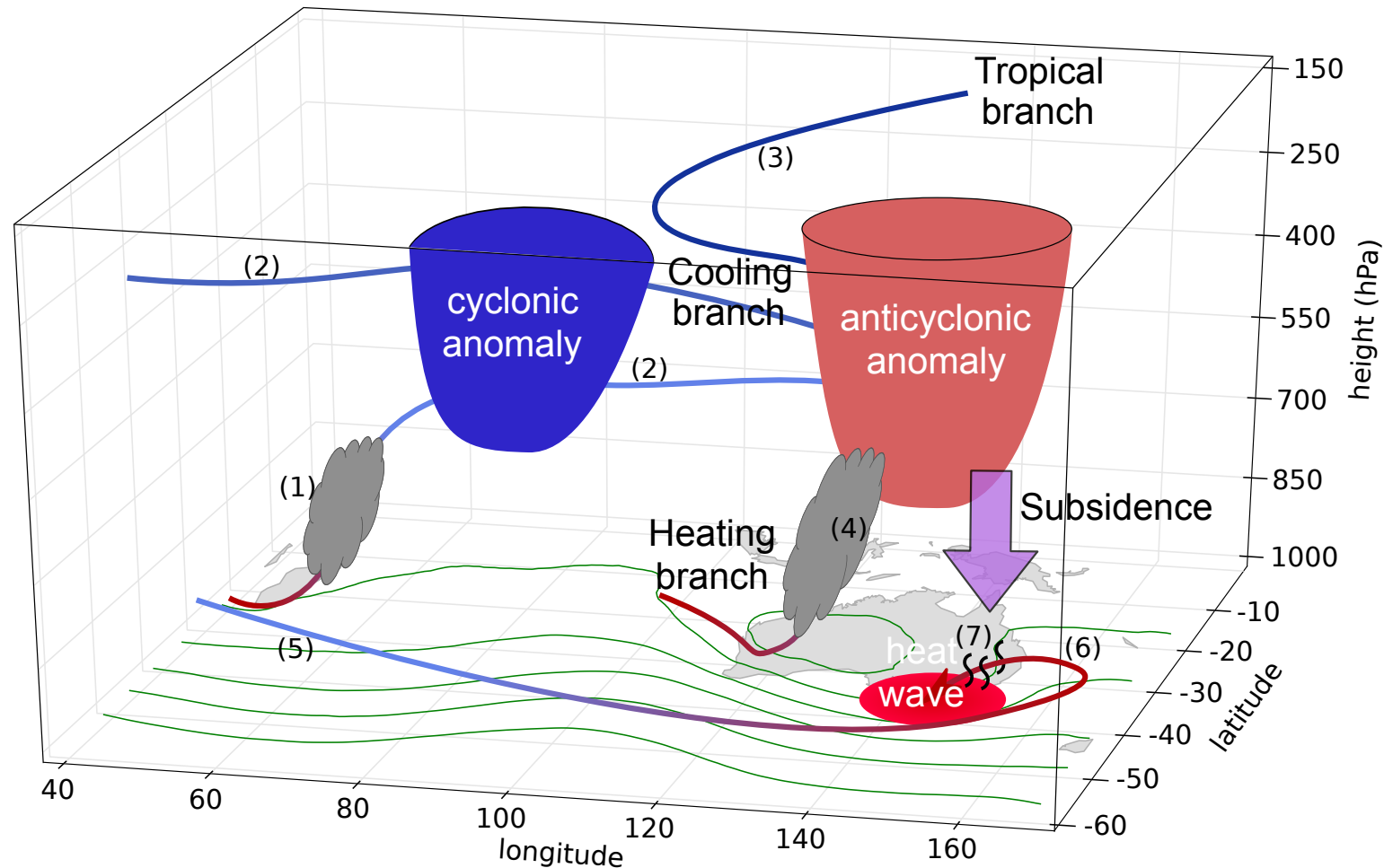
Parker, T. J., G. J. Berry, and M. J. Reeder. 2013. The structure and evolution of heatwaves over southeastern Australia. *J. Clim.*, 27, 5768 - 5785.

Cross-Section of the Composite Mean



Parker, T. J., G. J. Berry, and M. J. Reeder. 2013. The structure and evolution of heatwaves over southeastern Australia. *J. Clim.*, 27, 5768 - 5785.

Origin of the Upper-Level Anticyclone

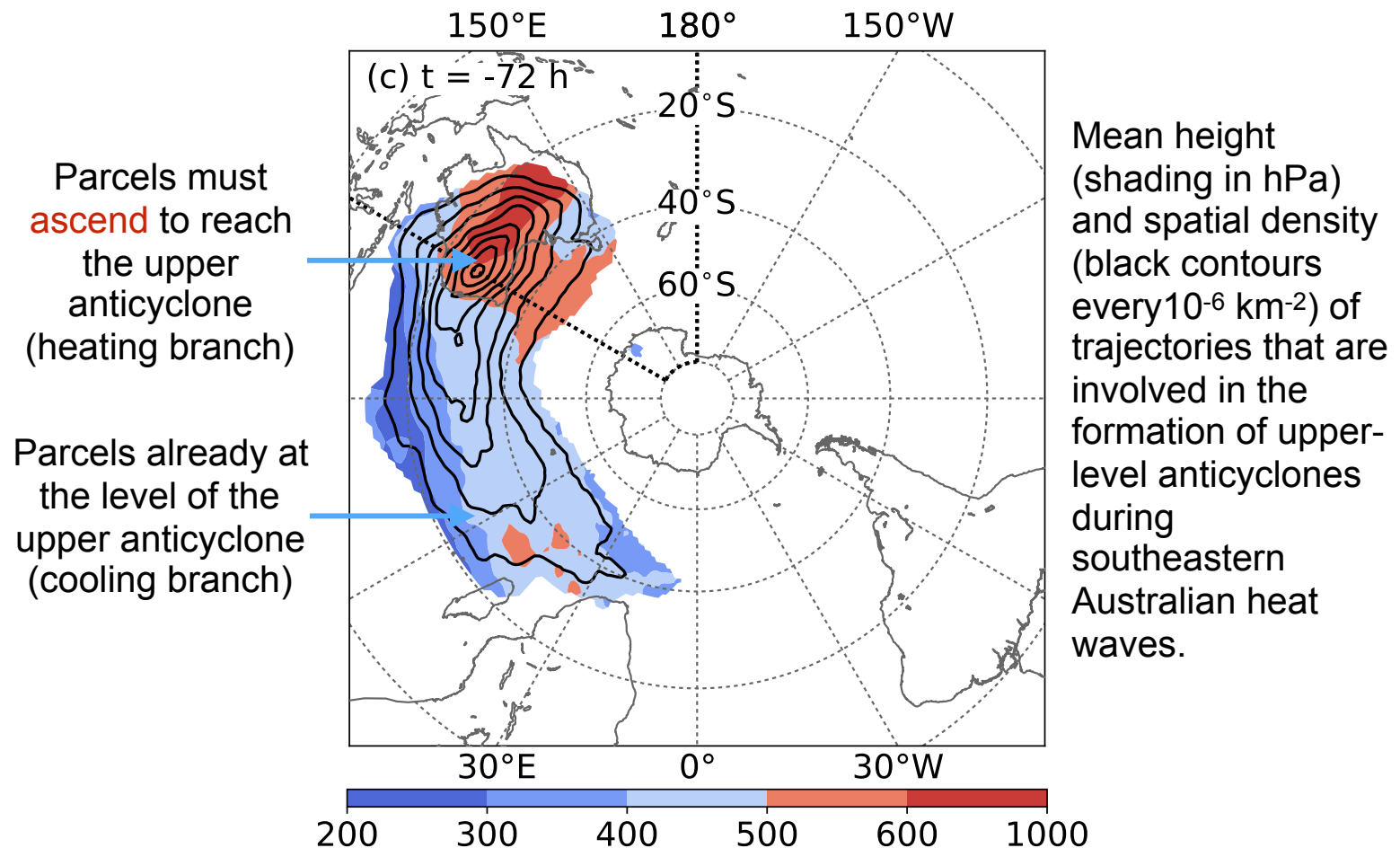


Trajectories coloured by pressure where reds indicate low levels and blues indicate upper levels. Green contours show the low-level potential temperature field. Blue (red) cone marks the upper-level negative (positive) PV anomaly.

Quinting, J. F., and M. J. Reeder. 2017. Southeastern Australian heat waves from a trajectory viewpoint. *Mon. Wea. Rev.*, 145, 4109 – 4125

Origin of the Upper-Level Anticyclone

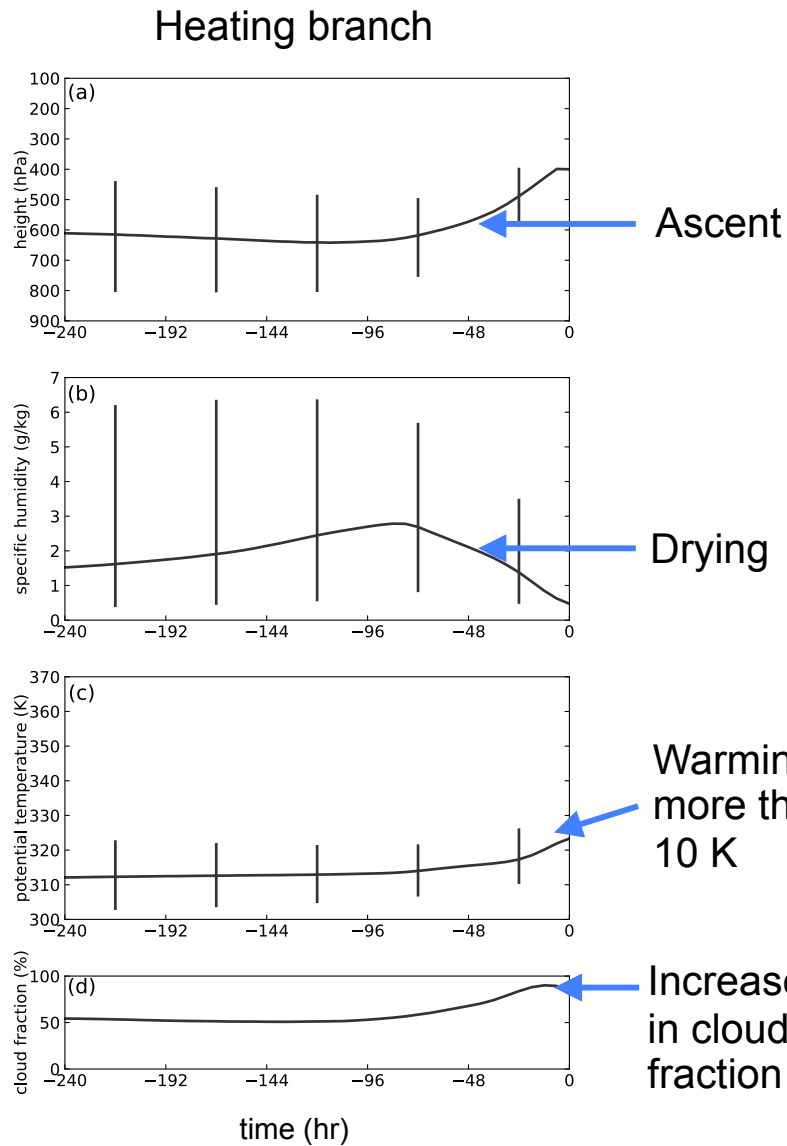
Given that many parcels ascend to reach the upper-level anticyclone, what is the role of diabatic heating?



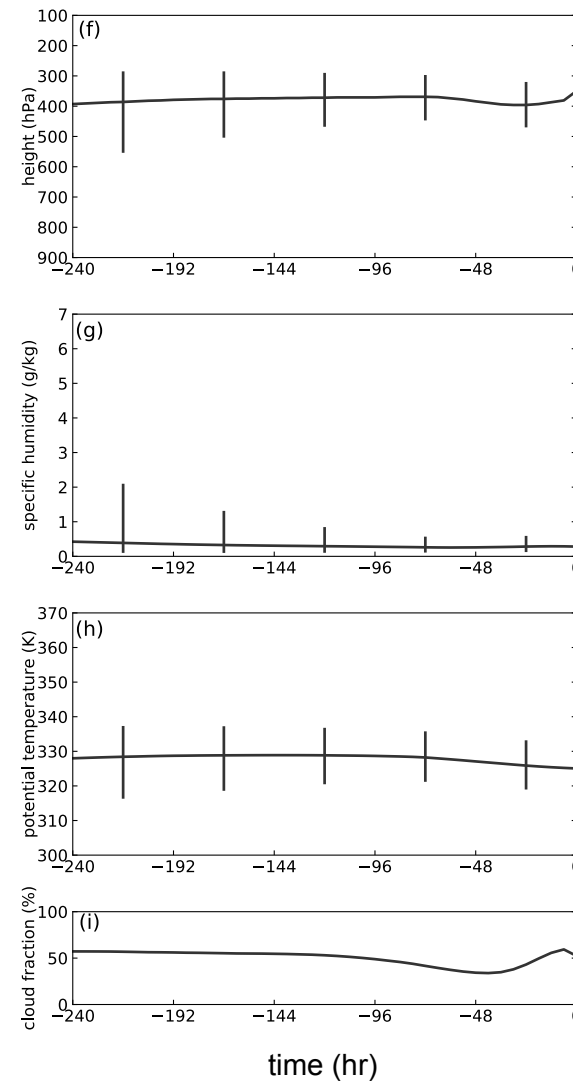
Quinting, J. F., and M. J. Reeder. 2017. Southeastern Australian heat waves from a trajectory viewpoint. *Mon. Wea. Rev.*, 145, 4109 – 4125

Origin of the Upper-Level Anticyclone

Parcels lie mostly between S Africa and Australia in the middle troposphere



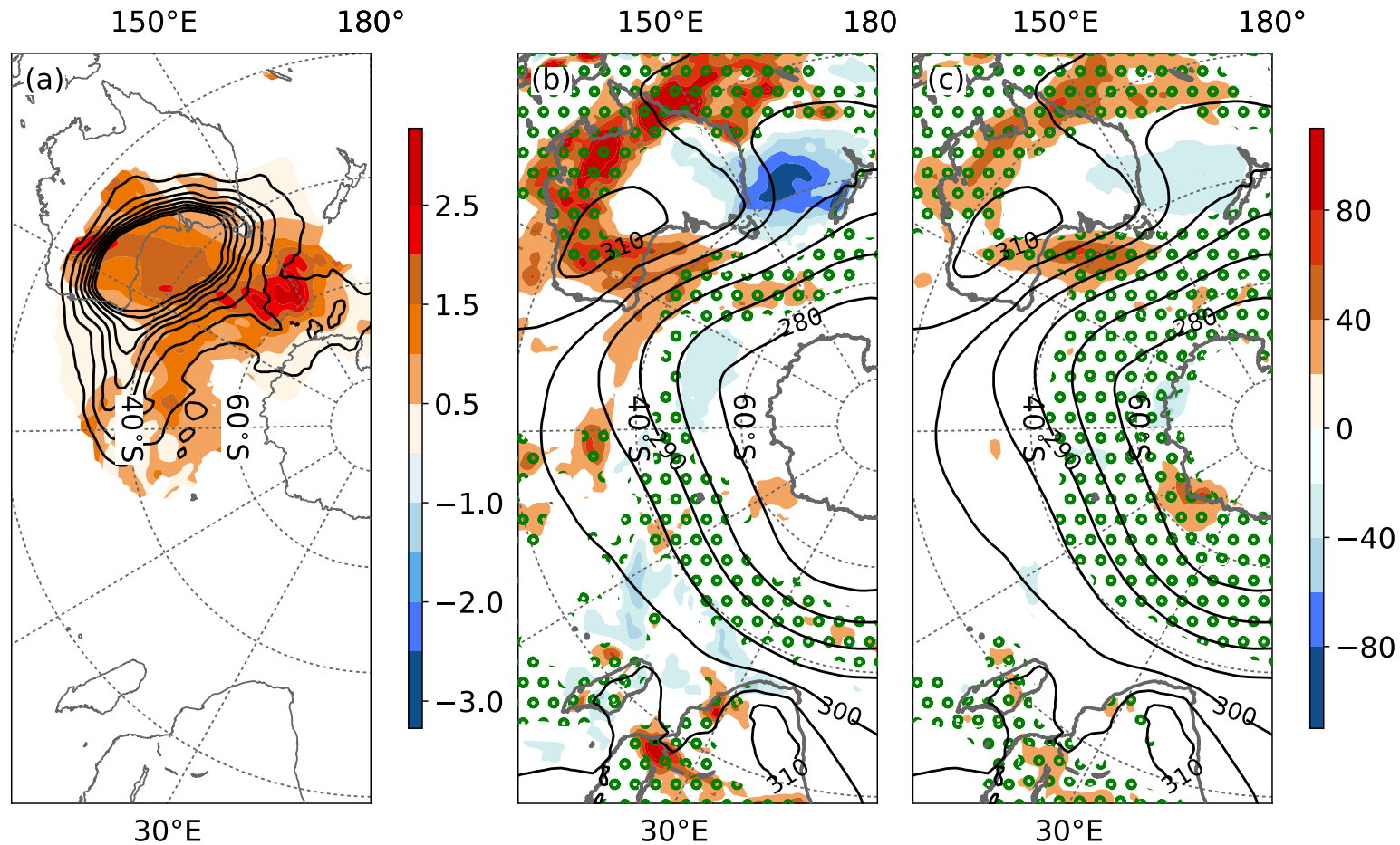
Cooling branch



Parcels lie mostly between Indian Ocean and S America in the upper troposphere

Quinting, J. F., and M. J. Reeder. 2017. Southeastern Australian heat waves from a trajectory viewpoint. *Mon. Wea. Rev.*, 145, 4109 – 4125

Heating branch at $t = -24$ h



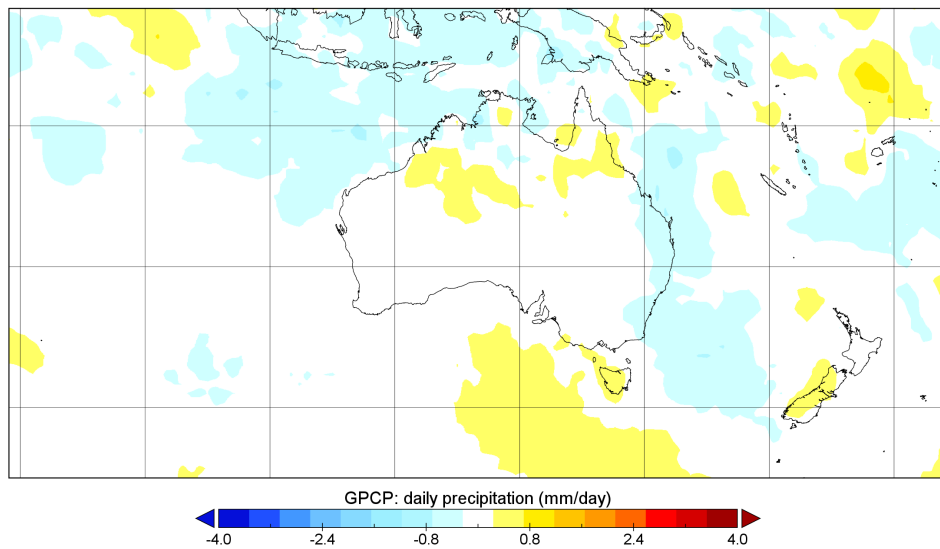
(a) Spatial density (black contours every 10^{-6} km^{-2}) and mean potential temperature change (K d^{-1}) of trajectories on the heating branch at $t = -24$ h.

Anomalies of (b) cloud liquid and (c) ice water path relative to climatology (shading in g m^{-2}), composite mean of (b) cloud liquid and (c) ice water path (stippled where greater than 100 g m^{-2} and 50 g m^{-2} , respectively).

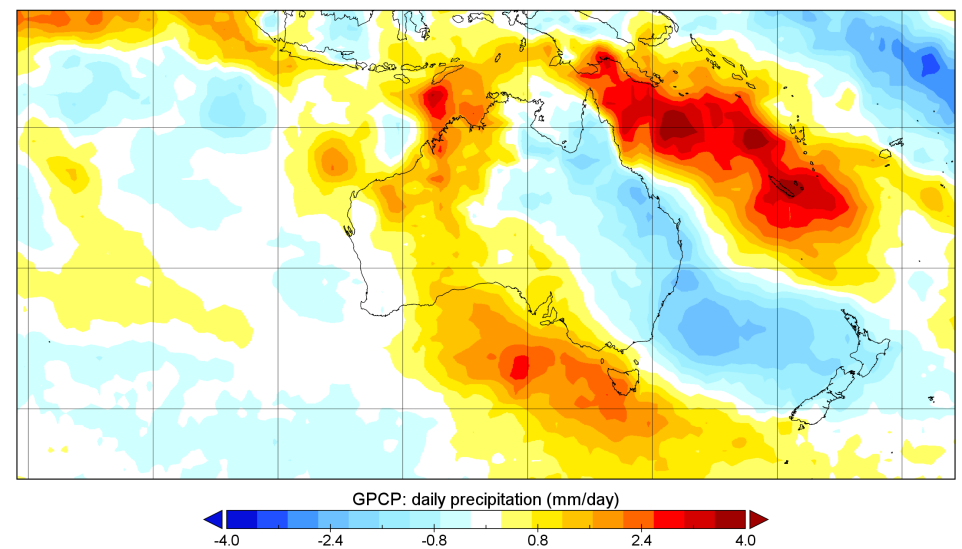
(b, c) 850-hPa potential temperature (black contours every 5 K) at $t = -24$ h.

Tropical Convection and Heat Waves

Precipitation anomalies when non-heatwave strong upper-level anticyclones lie over SE Australia

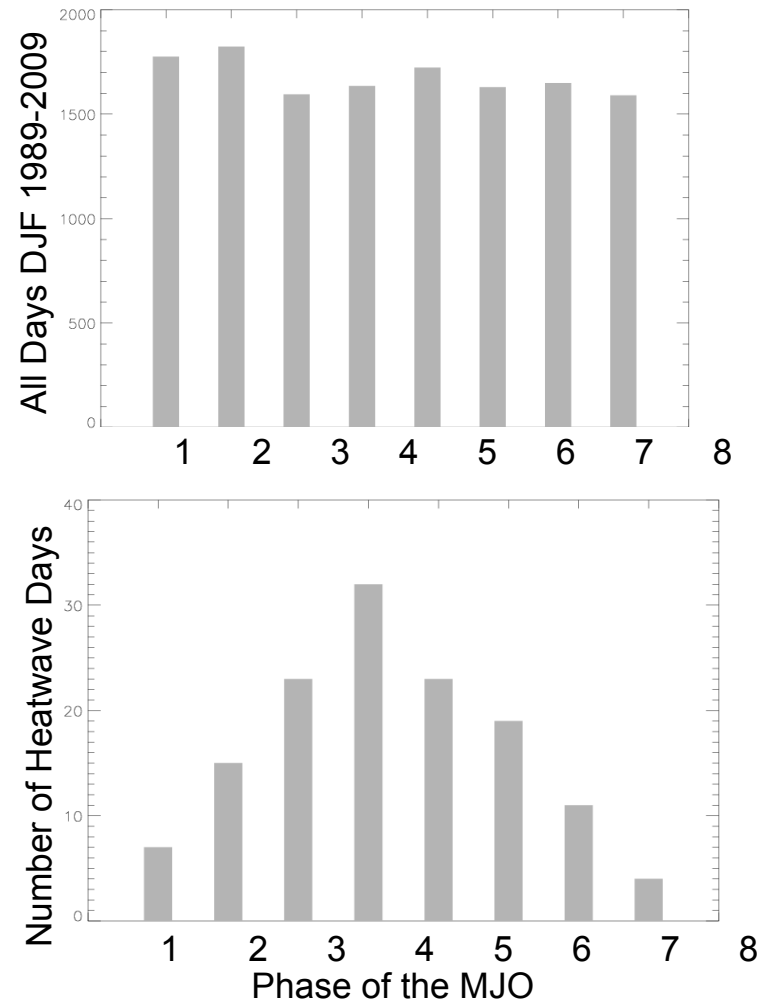


Precipitation anomalies when heatwave strong upper-level anticyclones lie over SE Australia



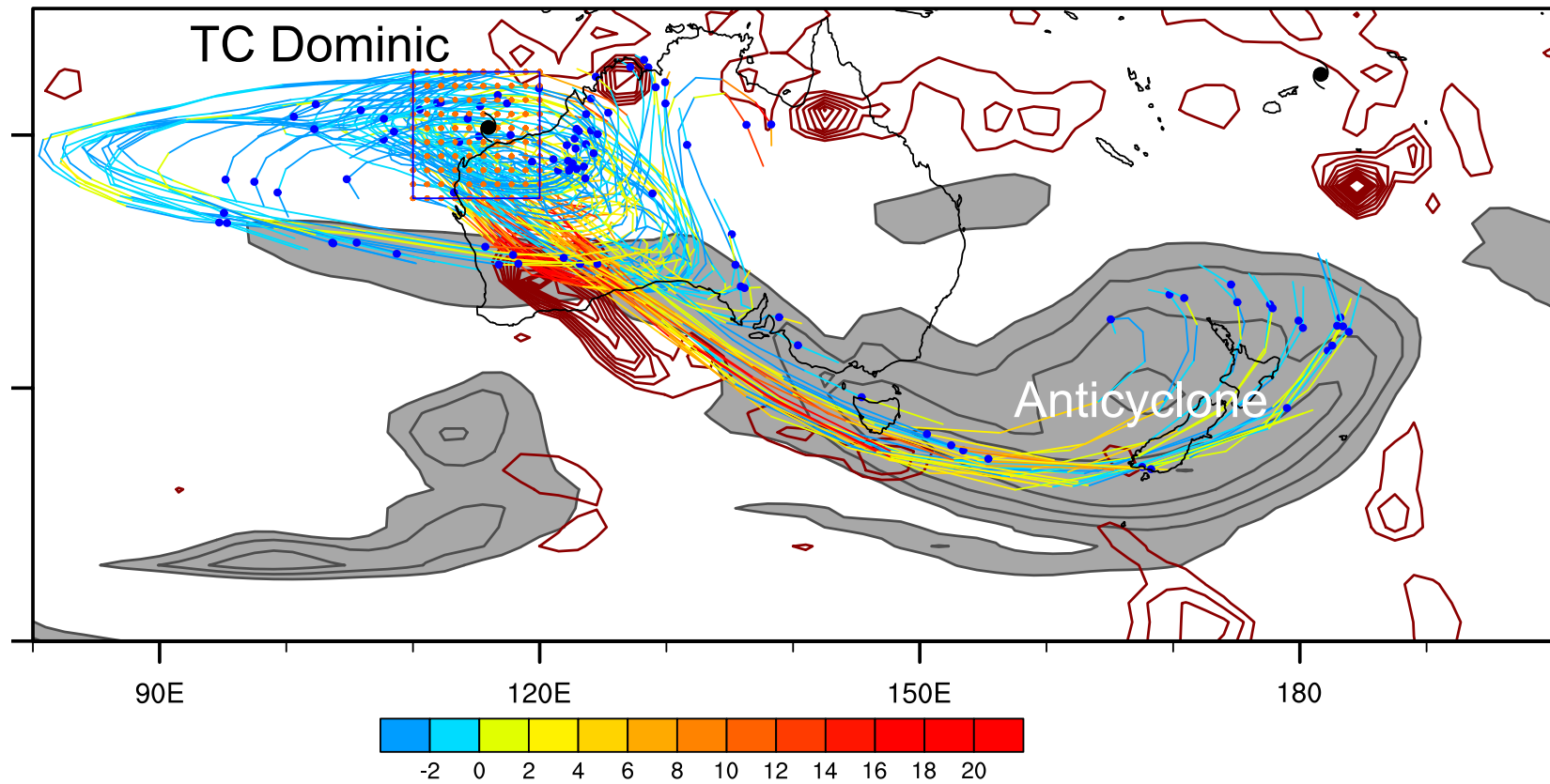
Calculation by Malcolm King

Tropical Convection and Heat Waves



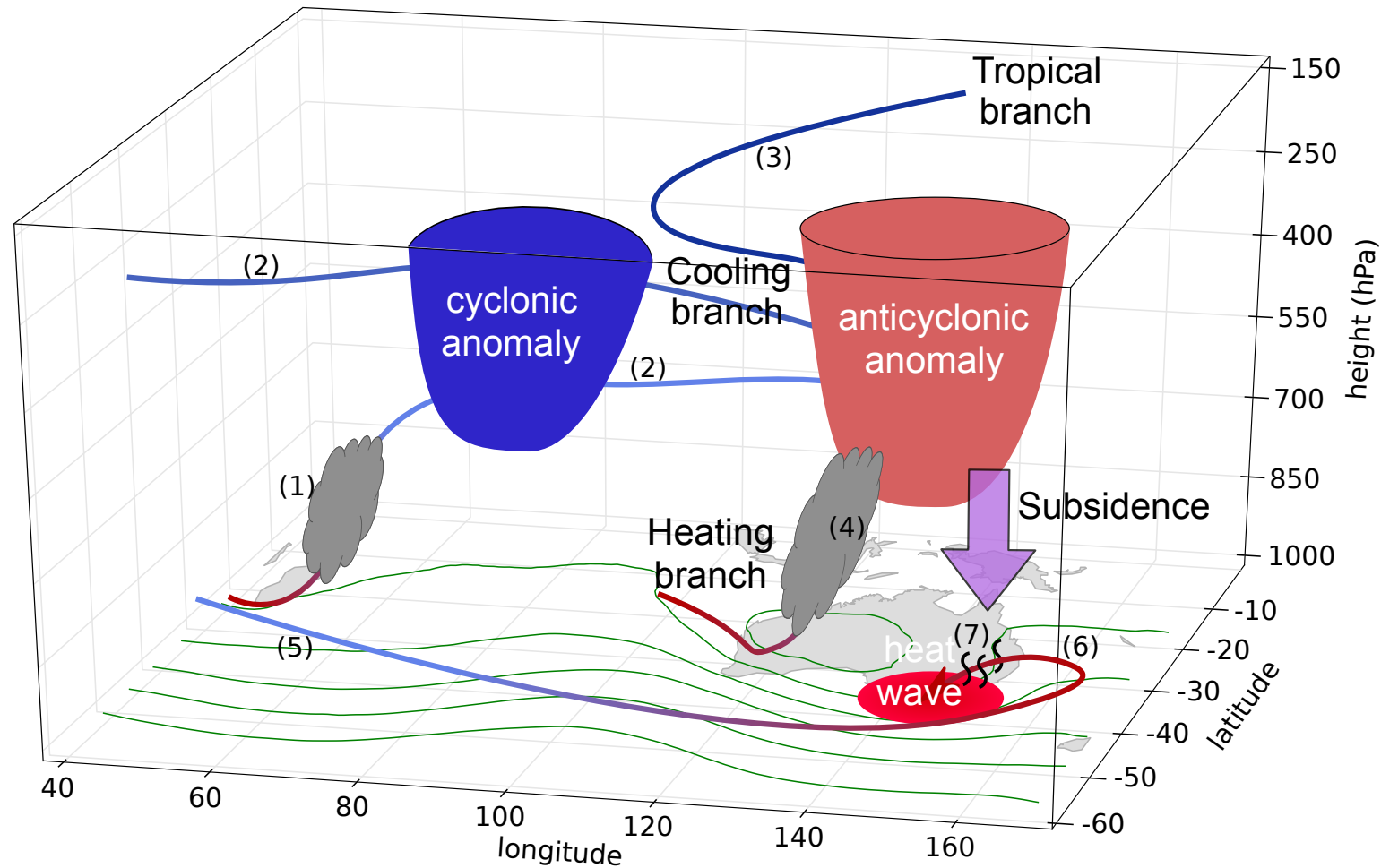
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Tropical Convection and Heat Waves



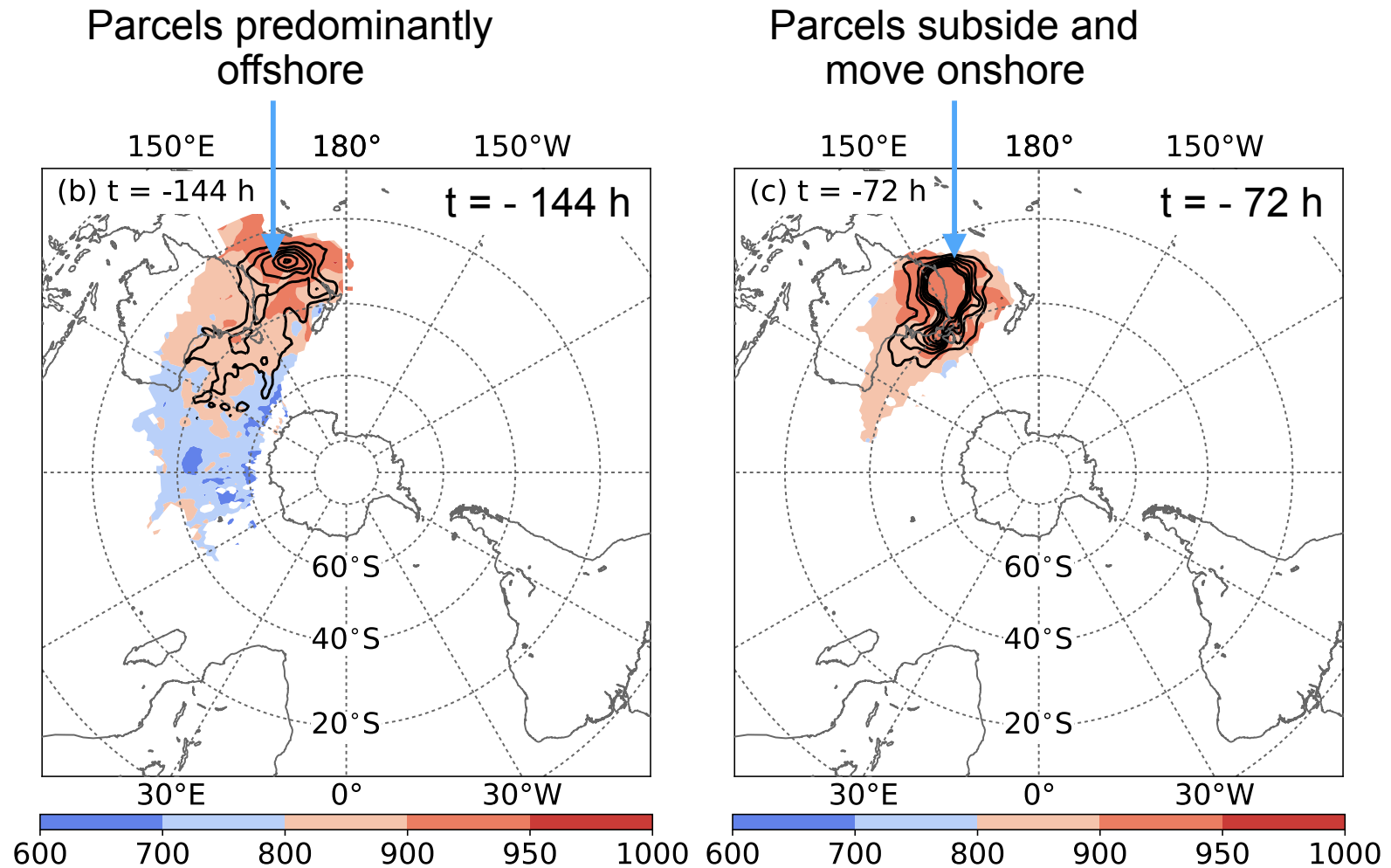
Parker, T. J., G. J. Berry, and M. J. Reeder. 2013. The influence of tropical cyclones on heatwaves in southeastern Australia. *Geophys. Res. Lett.*, 40, 1 – 7.

Origin of the Near Surface Heated Air



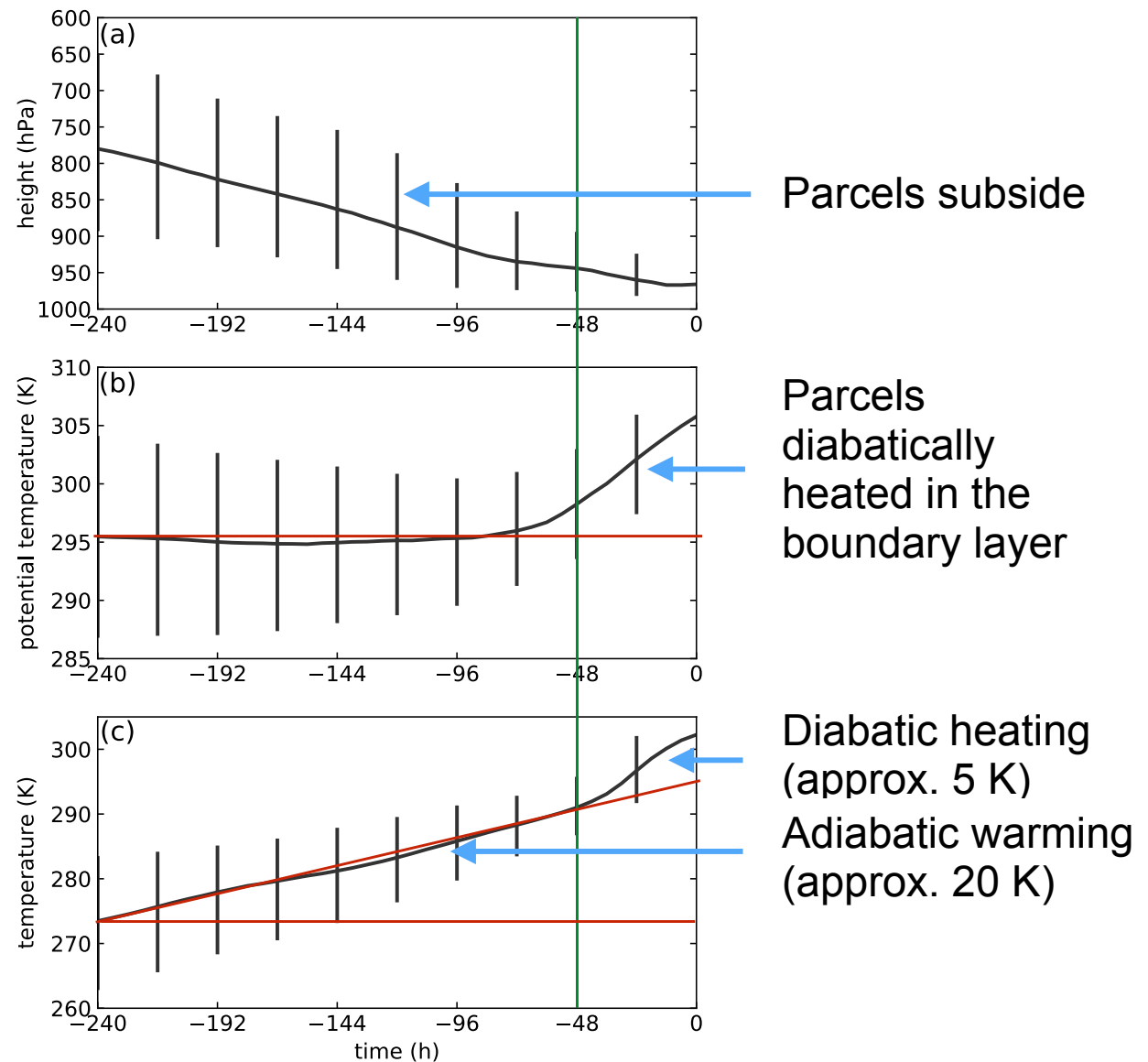
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Origin of the Near Surface Heated Air



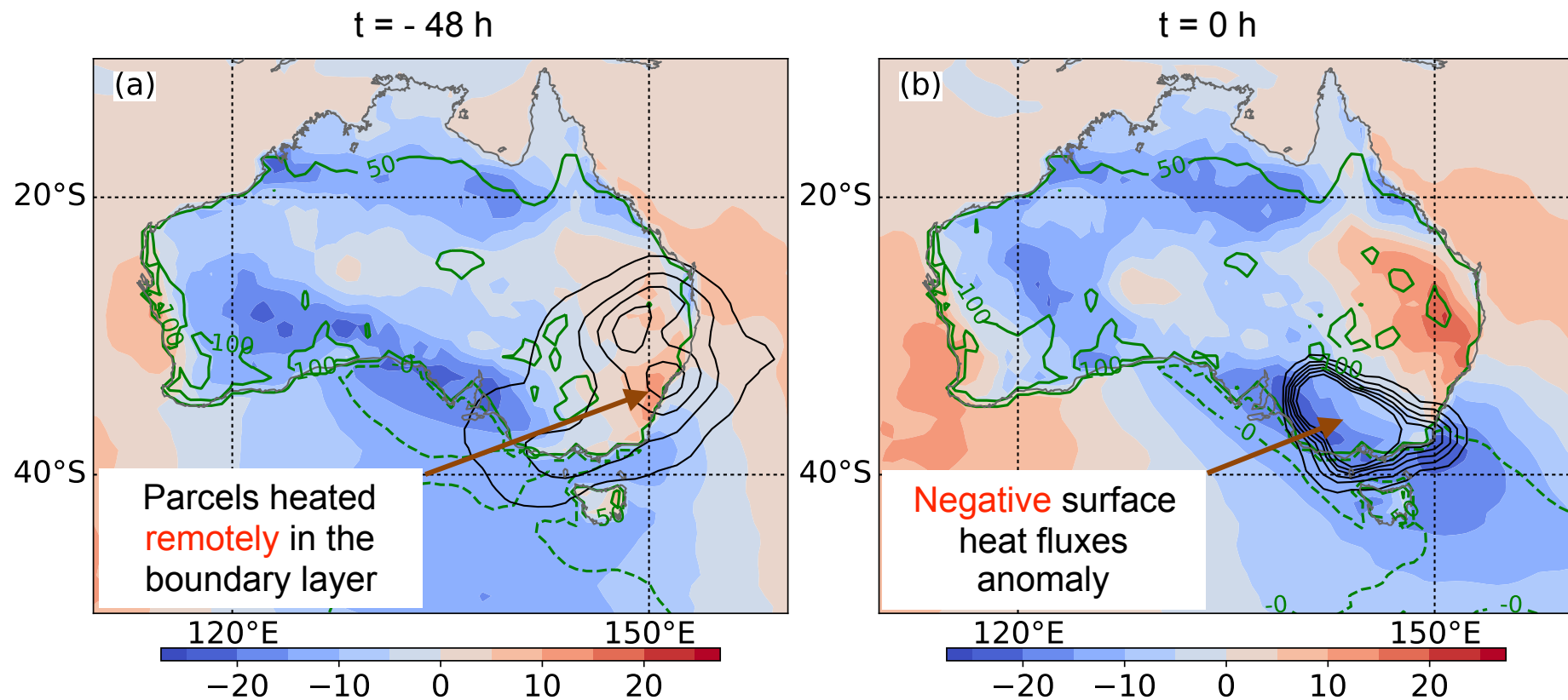
Quinting, J. F., and M. J. Reeder. 2017. Southeastern Australian heat waves from a trajectory viewpoint. *Mon. Wea. Rev.*, 145, 4109 – 4125

Thermodynamic History of the Near Surface Heated Air



Quinting, J. F., and M. J. Reeder. 2017. Southeastern Australian heat waves from a trajectory viewpoint. *Mon. Wea. Rev.*, 145, 4109 – 4125

Surface Sensible Heat Flux



Anomalies of surface sensible heat flux (shading in W m^{-2}).

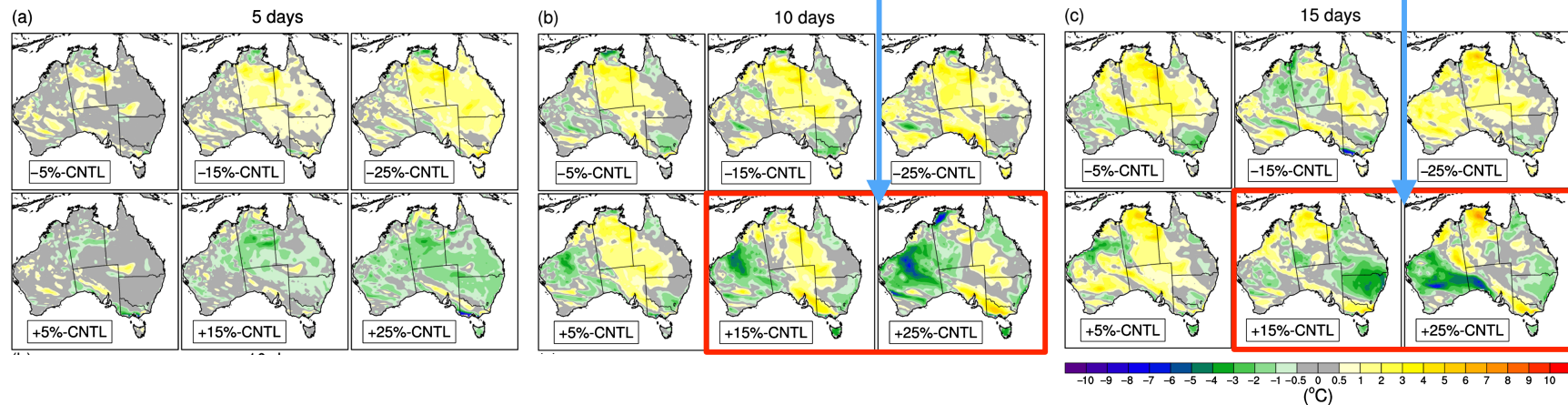
Average surface sensible heat flux during southeastern Australian heat waves (green contours in W m^{-2})

Spatial density of trajectories that arrive close to the surface at $t = 0$ h (black contours at 10, 30, 50, 70, 90, 120 10^{-6} km^{-2}).

Quinting, J. F., and M. J. Reeder. 2017. Southeastern Australian heat waves from a trajectory viewpoint. *Mon. Wea. Rev.*, 145, 4109 – 4125

Numerical Experiments with Soil Moisture

Increases in soil moisture increase the maximum temperature over SE Australia



Difference in maximum 2 m temperature (TMAX) on 7 February 2009, between each experiment and the control (experiment – CNTL) started at (a) 5 days, (b) 10 days, and (c) 15 days lead time. Positive values indicate that the experiment was warmer than the control (CNTL) simulation.

Kala, J., J. P. Evans, and A. J. Pitman. 2015. Influence of antecedent soil moisture conditions on the synoptic meteorology of the Black Saturday bushfire event in southeast Australia. *Quart. J. R. Meteor. Soc.*, 141, 3118 – 3129.

References

- Bluestein, H. B., 1992. Principles of Kinematics and Dynamics. Vol. I, Synoptic - Dynamic Meteorology in Midlatitudes. Oxford University Press, 431 pp.
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