USE OF SEASONAL FORECASTING SYSTEM IN UNDERSTANDING THE ROLE OF THE INDIAN OCEAN IN RECENT AUSTRALIAN SPRING HEAT RECORDS

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Introduction

The Australian springs (SON) of 2013, 2014, and 2015 were anomalously hot, with the heat records broken in September, October-November and October in each respective year (Australian Bureau of Meteorology).

Anomalous Australian Spring Heat Events

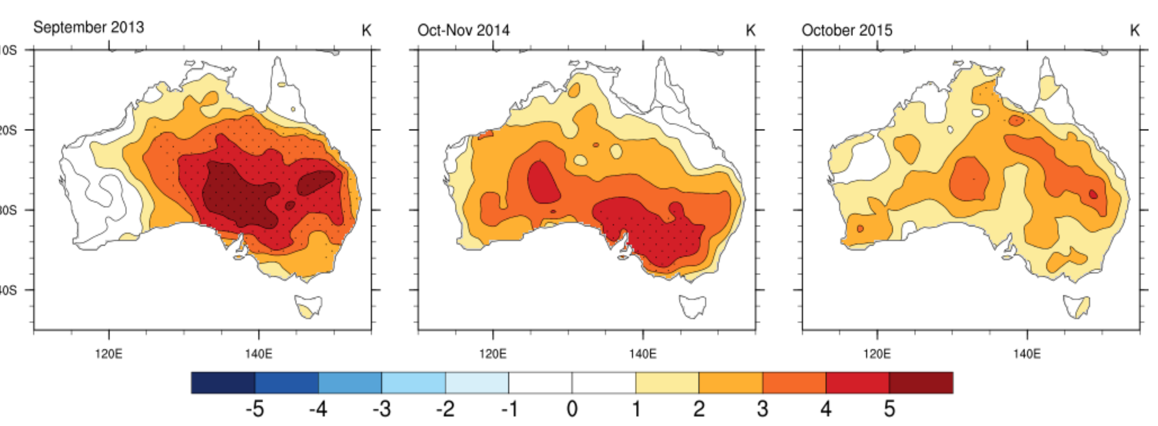

Figure 1 Australian maximum temperature anomalies against 1980 to 2010 climatology period for the record heat events of September 2013 (left), October-November 2014 (middle), and October 2015 (right). Stippling indicates anomalies are more than 1.96 standard deviations from climatological mean.

- Much of the anomalous heat was attributed to climate change.
- Remainder: different climate drivers were active/stronger in each respective spring period (e.g. Gallant and Lewis 2016).
- High geopotential height over Australia in Oct-Nov 2014 associated with the heat formation possibly enhanced by a Rossby wave triggered by anomalous convection in central tropical Indian Ocean (Hope et al. 2015)
- Observations are restricted to a limited time period, and GCMs may not capture specific seasonal events.
- Seasonal forecasting systems have as many realisations of a specific event as they have ensemble members.
- Examining the differences between each forecast ensemble member and how well it captured an observed event presents an opportunity to explore underlying atmospheric dynamics of that event.

Is there a source of predictability Australian spring temperatures in the Indian Ocean? We explore this possibility using reanalysis data and members of a seasonal forecasting ensemble.

Methods

1. Determine observed atmospheric circulation (taken to be 200hPa geopotential height from ERA-Interim reanalysis) associated with Australian maximum temperature (AWAP dataset). Height and wave flux anomalies **(fig. 2)** from spring heat records are compared to monthly linearly regression **(fig. 4)** of gridded height anomalies against the standardised Australian max temperature timeseries.
2. Take the average of the hottest and coldest 10% of Australian Bureau of Meteorology's seasonal forecasting system, POAMA, ensemble member forecast (refer **Table** 1) 200hPa geopotential height anomalies and wave flux for each of the record spring heat events **(fig. 3).** Do they match observations? Are the hottest ensemble members capturing the heat because they are capturing a teleconnection to the Indian Ocean?
3. Is the connection between high 200hPa geopotential height over southern Australia (blue box in figure 2) and high Australian forecast temperature true for all ensemble members across spring months in recent hot years? Scatter plot **fig. 5.**
4. Rossby wave activity flux (Takaya and Nakamura (2000) travels in the direction of the group velocity and can be used to track the progression of wave energy and wave formation. Regions of vector convergence and divergence indicate regions of Rossby wave dissipation and formation respectively. Monthly values calculated from the 200hPa geopotential height anomaly (or regression coefficient) against a climatological mean background flow. Vectors are overlaid onto height anomalies in **figures 2, 3 and 4.**

Table 1: POAMA seasonal forecasting system and forecast dates

33 ensemble members, 250km horizontal resolution, 17 vertical levels			
Forecasts initialised:	September	October	November
Hindcast: 1981 to 2013	Sep 1	Oct 1	Nov 1
2014	Aug 31	Sep 28	Oct 30
2015	Aug 30	Sep 27	Oct29

Results

The height anomalies and Rossby wave activity flux in **Figure 2**:

- September 2013 has weak high anomaly over Australia compared to the linear regression in figure 4.
- Oct-Nov 2014, and Oct 2015 have similar patterns to linear regression (fig. 4), with stronger high over Australia and wave flux from Indian Ocean, including some influence from tropics.
- October 2015 has a stronger, broader high and more Pacific Ocean influence (Note: strong El Niño occurred in 2015).
- Different dynamical setups evident across each month and year.

The 10% hottest and coldest member forecasts in **figure 3**:

- Hot forecasts generally match observed anomalies from figure 2 better than cold forecasts.
- Particular emphasis is placed on 200hPa high anomaly over Australia in hot forecasts. The cold forecasts have comparatively weak or no high anomaly over Australia.
- October 2015 hot and cold forecasts have a high anomaly, with greater strength and extent occurring in hotter forecasts, similar to reanalysis (fig. 2), possibly indicative of El Niño influence.
- Unlike observations, ensemble members do not capture wave flux out of Indian (tropical or mid-lat) Ocean. Weak flux occurs in hot forecasts of October 2015 only.

The linear regression in **Figure 4**:

- Confirms high 200hPa geopotential height (red contours) over southern Australia is strongly related to heat formation.
- The Rossby wave activity flux (vectors) shifts from coming out of the mid-latitudes in Sep, to more out of tropical Indian Ocean by October and November.
- September 2013 (fig. 2.) did not have as high an anomaly over Australia as may normally be expected for heat development.
- Comparison to fig. 3 suggest that lack of wave flux out of Indian Ocean, particularly from tropics in Oct-Nov suggests that POAMA is missing this teleconnection is not capturing the height or heat anomalies completely.

Observed Wave Flux and 200hPa Geopotential Height Anomalies for Recent Heat Records

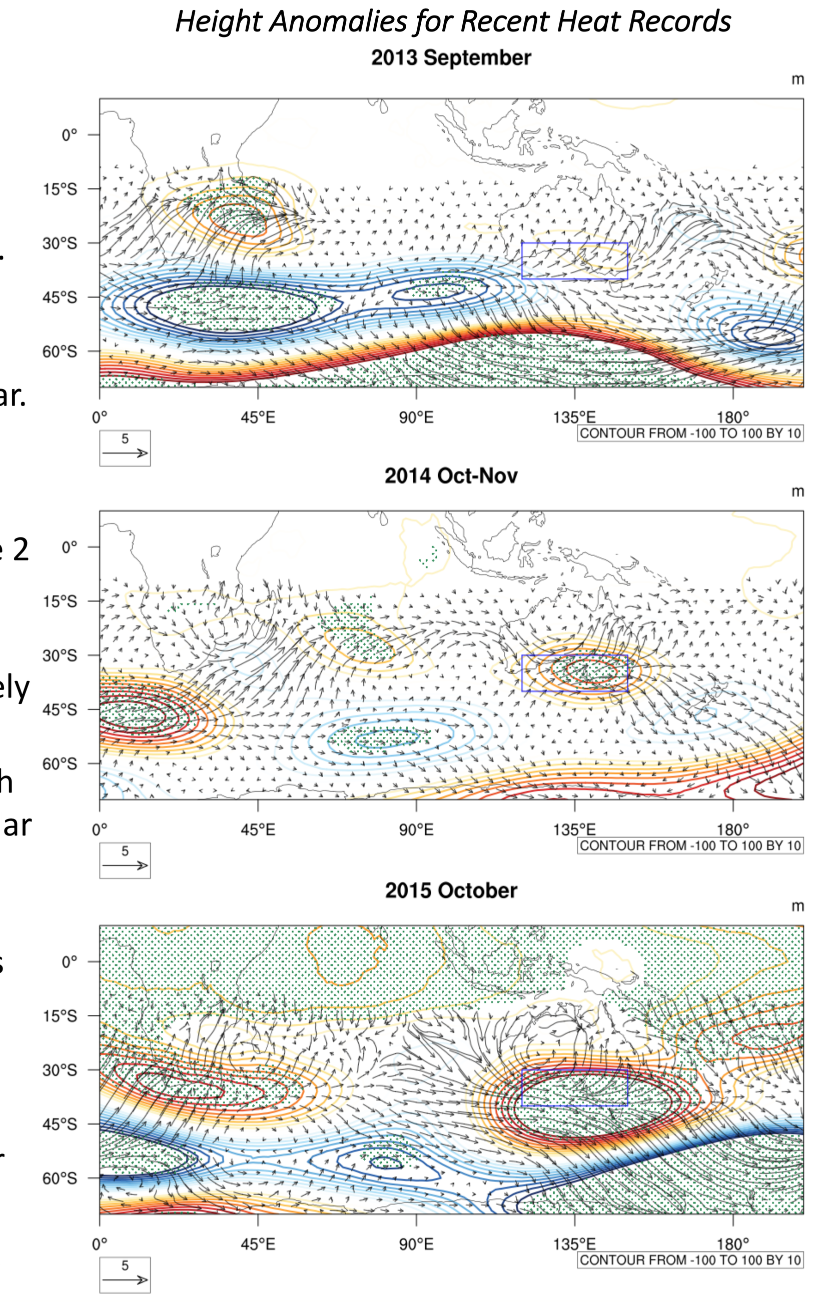

Figure 2 (above) Observed 200hPa geopotential height anomalies (m) and Rossby wave activity flux (m^2s^{-2}) for the Australian spring record heat events. Stippling indicates anomaly greater than 1.96 standard deviations from mean. Blue box: region of 200hPa geopotential height significant to Australian maximum temperature development indicated in Fig. 4 and Gallant and Lewis (2016).

Hottest and Coldest 10% of POAMA Ensemble Member forecasts of Wave Flux and 200hPa Geopotential Height Anomalies for Recent Heat Records

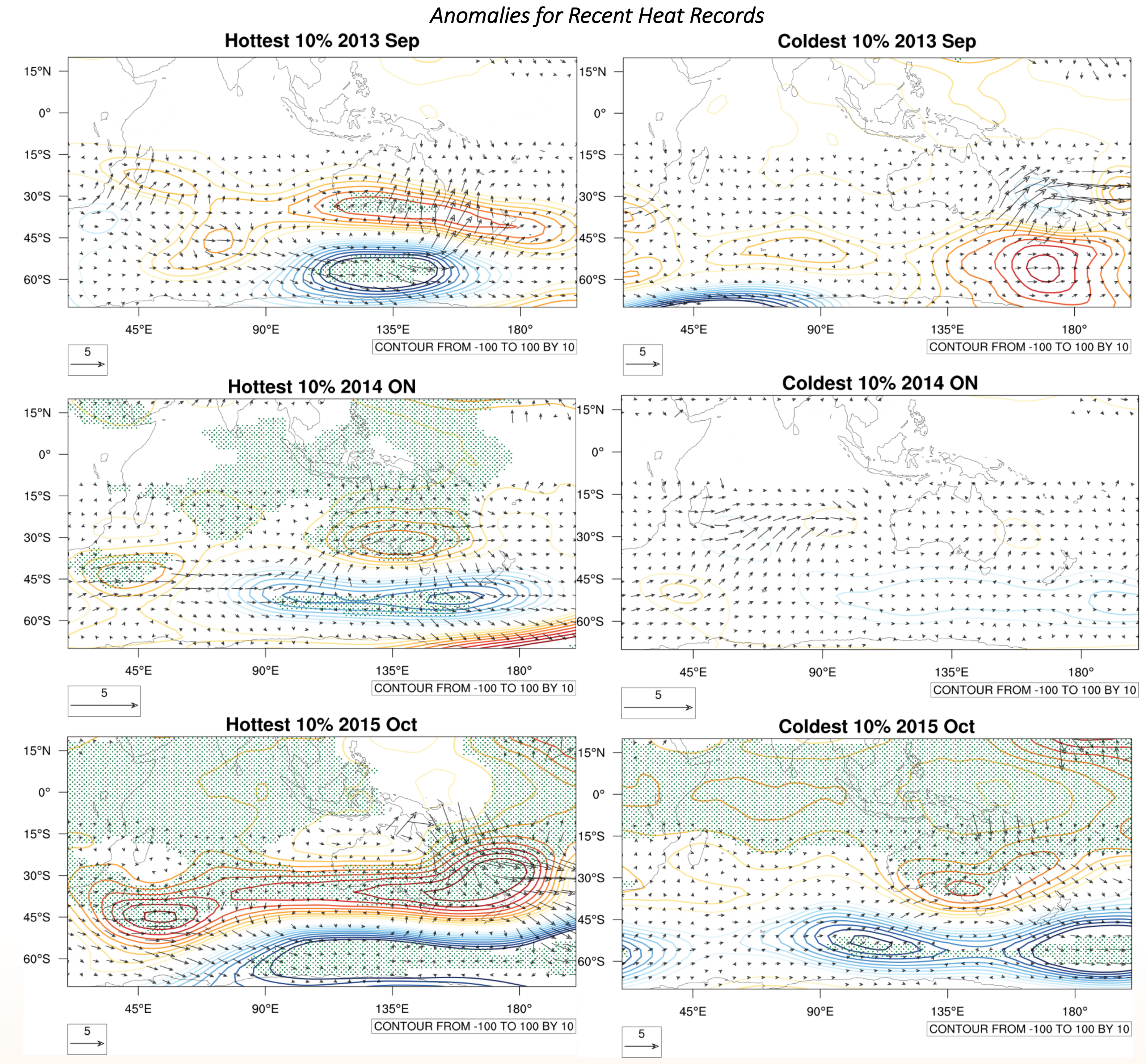

Figure 3 (above) Average forecasts of 200hPa geopotential height anomalies (m) and Rossby wave activity flux (m^2s^{-2}) of the 10% hottest (left column) and 10% coldest (right column) ensemble members for the Australian spring record heat events: September 2013, October-November 2014 (middle), and October 2015 (bottom). Stippling indicates difference from ensemble mean by more than 1.96 standard deviations. Note: different vector length scales between forecasts and reanalysis figures.

Observed Monthly Regression of 200hPa Geopotential Height and Wave Flux against Aus max temperatures

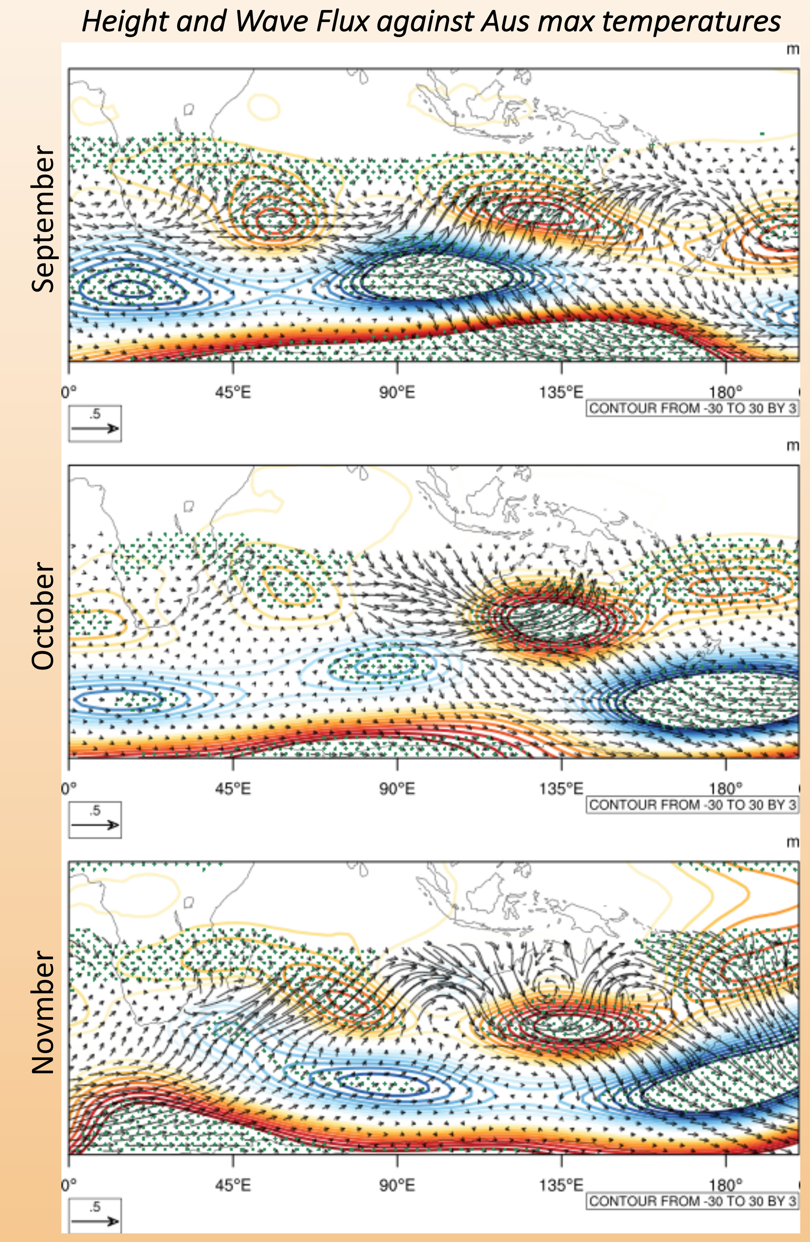

Figure 4 (above) Linear regression of 200hPa geopotential height (m) against standardised Australian max temperate timeseries and associated Rossby wave activity flux (m^2s^{-2}) for September (top) to November (bottom) using ERA-Interim reanalysis. Stippling indicates significance at 95% confidence interval. Climatology period 1981 to 2010.

Monthly POAMA member forecasts of southern Aus 200hPa Geopotential Height vs Aus Max Temperature.

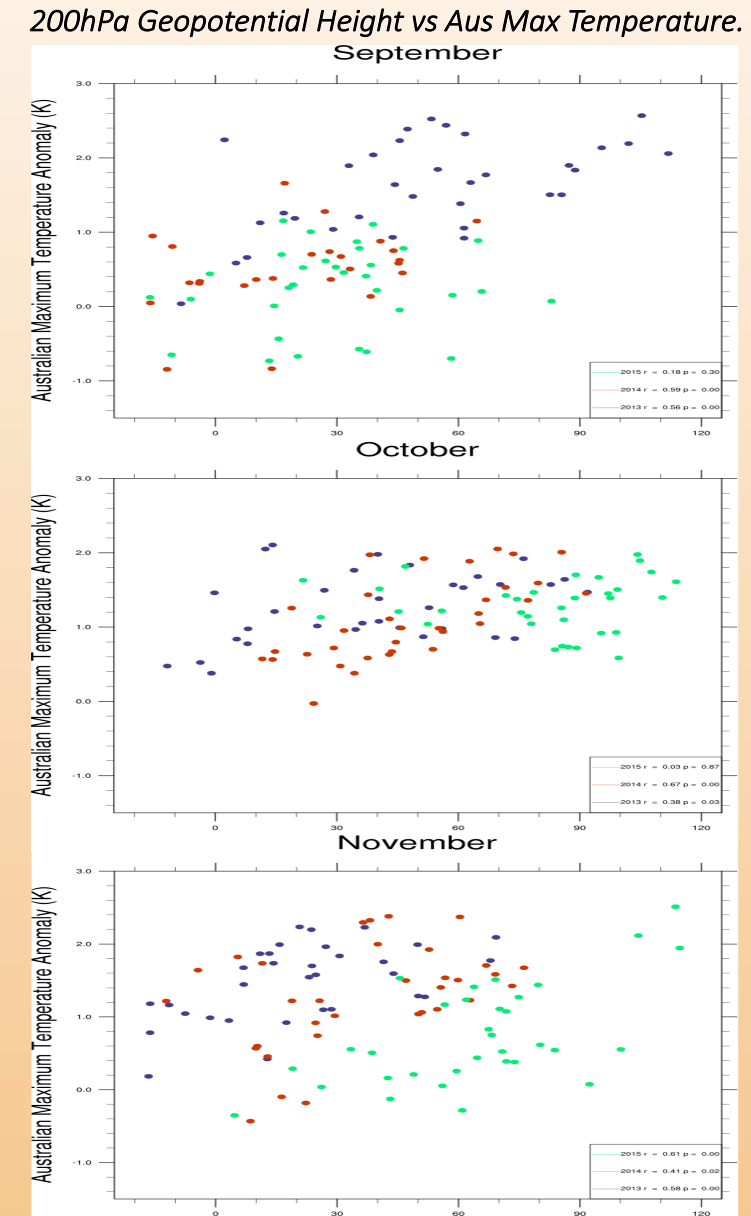

Figure 5 (above) POAMA ensemble member forecasts of Australian maximum temperature (K) against 200hPa geopotential height anomaly (m) averaged over blue box (figure 3) for September (top) to November (bottom) for 2015 (green), 2014 (red) and 2013 (blue). Yearly r and p-values from linear regression in bottom right corner of each month.

Results (continued)

The scatter plots of individual ensemble member forecasts **(figure** 5):

- Nearly all years and months plotted show statistically significant linear relationship with r-values around 0.6, though relationship is weaker in 2015, possibly indicative of the strong El Niño influence on POAMA's forecasts. Comparison to fig. 3 also shows the broader, stronger high anomaly and stronger link to Pacific Ocean in 2015.
- Members that forecast high geopotential height over southern Australia generally forecast hotter maximum temperatures across spring months in these years.
- Confirms importance of how and why POAMA captures high 200hPa geopotential height anomaly over southern Australia for temperature forecast, and is consistent with regression in fig. 4.
- While it seems hotter forecasts capture the circulation better than colder forecasts, it appears that these forecasts are missing an important teleconnection to the tropical Indian Ocean that would further enhance this circulation and, therefore, their development of heat across Australia (compare fig. 3 to figs. 2 and 4)

Conclusion

1. The Indian Ocean appears to strongly related to heat development in spring in Australia, and should provide a source of predictability. The shift from a mid-latitude to tropical Rossby wave source suggests that austral spring (SON) may be too long a period to average over when examining heat drivers around Australia and the monthly change in dynamics across the year will be an interesting area of further study. In particular, the stronger teleconnection to the tropics in Oct-Nov should make heat predictability easier in this period.
2. The hottest ensemble members do capture the circulation patterns associated with heat development in Australia and may be of limited use to explore the dynamics associated with Australian spring heat.
3. However, these members are missing teleconnection in the observed wave flux from the Indian Ocean that was of particular importance in October and November, and may be underperforming as a result.
4. Including the stronger teleconnection from the tropics may improve forecast skill of Australian maximum temperatures in October and November.

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