Hi I'm Eunpa Lim working in the CAWCR in the Bureau of meteorology. My colleagues and I have been investigating the role of SST trend that operated with strong La Nina of 2010-11 on the record breaking high rainfall over Australia in spring 2010.

As you remember, 2010 and 11 La Nina was one of the strongest La Nina events in the last 50 years. The development of this la nina was pretty fast after the termination of 2009 El Nino, so this **la nina** became fully developed by the beginning of austral spring, or say boreal autumn, and there was strong negative Indian Ocean Dipole developing together with this strong La Nina, **which is not unusual in austral spring season**. According to Hendon et al.'s study, this strong La Nina and associated negative IOD was a major driver of the anomalous wet condition over eastern Australia.

Furthermore, the tropical western Pacific and eastern Indian Ocean was very warm in this season, which was far warmer than what canonical La Nina **and** negative IOD could explain. Indeed, Hendon et al.'s study claims that a half of this warming was due to La Nina and negative IOD but the other half was due to the 50 year long term warming trend there, **and they argue that the warmer SSTs due to the trend north of Australia substantially contributed to the wet condition over Australia in this season**. So, our question for this study is what's the mechanism of this SST warming trend to affect Australian rainfall in this season?

Before addressing this question, there is one more very important climate feature I have to mention regarding spring 2010 climate, which is the extraordinary strength and persistence of the positive phase of the Southern Annular Mode SAM that **occurred in this season**. The positive phase of the SAM is characterised by a poleward shift of the high latitude eddy driven jet, causing the surface pressure anomaly to be positive in the mid latitudes but negative in the high latitudes with strong zonal symmetry. And the positive SAM tends to promote rainfall to the subtropical regions of Australia in spring season.

So Harry and I investigated why the SAM was **persistently positive** in spring 2010, and what it did to Australian record high rainfall. And we found out that a large portion of this positive SAM was driven by the strong La Nina, and this positive SAM turned the wet **condition** associated with the strong La Nina into the extreme wet **condition**. The fact that the +ve SAM played an important role in the extremity of the Australian rainfall in spring 2010 is very important in this talk because I'll show you that the SST warming trend that operated with La Nina brought rainfall to Australia via strengthening this +ve SAM that was, as I said, forced by strong La Nina.

So, let me show you how we got to this point.

For this study, we conducted some coupled model forecast experiments using the Australian Bureau of Meteorology's dynamical seasonal forecast system POAMA. POAMA is an atmosphere and ocean fully coupled system. For operational subseasonal to seasonal forecasts, POAMA is initialised with high quality atmosphere and ocean conditions generated from the Bureau's state of the art data assimilation systems.

For this study, we initialised the POAMA model on the 1st of September 2010 and ran it for 3 months. And we conducted four different experiments as follows. Firstly, In all four experiments the atmosphere model and the land surface scheme were initialised with random conditions of 1st of September of the previous 30 years in order to exclude any influence coming from the realistic atmosphere and land initial conditions. Also, this was an easy way of generating multiple forecasts. For our control experiment, the ocean model was initialised with **high quality realistic ocean conditions** of the 1st of September 2010. Then in our dtrend experiment, we initialised the ocean model with the same conditions as the control but the 50 year long-term trend of ocean temperature was removed from the ocean initial conditions. So the difference of three months forecasts between these two experiments will show the climate response to the long term temperature trend in the ocean conditions that operated with La Nina of 2010. Then we conducted

Trend experiment by initialising the ocean model with this 50 year long-term ocean temperature trend added to the climatological ocean conditions of the 1st of September of 1980-2009. And our last experiment was to initialise the ocean model with the climatological conditions of the 1st of September. Therefore, the difference of three months forecasts between these two experiments will show the climate response to the same long term temperature trend in the ocean initial conditions that operated on the climatological ocean conditions.

Finally, then the difference between these two will tell us something about the nonlinearity of climate response to the ocean temperature trend **arising from** the different background states the trend operates on, which are La Nina versus climatology.

Then, let's look at some results

1. Here I display 2010 September to November mean anomalies of SSTs, mean sea level pressure and rainfall from the observation, control experiment and detrend experiment.
2. As you can see, the main characteristics of spring 2010 climate are skilfully reproduced in the control experiment and detrended experiment although the magnitudes of the anomalies are somewhat weaker in the forecasts.
3. In detail, La Nina and negative IOD are both well captured in these two experiments, and so, the associated rainfall anomalies are correctly simulated with excessive rainfall over the western Pacific and tropical eastern Indian Ocean and over Australia.
4. Furthermore, the pressure anomalies associated with the positive SAM are also skilfully captured in these two experiments, which highlights the fact that the positive SAM of spring 2010 was indeed forced by the low boundary conditions associated with this La Nina because the atmospheric initial conditions were random in these experiments.

Then in the next slide,

1. the top panel shows **the difference of SST forecasts between the control and detrend experiments**,
2. and the SST difference pattern looks reasonably similar to the observed long term SST trend with **warming in** the Indian Ocean, the western Pacific Ocean and the North Atlantic Ocean. This indicates that 3 month forecasts from these two experiments well maintained the difference in their initial conditions, which **was again the ocean temperature trend**.
3. And the lower plots suggest that the SST trend that operated with strong La Nina lowers the pressure over the eastern Indian Ocean and increases rainfall over the western Pacific and the tropical eastern indian ocean and over Australia.
4. **In fact, These regions receive a lot of rainfall during La Nina**. Therefore, the SST trend that operated with La Nina seems to make **the wet region due to La Nina** get **wetter <u>in the far western Pacific</u>**.
5. **What is really interesting and somewhat unexpected is this positive SAM response to the SST trend. So, some of this increased rainfall over Australia is likely to be induced by this positive SAM.**

In comparison,

1. when the temperature trend was added to the climatological ocean conditions **<u>at the initial state</u>**, the difference of the following three month SST forecasts looks similar to that of this control minus detrend experiment.
2. And there is a decrease of pressure over the eastern Indian Ocean and an increase of rainfall in the northern hemisphere western Pacific and tropical eastern indian ocean like in this difference.
3. However, the rainfall response over Australia and surrounding ocean is very small. **<u>And the extratropical atmospheric circulation looks quite different to this as well.</u>**

And the difference between these two responses highlights that SST trend operating with La Nina induces more rainfall over the maritime continent and Australia and promotes more +ve SAM like response than the SST trend operating with climatological SSTs. (12min 30 sec)

Our final question is then why positive SAM is promoted by the SST trend that acts together with La Nina?

1. We found an answer in the fact that SST trend and La Nina both cause SSTs to be warmer over the western side of the climatological warm-pool, which is the tropical eastern Indian ocean to western Pacific Ocean.
2. So when both of La Nina and SST trend are present, diabatic heating is largely amplified in that region, which results in strong warming in the upper troposphere in the tropics across the globe as you can see here.
3. Therefore, the meridional temperature gradient between the low and high latitudes of the SH becomes steeper.
4. And this increased meridional temperature gradient promotes more eddy generation in the high latitudes especially the generation of the eddies with faster phase speed.

1. For example, these plots display eddy momentum flux convergence as a function of eddy phase speed in the high latitudes and the mid latitudes of the SH.
2. The green line shows EMFC from the control experiment, and the dark blue line indicates it from the dtrended experiment.
3. As you can see, there is a significant increase of emfc in the high latitudes by faster speed eddies in the control experiment relative to the detrend experiment,
4. and there is an significant decrease of eddy momentum flux convergence, in other words, significant increase of eddy momentum flux divergence in the midlatitudes by faster speed eddies in the control experiment.

5. These changes mean that when SST trend operates with strong La Nina , there is westerly forcing in the high latitudes but easterly forcing in the midlatitudes **to the mean flow** by faster speed eddies, which would result in a poleward shift of the high latitude jet and therefore, a positive swing of the SAM.

What's really interesting is that this chain of processes is very similar to that projected for the future climate with increasing greenhouse gases. On the other hand, the temperature trend added to climatological ocean condition causes a similar pattern of temperature change, but the magnitude is much smaller, so its impact on the SH extratropical circulation appears to be very different to this.

So, a summary of this talk is that in 2010, Australia received a record high spring rainfall, and previous studies showed that strong La Nina and associated SST anomalies including negative IOD were a major driver of this wet event, and the strong positive SAM, which was largely driven by La Nina, made the wet condition associated with La Nina more extreme. Our coupled model experiments with and without temperature trend in the ocean initial conditions of 1st of September 2010 and climatology revealed that the long-term SST trend that operated with strong La Nina of 2010 amplified the wet condition associated with La Nina over the maritime continent and also over Australia and induced +ve SAM, and therefore, increased Australian rainfall through it.

Our analysis showed that the mechanism of the SST trend operating with La Nina to promote the +ve SAM was similar to that of climate change with increasing CO2 scenarios. **So this extraordinary strong positive SAM of spring 2010 was not only driven by La Nina but also driven by the SST long term trend that operated with La Nina.**

On the other hand, the same SST trend that operated with climatological SSTs did not promote the +ve SAM response and the impact of the trend on Australian rainfall was small

Therefore, in terms of regional climate point of view, our results imply that SST trend can amplify the extreme climate conditions caused by ENSO, and therefore, to get better understanding on the long-term impact of SST trend on regional climate, improved knowledge of the multi-year to decadal variability of ENSO and improved modelling capability for ENSO seem critical.