The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

Report on the Victorian Climate Initiative (VicCI) science Day – 12/02/2015

Revision history

Date	Version	Description	Author
20/02/2015	1	Compiled from notes taken during the meeting by P. Hope and M. Ekström	Pandora Hope (BoM)
13/04/2015	2	Modified with inputs from several presentation authors	P. Hope, B. Timbal and H. Herndon
22/04/2015	3	Final version	P. Hope, B. Timbal and H. Hendon

The Meeting

The meeting was held at the Bureau of Meteorology venue in the Docklands, Melbourne. Thirty scientists attended (many are gathered here during one of the coffee break) with a few more on video connections. Meeting organisers: Bertrand Timbal and Val Jemmeson.

Aims

The aim of the day was to summarise the VicCI-sponsored work to date, refine research foci for the final year and flesh out potential longer term research directions. Three key questions were asked for each of the three themes, cutting across the VicCI 7 research projects:

1) What have we learnt?
2) What are the key scientific issues?
3) What are the implications for VicCI workplans?

VicCI aims to bridge the science/policy divide for improved management of Victorian water resources – maximising sound decision making based on informed science. The program embraces the opportunities and challenges that arise from the close collaboration between scientists and the managers of Victoria's water resources. A whole-of-climate approach is utilised towards the development of useful seasonal to multi-year climate and hydrological outlooks. In order to develop future workplans and place the VicCI research in the context of wider climate research that is of relevance to hydro-climate in south east Australia, plus providing a long-term vision for the program, the science day was organised to alternate presentations from VicCI scientists for one of the seven projects and presentations from scientists outside the program on a topic closely related to the VicCI focus.

Overview of day

The day began with a welcome and introduction provided by Graham Hawke (Deputy Director, BoM) providing the perspective from the research agencies on the usefulness to invest in program such as VicCI and a response by Geoff Steendam (DELWP) who provided a perspective on the value and usage of the knowledge and products which are being developed as part of VicCI. Both introductions outlined the history leading to where VicCI is today and the strengths gained by 'staying the course'. The day was full as indicated by the below program, which outlined the structure of the day in themes, the speakers and their topics for the day.

Theme	Presenter* and content. * Presenters are part of VicCI if name is in italics
9.30-9.50:	**Graham Hawke** (Bureau of Meteorology, Deputy Director Environment and Research Division) **Geoff Steendam** (Department of Environment, Land, Water and Planning – DELWP, Victoria)
Theme 2 Improved understanding of past climate variability and change	**Richard** Seager (LDEO, USA, recorded presentation) *Cause and Predictability of the 2011-14 California Drought*
	Hanh Nguyen (Bureau of Meteorology, E&R Division, VicCI) *Longitudinal computation of indices of the Mean Meridional Circulation: particularities of the Australian sector*
	Benjamin Henley (Melbourne University, Australia) *Utilising paleoclimate data in water resource planning*
	Chris Lucas (Bureau of Meteorology, E&R Division, VicCI) *Attribution of observed tropical expansion*
	Matt England (UNSW, Sydney, Australia) *Oceanic circulation role in the ongoing warming hiatus*
Theme 3 Improved understanding of future climate and associated risks to water resources	***Marie Ekström*** (CSIRO, Land and Water flagship, VicCI) *Moving to very fine resolution downscaling, motivation and hesitation.*
	Aurora Bell (Bureau of Meteorology, Services branch) *High resolution modelling: insight from the forecast demonstration project*
	Nick Potter (CSIRO, Land and Water flagship, VicCI) *Using information about climate change in real word applications*
	Bertrand Timbal (Bureau of Meteorology, E&R Division, VicCI) *Can we circumnavigate the hydrological model for stream flow projections?*
	Jai Vaze (CSIRO, Land and Water flagship) – over the phone *Introducing the AWRA model – a method for regional streamflow projections?*
Theme 1 Improved seasonal prediction	**Christine Chung** (Bureau of Meteorology, E&R Division) *ENSO and climate change: what to expect?*
	Eun-Pa Lim (Bureau of Meteorology, E&R Division, VicCI) *Disentangling inter-annual variability and global warming: the case of La Nina of 2010-11*
	Jing-Jia Luo (Bureau of Meteorology, E&R Division, VicCI) *Multi-year predictions*
	Harry Hendon (Bureau of Meteorology, E&R Division, VicCI) *Decadal variability of Predictability: a curse or a blessing?*
	Scott Power (Bureau of Meteorology, E&R Division) *Decadal variability: understanding and physical mechanisms*

Summary of the Presentations

Theme 2: Improved understanding of past climate variability and change

- *Project 2:* Understanding the mean meridional circulation and its relevance to Victoria
- *Project 3:* Understanding sub-tropical – extra-tropical interactions and their relevance to Victoria
- *Project 4:* Exploration of the causes of tropical expansion

Richard Seager (LDEO, USA) reported on research related to the ongoing California drought, which demonstrated the value that can be gained from examining individual extreme climate events. A key finding of Seager is that the ongoing California drought since 2011 has largely stemmed from unusual tropical Pacific Ocean surface temperatures (warm in the far western Pacific) that are acting to drive a long-wave ridge on the west coast of North America. Future projected changes of rainfall on the west coast are, in fact, upward, emphasizing that the current drought is largely due to internal variability. However, this variability is not well predicted or understood (e.g. why has it persisted for 3+ years). The lesson that we can learn for VicCI is that enhanced understanding of the drivers associated with high or low rainfall seasons will provide a stronger basis for future seasonal forecasting. Once we understand these features in the current climate, it will provide the framework for analysis of how those connections are simulated in the CMIP5 models and any future shifts in those. The approach he used to extract the extratropical circulation anomalies that are driven by variations of tropical SST could also be applied to SEA.

The specifics of the work by Seager and colleagues include the analysis of 7 atmospheric-only GCMs, forced with observed SSTs. They found that different SST datasets led to different results. The importance of SST for driving wet/dry years was revealed by forming composites of wet and dry years separately and separating our El Nino and La Nina years.. They found that the SST forcing of dry years during La Nina was not the only important feature for the set-up of the ridge along the west coast, which is the hallmark of dry conditions. However, the forcing of a wet winter by El Nino was much more robust. They further examined the EOFs of the ensemble mean of Nov-Apr 200hPa heights in the NH from the forced runs, and showed aa wave train linking the west tropical Pacific and Californian precipitation that was driven by warm SST in the western Pacific. The increasing warmth in the western tropical Pacific is a signature of the recent trend in SST, where the west has been warming faster than the east, suggesting the recent trend in SST is a key driver of the California drought.

Transferring this work to the Australian context begs some questions. One to consider is that the latitude of the shift from dry anomalies compared to wet in California is at the equivalent latitude of Tasmania, and so the dynamics in play for California drought may not be applicable to the subtropical latitudes of south east Australia. Furthermore, long-term La Nina-like conditions in the Pacific should result in wetter conditions in south east Australia. While it is true the south-east Australia has not been as dry in the past 4 years as it was in the previous decade, it is not clear that recent SST trends played an important role for the recent drying of in south east Australia. *The AGCM simulations that* Seager *used are available for our own analysis and they might be pursued to further quantify the role of recent trends in SST for SEA rainfall.*

Building on the on-going understanding of the link between Victorian rainfall and the intensity of the sub-tropical ridge (STR), **Hanh Nguyen and Chris Lucas** (BOM, R&D division) described their most recent work. They have identified methods to capture regional measures of the extent of the Hadley Cell, which is not trivial mathematically. This allows reliable land-based observations to be used to identify changes in the extent of the Hadley Cell, providing greater confidence in the result of an expanding Hadley Cell in the Australian region. They found that there is a link between the edge of the Hadley Cell and the intensity of the sub-tropical ridge on a regional basis in the Australian region. They then explored the links between the expansion of the Hadley Cell and sea-surface temperatures and found a strong link. Local expansion of the Hadley cell over Australia is correlated with a pattern of interannual variation of tropical SST that looks reminiscent of the cold phase of the Interdecadal Pacific Oscillation, or in other words, a broadened version of La Nina. Further work will be to explore the cause of this association.

Chris Lucas described that observations of the tropical edge derived directly from radiosondes show an expansion of 0.45±0.23° decade^{-1} in the Southern Hemispheres (SH) over the period 1979-2010, much larger than the 0.1-0.2° decade^{-1} rate deduced from climate models. The objective is to build an understanding of the factors driving tropical expansion in the SH with a combination of statistical analysis and experiments using the NCAR Community Climate System Model 4 (CCSM4). Historical 'full-forcing' runs are compared to 'single-forcing' simulations using only ozone, greenhouse gas, anthropogenic aerosol or natural forcings to estimate the contribution of each of these factors to the overall trend. Three-member ensembles are used for each simulation and the period 1960-2005 is analysed. Ozone and greenhouse gases are the dominant drivers behind tropical expansion, with a slightly larger effect ascribed to ozone. When considering only the period since 1979, natural forcing from volcanic aerosol plays a more significant role, reducing the contribution from greenhouse gas forcing.

Using multiple linear regressions, approximately 60% of the variance is explained by considering ENSO, global volcanic aerosol, SH and global average temperature and the size of the Antarctic ozone hole as predictors. These are observational proxy variables for the climate forcings examined in the simulations. Of these factors, ozone explains ~30-60% of the trend. Global or SH temperature, representing greenhouse gas forcing, accounts for the remaining 10-40% of the trend. Volcanic aerosol accounts for ~20% and ENSO about 10%; these two natural factors are short-lived and their apparent effect on the trend is a result of the period chosen.

Thus, about 30-40% of the observed Hadley Cell expansion rate since 1979 in the Australia-New Zealand region is due to the apparent trend in ENSO and strong volcanic eruptions. This result is consistent with findings regionally across the globe that shows that teleconnections ('modes of climate variability') can account for some part of the observed expansion (perhaps up to 50% in Asia). Accounting for these effects makes the expansion more uniform around the globe, and more in line with what longer term climate projections suggest (i.e. 0.1-0.2 degrees per decade), rather than the 0.5-1.0 suggested by most observations. In the Southern Hemisphere, other factors driving the trend are both variations in the stratospheric ozone and GHG. The ozone effect is slightly larger since 1979, 30-60% of total against 10-40% for GHG.

Invited speaker **Ben Henley** (University of Melbourne) presented work on understanding decadal hydrologic variability using paleoclimate data. Australasia's paleoclimate network of tree-rings, ice cores, coral records and historical records provides unique insight into the nature of past climate variability. The value of paleoclimate reconstruction was highlighted in recent studies that put the millennium drought into a broader context. A study by Gallant & Gergis (2011) used a statistical model calibrated to paleo streamflow reconstructions to estimate that the River Murray streamflow deficit for 1998-2009 had an average recurrence interval of 1 in 1500 years. A study by Gergis et al. (2012) reconstructed southeast Australian rainfall back to 1783, capturing 33% of interannual variance and 72% of decadal variance in May-April rainfall using a small number of predictors. Recent and ongoing work on tracking and reconstructing decadal climate variability associated with the Interdecadal Pacific Oscillation (IPO) was also presented. A new index for the IPO was developed by Henley et al. (2015), termed the IPO Tripole Index (TPI). This index provides a simple, non-PCA based method for tracking the IPO using box-averaged sea surface temperature in the Pacific. The TPI has native units of °C and is more consistent with indices used to track other climate modes. A skillful paleoclimate reconstruction of the IPO was then presented, using 24 coral records from around the Pacific.

A proposed ARC linkage project was then outlined. The project builds on, is complementary to, and has strong linkages with SEACI and VicCI. The project seeks to better understand the risk of mega droughts to water resources in southeastern Australia, and aims to*:* 1) extend the observed hydrologic record with a set of new paleoclimate reconstructions of rainfall and streamflow; 2) Develop a new suite of stochastic hydrological simulations that capture information from paleoclimate and climate models; and 3) undertake a detailed series of drought risk assessments in the partner catchments. The project brings together a team of climate scientists, paleo-climatologists, hydrologists and water resource industry leaders from Melbourne Water, the Victorian Department of Environment, Land, Water and Planning (DELWP) and the Bureau of Meteorology, and is scheduled to be announced in June 2015.

Matt England reported on his work to diagnose the cause of the recent hiatus in global surface temperature warming. He attributes this to the swing towards a negative phase of the IPO, thereby resulting in more heat uptake by the subsurface ocean and a slowdown in global mean surface temperature rise. He attributes the multi-decadal swing to the cold phase of the IPO to be caused by internal variability of the atmosphere/ocean climate system, and so accelerated warming due to anthropogenic forcing is expected in the future when the natural variability begins to act with (or at least not against) the forced trends. England highlighted that the swing to the negative phase of the IPO is not well represented in historical climate simulations, so improved understanding of its cause (and possible interaction with anthropogenic climate change) is required in order to improve projections of future climate.

Theme 3: Improved understanding of future climate and associated risks to water resources

- *Project 5:* Critical assessment of climate model projections from a rainfall perspective
- *Project 6:* Convection-resolving dynamical downscaling
- *Project 7: Identification of improved methodologies for water availability projections*

This part of the science day focused on methods used to further understanding on future climate-related risks to regional water resources. Talks detailed motivation of ongoing research into potential added value of very fine resolution convection permitting dynamical downscaling (Marie Ekström, CSIRO) and methods used to reduce the bias in output from downscaling methods to enable their use in run-off models (Nick Potter, CSIRO). Others spoke to what learnings and opportunities can be gained from related work on convective storms in the numerical weather prediction field (Aurora Bell, BoM) and hydrological models used in national water accounting (Jai Vaze, CSIRO).

With regards to convective permitting dynamical downscaling, **Marie Ekström** (CSIRO) presented the clear theoretical reasons for why increasing the resolution can lead to improved 'realism' in the output: improved representation of surface environment (including topography), finer discretization of continuous differential equations into discrete difference equations (particularly relevant around boundaries e.g. around topography and coastlines), and the ability to avoid parameterisation schemes for processes that can be explicitly resolved at the finer resolution (e.g. convection). National (NARCliM, University of New South Wales) and international (the CONVEX program, UK) research has demonstrated added value of simulations on increased resolution, particularly for extreme rainfall events. However, the added value is not necessarily given in the context of water resource work as characteristic time and space scales are different to those of extreme events. In VicCI ongoing research test the relative merits of fine convective permitting simulations versus parameterised convection simulations using the Weather Research and Forecasting model.

Aurora Bell (Bureau of Meteorology, Services branch) illustrates what can be gained by going to finer resolution models in the case of Numerical Weather Prediction (NWP). In her case she described the importance of knowing where downdrafts, updrafts and outflow will occur. These convective features require models with scales of 100-200m in order to resolve them. However, models on the scale of 1.5km can provide information about areas favourable for convection, and are also useful for capturing the impacts of land/sea contrast (e.g. sea breezes) and orography. These basic features will strongly influence the location of rainfall and temperature variability across varied landscapes such as coastal urban environments or mountains. Initialisations of these fine-scale models require a dense observation network and careful implementation of the initial conditions. Models at this scale are required if you want to understand the climatology of extreme rainfall, and will likely alter resulting climatologies of mean rainfall also, though it is unclear to what extent.

Previous work in VicCI and SEACI has looked at different methods for downscaling climate data to spatial scales suitable for hydrological modelling. These include: empirical scaling; analogue downscaling; NHMM (Nonhomogeneous Hidden Markov Model) downscaling; and dynamic downscaling. **Nick Potter** (CSIRO, LW) summarised the main differences between methods. Overall, no particular downscaling method is superior as each has its own strengths and benefits. Dynamic downscaling using WRF was assessed for hydrological applications in Victorian catchments using a split sampling approach (i.e. bias correction from wet to dry period and vice versa). Although WRF provides better climate data than GCMs for hydrological applications, the raw WRF output needs to be bias corrected. Several different bias correction methods were examined (linear scaling, distribution mapping using two different distributions, and empirical quantile mapping). The WRF bias is not stationary (WRF was relatively more biased during the dry period), and this resulted in over- and under-correction of WRF rainfall, regardless of which scaling method was used. Downscaling SILO rainfall data aggregated to GCM spatial scale was considered as a “best possible” case, i.e. if GCM output perfectly predicted observations at GCM scale, can we downscale this to SILO/point scale? The bias is relatively low for this, and this suggests that bias correction of dynamically downscaled climate data could provide low-bias projections provided that the non-stationarity of bias can be eliminated.

Methods to model the water in the landscape were also discussed at length. These models tend to be limited by either the budget of energy or water. Those used in climate models (CABLE) or to develop the AWAP dataset (WaterDyn) balance energy, while AWRA models all the landscape and river physical processes including surface and subsurface routing of flows from every part of the catchment to the catchment and eventually river basin outlet. AWRA is a fit-for-purpose model developed for the Bureau of Meteorology continental water resources assessments and national water accounts. The AWRA modelling system uses available observations and an integrated landscape (AWRA-L) – river (AWRA-R) water balance model to estimate the stores and fluxes of the water balance required for planning, management and reporting purposes. AWRA-L is a daily hydrological model that uses daily climate products (gridded precipitation and climate data) to simulate consistently hydrological fluxes and stores (in order of importance/accuracy, total runoff, evapotranspiration, soil wetness, runoff components, groundwater recharge, etc…) for the range of temporal (daily, monthly and annual) and spatial scales. The water balance fluxes from AWRA-L are used as inputs to the regulated river system model (AWRA-R) to undertake basin scale water balance modelling. The regulated river system model includes river routing, irrigation diversions, reservoir storage, floodplain inundation and river to groundwater interaction components. This constitutes a unique example of implementing a coupled landscape and regulated river system model at a continental scale. The AWRA modelling system also includes an automated benchmarking system which is used for evaluating all key outputs (stores and fluxes) against observations and outputs from peer models. **Jai Vaze** (AWRA Project Leader, CSIRO, Land and Water Flagship) presented the AWRA modelling methodology and showed the comparison of model results with other models (CABLE, WaterDyn, Sacramento and GR4J). The AWRA modelling system results are substantially better than the land surface models and similar to or slightly better than those from conceptual hydrological models for all the water balance fluxes and stores. The Bureau of Meteorology is implementing this model operationally for water resource assessments and water accounting across the nation. The AWRA modelling system is also used for hydrological modelling in a number of large scale projects including the Bioregional Assessments and the Northern Australian Central northern rivers and dams project.

There are simpler models as well. In particular the new simple approach reported by **Bertrand Timbal** (BoM, R&D division) relates inflow directly to high resolution gridded rainfall across the catchment, using rainfall memory (up to last 10 years). Trends using this approach since 1980 match very well the observed one but are too weak since 1910, pointing to a possible inaccuracy in the gridded rainfall earlier in the record. Most importantly the depth of the streamflow reduction during the Millennium Drought (MD) is captured in full, something many statistical hydrological models fail to capture. This was an important motivation to initiate this work as many future projections indicate a rainfall reduction comparable to the depth of the deficit during the MD and hence it is important to ensure that the hydrological response for anomalies of this size are well reproduced by the hydrological cycle. Once the approach is validated across a range of catchments, given the broad scale nature of climate model data, the Statistical Downscaling Model developed by the Bureau of Meteorology (BoM-SDM) has been applied to 22 CMIP5 model simulations of the historical climate and two future climate projections (RCP4.5 and 8.5). Combining the downscaled rainfall with the inflow model above result in an under-representation of the variability while the means are generally close to observations, or in some cases too wet. The approach provides an opportunity to deliver streamflow projections for selected catchments across the state. Only by 2080 do the two RCP scenarios diverge. As future rainfall projections are in general no more severe than the deficit during the MD, it is expected that these models are suitable under conditions projected for the future. The issue of the relevance of the temperature changes associated with global warming was tested using the statistical model with and without temperature as a predictor and was found to be negligible. However, other changes than mean temperature such as surface vegetation and soil properties may influence the results beyond what this simple approach can capture.

Theme 1 **Improved seasonal prediction**

- *Project 1:* Understanding decadal variation of seasonal climate predictability and the potential for multi-year predictions
- *Project 3:* Understanding sub-tropical – extra-tropical interactions and their relevance to Victoria

The session had a strong focus on the Pacific because ENSO is the key source of predictive capability for Australia. Christine Chung (BoM) described how we might expect ENSO to alter under climate change, while Eun-Pa Lim (BoM) described how recent trend in SST can combine with La Nina to modify the impacts over Australia. The session then shifted to a focus on decadal variability, with the next three speakers describing how the background state of the Pacific can influence the intensity and impact of ENSO events.

Looking to the future, **Christine Chung** (BoM) showed that a robust impact of anthropogenic climate change will be increased impacts on rainfall (stronger and shifted east) during ENSO as a result of El

Nino SST anomalies operating on a mean state that warms more in the eastern Pacific than western Pacific. Her work provides no insight as to whether ENSO predictability/variability might change in a future climate, but does suggest that ENSO impacts will increase.

The understanding of how ENSO interacts with underlying trends in SST and other climate features such as SAM and the STR will enhance the scope of predictive skill of regional climate in SEA. **Eun-Pa Lim** (BoM) showed that the record rainfall in spring 2010 was partly due to a nonlinear combination of the La Nina event occurring in conjunction with the underlying background upward trend in SST in the Indian Ocean and far western Pacific thereby that resulted in excitation of a large positive SAM response. This contributed additional rainfall in eastern Australia on top of what was driven by the La Niña and the positive SAM on their own. These interactions are key to understanding the extent and variability of the impacts associated with ENSO. *Exploring extreme months or seasons such as 2010 can also help explain why some events have better predictability than others*.

ENSO is the one key feature of the climate system that is predictable for months to seasons, and potentially years ahead, which of course has significant implications for water resource management in SEA because ENSO plays a primary role in driving pluvial during La Nina and drought during El Nino. Although dynamical seasonal prediction models are improving, our skill for forecasting ENSO is not (Barnston et al., 2012). **Harry Hendon** (BoM) described that this is due to the decadally varying background state of the Pacific especially due to the IPO Experiments using POAMA reveal that the recent decreased variability and predictability of ENSO is also accounted for by the change in background stat due to the swing to the cold phase of the IPO. This cold phase of the IPO ('La Nina-like') is characterised by a strong increase in easterlies in the central and western Pacific, a steepening thermocline, and enhanced variability in the West Pacific Warm Pool and reduced variability in the east Pacific. This limits the capacity for the classic 'discharge-recharge' model of ENSO development to occur and reduces the response of the atmosphere to the underlying sea-surface temperatures. This reduces the predictability of ENSO. This is in contrast to decades when the background state of the Pacific Ocean is more El Niño-like, such as through the 1980s and 1990s, when ENSO variability and predictability were high. Current climate models suggest that that shifts into each state of the IPO are sensitive to small fluctuations in initial conditions and so are not predictable(Wittenberg et al., 2014), thus suggesting that it will be challenging to anticipate future changes in ENSO predictability. However, the mechanisms responsible for the swing in IPO state and especially the feedback of the changed ENSO behaviour onto the IPO are not understood. An improved understanding of the mechanism for the swing in the IPO and the two-way interaction with ENSO would promote improved understanding of predictability of SEA climate in the future.

Jing-Jia Luo (BoM) reported on the potential to predict some ENSO episodes for lead times of up to 2 years. While predictability of certain events was demonstrated, the actual skill level at these long leads is practically low, and there is not yet an indication of which events might be predictable in advance. Luo suggested that the source of the long lead prediction skill might be inter-basin interactions (i.e. upward trends in the Indian Ocean and Atlantic may act to favour La Niña in the Pacific). In order to capture these important cross-basin interactions we need better models that capture key physical processes at higher resolution, including better representations of the stratosphere, the land-surface, vegetation and ice. He also said that recent improvements to reduce the shock from the input of initial conditions need to continue, perhaps using ensembles. While these improvements in the basic modelling system are on-going, there is also scope for using downscaling and developing better metrics in order to make the best use of the outputs.

Scott Power (BoM) reviewed the current state and future prospects for decadal climate prediction. At this point, the main skill for terrestrial climate stems from being able to predict the forced trend, plus in certain sectors (North Atlantic) some decadal predictability exists due to long timescale variation of the climate. He emphasized, however, that the ocean provides a natural source of decadal variability and much of this variation in the subsurface ocean is predictable, suggesting that the full expression of decadal predictability has yet to be realized. He also emphasized that decadal variations of the background climate express themselves as decadal variations of interactions of our local climate with ENSO and other modes of variability and at the very least a better understanding of these variations will aid future management of water resources.

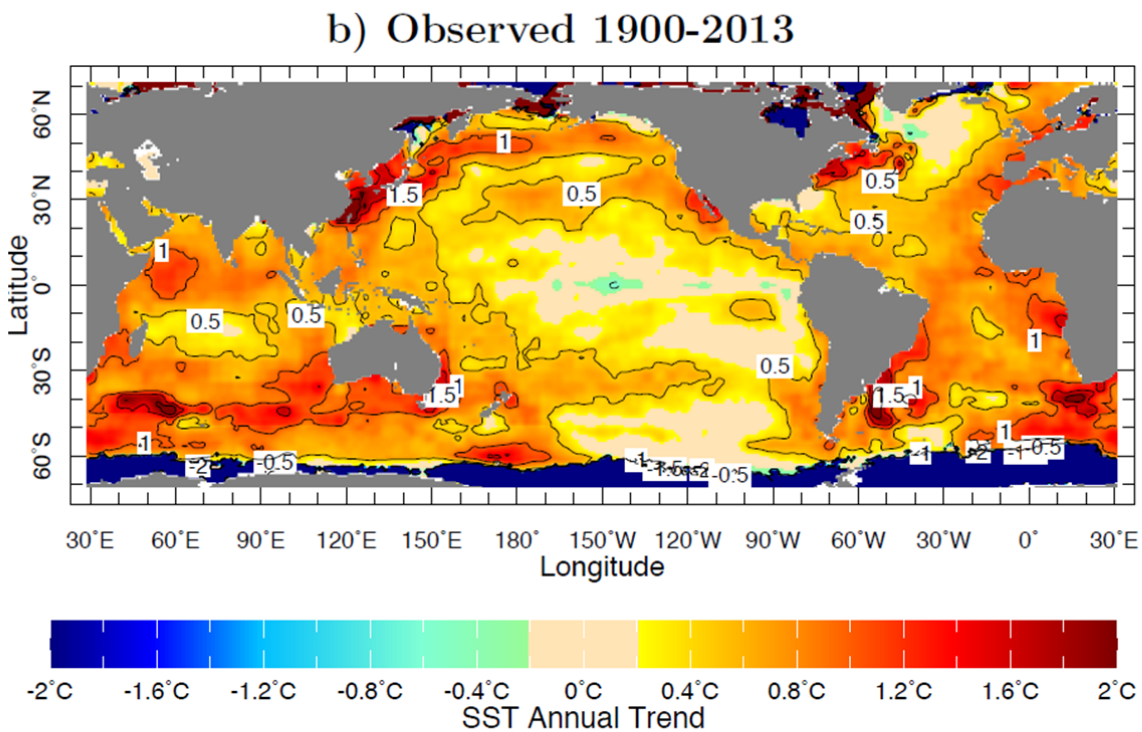

Figure 1: Observed SST trend 1900-2013, from Seager's talk.

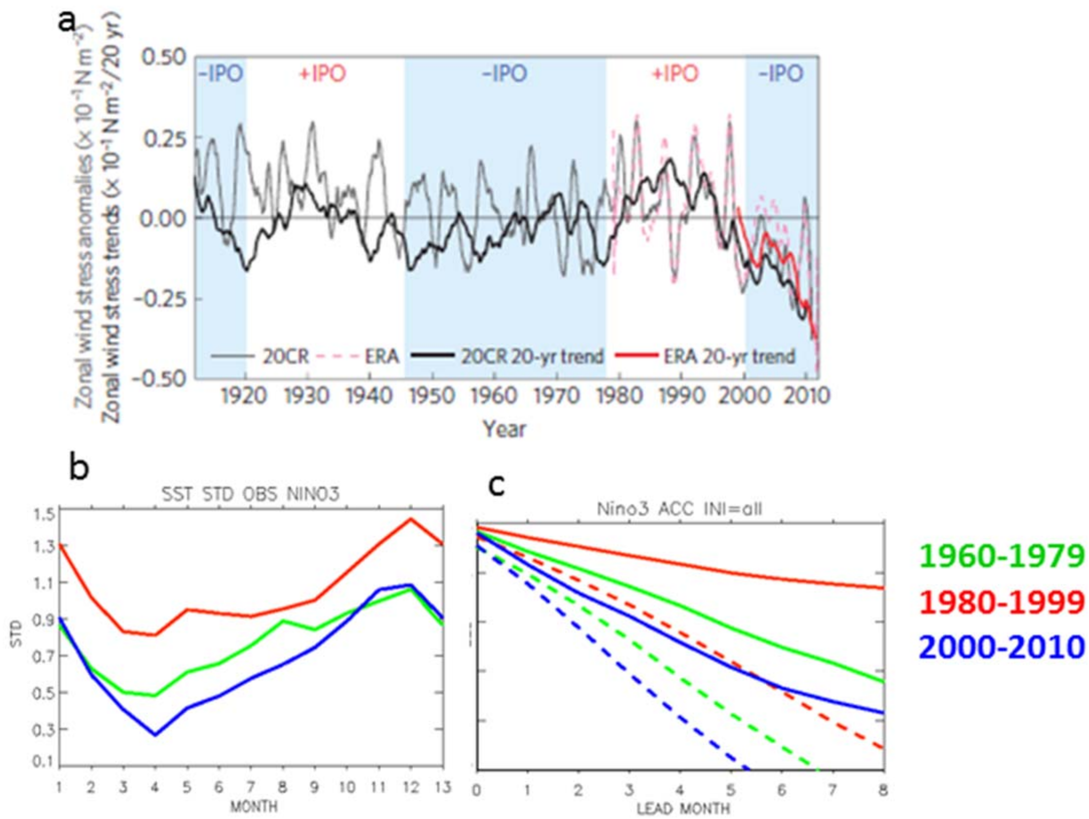

Figure 2: IPO and ENSO Predictability of ENSO using POAMA. (a) Epochs defined as positive (shaded white) or negative (blue) IPO. (b) Annual cycle of the variance of Nino3 during different IPO phases. (c) Average skill in predicting ENSO during different IPO phases.

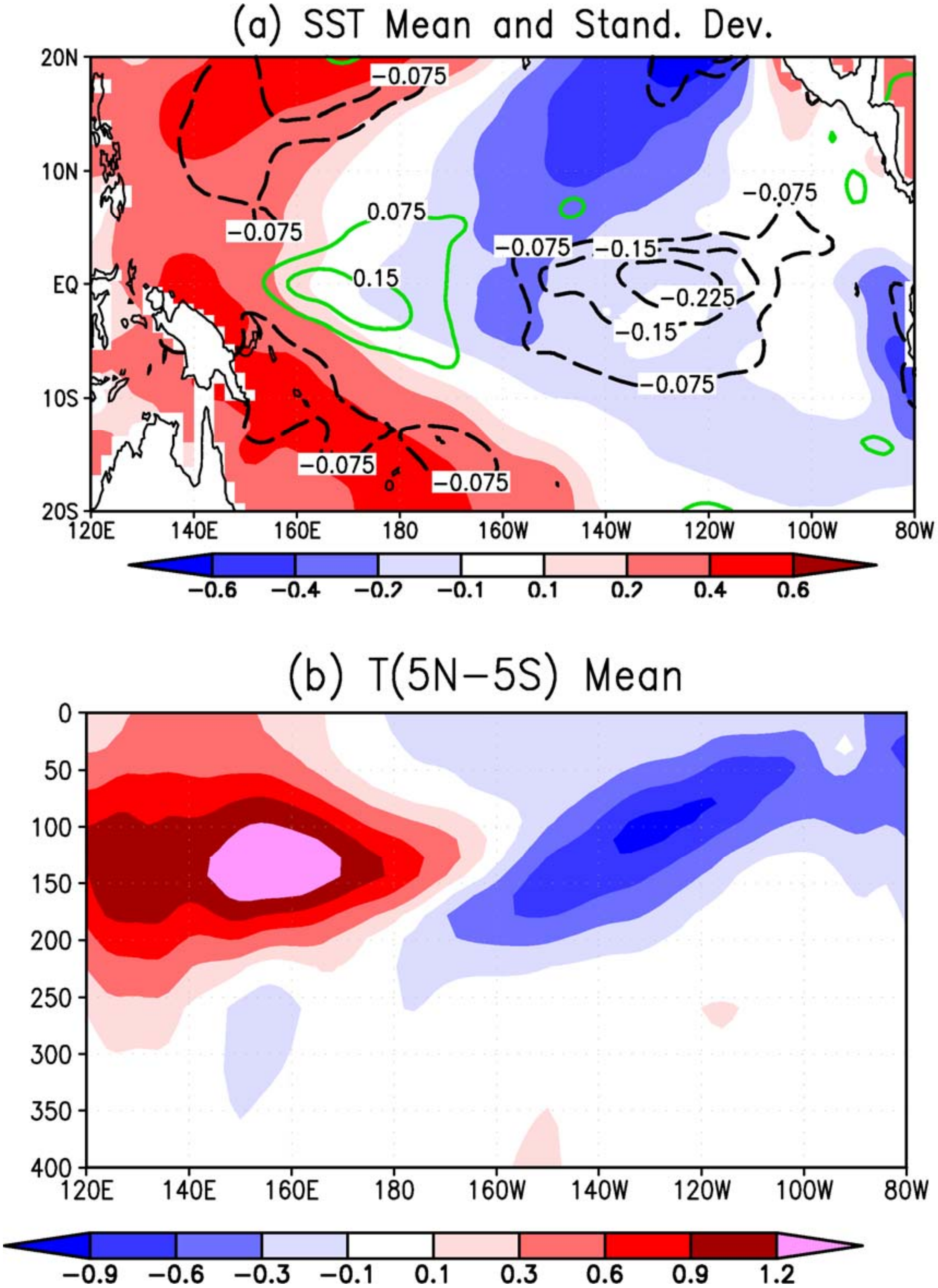

Figure 3: The epochal change in (a) SST (shaded) and standard deviation of SST (contours) and (b) equatorial sub-surface temperatures due to the swing to the cold phase of the IPO after 1998.: SST and its variability have gone down in the east, up in the west and the thermocline has steepened.

Possible future work – both small and big steps

Theme 1:

It is becoming clear that ENSO interacts not only with IOD to influence Victoria's climate, but also higher latitude variability, such as SAM, and also the underlying global warming trend. This was strongly evident in spring 2010. These findings ties back to the work under Theme 2 between the STR and the tropical oceans. Further work should include an understanding of these features. Shall we extend to heatwaves and related forcings?

Are there ways we can improve the potential for decadal variability? It seems that improving models' ability to simulate the variability in the West Pacific Warm Pool would help improve this. This is most likely beyond the scope of VicCI, but could it be the topic of wider collaboration?

A recent study (Jia et al. 2015) shows seasonal forecast skill in the NH extra tropics goes up in 1980-2000 compared to 1960-1980 due to stronger ENSO variability. Behaviour in the SH was not examined. Their study also was not extended to recent epoch (2000-2013) of low ENSO variability. Thus we explore a similar study for SH winter/spring in order to understand better the decadal variation of climate predictability for SEA.

Theme 2:

Local expansion of the Hadley cell over Australia is correlated with a pattern of interannual variation of tropical SST that looks reminiscent of the cold phase of the Interdecadal Pacific Oscillation, or in other words, a broadened version of La Nina. Further work will be to explore the cause of this association. A first step could be to remove the background trends in the expansion of the Hadley Cell and sea-surface temperatures to explore this association further. How do the known links between the Hadley and Walker cells contribute to the expansion? Ultimately, we want to know the drivers of Victoria's rainfall variability, and what contributes to their changing teleconnections. What influence does the ocean have? Can models' capture that?

Some future questions to consider include considering the impacts of the expansion on drought. In particular, how will these impacts vary over the next few decades? More generally, what will happen to tropical expansion over the next few decades as the ozone forcing is reduced? Will the tropics contract somewhat before expanding again, or remain somewhat neutral? Of particular interest is the seasonal partitioning of the influences on the trend. The ozone effect is primarily in SH summer, while there have been strong rainfall declines in autumn and winter.

Richard Seager and his team have a very large ensemble of climate model experiments (ensemble of SST forced simulation) that are available for us to access if we would like to explore the drivers behind similar periods of drought or flood across Victoria. Using the model simulations and applying some of the analysis methods used by Richard Seager and his team when he examined the cause and predictability of the 2011-14 California drought could be an avenue to consider.

Utilising paleoclimate data in water resource planning would be useful to extend the observed record with rainfall and streamflow reconstructions and to track and reconstruct the Interdecadal Pacific Oscillation. There is the current ARC Linkage Project proposal which is aiming for this with the final goal to incorporate paleoclimate and climate model data into water supply

Theme 3:

Future work using dynamical downscaling seeks to conduct multi-year simulations of WRF, using different spatial resolutions, to quantify their relative merits for water resource applications. It may also be useful to develop an ensemble of these outputs in order to provide robust statistics about the variability of rainfall across Victoria. For the validation of these it will also be useful to consider using radar data.

When it comes to generate hydrological projections, the bias correction of dynamically downscaled climate data could provide low-bias projections provided that the non-stationarity of bias can be eliminated.

The simple inflow model (Timbal et al, 2015) that includes long-term memory of past rainfall could be extended to estimate the influence of surface vegetation and soil properties, or perhaps collaboration could lead to inclusion of long-term past memory terms in other inflow models.
The AWRA modelling system could be used with the climate change projections from VicCI (generated from the CMIP5 dataset downscaled to a finer resolution using the BoM-SDM approach) for providing future water availability projections across Victoria.

An emerging Cross-cutting issues: *the IPO*

A major component of the discussion of the day was the state of the decadally-varying component of Pacific variability (termed the Pacific Decadal Oscillation, PDO or Interdecadal Pacific Oscillation, IPO). Much was made of the impact that the La Niña-like state of this (negative IPO) since 2000 has had. This state is characterised with a strong increase in trade easterlies in the central Pacific, a steepened equatorial thermocline, and enhanced variability in the West Pacific Warm Pool and reduced variability in the east Pacific. The on-going warming in the Atlantic and Indian Oceans was also highlighted as a factor enhancing the La Niña-like response. The analysis of the 2010 extreme wet conditions across Australia revealed that the spatial pattern of the 50-year trend in ocean temperatures acts to enhance La Niña. Thus one question arose as to what the basic state of the Pacific will be in a warmed world and can we better anticipate swings in the IPO

This slowly varying background state was implicated in limiting the scope for a strong El Niño to occur in 2014, the on-going dry conditions in California and a 'hiatus' in global surface temperature. It was also found to limit the predictability of ENSO events due to less capacity for the classic 'discharge-recharge' model of ENSO development to occur and reduced response of the atmosphere to the underlying sea-surface temperatures. This is in contrast to decades when the background state of the Pacific Ocean is more El Niño-like. Understanding the cause of the decadally varying background state of the Pacific might is important for VicCI. However, climate models don't well represent the IPO, and so tackling model errors that are limiting the simulation of the IPO would be a pathway forward toward improved predictions and projections. The forecast experiments described by Hendon could be explored to better understand how the model errors in representation of the IPO state evolve with lead time, and so provide insight into the key model errors in the depiction of the IPO.

Ben Henley presented work he is doing with Joelle Gergis to use simpler measures of this slow-varying pattern to allow the development of far longer records using paleoclimate data.

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