IPCC Report: Tropical Phenomena and ENSO

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1 Applied Mathematician: Isaac Nault

1.1 Modelling Challenges

There are fundamental challenges that currently limit the effectiveness of modelling tropical phenomena. The current generation of climate models (CMIP5) do not consistently predict the same results for particular phenomena. These phenomena include precipitation patterns, SST patterns, Madden-Julian Oscillation and ENSO. Whenever models disagree on a specific aspect of any of these phenomena, it makes future prediction must less certain. Therefore, it is necessary to identify the deficiencies in modelling which cause the discrepancies in model results.

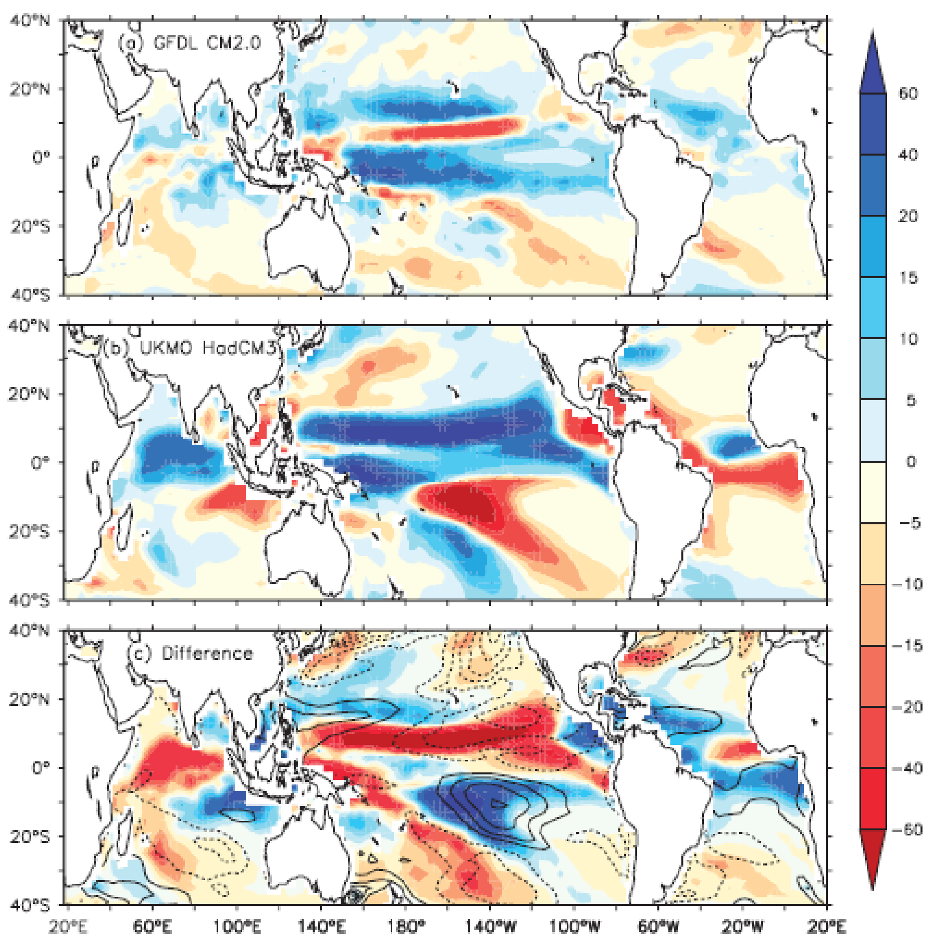

FIG. 1. Comparison of annual mean rainfall changes (color shading, mm month^{-1}) between (a) GFDL CM2.0 and (b) HadCM3 in the CMIP3 ensemble under the SRES A1B emission scenario. (c) Their difference along SST difference in contours [contour interval (CI): 0.2 K; 0 K contour omitted].

Rainfall projections are an important aspect of tropical modelling. According to the IPCC report, there is a wide range of inter-model variability in future rainfall projections. Obvious model differences can be seen in Figure 1.1 above. A third of the variability was shown to be caused by differences in the SST warming pattern (Ma and Xie, 2013). According to Ma and Xie, there is a strong correlation between warmer-than-average SST and increased precipitation within regions. Thus modeling SST warming patterns is very important for predicting future rainfall. While

SST is projected to increase in general, the pattern of warming is not projected to be uniform. Further, this pattern of warming is not consistent among models. Due to the correlation of SST warming and precipitation, any inaccuracy in predicting SST warming patterns is inherited by the modelling of future rainfall. This is a modelling challenge because SST pattern formation involves complicated processes such as ocean-atmosphere interactions and the interaction between convection and large-scale environment which are not well-understood.

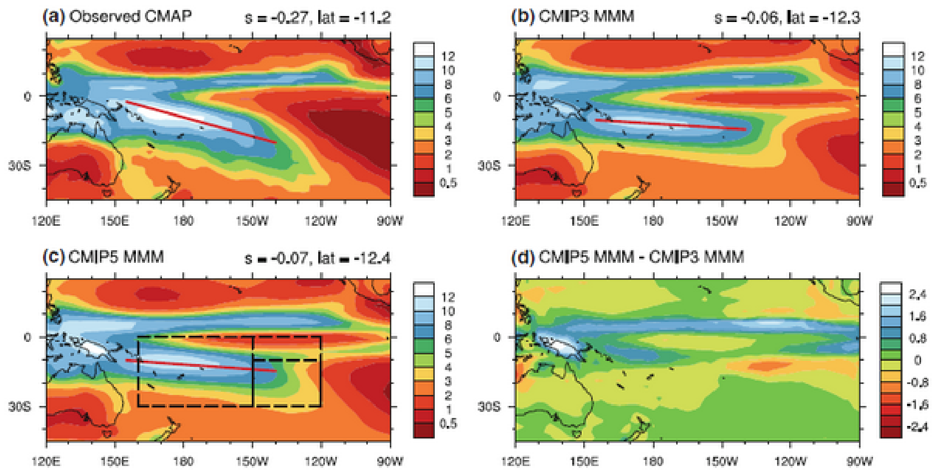

Fig. 1 DJF seasonal average precipitation (mm/day) for 1980–1999 from **a** CMAP observations, **b** CMIP3 (24 models) multi-model mean (MMM), **c** CMIP5 (26 models) multi-model mean and **d** CMIP5 minus CMIP3 multi-model mean. In plots (a–c), the SPCZ line fitted to points of maximum precipitation in the range 155°E–140°W is shown in red and the SPCZ line slope (s) and mean latitude (lat) are given at *upper right*. The SPCZ ALL,SPCZ WEST and SPCZ EAST domains are shown in (c)

The study of the the Intertropical Convergence Zone (ITCZ) is another modeling pursuit that is very relevant to the projection of future precipitation in the tropics. A major issue in modelling this feature is the appearance of an unrealistic double ITCZ pattern in many models.
An example of this double ITCZ is seen in the eastern Pacific ocean, where models project a higher level of precipitation both North and South of the equator, as opposed to reality, where a diagonally oriented convergence zone is present in the south. This can be seen in Figure 1.1 above. In a study, Brown used a regime sorting technique, in which precipitation change is decomposed into dynamic, thermodynamic, and covariant components (Brown et al., 2012). This study showed that, in the regions where models most often disagree with reality, the dynamic and thermodynamic components of the precipitation change were also most different from reality. This suggested that reduced atmospheric moisture and reduced ascent are to explain for the apparent bias. In a previous study by Brown, it was shown that models that use flux adjustments are the most accurate in reproducing the observed spatial ITCZ pattern, while models that do not use flux adjustments fail to capture the diagonal orientation (Brown et al., 2011).

This result suggest the absence of ocean-heat flux adjustments in most CMIP5 models may be responsible for their inaccuracy in modeling the observed ITCZ pattern. Once again, the influence of SST warming, and in this case zonal SST gradient, is an important factor in modeling another climate phenomena.

Considering the above result, one might wonder why more models do not use ocean-atmosphere flux adjustments, since doing so enables better modelling of the ITCZ. The answer is there is a tradeoff. The inclusion of ocean-atmosphere flux adjustments can cause climate drift over long periods of time within a model (Gordon et al., 2000). If the ocean heat transports implied by atmospheric surface fluxes are significantly different from the ocean model, SST might drift to establish a new balance. Thus, while flux adjustments might be useful for predicting ITCZ pattern, their universal effect could cause other undesirable issues.

Madden Julian oscillation is the dominant mode of tropical intraseasonal variability. However, the IPCC reports that modelling of this phenomena remains challenging, leading to future projections of MJO having low confidence. Like with precipitation change and ITCZ pattern, MJO has been shown to be highly sensitive to the pattern of SST warming (Maloney and Xie, 2012). So, like before, the uncertainty in projecting future SST warming patterns is a leading cause of uncertainty in projecting MJO properties.

According to the IPCC report, most CMIP3 and CMIP5 models disagree on the response of the zonal SST gradient to the El Nino Southern Oscillation (ENSO) across the equatorial Pacific. ENSO properties have been shown to be influenced by the background state of the tropical Pacific, which includes SST properties and the sensitivity of the atmosphere to SST changes (Yeh et al., 2012). The magnitude of the SST trend in the tropical Pacific has been reduced from CMIP3 to CMIP5. Yeh suggests that this change may be due to overestimation of the response to natural forcing and aerosols by including Earth system models. If this is true, it emphasizes the need to examine how the addition of Earth System models, and their detailed physical processes, affects the larger models of which they are a part.

1.2 Trends

Within all these issues are a few common trends. One trend is that many phenomena depend on the modelling of other phenomena. And thus, if the modelling of one phenomena is flawed, than it would be unrealistic to expect accurate results from any phenomena that depend on it. This is exemplified by the dependence of most tropical phenomena on the SST spatial and gradient patterns. Since there are many questions raised about the accuracy of SST modelling, and the proper way to model (whether to use flux adjustments or not), this uncertainty extends to the modelling of precipitation patterns, ITCZ patterns, MJO, and ENSO. While SST itself may not be very relevant to humans, the phenomena that depend on it certainly are. Therefore, better modelling of SST is needed.

Another trend is the trade-off between different modelling approaches. Sometimes a particular approach is better at modeling a specific phenomenon than another approach. However, this approach might have side-effects that negatively affect the model as a whole. This is best exemplified by the tradeoff between using flux-adjustments or not. As described above, using flux adjustments within a model can produce better results for simulating ITCZ, but as a consequence, can cause climate drift across the entire model as a whole.

The last trend is the importance of properly weighing the influence of various modelled processes. If a particular process is excessively simulated its effects might exceed those seen in reality or diminish the effects of other important processes. This is best exemplified by the overestimating of forcing that Yeh suggests is causing disparity in the SST trend of ENSO. A key challenge in modelling is making sure some processes are not overly accounted for by multiple models.

Overall, the challenge for Applied Mathematicians moving forward is to better model SST in the tropics, or more specifically, better model the interaction between SST and atmosphere. If the most advanced climate models had a more robust prediction of future SST warming, this by itself, would provide more consistency to predictions of precipitation, MJO, and ENSO. Its possible SST is not the only issue plaguing tropical climate predictions, but resolution of the issue would highlight the other issues which are not as noticeable at this time.

1.3 References

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2 Computational Scientist: Morgan Frank

2.1 Summary

- it is believed tropical convection influences changes in SST (model)
- SPCZ GCMs and model do not correctly account for the orientation of SPCZ (model and data)
- ITCZ is modeled unrealistically in several prominent models (data)
- South Pacific island rainfall explained by ITCZ (model and data)
- SACZ explains flood/dry conditions in south east Brazil (data)
- ENSO may display variability explained by natural variability or by forcing. Models mimc observed data without external forcing, but better understanding of the underlying mechanisms is required to justify this assumption.
- ENSO will remain a dominant mode of inter annual variability with global influences. Namely, ENSO induces rainfall intensity variability because of increased moisture

2.2 Wants

- there is a demand for improved modeling of SST warming patterns to improve rainfall estimates in climatological convergence zones
- improve annual estimates of SST warming patterns to the confidence of seasonal estimates

  - (COMPUTATIONAL SCIENTIST) improvements in prediction can be achieved with more computationally expensive model runs
- correct modeled orientation of SPCZ

  - (COMPUTATIONAL SCIENTIST) seems fair enough. I do not imagine this being computationally difficult
- more knowledge of zonally-oriented SPCZ events
- better knowledge of IOB formation from ENSO
- better understanding of annual SST change (data taken from coral isotopes)
- model for tropical Atlantic Climate variability in boreal summer

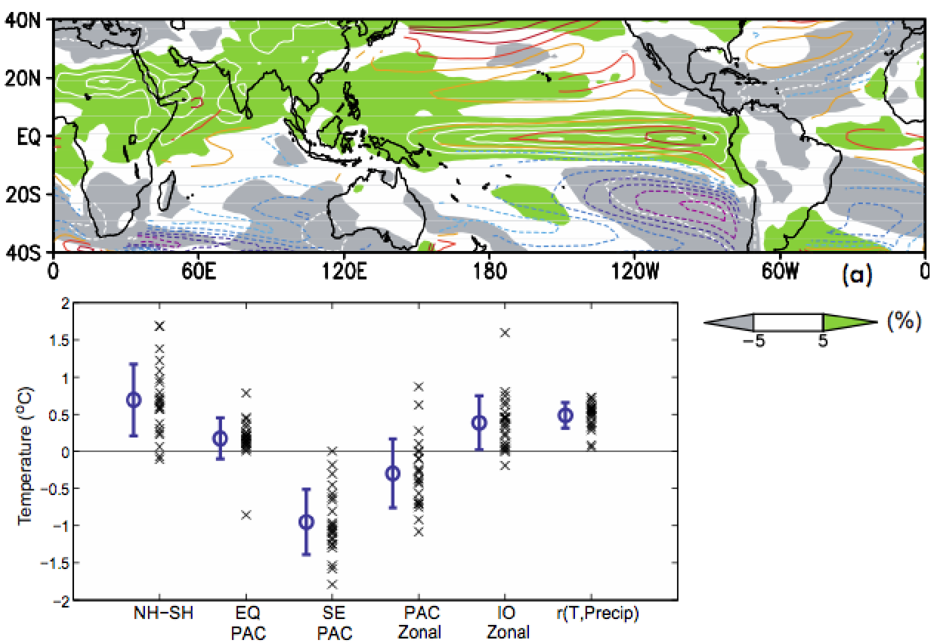
  - possibly incorporate feedback loops between surface wind, evaporation, and SST
- better predictions of AMM activity
- better MJO modeling

  - sensitive to SST warming pattern, which itself has high uncertainty
- demand for better understanding of how a warmer climate influences ENSO

3 Climate Scientist: Andy Reagan

3.1 Sources of uncertainty

In responce to increasing SST, the changes in climate tend to agree in a handful of observed "convergence zones." Convergence zones are long and narrow bands of tropical convection anchored by SST structures. These changes include a wet-get-wetter paradigm and a warmer-get-wetter mechanism, for uniform and projected SST increases, respectively. The spatial pattern of SST change is the main driver of uncertainty between these two modes of precipitation change in the observed convergence zones. SST change and preciptiation plotted over one another can be seen in Figure 3.1.



Over the tropical Atlantic, models agree poorly over current conditions due mainly to a northernly biased ITCZ and a cold tongue in (our) summer. Models are able to capture the general warming trend over the past century in the Atlantic, but this results in a southward displaced Atlantic ITCZ.

Observational uncertainty, limited data, and changing measurement techniques all make the projection of zonal SST gradient difficult, and some models show strengthening while other models show weakening. The ENSO variability over the past century is reproduced both in variability and spatial pattern by models with external forcing and without forcing, such that there is little agreement on whether external forming plays a role in the observed changes in ENSO.

Again due to uncertainties in SST projections, the ENSO spatial pattern change has low confidence.

3.2 Agreement in convergence zones

The three main convergence zones are the ITCZ, the South Pacific Convergence Zone (SPCZ), and the South Atlantic Covergence Zone (SACZ).

The ITCZ suffers an unrealistic double-ITCZ pattern over the tropical Pacific and the Atlantic, which results in excessive rainfall over the southern flank. This is due to the incorrect orientation of the SPCZ, missing the southeastward orientation of the SPCZ and aligning it with the ITCZ. Changes in ENSO displace and change the orientation of the SPCZ as well, moving the SPCZ northeast and aligning it zonally in response to stronger events. This shift to zonally-oriented SPCZ is consistent in both the CMIP3 and CMIP5 models, and increasing in frequency in the future. This relies on a reduction in near-equatorial SST gradient, a consitent finding in response to human forcing. A consistent shift of the SPCZ woudl result in major changes for the southwest Pacific, including potentially a longer dry spell.

In the SACZ, changes have a major impact on the precipitation over southeast South America. The projected southward displacement and intensification will likely result in changes in the flood and dry conditions of South America, to which the current SPCZ pattern effects over Brazil.

3.3 ENSO persistence

Depsite the uncertainties in the spaital particularities of the ENSO, the amplitude modulation are well reproduced over the past century by models and the generation of the 10-100 year modulations by coupled GCM's without forcing. Poor observations of the detailed coupled air-ocean feedbacks before 1970 make the discernment of forcings' role in ENSO uncertain, as mentioned earlier.

The improvement in the modelling of ENSO intensity from CMIP3 to CMIP5 is significant, and due to increased moisture with rainfall variability is expected to increase regionally. Although the future changes in intensity are not confident due to the many factors on which ENSO depends, we remain very likely that this will continue to be the dominant mode of climate variability. In Figure 1 we can see how likely this is.

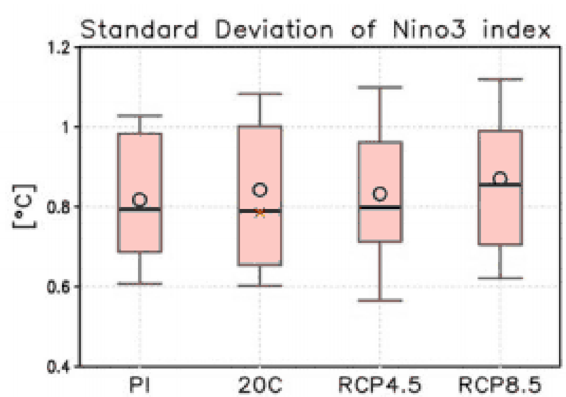


Figure 1: Standard deviation of Nio3 SST anomalies from CMIP5 model experiments. PI is the pre-industrial control experiment, 20C is the 20th Century control experiment, RCP4.5/8.5 are the 21st Century projections. The cross mark on 20C is the current observation.

3.4 Future goals for Climate Scientists

To make better predictions of the climate, we need to focus on our ability to reproduce the known large scale structures such as covergence zones that drive regional climate changes. A better understanding of these structures, coupled with better observations, will allow us to ensure that the models accurately represent these structures togay and how they have changed during our observations, such that we can have confidence in future predictions. In addition, the convergent structures drive regional precipitation patterns, which are economically and socially important outputs of climate modelling for the future.

A case study for this work has been the work of the past few decades on the ENSO. Once poorly understood, it was foreseen by Charney and the vast amounts of work we have put forth to understand this phenomena have allowed us to be able to predict how it will change in the future. Only with better observations, over a longer time, can we be more sure of the changes in intensity of these structures as well.