SUMO - Supermodeling by combining imperfect models

Workpackage 5: Year 3

Mao-Lin Shen and Noel Keenlyside

May 16, 2014
Contents

Comments of the authors ................................................. 3

Summary ............................................................................. 4

1 Introduction ..................................................................... 5

2 SUMO over Training Period (1948-1979) ......................... 8
   2.1 Data ........................................................................... 8
   2.2 Mean State ................................................................. 8
   2.3 Air-Sea Feedback ....................................................... 8
   2.4 ENSO Anomalies ....................................................... 12

3 SUMO over historical period (1900-2005) ....................... 14

4 Climate Projection by SUMO ............................................ 14

5 Initial results from the Kiel Climate Model ...................... 18

6 Simulation of the Madden-Julian Oscillation ................... 20

7 Conclusions and Future Perspective ................................. 22
   7.1 Conclusions .............................................................. 22
   7.2 Future Perspective .................................................... 22

References ........................................................................... 23
Comments of the authors

This report describes the work done in workpackage 5 of the SUMO project in year three, i.e. task 5.6, 5.7 and 5.8. The description of work says the following on the tasks:

Task 5.6, define a second version of the super-climate model: A refined version of the model will be made based on results of task 1-4 and recommendations from WP1-4. It will be trained over the period 1870-1980, and tested on the period 1980-2010.

Task 5.7, perform a scenario simulation for the 21st century with the super climate model and contrast it with conventional multi-model scenario simulations.

Task 5.8, final recommendation on the super climate modelling strategy: Results of the application of the super-modelling strategy to the hierarchy of models in the whole project will be summarised. The utility of the approach to climate modelling and the potential to reduce uncertainties in future climate projections will be assessed. Recommendations on future work on this topic will be made. These will be described in a report.
Summary

A set of optimal weights for coupling two atmospheric GCMs (AGCM) with one ocean GCM (OGCM) was found by using Nelder-Mead method. With these optimal coefficients the synchronization of surface wind field of two AGCMs was increased and the well-known systematic error over tropical Pacific was reduced, and simulated climate variability was improved. Furthermore, the model with optimal coefficients has not only good performance over the surface temperature and precipitation, but also the positive Bjerknes feedback and the negative shortwave heat flux feedback match observations/reanalysis well. This leads to a substantially improved simulation of ENSO. The robustness of these results was demonstrated by applying the same approach to another climate model with higher model resolution.

The supermodel was tested in historical simulations covering the period 1900-2010. The performance of the model in terms of the global mean temperature is comparable to other models. A good representation of tropical climate was maintained for different sub-periods, including over the period 1980-2005.

Climate change projections were performed with the three models (two individual coupled models and the super model). We focused on the response over the tropics, because of the models improved performance in this region. The individual coupled models simulated a strengthening of the zonal equatorial SST gradient, strong precipitation increase over the western Pacific, and an eastward shift of the Walker Circulation. In contrast, the supermodel showed a weakening of the zonal equatorial SST gradient, weak precipitation increase over the tropics, and a weakening of the Walker Circulation. The supermodels better representation of the basic state and ocean-atmosphere interaction suggests it may depict a more realistic global warming response in the tropics.

There are two key recommendations:

- A super climate model for the Tropical Pacific was produced through partial synchronization of two AGCMs. A super climate model that performs well at global scales can be only achieved through synchronization of the 3D ocean and atmosphere states. For the atmosphere this can be achieved through coupling of temperature fields (WP4), and similar results can be expected for the ocean. Nevertheless, 3D coupling of climate models is not a trivial task, and new non-intrusive approaches to achieve this should be investigated.

- The performance of the supermodel depends ultimately on the ability to compensate model errors. Thus, the inclusion of more global model in the supermodel can be expected to lead to a more superior supermodel than one based on two single AGCMs differing only in convection scheme.
1 Introduction

Most of the models share similar systematics errors or deficiencies [1, 2], e.g. double Intertropical Convergence Zone (ITCZ), wrong equatorial sea surface temperature (SST) gradient as well as warm bias over southern ocean. The bias pattern of CMIP5 is similar to that of CMIP3 [2, 3] implies the improvement of climate models is modest in the last decade. Therefore this strong motivation for using the SUMO approach to reduce model systematic errors.

From other WPs, we learned that chaos synchronization is regarded as a common phenomenon in the atmospheric circulation [4, 5, 6] and nonlinear dynamics. This classical concept was considered in altering intrinsic dynamics in a nonlinear system. Former studies demonstrated nonlinear models, such as Lorenz 63 model [7], quasi-geostrophic models as well as AGCMs [8], can be synchronized by fairly weak connection coefficients. Following this concept, a climate model base on COSMOS [9] (ECHAM5/MPIOM, developed at Max-Planck-Institut für Meteorologie, Germany), and involving two AGCMs was built. We applied different cumulus parameterization, Nordeng [10] and Tiedtke [10], to increase model diversity because cumulus convection schemes normally have strong impact on the climate state [11, 12, 13]. Hence, the ocean model can continuously interact with the ensemble AGCMs (i.e., Nordeng atmosphere and Tiedtke atmosphere). Furthermore, AGCMs are problematic in representing air-sea fluxes to different degrees. Namely, some may be better in representing momentum flux and some in heat flux [14]. Here we used different weights for each fluxes, and keep the sum of the weights to be unit in order to maintain conservations globally. In general, we were seeking through synchronization of the AGCMs with T31L19 resolution and by changing ensemble weights over mass, momentum and heat fluxes to develop a super model.

A machine learning technique, Nelder-Mead method [15] was suggested by WP2 and applied here to get the optimal weights for each fluxes in this nonlinear system. The Nelder-Mead method is also known as simplex method, which is used to find a local minimum in multi-dimensional domain. We use the sea surface temperature over Pacific over $160^\circ$E-90$^\circ$W, 10$^\circ$S-10$^\circ$N for calculating the performance index [3], as a metric because there is only partial synchronization over tropical Pacific in this configuration, and thus improvement can only be expected for this sector (Figure 1). The assessment was started from equal weights and followed by the weights suggested by simplex method. Each case was spun up for ten years and run for another 30 years to get a reasonable climatology. Over 300 cases were tested and we reduced the averaged SST bias over the metric area from around 1 degree (for COSMOS(N) + COSMOS(T) ensemble mean) to only 0.48 degree (as shown in Figure 1). The correlation between zonal wind stress anomaly of two AGCMs is also high (Figure 2). Note that the variability of AGCMs may cancel each other in a certain manner over non-synchronized area and thus reducing the

\[^1\]Triangular truncation at total wavenumber 31 in spectral grid and 19 vertical levels, horizontal resolution is approximately 3.75 degree.
ocean variability as well. Furthermore, improvements are limited to the tropics (Figure 1).
Figure 2: Point-wise correlation of the zonal wind stress and velocity potential between two connected AGCMs. Insignificant area was set to be blank. Partially synchronization was found over tropical Pacific. There is no significant correlation between the unconnected AGCMs, and the figure is not shown.

The remainder of this report is organized as follows: Section 2 provides the examination of SUMO, COSMOS(N), and COSMOS(T) performance in simulating precipitation, air-sea interaction, and ENSO anomalies over the training period. Section 3 presents the performance of SUMO over in historical simulation covering the period 1900-2010. Section 4 contrasts the responses of tropical circulation to global warming in climate projection using SUMO and COSMOS models. Section 5 introduces initial results of a super model constructed from the Kiel Climate Model that show the robustness of our results. The potential of applying SUMO to improve the simulation of the Madden-Julian Oscillation is discussed in section 6, and some result on the role of ocean-atmosphere interaction are summarized. Lastly, we summarise the conclusions of this work and
present future perspective.

2 SUMO over Training Period (1948-1979)

2.1 Data

For the following comparison, we take sea surface temperature (SST) from Met Office Hadley Centre’s sea ice and SST data set, HadISST [16], and the precipitation from Global Precipitation Climatology Project (GPCP) data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/, which combined precipitation data were developed and computed by the NASA/Goddard Space Flight Center’s Laboratory for Atmospheres as a contribution to the GEWEX Global Precipitation Climatology Project. The period of SST climatology is from 1948 to 1979. However the period of precipitation climatology is from 1979-2010 because of the data of precipitation is available only after 1979.

2.2 Mean State

The mean state of SUMO was dramatically improved as shown in Figure 3, in which both of the SST and precipitation have better agreement with the observations. In SUMO the equatorial cold tongue extends to around International Date Line, indicating SUMO is able to simulate the west Pacific warm pool. This is unlike COSMOS(E), in which the cold tongue penetrates past the International Date Line to western Pacific and the variability of SST is much larger (not shown). The reduced SST bias in SUMO is associated with a much more realistic low level wind system and a better latitudinal position of ITCZ, because both cumulus schemes favor convections in regions with maximum boundary layer moist static energy [17]. It is still too wet in South Pacific convergence zone. The changes in precipitation are tied to changes in convection as well as high level cloud formation, altering the pattern of short wave radiation. As a result the net heat flux into ocean is improved (figure not shown). The latitudinal location of precipitation in SUMO is close to that of GPCP climatology, compared to that of COSMOS(E) in which the precipitation is off equator and it is too dry over equatorial Pacific.

2.3 Air-Sea Feedback

Air-sea interaction appears to play a key role in the mean state improvement of SUMO. The dynamic Bjerknes feedback and thermodynamic shortwave feedback over equatorial Pacific were assessed by linear regression (Figure 5). The Bjerknes feedback relates the remote zonal wind response to the eastern equatorial Pacific SST anomaly. The Bjerknes feedback in COSMOS(E) is underestimated, similar to most of CMIP5 models1.

In SUMO the Bjerknes feedback has near perfect agreement with observations. The
Figure 3: The climatology SST (left panel, scale in °C) and precipitation (right panel, scale in mm/day) of observation and models. The SST is from HadISST (1948-1979, the period applied as training set) and precipitation is from GPCP (1979-2012, due to the available data). The improved SST over equatorial region in SUMO and the double ITCZ of the COSMOS model is ameliorated. The precipitation was reduced from -6 mm/day off equator in COSMOS(E) to -2 mm/day over central Pacific, closer to the observations. The results show that the interactive ensemble can alter the structure of systematic errors even though the patterns of COSMOS(N) and COSMOS(T) are similar (Figure 4); the two standalone models show the classical systematic errors found in COSMOS(E) associated with the cold bias over equator.
thermodynamic shortwave feedback in COSMOS(E) is much stronger than observed, implying anomalous SST will be damped more quickly than observed. The representation of shortwave feedback in SUMO is better but the strength is still too strong.

The SST variability in COSMOS(N) and COSMOS(T) are much larger than observed, while that of SUMO appears quite realistic (Figure 5). The stronger variability of the COSMOS models is consistent with a greater sensitivity of the SST to zonal wind stress variations, as the shortwave feedback appears to be stronger than observed. The more realistic SST variability of SUMO appears to result from a more realistic Bjerknes feedback and weaker short wave damping. The regression of short wave heat flux against SST reduces from 261% to 165% of the observed. These results indicate the representation of air-sea fluxes over equatorial Pacific is more realistic in SUMO. We posit that this is the main reason for the model’s improved mean state. In particular, the Bjerknes feedback will cause the growth of an initial warm anomaly in the equatorial cold tongue, through mutual reinforcement of with weakened Trade Winds and SST warming tendency along equator. The increase in SST is eventually limited by the thermodynamic damping. The same feedbacks apply to cold SST anomalies. In this way the two feedbacks appear to lead to an improved representation of the ENSO and also the mean state.

To understand better the mechanism for the SUMO model’s improvement a perturbation analysis is performed. Perturbation analysis is a useful tool to interpret the behavior of a nonlinear system. In particular, we perturb the weights of the fluxes to identify not only the role played by each of the fluxes in air-sea interaction but also the properties of the fluxes in the individual AGCMs. In these experiments the weights for heat and
Figure 5: The left panel shows the relation between eastern Pacific SST anomalies (over 5°S-5°N, 150°W-90°W, Niño 3 region) and remote wind stress changes over the western Pacific (5°S-5°N, 160°E-150°W, Niño 4 region); the regression relation is a measure of the Bjerknes feedback. The right panel shows the relation between shortwave radiation and SST over the Niño 3 area; the regression relation is a measure of the shortwave feedback Coefficients of regression and correlation are noted in legend.

Figure 6: The Bjerknes feedback (left panel) and the thermodynamic shortwave damping (right panel) in each atmospheric model components of SUMO. The Nordeng atmosphere has a stronger Bjerknes feedback than the Tiedtke atmosphere when coupled to one ocean model.
momentum were separately increased (and decreased) by 10% for one model, while they were decreased (and increased) by 10% for the other model.

The change of heat flux source mainly impacts SST west of the International Date Line. It does not significantly change the equatorial SST over eastern Pacific (160°W-100°W). The main impact is due to increasing the heat flux from the Tiedtke model, which also impacts the winds over the Western Pacific. Increasing the heat flux contribution from Nordeng has little impact on SST or winds.

Changing the source of momentum flux impacts SST most strongly in the central and eastern equatorial Pacific, but significant changes are also found over the western Pacific. The change between increasing and decreasing momentum contribution results in nearly symmetric changes in SST and also wind. Increasing the momentum flux from Nordeng by 10% results in a warming of the central and eastern Pacific and cooling in the west. The maximum warming of around 0.7°C occurs in the central Pacific. To first order the wind changes show a strengthening across the Pacific that would imply a cooling of SST, through enhanced upwelling and evaporation. The localized maximum in the warming over the central Pacific is consistent with the easterly anomaly and weaker strengthening of the Trade Winds there. Nevertheless, it is difficult to explain the overall SST changes in terms of mean wind changes. However, perturbing the momentum flux also changes the Bjerknes feedback, because Nordeng atmosphere has slightly stronger regression relation between Niño4 zonal wind stress and Niño3 SST, and Tiedtke atmosphere has a weaker relation. While further analysis is required to confirm this, it seems that changes in the feedbacks are important to explain the improved mean state of SUMO. In this respect, it is interesting to note that the model simulated Trade Winds are much stronger than the reanalysis, even in the SUMO model.

2.4 ENSO Anomalies

The improvement of equatorial air-sea interaction leads also to an improvement of simulated ENSO variability (Figure 8). The patterns of SST, wind, and precipitation associated with ENSO variability are shown by regressing against Niño 3 SST anomalies. Observations show the anomalous SST warming is strongest in the east and extends to International Date Line. A similar pattern is found in SUMO. However, the anomalous SST warming in COSMOS(N) and COSMOS(T) extends across the entire equatorial Pacific, as there is no stable warm pool in western Pacific. In SUMO there is unrealistic warm SST north of the equator that might be associated with a weakening of the winds.

The representation of anomalous winds also reflects the anomalous SST pattern. The main anomalous westerly winds sits around International Date Line in observation as well as in SUMO, because there is a major anomalous SST gradient. However, the largest anomalous westerly winds are around Maritime Continent in COSMOS(N) and around west of International Date Line in COSMOS(T), also reflecting the anomalous
Figure 7: Equatorial SST (a) and zonal wind velocity (b) of observation and model results of SUMO as well as four weight-perturbed SUMO. Perturbing wind flux between two AGCMs has largest SST variation over eastern Pacific, in which anomalous downwelling and upwelling are found around 150°W in increasing momentum flux from Nordeng atmosphere and Tiedtke atmosphere respectively. The cold anomalous is a common bias of all the CMIP3 and CMIP5 models [2].
SST gradient. The anomalous precipitation has major difference between ensemble and supermodelling. SUMO simulates reasonably the observed migration of precipitation from western Pacific to east of International Date Line during El Niño events. The COSMOS models fails to represent this feature. This may be due to the strong cold bias over equator as well as the double ITCZ.

3 SUMO over historical period (1900-2005)

We follow the CMIP5 protocol to perform both historical and climate projection simulations with the SUMO model as well as with the two COSMOS models. The known forcing in CMIP5 includes orbital parameters, greenhouse gases, aerosols, solar irradiance as well as vegetation. Here we used only greenhouse gases from CMIP5 configuration. Thus, this simulation cannot represent (anthropogenic and natural) aerosol driven cooling, which are believed to have played an important role over the 20th century, at both global and regional scales [IPCC, 2013]. Each simulation extends from 1900-2100, and consists of eleven ensemble members.

Over the last century global surface temperature increased by almost 1°C. All three models show similar temperature changes to observations, but COSMOS(N) warms the least, and COSMOS(T) the most (Figure 9). The SUMO model warming is closest to COSMOS(N). In SUMO, the Nordeng model has weights for momentum and heat flux of 0.43 and 1.21, respectively. This may suggest that the momentum flux weighting plays a more important role in the global warming response. Nevertheless, given the non-linearity of the system further work is required to understand the reasons for this behavior.

We assessed the changes in surface temperature for the period 1980-2010 for the three simulations, but little agreement was found with observations at a regional level (not shown). This is not surprising as internal climate variability and aerosol forcing is expected to contribute to climate variations at these spatial and temporal scales [18]. Instead we evaluated the mean SST and precipitation patterns over different periods, and apply Taylor diagram to assess the pattern correlation and ratio of standard deviation over the metric region. The evaluation of SST and precipitation patterns is summarised in Figure 10. The results of SUMO remain in high agreement with observation in all the testing periods, with pattern correlations ranging from 0.9 and 0.8 for SST and precipitation, respectively.

4 Climate Projection by SUMO

Global temperature is projected to increase by about 4°C by COSMOS(T), 3.5°C by SUMO, and 3.2°C by COSMOS(N). These values are higher than those of the CMIP3
Figure 8: ENSO related SST (contour), precipitation (shading) and 10 m wind velocity (vector). These patterns are obtained by linear regression against Niño 3 SST anomalies. The three observables are all from NCEP-Reanalysis.
Figure 9: Global surface temperature from observations and simulations with COSMOS(T), COSMOS(N) and SUMO models. The models are forced with greenhouse gas forcing following historical observations and the IPCC5 RCP8.5 scenario.

Figure 10: SUMO performance over testing period. It indicates with improved air-sea feedback, SUMO has good agreement over the five testing decadal periods of SST and two testing decadal periods of precipitation.
models, which show warming of between 2°C and 3°C under the A1B scenario. This is partly because we only consider greenhouse gas changes. Here we focus on the changes in the tropics, as SUMO was shown to have superior performance in simulating mean climate, interannual variability, and more realistic ocean-atmosphere interaction.

There is a large uncertainty in how future global warming will impact tropical climate. Models are often characterized by whether they produce an El Niño like warming or a La Niña like cooling, which essentially describes whether the zonal gradient in equatorial SST weakens or strengthens, respectively [19]. A weakening of the zonal SST gradient is often attributed to the cloud-albedo feedback, which operates more strongly in the east; shallow mixed layers in the east can also enhance the warming there. A strengthening of the zonal SST gradient because mean equatorial upwelling damps SST changes in the east. There is a weak tendency to weaker zonal SST gradient in the current generation of climate models [20], consistent with previous studies [21].

The sign of the warming over the Tropical Pacific is tied to regional precipitation changes, because of the importance of ocean atmosphere interaction in the tropics [22]. A weakening of the gradient will lead to an eastward shift in precipitation, and strengthening to a westward shift. The location of the precipitation response, is however, highly sensitive to the model climatology and remains highly uncertain given that most models simulate a cold tongue that extends too far west [23].

Uncertainty also exists in how the large scale atmospheric circulation will change over the tropics [20]. Theoretical arguments suggest stabilization of the atmosphere under global warming will lead to a weakening of the Walker Circulation [24, 25]. The stabilization occurs because of the greater diabatic heating at upper levels in the tropics associated with increased precipitation, which is a direct result of a warmer and thus more moist atmosphere. Ocean-atmosphere feedbacks may modify the impact of global warming on the Walker Circulation [20, 26].

There is a big contrast between SUMO and the COSMOS models in the changes in Tropical SST, precipitation and Walker Circulation projected for the end of the 21st century. SUMO produces a weakening of the SST gradient and a general increase in precipitation along the equatorial Pacific, while both the COSMOS models show a strengthening of the zonal SST gradient with more precipitation over the far western Pacific (Fig. 11). The response in COSMOS(N) is much stronger than COSMOS(T).

The Walker Circulation changes are depicted in terms of upper level velocity potential. The simulation of velocity potential by SUMO and COSMOS models show upward motion (negative values) over the maritime continent and western Pacific, and subsidence over the eastern Pacific, consistent with observations (not shown). The centre for upward motion is found further to the east in the Tiedtke model than in Nordeng, in both SUMO and COSMOS models, but the difference is amplified in the COSMOS models (as expected). Despite the first order similarities in the simulated climatological
velocity potential patterns, the projected changes differ greatly (Figure 12). The SUMO simulates a general weakening of the Walker Circulation that appears consistent with the projected SST changes (Figure 11). The average COSMOS model response describes an eastward shift in the Walker Circulation.

The very different response of the SUMO compared to both the COSMOS models might be surprising, as one may have expected the ensemble mean response of the SUMO and COSMOS atmosphere to be similar. The result is another indication of the non-linearity of the system, and highlights the differences between interactive and standard ENSEMBLE approaches. It remains unclear which of the projected changes are most realistic. However, we may have more confidence in the results from the SUMO, given that the mean state and ocean-atmosphere interaction likely play an important role in the response of tropical climate to global warming and both are more realistically simulated by SUMO. Nevertheless, further work is required to understand the differences between the three models.

5 Initial results from the Kiel Climate Model

In order to test the robustness of our results, we applied the SUMO approach to the Kiel Climate Model (KCM). This work was done in collaboration with Jin Ba, Wonsun Park, and Mojib Latif from the GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany. KCM consists of the ECHAM5 atmospheric model coupled to the
Figure 12: Projected changes in 250hPa velocity potential for SUMO and COSMOS models for 2081-2100 compared 1986-2005. In both SUMO and COSMOS the ECHAM5 models are averaged. Positive values represent subsidence.
NEMO ocean model [27]. The main difference to the COSMOS model is thus the ocean component. The simulations were performed with T42 spectral atmospheric resolution (2.8°x2.8°). The ocean resolution was 2 degree, with an equatorial meridional refinement of 0.5 degrees with in 10 degrees of the equator. Thus, oceanic and atmospheric resolutions are substantially enhanced compared to the COSMOS model employed above.

A super model was constructed following the strategy above. Specifically, we coupled two versions of ECHAM5 that only differed in the convection scheme to one realization of the NEMO model. One ECHAM5 model used the Tiedtke convection scheme, and the other the Nordeng scheme. With insights from COSMOS SUMO, we tested several weights for momentum and heat flux. The best results from this manually trained model are presented here. The KCM-SUMO model is able to simulate a realistic representation of SST along the equator that is substantially improved compared to the stand alone coupled models (Figure 13). This is despite too strong Trade Winds (Figure 13). This result appears consistent with those from the COSMOS SUMO described above. The phase locking of SST variability was also substantially improved in KCM-SUMO (Figure 14). This was not the case for the COSMOS SUMO (not shown). Further analysis and experiments are being performed to better understand the KCM-SUMO results, and differences to COSMOS SUMO. Nevertheless, these results help to show the robustness of our approach.

6 Simulation of the Madden-Julian Oscillation

The MJO is a phenomenon dominating intraseasonal variability in the tropics. Observations indicate that ocean-atmosphere interaction is important for the MJO. Unfortunately, climate models simulate the MJO poorly [28] and much uncertainty exists in how it will change under global warming. The simulation of the MJO is also sensitive to the background mean state including westerly winds and precipitation that are often...
poorly simulated by coupled models [29]. Given the improvements simulated above in the mean state and ocean-atmosphere interaction, the MJO may be considered as a case study for SUMO and some preliminary work on this subject was performed in collaboration with colleagues from Taiwan (Wan-Ling Tseng, June Chang, Huang-Hsiung Hsu).

We worked on understanding the role of ocean-atmosphere interaction for this phenomenon. While we were not able to demonstrate improvements in the simulation of the MJO in SUMO, some interesting insights into ocean-atmosphere interaction were gleaned. In particular, we showed that coupling a high-resolution one-column ocean model to an atmospheric general circulation model (AGCM) dramatically improves simulation of the MJO to have realistic strength, period, and propagation speed. Better resolving the fine structure of upper ocean temperature, especially the warm layer, produces more vigorous atmosphere-ocean interaction and strengthens intraseasonal variations in both SST and atmospheric circulation. This helps organise and strengthen deep convection, inducing a stronger Kelvin-wave like perturbation and near-surface convergence to the east. In addition, the warmer SST ahead of the MJO also acts to destabilize the boundary layer. These lead to a more realistic eastward-propagating MJO. Mean state differences as well as the diurnal cycle of SST are not the main contributors to the improved simulation of our coupled model. Our coupled model results are consistent with observations and demonstrate a simple but effective means to significantly improve MJO simulation and potentially also forecasts. These results are summarized in a paper that has been submitted for publication [30]. In future work we wish to assess the potential of super modeling to improve the simulation of the MJO.
7 Conclusions and Future Perspective

7.1 Conclusions

In this project we built a super model through coupling two atmospheric models with one ocean model. This is a relatively simple strategy to connect the atmospheric components. The connection is relatively weak, as there are many degrees of freedom in the upper layers of the AGCM and many regions where the atmosphere plays a dominant role in driving SST variations. Thus, over most of the globe the atmospheric models are not-synchronized with each other. In the tropical Pacific, however, ocean-atmosphere interaction is sufficiently strong to achieve partial synchronization of the two atmospheric models. We take advantage of this to demonstrate that supermodelling can be used to improve the simulate of climate. Furthermore, the super model is shown to be superior to the ensemble mean of the individual models. The robustness of the approach is demonstrated by applying the technique to two different climate models: COSMOS and KCM.

This 2D surface coupling is also a good tool to explore the characteristic of AGCMs. By comparing the individual atmosphere components in SUMO, we learned that the Nordeng-atmospheric model presents stronger easterlies (over Niño 4) related to one degree anomalous SST increasing (over Niño 3) than the Tiedtke-atmospheric model. Precipitation and wind patterns also differ. These characteristics are not easily revealed by standalone coupled models, as they exhibit different basic states.

We demonstrate that SUMO exhibits a markedly different response to global warming than the standalone COSMOS models. Even though SUMO shows superior tropical Pacific, it is still unclear whether SUMO climate change response is more realistic than that of the COSMOS models. If the basic state and representation of ocean-atmosphere interaction are important for tropical climate change, then we may trust more the SUMO simulated climate change patterns.

7.2 Future Perspective

A super climate model that performs well at global scales can be only achieved through synchronization of the 3D atmosphere states. For the atmosphere this can be achieved through coupling of temperature fields (WP4), and similar results can be expected for the ocean. Nevertheless, 3D coupling of climate models is not a trivial task, and new non-intrusive approaches to achieve this should be investigated.

The performance of the supermodel depends ultimately on the ability to compensate model errors. Thus, the inclusion of more global model in the supermodel can be expected to lead to a more superior supermodel than one based on two single AGCMs differing only in convection scheme.
Lastly, in depth analysis of the super model simulations could provide insights into the mechanisms for climate variability and predictability. This may in the long term also contribute the improvement of individual models.

References


