SUMO Final Meeting, KNMI, De Bilt, the Netherlands.

WP5: SUMO Applied in Complex Climate Model
- Improving Model State over the Tropical Pacific

Final Report
Mao-Lin Shen and Noel Keenlyside
Geophysical Institute, University of Bergen, Norway.
Precipitation bias in climate models

Are we confident in the project changes?

Precipitation 2081-2100 scaled by global T

Multi Model Mean Precipitation Bias

IPCC, 2013
Objectives

• The overarching aim of this WP is to construct, assess, and apply a **Super Climate Model** to simulate and predict climate over the 20th and 21st century. Theory on constructing and training super-model (WPs 1-3) will be applied to complex climate models based on results from tests on intermediate climate models (WP4).
Ensemble vs. Interactive Ensemble

- SUMO: Super modelling
  - interactive ensemble for synchronization

Multi model simulation of real complex systems

Exchange information between models while integrating
Annual mean SST along the Equator in Ensemble Cases

- The bias pattern of CMIP5 is similar to that of CMIP3, implies the improvement is modest.
- Large systematic errors are found over the tropics.
- The cold bias is $\sim 1.2^\circ$C for CMIP5 models.

Bellenger et al. (2014)
Annual mean SST along the Equator in **SUMO**

- **SUMO** is better than CMIP5 models over the equatorial Pacific.
Annual mean SST along the Equator in SUMO

- **SUMO** is better than CMIP5 models over the equatorial Pacific.

- Q1: What is reason for model improvement?

- Q2: What is the climate projection pattern?
Structure of Super Model

- COSMOS model (MPI, Germany)
  - AGCM: ECHAM5, T31L19 (~3.75 degrees horizontally)
  - OGCM: MPIOM, GR30L40 (~3 degrees)

Momentum flux:

\[ H = \alpha H_{\text{Nordeng}} + (1 - \alpha) H_{\text{Tiedtke}} \]

Heat flux:

\[ Q = \beta Q_{\text{Nordeng}} + (1 - \beta) Q_{\text{Tiedtke}} \]

Extension of interaction ensemble from Kirtman et al., 2003.
Comparison of COSMOS and Equal Weight SUMO
Correlation of Zonal Wind Stress Anomaly
Performance Index

- Performance Index (PI):
  - Reichler & Kim, 2008, BAMS
  - $s_{vnm}$ is the simulated climatology of climate variable ($v$), model ($m$) and grid point ($n$); $o_{vn}$ is the corresponding observed climatology.
  - Training Period: 1948-1979

\[
E^2 = \sum_{n} \frac{\sum (s_{vnm} - o_{vn})^2}{\sigma_v^2}
\]

Equal Weighted, PI=10.9
Performance Index

- Performance Index (PI): $E_m^2 = \sum \frac{(s_{um} - \sigma_m)^2}{\sigma_v^2}$
- Reichler & Kim, 2008, BAMS

- Weight of momentum flux: $\alpha = 0.43$
- Weight of Heat flux: $\beta = 1.21$

Equal Weighted, PI=10.9
Opt. (after learning), PI=0.9
- **Observation**
  - Cold tongue stopped around dateline
  - Single ITCZ

- **SUMO**
  - Cold tongue stopped around dateline as well.
  - Also single ITCZ.
  - More precip. in SPCZ

- **Ensemble mean**
  - Cold tongue extends to WP.
  - Double ITCZ
  - Too much precip. in SPCZ.
Are all the mean states improved?
Zonal Wind is NOT Improved

- It is not possible to explain the reason for the improvement from the climatological pattern of wind.
Zonal Wind is NOT Improved

- It is not possible to explain the reason for the improvement from the climatological pattern of wind.

Perturbation experiments were used to investigate the impact of different weight.
Ensemble vs. Interactive Ensemble

- SUMO: Super modeling
  - interactive ensemble and synchronization

Multi model simulation of real complex systems

Exchange information between models while integrating
• Supermodel is better than any weighted average of model outputs.
Bjerknes Feedback & Heat Flux Feedback

• The Bjerknes feedback states the relation of east Pacific SST anomaly (over Niño 3 region) and the remote wind stress over west Pacific (Niño 4 region).

COSMOS-Tiedtke
COSMOS-Nordeng
Bjerknes Feedback & Heat Flux Feedback

- The Bjerknes feedback states the relation of east Pacific SST anomaly (over Niño 3 region) and the remote wind stress over west Pacific (Niño 4 region).
- Modeled shortwave feedback has only limited improvement.
Bjerknes Feedback in SUMO

Stronger BF

Weaker BF
ENSO related precipitation pattern
SUMO – Better ENSO related precipitation pattern

- **SUMO**
  - Anomalous precipitation in central Pacific.

- **COSMOS**
  - Anomalous precipitation in western Pacific.
Supermodelling for Kiel Climate Model (KCM)

- KCM model (G, Kiel, Germany)
  - AGCM: ECHAM5, T42L19 (~2.8 degrees horizontally)
  - OGCM: NEMO, ORCA2 (~2 degrees, finer over the tropics)
- Applying the 2D coupling structure used in SUMO.
Supermodelling for Kiel Climate Model (KCM)

- Improving the mean state.
Supermodelling for Kiel Climate Model (KCM)

- Improving not only the mean state, but also the phase lock phenomena of ENSO.

Monthly standard deviation of Niño 3
Global Warming Experiments

- **Models**
  - SUMO
  - COSMOS_Tiedtke
  - COMSOS_Nordeng

- **Experiment**
  - 11 member ensembles for each model
  - Historical and RCP8.5 scenario for greenhouse gases
Projected Sea Surface Temperature Changes 2081-2100 Relative to 1986-2005

SUMO - Weaker zonal SST gradient

COSMOS_Nordeng
Stronger zonal SST gradient

COSMOS_Tiedtke
Weakly enhanced zonal SST gradient
Projected Precipitation Changes 2081-2100 Relative to 1986-2005

**SUMO** - Weaker zonal SST gradient

**COSMOS_Nordeng**
Stronger zonal SST gradient

**COSMOS_Tiedtke**
Weakly enhanced zonal SST gradient
Conclusions

• Low-resolution (~3.75 degrees horizontally) model. A higher resolution model is training.
• Improving simulation of equatorial Pacific climate:
  – SST, precipitation, atmosphere-ocean interaction.
• The improvement of air-sea feedback of Pacific leads to good Pacific mean state.
• It is still unclear whether SUMO climate change response is more realistic than that of the COSMOS models
Future Perspective

• Full synchronization is necessary. It’s can be achieved by coupling of the 3D atmosphere states.

• Increasing of diversity. Have different AGCMs joins SUMO.

• Contributing to the improvement of individual models.
Thanks for your attention.
Performance over Historical Period

- Taylor diagrams:
  - how well patterns match each other in terms of their **correlation**, their root-mean-square difference and the ratio of their **variances**.
Perturbing Case 1

- Weight of momentum flux: \[ H = \alpha H_{Nordeng} + (1 - \alpha) H_{Tiedtke} \] \[ \alpha = 0.43 \]

- Change alpha to 0.33. Namely, ocean will receive more momentum flux (from 0.57 to 0.67) from Tiedtke atmosphere.

- SUMO(+T) - SUMO

+Tiedtke Momentum Flux → 1 m/s
Perturbing Case 2

- Weight of momentum flux: \( \alpha = 0.43 \)
  \[ H = \alpha H_{\text{Nordeng}} + (1 - \alpha) H_{\text{Tiedtke}} \]
- Change alpha to 0.53. Namely, ocean will receive more momentum flux from Nordeng atmosphere.
- SUMO(+N) - SUMO

+ Nordeng Momentum Flux

→ 1 m/s
+Nordeng Momentum Flux
→ 1 m/s

+Tiedtke Momentum Flux
→ 1 m/s

Dr. Mao-Lin Shen
maolin.shen@uib.no
Bjerknes Feedback & Heat Flux Feedback

- The Bjerknes feedback states the relation of east Pacific SST anomaly (over Niño 3 region) and the remote wind stress over west Pacific (Niño 4 region).

COSMOS-Tiedtke
COSMOS-Nordeng
Bjerknes Feedback & Heat Flux Feedback

- The Bjerknes feedback states the relation of east Pacific SST anomaly (over Niño 3 region) and the remote wind stress over west Pacific (Niño 4 region).
- Modeled shortwave feedback has only limited improvement.
Dynamic Feedback (Bjerknes Feedback)

- In SUMO:
Thermodynamic Feedback (Bjerknes Feedback)

- In SUMO:
• Two groups of temperature field result from using different convection scheme.
Climate-related Parameters

a). convective cloud mass-flux above the level of non-buoyancy

(Mauritsen, et al., 2012, JAMES)

b). shallow convective cloud lateral entrainment rate

c). deep convective cloud lateral entrainment rate

d). convective cloud water conversion rate to rain

e). liquid cloud homogeneity

f). liquid cloud water conversion rate to rain

g). ice cloud homogeneity

h). ice particle fall velocity
Parameter-perturbed (PP) Experiments (250 cases)

Table 1. List of parameters with corresponding default values for ECHAM5 (T31L19).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Default Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud mass-flux above level of non-buoyancy</td>
<td>0.1-0.333</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Entrainment rate for shallow convection</td>
<td>$3 \cdot 10^{-4} - 1 \cdot 10^{-3}$</td>
<td>$3 \cdot 10^{-4}$</td>
<td>m$^{-1}$</td>
</tr>
<tr>
<td>Entrainment rate for penetrative convection</td>
<td>$3 \cdot 10^{-5} - 5 \cdot 10^{-4}$</td>
<td>$1 \cdot 10^{-4}$</td>
<td>m$^{-1}$</td>
</tr>
<tr>
<td>Conversion rate from cloud water to rain</td>
<td>0.0001-0.005</td>
<td>0.0004</td>
<td>s$^{-1}$</td>
</tr>
<tr>
<td>Inhomogeneity of liquid clouds</td>
<td>0.65-1</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Inhomogeneity of ice clouds</td>
<td>0.65-1</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Correction to asymmetry parameter for ice cloud</td>
<td>0.75-1.0</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>Ocean model configuration</td>
<td>2D nodes</td>
<td>3D nodes</td>
<td>Resolution between 15°N and 15°S</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------</td>
<td>------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Setup 1: Ref mesh</td>
<td>43,943</td>
<td>1,250,994</td>
<td>About 1°</td>
</tr>
<tr>
<td>Setup 2: Ref87k mesh</td>
<td>86,803 (&quot;87k&quot;)</td>
<td>2,857,515</td>
<td>0.25° at the equator gradually decreasing to 1° at ±15°</td>
</tr>
</tbody>
</table>

- ECHAM6(T63)
- FESOM (Finite-Element, Ref & Ref87k)
Bellenger and Guilyardi et al. (2013)
KIEL CLIMATE MODEL SYSTEM (KCMS)

ECHAM5(N) (Nordeng Scheme)
ECHAM5(T) (Tiedtke Scheme)

Coupler
OASIS3/4

Sea ice
LIM2/3

Ocean circulation
OPA9

Biogeochemistry

Nucleus for European Modelling of the Ocean (NEMO):
ORCA2 / ORCA05 / ORCA025 / ORCA12 / AGRIF
Machine Learning: Nelder-Mead method

- Finding local minima of cost function $F(x)$ without calculating derivatives/tendencies of $F(x)$.
- Using three basic strategies (reflection, expansion and constriction), and one exception handler (shrink)

Searching for minimum in cost function
Insight from 10% Perturbation Experiments

- Exp 1: +10% Tiedtke momentum flux; -10% Nordeng momentum flux
- Exp 2: +10% Nordeng momentum flux; -10% Tiedtke momentum flux
- Similar for heat flux (Exp 3 and Exp 4)
Perturbation Experiments

Perturbing Case 1
- Weight of momentum flux: \( \alpha = 0.43 \)
  \[ H = \alpha H_{\text{Nordeng}} + (1 - \alpha)H_{\text{Tiedtke}} \]
- Change alpha to 0.33. Namely, ocean will receive more momentum flux (from 0.57 to \(0.67\)) from Tiedtke atmosphere.
- SUMO(+T) - SUMO

Perturbing Case 2
- Weight of momentum flux: \( \alpha = 0.43 \)
  \[ H = \alpha H_{\text{Nordeng}} + (1 - \alpha)H_{\text{Tiedtke}} \]
- Change alpha to 0.53. Namely, ocean will receive more momentum flux from Nordeng atmosphere.
- SUMO(+N) - SUMO

Dr. Mao-Lin Shen
maolin.shen@uib.no
Perturbing Case 1

- Weight of momentum flux: \( \alpha = 0.43 \)
  \[
  H = \alpha H_{Nordeng} + (1 - \alpha) H_{Tiedtke}
  \]
- Change alpha to 0.33. Namely, ocean will receive more momentum flux (from 0.57 to 0.67) from Tiedtke atmosphere.
- **SUMO(+T) - SUMO**

![Diagram showing perturbing case 1 with +Tiedtke Momentum Flux of 1 m/s](image)
Perturbation Cases

- Perturbing Case 3
  - More heat flux from Tiedtke atmosphere.

- Perturbing Case 4
  - More heat flux from Nordeng atmosphere.
Upper level (250hPa) Velocity Potential

NCEP

SUMO

COSMOS
Differences in Walker Circulation Response
2081-2100 Relative to 1986-2005

Upper level (250hPa) velocity potential

SUMO
Weaker
Walker circulation

COSMOS
Eastward displacement of Walker Circulation