The 4th International Workshop on Nonhydrostatic Models, Nov. 30 (Wed) - Dec. 2 (Fri), 2016, The Prince Hakone Lake Ashinoko, Hakone, Japan. http://157.82.240.172/~nhm/index.html

RCEMIP: Radiative Convective Equilibrium Model Inter-comparison Project

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Background

Radiative Convective Equilibrium Model Inter-comparison Project (RCEMIP) is proposed. Radiative-convective equilibrium (RCE) is referred to as atmospheric quasi statistical balance between convection and radiation processes (Manabe and Strickler 1964). Historically, RCE has been argued mainly with one-dimensional models, but in recent years more computationally intensive numerical calculations of RCE have been conducted with three-dimensional numerical models with explicitly resolved convection and domain lengths of 100-1000 km. A simple horizontally uniform boundary condition is prescribed with a constant sea surface temperature (SST) or a slab ocean model with uniform solar insolation. Since clouds are a most ambiguous part of climate models, the simple framework of RCE is suitable for understanding how clouds are simulated in numerical models. RCE is also useful to clarify the sensitivities of clouds to the details of cloud schemes implemented in numerical models (e.g., Satoh and Matsuda 2008). A number of RCE numerical studies have been conducted until recently with their own various configurations. One category is RCE on the sphere either with or without a cumulus parameterization scheme (e.g., Popke et al., 2013; Arnold and Randall, 2015; Reed et al., 2015; Bony et al., 2016; Satoh et al., 2016; Ohno and Satoh, 2016). The other category is RCE with regional models in an arbitrary domain size , primarily with explicitly resolved convection (e.g., Wing and Cronin 2016; Silvers et al. 2016). In order to systematically understand differences or similarities of various model results, a more coordinated framework for RCE numerical studies is demanded as "RCEMIP".

- Geometry: sphere / plane (square or channel)
- Domain size: Earth radius R / length=40,000 km × factor (e.g., 0.1–1.0)
- Horizontal resolution: Δx = 1–10 km for explicit convection, or coarser resolution (1–2 degree) with a cumulus parameterization
- Boundary condition: fixed SST (e.g., 296, 300, 304K) or a slab ocean
- CO_2: a current value or increased (e.g., $4\times CO_2$)
- Physics dependency: cloud microphysics, turbulence, radiation,; switch on/off of cumulus parameterization
- Interactive radiation or non-interactive, with/without clouds
- With or without diurnal cycle
- Without rotation, or with rotation

Among a lot of varieties listed above, we will discuss the experimental design of RCEMIP, scientific targets, and how to proceed. One strength of RCEMIP is the numerous scientific questions that could be explored, such as better understanding of uncertainties of climate sensitivities and changes in clouds and circulations, or convective aggregation, associated with global warming.

The main motivations for doing an RCEMIP

1. If we think that RCE is a useful framework for thinking about tropical circulations, climate sensitivity, etc..., then we should characterize the full range of how different models simulate it with the same setup/parameters.
2. RCE is an opportunity for comparison between CRMs with explicit convection and GCMs with parameterized convection, a pairing that is usually not represented in the same model hierarchy.
3. The chance to develop a standard "RCE config" that could be used as a starting place for future studies employing RCE. This could also be very useful for model development and evaluation.
4. There is a large variety of scientific questions that could be explored with an RCEMIP. The hope is that there would be some emergent, robust behaviors.
   - climate sensitivity/net feedback parameter
   - circulation strength with warming (if the model self-aggregates to generate circulations), degree of aggregation with warming, mechanisms of aggregation, spatial scale of aggregation, effect of cloud rad feedback
   - cloud changes with warming, precip extremes, circulation regimes, humidity variability, cloud amounts
   - process-oriented comparison to observations
5. A coordinated set of experiments that are setup in a consistent manner will help us get a better handle on the robustness of self-aggregation and will be very helpful for interpreting the results of previous studies on self-aggregation.
6. Encourage other comparisons (secondary tiers or branches of the MIP, or just general future work in the community) such as sphere vs. plane, explicit vs. parameterized convection, different dynamical cores with the same physics, different physics with the same dynamical cores, comparison to aquaplanet MIP.

Discussion

1. Is RCE a meaningful benchmark, since it is so sensitive? Is there some RCE state that we should converge on? This is something that an RCEMIP could potentially answer, but we want to make sure it is a well-posed problem in the first place.
2. Will the range of climate sensitivity be smaller/larger than that of comprehensive GCMs? Will it be different in RCE than for the standard configuration of a given model? What will we learn from this?
3. Would it be useful to have, as one of the simulations, a baseline case that is very simple as a control to compare across models and as a control to compare more complex cases to? For example, a case where all models use the same prescribed surface fluxes, fixed radiation etc... This would maybe be something that we might expect all models to agree on, and if it is very simple, it might be easier to track down causality for any difference. But, we also don't want to limit the types of questions that could be explored with our suite of simulations.

Scientific targets & diagnosts

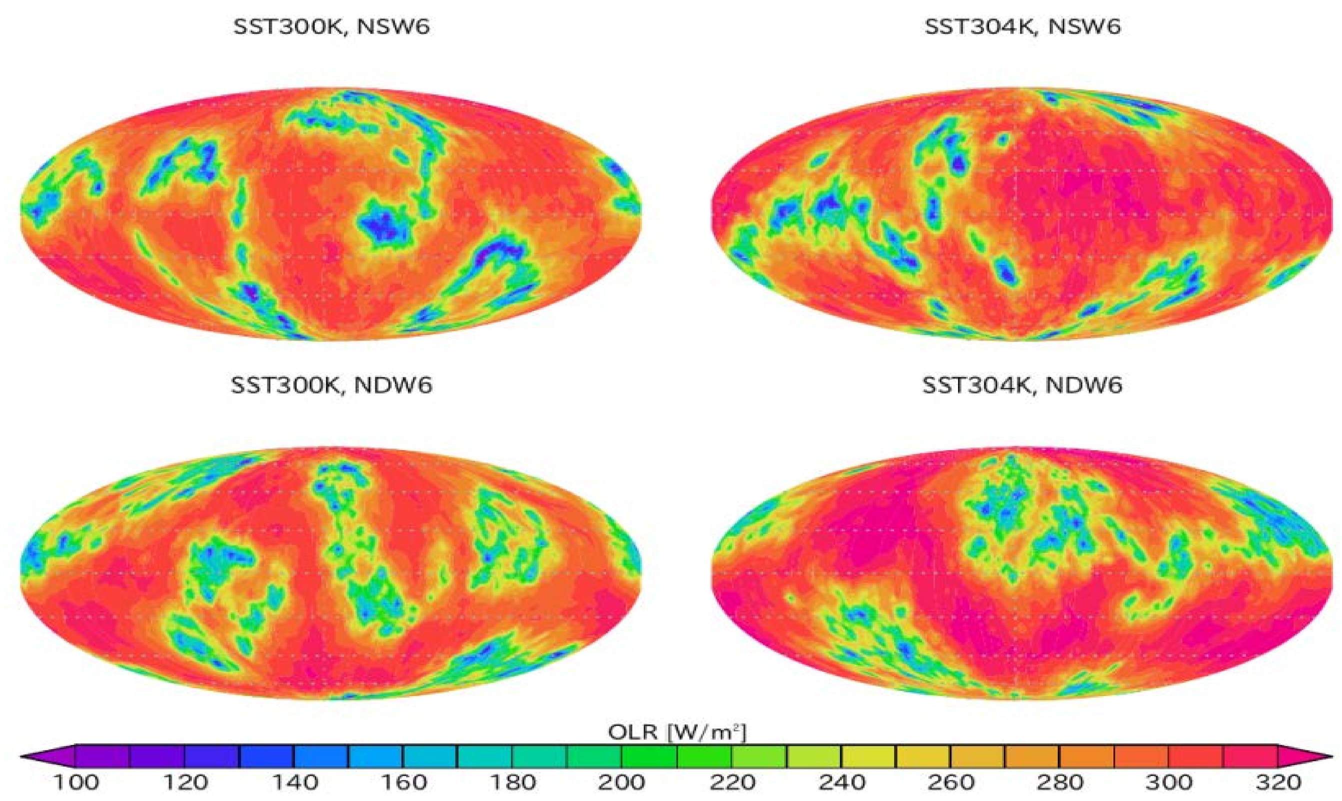
High priorities that everyone will do and that will address a couple of key questions

Cloud and circulation changes with warming
- High cloud cover & Ice Water Path
- Aggregation

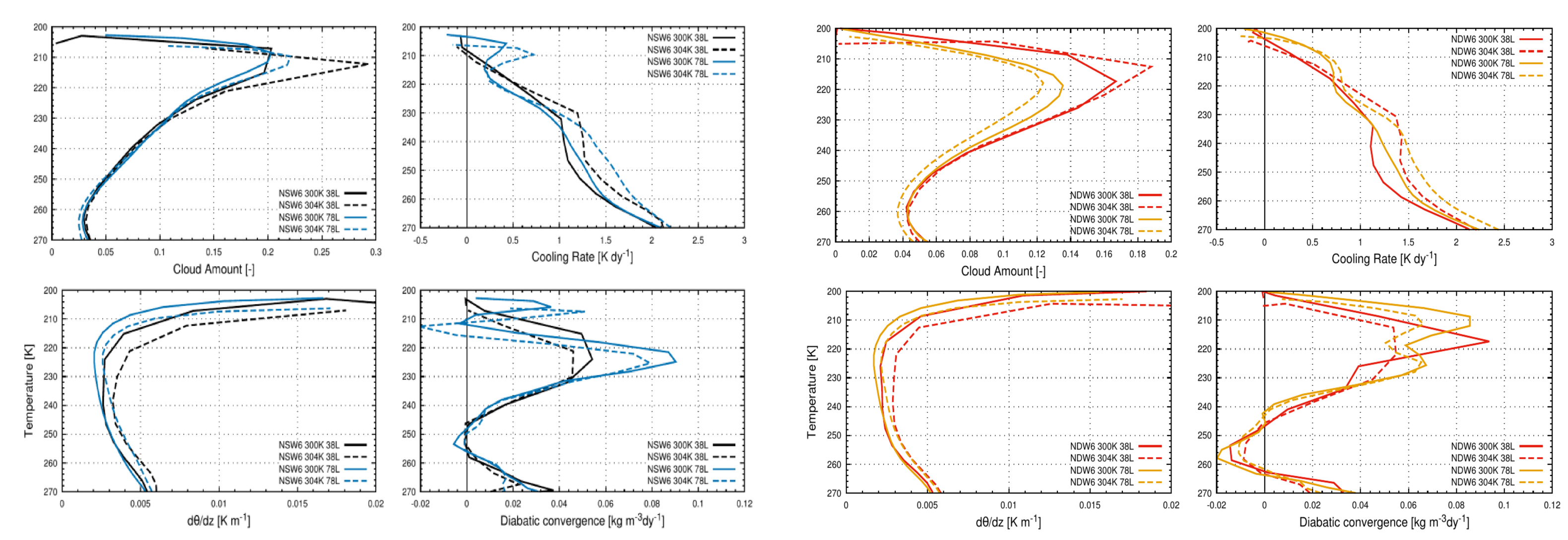
Climate sensitivity/net feedback parameter

Less priorities to explore sensitivities to the set up or the physics or other questions.

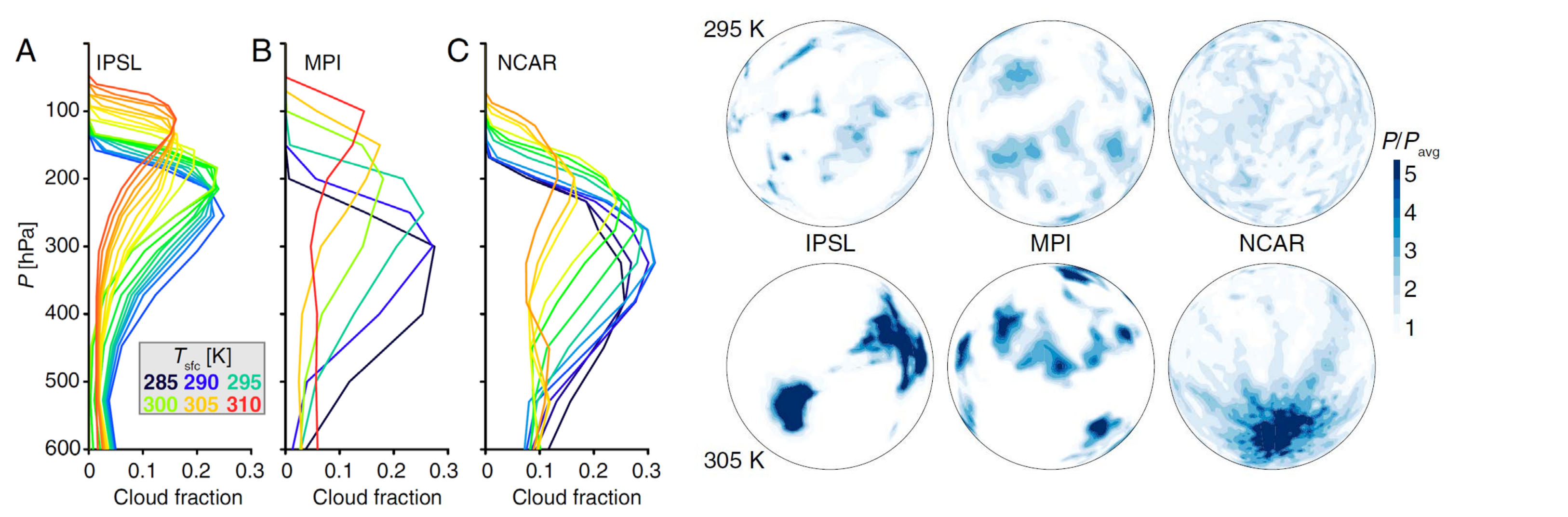
Output variables & Standard diagnosis, to be defined
- MSE budget, MSE sorting, cloud area etc.



RCE experiments by NICAM. Hourly averaged OLR distributions (150day, 38L) by Ohno and Satoh (2016)



Vertical profile of the cloud amount (top left), cooling rate (top right), static stability (lower left), and divergence (lower right) simulated by NICAM with the single moment bulk scheme (NSW6, left) and the double moment bulk scheme (NDW6, right) for different surface temperatures and vertical layers (Ohno and Satoh., 2016).



Vertical profile of the cloud fraction (left) and monthly precipitation (normalized by its global mean value) simulated by (A) IPSL, (B) MPI, and (C) NCAR GCMs for different surface temperatures (Bony et al., 2016).

RCE settings for NICAM

Horizontal resolution: a quasi-uniform 14-km mesh
Vertical resolution: 38 and 78 layers
Periods of integration: 200 / 150 day for simulations with 38 / 78 layers
Time step: 30 / 60 sec. for simulations with 38 / 78 layers
Solar irradiance: a value of 434 W m^{-2}, which corresponds to the daily and yearly average of the solar irradiance at the equator
Boundary conditions: globally constant SSTs of 300 and 304 K
Physics parameterizations:
Cloud microphysics: single moment (NSW6; *Tomita*, 2008) and double moment (NDW6; *Seiki and Nakajima*, 2014; *Seiki et al.*, 2015) of six water categories schemes
Turbulent closure: a level 2 of the Mellor—Yamada—Nakanishi—Niino (MYNN) model (*Nakanishi and Niino*, 2004, 2006, 2009)
Radiative transfer: MstrnX scheme (*Sekiguchi and Nakajima*, 2008)
Bulk surface flux: based on Louis (1979), Uno et al. (1995), and Moon et al. (2007)
Absorption gases: CO_2: 348 ppmv; CH_4: 1,650 ppbv; N_2O: 306 ppbv; CFC: 100 pptv; O_3: a tropical climatological value
Initialization:
38-layer simulations: A zonally-averaged profile on the equator of National Centers for Environmental Prediction global analysis data at 0000 UTC 1 June 2004
78-layer simulations: Vertically interpolated / extrapolated three-dimensional snapshot data of the simulation with same SST and cloud microphysics scheme and 38 vertical layers
Output interval: 1 / 6 hr for 2- / 3-D variables

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