Aqua Planet Experiment Project

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The influence of the large-scale meridional sea-surface temperature curvature on tropical circulation regimes

In this paper we show how the large-scale meridional curvature of the sea surface temperature (SST) influences the general circulation in an earth-type aqua-planet atmosphere. Three circulation regimes can be distinguished. For SST distributions with strong curvature one gets a single narrow intertropical convergence zone (ITCZ) at the maximum of temperature. The maximum of latent heat flux coincides with the convergence zone. For SST distributions with intermediate curvatures a single broader meandering ITCZ forms at the maximum of temperature. In this case the maximum of latent heat flux is outside the ITCZ and the dynamics is determined by moisture convergence. Flattening the SST distribution further a transition occurs to a circulation regime with two ITCZs not coinciding with the maximum of temperature and straddling along the equator. The convergence zones are weak and intermittent and the maximum of latent heat flux is shifted poleward. In addition the spatial organization and dynamics of convective structures strongly depend on the large scale SST curvature. Large curvatures around the temperature maximum favour thin zonally aligned banded structures. Small curvatures around the temperature maximum favour patch-like intermittent structures in a broad region with an increased tendency of tropical cyclone formation.

The transition between the single and double ITCZ regime occurs for SST distributions which are close to the SST distributions presently observed. The transition is accompanied by drastic global-scale changes in the atmospheric response and seems therefore also relevant for the present climate. Dynamically it is very interesting that near the critical curvature the single and double ITCZ circulation regimes can exist both for the same SST distribution. Complex non-local feedback mechanisms between planetary boundary layer and global circulation lead to this multi-equilibrium state.

Finally we derive criteria for the transition between the single and double ITCZ-regime using a simple analytical zonally symmetric model with concentrated convective zones. The model is based on angular momentum and temperature homogenization within the Hadley cell.

The behaviour of single and double ITCZ regimes for ocean temperature distributions with poleward shifted maxima

In this paper we investigate how the poleward shift of sea surface temperature (SST) distributions with different meridional curvature influences the tropical circulation. Our results were obtained with an earth-type atmospheric general circulation model (AGCM) in aqua-planet mode and a simplified analytical model of the tropical circulation.

In a series of numerical runs we found that the position of the ITCZ, the rate of precipitation and the asymmetry of the summer and winter Hadley cells are very sensitive to the meridional curvature of the poleward shifted SST distributions. We can distinguish between two types of atmospheric responses. The first occurs for the poleward shift of a SST distribution connected to a single ITCZ regime. In this case moderate poleward shifts of the temperature maximum lead to a weakening of the total lower tropospheric convergence and at the same time to a reduction of the precipitation within the ITCZ. For larger poleward shifts the convergence and precipitation will again increase. The second type occurs for the poleward shift of a SST distribution connected to a double ITCZ regime. Moderate poleward shifts of the temperature maximum lead in this case to an intensification of convergence and precipitation at the ITCZ in the winter hemisphere, whereas the ITCZ in the summer hemisphere becomes less well pronounced. For larger poleward shifts we get a transition to a single ITCZ regime with convergence zones which are the stronger the further poleward the temperature maximum is shifted. Only if a threshold latitude is passed the convergence zones weaken again with increasingly poleward shifted temperature maxima.

Our investigations show that the double ITCZ regime can survive even for a SST distribution which is asymmetric about the equator. For the shifted flat SST distribution a two jet structure forms in the upper troposphere of the summer hemisphere. Shifted SST distributions with a stronger meridional curvature only develop one jet.

In parallel to the numerical runs a zonally symmetric analyticalmodel with one or two concentrated convective zones was developed. It can explain the results of the numerical runs through the simple mechanism of temperature and angular momentum homogenization within the Hadley cell. The solutions of the analytical model show in good qualitative agreement with the full AGCM runs how position and strength of the ITCZ depends on the meridional large scale curvature of the SST distributions. The model can distinguish between the two types of behaviour for poleward shifted temperature maxima. The results suggest that the strength and structure of the tropical circulation can be strongly influenced by the global scale meridional zonally symmetric characteristics of the SST distributions.

Our investigations seem particularly interesting for an understanding of the variability of the tropical circulation since the SST distributions used in our investigation are close to the climatological mean presently observed on Earth. Up to now it is not clear if single or double ITCZ regimes are a better representation for the recent atmospheric circulation dynamics in the tropics.

Liang Guo

LASG

Response of the atmospheric precipitation and streamfield to the tropical SST in APE GCMs

Though initial fields and external forcing are specified, the precipitation patterns among these models are different not only in axisymmetric experiments (Control, Peaked, Flat, Qobs and Control5N) but also in those have a SST anomaly (1KEQ, 3KEQ, 3KW1).

The zonal averaged precipitation patterns in axisymmetric experiments show that, the precipitation patterns are sensitive to the SST distribution. With the peak of SST which located on equator becomes flat (from Peaked to Flat), the single precipitation peaks which also located on equator are disappear and are replace by two smaller precipitation peaks located on the north and south fringes of the equator. The SST sensitivity is different in each model and is contributed from different types of precipitation (convective precipitation or large scale precipitation).

We also examine the precipitation anomaly in 1KEQ experiment; the patterns are different in each experiment, too. In most of models, the precipitation anomaly center located on the west of SST anomaly. However, there are not all the same. In CSIRO's and GSFC's model, the precipitation anomaly sits in the center of the SST anomaly. In DWD's and ECMWF's model, the precipitation anomaly deflects to east. This difference is caused by the difference of the intensity of easterlies on lower tropospheric equator. By comparing to satellitic data (TRMM), and reanalysis data (JRA25, NCEP2 and ERA40), we find that those results which precipitation anomaly deflects to west are reasonable.

Kavirajan Rajendran

MRI

The effect of SST variation on equatorial ITCZ in Aquaplanet General Circulation Models

Nils P. Wedi, Peter Bechtold and Thomas Jung

ECMWF

Idealised simulations with the ECMWF model.and the MJO

Recent aquaplanet and 'climate-type' simulations with the IFS forecasting system have indicated an insufficient level of wave activity in particular in tropical regions. Furthermore, there has been little skill in the prediction or propagation of MJO events. In this talk we describe and motivate the recent changes to the IFS forecasting system at ECMWF, which achieve a better representation of both hemispheric and tropical wave activity. By employing a hierarchy of experiments from laboratory-scale beta-plane simulations to Held-Suarez (dry), Aquaplanet (moist) and full 'climate-type' simulations, we indicate the relative importance of (dry) 'dynamical core' wave activity and the potentially detrimental effect of balance constraints between the large-scale model tendencies and convection. Finally, we briefly discuss the potential role of weakly-nonlinear wave dynamics for the MJO by considering a simplified dynamical apparatus to reproduce MJO-like structures in a virtual laboratory analogue, in the spirit of the Plumb-McEwan experiment for the quasi-biennial oscillation.

Kazuyoshi Oouchi

FRCGC

Aqua-Planet MJO's in NICAM

Madden-Julian Oscillation (MJO)-like eastward-propagating disturbance is one of the recent hot research topics in the NICAM group. Making full use of the advantage of global-cloud-resolving model, results from a couple of numerical experiments will be disucssed to clarify the mechanism of the maintenance of MJO. The presentation will focus on possible role of meso-to-synoptic scale convections including super cloud cluster.

Yoshi-Yuki Hayashi

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TBD

Zaizhi Wang

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CMA

The influence of zonally varied SST forcing to tropical convectively coupled waves in APE GCMs

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Role of midlatitude oceanic frontal zones in the mean state and variability in the atmospheric general circulation: Aqua-planet experiments

A close association among a mid-latitude storm-track, a westerly polar-front jet (PFJ) and an underlying oceanic frontal zone is observed most typically in the situation where a subtropical jet (STJ) is relatively weak, as in the South Indian Ocean or in the North Atlantic. Along a near-surface baroclinic zone that tends to be anchored around a frontal zone, enhanced storm-track activity maintains a well-defined PFJ with strong surface westerlies. It is this eddy-driven jet whose axial fluctuations are manifested as the annular mode.
In order to assess the particular importance of a mid-latitude oceanic frontal zone in the mean state of a storm-track and PFJ and in their low-frequency variability, a pair of perpetual “aqua-planet experiments” was conducted with a relatively high-resolution AGCM. In

the experiment where frontal SST gradient as observed was prescribed at 45° latitude, the main storm-track is anchored firmly around the frontal zone and a well-defined PFJ form slightly poleward, both in the model winter and summer hemispheres. The surface baroclinicity is restored effectively via differential heat supply from the ocean across the frontal zone. In that experiment, the most dominant mode of variability in the extra-tropical zonal-mean zonal wind exhibits certain resemblance to the observed Southern Hemisphere annular mode. In the other experiment where the frontal SST gradient is eliminated, the mean intensities of the storm-track and PFJ both weaken substantially. In addition, the amplitude of the model annular mode is also reduced substantially, and its meridional structure is apparently distorted especially in the presence of the intensified wintertime STJ. Though idealized, our AGCM experiments suggest that the extra-tropical general circulation and its annular variability can be better understood from the viewpoint of air-sea interactions associated with the mid-latitude oceanic frontal zone, storm-track and PFJ.

Chihiro Kodama

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Tohoku University

Influence of the uncreased SST on Baroclinic instability wave activities under the aqua planet condition

Kensuke Nakajima

<AGU for APE>
Kyushu University

TBD

David Williamson

NCAR

Convergence of Aqua-planet Simulations with Increasing Resolution in CAM3

The convergence of simulations from the Community Atmosphere Model with increasing resolution is determined in an aqua-planet context. Convergence as a function of scale is considered. Adjustable constants in the parameterization suite are held fixed. Horizontal resolution (T42 to T340) and time step (40 to 5 minutes) are varied separately. The simulations are sensitive to both. Global averages do not necessarily converge with increasing resolution. The zonal average equatorial precipitation shows a strong sensitivity to time step. This implies that parameterizations should be applied in a range of time steps where such sensitivity is not seen. The larger scales of the zonal average equatorial precipitation

converge with increasing resolution. There is mass shift from polar to equatorial regions with increasing resolution with no indication of convergence. The zonal average cloud fraction decreases with increasing resolution also with no indication of convergence. Perhaps parameterizations should be tuned to yield convergence of the large scales, rather than the best simulation for each resolution. Equatorial wave propagation characteristics converge with increasing resolution, however a relatively high truncation of T170 is required to capture wavenumbers less than 16. Extremes are studied in the form of the probability density functions of precipitation. The largest half of the scales included in the model converge for resolutions above T85.

Michael Blackburn

<CGAM>
NCAS-Climate

TBD

John McGregor

CSIRO

Extra simulations using the latest version of CCAM

Hartmut Broth

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The moisture, energy and momentum cycle in GME long-term experiments with idealized and realistic boundary conditions

In this paper we start by a comparison of the German global weather forecast model (GME) and the European global weather forecast model (IFS). We concentrate on the strong sensitivity of the general circulation to boundary conditions and model physics. We mainly show how the momentum, energy and moisture cycles change and what the consequences are for the atmospheric flow systems especially in the tropics. The GME and IFS have roughly the same total atmospheric energy-budgets for the control and flat sea surface temperature (SST) distribution of the aqua-planet experiment (APE). At the same time they show substantial discrepancies in surface fluxes and radiation budgets. This leads to a different model behaviour for SST distributions with curvatures which are intermediate between the control and flat case. The IFS shows a transition to a double-ITCZ for stronger curved SST distributions.

In addition we have carried through long-term experiments with the GME where we added realistic continents and orography and kept the idealized SST distributions of the control or flat case in the oceans. A comparison of runs with and without orography reveals that the basic structure of the aqua-planet tropical circulation survives if continents are added. For curved SST distributions the influence of continents is weaker than for flat SST distribu-

tions. The continents deform the ITCZ's and induce a mean zonal circulation which leads to drier subsidence zones, e.g. over the Sahara. The precipitation is suppressed West of South America, South Africa and Australia even without cold upwelling water in the western boundary currents, which is not present in our simple model with fixed ocean temperatures.

The close relation between the tropical circulation on the aqua-planet and the corresponding full model with realistic continents suggests that the dynamical behaviour of a model in aqua-planet mode can be translated in a quite straightforward manner to the properties of the model in weather forecast or climate mode. This might be very useful to understand and improve seasonal forecasts where data assimilation methods cannot be used.

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Aqua-planet Experiments with a Simple Mixed-layer Ocean

We have conducted the aqua-planet experiments that proposed by Neale and Hoskins, but a simple mixed-layer ocean is embedded to enable air-sea coupling and the prediction of surface temperature. The mixed-layer ocean of finite heat capacity is assumed to consist of single layer with no vertical temperature gradient, and its temperature is simply controlled by the net incoming heat fluxes onto the ocean surface. In calculations with several AGCMs, this idealization produces very strong zonal mean flow and exaggerated ITCZ strength, but the model simulations remain sufficiently realistic to justify the use of this framework in isolating key differences between models. Because surface temperatures are free to respond to model differences, the simulation of the cloud distribution, especially in the subtropics, affects many other aspects of the simulations. We will highlight our key findings from comparisons of the zonal-mean state, the tropical Madden-Julian Oscillation, and climate sensitivity induced by doubling CO2 concentration.

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