# Distinct patterns of cloud changes associated with decadal variability and their contribution to observed cloud cover trends

Yong-Jhih Chen[1], Yen-Ting Hwang[1*], Mark D. Zelinka[2], Chen Zhou[3]

1 Department of Atmospheric Sciences, National Taiwan University, Taiwan

2 Cloud Processes Research and Modeling Group, Lawrence Livermore National Laboratory, USA

3 Department of Atmospheric Physics, Nanjing University, China

*Correspondence to: ythwang@ntu.edu.tw

With the goal of understanding the relative roles of anthropogenic and natural factors in driving observed cloud trends, this study investigates cloud changes associated with decadal variability including the Pacific Decadal Oscillation (PDO) and the Atlantic Multi-decadal Oscillation (AMO). In the pre-industrial simulations of CMIP5 global climate models (GCMs), the spatial patterns and the vertical structures of the PDO-related cloud cover changes in the Pacific are consistent among models. Meanwhile, the models show consistent AMO impacts on high cloud cover in the tropical Atlantic, subtropical eastern Pacific, and equatorial central Pacific, and on low cloud cover in the North Atlantic and subtropical Northeast Pacific. The cloud cover changes associated with the PDO and the AMO can be understood via the relationships between large-scale meteorological parameters and clouds on interannual timescales. When compared to the satellite records during the period of 1983 to 2009, the patterns of total and low cloud cover trends associated with decadal variability are significantly correlated with patterns of cloud cover trends in ISCCP observations. On the other hand, the pattern of the estimated greenhouse gas (GHG) forced trends of total cloud cover differs from that related to decadal variability, and may explain the positive trends in the subtropical Southeast Pacific, negative trends in the mid-latitudes, and positive trends poleward of 50oN/S. In most models, the magnitudes of the estimated decadal variability contribution to the observed cloud cover trends are larger than those contributed by GHG, suggesting the observed cloud cover trends are more closely related to decadal variability than to GHG-induced warming.

**Key words:** PDO; AMO; Satellite; Cloud cover trend

**The Effect of Microphysics Parameterization on Environment and Convections**

Jin-De Huang and Chien-Ming Wu

Department of Atmospheric Sciences, Nation Taiwan University, Taipei, Taiwan

This study investigates the effects of condensation on precipitation spectrum in a strongly forced environment using a vector vorticity cloud-resolving model (VVM). Two experiments are performed under strong large-scale forcing with two microphysics parameterizations, predicted particle properties scheme (P3) and Lin scheme (Lin). The results show that even though the domain-averaged precipitation is similar in two experiments, P3 exhibits stronger extreme precipitation in the spectrum. Compared to Lin, convective core clouds tend to produce more intense precipitation in P3. The isentropic analysis shows that P3 environment profiles of equivalent potential temperature is more unstable than Lin; besides, stronger updraft and higher saturation deficit occur in the convections in P3. The cause of such differences is possibly related to the difference in the condensation processes between two schemes. The further experiment (modified Lin) is carried out to identify the impact of the condensation processes through adjusting the criteria of the condensation from 100% to 110% in Lin scheme. Modified Lin and P3 share corresponding differences in comparison with Lin: more intense precipitation, more unstable environment, stronger updraft, and higher saturation deficit in both P3 and modified Lin. According to those results, it can be concluded that the environment, the convections, and the extreme precipitation are considerably influenced by the criteria of the condensation processes.

**Key words**: Convections, Environment, Microphysics Parameterization

## References

Chien, M.-H., and C.-M. Wu* (2016), Representation of topography by partial steps using the immersed boundary method in a vector vorticity equation model (VVM), J. Adv. Model. Earth Syst., 8, 212–223.

Morrison, H., and J. A. Milbrandt, 2014: Parameterization of cloud microphysics based on the prediction of bulk ice particle properties. Part I: Scheme description and idealized tests. J. Atmos. Sci., 72, 287–311, doi:10.1175/JAS-D-14-0065.1.

Pauluis, O. M., and A. A. Mrowiec, 2013: Isentropic analysis of convective motions. J. Atmos. Sci., 70, 3673–3688, doi:10.1175/JAS-D-12-0205.1.

# Improvement of a single moment bulk microphysics scheme for mixed-phases clouds over the Southern Ocean using Joint simulator and CALIPSO

Woosub Roh*[1], Masaki Satoh[1], Tatsuya Seiki[2], and Tempei Hashino[3]

1 AORI, The University of Tokyo, Kashiwa, Japan
2 JAMSTEC, Yokohama, Japan
3 Kochi university of technology, Kochi, Japan
*Correspondence to: ws-roh@aori.u-tokyo.ac.jp

It is important to evaluate and improve the cloud properties in global non-hydrostatic models like a Nonhydrostatic ICosahedral Atmospheric Model (NICAM, Satoh et al. 2014) using observation data. One of the methods is a radiance-based evaluation using satellite data and a satellite simulator (here Joint simulator, Hashino et al. 2013), which avoids making different settings of the microphysics between retrieval algorithms and NICAM.One of the challenging issues is an evaluation of mixed-phase clouds, which consist of water vapor, ice particles, and supercooled water droplets. It is known one of the main reasons why climate models reveal large errors about the reflection of solar radiation over the Southern Ocean and Arctic. This study is an evaluation and improvement of mixed-phase clouds over the Southern Ocean in NICAM using a Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and a satellite simulator. We evaluated thermodynamics phase of mixed phases clouds over the Southern Ocean in a regional version of NICAM between 45°S to 65°S and 170°E to 170°W following Yoshida et al. (2010) method. We found underestimation of supercooled water clouds in our single moment scheme. We improved the single moment microphysics scheme using a double moment microphysics and a single column model. If I have time, I will introduce the recent development progresses of Joint simulator shortly.

**Key words:** Mixed-phases clouds, Southern Ocean, CALIPSO, NICAM

**References**

Hashino, T., M. Satoh, Y. Hagihara, T. Kubota, T. Matsui, T. Nasuno, and H. Okamoto, 2013: Evaluating cloud microphysics from NICAM against CloudSat and CALIPSO. *J. Geophys. Res.*, 118, 1-20, doi:10.1002/jgrd.50564.

Yoshida, R., H. Okamoto, Y. Hagihara, and H. Ishimoto, 2010: Global analysis of cloud phase and ice crystal orientation from cloud-aerosol lidar and infrared pathfinder satellite observation (CALIPSO) data using attenuated backscattering and depolarization ratio, *J. Geophys. Res.,* 115, D00H32, doi:10.1029/2009JD012334.

# Fractal property in horizontal geometry of tropical clouds from high-resolution observation and simulation

Takuya Jinno*[1], Hiroaki Miura[1]

1 School of Science, The University of Tokyo, Tokyo, Japan

*Correspondence to: jinno@eps.s.u-tokyo.ac.jp

In the tropics, deep convection spontaneously organizes over a variety of spatiotemporal scales, characterized by hierarchical structure of cloud clusters. Cloud-resolving models, which explicitly calculate individual clouds, have been developed for the purpose of understanding the effect of cumulus convection on large-scale circulation. There has been an increasing need for quantitative index for geometry of cloud clusters to validate observations and cloud-resolving simulations. As a measure, previous works have addressed fractal analyses (Lovejoy, 1982). Yet, it is unclear if the results of those fractal analyses have any valuable implications for the dynamics of convection. Thus, the science of fractal has not been properly incorporated into meteorology. Here we newly formulate a version of fractal dimension as a function of horizontal scale. From satellite observations, we find a self-similarity that is confined to certain range of scales instead of ideal fractal. We show that there is a typical length scale at about 30 km, which characterizes the scale separation of cumulus convection. On the other hand, a simulation with Non-hydrostatic Icosahedral Atmospheric Model displays a different self-similarity. These findings illustrate that even a cloud-resolving model with sub-kilometer resolution cannot fully reproduce the geometrical features of tropical clouds. The characteristic length scale at 30 km mostly corresponds to that of precipitative cold pools (Haerter et al., 2019), implying a relation between formation of convections and collision of cold pools. Since the horizontal distribution of clouds have a significant effect on the Earth's radiation balance, fractal properties must be incorporated into cloud-resolving models to simulate convective extremes and their effect on climate more realistically.

**Key words:** Fractal, HIMAWARI-8, NICAM

## References

Lovejoy, S. (1982) Area-perimeter relation for rain and cloud areas. *Science*, **216**, 185–187, doi:10.1126/science.216.4542.185.

Haerter, J. O., Böing, S. J., Henneberg, O., and Nissen, S. B. (2019) Circling in on convective organization. *Geophys. Res. Lett.*, **46**, doi:10.1029/2019GL082092.

# Implementation of the Unified Representation of Moist Convection in the Gray Zone CWBGFS

Chun-Yian Su[1], Chien-Ming Wu[1], Wei-Ting Chen[1] and Jen-Her Chen[2]

1 Department of Atmospheric Sciences, National Taiwan University, Taipei city, Taiwan

2 Central Weather Bureau, Taipei city, Taiwan

This study implements the unified parameterization (UP) in the gray zone Central Weather Bureau Global Forecast System, which aims to generalize the representation of moist convection between conventional general circulation and cloud-resolving models, in order to better represent the variability associated with aggregated convection. The generalization is based on reducing the effect of parameterized convection according to the diagnosed convective updraft fraction (σ). Two simulations are carried out to investigate the impacts of the UP on the short-term hindcasts and associated aggregated convection, which uses the relaxed Arakawa-Schubert scheme (RAS) and the same scheme with the UP (URAS), respectively. The result shows that the UP gives rise to the evolution of grid-scale convection, contributing to the stronger extreme precipitation, the less rain weaker than 10 mm $h^{-1}$, the weaker diurnal amplitude and the smoother diurnal variation of precipitation over land in the URAS. It is also found that the UP has the greater impact on the larger convective system, supported by piggybacking the diagnosis of σ to the RAS. In conclusion, the UP increases the variability of grid-properties associated with aggregated convection, and better represents the difference in characteristics between various size ranges of convective system.

**Key words:** moist convection, gray zone, unified parameterization

**References**

Arakawa, A., & Wu, C. M. (2013). A unified representation of deep moist convection in numerical modeling of the atmosphere. Part I. Journal of the Atmospheric Sciences, 70(7), 1977-1992.

Wu, C. M., & Arakawa, A. (2014). A unified representation of deep moist convection in numerical modeling of the atmosphere. Part II. Journal of the Atmospheric Sciences, 71(6), 2089-2103.

Su, C. Y., Wu, C. M., Chen, W. T., & Chen, J. H. (2019). Object-based precipitation system bias in grey zone simulation: the 2016 South China Sea summer monsoon onset. Climate Dynamics, 1-14.

# A statistical study on precipitation characteristics coupled with equatorial Kelvin wave and equatorial Rossby wave.

Yuhi Nakamura*[1], Yukari N. Takayabu[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

Coupling structures between convection and equatorial waves are investigated using space-borne precipitation radar observation. Recent theoretical studies suggested that different equatorial wave modes can have different coupling mechanisms. However, investigations on precipitation characteristics based on observation is still not enough. In order to shed light on this problem, we quantify precipitation and its characteristics coupled with equatorial Kelvin wave and equatorial Rossby wave, and compare their structures.

Based on the wave phase determined with brightness temperature observed from the Geostationary Meteorological Satellites, a composite analysis is conducted. TRMM 2A25 and 2H25 products are used for analysis of precipitation characteristics and we prepare rainfall-area dataset that is the area of consecutive precipitating pixels. ERA-interim dataset is used for analysis of synoptic scale wave structures.

In Rossby wave case, organized convective systems dominate following shallow convection without a developing convection phase. This evolution may be caused by the upright vertical structure of the wave disturbance. The cyclonic circulation triggers shallow convection, and successive deep upward velocity and moisture support that convections organize. On the other hand, in Kelvin waves, precipitation shows a tri-modal evolution: shallow convection, developed convection, organized convective systems. The vertical tilting structure of the Kelvin wave disturbance, so-called boomerang shaped, for moisture and vertical velocity fields corresponds to this evolution of precipitation characteristics.

We found a contrast of column water vapor (CWV) anomaly from climatology between Rossby and Kelvin waves. In case of Rossby waves, positive and negative anomalies of CWV have similar amplitudes. However, negative CWV anomaly in Kelvin waves is not clear.This contrast may cause differences in coupling processes between convection and wave disturbances.  We are now investigating this point further in details.

These differences of precipitation characteristics and an asymmetry between Rossby and Kelvin waves in the relationship between moisture and precipitation imply the differences in their coupling processes. As further work, we will investigate precipitation characteristics comparing to snapshot and transient of wave phase.

**Key words:** Equatorial waves, moist convection, precipitation characteristics

# A Preliminary Observational Analysis of Rainfall Characteristics and Convective Organization Associated with the Interaction between Different Tropical Waves

Buo-Fu Chen and Chung-Hsiung Sui

Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan
Correspondence to: bfchen777@gmail.com

Different types of convectively-coupled tropical waves often interact with each other, but the modulation of convective organization [e.g., the activity of mesoscale convective systems (MCS) and tropical cyclone formation] by these interaction events still needs further investigation, which is critical to a comprehensive understanding linking large-scale dynamics and mesoscale weather extremes. We analyzed rainfall characteristics and convective organization under the influence of tropical waves interaction events (TWIEs) during April−June and July−September in the South China Sea and the western North Pacific. A space-time bandpass filter following Wheeler and Kiladis (1999) was applied to an outgoing long-wave radiation (OLR) dataset for identifying four types of convectively-coupled tropical waves: intraseasonal oscillation (ISO), Kelvin wave (KW), Equatorial Rossby wave (ER), and mixed Rossby-gravity wave and tropical depression type disturbance (MRG-TD). Subsequently, various types of interaction events were selected according to the magnitudes of the filtered OLR anomalies of these waves. Furthermore, we applied an objective method using both infrared satellite images and micro-wave rain rate data to represent the status of convective organization in the region of interest. Preliminary results highlighted that the interaction between ER and KW waves contributes to significant and non-linear enhancement in rain rates and MCS activity. This enhancement is presumably related to the establishment of cross-equatorial flows. The presentation will also address the ongoing works of investigating the relationship between a TWIE and the synoptic environment and examining their modulation on mesoscale conditions for convective organization.

**Key words:** Equatorial waves, Convective organization, Tropical rainfall

**Reference**

Wheeler, M., and G. N. Kiladis, 1999: Convectively coupled equatorial waves: Analysis of clouds and temperature in the wavenumber frequency domain. J. Atmos. Sci., 56, 374-399.

**The Comparison of the Modulation of Diurnal Rainfall by the MJO and ENSO over Western Maritime Continent during Boreal Winter**

Chung-Wei Lee*, Chung-Hsiung Sui, Chi-Pei Chang, Mong-Ming Lu
Department of Atmospheric Sciences, National Taiwan University
*E-mail: r05229029@ntu.edu.tw

The diurnal rainfall cycle in the Western Maritime Continent (WMC) during austral summer concentrates over the major islands (Sumatra, Java, Borneo, and Sulawesi) during 16-24 LST, and over the coastal ocean during 04-12 LST. The amplitude of diurnal rainfall cycle of 12.0 mm per day is stronger than that of the seasonal cycle (4.8 mm per day), the Madden-Julian Oscillation (MJO; 4.2 mm per day), and the El Niño-Southern Oscillation (ENSO; 0.6 mm per day). About 40 (10) percent of the daily total rainfall occurs within the six-hour wet (dry) phase of the diurnal cycle. Also, the daily mean moisture flux convergence (MFC) into WMC is mostly consumed during the wet phase of the diurnal cycle. By converging the mean moisture with anomalous winds, the MJO and ENSO evidently modulate the amplitude of the rainfall diurnal cycle.

The MFC associated with the MJO is dominated by the zonal component, which is offset by the smaller meridional component. However, the off-equator heating and the meridional wind anomalies are relatively stronger in ENSO than in MJO, so the meridional and zonal components largely cancel out each other in ENSO scenarios. Hence, the strength of MFC is weaker during ENSO events than during MJO events, and so is the modulation of the rainfall diurnal cycle and the associated daily mean precipitation anomaly.

**Key words:** ENSO, MJO, Maritime Continent, Diurnal Cycle

**Reference**

Chang, C.-P., Z. Wang, J. Ju and T. Li, 2004: On the relationship between western Maritime Continent monsoon rainfall and ENSO during northern winter. *J. Climate*, **17**, 665-672.

Jiang, L., and T. Li, 2017: Why Rainfall Response to El Niño over Maritime Continent is Weaker and Non-uniform in Boreal Winter than in Boreal Summer. *Clim. Dyn*. **51**1465-1483

Peatman, S. C., A. J. Matthews, and D. P. Stevens, 2014: Propagation of the Madden-Julian Oscillation through the Maritime Continent and scale interaction with the diurnal cycle of precipitation. *Q. J. R. Meteorol. Soc.*, doi:10.1002/qj.2161.

Qian, J.H., Robertson, A.W., Moron, V., 2010: Interactions among ENSO, the monsoon, and diurnal cycle in rainfall variability over Java, Indonesia. *J. Atmos. Sci***. 67**, 3509–3524.

Qian, J.H., Robertson, A.W., Moron, V., 2013: Diurnal cycle in different weather regimes and rainfall variability over Borneo associated with ENSO. *J. Clim*. **26**, 1772–1790.

# Modulation of the South China Sea and Maritime Continent Subseasonal Peak Precipitation by MJO and Convectively Coupled Equatorial Waves in Boreal Winter

Wayne Yuan-Huai Tsai*, Mong-Ming Lu, Chung-Hsiung Sui
Department of Atmospheric Sciences, National Taiwan University
*Correspondence to: r06229002@ntu.edu.tw

Tropical South China Sea (SCS)-Maritime Continent (MC) is one of the precipitation centers in the tropics during the boreal winter half year (NDJFMA). The abundant winter rainfall amount over this region involves multiple-scale phenomena such as the annual cycle, monsoon systems, ENSO, Madden-Julian Oscillation (MJO), and convectively coupled equatorial waves (CCEWs). However, it has not been fully documented yet how winter precipitation is modulated by these phenomena. In this study we aim to document the modulation effects of MJO and CCEWs on the subseasonal peak precipitation event over the SCS-MC region. Here, the sub-seasonal peak precipitation event is defined as a period of successive 3 pentads of which the accumulated rainfall amount reaches the maximum of 15-day accumulated rainfall during the four months from November to February. The result suggests that the timing and intensity of the peak precipitation is strongly modulated by the MJO and CCEWs. To illustrate the importance of understanding the multi-scale contribution to the SCS-MC peak precipitation, we analyzed the peak precipitation event in the winters of 2016/17 and 2017/18, during which the South China Sea Two Island Monsoon Experiment (SCSTIMX) were conducted. We found that the seasonal cycle is more dominant over SCS region, while MJO and CCEWs enhanced the intensity. The stronger-than-normal mean precipitation intensity of the 2017/18 peak event, especially over central SCS, Philippines and the western Philippine Sea areas, is strongly modulated by the Equatorial Rossby (ER) wave. On the other hand, the three-week delay of the peak precipitation over western Borneo and the SCS between Sumatra and Borneo in 2016/17 winter can be contributed to the suppression by the dry phase of MJO in the earlier half month of December. Our findings point out understanding the MJO and CCEWs modulation on the SCS-MC precipitation is important for S2S prediction in this region. Further analysis of the influence of monsoon surges and ENSO influence using high-quality reanalysis and observational data is currently under study. The methodology of this study can be applied to, for example, the S2S prediction database to assess multi-scale influence on dynamical model predictability.

**Key Words:** South China Sea and the Maritime Continent precipitation, rainfall annual cycle, convectively coupled equatorial waves, MJO, South China Sea

**References**


Kiladis, G. N., M. C. Wheeler, P. T. Haertel, K. H. Straub, and P. E. Roundy, 2009: Convectively coupled equatorial waves. *Rev. Geophys.*, **47**(2), 1–42. https://doi.org/10.1029/2008RG000266.

Kim, H., F. Vitart, and D. E. Waliser, 2018: Prediction of the Madden–Julian Oscillation: A Review. *J. Climate*, **31**:23, 9425-9443.

Lubis, S. W. and C. Jacobi, 2015: The modulating influence of convectively coupled equatorial waves (CCEWs) on the variability of tropical precipitation. *Int. J. Climatol.*, **35**(7), 1465–1483. https://doi.org/10.1002/joc.4069.

Matsuno, T., 1966: Quasi-Geostrophic Motions in the Equatorial Area. Journal of the *Meteorological Society of Japan. Ser. II*, **44**(1), 25–43. https://doi.org/10.2151/jmsj1965.44.1_25.

Schlueter, A., A. H. Fink, P. Knippertz, and P. Vogel, 2019: A Systematic Comparison of Tropical Waves over Northern Africa. Part I: Influence on Rainfall. *J. Climate*, **32**(5), 1501–1523. https://doi.org/10.1175/JCLI-D-18-0173.1.

Stan, C., D. M. Straus, J. S. Frederiksen, H. Lin, E. D. Maloney, E. D., and C. Schumacher, 2017: Review of Tropical-Extratropical Teleconnections on Intraseasonal Time Scales. *Reviews of Geophysics*, **55**(4), 902–937. https://doi.org/10.1002/2016RG000538

van der Linden, R., A. H. Fink, J. G. Pinto, T. Phan-Van, and G. N. Kiladis, 2016: Modulation of Daily Rainfall in Southern Vietnam by the Madden–Julian Oscillation and Convectively Coupled Equatorial Waves. *J. Climate*, **29** (16), 5801–5820, doi:10.1175/JCLI-D-15-0911.1.

Wheeler, M. and G. N. Kiladis, 1999: Convectively Coupled Equatorial Waves: Analysis of Clouds and Temperature in the Wavenumber–Frequency Domain. *J. Atmos. Sci.*, **56**, 374–399, https://doi.org/10.1175/1520-0469(1999)056<0374:CCEWAO>2.0.CO;2.

# Modulation of MJO propagation speed by the fluctuation of large-scale zonal circulation

Tamaki Suematsu*[1], Hiroaki Miura[2]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

2 Department of Earth and Planetary Science, The University of Tokyo, Tokyo, Japan

*Correspondence to: suematsu@aori.u-tokyo.ac.jp

Eastward progression of convectively active region is one of the distinguishing characteristics of the Madden-Julian Oscillation (MJO). However, understanding on the mechanisms of their eastward propagation and what determines their propagation speeds is still limited. Taking this into consideration, this study investigated how the boreal winter MJO propagation speed is modulated by the background environment, and sought for an intrinsic relationship of the MJO with the background atmospheric states.

MJO events were identified by application of the real-time-multivariate MJO index (RMM). Propagation speed, consistent with the angular phase speed on the RMM phase space, was calculated for each of the detected events by constructing a MJO convection tracking method. Then, building onto our recent finding of MJO enhancement with background zonal SST gradient, we examined how MJO propagation speed was influenced by the background SST. The analysis revealed a tendency of the MJO to propagate slower under low-frequency SST distribution with zonal gradient that peaks over the western Pacific. In contrast, there was little dependency of MJO propagation speed to the high-frequency SST distribution. To further investigate the influence of low-frequency SST, relationship between MJO propagation speed and large-scale zonal circulation. The results showed that MJO tended to propagate slower when the background large-scale zonal circulation was stronger. The findings of this study points to a view that MJO is an integral part of the large-scale zonal circulation, and that slower and stronger MJO events manifests with intensification of the large-sale zonal circulation.

**Key words:** Madden-Julian Oscillations, Walker Circulation

**References**

Suematsu, T. and H. Miura, 2018: Zonal SST Difference as a Potential Environmental Factor Supporting the Longevity of the Madden–Julian Oscillation. *J. Climate,* **31**, 7549–7564

Suematsu, T. and H. Miura, 2019: Modulation of MJO propagation speed by the fluctuation of zonal SST gradient driven large-scale zonal circulation. *J. Climate, (in preparation)*

# The Effect of Upper-tropospheric Jet for Atmospheric Rivers and Precipitation in Pacific Region

Wataru Kaneko*[1] and Yukari N. Takayabu[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

*Correspondence to: w-kaneko@aori.u-tokyo.ac.jp

In the Pacific region, moisture transports from tropics to mid-latitudes are often associated with Atmospheric Rivers (ARs), in some cases causing heavy rain events (e.g. the heavy rainfall event of July 2018 in Japan). Some of these ARs accompany upper-tropospheric troughs, and extend eastward along the jet stream. The goal of this study is to clarify how AR transport events and precipitation from ARs are affected by the upper-tropospheric jet stream and its meandering (trough) depending on these seasonality or regional distributions in the Pacific region.

First, to see the degree of the upper-tropospheric jet meandering, a “Sinuosity” index is calculated daily at each longitude grid, using potential vorticity (PV) obtained from the JRA-55 reanalysis data. The region where PV on the 350K isentropic surface is around 2 PV Unit (PVU) approximately consistent with the subtropical jet axis. In the Northern Hemisphere, the sinuosity is larger in summer than in winter, as well as larger over the ocean than over continental region. Maximum values of the sinuosity index are located over the western Pacific Ocean in summer and over the eastern Pacific Ocean in winter, respectively. A large effect of ENSO on the sinuosity is also found.

Next, ARs are detected using precipitable water (PW) data, referring to Guan and Wailser (2015). In the Pacific region, many ARs are tapped to the western Pacific warm pool or the eastern Pacific ITCZ. In this workshop, the relation among ARs, AR-related precipitation, and upper-tropospheric troughs or “sinuosity” will be reported.

**Key words:** Upper-tropospheric jet, Atmospheric Rivers, heavy rain event

**References**

(Guan,B.,andD.E.Waliser (2015), Detection of atmospheric rivers:Evaluation and application of analgorithm for global studies,J. Geophys. Res. Atmos.,120,12,514–12,535)

# A study on future projections of precipitation characteristics around Japan in early summer combining GPM DPR observation and CMIP5 large-scale environments

Chie Yokoyama*[1], Yukari N. Takayabu[1], Osamu Arakawa[2], and Tomoaki Ose[3]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

2 Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan

3 Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan

*Correspondence to: chie@aori.u-tokyo.ac.jp

In this study, we estimate future changes in precipitation characteristics around Japan in early summer, by combining Global Precipitation Measurement (GPM) satellite-borne Dual-frequency Precipitation Radar (DPR) observation and Coupled Models Intercomparison Project Phase 5 (CMIP5) climate model large-scale projections. We first classify rainfall events (REs) observed with the GPM DPR during May-July 2014-2017 into “small”, “organized”, and “midlatitude” types according to their characteristics. Environments favorable for these three types of REs differ from one another in terms of the lower-tropospheric convective instability and the subtropical jet (Yokoyama et al. 2017). Based on this knowledge, we relate precipitation in each type of REs to the large-scale environment. Two environmental fields are chosen to determine the large-scale conditions of the precipitation: the sea surface temperature and the mid-level large-scale vertical velocity. Using these precipitation-environment relationships, we then reconstruct precipitation distributions for each type with reference to the large-scale environmental indices in climate models for the present and future climates.

As a result, future changes in the reconstructed precipitation are found to vary widely between the three types in association with the large-scale environment. In more than 90% of models, the region affected by organized-type precipitation will expand northward, leading to a substantial increase in this type of precipitation in areas where its present amount is relatively small. An increase in organized precipitation suggests an elevated risk of heavy rainfall, because the maximum precipitation intensity is more intense in organized-type precipitation than in the other two types. Validity of the method to reconstruct precipitation of each type of REs with large-scale environments is also discussed.

**Key words:** precipitation characteristics, future change, GPM, CMIP5

**References**

Yokoyama, C., Y. N. Takayabu, O. Arakawa, and T. Ose, 2019: A study on future projections of precipitation characteristics around Japan in early summer combining GPM DPR observation and CMIP5 large-scale environments. *J. Climate*, in press.

Yokoyama, C., Y. N. Takayabu, and T. Horinouchi, 2017: Precipitation characteristics over East Asia in early summer: Effects of the subtropical jet and lower-tropospheric convective instability. *J. Climate*, **30**, 8127–8147.

# A Modeling Study of the Severe Afternoon Thunderstorm Event at Taipei on 14 June 2015: The Roles of Sea Breeze, Microphysics, and Terrain

Jyong-En Miao, and Ming-Jen Yang*

Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

*Correspondence to: mingjen@as.ntu.edu.tw

On 14 June 2015, a severe afternoon thunderstorm event developed within the Taipei basin, which produced intense rainfall (with rainfall rate of 131 mm $h^{-1}$) and urban-scale flooding. Cloud-resolving simulations using the WRF model were performed to capture reasonably well the onset of see breeze, the development and evolution of this afternoon thunderstorm system. The WRF model had four nested grids (with the finest grid size of 0.5 km) in the horizontal and 55 layers in the vertical to explicitly resolve the deep convection over complex terrain. It is found that convection was initiated by sea breeze at foothill and by upslope wind at mountain peak, respectively. Convective available potential energy (CAPE) was increased from 800 to 3200 J $kg^{-1}$ with abundant moisture transport by the sea breeze from 08 to 12 LST, fueling large thermodynamic instability for the development of afternoon thunderstorm. Strong convergence between sea breeze and cold-air outflow triggered further development of intense convection, resulting in heavy rainfall over Taipei city. Microphysics sensitivity experiments show that evaporative cooling played a major role in the propagation of cold-air outflow and the production of heavy rainfall within basin plain (terrain height < 100 m), while melting cooling played a minor role. The terrain-removal experiment indicates that the local topography of Mount Datun at coastal region may produce the channel effect through Danshui River Valley, intensify sea-breeze circulation and transport more moisture. This terrain-induced modification of sea breeze circulation made its dynamic and thermodynamic characteristics more favorable for convection development, resulting in stronger afternoon thunderstorm system with heavier rainfall within the Taipei City.

**Key words:** afternoon thunderstorm; heavy rainfall; sea breeze; cold pool; terrain effect

## References

Miao, J.-E., and M.-J. Yang*, 2018: Cell merger and heavy rainfall of the severe afternoon thunderstorm event at Taipei on 14 June 2015 (in Chinese with English abstract). *Atmos. Sci.*, **46**, 427–453.

Miao, J.-E., and M.-J. Yang*, 2019: A modeling study of the severe afternoon thunderstorm event at Taipei on 14 June 2015: The roles of sea breeze, microphysics, and terrain. *J. Meteor. Soc. Japan*, submitted.

**From sea level changes to land-atmosphere interactions**

Min-Hui Lo

Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan
*Correspondence to: minhuilo@ntu.edu.tw

While the ice sheets and mountain glaciers continue melting, changes in climate over the past decade have led to Earth's continents to store extra water in land (over soils, lakes and underground aquifers), temporarily lowering the rate of sea level rise by about 20% called “climate-driven sea level changes”. Such changes in land water storage, in fact, affect the land-atmosphere interactions, especially over several “hot spots” globally, including Australia. The high spatial and temporal variability in soil water storage over Australia plays an essential role in affecting the variability of land-surface coupling strength. While previous studies focused more on the spatial variations of land-atmosphere interaction and resulting hotspots, in this study, we attempt to explore temporal changes of the land-surface coupling strength in the semi-arid regions. Furthermore, recent advances in satellite measurement of time-variable gravity (GRACE data (Launched in 2002, NASA's Gravity Recovery and Climate Experiment)) indicate the agricultural irrigation’s fingerprint in land water storage variation that will also be covered in this talk, and discuss how irrigation can largely affect the land-atmosphere interactions and thus, the local and regional hydroloclimatology.

**Key words:** Sea Level Changes, GRACE, Water Storage, Land-Atmosphere Interactions.

# Effects of orographically induced low-level moisture convergence and inversion strength on upslope fog: a case study at Xitou

Min-Ken Hsieh[1,2*], Chien-Ming Wu[1], Po-Hsiung Lin[1]

1 Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

2 Weather Forecast Center, Central Weather Bureau, Taipei, Taiwan

*Correspondence to: miles0919@gmail.com

Previous observational studies on the orographic fog at Xitou of Taiwan suggested that the upslope winds induced by topography is a key factor to the fog formation (Wey et al., 2016). However, the moisture supply associated with the upslope winds is not evident. The relationship between the synoptic environment and the variations of the fog duration is also unclear. In this study we applied a large eddy simulation framework called TaiwanVVM to explicitly simulate 3-dimensional flow structure and vertical turbulence processes in the valley boundary layer at Xitou. TaiwanVVM is a large eddy simulation framework with realistic land surface processes over complex topography of Taiwan. Wu et al. (2019) developed this framework and demonstrated that it is suitable to investigate the local phenomenon associated with the orographically induced circulation such as the afternoon thunderstorm. A series of idealized simulations are carried out under different prescribe temperature inversion strengths to understand the synoptic control on the duration of the orographic fog at Xitou. This is the first attempt to understand the local circulation associated with the formation of the orographic fog at Xitou using a high-resolution (500 m) cloud-resolving model. The results show that the effects of orographically induced low-level moisture convergence are the essential processes to supply moisture in Xitou valley, and the capping inversion helps the fog formation by limiting the development of convections and preserve moisture in the valley. With stronger capping inversion above Xitou valley, the moisture is trapped in the valley, and the duration of the orographic fog is consequently longer.

**Key words:** fog, upslope wind, orographic effect, cloud-resolving model, large eddy simulation

**References**

Wey, T.-H., Y.-J., Lai, M.-C., Chen, and P.-H., Lin, 2016: The Studies on the Relationship Between Mountain Valley Breeze and Upslope Fog at Xitou Region in Central Taiwan, in: Proceeding of the 7th International Conference on Fog, Fog Collection and Dew, Wroclaw, Poland, 24-29 July 2016.

Wu, C.-M., H.-C. Lin, F.-Y. Cheng, and M.-H. Chien, 2019: Implementation of the land surface processes into a vector vorticity equation model (VVM) to study its impact on afternoon thunderstorms over complex topography in Taiwan. Asia-Pacific J. Atmos. Sci., accepted.

# The Role of ENSO in Modulating the Impacts of Deforested Maritime Continent

Ting-Hui Lee[1] and Min-Hui Lo[1]

1 Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan
*Correspondence to: lth313836@gmail.com

The Maritime Continent (hereafter MC) has suffered from severe deforestation in the past few decades. Studies have shown that deforestation will lead to local warming. Chen et al. (2019) used CESM (Community Earth System Model) to investigate the effect of deforested MC based on using the climatological sea surface temperature (SST), and found an increasing zonal surface temperature gradient in tropical Pacific, which is accompanied with intensified trade wind. They also indicated that even the evapotranspiration was reduced due to deforestation over the MC's islands, the moisture convergences from ambient oceans increase, leading to increased precipitation. The amount of the increased precipitation is comparable to the positive anomalous precipitation in La Niña years. However, the interaction of deforested MC and ENSO (El Niño–Southern Oscillation) is not clear. In this study, we try to find out the role of local atmospheric response induced by deforested MC during ENSO and particularly focus on changes in the trade wind over the central Pacific by using CESM CAM (Community Atmosphere Model) and CLM (Community Land Model) with prescribed El Niño and La Niña SSTs, respectively. The model simulation shows that the zonal temperature gradient (surface temperature in MC minus Niño3.4 SST) are highly correlated to zonal wind at 850hPa (140E to 170W). After deforestation, the temperature in MC increased. Preliminary results show that the rising zonal temperature gradient accompanies with intensified easterly wind anomaly in La Niña simulations. However, the westerly wind also intensified under the decreasing zonal temperature gradient in El Niño simulations.

**Keywords: Deforestation、ENSO、CESM、Equatorial trade wind**

**References**

Chen, C.C., M.H., Lo, E.S., Im, J.Y., Yu, Y.C., Liang, W.T., Chen, I.P., Tang, C.W., Lan, R.J., Wu, and R.Y., Chien (2019) Thermodynamic and Dynamic Responses to Deforestation in the Maritime Continent: A Modeling Study. J. Cli., Vol. 32, 3505-3527.

# Role of coastal convection to moisture buildup during the South China Sea summer monsoon onset

Wei-Ting Chen*, Wei-Ming Tsai, Chien-Ming Wu, and Peng-Jen Chen

Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

*Correspondence to: weitingc@ntu.edu.tw

In this study, the climatological characteristics of object-based precipitation systems (OPS) and moisture development are analyzed over the South China Sea (SCS) during the sharp transition of summer monsoon onset. The satellite observed OPS statistics showed that during the pre-onset period, small (<100 km) to medium size (100-300 km) OPS are active over surrounding land, while convection over the ocean is mostly suppressed. During post-onset, large OPS develop over the coastal ocean and contribute to over 60% of the total precipitation. The results suggest that when the convection is strong over the surrounding islands, a local circulation with anomalous subsidence over the ocean can develop and suppress convection. The number of observed large OPS significantly increases along with the sharp moisture buildup during the SCS onset period. The moisture budgets suggested that local contribution from convection vertical mixing is the major moisture source during monsoon onset pentad, while large-scale moisture advection tends to be weak. The relationship between moisture buildup and convection organization is then examined using a set of idealized cloud-resolving model (CRM) experiments, with a land-ocean configuration approximating the SCS basin. The CRM appropriated represents the observed development of coastal convection. With a non-shear environment, the strong basin-scale circulation is formed, which suppresses the ocean moisture development. When large-scale vertical wind shear is imposed to represent the changes of large-scale circulation during the onset pentad, organized convection systems are increased over the coastal ocean and propagate toward the open ocean, accompanied by fast ocean moistening. We identified through the CRM simulations that the moistening time-scale by the transition of coastal convection organization is within 5-10 days.

**Key words:** Convective Organization, Coastal convection, Moisture, TRMM, CloudSat, Cloud-Resolving Model

## References

Chen, W.-T.*, C.-M. Wu, W.-M. Tsai, P.-J. Chen, and P.-Y. Chen (2019), Role of coastal convection to moisture buildup during the South China Sea summer monsoon onset, J. Meteo. Soc. Japan, in revision

# Combining Effects of IOD, ENSO and Deforestation on the Maritime Continent Rainfall

He-Ming Xiao, Min-Hui Lo
National Taiwan University, Department of Atmospheric Sciences

## Abstract

During northern autumn, the mature phase of Indian Ocean Dipole (IOD) and the developing phase of El Nino/ Southern Oscillation (ENSO), maritime continent rainfall is strongly affected by both the IOD and the ENSO. When the IOD and the ENSO are in the same phase, for example, an event that the El-Nino is coupled with the IOD positive phase, the autumn rainfall of the maritime continent is significantly reduced compared to the climatology. Recent years, the maritime continent undergoes large-scale land cover change due to deforestation and agricultural expansion, and further changed surface energy budget and water cycle: reducing evaporation and then increasing surface temperature, which in turn potentially affects the local convection and precipitation. However, during the period of IOD coupled with ENSO, when large-scale deforestation occurs, will rainfall change linearly? We hypothesize that the impacts of deforestation might be enhanced under La Nina + IOD negative phase. This study will analysis the reanalysis data, try to understand the role of land-atmosphere interaction in MC precipitation at the first, and then will conduct several ideal numerical simulations through the Community Earth System Model (CESM 1.2.2), attempt to answer the above questions and explain the mechanisms behind them.

Key words: Maritime Continent, IOD, ENSO, Land-Atmosphere interaction, Deforestation

**References**

Saji, B. N. Goswami, P. N. Vinayachandran, and T. Yamagata, 1999: A dipole mode in the tropical In dian Ocean. Nature, 401, 360–363.

Chang, C., Z. Wang, J. Ju, and T. Li, 2004: On the Relationship between Western Maritime Continent Monsoon Rainfall and ENSO during Northern Winter. J. Climate, 17, 665–672, https://doi.org/10.11 75/1520-0442(2004)017<0665:OTRBWM>2.0.CO;2

Hamada, J.-I. SOLA (2012): Interannual Rainfall Variability over Northwestern Jawa and its Relation to the Indian Ocean Dipole and El Niño-Southern Oscillation Events

Qian, J., A.W. Robertson, and V. Moron, 2013: Diurnal Cycle in Different Weather Regimes and Rainf all Variability over Borneo Associated with ENSO. J. Climate, 26, 1772–1790, https://doi.org/10.11 75/JCLI-D-12-00178.1

Tölle, M.H., S. Engler, and H. Panitz, 2017: Impact of Abrupt Land Cover Changes by Tropical Defor estation on Southeast Asian Climate and Agriculture. J. Climate, 30, 2587–2600, https://doi.org/10. 1175/JCLI-D-16-0131.1

Jiang, L. & Li, T. Clim Dyn (2018) 51: 1465. https://doi.org/10.1007/s00382-017-3965-6

Chen, C., M. Lo, E. Im, J. Yu, Y. Liang, W. Chen, I. Tang, C. Lan, R. Wu, and R. Chien, 2019: Th ermodynamic and Dynamic Responses to Deforestation in the Maritime Continent: A Modeling Stu dy. J. Climate, 32, 3505–3527, https://doi.org/10.1175/JCLI-D-18-0310.1

# Interannual variability of the summertime western north Pacific subtropical High and its relation to local and remote SST.

Hiroshi Morii*[1], Masaki Satoh[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

*Correspondence to: h-morii@aori.u-tokyo.ac.jp

In summer, the position of Pacific High has a strong influence to East Asian summer climate, so it is important to clarify and quantify the mechanism of the zonal displacement of Pacific High in the western north Pacific (WNP) region. This study investigates the interannual variability of Pacific High using reanalysis data and its relation to the local and remote SST. As previously studies mentioned (e.g. Xie et al 2010), anomalous high exists in the WNP region in the El Nino decaying summers. In the composite of the strong pacific high years, Indian Ocean and Maritime Continent warm SST anomaly exist. It is said that Indian Ocean SST make a strong influence to WNP anomalous high in late summer (e.g. Wu et al 2010). On the other hand, local cold SST anomaly is said to be important in early summer (e.g. Xiang et al 2013), and this cold SST anomaly is maintained through the wind-evaporation feedback. The presenter is going to investigate the contribution of this cold SST anomalies to WNP anomalous high.

**Key words:** Western North Pacific Subtropical High, Air sea interaction

**References**

Xiang, B. Q., B. Wang, W. D. Yu, and S. B. Xu, 2013: How can anomalous western North Pacific subtropical high intensify in late summer? *Geophys. Res. Lett.*, **40**, 2349–2354,

Wu B, Li T, Zhou T-J (2010) Relative contributions of the Indian Ocean and local SST anomalies to the maintenance of the Western North Pacific anomalous anticyclone during the El Niño Decaying Summer. J Clim 23:2974–2986

Xie, S.-P., K. Hu, J. Hafner, H. Tokinaga, Y. Du, G. Huang, and T. Sampe, 2009: Indian Ocean capacitor effect on Indo-western Pacific climate during the summer following El Nino. J. Climate, 22, 730–747, doi:10.1175/2008JCLI2544.1.

# Impact of ocean resolution on simulating sea surface temperature in the Arabian Sea and precipitation in the western India

Yoko, Yamagami*[1], Masahiro Watanabe[1], and Hiroaki Tatebe[2]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan
2 Japan Agency for Marine-Earth Science and Technology
*Correspondence to: yamagami@aori.u-tokyo.ac.jp

**Abstract**

Using MIROC6 (Tatebe et al. 2018) and 0.25° ocean version of MIROC6 (hereinafter, referred to as Subhires) climate simulation, impacts of ocean resolution on simulating sea surface temperature (SST) and precipitation are examined. It is shown that mean cold SST biases in the Arabian Sea are improved in Subhires during the summer monsoon season. Since MIROC6 treats the Red Sea and Persian Gulf as land, there is no outflow of high temperature water towards the Arabian Sea. On the other hands, since Subhires resolves the realistic land-sea topography, high temperature outflow transported by meso-scale eddies is well reproduced, which suppresses the cooling due to coastal upwelling off the coast of southeast Arabian Peninsula. It is also found that higher SST increases water vapor supply and precipitation of the western Indian summer monsoon (ISM).

Impact of resolving the Red Sea and Persian Gulf on the midlatitude climate variability are also examined. Relatively higher correlation between interannual variations of ISM rainfall and descent over the eastern Mediterranean region in Subhires indicates that the "monsoon-desert mechanism" at interannual timescale is captured relatively well in Subhires. Further statistical analysis reveals that the relationship between SST anomalies in the north/southwestern part of the Arabian Sea and descent over the Mediterranean. This implies that strong SST anomalies in the north/southwestern Arabian Sea lead to diabatic heating anomalies in the western India, and thus impact on descent anomalies over the Mediterranean.

**References**

Tatebe, H., Ogura, T., Nitta, T., Komuro, Y., Ogochi, K., Takemura, T., ... & Chikira, M. (2018). Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6, Geosci. Model Dev. Discuss.

# Estimating $PM_{2.5}$ Emission from Brick Kilns and Biomass Burning over Northern India with Numerical Model and Remote Sensing Observation

Ardhi Adhary Arbain*[1], Ryoichi Imasu[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan
*Correspondence to: ardhi@aori.u-tokyo.ac.jp

This study examines contribution of brick kiln (BK) industry and biomass burning from agricultural crop residue to $PM_{2.5}$ emission which is the major component of air pollution which is now choking India (Bond et al. 2013; World Health Organization (WHO) 2016). NASA's MODIS land-atmospheric products with 3887 BK locations over the region were analyzed in the period of the highest $PM_{2.5}$ concentration during December 2016 to February 2017. Our preliminary results show that more than 60% of BK occupied silt-rich areas, with more than 80% of them were located over croplands on the outskirts of urban areas, indicating proxies for $PM_{2.5}$ emission over Northern India. We also utilized land products of JAXA's GCOM/SGLI Visible and Near Infrared Radiometer (VNR) and Thermal Infrared (TIR) for identifying the burned croplands in the region. Initial WRF-Chem model (Grell et al. 2005) simulations using locations of BKs and burned croplands showed prominent diurnal variation of the pollutant with averaged peak concentration exceeding 1μg/$m^3$ over the capital city of New Delhi. Future works will introduce the use of Google Earth Engine (GEE) cloud platform (Gorelick et al. 2017) for identifying BK locations and incorporate them into the model to improve the simulation results.

**Keywords**: Biomass burning, brick kiln, PM2.5, WRF-Chem

**References**:

Bond, T. C. et al. 2013. "Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment." *Journal of Geophysical Research Atmospheres* 118(11):5380–5552.

Gorelick, Noel et al. 2017. "Google Earth Engine: Planetary-Scale Geospatial Analysis for Everyone." *Remote Sensing of Environment*.

Grell, Georg a. et al. 2005. "Fully Coupled 'Online' Chemistry within the WRF Model." *Atmospheric Environment* 39(37):6957–75. Retrieved (http://linkinghub.elsevier.com/retrieve/pii/S1352231005003560).

World Health Organization (WHO). 2016. *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*.

# The diurnal surface fluxes-atmosphere relations in Taiwan's montane cloud forest

Rong-Yu Gu[1], Min-Hui Lo[1], Chi-Ya Liao[2], Jehn-Yih Juang[3], Choy Huang[3], Shih-Chieh Chang[4], Cheng-I Hsieh[5], Ming-Hsu Li[6], Yi-Ying Chen[7], Housen Chu[8]

[1]Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

[2]Central Weather Bureau, Taipei, Taiwan

[3]Department of Geography, National Taiwan University, Taipei, Taiwan

[4]Department of Natural Resources and Environmental Studies, National Dong Hwa University, Hualien, Taiwan

[5]Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei, Taiwan

[6]Graduate Institute of Hydrological and Oceanic Sciences, National Central University, Taoyuan, Taiwan

[7]Research Center for Environmental Changes, Academia Sinica, Taipei, Taiwan

[8]Lawrence Berkeley National Laboratory, University of California, California, USA

*Correspondence to: r07229016@ntu.edu.tw

In mountainous Taiwan, surface fluxes and atmospheric conditions play a vital role in modulating the processes of land-atmosphere interactions. Daytime mountain wind brings water vapor from valley uphill, which then accumulates till the afternoon. After 3 p.m., the temperature declines, resulting in water vapor saturation, thus favoring the fog formation in Chi-Lan. When fog occurs, fog drips serve as an additional water source to ecosystems. The decrease of incoming solar radiation also causes the reduction of latent heat flux and carbon flux (Mildenberger et al., 2009). In Taiwan's montane cloud forest, although some short-term field measurements were conducted, the interactions among energy cycle, water cycle, and carbon cycle are not thoroughly understood, especially its hydroclimatological characteristics. Our study utilized long-term observation from two flux towers in Taiwan: Chi-Lan and Xi-Tou as well as using the Community Land Model to analyze the diurnal characteristics of latent heat flux and carbon flux and to further investigate the effects of cloud and fog on surface fluxes. Also, Lienhuachih flux tower dataset, another dataset of a pre-montane forest in Taiwan, was used to emphasize the uniqueness of surface fluxes in montane cloud forests: an asymmetric diurnal latent heat flux with an early peak in the morning was found in Chi-Lan montane cloud forest, while this phenomenon was not found in Lienhuachih. Results indicate that fog and dew both contribute to the canopy water in Chi-Lan that causes high canopy evaporation after the sunrise, resulting in the asymmetric diurnal latent heat flux. However, such asymmetric latent heat flux seems not to affect the cloud formation in the morning.

**Key words:** fog; latent heat flux; $CO_2$ flux; downward solar radiation; canopy water;

montane cloud forest

## References

Mildenberger, K., Beiderwieden, E., Hsia, Y. J., & Klemm, O. (2009). CO2 and water vapor fluxes above a subtropical mountain cloud forest—The effect of light conditions and fog. *Agricultural and Forest Meteorology*, *149*(10), 1730-1736.

# Improvement of regional model, AIST-MM and construction of assimilation model using LETKF method for estimation of $CO_2$ emissions and sinks around mega city, Tokyo

Yutaka Arai*[1], Ryoichi Imasu[1], Hiroaki Kondo[2], Yosuke Niwa[3]

1 Atmosphere and Ocean Research Institute, The University of Tokyo (AORI)
2 National Institute of Advanced Industrial Science and Technology (AIST)
3 National Institute for Environmental Studies, Independent Administrative Institutions (NIES)
*Correspondence to: yarai@aori.u-tokyo.ac.jp

Carbon dioxide (CO2) is one of greenhouse gases, and it is important to know how they distributed precisely around cities. Presently, there are many researches using observations and model simulations. But it has been often pointed out that regional model has some problems in its calculations. Especially, CO2 emissions and sinks are the problem as they include large errors. CO2 emissions are originated from mainly human activities using fossil fuels and plant respirations, and CO2 sinks are plant photosynthesis and absorption to the ocean. In the Kanto Plain, anthropogenic emissions affect to CO2 distributions as there are mega cities in the area. Moreover, plant activities also affect CO2 distributions as there are mountains and fields to surround the urban areas. Because of their complexed existences, it is difficult to simulate CO2 distributions accurately in Kanto Plain using a numerical model.

In this research, as the model improvement to represent accurate CO2 distributions is essential to estimate CO2 emissions and sinks in the target area. We tried to improve the regional model, AIST-MM (Kondo et al., 2001) and to represent the CO2 distributions accurately replacing some input files with renewal data. To represent CO2 distributions accurately, assimilation model based on the Local Ensemble Transform Kalman Filter (LETKF) method was constructed. It was tested whether the assimilation model works properly using Observing System Simulation Experiment (OSSE). We applied the model for two cases, namely a case using CO2 observation data which were assumed as satellite data and a case using CO2 observation data which were assumed as in-situ data. The results for the two cases, it showed a good performance. This is the first step for estimation of CO2 emissions and sinks based on the assimilation system.

**Key words:**
$CO_2$ transport model, data assimilation, Local Ensemble Transform Kalman Filter (LETKF)

**References:**

Kondo, H., N. Saigusa, S. Murayama, S. Yamamoto, A. Kannari, A numerical simulation of the daily variation of CO2 in the central part of Japan -summer case-. J. Meteorol. Soc. Jpn. 79, 11–21, 2001.

# Estimating biogenic carbon dioxide fluxes in Kantō plain and how it contributes to the update of anthropogenic carbon dioxide emission inventory of mega-city Tokyo

Qiao Wang*[1], Ryoichi Imasu[1], Satoshi Ito[1], Takahiro Sasai[2] and Hiroaki Kondo[3]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan
2 Department of Geophysics, Graduate School of Science, Tohoku University, Sendai, Japan
3 National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan
*Correspondence to: qwang@aori.u-tokyo.ac.jp

To check the effectiveness of carbon mitigation policies and verifying reported $CO_2$ emission reductions from cities, it requires inventory data at relevant spatial and temporal scales (DeCola *et al.* 2017). Atmospheric $CO_2$ observations from GOSAT (Greenhouse gases Observing SATellite) and GOSAT-2 provide such information for finer inversion analysis to update emission inventory, particularly, in mega-cities like Tokyo, where the largest human-induced carbon source occurs. In addition to anthropogenic emissions, biogenic $CO_2$ fluxes and atmospheric transport processes (Ahmadov *et al.* 2007) also affect the spatiotemporal variability of atmospheric $CO_2$ concentrations at regional scale. In summer, forests west and north of Tokyo Metropolis in the Kantō plain generate significant $CO_2$ fluxes (photosynthesis uptake + respiration release). These land-atmosphere $CO_2$ exchanges, however, have yet to be realistically simulated in regional atmospheric transport model AIST-MM (National Institute of Advanced Industrial Science and Technology-Mesoscale Model, Kondo *et al.* 2001). This study adjusts BEAMS (Biosphere model integrating Eco-physiological And Mechanistic approaches using Satellite data, Sasai *et al.* 2005) and makes necessary changes to meet the demand of future model coupling with AIST-MM. We have compared our preliminary results (gross primary production and net primary production) and MODIS 8-day GPP product (Running *et al.* 2015). However, as MODIS GPP product's limitation to estimate vegetation carbon capture over heterogeneous terrain is well-known, we will use AsiaFlux data to further calibrate and validate our simulation of biogenic $CO_2$ fluxes at regional scale.

**Key words:** urban $CO_2$ emission inventory, biogenic $CO_2$ flux, GOSAT/GOSAT-2

**References**

Ahmadov, R., Gerbig, C., Kretschmer, R., Koerner, S., Neininger, B., Dolman, A. J., & Sarrat, C. (2007). Mesoscale covariance of transport and CO2 fluxes: Evidence from observations and simulations using the WRF‐VPRM coupled atmosphere‐biosphere model. *Journal of Geophysical Research: Atmospheres*, 112(D22).

doi:10.1029/2007JD008552, 2007

DeCola, P., & Secretariat, W. M. O. (2017). An integrated global greenhouse gas information system (IG3IS). WMO Bulletin, 66, 38-45.

Kondo, H., Saigusa, N., Murayama, S., Yamamoto, S., & Kannari, A. (2001). A Numerical Simulation of the Daily Variation of CO2 in the Central Part of Japan—Summer Case—. *Journal of the Meteorological Society of Japan*. Ser. II, 79(1), 11-21.
doi : https://doi.org/10.2151/jmsj.79.11

Running, S., Mu, Q., Zhao, M. (2015). *MOD17A2H MODIS/Terra Gross Primary Productivity 8-Day L4 Global 500m SIN Grid V006* [MOD17A2H.A2017185.h29v05.006.2017199123537.hdf]. NASA EOSDIS Land Processes DAAC.
doi: 10.5067/MODIS/MOD17A2H.006

Sasai, T., Ichii, K., Yamaguchi, Y., & Nemani, R. (2005). Simulating terrestrial carbon fluxes using the new biosphere model "biosphere model integrating eco‐physiological and mechanistic approaches using satellite data" (BEAMS). *Journal of Geophysical Research: Biogeosciences*, 110(G2). doi:10.1029/2005JG000045.

# Impacts of Irrigation in Central Asia on Local and Regional Hydroclimatology

Tzu-Ying Wu*, Min-Hui Lo

Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

*Correspondence to: r06229009@ntu.edu.tw

The desiccation of the Aral Sea indicates the great impact anthropogenic effects can have on a natural hydroclimate system. The cause of the shrinkage has been attributed to the Soviet-era expansion of canals and the irrigation network. In this work, we hypothesize that this irrigation expansion also has significant impacts on local hydrological budget, atmospheric circulation, and thereby regional precipitation. Previous studies have shown an enhanced evapotranspiration after adding irrigation from the observed river discharges. However, how the irrigation water contributes to precipitation have not been extensively explored. In addition, studies have shown that irrigation generally contributes significantly to increased precipitation in downwind regions, while surface temperatures are not cooled by local increases of latent heat flux and added moisture from the irrigated land is transported into this region. In this regard, we examine the irrigation impact not only over Central Asia but the northwestern China farther to the east. Coupled and offline simulations are performed using Community Earth System Model (CESM) to consider the direct and indirect effects of irrigation on the atmospheric response. The inputs of irrigation water are estimated using both water balance model and observations, as derived by Wada and Bierkens (2014). A forward-trajectory method will also be used to estimate the contribution of irrigation water to the recent precipitation enhancement of Central Asia and the northwestern China.

**Key words:** irrigation, hydrological cycle, precipitation

**References**

[1] Wada, Y., & Bierkens, M. F. (2014). Sustainability of global water use: Past reconstruction and future projections. Environmental Research Letters, 9(10), 104003. doi:10.1088/1748-9326/9/10/104003

# High Cloud Annual Variation and Its Responses to Global Warming in the NICAM AMIP Experiment

Ying-Wen Chen[1] in collaborate with Masaki Satoh[1&2], Chihiro Kodama[2], Akira T. Noda[2] and Yohei Yamada[2]

1. Atmosphere and Ocean Research Institute, the University of Tokyo
2. Japan Agency for Marine-Earth Science and Technology

Uncertainties in climate sensitivity mainly come from the ambiguities in simulations of both high- and low-level clouds. The previous studies using NICAM's short time simulation showed that the both the altitudes and amount of high clouds increase under the global warming condition (Chen et al. 2016), while high cloud amount contrarily decreases in other studies with climate models. Due to the progress in computer science, long term climate simulation with $\Delta x < 20$ km becomes available. A pair of 25-year climate simulation (present and warming climate) with 14-km horizontal resolution (NICAM AMIP-like simulation, Kodama et al. 2015) has been performed by K computer. In this study, we analyze how the annual variation in high clouds is presented in the NICAM AMIP-like simulation. Satellite and in-situ data are used to investigate whether NICAM captures the observed responses of high clouds to the mean sea surface temperature (SST). Regressions between the high cloud amount variation and the SST variation is different with altitudes; positive regressions appear at altitudes above 100 hPa while negative regressions are found in altitudes below 100 hPa. The results are consistent with previous study based on observations (Zelinka and Hartmann 2011). Further analysis showed that the spatial pattern of high clouds is mainly associated with the El Nino response; as SST warmer, the high clouds shift in the eastern Pacific with higher. The increase of high clouds is associated with the increase of ice water content of cloud ice and snow. We argue that the response of high clouds to global warming is also explained by the change in the spatial distribution of the high clouds.

# Potential vorticity mixing and rapid intensification in numerically simulated Supertyphoon Haiyan (2013)

Satoki TSUJINO
(Department of Atmospheric Sciences, National Taiwan University)

Full understanding of rapid intensification (RI) in tropical cyclones (TCs) remains a big issue. RI can be controlled by environmental conditions such as sea surface temperature and vertical shear of large-scale flows, and internal processes such as convective bursts, strong boundary-layer inflow, and eye-eyewall interactions. In the intensification through the internal processes, convective-scale heating can be interacted with storm-scale flows. Then, potential vorticity (PV), which represents flows and mass (thermal) fields, is useful for the understanding of the internal processes in RI.

The present study examines a role of PV-mixing process around eye and eyewall on RI in Supertyphoon Haiyan (2013) simulated with a fine resolution. The PV field in the simulated storm indicates clearly elliptical and polygonal shapes in lower troposphere, and forms a PV hollow tower associated with an eyewall around a RI onset. Then, the PV changes to more monopole shape in the lower troposphere during the later period of RI. A PV budget analysis is diagnosed to quantitatively estimate contribution of the PV mixing to evolution of the PV field around the RI onset. The budget results show (1) the PV hollow tower generated by convective heating associated with the eyewall, and (2) radially inward advection of the PV associated with asymmetric flows along the inner edge of the eyewall (indicating the PV mixing). Around the RI onset, pressure falling associated with evolution of the PV field is diagnosed by a piecewise PV inversion technique. The diagnosed pressure falling is qualitatively consistent with actual pressure falling. Consequently, the PV mixing around the RI onset can induce deepening of the central pressure in the early stage of RI. The pressure deepening is related to increase of low-level inflow on an axisymmetric view. Eyewall updraft related to the increase of the low-level inflow is located in the inside of the radius of the maximum tangential wind speed. The enhanced low-level inflow suggests enhancement of tangential wind speed (i.e., RI) through inward advection of absolute angular momentum.

# The effect of the SST over the PMM region and the eastern northwestern Pacific on tropical cyclone genesis over WNP in 2018

Takahiro, Ishiyama*[1], Masaki Satoh[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

*Correspondence to: t-ishi@aori.u-tokyo.ac.jp

Typhoons in the northwest Pacific in 2018 exceeded the average for 29 occurrences, the number of landings to Japan to 5, and for the typhoon which became extreme strength it was updated with the most record and the activity was active. In the ENSO phase, during the most active period of the typhoon (from June to November), the ENSO phase was still in a neutral state. Therefore, PMM is focused recently. Previous studies have pointed out that this positive PMM favors TC activities in the northwest Pacific (e.g. Zhang et al. 2016). Looking at the PMM index from 1948 to 2018, there was positive PMM in 2018.

The purpose of this research is to focus on the monthly SST variation such as ENSO and PMM and to evaluate the Potential of the 2018 typhoon activity. We also focus on the PMM and the SST over the eastern of northwest Pacific, and investigate how they affect the 2018 typhoon activity.

For the above purpose, we conducted perpetual experiments in which boundary conditions were fixed from July to October, respectively, using a non-hydrostatic model NICAM. The horizontal resolution was 56 km. Comparing the experimental result of SLP with JRA-55, although the position of the maximum value of the high pressure in July is misaligned, the position and overhang of the high pressure does not dif9fer greatly in each month, and perpetual experiments also reproduce the reality well. Both reanalysis and perpetual experiments have more typhoons in July and August than in September and October. Also, the occurrence position of the typhoon occurs more frequently in the eastern side of the northwestern Pacific in order of July, August, September. The same tendency was observed. Such differences in active areas of typhoon activity had an effect on the monsoon trough.

**Key words:** Tropical cyclone, Pacific Meridional Mode, NICAM

**References**

Zhang, W., G. A. Vecchi, H. Murakami, G. Villarini, and L. Jia, 2016: The Pacific meridional mode and the occurrence of tropical cyclones in the western North Pacific. J. Climate, **29**, 381–398, doi:10.1175/JCLI-D-15-0282.1.

# An Initiation Process of TD-type Disturbances under an Influence of Upper-Level Troughs

Yuya, Hamaguchi*[1], Yukari, N. Takayabu[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

*Correspondence to: yuya_h@aori.u-tokyo.ac.jp

Tropical depression-type disturbances (TD-type disturbances, or TDDs) are widely known as westward-moving disturbances with 3-5-day periods and ~3000-km wavelengths over the western Pacific (Takayabu and Nitta 1993). As Ritchie and Holland (1999) reported, roughly 50% of western Pacific tropical cyclones form in association with TDDs. In spite of their social importance in terms of tropical cyclogeneses over the western Pacific, their initiation processes have not been fully understood. At the same time, recent satellite products reveal that upper-tropospheric wavy structures are often observed prior to TDDs' occurrences. Though TDDs are thought to be originated from lower-tropospheric eddies in association with convection, some researches have indicated possible upper-tropospheric contributions in energetics of TDDs (*e.g.* Maloney and Dickinson 2003). From these perspectives, we focused on the relationship between TDDs and the upper-level perturbations to understand the mechanism of the initiation process of TDDs. After analyzing the relation using JRA-55 products (velocity anomaly, water vapor variables, and potential vorticity) and CLAUS datasets (brightness temperature) in both time-space and frequency-wavenumber domains, we found that a considerable number of TDDs are given birth in upper-level anomalous southerly wind region in front of troughs. Convections are likely to be initiated through processes such as the destabilization of the atmosphere and sustained upward flow induced by the upper-level trough. In addition, our analysis on the water vapor budget shows that the trough-related initiation process of TDDs are severely confined to wet area, which may indicate the necessity of consideration of a synergistic effect of the upper trough and large-scale distribution of water vapor which is largely influenced by the sea surface temperature (SST).

**Key words:** TD-type Disturbance, Upper-Tropospheric Trough, Initiation Process

## References

Takayabu, Y. N., and T. Nitta, 1993: 3–5-day period disturbances coupled with convection over the tropical Pacific Ocean. *J. Meteor. Soc. Japan,* **71,** 221–246.

Ritchie, E. A., and G. J. Holland, 1999: Large-scale patterns associated with tropical cyclogenesis in the western Pacific. *Mon. Wea. Rev.,* **127,** 2027–2043.

Maloney, E. D., and M. J. Dickinson, 2003: The intraseasonal oscillation and the energetics of summertime tropical western north Pacific synoptic-scale disturbances. *J. Atmos. Sci.*, **60**, 2153-2168.

# A study on terrain-induced mesoscale circulations of landfalling typhoons with different storm characteristics

Wei-Ting Fang[*1, 2] and Ming-Jen Yang[2]

1 Central Weather Bureau, Taipei, Taiwan

2 Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

*Correspondence to: wtinfang@cwb.gov.tw

In order to retrieve the typhoon circulation correctly from radar-observed Doppler velocity, a vortex-based Doppler velocity dealiasing (VDVD) algorithm for tropical cyclones (TCs) is developed to recover the aliased Doppler velocity due to the strong winds from typhoons. The algorithm is based on an inner-outer iterative procedure with a Rankine-combined-vortex model as a reference field for velocity dealiasing. The structure of the reference vortex is adjusted in the inner iterative procedure which applies the ground-based velocity track display (GBVTD) technique. The outer loop, based on the GBVTD-simplex, is used for correction of TC center location.

The VDVD algorithm is applied to dealias the Doppler velocity of TY Soudelor (2015), a relatively large typhoon (R17 ~3.2°), and TY Nesat (2017), a relatively small one (R17 ~1.9°), observed by the Wu Feng Shan radar in Taiwan. The retrieved symmetric tangential wind shows that the radius of maximum wind (RMW) of TY Nesat shrunk gradually when it was approaching Taiwan. In contrast, TY Soudelor only had a minor change on its RMW. Moreover, a split of the eyewall strong wind area was observed before its landfall. To diagnose the unique features of TY Soudelor, a numerical model simulation with radar data assimilation (DA) is conducted. Compared to the simulated typhoon without radar DA, the simulated one with radar DA has the kinematic feature closer to observed one. In order to reproduce a more reasonably simulated typhoon similar to TY Soudelor, different assimilation strategies will be investigated in the future. Angular momentum budget will be calculated to understand the mechanism of momentum change which is responsible for the unique features of TY Soudelor.

**Key words:** Typhoon, radar, Doppler velocity, dealias, size

## References

Chang, P.-L., W.-T. Fang, P.-F. Lin, and M.-J. Yang, 2019: A vortex-based Doppler velocity dealiasing algorithm for tropical cyclones. *J. Atmos. Oceanic Technol.,* accepted.

Lee, W.-C., J.-D. Jou, P.-L. Chang, and S.-M. Deng, 1999: Tropical cyclone kinematic structure retrieved from single Doppler radar observations. Part I: Interpretation of Doppler velocity patterns and the GBVTD technique. *Mon. Wea. Rev.*, **127**, 2419–2439.

Lee, W.-C., and F.D. Marks, 2000: Tropical cyclone wind fields retrieved from single

ground-based Doppler radar. Part II: The GBVTD-simplex center finding algorithm. Mon. *Wea.* Rev., **128**, 1925-1936.

Yang, M. J., T. C. Chen Wang, Y. Zhang, and C. Y. Weng, 2011: Momentum budget evolution of Typhoon Nari (2001) during the landfall process. *Terr. Atmos. Ocean. Sci.*, **22**, 595-612.

Title: The resent progress of NICAM-LETKF forecast system

Ying-Wen Chen[1], collaborate with Kaya Kanemaru[2], Masaki Sato[1], Koji Terasaki[3], Shunji Kotsuki[3], Takemasa Miyashi[3], and Takuji Kubota[4]

1 Atmosphere and Ocean Research Institute, the University of Tokyo
2 Applied Electromagnetic Research Institute, National Institute of Information and Communications Technology
3 Center for Computational Science, RIKEN
4 Japan Aerospace Exploration Agency

A near-real time weather forecast system based on a data assimilation system of Local Ensemble Transform Kalman Filter (LETKF, Terasaki and Miyoshi 2017, Kotsuki et al., 2017a, b) for the Nonhydrostatic ICosahedral Atmospheric Model (NICAM, Satoh et al., 2017) called NEXRA is developed by the collaboration of JAXA, RIKEN, and the University of Tokyo. The operational system with horizontal resolution at 112 km and the data is available on the website (https://www.eorc.jaxa.jp/theme/NEXRA/index_j.htm) . At present, the operational system provides 5-day forecast every 6 hours. However, this forecast system faces limitations to catch the characteristics of coming severe weather systems due to the horizontal resolution is too coarse to revolve mesoscale systems. As the first step to make this forecast system better, the resolution has been changed to 14 km and the single moment cloud microphysics scheme (NSW6, Tomita 2008) is used. In this presentation, we show how the prediction skill is changed by analyzing the heavy rain event occurred in the Yakushima Island in 18th May, 2019.

# Precipitation enhancement via the interplay between atmospheric rivers and cutoff lows

Hiroki, Tsuji*[1] and Yukari N. Takayabu[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

*Correspondence to: h-tsuji@aori.u-tokyo.ac.jp

A significant precipitation enhancement can result from the interplay between two independent, largescale phenomena: an atmospheric river (AR) and a cutoff low (COL). An AR is a long, narrow area with a deep moist layer. A COL is an upper tropospheric cyclonic disturbance isolated from the meandering upper-level westerly jet. Here, we construct composites of COLs which are close to an AR (AR-close category) and of those which are distant from an AR (AR-distant category) over a 14-yr period across the western North Pacific. We assume that the interplay enhances precipitation around COLs in the AR-close category and the interplay has little effects on COLs in the AR-distant category. A comparison between the two categories shows an enhanced precipitation area to the northwest of the COL and to the south of the AR axis in the AR-close category. The horizontal formation among the AR, COL, and enhanced precipitation area in the composite coincides with that in a rainfall event occurred in Hiroshima, Japan, in 2014. The deep moist layer related to the AR, and the destabilization and isentropic up-gliding effect related to the COL are also observed both in the composite and in the Hiroshima rainfall cases. Moreover, we evaluate the distribution of quasi-geostrophic forcing (Q-vector divergence) for vertical motion. The result demonstrates that warm air advection associated with the AR overcomes the descending forcing inherent in the northwest of the COL and makes the instability and up-gliding effect in that region more effective. These results indicate that the interplay between ARs and COLs is a common mechanism in the enhancement of precipitation and the Hiroshima rainfall case is an extreme precipitation event caused by this interplay.

**Key words:** atmospheric river, cutoff low, rainfall event

## References

Tsuji, H., and Takayabu, Y. N. (2019) Precipitation Enhancement via the Interplay between Atmospheric Rivers and Cutoff Lows. *Mon. Wea. Rev.*, **147**, 2451–2466, doi:10.1175/MWR-D-18-0358.1.

# Influence of CCN on Summer Afternoon Thunderstorms in Taiwan

Chang, Yu-Hung[1], Wei-Ting Chen[1], Chien-Ming Wu[1]

[1] Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

This study investigates how increasing cloud condensation nuclei (CCN) affects summer afternoon thunderstorms ($TS_A$) in Taiwan using the Vector Vorticity equation cloud-resolving Model (VVM) with interactive land surface model (Wu et al. 2019) and the Predicted Particle Properties (P3) microphysics scheme (Morrison et al. 2015). We select nine $TS_A$ cases from 2006 to 2010 under southwesterly (SW) or weak synoptic (WS) conditions based on the Taiwan Atmospheric Events Database (TAD, Su et al. 2018) as well as the Central Weather Bureau (CWB) surface rain gauge observations and Tropical Rainfall Measuring Mission (TRMM) 3B42 satellite rainfall estimates. Semi-realistic large-eddy simulations (LES) for the nine selected cases are carried out over the high-resolution complex terrain of the Taiwan Island, driven by the simplified observational soundings. High convective available potential energy ($> 900 J/kg$) and column water vapor ($> 43$mm) are features that these soundings share, while the depth of southwesterly varies. In the control simulations, the CCN number mixing ratio is fixed at $3 \times 10^7$ $\#/kg$ in the entire domain to represent the clean scenario, while in the experimental (polluted) simulations the CCN number mixing ratio is increased to $3 \times 10^{10}$ $\#/kg$. The composite of the simulated results reveals a precipitation hotspot around Alishan Mountain Range (AMR), which corresponds with observational study by Lin et al. (2012). The CCN delay the initiation of $TS_A$, while the other characteristics related to precipitation, such as duration of rain and total precipitation, are highly variable. Three types of $TS_A$ precipitation response to increasing CCN are distinguished over the AMR region: low precipitation, strengthened precipitation peak, and time shift in precipitation peak. The first type is characterized as peak precipitation intensity lower than $2\,mm/hr$. The second type shows that peak precipitation intensity in polluted scenario is at least $1\,mm/hr$ higher than that in clean scenario. There is no significant difference in peak precipitation intensity between the two scenarios in the last type, but the timing delays in polluted scenario. These different responses are likely controlled by initial atmospheric conditions and local circulation developed over the complex topography of the AMR region. The changes in precipitation intensity spectra and the size distribution of convective cloud objects will also be investigated.

**Key Words:**

cloud condensation nuclei, Taiwan topography, afternoon thunderstorm, large-eddy simulation

**References:**

Lin, P.-F., P.-L. Chang, B. J.-D. Jou, J. W. Wilson, and R. D. Roberts. 2012. Warm Season Afternoon Thunderstorm Characteristics under Weak Synoptic-Scale Forcing over Taiwan Island. *Weather and Forecasting* 26(1): 44-60.

Morrison, H., and J. A. Milbrandt. 2015. Parameterization of Cloud Microphysics Based on the Prediction of Bulk Ice Particle Properties. Part I: Scheme Description and Idealized Tests. *Journal of the Atmospheric Sciences* 72(1): 287-311.

Su, S.-H., J.-L. Chu, T.-S. Yo, and L.-Y. Lin. 2018. Identification of Synoptic Weather Types over Taiwan Area with Multiple Classifiers. *Atmospheric Science Letters* 19(12).

Wu, C.-M., H.-C. Lin, F.-Y. Cheng, and M.-H. Chien. 2019. Implementation of the Land Surface Processes into a Vector Vorticity Equation Model (VVM) to Study its Impact on Afternoon Thunderstorms over Complex Topography in Taiwan. *Asia-Pacific Journal of Atmospheric Sciences*.

# Impact of distantly located typhoon and the North Pacific subtropical high on precipitation in Japan

Shinichi, Kodama*[1], Masaki Satoh[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

*Correspondence to: kodama@aori.u-tokyo.ac.jp

It is known that the effects of typhoon on precipitation can be divided into direct effects and indirect effects depending on the location of the typhoon [e.g., Wang et al. 2009]. In other words, it is distinguished whether the cloud area which caused precipitation is the typhoon itself. In this study, we mainly investigated the effects of distantly located typhoon on precipitation in Japan, that is, indirect effects. During the Baiu/Meiyu season and Akisame (autumn rain) season, typhoon increases the inflow of surrounding water vapor to the rain front. As a result, enormous rainfall is produced in Japan, so typhoon has a key role in the viewpoint of heavy rain forecasting. Although there are more than 10 typhoons approaching Japan each year, it will not rain if there is no front over Japan at that time, so there are not many cases of remote precipitation. Therefore, the analysis focused on some typical cases that occurred after the year 2000. In general, the subtropical high is a divergent area of water vapor flux and the amount of evaporation is larger than precipitation, suggesting that it is a water vapor source like a typhoon.

We characterized the global environmental field of remote precipitation which is covered not only around the typhoon but also a wide region, using the reanalysis data and the satellite precipitable water vapor data. In addition, we used Nonhydrostatic Icosahedral Atmospheric Model (NICAM) for simulations of horizontal resolution 14 km. The typhoon targeted for simulations are Songda (2004) and Melor (2009). Among the remote precipitation cases, we compared the differences in the precipitable water and the location of the subtropical high. This time, we will introduce an interim report about the obtained results.

**Key words:** Remote Precipitation, Water Vapor Transport, NICAM

## References

Wang, Y. Q., Y. Wang, and H. Fudeyasu (2009), The role of Typhoon Songda (2004) producing distantly located heavy rainfall in Japan, Mon. Weather Rev., 137, 3699–3716.

# Convective self-aggregation in a large square domain

Shuhei, Matsugishi*[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

*Correspondence to: matsugishi@aori.u-tokyo.ac.jp

There are many organized cloud systems in the tropics. These cloud systems release a large amount of latent heat and play an important role in the atmospheric general circulation. Thus, it is important to advance our knowledge about cloud organization for better understanding the variability of the tropical weather systems and their roles in the global circulation. It is useful to consider cloud organization under simple environment, such as under the radiative convective equilibrium(RCE). In RCE simulation, convection spontaneously organizes without extra forcing. It is referred as convective self-aggregation.

The purpose of this study is to understand the spatial scales of the self-organized cloud systems and how interact hierarchical structure of clouds in this organized cloud systems. Larger simulation domain is needed to be enable to represent the large-scale circulation spontaneously created and interactions of clouds with multiple scales within it. Here I conducted about 5000 km square domain RCE simulation. In this simulation, like a small domain self-organization studies, the wet area becomes to form one cell within about 40 days. Individual clouds form several clusters with the horizontal scale about several hundred kilometers in the moist patch with thousand kilometers. Oscillating behavior of those clusters is observed in units of days. Horizontal scale of self-aggregation also fluctuates.

**Key words:** Self-aggregation, RCE, Convection, Horizontal scale

# The Study of the Record-Breaking Rainfall in Japan in July 2018 based on Ensemble Simulation using the Non-hydrostatic Icosahedral Atmospheric Model

Kohsuke Ikehata*[1], Masaki Satoh[1], Junshi Ito[1], and Kaya Kanemaru[2]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan
2 National Institute of Information and Communications Technology, Tokyo, Japan
*Correspondence to: ikehata@aori.u-tokyo.ac.jp

The record-breaking rainfall in Japan in July 2018 damaged a large area of western Japan. Main reasons of this event are considered as follows: (1) Concentration of water vapor in two very moist airstreams maintained over western Japan, (2) Persistence of upward flow associated with activation of a stationary Baiu front, (3) Formation of mesoscale line-shaped precipitation systems (Tsuguti et al. 2018). This study especially focuses on the environmental field before the formation of the linear precipitation zones and the active convection in East China Sea, which has contributed moistening the middle-to-upper troposphere above the area and thereby the continual influx of the moist atmosphere to western Japan was reinforced (Shimpo et al. 2019). To investigate the relationship between these, numerical ensemble simulation using the cloud system resolving model (NICAM; Non-hydrostatic Icosahedral Atmospheric Model) is conducted, and the result is amply similar to reanalysis data. Firstly, from the analysis of the result, convective activity in East China Sea and the environmental field of line-shaped precipitation systems are related to each other. Secondly, the active convection is related to the depth of upper trough and ridge located above China at 200hPa. Considering these results, the meandering of Polar jet is linked to the line-shaped precipitation systems occurrence in western Japan via continuous active convection in East China Sea.

**Key words:** NICAM, Line-shaped Precipitation Systems, Heavy Rainfall, Convection

**References**

Tsuguti, H., N. Seino, H. Kawase, Y. Imada, T. Nakaegawa, and I. Takayabu, 2018: Meteorological overview and mesoscale characteristics of the Heavy Rain Event of July 2018 in Japan. Landslides, Vol. 16, pp. 363–371, doi:10.1007/s10346-018-1098-6.

Shimpo, A., K. Takemura, S. Wakamatsu, H. Togawa, Y. Mochizuki, M. Takekawa, S. Tanaka, K. Yamashita, S. Maeda, R. Kurora, H. Murai, N. Kitabatake, H. Tsuguti, H. Mukougawa, T. Iwasaki, R. Kawamura, M. Kimoto, I. Takayabu, Y. N. Takayabu, Y. Tanimoto, T. Hirooka, Y. Masumoto, M. Watanabe, K. Tsuboki, and H. Nakamura, 2019: Primary factors behind the Heavy Rain Event of July 2018 and the subsequent heat wave in Japan. SOLA, 15A, 13−18, doi:10.2151/sola.15A-003.

# Development of size-resolving aerosol microphysics scheme for use in a global non-hydrostatic cloud-resolving model

ChiuTung Cheng*[1], Kentaroh Suzuki[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan

To simulate the evolutions of aerosol size distributions and their contributions to the aerosol-radiation and aerosol-cloud interactions, we develop the size-resolving scheme as an extension from the original NICAM-SPRINTARS (Suzuki et al., 2008) framework. A flexible bin-type size representation is introduced for the major atmospheric aerosol species considered in SPRINTARS: sea salt, mineral dust, sulfate and carbonaceous aerosols. Each size bin is characterized with size-dependent properties such as terminal velocity, CCN property and optical parameters, and evolves as an independent tracer. For sulfate aerosols, aerosol dynamical processes (new particle formation, condensation and coagulation processes) are represented with explicit size-dependency of the processes.

Here we present the early results from the ongoing model development, including its validation through comparisons to ground-based observations from AERONET and satellite observations from MODIS. While aerosol models are usually validated using observed aerosol optical depths and Ångström exponents, the knowledge of size distributions provided by the size-resolved model also allows direct comparisons with the observed size distribution from ground based measurements. For example, the annually averaged size distributions at several AERONET sites are fairly reproduced by the size-resolved model, and the underlying compositions by different aerosol species can also be inferred.

In comparison with the original version, the size-resolving model produces contrasting spatial distribution, optical depths and mass budgets due to explicit representations of size dependency of optical properties and physical process rates. Results indicate a more distant transport of sulfate aerosols owing to the size-resolved distributions. These results suggest that size-resolving microphysics will lead to different estimates of aerosol forcing, and should be considered in global models in order to reduce the uncertainties of aerosol radiative forcing.

**Key words:** aerosols, size distribution, NICAM, SPRINTARS, MODIS, AERONET

**References**

Suzuki, K., Nakajima, T., Satoh, M., Tomita, H., Takemura, T., Nakajima, T. Y., & Stephens, G. L. (2008). Global cloud‐system‐resolving simulation of aerosol effect on warm clouds. Geophysical research letters, *35*(19).

# A study on the paleoclimatic change in the Asia during the Cretaceous (145~65Ma) with MIROC AOGCM

Taro, Higuchi*[1], Ayako Abe-Ouchi[1], and Wing-Le Chan[1]
1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan
*Correspondence to: taro-h@aori.u-tokyo.ac.jp

The Cretaceous (145~65 Ma) is known as one of the warm periods, comparable to global warming prediction of near future due to rising $CO_2$ concentration in the atmosphere. Paleoclimatic study in the Cretaceous is important for the understanding of Earth system operating during greenhouse conditions. The “mid-Cretaceous” (125~90 Ma) was a time of extraordinarily high atmospheric $CO_2$ concentration (>1000 ppm) during the Cretaceous, and many studies have reported the aridification in the Asia associated with water cycle change during the mid-Cretaceous. Hasegawa et al. (2012) suggested the paleoclimatic change may be attributed in the equatorward shift of the subtropical high-pressure belt caused by Hadley cell shrinkage due to increasing $CO_2$ levels. However, this hypothesis is inconsistent with the global warming prediction with GCM. In this study, we set up the Cretaceous configuration experiments using AOGCM MIROC 4m which differ only in the atmospheric $CO_2$ concentration, and aim to investigate the water cycle response on the Cretaceous geography and continental distribution due to increasing $CO_2$ concentration. We found the precipitation in the Asia decreases with increasing atmospheric $CO_2$ concentrations on the Cretaceous geography, while increases on the Present Day. This precipitation change obtained by the Cretaceous experiments is consistent with the paleoclimatic change in the Asia during the mid-Cretaceous, despite no remarkable change of the meridional atmospheric circulation change Hasegawa et al. (2012) proposed. This implies that the paleoclimatic change in the Asia during the Cretaceous can be explained by local water cycle change with increasing $CO_2$. Additionally, to evaluate the difference of the water cycle response between Present Day and Cretaceous experiments due to increasing $CO_2$, we focus on the Tibet plateau and similarly set up the sensitivity experiments to the CO2 levels using the Present Day configuration “without Tibet Plateau”. The experiments show the precipitation in the Asia decreases with increasing atmospheric $CO_2$ concentrations, which is comparable with Late Cretaceous experiments. These results indicate that local water cycle change due to increasing $CO_2$ is strongly dependent on the mountains or continental distribution and Tibet plateau is important to determine the basic field and climate change in the Asia to increasing $CO_2$.

**Key words:** Paleoclimate, Cretaceous, MIROC AOCGM, Tibet plateau

**References**

Hasegawa, H., R., Tada, X., Jiang, Y., Suganuma1, S., Imsamut, P., Charusiri, N., Ichinnorov, and Khand, Y. (2012) Drastic shrinking of the Hadley circulation during the mid-Cretaceous Supergreenhouse. Clim. Past, **8**, 1323-1337, doi:10.5194/cp-8-1323-2012

# Role of seasonal climate-vegetation feedback in the northern high latitude climate changes driven by obliquity and precession-eccentricity forcing

Kanon Kino*[1], Ayako Abe-Ouchi[12], Ryouta O'ishi[1], Fuyuki Saito[3], and Masakazu Yoshimori[1]

1 Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan
2 National Institute of Polar Research, Tachikawa, Japan
3 Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan
*Correspondence to: kanon@aori.u-tokyo.ac.jp

Comprehensive understanding of systematic surface climate responses to the orbital forcing is expected to contribute to further understanding of paleoclimate changes, such as the glacial cycles. In this study, we investigate the surface climate responses to individual changes of obliquity and precession-eccentricity, as the boreal summer insolation increasing, and estimate relative contributions of surface climate feedback processes. Idealized climate simulations using MIROC-GCM coupled to a global dynamical vegetation model (O'ishi and Abe-Ouchi, 2011) are conducted. A surface feedback analysis method, which proposed by Lu and Cai (2009) for an investigation of polar amplification compared to the global warming in the future, is then applied to the results. We reveal that the seasonality of the insolation is important in the northern high latitude, since it crucially effects on duration of each season and strength of climate feedbacks as well. On both land and the Arctic sea, the obliquity forcing, by which insolation increases in summer half of a year, largely amplifies the surface climate feedbacks. On the contrary, the precession-eccentricity forcing, by which insolation increases but in relatively shorter summer season, moderately amplifies the surface climate feedbacks. Vegetation distribution change which accompanied by vegetation-snow-albedo feedback has a decisive contribution on the difference of the amplification on the land. Another point of this study is that strength of winter warming on the Arctic sea is influenced by the duration of the summer season, rather than the intensity, and it is in favor of the obliquity forcing.

**Key words:** Orbital forcing, climate-vegetation feedback, the Arctic warming amplification, MIROC-GCM

**References**

Lu, J., and M. Cai. 2009. "Seasonality of Polar Surface Warming Amplification in Climate Simulations", *Geophysical Research Letters*, doi:10.1029/2009GL040133.

O'ishi, R., and A. Abe-Ouchi. 2011. "Polar Amplification in the Mid-Holocene Derived from Dynamical Vegetation Change with a GCM: Mid-Holocene Warming by Dynamic Vegetation", *Geophysical Research Letters,* doi:10.1029/2011GL048001.