博士論文

Exploring the covariations of cloud and atmospheric circulation on different spatiotemporal scales

異なる時空間規模における雲と大気循環の共変動に関する研究

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Exploring the covariations of cloud and atmospheric circulation on different spatiotemporal scales

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Abstract

Cloud plays a central role in the hydrological cycle and impacts the Earth's radiation budget through active interactions with the atmospheric circulation, crossing various spatiotemporal scales. This study focuses on the cloud variation on both inter-annual and diurnal scales and solved scientific problems by conducting data analysis with state-of-art techniques, as well as developing a new cloud retrieval algorithm with the deep neural network. Main achievements are summarized as below:

First, the cloud response to the poleward shift of the regional Hadley cell is investigated on an inter-annual scale from 1982 to 2016, with a focus on the western North Pacific. The subsiding branch of the Hadley cell tend to move northward and its climatological position around 35˚N is marked by large-scale decreased static stability, an anomalous upward motion, and corresponding increase of the mid-level cloud fraction. By applying a radiative kernel method, the most responsive cloud type to the position change of the Hadley cell subsiding branch is further identified to be the cumulus congestus, whose cloud tops are in the range of 440–680 hPa, and cloud optical depths in the range of 23–60. This increase of the cumulus congestus would lead to a net cooling effect at the top of the atmosphere and induce more precipitation over the east Asia, as in conjunction with the local HC expansion.

Second, extending from the research on inter-annual scale, a case study on the diurnal scale cloud evolution is conducted with the 2015 Super Typhoon Atsani as the object of research. By utilizing the cloud properties that retrieved from the Himawari-8 infrared measurement, high clouds in Atsani are divided into three types: opaque high cloud, cirrostratus, and cirrus, according to their optical thickness values. In the cloud-top-height (CTH) field, two peaks and their corresponding outward-propagation processes are identified within the storm central area. These two processes can be seen as two pulses and they show different features: the main pulse covers a 24-hour period and starts at dawn around 0500–0700 local solar time (LST), while the second pulse lasts for half a day and the maximum distance it can reach is limited to 1000 km from the storm center. When the first CTH pulse ends in opaque high cloud, cirrostratus, and cirrus in the outward radial direction, the cloud fraction and the cloud optical thickness of these three cloud types also reach maximum accordingly.

The cloud properties used in the second study were retrieved by a physics-based model, which cannot output cloud optical thicknesses that larger than ~10, this is a weakness commonly shared by the physics-based algorithms using infrared measurement as input. To overcome this deficiency, we developed a new cloud retrieval model with an image-based deep neural network (DNN). The DNN model was trained with brightness temperature from 4 bands of Himawari-8 as input, and cloud properties from CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO as target for learning. Supplementary variables, including the temperature profile, the geo-location information, and the satellite angles are added to further improve the retrieval accuracy. The DNN model can directly capture and learn from the spatial patterns imprinted on the input image and has been validated to have better performance than the previous neural networks that process image information pixel by

pixel. When comparing to the physics-based models, the DNN has quite comparable accuracy for CTH estimation, and the correlation coefficient of high ice cloud is computed to be 90% overall, when $\tau \geq 0.3$. More importantly, the DNN as an infrared method in nature, it extends the predictable ice-COT to be as large as 200, with the relative biases to be 20% for high ice cloud with $\tau > 1$. Regarding the computation efficiency, it takes only ~20 min to complete one full Himawari-8 disk estimation when using one processor, we thereby expect the DNN model can be realistically applied for real-time cloud monitoring, mesoscale convective-system study, and dynamic models' constraint.

Chen et al. (2019) and previous studies show different rainfall diurnal cycles over the offshore and inland regions of the south China coastal area (SCCA). Inspired by their findings, and to apply the DNN retrieved cloud properties for a case study, we investigate the diurnal evolution features of cloud systems, and the cloud properties inside, for both the SCCA offshore and inland areas. The diurnal rainfall patterns are first reproduced with the Integrated Multi-satellitE Retrievals for GPM (IMERG) data of June 2017, then the rainy days of that time period are selected for the following cloud analysis. It is found that the ice-cloud optical thickness (ICOT) and top height (ICTH) reach their peak intensities at noon ~12 LST (local standard time) over the offshore region, about 2 hours later than the rainfall peak. While over the inland region, the cloud and rainfall peak simultaneously appear from ~18 to 20 LST. When further examining the cloud-amount variation of different ice cloud types, we found the medium-thick cloud amount has a clear diurnal oscillation over the offshore region, while for the inland area, it has no obvious diurnal peak and keeps to be in a low amount throughout the day. This phenomenon suggests different inner-structures and intensities between offshore and inland convections. To better elucidate the features of convections over different regions, a tracking algorithm is applied to obtain the parameters such as size, number, and duration time of mesoscale convective systems (MCS). The strongest convections, that last over 12 hours, tend to be abundant over the offshore region from ~03 to 12 LST, and an inland-to-offshore migration is observed at ~03 LST, as facilitated by the beneficial meteorological conditions during that time around 113 – 116˚E, 20.5 – 22.5˚N.