MALAYSIAN METEOROLOGICAL DEPARTMENT
MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION

# MALAYSIAN METEOROLOGICAL DEPARTMENT (MMD)
# MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION (MOSTI)

**Research Publication No. 4/2017**

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# RESEARCH PUBLICATION NO. 4/2017

# INFLUENCE OF WINTER MONSOON ON CLOUD THERMODYNAMIC PHASE OVER CENTRAL AND SOUTH-EAST ASIA

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Perpustakaan Negara Malaysia Cataloguing in Publication Data

Published and printed by

Malaysian Meteorological Department
Jalan Sultan
46667 PETALING JAYA
Selangor Darul Ehsan
Malaysia

## Abstract

Ice crystal number concentration (Ni) is known as a key factor for the calculation of cloud radiative forcing (CRF). A large variability of Ni at specific temperature in previous observations indicated that Ni might be perturbed due to thermodynamical, dynamical and aerosol factors. Here, we investigated anomalously low supercooled cloud fraction (SCF; Ni relative to the total concentration) at -20°C isotherm during Asian Winter Monsoon (November to March) by analyzing the vertical profile of cloud thermodynamic phase from Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP). The focused areas are over Central Asia (Tibet, 31°N - 45°N, 75°E - 105°E) and South-East Asia (SEA, 10°S - 20°N, 95°E - 130°E) since these regions showed significantly low (SCF) values; 20 % lower SCF over Tibet and 18 % lower SCF over SEA compared to the global 3- year average. Thus the Winter Monsoon provides important dynamical constraint that manipulates the cloud microphysical processes for each region. Over Tibet, the Winter Monsoon supplies more ice nuclei (IN) by forcing dust aerosols together with snow particles to the higher levels. Over SEA, the deep convective cloud structure plays important role in the changes of cloud thermodynamic phases. Recognizing the WM is the most energetic phenomenon in our atmosphere, it distributes energy to enhance the atmospheric synoptic conditions such as deepening the low and high pressure systems, strengthening the winds, intensifying the rising motion, and enhancing the distribution of the atmospheric moisture and aerosols. The present study implies that the Winter Monsoon would serve to warm the surface by decreasing SCF, and therefore cloud albedo.

## 1. Introduction

Fundamentally, it is well known that clouds play an important role in the dynamical, hydrological, and radiation cycle of our climate system (Wielicki et al., 1996; Arakawa 2004; Fan et al., 2013). Changing the cloud structures and compositions may alter these cycles, either increasing or decreasing the magnitudes of the atmospheric components. Previous studies stated that ice crystal number concentration ($N_i$) is an important parameter for studying climate change and the general circulation of the atmosphere (Donner et al., 1997; Ghan et al., 1997). Gultepe et al. (2001) showed how the $N_i$ has strong influences on the calculation of cloud optical and microphysical parameters and indirectly affecting the heat and moisture budget of the atmosphere. Ghan et al. (1997) showed that one order of magnitude changes in ice crystal concentration ($N_i$=100 to 1000 $m^{-3}$) resulted in 70% change in net radiative forcing (NRF). With the same goal, Choi et al. (2010) presented the 20% decrease in liquid water path (i.e., 20% increase in ice water path) of the -20°C cold cloud resulting in the changes of about 10-20 $Wm^{-2}$ of local CRF. Most of the earlier studies have mentioned how important it was to estimate $N_i$ correctly in order to understand the radiative budget of the earth's atmosphere. It's has been emphasized previously, the $N_i$ is an important parameter for studying climate change and the general circulation of the atmosphere since it may affect precipitation amount, radiative fluxes, and heat and moisture budget of the earth's atmosphere (Donner et al., 1997; Ghan et al., 1997).

We are focusing on cold cloud at -20°C isotherm level where most of the previous cloud chamber experiments showed that the ice- and liquid-cloud fractions are nearly equal. In the global data average, the cold cloud consists approximately 43% of supercooled cloud fraction (SCF; the ratio of $N_i$ to the total concentration) and 57% of ice cloud fraction.

Without being affected by any other factors, temperature and supersaturation ratio with respect to ice are the two parameters which determine ice nucleation (Lopez and Avila, 2013). In general, the homogeneous freezing of supercooled droplets occurs at temperature nearly

-38°C (Pruppacher and Klett, 1997). Since the temperature is very low for ice nucleation to occur homogeneously in the lower atmosphere, any changes of SCF compared with the approximately 43% average in this isotherm level can give a suspicion thought. Choi et al. (2010) presented that smaller SCF values (<30%) are dominant in Asia and South America, while higher SCF values (>70%) are dominant in the high latitudes (60-90°). As shown in their observational study, a large variability in $N_i$ (or SCF) for a specific temperature indicated that $N_i$ (or SCF) might get perturbation from thermodynamical, dynamical and aerosol factors (DeMott et al., 1994).

Recently, there have been large numbers of field studies on how aerosol particles affect the cloud thermodynamic phase and radiation balance (Demott et al., 2003; Choi et al., 2010; Tan et al., 2013). In 2013, Tan et al. presented the relationship between SCFs at the

-10°C, -15°C, -20°C and -25°C isotherms and several possible aerosol types which have the ability to act as ice nuclei in a global scale. They clarified that dust and polluted dust can globally alter SCFs based on the observations from space. However, there are relatively limited studies focused on dynamical constraint controlling the cloud microphysical processes by altering the cloud structures and atmospheric conditions (Rosenfeld et al., 2013). Fan et al., (2013) showed the cooling and warming effect at the surface and top of atmosphere (TOA) due to deep convective clouds (DCCs). They noticed that cloud top height (CTH), cloud thickness and microphysical properties are important properties of DCCs that influence their radiation effects. For that reason, investigating dynamical constraint on the microphysical processes is essential for better understanding how it controls the cloud microphysics and disturbs the natural relationship between $N_i$ and temperature in specific region.

In this study, we discovered that the WM is the largest heat source and transport system in our atmosphere. The monsoons begin due to the cooling from two mainland sources (Siberia deserts for WM, and Australia deserts for Summer Monsoon). Based on Chang et al (1979) study, the northern Winter Monsoon is one of the most energetic convective systems of the atmosphere. It produces a strong north-south heating gradient between Asia land mass and equatorial maritime continent region. This brings heavy convective precipitation and the associated latent heat release into the near equatorial latitudes. We believe that WM is the backbone component that manipulates the microphysics processes by changing the cloud structures and atmospheric synoptic background conditions over Tibet and SEA. The WM is characterized by atmospheric synoptic background conditions such as development of the low and high pressure systems, strengthening of the winds, intensifying the rising motion, sufficient atmospheric water content and transporting of aerosols to higher levels. The beginning of WM strongly correspondences to a high pressure system that develops over the Siberian and northern China. Air mass propagates from the Siberian cold region to the warm tropical region due to a strong baroclinic zone (Lim and Chang, 1981). The interaction between the propagation of air mass reaching the Asia continent and the convective disturbances in the near equator region has been described by Chang et al. (1979, 1980, and 1981). They identified that the divergent outflow from cold surge (anticyclone) moved toward the equatorial convergence convective zone as there is a quasi-stationary low pressure system (cyclonic center). The low pressure system near equator develops very intensely and organizes the formation of convective clouds over SEA.

Recent observational studies by Rosenfeld et al. (2013) proved that the vertical distance from the cloud based to the freezing level can influence the cloud microphysics by ice multiplication process in convective maritime tropical clouds. They documented the in situ aircraft measurements over Florida, Thailand and northeastern South Africa. They mentioned that pristine air mass with very low concentration of cloud condensation nuclei (CCN) and IN provides the ideal conditions for the formation of larger cloud droplets such as supercooled drizzle. Furthermore, they fixed $12ms^{-1}$ as a reference updraft speed above the 0°C isotherm, so if the updraft is less than the reference speed, there is a possibility of ice multiplication in progress. However, if the updraft is larger than $12ms^{-1}$ they assumed all the raindrops are lifted upward. These explain that some of the unique microphysical factors have been controlled by updraft which links to the dynamical factor.

Here, we present how the WM plays a role as a dynamical factor and alter the liquid and ice cloud fraction of cold cloud over Tibet and SEA region. Besides, we also enquire if the changing of the SCF at specific temperature will give the different impact to the Earth's radiation balance.

## 2. Materials and Methods

### 2.1 CALIOP ratify the SCFs in cold clouds

A new approach in cloud thermodynamic studies based on satellite observation has been achieved with the presence of Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite. With the payload consisting nadir-viewing polarization lidar sensor known as CALIOP, the cloud thermodynamic phase either water, randomly-oriented ice (ROI), or horizontally-oriented ice (HOI) and six different aerosol types can be distinguished. Note that CALIOP off-nadir-viewing angle was upgraded from 0.3° to 3° in November 2007 to reduce the difficulties in differentiating between water and horizontally oriented particles which are also nearly non-depolarizing, even with multiple scattering [Winker et al., 2009; Hu et al.,2009 and Tan et al., 2014]. This dataset allows fundamental advance in our understanding of the link between clouds, aerosols and radiation that predicting future climate change. The CALIOP is unique among the satellites because it gives the information on the vertical distributions of aerosols and clouds, cloud ice/water phase (via the ratio signals in two orthogonal polarization channels), and a qualitative classification of aerosol size (via the wavelength dependence of the backscatter) [Winker et al., 2003].

We analyzed 60°E to 180°E of longitudes and 15°S to 45°N of latitudes of the CALIOP level 2 Vertical Feature Mask (VFM) product Version 3.01 with data from 1 April 2008 till 31 March 2011 to examine the relationship between SCF and the WM. We categorized these datasets in three periods as follows: i) WM average for 1 November 2008 till 31 March 2009, 1 November 2009 till 31 March 2010, and 1 November 2010 till 31 March 2011, ii) Average of 36 months from 1 April 2008 till 31 March 2011, and iii) An anomaly was calculated by the difference between WM data point and the averages of 36 months, i.e., anomaly = WM – average (36 months). The CALIOP level 2 VFM data has been produced after getting through three processes, which are identifying layer boundaries within a single lidar profile, discriminating between cloud layers and aerosol, and then matching between the retrieval algorithm(s) and each major class of data products [Vaughan et al., 2004].

The cloud thermodynamic phase (water or ice) is identified based on temperature, height, and the depolarization of backscattered light measured by CALIOP [Hu et al., 2009]. It assumes that backscattered light from ice crystal is depolarized while water drops are spherical, resulting in minimal depolarization [Hu et al., 2009]. In this study, we analyzed the data from 2008, after which the data become free from the doubts in identified between water cloud and HOI. Our focus here is on cold cloud composition at -20°C isotherm level since at this level, the global average value of SCF in the total cloud population is found to be about 43% in the data period and the present smaller SCF value is dominant in Asia. Calculating SCFs based on the number of liquid-phase footprints to the number of the total (liquid- and ice-phase) footprints in a 10°×10° latitude longitude grid has been described by [Choi et al., 2010]. Here, ice-phase includes HOI and ROI, eventually SCF = liquid/ (liquid+ (HOI+ROI)). SCFs were calculated only in 10° latitudes by 10° longitude grid boxes where the total numbers of liquid and ice footprints were ≥30.

The co-existence of aerosols and clouds in the same atmospheric give a big challenge to CALIOP as CALIOP may misclassify between aerosols and clouds, i.e.; optically thin cirrus can be identified as aerosols and optically thick dust particles can be identified as clouds (H.Yu, Z. Zhang, 2013). However, we believe this limitation undergoing continuous improvement by CALIOP scientist team. To ensure that CALIOP do not misclassify the snow cover over Tibetan Plateau we verified the VFM images when CALIOP passed over Tibetan Plateau (33°N, 88°E) on 1st January 2009. Presumably there should be a lot of snow covered the Tibetan Plateau surface within these periods. Figure 1(a) showed the CALIOP can distinguish well between cloud and snow covered surface. Figure 1(b) showed pretty clear the CALIOP only count the liquid- and ice- phase in cloud. Besides, from the Figure 1(a), we can see the presence of aerosols over Tibetan Plateau. As mineral dust particles have been well-known to have strong potential to nucleate ice crystal, we are focusing only on dust aerosol. The relative dust frequency has been calculated by the ratio of the number of dust footprints to the total measured footprints in the same grid when a number of samples were sufficient ($\geq$30). Total measured footprint includes the cloud thermodynamic phase and six different aerosol types as explained by Choi et al., [2010].

### 2.2 Clouds information and atmospheric synoptic background conditions

For the clouds information and atmospheric condition, such as CTT and atmospheric water vapor (IR Retrieval) within 700 to 300 mb, we used Level-3 Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 5.1 from the Terra satellite (at atmosphere Monthly Global 1°×1° Products). MODIS cloud top pressure (CTP) is determined using radiances measured in spectral bands located within the broad 15 μm $CO_2$ absorption region. The $CO_2$ slicing technique is based on the assumption of the atmosphere becoming more opaque due to $CO_2$ absorption as the wavelength increases from 13.3 to 15 μm. The bands located closer to the center of the $CO_2$ band at 15 μm are sensitive to high clouds only, while the band away from the $CO_2$ band center are sensitive to the presence of midlevel clouds. The four channels in the $CO_2$ absorption band (channel 33 at 13.34, channel 34 at 13.64, channel

35 at 13.94, and 36 at 14.24 µm) are used to differentiate cloud latitudes. The CTT is derived from the MODIS cloud pressure through the gridded meteorological products that provide temperature profiles at 25 hPa intervals from 1000-900 hPa, 50 hPa intervals from 900-100 hPa, and at 70, 50, 30, 20, and 10 hPa every 6hour (King et al., 2013).

The MODIS moisture profile is produced at 20 vertical levels. A clear-sky synthetic regression retrieval algorithm is used, where regression coefficients are derived by using a fast radiative transfer model with atmospheric characteristics taken from a dataset of global (radiosonde and model) profiles. The MODIS atmospheric water-vapor product is an estimate of the total column water vapor made from integrated MODIS infrared retrievals of atmospheric moisture profiles in clear scenes. This class of techniques uses the difference in water-vapor absorption that exists between channel 31 (11 µm) and channel 32 (12 µm). Data validation will be conducted by comparing results to in situ radiosonde, Microwave Radiometer and GPS measurements, GOES sounder operational retrievals, NCEP analyses, and retrievals from the AIRS/AMSU-A/HSB instrument package on the Aqua platform. Quality control will consist of manual and automatic inspections, with regional and global mean temperatures at 300, 500, and 700 hPa monitored weekly, along with 700 hPa dew-point temperatures and atmospheric water vapor.

For pressure vertical velocity at 500 hPa and mean winds at 1000 hPa and 850 hPa, we used the reanalysis data from Japanese 25-years Reanalysis data (JRA-25). These dataset was completed using the Japan Meteorological Agency (JMA) numerical assimilation and forecast system (Onogi et al., 2007). We use Convective Mean Rain Rate (CMRR) data from the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR), which is the first satellite-borne radar capable of measuring the detailed three-dimensional structure of rain.

Convective precipitation regions are generally identified with intermittently strong vertical velocities (>±1 $ms^{-1}$), high rain rates (> 5 mm $h^{-1}$), and small (~1– 10 km horizontal dimension), intense, horizontally inhomogeneous radar echo (Schumacher and Houze, 2002). Generally, the CMRR ranges from 4.3 to 7.1 mm $h^{-1}$. However, the analyses and visualizations of CMRR used in this study were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC.

## 3. Results and Discussion

### 3.1 Reduction of SCFs in WM

The cold clouds at -20°C isotherm show drastic changes in SCFs over Tibet and SEA during WM within the three-year period. The minimum average value of SCF in WM over Tibet is 10 % while it is 28 % over SEA (Fig. 2(a)). Anomalies showed the reduction of SCFs approaching 20 % over the Tibet region and around 18 % over SEA region (Fig. 2(b)). We calculated anomaly percentages just to highlight the departure of SCF during WM from the average of 36 months. As the SCF values are calculated by the ratio of the number of liquid-phase footprints over the number of the total (liquid- and ice-phase) footprints, the reduction in SCF means increase of ice cloud fraction. A number of observations in natural cloud have shown that over the SEA, the atmosphere is relatively clean compared to Tibet, which is well known as a polluted area with high concentration of dust and polluted dust aerosols. Therefore, we expect that cold clouds over SEA is less affected by aerosol particles that could act as IN. In this study, the microphysical processes are different between Tibet and SEA due to both experienced a different type of aerosols and different atmospheric synoptic background conditions. Each of these atmospheric synoptic conditions has important implications for the microphysical behavior in WM.

### 3.2. The WM controls the Ice Cloud Fraction over Tibet

Considering the reduction of SCF over Tibet highly related to the ice nucleating by dust aerosol. An anomaly of relative dust frequency for the period of 2008– 2011 shows very significant over Tibet and Northern China (Fig. 3). We expected the heterogeneous ice nucleation occur via several possible processes such as immersion, deposition, condensation, or contacts and then alter the cloud thermodynamic phase (Vali, 1985; Pruppacher and Klett, 1977). Previous laboratory studies and in situ measurements have proved that dust aerosol have the ability to nucleate ice crystals at higher level (DeMott et al., 2003; Choi et al., 2010; Tan et al., 2013). Even so, our finding is the reduction of SCFs occurs in the monsoonal periods significantly in WM. For this reason, it is feasible that this reduction not only associated to the microphysical process, but also dynamical process that forced cold air mass together with surface particles to the higher level. Due to the Tibetan plateau is near to Gobi Desert and the topography is very high with average elevation exceeding 4,500 meters and peak in south part reaching 8,850 meter. We believed that the strong cold air mass forced the dust aerosols together with snow particles to the higher level by ascending the elevation of Tibet plateau and obstacle of Himalaya ranges and initiate the formation of ice particle (Chang, Erickson and Lau, 1979). As we will show later in Fig. 7, the analysis of pressure vertical velocity at 500 hPa indicates strong and semi-permanent rising motion over Tibet due to the strong cold air mass hit the obstacles of Himalayan ranges and goes upward (de la Torre et al., 2008).

### 3.3. The WM controls the Clouds Development over SEA

Opposite to Tibet, the reduction of SCF over the SEA region reveals the same spatial correlation with the low values of CTT (Fig. 4). Our results showed the CTT dropped down to minimum -41°C over SEA collocated with the region have high intensity of Convective Mean Rain Rate (CMRR) (Fig. 5). The CTT is commonly used to identify the cloud thickness in cloud atmospheric studies (Mapes and Houze, 1993; Hendon and Woodberry, 1993; Liu et al., 1995; Hong et al., 2005) while CMRR is to justify that SEA experienced the DCCs. Moreover, an anomaly of CTT emphasizes that DCCs over SEA usually occur during winter time implies that DCCs play an important role in the changes of cloud thermodynamic phases in WM. Hence, the changes of cloud thermodynamic phase over SEA related to the time- and temperature-dependents which promotes the formation of ice particles by the expensed of liquid droplets in DCCs (Pruppacher and Klett. 1978; Cober et al., 1996; Gultepe et al., 2001; A.Korolev and G.Isaac, 2001; Yoshida et al., 2010; Rosenfeld et al., 2013). Here, time-dependent refer to the time that liquid droplet passing the vertical distance from cloud base to the freezing level. The in-situ observation by Rosenfeld et al. (2013) provided valuable information on the formation of supercooled drizzle in the convective maritime tropical clouds and layer clouds. They showed that updraft motions over the convective maritime tropical clouds are mostly smaller than the terminal fall velocity of raindrops. This allows the ice multiplication to progress in DCCs (Zipser, 1994; Stith et al., 2002). However, this process only valid in the pristine air mass with low concentration of the CCN and IN. Even though this mechanism may happen in SEA region, but it would be difficult to prove them in any precise manner due to our investigation based on satellite data.

In this present study, our findings show that WM bring the ideal atmospheric conditions to organize the formation of DCCs in pristine air mass (Yano and Phillips, 2011). Our analysis in Figure 8 shows that the atmospheric water vapor (AWV) within 700 to 300 mb over SEA region is larger in WM compare to average months. In the cold clouds where ice particle and supercooled liquid droplet coexist, water vapor diffuses from supercooled liquid droplets to ice particles and ice particles will grow relatively fast to become graupel. Therefore, the sufficient atmospheric water vapor content is the major condition for growth rate of ice particles. Aside from the diffusion of water vapor from supercooled liquid droplet to ice particle, we believed that coalescence, riming and continue with splintering of freezing drops happen in the temperature much lower (J.C.H. van der Hage, 1995). Another important premise here is during WM, the formation of deep, suitable rate of rising motion and semi-permanent convective clouds provide the longer vertical distance from cloud base to freezing level may give more time for coalescence and riming to operate and allow the formation of graupels (Rosenfeld et al., 2013).

Presumably, convective clouds normally associated with the turbulent inside the cloud offer a high possibility for the production of secondary ice particles. Secondary ice production refers to the production of ice particles through processes without initiation by IN. There are several processes have potential to produce new small ice crystal such as rime/splintering process (Hallet and Mossop 1974); droplet shattering (Hobbs and Alkezweeny 1968); and fragmentation of existing ice particles (Brewer and Palmer 1949). Rime/ splintering and droplet shattering refer to a buildup of pressure in the liquid core of freezing droplet, which ultimately explodes and produces a large of new small ice particles. While the fragmentation of the existing ice particles refers break up of delicate ice particles due to collisions with other ice particles. The key conditions for these processes to happen are the growth of cloud droplets with the suitable rising motion in the DCCs. Here, we want to emphasize that WM bring the ideal conditions to manipulates the microphysical processes alter the cloud thermodynamic phase.

## 4. Conclusion and Further Remark

We present new results as to how the WM plays a role as dynamical factor that brings the different atmospheric synoptic background and control the cloud development and thermodynamic phase. Our anomalies results shown reduction of SCFs approaching 20 % and 18 % over Tibet and SEA respectively, highly corresponding to the increasing in ice cloud fraction by ice nucleation and ice multiplication processes. As SCF anomaly is significant low during WM, we claim that this changing have been influenced by the movement of air mass i.e., propagation of the high pressure system over Siberia and Northern China continents. The spatial correlation results of six atmospheric parameters from the MODIS satellite, TRMM and JRA25 reanalysis data agreed well with the CALIOP satellite observations of SCF:

i. The low SCFs at -20°C isotherm were collocated with the low CTT over Tibet and SEA in the WM.

ii. DCCs over SEA was define by the region have significant low in CTT with high intensity of CMRR in a period of WM.

iii. AWV within 700 to 300 hPa over SEA is relatively high in WM is the main condition for growth rate of larger cloud droplets.

iv. Mean Winds at 1000 hPa and 850 hPa illustrate the direction of wind blows from high to low pressure systems and the present of Himalaya ranges restrict the movement of air mass.

v. Both regions show negative values in 500 hPa pressure vertical velocity that give the meaning strong rising motion happen over Tibet bring the surface particles to higher level.

Neglecting the aerosols may affect the increasing in ice cloud fraction over SEA. The basic premise here is the formation of deep, suitable rate of rising motion and semi-permanent convective clouds provide the longer vertical distance might give more time for coalescence and riming to operate. Furthermore, the sufficient atmospheric water content in higher level allows the formation of larger cloud droplets and in turn active the possible mechanism i.e. ice multiplication processes which can produce the secondary ice crystals.

On the other hand, the Summer Monsoon (SM) does not show any significant reduction in SCF and CTT. This is due to SM bring the totally different characteristic to the atmospheric synoptic background conditions. There are several factors might restrict the formation of DCCs and disturb the formation of larger droplet such as hot and dry weather with frequent forest fires. The insufficient atmospheric water vapor was the major factor retarded the growth of cloud droplet and hinders the formation of larger cloud droplets. Since there are shortages of the larger cloud droplet the secondary ice crystals cannot be made. Furthermore, the nonexistent semi-permanent DCCs left less time for coalescence and collection to operate. Apart from this, the high concentrations of particulate matter due to forest fires shown by many previous studies has potential to increases cloud droplet number and suppresses the cloud droplet size, in turn hindering the formation of larger cloud droplets.

Finally, calculation from the radiative transfer model shows that the decreasing of 20% of SCF in cold cloud would significantly reduce cloud optical thickness approximately 25% and local cloud radiative forcing of about 10-20 $Wm^{-2}$ (Choi et al., 2010). It is important to estimate the SCF correctly in order to studying the radiative budget of earth's atmosphere precisely.

## 5. Acknowledgments

CALIOP data are available online at Langley Atmospheric Sciences Data Center website (https://eosweb.larc.nasa.gov/order-data). We acknowledge the MODIS mission scientists and associated NASA personnel for the production of the CTT and Atmospheric Water Vapor dataset used in this research effort. The Pressure Vertical Velocity and Mean Winds dataset are provided from the cooperative research project of the JRA-25 long-term reanalysis by the Japan Meteorological Agency (JMA) and the Central Research Institute of Electric Power Industry (CRIEPI). Analyses and visualizations of Convective Mean Rain Rate used in this paper were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC. The author would like to acknowledge The Malaysia Meteorological Department for provision of $PM_{10}$ data from the Global Atmosphere Watch (GAW) stations over Peninsular Malaysia and Borneo. Author wishes to thank Hye-Ryun Oh and Hye-Sil Kim for their assistance in data handling at the initial stages of research.

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**Figure 1(b)** Ice/Water Phase on 1st January 2009. The CALIOP only count the water- and ice-phase inside cloud

**Figure 2(a)** The SCF on WM for the period of 2008-2011 shows drastically changes over Tibet (latitudes 33°N to 40°N and longitude 88°E to 110°E) and SEA (latitudes 10°S to 20°N and longitude 100°E to 130°E). The minimum percentages of SCF over Tibet is 10.27% while 28.44% over SEA. The white color indicate global average of SCF and red (blue) color indicates higher (lower) SCF at -20°C isotherm cold clouds.

**Figure 2(b)** An anomaly of SCFs for the period of 2008-2011 shows reduction of SCFs approaching 19.52% over the Tibet region and around 17.88% over SEA region. The red (blue) color indicates positive (negative) changing of SCF percentages and white color indicates no changes. Anomaly of 2008 till 2011 was calculated by the different between WM data point and the average of 36months.

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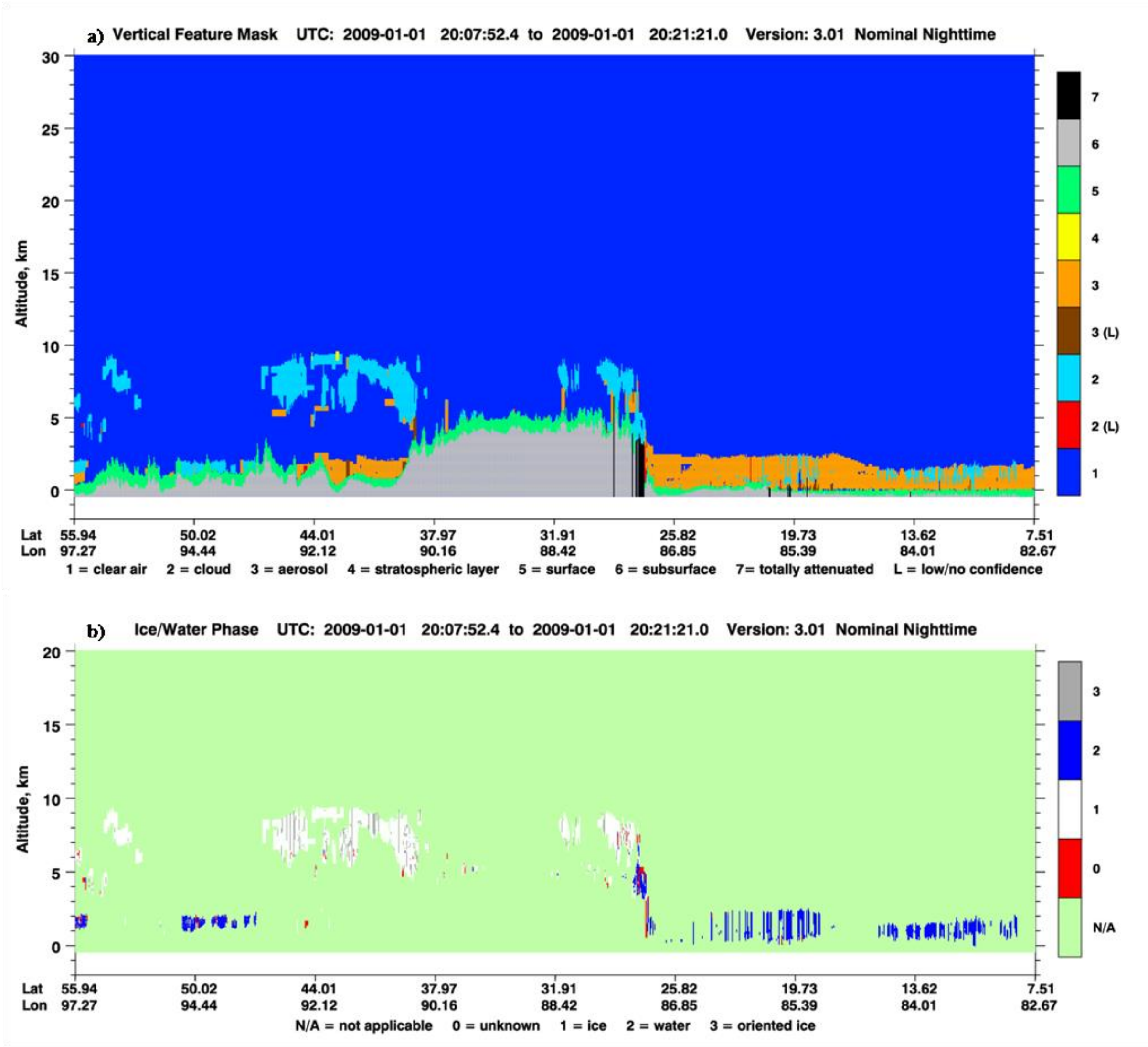


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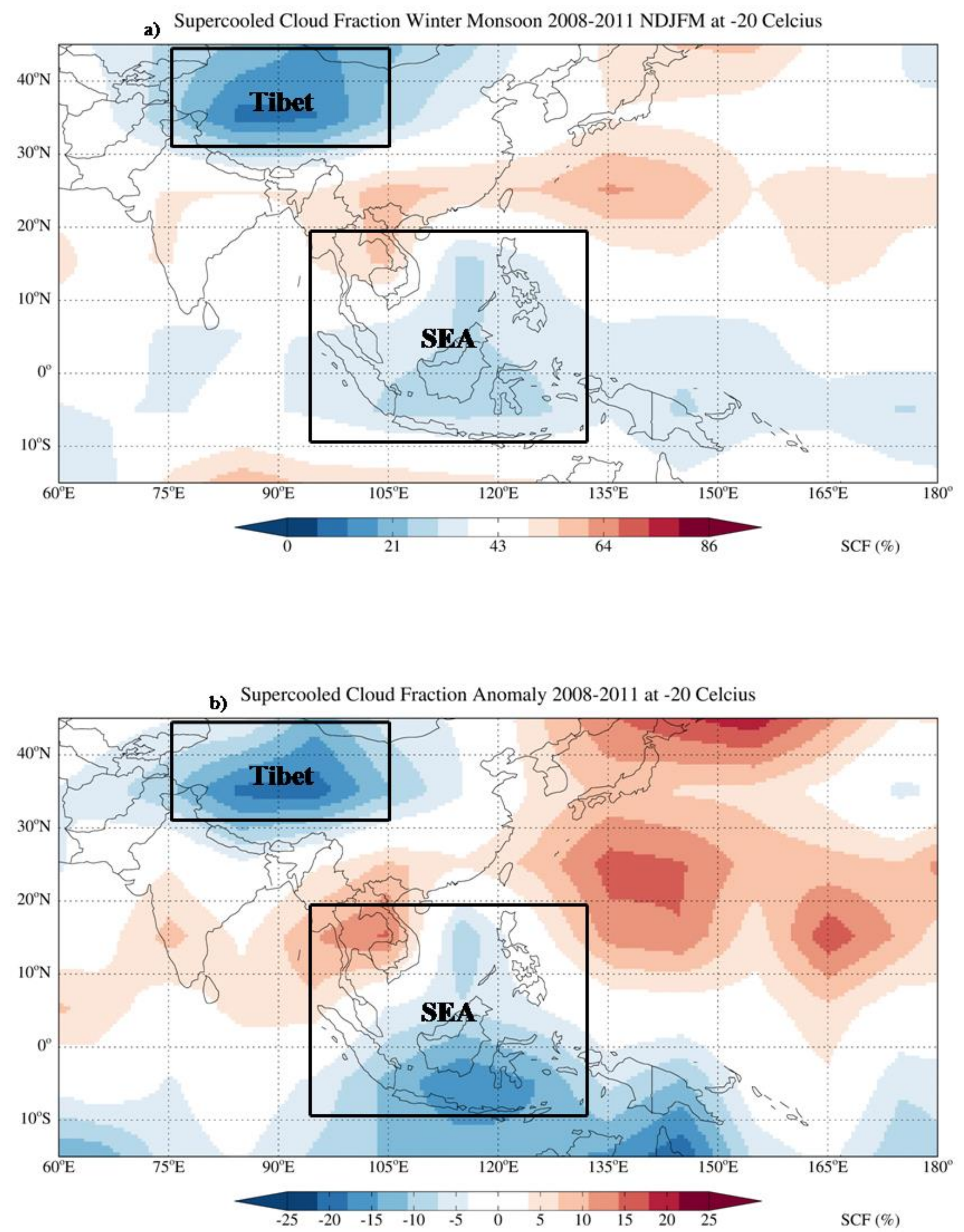


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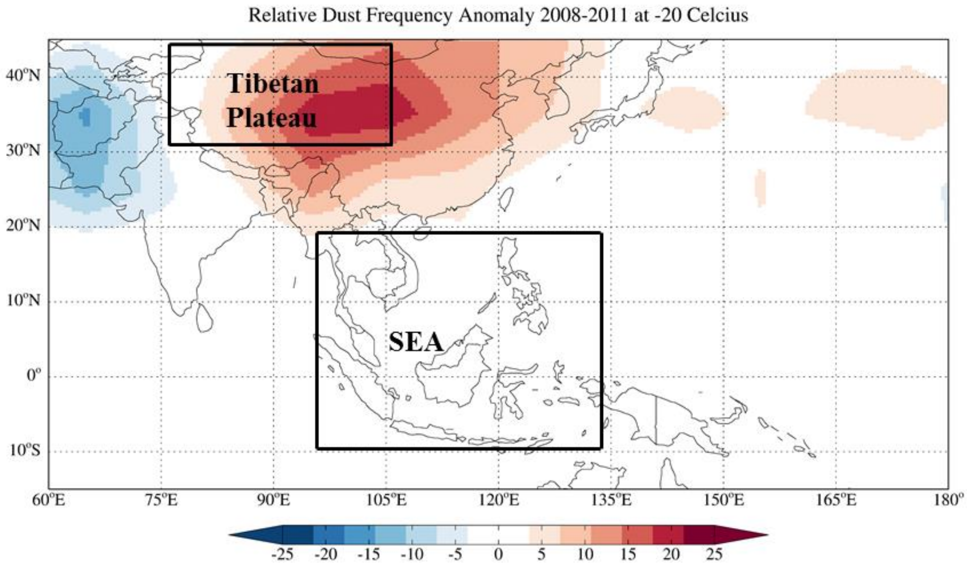


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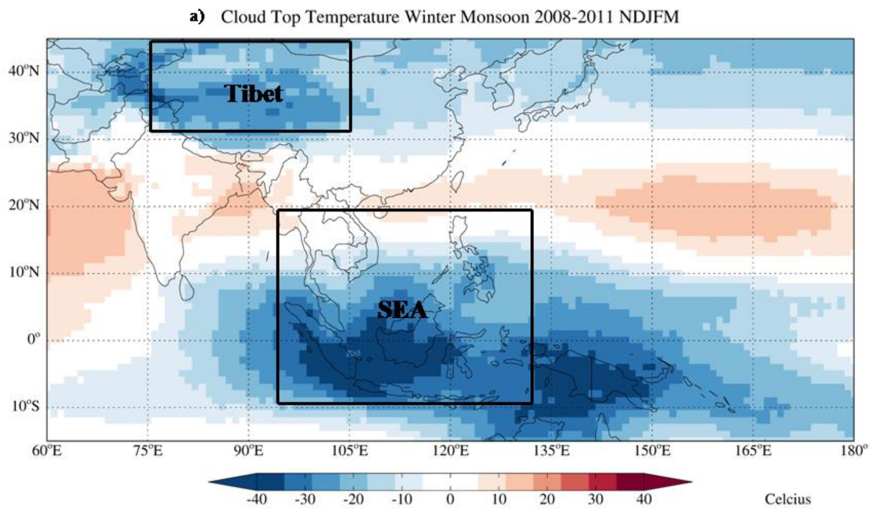


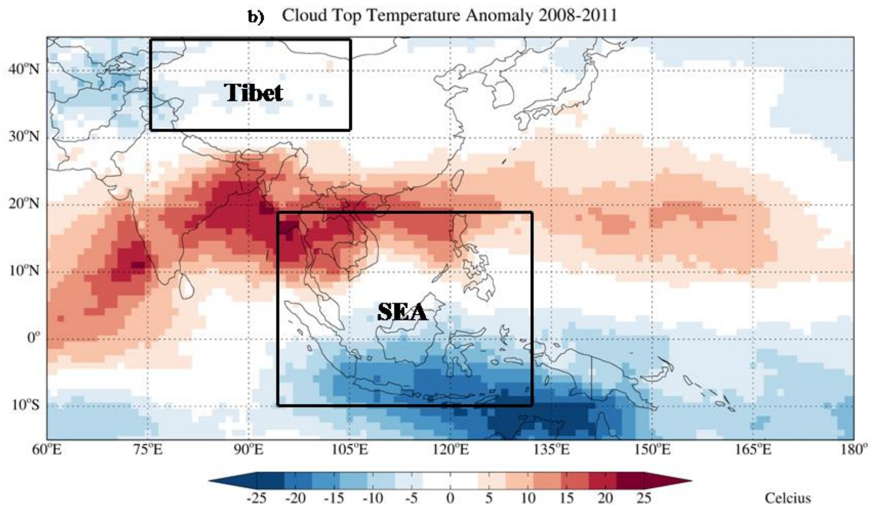


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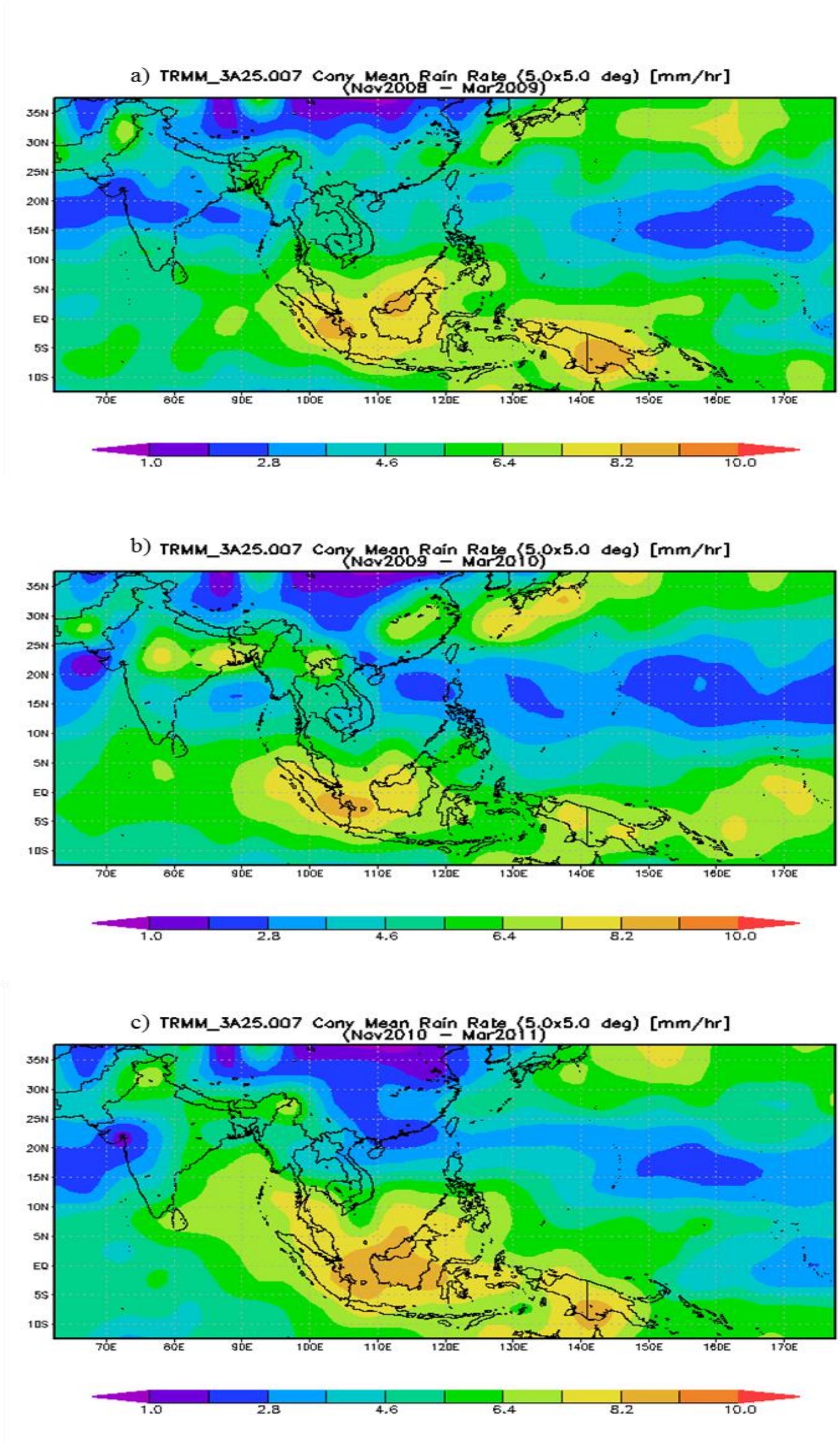


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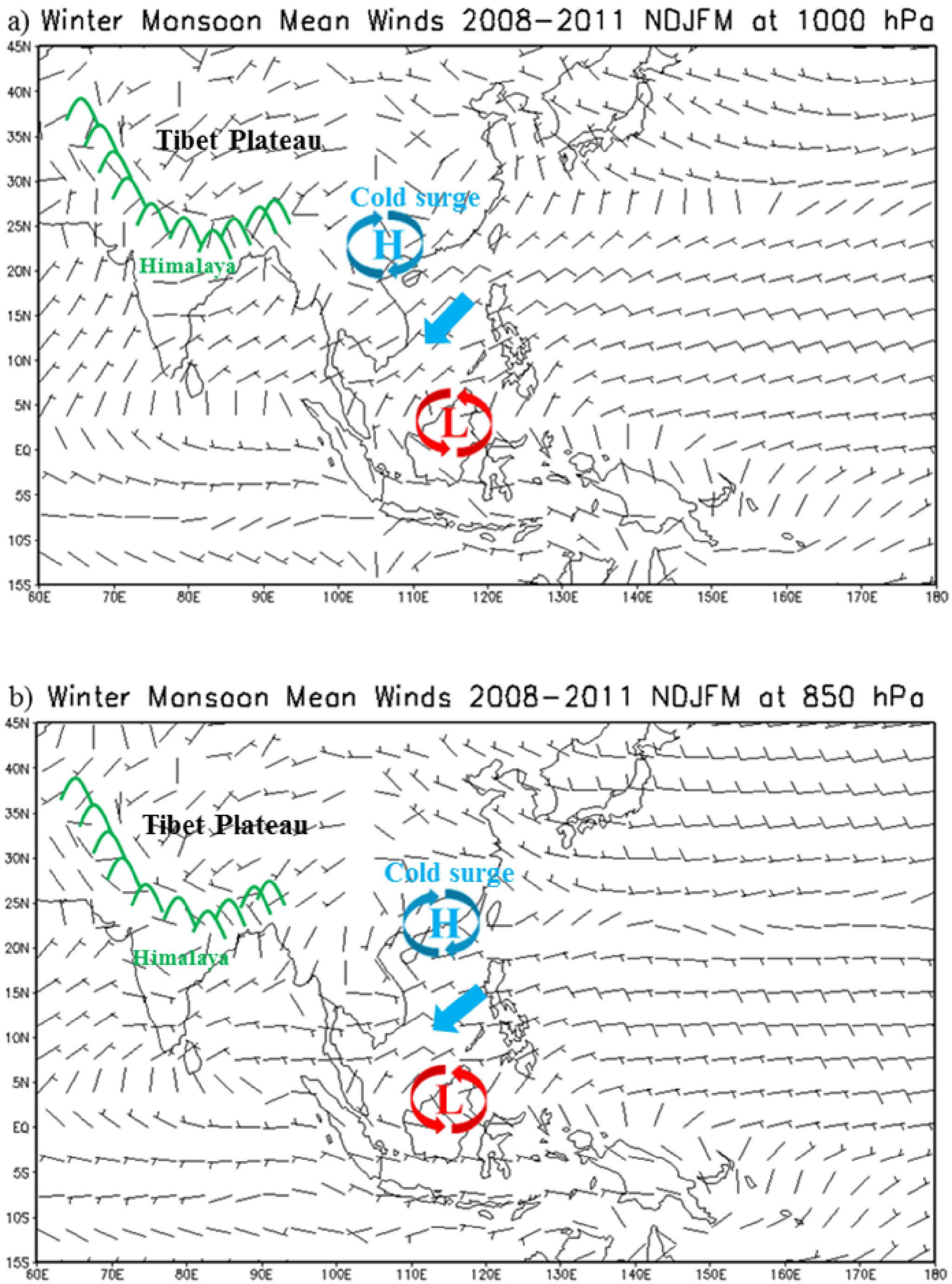


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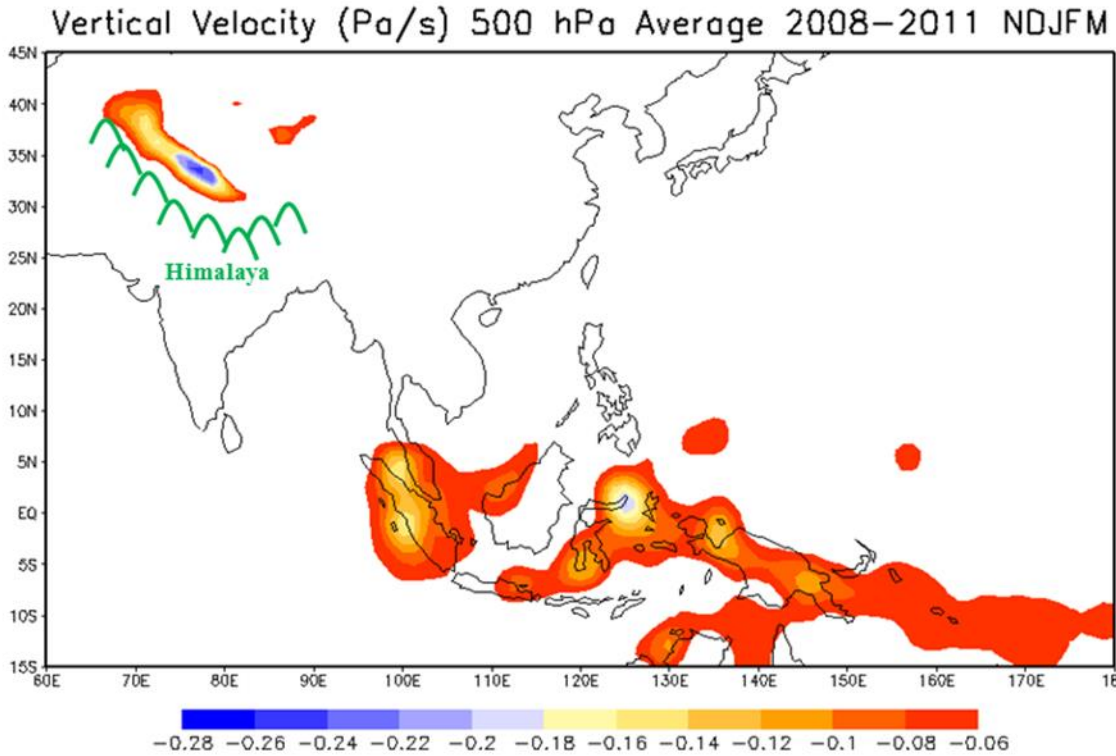


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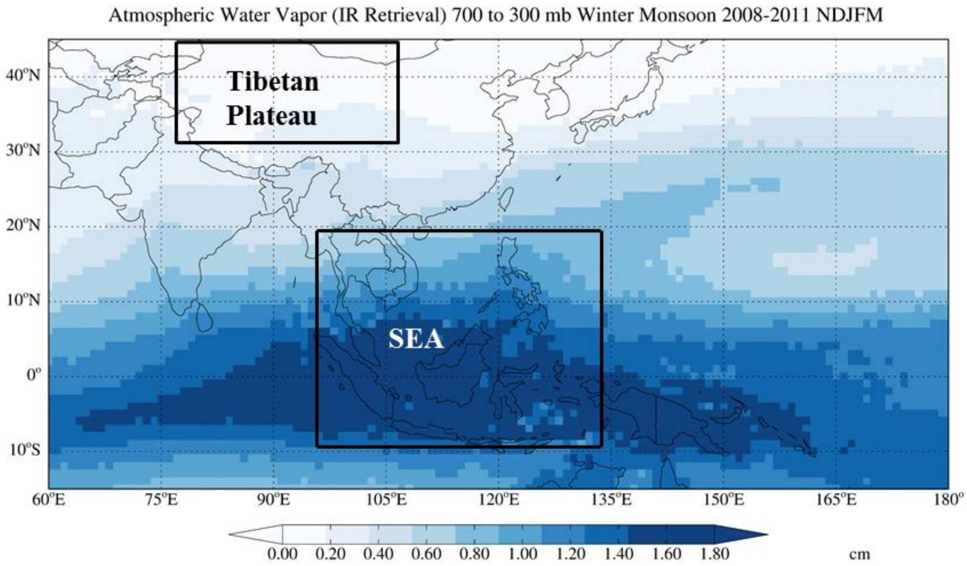


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ISBN 978-967-5676-94-9