Tropical cirrus clouds variation during the southern stratospheric sudden warming in 2006 and 2007

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Abstract

We investigated the tropical cirrus cloud variation during the stratospheric sudden warming (SSW) in October 2006 and September 2007 by using the CALIOP data. The result of our analysis shows that the variation of the cirrus cloud top and the tropopause height (temperature) is positively (negatively) correlated during both SSW events of 2006 and 2007. Averaged tropopause height and cirrus cloud top in the tropics increased by approximately 1 km after the SSWs.
There are, however, important differences between the two events because of the different of background meteorology field, such as QBO, ENSO and Monsoon. In the case of the SSW of October 2006, convectively active and frequent cirrus cloud formation regions are located in both north and south sides of the equator at the beginning and the during the SSW. After the SSW the convection became more active on the equator and at the south side of equator, in particular, in the western Pacific, Africa and South America.
In the case of the SSW in September 2007, the cirrus cloud frequency and the top height increased at the south side of equator. However, the convective activity was not increased in the SH tropics after the onset of SSW. Instead, convective clouds in the northern hemisphere inter tropical convergence zone (ITCZ) became active and the northerly wind across the equator became stronger in the upper troposphere. It is suggested that high frequency cirrus clouds in the tropical region after the SSW is caused by the moisture air from the convection and low temperature due to the Kelvin wave response to a deep convection in the northern tropical region triggered by the SSW.

Introduction

Although cirrus clouds play an important role in climate variation, there is only limited information on cirrus clouds because the detection of the thin cirrus clouds is difficult. Using cloud data from MODerate resolution Imaging Spectroradiometer (MODIS), Eguchi and Kodera [GRL, 2007] found a variation of the tropical cirrus clouds caused by the southern hemisphere (SH) stratospheric sudden warming (SSW) event in September 2002. However, the MODIS data do not provide a vertical profile of the cloud which is important for understanding the involved processes.

In the present study the impact of SSWs of 2006 and 2007 are investigated by making use of the Cloud Aerosol LIdar with Orthogonal Polarization (CALIOP) on board CALIPSO. We chose to study the SH SSW because the background cirrus cloud variation is less important in September-October than January-February due to higher temperature in the tropical tropopause layer (TTL).

The cirrus cloud variation in the tropical tropopause region is closely related with both tropospheric and stratospheric phenomena. In 2006 and 2007, the QBO is westerly and easterly phase, respectively. Also the ENSO is warm for 2006 and cold phase for 2007. Further, the Asian monsoon remained during September 2007.

The aim of this study are to clear the tropical cirrus variation associated with the stratospheric sudden warming under the different background conditions, such as Monsoon, ENSO and QBO.

Analysis data

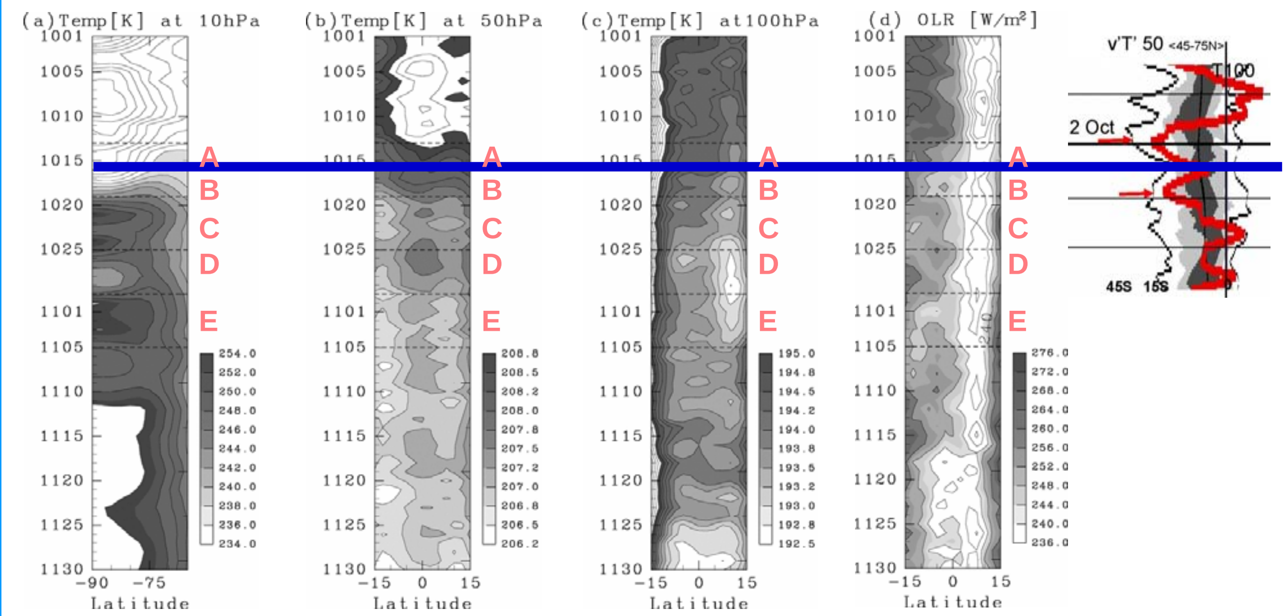
For the accurate clear sky information, we used the satellite lidar data. The lidar is active sensor, and it can detect more thin cirrus clouds and aerosol layers ($\tau > 0.01$) than the passive sensors (e.g. MODIS). **The definition of “clear-sky ratio” is the ratio of the numbers of non-cloud data to data that detected ground and were identified as having good quality (e.g. for CALIOP, Feature finder QC is good. The data ratio with good quality is approximately 99% of the whole data.)**

● **CALIPSO/CALIOP (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation / Cloud-Aerosol Lidar with Orthogonal Polarization) (V201)** [Winker et al., CALIOP ATBD Part.1, 2006]

- Three receiver channels measure 1064 nm backscatter signal and orthogonally polarized components of 532 nm backscatter signals to obtain the heights and optical parameters of clouds and aerosol.
- The laser footprint is about 100 m; data are taken at 20.25 Hz (horizontal resolution is 333m.) ; and the vertical resolution is 30-60 m.
- Period for analysis: 1 October - 30 November, 2006 and 1 September - 31 October, October, 2007.

Results

2006



2007

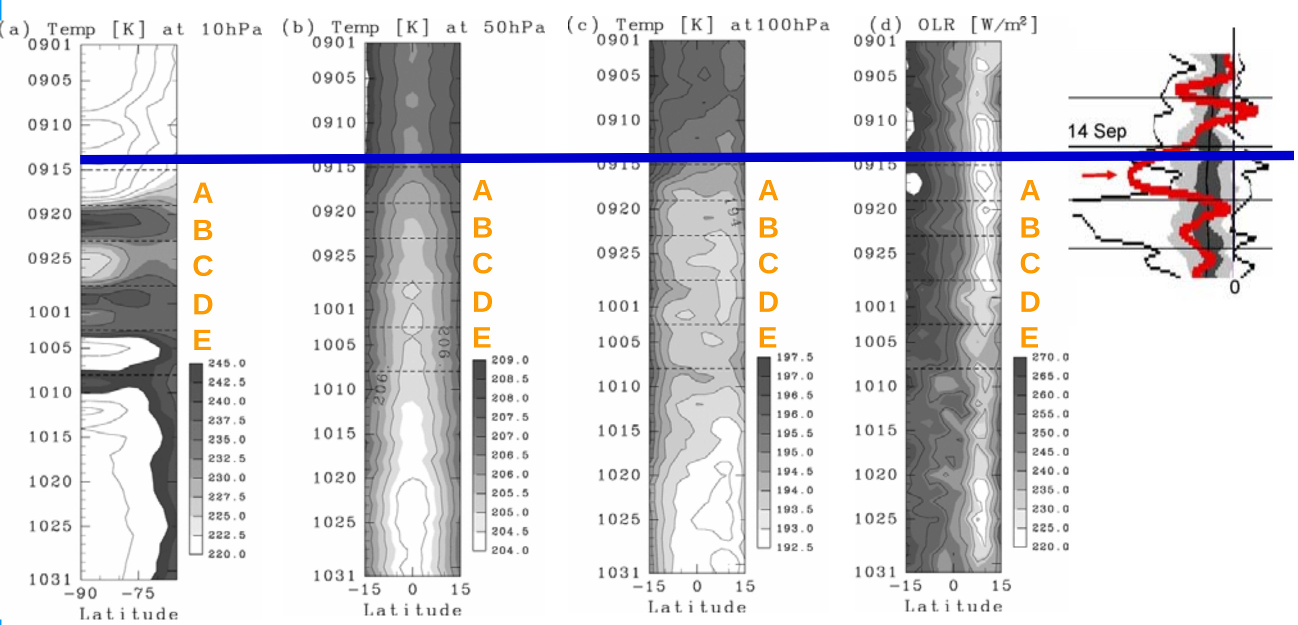


Figure1: <u>(top panels)</u> Latitude-time sections of (a) temperature at 10 hPa in the southern high latitude, (b) temperature at 50hPa in the tropics, (c) temperature at 100 hPa in the tropics and OLR in the tropics. The most right panel shows the wave activity at 50 hPa. The time period is from 1 October to 30 November, 2006. <u>(bottom panels)</u> Same as top panels but for 2007. The time period is from 1 September to 31 October in 2007.

The first SSW was occurred around 20 Oct. 2006 and 20 Sep, 2007, respectively. Before the SSW, the wave activity at 50 hPa was significant variation. With increasing temperature in the southern polar region with being active SSW, the temperature in the tropics at 50 and 100 hPa became low. At 100 hPa, the lower region extended southward with time. It is found that the change of temperature before and after the SSW in 2007 was clearer than that in 2006. From the OLR field, the active convective region in 2006 extended southward, but the convection in 2007 was stable at the north side of equator.

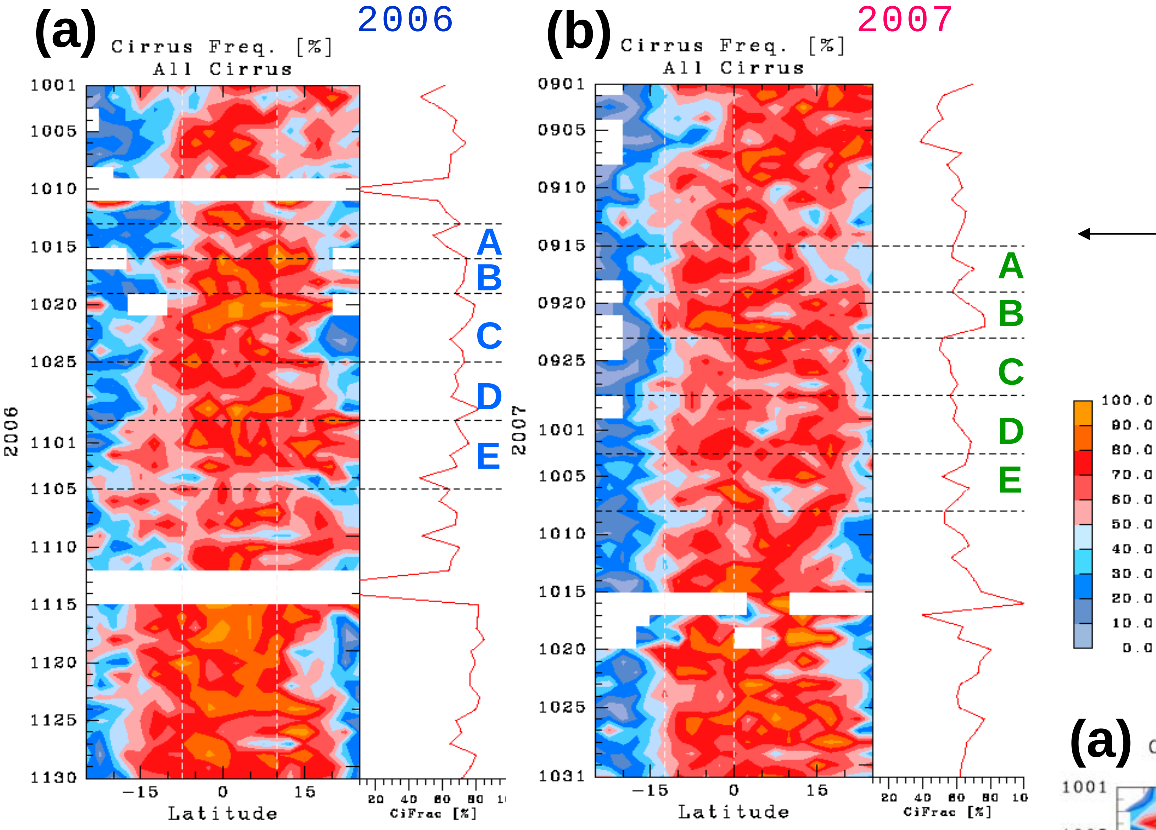
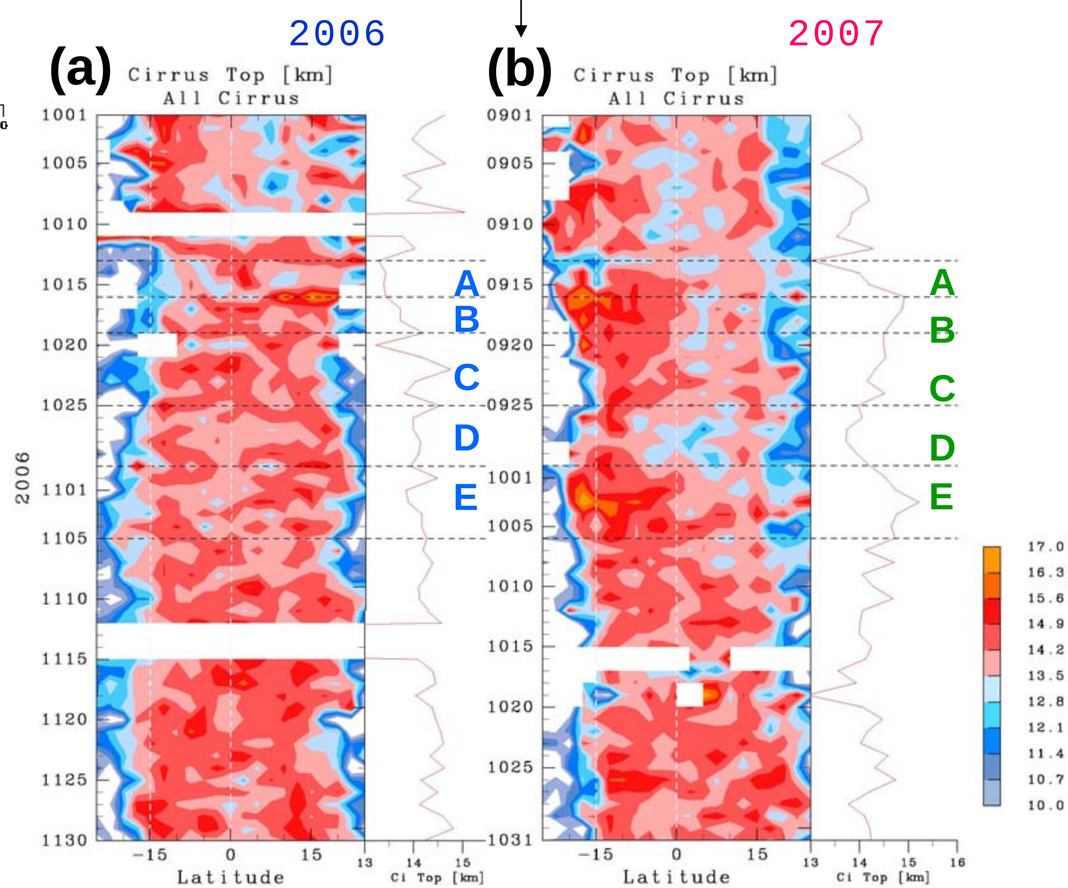


Figure2: (a) Latitude-time sections of cirrus cloud frequency [%] in October and November in 2006 (a) and September and October in 2007 (b). The right panels indicate the temporal variation of cirrus frequency of the latitudinal band between 10S and 10N in 2006, and the latitudinal band between 20S and 5N in 2007.

Figure3: Same as Figure 2 but for the cirrus cloud top altitude [km].



The change of cirrus cloud frequencies both 2006 and 2007 around the onset of SSWs was not dramatically, but the cirrus occurred frequently around the equator in 2006 and at the south side of equator in 2007.
The cirrus top height around the SSW in 2007 became higher especially at the south side of equator. But there characteristics was not seen in the cirrus top field in the period of SSW of2006.

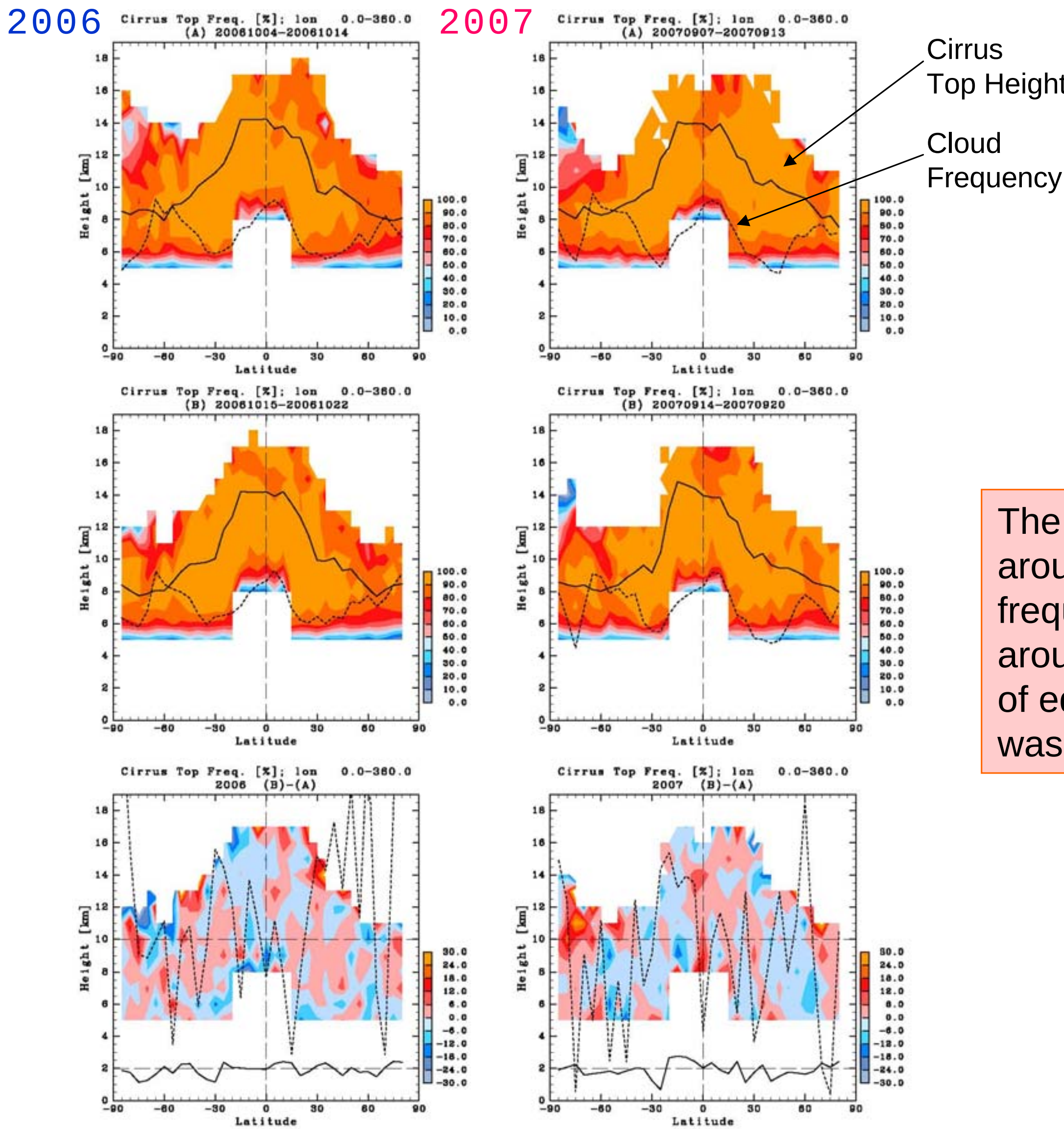


Figure4: Latitude-height section of cirrus cloud frequency [%] (shade), and latitudinal distribution of cirrus cloud top (black solid line) and cloud frequency [%]. Top left and right panels are the average of the period (A) 2006/10/04-10/14 and 2007/09/07-0913 (before Sudden Warming), respectively. Middle panels are the period (B) 2006/10/15-10/22 and 2007/09/14-0920(after Sudden Warming), respectively. Bottom panels are the difference between periods of (A) and (B).

The cirrus cloud frequencies in 2006 and 2007 increased around 15km and 16km, respectively, on the other hand the frequency just below the highest frequency decreased, eg around 14km in 2007. The top height increased at south side of equator at both year, although the high cloud frequency was located at north side of equator.

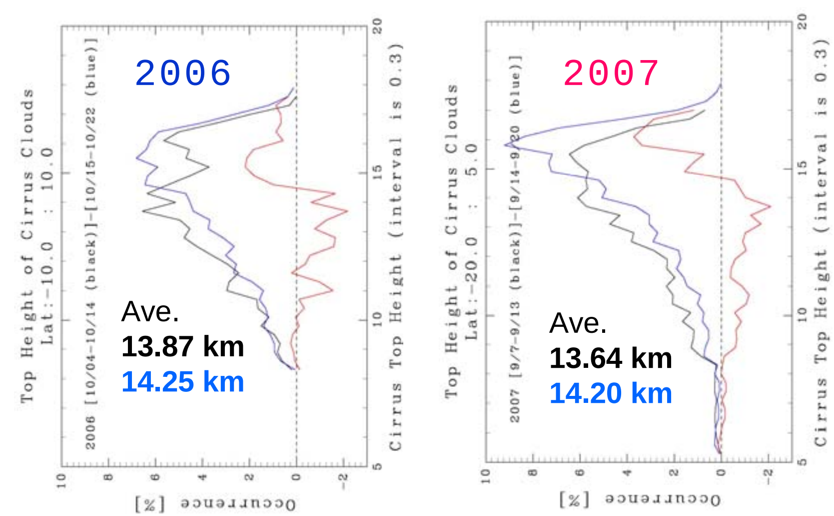


Figure5: Zonal mean of cirrus top frequency and its different between periods (A) and (B) in 2006 (left) and 2007 (right). Black and blue lines are (A) and (B) periods in Figure 4, red line indicates the difference between (A) and (B).

Anomaly of LRT of NCEP

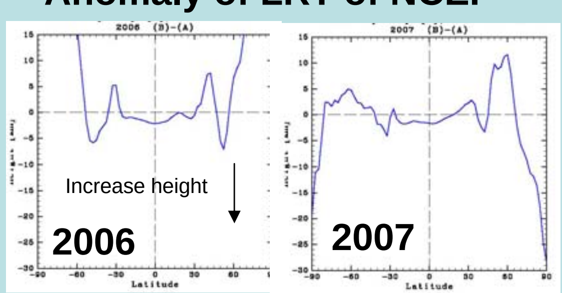


Figure for Reference

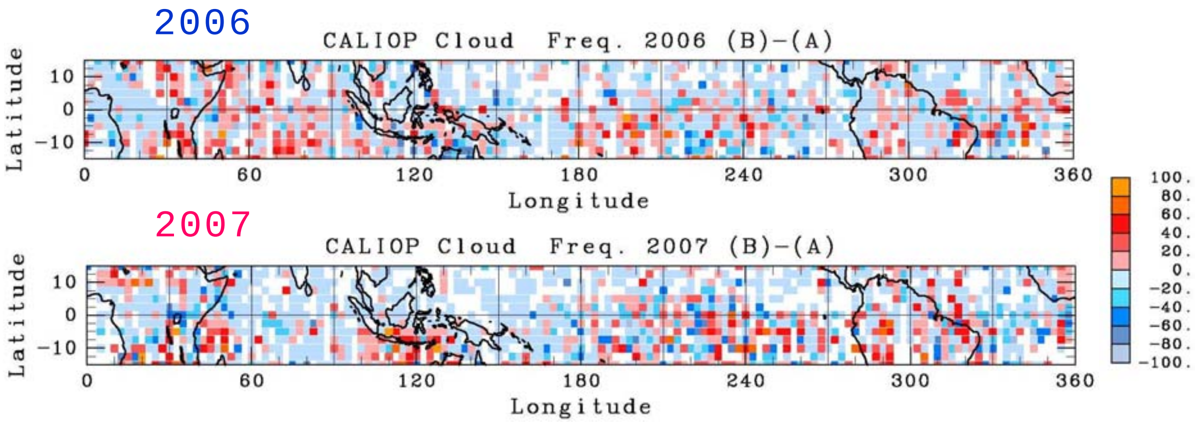


Figure6: Horizontal map of change of cloud frequency between period (A) and (B) in 2006 (top) and 2007 (bottom).

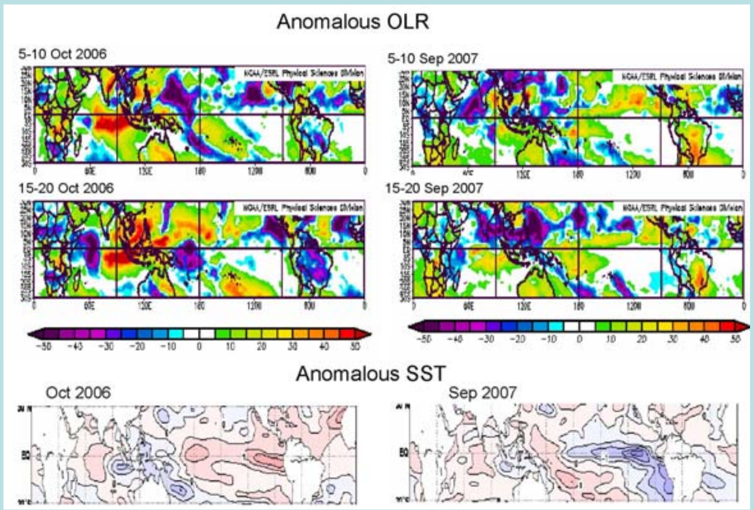


Figure for Reference

As well as the cloud frequency (not shown), the high cirrus frequency region in 2006 was seen in eastern pacific because of warm phase of ENSO. In the field of the change of cirrus frequency before and after the SSW, cirrus clouds occurred over the western Indian ocean and South America in 2006 and marine continental region and South America in 2007.

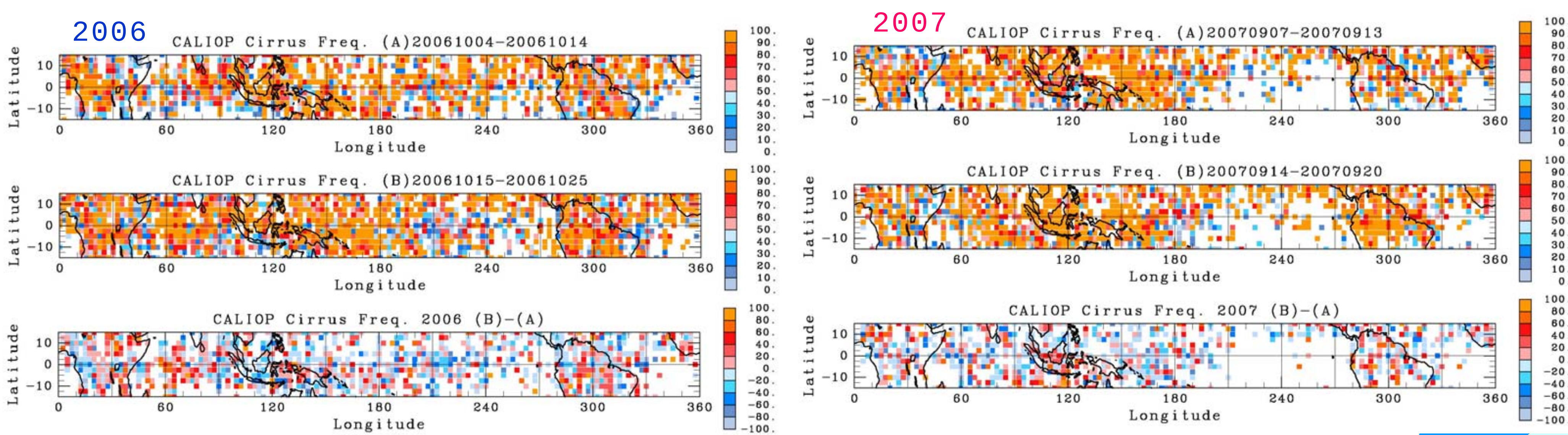
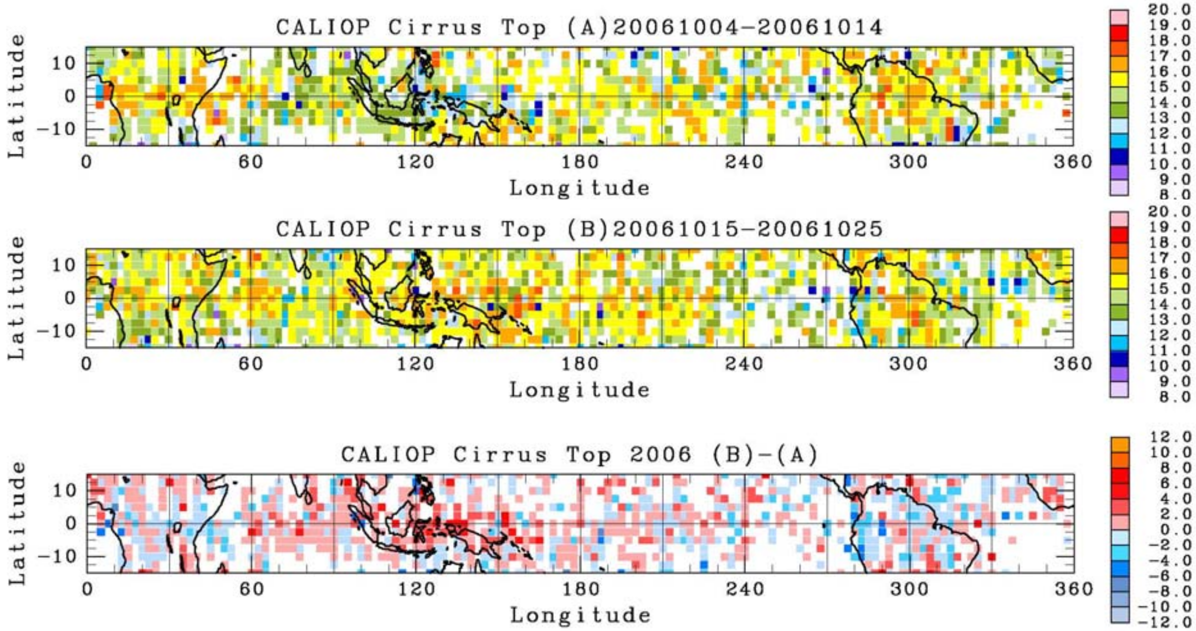


Figure7: Horizontal maps of cirrus cloud frequency period (A) (top) and (B) (middle) and the difference between period (A) and (B) in 2006 (left) and 2007 (right).

2006



As shown in the cloud and cirrus frequencies, the cirrus top height was high in the middle Indian Ocean, the middle and eastern Pacific in 2006, and marine continental region and Africa and South America in 2007 associated with the ENSO. The change associated with the SSW is clearly seen in the cirrus top height field.

2007

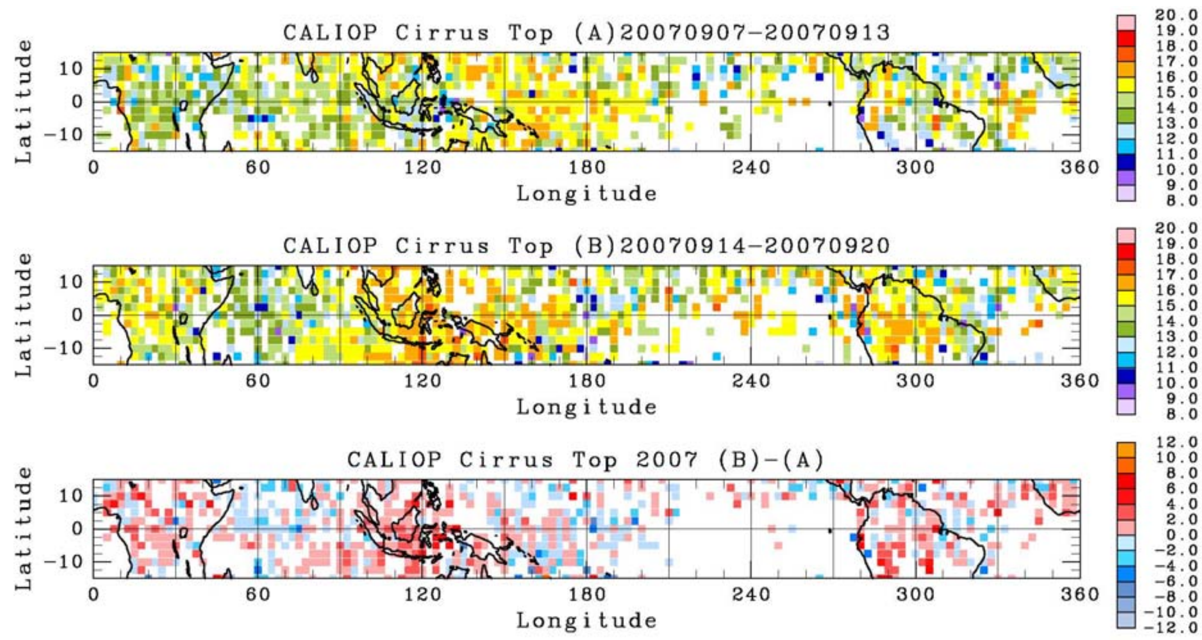


Figure8: Same as Figure 7 but for cirrus top height [km] in 2006 (top three panels) and 2007 (right three panels).

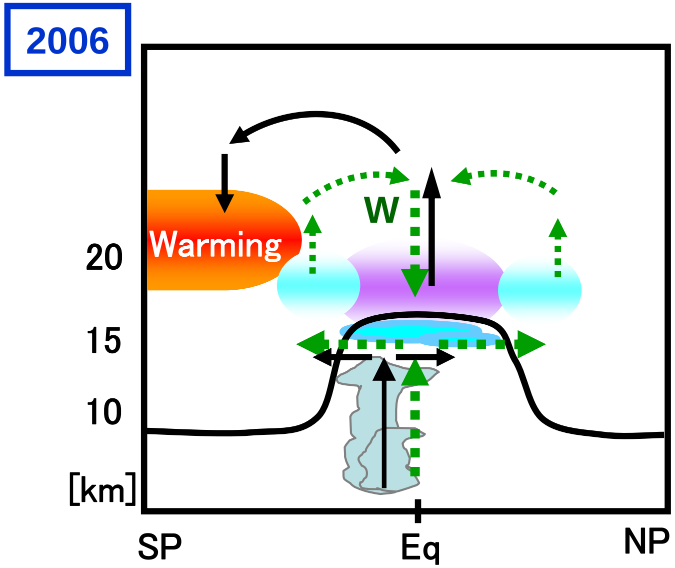
Summary

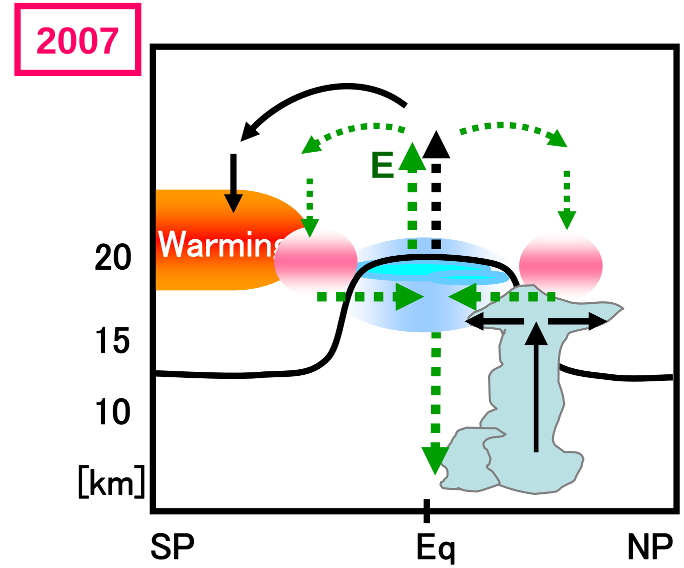
The result of our analysis shows that the variation of the cirrus cloud top and the tropopause height (temperature) is positively (negatively) correlated during both SSW events of 2006 and 2007. Averaged tropopause height and cirrus cloud top in the tropics increased by a few km after the SSWs. Low temperature in the TTL due to the upwelling induced by the SSW led to an increased cirrus formation and a higher cirrus cloud top. The tropopause temperature was lower after the SSW than before with the maximum difference of 10 K.

There are, however, important differences between the two events. In the case of the SSW of October 2006, convectively active and frequent cirrus cloud formation regions are located in both north and south sides of the equator at the beginning and the during the SSW. After the SSW the convection became more active at the south side of equator, in particular, in the western Pacific, Africa and South America. These features are similar to those found during the 2002 SSW. It is noted that not only the frequency but also the top height of cirrus clouds in the tropics increased in the SH after the SSW.

In the case of the SSW in September 2007, the cirrus cloud frequency and the top height increased at the south side of equator. However, the convective activity was not increased in the SH tropics after the onset of SSW. Instead, convective clouds in the northern hemisphere inter tropical convergence zone (ITCZ) became active and the northerly wind across the equator became stronger in the upper troposphere. It is suggested that high frequency cirrus clouds in the tropical region after the SSW is caused by the moisture air from the convection and low temperature due to the Kelvin wave response to a deep convection in the northern tropical region triggered by the SSW. During August-September 2007, convective activity zone was anomalously shifted northward. The difference of the spatial structure of the response to the SSW between 2006 and 2007 events could be attributed to the difference of the distribution of the convective activity in the tropics.

Discussion





Black (green) arrow: SW (QBO) circulation

	October 2006		September 2007	
Cirrus Frequency	High in the tropics after beginning SW		After beginning SW, high frequency region extended south side of equator.	
Cirrus Height	No change signal before and after SW Monthly Ave. LRT 16.32km, Top 14.34km		After beginning SW, top height in the southern tropic increased; Monthly Ave. LRT 15.99km, Top 14.27km	
Impact of Cirrus Formation	Tropopause temperature decreased by SSW and QBO makes convection active←→Tropopause temperature increased by QBO.		SSW and QBO make tropopause temperature low, and height high; QBO and Monsoon translated moist air to tropical region.	
Monsoon	Finished		Active	There are active convection region in the northern subtropics, especially in Asian region.
ENSO	Warm (ElNino)	In middle and eastern Pacific, the convection was active.	Cold (La Nina)	In western Pacific and Asian monsoon region, the convection was active.
QBO	Westerly	Tropical tropopause height decreased and temperature increase; there is a sense that the tropical convection becomes active.	Easterly	Tropical tropopause height increased and temperature decrease; there is a sense that the tropical convection becomes inactive.