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三重大学大学院　生物資源学研究科

修士論文

Why was Arctic Oscillation (AO) amplified and modulated at the end of 20th century?

北極振動の増幅と転調は何故 20 世紀末に生じたか？

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ABSTRACT

The Arctic Oscillation (AO) was amplified and modulated in 1980s'. In previous study show that the AO was formed by propagation of polar vortex from stratosphere to troposphere, in this study we suggest another unknown process how the AO is formed. The fact that the Sea Surface Temperature in mid-latitude was increased at 1980's that lead to strength eastward energy transport from the Atlantic through the stratosphere and furthermore energy was supplied again by the warming Pacific. The jet was strengthened by excited storm track. Consequently, the AO was amplified and modulated.

Contents

1. Introduction

In recent years, we often heard the word “Abnormal weather”. For example in 2005 December, various regions over Japan were hit by heavy snowfall, and over the eastern USA was also hit in winter 2011. These abnormal snowfall conditions were closely related to the Arctic Oscillation (AO) (Park et al. 2011). The AO is one of the most important components of atmospheric circulation in winter over the Northern Hemisphere, as defined by Thompson and Wallace (1998) by performed EOF analysis for monthly mean SLP poleward from 20N. The structure of the AO is annular mode and inversely correlated south and north division at 60N. This pressure anomaly pattern count among the teleconnection pattern, has three significant activity areas where is the Pole, the Pacific and the Atlantic. To understand the relationships of the AO with the global warming, declining sea ice in the Arctic, ocean circulations, solar activity cycle were important, because these may play important roles on the long-term AO variation. However these detailed relationship were not known. It has also been studied for association with the winter climate of Japan. Tanaka (2008) shows that when the AO is negative phase the cold air brings about Japan. According to Thompson and Wallace (2000) there is trend toward an increase in AO index recently. Baldwin and Dunkerton

(2001) confirmed that as one of the formulation mechanisms of AO pattern is propagation of polar vortex from stratosphere to troposphere, and it persist for 60 days. In some cases, the AO formed by the aforementioned mechanism has so tall structure as reached stratosphere. We discovered the AO was amplified and modulated at the end of 20th century. It is possible to know the change atmospheric circulation over the Northern Hemisphere in winter by elucidating the amplified and modulated mechanisms the AO. Behavior of the AO is regarded to reflect the change of strength and route of the jet stream that effects to Japan directly. Therefore the AO is result of some phenomena, but can also cause the AO own weather phenomena. We expect that it is possible to predict more for the abnormal weather of large time scale by elucidating amplified and modulated cause of the AO.

In this paper we would like to discuss another formulation process of the AO and clear why the AO was amplified and modulated at the end of the 20th century.

2. Data and Methods

We used daily and monthly data of large scale atmospheric fields from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis dataset (Kalnay et al. 1996) in this study, to calculate the climatology and anomalies of the meteorological field (i.e., temperature, geopotential height, and wind velocity). Monthly mean sea surface temperature (SST) data are from the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) dataset (Rayner et al., 2003).

We performed an empirical orthogonal function (EOF) analysis for geopotential height field 1000hPa for the area poleward of 20°N from 1958 to 2012 in December.

EOF analysis extract the mode that has orthogonal condition, that is the most distinguished atmospheric pattern be calculated. Calculates a score, objectively determine the amplitude and period at any time in the series. This method is often used for understanding complex events such as weather phenomena.

From EOF analysis, we determined the active center areas for AO, where is the Arctic area, the Pacific area, and the Atlantic area. We calculated pressure anomaly from climatology and made area average index (areal index) for each area from 1958 to 2012

in December. Using areal index, we estimated the period AO was amplified and modulated from results of the correlation coefficient and the standard deviation.

We performed EOF analysis again divided into two period (before period : from 1958 to 1988, after period : from 1989 to 2012). We also calculated regression coefficient of geopotential height field and area index.

Here we assumed that the SST warming is the cause of the amplification and modulation of the AO, comparing the SST field to before and after period.

Furthermore we analyzed about the temperature field and the storm track that indicator of the zonal wave propagation. The storm track is a measure to estimate the area that passes through many extratropical cyclone and mobility anticyclone. The zonal wind is enhanced in the north of the area value of the storm track is large.

We investigated the change in the energy source by calculating the EP-flux.

3. Result

3.1 The Arctic Oscillation was Amplified and Modulated

Figure 1 shows the time series of AO index created in a new way using areal index in December from 1958 to 2012. When the pressure anomaly is low in the Arctic and in the Pacific and the Atlantic is high, index indicates plus value. In a contrasting situation, when the pressure anomaly is high in the Arctic, low in the Pacific and the Atlantic, index indicates minus value. The magunitude of the value refers to the amplitude. 0 value means the AO was not occur the year. The correlation coefficient the AO index and EOF-1 index was 0.8. In 1988 previously, frequency and amplitude of the AO was low, but it both has increased since 1989. To pursue the cause of the amplification of the AO, we performed analysis divided into two period.

Figure 2 shows result of EOF analysis divided into two period in November, December and January. In before period, EOF-1 has not the AO pattern at each three month, rather the NAO (North Atlantic Oscillation) pattern was dominated in January. In after period, EOF-1 pattern in November was not the AO as before. In December and January the AO pattern began to dominate in the Northern Hemisphere. In particular, EOF-1 pattern has annular mode and become high contribution rate at December. We focus on the amplification of the AO in December.

3.2 The Warming of Sea Surface Temperature in Mid-latitudes

We assumed that the SST change in November cause change of atmospheric general circulation in December. Figure 3 shows the SST area significantly increased comparing before and after period in November. The SST has risen on global scale, especially at the Pacific and the Atlantic recently. We guessed that the significant warming of SST in mid-latitude affect the atmosphere.

Figure 4 shows change of the temperature at 850hPa in November. Significant warming area appears in the Eastern Pacific. We found that the warming from the ground up to 400hPa. Although we performed the same analysis even for December, there is no significant area as warming at mid-latitude. The warming SST in November effect on above the temperature field is suggested.

We calculated storm track change using the following formula and show in Figure 5.

$$\overline{v^2} - \bar{v}^2 (\mathrm{m}^2/\mathrm{s}^2)$$

v: daily mean meridional wind

$\bar{v}$: monthly mean meridional wind

Here, line on the character refers to the monthly mean.

In general, the storm track is connected to the Atlantic from center of the Pacific. But in recent, storm track is circling the earth through the stratosphere, and be strengthened at

the Pacific.

Finally we investigated the changes in the jet stream. We prepared zonally-averaged zonal wind index (at 60N, 300hPa) and use it for calculating regression coefficient. Figure 6 description result of regression coefficient of the index and zonally-averaged zonal wind field, result of similar analysis for index and EP-flux (Eliassen-Palm flux). EP-flux is defined following formula.

$$\mathbf{F} = a\cos\varphi\left(-\overline{u'v'}, f\frac{\overline{v'\theta'}}{\theta_p}\right)$$

f： the Coriolis parameter

φ：latitude

θ：the potential temperature

u, v：zonal and meridional wind

The jet stream enhanced in the after period and couple to the stratosphere. In addition when the jet stream is strong, energy propagation occurs from mid-latitude sea through mid-troposphere in after period.

4. Discussion

In this study we discussed from the point of view of mid-latitude SST warming caused to amplification and modulation of the AO at the end of 20th century. The AO is the excellence of since the 1989 winter, especially in December, revealed that it is amplified.

The temperature in November became warmer that means disturbance was likely occur, and strengthening of storm track above the Pacific especially at 200hPa. The jet stream also enhanced by increasing many disturbance and it structure became taller than in before period that changed atmospheric circulation in mid-latitude. This result means that atmospheric variation in the Pacific and the Atlantic became coupled through stratosphere because the energy transport was increased from the Atlantic, reached to the stratosphere, and activated again in the Pacific.

Acknowledgment

I express gratitude to Professor Tachibana, my supervisor. He taught me the basic knowledge of the physics and detailed knowledge of the physical oceanography and the atmospheric dynamics. Additionally, many professors of Geosystem Science, Graduate school of Bioresources, Mie University advised me. I thank that very much.

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List of Figures

Fig.4. The change of temperature at 850 hPa between before period and after period in November. Contours are regression coefficient and shades are significance levels of 90%, 95% and 99% based on t-test.

Fig.5. The change of storm track in before and after period in December. The unit is [m^2/s^2]. The vertical cross-section (a) and the latitude and longitude cross-section (b).

Fig.6. The regression map of the zonal mean wind index and zonal mean zonal wind (contour : regression coefficient, shade : significant level 90%, 95% and 99% based on t-test). The vector is the regression of the zonal mean wind index and EP-flux.

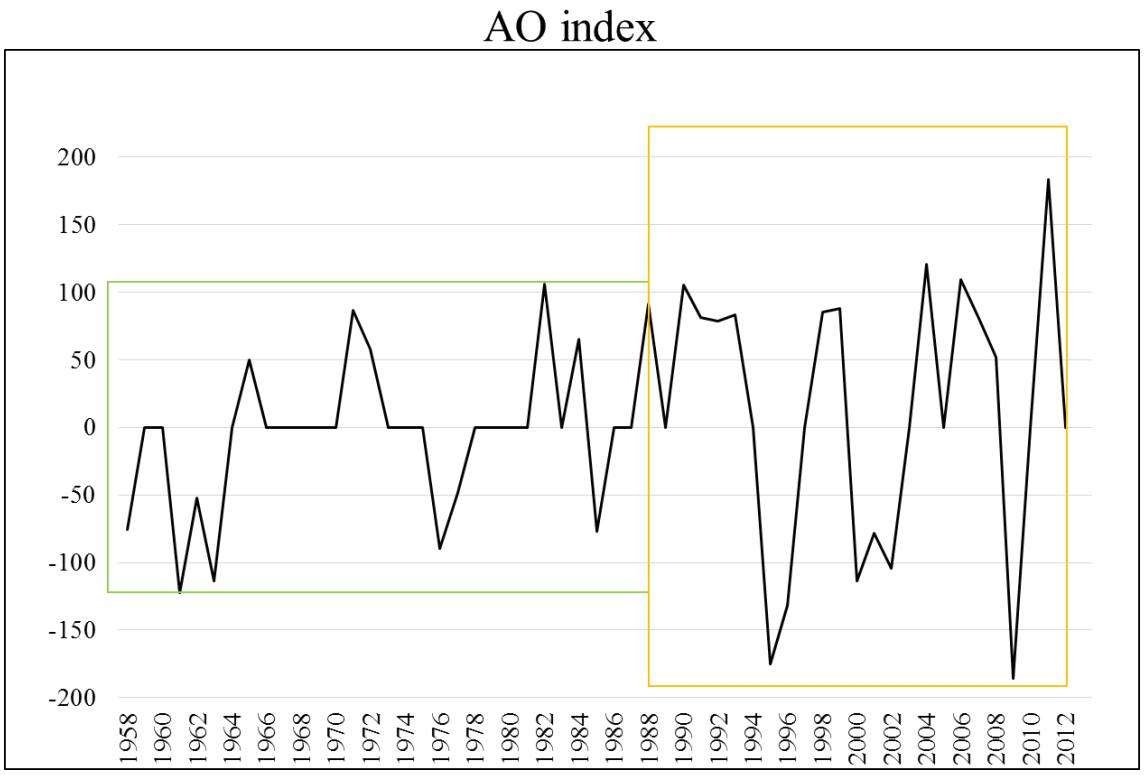


Fig.1. The time series of AO index in December defined by comparing area averaged pressure anomaly among the Arctic (61-84°N, 316-30°E), the Pacific (26-51°N, 160-231°E), the Atlantic (36-51°N, 326-4°E). If in the Arctic > 0 and in the Pacific, the Atlantic < 0 then index value is minus. On the other hand if in the Arctic < 0 and in the Pacific, the Atlantic > 0 then index value is plus. The sum of the absolute value regarded as the amplitude. The unit is meter. Before period (1958-1988) is hem in green, after period (1989-2012) hem in yellow square.

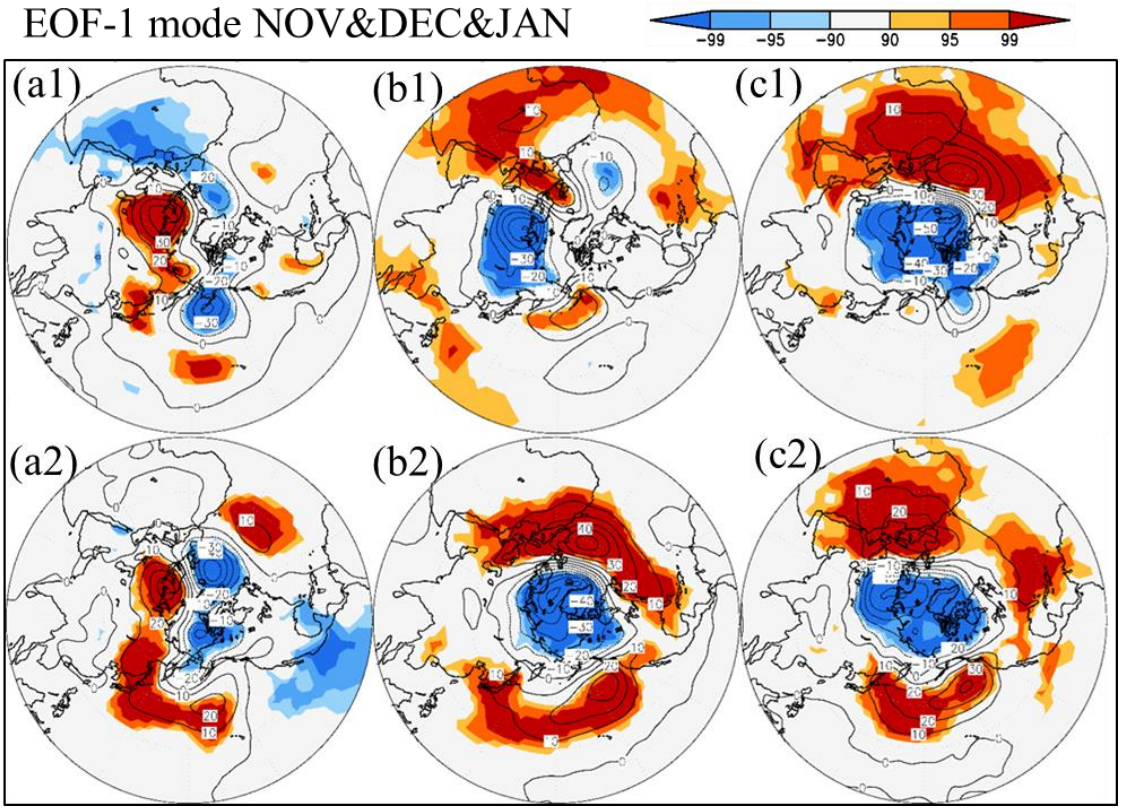


Fig.2. The regression map of EOF analysis for geopotential height at 1000hPa, range is 20°N -90°N. (a1), (b1) and (c1) are in before period. (a2), (b2) and (c2) are in after period. (a1) and (a2) are both in November, (b1) and (b2) are both in December, (c1) and (c2) are both January. Contours are regression coefficient and shades are significance levels of 90%, 95% and 99% based on t-test.

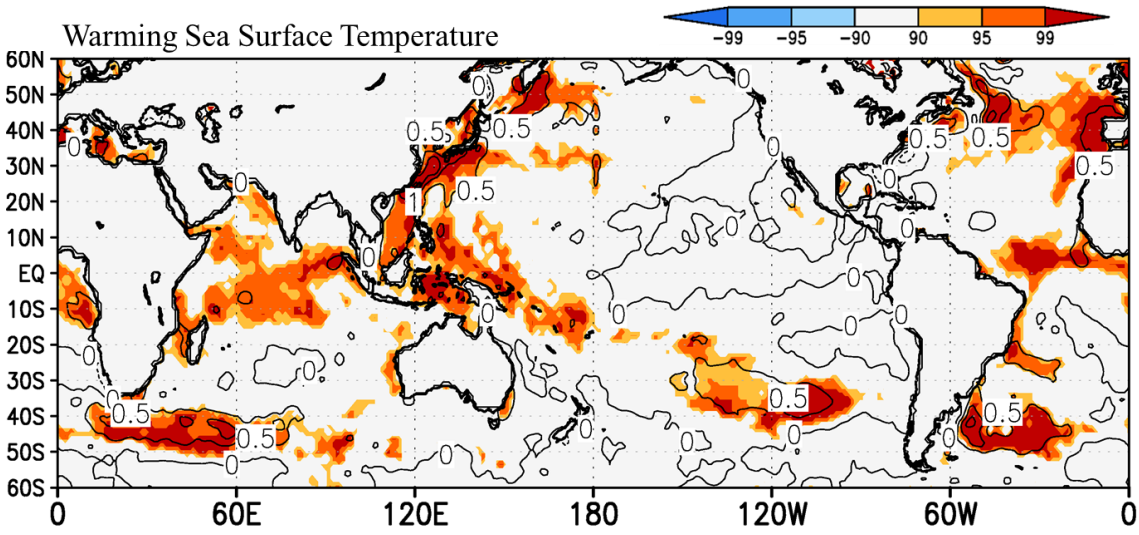
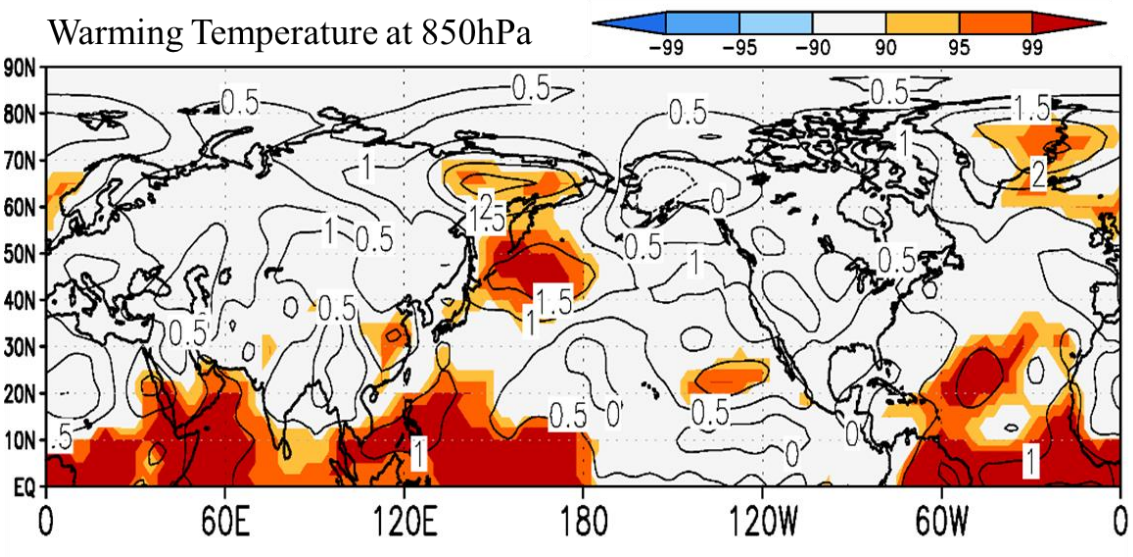


Fig.3. The change of SST between before period and after period in November. Contours are regression coefficient and shades are significance levels of 90%, 95% and 99% based on t-test.



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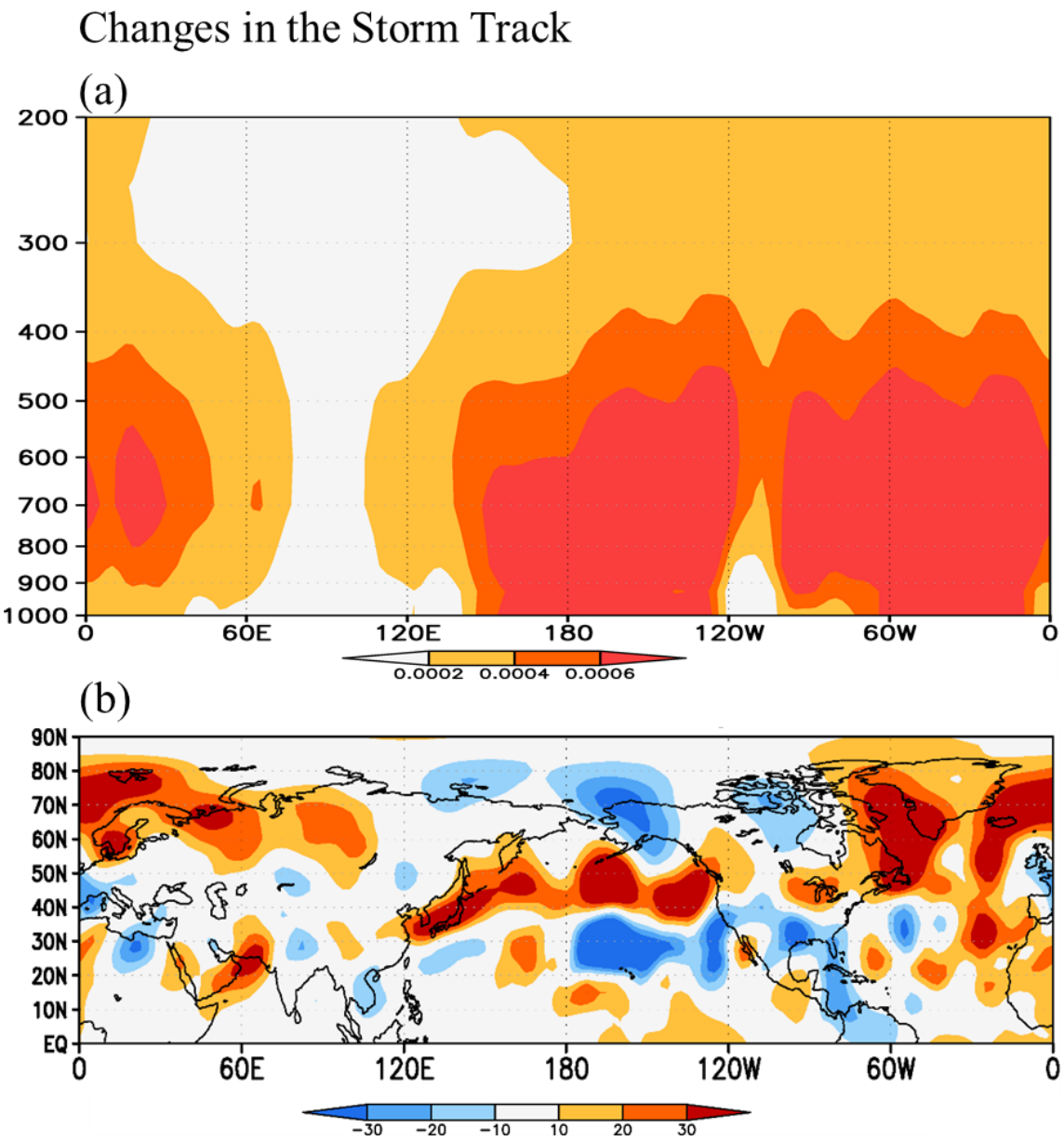

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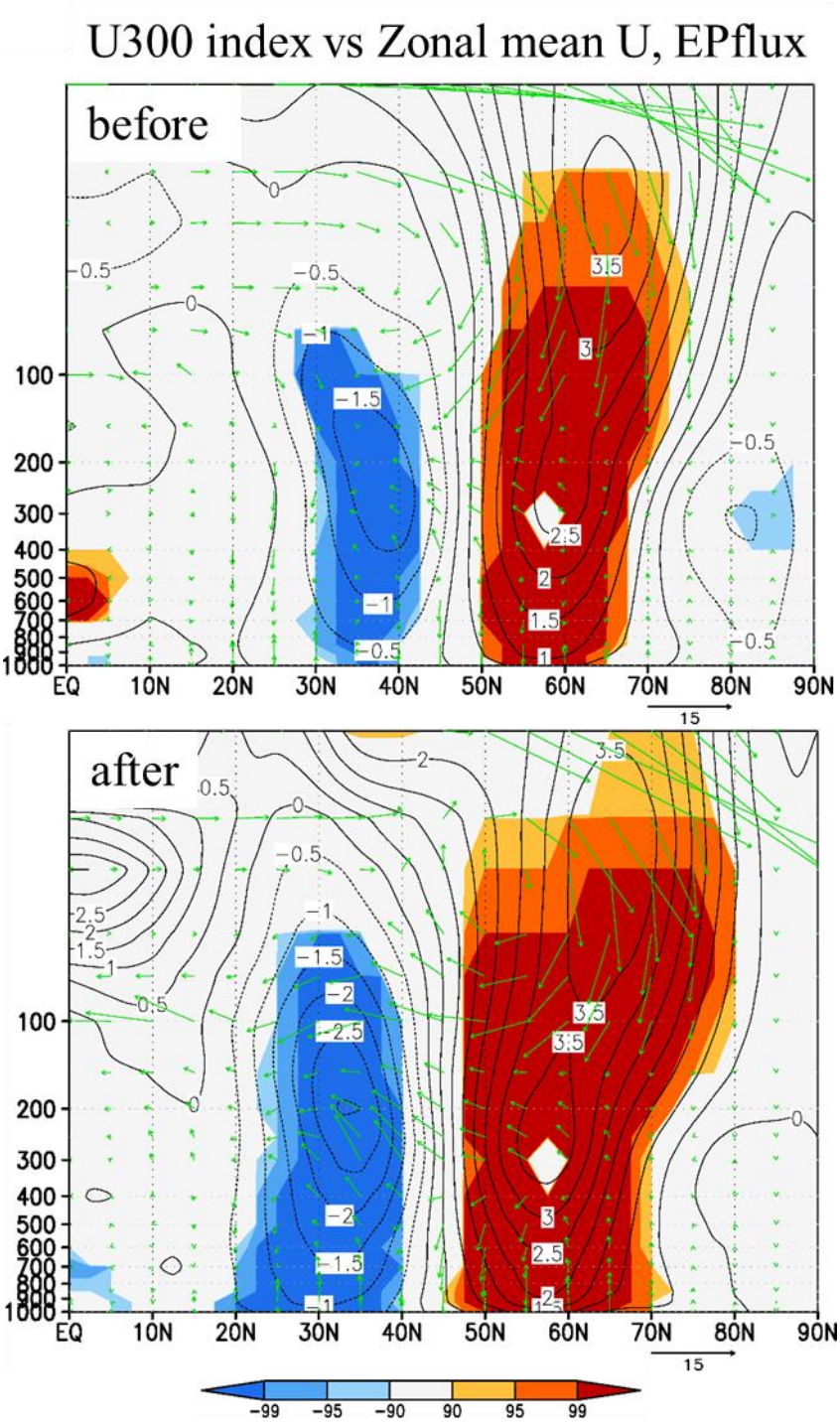

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