Climatology and variability of polar cold air mass based on isentropic coordinates

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博士論文

Climatology and variability of polar cold air mass based on isentropic coordinates

（温位座標に基づく極域寒気の気候学的特性と変動特性）

菅野　湧貴

平成２９年

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要約

Polar cold air mass (PCAM) is one of the fundamental components in the extratropical troposphere. It covers a large part of the extratropics in the winter hemisphere, and its latitudinal extent influences daily weather in the mid-latitudes. Intermittent outflows of PCAM are known as cold air outbreaks (CAOs) or cold surges. They dominate the climate variability in the winter extratropics and sometimes cause serious damages for populated regions in the mid-latitudes. Despite their importance in the climate system, quantitative understanding of PCAM and CAO has not been achieved yet. The goal of this thesis is to quantify the climatological and variational characteristics of PCAM and CAO. For this purpose, I use an isentropic analysis method, which defines PCAM as the atmosphere below a designated potential temperature. A strong advantage of this method is that the PCAM is conserved under adiabatic conditions. In addition, the method distinguishes a diabatic generation/loss process from an adiabatic advection process. To estimate a total hemispheric PCAM amount, I introduce a zonal-mean two-box model. This model separates the total hemispheric PCAM amount into high- and mid-latitude boxes and represents a hemispheric PCAM flux from the former to the latter.

The climatological and variational characteristics of the PCAM and CAO are presented in five chapters. The first chapter discusses the climatological characteristics of the PCAM amount based on the zonal-mean two-box model. The specific question addressed in this chapter is that which hemisphere has much PCAM in winter. From the analysis of JRA-55 reanalysis dataset for the period from 1981 to 2010, I show that the total hemispheric PCAM amount below the designated potential temperature of 280 K in the Northern Hemispheric winter is larger than that in the Southern Hemispheric winter by 40%. However, the hemispheric PCAM fluxes of the two winters, the PCAM flux across 45°N (50°S), are of approximately the same magnitude. The difference in the total hemispheric PCAM amount is attributed to a time constant of the high-latitude box, called the residence time. The difference in the residence time is interpreted as the differences in land-sea contrast and mid-latitudinal orography between the two hemispheres.

The second chapter addresses the intraseasonal and interannual variabilities of the PCAM amount. The charge-discharge concept of PCAM was proposed in 1950s to explain the variability of the index cycle. Although understanding of tropospheric westerly jet has deepened, quantitative understanding of the variability of PCAM has not been achieved. I show that the zonal-mean two-box model well expresses an idealized charge-discharge concept of PCAM. A lagged-regression analysis against the daily hemispheric PCAM flux in January shows that the time scale of hemispheric CAO events is typically 5 days. In the high-latitude box, the PCAM amount gradually increases before CAO events, and then it drastically decreases due to CAO events. After CAO events, it takes about 20 days for the PCAM amount in the high-latitude box to recover to the normal level. In the mid-latitude box, on the other hand, the PCAM temporally

increases after CAO events, but it returns to the normal level in a few days. Because about 90% of the PCAM amount is in the high-latitude box, the total hemispheric PCAM amount follows a similar time evolution as that in the high-latitude box except for the timing of reduction. The lagged-regression also shows that the PCAM amount increases over East Asia, the east coast of North America, and East Europe on the peak day of hemispheric CAO events, these anomalous PCAM patterns correspond to surface temperature anomalies. This charge-discharge relationship is applicable to the interannual variability of the PCAM amount. The January mean PCAM amount in the high-latitude (mid-latitude) box tends to decrease (increase) with increasing January mean hemispheric PCAM flux. In addition, the January mean total hemispheric PCAM amount decreases with increasing January mean hemispheric PCAM flux.

The North American stream is one of the major cold air streams in the boreal winter. Although intraseasonal and interannual variabilities of the other cold air stream, the East Asian stream, have clarified in previous studies, these variabilities of the North American stream have not studied. Thus, the third chapter presents the interannual variability of the North American stream and associated synoptic circulations. A metric of the intensity of the North American stream is the meridional PCAM flux integrated across 60°N between 50°W and 130°W. The first and second Empirical Orthogonal Function (EOF) modes of the January mean meridional PCAM flux at this location represent the variation in intensity and the longitudinal shift of the North American stream, respectively. When the first EOF mode is highly positive, the central part of the North American stream is intensified, with cold anomalies east of the Rocky Mountains. When the second EOF mode is highly positive (negative), the North American stream tends to shift east (west), which results in a cold anomaly over the northeastern Canada (from western Canada to the Midwestern United States with anomalous heavy snowfall in the northeastern United States). The first and second EOF modes are highly correlated with the Tropical Northern Hemisphere pattern and the Arctic Oscillation, respectively, indicating that these teleconnections largely affect the climate variability in the North American winter through modulating the intensity and location of the North American stream.

As a long-term variation, the fourth chapter discusses the historical trends of the PCAM amount and PCAM flux with several atmospheric reanalysis datasets. The reanalysis datasets used in this chapter are JRA-55, ERA-interim, CFSR, JRA-25, and NCEP-NCAR. In addition to these reanalysis datasets, JRA-55 related datasets: JRA-55C and JRA-55AMIP are also analyzed. I demonstrate that the total hemispheric PCAM amount has significantly decreased since 1959 in the Northern Hemispheric winter, whereas a change in the hemispheric PCAM flux is not statistically significant. An insignificant trend in the hemispheric PCAM flux is attributed to its large internal variability. These results agree well among reanalysis datasets. Spatial patterns of the PCAM trends are distinct between the periods 1959-2012 and 1980-2012, indicating the influences of low-frequency atmospheric internal variabilities. In the Southern Hemispheric winter, on the other hand, large discrepancies are found between the reanalysis datasets in the linear trends of the total hemispheric PCAM amount and hemispheric PCAM flux. In addition, the comparisons of trends between JRA-55 and JRA-55C, in which only conventional observational data are assimilated, reveal that assimilation of satellite observation data causes artificial trends in the Southern Hemisphere. Through this analysis, I show that the total hemispheric PCAM amount is potentially a good indicator for the polar climate change.

The fifth chapter addresses the future changes of the PCAM amount and PCAM flux with five climate model outputs from the Coupled Model Intercomparison Project Phase 5 archive. The climate models that used in this chapter are MRI-CGCM3, MIROC5, GFDL-CM3, CanESM2, and HadGEM2-ES. Climate model experiments forced with the two distinct Representative Concentration Pathway (RCP) scenarios, RCP8.5 and RCP4.5 scenarios, are used. All climate models forced with the two scenarios project a large reduction of the total hemispheric PCAM amount in the mid-21st century (2046-2065) and late-21st century (2081-2100) in the Northern and Southern Hemispheric winters. A large inter-model difference in the projected changes is attributed to the difference in a global average surface temperature change. In the two hemispheric winters, the hemispheric PCAM flux is projected to decrease in the future, and the decrease in the mid-21st century is as large as its internal variability. A weakening of the equatorward PCAM flux is projected over East Asia, North America, and East Europe, and particularly the decrease in East Asia is larger than its internal variability. In addition to the seasonal mean hemispheric PCAM flux, changes in the characteristics of CAO events are investigated. The intensity of hemispheric and regional CAO events is projected to decrease, despite the insignificant changes in the frequency and duration. The projected decrease in the meridional heat transport is confirmed, indicating the weakening of the hemispheric PCAM flux is attributed to both dynamical and thermodynamical factors.

This thesis contributes to address the quantitative aspects of PCAM and CAOs from a series of analyses based on the isentropic definition of PCAM.