Three Dimensional Structures of the Arctic Cyclones

Takuro AIZAWA[1,3] and Hiroshi L. TANAKA[2]
[1]*Life and Environmental Sciences, University of Tsukuba*
[2]*Center for Computational Sciences, University of Tsukuba*
[3]*National Institute of Polar Research*

Arctic cyclones are unique low pressure systems appearing in the Arctic, which are different from the tropical cyclones and the mid-latitude cyclones. Three typical Arctic cyclones having longer duration in summer were analyzed by Tanaka et al. (2012). They provided a new insight that the surface Arctic cyclone connects to an upper polar vortex producing a deep barotropic vortex. They also noted that the characteristic thermal and the vortical structures are maintained throughout a life cycle. Aizawa et al. (2014) analyzed the same thermal structure and a deep wide-spread tropopause folding just over the cyclone center related to the intensification of the polar vortex. But, the three dimensional stereoscopic structure of the Arctic cyclones was not investigated by their studies. The purpose of this study is to show the three dimensional structure of the typical Arctic cyclones.

The Arctic cyclones chosen in this study (Aizawa and Tanaka 2016) are cases of June 2008 (Tanaka et al. 2012, Aizawa et al. 2014) and August 2012 (Simmonds and Rudeva 2012). The original data used this study are the reanalysis data of JRA-25/JCDAS (Japan 25year Reanalysis/JMA Climate Data Assimilation System; JMA: Japan Meteorological Agency). The case 2008 appeared above the Arctic Ocean at 00Z 10 June 2008, roamed around the Arctic Ocean for more than two weeks. The minimum pressure in the life cycle is 977 hPa. The case 2012 arose above the Central Siberian at 18Z 2 August 2012, and moved to the Arctic Ocean showing a development in the central pressure. The minimum pressure in the life cycle is 965 hPa. To investigated the three dimensional structure of the Arctic cyclones, we converted the meteorological data from a latitude/longitude coordinate system into the cylindrical coordinate system around the cyclone center using a bi-cubic spline interpolation. The resolution of the cylindrical data is 10 km in a radial direction with 1 degree in deflection angle.

Since the cyclone of case 2008 had a steady structure, we calculated the space-time averaging through the life cycle to extract the typical structure of the Arctic cyclone. The figures are time average during 00Z 10 June 2008 to 18Z 26 June 2008 (for 17days). Figure 1 shows the lifetime mean potential vorticity (PVU, $10^{-6}m^2s^{-1}kg^{-1}K$), geopotential height (m) at 250 hPa and 500hPa, and sea level pressure (hPa) of the Arctic cyclone. We find from Fig. 1 (a) that there is an isolated potential vorticity anomaly, associating with the intense upper polar vortex having symmetric circulation at lower stratosphere. This stratospheric vortex vertically binds to the tropospheric vortex tightly (Fig. 1b), indicating cyclonic potential vorticity anomaly. The surface cyclone appears just under the upper polar vortex in the high potential vorticity region at 850 hPa (Fig. 1c). The horizontal scale of cyclone showing symmetricity from lower and upper altitude is 1500 km in radius.

Figure 2 illustrates the radius-height cross section of azimuthally averaged tangential wind, radial wind, vertical velocity, relative vorticity and temperature deviation from the environmental mean for the case 2008. The dynamical tropopause (2 PVU surface) is also shown in Fig. 2 by the bold contours. The snapshot figures during the life cycle show the same structures as the Fig. 2 (not shown), although there are some fluctuations for the intensities of the secondary circulation in time. The upper jet locates at 300 hPa, in radius of 400-1000 km, and its maximum is over 20 m/s. The cyclonic wind covers the whole length of graphic, exceeds a radius of 1500 km in radius. This huge cyclonic circulation with the jet is related to the upper polar vortex. The Arctic cyclone is a wide-scale vortex of a deep cyclonic primary circulation from the surface up to the stratosphere. There is a secondary circulation within the vortex of the cyclone. The outflow at the upper troposphere (200 -500 hPa) is seen in Fig. 2(b). In the boundary layer, it is an inflow (Fig. 2d). It shows updraft within the 1000 km radius, the region of peak intensity locates at 500 hPa level of a cyclone center.

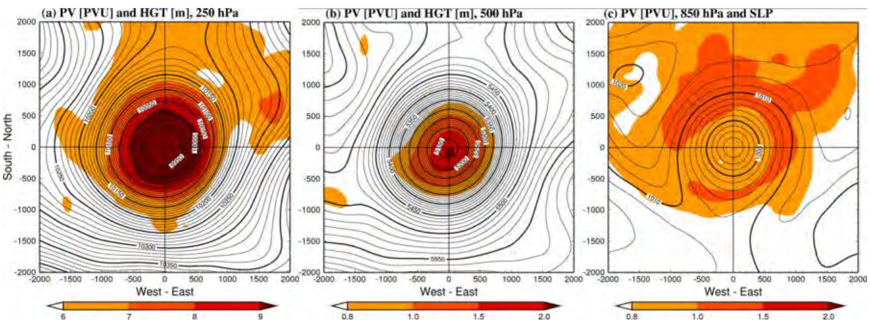

Fig.1 Time averaged potential vorticity (PVU) at (a) 250 hPa, (b) 500hPa and (c) 850 hPa, geopotential height (m) at (a) 250 hPa, (b) 500hPa and (c) sea level pressure (hPa) for the case 2008. The figures are time average during the life cycle (00Z 10 June – 18Z 26 June, 2008). The shades show the potential vorticity, and the contours show the geopotential height and sea level pressure. The contour interval in (a), (b) and (c) is 20 (m/s) and 2 hPa, respectively.

On the other hand, the figure shows the downward current outside the 1000 km radius. Note that it shows a downdraft at the lower stratosphere (70-250 hPa) around the cyclone center. The positive relative vorticity related to the deep cyclonic circulation stretches up to stratosphere from the surface. The temperature deviation indicates a cold core in the troposphere and a warm core in the stratosphere as seen in Fig. 2(f). The center of the warm core locates at 300 hPa in agreement with the previous study by Tanaka et al. (2012) and Aizawa et al (2014). The tropopause at the cyclone center descends from 300hPa to 500 hPa associating with the potential vorticity anomaly at the lower stratosphere. The tropopause folding above the cyclone center implies the upper polar vortex. The sustained downward airflows at the lower stratosphere are able to intensify the warm core by the adiabatic heating process. This effect has the potential to maintain the upper air and surface cyclones, causing the adiabatic cooling by the ascent flows in the troposphere through the boundary layer Ekman pumping.

Note that the cyclone of June 2008 appears showing axisymmetric cyclonic circulations at the surface level. The cyclone of 2012 is characterized by the structure change from the cold core to the warm core at the lower stratosphere, indicating a shift from the ordinary baroclinic cyclone to the typical Arctic cyclone (not shown).

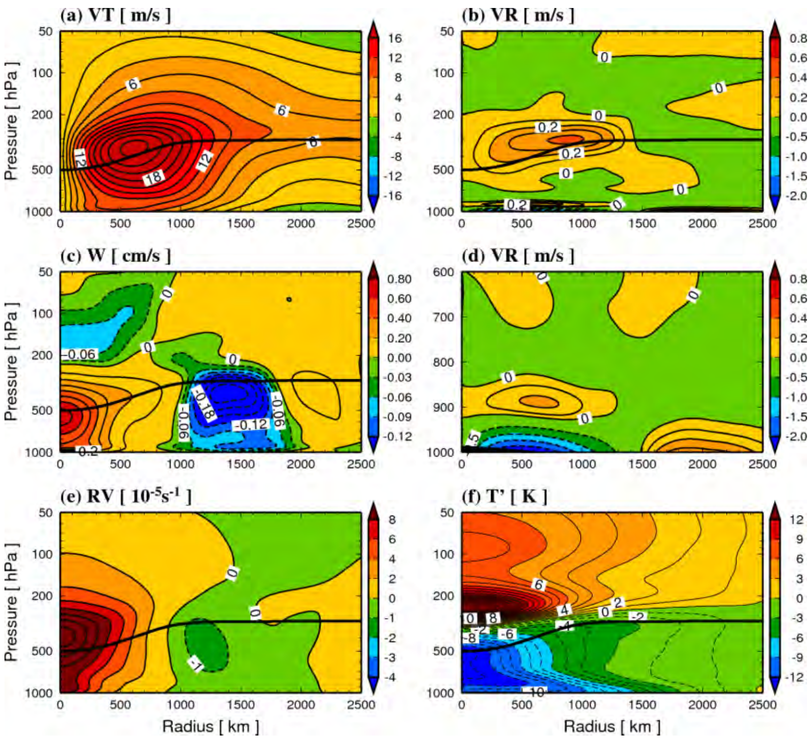

Fig.2 Radius-height cross sections of azimuthal mean (a) tangential wind speed (m/s), (b) radial wind speed (m/s), (c) vertical velocity (cm/s), (d) enlarged plot of (b) near the surface (m/s), (e) relative vorticity ($10^{-5}s^{-1}$) and (f) temperature deviation (℃) for the case 2008. The figures are time average during the life cycle (00Z 10 June – 18Z 26 June, 2008). The bold contours show the dynamical tropopouse (2 PVU surface). The solid lines and the dashed lines indicate positive and negative values. The intervals of the dashed line in (c), (b, d) and (e) are 0.03 (cm/s), 0.5 (m/s) and 1 ($10^{-5}s^{-1}$), respectively.

Tropopause polar vortices are often found on the tropopause in the Arctic. Cavallo and Hakim (2010) provided the structure of the tropopause polar cyclones. Compared with their results, though the basic structure of the Arctic cyclones is similar to the tropopause polar cyclone, the scale and the intensity of the Arctic cyclones are significantly larger than that. The major difference in the Arctic cyclone is found in the vertical structure producing the surface cyclonic circulation while it is absent in the tropopause polar vortex. It is found that the Arctic cyclone is characterized as one of the tropopause polar vortices, but it is connected with the polar vortex of all the stratosphere, and the cyclonic circulation reaches to the ground, generating a secondary circulation which produces the cold core in the troposphere by the updraft from the surface level. Although additional studies are needed, a schematic diagram of the Arctic cyclone is proposed in this study.

References

Aizawa, T., H.L. Tanaka and M. Satoh, Rapid development of Arctic cyclone in June 2008 simulated by the cloud resolving model NICAM, Meteorology and Atmospheric Physics, 137(660), 105-117, 2014.

Aizawa, T. and H.L. Tanaka, Axisymmetric structure of the long lasting summer Arctic cyclones, Polar Science, 2016. (Submitted)

Cavallo, S.M. and G.J. Hakim, Composite structure of tropopause polar cyclones, Monthly Weather Review, 138, 3840-3857. 2010.

Simmonds, I. and K. Rudeva, The great Arctic cyclone of August 2012, Geophys. Res. Lett., 39, L23709, doi:10.1029/2012GL054259., 2012.

Tanaka, H.L., A. Yamagami and S. Takahashi, The structure and behavior of the Arctic cyclone analyzed by the JRA-25/JCDAS data, Polar Science, 6, 54-69, 2012.