Response to Reviewer 2 for

Development Processes of the East Asian Cyclones over the Korean Peninsula

submitted to *Weather and Climate Dynamics*

The authors thank the reviewer for carefully reviewing the manuscript. The reviewer's comments are answered in detail, after the general comments from the reviewer.

General Comments

The authors investigate the development processes of the cold-season East Asian Cyclones over the Korean Peninsula using a potential vorticity tendency analysis of cyclone-tracking composites. Through the detailed PV budget analysis, they reveal the different roles of the horizontal PV advection, vertical PV advection, latent heating release in the development of two groups of extratropical cyclones passing the Korean Peninsula (northern- and southern-track cyclones). They found that northern-track cyclones are dynamical dominant while the southern-track cyclones are both dynamical and thermodynamical driven.

Several prior studies on the extratropical cyclones from potential vorticity tendency analysis have been predominantly statistical in nature. These studies put their focuses on oceanic extratropical cyclones either in North Pacific or North Atlantic. I believe that this study brings an important contribution by assessing the dynamical and thermodynamical processes in the development of continental extratropical cyclones. I thus recommend the authors to perform a major revision by considering the comments listed below.

Major Comments

(1)

Reviewer: *The advantage of using the PV framework is that it provides a simple way to include the role of diabatic heating due to latent heating release and radiation. In this manuscript, the radiation and friction are put together into one term Fres as in Eq. (1). And in the following sections, the contributions from radiation and frictions are not shown as well. However,as suggested in Tamarin and Kaspi 2016, the radiation contribution seems larger than the vertical PV advection in the cyclone development. Could the authors add some discussions on the estimation of radiation effects on the East Asian extratropical cyclones?*

Response: We thank the reviewer for the constructive suggestion. The PV tendency from radiative heating, Q_{RAD}, can be expressed as follows.

$$Q_{RAD} = -g(\zeta + f)\frac{\partial \dot{\theta}_{RAD}}{\partial p}$$

Here, $\dot{\theta}_{RAD}$ is the radiative heating obtained from the ERA-Interim model. Figures R1a and b show the vertical cross-sections of the radiative heating for NT and ST cyclones at t_{max}. The overall pattern is dominated by longwave cooling in the upper troposphere. This cooling can contribute to diabatic PV reduction in mid to lower troposphere.

The Q_{RAD} at 850 hPa is shown in Figs. R2a and b. Unlike Tamarin and Kaspi (2016), it is considerably smaller than $-\omega\frac{\partial q}{\partial p}$ for both NT and ST cyclones (compare Figs. R2a,b and R2c,d).

This is also clear from the vertical cross-section shown in Fig. R3. Owing to this minor forcing, we decided not to include the analysis on radiative heating. This finding is briefly discussed in the revised manuscript as follows.

Lines 316-320: A preliminary analysis, based on the radiative heating of the ERA-Interim model data, reveals a weak but statistically significant radiative cooling (mostly due to longwave cooling) indeed appears in the upper troposphere above the level of maximum LH. However, its contributions to the PV tendency for both NT and ST cyclones are much smaller than Q_{LH} and the advection terms (not shown). Further analyses using numerical models could be useful.

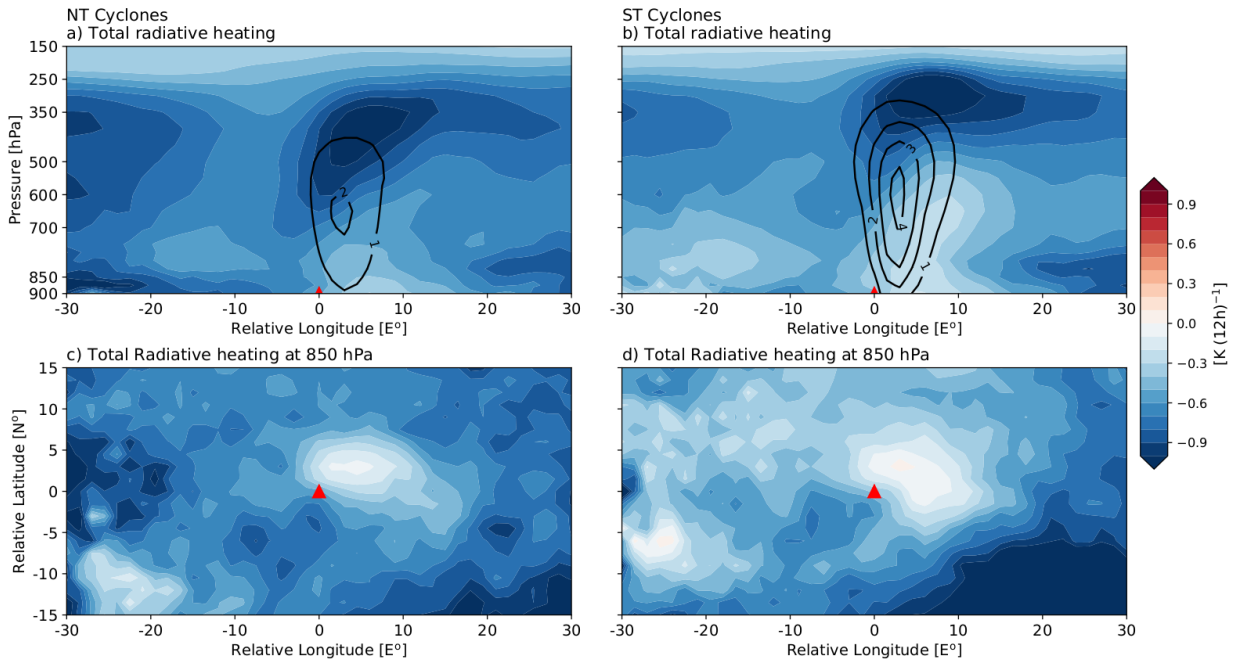

Figure R1. Vertical cross-section of total radiative heating (shading, units: K $(12h)^{-1}$) with respect to the center of **(a)** NT and **(b)** ST cyclones at t_{max}. Total radiative heating at 850 hPa (shading, units: K $(12h)^{-1}$) with respect to the center of **(c)** NT and **(d)** ST cyclones at t_{max}. In **(a)** and **(b)**, the vertical cross-section of LH is also shown in black contours (units: K $(12h)^{-1}$).

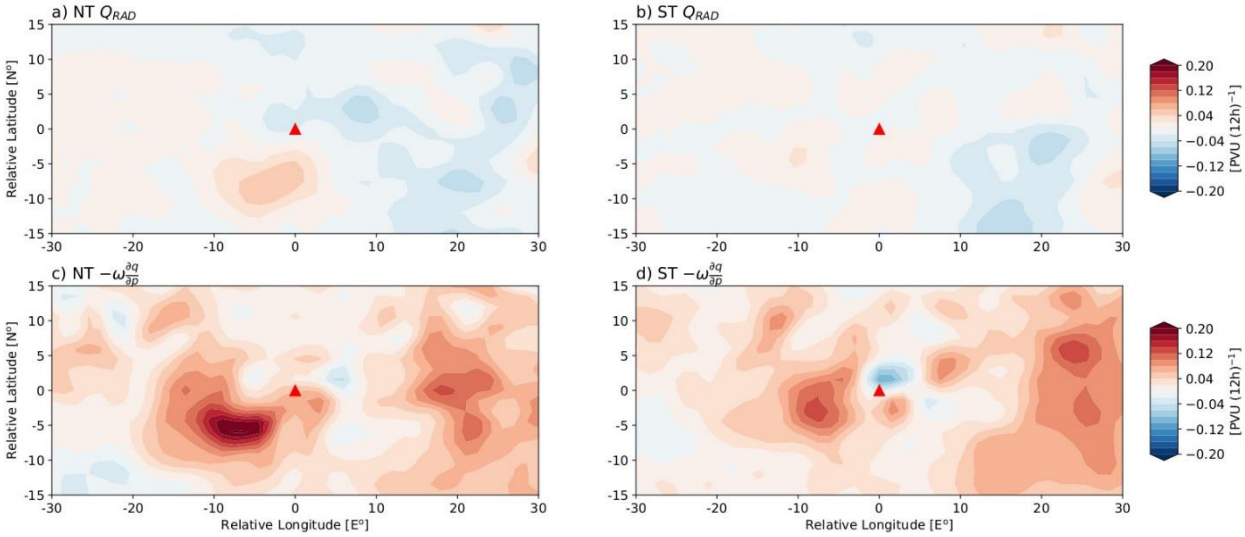

Figure R2. PV tendency from Q_{RAD} (shading, units: PVU $(12h)^{-1}$) with respect to the center of **(a)** NT and **(b)** ST cyclones at t_{max}. **(c, d)** Same as **(a, b)**, but for $-\omega\frac{\partial q}{\partial p}$.

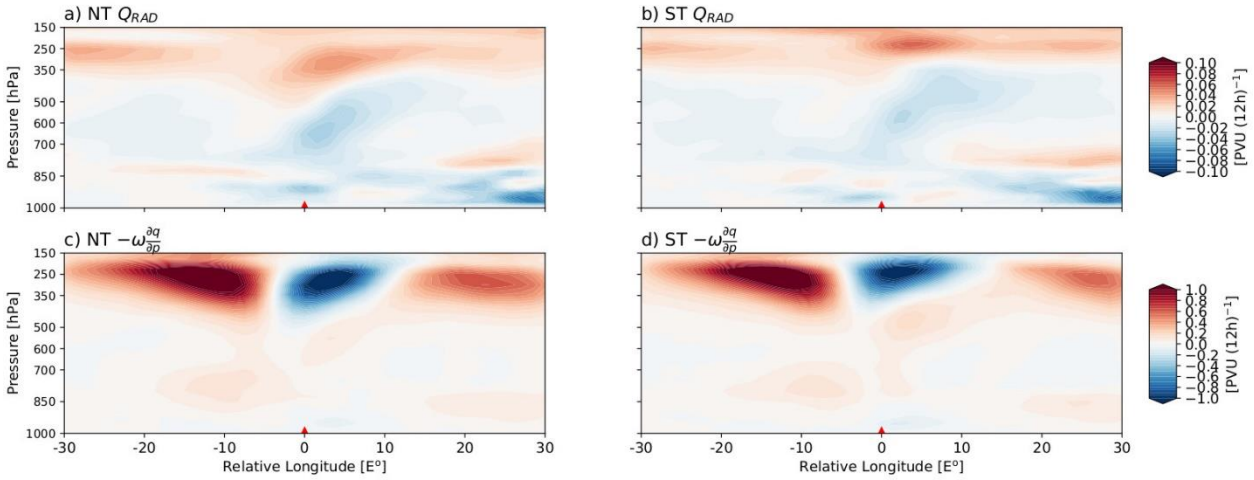

Figure R3. Vertical cross-section Q_{RAD} (shading, units: PVU (12h)$^{-1}$) with respect to the center of **(a)** NT and **(b)** ST cyclones at t_{max}. **(c, d)** Same as **(a, b)**, but for $-\omega\frac{\partial q}{\partial p}$.

(2)

Reviewer: *In Fig.8, the authors quantify the relative contributions of each component to the 850-hPa relative vorticity tendency from upper troposphere and lower troposphere. However, the detailed method for the algorithm and vertical decomposition is not described in the manuscript. Is it a piecewise PV inversion method in which the wind is decomposed from upper level and lower level? Could the authors explain the reason to choose the 600-hPa level to understand the behavior of 850-hPa relative vorticity? Please also specify the range of the upper-troposphere and lower-troposphere in line 257. For example, 175-600 hPa for upper troposphere and 600-875 hPa for lower troposphere. Is it a vertical average?*

Response: Thank you for pointing this out. We have made it clearer in the revised manuscript as follows.

Lines 262-265: The decomposition of upper- and lower-tropospheric advection is done by setting the lower-level (875–600 hPa) PV tendency to zero when inverting upper-tropospheric (600–175 hPa) PV tendency, and vise versa. The 600-hPa reference level is chosen since positive PV tendency from horizontal advection in the upper troposphere intrudes down to this level (Figs. 4c and d), showing distinctive feature from the levels below.

Minor Comments

(1)

Reviewer: Line 12: "… the respective contributions to the ST cyclones are 71.8% and 43.5% for the ST cyclones…" Two times of ST cyclones are found in this sentence. Maybe delete one of them?

Response: Corrected in the revised manuscript.

(2)

Reviewer: Line 76: travels→travel

Response: Corrected in the revised manuscript.

(3)

Reviewer: Line 79: is selected→are selected

Response: Corrected in the revised manuscript.

(4)

Reviewer: Line 80: More than 25 ETCs impact the region in each along the two distinct ETC tracks. Could the author specify the time period (e.g. per year) to help the reader?

Response: Modified as reviewer's suggestion in the revised manuscript.

(5)

Reviewer: Line 195: …at a single level as in Figs. 4c and d…, perhaps the authors mean Figs. 5c and d?

Response: This sentence has been modified as follows.

Lines 199-201: This result clearly indicates that diagnosing the PV tendency at a particular level is insufficient at gauging its effect on ETC development, highlighting the advantage of inversion calculation.

(6)

Reviewer: Line 261: is derived→ are derived

Response: Corrected in the revised manuscript.

(7)

Reviewer: Line 291: exist→ exists, then than→ then

Response: In this sentence, ‘at then’ refers to ‘at the initial stages’.