SYNOPTIC CHARACTERISTICS OF THE JAPAN TSUKUBA TORNADO

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Outline

1. Introduction

- Tornadoes are most frequently observed during the warm season in the U.S., but Japan and Korea in which 70% of land is covered by mountains also has annual tornado occurrence.
- On 6 May 2012, multiple tornadoes occurred between 0300UTC and 0500UTC in Japan's Kanto district. Among theses tornadoes, the most violent tornado rated F3 in Enhanced-Fujita scale (EF-scale) occurred in the northern suburbs of Tsukuba (hereafter Tsukuba tornado) at 0335UTC (JMA, 2012).
- There were 59 casualties and 978 houses completely or partially destroyed during the event.
- Although there have been some reports on the 6 May 2012 Tsukuba tornado with radar and microscale analyses, there has not been a thorough analysis of the synoptic and mesoscale environment which instigated the tornado development. We report such findings in this study.

2. Data and Method

Case Overview

The Location of three mountain ranges that form the Japan Alps, and photos of the Tsukuba tornado and its destruction. The time and track of four tornadoes that spawned on 6 May 2012 is shown as well.

On the morning of 6 May 2012, a thunderstorm developed around 0100 UTC and subsequently a tornado touched ground at 0335 UTC near Tsukuba, Japan. The timing from thunderstorm development to tornado initiation was quite short (~ 3 hours) compared to the climatological timing of 6 - 7 hours in the Kanto Plain (Niino et al., 1993).

Research Method

Data

- MERRA data
  - NASA reanalysis for the satellite era
  - Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5)
  - 6hr 0.7°×0.5° & 42-levels (1000~0.1hPa)
  - 3hr 1.25°×1.25° & 42-levels (1000 ~ 0.1hPa)
  - 1hr 0.7°×0.5° surface data
- Weather charts, COMS imagery, and GPCP, ICAO, soundings data etc.

PV

$$PV = -g\left(f + \hat{k}\bullet\nabla_{\theta}\times\vec{V}\right)\left(\frac{\partial\theta}{\partial p}\right)$$

- PV: potential vorticity
  - Dynamic tropopause by PVU [10^{-6} K kg^{-1} m^{-2} s^{-1}]
  - 1~3PVU in transition zone between upper troposphere and lower stratosphere
  - 0.3~0.5PVU in the troposphere
  - 1.6 PVU = dynamic tropopause (Santurette & Georgiev 2005)

Indices

$$\mathrm{CAPE} = \int_{p_n}^{p_f} (\alpha_p - \alpha_e)\, dp$$

- CAPE: convective available potential energy [J kg^{-1}]
- **SWEAT**=12×Td(850 hPa)+20×(TT-49)+2×WSP(850hPa)+WSP(500 hPa) + SHEAR
- **LI** = T'500 - T500 (parcel @surface)
- **SI** = T'500 - T500 (parcel @850 hPa)

SREH

$$\mathrm{SREH} = -\int \left(\vec{V} - \vec{C}\right)\cdot\left(\nabla\times\vec{V}\right) dz$$

- SREH: storm relative helicity [$m^2 s^{-2}$]
  - **V**: environmental wind velocity [ms^{-1}]
  - **C**: storm velocity [ms^{-1}]
  - z: altitude [m]

SREH	Description
150~299	Supercells possible with weak tornadoes according to Fujita-scale
300~449	Very favorable to supercells development and strong tornadoes
> 450	Violent tornadoes

Froude

$$F_r = \frac{U}{N h_m}$$

- U: mean wind-speed between surface~850hPa
- N: Brunt-Väisälä frequency (~0.01)

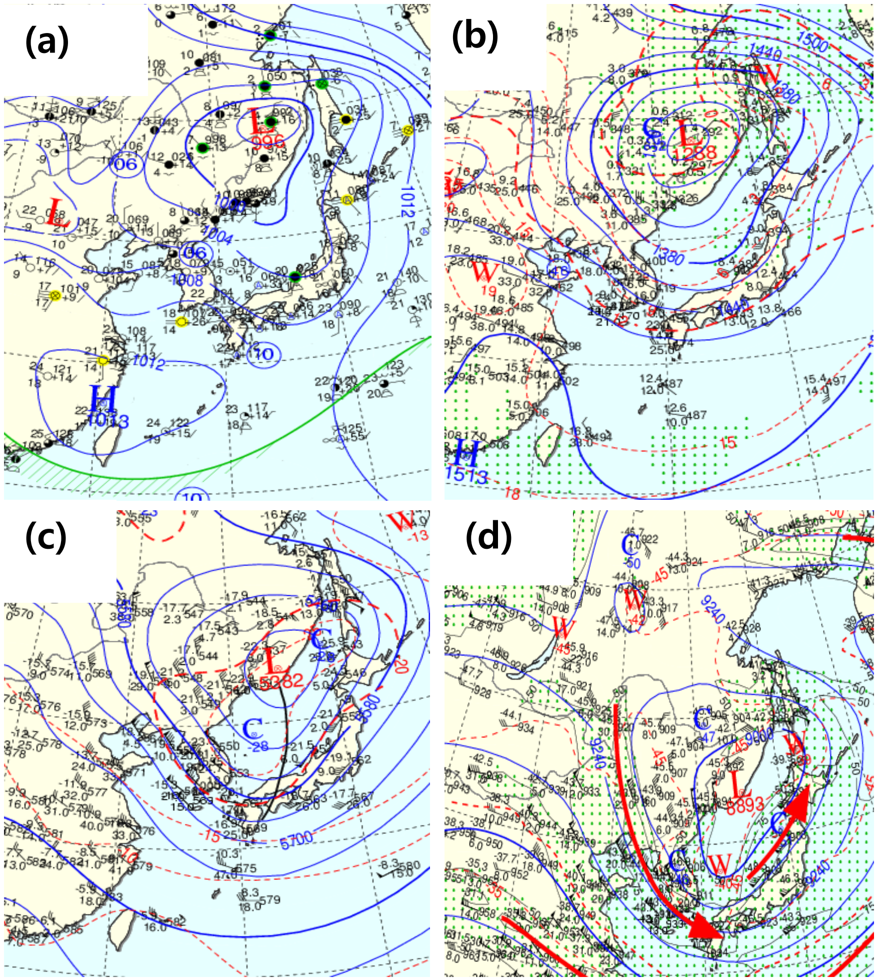
$$N = \sqrt{\left(\frac{g}{\theta}\right)\left(\frac{\partial\theta_v}{\partial z}\right)}$$

- h_m: perturbation fluid depth (~1000m)
- F_r >1: gravity waves are able to propagate upstream relative to the mean flow (i.e. fluid is able to move over the mountain to produce perturbation pressure gradients)

We analyzed the possible synoptic forcings, thermodynamic and dynamic mechanisms, and the role of topography in the formation and development of the Tsukuba tornado. Further, we analyzed stability indices, moisture flux, SREH, isentropic analysis, PV, and Froude number during the onset of the tornado.

3. Analysis Results

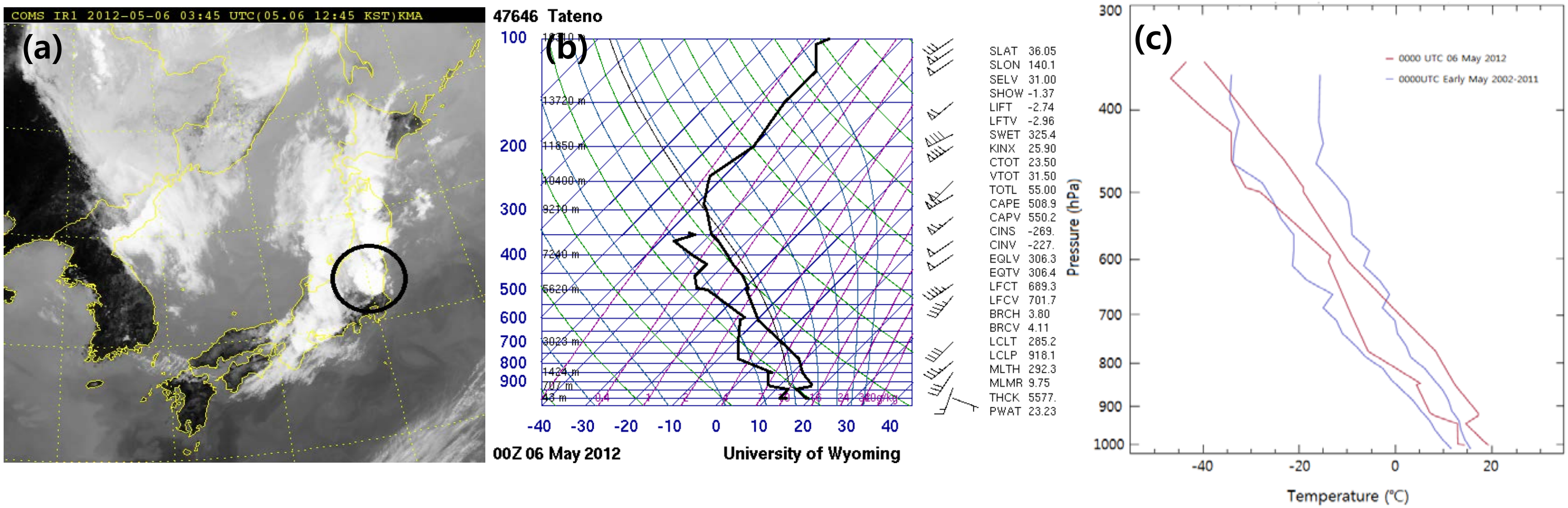
Synoptic Environment



A circular jet stream detached from the main polar jet is over the Japan on 0000UTC 6 May . The polar jet advects cold air in the area beneath the circular jet stream as described by Davies (2006). The temperature distribution of the 700 & 850 hPa chart represents this well. At 850hPa, the temperature over Tsukuba decreased from ~12^{o}C at 1200UTC 5 May to 9^{o}C at 0000UTC 6 May.

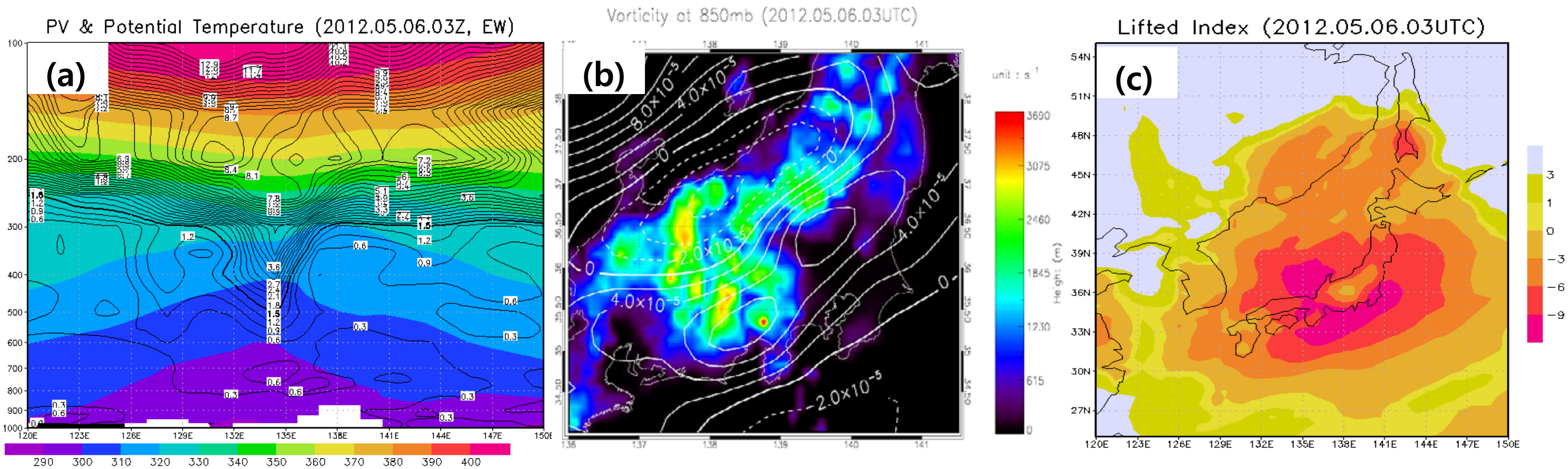
Weather charts for 0000UTC 06 May 2012 at (a) surface, (b) 850 hPa, (c) 700 hPa, and (d) 300 hPa, respectively.

Thermodynamic Analysis



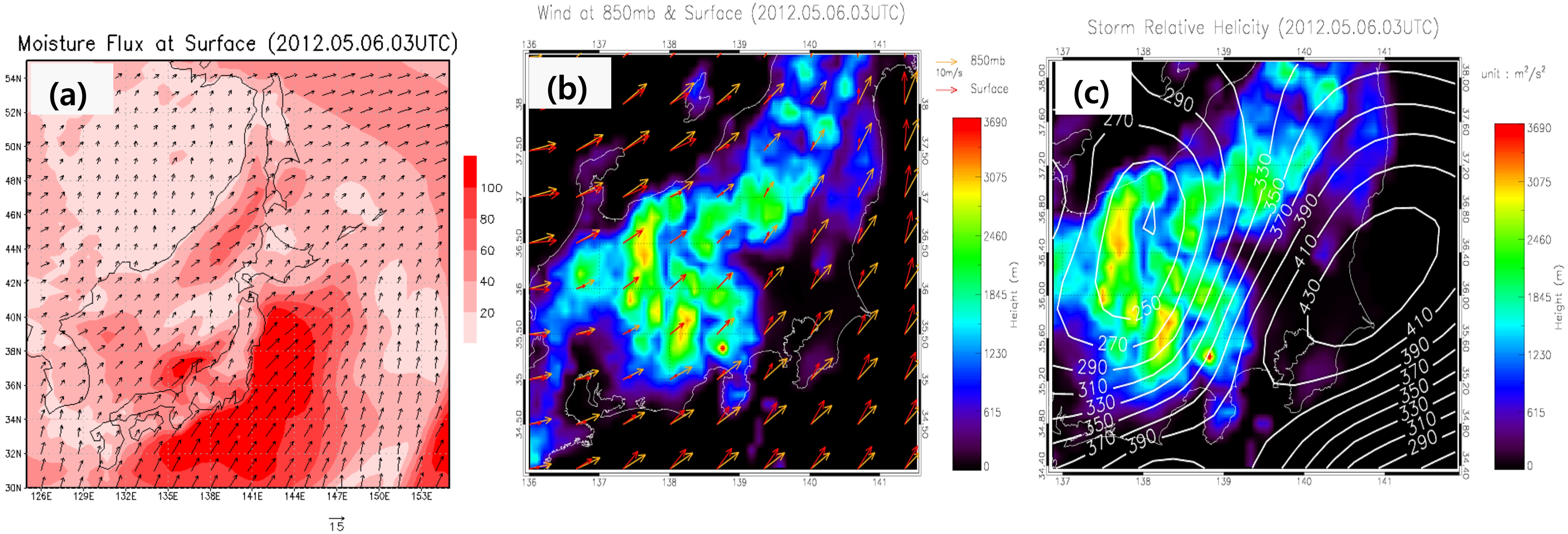
A severe convective clouds developed on the lee of the Japanese Alps prior to tornado event and conspicuous supercell developed over Tsukuba (a). The overall vertical structure shows upper-level is quite dry ($T - T_d > 6^{o}C$), whereas the layer beneath 950hPa is moist ($T - T_d < 6^{o}C$). There is a capping inversion under 900hPa, with inversion top temperature of about 15^{o}C (b). The cause of the Tsukuba tornado differs from that of the typical U.S. Great Plains tornado. Tateno's climatological profile of temperature and dew-point with that of tornado outbreak showed mid-level was moister (3~4 ℃) than typical sounding (c).

Mesoscale Analysis



PV anomaly associated with tropopause folding approached Japan from the west before the outbreak (a), and its intensity increased. Cyclonic circulation was accelerated at 850 hPa level with downstream vortex stretching (b). Strong convective instability with LI smaller than -9 is located along the southern coast of Japan (c).

Mesoscale Analysis



There was an influx of moisture from the adjacent Pacific Ocean (a) and equivalent potential temperature decreased from surface to 600hPa indicating strong thermodynamic instability. In addition, there were strong vertical shear of 20 ms^{-1} or more (b) and cyclonic vorticity of 1.0×10^{-4} s^{-1} in the lower-level, and the value of SREH reached up to 480 m^{2}s^{-2} showing the atmospheric environment was ripe for tornado outbreak to occur (c) .

4. Summary

Table 1 Stability indices calculated by MERRA data from 0000 UTC to 0600 UTC 06 May 2012 at Tateno. The values in the parenthesis are from the 0000 UTC 6 May radiosonde data.

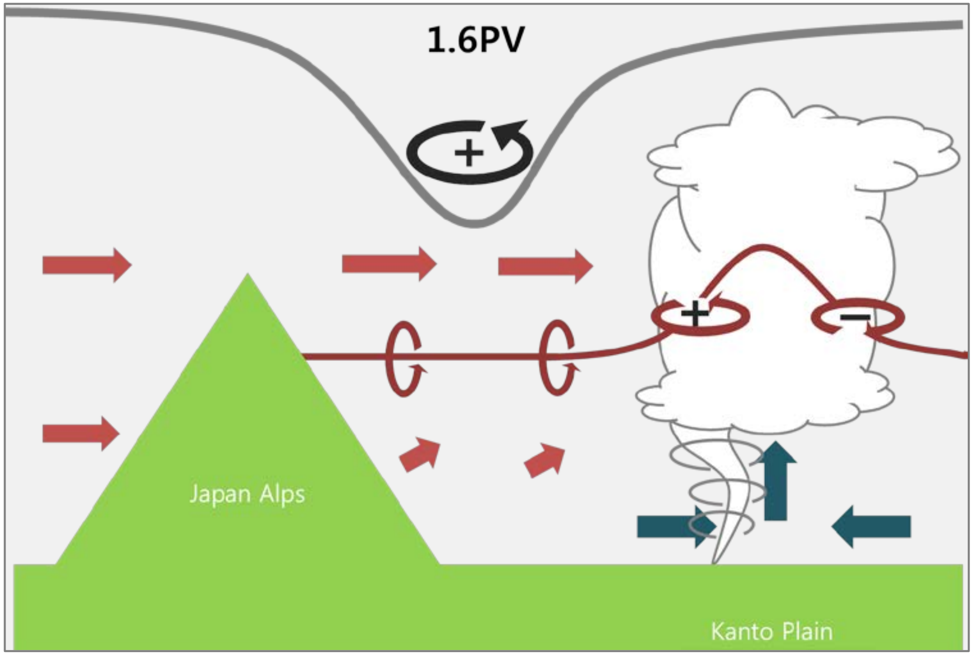
Stability Indices	0000 UTC 06	0300 UTC 06	0600 UTC 06
CAPE ($J\ kg^{-1}$)	656 (508.9)	1226	1143
SWEAT	255.32 (325.4)	166.27	180.91
LI	-3 (-2.74)	-5	-4
SI	2.14 (-1.37)	3.64	2.02

Table 2 Froude number from 1500 UTC 05 to 0000 UTC 06 May 2012 at 35°N 137°E.

Fr #	1500 UTC 05	1800 UTC 05	2100 UTC 05	0000 UTC 06	0300 UTC 06
850 hPa	0.8	1	1.3	1.4	1.4
975~850 hPa	0.4	0.8	1.3	1.3	1.3

The stability indices at 00UTC 6 May showed favorable environment for supercell development. CAPE was 508.9 Jkg^{-1}, SWEAT 325.4, LI -2.74, and SSI -1.37, all indicating moderate possibility of severe thunderstorm with some chance of tornado. Further, calculation of Froude number, which was greater than 1 throughout the period of Tsukuba tornado, indicated that the Japanese Alps acted as a mountain barrier that allowed column of air to flow over and enhance vorticity by vortex stretching, which affected the tornado outbreak.

5. Conclusions



Niino et al. (1997) conducted a statistical study of tornado occurrence and found that the Kanto plain was the only region not located at the shore among regions where tornado intensively occurred in Japan. He hypothesized that tornados occurred in Kanto plain may result from topographical effect. Our study shows that 6 May 2012 Tsukuba tornado development is due to a combination of:

1) **topography and PV anomaly, which increased vorticity over the Kanto Plain,**
2) **vertical shear, which produced horizontal vortex line to develop and**
3) **thermodynamic instability, which triggered supercells and tilted the vortex line in the vertical direction.**

References

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