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Structure and Environment of Polar Meso-cyclones over the Sea of Japan: Composite Analysis and Numerical Experiments

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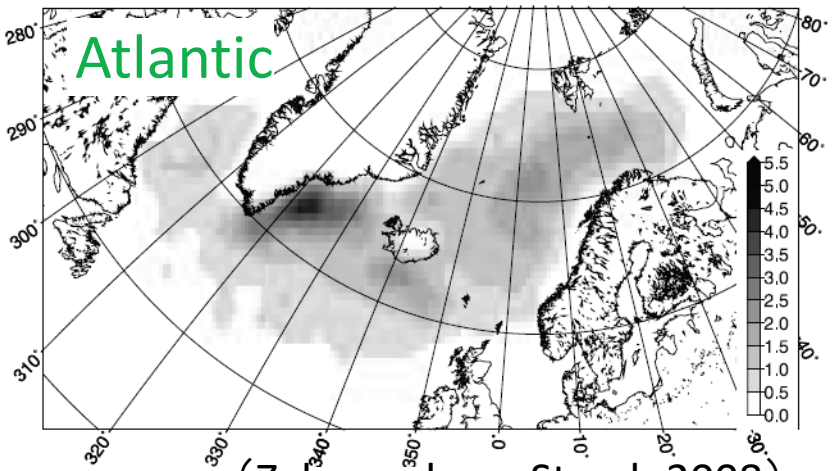
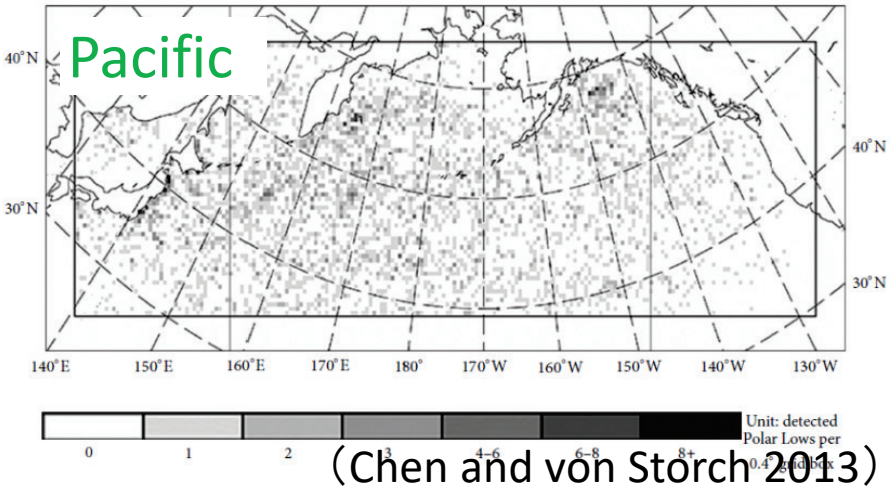
1. Introduction

Polar mesocyclones (PMCs) : mesoscale cyclones that develop in the colder side of the polar front over high-latitude oceans in winter

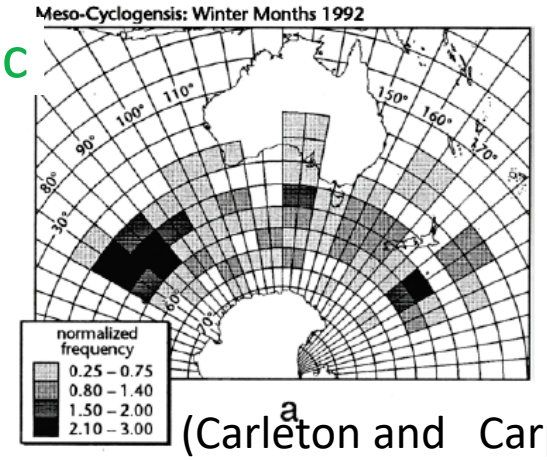


（Zahn and von Storch 2008）



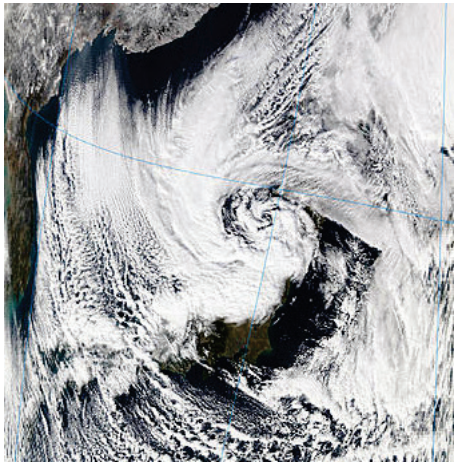
（Chen and von Storch 2013）

Antarctic



（Carleton and Carpenter 1990）

The Sea of Japan



20 DEC 2003 (MODIS)

Previous studies

- Dynamics

  Baroclinic instability (e.g.,Reed & Duncan, 1987)
  Diabatic processes (e.g., Bratseth,1985; Emanuel & Rotunno, 1989)
  Both (e.g., Yanase & Niino, 2007), Upper PV anomaly

- Climatology

  Asai(1988), Ninomiya (1989), Yarnal and Henderson (1989), Carleton and Carpenter (1990), Zahn and von Storch (2008), Kolstad (2011), Noer et al.(2011), Chen and von Storch (2013), Rojo et al. (2015)

- Case studies (The Sea of Japan)

  Miyazawa(1967), Kuroda (1992), Yamagishi et a.l (1992)
  Ninomiya(1989,1990, 1991, 1994), Fu et al. (2004a, 2004b), Yanase et al. (2004)
  Tsuboki and Asai (2004), Shimada et al. (2014), Watanabe and Niino (2014)

A few composite analyses of time-evolving environment:

- Blechschmidt et al. (2009): Nordic Seas
- Mallet et al. (2013) : Norwegian, Barents and Labrador Seas
- Yanase, Niino & Watanabe (2015): The Sea of Japan

The purpose of the present study

- clarify the time-evolving environment of the PMCs (including meso-β-scale vortices) over the Sea of Japan by composite analysis using objective analysis data.

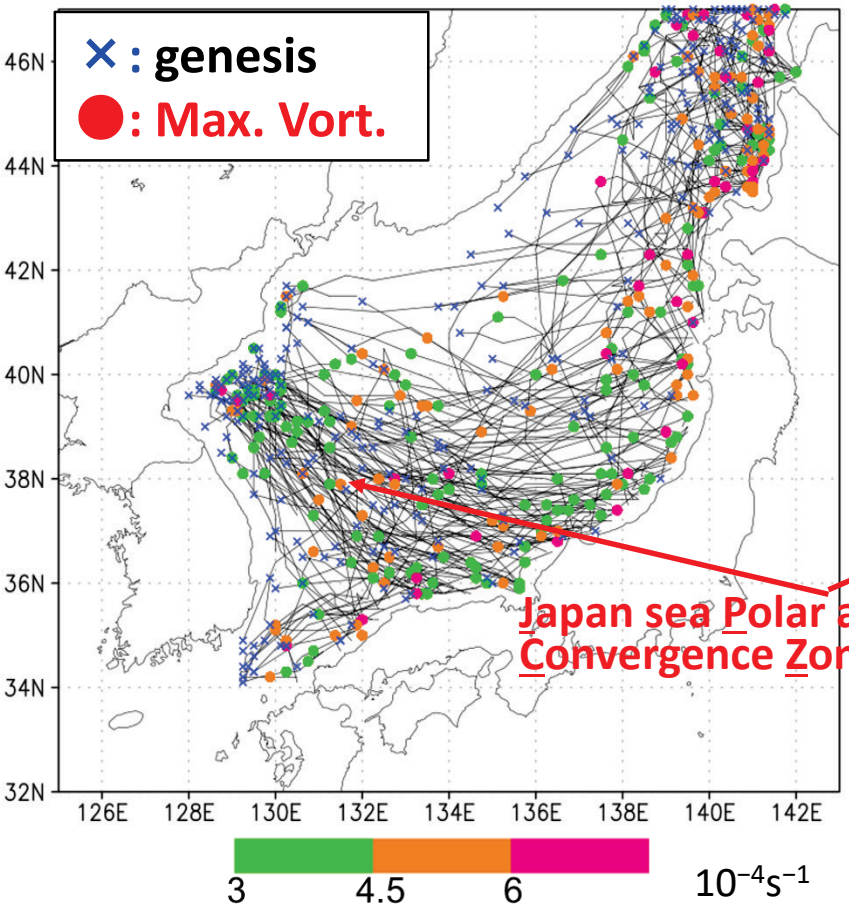
- In order to examine how representative the composite is, preform a numerical simulation in which the time-evolving composite is used as the initial and boundary conditions to see if a PMC is reproduced.

- If a PMC is successfully reproduced, examine factors important for the PMC development using sensitivity experiments.

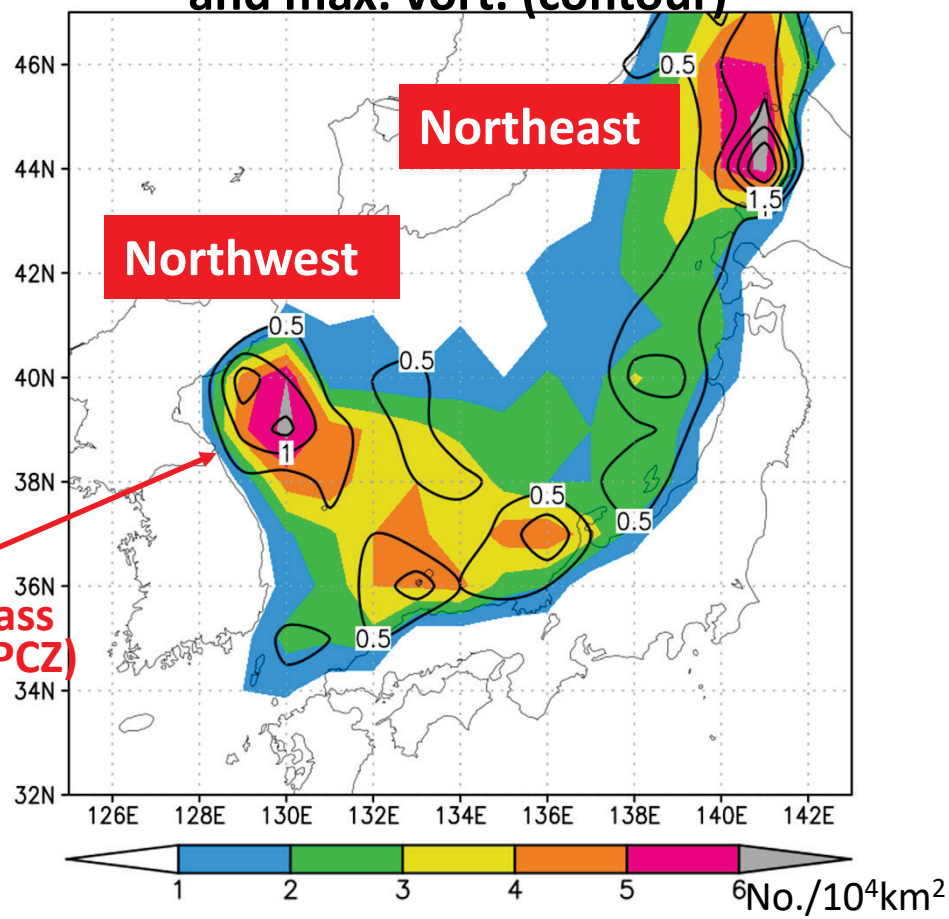
2. Geographical distribution and movements of PMCs

- **Data:** JMA Mesoscale Analysis 3 hourly; horizontal resolution: about 10km
- **Period of analysis:** 6 cold seasons (Nov.-Mar. between 2009 and 2015)
- **Tracking:** Vorticity at 950hPa after mobing average over 40km x 40km

Tracks of PMCs



Area density of tracks (shade) and max. vort. (contour)

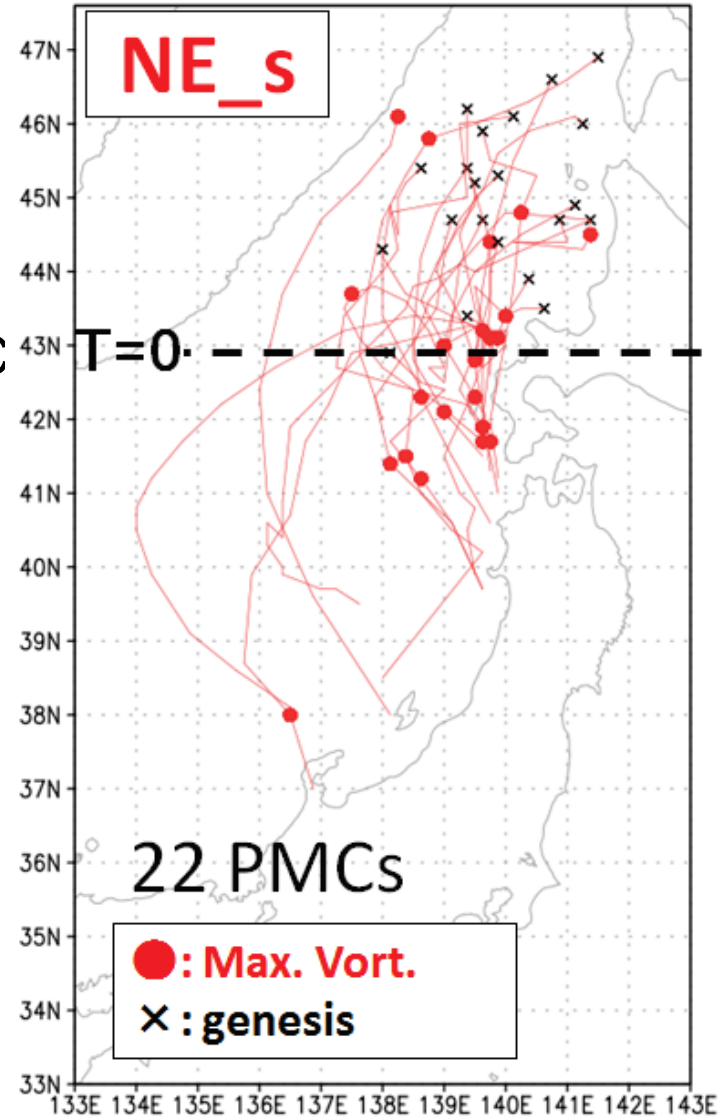


Japan sea Polar airmass Convergence Zone (JPCZ)

Watanabe, Niino and Yanase (2016 MWR)

3. Composite Analyses (Watanabe, Niino and Yanase, 2016, 2017MWR)

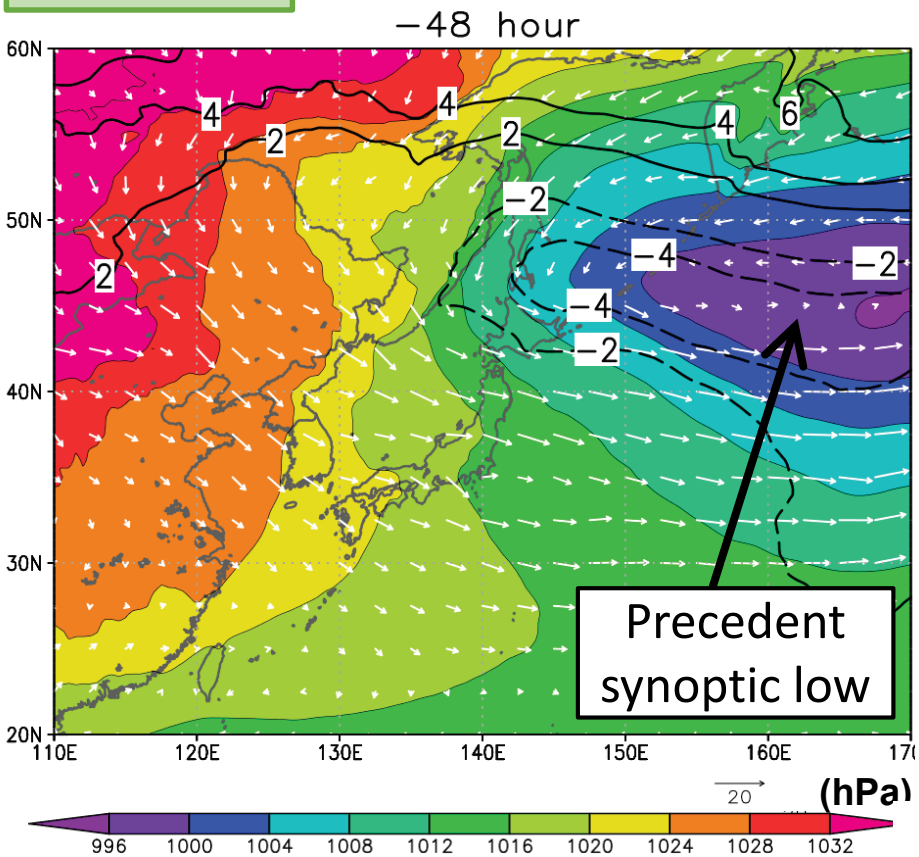
- Method
  - Data: JMA Global Analysis (GA)
    6 hourly; interpolated to 50km grid
  - Reference time (T=0): Time when a PMC is closest to 43N
  - Composite: Simple averaging of physical variables for fixed longitude and latitude
  - Mean field: 14 days average around T=0.
  - Anomaly field: (composite) – (mean)



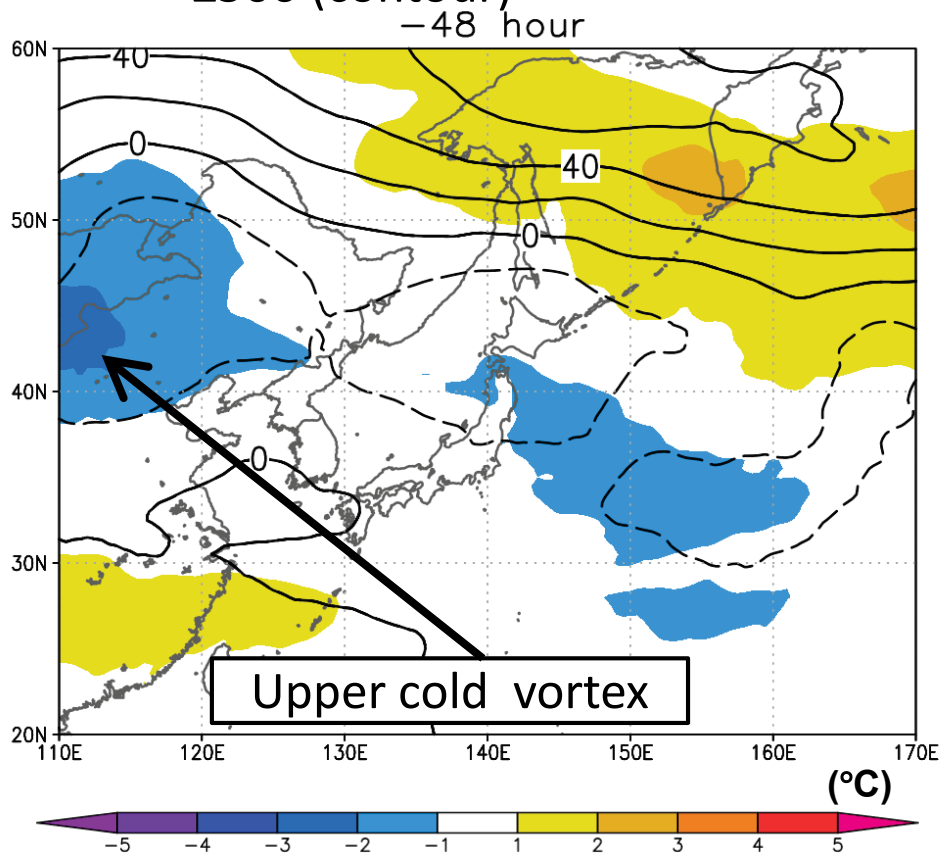
Synoptic-scale environment （GA）

T=−48h

SLP（shade）&SLP anomaly



Anomolies of T500（shade）& Z500 (contour)



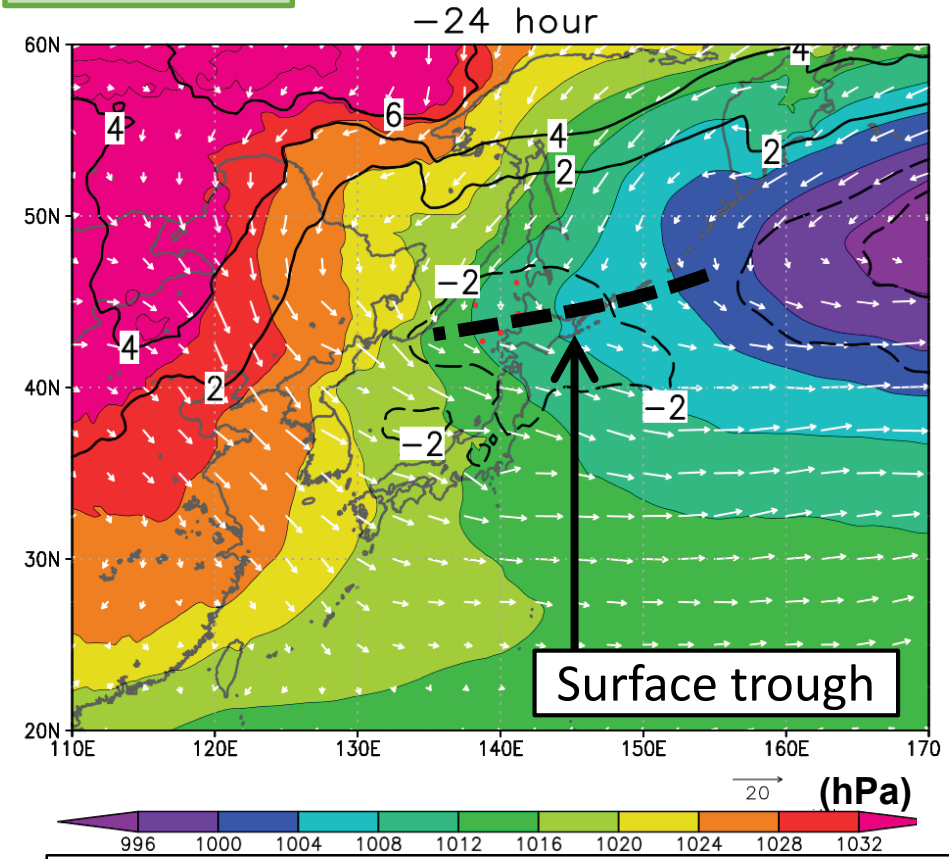
anomaly=composite−(14days-mean)

●:location of PMC

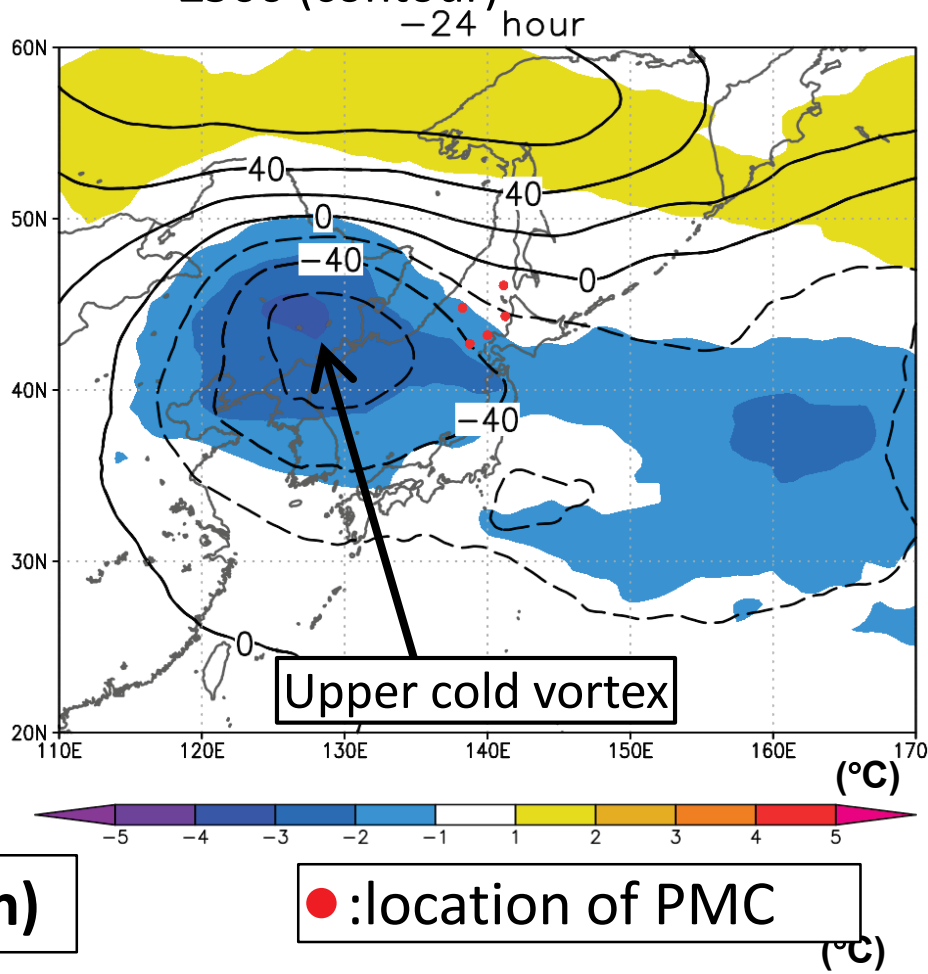
Synoptic-scale environment （GA）

T=−24h

SLP（shade）&SLP anomaly



Anomolies of T500（shade）& Z500 (contour)



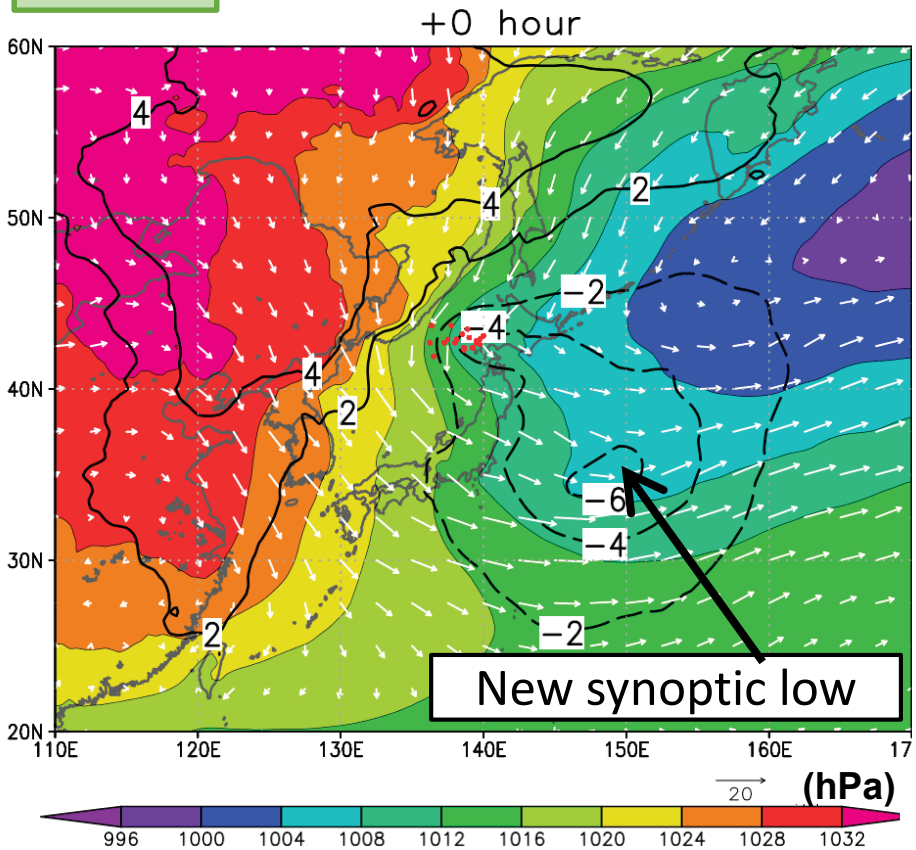
anomaly=composite−(14days-mean)

●:location of PMC

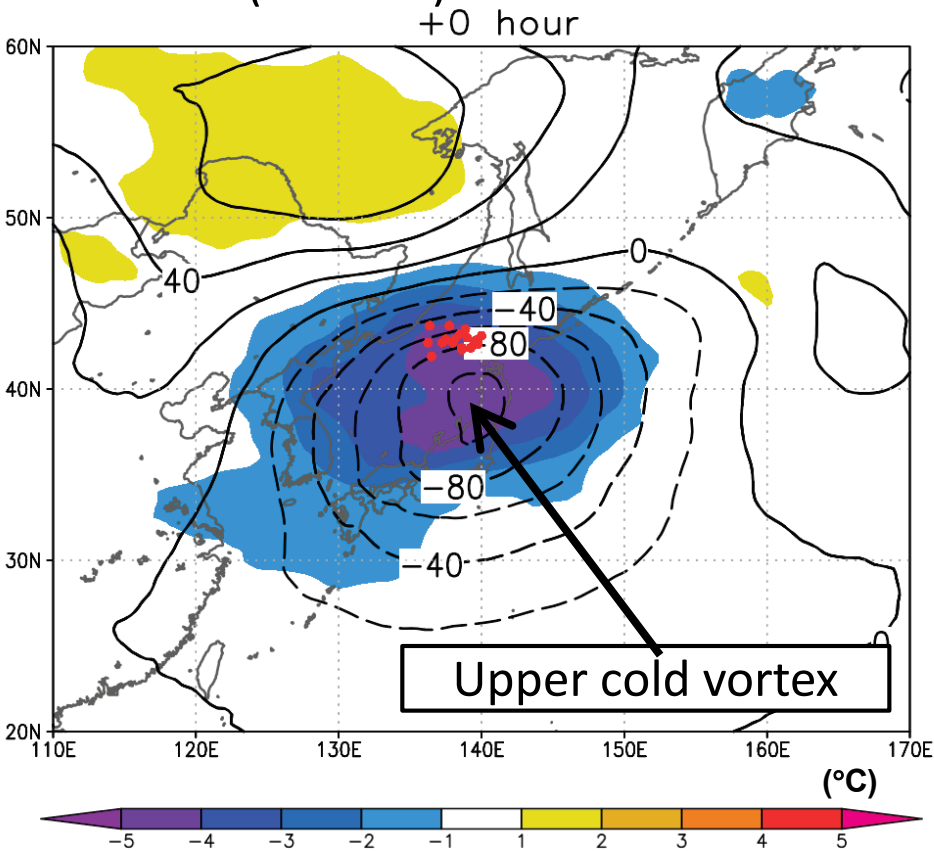
Synoptic-scale environment （GA）

T=0h

SLP（shade）&SLP anomaly



Anomalies of T500（shade）& Z500 (contout)



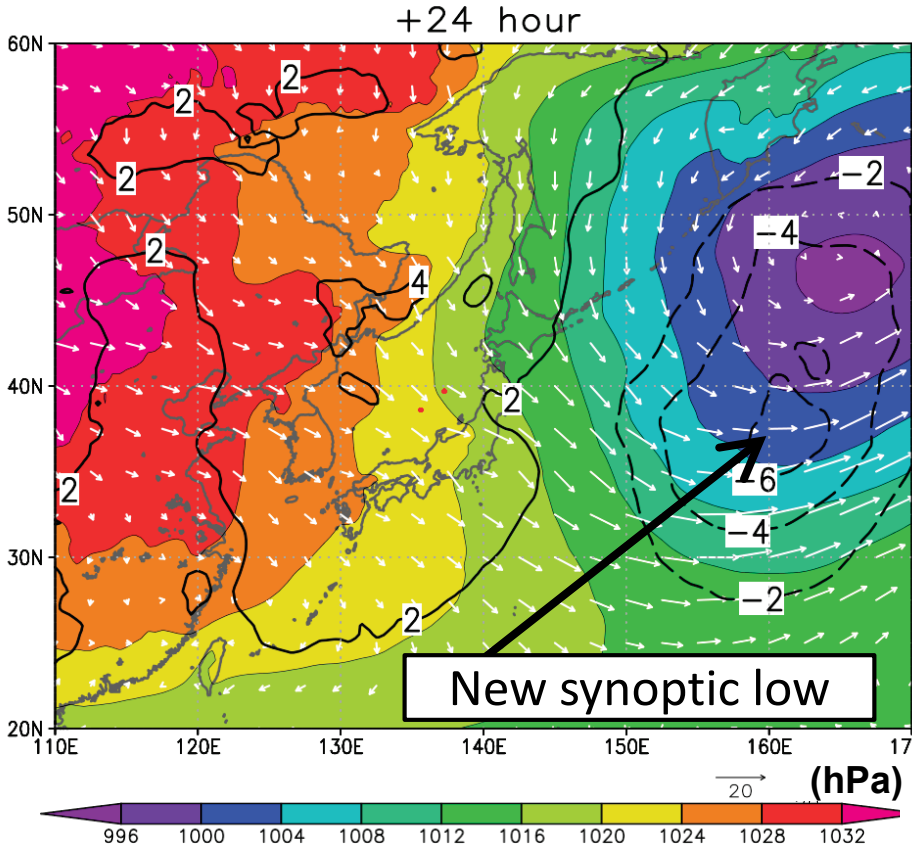
anomaly=composite−(14days-mean)

●:location of PMC

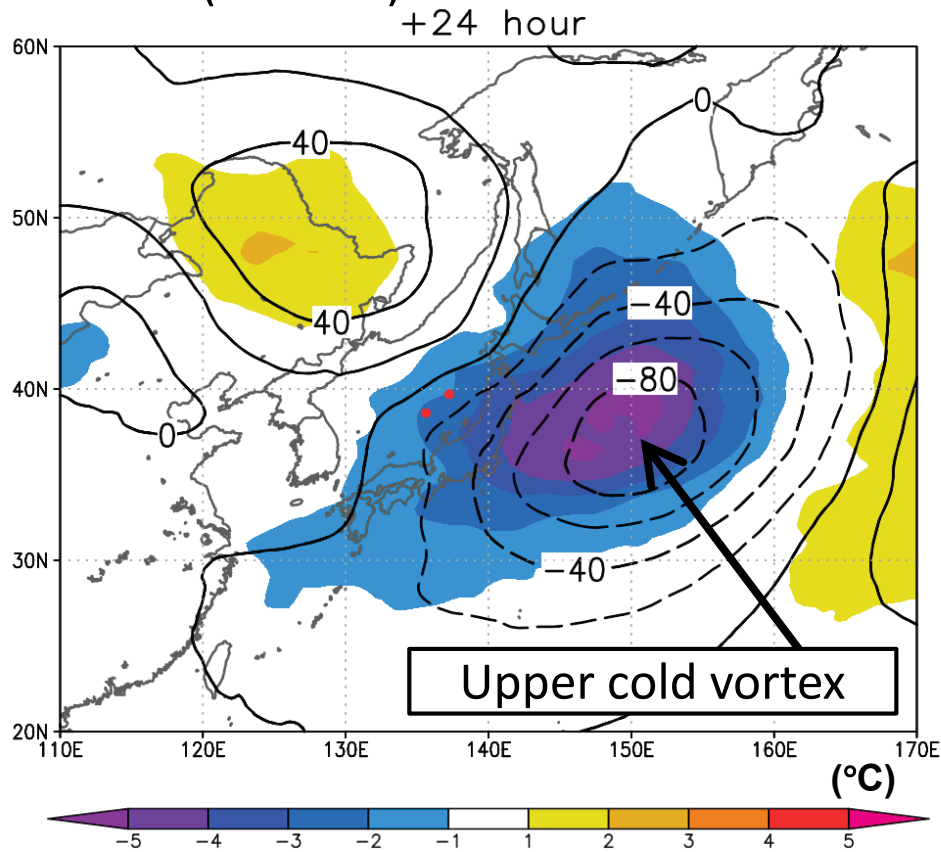
Synoptic-scale environment （GA）

T=24h

SLP（shade）&SLP anomaly



Anomalies of T500（shade）& Z500 (contout)



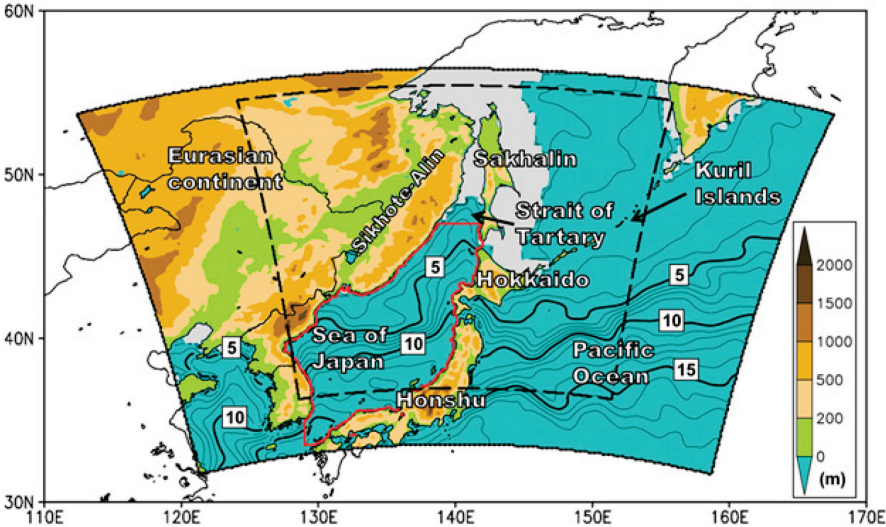
anomaly=composite−(14days-mean)

●:location of PMC

3. Simulation using composite field of GA

Numerical model	JMA-NHM
Initial & boundary conditions	Composite of GA
Initial and integration times	*T*=-48 h and 72 h
Calculation domain Vertical	The figure in the right 20m~22.1km
Horizontal resolution Vertical resoluition	10km 40m~1180m
Cloud physics	2-moment bulk (mixing ratios of cloud water, rain, cloud ice, ・snow, graupel and number density of cloud ice
Cumulus parameterization	Kain-Fritsch scheme
Turbulence	MYNN（Level3）

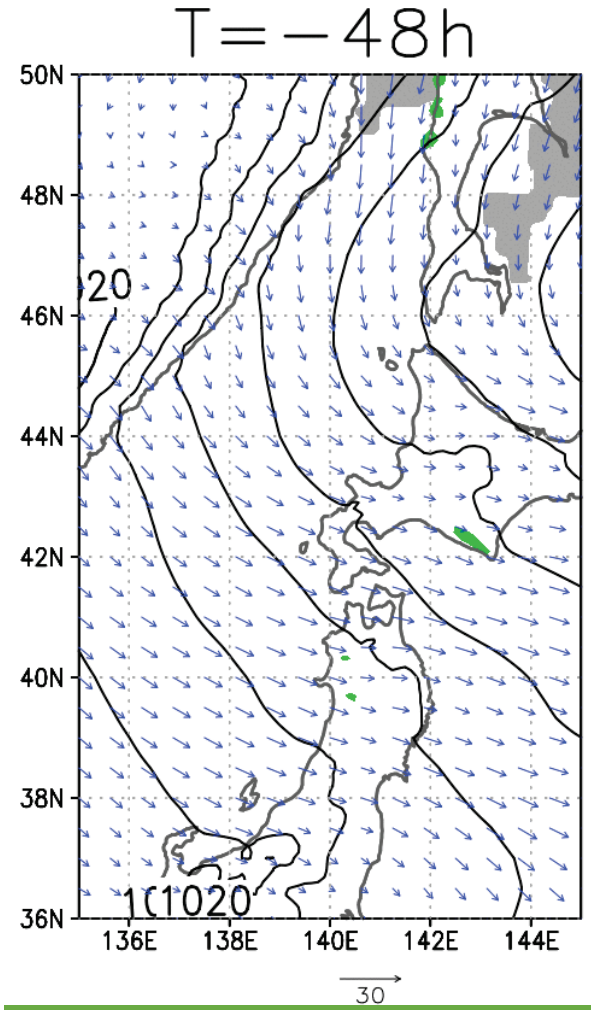
Model domain, SST and topography



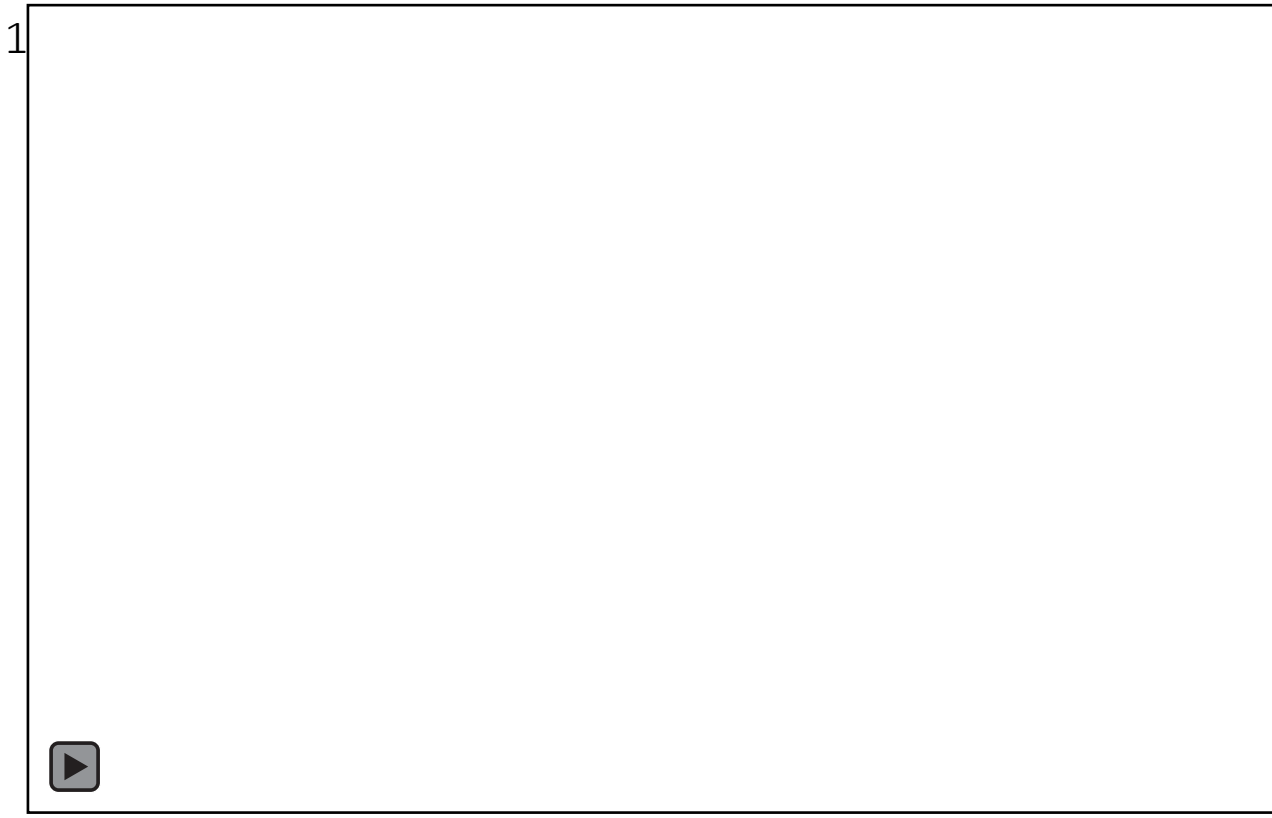
Watanabe, Niino and Yanase (2017MWR)

Simulation results

SLP, Vor.@950hPa & wind



Simulated PMC on 21 January 1997



Yanase, Niino and Saito (2002, GRL)

A PMC similar to observed cases is realistically reproduced.

Structure of the PMC

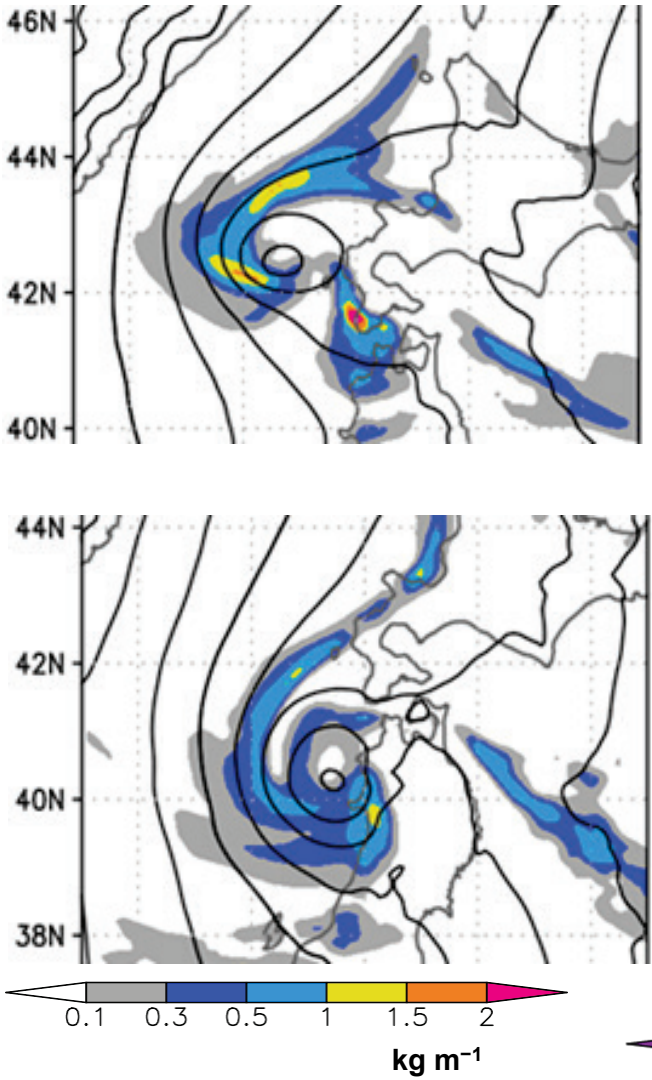
T=6h

Comma-shaped

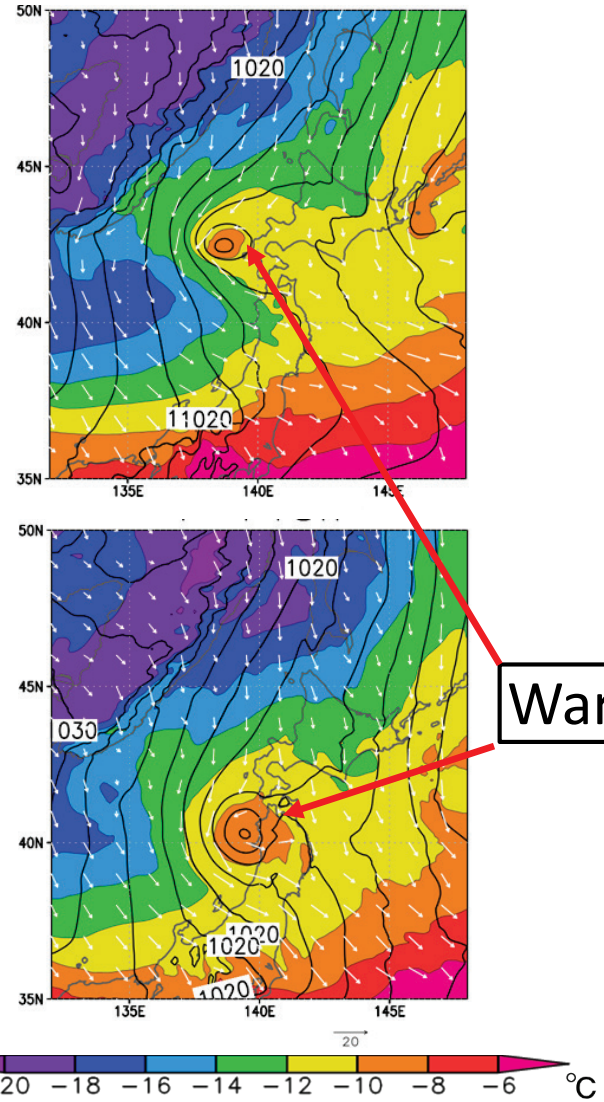
T=18h

Spiraliform

Vertically-integrated water substances



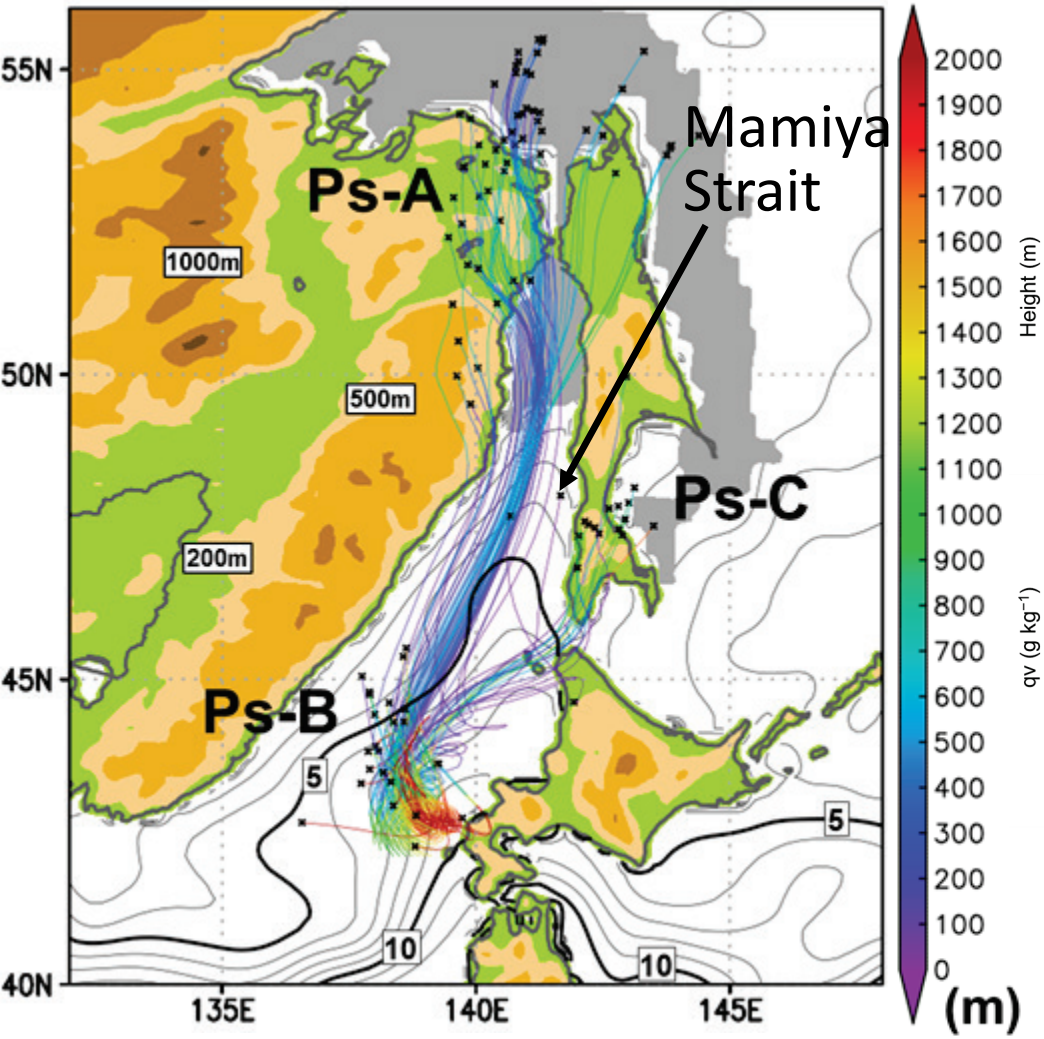
T @ 850 hPa & SLP



Warm core

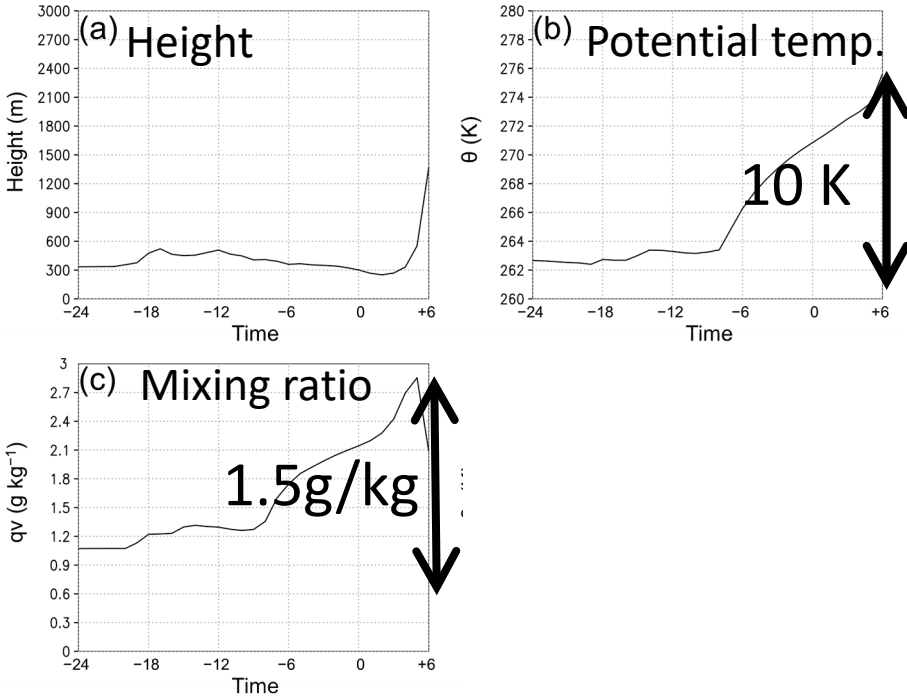
Formation process of the warm core

Backward trajectories（after −24 h）



98 parcels at z=1350m at T=6 hours

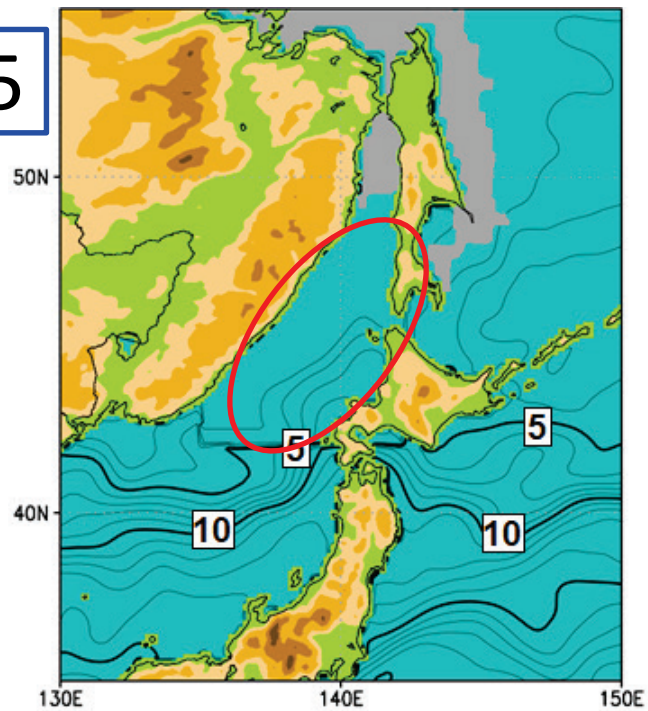
For Ps-A:

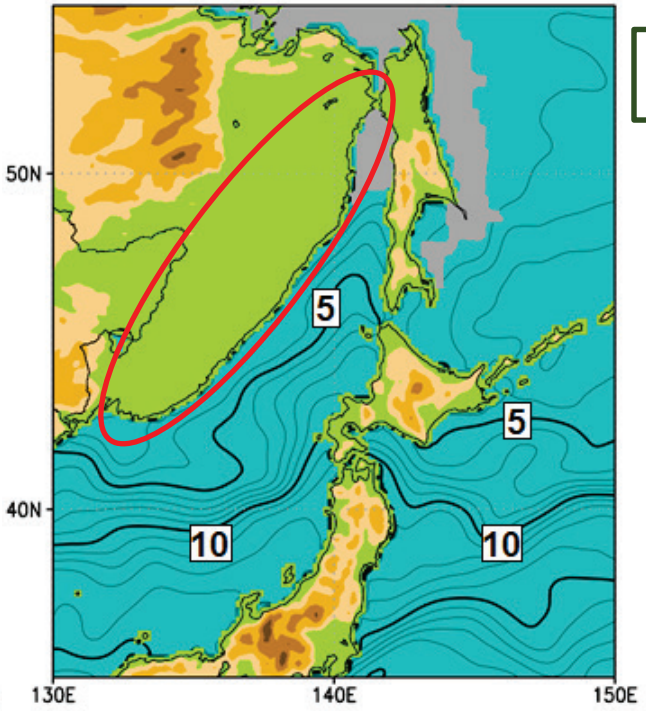


Sensitivity experiments

Experiments	
CNTL	Control
DRY_T−24	Dry exp. after T=−24 h when the PMC is formed in CNTL.
DRY_T0	Dry exp. After T=0h when the PMC is at a development stage in CNTL.
SST−5	SST to the west of Hokkaido island is 5 degree lower.
No_Mt	Topography higher than 100m ASL along the Russian coast is removed.

SST−5

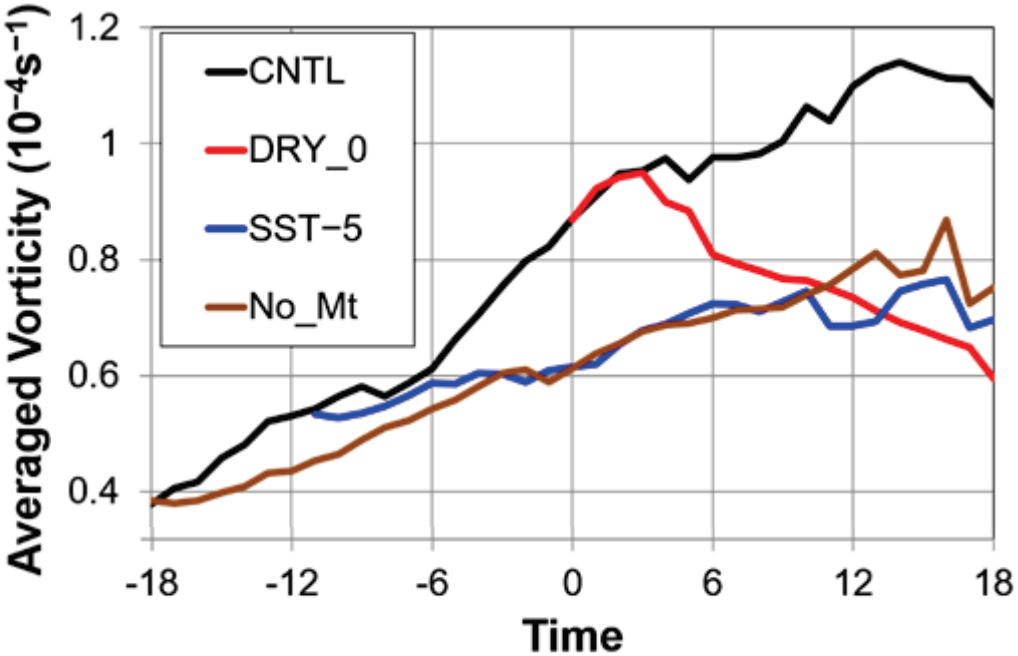




No_Mt

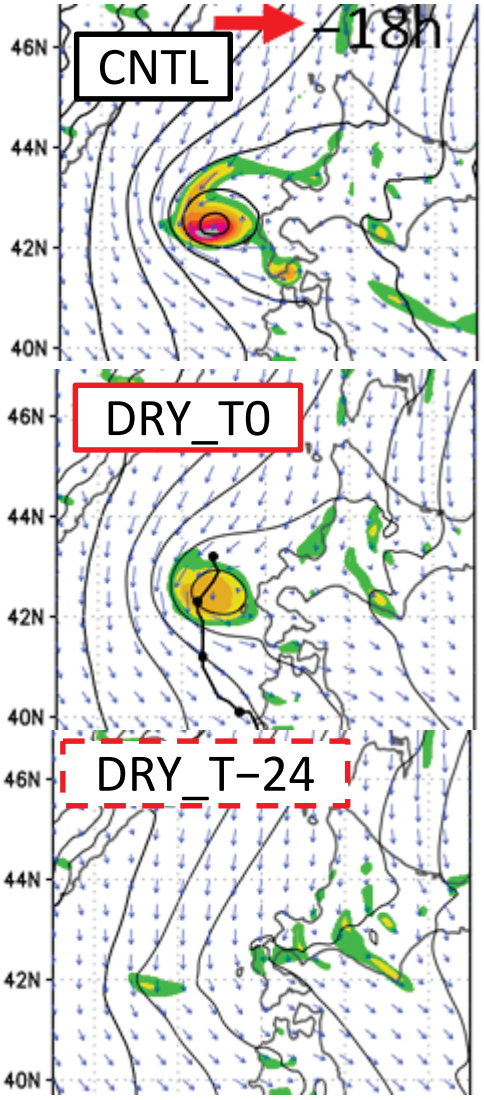
Sensitivity experiments

Average vorticity within 150km radius (850-950 hPa)



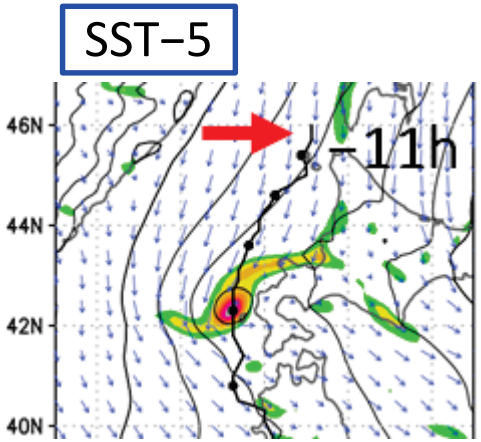
SLP(contour),Vorticity (shade) & wind at 950hPa

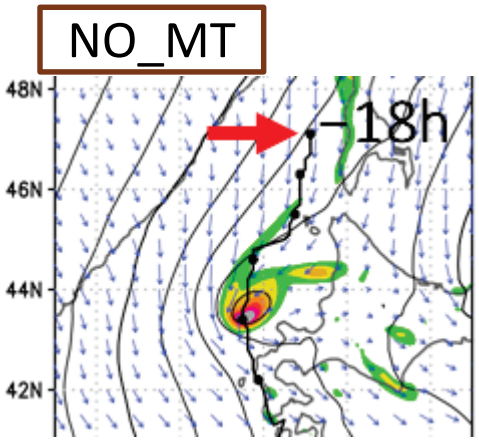
T=+6h



Condensational heating essential for genesis and development of the PMC.

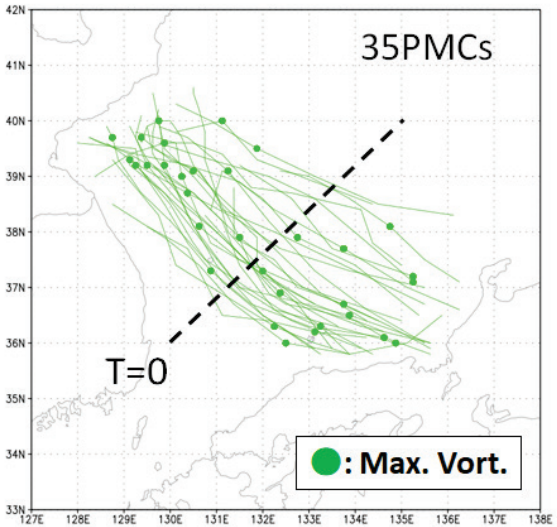
Topography and SST important for the development through airmass transformation

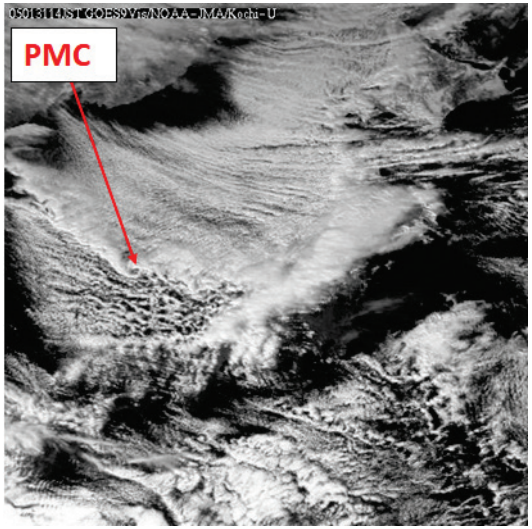




→: location of the PMC genesis

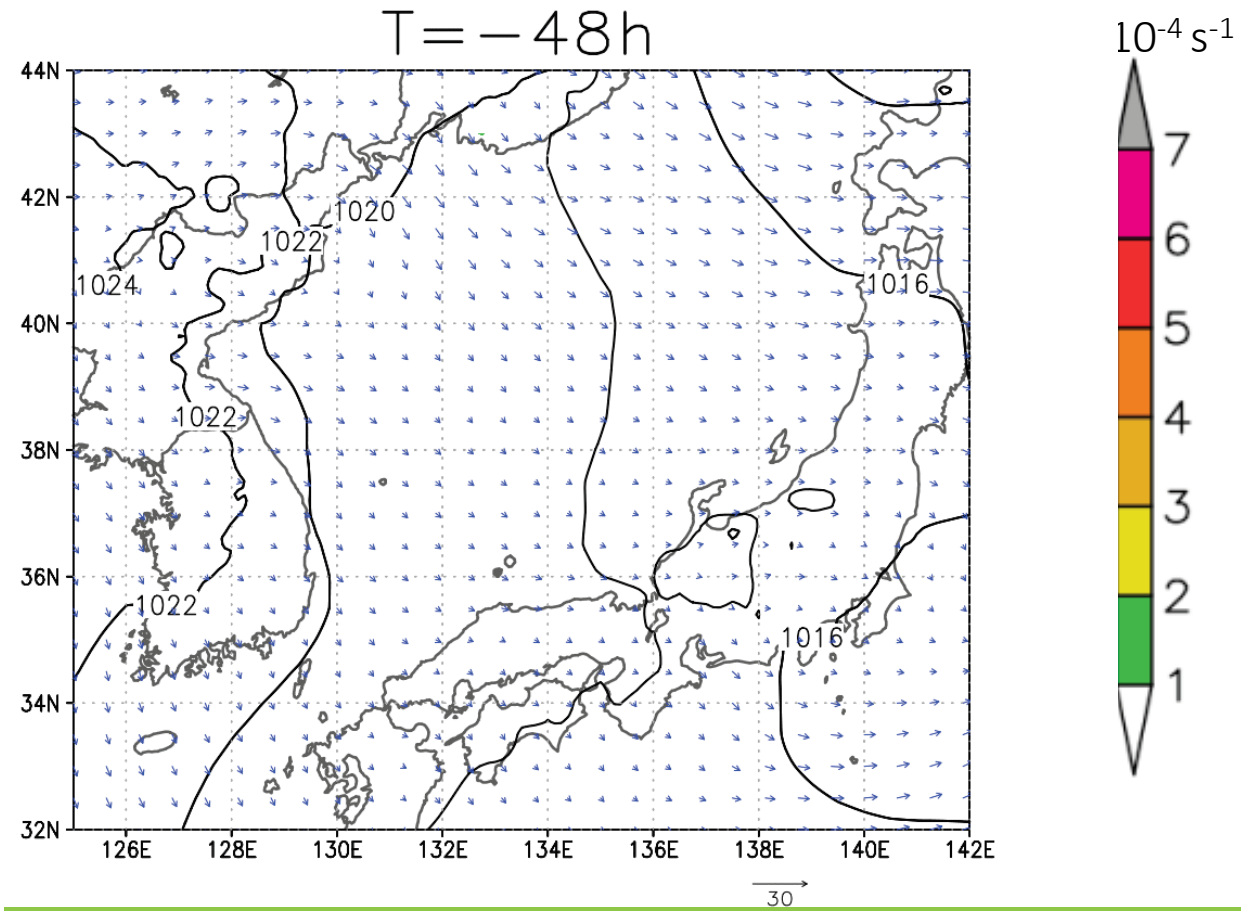
PMCs in the northwest part (of the Sea of Japan)





Watanabe, Niino and Yanase (2017, MWR submitted)

Vort. (shade) and wind (arrow) at 950hPa & SLP (contour)



PMCs similar to observations were successfully reproduced.→Importance of Baekdu mountain, upper cold vortex and condensational heating

4. Summary

- **Composite analyses of environment and structure of PMCs (including meso-β-scale)**
  - surface trough extending westward from synoptic low
  - zonal temperature gradient due to zonal advection
  - upper cold vortex
- **Successful reproduction of a realistic PMC using the composite fields as the initial and boundary conditions.**
  - representative environment given by the composite
  - warm core formation mechanism
- **Sensitivity experiments revealed important factors for the PMC development.**
  - condensational heating
  - airmass transformation elatively warm SST
  - mountains at the east coast of the Eurasian continent

20 DEC 2003
(MODIS)