Future changes in winter storm activity in a high-resolution AGCM

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Temperature change by global warming

- In the upper troposphere, warming is smaller in the high latitudes than the tropics
  → larger meridional temperature gradient
  →Storm activity seems to become stronger.

- Near the surface, warming is larger in the high latitudes than the tropics
  → smaller meridional temperature gradient
  → Storm activity seems to become weaker.

T [K] DJF HF(2075−2099)−HP(1979−2003)
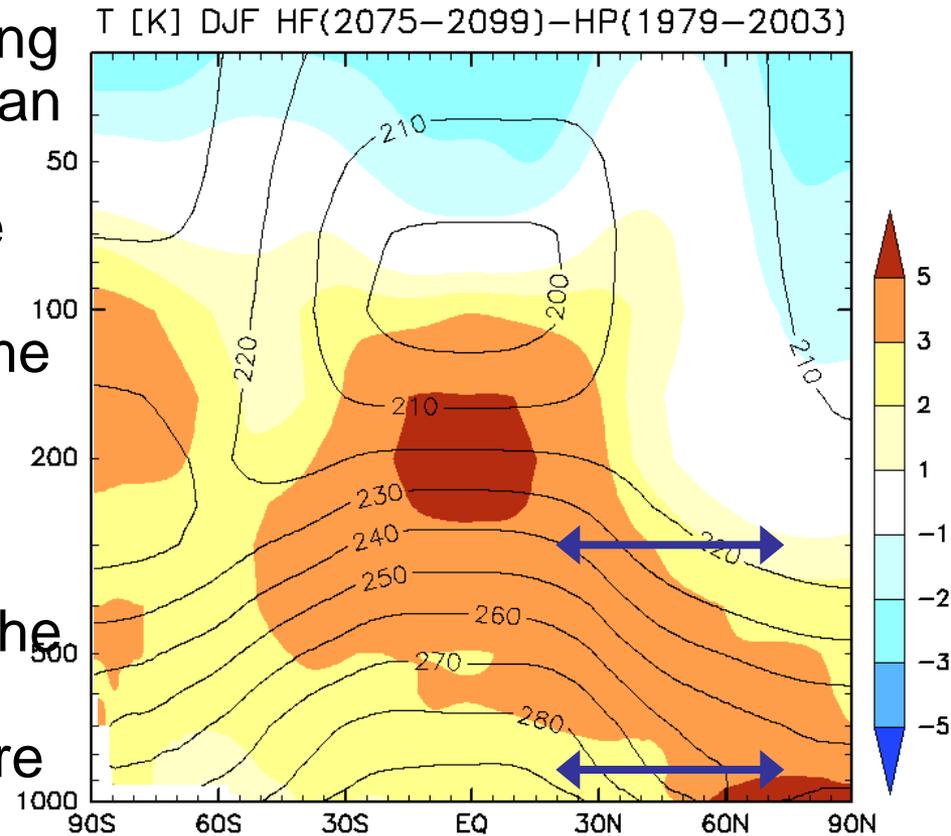
Zonal-mean Temperature (DJF)
[Future experiment] – [Present experiment]

Future change in CMIP3(IPCC-AR4) multi-model ensemble

(a) DJF EKE (m²s⁻²)
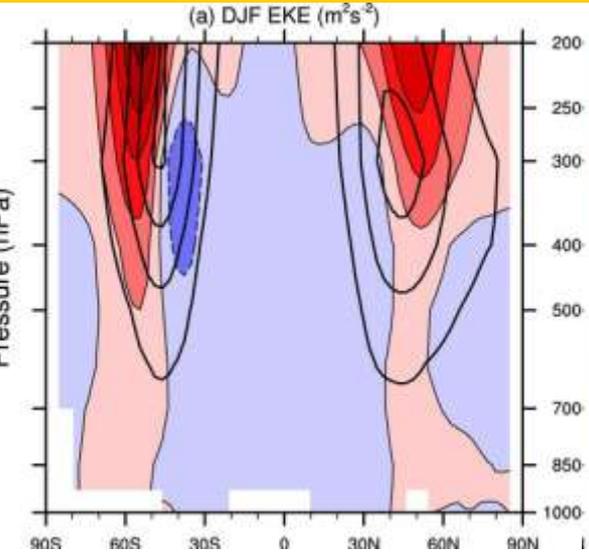
2.5-8day Eddy Kinetic Energy

multi-model ensemble mean (DJF)

Yin (2005)

- Synoptic-scale activity ("storm tracks")
  - More increase in the upper levels
  - Increase at the polar side of the present peak
  - Increasing signal even near the surface

Total cyclone number   "Strong" cyclone number (<970hPa)

~+10%

0

Present   2100   Present   2100

multi-model results (NH,annual)   Lambert and Fyfe (2006)
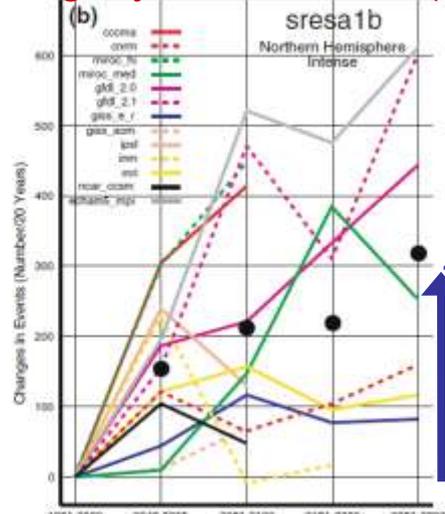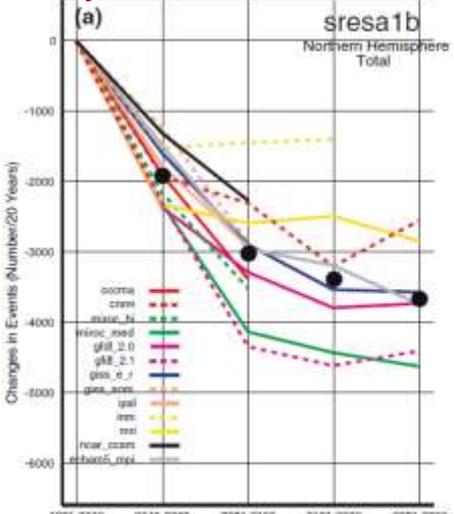
- When tracking extratropical cyclones..
  - Number of cyclones decreases
 - Only "strong" cyclones increase

In this study..

- Changes in the storm activity in the future climate, especially in the Northern winter, is investigated..

  - by using high-resolution atmospheric general circulation models that can simulate detailed structures of cyclones and can simulate future change similar to the multi-model ensemble

  - how the storm activity change corresponds to the change in the number of cyclone tracks

  - correspondence between the upper tropospheric change and the near-surface change

Model and Experimental settings

- JMA/MRI global atmospheric climate model
- Long-term climate experiments using the Earth Simulator
- 20km(TL959L60), 60km (TL319L60), 120km (TL159L40)

- Present-day climate experiment (1979-2003)
  - the observed SST and sea-ice concentration
- Future climate experiment (2075-2099)
  - the SST warming in the CMIP3 multi-model ensemble mean is added to the observed SST
- 3 initial value ensembles with the 60km model

Mizuta et al. (2008)
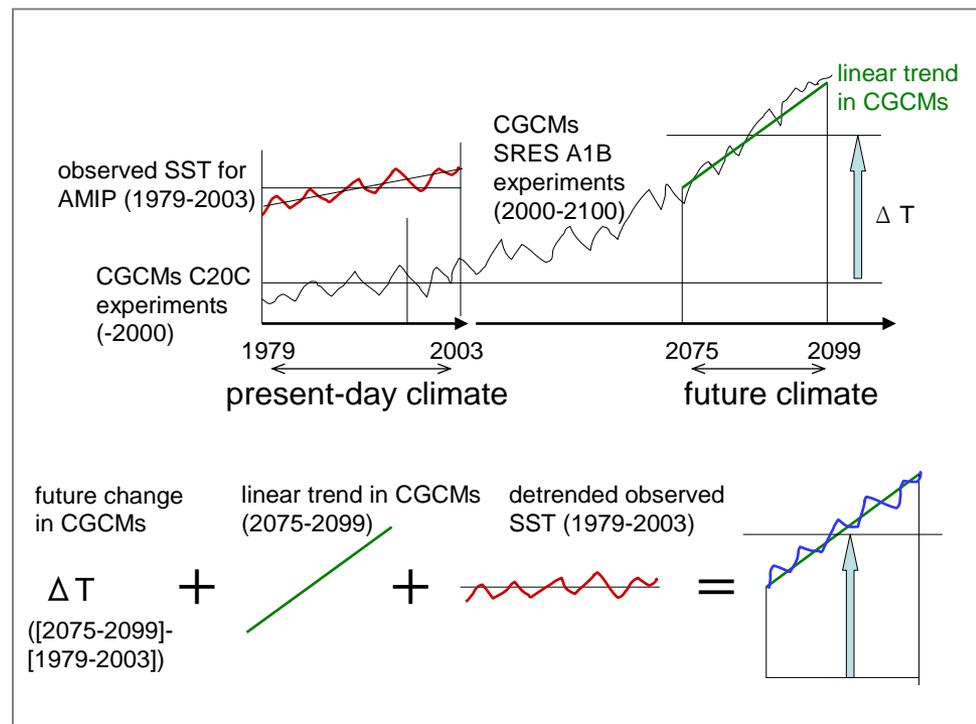
Cyclone tracking method

- Following Geng and Sugi (2001,2003),

- using 6-hourly SLP interpolated into 1.25 degree grid,

    1. A point is identified as a cyclone if its SLP is lower than any of surrounding 8 points and lower than the average of the 8 point by 0.3hPa (points with altitudes higher than 1500m are excluded).

    2. When a cyclone is advected for 6 hours by 700hPa 15day running mean wind, if a cyclone at the next step is found within 300km, a sequence of cyclones is regarded as one track.
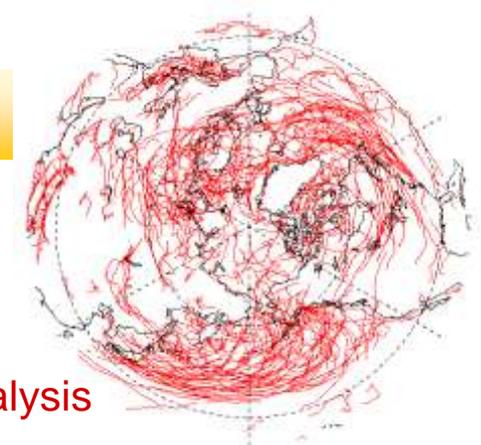
JRA25 Reanalysis
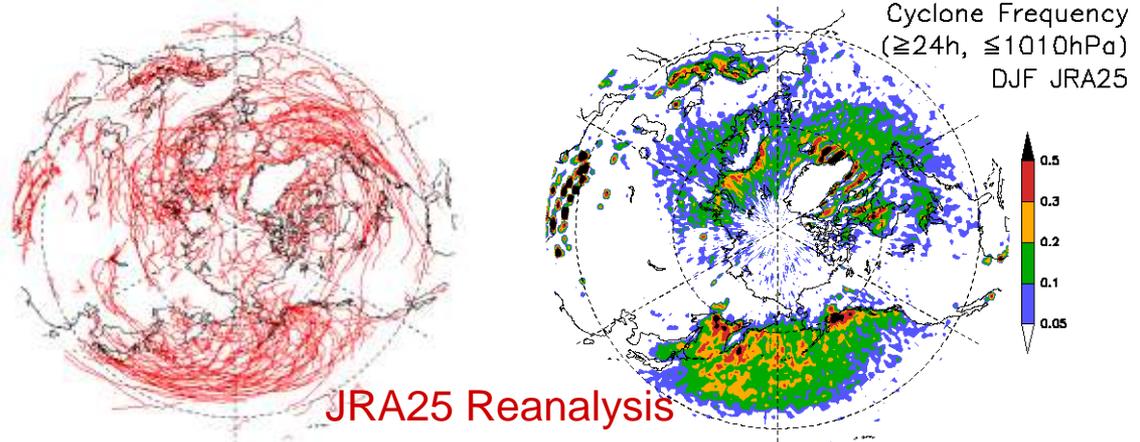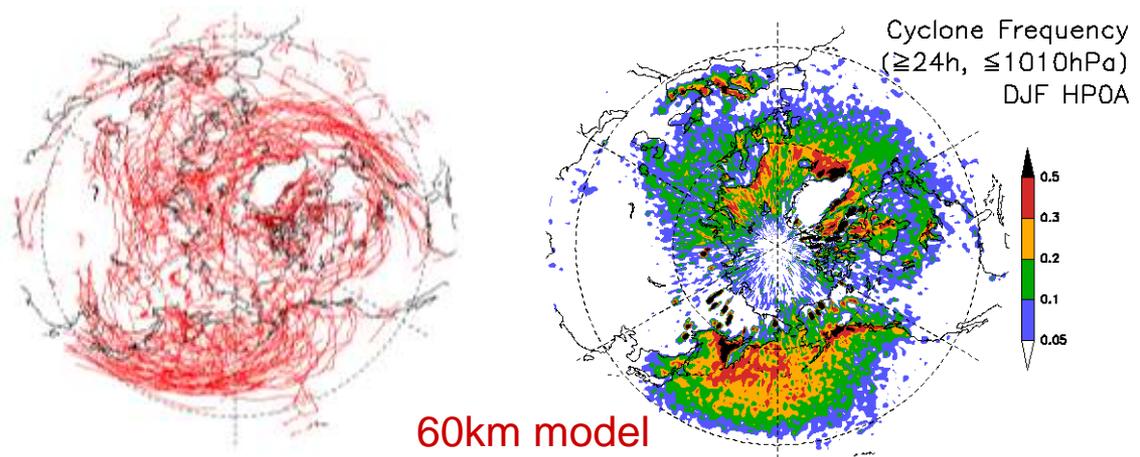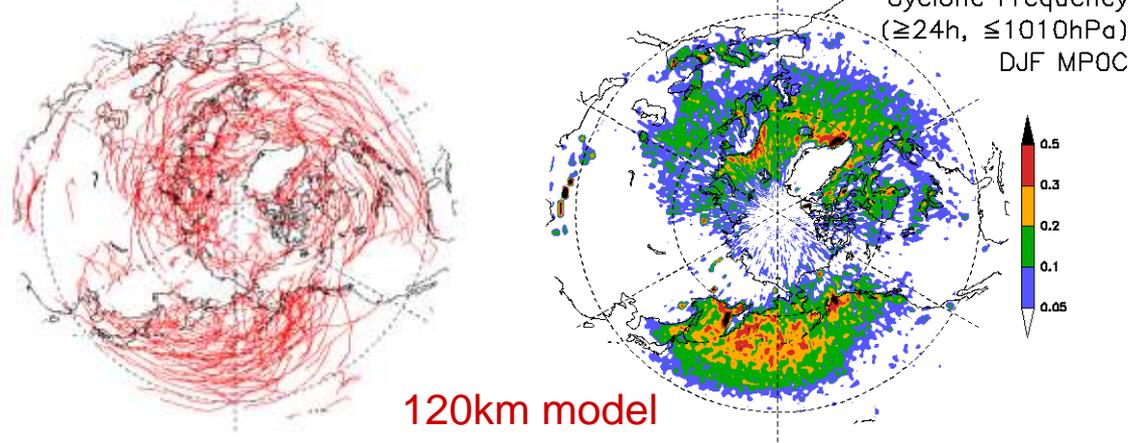
Cyclone Tracks (2001-2002,DJF)
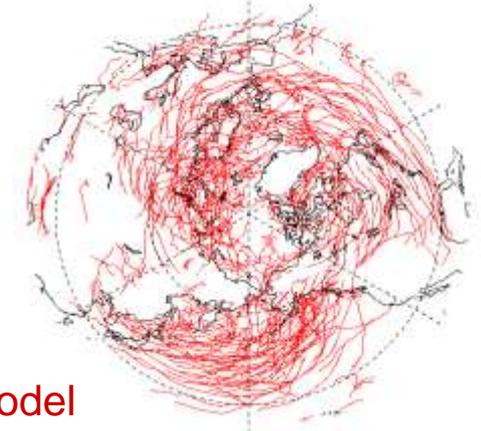
120km model
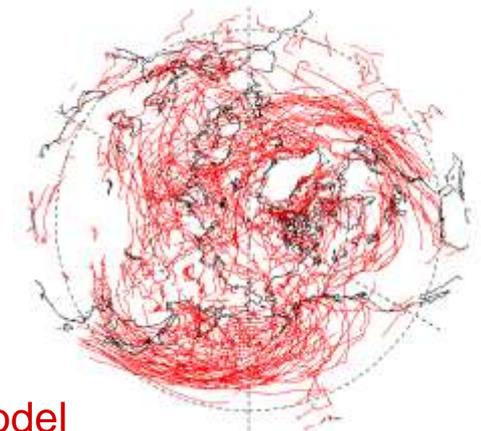
60km model

Cyclone tracking

JRA25 Reanalysis

Cyclone Tracks (2001-2002,DJF)   Cyclone Frequency (1979-2003,DJF)

120km model

60km model

- JRA25(T106,120km) and 120km model results are comparable

- More cyclones are picked up by increasing resolution

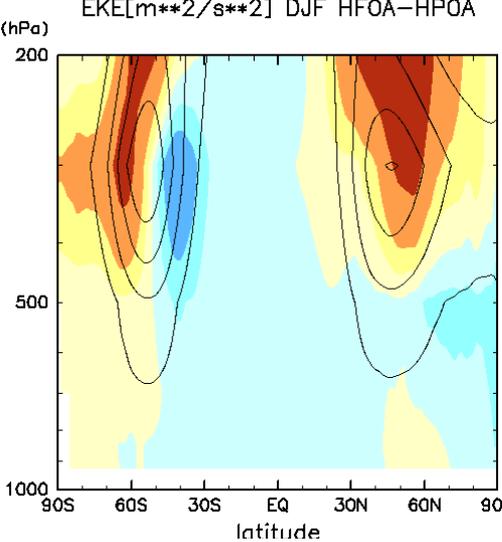- Spatial distributions are well simulated in any resolutions

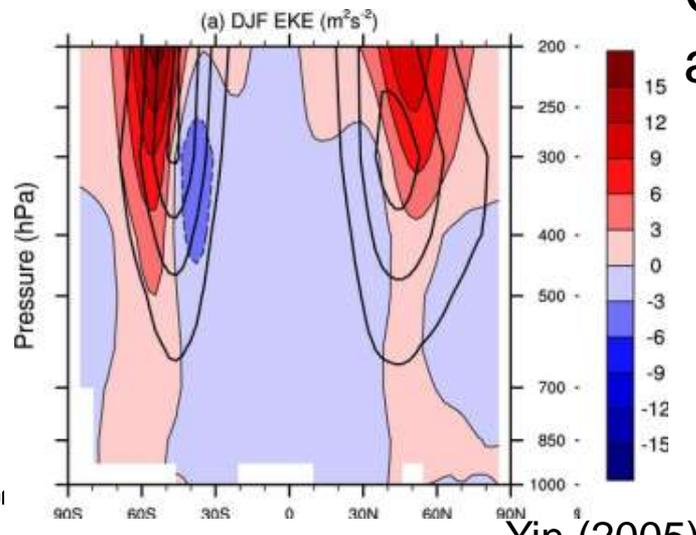# *Changes in storm track activity*

2.5-8day Eddy Kinetic Energy (DJF) [Future] - [Present]

60km model

multi-model ensemble mean

Yin (2005)

HFx3-HPx3 850hPa DJF

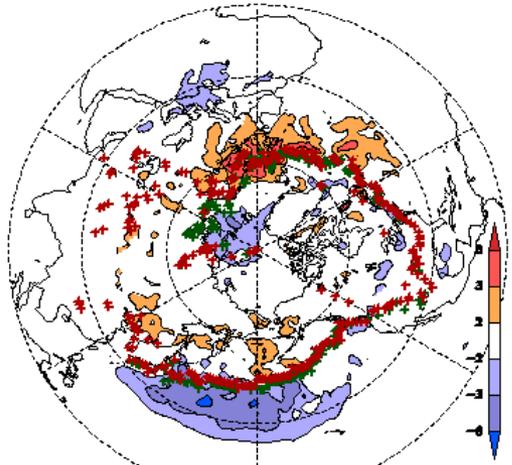850hPa, 60km model, 3 ensembles

SLP, std.dev. multi-model ensemble mean Ulbrich et al. (2008)
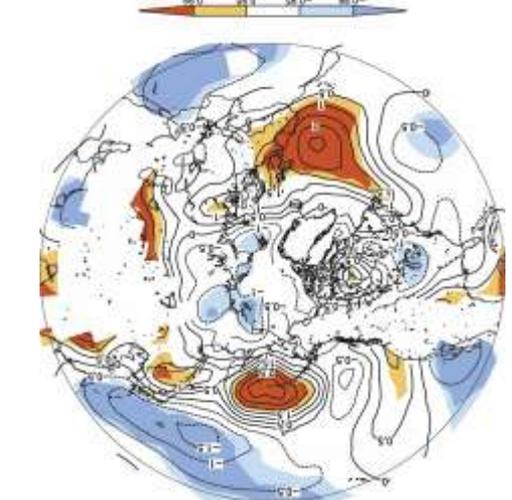
- Changes in storm track activity
  - More increase in the upper levels
  - Increase at the polar side of the present peak
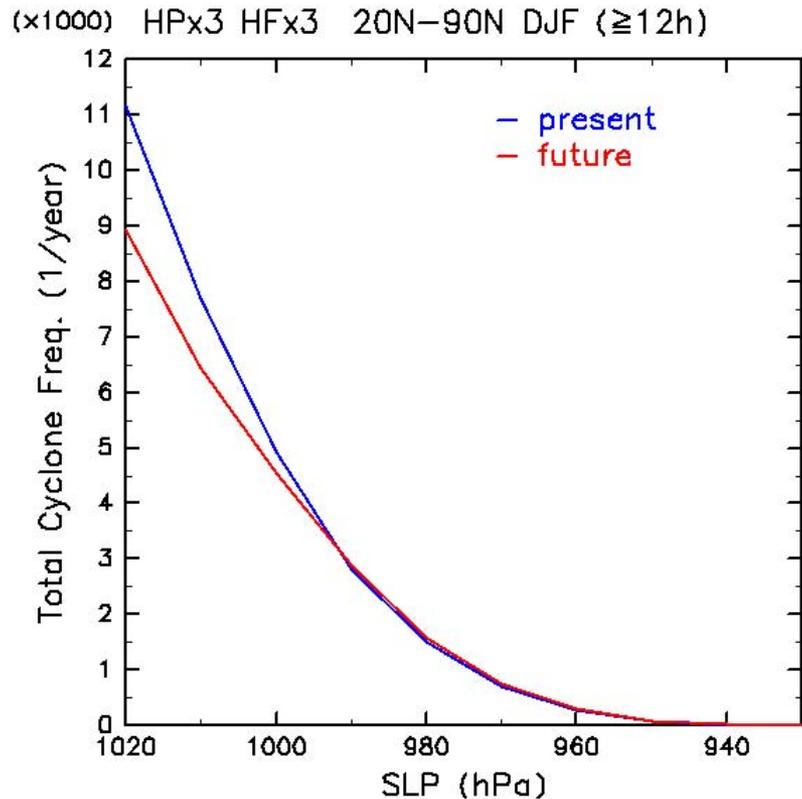 - Increasing signal even near the surface
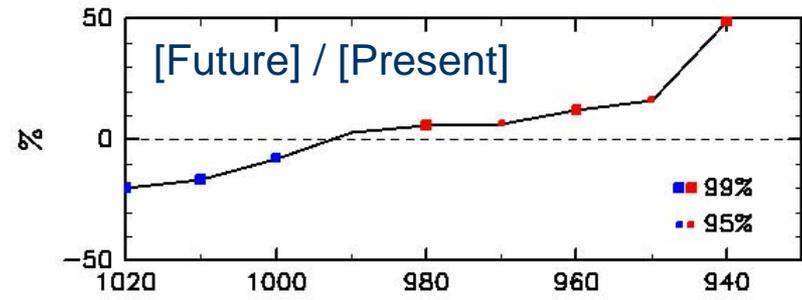
- Change in the lower levels
  - Increase in the down-stream of the storm track
  - Decrease in the upstream

Changes in cyclone frequency

(×1000) HPx3 HFx3 20N−90N DJF (≥12h)

Frequency of cyclones as a function of threshold pressure

(60km model, 3 ensembles)

[Future] / [Present]
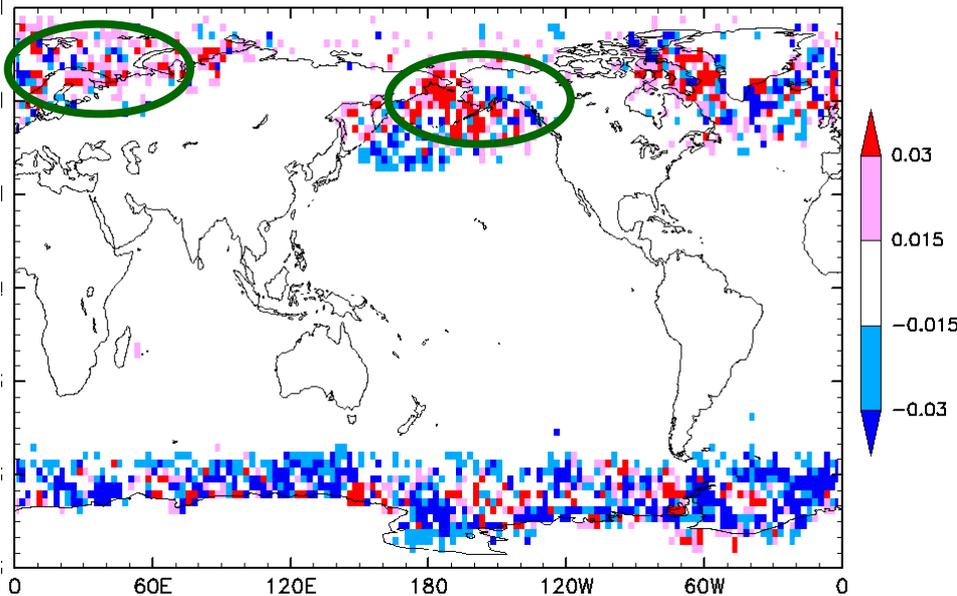
- Frequency of the cyclones detected by the tracking method
- Total number of cyclones significantly decrease
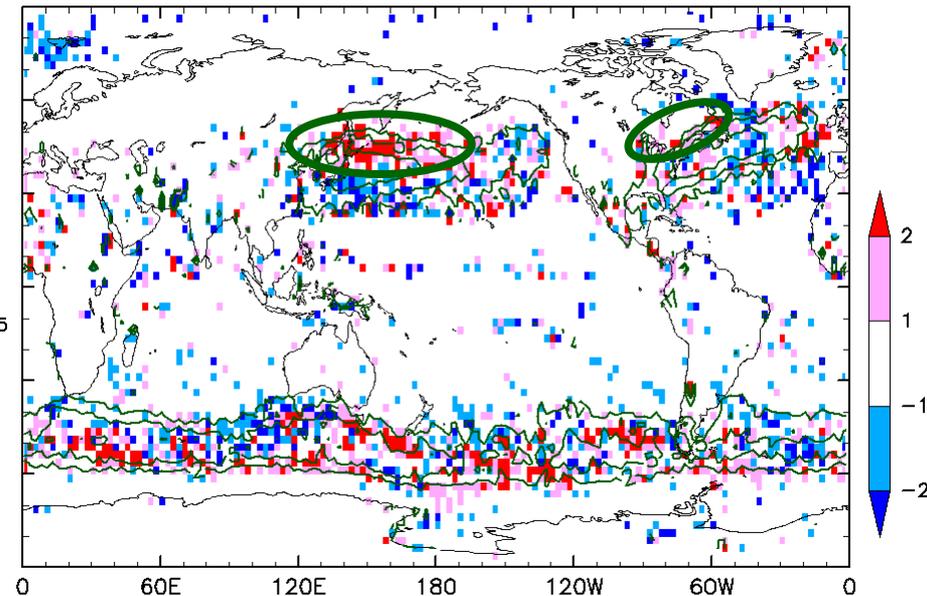- Strong cyclones significantly increase

Changes in cyclone frequency, cyclone growth rate

Cyclone Frequency (≧12h, ≦980hPa)
DJF HFx3−HPx3

Cyclone Growth Rate HF0Ax3−HP0Ax3 DJF

Cyclone Frequency (strong) [Future] - [Present]

Cyclone Growth Rate   [Future] - [Present]

- Strong cyclones increase in the downstream of the storm tracks
  → contribute to the enhancement of activity
  → enhanced cyclone development ?

- Growth Rate = temporal change of SLP along the track

$$\sigma_{\text{SLP}} = -(\text{SLP}_{t+} - \text{SLP}_{t-})$$

  – Increase at the polar side of the present peak

Changes in baroclinicity

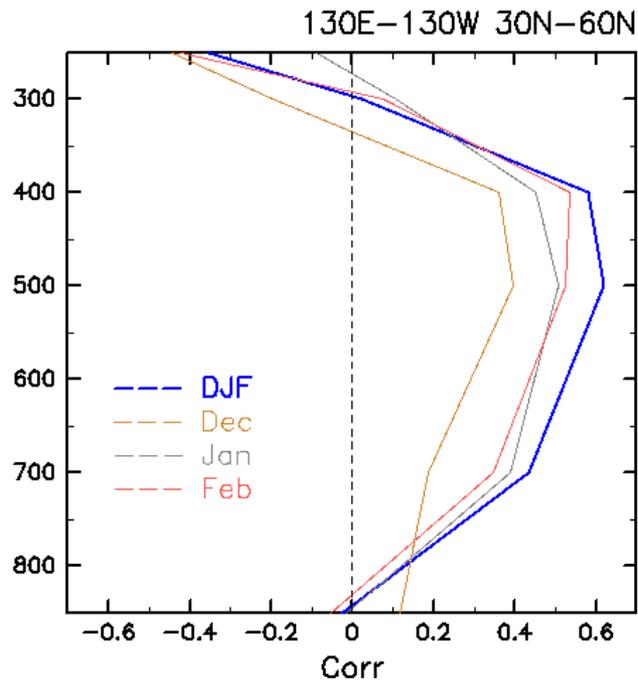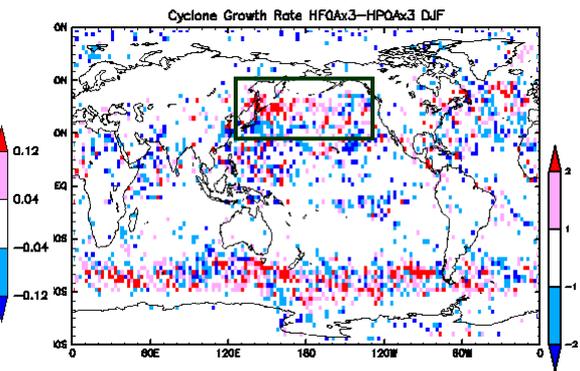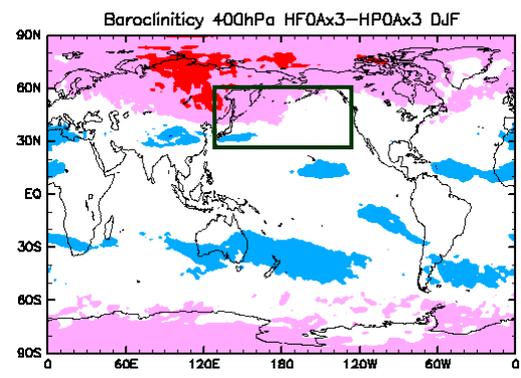- Baroclinicity (maximum Eady growth rate; Lindzen and Farrell 1980)

$$\sigma_{\mathrm{BI}} = 0.31 g N^{-1} T^{-1} \nabla T$$

  – Increase at higher levels of polar region

Baroclinicity 400hPa HF0Ax3-HP0Ax3 DJF

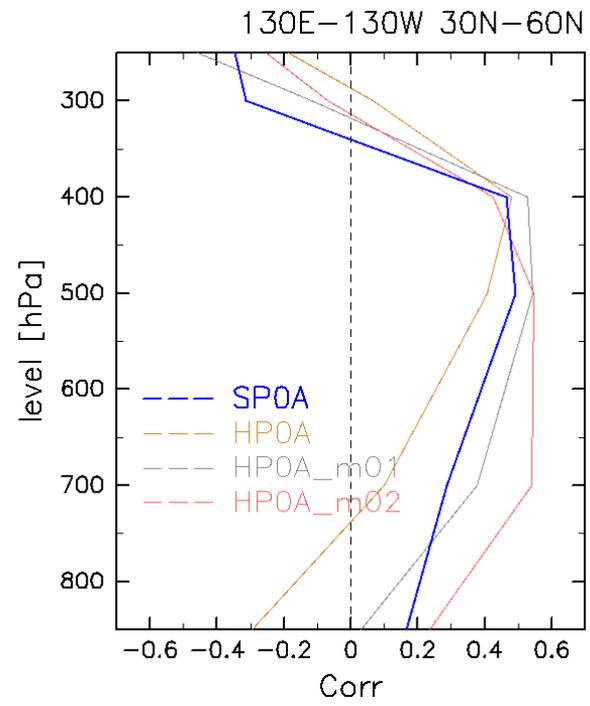T [K] DJF HF(2075-2099)-HP(1979-2003)

Baroclinicity 850hPa HF0Ax3-HP0Ax3 DJF
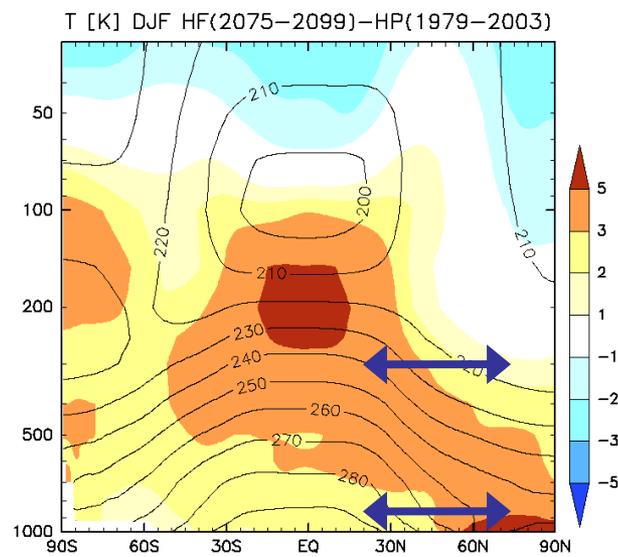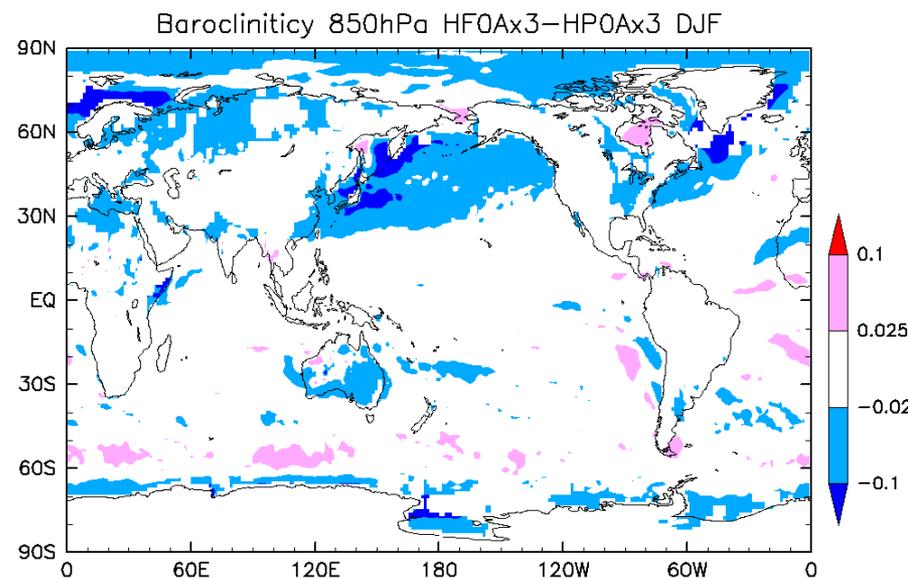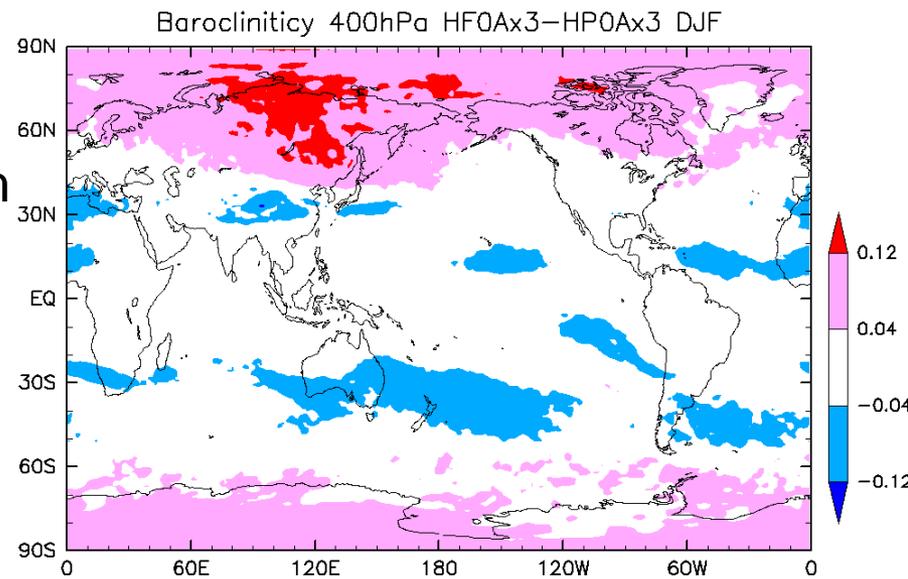
Changes in baroclinicity

- Pattern correlation between the cyclone growth rate change and baroclinicity change (Pacific region)

Baroclinicity 400hPa HF0Ax3-HP0Ax3 DJF

Cyclone Growth Rate HF0Ax3-HP0Ax3 DJF

130E-130W 30N-60N

DJF
Dec
Jan
Feb

130E-130W 30N-60N

SP0A
HP0A
HP0A_m01
HP0A_m02

Each month of 3-member ensembles   DJF of each member

Changes in the upper levels

- Contributions of the terms of $\Delta\sigma_{BI}$ (400hPa)

$$\sigma_{BI} = 0.31 g N^{-1} T^{-1} \nabla T$$

$$\Delta\sigma_{BI} \sim \sigma_{BI} \cdot \frac{\Delta(\nabla T)}{\nabla T} + \sigma_{BI} \cdot \frac{\Delta(\nabla N^{-1})}{\nabla N^{-1}}$$

- poleward shift of large temperature gradient = poleward shift of the jet
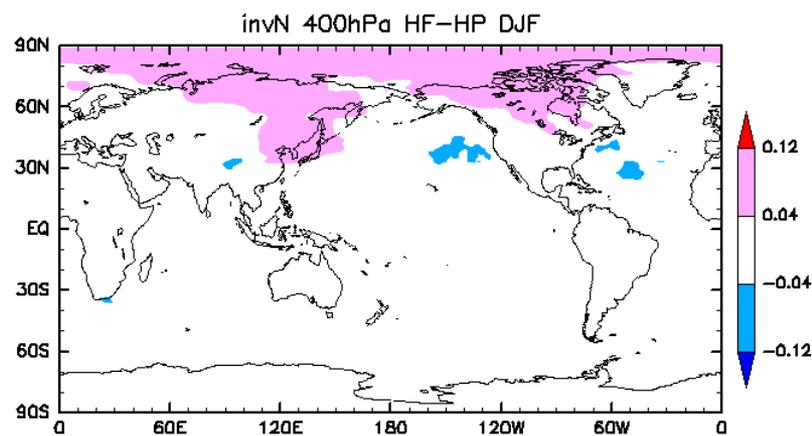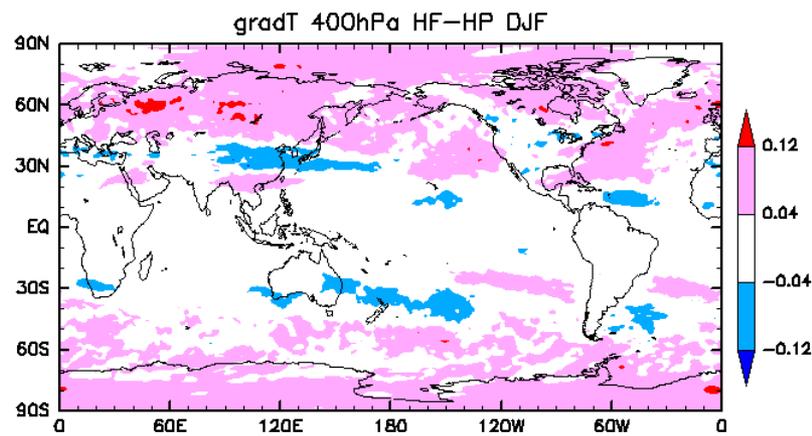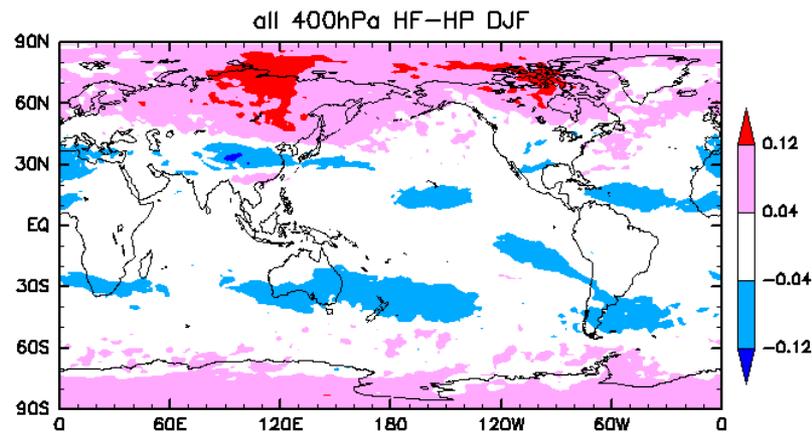
- decrease in the stability

Total

$\Delta\sigma_{BI}$

Contribution by temperature gradient

$$\sigma_{BI} \cdot \frac{\Delta(\nabla T)}{\nabla T}$$

Contribution by stability

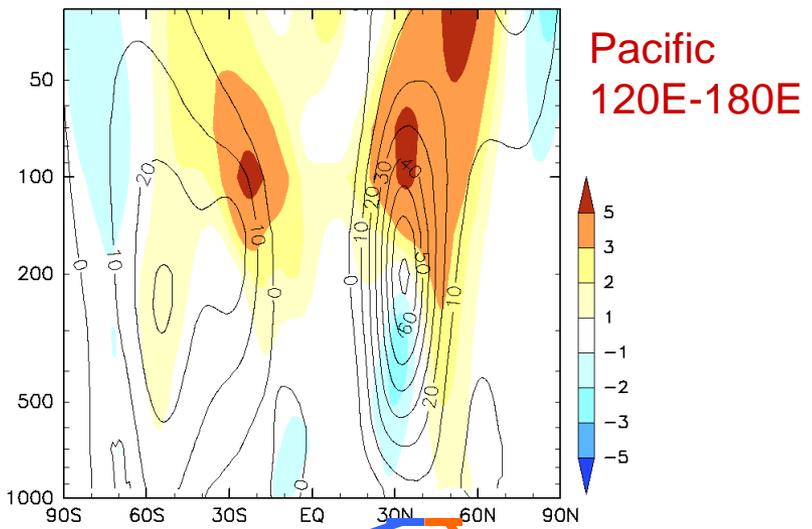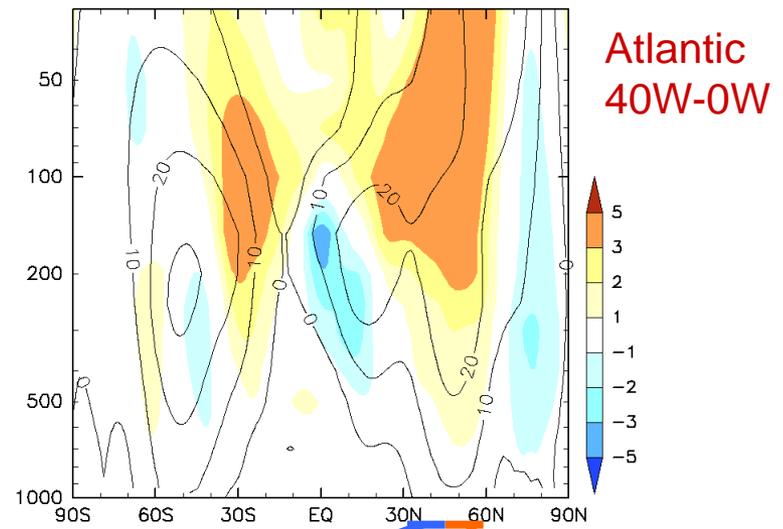$$\sigma_{BI} \cdot \frac{\Delta(\nabla N^{-1})}{\nabla N^{-1}}$$

all 400hPa HF-HP DJF

gradT 400hPa HF-HP DJF

invN 400hPa HF-HP DJF

Correlation between jet and cyclone growth rate

U [m/s] HF0Ax3−HP0Ax3 120E−180E DJF

Pacific
120E-180E

U [m/s] HF0Ax3−HP0Ax3 40W−0W DJF
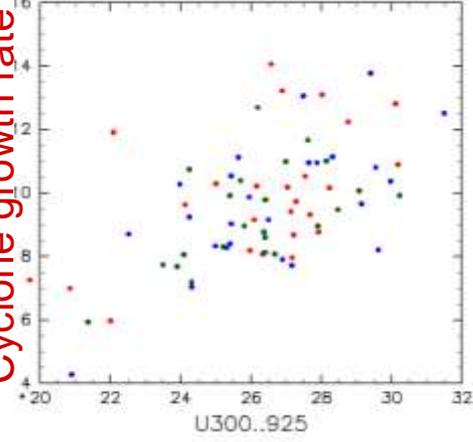
Atlantic
40W-0W

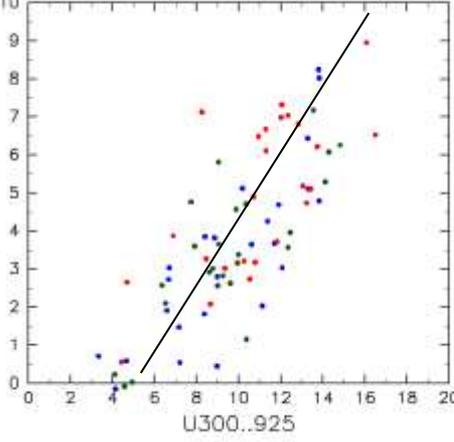25N-40N   40N-55N   30N-45N   45N-60N
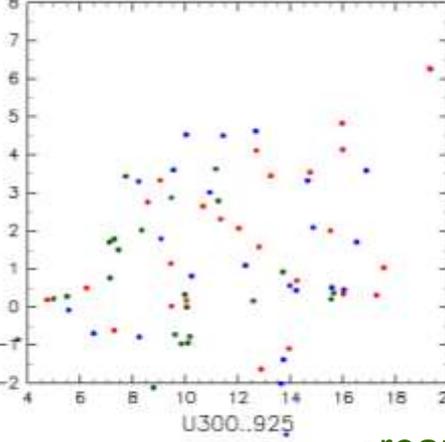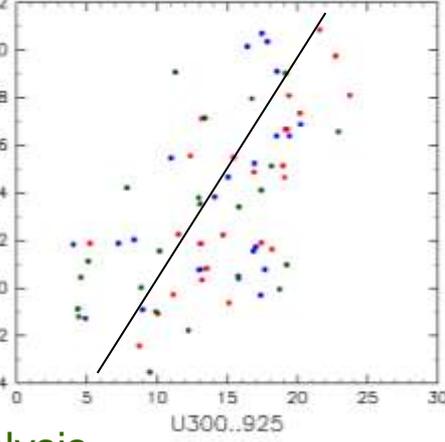
Cyclone growth rate

120E-180W 25N-40N Jan   120E-180W 40N-55N Jan   40W-0W 30N-45N Jan   40W-0W 45N-60N Jan

U300..925

Vertically averaged zonal wind

· reanalysis
· present
· future

Summary

- Future changes in the wintertime cyclone behaviors are investigated using a high-resolution AGCM forced by the SST change expected by the CMIP3 multi-model ensemble.

- The total cyclone number decreased in the future experiments, associated with the decrease of baroclinicity near the surface.

- On the other hand, storm activity and number of strong cyclones are increasing in the downstream of the storm track, which is associated with the enhancement of cyclone developments.

- Baroclinicity in the upper troposphere increases, and spatial pattern of this change is found to be similar to the pattern of change in cyclone growth rate, especially in the Pacific. Poleward shift and enhancement of the jet can affect the change in the cyclone growth.