Analysis of realization of Northern Hemisphere storm-tracks in simulations of climate model INM RAS CM5

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CITES-2019, Moscow, 4 June 2019

Outline

- Storm tracks in Northern Hemisphere
- Data and analysis method: INM CM5 historical simulations & NCEP, ERA-Interim reanalysis
- Results

- Realization of storm tracks in model simulation
- Storm tracks response on Strong / Weak Arctic stratospheric polar vortex events with tropospheric impacts
- Storm tracks response on Arctic amplification

- Summary

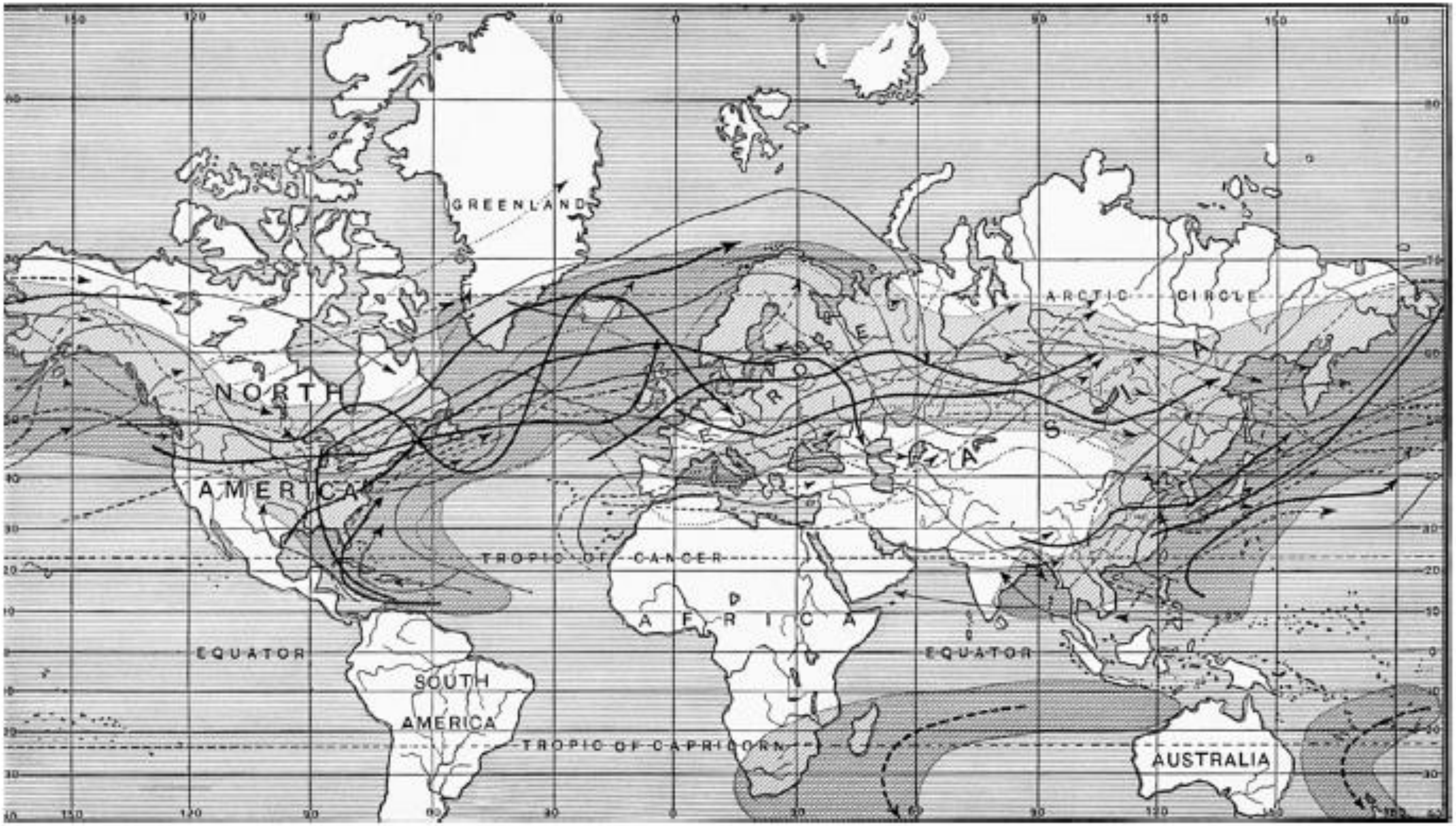
Storm tracks (ST)

- ST are marked by regions with strongest meridional temperature gradient where extratropical cyclones are generated
- These strongest (storm) cyclones bring strong winds and heavy precipitation, affecting regional weather & climate
- The storm tracks transport large amounts of heat, momentum, and moisture poleward, and make up an important part of the global circulation
- Blocking anticyclones often develop on eastern edge of ST

Motivation of the present study:

Considering significant impacts of storm tracks on global weather and climate as well as possible change of storm tracks due to climate change its realization in climate model simulations is actual topic of research

First map of storm frequency distribution (1888)



Black lines – individual storms

[Chang & Fu 2002]

Data & method

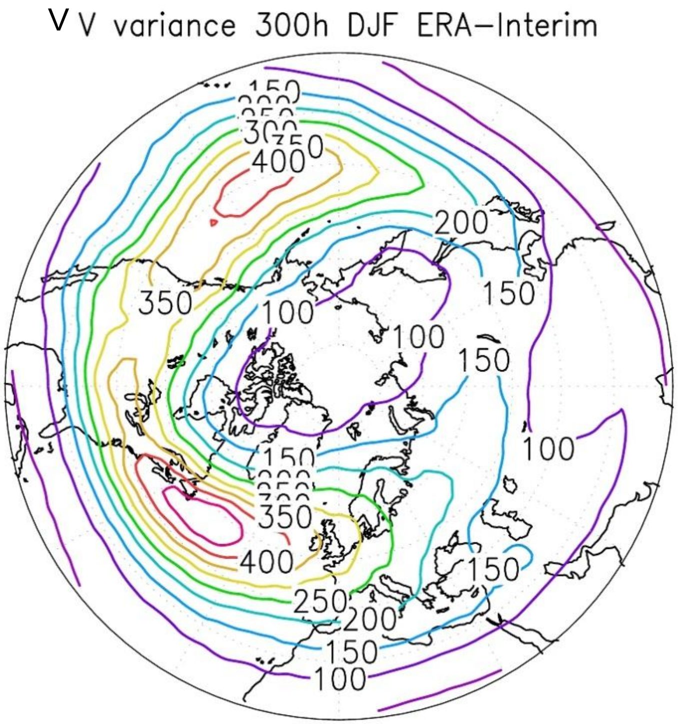
- five 50-year realizations of ensemble calculations with the INM-CM5 climate model over 1965-2014 (245 winter seasons October - April).
- NCEP (1968-2018) and ERA-Interim (1979-2018) reanalysis
- Daily data of meridional (V), zonal wind (U), temperature (T) & specific humidity (Q) from 1000 to 100 hPa (Q up to 300 hPa)
- The daily V, U, T, Q data were first filtered using a 24-hours difference filter (Wallace et al.1988) to get only synoptic scale variability

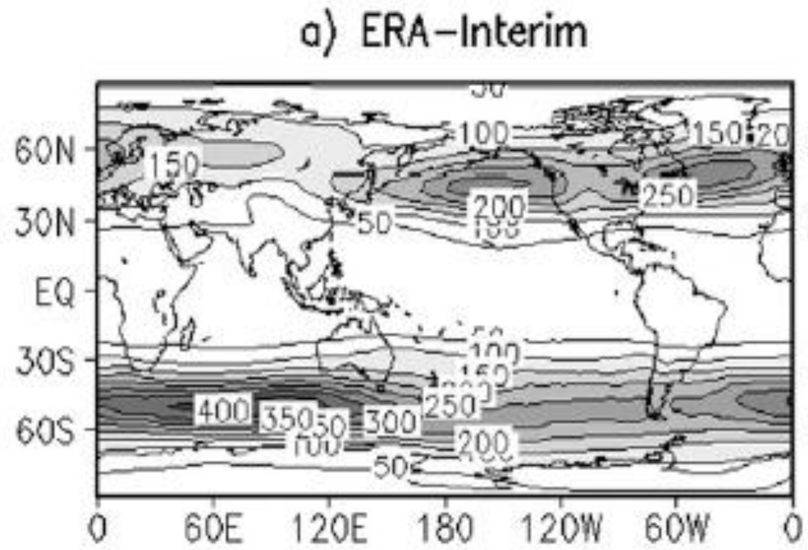
- variance $vv = \overline{[v(t+24)-v(t)]^2}$
- momentum flux $uv = \overline{[u(t+24)-u(t)]\cdot[v(t+24)-v(t)]}\cos\varphi$
- heat flux $vT = \overline{[v(t+24)-v(t)]\cdot[T(t+24)-T(t)]}$
- moisture fluxes $vq = \overline{[v(t+24)-v(t)]\cdot[q(t+24)-q(t)]}$

(Chang, J. Climate 2013)

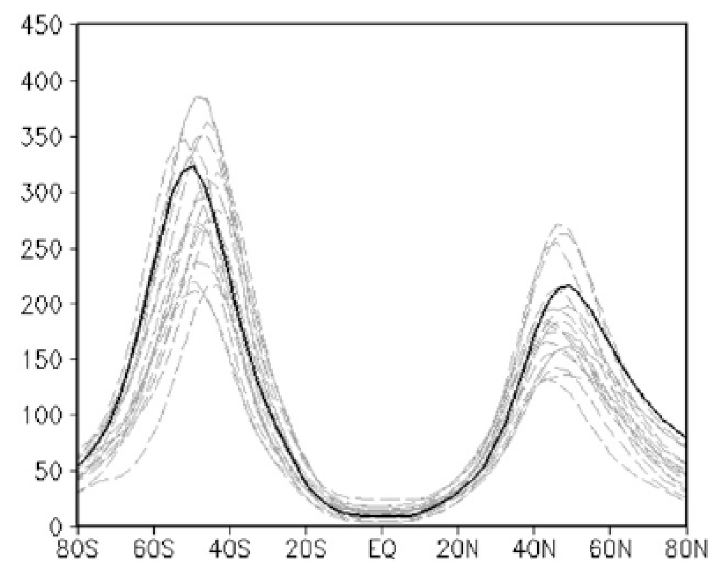
** (t+24h) = (t+1 day)*

Storm track variance





VV [m2/s2] 300 hPa mean 1980-1999 (Chang 2013)



Zonal mean VV [m2/s2] at 300 hPa mean 1980-1999 (Chang 2013)

Factors affecting Storm tracks

- Strong El-Nino -> ST equatorward shift and eastward extension [Wang 2018]
- Arctic stratospheric polar vortex variability: ST pole-/equator-ward shift by vortex strengthening / weakening [Walter 2005, Kidston 2015]
- Decadal variability: ST were stronger in 1988 –1999 than in 1961–1971 [Chang 2002]
- Arctic amplification: weakening of Atlantic ST and extension toward high latitudes of Pacific ST [Wang 2017]

Storm tracks and climate change

- Poleward shift of ST under hard GHG increase scenario [Scaife 2012]
- Under CO_2 doubling poleward latitudinal shift of ST could reach up to 2° in Southern Hemisphere [Mbengue 2013, Barnes 2013]
- Poleward latitudinal shift was also revealed in NH [Bengtsson 2006, Martynova 2015]

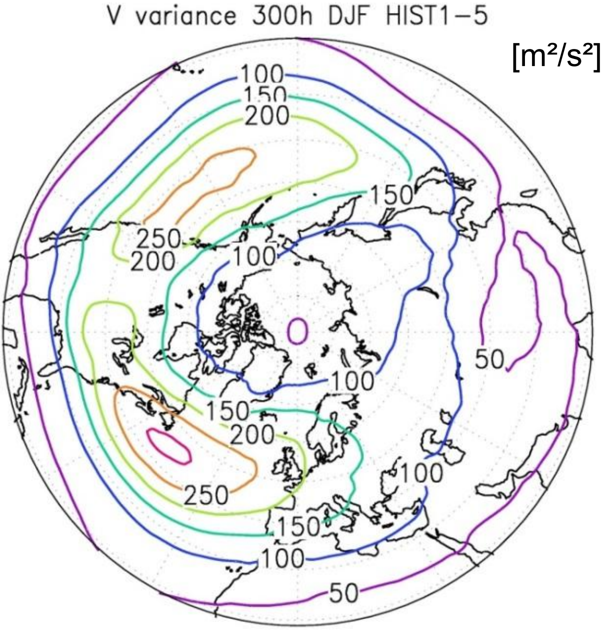
INM CM5 historical simulations (1850-2014)

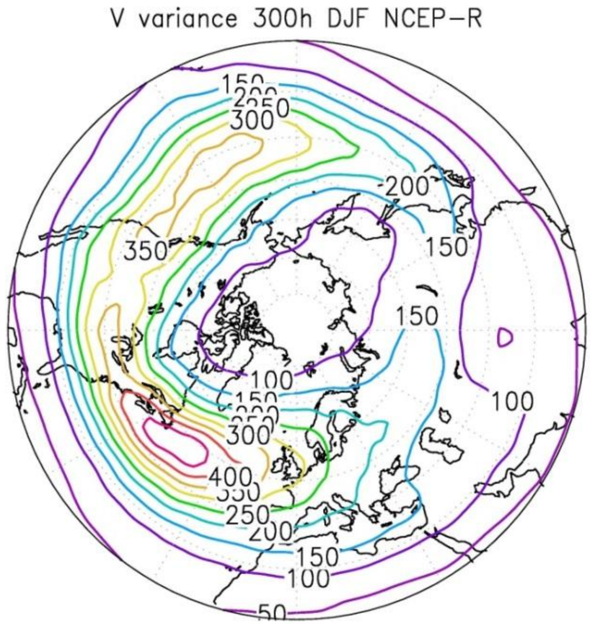
- Five 50-year (1965–2014) realizations of the ensemble simulation (HIST1-5) with INM-CM5 carried out in accordance with the requirements of CMIP6 are analyzed.
- HIST1–HIST5 differ from each other by slightly disturbed initial conditions
- Improvement of the atmosphere model: the increase in the vertical resolution for the upper stratosphere and lower mesosphere and the improvement of the parameterization of large-scale condensation and cloudiness, the addition of the aerosol module & Simulation of the QBO, better Sudden Stratospheric Warming events statistics.
- The lon-lat resolution of INM-CM5 in the atmosphere is 2° × 1.5°, the number of vertical levels up to 0.2 hPa (~60 km) is 73; the respective values for the ocean model is 0.5° × 0.25° (by two times higher than in INM CM4) and 40 levels.
- The ocean model includes the module for the sea ice calculation. The atmosphere model includes modules responsible for the calculation of soil, underlying surface, and vegetation parameters. The model components responsible for the computation of ocean and atmosphere parameters exchange data every two hours.
- CO_2 increase over 1979 - 2008 from 336 to 385 ppm, CH_4 from 1530 to 1760 ppb

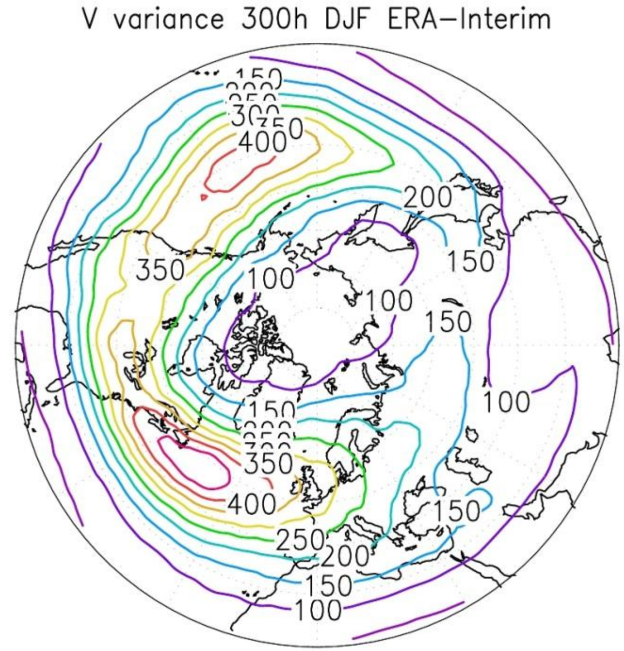
More: Volodin et al. 2017, Volodin & Kostrykin 2016

1. Realization of storm-tracks in simulations of INM CM5: winter (DJF) variance

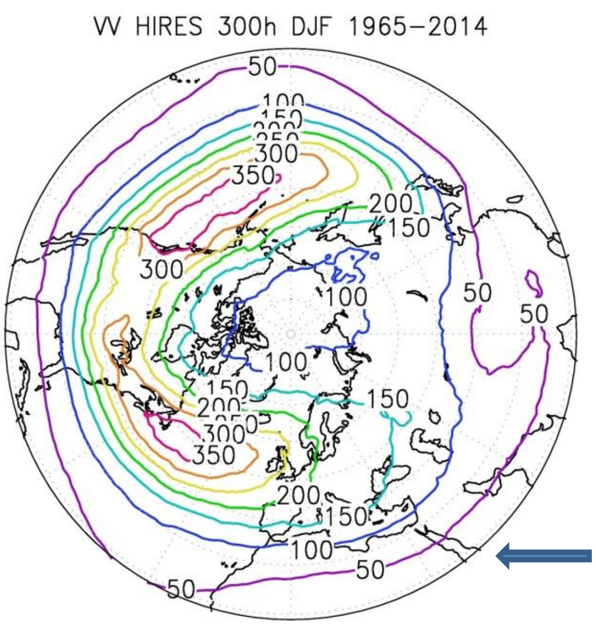
Lon-Lat resolution 2° × 1.5°







High resolution INM CM5 version (0.67° x 0.5°)



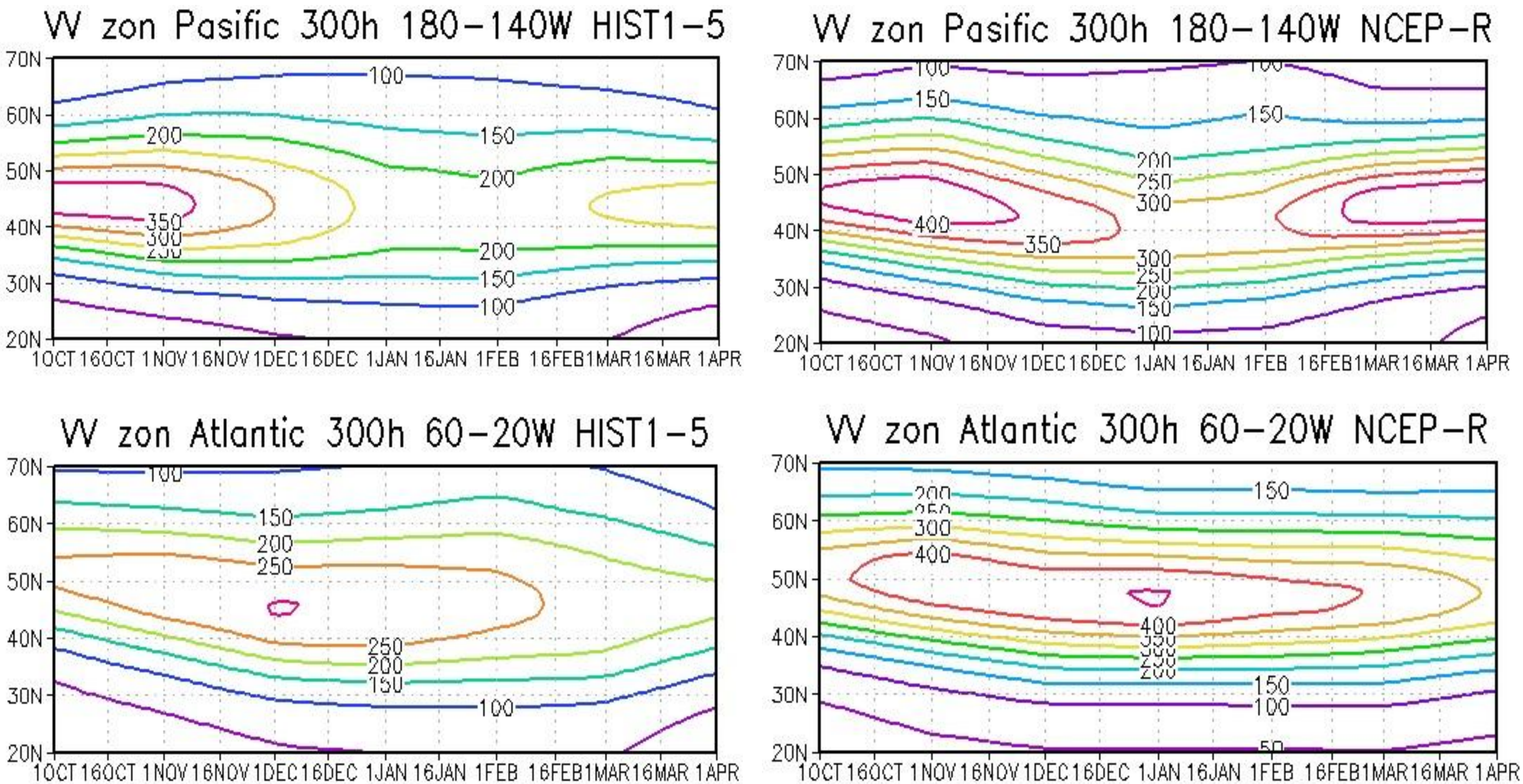
Spatial structure and temporal variability of storm tracks in INM-CM5 simulations is comparable with reanalysis .

However the maximum variance of both storm tracks (Pacific & Atlantic) in model simulation is weaker on 20-25% in comparison with reanalysis.

Note: only 2 from 17 climate models reproduce ST variance within 10% difference from ERA-Interim [Chang 2013]

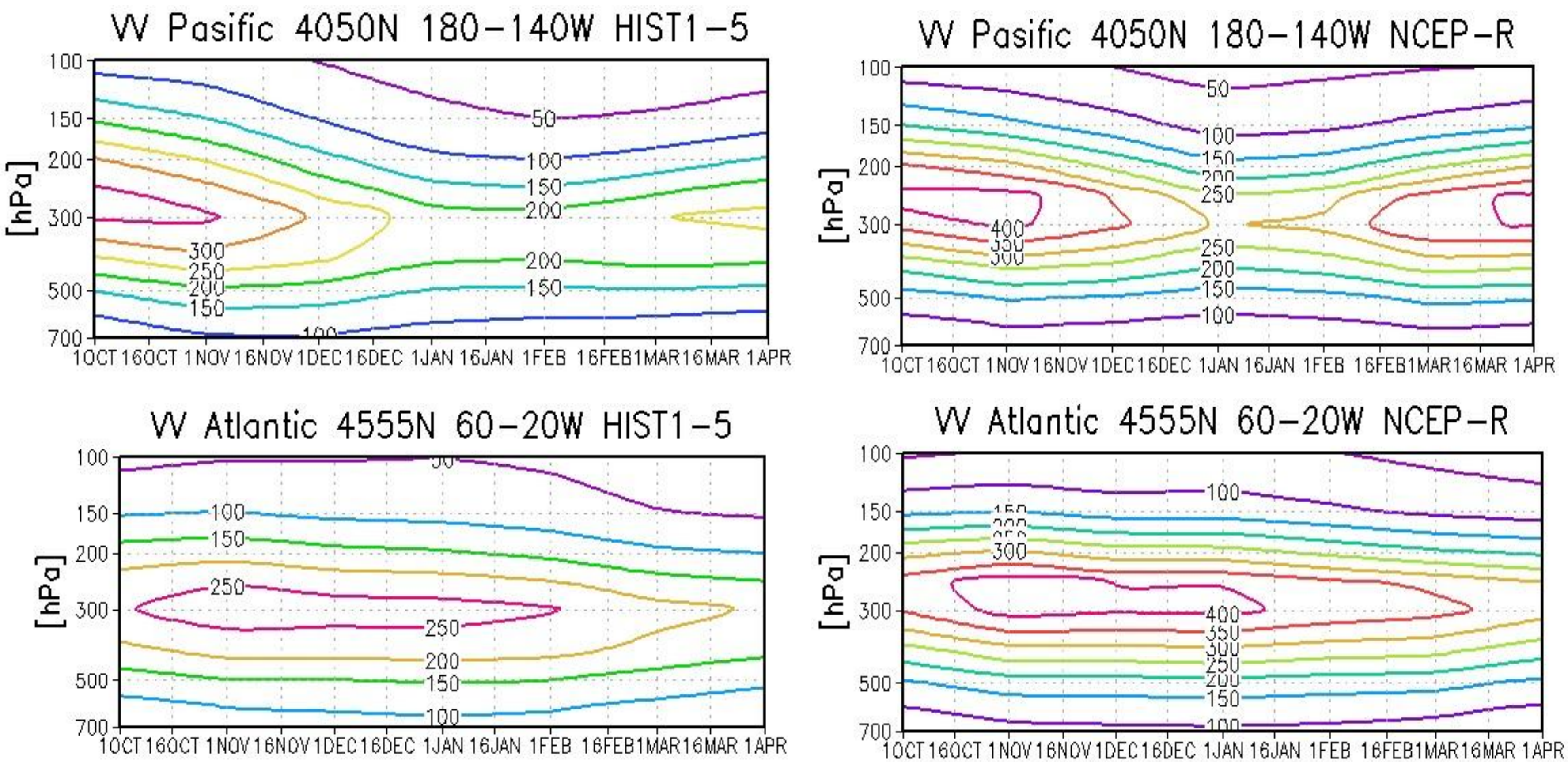
High resolution version of CM5 reproduces storm tracks better: its variance is close to observation

2. Realization of storm-tracks in simulations of INM CM5



Variance of Pacific ST [m^2/s^2] (mean 180°-140° W) & Atlantic ST (mean 60°-20° W) at 300 hPa in model simulations (left) and NCEP reanalysis (right)

3. Realization of storm-tracks in simulations of INM CM5

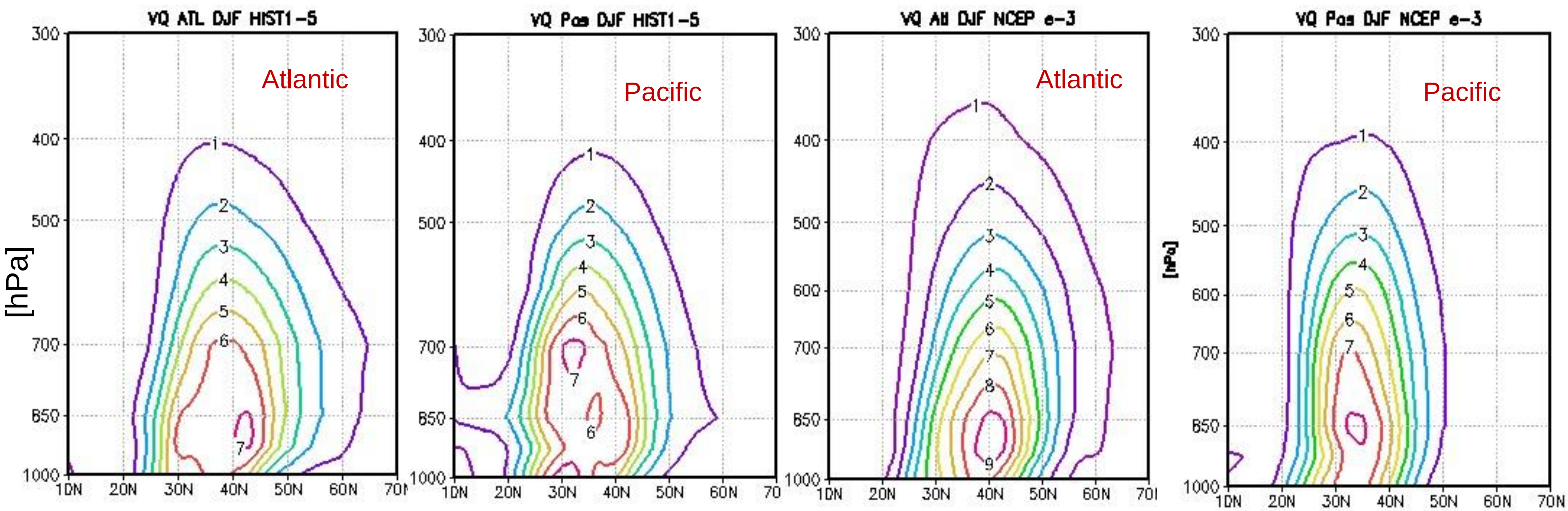


Variance of Pacific ST [m^2/s^2] (mean 40-50°N & 180°-140° W) & Atlantic ST (mean 45-55°N & 60°-20° W) in model simulations and NCEP reanalysis

4. Realization of storm-tracks in simulations of INM CM5: moisture flux

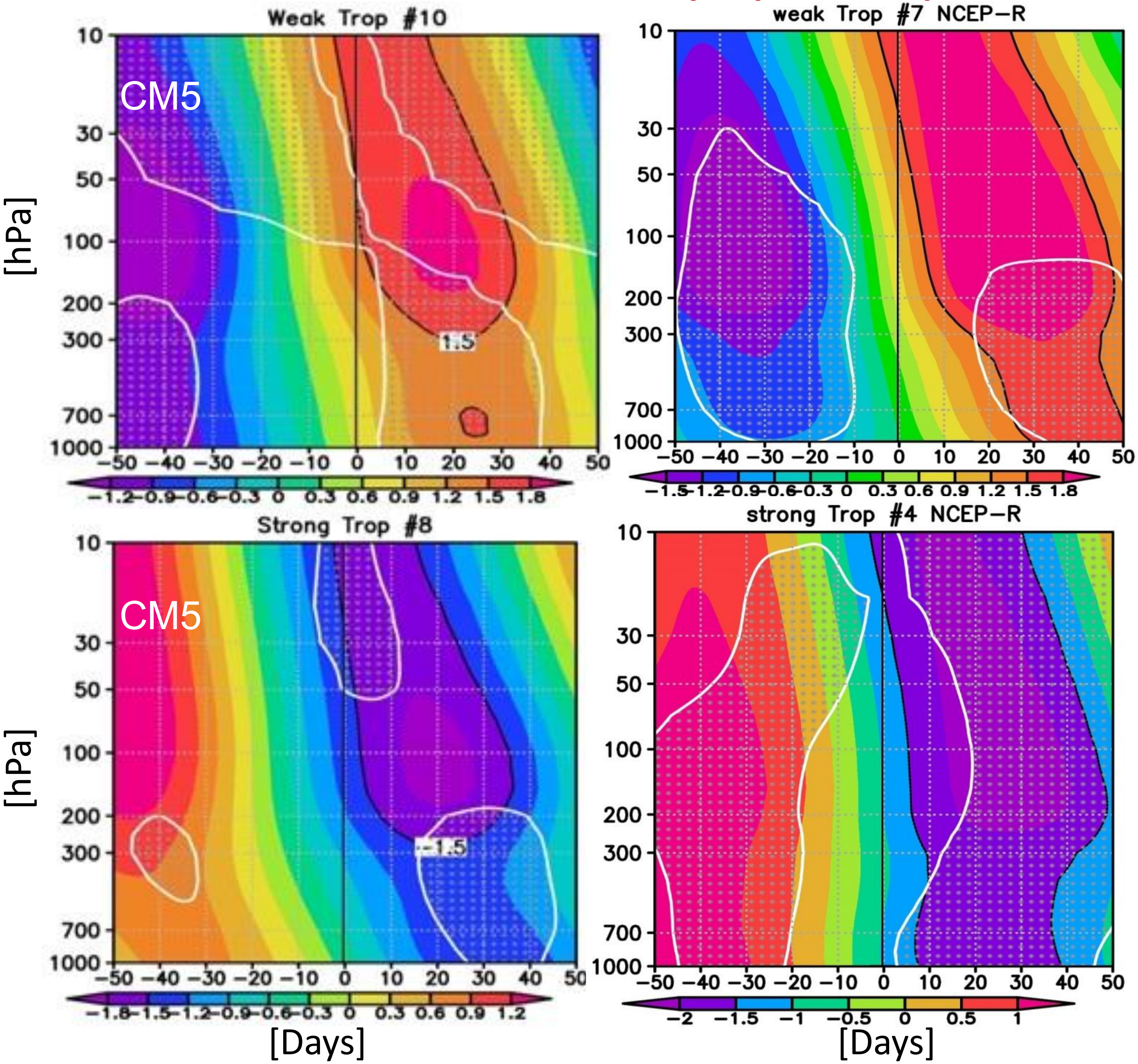
INM CM5 mean HIST1-5

NCEP-R



Moisture flux [10^{-3} m/s] from 1000 to 300 hPa mean Dec-Feb of Atlantic ST (100-30° W) and Pacific ST (120-180° E)

Composites of strong / weak Arctic stratospheric polar vortex with tropospheric impact

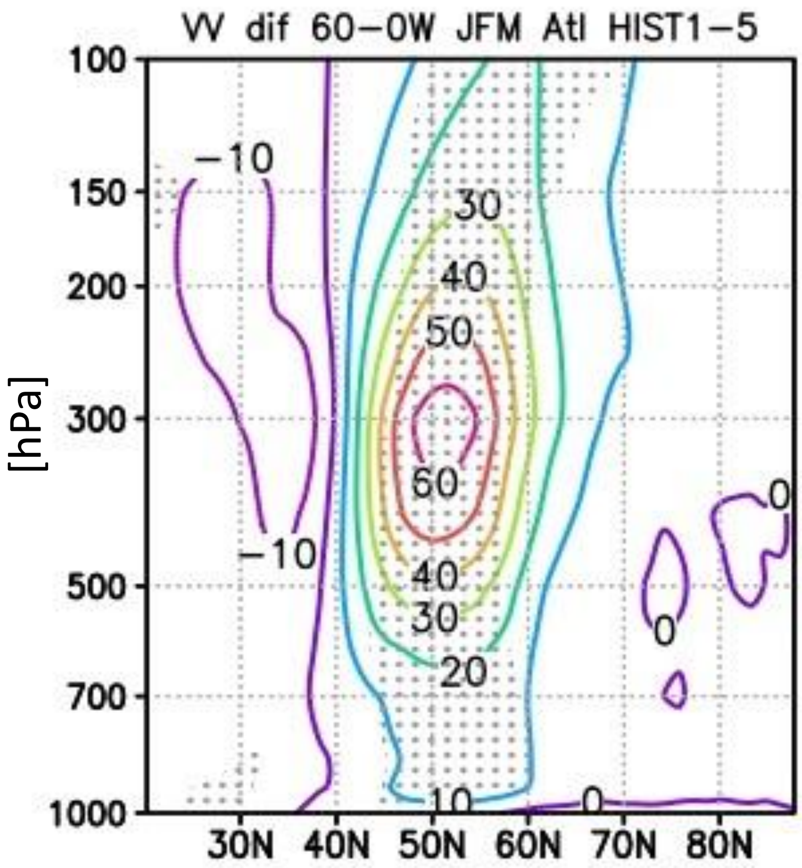


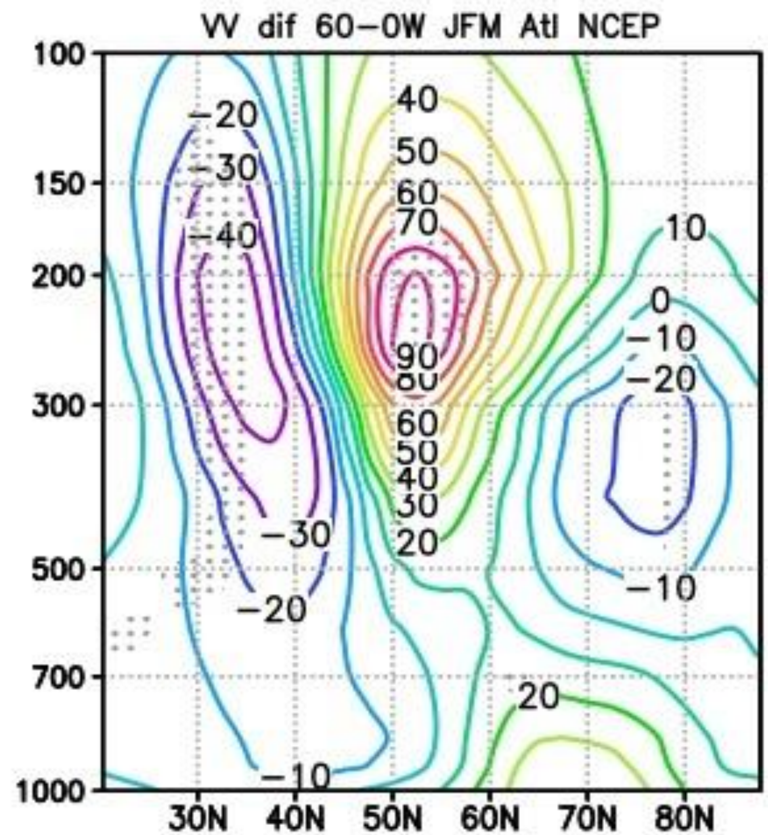
Strong / Weak Trop events: geopotential height anomalies (or NAM index) from climatology averaged over 60-90N normalized on standard deviation (STD) with absolute value more than 1.5 σ and with continuously downward propagation from 30 hPa to 300 hPa

The zones where the difference between the composites with the tropospheric forcing and without it is statistically significant at the confidence level of 95%, are marked with the white contour and dots.

[Vargin et al., 2018]

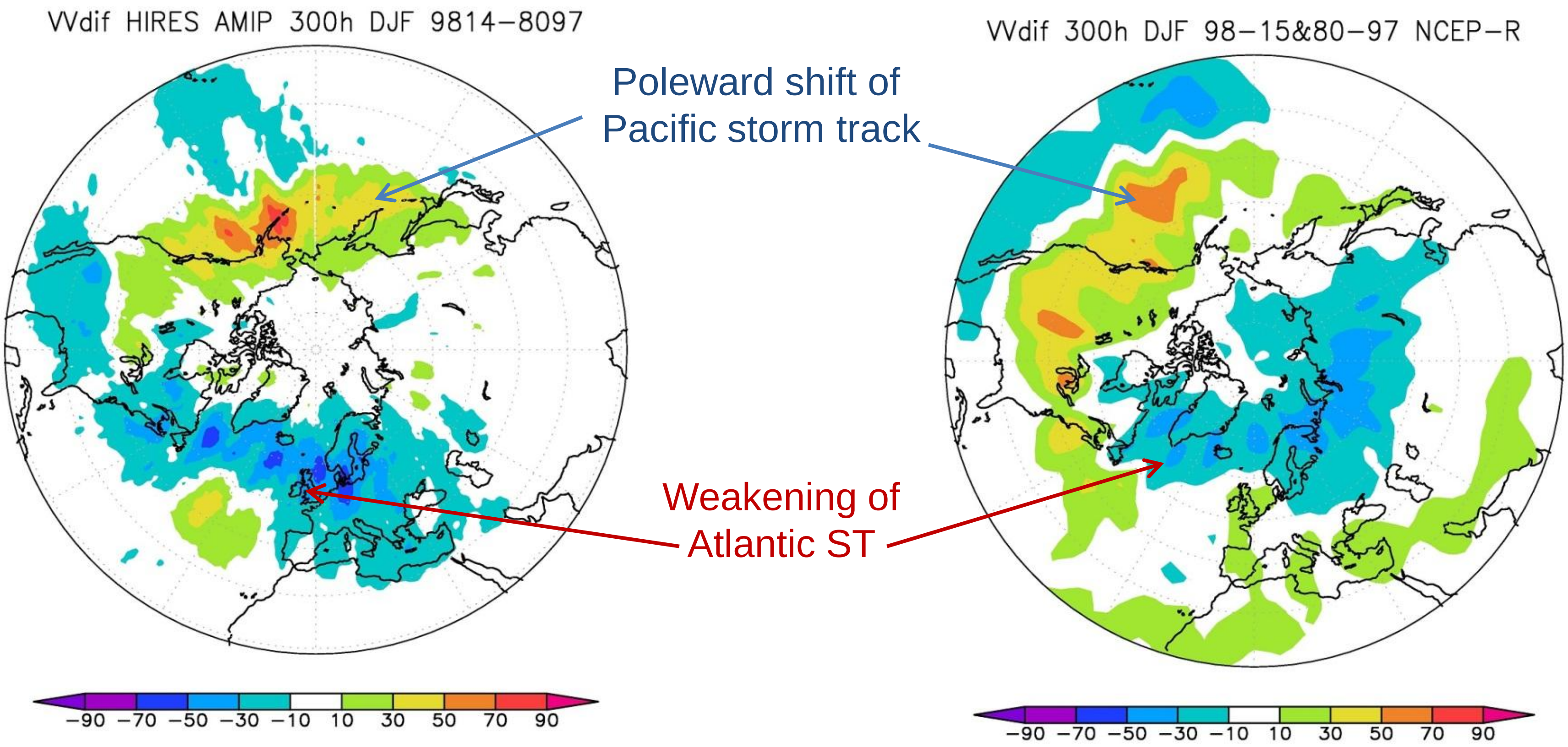
Atlantic ST (mean 60-0° W) difference between composites of strong and weak polar vortex events with tropospheric impact





Regions with statistical significant difference between composites on 95% level are marked by dots.

Storm tracks DJF variance difference between 1998-2014 (warm) & 1980-1997 (cold) periods



These changes were also revealed in NCEP-R (and early by Wang et al., 2017).
The plausible cause – changes of meridional temperature gradient due to Arctic warming (amplification)

Summary

- Spatial structure and variance of NH storm tracks in INM-CM5 simulations are comparable with NCEP & ERA-Interim reanalysis.
- Maximum variance of both storm tracks in model simulation is weaker on 20-25% in comparison with reanalysis.
- High resolution version of INM CM5 reproduces storm tracks better: its variance is close to observation
- Strengthening of Arctic stratospheric polar vortex with tropospheric impact lead to extension of North Atlantic storm track toward high latitudes: its strengthening is observed nearby 50°N and weakening at 30-40°N
- Arctic amplification over recent years led to changes of Atlantic and Pacific storm tracks.

Thank your for attention