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Warming of Eurasian and its Relationship with the NAO, AO, PJO, and EU-pattern (Extended Abstract)

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Recent warming over the northern hemisphere in the cold season is characterized by its dynamical aspects (Hurrell, 1996 ; Kodera and Koide, 1997 ; Thompson *et al.*, 2000). The dominant spatial structure of the warming can be understood as changes in the occurrence frequency of an internal mode of variability of the atmospheric circulation. Because changes in any internal mode can be caused by different forcing mechanisms, it is important to investigate not only the mean states, but also the evolution of the flow in the formation of the circulation anomaly.

Four indices are introduced to investigate the evolution of the circulation from autumn through the winter : (a) October-November mean Siberian surface air temperature (averaged over the region 60°-130°E, 45-55°N) index ; (b) November-December mean Eurasian stationary wave source index (mean of Eurasian (EU) teleconnection pattern index and stationary eddy heat flux) ; (c) December-January mean stratospheric Polar-night Jet Oscillation (PJO) index (the zonal-mean zonal wind velocity at 60°N, 50-hPa) ; (d) January-February mean AO index by Thompson and Wallace (2000) (leading empirical orthogonal function of the sea-level pressure). These normalized indices are shown in Fig. 1a-d. Visual inspection of the indices reveals similar interannual variability superimposed on an increasing trend of the indices.

The data used in the present study are the National Centers for Environmental Prediction (NCEP) reanalysis data (Kalnay *et al.*, 1996), except for the surface temperature data complied by Jones (1994). Figure 2 shows the correlation coefficients between the PJO index (Fig. 1d) and (a) the zonal-mean zonal wind, (b) the zonal-mean temperature, (c, d) the 30- and 500-hPa geopotential height, and (e) surface air temperature. The columns display, from left to right, the September-October, November-December, and January-February means. In order to show the spatial structure more clearly, only absolute values of correlation coefficients equal or larger than 0.3 are plotted.

In autumn (September-October), an increase of the Siberian surface air temperature begins, causing an increase in overlying geopotential height at 500-hPa. In early winter (November-December), the surface warming intensifies over Siberia and the EU pattern manifests in the 500-hPa geopotential height map, which is characterized by positive and negative anomalies around Lake Bikal and the eastern part of Scandinavia, respectively. A pair of height anomalies over the eastern part of Eurasia produces northward wind anomalies. Accordingly, there is less southward advection of cold polar air and the stationary eddy heat flux decreases over Eurasia, consistent with a development of warming over Siberia. Because the heat flux is proportional to the vertical component of Eliassen-Palm flux, this means a decrease of planetary wave forcing from the troposphere. This decrease of the wave driving can be seen in zonal-mean temperature

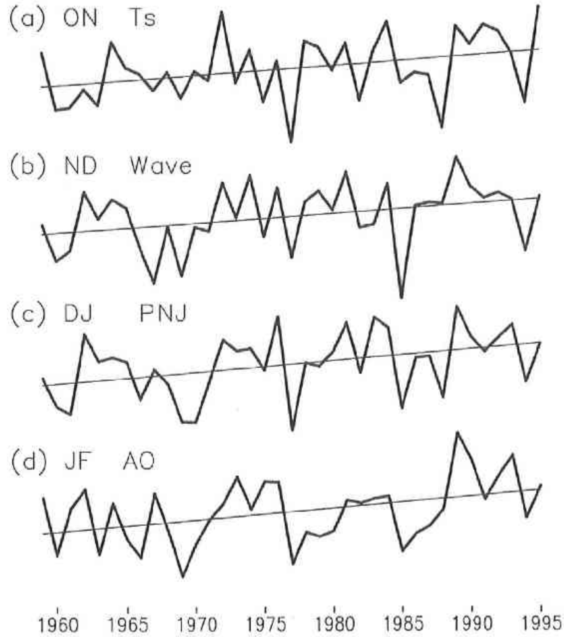

Fig. 1. Standardized indices: (a) October-November mean Siberian surface air temperature index, (b) November-December mean Eurasian stationary wave source index, (c) December-January mean PJO indSex, (d) January-February mean AO index.

as a dipolar pattern of warming and cooling at low and high latitudes in the lower stratosphere. Consequently, a stronger polar vortex is formed in the middle stratosphere (30-hPa). Note that unlike the localized, wave-like pattern in the troposphere, the stratospheric pattern exhibits a zonal structure extending over the northern hemisphere.

In late winter (January-February), although positive temperature anomalies appear at the top level, the lower stratospheric temperature anomalies persist. Hence, the stronger stratospheric polar-night jet and polar vortex also persist in the lower stratosphere. It can be seen that when the stronger polar night jet extends into the troposphere, the EU pattern is replaced by the AO pattern at 500-hPa as mentioned in previous papers (Kuroda and Kodera, 1999; Kodera *et al.*, 2000). According to the circulation changes, the late-winter surface warming expands from the Eurasian to the North American sectors. Clearly, the correlations between the PJO index and the different maps capture remarkably well diverse aspects of recent trends in different seasons, regions and variables.

An important issue so far not discussed here, is the decreasing trend in stratospheric ozone (WMO, 1999), which should also be involved in the present problems. Because of the decreased wave activity and the stronger polar vortex, less ozone is transported to the higher latitudes on one hand, while on the other hand the cold, strong polar vortex (Fig. 2) facilitates the formation of polar stratospheric clouds (PSCs), and hence, the destruction of ozone by heterogeneous chemistry in spring (Tie *et al.*, 1997). Thus, recent trends in different fields are inter-related and should not be considered in isolation.

Then the question arises as to what could be the cause of the recent warming over Eurasia?

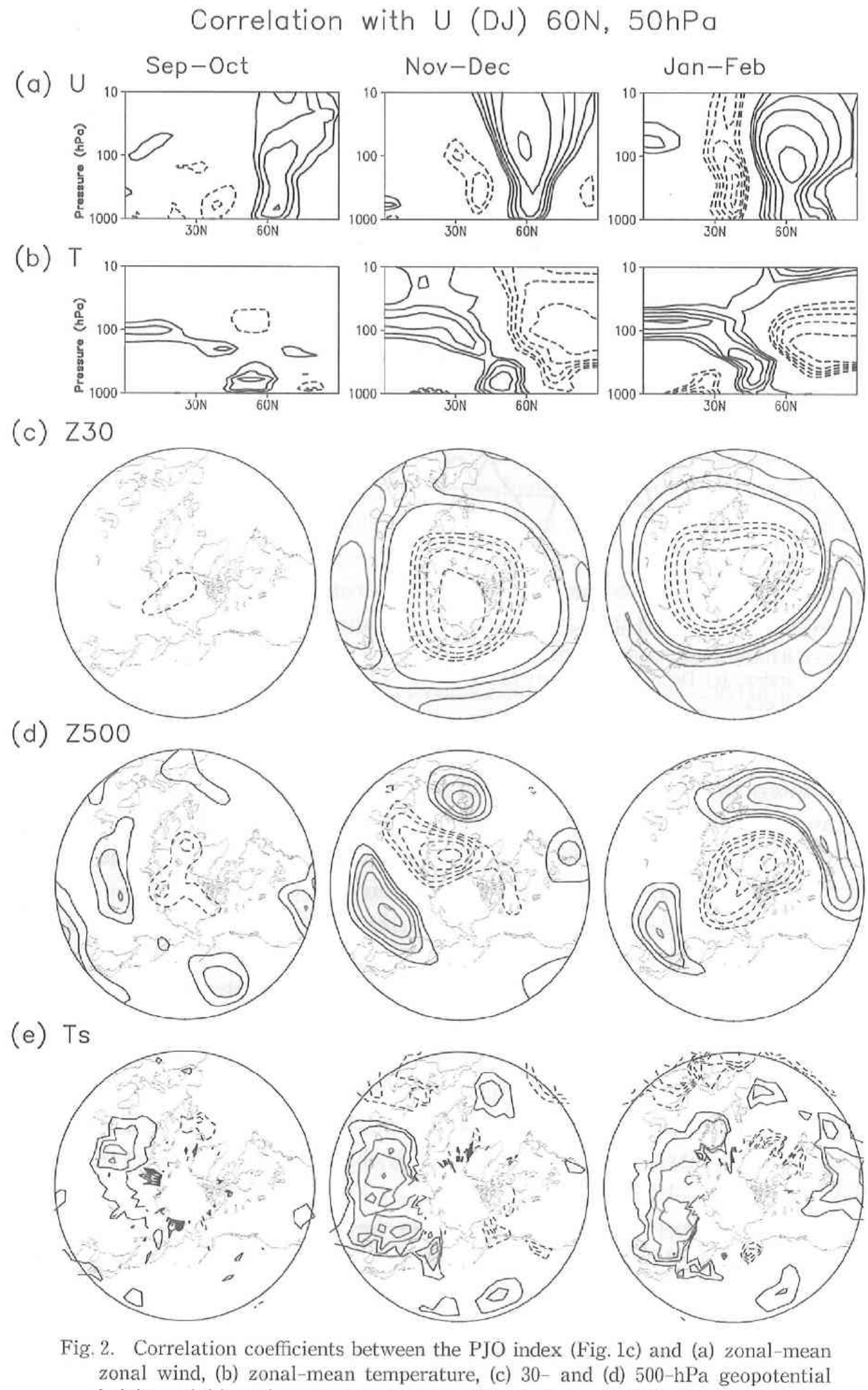

Fig. 2. Correlation coefficients between the PJO index (Fig. 1c) and (a) zonal-mean zonal wind, (b) zonal-mean temperature, (c) 30- and (d) 500-hPa geopotential height and (e) surface air temperature. (from left to right) September-October, November-December, and January-February mean. Contour interval is 0.1. Values larger than 0.4 are shaded in (c)-(e). Negative values are indicated by dashed lines.

The increase of greenhouse gas concentrations could be a possible cause of the original warming of the troposphere, the effect of which is amplified over Eurasia through changes in snow coverage. But, it is also possible that a stronger polar vortex due to the increase of greenhouse gases in the stratosphere produces surface warming over Eurasia during the winter and spring through changes in the AO (Shindell *et al.*, 1999). If the effect of circulation change is memorized until the next autumn (Kodera and Koide, 1997), for instance by snow, ice, permafrost and vegetation, larger impacts would be expected through positive feedback involving the dynamical process discussed here.

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