A vortex dynamics perspective on stratospheric sudden warmings: observed structure and variability

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Abstract

The vertical structure of the polar vortex is investigated for observed stratospheric sudden warmings (SSWs) during the period 1957-2002, using ECMWF ERA-40 reanalysis fields. The observed events are divided into 15 wave-1 (displacement) and 13 wave-2 (splitting) events. Composites of a suitably scaled potential vorticity are used to illustrate typical vortex behaviour with an emphasis on highlighting differences in the evolution of the vertical structure of the vortex during each type of event.

Datasets and Methodology

Dataset and SSW definition

We consider all displacement and splitting SSWs occurring in the period 1957-2002 as classified by Charlton & Polvani (2007) [1]. For this study we use ECMWF ERA-40 Ertel's potential vorticity and temperature fields obtained at $1^\circ \times 1^\circ$ horizontal resolution on 16 standard pressure levels between 400 hPa and 1 hPa. The temperature fields are then used to interpolate the PV onto 36 isentropic surfaces in the range 380-2850 K. The polar vortex is taken to be the region enclosed by a carefully chosen isosurface of the vertically weighted Lait PV [2].

Composite Fields

In this study, vortex displacement SSWs (15 events) and vortex splitting SSWs (13 events) are treated separately when generating composite fields. For each of the two types of SSW, composite fields are generated by averaging the Lait PV on each of the isentropic surfaces over all SSWs of that type.

Elliptical diagnostics

It is desirable to describe the position, orientation and elongation of the polar vortex at a given time on each isentropic surface by a few key parameters. Therefore, following Waugh (1997) [3], moment integrals of the Lait PV distribution are used to define an equivalent ellipse on each isentropic surface, that is an ellipse which best fits the polar vortex cross-section on that particular surface at a given time.

Vortex displacement SSWs

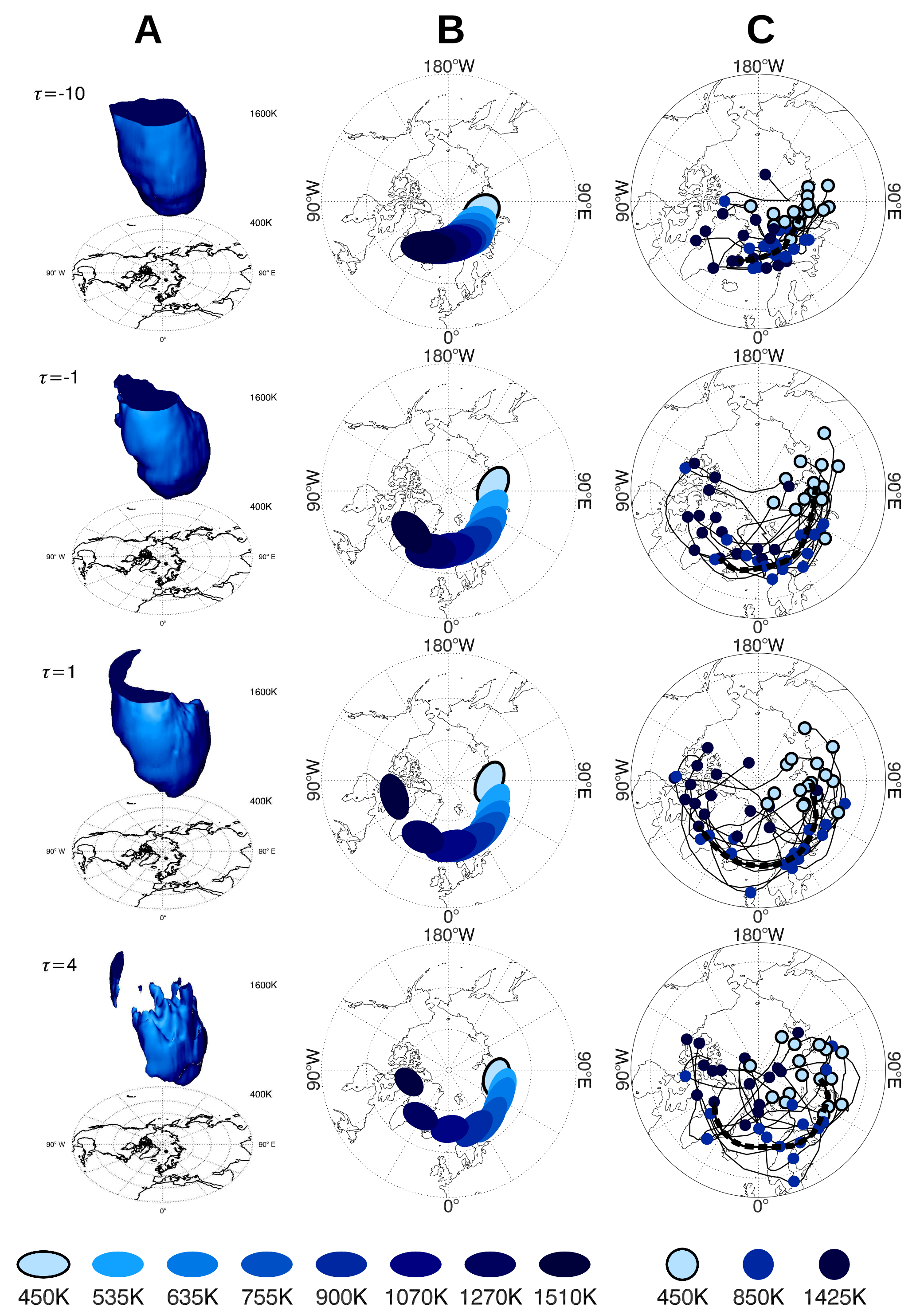

Figure 1: Composite vortex displacement SSW: A - Three-dimensional polar vortex evolution; B - Evolution of the equivalent ellipse; C - Observed variability in centroid location for individual displacement SSWs.

Features of vortex displacement SSWs:

- There is relatively little variation between individual SSWs in the orientation of the developing vortex relative to the underlying topography.
- During the polar vortex breakdown, the lower vortex is displaced over Siberia and the upper vortex is displaced over northernmost Canada.
- For all displacement SSWs, at mid-altitudes the polar vortex is only displaced into the 'Atlantic hemisphere'.
- At low altitudes the polar vortex remains relatively undisturbed during, and after, the breakdown. In contrast, the polar vortex is almost completely destroyed at higher altitudes.

Vortex splitting SSWs

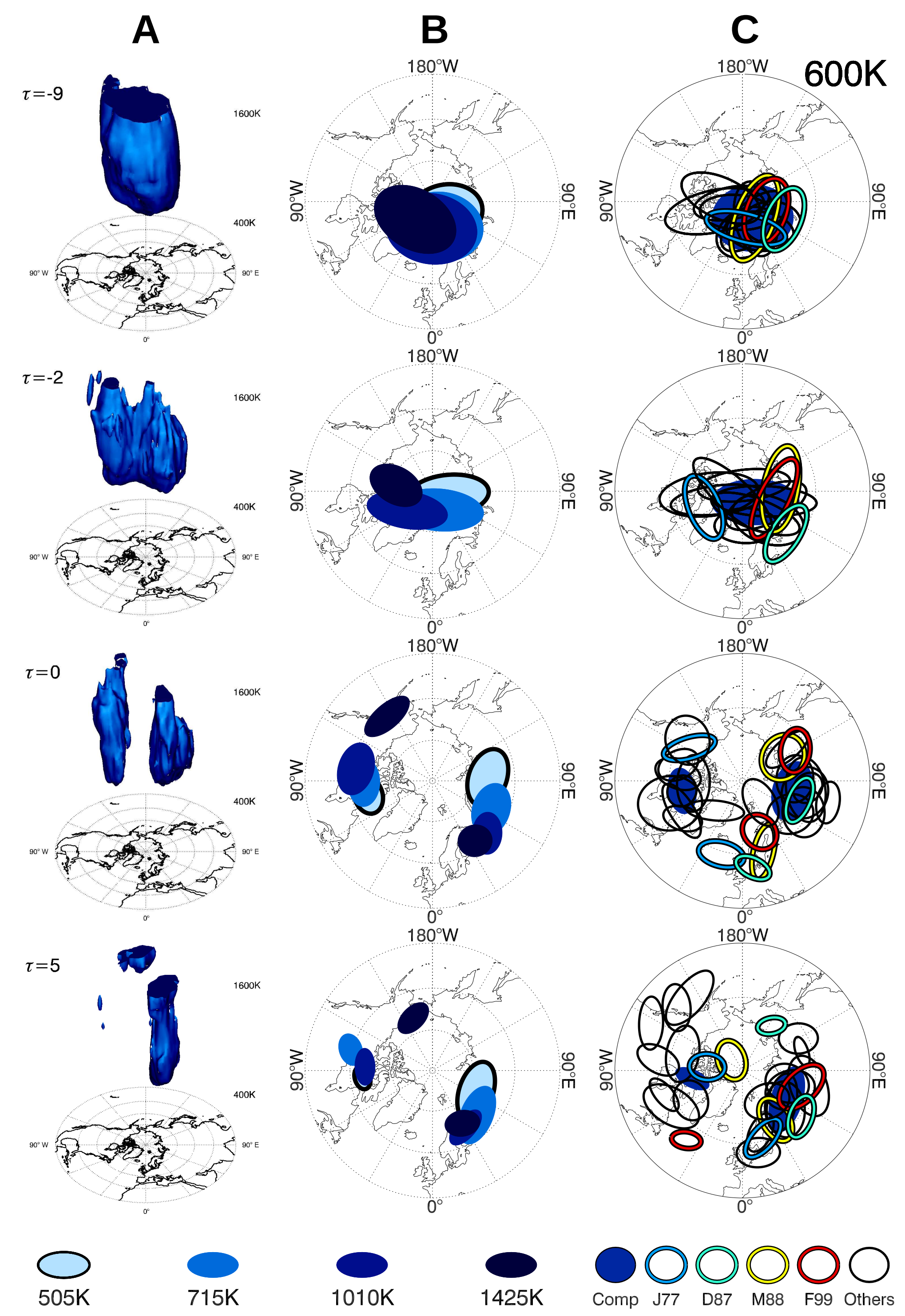

Figure 2: Composite vortex splitting SSW: A - Three-dimensional polar vortex evolution; B - Evolution of the equivalent ellipse; C - Observed variability in equivalent ellipse evolution on the 600 K isentropic surface for individual splitting SSWs.

Features of vortex splitting SSWs:

- The polar vortex splits into two 'daughter' vortices of comparable magnitude. For the majority of splitting SSWs, one of the daughter vortices is located over Siberia and the other is located over Canada.
- Typically, the breakdown of the polar vortex is barotropic in nature. That is, the polar vortex split occurs almost simultaneously at all heights of the vortex.
- The Siberian vortex tends to be the more dominant of the resulting vortex daughter vortex pair.
- After the SSW onset at $\tau = 0$, retrograde rotation of the vortex pair around their common centroid usually leads to the destruction of the Canadian daughter vortex followed by a reformation of the main vortex around the stronger Siberian vortex.

A resonant mechanism?

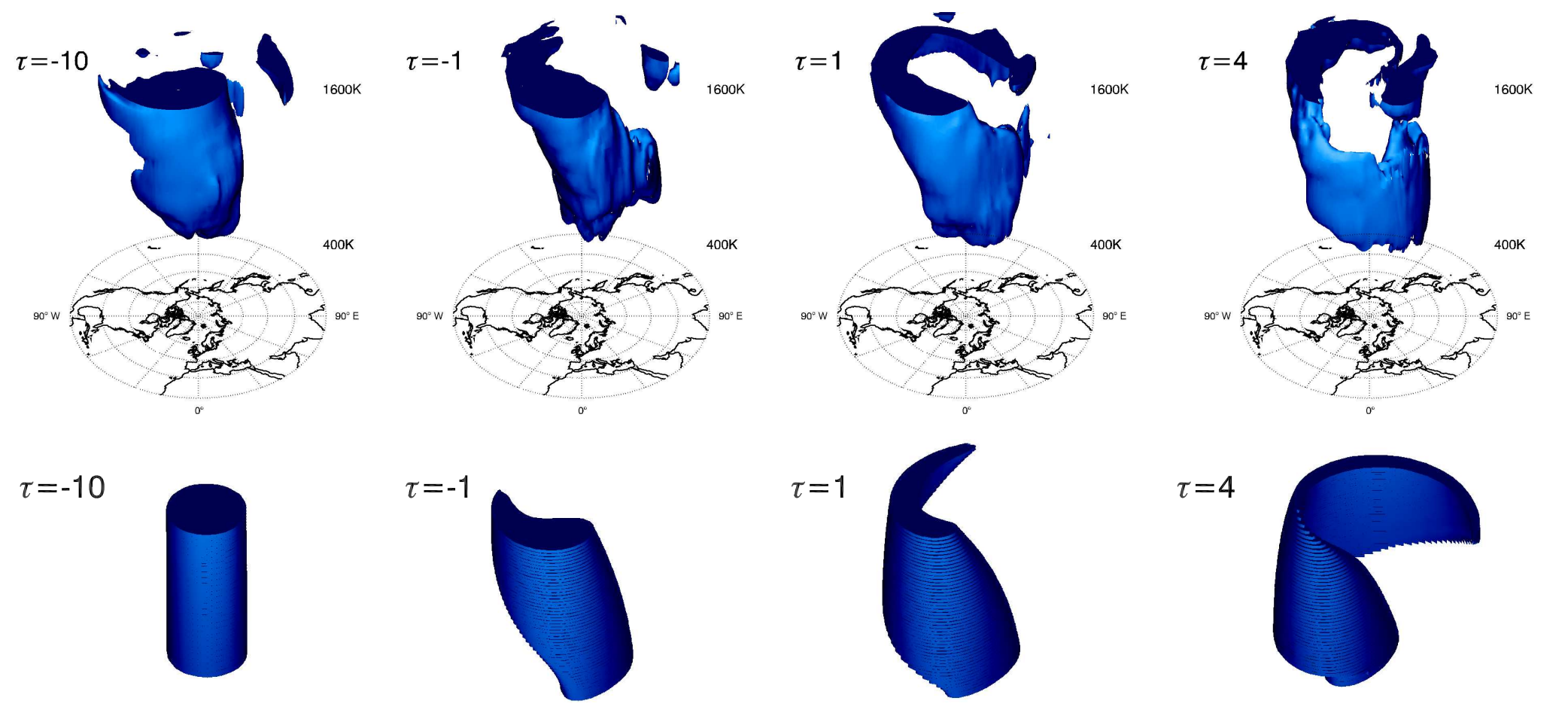

Figure 3: Polar vortex evolution during the January 1987 displacement SSW (top panels) compared with evolution of an idealized barotropic vortex in a fully nonlinear quasi-geostrophic model with wave-number 1 lower boundary forcing (lower panels).

- Possible mechanism for the polar vortex behaviour during SSWs is that of a resonance of the vortex with forcing at the tropopause [4][5].
- Experiments involving an idealized fully nonlinear quasi-geostrophic model suggest that resonance of the vortex with lower boundary forcing may lead to recognizable SSW type behaviour (Figure 3).
- Work is ongoing to introduce an appropriate 'realistic' lower boundary forcing into the idealized model.
- One aim of this work is to investigate whether resonance of the vortex with a given 'realistic' lower boundary forcing may lead to both vortex splitting and vortex displacement SSW type behaviour.

References & Acknowledgments

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