The Dynamics of the Stratospheric Polar Vortex

Alan O’Neill
University of Reading
Outline

• Structure of the stratospheric polar vortex
• Phenomenology
  – vortex-vortex interactions during stratospheric sudden warmings
  – impacts (on trace gases & on troposphere)
• Some theoretical considerations
Stratospheric Polar Vortices
50 mb (about 20 km)
NH & SH
Minimum Air Temperatures in the Polar Lower Stratosphere

-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
-130
-135
-140
-145

May June July August Sep Oct

40° to 90° Latitude

Arctic

PSC formation temperature

Antarctic

Range of Values

Average winter values

Arctic 1978-79 to 2001-02

Antarctic 1979 to 2001
Cross-Section of Methane October
Stratospheric Polar Vortex

- Heating
- Vertical gradient
- Horizontal gradient
- Cooling
- Downward spiral
- Tracer isopleth
- Polar vortex

Equator
N. Pole

heating
vertical gradient
horizontal gradient
cooling
downward spiral
tracer isopleth
polar vortex
Consequence 1: Forecasting

- If the stratosphere has an impact on the tropospheric state 10-60 days in the future then there is potential to use this information for sub-seasonal forecasting.

Baldwin et al. (2003)
Impact of Stratosphere 2

Charlton et al.

- Changing the stratospheric initial conditions results in a tropospheric impact 15-20 days into the run.
Effect of SH Ozone Depletion

- Recent trends in the Antarctic can be well simulated by forcing a model with ozone trends confined to the stratosphere.

Gillett and Thompson (2003)
Two Dynamical Paradigms for Dynamical Variability of the Stratospheric Polar Vortex

- Wave, mean-flow interaction.
- Vortex-vortex interaction.
Some Textbook Quotes

• “Numerous observational studies confirm that enhanced propagation of planetary waves from the troposphere, primarily zonal wavenumber 1 and 2, is essential for the development of warmings.”

• “Most of the dramatic mean-flow deceleration that occurs during a sudden warming is caused by amplification of quasi-stationary planetary waves in the troposphere followed by propagation into the stratosphere.”

• “It is generally accepted that sudden warmings are an example of transient mean-flow forcing due to planetary wave driving.”

The basic notion: the troposphere acts as a wave maker, and disturbances propagate quasi-linearly into the stratosphere where they “break”.

vertically propagating “pulse of wave activity”

tropopause

tropospheric planetary wave maker
EP Fluxes and Divergence

Adapted from Dunkerton et al., 1981
The Seductive Transformed Eulerian Mean Momentum Equation

\[
\frac{\partial \overline{u}}{\partial t} - f \overline{v}^* = \rho_0^{-1} \nabla \cdot F
\]

\[
\frac{\partial \overline{u}}{\partial t} - f \overline{v}^* - \rho_0^{-1} \nabla \cdot F = 0
\]
Idealised 3D Vortex-Vortex Interactions in the Winter Stratosphere

**FIG. 9.** Evolution for $-\kappa_2/\kappa_1 = 0.8$, $z_2 - z_1 = 0$, at $t = 0, 4, 8, 12, 16$, and 20 days (from upper left to lower right; top view).
Wind Speed Near Localised PV Anomaly
NH Dec/Jan 84/85: Geo Ht 10 hPa
NH Dec/Jan 84/85: PV 840K
Zonal-mean wind & polar cap temperature, 10 hPa, NH winter 1984/85
NH Dec/Jan 84/85: PV 450K
NH Jan 87: PV 840 K
NH Dec/Jan 84/85: PV isosurface

Lait's PV isosurface at 0000UT on 13-Dec-1984

[Diagram showing a PV isosurface with isopleths at 400K and 1600K]
The Polar Vortex: NH 2005/6

01 November 2005

Theta (K) | Altitude (km)
---|---
2000 K | 47 km
1800 K | 45 km
1600 K | 42 km
1400 K | 40 km
1200 K | 37 km
1000 K | 33 km
900 K | 31 km
800 K | 29 km
700 K | 26 km
600 K | 23 km
550 K | 22 km
500 K | 20 km
450 K | 18 km
400 K | 15 km
380 K | 14 km
360 K | 13 km
340 K | 10 km
320 K | 7 km
300 K | 3 km

Temperature

Courtesy of Lynn Harvey
SH Sep 2002: 850K PV

1 22
25 28
SH Oct 2002: 850K PV

(e) (f) (g) (h)
SH 21 Sep 2002: PV 350K & p*
Merger of anticyclones, SH, 10 & 13 Oct 1992, PV 1100K

Lahoz et al., QJRMS, 1996
Schematic of Top-Down Breakdown of SH Polar Vortex

quasi-stationary anticyclone

tracer isopleth

cyclonic polar vortex

radiative cooling rate

Lahoz et al., QJRMS, 1996
Variability of the Polar Vortex

• Evolution of coherent vortical structures, involving strongly local, nonlinear dynamics (e.g. during vortex merger) and the interaction of anticyclones with the polar vortex.
• Deep, nonlinear evolution between axi-asymmetric states in the upper troposphere and stratosphere.
• Possibility for instability of highly distorted polar vortex to finite-amplitude perturbations (e.g. cyclogenesis in the troposphere).
• Tropospheric wave maker & vertical propagation?
• Troposphere-stratosphere as a coupled system?
SPARC & IPY

- Characterise the structure and evolution of the (meteorological and chemical) of the stratospheric polar vortex (NH & SH).
- Archive of data or metadata at the SPARC Data Centre
End