Selective Absorption Mechanism for the Maintenance of Blocking

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Summary

- ✓ A new maintenance mechanism of blocking (Selective Absorption Mechanism, SAM), which is associated with the Fujiwhara effect (Fujiwhara 1923), is proposed.
- ✓ Case studies and simple numerical experiments support the SAM.

1. Introduction

Block maintenance mechanism

Synoptic eddies blocked by blocking may enhance blocking itself (*e.g.*, Green 1977), and how the eddies interact with blocking?

Eddy Straining Mechanism (ESM; Shutts 1983)

✓ Synoptic eddies strained in the north-south direction by blocking provide negative (positive) vorticity to a blocking high (low) and this vorticity forcing maintains the blocking dipole against dissipation.

✓ Straining of eddies is essential for the intensification of blocking, *i.e.*, energy upward cascading.

Effectiveness of the ESM for some conditions

✓ The positive feedback effect is lost by a subtle change of the condition of synoptic eddies (Maeda et al. 2000, Arai and Mukougawa 2002).

✓ If blocking is an Ω-type (monopole), what happens?

Another 'maintenance' mechanism

Intense synoptic cyclones advect subtropical air into the block (Tsou and Smith 1990, Lupo and Smith 1995)

← Intense cyclones do not always accompany a blocking

➡ Propose a further perspective on the maintenance mechanism

2. Mechanism

Basic idea

✓ Maintenance mechanism as the supply mechanism of low (high)-PV air to blocking high (low)

✓ Interaction mechanism between the blocking high (low) and low (high)-PV eddies (Fujiwhara effect; Fujiwhara 1923)

→ Asymmetry between synoptic highs and lows

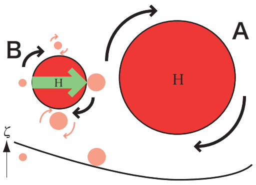

Fig. 1: Conceptual figure for the interaction between binary anticyclonic eddies and the vorticity distribution induced by eddy A.

Selective Absorption Mechanism (SAM): The blocking high (low) selectively attracts and absorbs anticyclonic (cyclonic) eddies, *i.e.*, eddies with the same polarity, but separates cyclonic (anticyclonic) eddies, and thus reinforces its own PV.

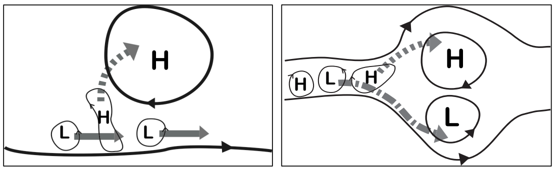

Fig. 2: Conceptual figure for the SAM for (left) Ω-type and (right) dipole-type block.

1) the SAM does not depend on the position of the stormtrack, the size of eddies, or how eddies impinge on blocking.
2) the SAM could explain the eddy feedback for a Ω-type blocking as well as a dipole type.

3. Trajectory Analysis

Data and Method

✓ Japanese 25-year reanalysis data (6-hour intervals and truncation of T106): Ertel's PV (EPV) and wind data on 320-K

✓ A cutoff period of 8 days, for separating high-frequency components including synoptic eddies from low-frequency ones including blocking.

Parcels are put on synoptic eddies upstream of the persisting blockings and are traced around the blockings (advected by the non-filtered wind) by 5 days after.

Results

red: trajectories of synoptic anticyclones
black: cyclones
closed contours: persistent blockings

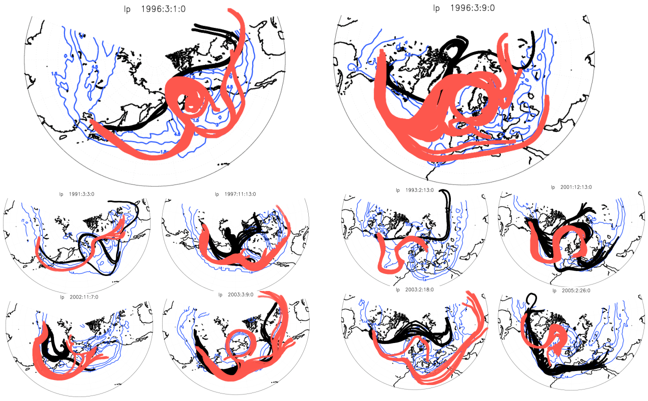

Fig. 3 : Trajectories of high-frequency negative (red)/positive (black) EPV parcels and low-frequency EPV (blue contour) for 10 blocking cases. Red/Black parcels are placed in the regions of highpass filtered negative/positive EPV less/more than -/+3 PVU upstream of the persistent blockings. The contour interval is 1 PVU.

The red/black parcels are absorbed/separated into/from the blocking high.

4. Numerical Experiments

Model description

✓Equivalent barotropic QGPV equation on a β-plane channel

✓Fully nonlinear model → Includes the asymmetry of eddies

$$\left(\frac{\partial}{\partial t}+U\frac{\partial}{\partial x}\right)q+\beta_*\frac{\partial\psi}{\partial x}+J(\psi,q)=\bar{J}(\psi_0,q_0)+F_1-\lambda\nabla^2\psi-\nu\nabla^6\psi$$

$$q=\nabla^2\psi-(1/L_d^2)\psi$$

$$\bar{J}(\psi_0,q_0)\equiv U\frac{\partial q_0}{\partial x}+\beta_*\frac{\partial\psi_0}{\partial x}+J(\psi_0,q_0)$$

if λ=ν=F_1=0, then $\bar{J}(\psi_0,q_0)=0$

L_d ;the Rossby deformation radius
$\beta_*=\beta+U/L_d^2$;effective beta effect
F_1 ;the wavemaker forcing
λ ;Ekman friction coefficient
ν ;hyper-diffusion coefficient
$2\pi L_x$; zonal width of the channel
πL_y ; meridional width of the channel

(nondimentionalized by U and L_y)

Spectral expansion

$$\psi(x,y,t)=\sum_l a_Z\cos(ly)+\sum_k\sum_l a_E\exp(ikx)\sin(ly)$$

✓k = ±1, ±2, …, ±K, l = 1, 2, …, L
✓truncation wavenumber is K=42, L=42

boundary condition

✓ cyclic at x=0,2π
✓ $\frac{\partial\psi}{\partial x}=0$ and $\int_0^{2\pi L_x}\frac{\partial}{\partial t}\left(-\frac{\partial\psi}{\partial y}\right)dx=0$ at y=0,π

Time integration

✓ Timestep; 6 minute
✓ Integration period; 40 day
✓4-d Runge Kutta method

Parameter settings

$U=13.8\ \mathrm{ms}^{-1}$,
$2\pi L_x=42{,}000$ km.
$\pi L_y=21{,}000$ km
$\beta_*=1.9\times10^{-11}\ [\mathrm{m}^{-1}\mathrm{s}^{-1}]$
$\nu=1.0\ \mathrm{day}^{-1}$ for K=42,L=21

Wavemaker setting

$$F_1=\tilde{F}\sin\left\{\frac{\pi(x-x_0)}{\Delta x}\right\}\cos\left\{\frac{5\pi(x-x_0)}{\Delta x}-\omega t\right\}\sin\left\{\frac{\pi(y-y_0)}{\Delta y}\right\}$$

✓ eddy wavelength: 4200 km
✓ period: ω/2π = 4.5 days
✓ F = 5.5×10^{-10} s^{-2}

Experiments

1) there is no wavemaker (no-eddy Exp.) 2) the wavemaker is put on the same latitude as the blocking center (no-shift Exp.) 3) the wavemaker is put on the latitude of 1000 km south of the blocking center (shift Exp.)

Dipole-type block

✓ Initial value: modon solution
✓λ=0.25 [day^{-1}](linearly stable)

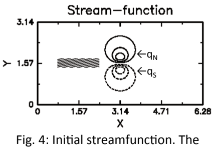

Fig. 4: Initial streamfunction. The stitch rectangle indicates the wavemaker region of the no-shift experiment.

$$q_{block}=\frac{1}{S}\int_S(q_S-q_N)dS$$

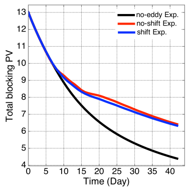

Fig. 6: Time changes of q_{block}.

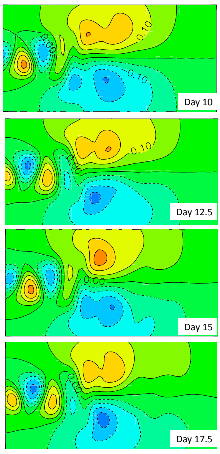

Fig. 5a: Time sequences of streamfunction for the no-shift experiment.

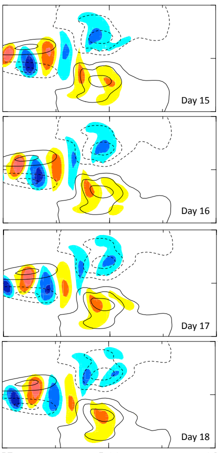

Fig. 5b: Time sequences of PV (shade) and 6-day lowpass filtered PV (contour) for the no-shift experiment. Warm (solid)/cold (dashed) color (line) shows positive/negative value.

Ω-type block

✓ Initial value: Gaussian
✓λ=0.25 [day^{-1}] (linearly stable)

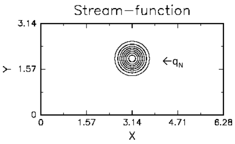

Fig. 7: As Fig. 4 but for the Ω-type blocking.

$$q_{block}=\frac{1}{S}\int_S(-q_N)dS$$

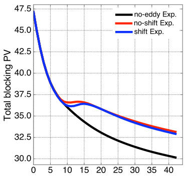

Fig. 9: As Fig. 7 but for the Ω-type blocking.

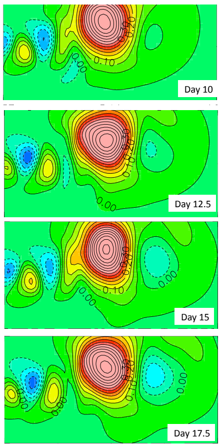

Fig. 8a: As Fig. 5a but for the Ω-type blocking.

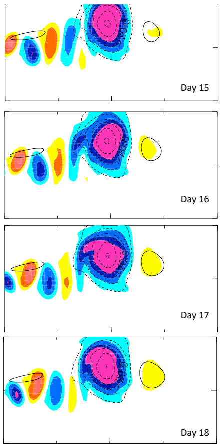

Fig. 8b:As Fig. 5b but for the Ω-type blocking.

- ✓ The two wavemaker experiments show more persistent block than the no-eddy experiment does.
- ✓ Time sequences of PV show that the essence of the mechanism for the maintenance is the absorption not but the straining.