A DIAGNOSTIC STUDY OF ATMOSPHERIC BLOCKING USING ANALOGY BETWEEN JET STREAM AND OPEN CHANNEL FLOW

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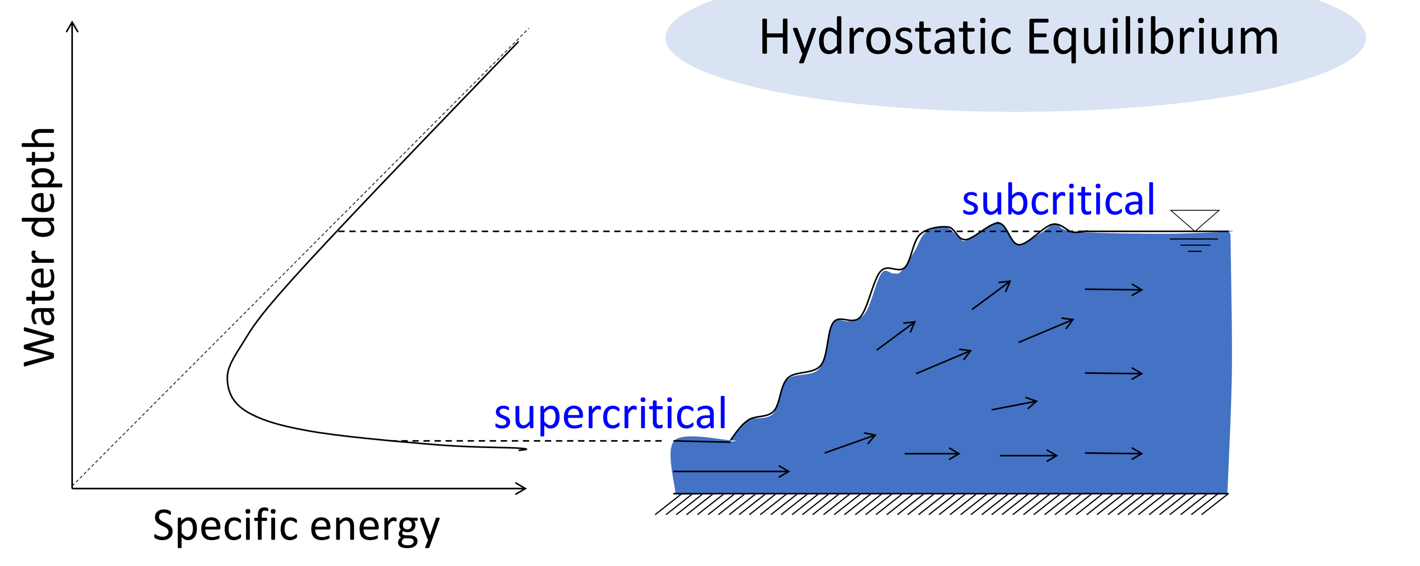
1. Introduction

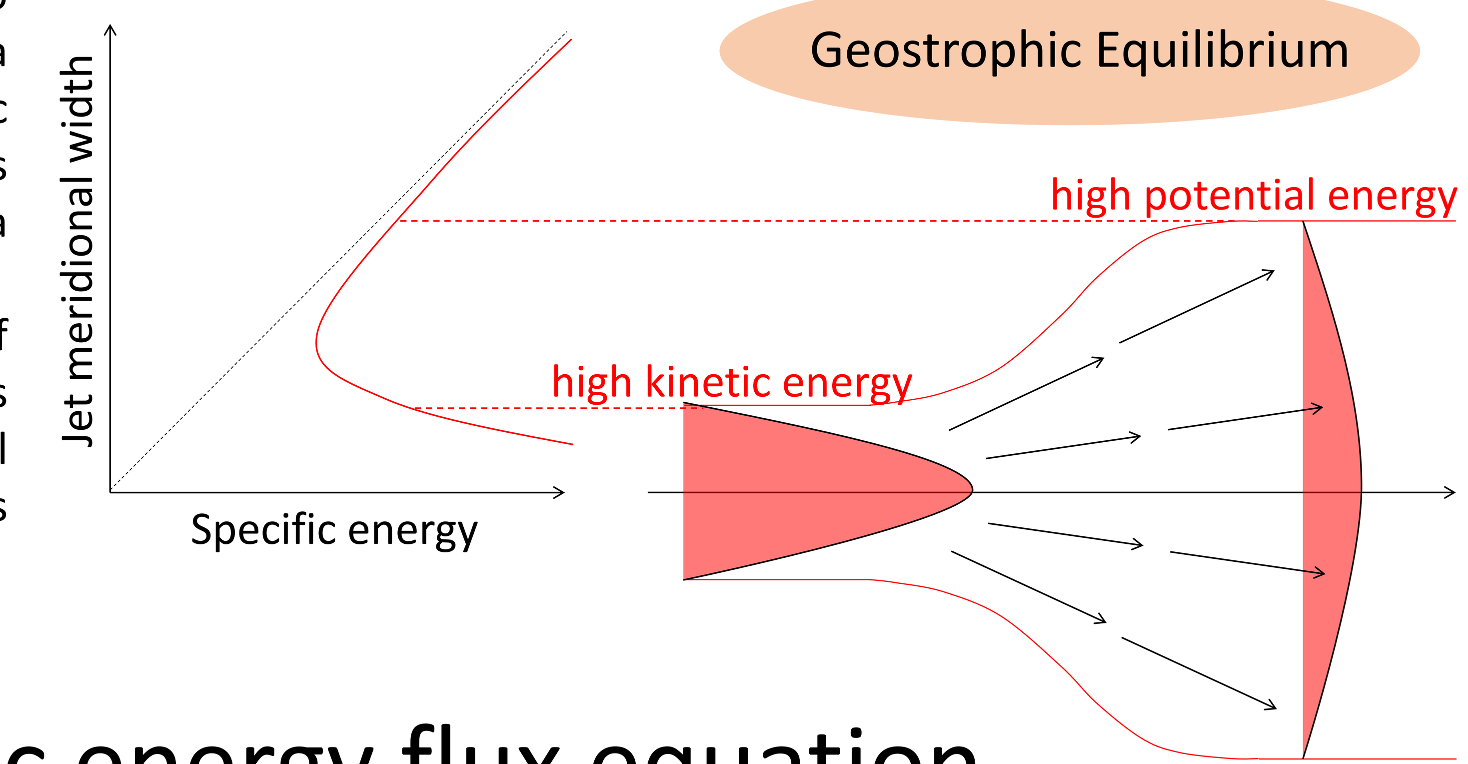
Atmospheric blocking is one of the important causes of meteorological extremes in mid-latitude, such as cold spells, heat waves, draught, and heavy rainfalls. Rossby (1950) focused on dynamical analogies between the hydraulic jump in open channel flow and the atmospheric blocking in jet stream, and proposed a theoretical formula to explain the two dynamically possible states in zonal currents which are compatible with supercritical and subcritical flow in an open channel flow. Armi (1989) focused on the specific energy flux in zonal currents and showed that a dimensionless parameter, which is called Froude/Rossby number, is analogous to the Froude number of open channel flow. Kitano and Yamada (2017) extended these theories to realistic conditions in atmosphere and showed a relationship between typical blocking flow and specific energy flux in jet stream. However, specific energy flux is not conserved quantitatively at jet-width expansion area because β-plane approximation is not satisfied.

The purpose of this study is to investigate behavior of the specific energy flux of jet stream in which Coriolis parameter approximation is not considered and reveal the usability of specific energy flux for blocking diagnosis method.

Open channel flow



Atmospheric Jet stream



2. Derivation of the specific energy flux equation

Energy of jet stream is given by

$$G = \int_{-a}^{a} u\left(\frac{u^2+v^2}{2} + \frac{p}{\rho}\right) dy\,. \qquad (1)$$

Considering the geostrophic equilibrium, pressure distribution is given by

$$p(y) = p_{-a} + \rho \int_{-a}^{y} f\, u\, dY\,. \qquad (2)$$

Unit depth volume transport V over north-south cross-section is defined by

$$V = \int_{-a}^{a} u\, dy = Const. \qquad (3)$$

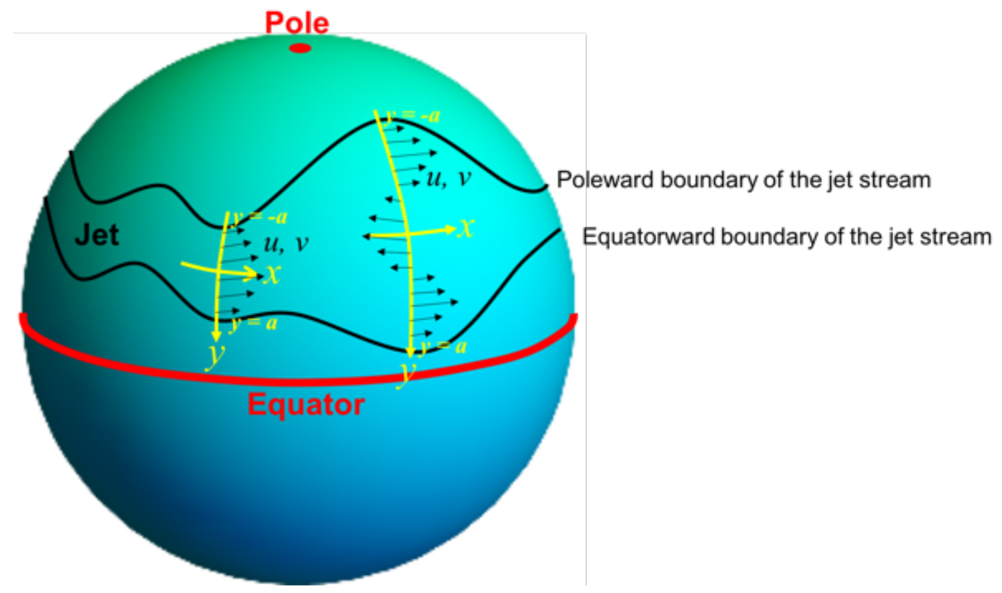
Substituting Eqs. (2) and (3) into (1), the energy equation is rewritten as follow.

$$G = \int_{-a}^{a} u \frac{u^2+v^2}{2} dy + \int_{-a}^{a} u \int_{-a}^{Y} f\, u\, dY\, dy + \frac{p_{-a} V}{\rho}. \qquad (4)$$

Here, third term is constant. First and second terms are defined by specific energy of jet stream G_0.

$$G_0 = \int_{-a}^{a} u \frac{u^2+v^2}{2} dy + \int_{-a}^{a} u \int_{-a}^{Y} f\, u\, dY\, dy\,. \qquad (5)$$

We use Eq. (5) and analyze a Pacific blocking episode utilizing ERA-Interim reanalysis dataset (Dee et al., 2011).



u	eastward wind velocity	v	equatorward wind velocity
p	pressure	ρ	density
y, Y	equatorward direction	a	half width of jet
f	Coriolis parameter	V	Unit depth volume transport over north-south cross-section
G, G_0	energy of jet stream	$Ro=VL/\Omega a^3$	Rossby number
Ω	rotation speed of the earth	*L*	distance between pole and equator
β	meridional gradient of Coriolis parameter	f_0	Coriolis parameter at jet center (*y=0*)
u'	non-dimensional eastward velocity	*y', Y'*	non-dimensional poleward direction
α_1', α_2'	velocity distribution coefficients		

3. Results

Figure 1 shows the specific energy flux derived by Eq. (5) between 21 February to 3 March 1989. Vertically averaged data between 2500-12000 m, which is set to exclude influence of terrain and stratosphere, is used. Poleward boundary of the jet stream ($y = -a$) is defined by a constant pressure line (p = 395 hPa). Equatorward boundary of the jet stream ($y = a$) is defined to let V becomes constant ($V = 8.7\times10^7$ m^2/s) by Eq. (3).

High specific energy flux ET1, ET2 in Figure 1 may represent energy transports from west to east. Figure 2-6 show the horizontal wind velocity and specific energy flux in each time step written by blue dashed lines in Figure 1. On February 22 and 26 (Figure 2, 4), high specific energy flux characterized by higher kinetic energy exists near Japan and its surroundings. After that (Figure 3, 4 and 5, 6), area of high specific energy flux is replaced eastward and Ω-type blockings are formed over central North Pacific region.

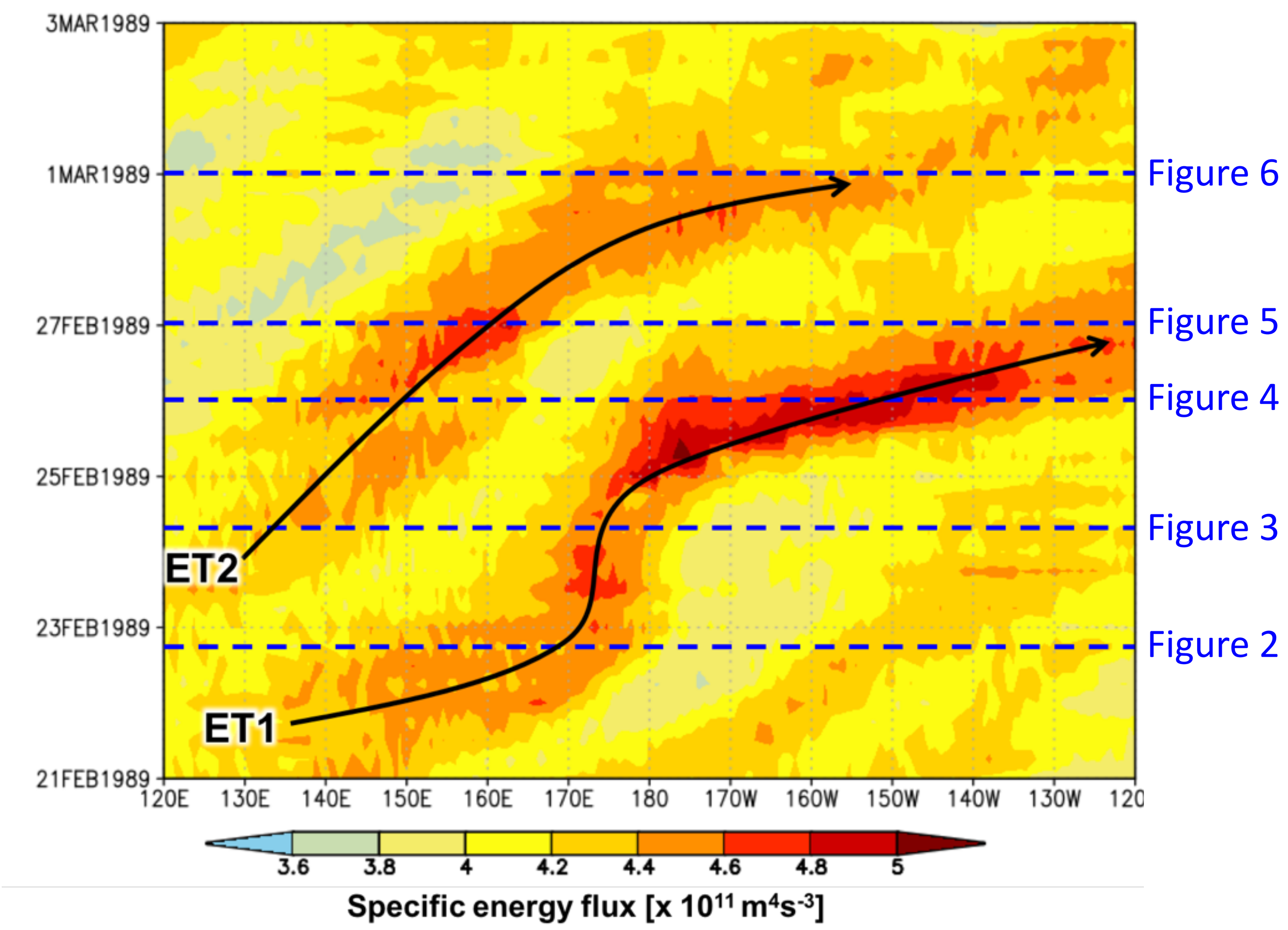


Figure 1: Specific energy flux derived by Eq. (5) between 21 February to 3 March 1989.

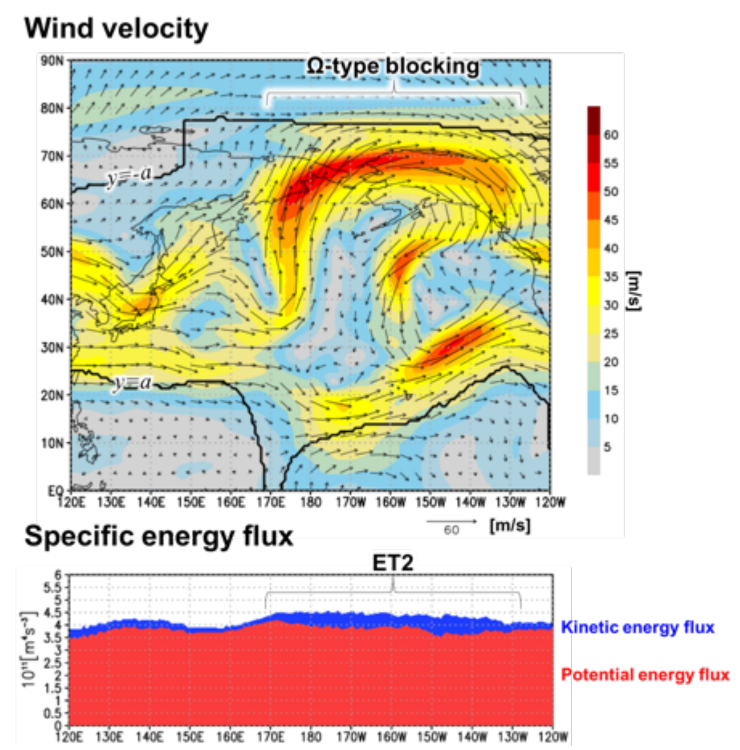


Figure 6: 1989/03/01 00:00 UTC

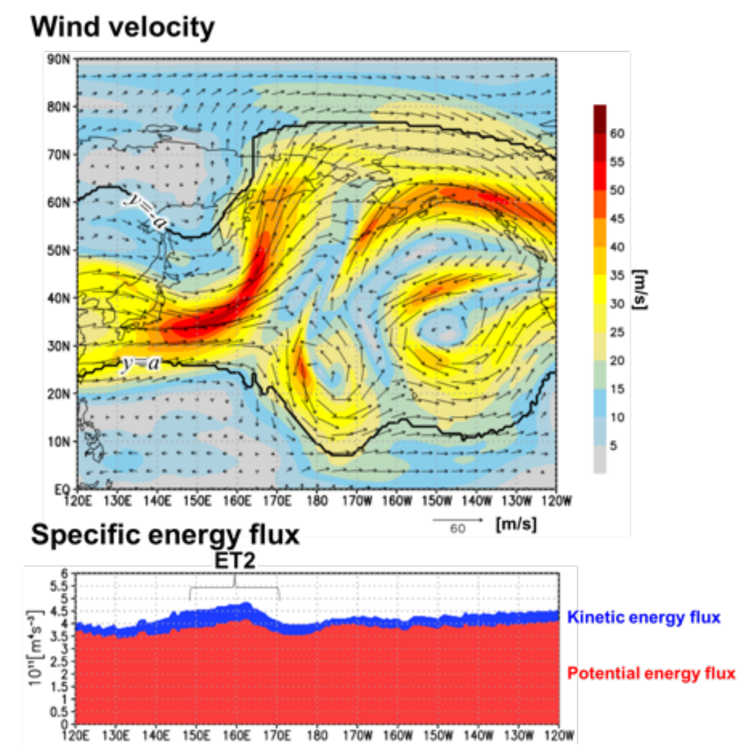


Figure 5: 1989/02/27 00:00 UTC

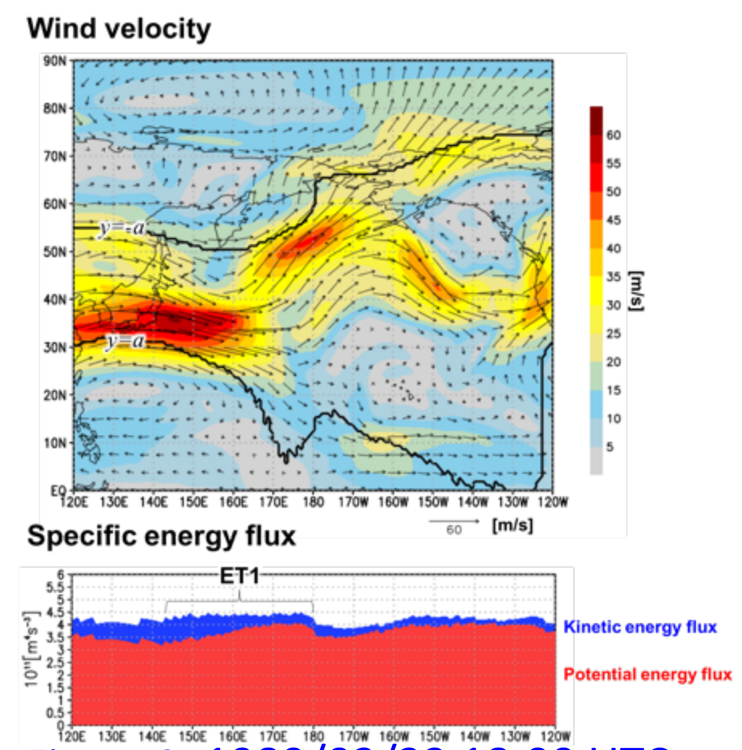


Figure 2: 1989/02/22 18:00 UTC

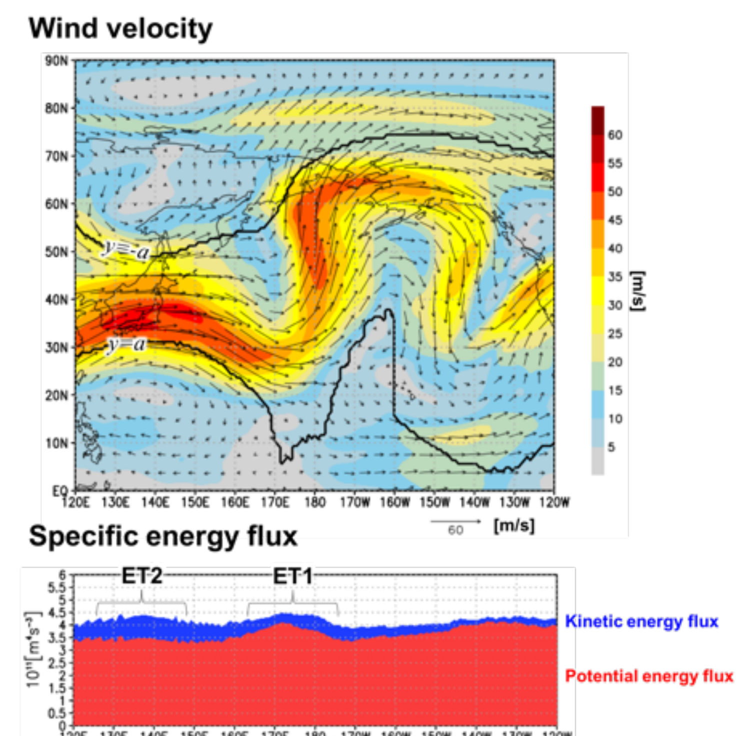


Figure 3: 1989/02/24 06:00 UTC

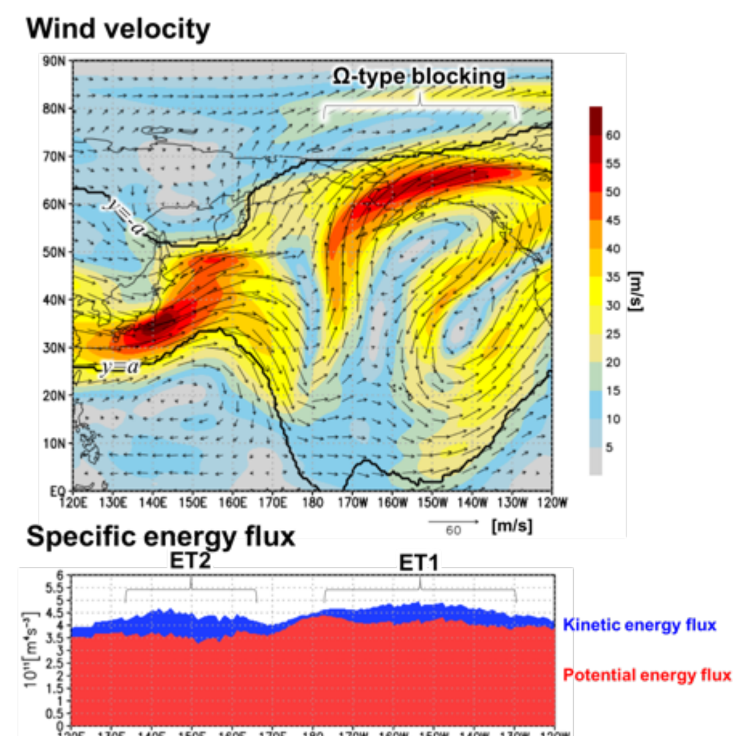


Figure 4: 1989/02/26 00:00 UTC

4. Summary

KY2017 stated that eastward flow in situation of atmospheric blocking characterized by wide width of jet ($2a$) and meridional profile of u theoretically needs high specific energy flux. In Figures 1-6, this feature is clearly observed. These results imply that high specific energy flux could be treated as a blocking diagnosis method. Furthermore, before the occasion of atmospheric blocking, high specific energy flux is generated over upstream region. This generation could be a trigger of the Pacific blocking episodes.

References

Armi, L. (1974). *Geophys. Fluid Dyn. Notes*, WHOI Ref.74-63(2): 1-14.
Armi, L. (1989). *J. Fluid Mech.*, 201:357-377.
Ball, F. K. (1959). *Quart. J. R. Meteorol. Soc.*, 85(363): 24-30.
Chow, V.T. (1959). McGraw-Hill Book Company.
Dee D. P. et al. (2011). *Q. J. R. Meteorol. Soc.*, 137:553-597.
Fultz, D. (1961). *Adv. Geophys.,* 7:1-103.
Henderson, F. (1966). Open Channel Flow. Macmillan.
Jaeger, C. (1956). Engineering Fluid Mechanics, Blackie & Son Limited, London Glasgow.
Kitano, Y., Yamada, T.J. (2017). *Annual journal of Hydraulic engineering JSCE*, 61: I_439-I_444.
Lejenäs, H., økland, H. (1983). *Tellus A*, 35: 350-362.
Long, R. R. (1955). *Tellus*, 7:341-357.
Rex, D. F. (1950). *Tellus*. 2(4): 275-301.
Riffler, M. (2005). University of Innsbruck for the degree of master of science, 1-62.
Rossby, C.-G. (1950). *J. Chinese Geophys. Soc.*, 2:1-13.
Tibaldi, S., Molteni, F. (1990). *Tellus A*, 42(3):343-365.
Yen, B. C. (1973). *J. Engng Mech.*, Div. ASCE, 99:979-1009.