Wind stress for curl as a driving force of annual waves in the upper ocean interpreting energetics at all latitudes

Kaiwen Ye[1], Hidenori Aiki[2,3]

1 Graduate School of Environmental Studies, Nagoya University, Nagoya, Japan
2 Institute for Space–Earth Environmental Research, Nagoya University, Nagoya, Japan
3 Application Laboratory, Japan Agency for Marine–Earth Science and Technology, Yokohama, Japan

***Progress in Earth and Planetary Science* (2024) 11:29**
https://doi.org/10.1186/s40645-024-00630-1

Correspondence:
Kaiwen Ye
yekaiwen1998academic@gmail.com

Abstract

The dynamics of waves and eddies in the upper ocean plays an important role in the climate variation of tropical and subtropical regions. Previous diagnoses for annual Rossby waves in oceanic model outputs manifested zonally alternating signals (ZASs) in the time-averaged distributions of wind input as well as pressure-flux divergence terms in the budget equation of wave energy. This is the case when the annual mean of the wind input is estimated as the inner product of simulated velocity vector and wind stress vector in previous studies. The present study proposes a new mathematical expression for estimating the wind input that is analogous to one derived from the quasigeostrophic potential vorticity equation. Namely, the wind input is estimated as the negative of the product of pseudo-streamfunction and wind stress curl, the latter of which is associated with the horizontal divergence of Ekman velocity. This can be interpreted as replacement of kinetic energy input with gravitational potential energy input. Pseudo-streamfunction in the present study is inverted from Ertel's potential vorticity anomaly and is seamlessly available at all latitudes. This contrasts with the quasi-geostrophic streamfunction which is singular at the equator. The new expression enables reducing ZASs in the horizontal distributions of both wind input and pressure-flux divergence terms, without harming the qualitative advantage of energy flux vectors to indicate the group velocity of waves at all latitudes.

Keywords: *Wave energy, Annual wave, Rossby wave, Wind input, Zonally alternating signals, Pseudo-streamfunction*

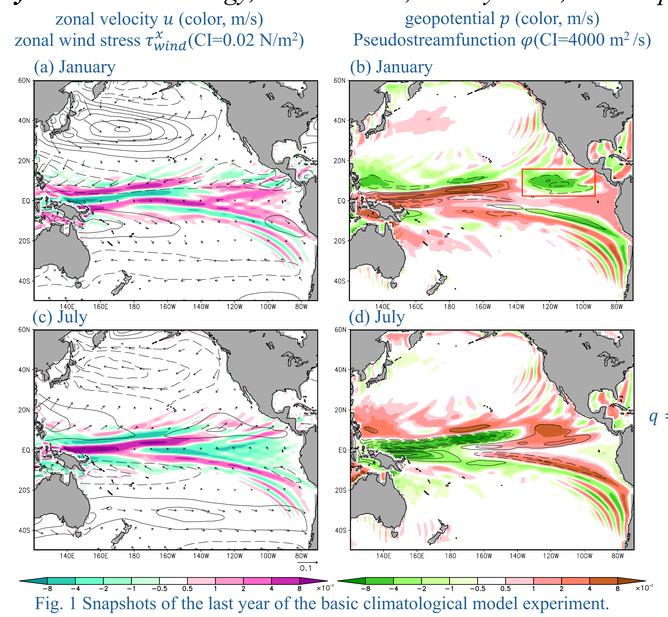

Fig. 1 Snapshots of the last year of the basic climatological model experiment.

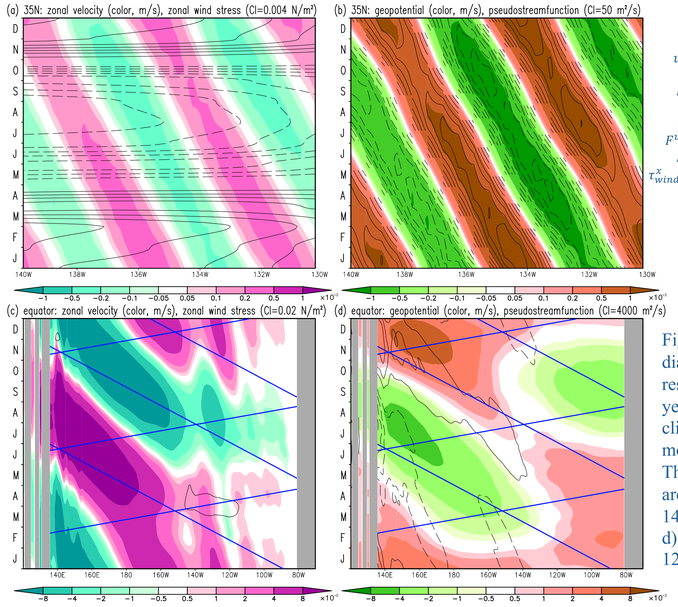

Fig. 2 Hovmöller diagrams for the results in the last year of the basic climatological model experiment. The research areas are at (a, b) 35° N, 140°–130° W and (c, d) the equator, 120° E–70°W

Classical expression

$$\frac{\partial}{\partial t}\left[\frac{H_1\rho_0}{2}(u^2+v^2)+\frac{H_1\rho_0}{2c^2}p^2\right]+$$

pressure-flux divergence $\frac{\partial}{\partial x}(H_1\rho_0 up)+\frac{\partial}{\partial y}(H_1\rho_0 vp)=$

wind input rate $u\tau^x_{wind}+v\tau^y_{wind}+$

dissipation rate $H_1\rho_0(uF^u+vF^v)+\rho_0 pF^h$

$$p=\frac{c^2}{H_1}(h-H_1),$$

$$q=\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}-\frac{f(h-H_1)}{H_1}$$

$$\nabla^2\varphi-\left(\frac{f}{c}\right)^2\varphi=q$$

u, v	zonal, meridional velocity
h	layer thickness
H_1	reference thickness
f	Coriolis parameter
c	gravity wave speed
F^u, F^v	eddy viscosity
F^h	forcing for layer thickness
τ^x_{wind}, τ^y_{wind}	climatological wind stress anomalies

Modified expression

$$\frac{\partial}{\partial t}\left[\frac{H_1\rho_0}{2}(u^2+v^2)+\frac{H_1\rho_0}{2c^2}p^2\right]+$$

$$\frac{\partial}{\partial x}\left(H_1\rho_0 up-\varphi\tau^y_{wind}\right)+\frac{\partial}{\partial y}\left(H_1\rho_0 vp+\varphi\tau^x_{wind}\right)=$$

$$-\varphi\, curl_{tau}+(u+\varphi_y)\tau^x_{wind}+(v-\varphi_x)\tau^y_{wind}+$$

$$H_1\rho_0(uF^u+vF^v)+\rho_0 pF^h$$

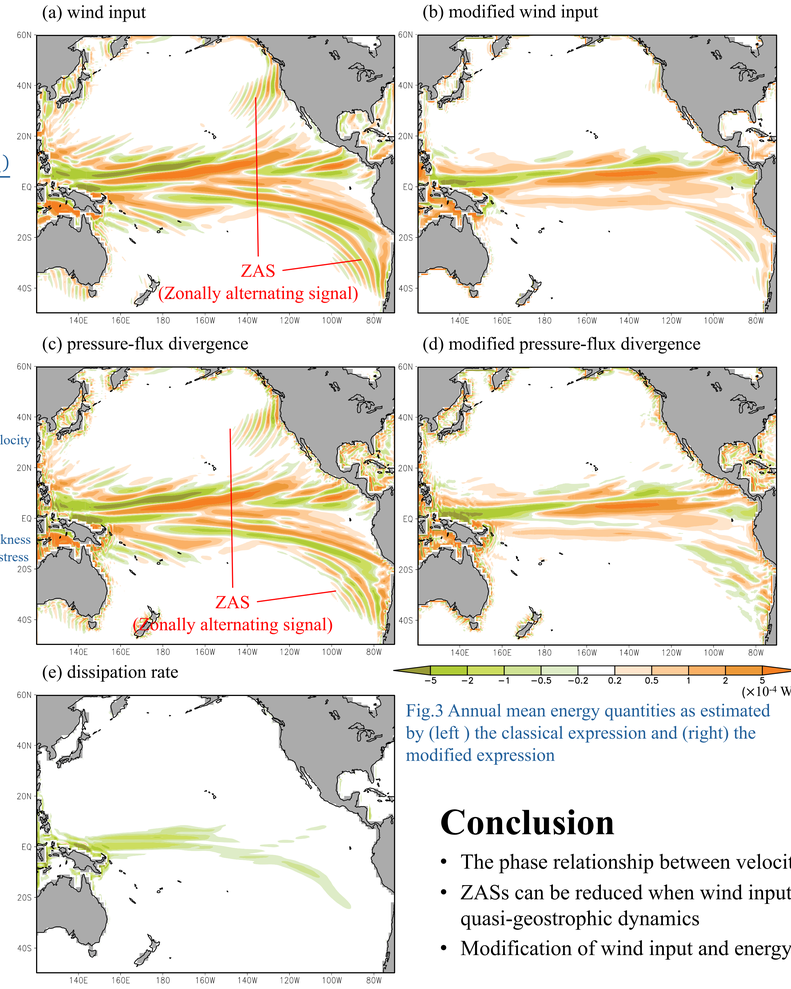

Fig.3 Annual mean energy quantities as estimated by (left) the classical expression and (right) the modified expression

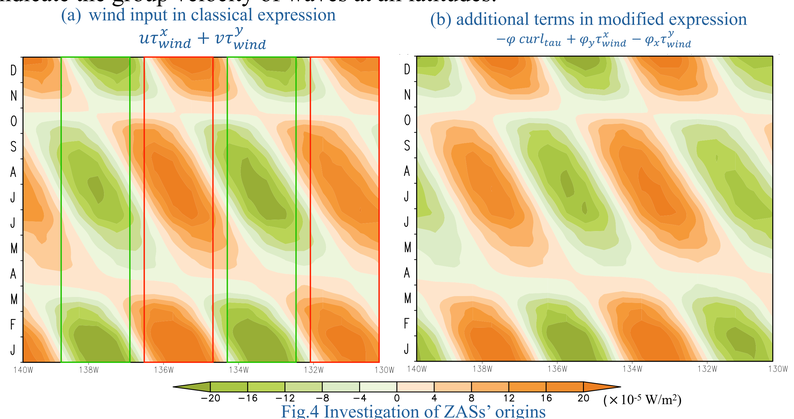

Fig.4 Investigation of ZASs' origins

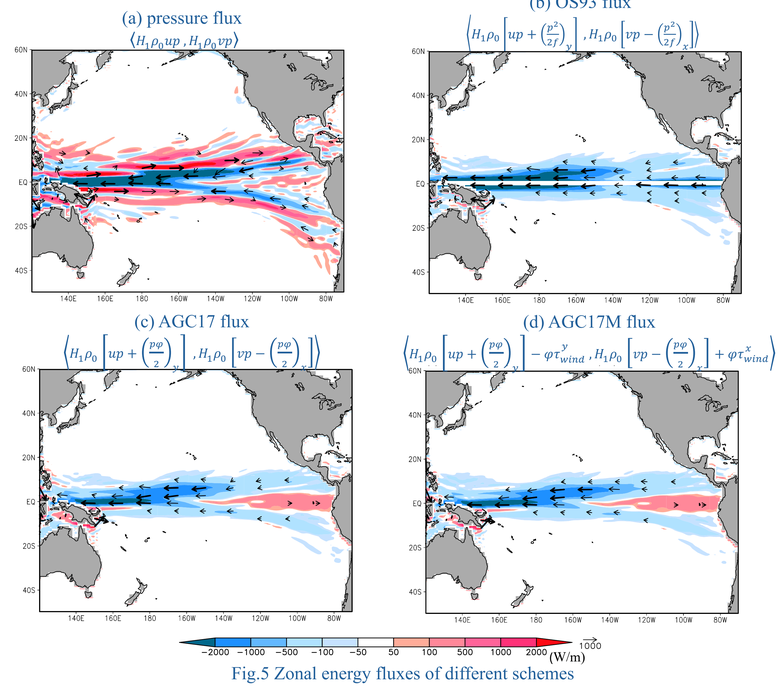

Fig.5 Zonal energy fluxes of different schemes

Conclusion

- The phase relationship between velocity and wind stress causes ZASs which disturb the understanding of the annual mean wind input.
- ZASs can be reduced when wind input is calculated as the negative of the product of streamfunction and wind stress curl associated with quasi-geostrophic dynamics
- Modification of wind input and energy flux vectors will not harm the qualitative advantage of the seamless energy-flux expression.