Midwinter suppression of the North Pacific storm track: local wave activity perspective

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Abstract

The North Pacific storm track, which is often quantified by band-passed filtered eddy variance, shows a relatively weak magnitude in midwinter than in its neighboring seasons. This midwinter suppression of the North Pacific storm track is well characterized by local wave activity (LWA) and its budget. The LWA variance, applied to the 250-hPa geopotential height field, well captures local waviness and its midwinter suppression. Although both cyclonic and anticyclonic wave activities contribute to the midwinter suppression, cyclonic wave activity (deepening of trough, cyclonic wave breaking and filamentation) exhibits a much more pronounced subseasonal cycle and explains about 73.6% of the midwinter suppression. The budget analysis of column-integrated LWA, computed for quasi-geostrophic potential vorticity, further reveals that the North Pacific LWA is primarily controlled by the convergence of zonal LWA flux with a non-negligible contributions of non-conservative LWA sources or sinks.

Data	ERA-Interim
Variable	geopotential height, relative vorticity, temperature, zonal wind, meridional wind
Resolution	1.5° x 1.5°, L37, 6-hourly
Period	1979.01-2016.12

Backgrounds

Storminess: quantified by 24-hour-difference filter

$$\overline{X^e} = \overline{[X(t+24hr) - X(t)]^2}$$

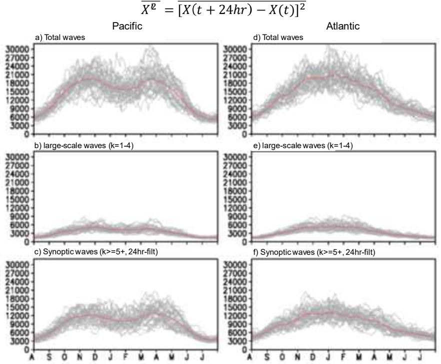

Figure 1. Monthly variation of area-averaged 24-hour difference filtered variance of geopotential height for total waves (a, d), large-scale waves (b, e) and synoptic-scale waves (c, f) at 250 hPa for Pacific (a-c) and Atlantic (d-f) domains. Units are m^2.

- Over the North Pacific, the storminess of the 250 hPa geopotential height exhibits a relative minimum in midwinter, especially for synoptic-scale waves.

LWA_Z results

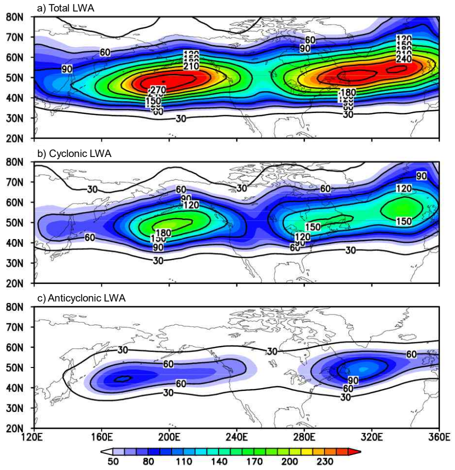

Figure 2. The horizontal distributions of the 24-hour-difference filtered variances of LWA_Z for total (a), cyclonic (b) and anticyclonic (c) components respectively at 250 hPa. Units are $10^{13} m^4$.

LWA diagnoses localized weather events and quantifies eddy-mean flow interactions on regional scales. In this study, LWA_Z and LWA_QGPV indicate the LWA defined by using geopotential height (Chen et al., 2015) and quasi-geostrophic potential vorticity (Huang and Nakamura, 2016), respectively.

LWA_Z

Polar section area: $S(Q) = \int\int_{q<Q} a^2 \cos\varphi \, d\lambda d\varphi$

Equivalent latitude: $\varphi_e(Q) = \arcsin[1 - \frac{S(Q)}{2\pi a^2}]$

Eddy component: $q_e(\lambda,\varphi,z,t) = q(\lambda,\varphi,z,t) - q_{ref}(\varphi_e,z,t)$

Cyclonic LWA_Z: $A_S(\lambda,\varphi,z,t) = \frac{a}{\cos\varphi}\int_{a_e\le 0,\varphi\le\varphi_e} q_e(\lambda,\varphi,z,t)\cos\varphi \, d\varphi$

Anticyclonic LWA_Z: $A_N(\lambda,\varphi,z,t) = \frac{a}{\cos\varphi}\int_{a_e\ge 0,\varphi\ge\varphi_e} q_e(\lambda,\varphi,z,t)\cos\varphi \, d\varphi$

Total LWA_Z: $A = A_S + A_N$

- Storminess of total LWA_Z is strong over the storm tracks (the North Pacific and the North Atlantic). This implies that LWA_Z can diagnose the synoptic-scale events.
- Cyclonic LWA_Z dominantly contributes to the storminess of total LWA_Z.

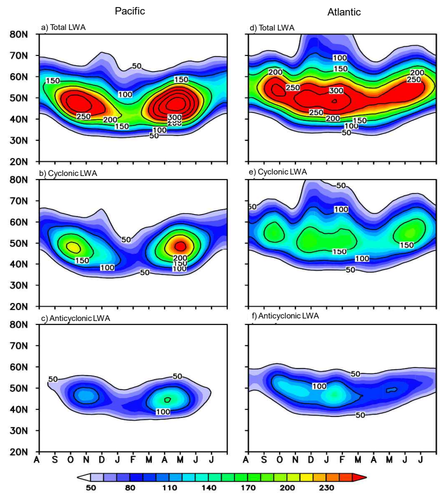

Figure 3. Seasonal variation of 24-hour-difference filtered variance of total LWA_Z (a, d), cyclonic LWA_Z (b, e) and anticyclonic LWA_Z (c, f) at 250 hPa for the Pacific (a-c) and Atlantic (d-f) domains. LWA is computed using spatially filtered geopotential height. Units are $10^{13} m^4$.

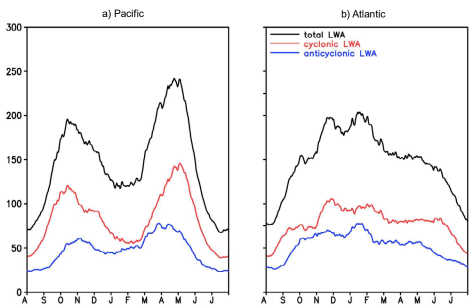

Figure 4. Monthly variation of area averaged 24-hour difference filtered variance of LWA_Z over the Pacific (a) and Atlantic (b) at 250 hPa. Units are $10^{13} m^4$.

- Over the North Pacific, storminess of total LWA_Z exhibits a double peak during October and May, with a relative minimum in February.
- Storminess of cyclonic LWA_Z adequately explains the seasonal suppression and the recovery of total storminess of LWA_Z to about 73.6%.

Budgets analysis

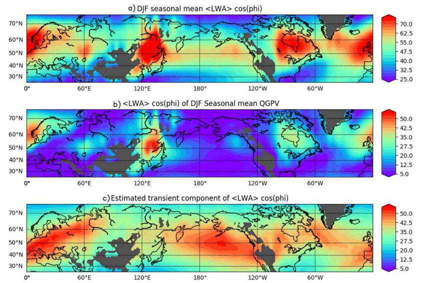

Figure 5. Horizontal distributions of seasonal mean column-averaged LWA (a), column-averaged LWA of seasonal mean QGPV (b) and estimated transient component of column-averaged LWA (c) in boreal winter. Units are $m\ s^{-1}$.

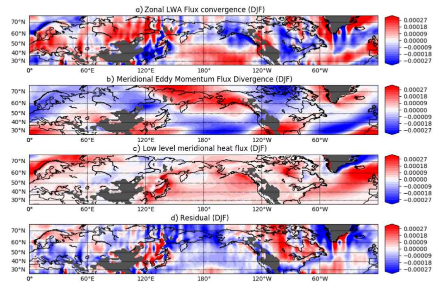

Figure 6. Horizontal distributions of seasonal mean zonal LWA flux convergence (a), meridional eddy momentum flux divergence (b), low-level meridional heat flux (c) and residual (d) in boreal winter. Units are $m\ s^{-1} day^{-1}$.

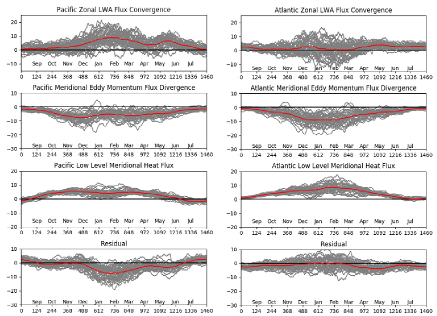

Figure 7. Monthly variation of area averaged budgets over the Pacific (left) and Atlantic (right). Unit is $m\ s^{-1} day^{-1}$.

LWA_QGPV and its budgets

LWA_QGPV:

$$\tilde{A}^*(\lambda,\varphi,z,t) = -\frac{a}{\cos\varphi}\int_0^{\Delta\varphi} q_e(\lambda,\varphi,z,t)\cos(\varphi+\varphi')\, d\varphi'$$

$$\frac{\partial}{\partial t}\langle\tilde{A}^*\rangle\cos\varphi = \underbrace{-\frac{1}{a}\frac{\partial F_A}{\partial\lambda}}_{\text{Zonal LWA flux convergence}} + \underbrace{\frac{1}{a\cos\varphi}\frac{\partial}{\partial\varphi'}\langle u_e v_e \cos^2(\varphi+\varphi')\rangle}_{\text{Meridional momentum flux divergence}}$$

$$\underbrace{+\frac{f\cos\varphi}{H}\left(\frac{v_e\theta_e}{\partial\tilde{\theta}/\partial z}\right)_{z=0}}_{\text{Low-level eddy heat flux}} + \underbrace{\langle\tilde{A}^*\rangle\cos\varphi}_{\text{Residual}}$$

- For the winter season, the transient component of the column-averaged LWA_QGPV is quite active over the North Pacific and the North Atlantic. This suggests that LWA_QGPV also well diagnoses temporal variability.
- For the North Pacific region, zonal LWA flux convergence increases LWA_QGPV during winter. Meridional eddy momentum flux divergence decreases LWA_QGPV. Low-level meridional heat flux increases LWA_QGPV. Residual term considerably reduces LWA_QGPV.
- During wintertime, zonal LWA flux convergence is notably increased over the North Pacific while changes over the North Atlantic are nearly zero.
- The residual term is a large negative value in winter over the North Pacific, in contrast with the near-zero value over the North Atlantic.

Summary and Discussion

- LWA_Z characterizes storm tracks for cyclonic and anticyclonic wave components separately and identifies the midwinter suppression fairly well.
- The storminess of cyclonic LWA_Z dominates to the midwinter suppression of total LWA_Z.
- LWA_QGPV over the North Pacific in wintertime is largely controlled by zonal LWA flux convergence and the residual term.

Acknowledgements
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