Intra-seasonal Periodicity Behavior of Finite-amplitude Wave Activity in the Mid- latitude Troposphere

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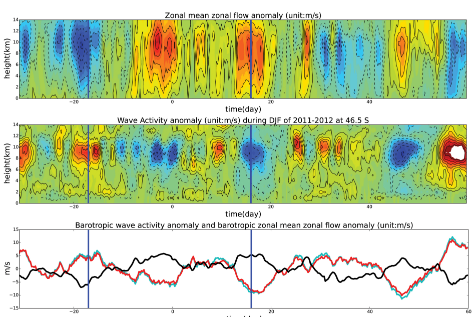
Motivation

- A new type of large-scale atmosphere variability *Baroclinic Annular Mode* (BAM) has recently been shown to exhibit a marked periodicity on time scales of approximately 20 to 30 days [*Thompson and Woodworth 2014*; *Thompson and Barnes 2014*]. Detectable from eddy kinetic energy and heat flux and precipitation, this new oscillation plays a profound role in driving climate variability throughout much of the mid-latitude Southern Hemisphere.
- Our work builts a closed three-equation momentum cycle, which provides latitude-by-latitude budgets of finite-amplitude wave activity [*Wang and Nakamura 2015a*]. We found wave activity possess a 25-day periodicity only in warm season and preferentially exists within 40 - 50 S. Question remains:

why this new variability favors such a season and location?

Here we address the role of mean state of austral summer on giving rise to this circulation variability via synoptic waves.

Part I: periodicity in wave activity



Interior Wave Activity

$$\frac{\partial}{\partial t}\langle A\rangle = \boxed{\frac{1}{a\cos^2\phi}\frac{\partial}{\partial\phi}\langle\overline{u'v'}\cos^2\phi\rangle} + \boxed{\left.\frac{f\overline{v'\theta'}}{H(\partial\tilde{\theta}/\partial z)}\right|_{z=0}} + \boxed{\langle\dot{A}\rangle}$$

Momentum Flux Convergence — Surface Heat Flux — non-conservative terms

Zonal Mean Zonal Flow

$$\frac{\partial}{\partial t}\langle\bar{u}\rangle = \boxed{-\frac{1}{a\cos^2\phi}\frac{\partial}{\partial\phi}\langle\overline{u'v'}\cos^2\phi\rangle} + \boxed{\langle\dot{U}\rangle}$$

- Momentum Flux Convergence — non-conservative terms

Surface Wave Activity

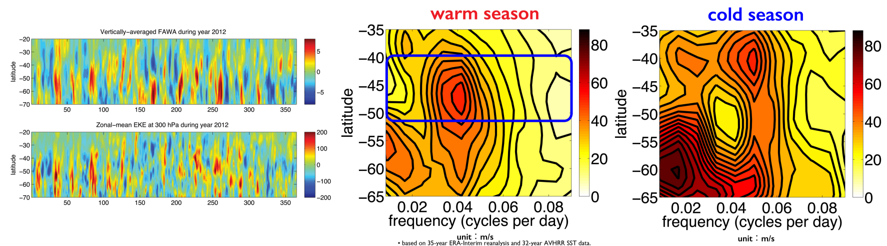
$$\frac{\partial B}{\partial t} = \boxed{\left.-\frac{f\overline{v'\theta'}}{H(\partial\tilde{\theta}/\partial z)}\right|_{z=0}} + \boxed{\dot{B}}$$

- Surface Heat Flux — non-conservative terms

where vertical density average is defined as:

$$\langle(\cdot)\rangle \equiv \int_0^\infty e^{-z/H}(\cdot)dz \Big/ \int_0^\infty e^{-z/H}dz.$$

Part II: mean state and wave activity statistics

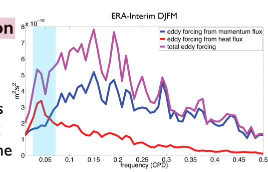


wave activity

Vave activities' 25-day eriodicity **only xists in warm eason and not in old season**. In warm eason, this periodicity ocates at 40-50 S. This titude band is marked y enhanced low-level Tdy.

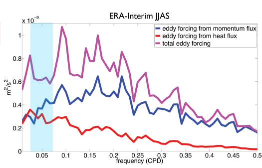
eddy forcing in warm season

Eddy forcing of wave activity is largely due to momentum flux convergence at high frequencies but the low-level eddy heat flux has a peak and is dominant at the BAM frequency



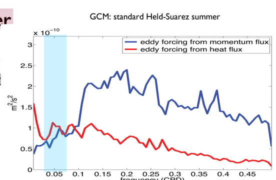
eddy forcing in cold season

Heat flux does not have a peak at the BAM frequency and has a near red noise spectrum in cold season.



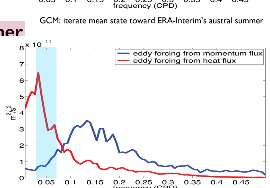
GCM: Held-Suarez summer

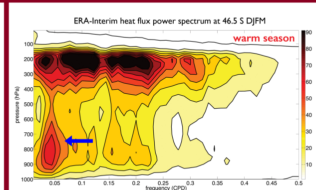
Standard HS94 summer configuration produces heat flux and momentum flux convergence whose spectra are both broad



GCM: toward austral summer

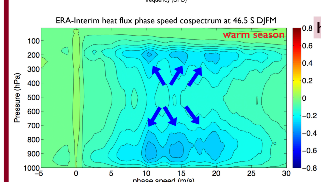
When the mean state is adjusted to the observed austral summer, eddy heat flux exhibits distinctive BAM-like spectral peak. A strong thermal damping controls the scales of eddy





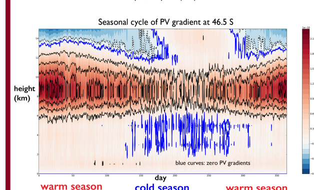
heat flux power spectra

25-day periodicity mainly exists in low-level. It is small, but important in vertical average due to pressure weighting.



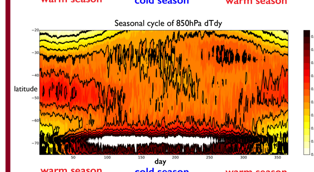
heat flux phase speed spectra

A series of discrete modes, with different phase speeds, could contribute to the periodicity in low-level heat flux.



PV gradient

Only during warm season, PV gradient exibits sharp vertical structure and positive values throughout troposphere.

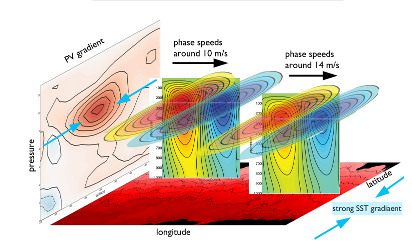


low-level dTdy

Only during warm season, low-level dTdy has sharp peaks in 40-50 S, which constrain the width of austral summer storm track.

Mode interference

narrow baroclinic zone in warm season



Conclusions

- Narrow and sharp PV gradient and SST gradient in austral summer storm track provide waveguide for synoptic atmospheric waves. This waveguide favors discrete synoptic waves in frequency, whose interference contributes to a 25-day periodicity in heat flux.
- In the standard HS94 both eddy heat flux and eddy momentum flux convergence have broad spectra. When configuring the dry model with a narrow storm track, however, eddy heat flux exhibits a BAM like peak at low frequency, leading to a BAM-like periodicity.
- A strong thermal damping controls the frequency of eddy heat flux spectra.
- The BAM-related periodicity in atmospheric finite-amplitude wave activity is located at strong SST gradient region. GCM simulations show the governing role of austral summer basic state, which confines the baroclinic zone.

Acknowledgment

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References:

Wang and Nakamura 2015, *Geophys. Res. Lett.* (Part I); Wang and Nakamura 2016, *J. Atmos. Sci.* (Part 2); Wang and Nakamura (in prep) (Part 3); Ogawa et al 2015, *Geophys. Res. Lett.*; Thompson and Woodworth 2014, *J. Atmos. Sci.*; Thompson and Barnes 2014, *Science*; Lee and Held 1993, *J. Atmos. Sci.*