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Estimation of Gravity Wave Spectral Characteristics from High-Resolution Idealized Baroclinic Wave Simulations

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Section 1

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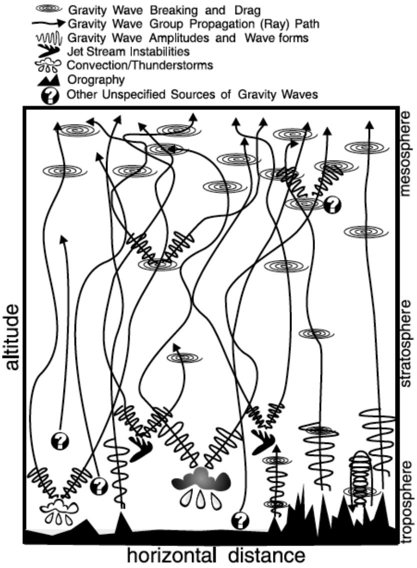
Basics of Gravity Wave Parameterizations



Kim et al. (Atmosphere-Ocean, 2003)

- Orographic Gravity Wave

One Source: Mountain
Narrow Spectrum in c, Since $c = 0$

- Nonorographic Gravity Wave

Multiple Sources: Convection, Jets, Fronts, and Instabilities
Broad Spectrum in c

Basics of Gravity Wave Parameterizations

- Momentum Flux $\rho_0\overline{u'w'}$ Is The Key!
  Eliassen and Palm's (1961) Theorem:
  $\overline{p'w'} = -(u_0 - c)\,\rho_0\overline{u'w'}$

- Parameterzied Wave-Induced Force $WIF_x = -\frac{1}{\rho}\frac{\partial\rho\overline{u'w'}}{\partial z}$
  A Body Forcing Term in the X-Dir Momentum EQN:
  $\frac{Du_0}{Dt} = CF + PGF + ... + WIF_x$

If $u_0 > c$ and $\overline{p'w'} > 0$, then $\rho_0\overline{u'w'} < 0$

$\therefore$ $WIF_x < 0$ at Gravity Wave Dissipating/Breaking Levels

$\therefore$ WIF_x is decelerating u_0 toward c

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Limitation of Current Parameterizations

- No Impact of Horizontal Gradients of Background
- No Impact of Time Change of Background
- Not Coupled to the Model's Meteorology
- The Neglect of Secondary Wave Generation and Breaking
- The Neglect of Reflection
- Wave Breaking Process is Simple

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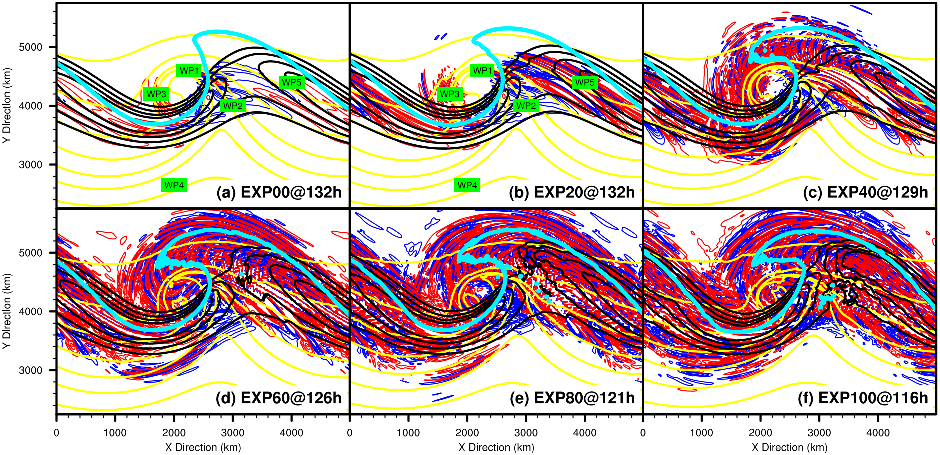
Wei and Zhang (2014, JAS)



- More Initial Moisture Suggests More Energetic Wave Field at Later Stage
- Gravity Wave Spectral Characteristics Are Sensitive to Meteorology Condition

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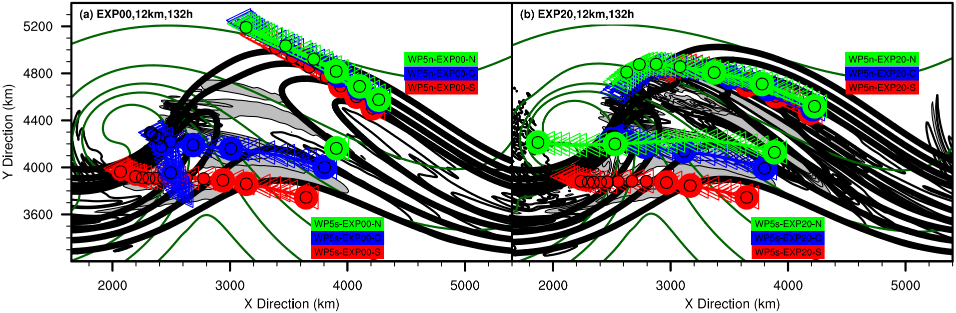
Wei and Zhang (2014, JAMES, accepted)

Trajectories of WP5s/WP5n in Dry Run versus Those in Weak Moist Run



- Long Distance of Propagation within Limited Time
- Dependence on the Spatial/Temporal Variability of Complex Background Wind
- Propagations of Gravity Waves May Be Sensitive to Meteorology Condition

Section 2

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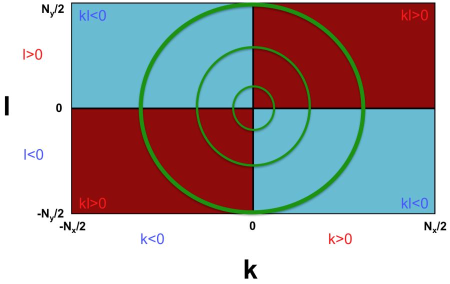
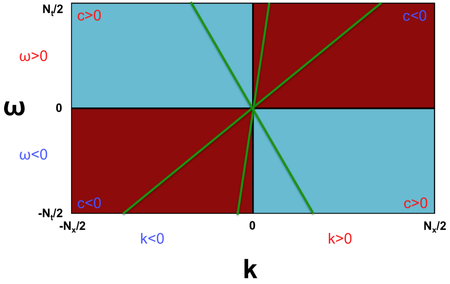
2D Fourier Transform





- $COEF_{u(k,l)} = FFT2DF\left(u\left(x,y\right)\right)$
  Obtain Magnitude and Phase
  For Each (k,l)

  Find Global Wavenumber K_H
  For Each (k,l):

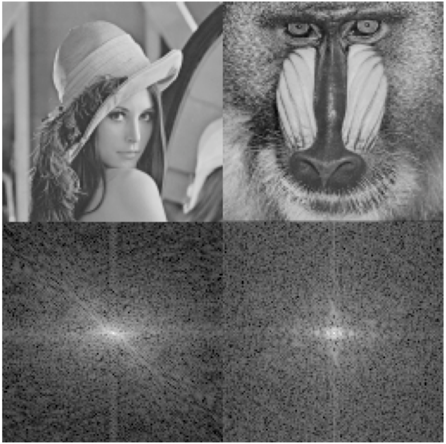
  $K_H{}^2 = K^2 + L^2$
  Where $K = k$; $L = l\frac{N_x \Delta x}{N_y \Delta y}$

- $COEF_{u(k,\omega)} = FFT2DF\left(u\left(x,t\right)\right)$
  Obtain Magnitude and Phase
  For Each (k,ω)

  Find Phase Velocity c
  For Each (k,ω):

  $c = -\frac{\omega}{k}\frac{N_x \Delta x}{N_t \Delta t}$

2D Fourier Transform: An Example



The original figure is from the website provided by Dr. John M. Brayer in Department of Computer Science, University of New Mexico

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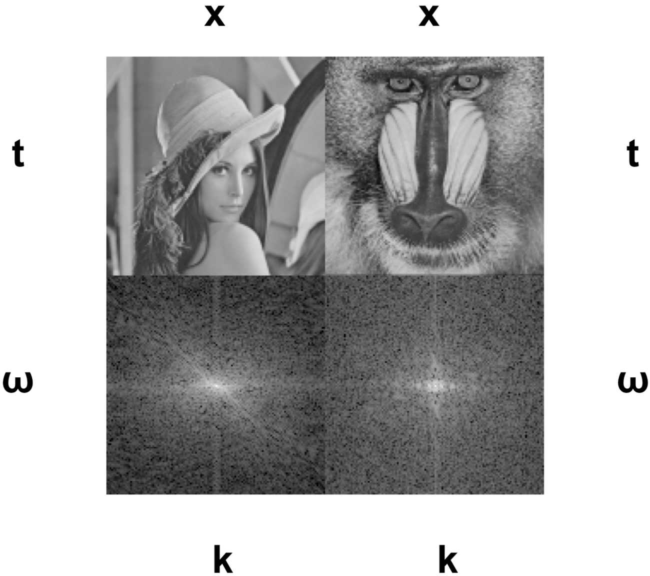

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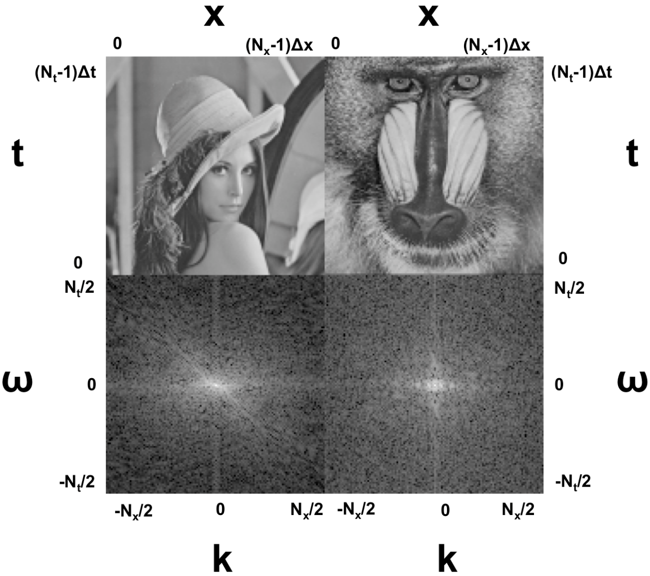

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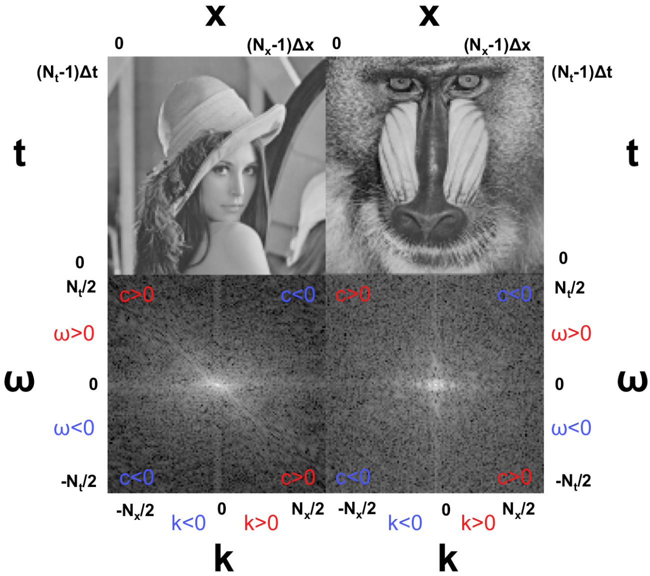

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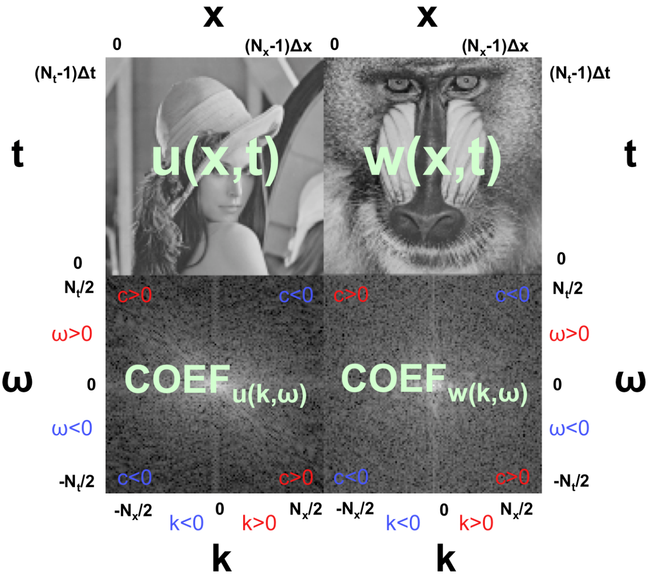

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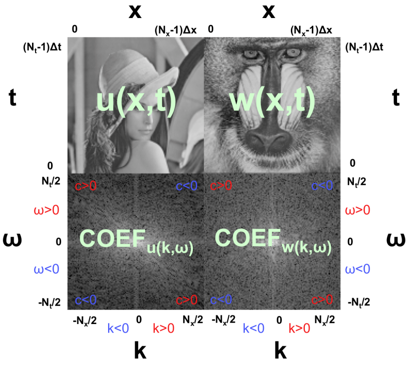
Calculate $\overline{u'w'}$ versus c

cospectrum(UW) = REAL($COEF_{u(k,\omega)}$ $COEF_{w(k,\omega)}^{*}$)

quadraspec(UW) = IMG($COEF_{u(k,\omega)}$ $COEF_{w(k,\omega)}^{*}$)



- Restart WRF for 120 hrs from 60 h
- WRF Output Temporal Interval $\Delta t = 1min$; $\Delta x = \Delta y = 10km$
- Find Spatial Scale: $50km \leqslant x \leqslant 800km$
- Find Temporal Scale: $t \geqslant 5min$
- Calculate $\overline{u'w'}$ versus c Based on 2D Fourier Transform

Section 3

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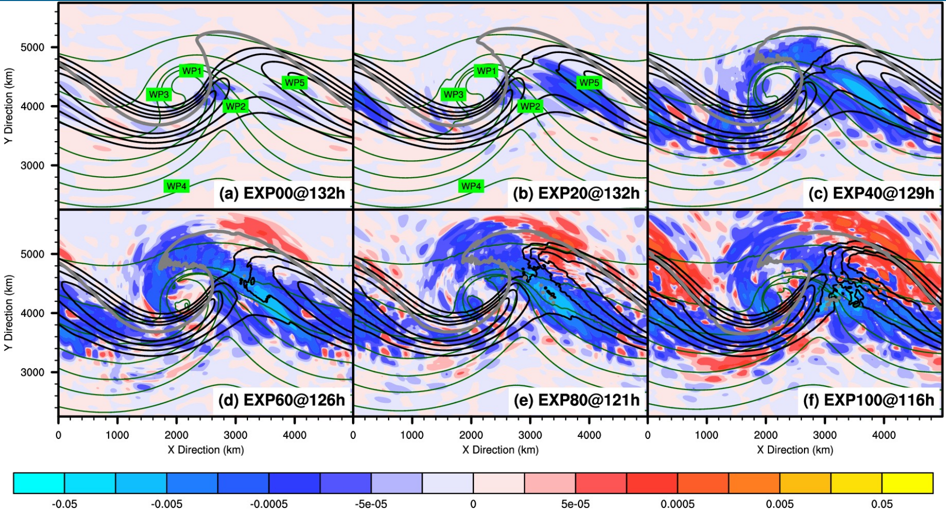
$\overline{\rho u' w'}$ at 12-km



- The Dominance of Negative Values in $\overline{\rho u' w'}$ at 12 km
- Larger Area of Positive Values With More Initial Moisture

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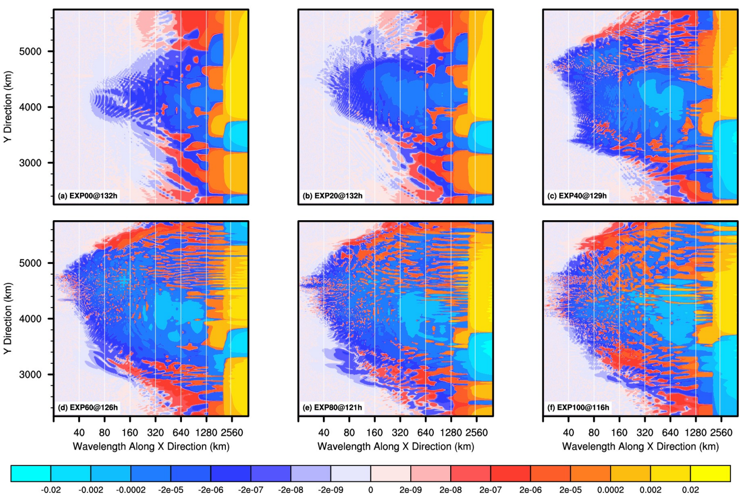
$\overline{u'w'}$ versus k

12-km cospectrum of u' & w' (color shading) at each latitude (smth=0; taper=0%)



- Negative Flux Valley Appears to Be Saturated in EXP40
- Sensitivity to Moisture for the Flux Below the Scale of 80 km

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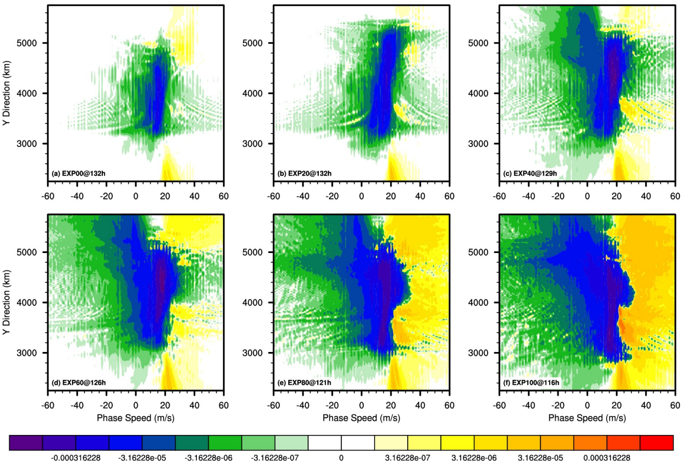
$\overline{u'w'}$ versus c ($N_t \Delta t = 96hr$)

12-km cospectrum of u' & w' (color shading) versus phase speed at each latitude



- Minimum of Negative Flux Locates Around BW Phase Speed (~13.9m/s)
- Dipole Structure in EXP80 and EXP100

Section 4

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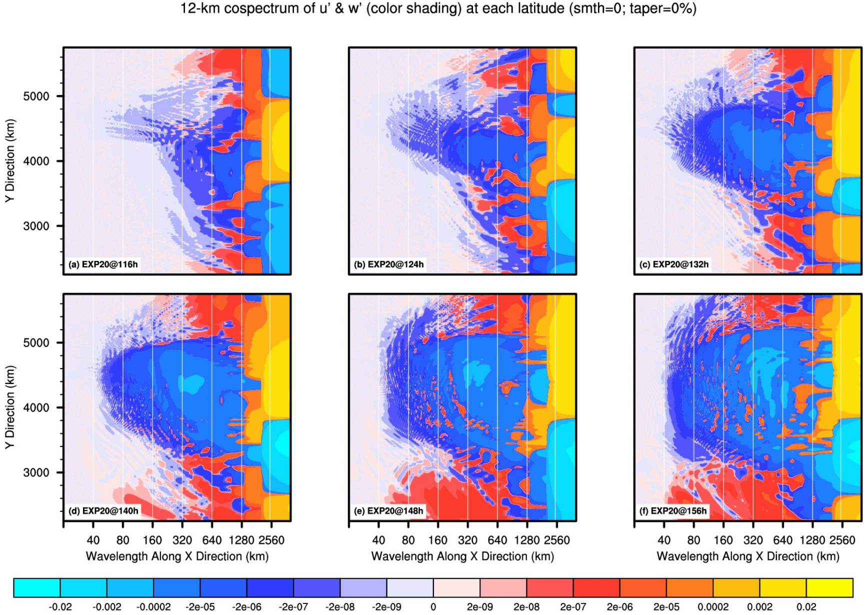
Conclusion

- For $\rho\overline{u'w'}$ at 12 km, there is a dominance of negative values. However, experiments with more initial moisture suggest larger area of positive values.
- For the cospectrum of $\overline{u'w'}$ at 12 km, $\overline{u'w'}$ below the scale of 80 km is sensitive to the initial moiture.
- For $\overline{u'w'}$ versus c, the minimum of negative flux appears to locate around the baroclinic wave phase speed (∼13.9m/s); A distribution that looks like the dipole structure is seen in EXP80 and EXP100.

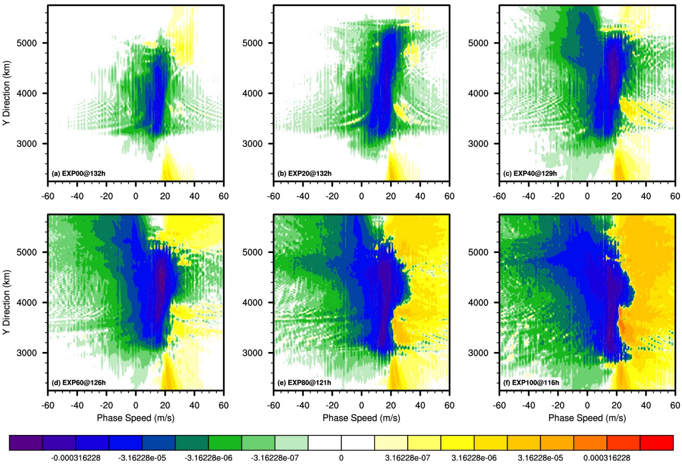
Section 5

u'w' versus k (same EXP)



$\overline{u'w'}$ versus c ($N_t \Delta t = 96hr$)

12-km cospectrum of u' & w' (color shading) versus phase speed at each latitude



- Minimum of Negative Flux Locates Around BW Phase Speed (13.9m/s)
- Dipole Structure in EXP80 and EXP100

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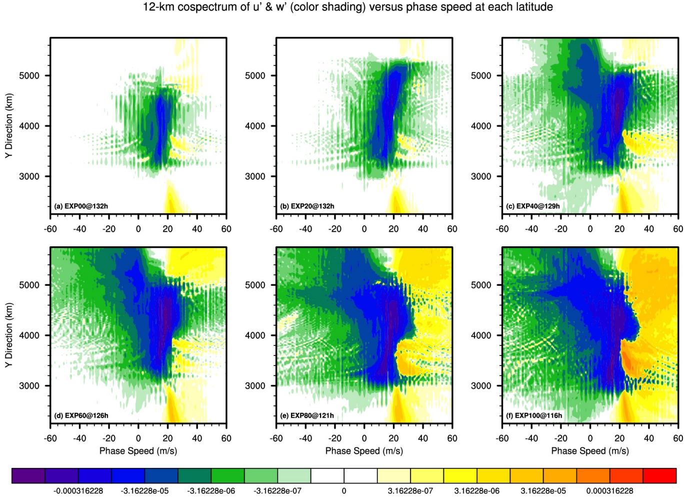
$\overline{u'w'}$ versus c ($N_t \Delta t = 72hr$)



- Minimum of Negative Flux Locates Around BW Phase Speed (13.9m/s)
- Dipole Structure in EXP80 and EXP100

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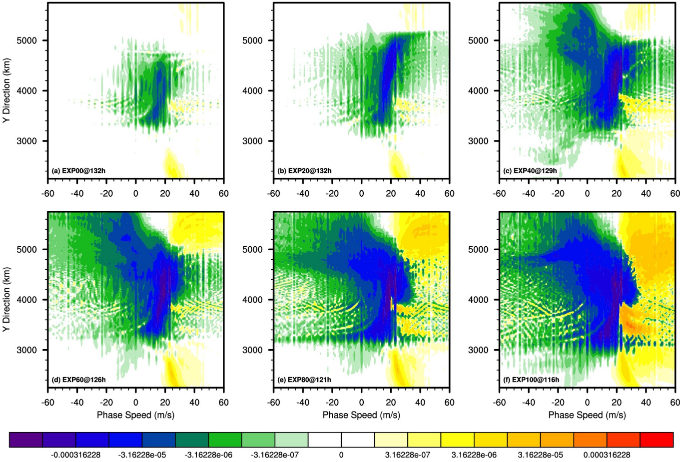
$\overline{u'w'}$ versus c ($N_t \Delta t = 48hr$)

12-km cospectrum of u' & w' (color shading) versus phase speed at each latitude



- Minimum of Negative Flux Locates Around BW Phase Speed (13.9m/s)
- Dipole Structure in EXP80 and EXP100

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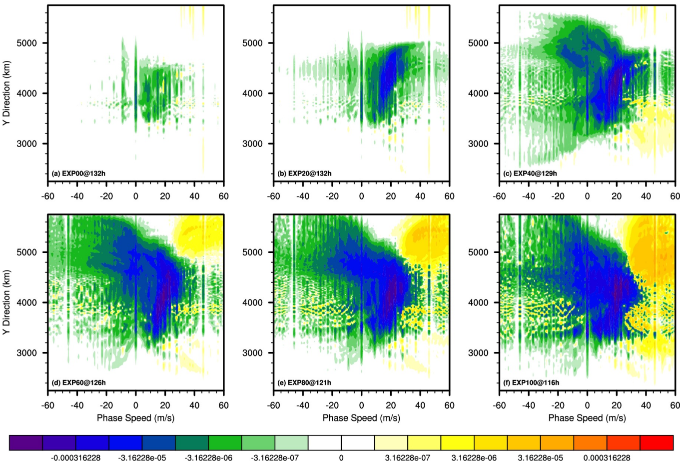
$\overline{u'w'}$ versus c ($N_t \Delta t = 24hr$)

12-km cospectrum of u' & w' (color shading) versus phase speed at each latitude



- Minimum of Negative Flux Locates Around BW Phase Speed (13.9m/s)
- Dipole Structure in EXP80 and EXP100