Aircraft Measurements and Numerical Simulations of Gravity Waves in the Extratropical UTLS Region during the START08 Field Campaign

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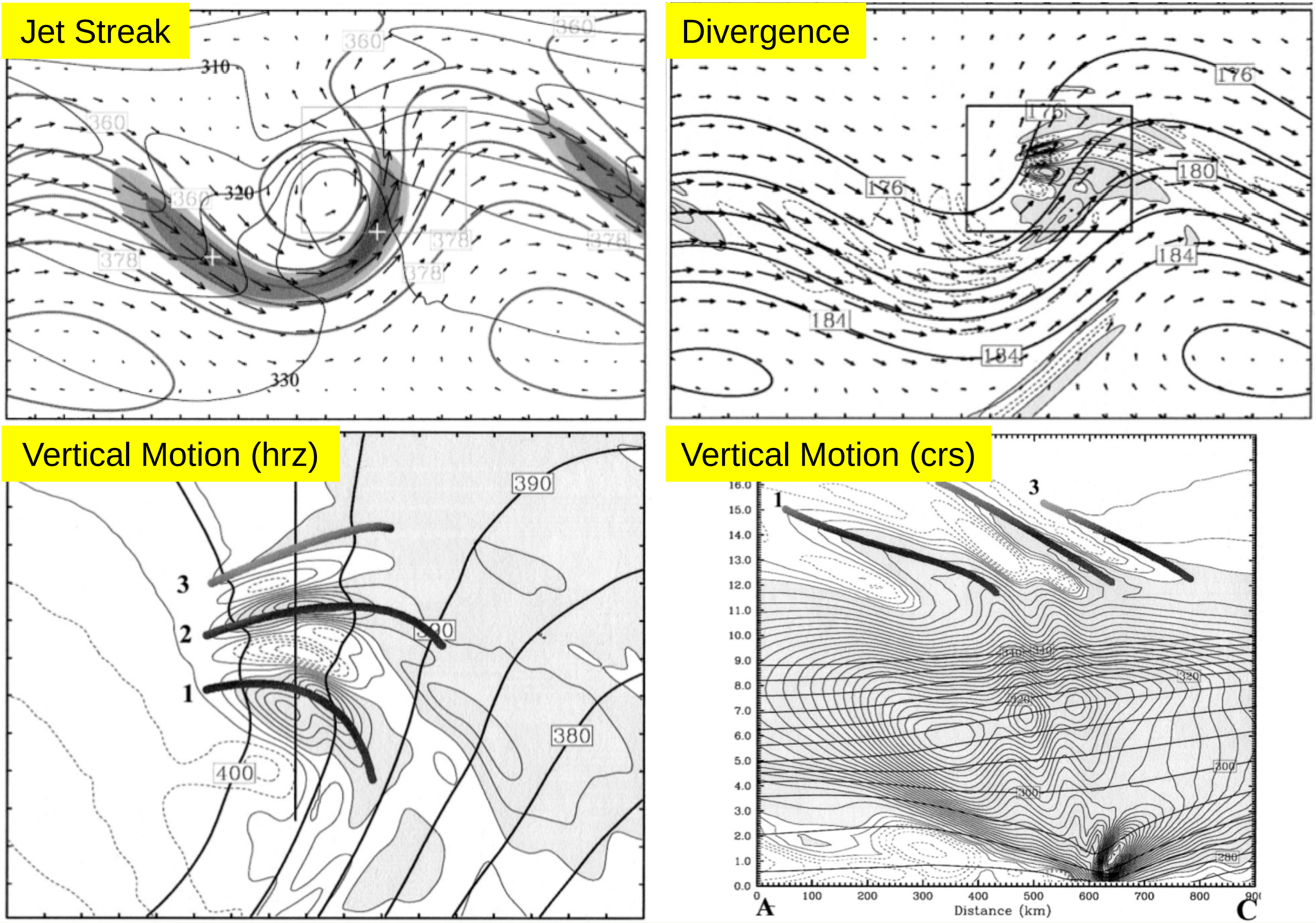
Outline:

- Importance of Mesoscale Gravity Waves in A Jet-Front System
- Flight Track Design in Research Flight 02 (RF-02) of START08 field experiment for jet-front gravity waves
- Spectral Analysis and Wavelet Analysis of Aircraft Measurement
- Phase and Amplitude Relation of Linear Theory in Wavelet-Filtered Observational Data
- Comparison with High-Resolution Mesoscale Model
- Sensitivity Experiment for the Generation Mechanism of Jet-Front Gravity Waves in RF-02

Importance of Mesoscale Gravity Waves:

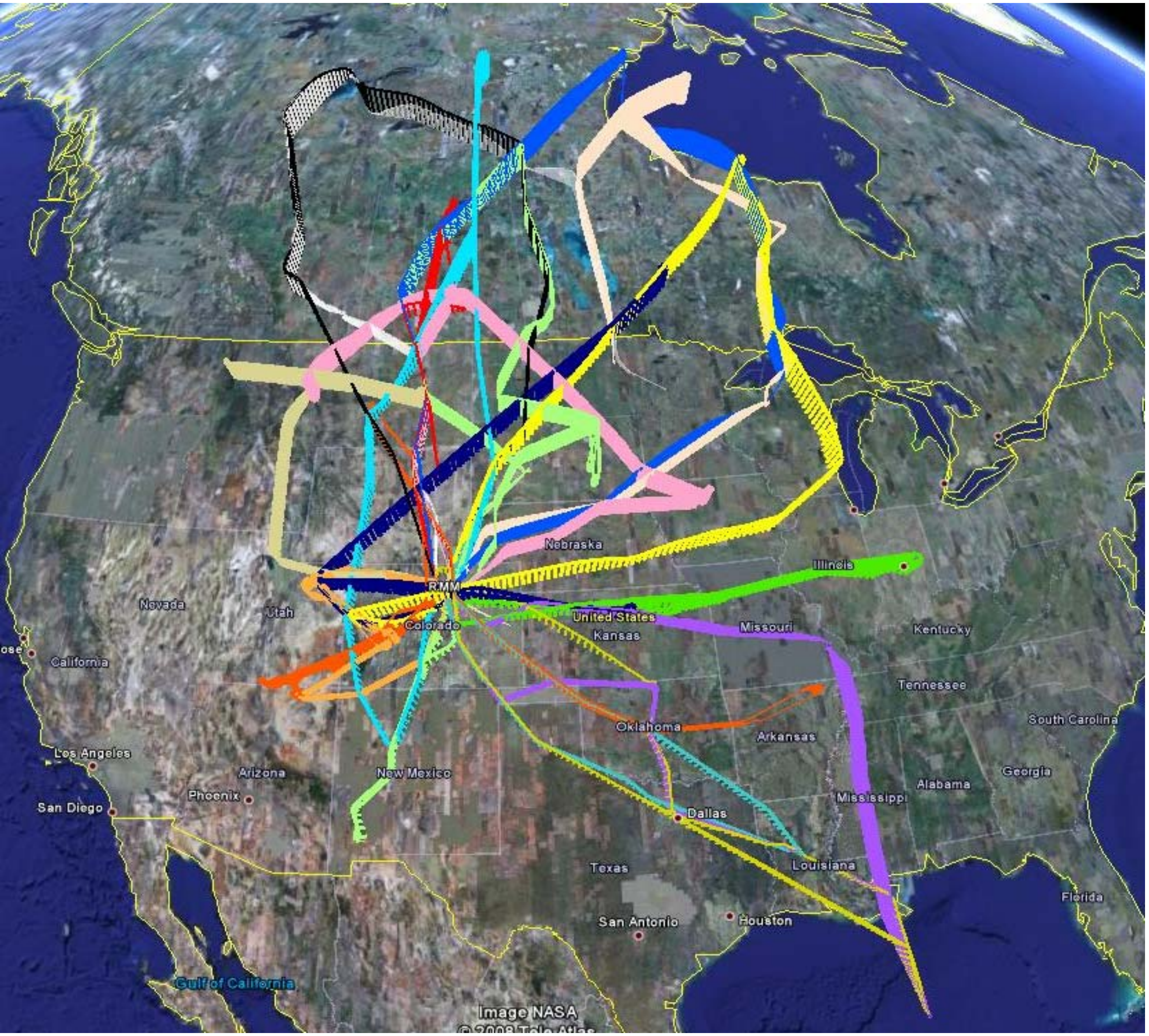
- Energy and Momentum Transfer (Eliassen and Palm 1960)
- Initiation and Organization of Convection (Zhang et al. 2001)
- Generation and Modulation of Atmospheric Turbulence (Shapiro 1981)
- Impacts on the General Circulation and Thermal Structure of the Atmosphere (Holton et al. 1995)

Generation of Baroclinic Jet-Front Gravity Wave



Simulated Long-lived Vertically Propagating Mesoscale Gravity Waves Originating from the Exit Region of the Upper-Tropospheric Jet Streak (*Zhang 2004*)

Stratosphere-Troposphere Analyses of Regional Transport Experiment 2008

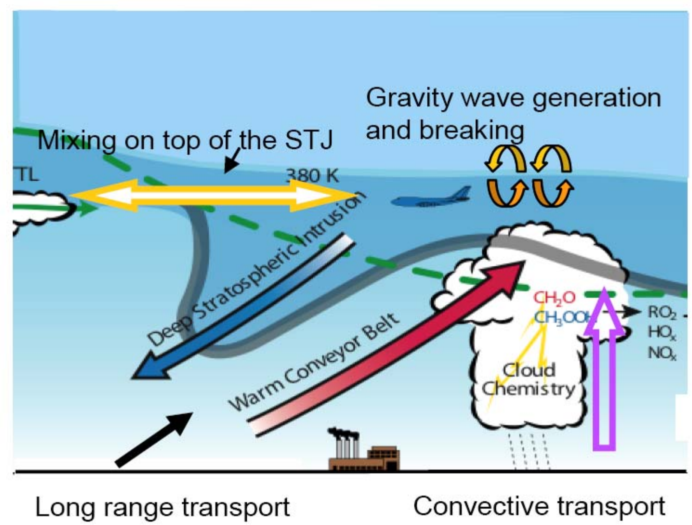


HIAPER Flight Tracks (18 flights; Phase I: April 18-May 16; Phase II: June 16-27)

Goals:

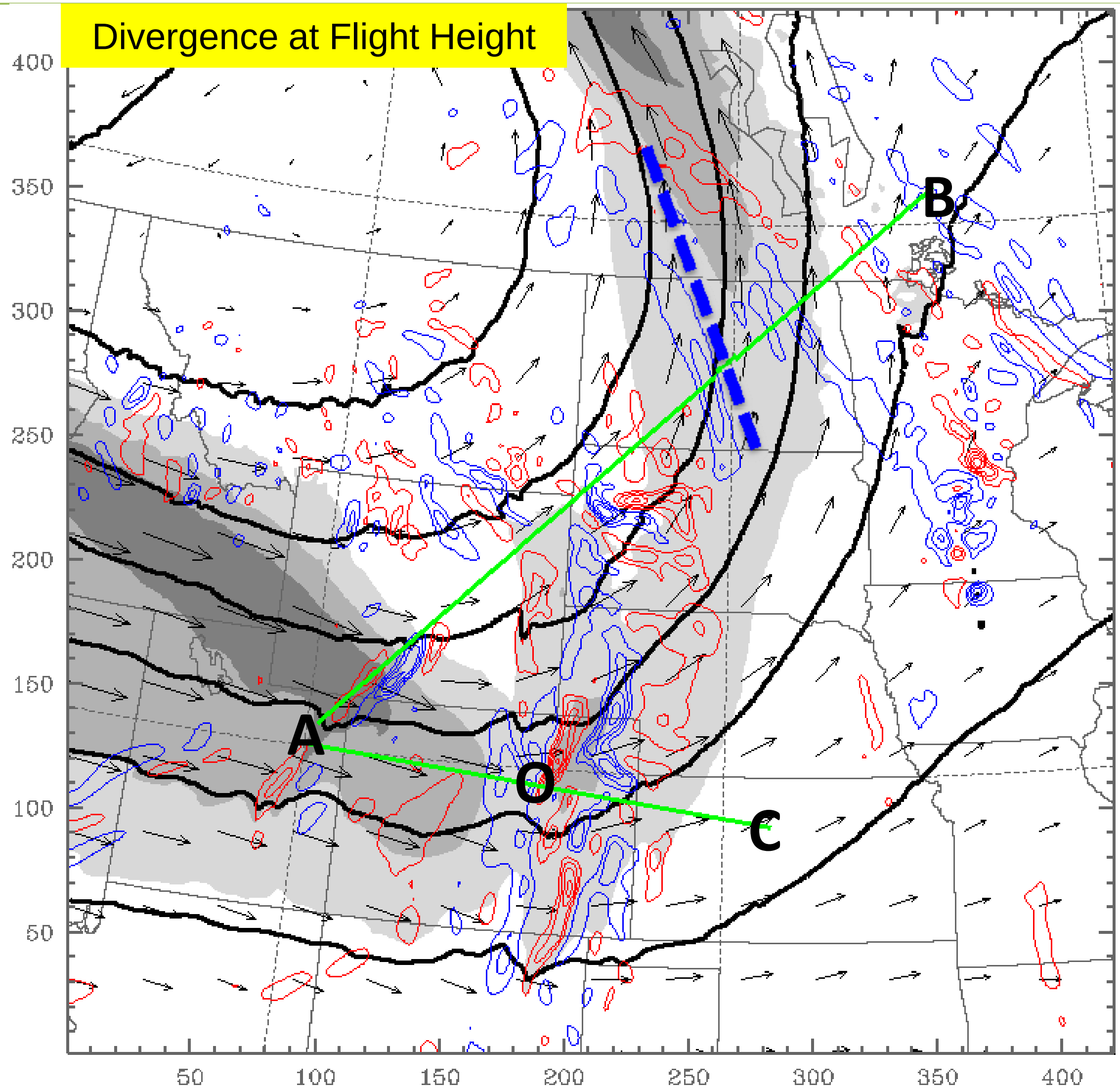
Targeting Major Transport Pathways in the Ex-UTLS

1. Extratropical UT/LS Survey (including cirrus clouds)
2. Stratospheric Intrusion (Tropopause Fold)
3. Tropospheric Intrusion
4. Convective Influence
5. Gravity Waves (RF 02)



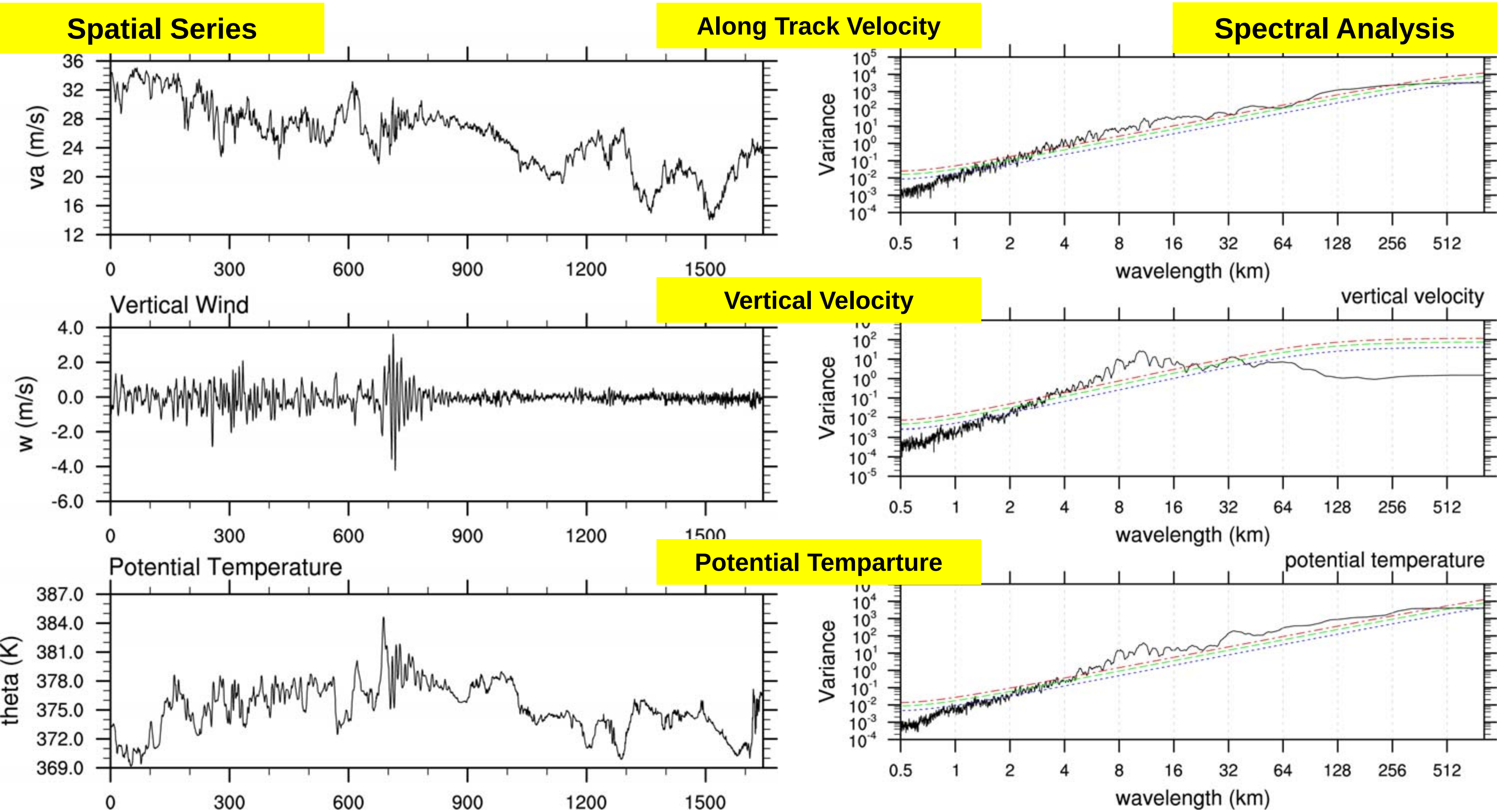
Flight Track of RF-02 in START08

1.67-km WRF simulations at 1800 UTC 04/22/2008 (1600 MDT 04/21/2008)



- Grey Shaded Area: 9-km Wind Speed (m/s)
- Blue/Red Contour: 12.5-km Divergence (pos/neg)
- Black Contour: 9-km Pressure
- Vector: 9-km Wind Field (m/s)

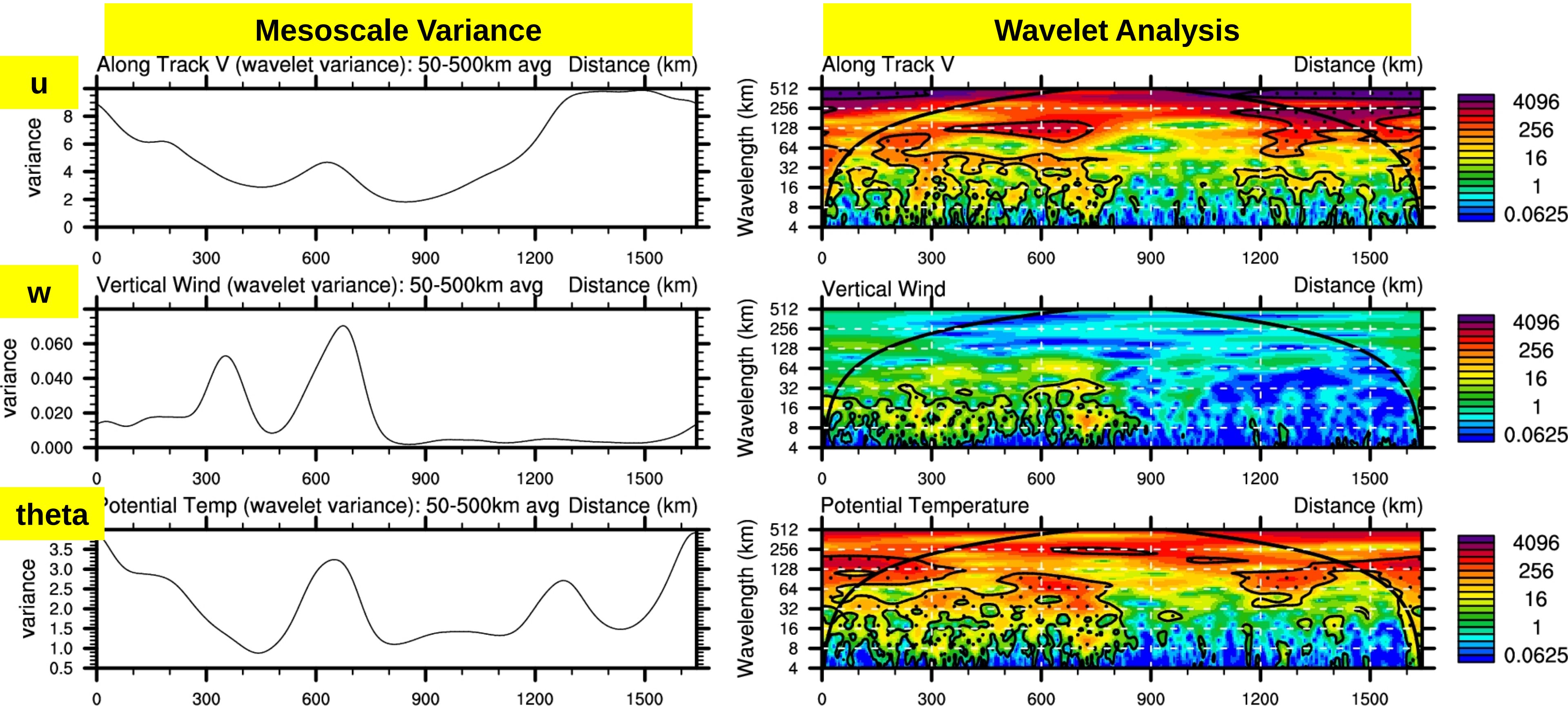
Spectral Analysis of Aircraft Measurements: Southbound Leg Along Jet



Power Spectra for Southbound Leg Along Jet. Color Lines Show the 5%, 50%, and 95% confidence levels.

- Significant Waves with Wavelength from 10 to 300 km
- Power Peaks at 10 km in Vertical Motion – Also Seen in T-REX Project (Ronald et al. 2008)

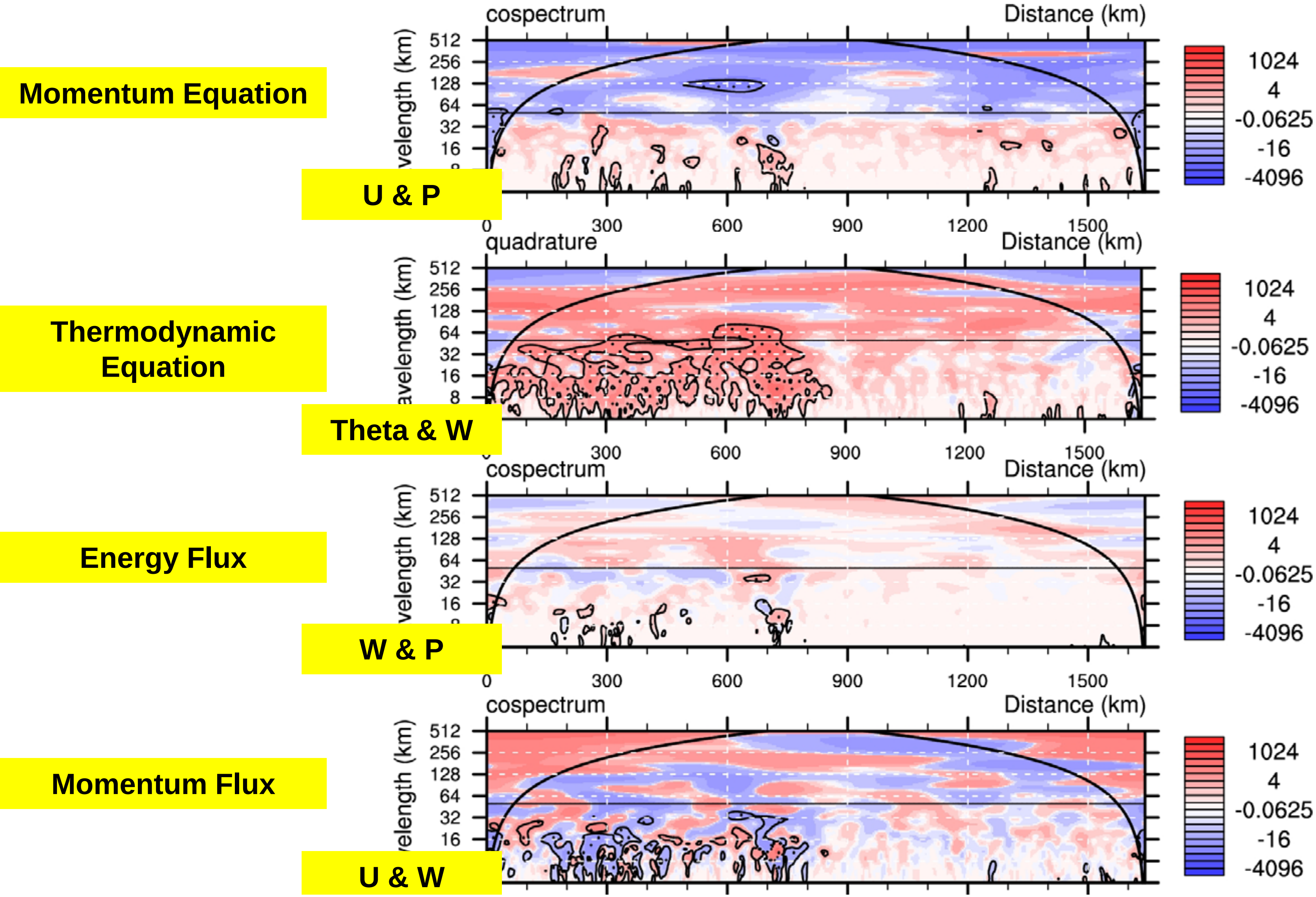
Wavelet Analysis of Aircraft Measurements: Southbound Leg Along Jet



Wavelet Analysis for Southbound Leg Along Jet. Shaded Area represent significant level over 95%

- Significant Localized Variations of Wave Signal
- Mesoscale Gravity Wave in Along-Track V
- Possible Wave-Wave Interaction
- Physical Reliability of 10-km Wave in W

Phase Relation in Aircraft Measurements: Southbound Leg Along Jet



- Remarkable Localized Quadrature Variance From 4 km to 64 km in Thermodynamic Equation
- Mesoscale Gravity Wave with Wavelength of 128 km in Momentum Equation
- Similarity and Inconsistency in Phase Relation Analysis – Possible Reason?

Amplitude Relation in Aircraft Measurements: Southbound Leg Along Jet

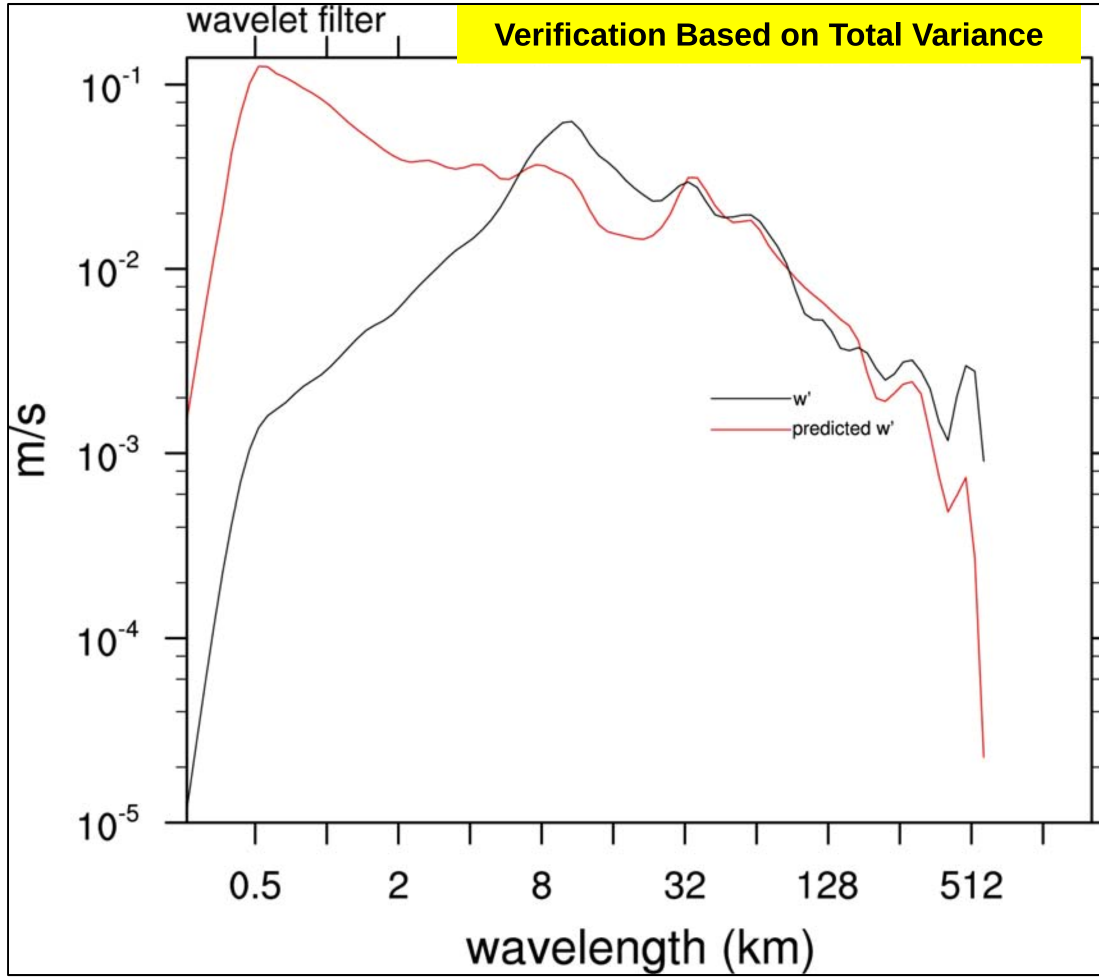
Linear Theory

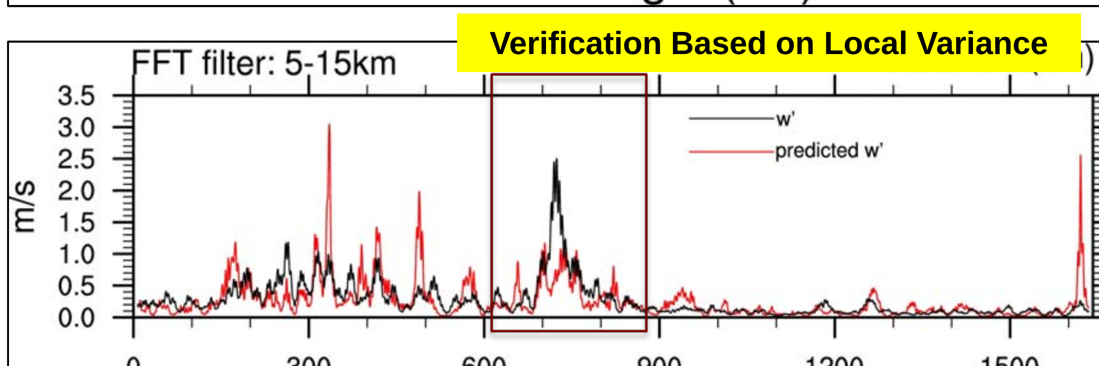
$$\left(\frac{\partial}{\partial t}+\overline{U}\frac{\partial}{\partial x}\right)u'=-\frac{1}{\overline{\rho}}\frac{\partial p'}{\partial x}$$

$$\left(\frac{\partial}{\partial t}+\overline{U}\frac{\partial}{\partial x}\right)\theta'+w'\frac{\partial\overline{\theta}}{\partial z}=0$$

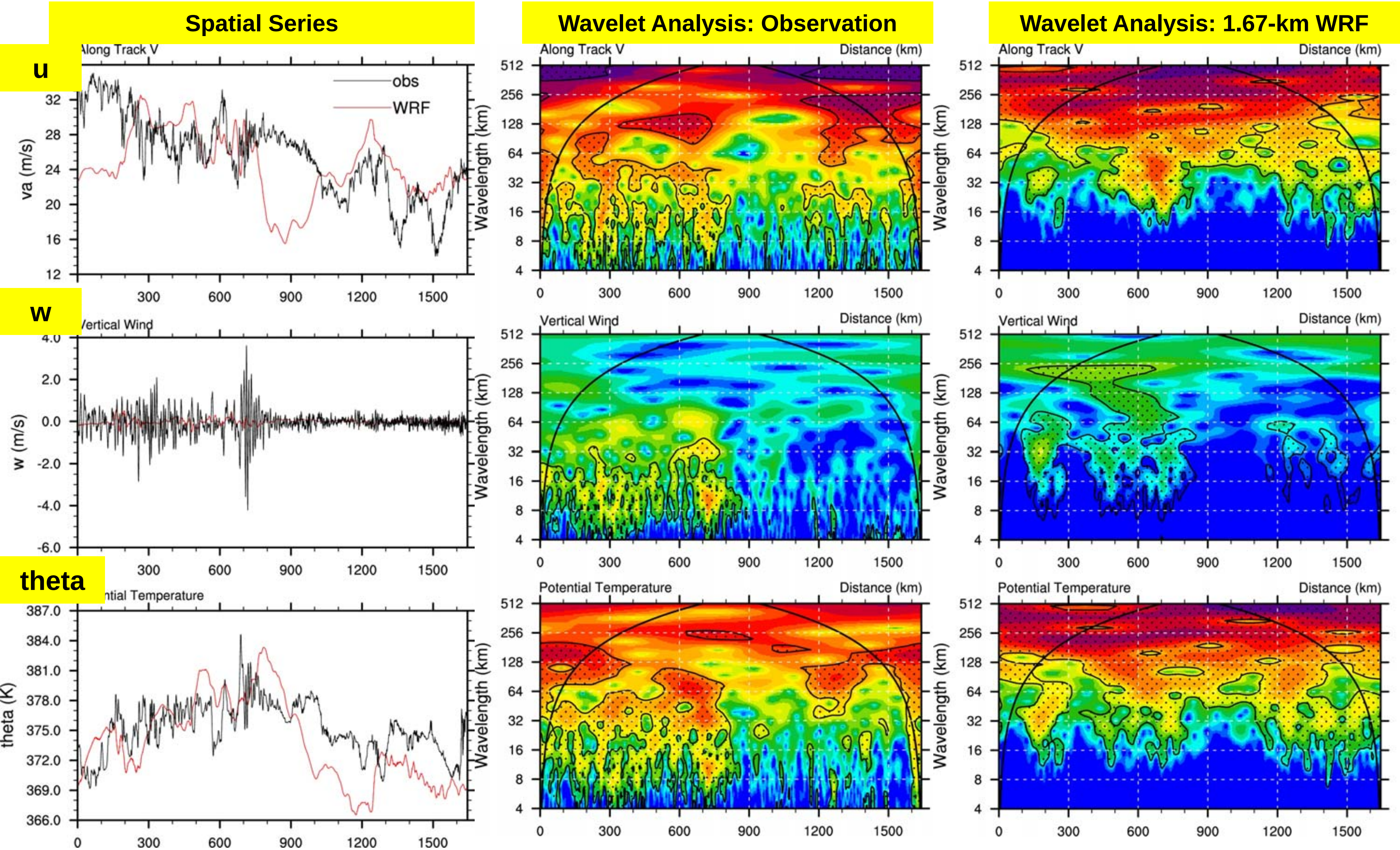
$$\Rightarrow w'=\frac{p'\theta' k}{u'\overline{\rho}\frac{\partial\overline{\theta}}{\partial z}}$$

- Based on the wave solution form of momentum equation and thermodynamic equation, the theoretical/predicted vertical motion perturbation can be derived as the abovementioned formula.



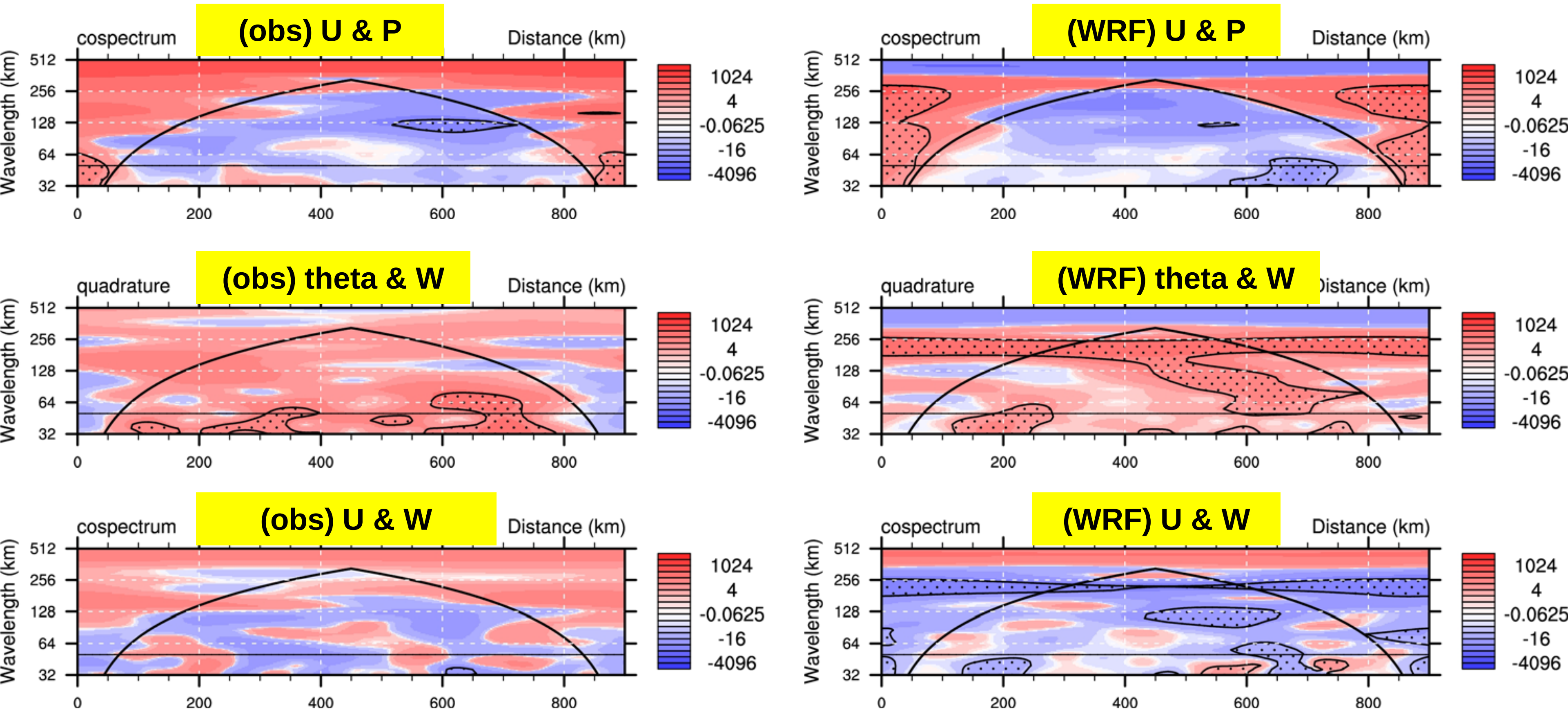


Comparison with High-Resolution Mesoscale Model: Wavelet Analysis



- Similarity Between Aircraft Data and Cloud-Resolving Simulation in Mesoscale Gravity Wave
- Significant Disagreement in The Small-Scale Component of Vertical Velocity

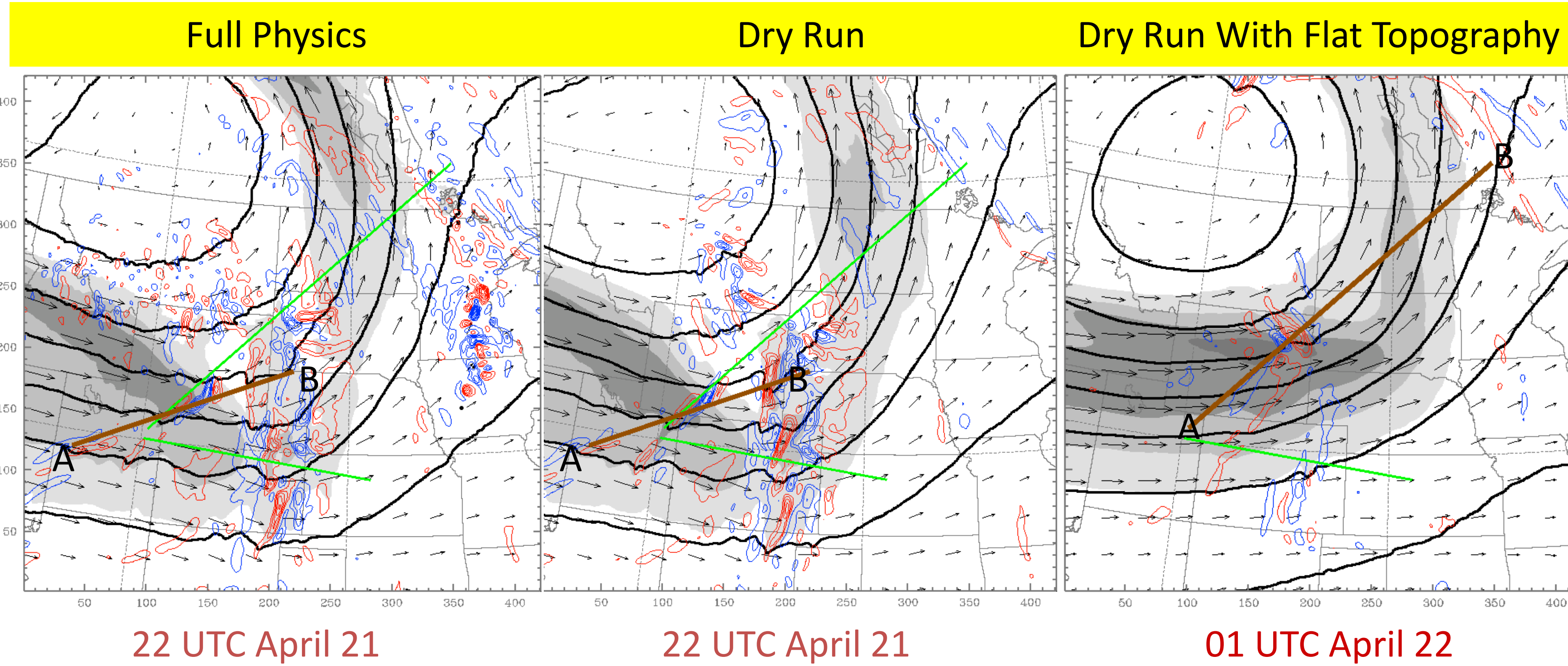
Comparison with High-Resolution Mesoscale Model: Phase Relation



Similarity Between Observation And Simulation

- 128-km Along-Track-Propagating Mesoscale Gravity Wave (Momentum Equation)
- Waves From Small Scale to Mesoscale Gravity Wave (Thermodynamic Equation)
- 128-km Downward-Propagating Wave in Momentum (Momentum Flux)

Numerical Sensitivity Exp for Jet-Front Gravity Waves during RF-02

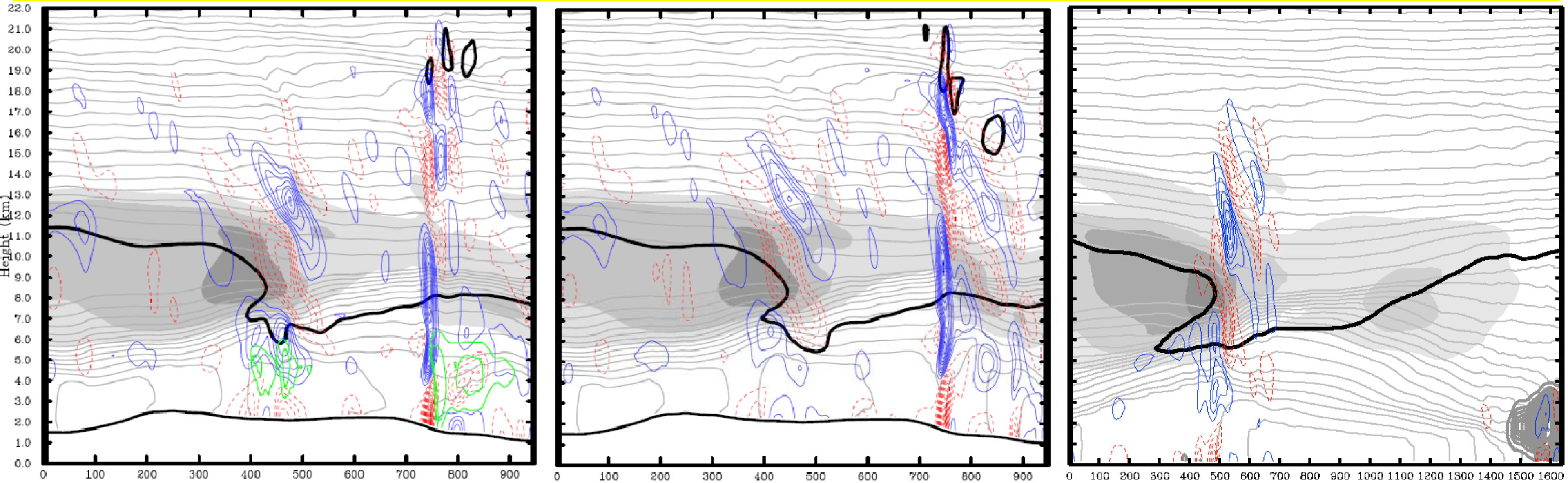


- *Similarity Between Full-Physics EXP and Dry Run over the Rockies, due to dry environment*
- *Weakened Wave Signal Across Surface Front in Dry Run*
- *In dry flat-topography Exp, the jet-front gravity waves are generated more slowly)*

Numerical Sensitivity Exp for Jet-Front Gravity Waves during RF-02

Cross sections (A-B): Tropopause (1.5 PVU), GWs (+,-divergence) and Convections (dbz)

Full Physics	Dry Run	Dry Run With Flat Topography



22 UTC April 21	22 UTC April 21	01 UTC April 22

- ***Dry dynamic (balance adjustment) may dominate over the Rockies***
- ***Convections only changed the lower-level structures, but not for the gravity waves propagating over the tropopause.***
- ***Similar features were found for the gravity waves in flat-topo Exp, but at higher level. It is said that the changes of background flow may have impacts on the critical level of them.***

Concluding Remarks

- **Long-Track G5 Flight Successfully Captured Mesoscale Gravity Waves.**

- **Spurious wave signal in vertical motion with wavelength about 10 km, which maybe related to 30-60s aircraft autopilot intrinsic period.**

- **The observed mesoscale gravity wave activities are simulated reasonably well by a high-resolution mesoscale model but not 1-to-1 match of individual waves.**

- **Sensitivity experiments show that convection mainly changes lower-level structures, while topography may result in the change of background flow.**