16th Weather Squadron

Aim High … Fly, Fight, Win

Near-Surface Turbulence Forecasting Challenges at the United States Air Force Weather Agency: Progress In Trapped Wave Forecasting

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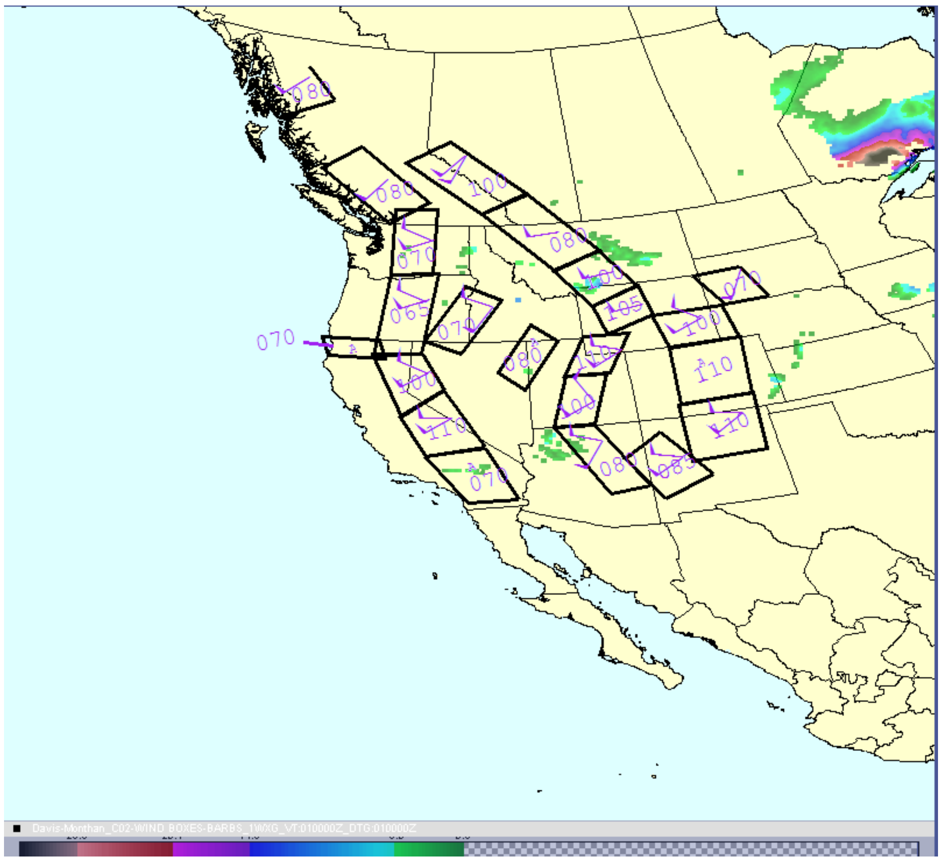
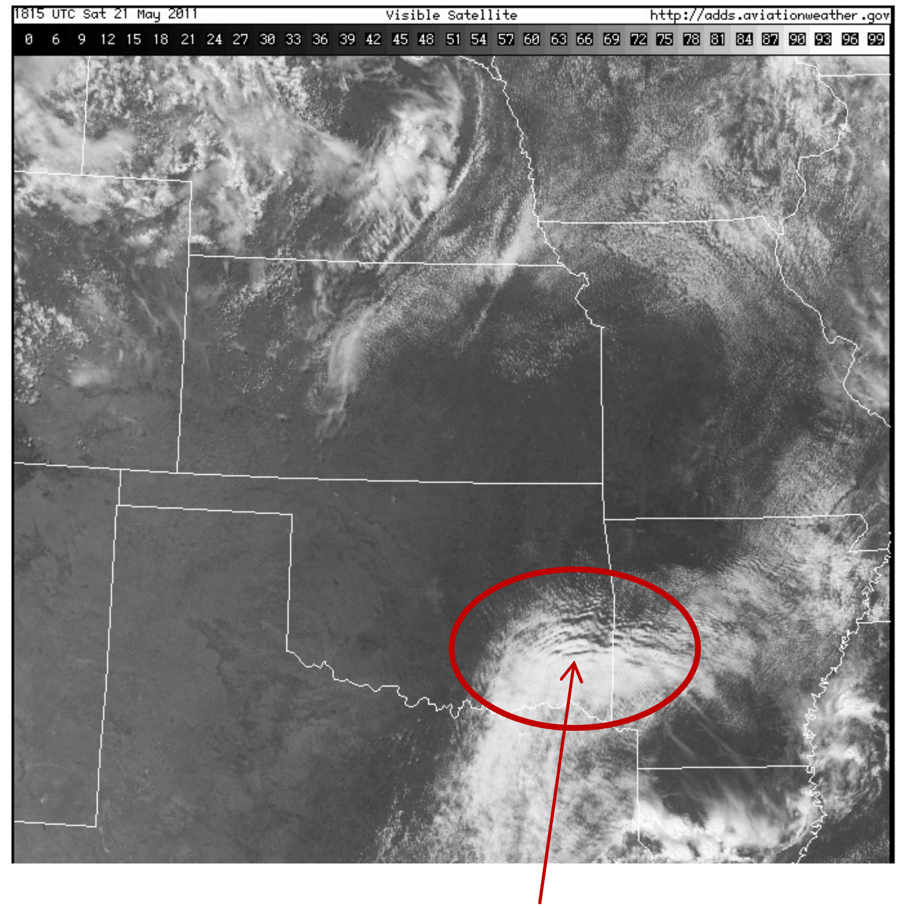
Motivation

- Currently:
  - “Mountain wave and other turbulent lee event forecasting methodologies need considerable attention.” – Air Force Weather Turbulence Forecasting Summary
  - Panofsky Turbulence Index for near-surface turbulence forecasting is quite good for synoptic wind shear events, but struggles in certain situations, such as with dry thermal convection and mesoscale waves
  - Current trapped lee wave forecasting methods can be cumbersome, and the nature of the process does not account for all regions or for propagation
  - Little has been done in the way of forecasting conditions favorable for other types of trapped waves (such as gravity waves, currents, etc.)

Currently



Box Forecasting Method (Mountain Waves)

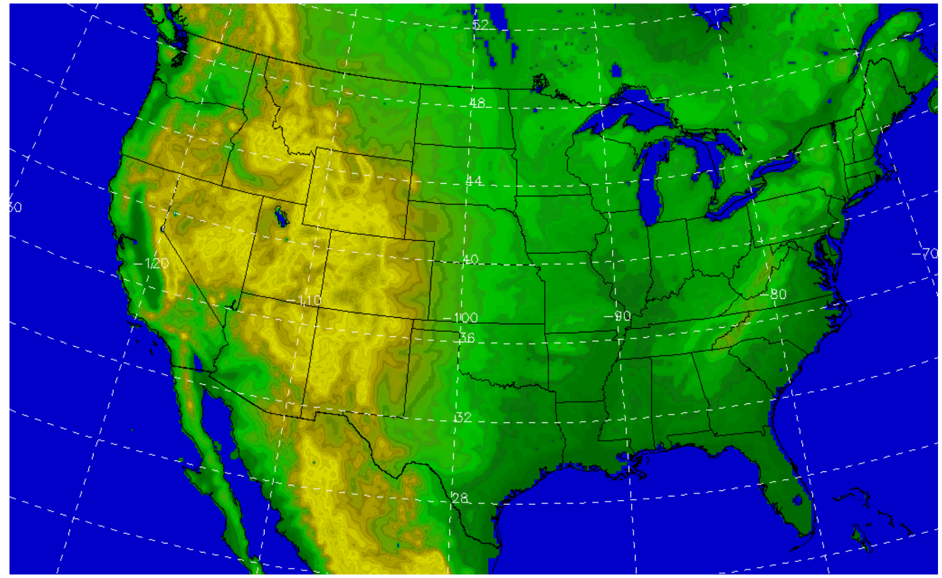


Terrain-Induced Wave: SE Oklahoma 21 May 2011

Approach

- Review research pertaining to simulations and observations of trapped waves
- Study trapped wave cases to find meteorological conditions likely most responsible for wave-trapping
- Use operational models to find clues that will aid in the forecasting of trapped waves – regions of enhanced turbulence probability, as well as enhanced turbulence severity

15 KM WRF Information



- Version 3.2
- Nested within 45 KM Domain
- 3DVAR Data Assimilation
- Resolution
  - Horizontal: 15 KM
  - Vertical: 56 levels
  - Grid Size: 343 x 211
- Physics Package
  - Longwave radiation: RRTM scheme
  - Shortwave radiation: Dudhia scheme
  - Cumulus Parameter Scheme: Kain-Fritsch scheme
  - Explicit scheme: WRF Single-Moment 5-class scheme
  - Planetary Boundary Layers: Yonsei University Scheme
  - Soil Model: Noah Land Surface Model

Challenges: Verification

- Nature of pilot reports
- If area is known to be turbulent, flights avoid the region
- Product-specific challenges:
  - Nocturnal wave identification
  - “Other” cloud cover can obscure evidence of trapped waves
  - Specific cause of turbulence
  - Specific level at which wave exists
  - Waves in dry atmosphere (below LCL)?

Challenges: NWP

- **Limited resolution of operational models**
  - **Traditional measures of turbulence, such as the Richardson number, can be difficult to forecast at necessary thresholds due to vertical resolution**
  - **Thickness differences in upper levels**
- **Not every wave can be simulated in operational models–**
  - **Want to focus on environments favorable for waves**
  - **Mesoscale processes may affect local environments**

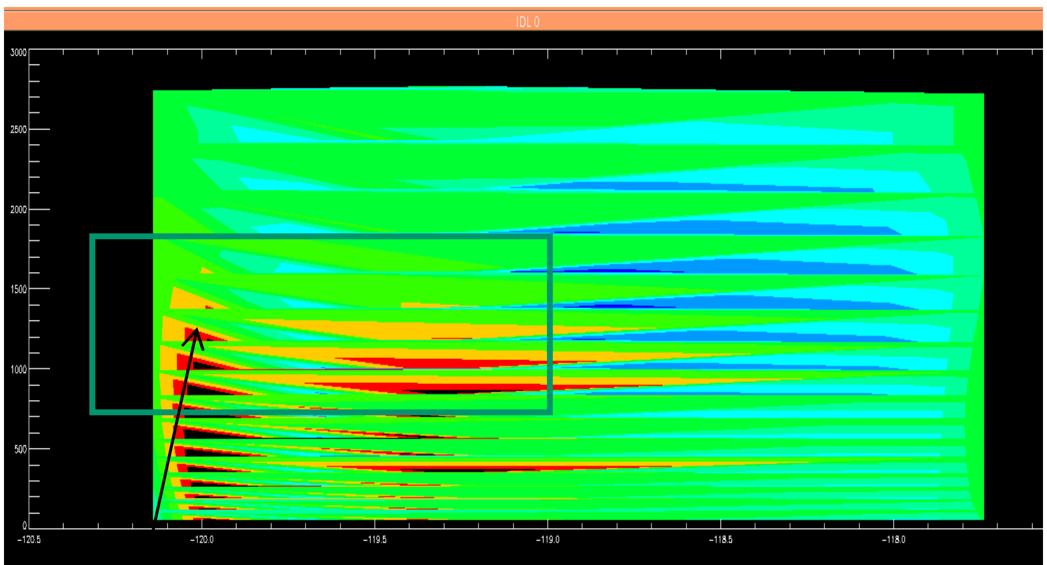
Research Review

- "Under ordinary conditions, an upward-propagating gravity wave may encounter a level where background flow characteristics such as N or u change quickly with height. When this happens, wave reflection can occur (Nappo 2002)."
- "$M^2 < 0$ implies that either stability is small or negative, or there is significant curvature in the wave-normal wind profile (Coleman et al 2009)."

Early Attempts…

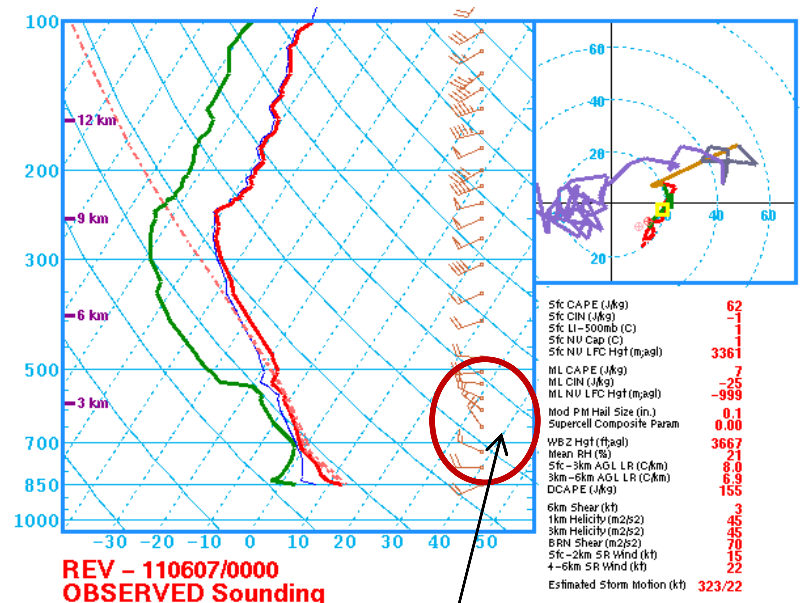
- **Use vertical velocities within the WRF data to attempt to identify wave motions**

00Z Reno Sounding



Contoured WRF vertical velocity
6 June 2011: Northern Nevada.
06Z 15 KM WRF valid 18Z.

Upper limit of negative vertical velocities: near 1500 meters AGL



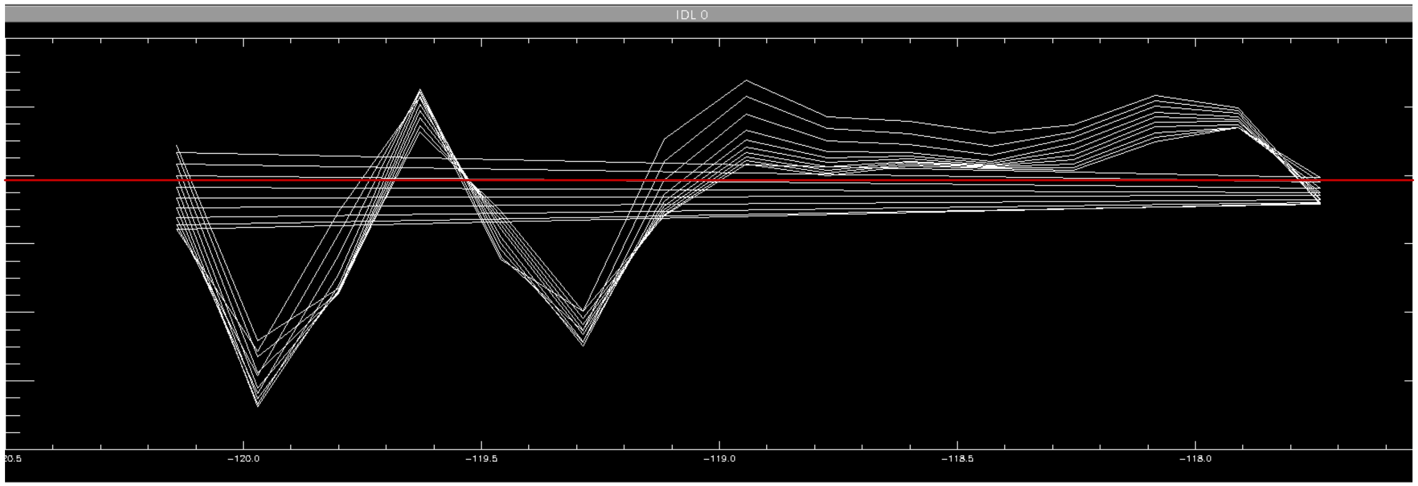
NWS/NCEP/SPC

Wind curvature near 650 mb (~1450 m AGL)

Vertical Velocity Cross Sections:

W-E Horizontal Display

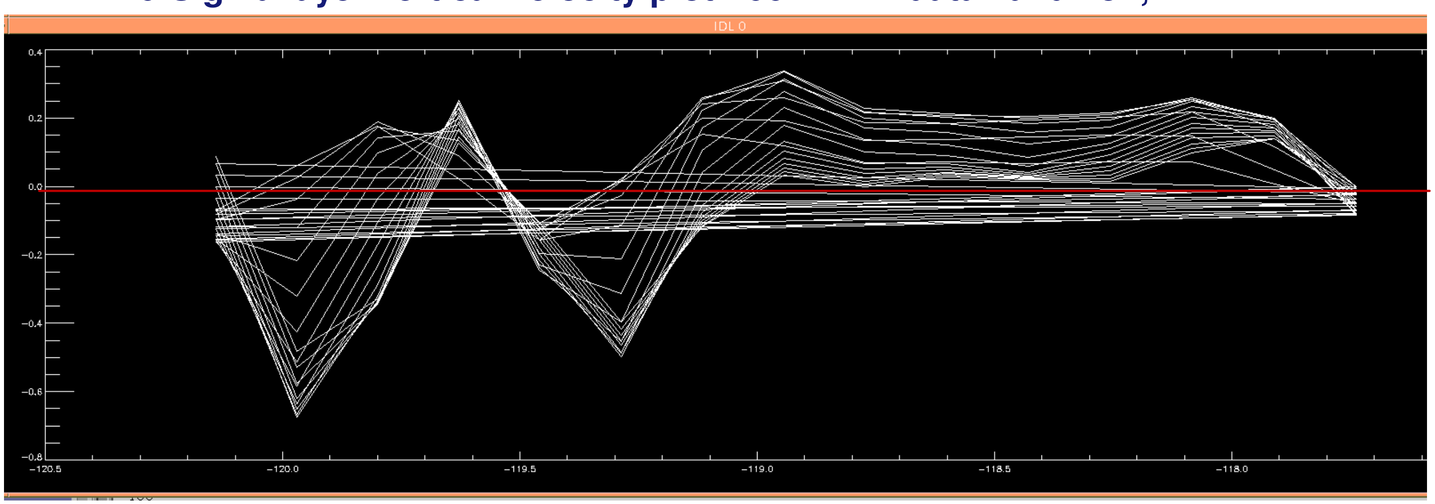
Vertical Velocity (m/s)



Longitude

10-Sigma layer vertical velocity plot: 06Z WRF data valid 18Z, NV

Vertical Velocity (m/s)



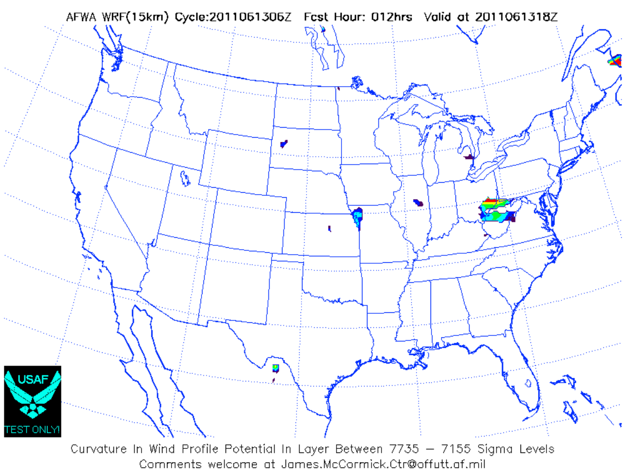
Longitude

17-sigma layer vertical velocity plot: 06Z WRF data valid 18Z, NV

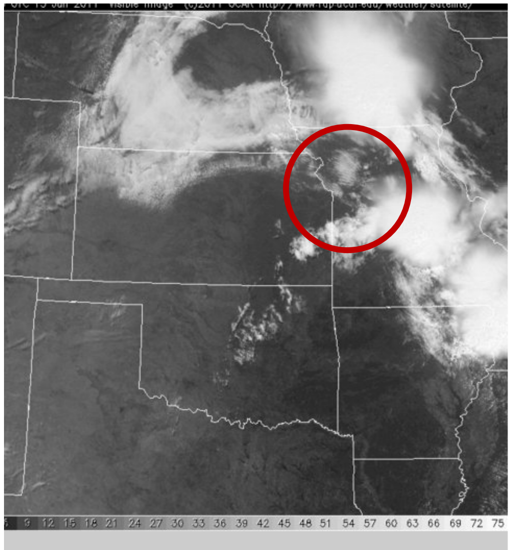
Forecast Product

- Single Layer:
  - Compute changes in wind components for each sigma layer
    - EX: DU(5120) = UCOMP(5425) – UCOMP(4760)
    - Layer product that will be represented by median level
    - Square DU and DV terms
  - Early Formula:
    - Add DU^2 and DV^2 terms, minimum 10 for each term
  - Updated Formula:
    - Multiply DU^2 term by DV^2 term
    - Emphasize significant changes
    - Minimum 6 for each term
    - If either term is less than 0, set entire product to 0
  - Caveat: Coarse vertical resolution in upper levels

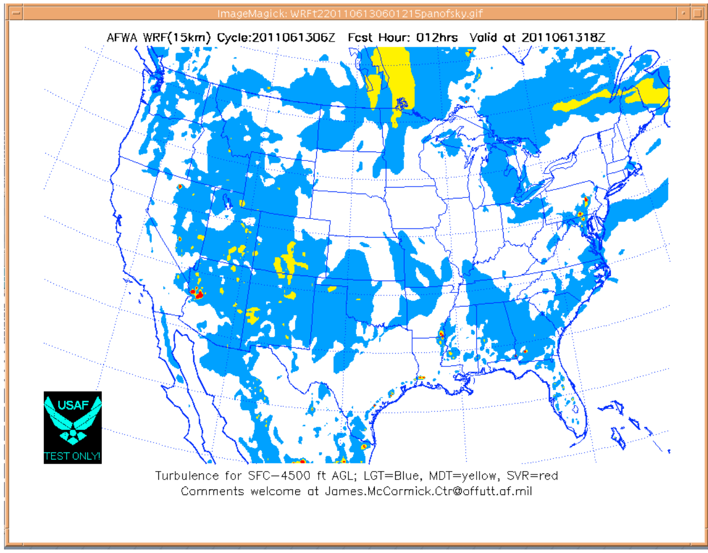
Graphical Display:
13 June 2011 – Early Formula



“Early” formula:
7745 sigma level



Visible satellite:
1815Z

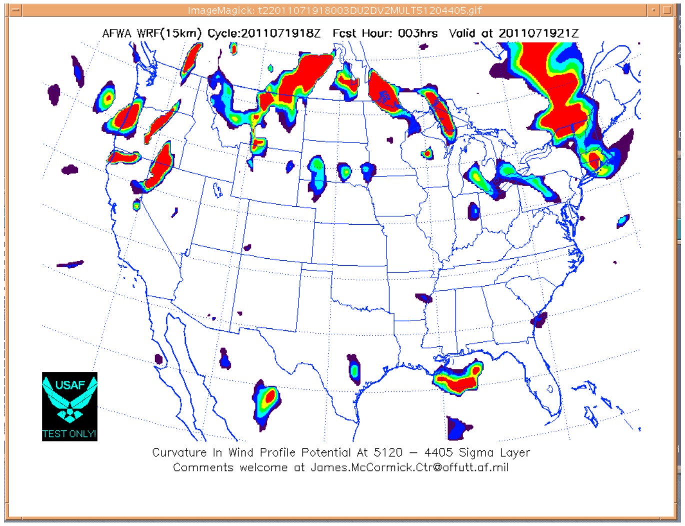


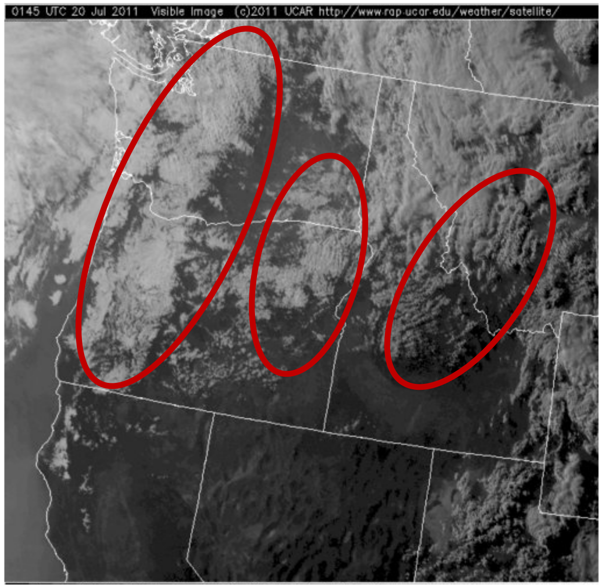
Panofsky Turbulence Index:
Valid 18Z

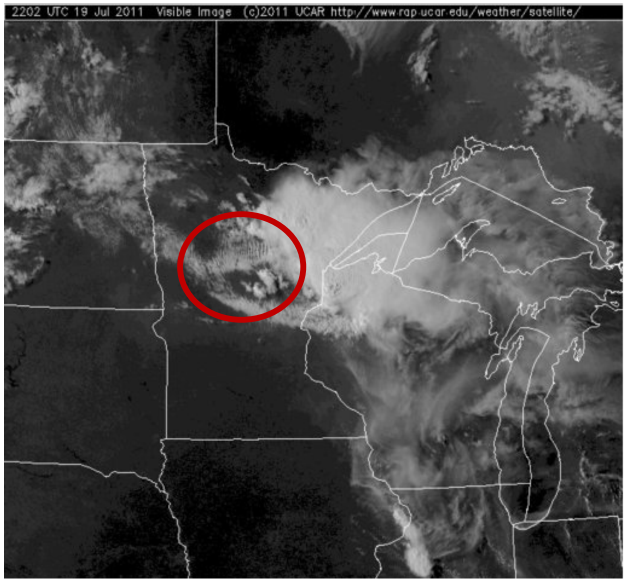
Pilot reports in NW Missouri:
Moderate turbulence
1806Z
1906Z

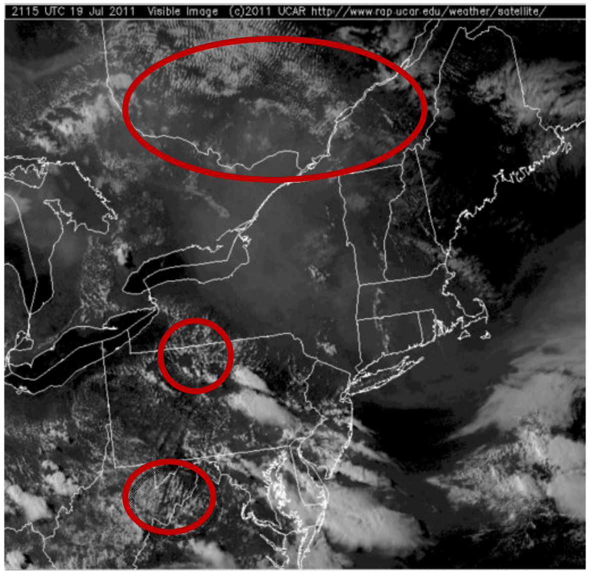
Graphical Display

19 July 2011 – Updated Formula

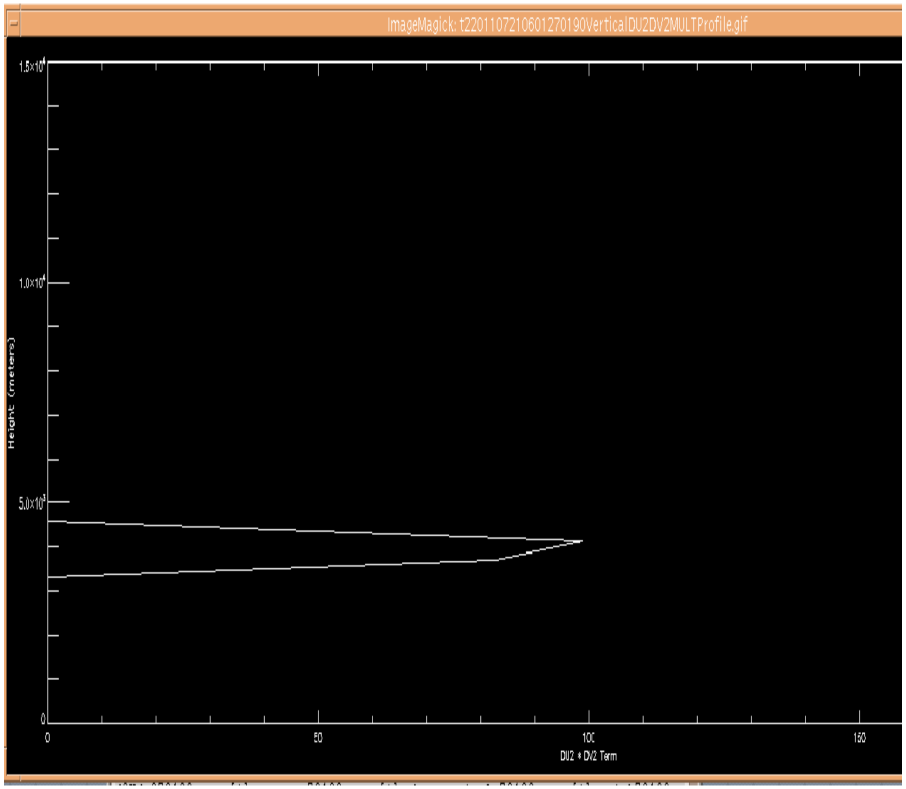




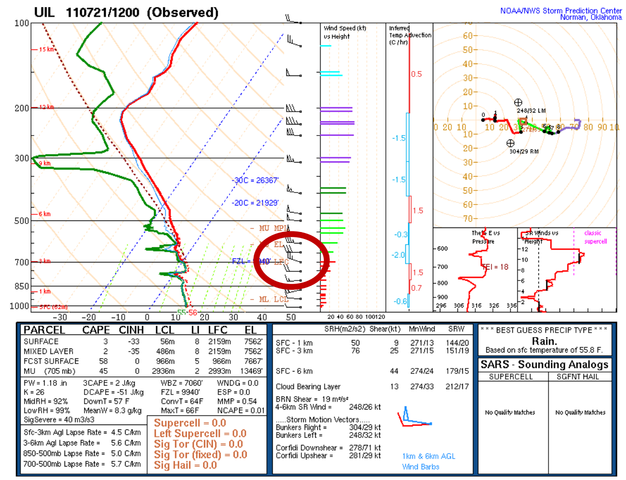




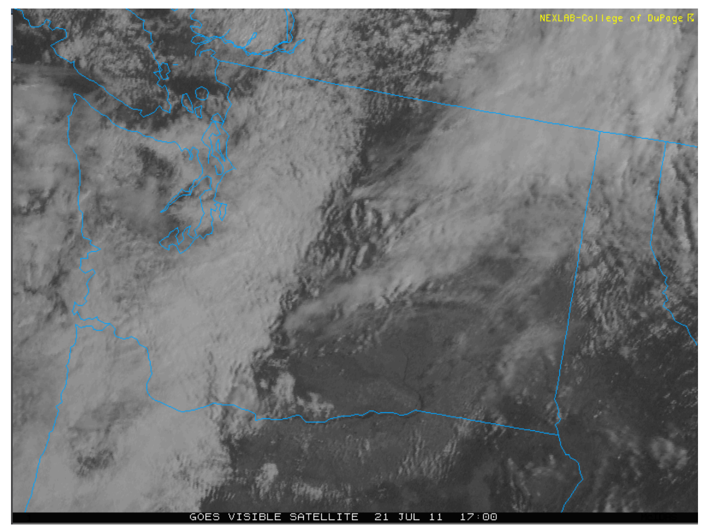
Vertical Profile:
DU^2*DV^2 Term



DU^2*DV^2 Term
06 Z WRF data: Valid 18Z
21 July 2011
NE of Seattle, Washington

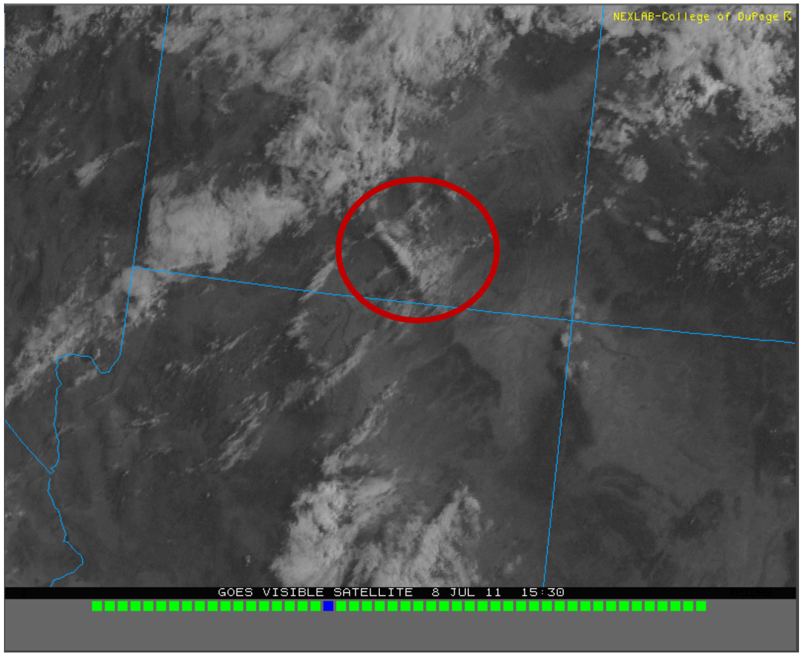


12 Z UIL sounding

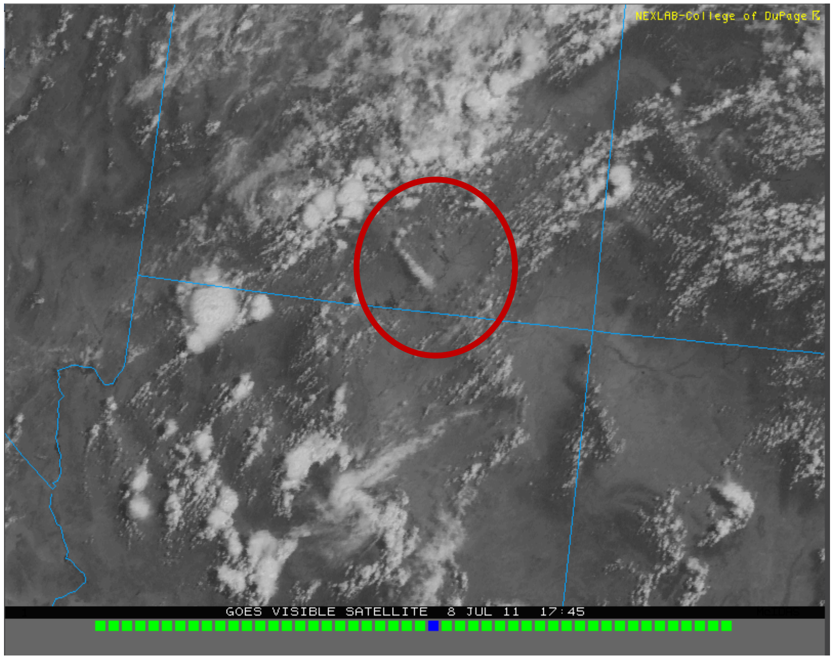


17Z visible satellite image

Data Display:
8 July 2011 - Utah



Visible satellite: 1530Z



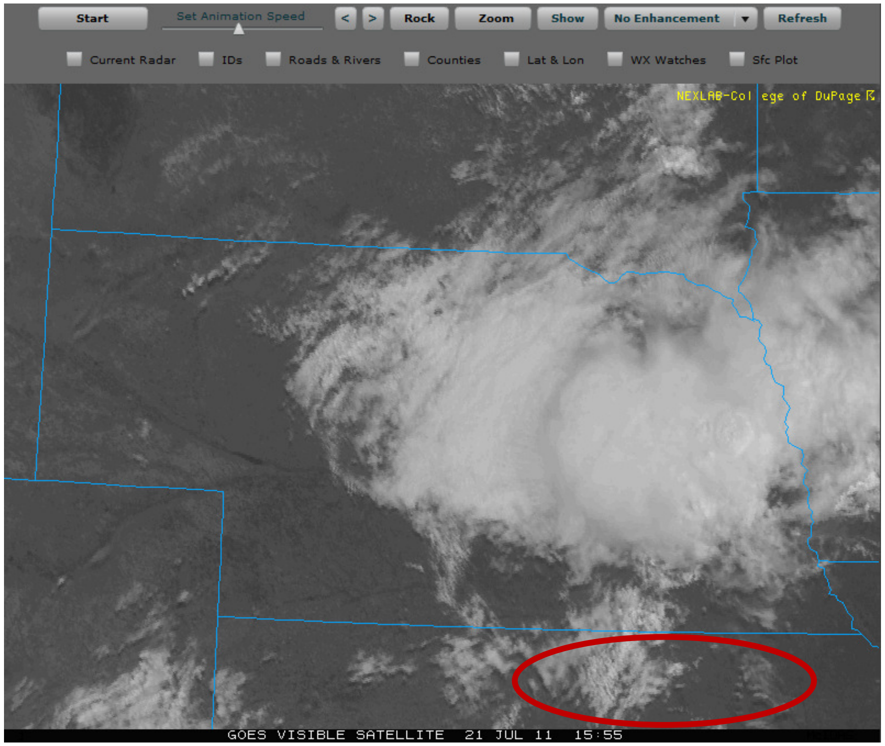
Visible satellite: 1830Z

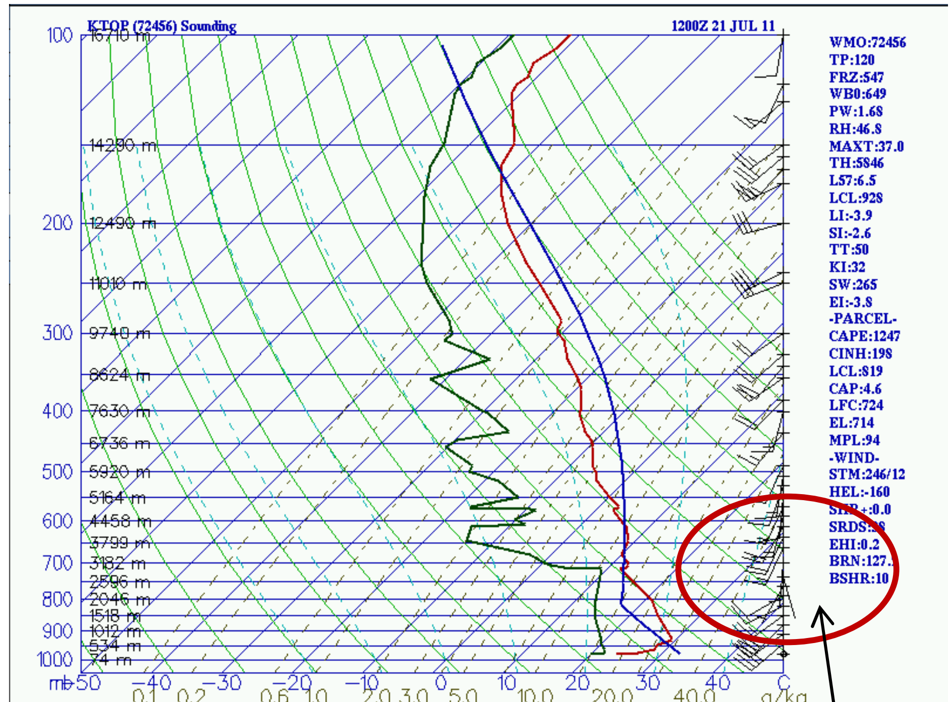
WRF data: Valid 15Z
DU^2*DV^2 terms:
5475-4760 layer: 147.0
5120-4405 layer: 244.3

WRF data: Valid 18Z
DU^2*DV^2 Terms
5475 – 4760 layer: 4.5
5120 – 4405 layer: 6.7

Not All Cases Successful:

21 July 2011 - Kansas





Most favored region for reflecting layer on 12Z Topeka sounding

Maximum WRF data calculated DU2*DV2 term : 11.3
12Z TOP sounding calculated DU2*DV2 term: 73.7

Preliminary Verification

- Identified 24 trapped waves using visible satellite imagery
- Reviewed WRF data: found evidence of reflecting layer meeting our criteria within WRF data in 21 cases
- For missed cases: found evidence of reflecting layer meeting our criteria within nearby sounding data
- “Missed” cases primarily tended to appear on imagery for short periods of time (< 1 hour) and over smaller geographical areas
  - “Missed” waves more likely the result of mesoscale influences

Summary/Conclusions

- **15 KM WRF shows ability to accurately and operationally forecast specific areas where reflecting layers are preferred**
- A combination of u-component change and v-component change can be used to display a likelihood that a reflecting layer will be present
- Not all reflecting layers are large-scale features in the atmosphere, particularly within the mountains
- Mesoscale features may alter a wind profile in favor of reflection when large scale conditions are unfavorable. Operational models may continue to struggle in these cases.

Future Work

- Product Development:
  - Multi-layer maps: Ease for user
  - Any “clues” available where events appear to be missed?
  - Account for thickness of upper sigma layers
  - Probabilistic and ensemble forecasting methodology
- Climatology Studies
  - Frequency of conditions favorable for reflecting layers
- Weather Forecasting:
  - Wave formation
  - Wave breaking

Acknowledgments

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References

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Thank You!

Questions? Comments?

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