Microphysical and dynamical structures of winter storms in the U.S. Pacific Northwest: Comparisons between regional mesoscale model output and operational weather radar observations

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Motivation

- Extend and refine conceptual models obtained from short duration field projects using continuously collected operational weather radar data sets.
- Develop methodologies to routinely evaluate how well numerical model output reproduces observed 3D precipitation and wind structures.
- Diagnose errors in model physics and parameterizations and evaluate proposed model enhancements.

Data Sets

This study uses radar data and model output for the Portland, OR region. This region has frequent winter precipitation with a strong orographic component. Storms typically move E or NE from the north Pacific Ocean, across the Coastal Range (average crest elevation 800-900 m), the Willamette River Valley, and the Cascade Mountain Range (average crest elevation 1500-1600 m).

Operational Radar Data: Winter storms (Nov. – Mar.) for 2003-04, 2004-05 and 2005-06 observed by Portland, OR National Weather Service WSR-88D S-band radar. Data were interpolated to a Cartesian grid with 3 km horizontal and 1 km vertical grid size.

Operational Upper Air Sounding Data: 12 hourly soundings from Salem, OR (SLE) in the Willamette River Valley.

Model Output: Winter storms for Nov 2005 – March 2006 using Penn-State/NCAR Mesoscale Model (MM5 Version 3.7) in non-hydrostatic mode. The model was run down 1.33-km grid spacing in a manner similar to current real-time regional forecast models using the GFS analyses and Thompson et al. (2004) bulk microphysics. The 4-km model output was remapped to a latitude-longitude grid with spatial resolution ~4 km in horizontal and 0.5 km in vertical.

Methodology

We build on radar climatology methodology of James and Houze (2005) to include model output and to accommodate shallow and variable depth rain layers. The variability of the melting layer height in winter storms near Portland, both storm-to-storm and within the storm, limits the utility of quantitative reflectivities for comparison between radar observations and model output.

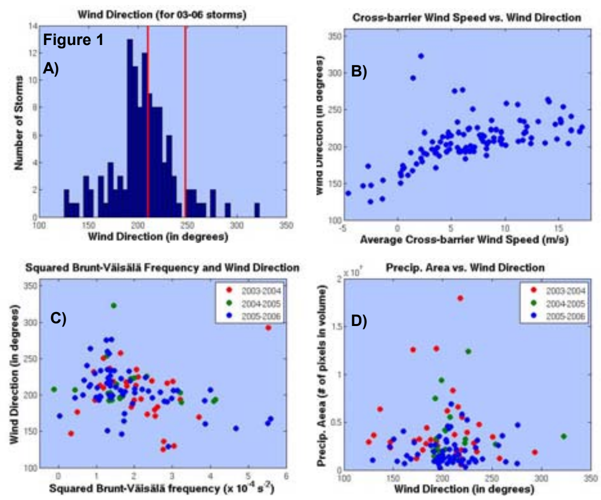

Figure 1.

A) Number of storms observed over 3 winters for each layer average wind direction.

B) Upslope wind speed (E-W) across Cascade Mountain range versus layer average wind direction.

C) Squared Brunt-Väisälä frequency versus layer average wind direction.

D) Radar observed storm-accumulated precipitation area versus layer average wind direction. Layer averages are for 61 m (altitude of SLE sounding) to 2.2 km MSL.

3D radar observations and model output are compared using:

- Frequency of precipitation occurrence. Grid points are defined as precipitating if
  - –Observed data: Z > 13 dBZ
  - –Model output: Precipitation Mixing Ratio (QR+QS+QG) >0.015 g/kg based on Z-M relation for rain (Hagen and Yuter, 2003).
- Average radial velocity:
  - –Observed data: Computed directly from interpolated observed field
  - –Model output: Derived from u and v wind fields

Southerly Storm Averages (Wind Direction≤210°) — **36 storms, 590 hours**

Southwesterly Storm Averages (210°>Wind Direction≥249°) — **21 storms, 309 hours**

Westerly Storm Averages (Wind Direction>250°) — **5 storms, 72 hours**

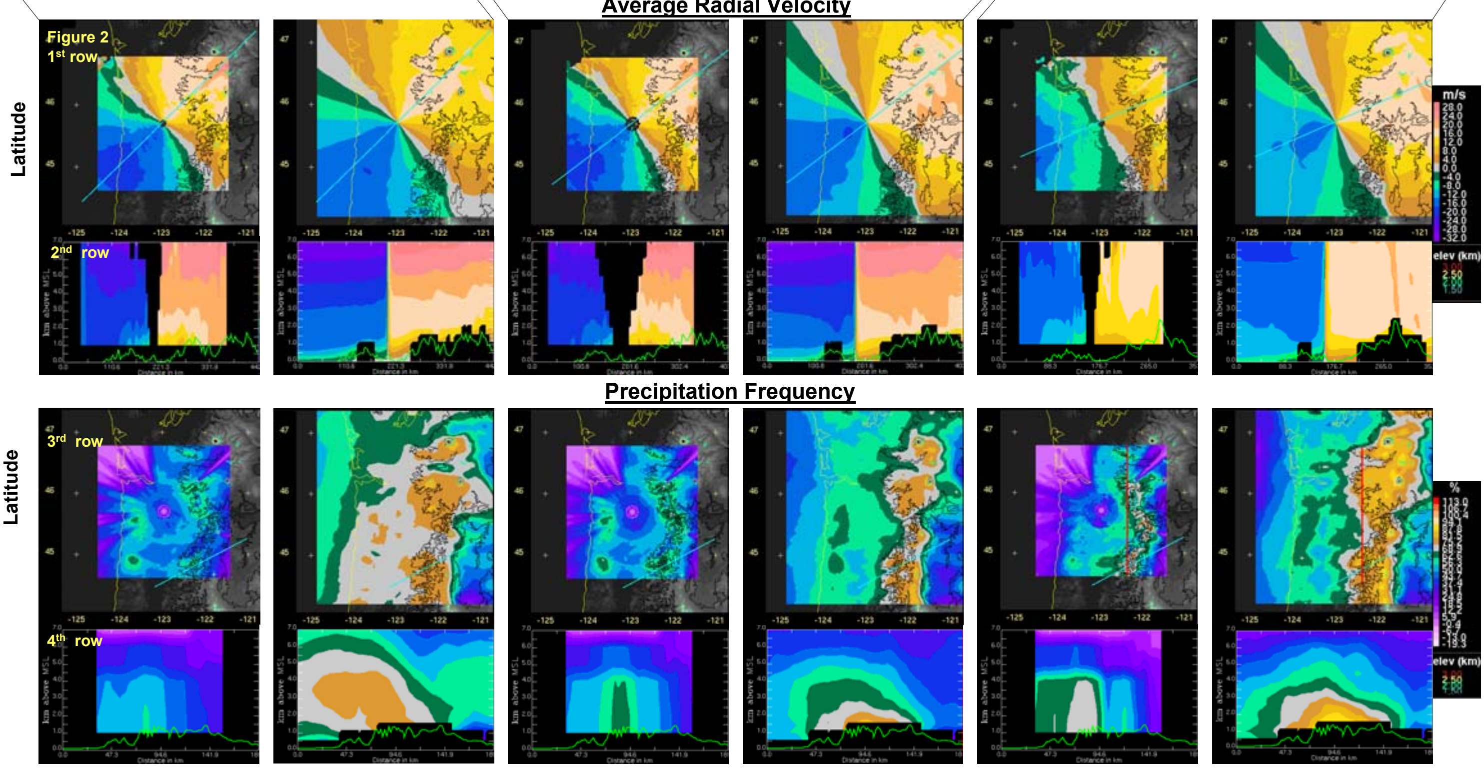

Figure 2. Radar observations and model output for sets of storms within three wind directi80on categories—Southerly (left column), Southwesterly (middle column), Westerly (right column). 1st row: horizontal cross-section at 2 km altitude of average radial velocity. 2nd row: vertical cross-section of average radial velocity along blue lines indicated in figure above. 3rd row: horizontal cross-section at 2 km altitude of precipitation frequency 4th row: vertical cross-section of precipitation frequency along blue lines indicated in figure above.

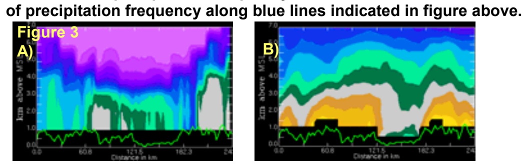

Figure 3. Vertical cross-sections of precipitation frequency along N-S red line on Cascade slope for Westerly storms. (a) radar observations. (b) model output.

Conclusions

- **Portland region winter storms have a distribution of squared B-V frequency from -0.1 to 5.5 x 10^{-4} s^{-2}, more stable than James and Houze's results for northern California and similar to the stable cases observed during the Mesoscale Alpine Programme (Medina and Houze, 2003).**
- **We compare 3D patterns of precipitation frequency and radial velocity, basic characteristics of the precipitation structures that are obtainable with minimal uncertainty from both operational radar data and forecast model output. These fields are not subject to the large uncertainties in converting model mixing ratios to reflectivities, the variable height of the freezing level in winter storms, or the impacts of radar attenuation.**
- **While the model output reproduces the horizontal radial velocity field well, the simulated winds show larger vertical wind shear near the surface and higher radial wind speeds at 2-3 km altitude compared to observations. The model's overestimation of vertical shear may be related to a misrepresentation of the planetary boundary layer in the model.**
- **The model output has up-wind tilted, gravity-wave-influenced precipitation structures, particularly for southerly flow storms. These tilted structures are not apparent in the observed precipitation frequency.**

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