Ice Microphysical Processes in Winter Storms Encountering the Olympic Mountains

Results from the Olympic Mountains Experiment: OLYMPEX

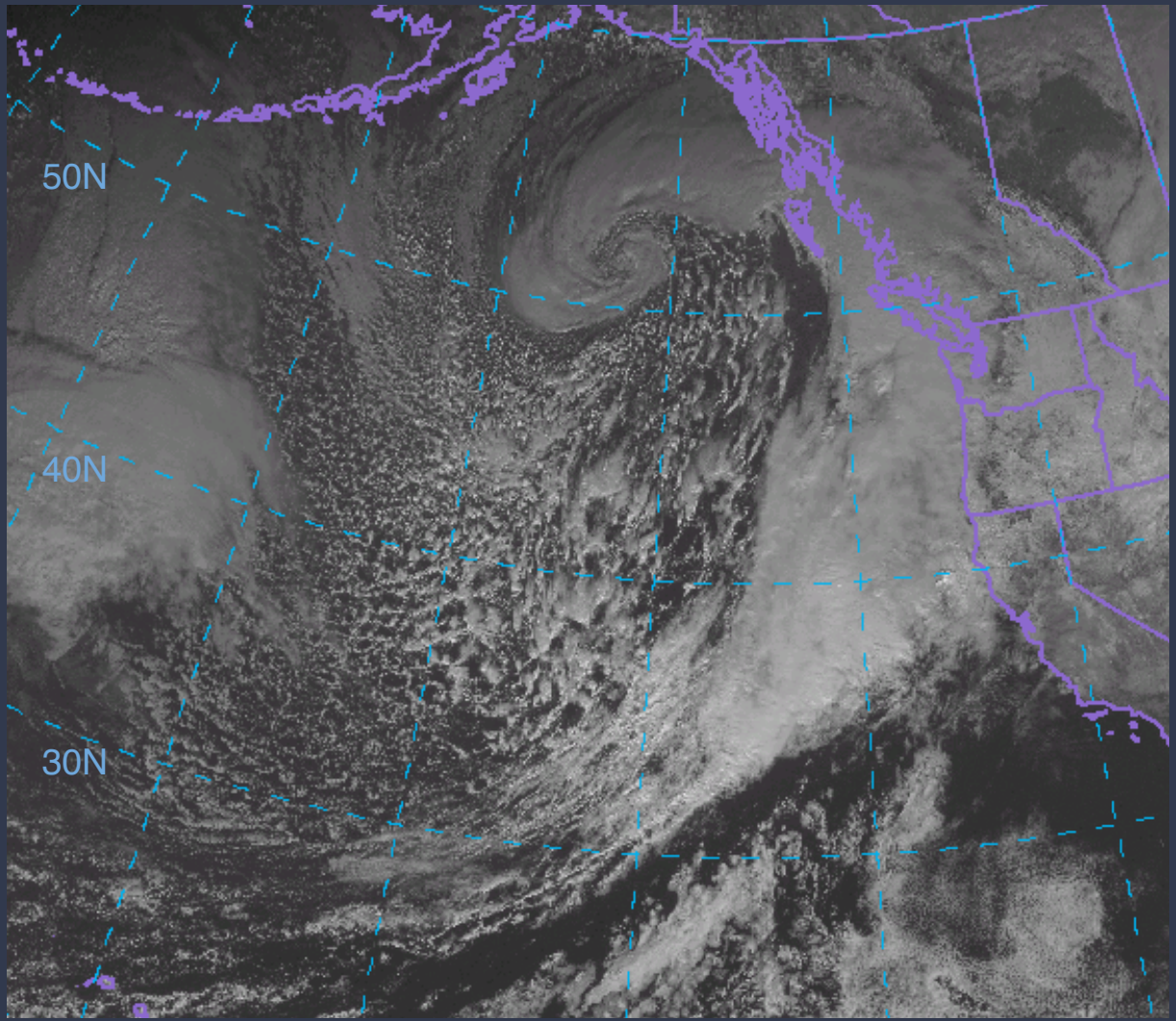
Andrew DeLaFrance
Department of Atmospheric Sciences,
University of Washington

Lynn McMurdie
Department of Atmospheric Sciences,
University of Washington

Angela Rowe
Department of Atmospheric and Oceanic Sciences,
University of Wisconsin-Madison

with input from Joe Finlon
Department of Atmospheric Sciences,
University of Washington

Winter storms in coastal mountain ranges



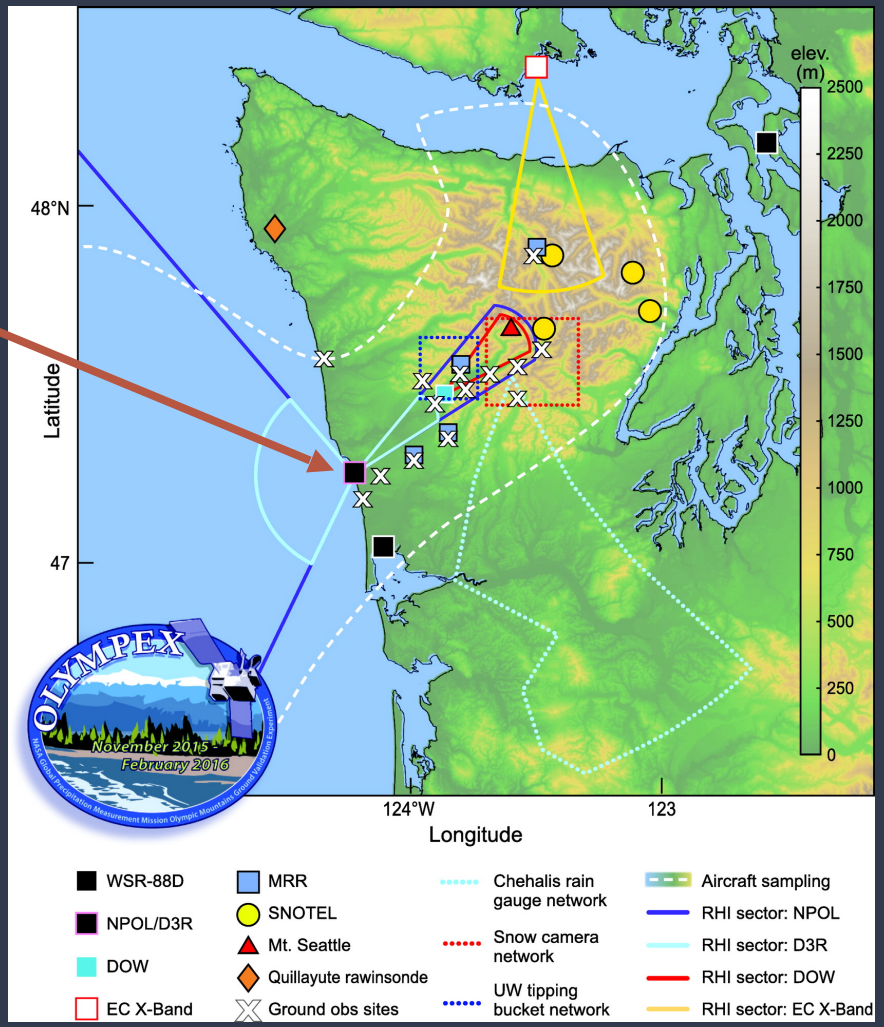
02 Dec 2015, 20 UTC

OLYMPEX

- Olympic Mountains, WA
- Ground-based radar
  - NPOL, dual-polarization S-band
- Rawinsondes @ NPOL site
- In situ aircraft observations
  - UND Citation
    - 2D-S particle imager
    - HVPS-3 particle imager
    - King hot wire probe (liquid water content)

Objective

Improve our understanding of the precipitation processes that contribute to enhanced precipitation on the windward slopes of the Olympic Mountains

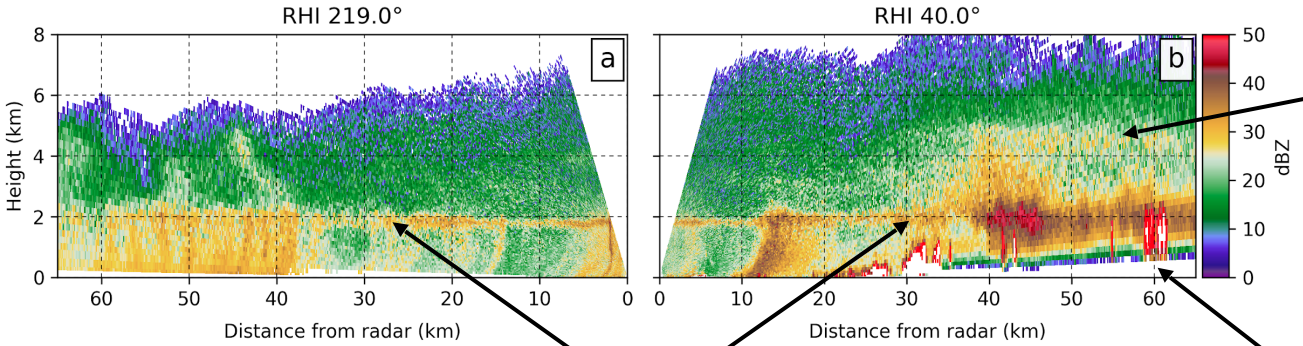


Houze et al. 2017, BAMS

Enhanced Reflectivity in the Ice Layer during OLYMPEX

03 Dec - Example

Z_h



Ocean, 14:41 UTC

Terrain, 14:54 UTC

Secondary Maximum: Layer of local reflectivity maximum above the bright band

Bright Band: Narrow, primary maximum in reflectivity

Terrain of Olympic Mountains

Research Questions

1. Is the secondary maximum in reflectivity an orographically-forced feature or is the secondary maximum inherent to a frontal storm system and potentially modified by the terrain?

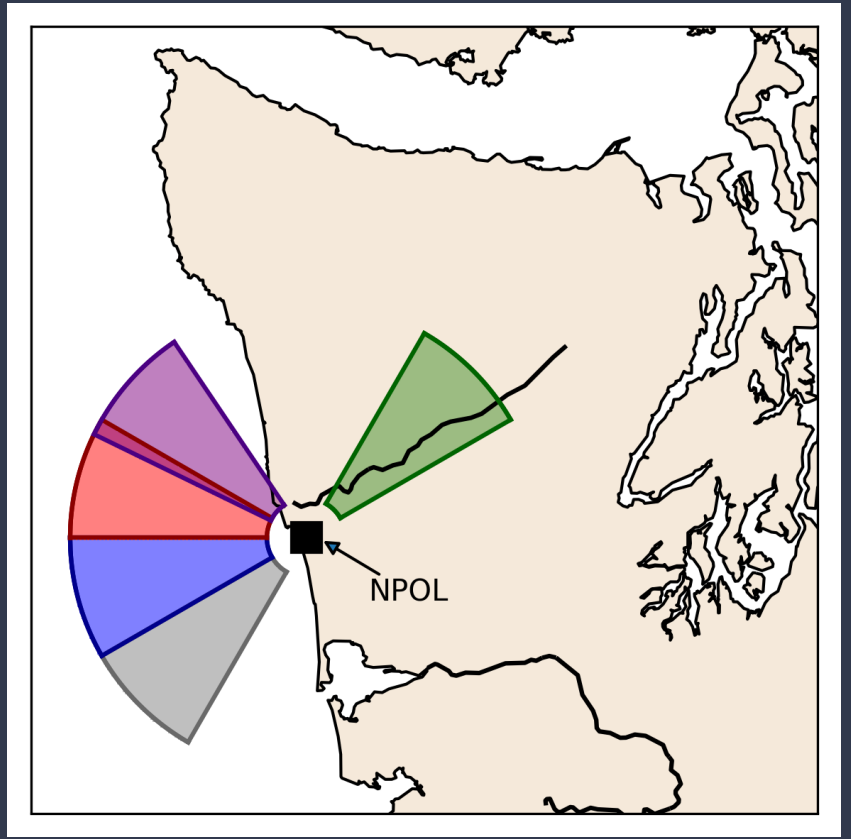
2. What are the physical properties of the particles found within a secondary maximum in reflectivity that cause a relative increase in reflectivity values?

NPOL Radar Data in OLYMPEX

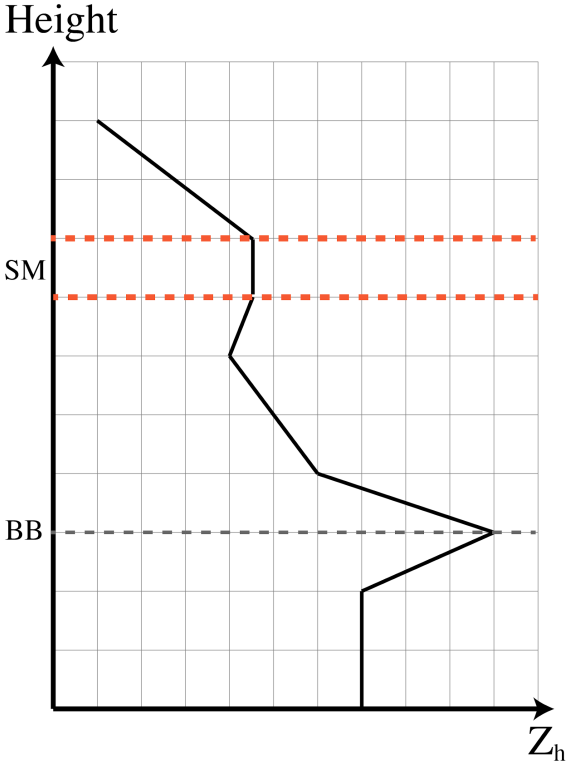
- 10 - 60 km radial range
- Designation of 5 equally sized regions
- Gridded data from individual scans
  - 0.5 km horizontal resolution
  - 0.25 km vertical resolution

NPOL data used: 12 Nov - 19 Dec, 2015

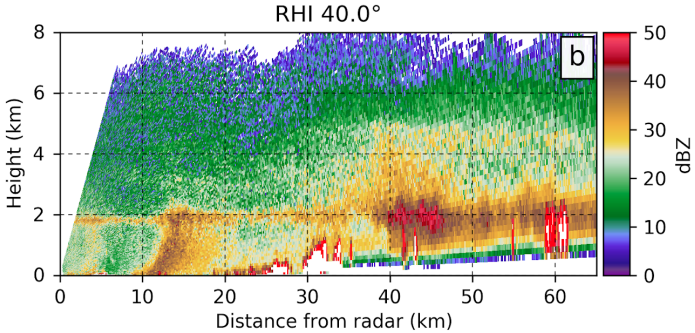
(observation period that spanned aircraft operations)



Can the secondary maximum be objectively identified?

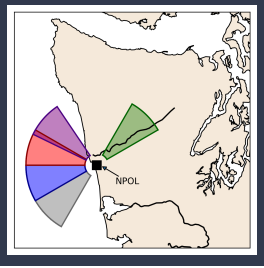


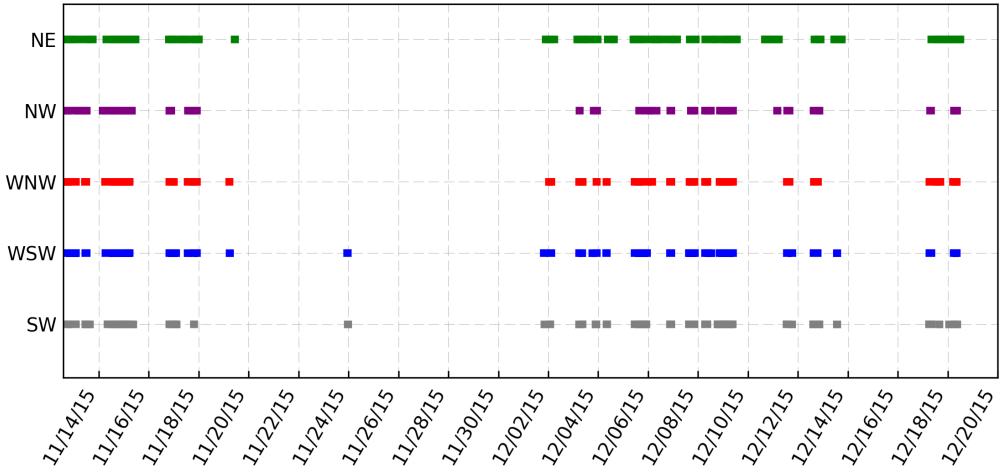
Secondary Maximum Identification Scheme



- Bottom-up search *when bright band is found*
  - >1 km above the bright band
- Increase in reflectivity with height
  - 0.5 km minimum layer of increase
  - Reflectivity > 17 dBZ
- Filtering to ensure horizontally continuous layer

Where and when did a secondary maximum occur during OLYMPEX?

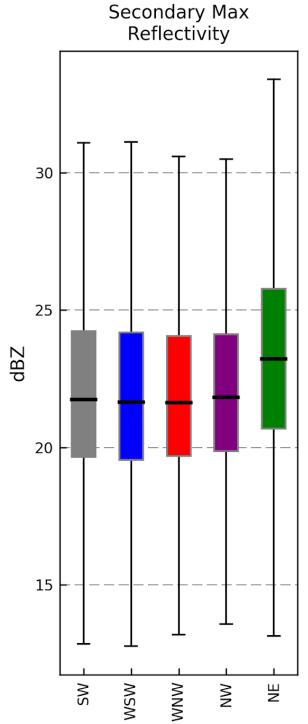




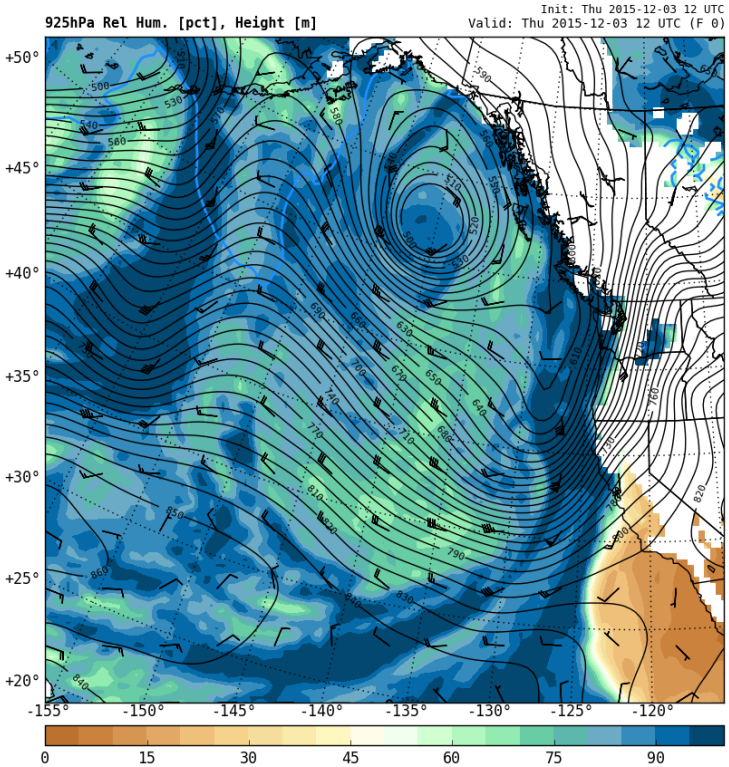
Fraction of time a secondary maximum was identified during OLYMPEX

- NE - **25%**
- NW - **10%**
- WNW - **13%**
- WSW - **11%**
- SW - **10%**

Higher reflectivity values observed within the secondary maximum layer over the terrain than over ocean



03 Dec Case Study



03 Dec 12Z

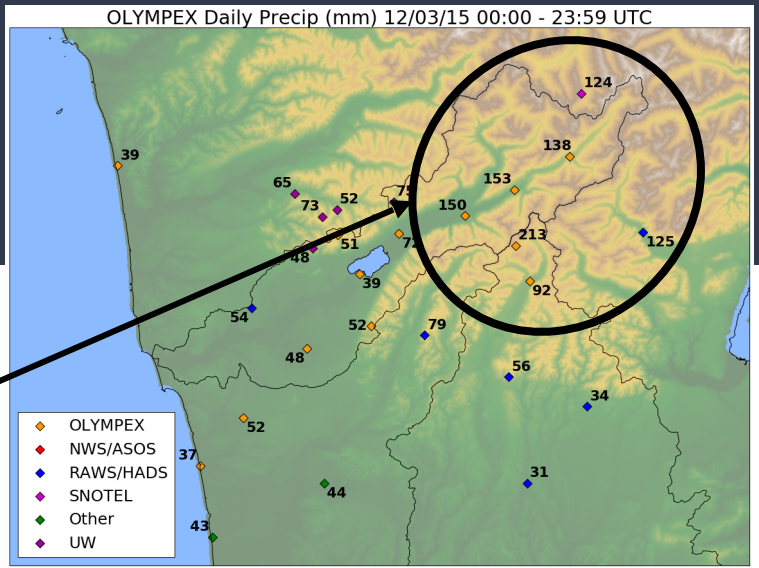
100-200 mm rainfall on southern slopes

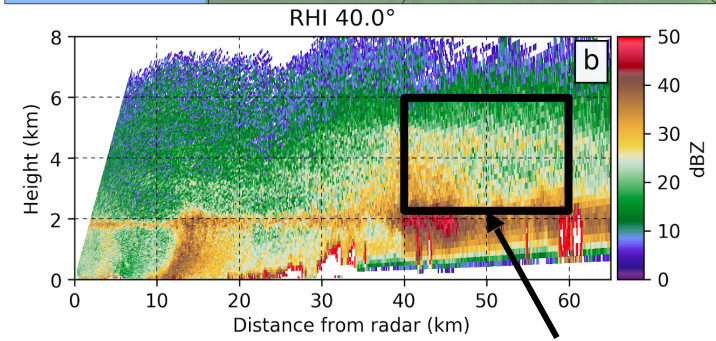
500 hPa trough

Saturated S - SSW low-level flow in the warm sector

High water vapor transport

Neutral stability



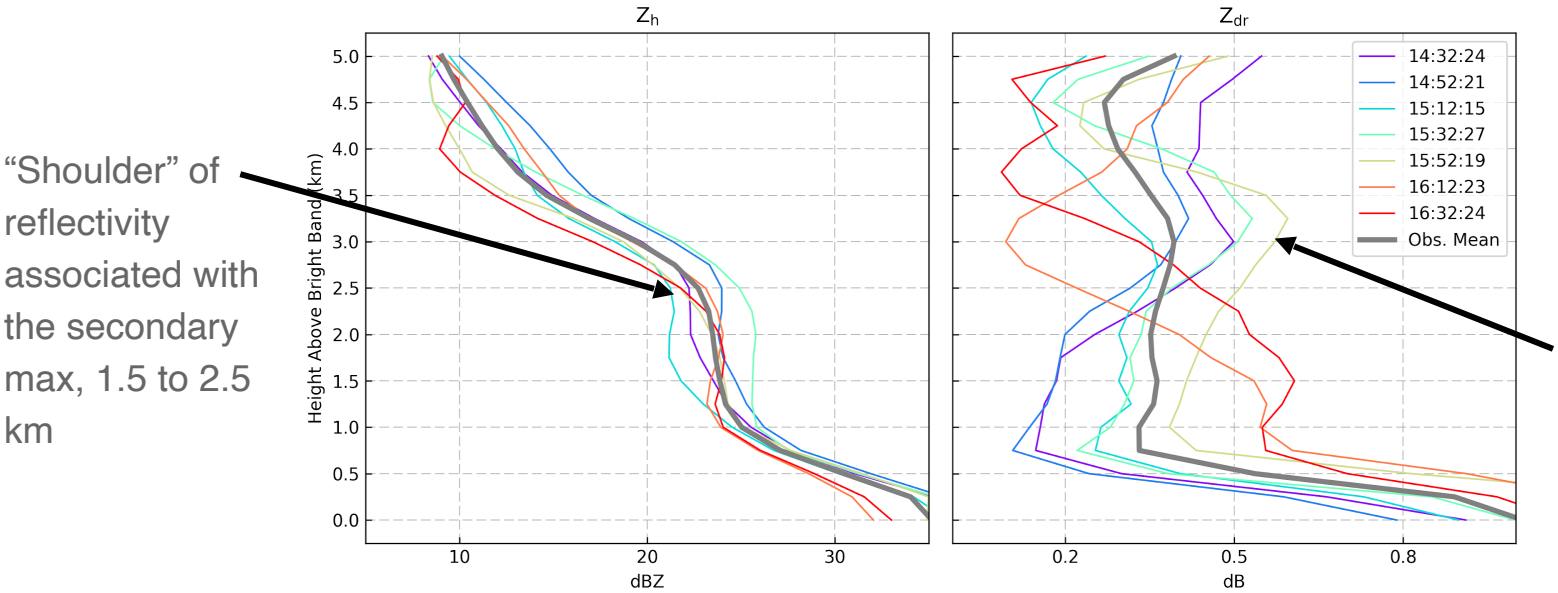


In situ observations from the Citation aircraft over the terrain in, above and below the secondary maximum during 03 Dec flight

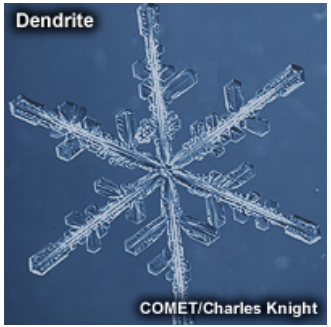
03 Dec Case Study - Radar Observations

Bright band relative reflectivity, differential reflectivity

Vertical profiles from radar scans coinciding with in situ aircraft observations over terrain

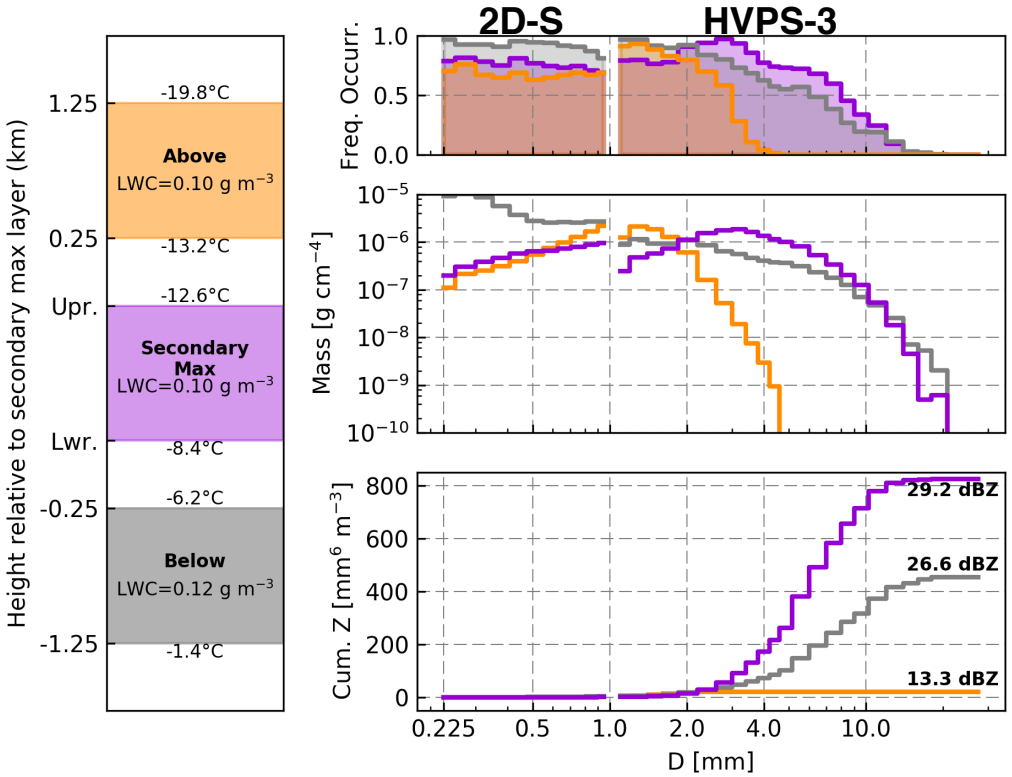


"Shoulder" of reflectivity associated with the secondary max, 1.5 to 2.5 km



Local maximum in differential reflectivity above secondary maximum layer

03 Dec Case Study - In Situ Observations



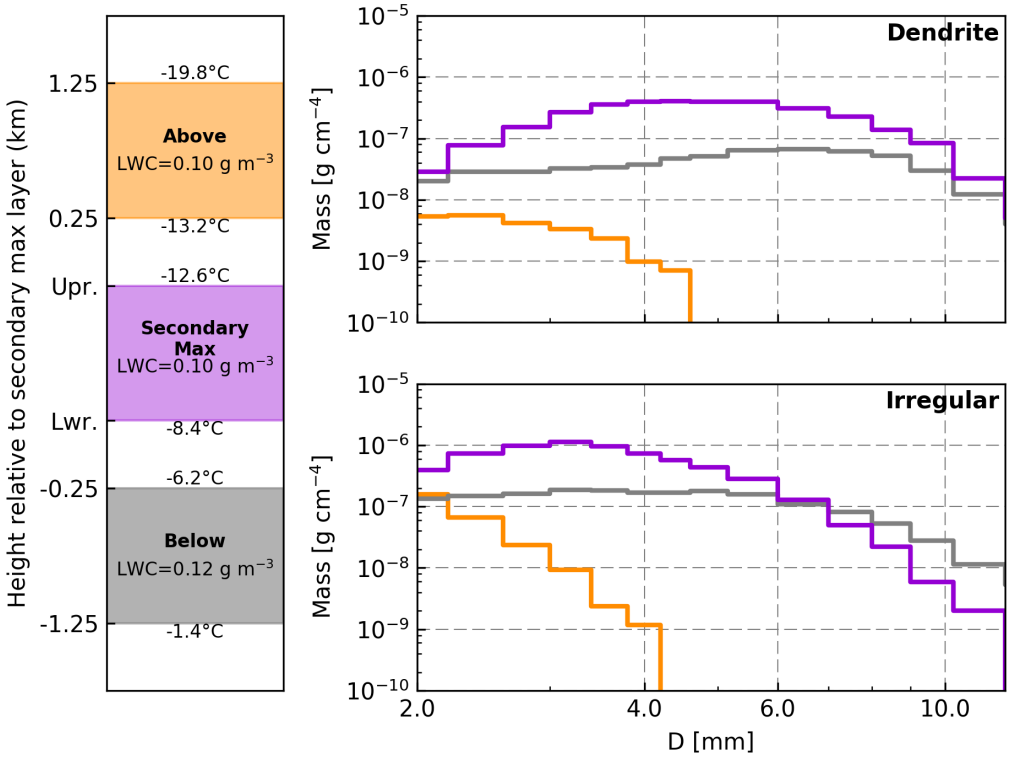
Coincident in situ data in each layer

- **Above:** 5 minutes, 30 seconds
- **Secondary Maximum:** 9 minutes, 1 second
- **Below:** 8 minutes, 48 seconds

Higher concentration of particles 2-10mm in size consistently found in secondary maximum events during OLYMPEX.

Non-secondary-maximum events above a bright band at comparable temperatures (ocean and land) did not have an increased mass relative to layers above and below.

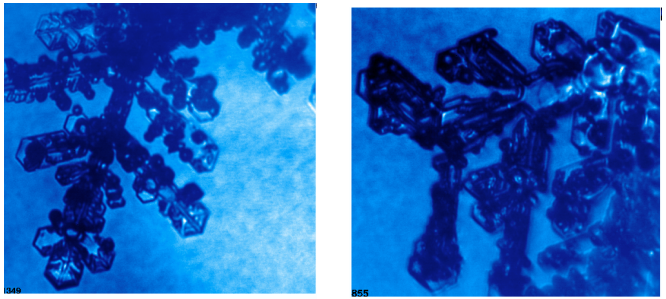
03 Dec Case Study - In Situ Observations
2mm to 10mm particles



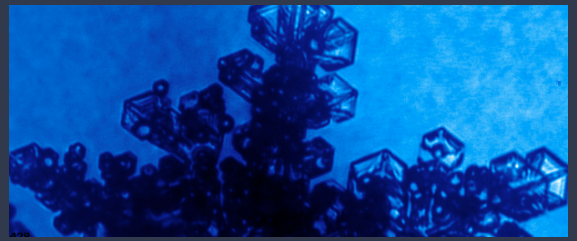
Habit classification; UIOOPS - University of Illinois/ Oklahoma Optical Array Probe (OAP) Processing Software
McFarquhar et al., 2018

Dendrite and **irregular** particles dominate the mass differences in the secondary maximum

Supercooled liquid water found in each layer; **Riming**



Non-secondary-maximum events at comparable temperature ranges averaged lower supercooled liquid water concentrations



Conclusion

1. We find evidence that a secondary maximum in reflectivity can be inherent to a frontal storm system. However, when compared to over the ocean, it occurs more frequently over windward slopes of the Olympic Mountains and the reflectivity values can also be enhanced.

2. Within the secondary maximum, we find that there are higher concentrations of the largest particles (~2mm to ~10mm) relative to the layers above and below. The increase in mass is dominated by dendrite and irregular particles.

3. Supercooled liquid water over the terrain (likely advected above the bright band via a low-level jet orographically forced aloft) caused riming to accelerate particle growth by aggregation to form the larger particles that appear to have contributed to the enhanced precipitation on the windward slopes of the Olympic Mountains.

Acknowledgements

This work was sponsored by NSF grant AGS-1657251

We would like to thank the National Park Service, U.S. Forest Service and the Quinault Indian Nation for permission to install and operate instrumentation on their lands.

UIOOPS software used for habit classification

McFarquhar, G. M., Finlon, J. A., Stechman, D. M., Wu, W., Jackson, R. C., and Freer, M.: University of Illinois/Oklahoma Optical Array Probe (OAP) Processing Software, https://doi.org/10.5281/zenodo.1285969, 2018.