Orographic Impacts on Liquid and Ice-Phase Precipitation Processes during OLYMPEX

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Introduction

- NASA Global Precipitation Measurement (GPM) mission Olympic Mountain Experiment (OLYMPEX) during winter of 2015-16
- Ground and airborne in situ and remote sensing measurements
- NASA S-band dual-pol radar (NPOL) used to analyze evolution of hydrometeor profiles as precipitation moved from the ocean and over mountainous terrain

Motivation

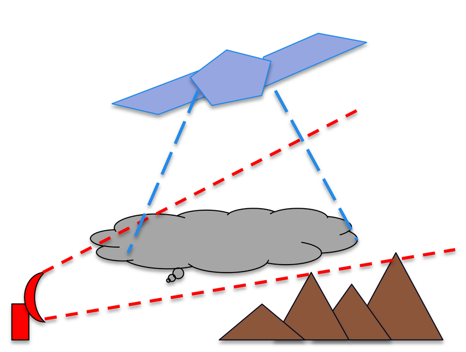
- Analysis suggests satellite-based precipitation products such as GPM IMERG underestimate by 57% over orography in the OLYMPEX domain (e.g., Cao et al., 2018)
- IMERG relies on combined passive microwave (PMW) and IR sensors to make a precipitation estimate.
- PMW sensors rely on ice scattering over land for precipitation estimation. Often underperform in warm-rain conditions.
- IR sensors see cloud top, often underperform in stratiform (shallow) clouds.
- Orographic enhancement of precipitation is observed ahead of and on windward slopes
- *Resultant enhancement of both warm and cold rain processes*

(1) What changes are occurring in the low levels due to orography?
(2) Are these changes systematic?
(3) Is IMERG capturing these changes?

Methodology

Radar-based approach with NPOL

- GPM satellite retrievals are limited by assumptions made about content and behavior of clouds and precipitation
- Use NPOL's ground-based perspective to estimate relative ice and liquid contributions within a cloud column
- Compare near-surface rain rate estimates from Integrated Multi-Satellite Retrievals for GPM (IMERG) with NPOL



Calculating water paths from an RHI

1. Use hydrometeor ID to discriminate ice and liquid hydrometeors
2. Calculate ice and liquid mass content (IWC, LWC) of hydrometeors by relating reflectivity (Z) and differential reflectivity (ZDR) to water mass content
3. Grid IWC and LWC, 1000 m x 500 m (x,z)
4. Integrate IWC and LWC to obtain ice and liquid water path (IWP, LWP)

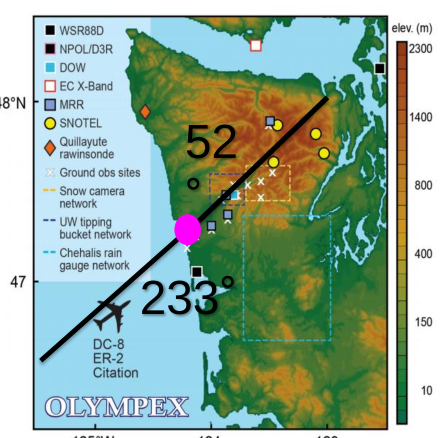
$$\mathrm{IWP} = \int_{h_{base}}^{h_{top}} \mathrm{IWC}\, dh.$$

Systematic Partitioning

-Extratropical cyclones (frontal systems) are the primary source of precipitation and provide rapidly changing dynamic and thermodynamic conditions

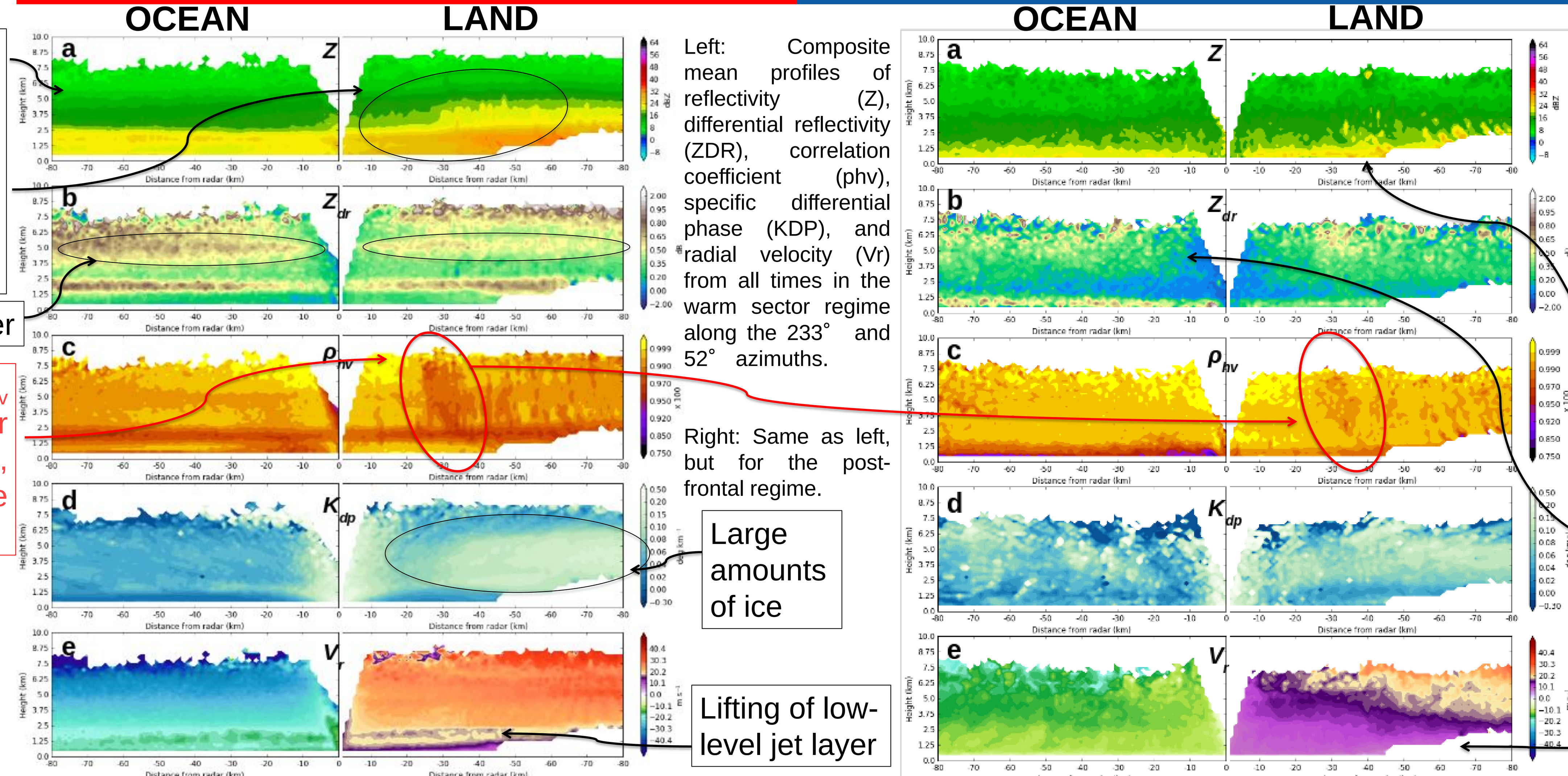
- Times of precipitation during OLYMPEX are categorized using four primary cyclone sectors with distinct characteristics: prefrontal, warm sector, frontal, and post-frontal. (cf. Houze et al., 2017)

Polarimetric Signatures



Elevation and instrument location in the OLYMPEX domain in northwestern Washington. Pink dot represents location of NPOL and black lines are selected RHI azimuths, 233 (ocean) and 52 (land).

- Clear differences in vertical structure of hydrometeors over ocean, land and mountains



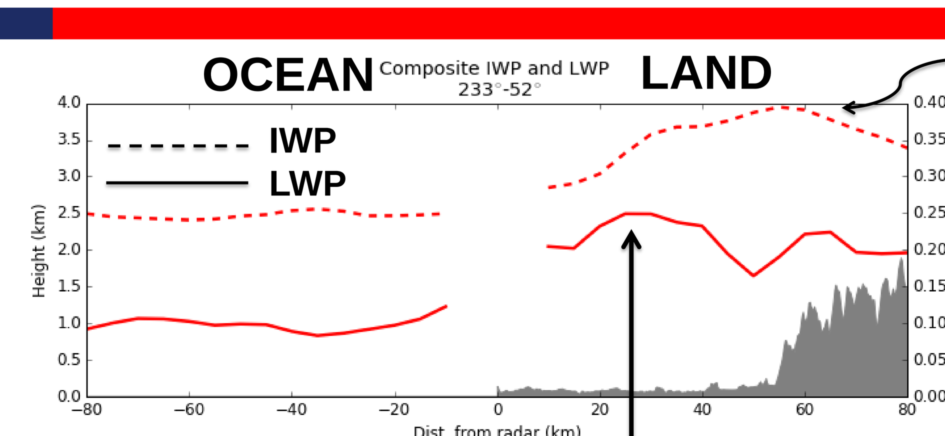
Left: Composite mean profiles of reflectivity (Z), differential reflectivity (ZDR), correlation coefficient (ρhv), specific differential phase (KDP), and radial velocity (Vr) from all times in the warm sector regime along the 233° and 52° azimuths.

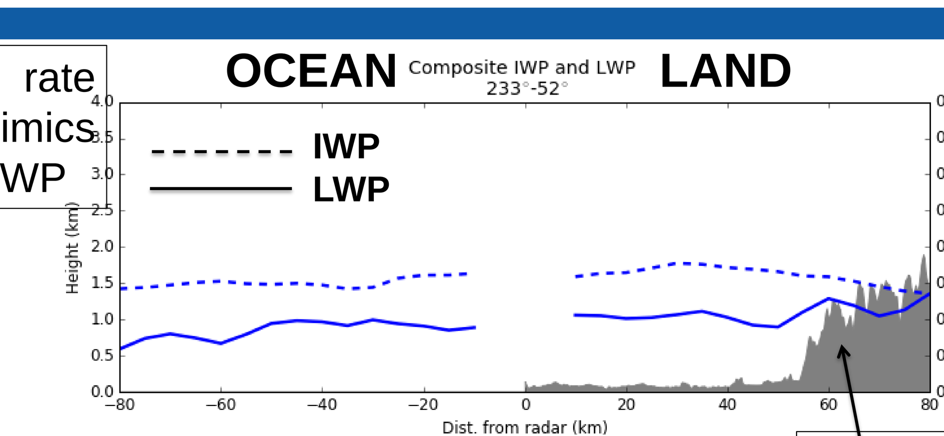
Right: Same as left, but for the post-frontal regime.

- Composite RHIs based on cyclone sector regime
- Warm sector exemplifies strong cross-barrier flow and stratiform precipitation, including atmospheric river (AR) events
- Post-frontal (PF) includes scattered, shallow convective cells

IWP and LWP

- Increasing ice production into terrain
- Liquid enhancement on windward slopes
- Ice and liquid enhancements begin upstream of terrain





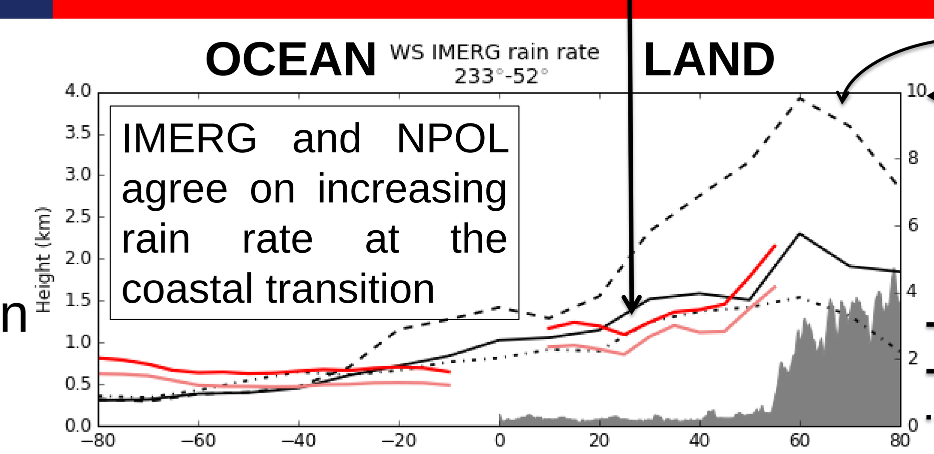
- PF IWP and LWP trends not as pronounced

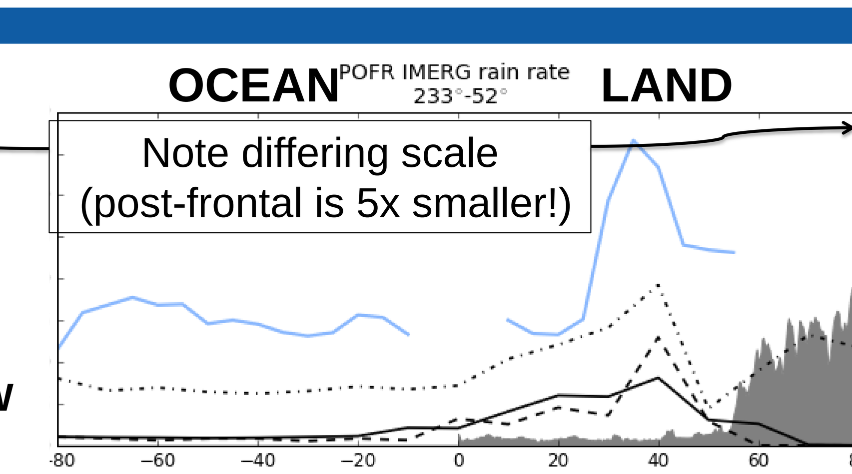
Left: Composite mean profiles of IWP and LWP profiles from all times in the warm sector regime along the 233° and 52° azimuths.

Right: Same as left, but for the post-frontal regime.

Rain Rates

- Microwave component heavily affected by ice, leading to *overestimation* of surface rainfall in warm sector regime
- Rain DSD indicates increased D_m and N_w moving inland (not shown)





Post-Frontal: IMERG underestimate compared to NPOL rain rate. DSD flat going into terrain (not shown)

Left: Composite mean profiles of IMERG rain rate estimates (calibrated, passive microwave, IR) and NPOL rain rate estimates (DROPS1 and DROPS2) from all times in the warm sector regime along the 233° and 52° azimuths.

Right: Same as left, but for the post-frontal regime.

Conclusions

- Warm sector and post-frontal regimes indicate different processes controlling ice and liquid enhancement
- Warm-sector lifting of low-level flow is observed ~40 km upstream of barrier, enhancing warm rain process, while mountain-induced uplift and turbulence enhances ice processes
- Coupling of warm and cold process yields heavy rainfall via the seeder-feeder mechanism
- Post-frontal exhibits cellular behavior and very limited signatures of a dendritic/branched crystal growth layer.
- When raining, IMERG IR tends to underestimate, PMW may, at times, overestimate due to ice contribution
- IMERG captures the approximate range, but not always the magnitude of near-surface rain rate

Future work

- Comprehensive analysis of *all* collected RHI azimuths with stricter categorization of regimes and more detailed analysis of processes using combinations of all available column-profiling data.
- Multivariable correlation index to evaluate the most meaningful combination of environment parameters for precipitation enhancement.

Acknowledgments

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References:

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