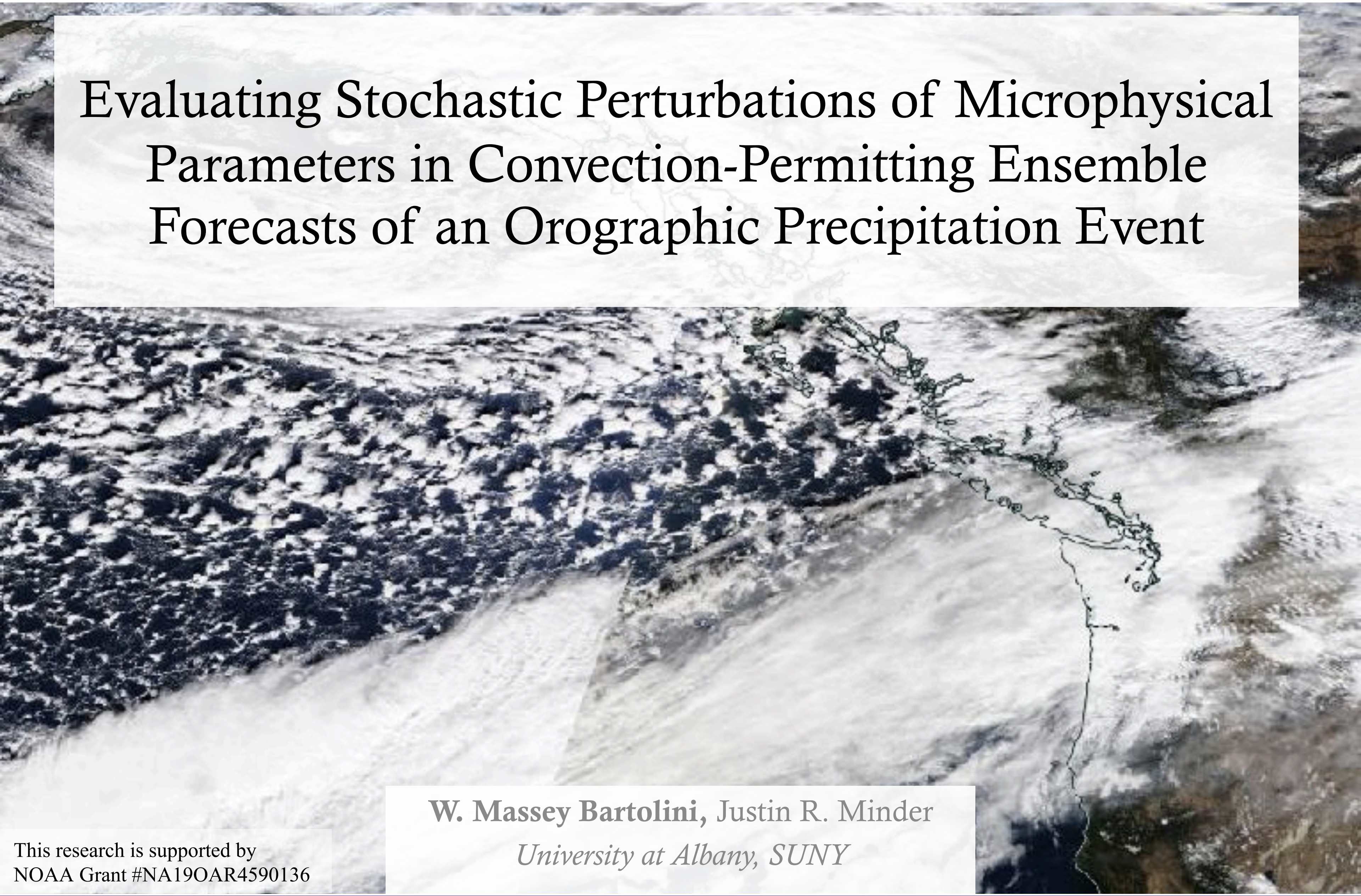

Evaluating Stochastic Perturbations of Microphysical Parameters in Convection-Permitting Ensemble Forecasts of an Orographic Precipitation Event

W. Massey Bartolini, Justin R. Minder

University at Albany, SUNY

This research is supported by
NOAA Grant #NA19OAR4590136

Where are mesoscale ensembles headed?

- Current multi-physics CAM ensemble (HREFv2.1)
  - ~ – High spread, from both multi-physics and initial and boundary condition (IC/BC) diversity, but an ensemble of opportunity
  - ✕ – Probabilistic forecasting difficult, not all members are equally likely, in part due to physics biases
  - ✕ – Maintenance/development of multiple physics schemes

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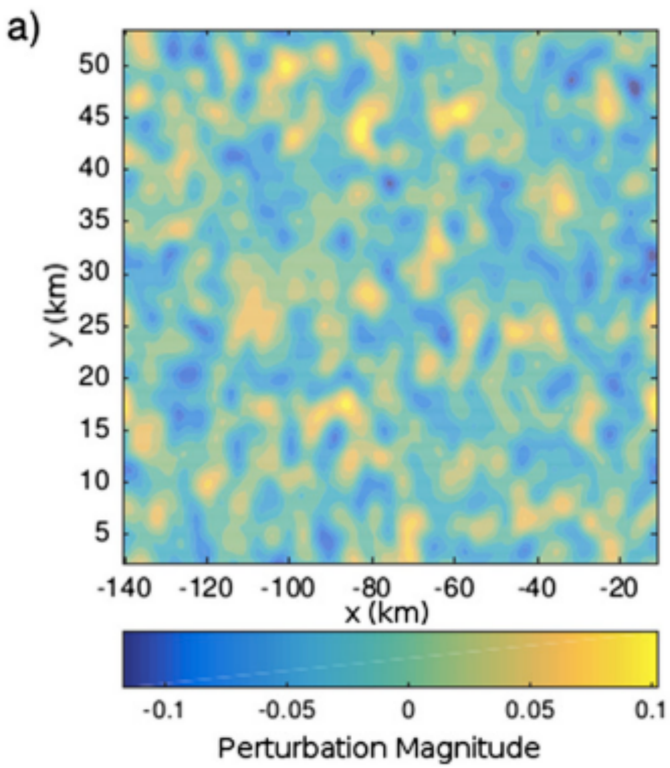
  - ✗ – Probabilistic forecasting difficult, not all members are equally likely, in part due to physics biases
  - ✗ – Maintenance/development of multiple physics schemes
- Likely future single-physics CAM ensemble (RRFS, FV3-SAR-based)
  - ✓ – High spread, using a combination of IC/BC and stochastic physics methods to represent both IC/BC and physics uncertainty
  - ✓ – Probabilistic forecasting easier since all members are equally likely
  - ✓ – Less code maintenance/development if using single physics and core

Stochastic Physics Overview

- Stochastic physics: representing uncertain model parameters or tendencies by multiplying them by a random noise pattern (varying in time/space) unique to each ensemble member
  - **SPP** – varying parameters
  - **SPPT** – varying tendencies
  - **SKEBS** – accounting for uncertainty from unresolved subgrid-scale processes

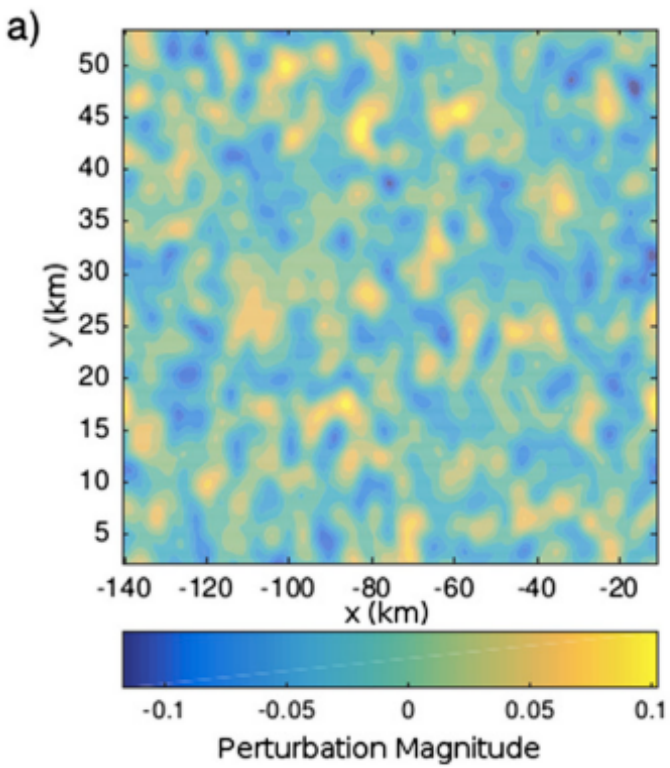


Adapted from Jankov et al. (2017)

Stochastic Physics Overview

- Combination of SPP/SPPT/SKEBS methods vital for increasing spread in ensemble forecasts (Berner et al. 2015, Jankov et al. 2017, 2019)

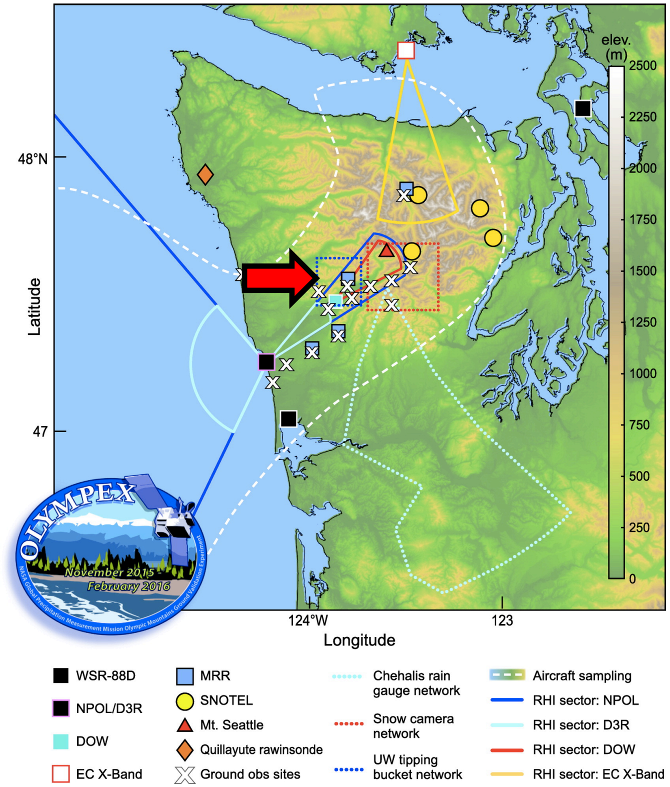
- **First step**: identify uncertain/empirically-derived parameters in microphysics (MP) scheme that affect orographic precip. forecast and could be perturbed using SPP, constrain using OLYMPEX observations



Adapted from Jankov et al. (2017)

Motivation: Orographic Precip. Challenge

- OLYMPEX: Nov. 2015 – Feb. 2016
  - Houze et al. (2017)
- Seasonal studies of surface drop size distributions (DSDs) during OLYMPEX show large variations, often within single storm
  - Zagrodnik et al. (2018)
- During OLYMPEX season, WRF consistently underpredicted windward precip., attributed to deficient warm-rain processes
  - Conrick et al. (2019)
- Varying snow crystal habit assumptions in MM5 model affects the distribution of orographic precip. over the Olympics
  - Woods et al. (2007)
- Idealized SPP studies of orographic precip. demonstrate similar spread to multi-physics ensemble
  - Morales et al. (2019)



Adapted from Houze et al. (2017)

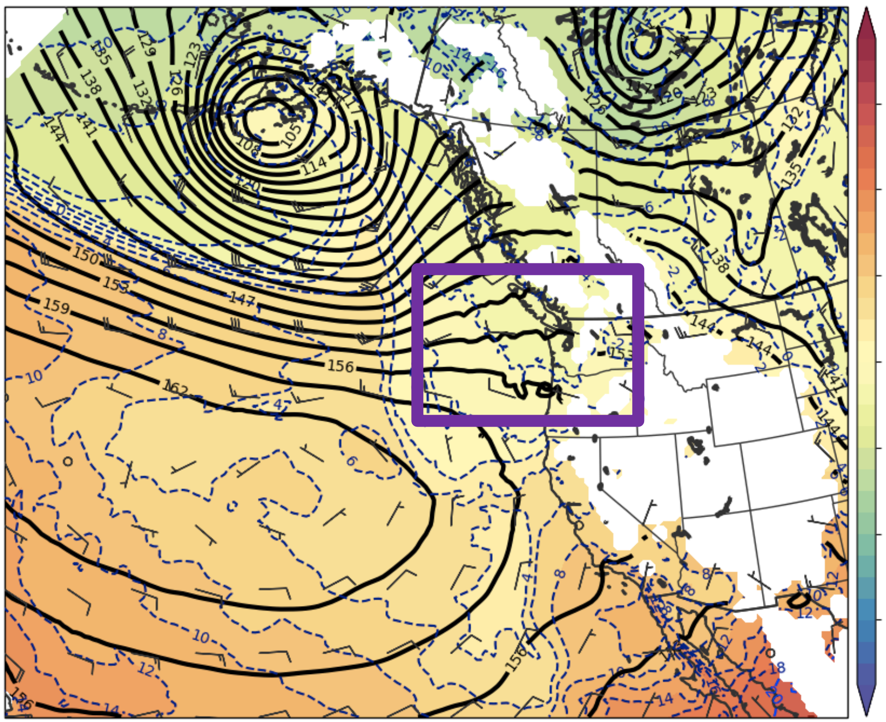
Presentation Goals

- **Single-scheme microphysics uncertainty:** Use OLYMPEX data from a single case study (12–13 Nov. 2015) to constrain uncertain MP scheme parameters in high-res. numerical forecasts of orographic precip. using a HRRR-like model setup
  - **Q1:** How well does Thompson-Eidhammer MP (THOM) forecast observed precip?
  - **Q2:** How sensitive is THOM MP to changes in assumed snow crystal habit?
  - **Q3:** How sensitive is THOM MP to changes in assumed rain distribution shape?

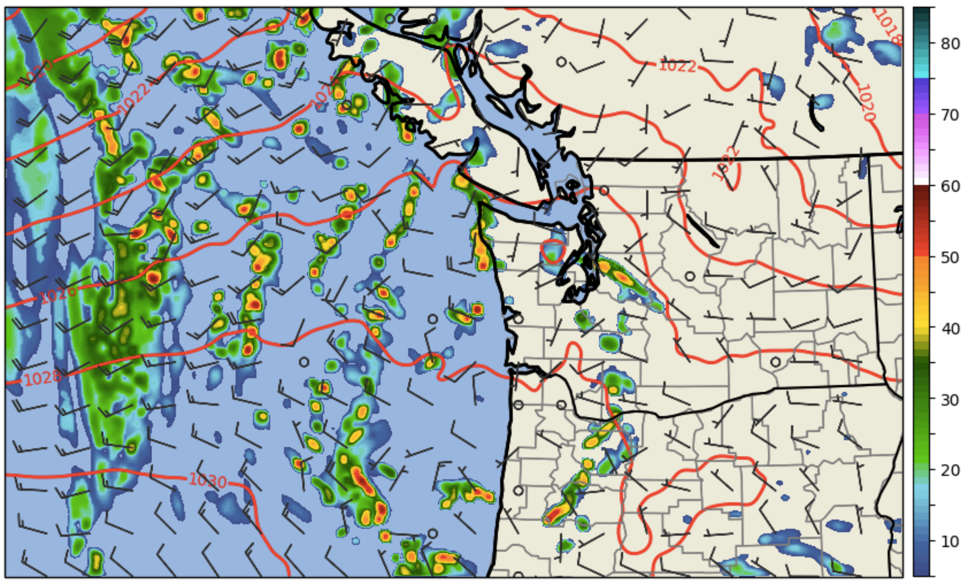
OLYMPEX EVENT OVERVIEW

Synoptic Overview

- 0000 UTC 12 Nov. 2015 (prefrontal)



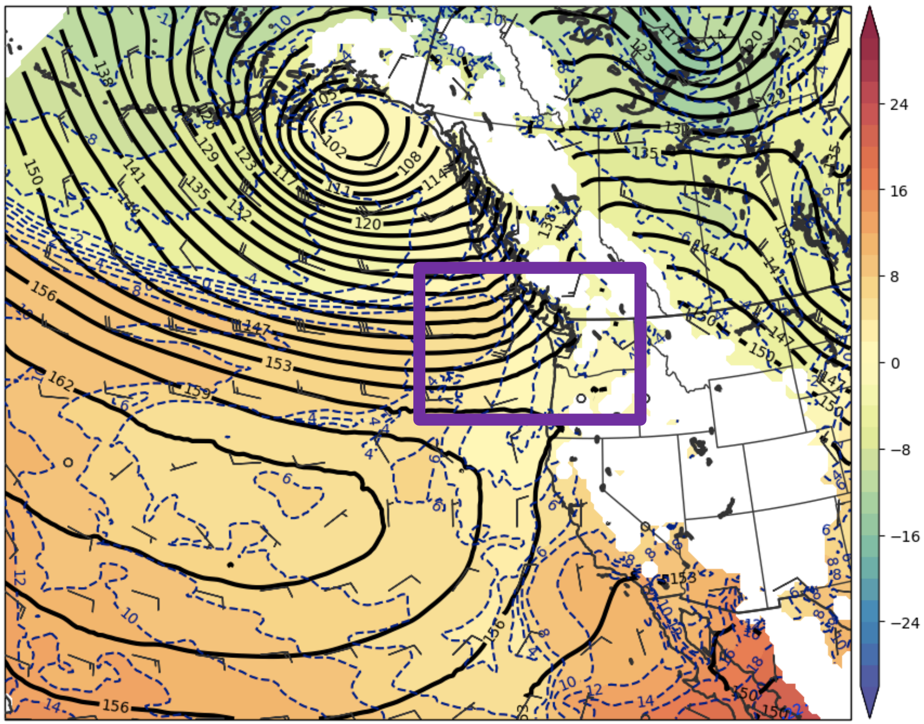
850-hPa temperature (fill/dashed contours, °C), height (solid contours, dam), and wind (barbs, m s^{-1})



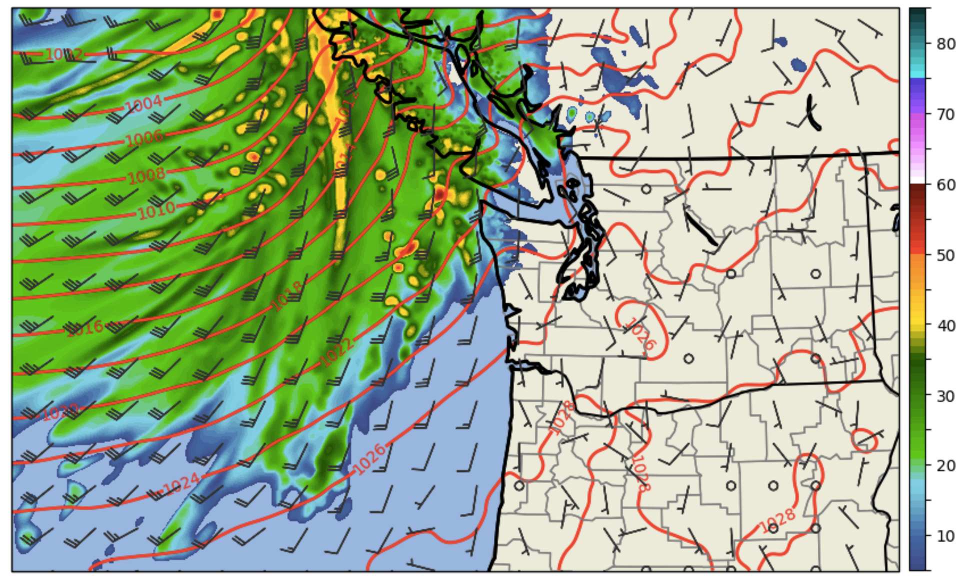
1-km AGL reflectivity (fill, dBZ), mean sea level pressure (solid contours, hPa), and 10-m wind (barbs, m s^{-1})

Synoptic Overview

- 1200 UTC 12 Nov. 2015 (prefrontal)



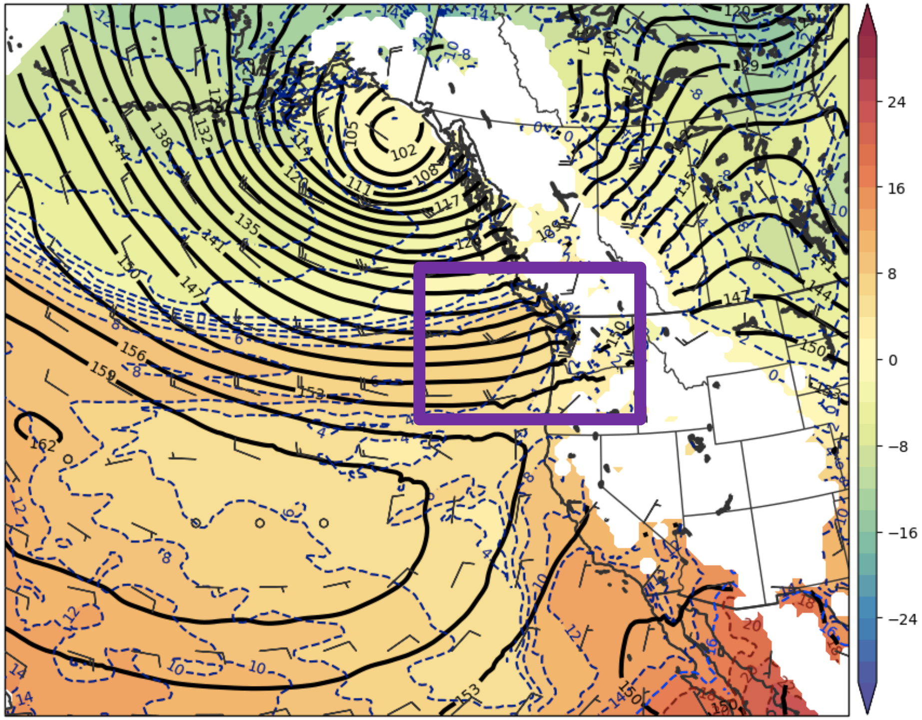
850-hPa temperature (fill/dashed contours, °C), height (solid contours, dam), and wind (barbs, m s^{-1})



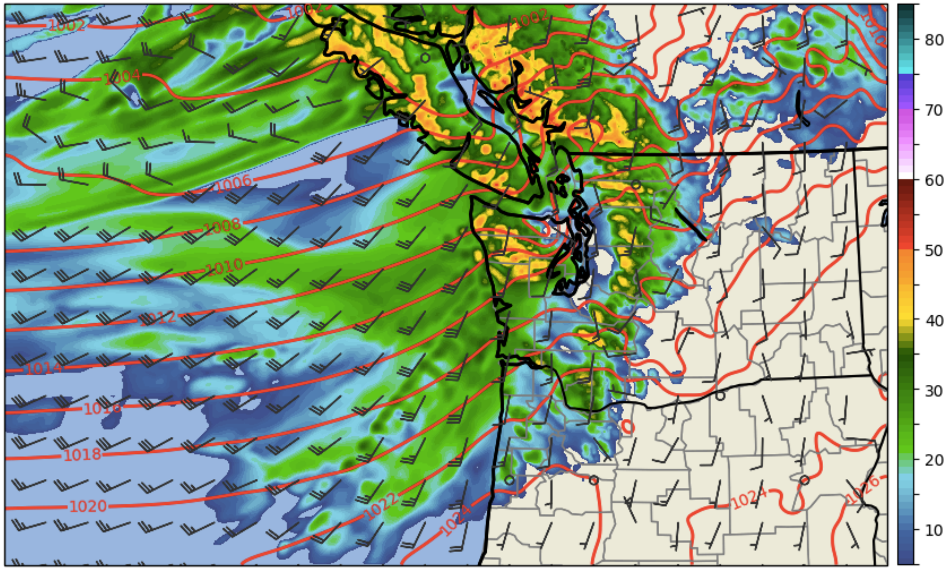
1-km AGL reflectivity (fill, dBZ), mean sea level pressure (solid contours, hPa), and 10-m wind (barbs, m s^{-1})

Synoptic Overview

- 0000 UTC 13 Nov. 2015 (warm sector)



850-hPa temperature (fill/dashed contours, °C), height (solid contours, dam), and wind (barbs, m s^{-1})



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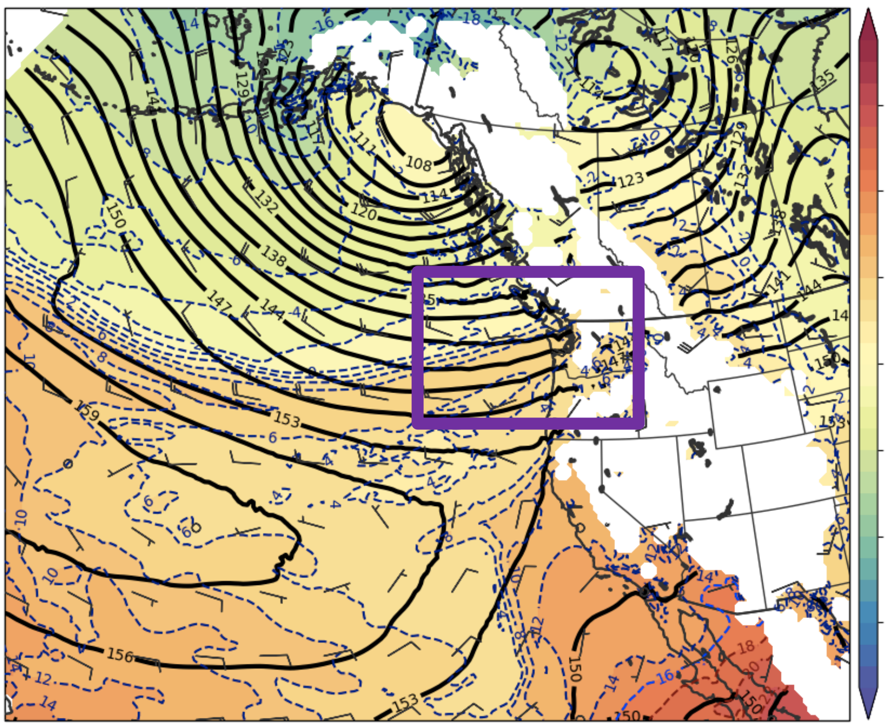
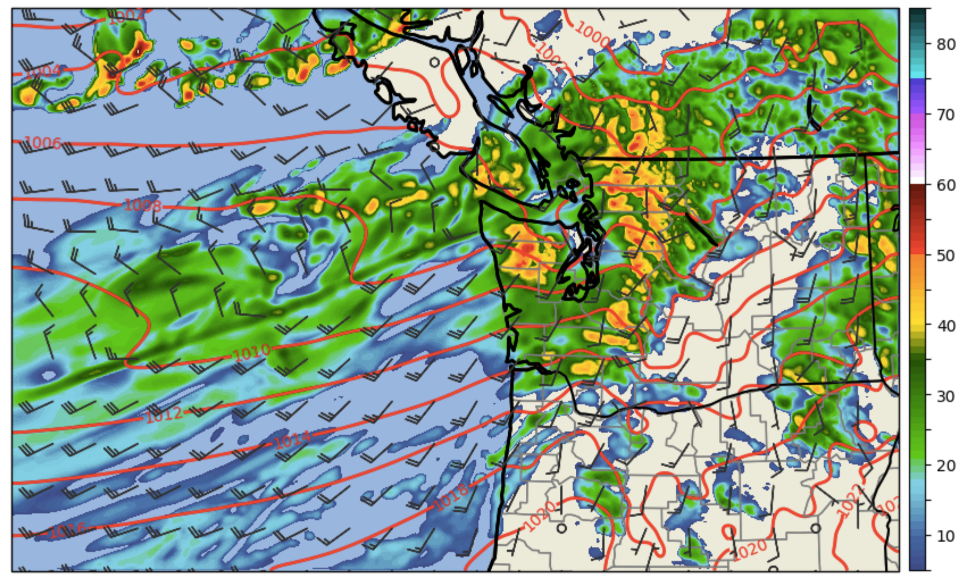


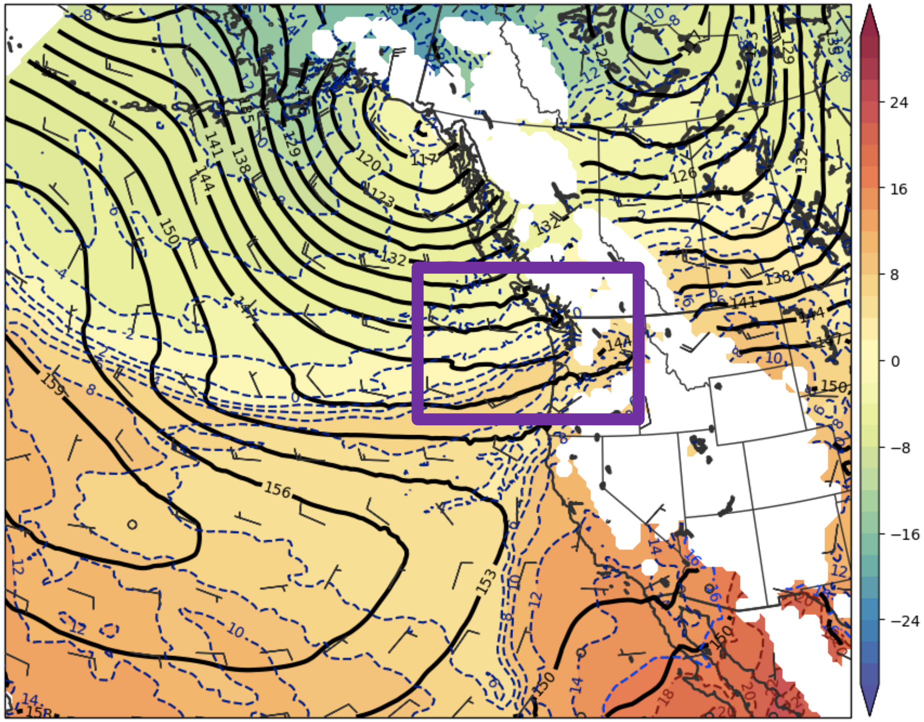
850-hPa temperature (fill/dashed contours, °C), height (solid contours, dam), and wind (barbs, m s^{-1})



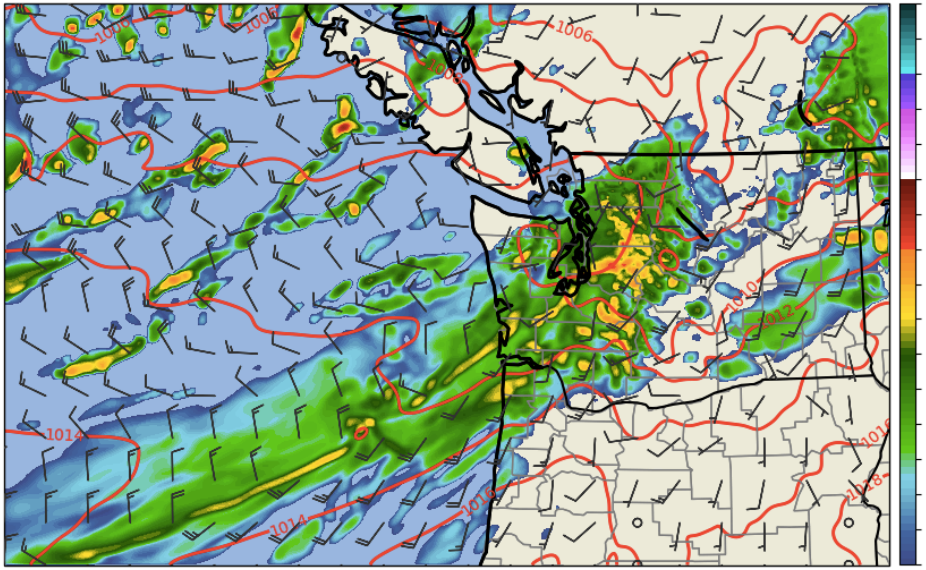
1-km AGL reflectivity (fill, dBZ), mean sea level pressure (solid contours, hPa), and 10-m wind (barbs, m s^{-1})

Synoptic Overview

- 0000 UTC 14 Nov. 2015 (postfrontal)



850-hPa temperature (fill/dashed contours, °C), height (solid contours, dam), and wind (barbs, m s^{-1})



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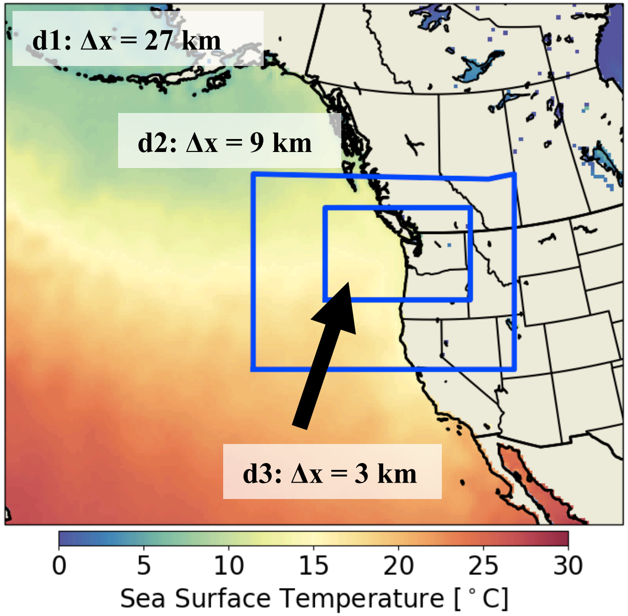
MODEL CONFIGURATION

HRRR-like WRF Configuration

- WRF v4.0.3
- Configured similarly to the current NCEP HRRR (v3)
- Nested domains
- Convection only parameterized on 27 and 9-km domain
- GFS atmospheric ICs/BCs
- Initialized 12 h prior to event (1200 UTC 11 Nov. 2015)
- MYNN Level 2.5 PBL scheme and Thompson-Eidhammer aerosol-aware MP (THOM)



- Sensitivity experiments **varying assumed parameters** within THOM MP scheme (e.g., rain and snow particle size distribution coefficients, snow mass- and terminal fall velocity-diameter relation coefficients)
- Experiments and parameter value ranges **motivated by OLYMPEX observations** (e.g., crystal habit imagery, disdrometer observations, and cloud physics data)

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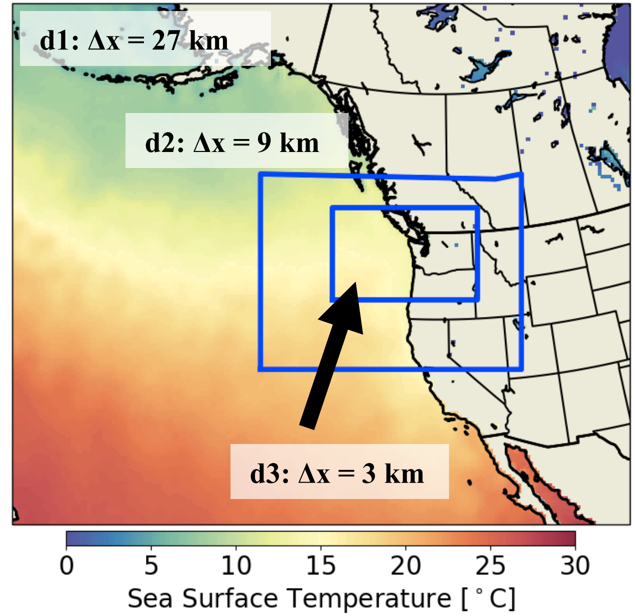


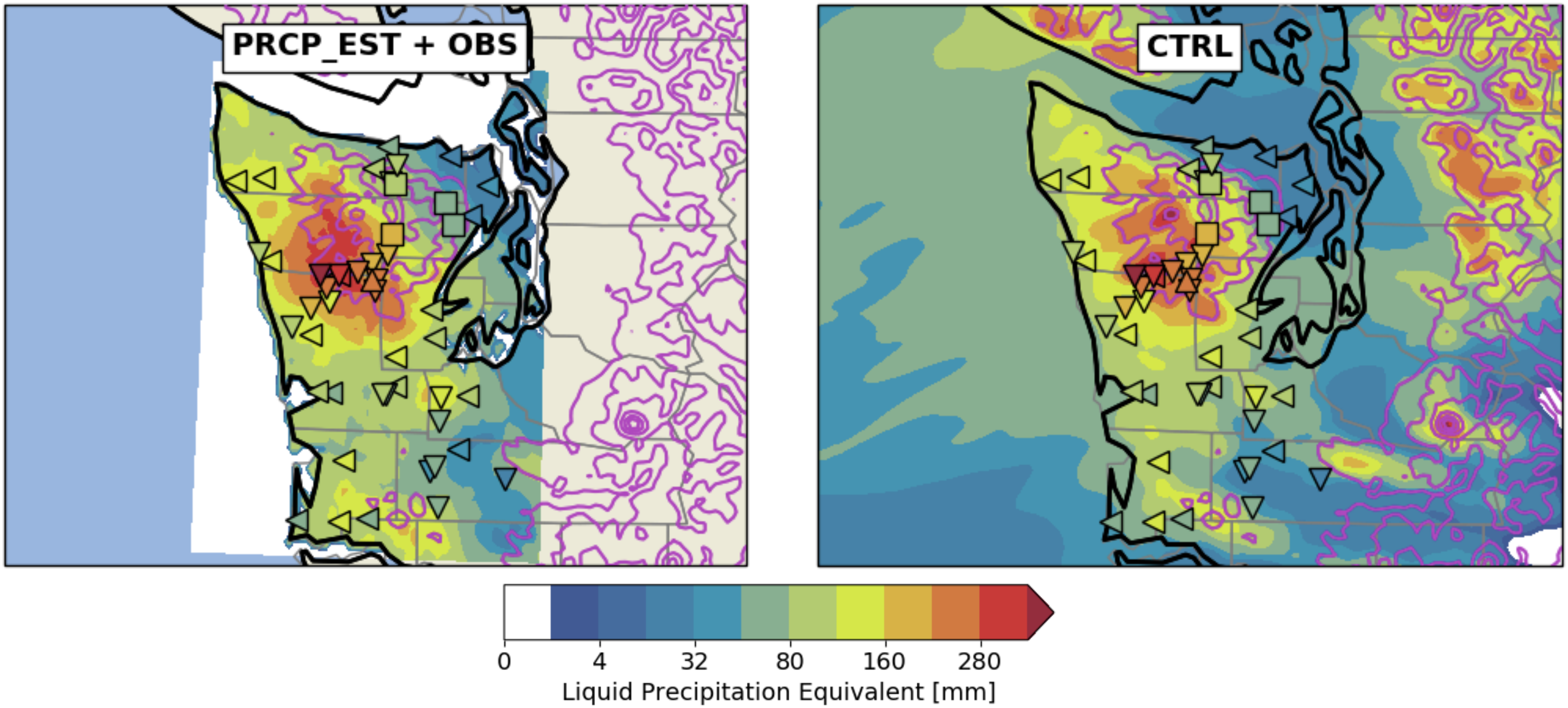
Parameter	Abbreviation	Description	Value(s)
a_{m_s}, b_{m_s}, a_{v_s}, b_{v_s}	**THOM_MFV_COLM, THOM_MFV_DDRT**	**Snow M-D and V-D coefficients**	**Those for dendrite and columnar crystals, normally fixed at intermediate habit**
Λ_1	THOM_SNOW_LAM1_1P6, THOM_SNOW_LAM1_4P9	Snow PSD slope parameter	Ranging between 1.6 and 4.9, normally fixed at 3.29
C_{snow}	THOM_SNOW_CAP_0P2, THOM_SNOW_CAP_0P5	Snow capacitance	Variable between 0.2 and 0.5 depending on temp.
Aerosol concentration	THOM_AERO_CLEAN, THOM_AERO_POLLUTED	Climo. aerosol concentration used in MP scheme	+/- 1 order of magnitude (clean/polluted)
μ_c	THOM_MU_C_2, THOM_MU_C_15	Cloud water PSD shape parameter	Variable between 2 and 15 (tried extremes) depending on N_c
CCN/IN boost	THOM_VTS_BOOST	Increasing CCN/IN	Positive perturbations only
N_{0_g}	THOM_GRAUP_N0_1E2, THOM_GRAUP_N0_1E7	Graupel intercept parameter	Variable between 10^2 and 10^7 (tried extremes)
μ_r	**THOM_MU_R_0P5, THOM_MU_R_5**	**Rain PSD shape parameter**	**Default=0, tried positive values up to 5**
Rain autoconv.	THOM_ACONV_+10%, THOM_ACONV_+50%	Perturbing rate of rain autoconv.	Tried +10%, +50% multiplicative perts.
Rain collection of cloud water	THOM_RACW_+10%, THOM_RACW_+50%	Perturbing rate	Tried 10%, +50% multiplicative perts.

CONTROL SIMULATION RESULTS

36-h Event-Total Precipitation

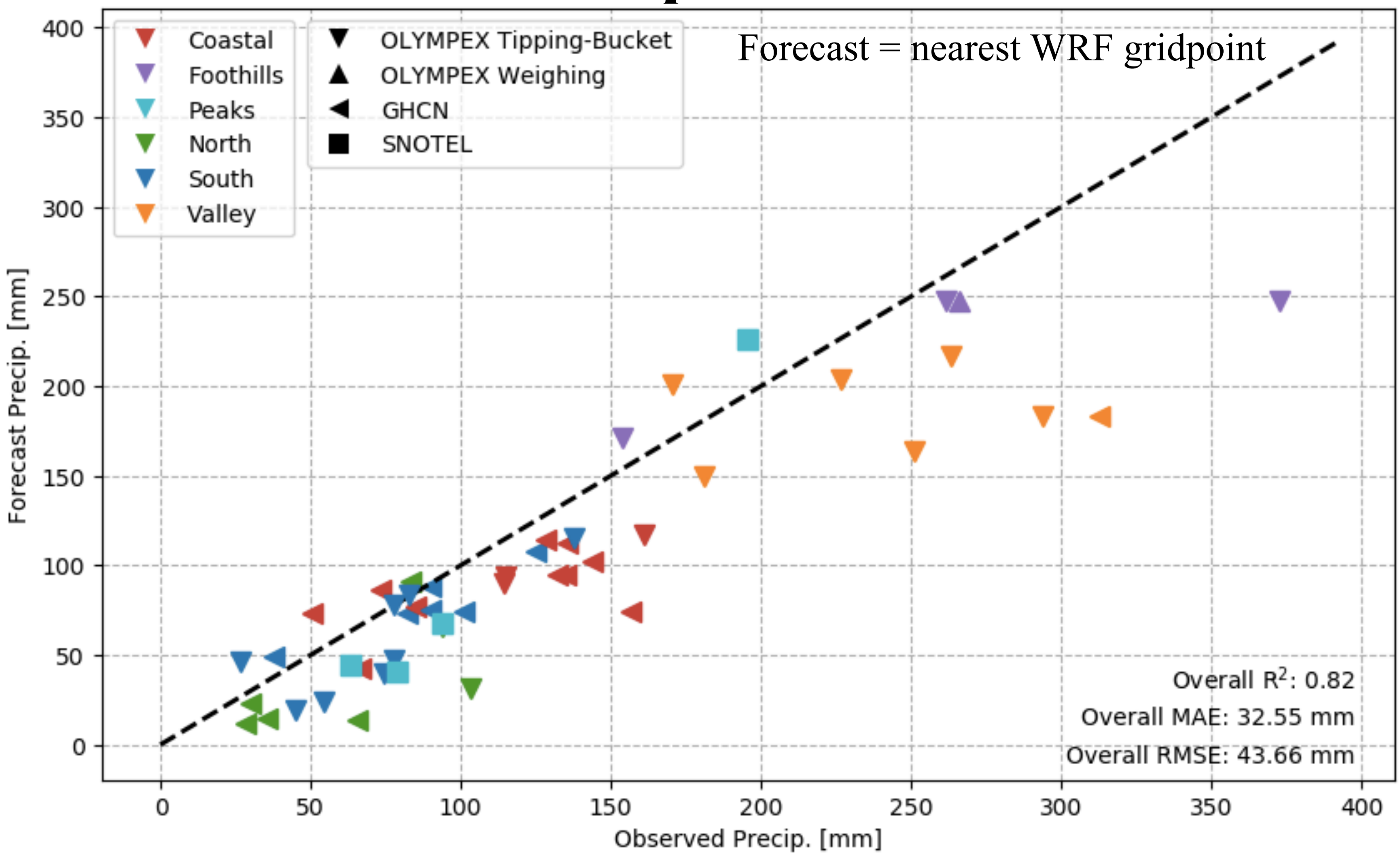
Observed Precip. (QPE)

Forecast Precip. (QPF)



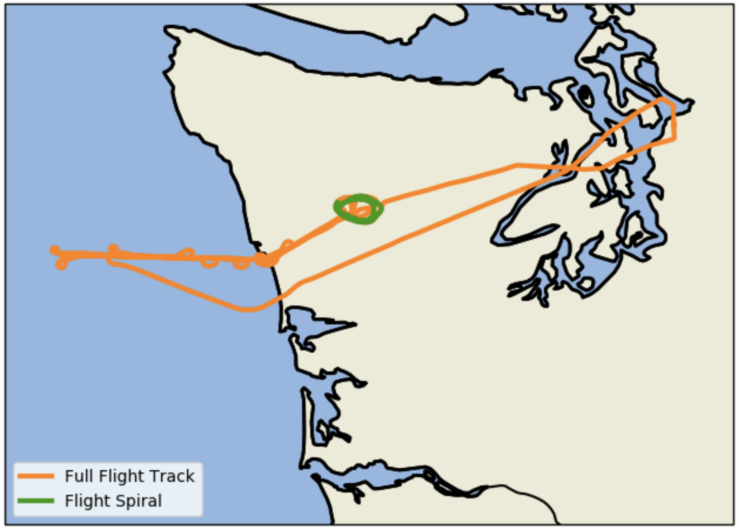
- Gridded QPE from radar estimate with gauge correction (Cao and Lettenmaier 2018)
- Max. obs. precipitation: 372 mm at Prairie Creek

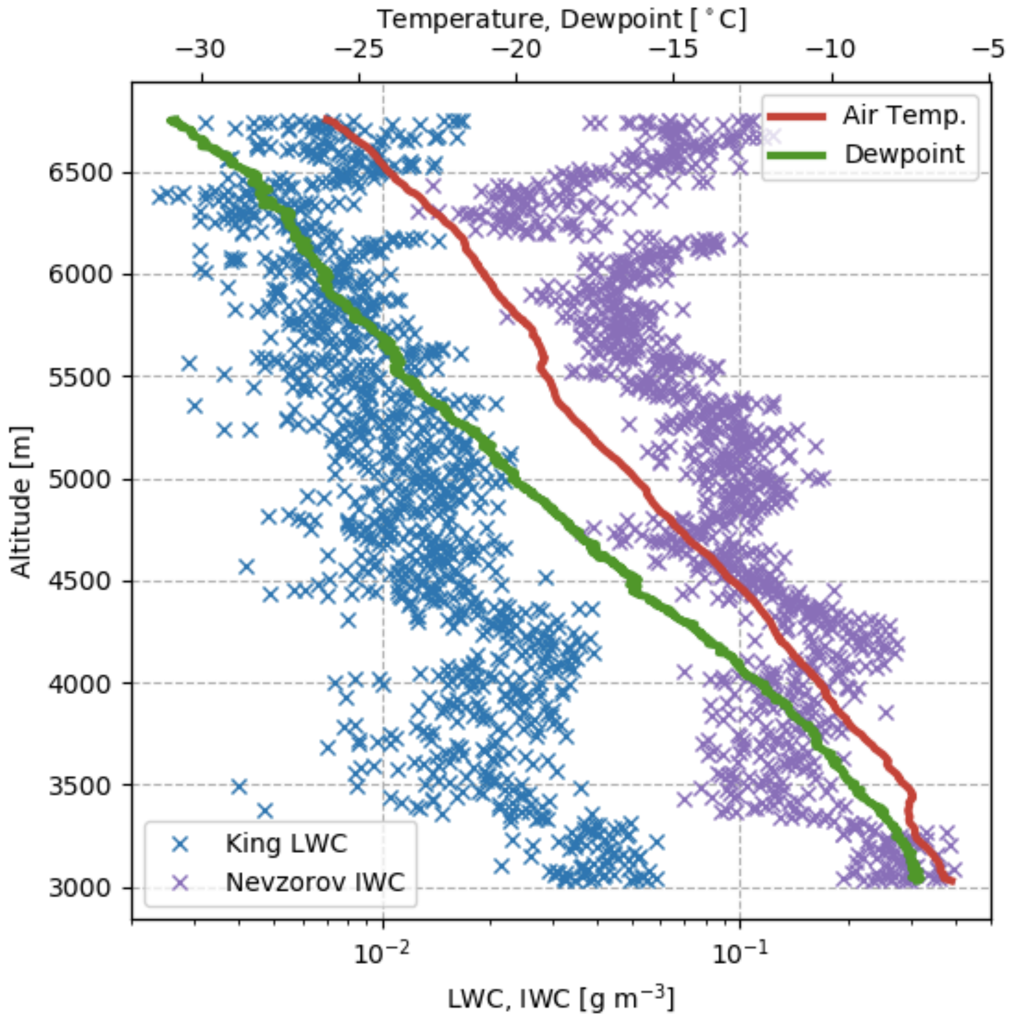
CTRL Precipitation Biases



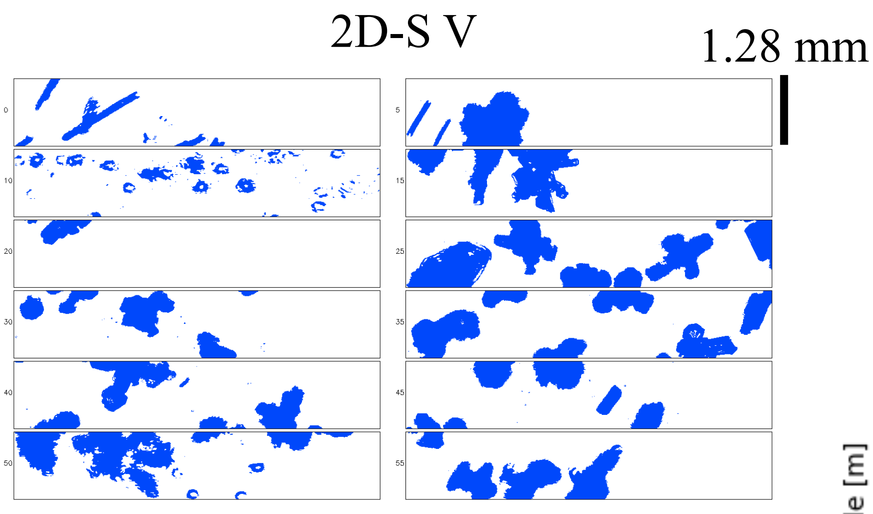
SENSITIVITY TO CRYSTAL HABIT: OBS. AND EXPERIMENTS

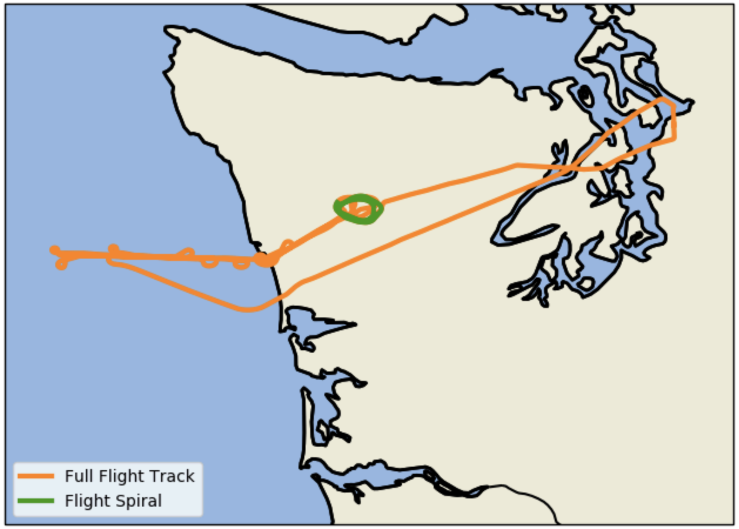
UND Citation Observations: 12 Nov. 2015

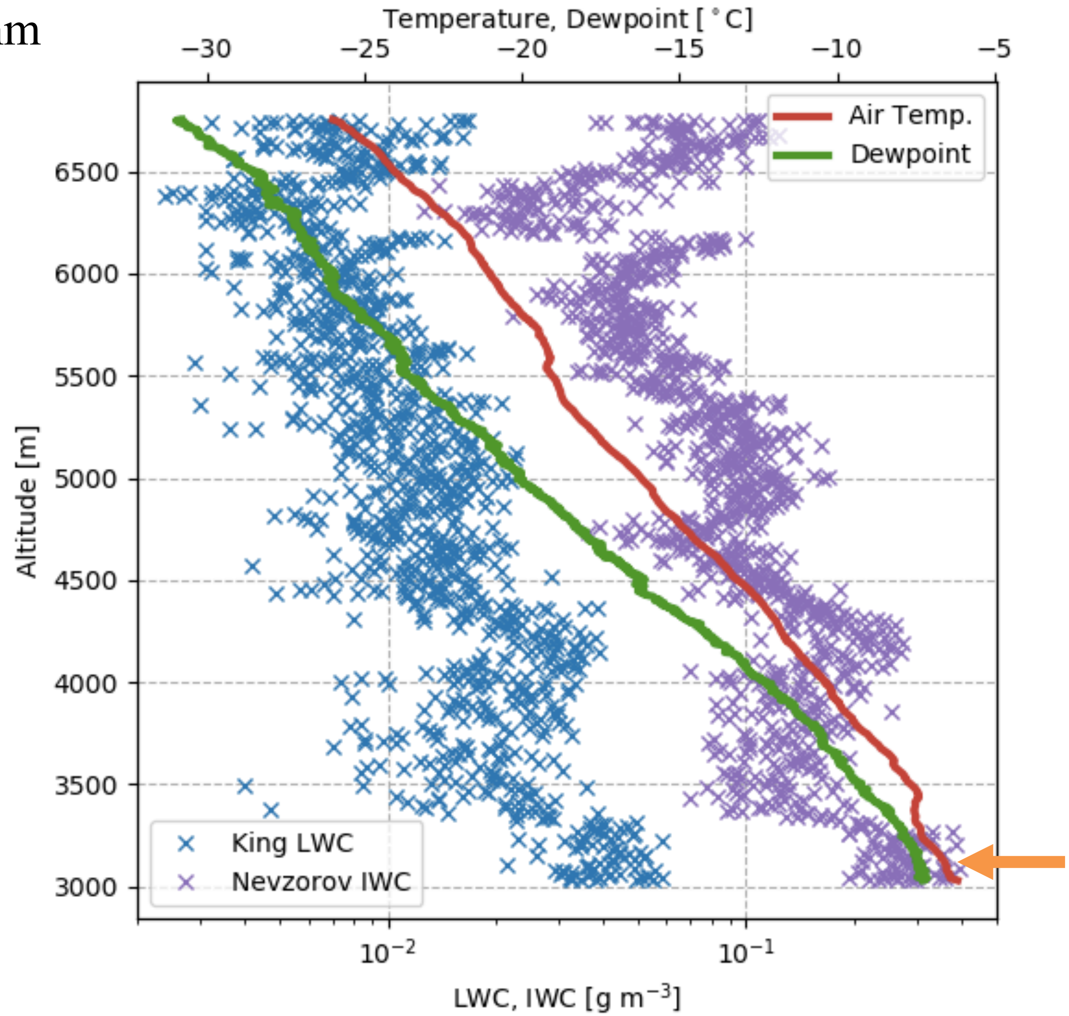




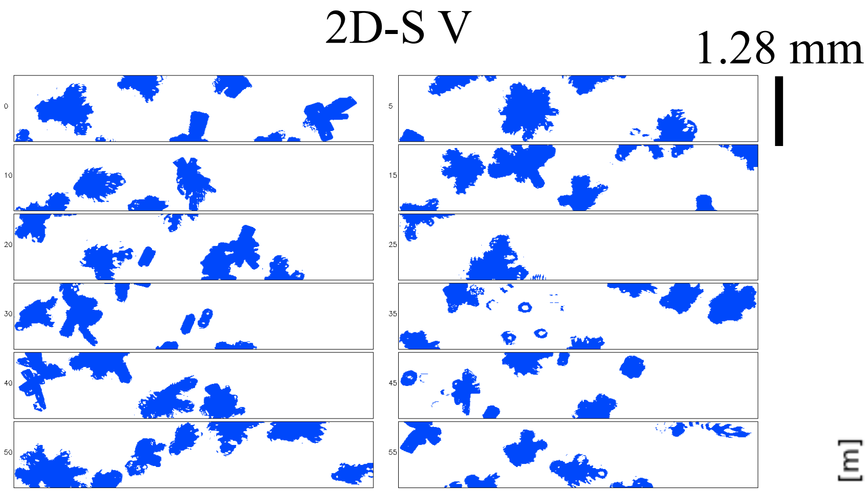
UND Citation Observations: 12 Nov. 2015

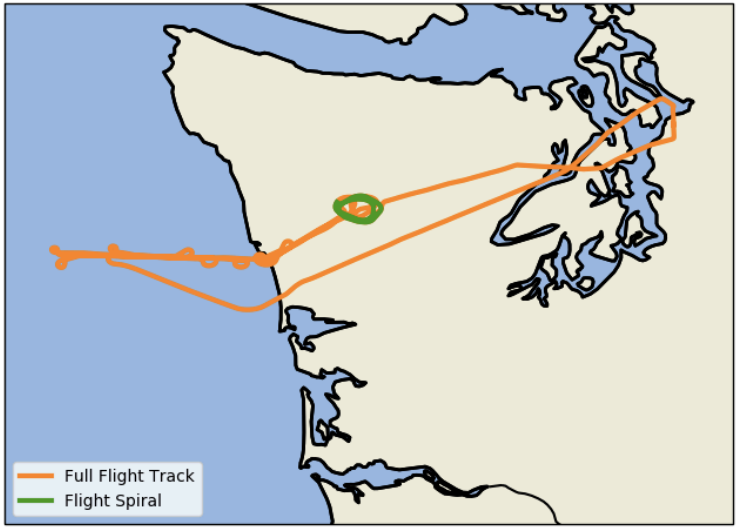


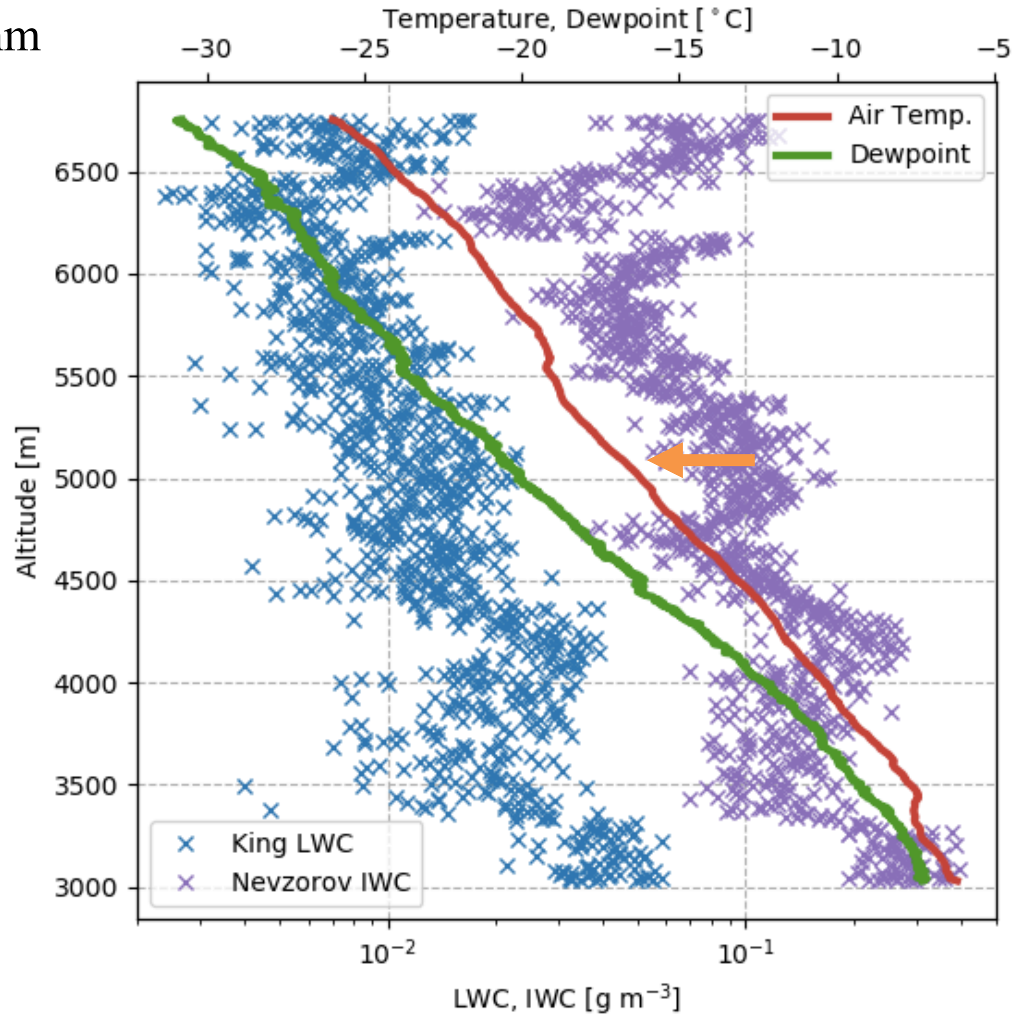




UND Citation Observations: 12 Nov. 2015



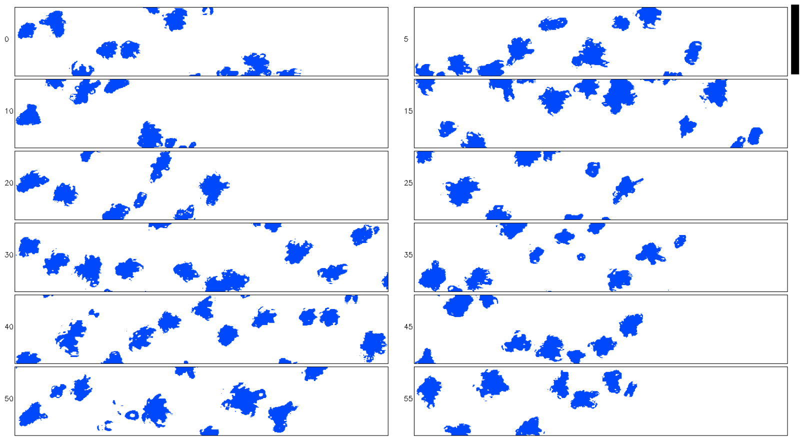


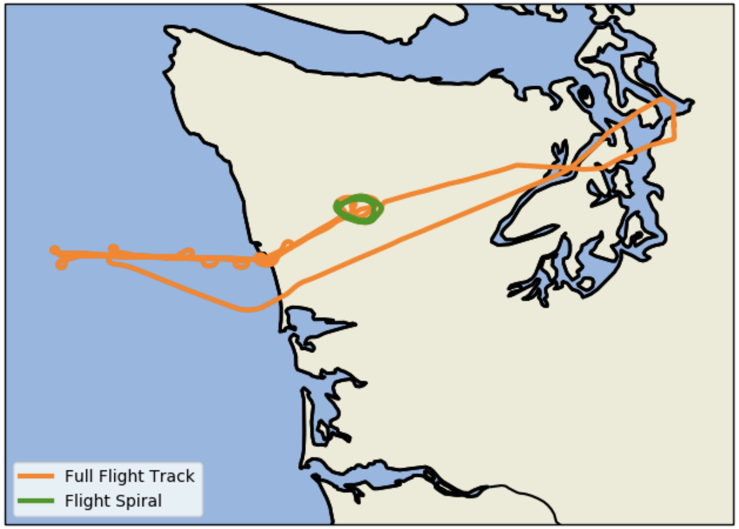


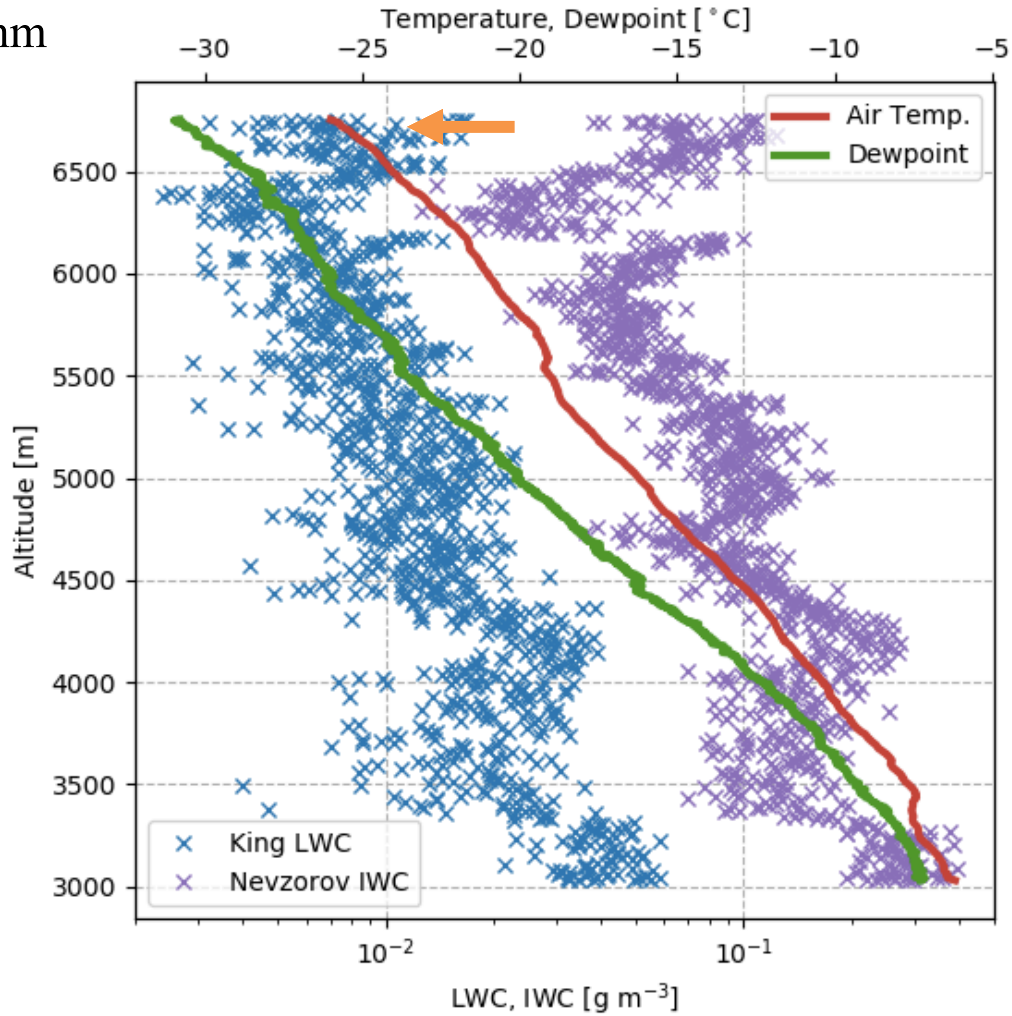
UND Citation Observations: 12 Nov. 2015

2D-S V

1.28 mm



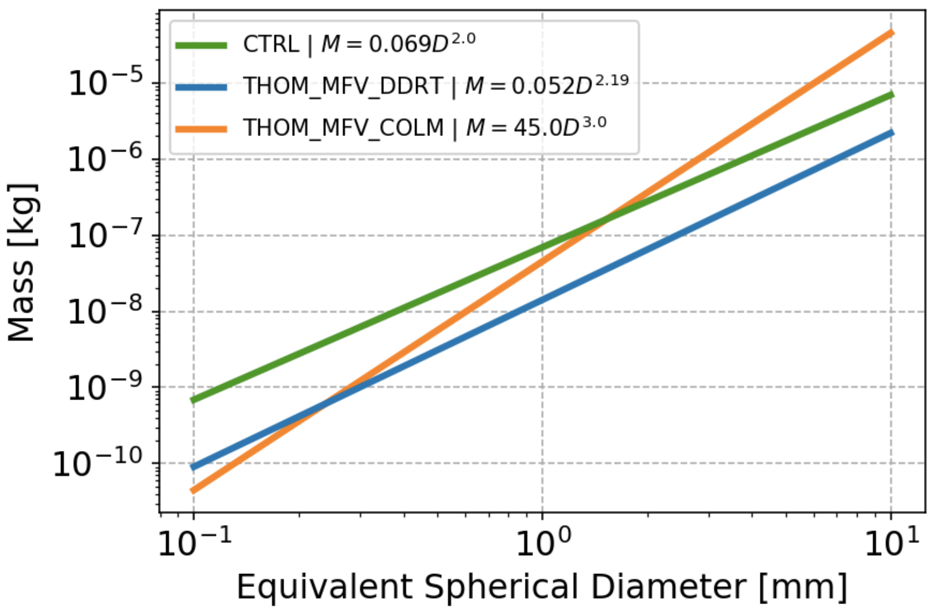




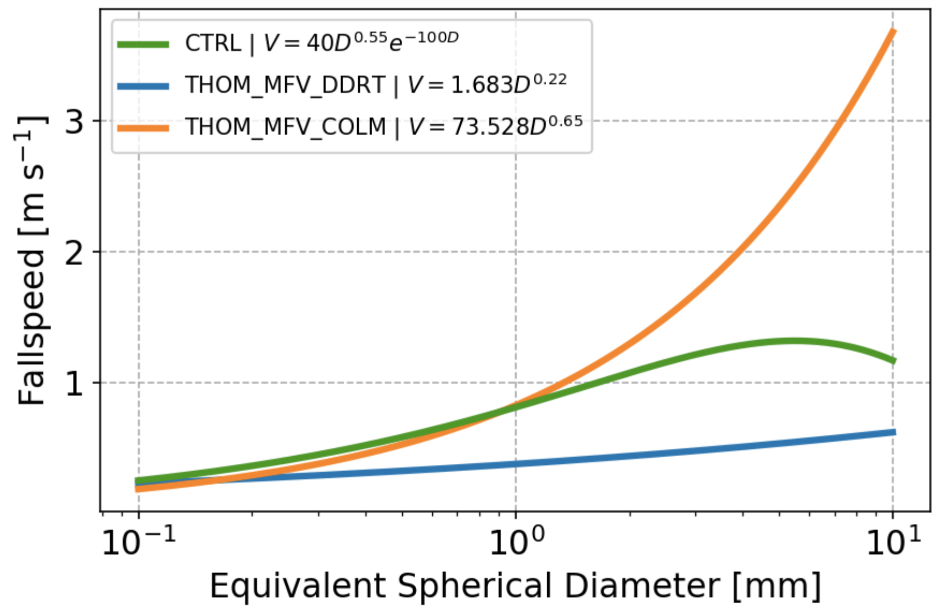
Snow Fallspeed- and Mass-Diameter Equations

- Simulating sensitivity of QPF to empirically-derived snow crystal habit properties (Woods et al. 2007)
- Coefficients (a_v, b_v, f_v, a_m, b_m) vary depending on the assumed crystal habit type (dendrites = DDRT, columns = COLM)

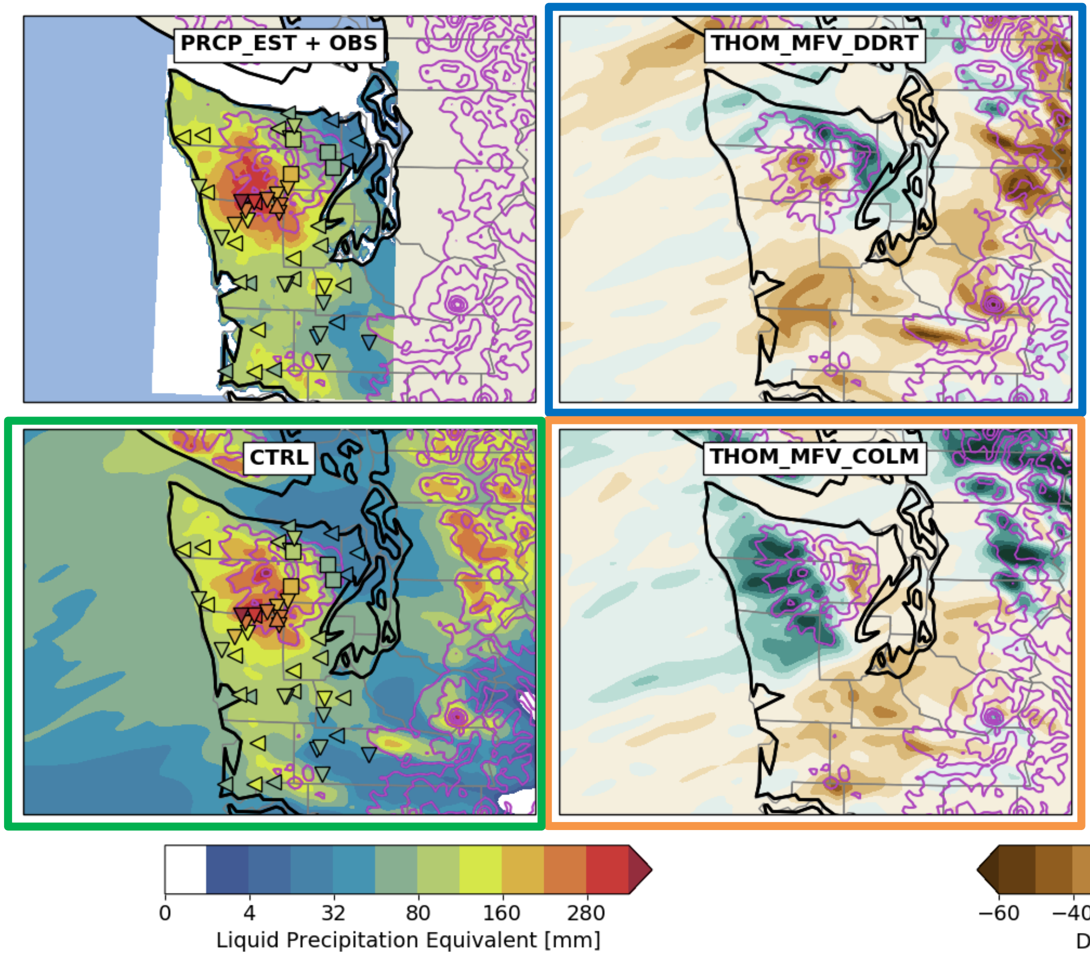
$$M = a_m D^{b_m}$$

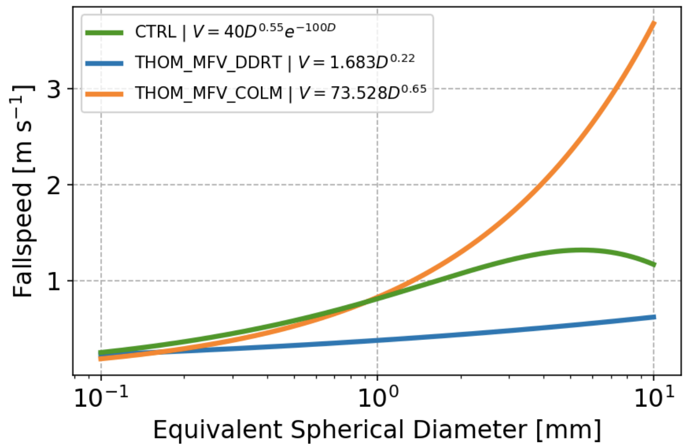


$$V = a_v D^{b_v} e^{-f_v D}$$



QPF Sensitivity to Crystal Habit

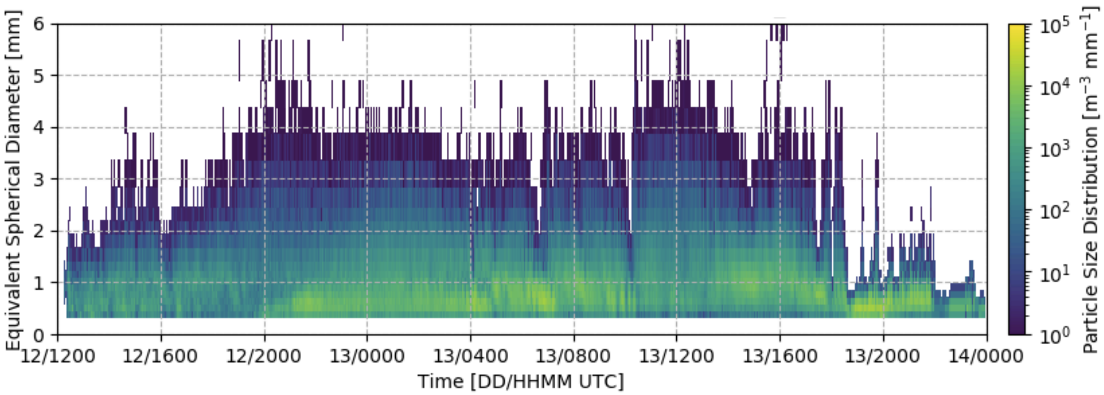




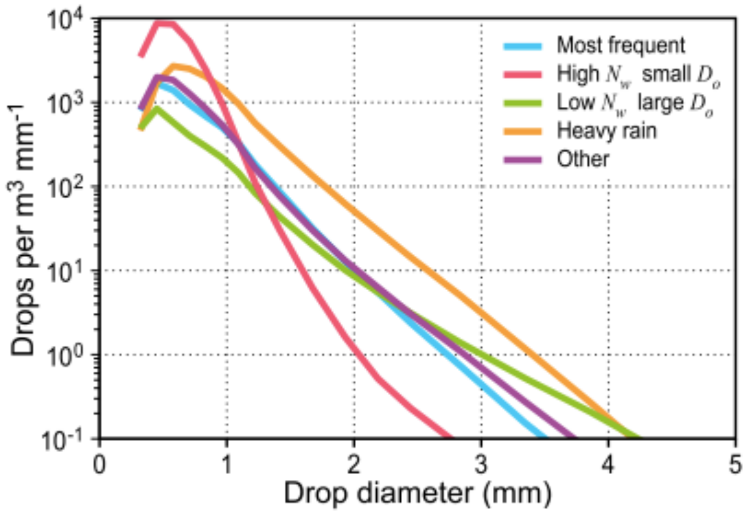
- Increased snow mass and fallspeed in COLM experiment reduces snow aloft, resulting in windward increase in QPF

SENSITIVITY TO RAIN DSD: OBS. AND EXPERIMENTS

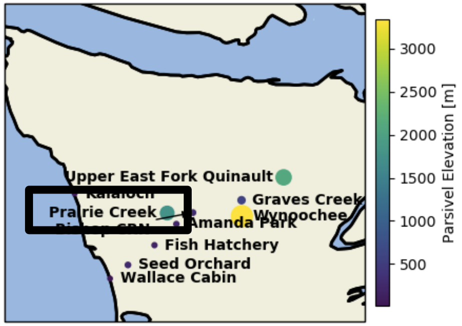
Rain DSD Observations from Parsivel Disdrometer



Prairie Creek Parsivel observations from 12-13 Nov. 2015 case study



Prairie Creek Parsivel observations from entire OLYMPEX campaign, by rain category (Zagrodnik et al. 2018)

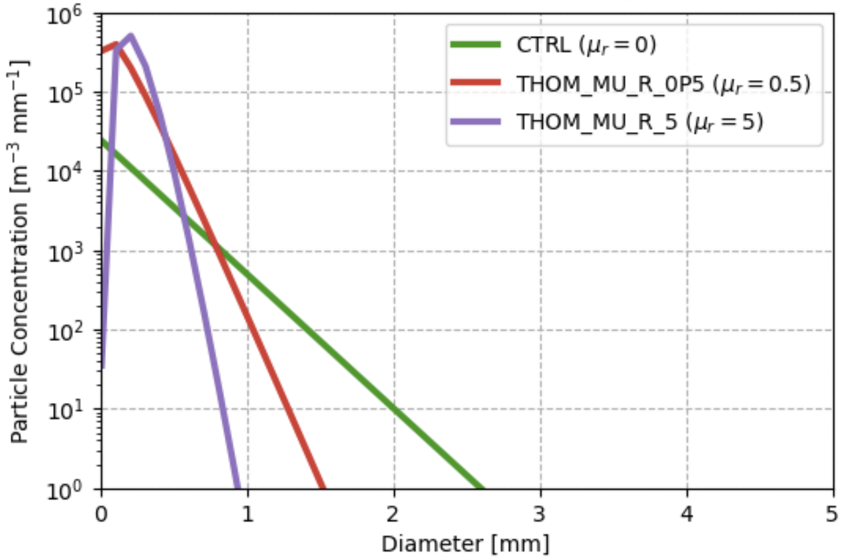


Parsivel disdrometer

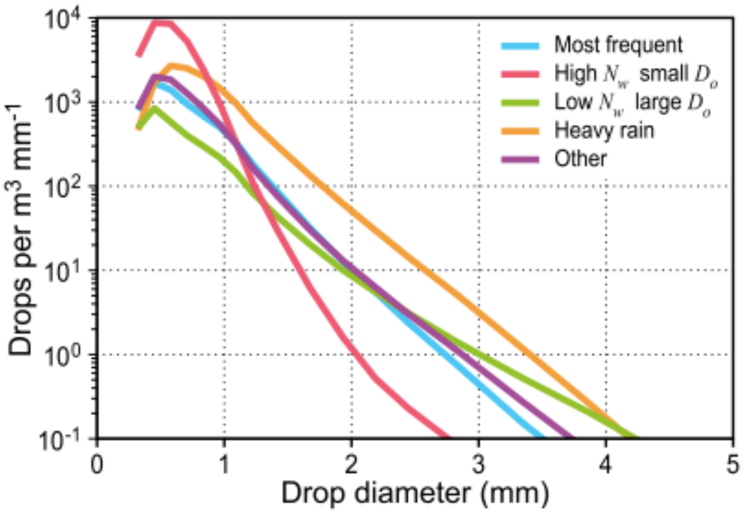
Rain DSD Equation

- Simulating sensitivity of QPF to rain DSD shape in THOM
- DSD is an exponential distribution if $\mu_r = 0$ (default, fixed value), otherwise a gamma distribution

$$N(D) = N_{0_r} D^{\mu_r} e^{-\lambda_r D}$$



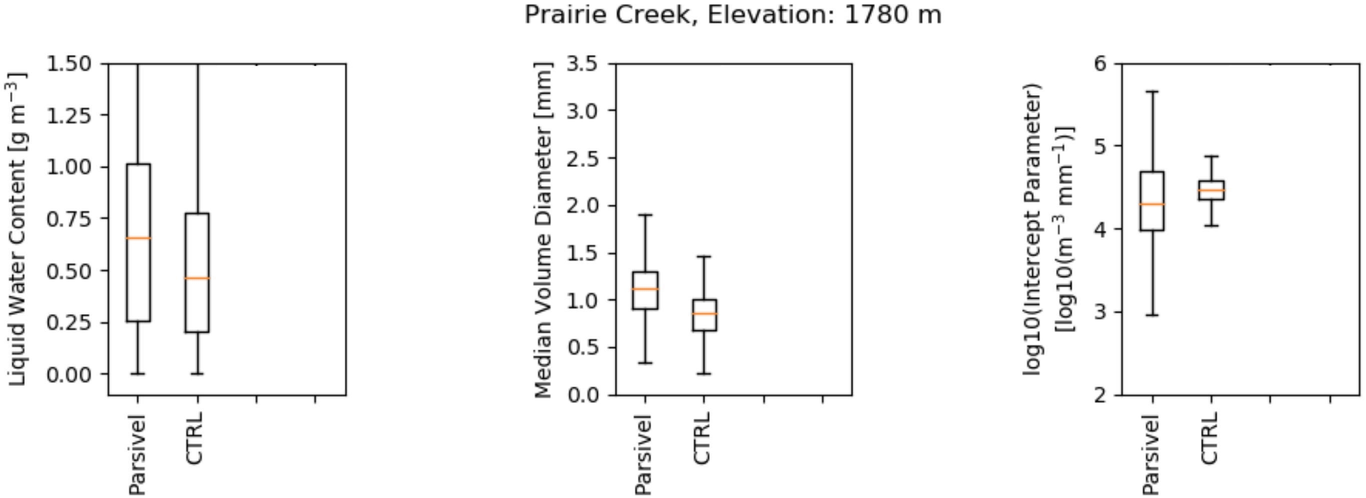
Model rain DSDs near Prairie Creek from several WRF experiments

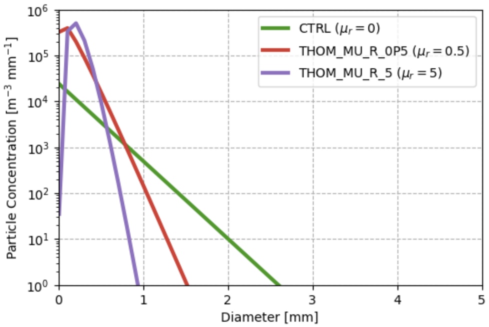


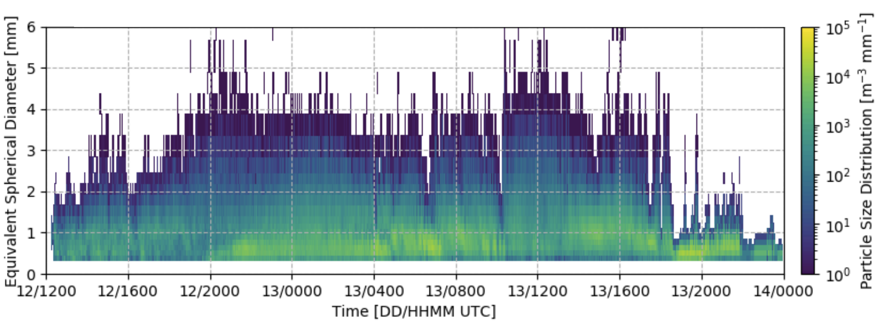
Prairie Creek Parsivel observations from entire OLYMPEX campaign, by rain category (Zagrodnik et al. 2018)

Comparing Parsivel and WRF Rain DSDs

Entire event: 1200 UTC 12 Nov. – 0000 UTC 14 Nov. 2015







- WRF calculations limited to observed size range from Parsivel (D > 0.25 mm)
- CTRL has too small median volume diameter and too little range of intercept parameter

Comparing Parsivel and WRF Rain DSDs

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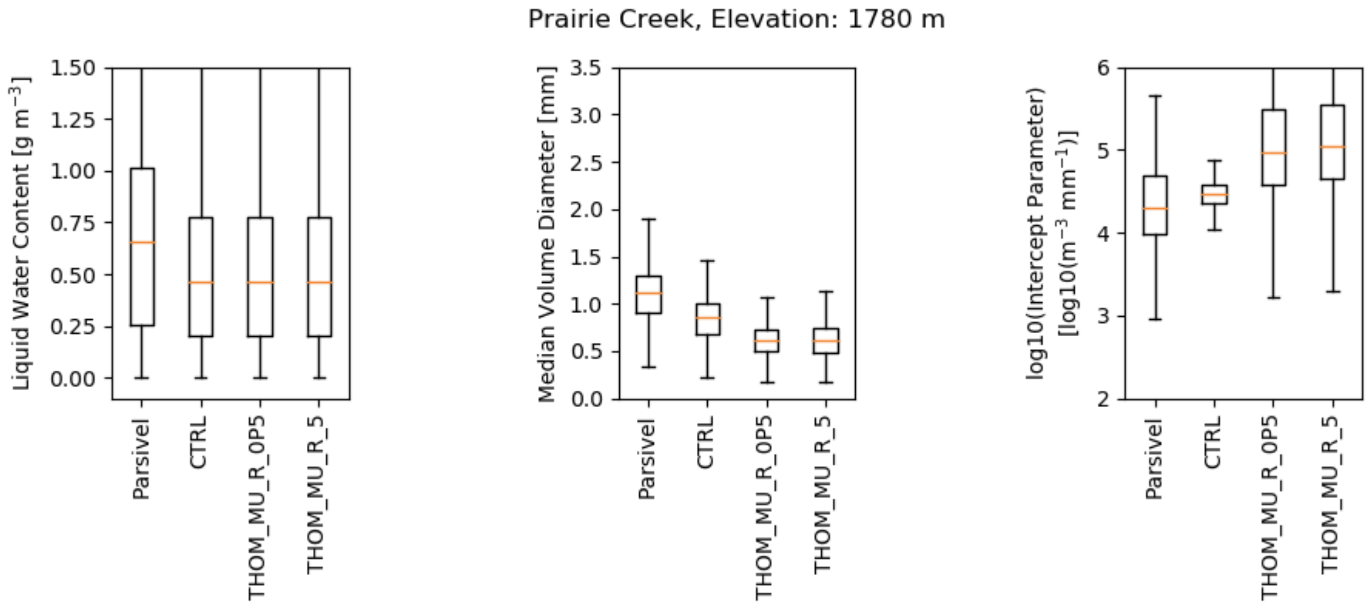
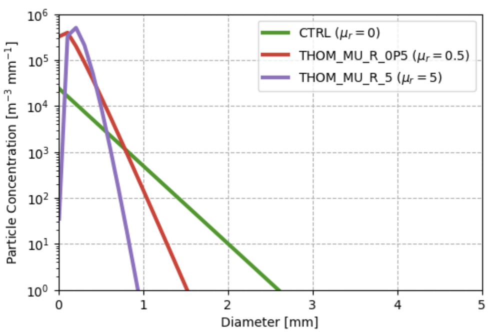
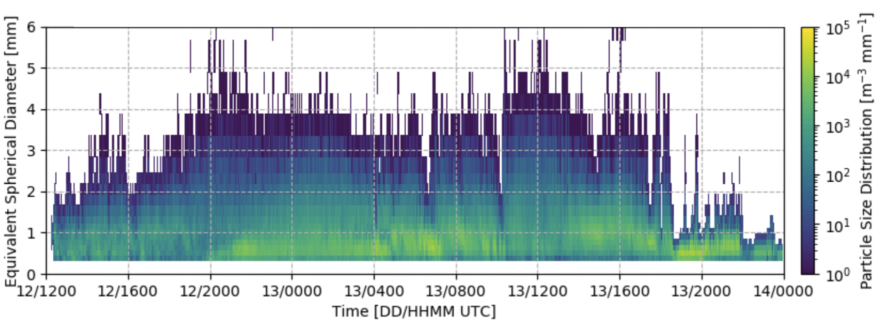
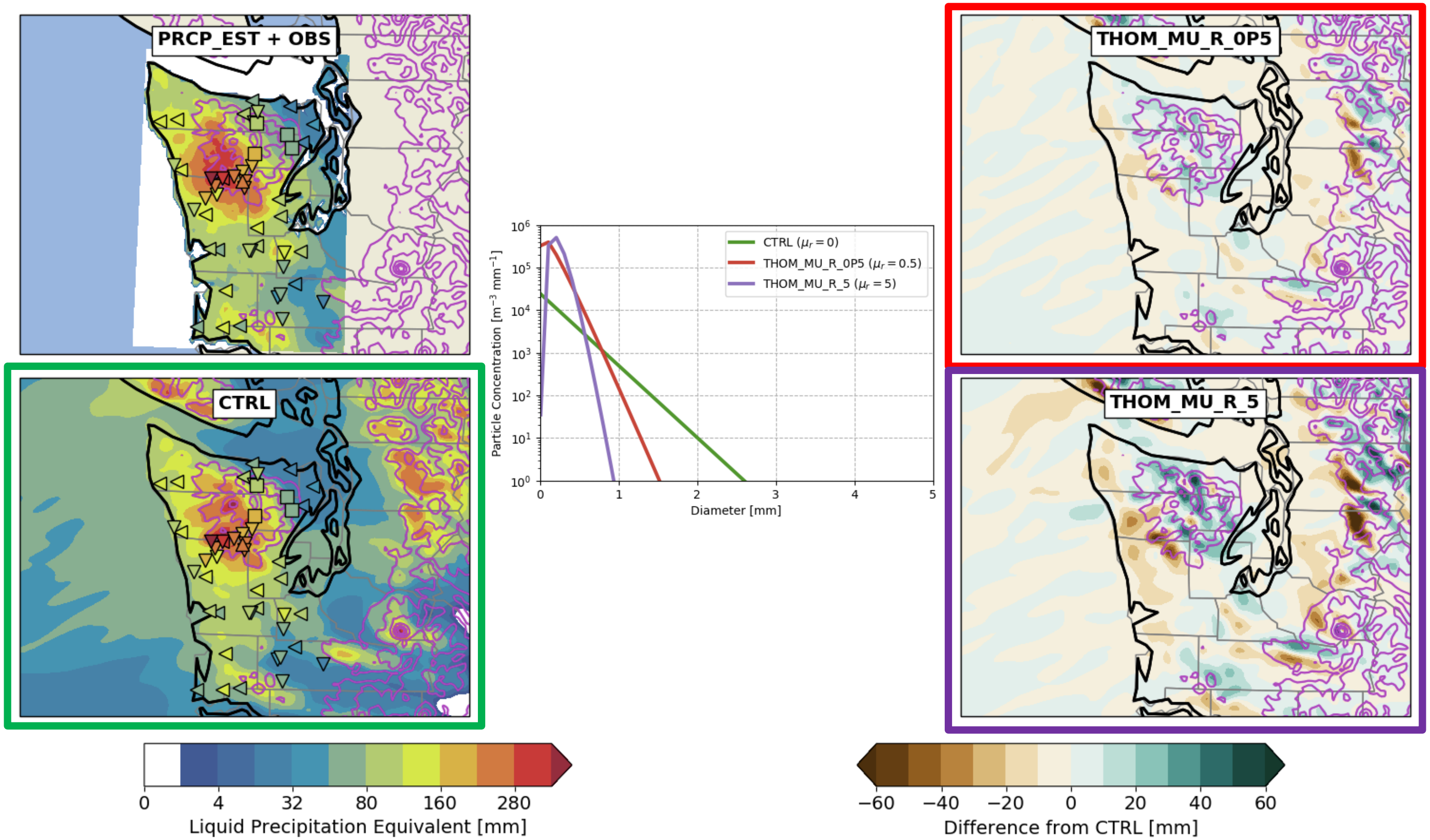






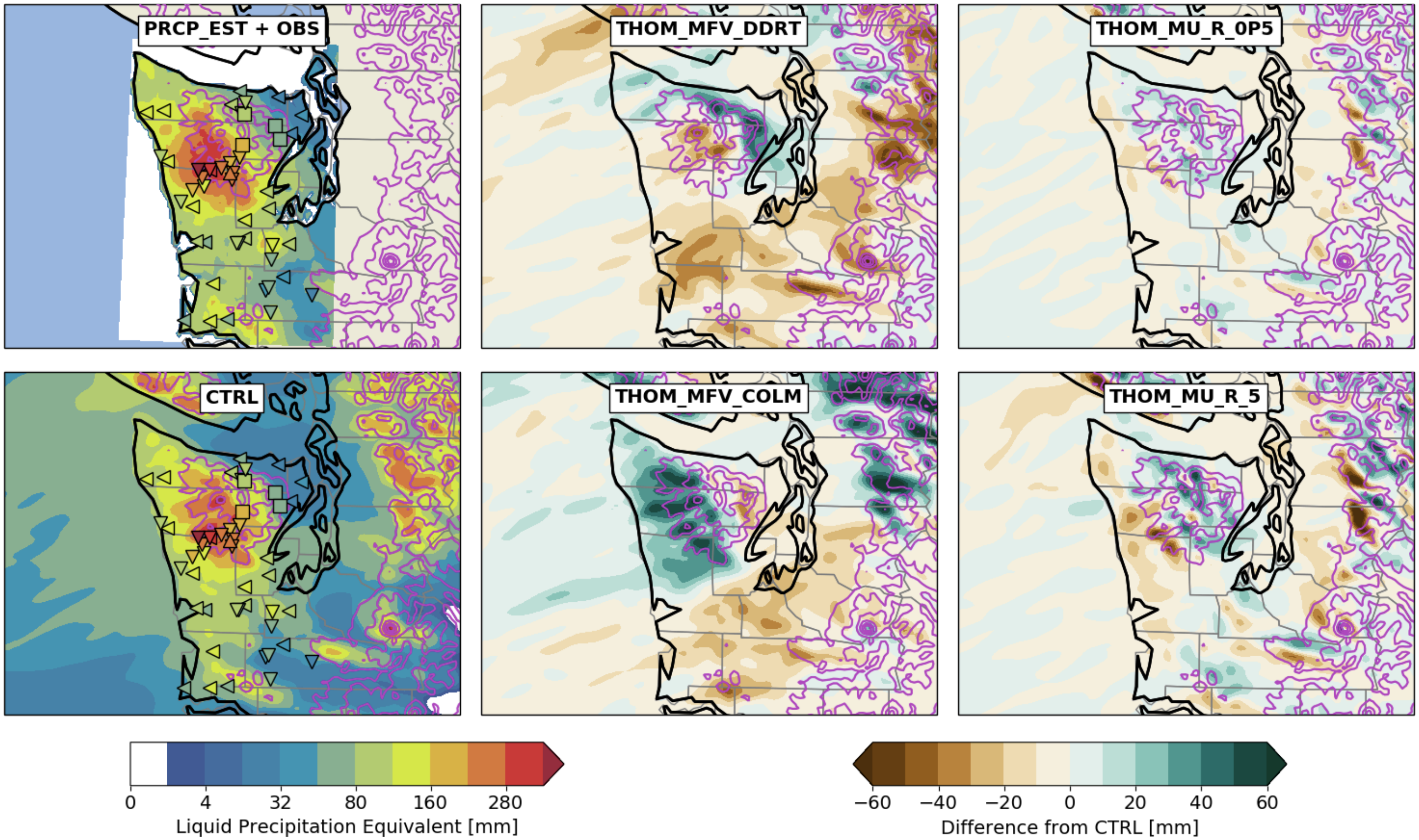
- WRF calculations limited to observed size range from Parsivel (D > 0.25 mm)
- CTRL has too small median volume diameter and too little range of intercept parameter
- Changing assumed DSD to gamma dist. in THOM causes increase in range of intercept parameter, but even smaller median volume diameter
- Thanks to R. Conrick for help with WRF DSD retrieval

QPF Sensitivity to Rain DSD



- For $\mu_r > 0$ experiments, reduction in rain median volume diameter (slower fallspeed) causes more displacement of rain into higher terrain

Overall QPF Sensitivity



Key takeaway: Need to represent uncertainty in processes that can't be described by single value, important to capture in design of next-generation ensemble model

Conclusions

- **Presentation goal:** Use OLYMPEX data from a single case study (12–13 Nov. 2015) to constrain uncertain MP scheme parameters in high-res. numerical forecasts of orographic precip. using a HRRR-like model setup
  - **Q1:** Evaluation of Thompson-Eidhammer MP forecast (CTRL)?
    - Accurate timing of frontal and orographic precip. features
    - Good overall QPF, but windward QPF biased low relative to gauge observations
  - **Q2:** Sensitivity of QPF distribution to assumed crystal habit?
    - Numerous habits observed in UND Citation imagery
    - Habit sensitivity has strong orographic signal, impacting cold rain processes
  - **Q3:** Sensitivity of QPF distribution to rain DSD?
    - Variety of rain DSD shapes observed by Parsivel disdrometers
    - Rain DSD shape sensitivity has moderate windward/peak signal, impacting warm rain processes
  - **Future work:** Implementing SPP into Thompson-Eidhammer MP scheme, testing additional parameters, and running stochastic ensemble experiments for this case and entire OLYMPEX period