Does WRF have a warm rain problem?

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2021 WRF/MPAS Users' Workshop

Microphysics schemes have increased in complexity…

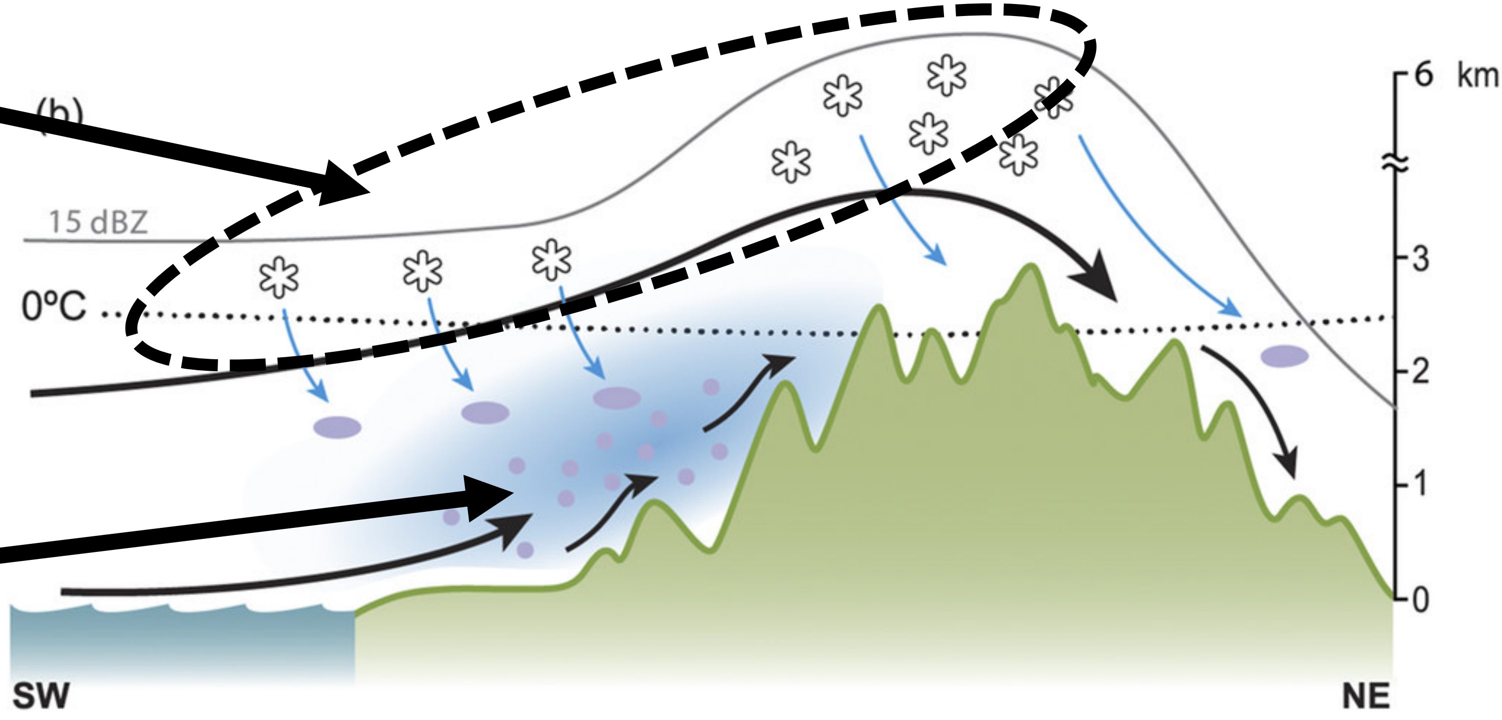
... but have these changes helped improve warm rain?

Improving microphysics

- After past field campaigns like IMPROVE (2001), we had quality in situ measurements of ice-phase hydrometeors aloft *for the first time*.

We used this data…

…to improve precipitation forecasts here.

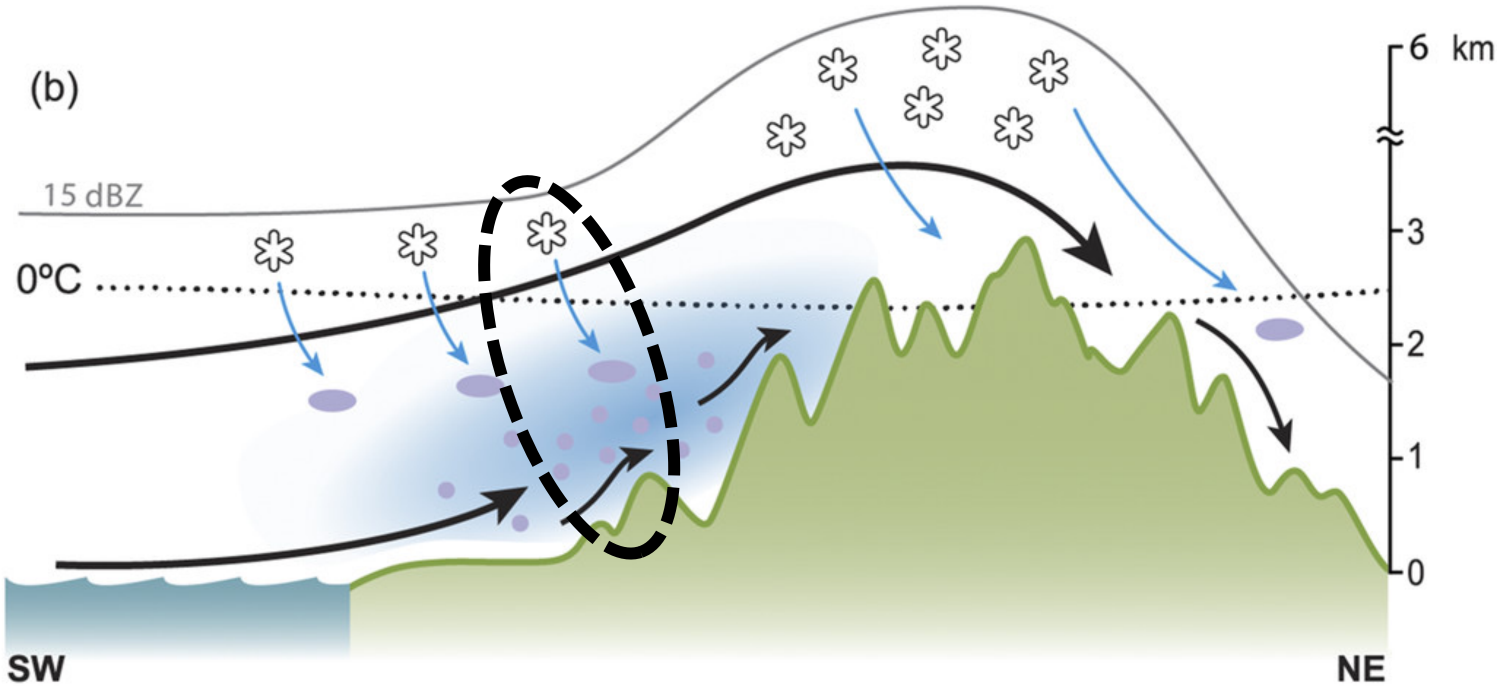


Zagrodnik et al. 2021

Improvements have been made.

- Focusing on ice-phase processes has been instrumental in understanding and simulating moist physics, including many new parameterizations.

A few examples:
Lin and Colle (2011)
Thompson et al. (2004,2008)
Milbrandt et al. (2008, 2010)
Morrison et al. (2009)
Morrison and Milbrandt (2015)
Lim and Hong (2010)
Bae et al. (2018)
Jensen et al. (2017)



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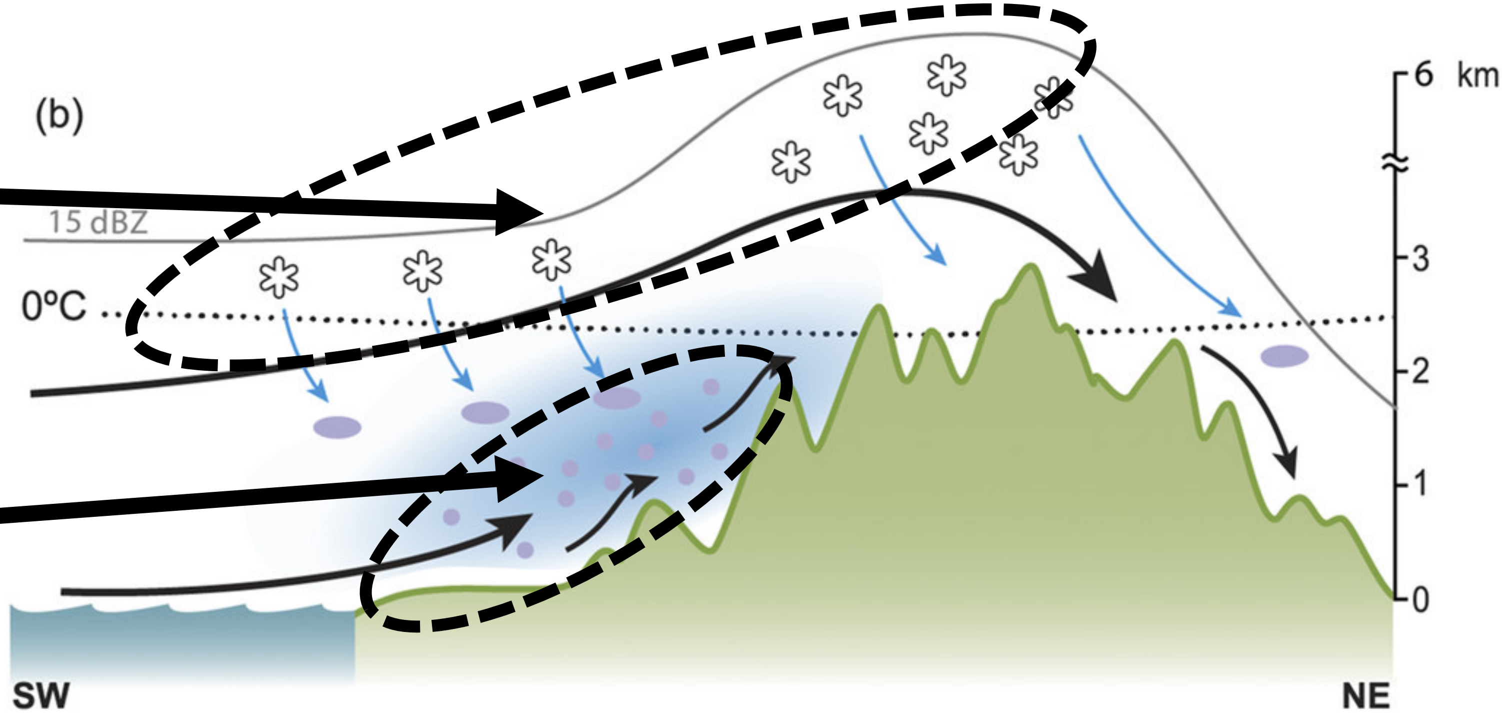
Still looking aloft…

- Now, we have quality low-level microphysical data (from OLYMPEX, 2015)…

  … but we're *still* looking for answers aloft.

Still looking here

…to improve forecasts here.

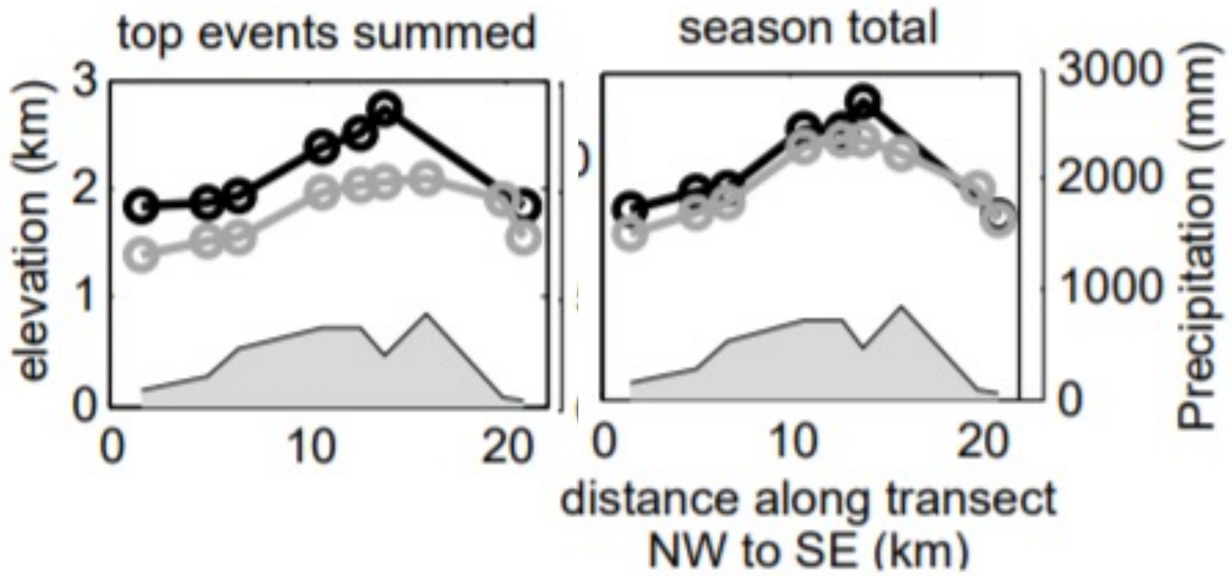


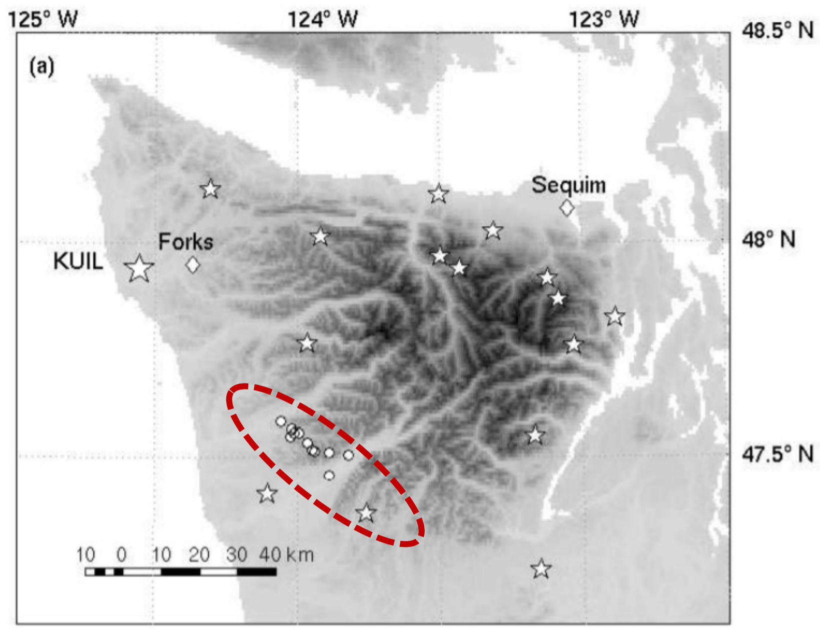
Zagrodnik et al. 2021

Have we ignored warm rain?

Have we ignored warm rain physics?

- As far back as the late 90’s *(MM5, anyone?)*, warm rain problems were apparent *(Colle et al. 1999, Colle and Mass 2000, Garvert et al. 2005)*
- Also using MM5, Minder et al. (2008) found a general underprediction of precipitation during water year 2005.





Have we ignored warm rain physics?

- Several other studies found similar problems with WRF microphysics; some examples:

Lin and Colle (2009)	[1,2] underprediction, windward slopes of Oregon Cascades.
Lin et al. (2013)	[1,3] underprediction, west coast.
Song and Sohn (2018)	[1,2] underprediction, South Korea.
Darby et al. (2019)	[1,3] underprediction, west coast.
Naeger et al. (2020)	[1,2] underprediction, Washington coast.

Multiple WRF versions and many different microphysics schemes.

Similarities:

[1] Coastal regions

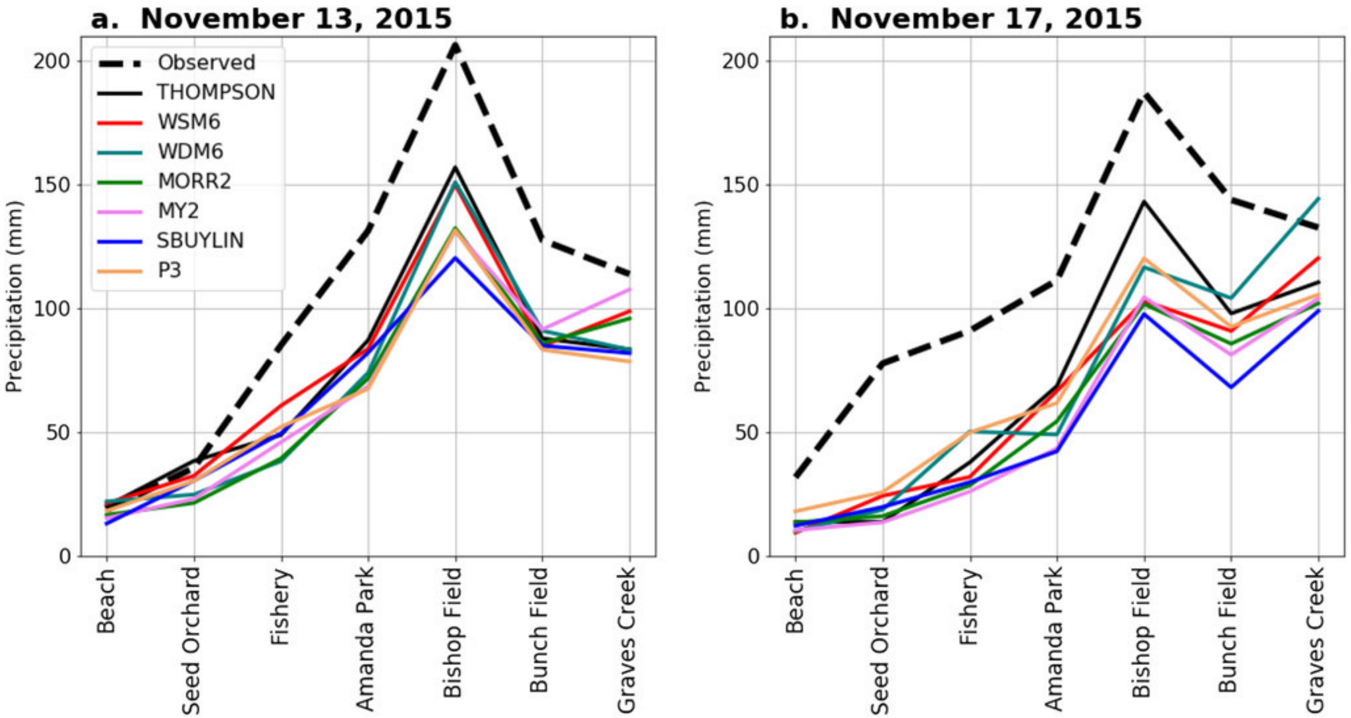
[2] Warm, atmospheric-river type storms.

[3] Long-term studies

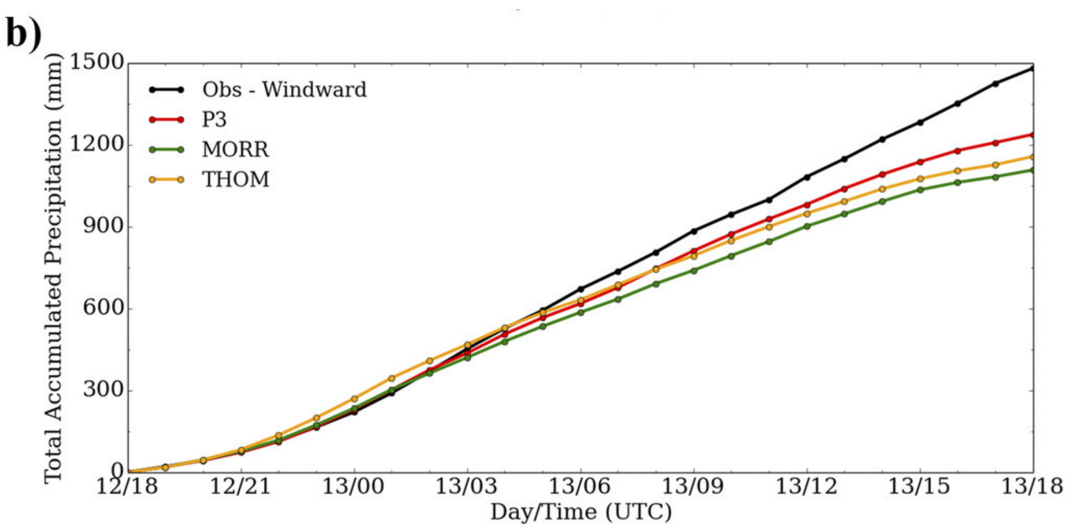
Recent evaluations

- Conrick and Mass (2019a,b) and Naeger et al. (2020) both showed that modern microphysics schemes still underpredict precipitation.
  (WRF v.3.7.1, v.3.8.1 … and still true with v.4.1.3)

Conrick and Mass (2019a): Two atmospheric river events in Washington State (2015)

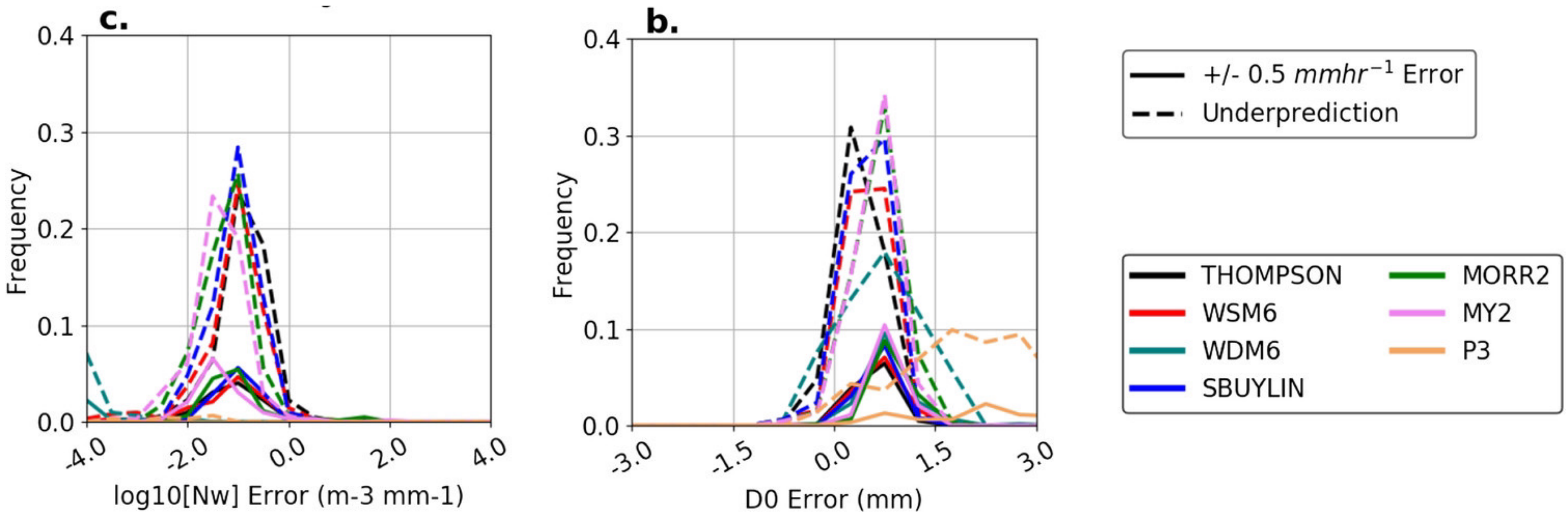


Naeger et al. (2020): An atmospheric river event in Washington State (2015)



Recent evaluations

- We also showed that WRF rain drop sizes are too large and too few compared to observations (Conrick and Mass 2019a) during events with warm rain enhancement.
    - More characteristic of cold rain.
    - No scheme dependence.



Back to basics

- The underprediction of precipitation and poor rain drop size / number representation is **scheme agnostic**.

  <u>Is there a common model deficiency?</u>

Most schemes use different formulae for warm rain processes.

Some schemes contain completely different processes than others.

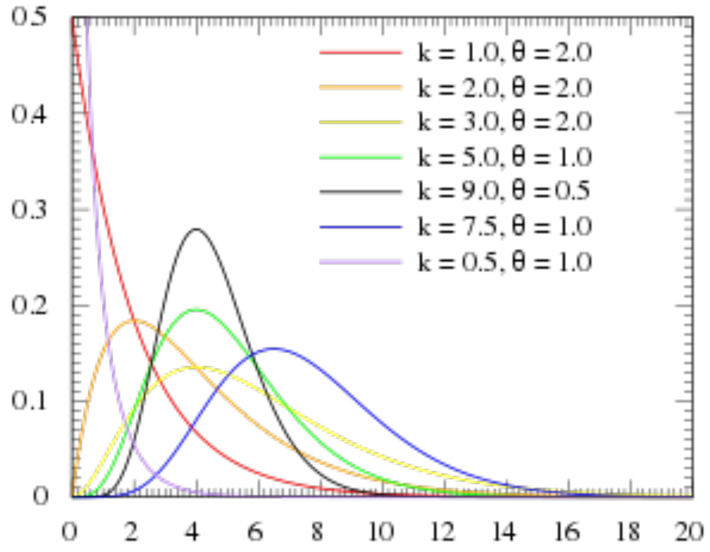
Different hydrometeor conversion thresholds, densities, etc.

Unlikely that these differences are to blame for a common bias.

Back to basics

But **all** bulk schemes use the same assumed size distributions.

Exponential for rain; gamma for cloud.



- Many studies have shown that exponential distributions are accurate representations of rain water distributions.
- But cloud water distributions are not easily nor commonly measured, especially near the surface.
- No OLYMPEX or IMPROVE observations of cloud water distributions in warm rain.

Let's focus on cloud water…

Our alternative:

- Run a spectral bin microphysics scheme and see what the cloud water distribution looks like during warm rain.

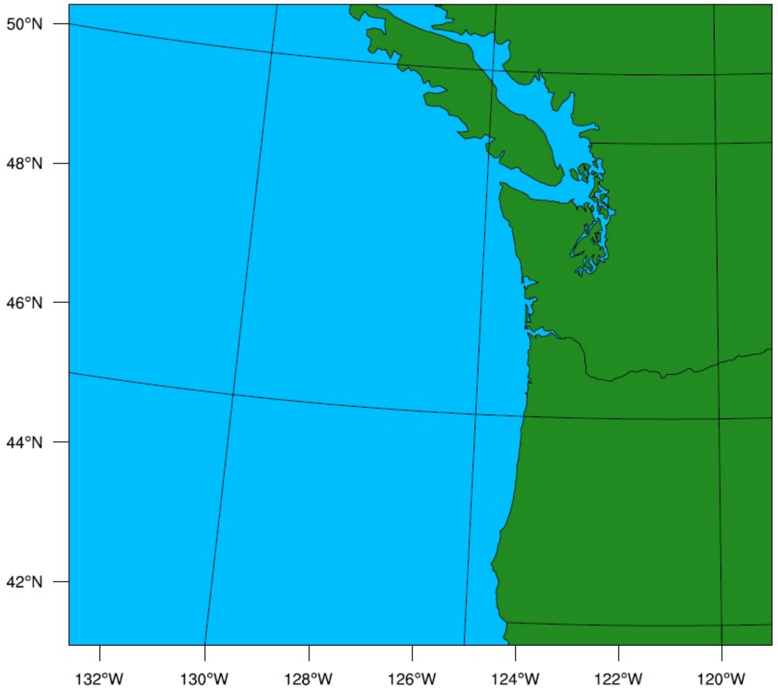
WRF Configuration:

v.4.2.2, HUJI SBM Microphysics (warm-only; Shpund et al. 2019).

YSU PBL, RRTMG Radiation.

Single, 4 km domain with 51 vertical levels.

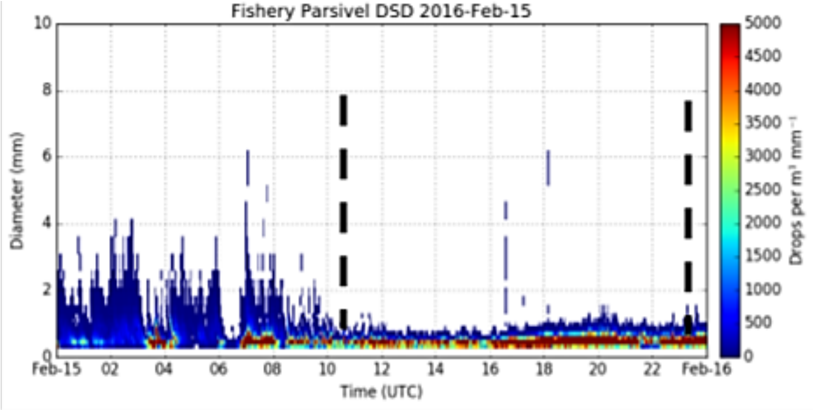
<ins>Control run</ins>: WRF v.4.1.3, Thompson-Eidhammer MP; warm-only.

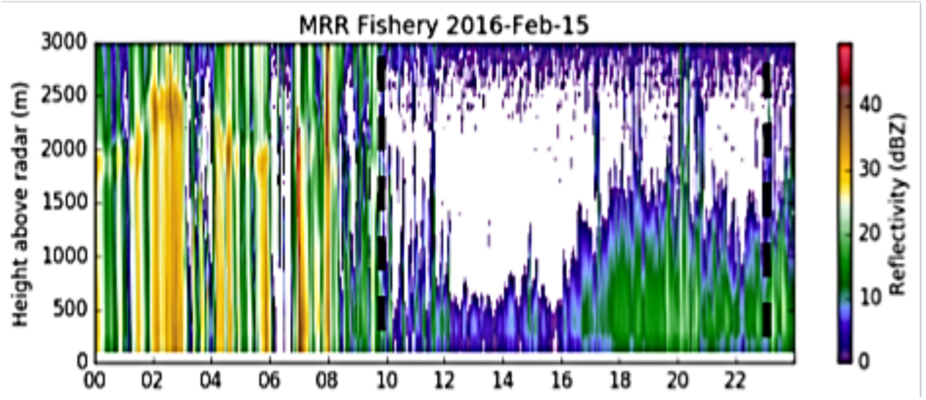


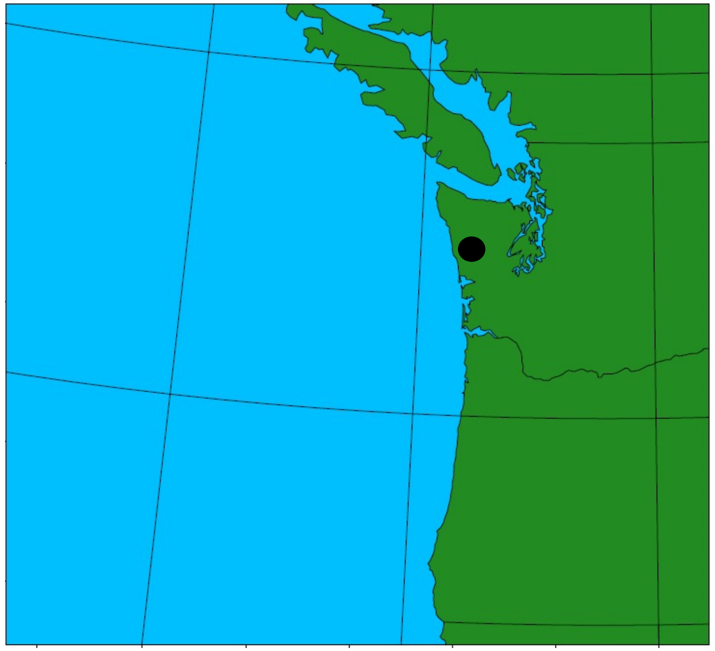
15 February 2016

Most OLYMPEX observing assets were removed in January, but a few remained.

- MRR, PARSIVELs, and rain gauges.



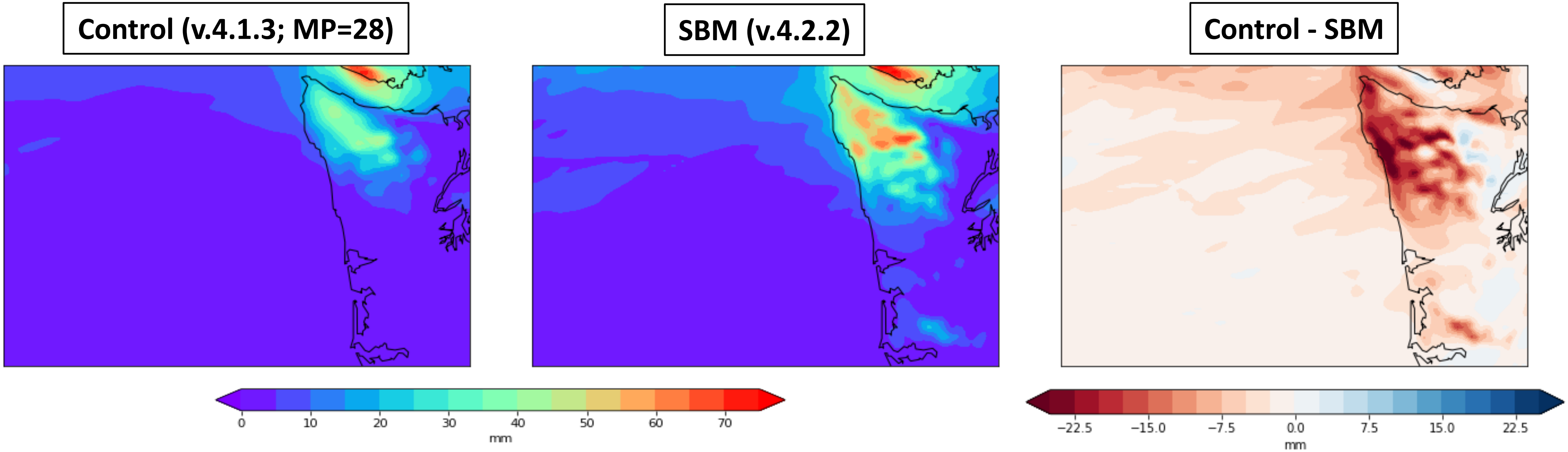




Cold rain early (before 10 UTC), then warm rain until 23 UTC.

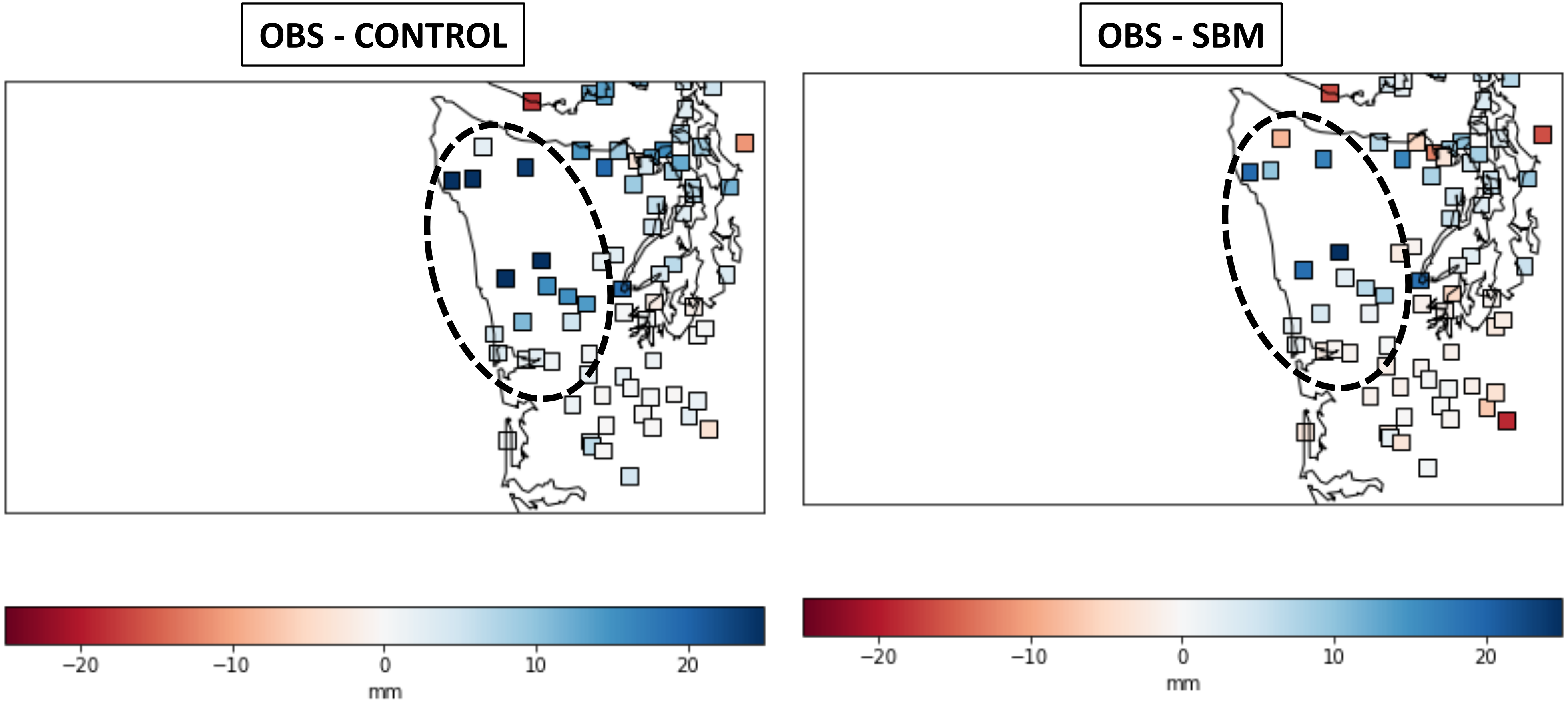
Warm-Period Precipitation

- Compared to the control, significantly more precipitation falls near the coast in SBM.



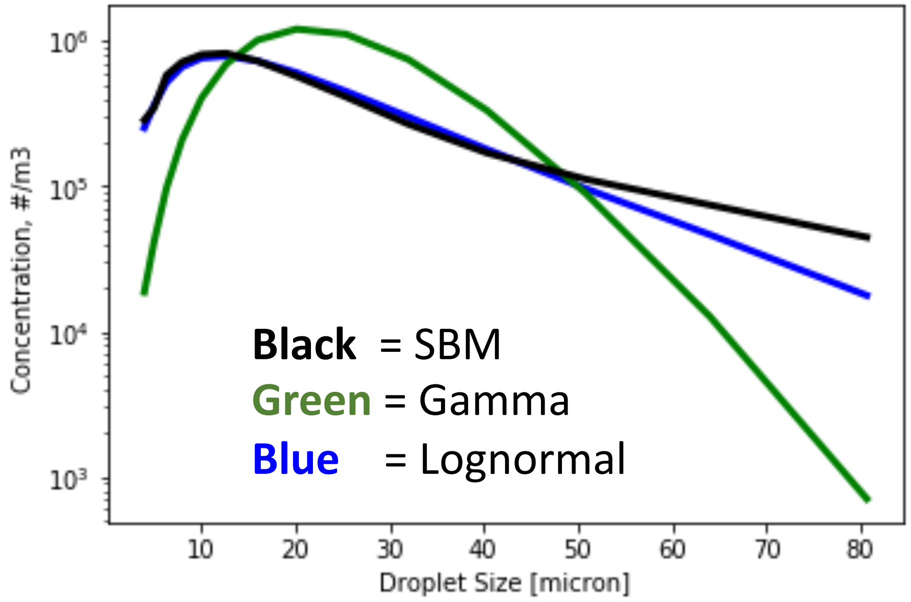
Warm-Period Precipitation

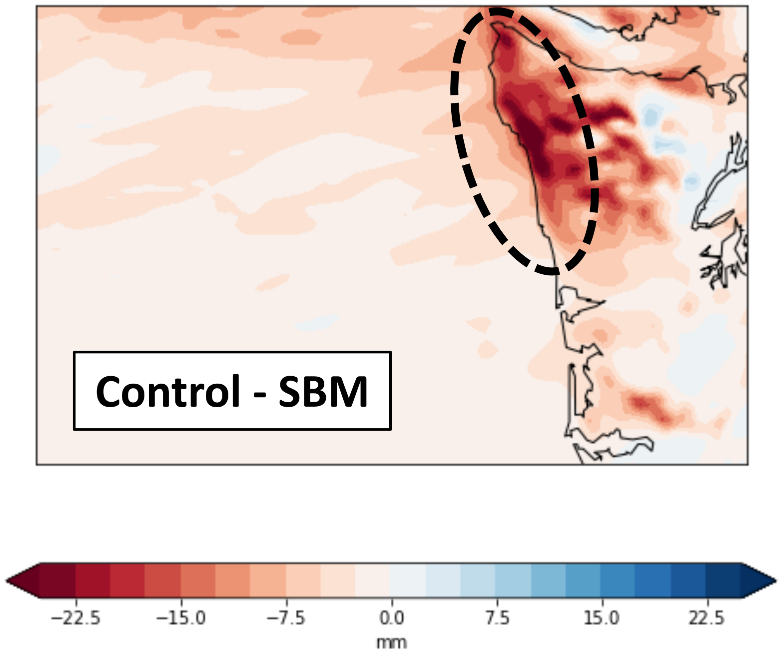
- Better agreement between observed and simulated precipitation, especially near the coast. Reduced underprediction.



Why?

- The SBM scheme tends to distribute cloud water lognormally during warm rain.

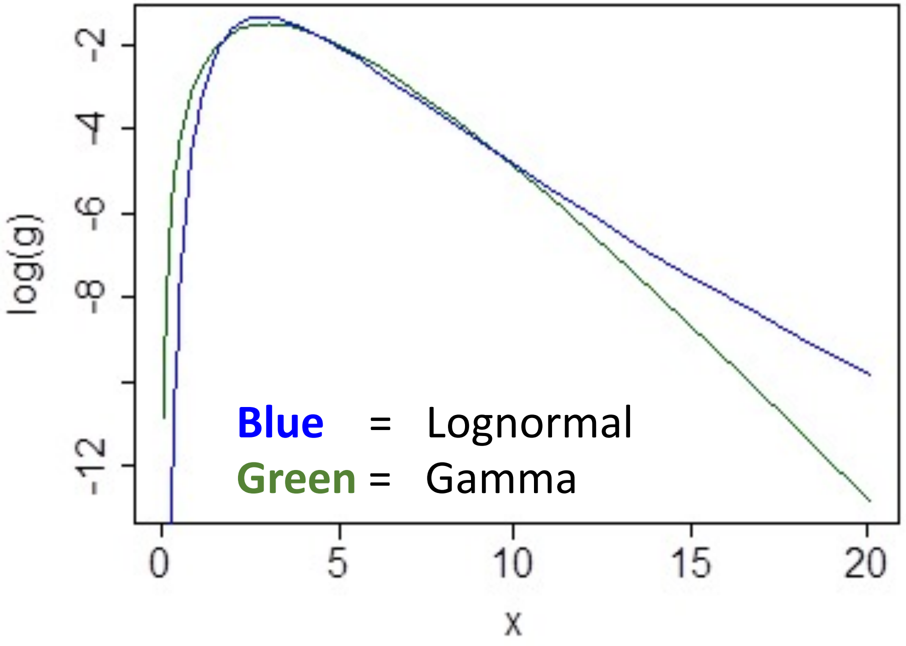




Why does it matter?

- Lognormal distributions have a longer 'tail' toward larger drop sizes compared to gamma distributions.

- <u>Result</u>:
  - More large droplets.
  - Enhanced warm rain processes.



Lognormal cloud water distribution added into the Thompson-Eidhammer microphysics scheme.

WRF Changes

- Two parameters in the lognormal distribution:
  - D_N is the median diameter.
  - σ is the width of the distribution.
    (Happy to discuss this one later)
- Replaced all droplet size, number, and mass calculations with their lognormal equivalents.
- Changed Berry-Reinhardt autoconversion characteristic diameters (Nickerson et al. 1986).
  - Secondary change: Adjusted rain number autoconversion.

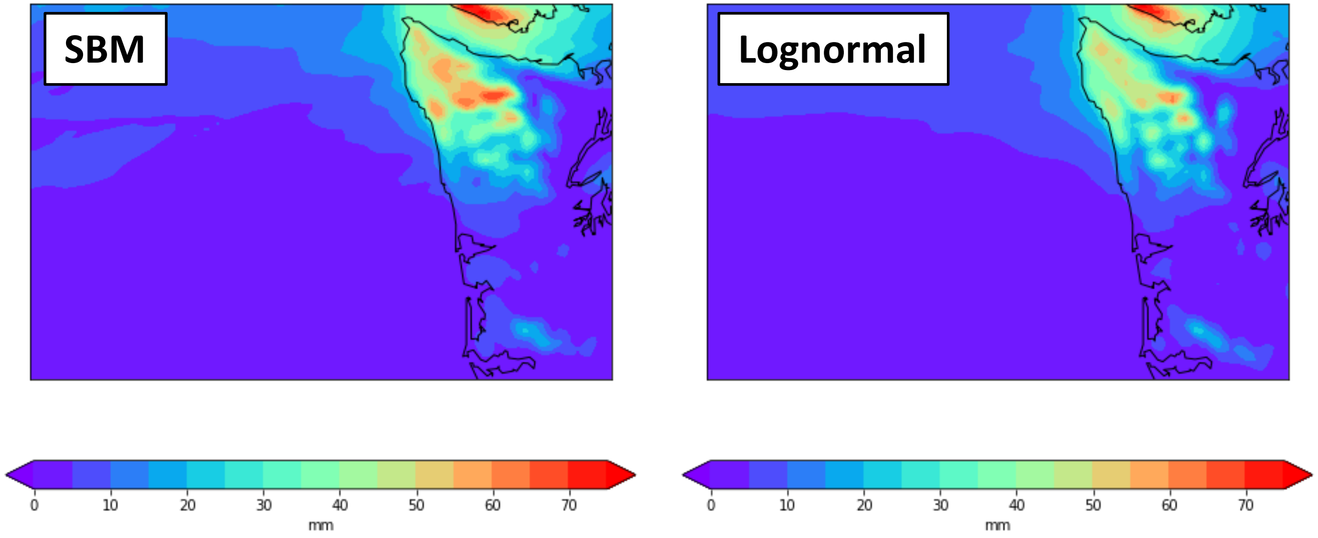
$$\mathrm{N(D)} = \frac{\mathrm{N_T}}{\sqrt{2\pi}\,\mathrm{D}\,\mathbf{ln\sigma}} \exp\left[-\frac{1}{2}\left(\frac{\ln(\frac{\mathrm{D}}{\mathbf{D_N}})}{\mathbf{ln\sigma}}\right)^2\right]$$

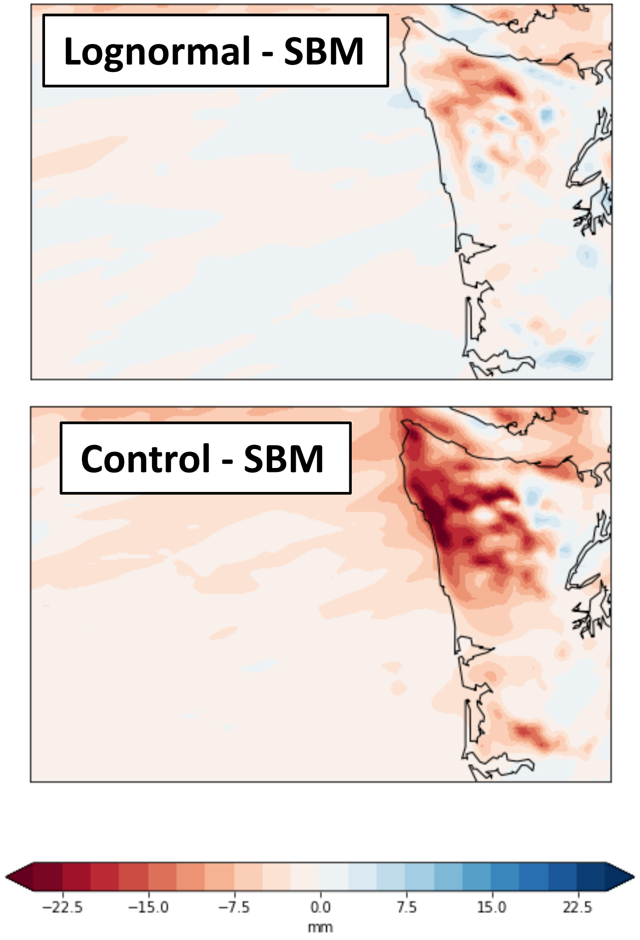
$$\mathrm{D_N} = \left(\frac{6\mathrm{Q_C}}{\pi \mathrm{N_T} \rho}\right)^{\frac{1}{3}} \exp(-1.5\sigma^2)$$

$$MVD_C = D_N \exp(3\sigma^2)$$

Results

Bin scheme precipitation at a bulk scheme cost!



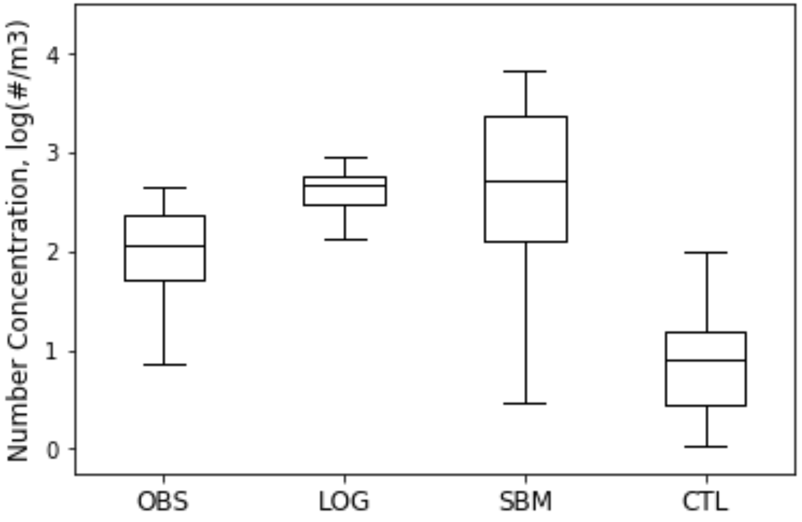


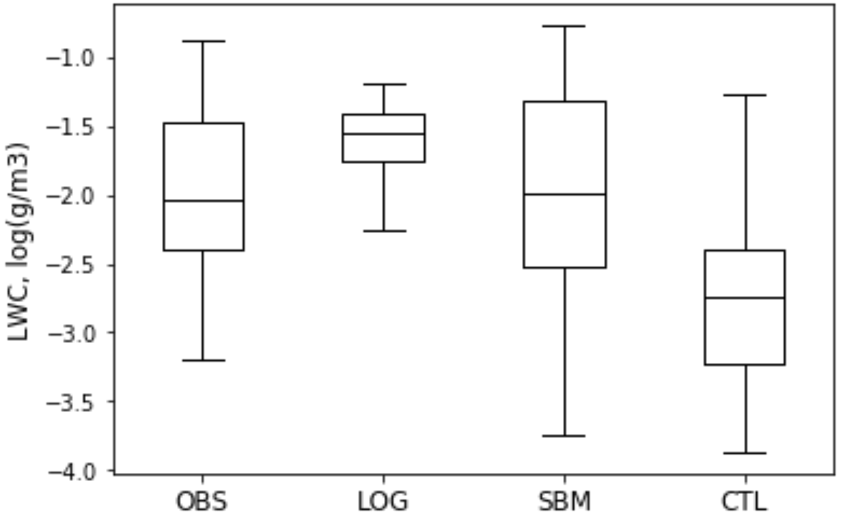
Reduction in underprediction along the coast and over windward slopes during 15 February 2016.

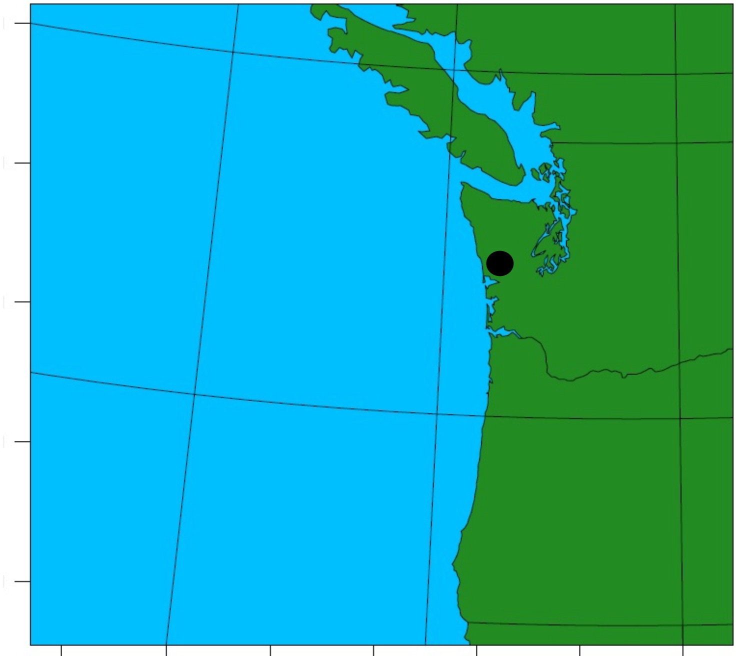
Similar results when ice physics are enabled.

Surface Microphysics

- Lognormal and SBM runs have better number concentrations and LWC than the control.



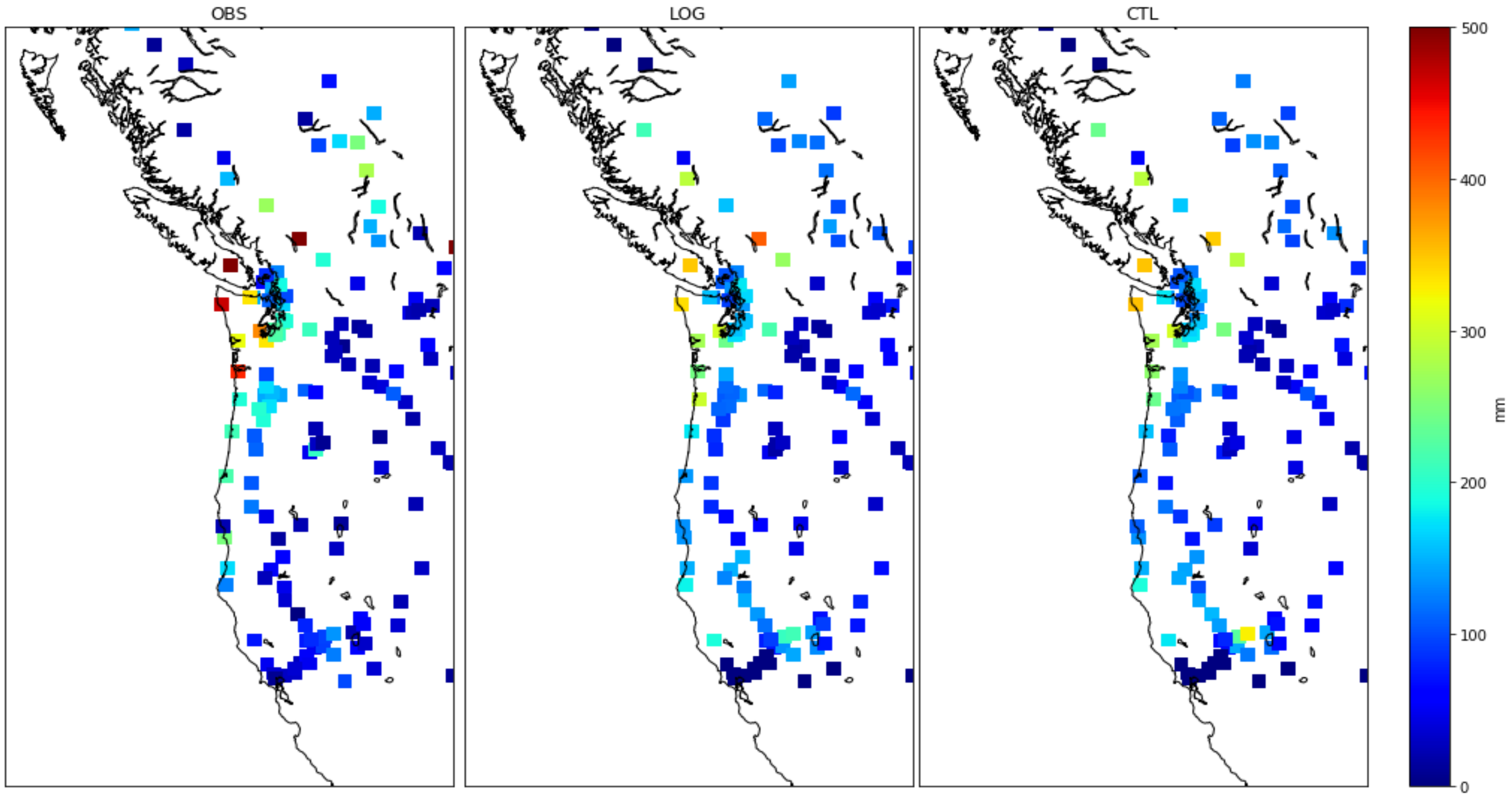




Long-term evaluations *(in progress)*

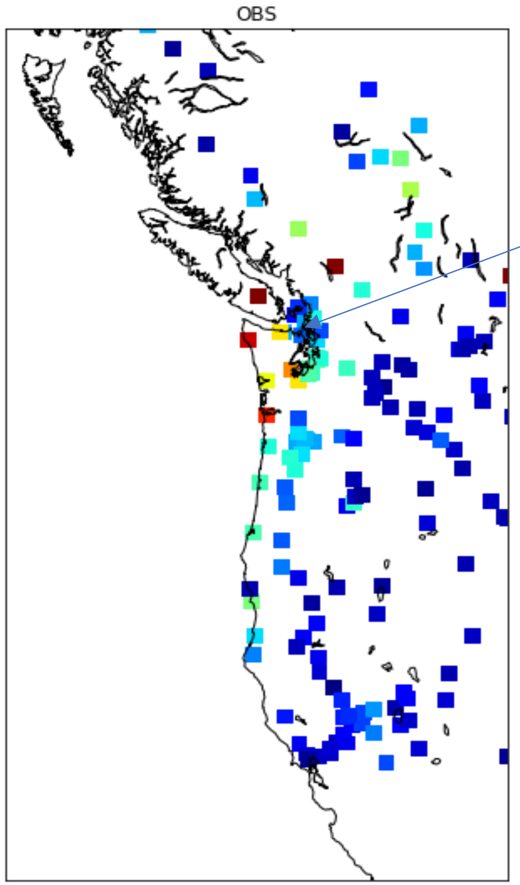
- Period: 1 November 2015 – 31 December 2015   *(OLYMPEX)*
- Widely varying environmental conditions!

Unsurprisingly, the long-term accumulations don't look much different.

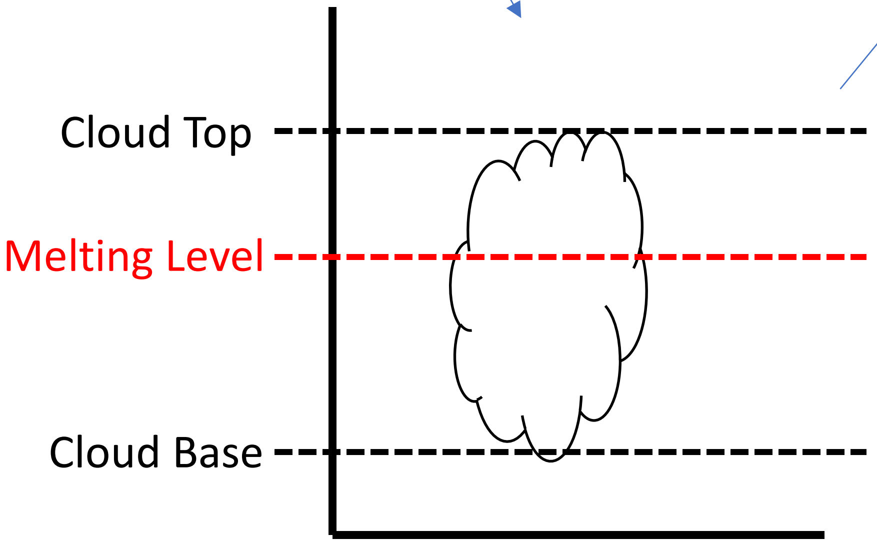


Long-term evaluations *(in progress)*

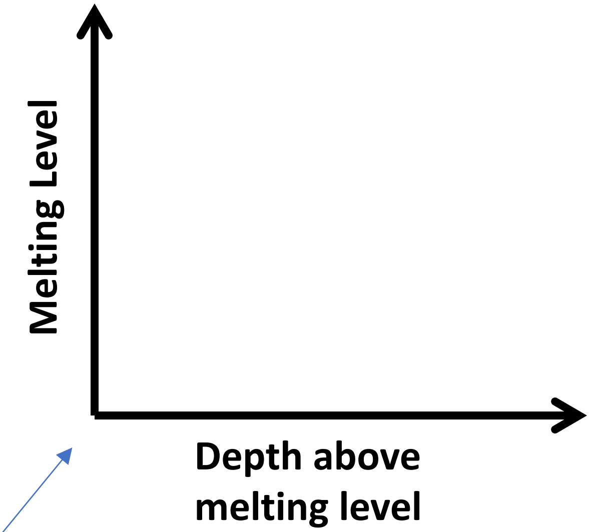
- Let's find the warm rain…



For each station, compute the model melting level and depth of cloud above the melting level.

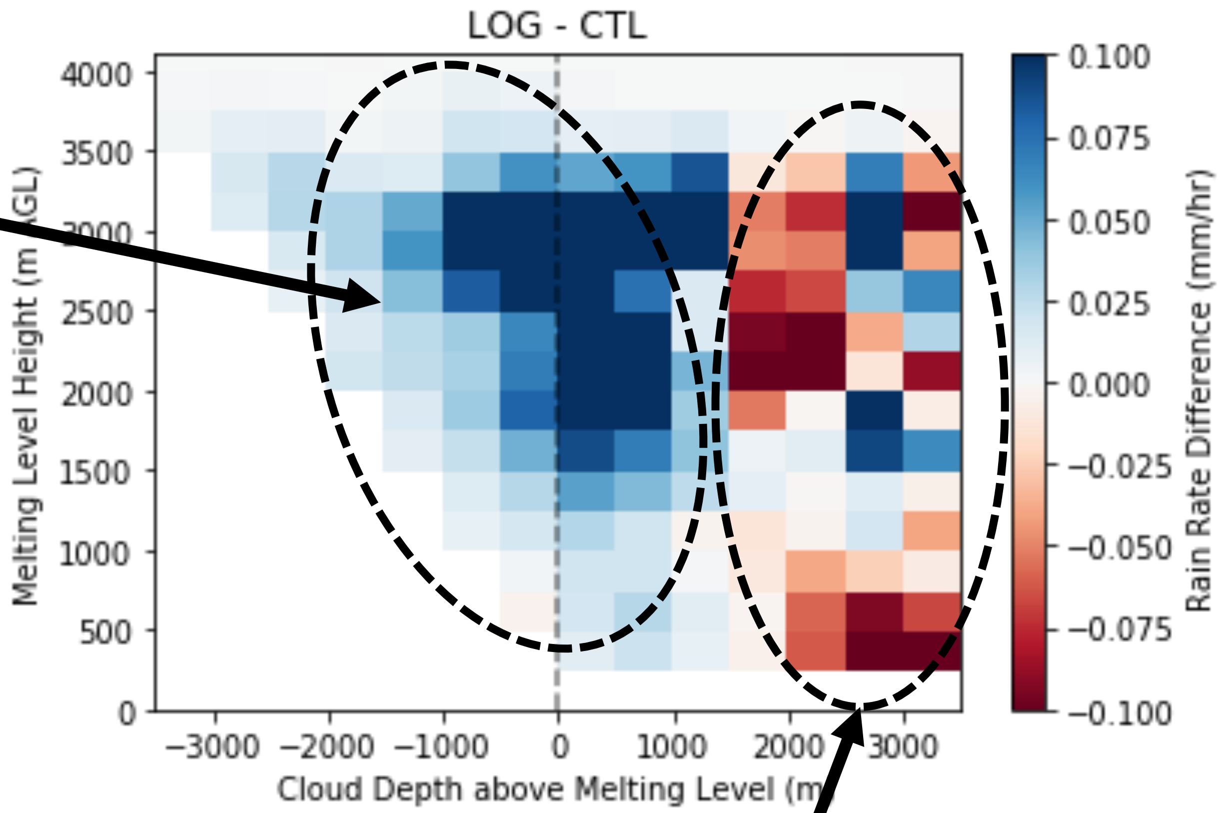


Depth above melting level.
(Can be negative…)



Long-term evaluations *(in progress)*

Increase in rain rates associated with warm clouds or clouds with tops < 1 km above melting level.



Not shown:

More rain mass, more rain drops, smaller drops.

=

More characteristic of warm rain.

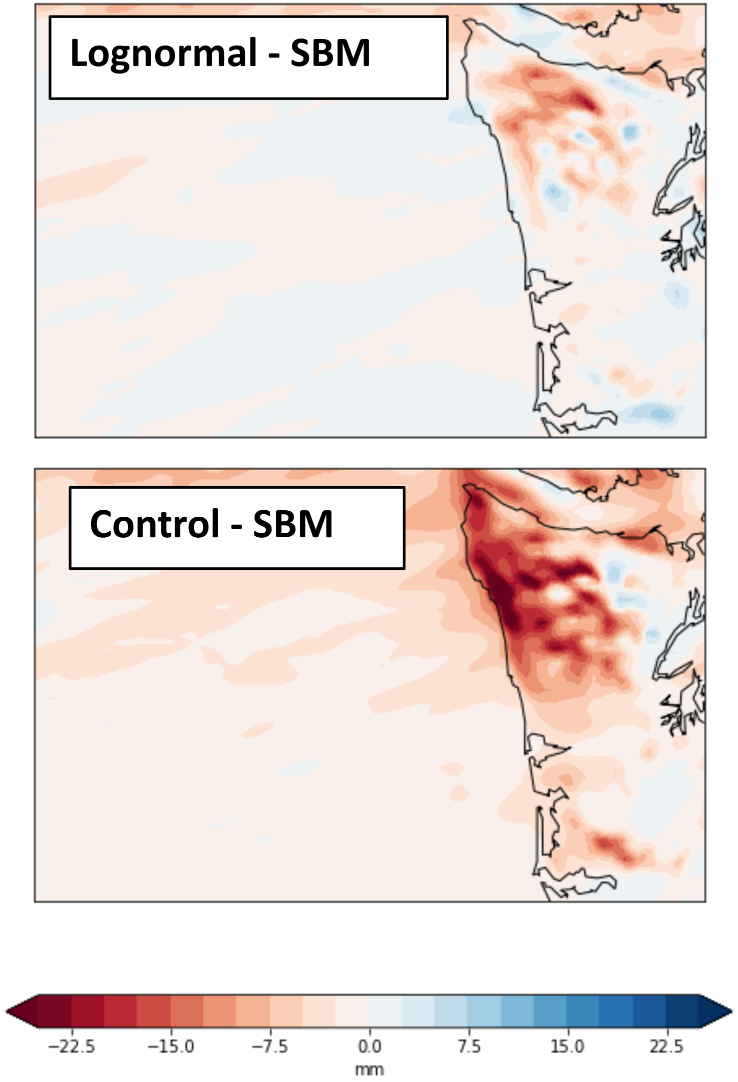
Incoherent signal with deeper mixed-phase clouds.

Conclusions

- WRF microphysics struggle to produce warm rain, despite years of model advancement.
  - Precipitation and near-surface microphysics poorly simulated where warm rain is common.

- Using a lognormal cloud water distributions increase the number of large cloud droplets in the model, invigorating autoconversion.

- Results indicate that warm rain is enhanced when lognormal distributions are used, with more numerous, smaller drops present.



Have we ignored warm rain physics?

- As far back as the late 90's *(MM5, anyone?)*, warm rain problems were apparent *(Colle et al. 1999, Colle and Mass 2000, Garvert et al. 2005)*

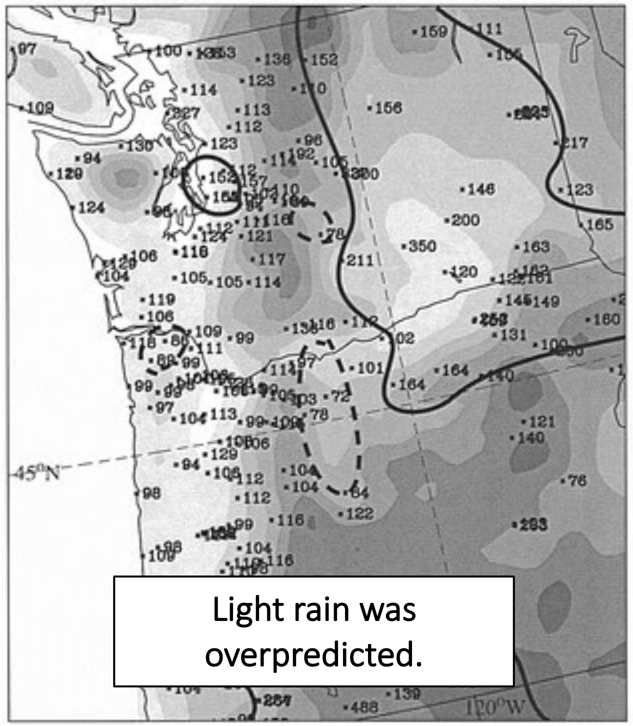
<u>From Colle et al. 1999</u>:

Wind direction 180-270 deg., which corresponds to the warm sector of a midlatitude cyclone.

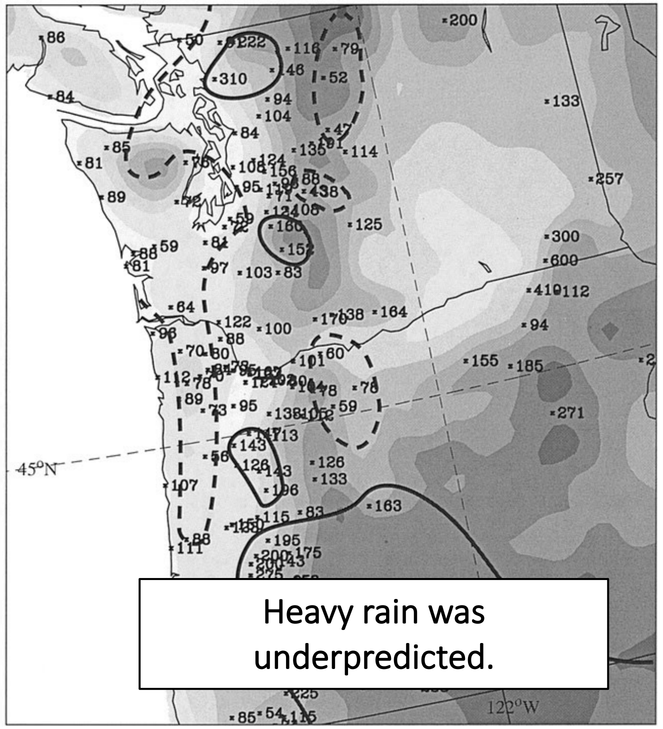
➔ **High melting levels**
➔ **Large moisture fluxes.**

Bias of light rain (2.54 mm in 12 hr)	Bias of heavy rain (10.16 mm in 12 hr)

(a) 12-km MM5 bias (2.54 mm in 12 h) for 180-270° 850 mb wdir



12-km MM5 bias (10.16 mm in 12 h) for 180-270° 850 mb wdir



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Our one unknown!

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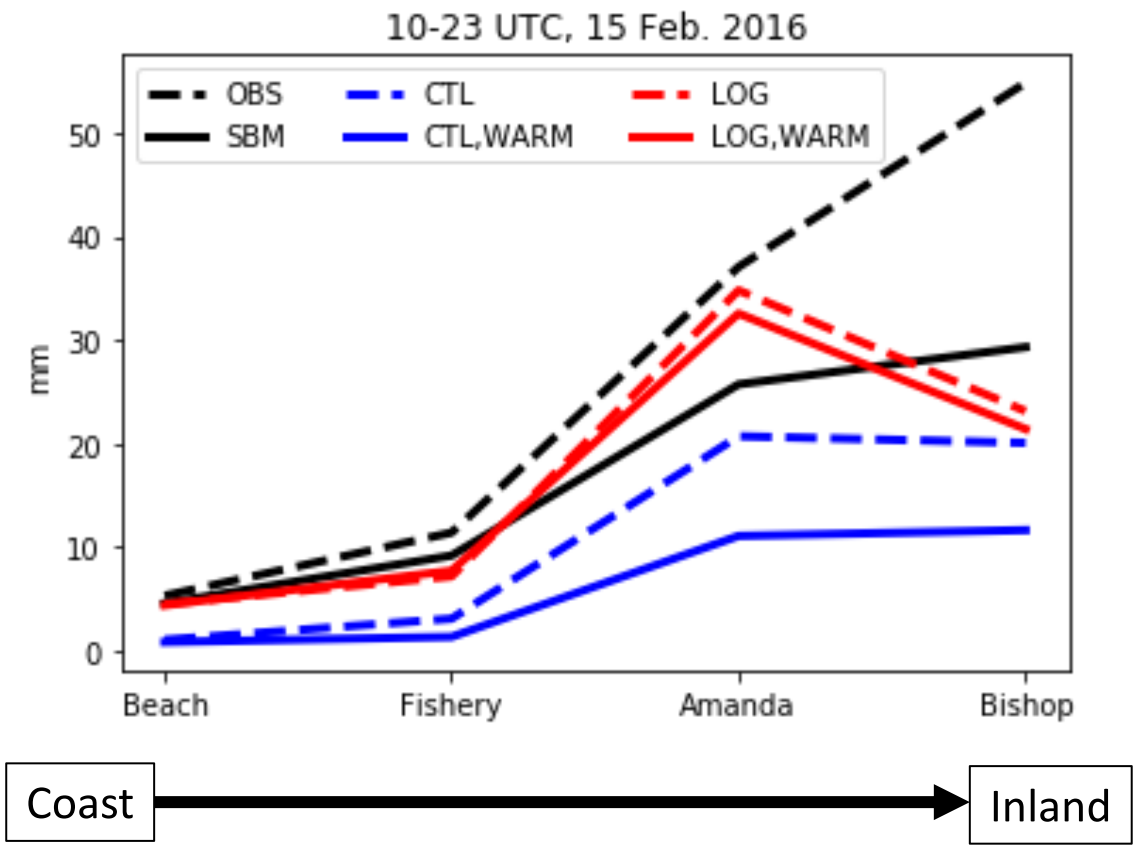
$$MVD_C = D_N\exp(3\sigma^2)$$

- Literature has constrained σ to 0.01-0.4 (Miles 2000, Geoffrey et al. 2010) **… in non-precipitating clouds.**

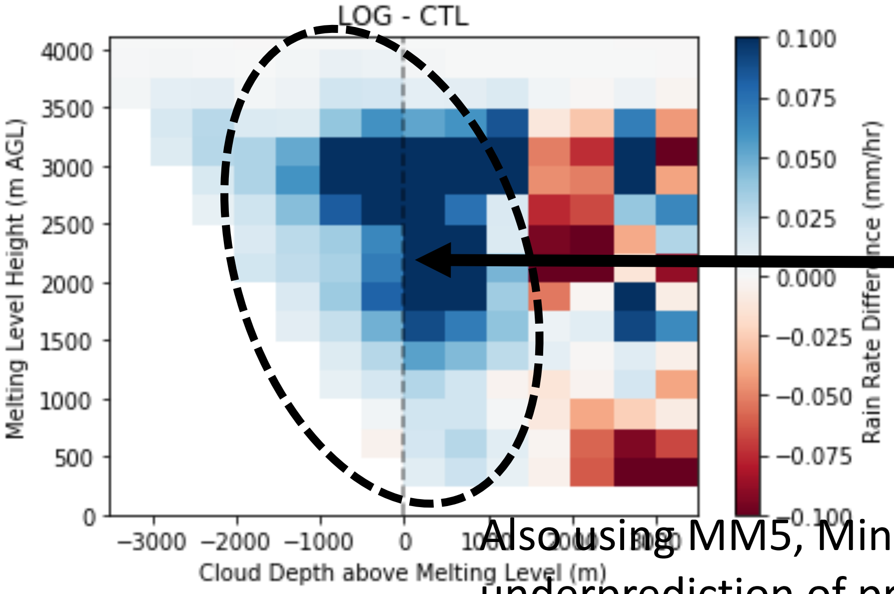
σ = 0.7 is necessary to reproduce the results of SBM scheme.

With ice physics…

- Similar performance with ice physics.
- Inland performance improves more at higher horizontal resolution (*not shown*).



Long-term evaluations *(in progress)*



Increased rain rates,
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more rain drops,
smaller drops.
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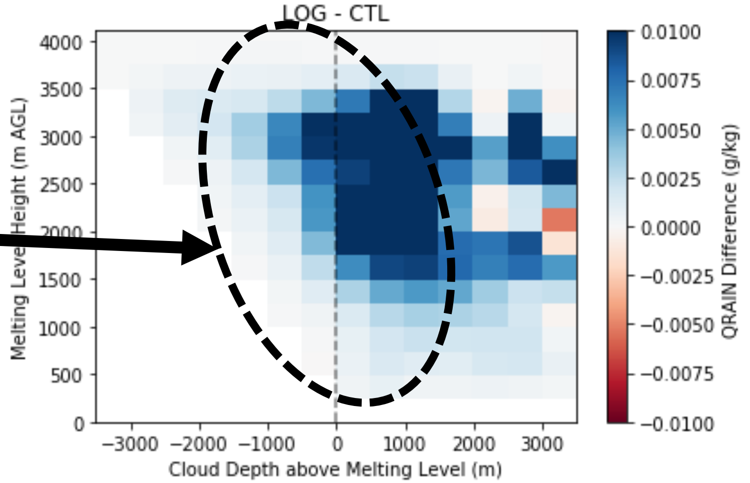
More characteristic of warm rain.



Also using MM5, Minder et al. (2008) found a general underprediction of precipitation during water year 2005.