A Cold-Bias Problem over Lowland Snow Using the Noah-MP LSM: Demonstration of the Problem and Possible Solutions

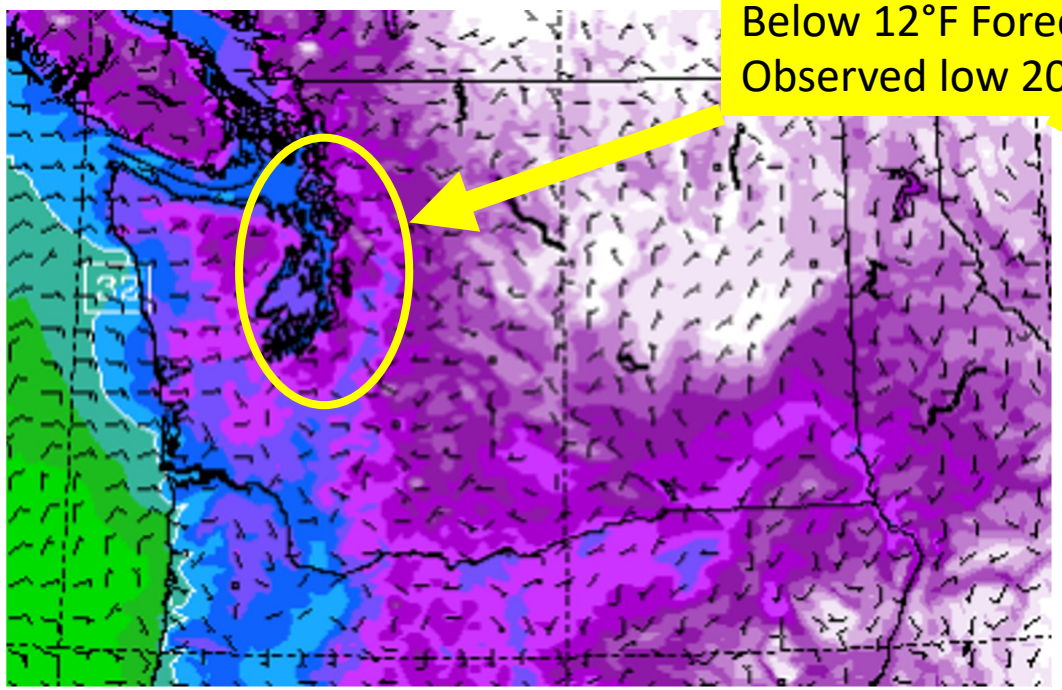
David Ovens and Cliff Mass

University of Washington

Unrealistic extreme cold for Western Washington Lowlands

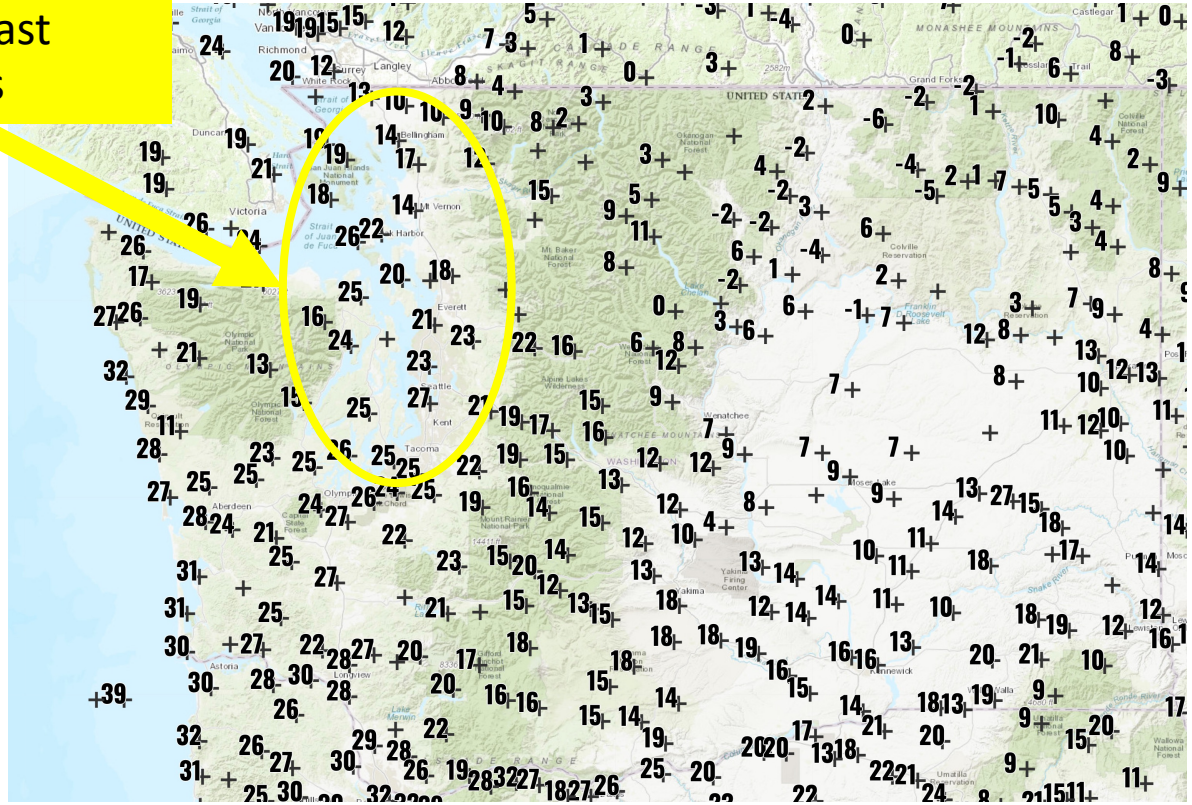
WRF 2m Temperature Forecast

12-hr Fcst valid 12 UTC 28 Dec 2021



Below 12°F Forecast
Observed low 20s

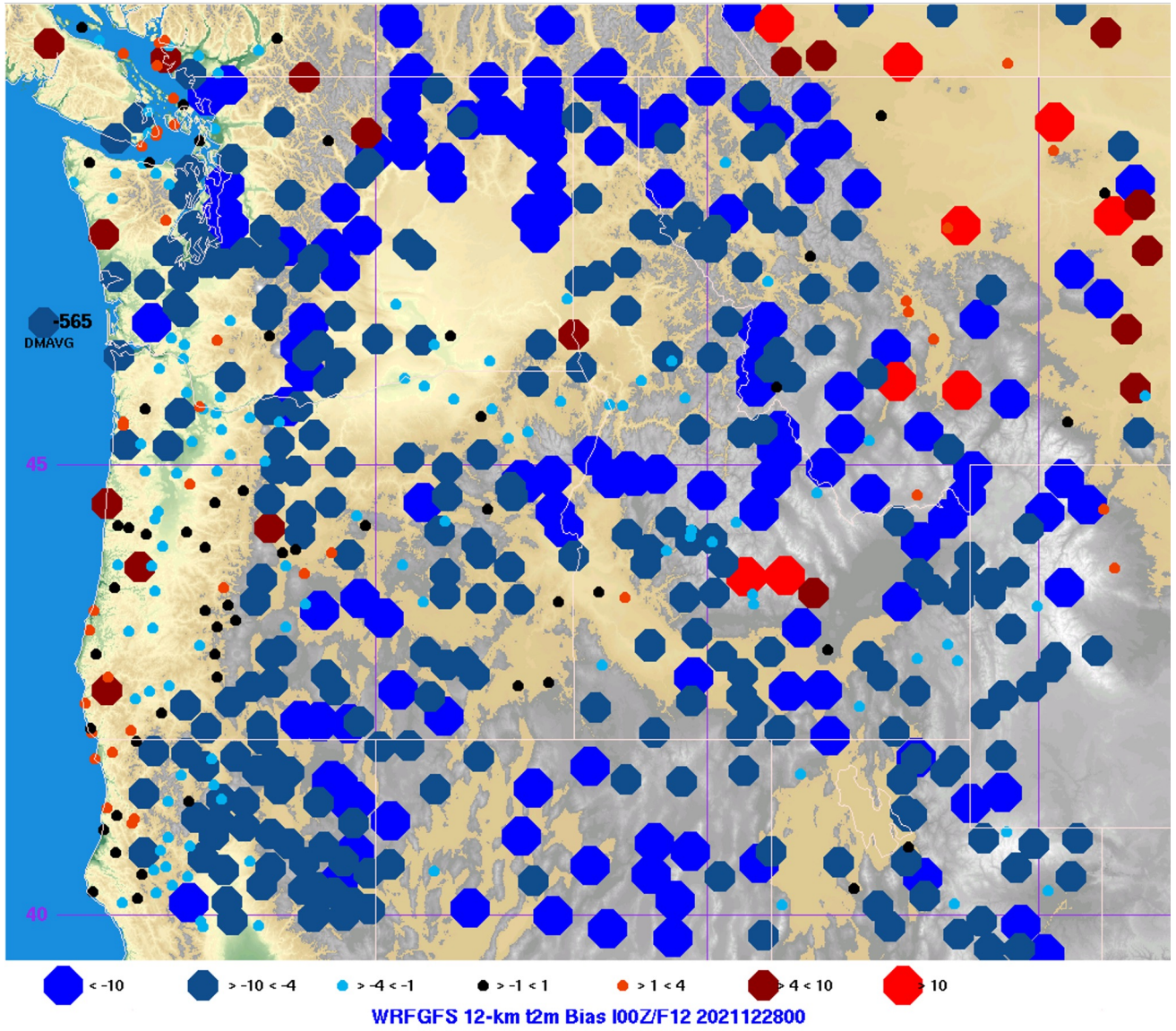
Observed 12 UTC 28 December 2021



Verification

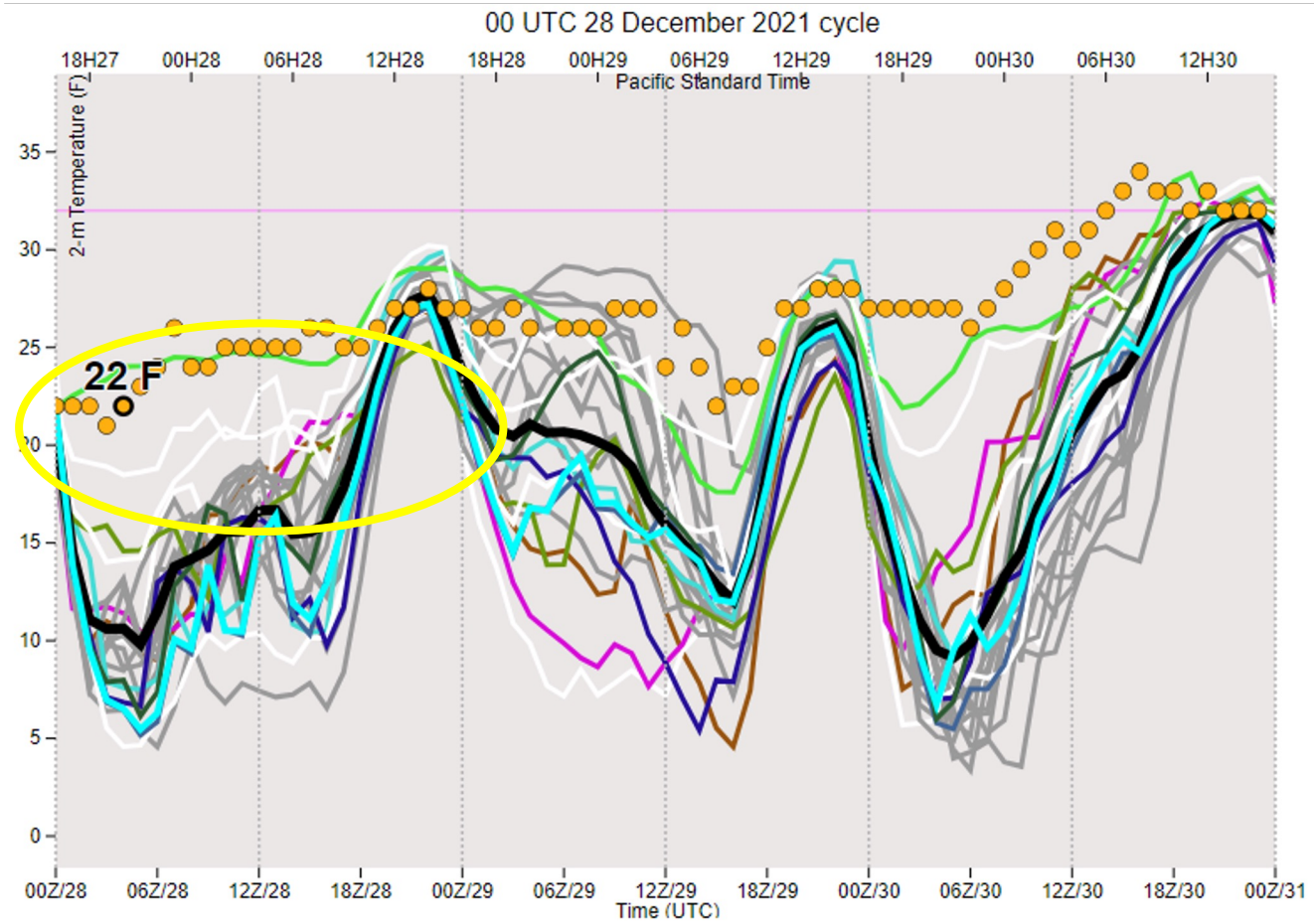
2m Temp Bias (Model minus Obs)

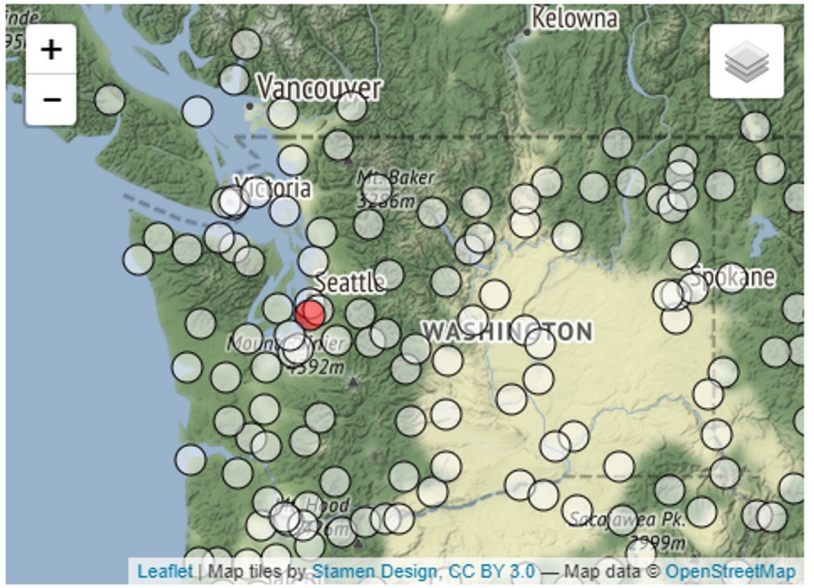
- Domain average bias = -5.65°F
- Many sites more than 10°F too cold



Looking at Sea-Tac, many ensembles also over 10°F too cold!

- 00Z 28 Dec 2021 WRF Ensemble Forecasts (lines) Obs (orange circles)
- One or two relatively realistic

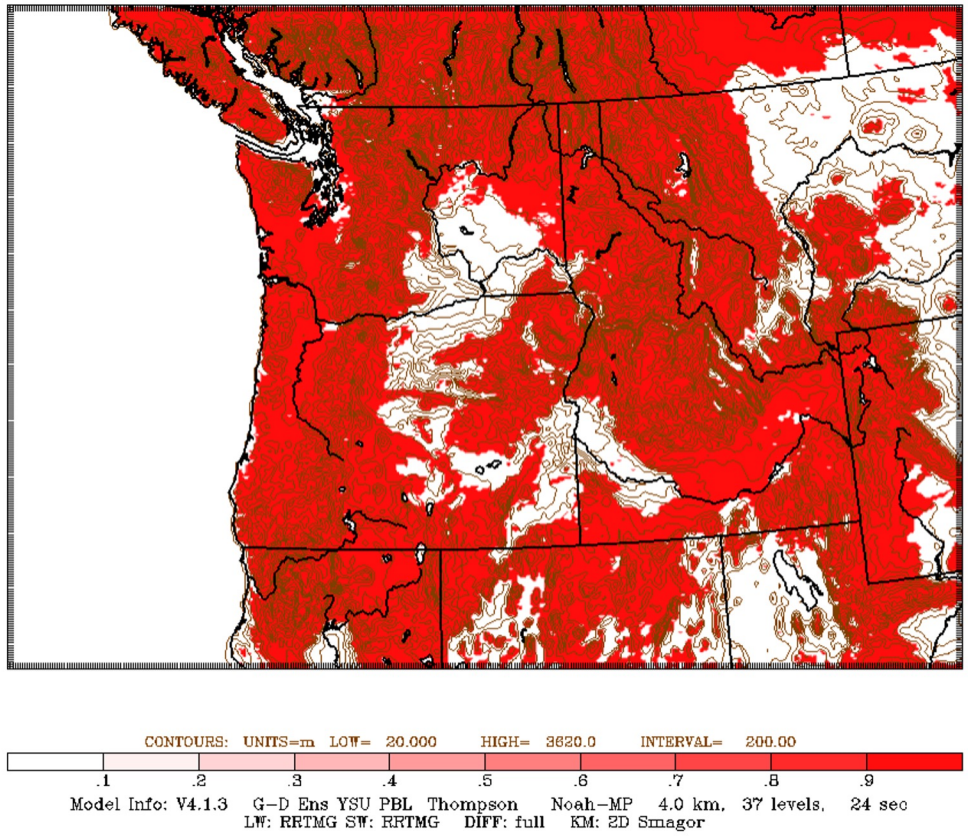




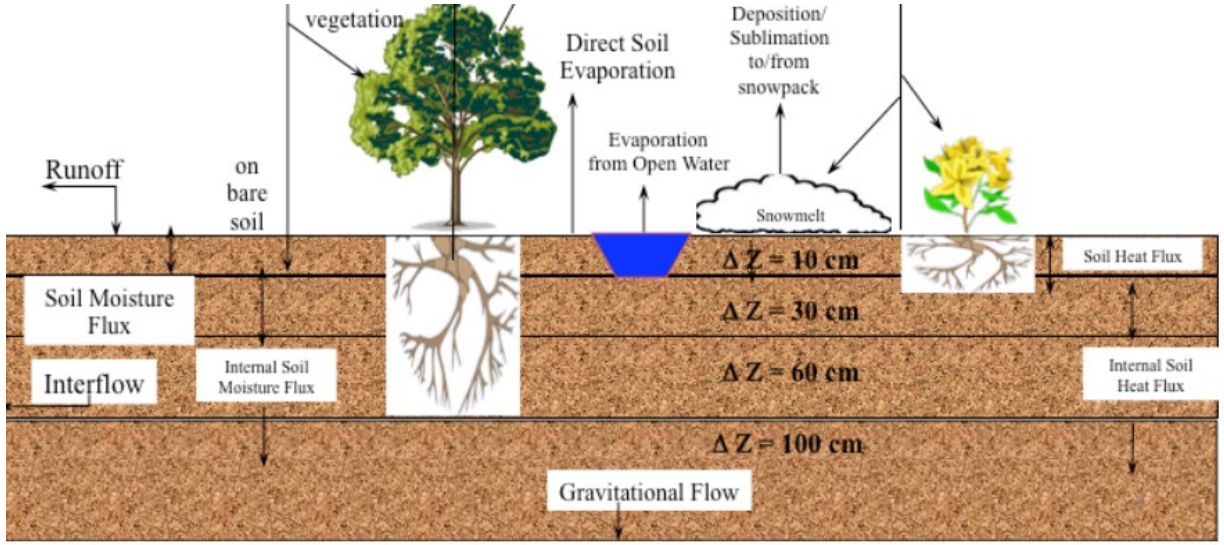
Variable: 2-m T Domain: 4-km Cycle: 2021122800

The unrealistic Extreme Cold Forecast in WRF in this and other events have two things in common:

Snow Cover



Noah-MP LSM



Some Questions

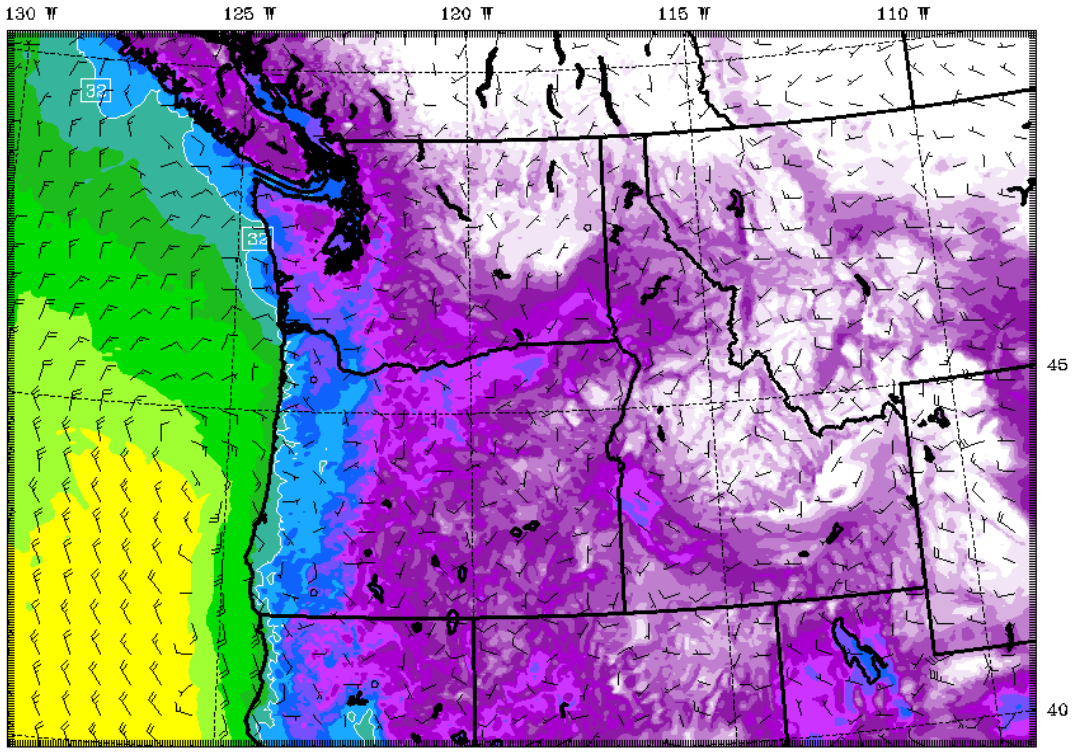
- **Why the extreme cold bias when using Noah-MP LSM during winter periods with snow cover?**

- **Are other LSMs better?**

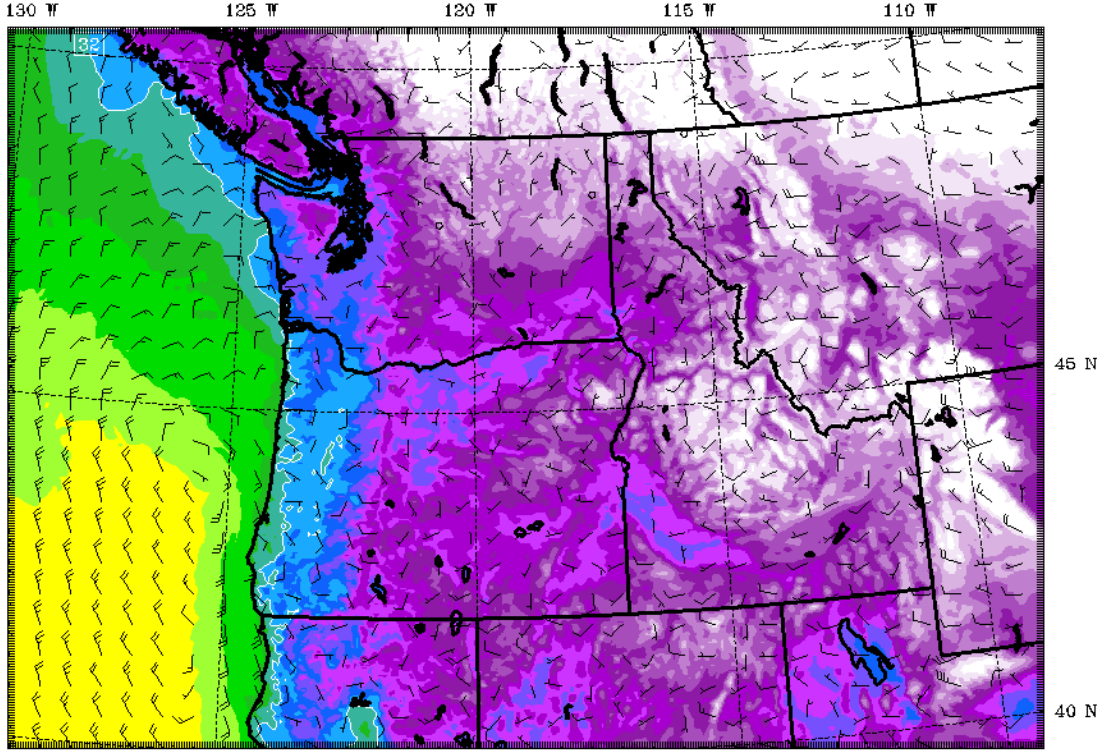
- **Can Noah-MP performance be improved with the right settings or physics options?**

Noah is Better than Noah-MP in Such Situations

Noah-MP

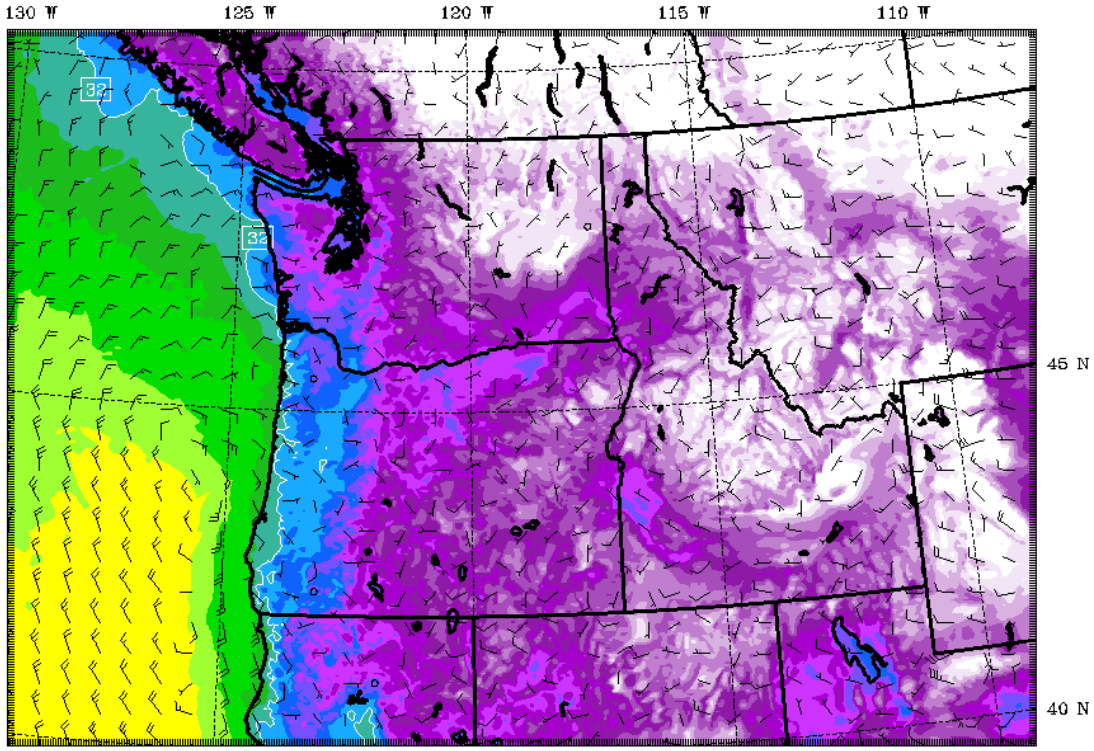


Noah

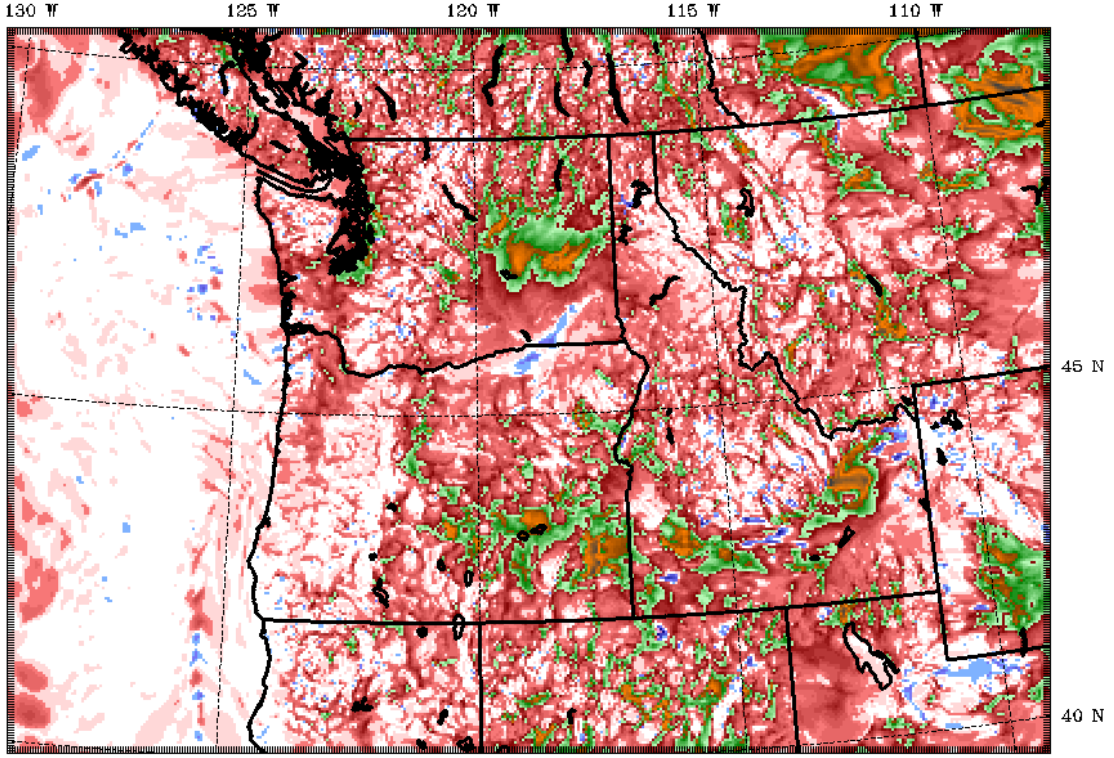


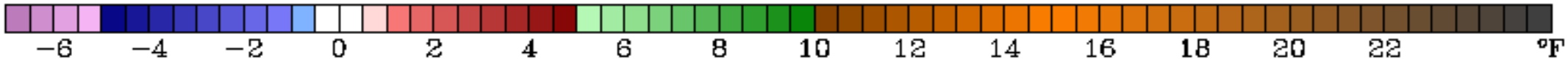
Noah is Better than Noah-MP in Such Situations

Noah-MP



Noah minus Noah-MP

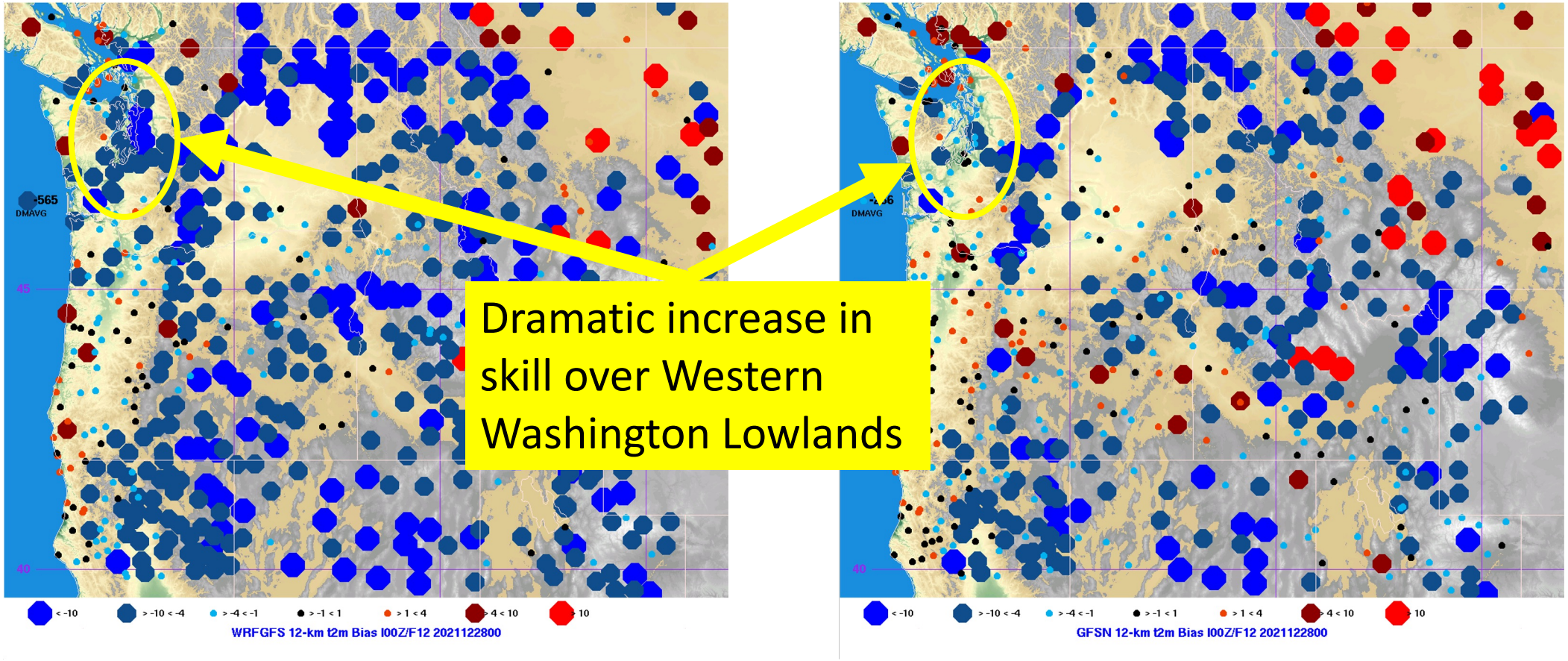




2m Temperature Bias Comparisons

Noah-MP
Domain average bias = -5.65°F

Noah
Domain average bias = -2.66°F



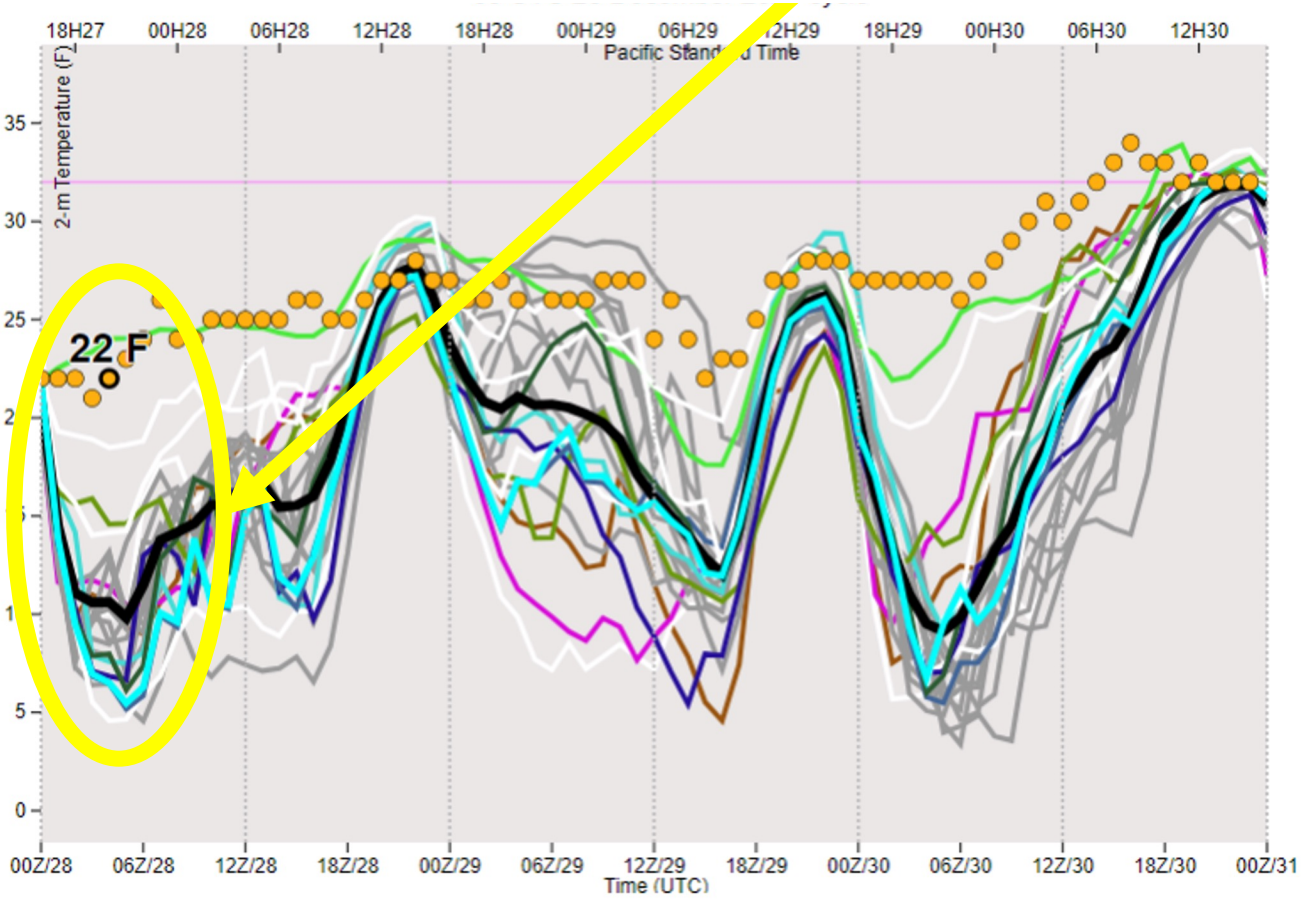
Next Steps

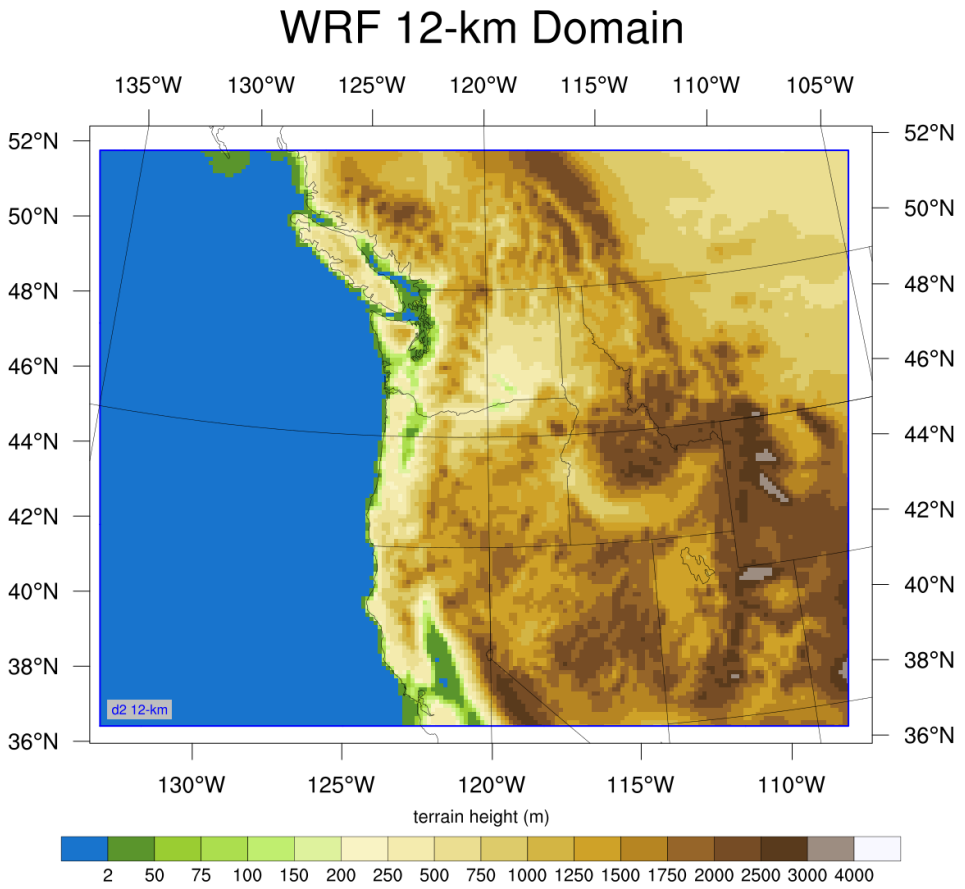
- Noah better for this snow cover case
- Noah-MP better for other times of year
- Can we somehow keep Noah-MP for winter?
- Experiment with Physics and Noah-MP Options to Lessen the Cold Bias Problem

Use Ensembles as Starting Point

- Attempt to address rapid cooling
- Use 12-km Domain

00Z 28 Dec 2021 WRF Ensemble Forecasts





Experiments to improve cold bias over snow

Physics	Real-time Configuration	Test Configurations
Code	WRF-ARW 4.1.3	WRF-ARW 4.3.2
Land Surface Model	Noah-MP, default namelist options	Noah, RUC, Noah-MP plus various Noah-MP namelist options
Shortwave Radiation	RRTMG	RRTMG and Goddard
Longwave Radiation	RRTMG	RRTMG and Goddard
Surface Layer	Revised MM5 Monin-Obukhov	Revised MM5 Monin-Obukhov, old MM5 (sf_sfclay_physics =91), and MYNN
Microphysics	Thompson	Thompson and Thompson aerosol-aware
PBL	YSU	YSU and MYNN Level 2.5 TKE
Other		Various Noah-MP code mods to limit effects of snow
Noah-MP Namelist Options	Default	Tried all other values for opt_snf and opt_stc

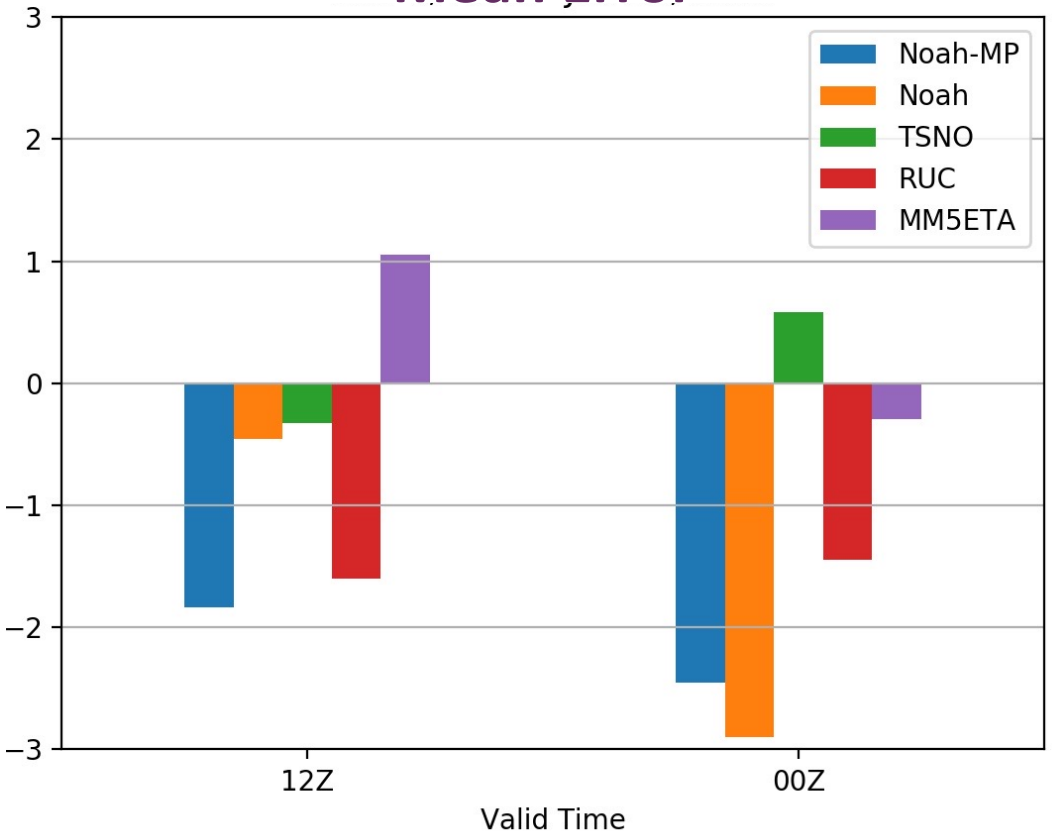
Experiments led to TSNO “Tuned Snow”:
Physics options, code mods, and preprocessing for use with Noah-MP

- Physics
  - MYNN level 2.5 TKE PBL
  - Goddard SW paired with RRTMG LW
  - Old MM5 surface layer (option 91)
  - Thompson aerosol-aware microphysics
- Noah-MP code mods – attempt to limit effects from shallow snow
  - Use Verseghy (1991) snow thermal conductivity and limit to <= 0.25
  - Require deeper SNOWH (0.15 vs 0.05) in snow surface temperature and ground snow cover fraction calculations
  - Set snow depth and snow water equivalent to 0 for larger SNOWH values (1e-3 vs 1e-6) and SNEQV (1 vs 1e-3)
- Preprocessing – limit effects of fresh snow on warm ground
  - Set SNOWH, SNOW, SNOWC = 0 when top soil layer temperature exceeds 0°C

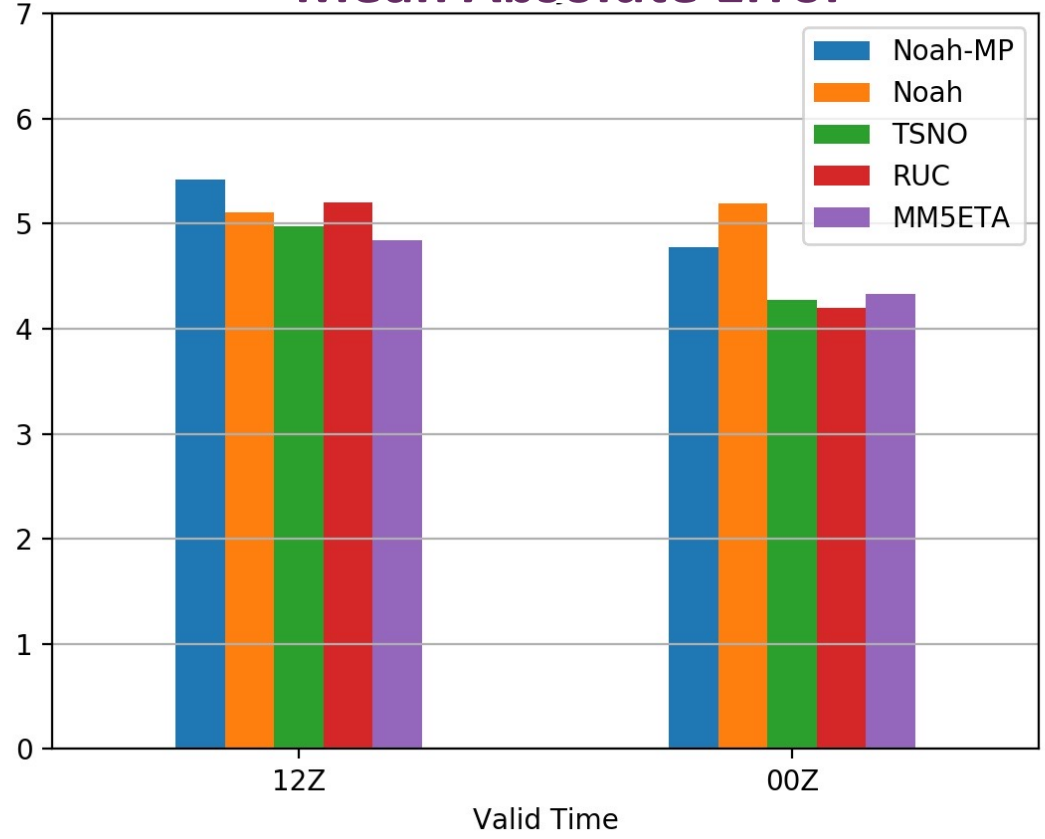
Results for 1 Dec 2021 – 31 Jan 2022 Select Cases 12-km Domain

- TSNO and other LSMs improve skill
- TSNO better for combination of 00Z and 12Z

Mean Error



Mean Absolute Error

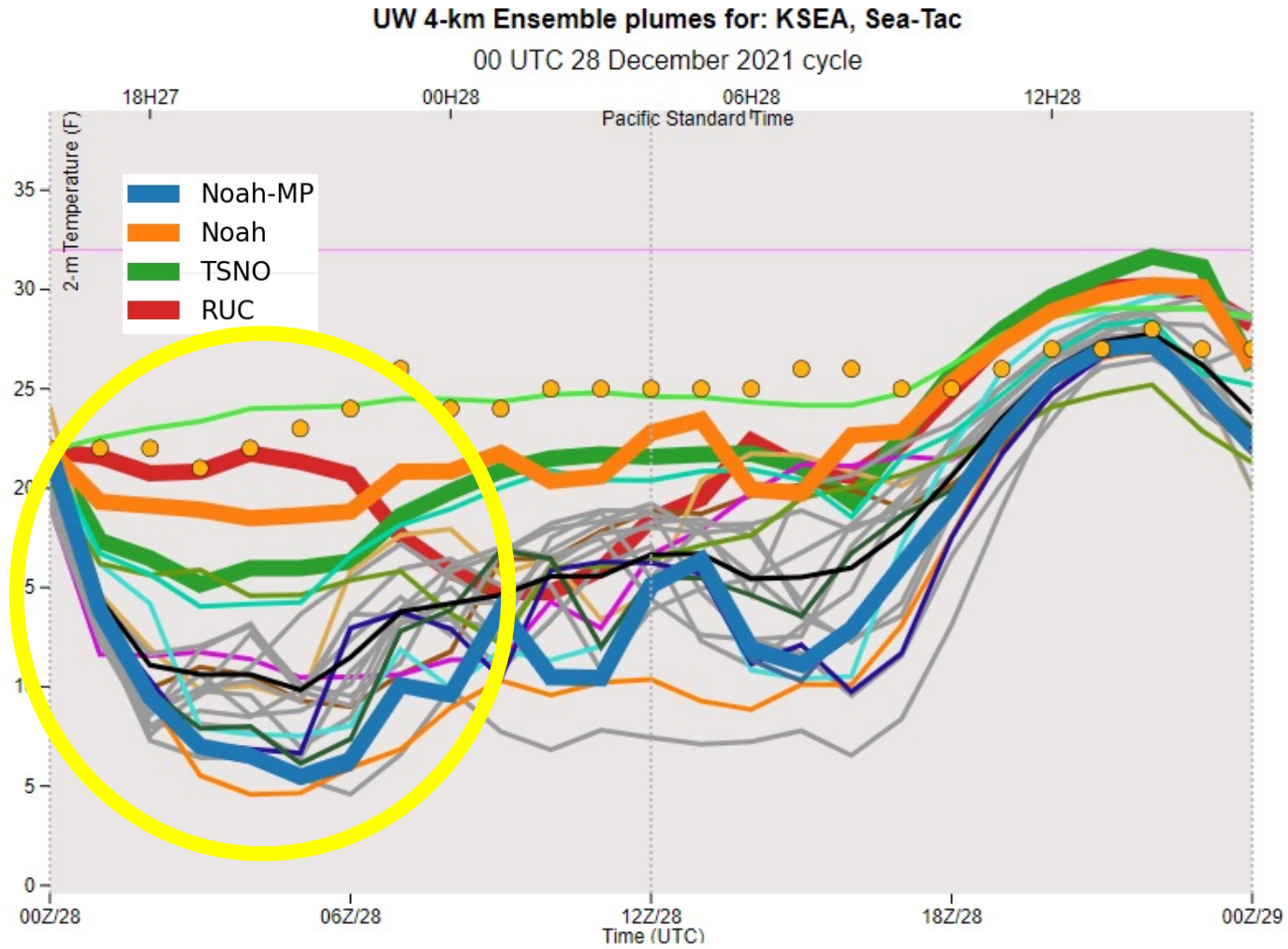


TSNO and Other LSMs vs 28 December 2021 Ensemble Runs

- **TSNO and other LSMs mitigate rapid cooling problem**

Sea-Tac
00 UTC 28 – 29 Dec 2021

- **Ensemble Forecasts (lines)**
- **Observations (circles)**



Summary

- Noah-MP exhibits cold bias over snow cover
- Other LSMs better at predicting 2m temperatures over snow especially the overnight low temperatures
- Noah-MP 2m Temperatures can be improved by:
  - Choosing different Physics
  - Using some Noah-MP code mods
  - Removing snow inputs when top soil level temperature exceeds 0°C

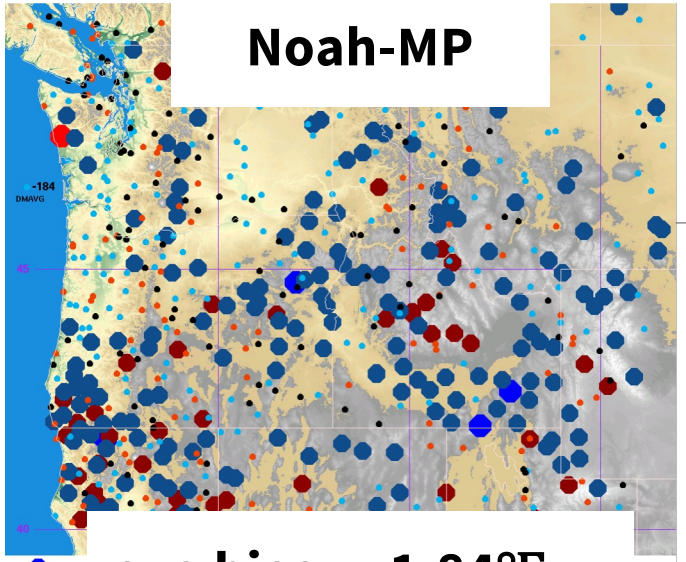
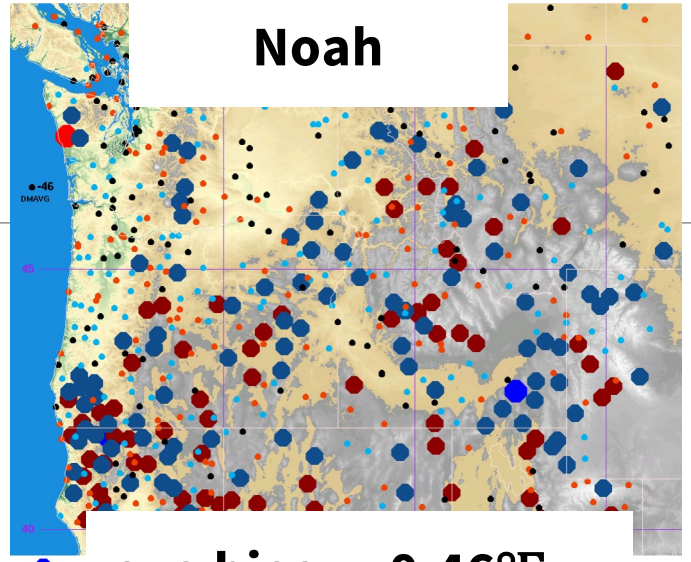
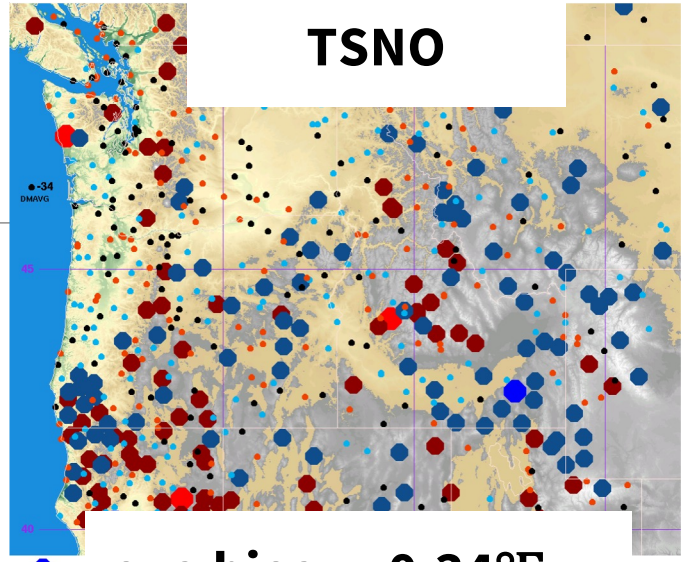
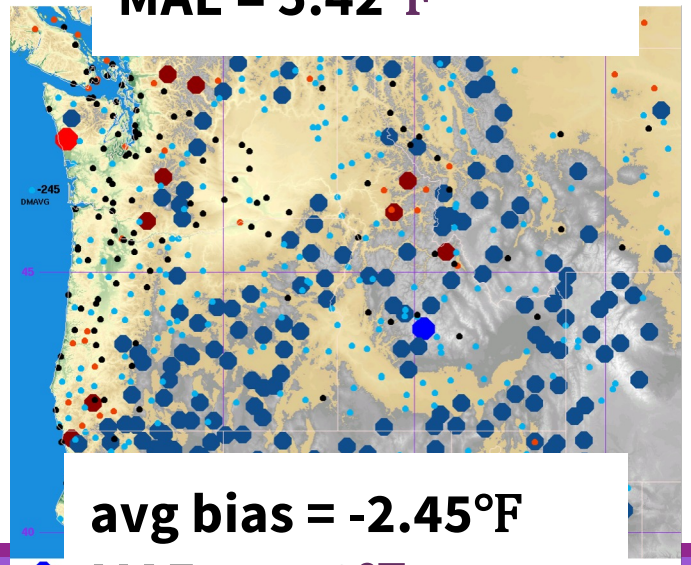
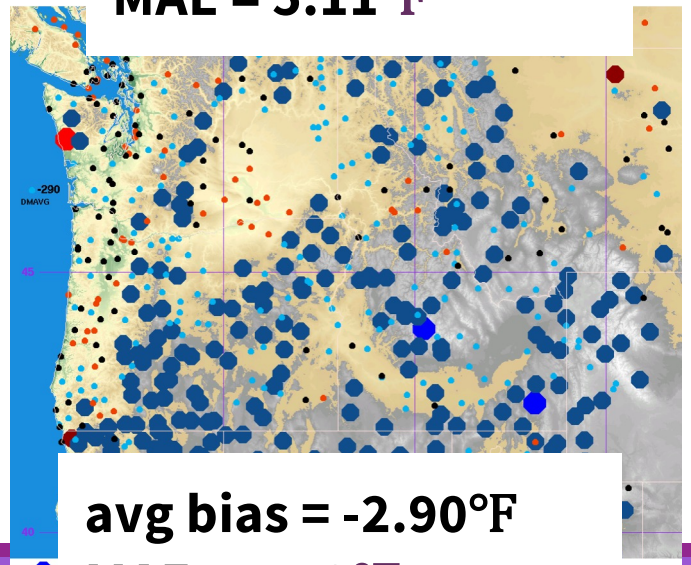
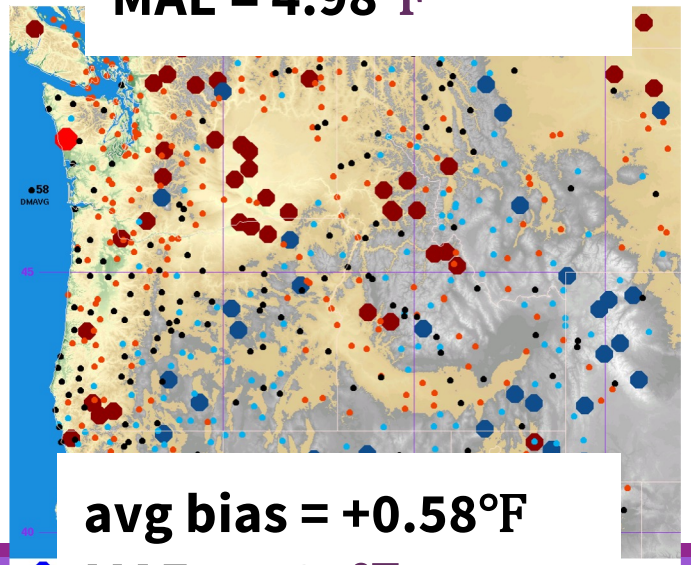
Questions or suggestions?

Experiments led to TSNO “Tuned Snow”:
Physics options, code mods, and preprocessing for use with Noah-MP

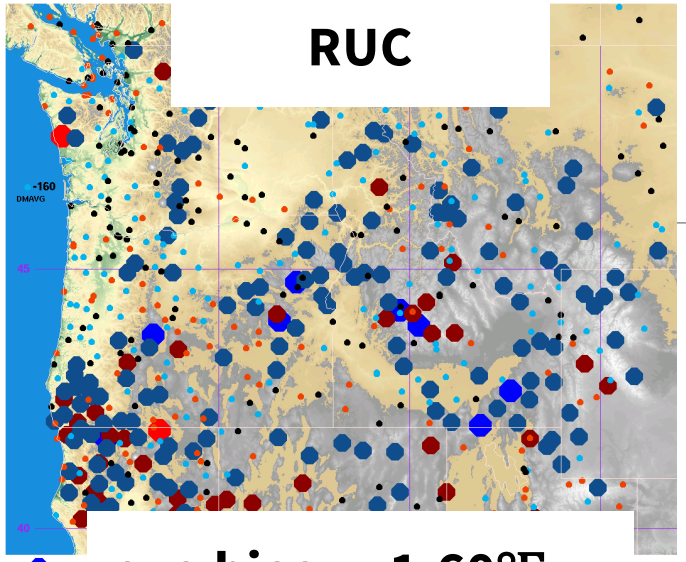
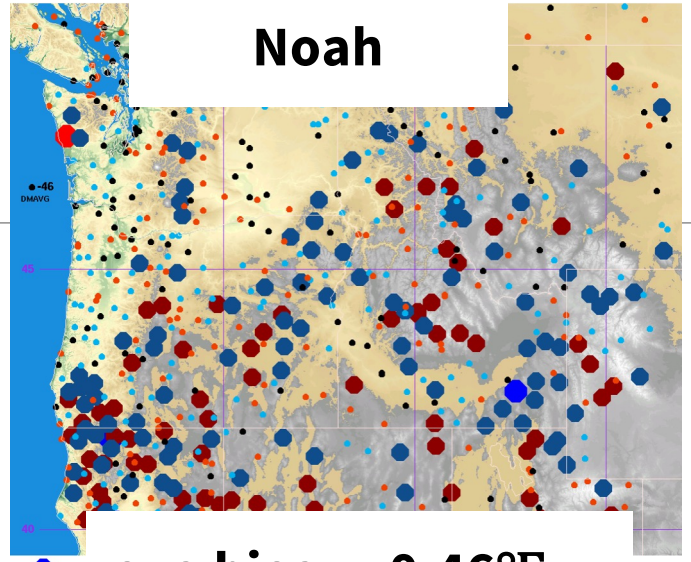
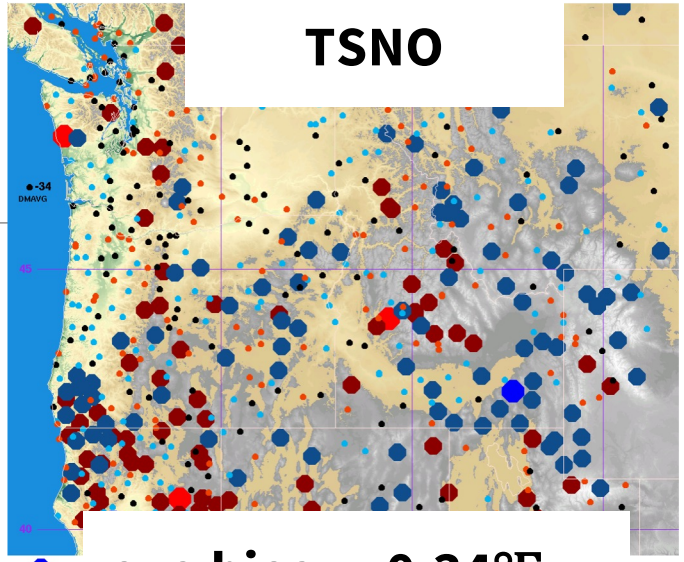
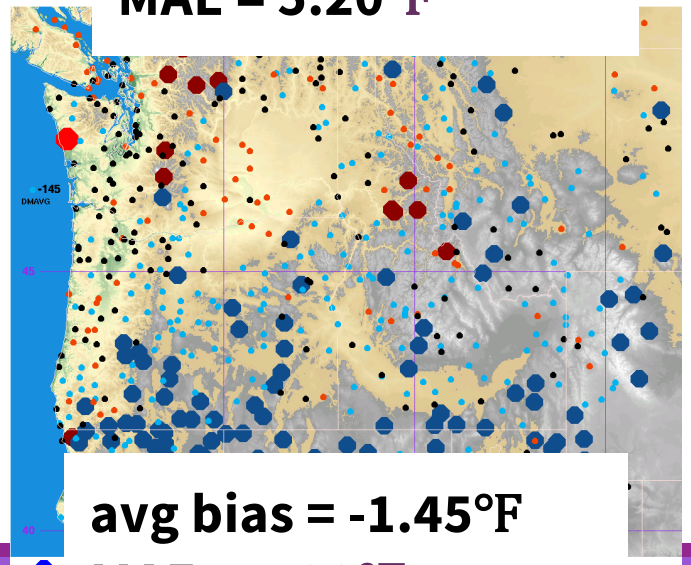
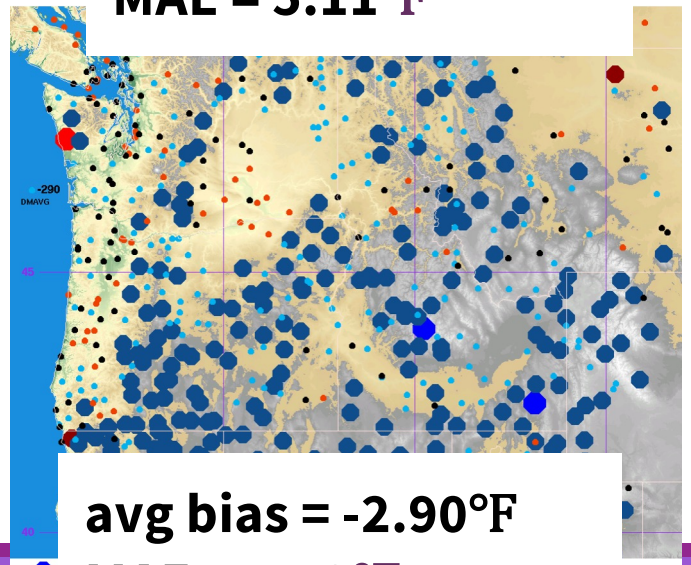
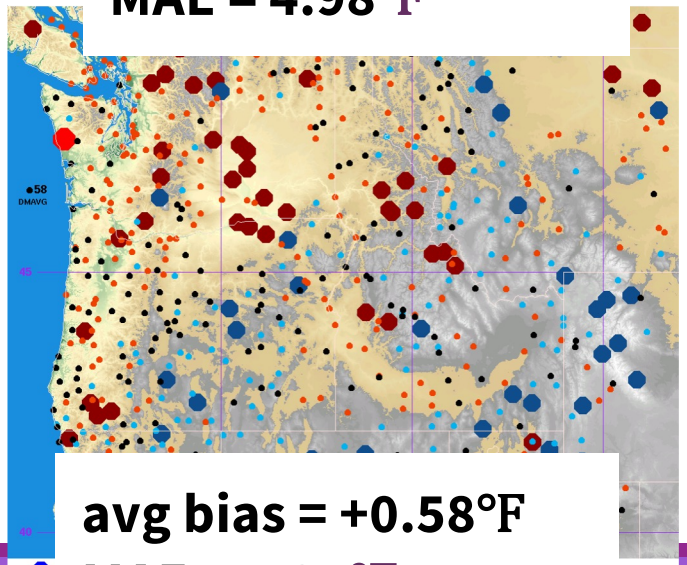
- Physics
  - MYNN level 2.5 TKE PBL
  - Goddard SW paired with RRTMG LW
  - Old MM5 surface layer (option 91)
  - Thompson aerosol-aware microphysics
- Noah-MP code mods – attempt to limit effects from shallow snow
  - Use Verseghy (1991) snow thermal conductivity and limit to <= 0.25
  - Require deeper SNOWH (0.15 vs 0.05) in snow surface temperature and ground snow cover fraction calculations
  - Set snow depth and snow water equivalent to 0 for larger SNOWH values (1e-3 vs 1e-6) and SNEQV (1 vs 1e-3)
- Preprocessing – limit effects of fresh snow on warm ground
  - Set SNOWH, SNOW, SNOWC = 0 when top soil layer temperature exceeds 0°C

Extra Slides

Examining statistics from Dec 1, 2021 through Jan 31, 2022.

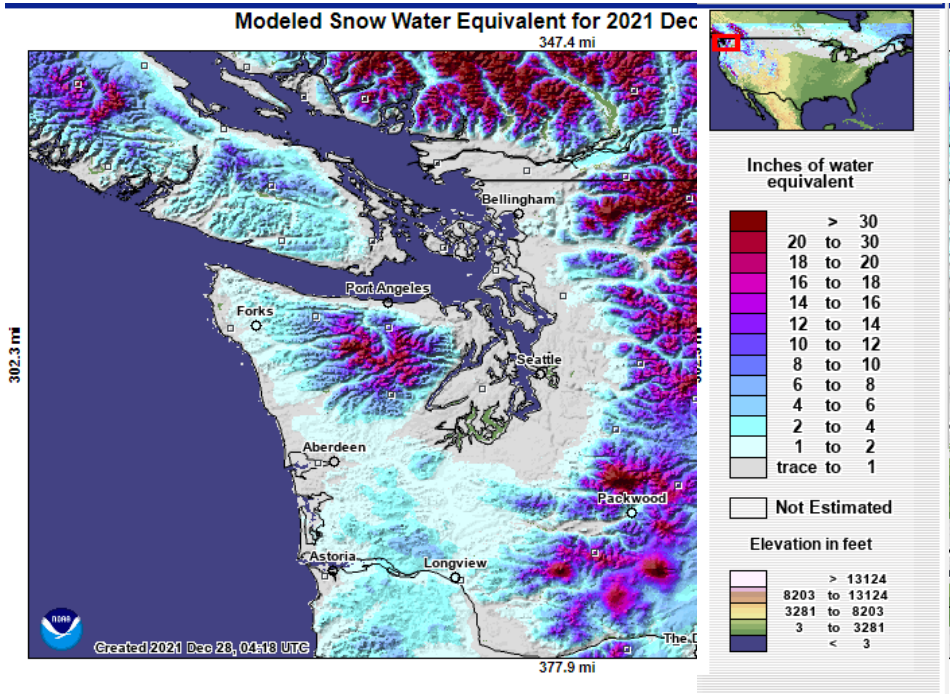
	Noah-MP	Noah	TSNO
12Z	 avg bias = -1.84°F, MAE = 5.42°F	 avg bias = -0.46°F MAE = 5.11°F	 avg bias = -0.34°F MAE = 4.98°F
00Z	 avg bias = -2.45°F MAE = 4.78°F	 avg bias = -2.90°F MAE = 5.19°F	 avg bias = +0.58°F MAE = 4.27°F

Examining statistics from Dec 1, 2021 through Jan 31, 2022.

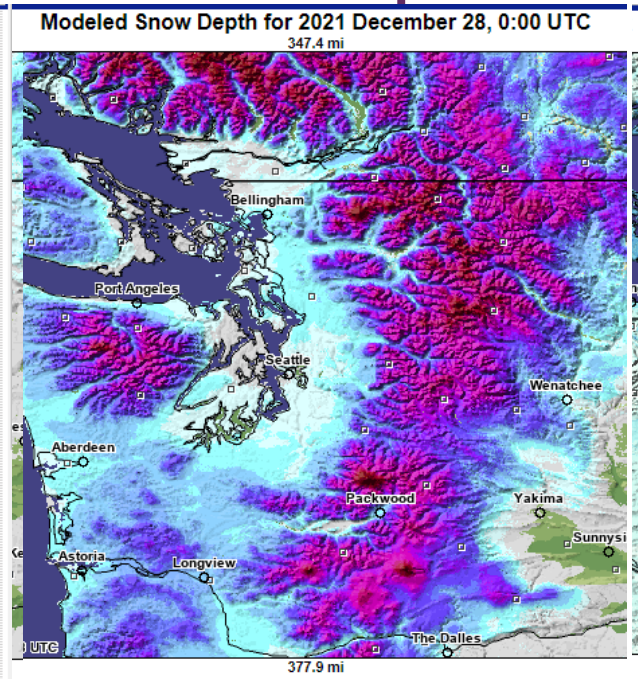
	RUC	Noah	TSNO
12Z			
	avg bias = -1.60°F, MAE = 5.20°F	avg bias = -0.46°F MAE = 5.11°F	avg bias = -0.34°F MAE = 4.98°F
00Z			
	avg bias = -1.45°F MAE = 4.20°F	avg bias = -2.90°F MAE = 5.19°F	avg bias = +0.58°F MAE = 4.27°F

Snow Cover from NOAA's Hydrologic Remote Sensing Center

SWE



Snow Depth



Snowpack Temperature