A Comprehensive Evaluation of the Noah LSM with Multi-parameterization Options (Noah-MP) within WRF

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Motivation and Overview

- Assess forecast performance of Noah-MP (Niu et al. 2011) within WRF-ARW for the Air Force Weather Agency (AFWA)
- Noah-MP: ***Improvement upon Noah with more physical representation of biophysical and hydrological processes*** with multiple options to parameterize:
  - Vegetation canopy layer
  - Modified two-stream radiation transfer scheme
  - Ball-Berry type stomatal resistance scheme
  - Short-term dynamic vegetation model
  - Simple groundwater model with runoff scheme
  - Physically-based three-layer snow model
  - Frozen soil scheme that produces greater soil permeability
- Test two configurations with the same namelist options with exception to the LSM **(Noah / Noah-MP)**

Physics Suite	Configuration
Microphysics	WSM5
Radiation (LW/SW)	RRTM/Dudhia
Surface Layer	Monin-Obukhov Similarity Theory
Land Surface	**Noah/Noah-MP**
PBL	YSU
Convection	Kain-Fritsch

```
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 opt_sfc = 1,
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 *opt_run = 3,
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 opt_alb = 2,
 opt_snf = 1,
 opt_tbot = 2,
 opt_stc  = 1,
 /
```
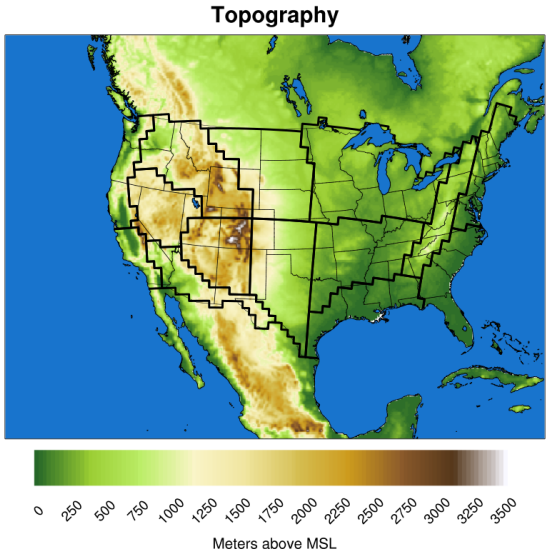

*Non-default option

Experiment and Evaluation

- **End-to-end system:** WPS, WRFDA, WRF-ARW, UPP, and MET
- **Test period:** July 2011 – June 2012, w/ 48-h warm start simulations initialized every 36 h (244 total cases)
- **Domain:** 15 km CONUS grid w/ 56 vertical levels and model top of 10 hPa
- **Evaluation:**
  - Surface and upper air [(BC)RMSE, bias] – temperature, dew point temperature, wind speed
  - Precipitation [Gilbert skill score, frequency bias] – 3- and 24-h accumulations
  - Statistical Assessment
    - Confidence Intervals (CI) at the 99% level
    - Statistical significance (SS) and practical significance (PS)
  - Verification by observation station - temperature, dew point temperature, and wind speed bias
  - Accumulated stats over domain - soil temperature and snow variables

Season	Date Range
Summer	July – Sept. 2011
Fall	Oct. – Dec. 2011
Winter	Jan. – March 2012
Spring	April – June 2012



LSM Difference Results

CONUS Analysis

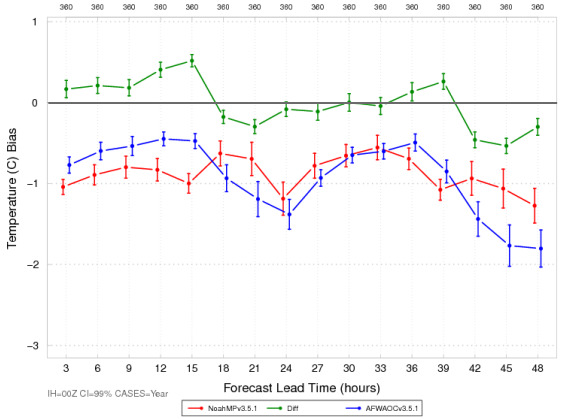
AFWA Operational Configuration (AFWAOC)

Noah-MP Replacement Configuration (Noah-MP)

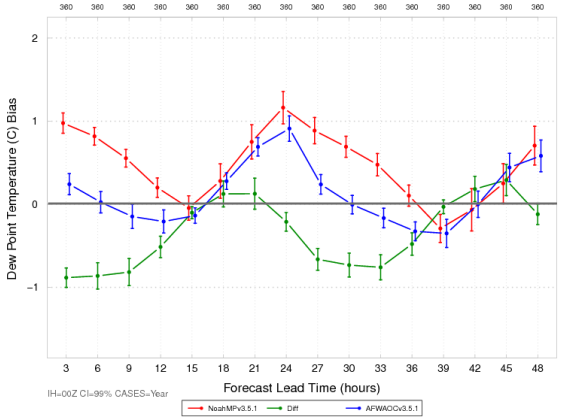
CONUS Surface Bias - Time Series

00 UTC Initializations

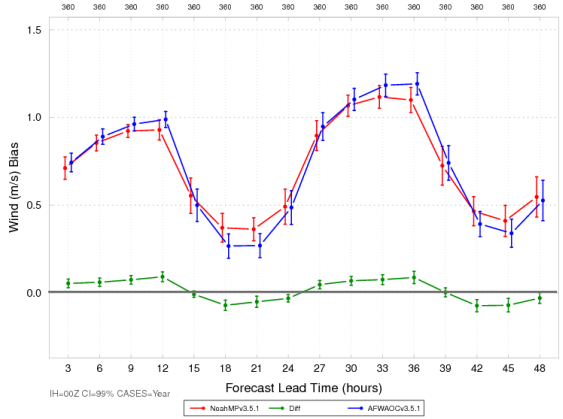
2 m Temperature



2 m Dew Point Temperature



10 m Wind Speed

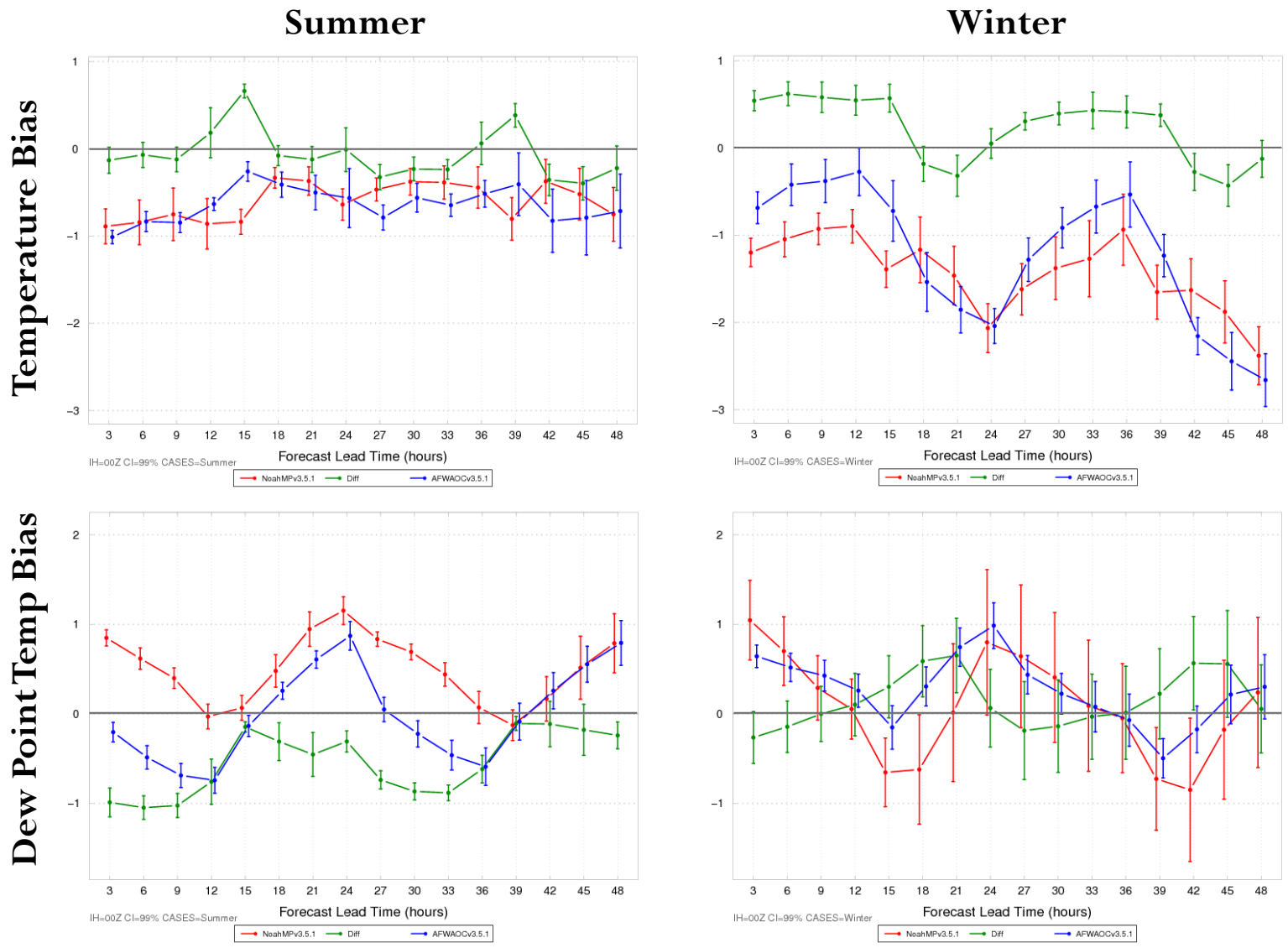


SS (light shading) & **PS (dark shading)** differences for *surface temp, dew point, & wind speed bias*

AFWAOC better performer **Noah-MP better performer**

00 UTC Initializations		f03	f06	f09	f12	f15	f18	f21	f24	f27	f30	f33	f36	f39	f42	f45	f48
2 m Temperature	Annual	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	NoahMP *	NoahMP *	--	NoahMP *	--	--	AFWAOC *	AFWAOC *	NoahMP *	NoahMP *	NoahMP *
	Summer	--	--	--	--	AFWAOC *	--	--	--	NoahMP *	NoahMP *	NoahMP *	--	AFWAOC *	NoahMP *	NoahMP *	--
	Fall	AFWAOC *	--	--	--	AFWAOC *	--	NoahMP *	--	--	--	--	--	AFWAOC *	NoahMP *	NoahMP *	NoahMP *
	Winter	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	--	NoahMP *	--	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	NoahMP *	NoahMP *	--
	Spring	--	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	NoahMP *	NoahMP *	NoahMP *	NoahMP *	NoahMP *	NoahMP *	--	--	NoahMP *	NoahMP *	NoahMP *
2 m Dew Point Temp	Annual	AFWAOC *	AFWAOC *	AFWAOC *	NoahMP *	NoahMP *	--	--	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	NoahMP *	--	AFWAOC *	NoahMP *	--
	Summer	AFWAOC *	AFWAOC *	NoahMP *	NoahMP *	NoahMP *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	NoahMP *	NoahMP *	NoahMP *	--	--	AFWAOC *
	Fall	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	--	AFWAOC *	NoahMP *	AFWAOC *	AFWAOC *	AFWAOC *	--	--	--	AFWAOC *	AFWAOC *	--
	Winter	--	--	--	--	--	AFWAOC *	NoahMP *	--	--	--	--	--	--	AFWAOC *	--	--
	Spring	AFWAOC *	AFWAOC *	AFWAOC *	NoahMP *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	NoahMP *	AFWAOC *	--	--	AFWAOC *
10 m Wind Speed	Annual	NoahMP	NoahMP	NoahMP	NoahMP	--	AFWAOC	AFWAOC	AFWAOC	NoahMP	NoahMP	NoahMP	NoahMP	--	AFWAOC	AFWAOC	--
	Summer	NoahMP	NoahMP	NoahMP	NoahMP	--	AFWAOC	--	AFWAOC	NoahMP	NoahMP	NoahMP	NoahMP	--	AFWAOC	--	--
	Fall	--	--	--	--	--	AFWAOC	AFWAOC	--	--	--	--	AFWAOC	--	AFWAOC	AFWAOC	--
	Winter	--	--	--	--	--	AFWAOC	AFWAOC	--	--	--	NoahMP	--	--	AFWAOC	AFWAOC	--
	Spring	NoahMP	NoahMP	NoahMP	NoahMP	NoahMP	--	--	--	NoahMP	NoahMP	NoahMP	NoahMP	--	--	--	AFWAOC

CONUS: 2-m Temp and Dew Point Temp Bias
00 UTC initializations

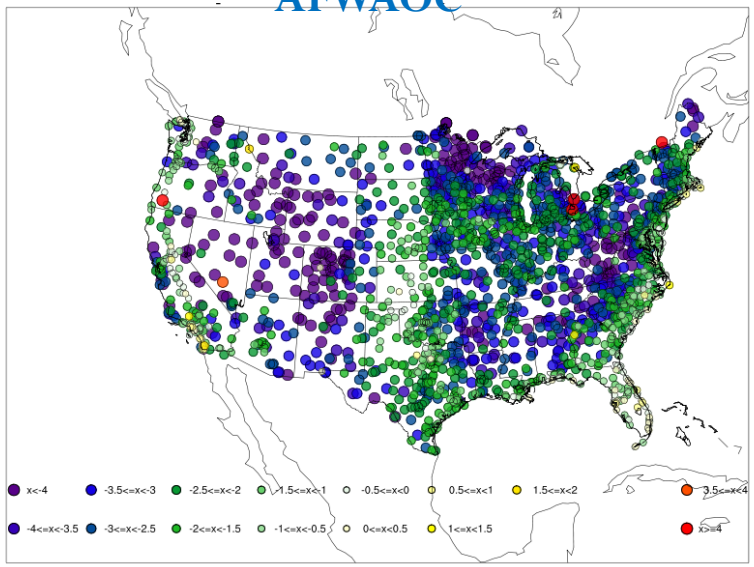


Point Verification

Winter 00 UTC Initializations – 48 h forecast

AFWAOC | **Noah-MP**

Temperature Bias



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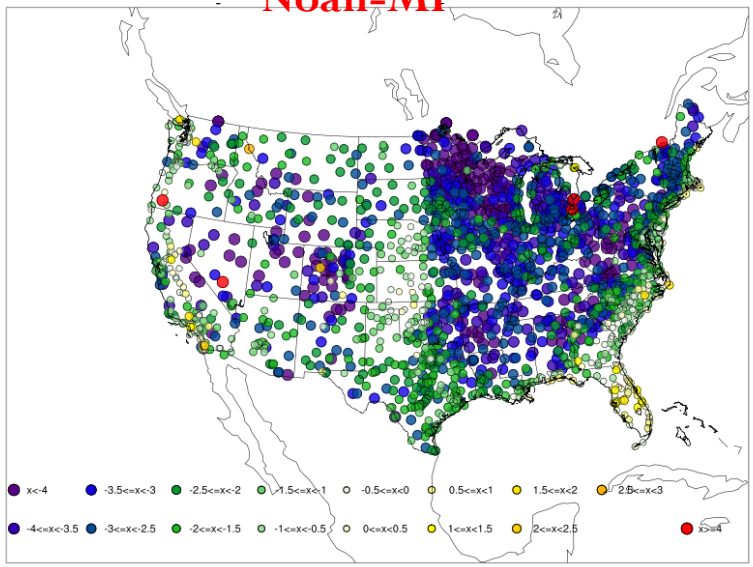

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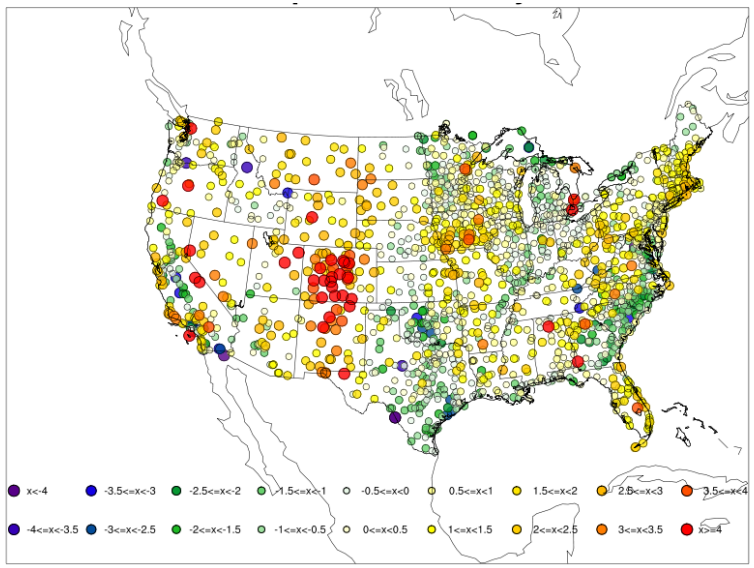
Dew Point Temp Bias



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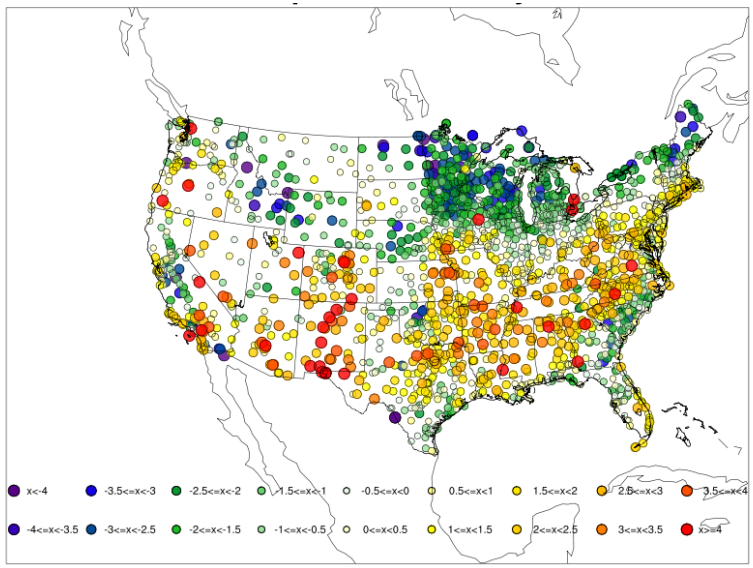


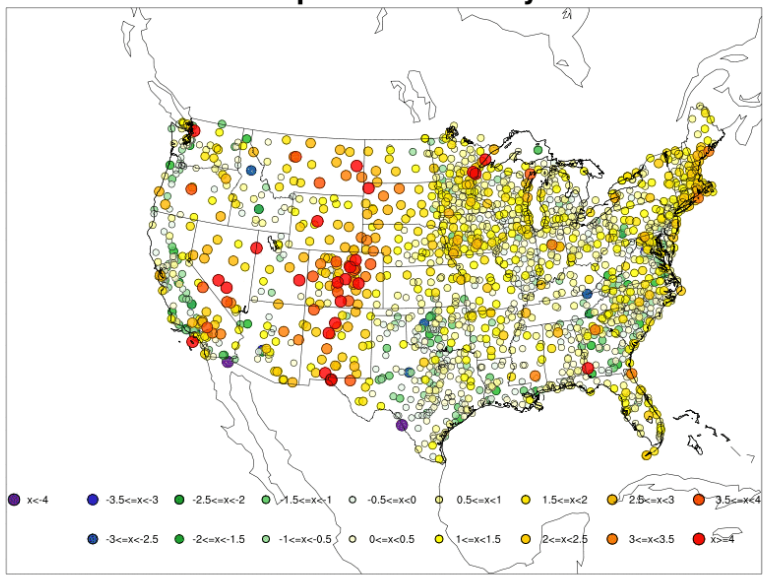
Config=NoahMP_WRFv3.5.1 Season=WINTER Init=00UTC Fcst Hr=48h

Point Verification

Winter 00 UTC Initializations – 2 m Dew Point Temperature

Fcst Hr: 03
Valid: 03 UTC

AFWAOC



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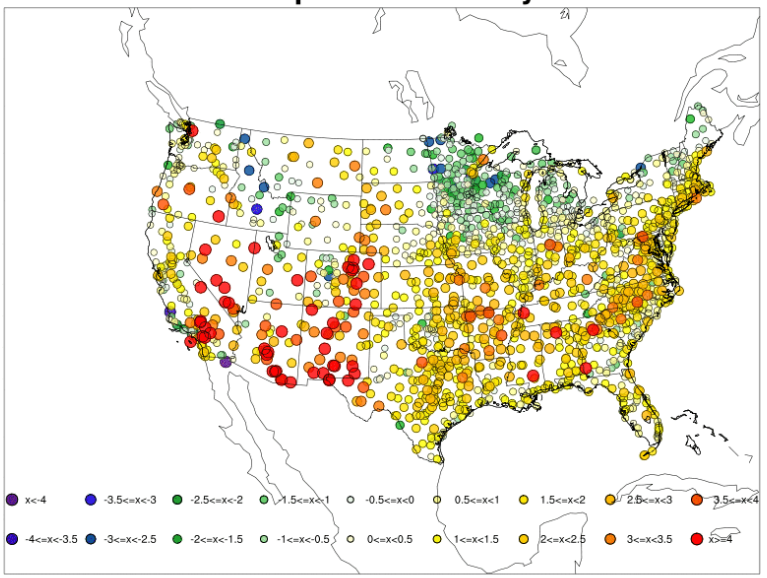
Noah-MP



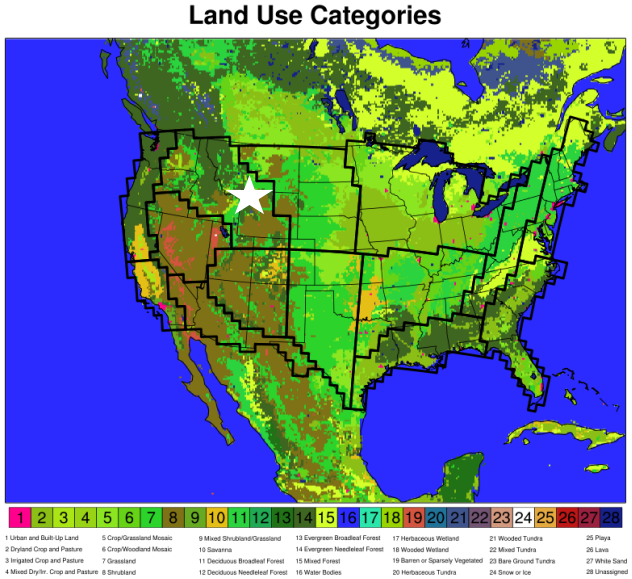
Config=NoahMP_WRFv3.5.1 Season=WINTER Init=00UTC Fcst Hr=03h

LSM Difference Results

Regional Analysis & Case Study

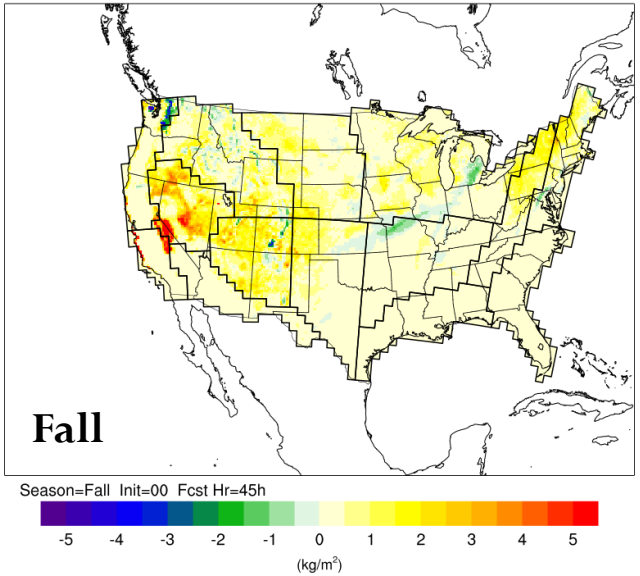
AFWA Operational Configuration (AFWAOC)

Noah-MP Replacement Configuration (Noah-MP)



Snow Water Equivalent (SWE)

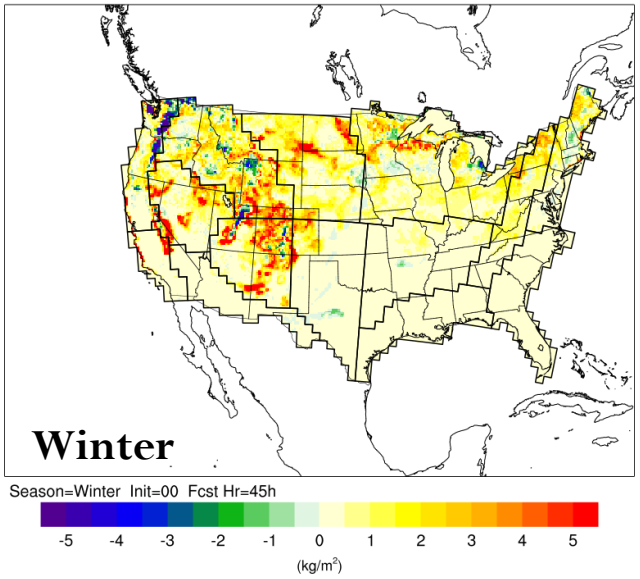
00 UTC Initializations – 45 h forecast

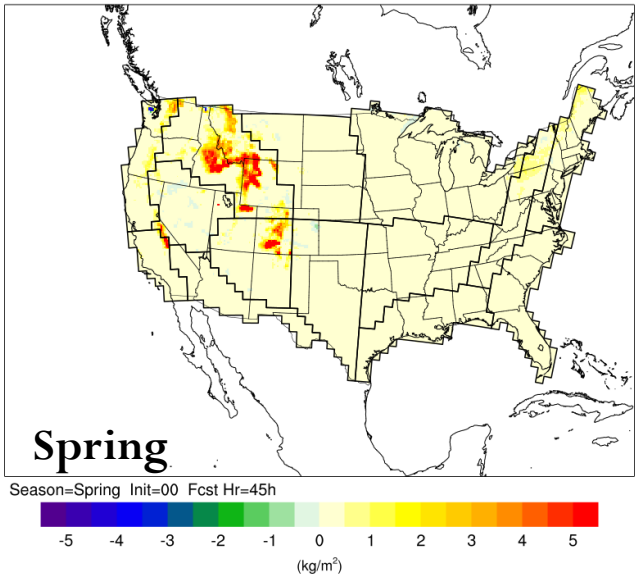


AFWAOC – Noah-MP

Diff > 0 → AFWAOC has larger values
Diff < 0 → NoahMP has larger values

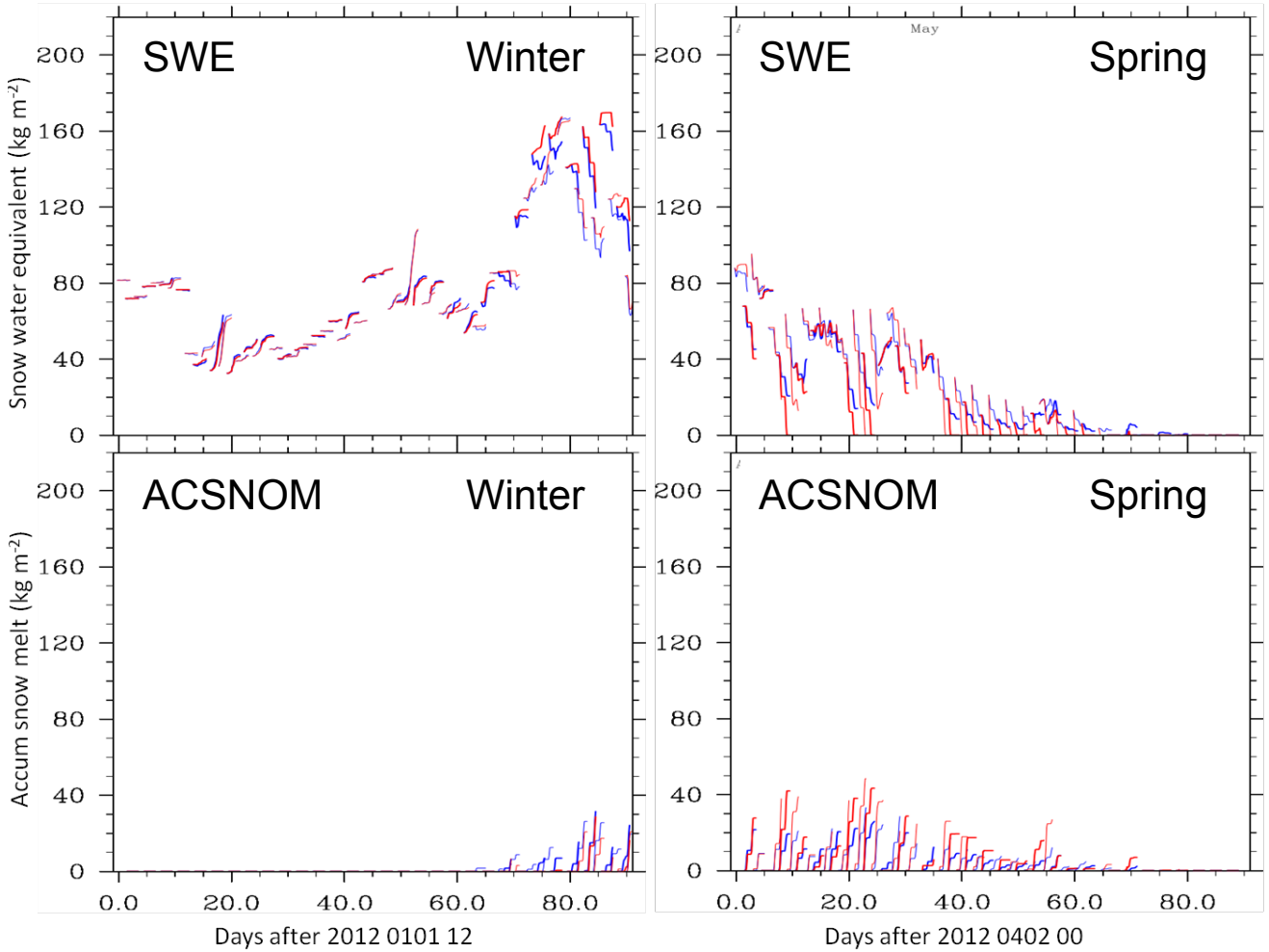
- **Overall CONUS mean shows Noah-MP has less SWE than AFWAOC**
- **Regional differences influenced by terrain height, land use, and season (e.g., Noah-MP has higher SWE over evergreen needleleaf forest)**





SWE & Accumulated Snow Melt (ACSNOM)

Time series of all initializations – Site 1

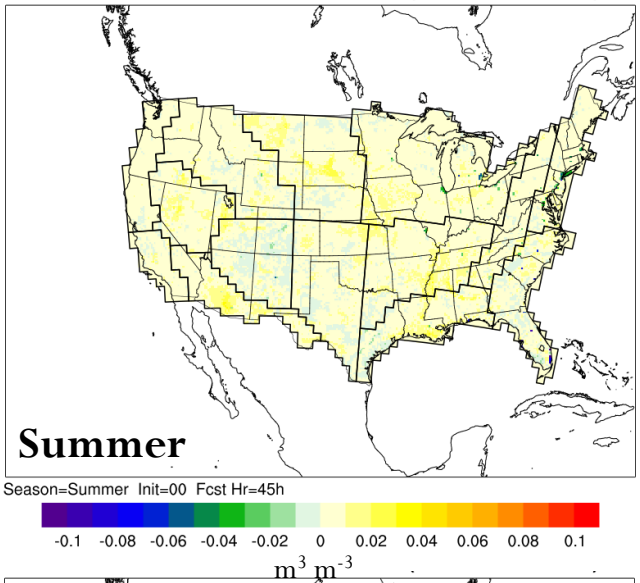


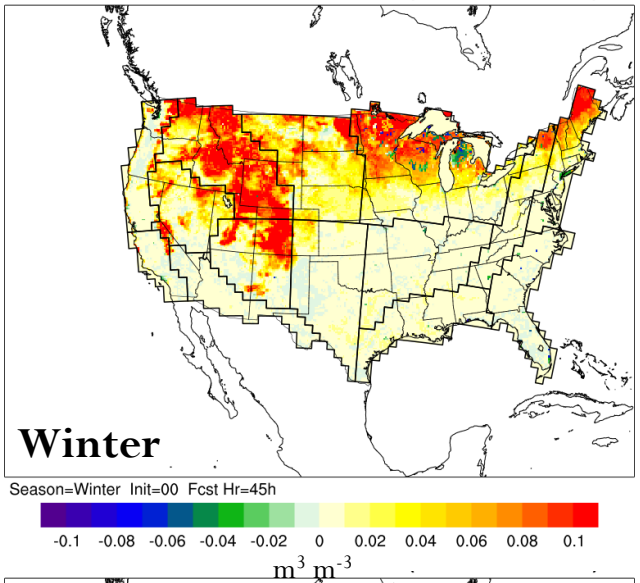
AFWAOC in blue
Noah-MP in red

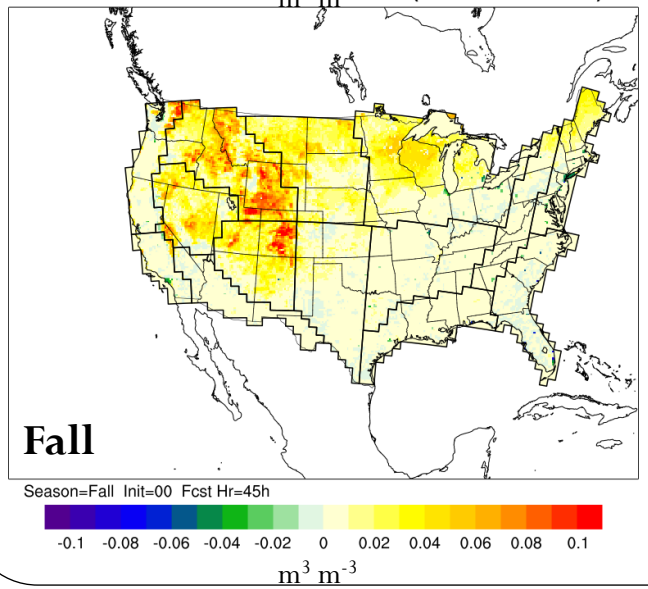
- Site land use type: Evergreen needleaf forest
- Noah-MP produces more SWE in March and less snow in April and May
- Noah-MP has less melting in March and more melting in April and May

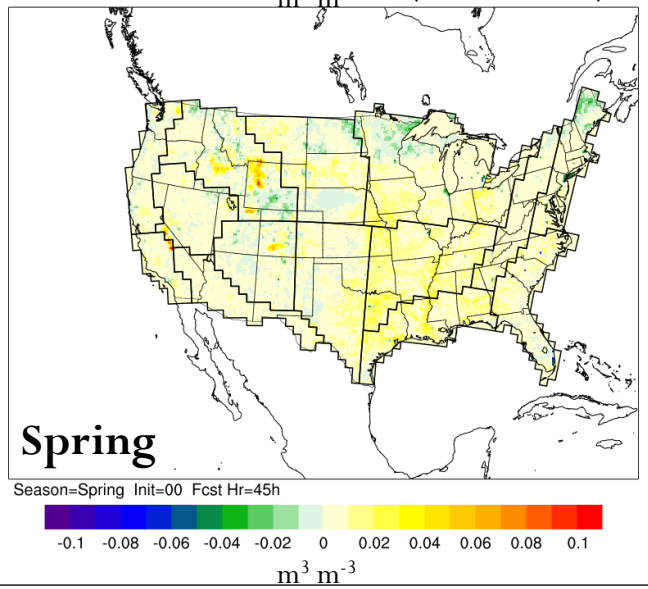
Soil Moisture (0–10 cm)

00 UTC Initializations – 45 h forecast









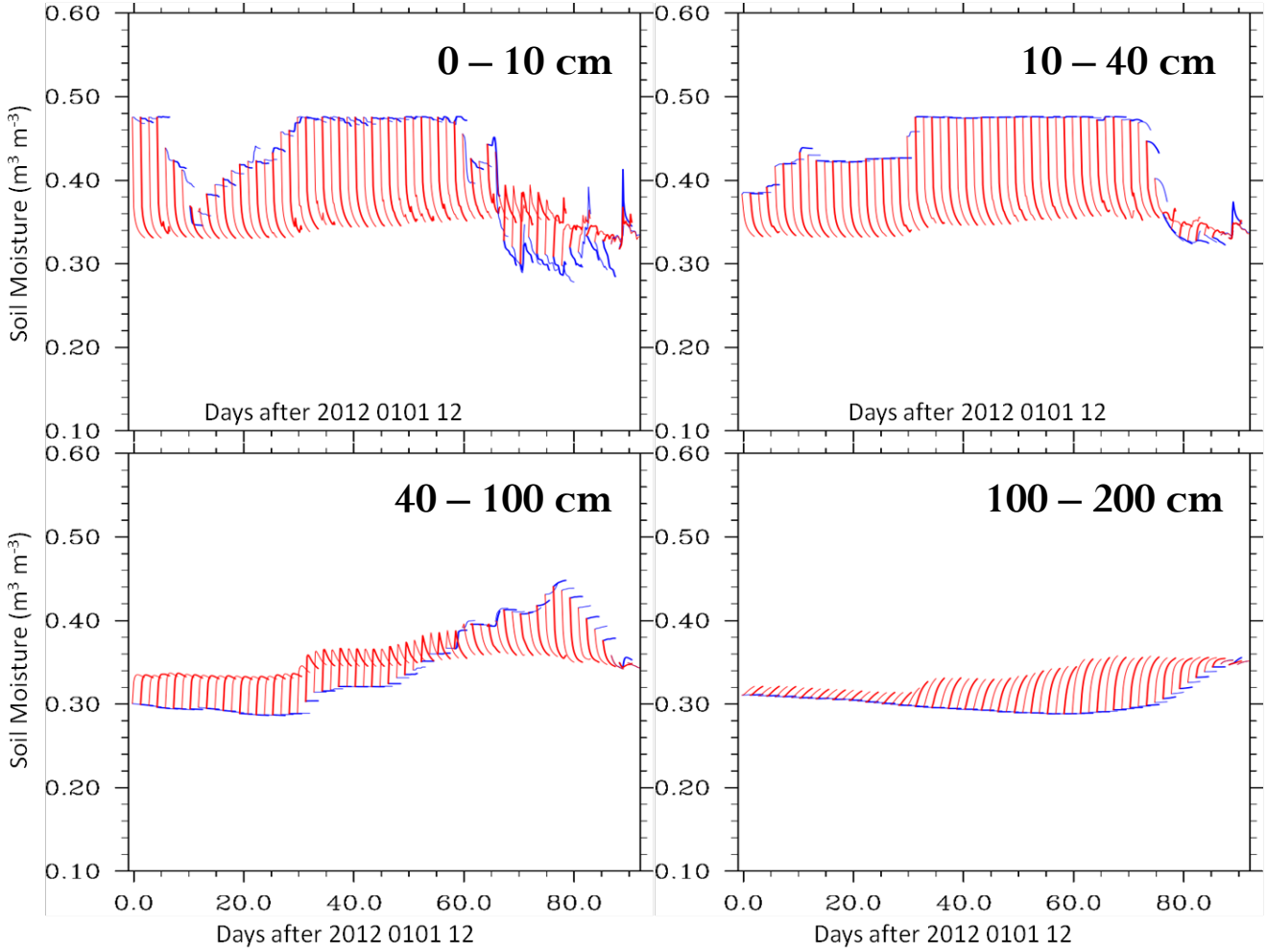
AFWAOC – Noah-MP

Diff > 0 → AFWAOC has larger values
Diff < 0 → NoahMP has larger values

- **Largest differences in the Fall and Winter seasons over the Mountain West and northern CONUS**
- **Noah-MP generally has less soil moisture than AFWAOC in the top soil level (0 – 10 cm)**
- **In Spring, Noah-MP has areas of higher soil wetness than AFWAOC → potentially due to more melting**

Soil Moisture by Level

Time series of all winter initializations – Site 1



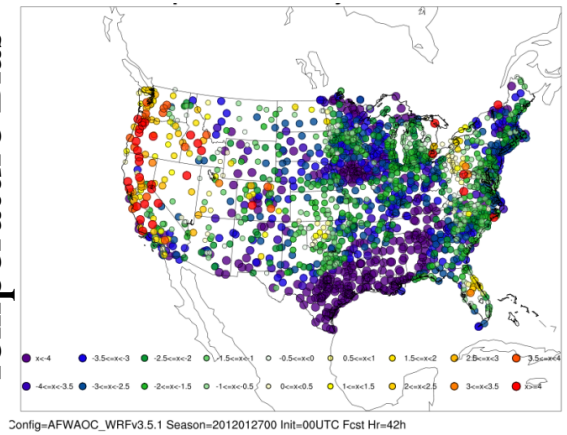
AFWAOC in blue
Noah-MP in red

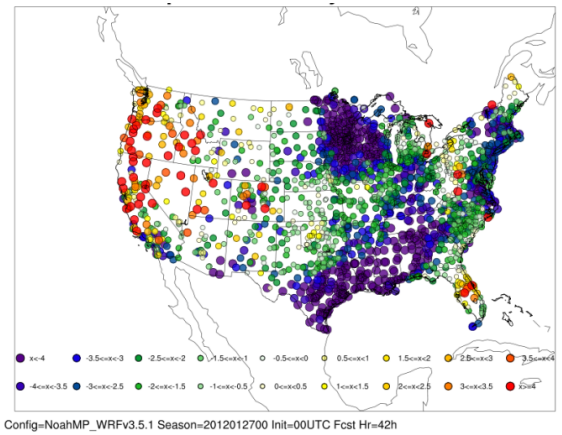
- **The top two levels have drying trend for Noah-MP for most initializations in Jan. and Feb.**
- **Reversal of behavior with deeper soil levels, Noah-MP has a moistening trend**
- **Relation to soil permeability option in namelist (*opt_inf*)**

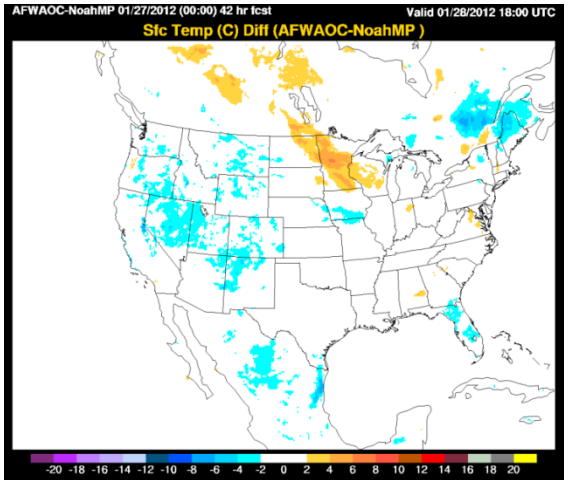
Case Study: 27 January 2012 i00f42

AFWAOC | **Noah-MP** | **Difference**

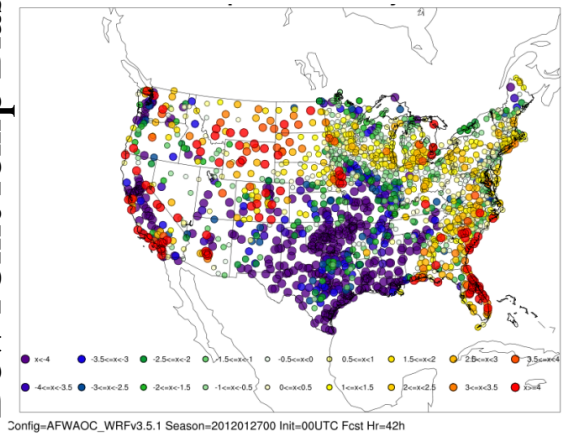
Temperature Bias

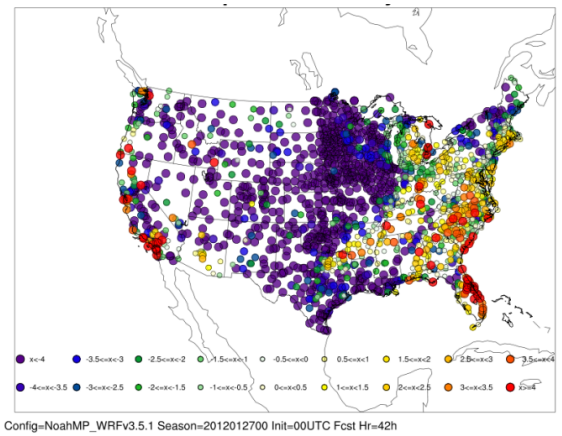


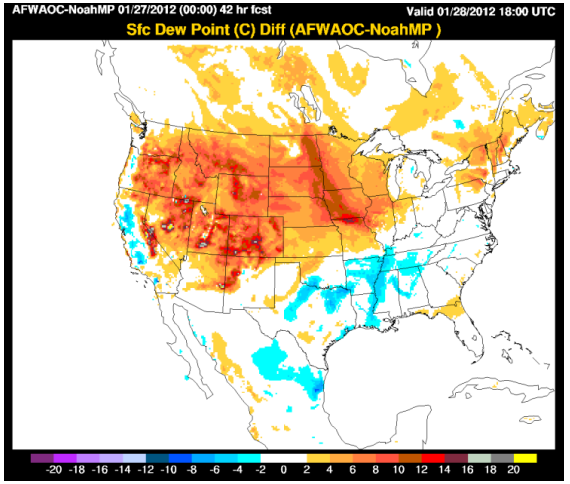




Dew Point Temp Bias

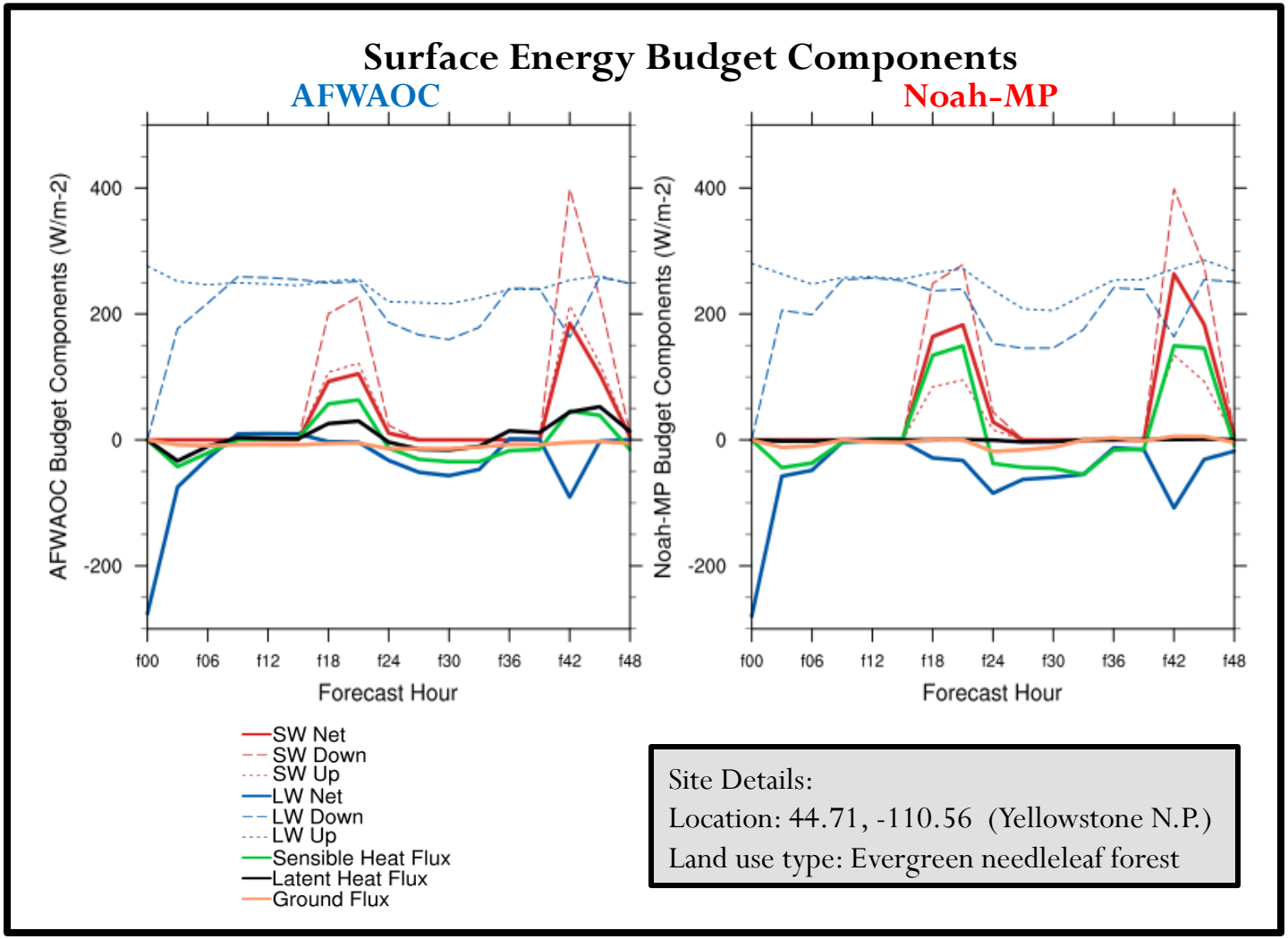






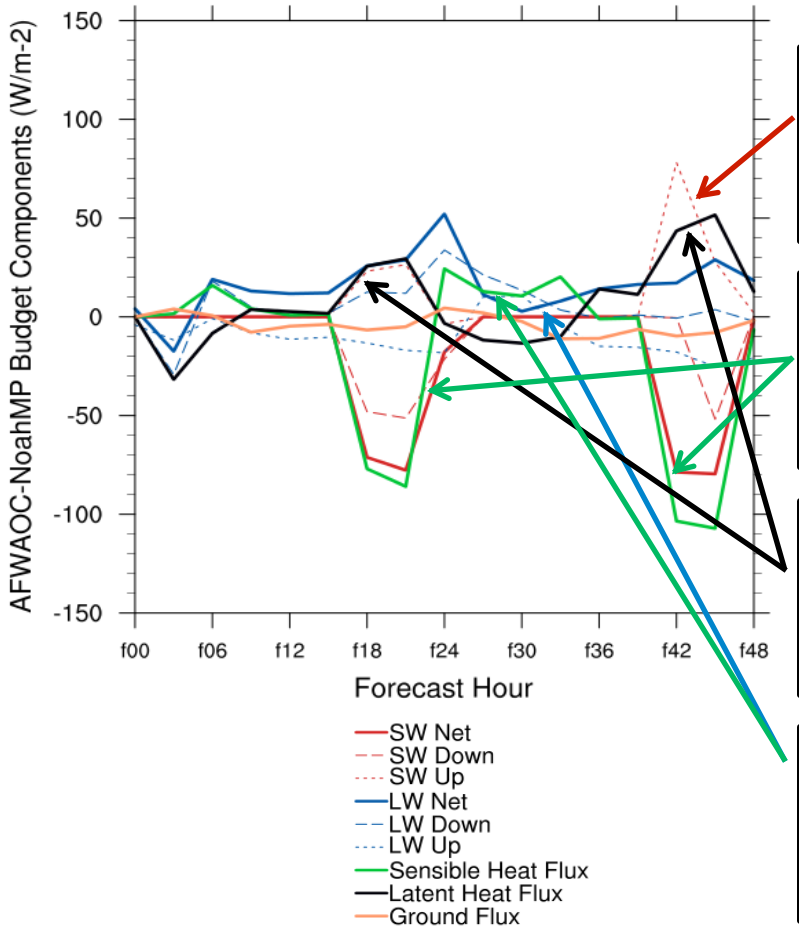
Case Study: 27 January 2012

Surface Energy Budget – Site 1



Case Study: 27 January 2012

Surface Energy Budget – Site 1



With respect to Noah-MP

Lower albedo, less reflected solar radiation over snow cover, warmer surface temps

Higher sensible heat flux, contributes to warmer surface temps

Lower latent heat flux, contributes to reduced cooling

Lower downward long-wave and sensible heat flux, cooler surface temps (cloudy skies)

Summary

- Performed extensive T&E on two WRF configurations in order to assess the performance of Noah-MP
  - Generally, a cold temperature bias for both configurations
  - Performance differs spatially and temporally:
    - In the Midwest during winter, Noah-MP has significantly cooler temperature biases at times valid from 03 – 15 UTC (AFWAOC typically closer to observations)
    - During the summer, in the central CONUS and desert SW, Noah-MP has significantly higher dew point biases (better performer is dependent on forecast hour)
- Areas of further investigation:
  - Differences in soil moisture (w/ emphasis on winter season)
  - Differences in snow water equivalent/snow depth/melting
    - Water/moisture budgets → where is it going?
  - Impact of differences in surface energy budget and/or effects of land use type
- For more information regarding testing set-up, model forecast graphics, full suite of verification results, supplementary information, and the final report:
  http://www.dtcenter.org/eval/meso_mod/afwa_test/wrf_v3.5.1/index.php