Implementation of the Community Land Model (CLM) 4.5 Lake Model in the NOAA Unified Forecasting System (UFS)

Tanya Smirnova, Samuel Trahan, Stan Benjamin

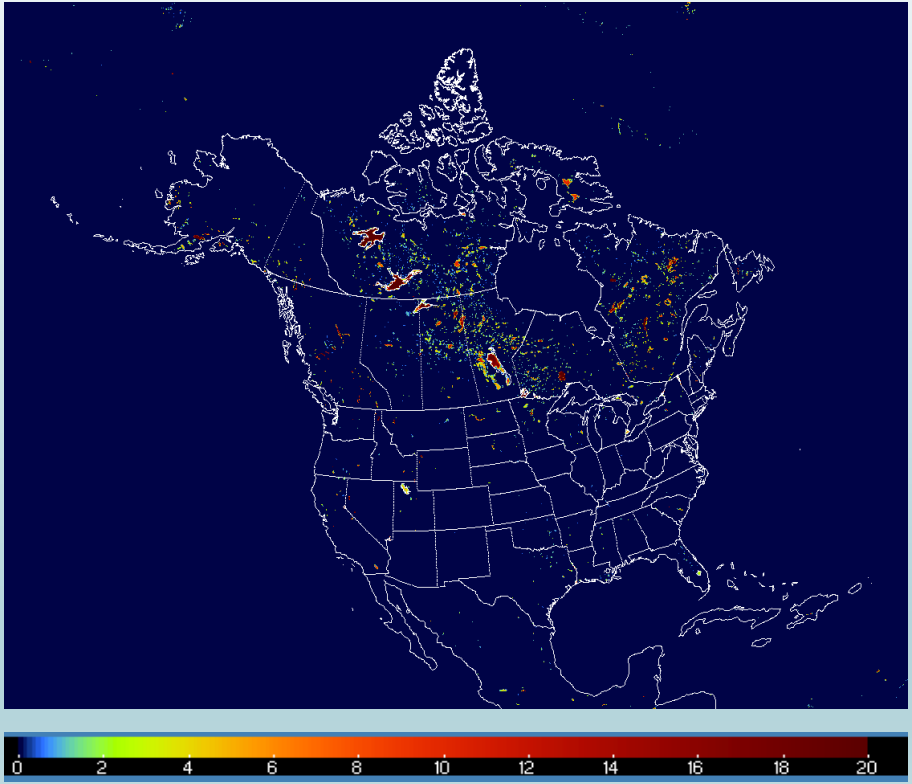
NOAA Global Systems Laboratory (GSL), CIRES at CU Boulder, CO, US

7th LAKES 2024 Workshop, Milan, Italy, 20-22 November 2024

UFS-based Rapid Refresh Forecasting System (RRFS) – a next-generation NOAA weather model

- Experimental RRFS is under testing at the NOAA Environmental Modeling Center (EMC)
- The RRFS runs on North America Domain with 3-km horizontal spacing
- RRFS physics – same as in current operational regional model HRRR:
  - RUC land-surface model
  - MYNN surface and boundary layer schemes
  - aerosol-aware Thompson microphysics
  - RRTMG radiation
  - The 1D CLM lake model (CLM-Lake) - implemented in the UFS in October 2023 via Common Community Physics Package (CCPP)

GLDBv3 Lake depths in North America RRFS



- If a lake covers >75% of grid cell, then this point is assigned to be a lake
- Large lakes (>15,000 km^2) are excluded from the lake mask
- The RRFS lake depth is initialized from GLDBv3 data, most of the lakes have constant depth (high-resolution bathymetry GLOBathy is in the testing stage)
- Lake variables are initialized from the previous forecast (cycled), ~10 months of cycling in the RRFS

CLM-Lake Model characteristics

Community Land Model (CLM) 4.5 Lake Model main characteristics (see Section 9 in CLM 4.5 documentation CLM version 4.5)

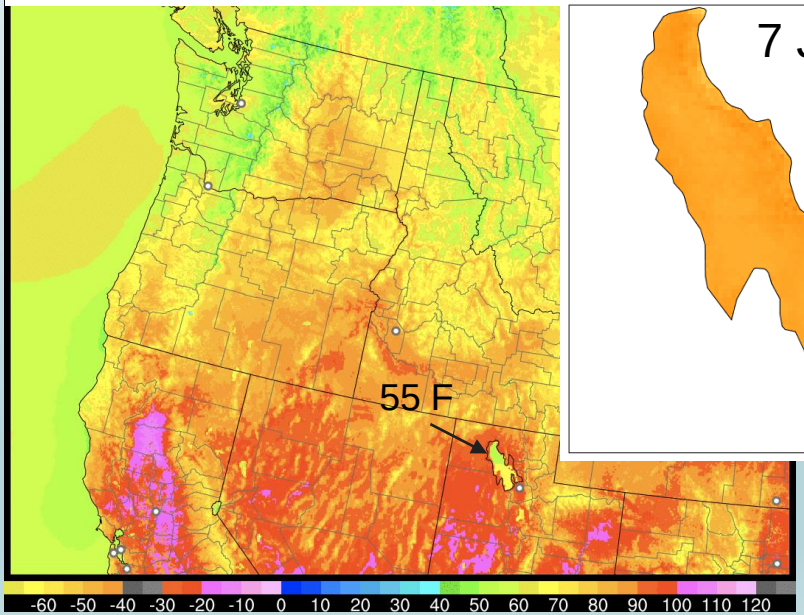
- Vertical structure:
  - Up to 5 levels in snow (if exists)
  - 10 levels in lake
  - 10 levels in bedrock
- Molecular, eddy and convective mixing;
- Freezing/thawing in snow/lake/soil, fractional lake ice;
- Surface fluxes computed using internal surface layer scheme;
- Temperature is continuous in the vertical from resolved snow layers (if present), then the lake body, and then the soil and bedrock - total 25 levels for temperature

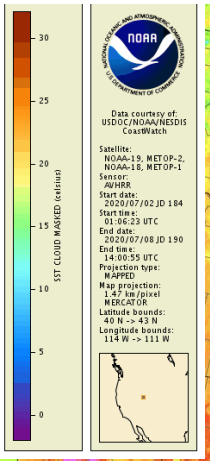
Modifications to the CLM-Lake in RRFS

- Bug fixes in lake initialization in WRF-based version of the CLM lake model
- Changes in the main lake subroutine:
  - COARE formulation for thermal roughness length
  - Bug fix for fractional sea ice during the thawing process which was preventing from complete lake ice melting in the cycled models
  - Salinity is not resolved in the CLM lake model, therefore, modifications were made for the Great Salt Lake (GSL): use bi-monthly lake climatology to limit temperature changes (+/- 3K), also freezing is not allowed
- All lake variables are continuously cycled (initialized from the previous forecast, Benjamin et al. 2022, https://doi.org/10.5194/gmd-15-6659-2022)

The “salinity fix” for the Great Salt Lake corrects too cold lake temperatures

Skin temperature analysis before the GSL “salinity fix”

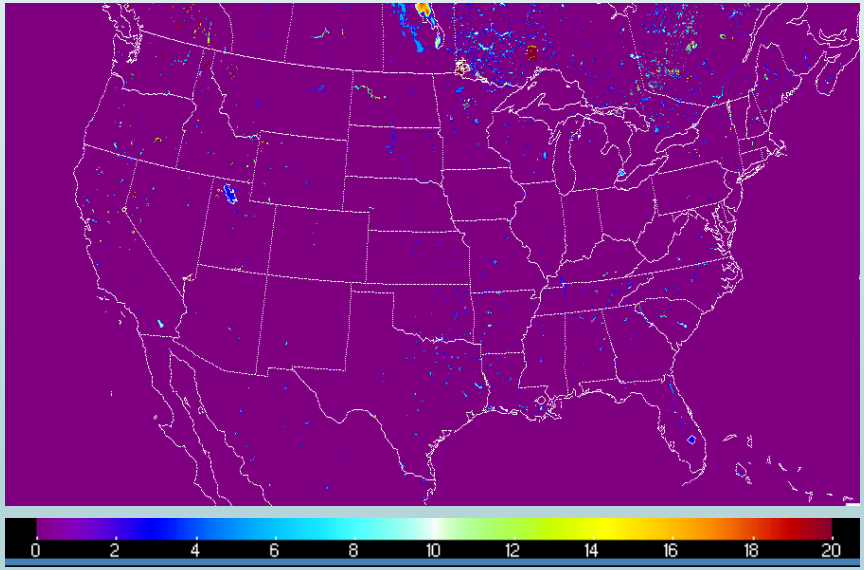




Skin temperature after the climatological bounding for the GSL

CLM-Lake's testing in cycled retrospective RRFS on CONUS domain

GLDBv3 Lake depth (m)



- Control – w/out CLM-Lake, Test – with CLM-Lake;
- The Great Lakes are excluded from the lake mask;
- Surface verification for 21 stations near lakes:

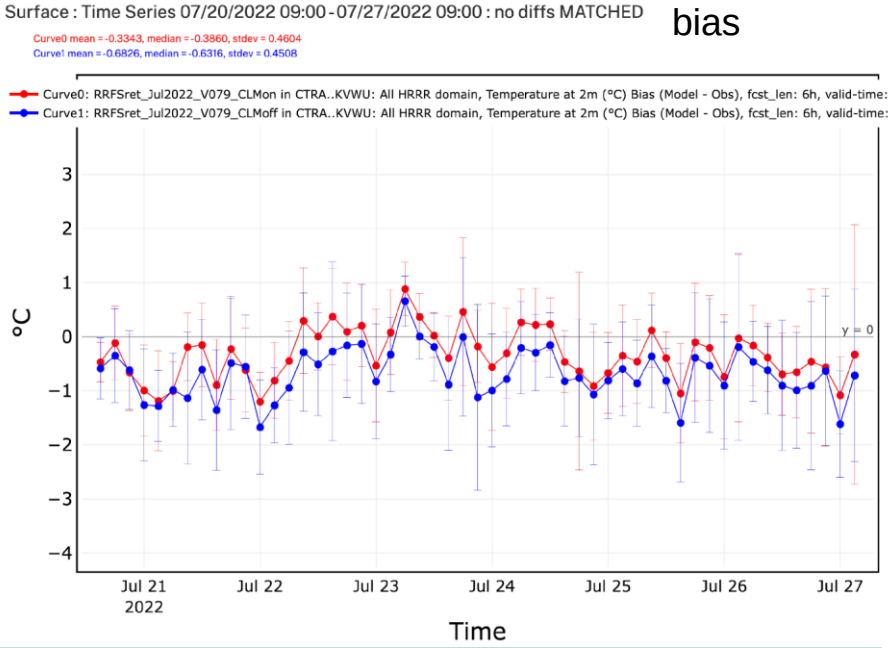
KPEO, KITH - Finger Lakes, NY
KMTC, CYQG - Lake St. Clair
CYRJ - Saint-Jean Lake
CYYW - Lake Nipigon
KFGN, KRRT, CYQK, KBDE, CTRA – Lake of the Woods
CXGH - Lake Winnipeg
CWOJ - Lake Manitoba
KVWU - Red Lake
KHIF, KSLC - The Great Salt Lake
KTVL - Lake Tahoe
KOSH - Lake Winnebago
KOBE - north of Lake Okeechobee
KEZS - Shawano Lake
CWGL - Lake Simcoe

Summer RRFS retro, 21-27 July 2022

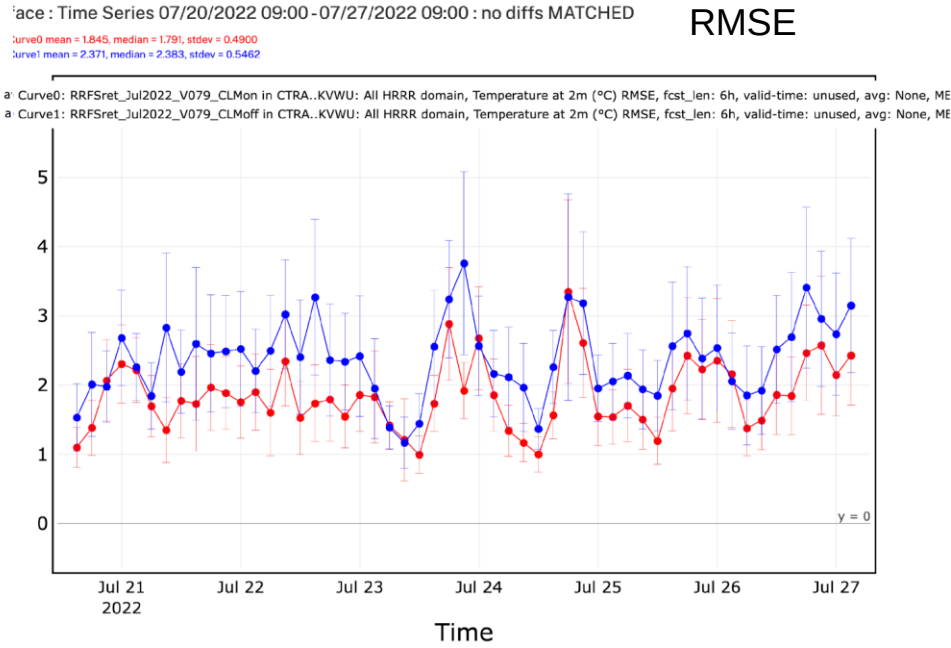
2-m temperature, 6-h forecast, lake stations

Red – with CLM-Lake
Blue – no CLM-Lake

bias



RMSE

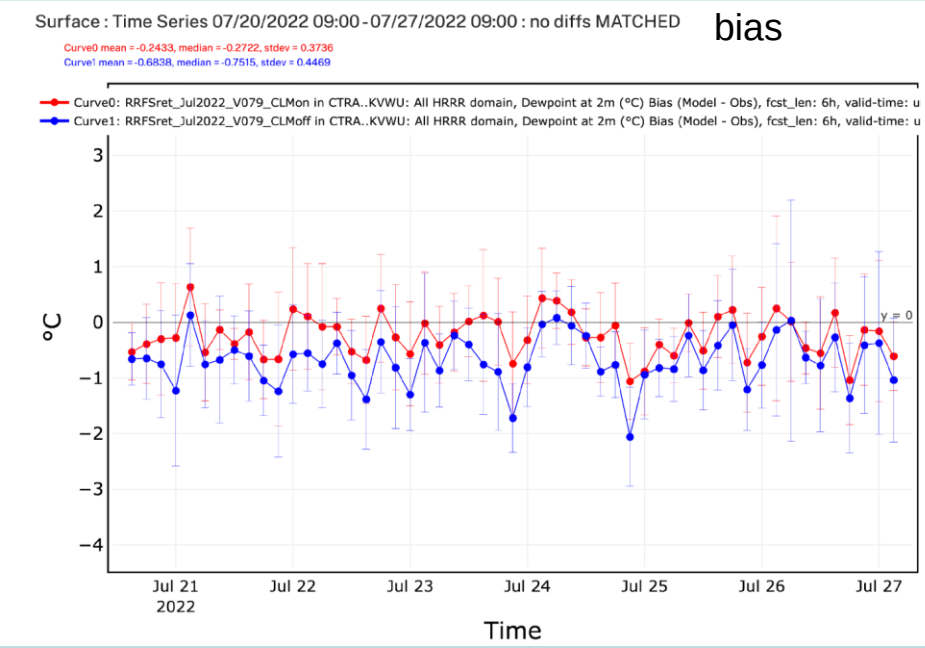


Summer RRFS retro, 21-27 July 2022

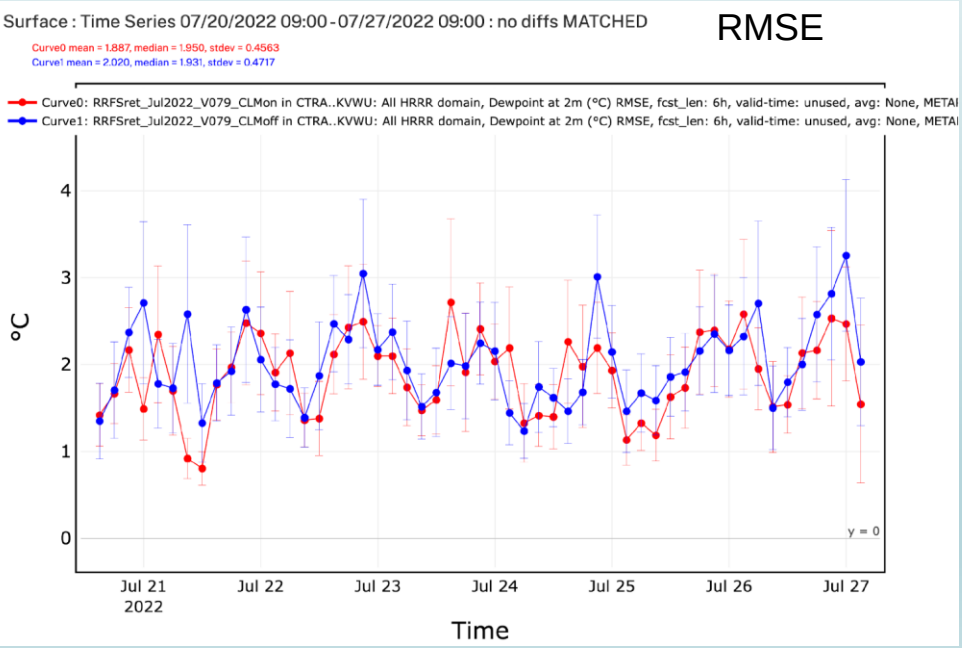
2-m dew point, 6-h forecast, lake stations

Red – with CLM-Lake
Blue – no CLM-Lake

bias



RMSE

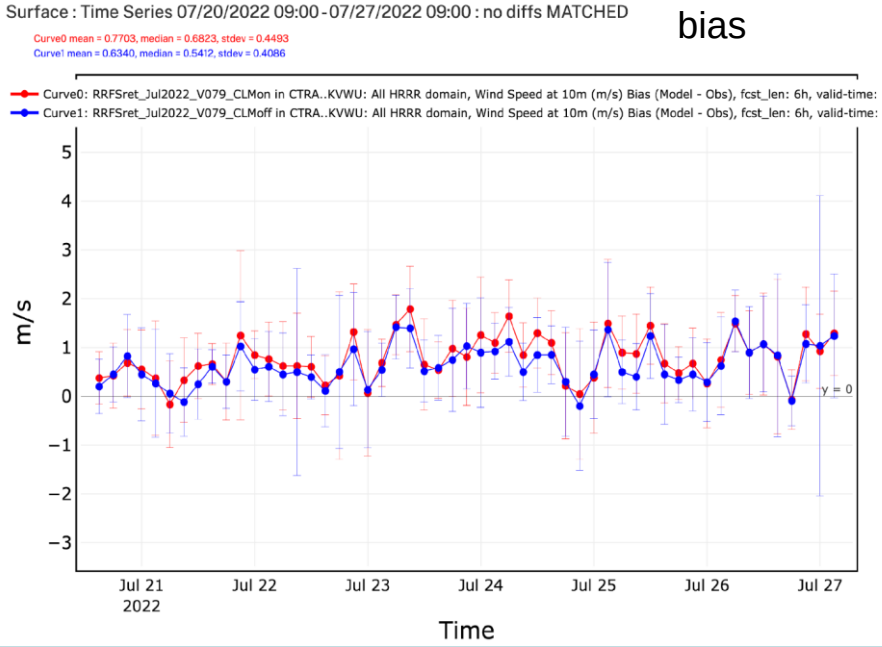


Summer RRFS retro, 21-27 July 2022

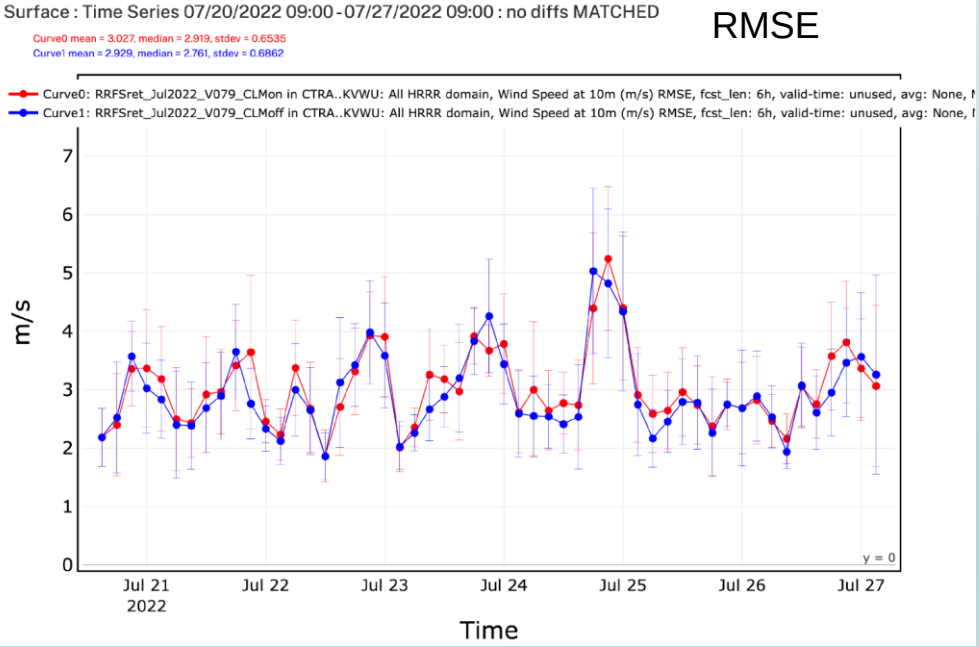
10-m wind, 6-h forecast, lake stations

Red – with CLM-Lake
Blue – no CLM-Lake

bias



RMSE

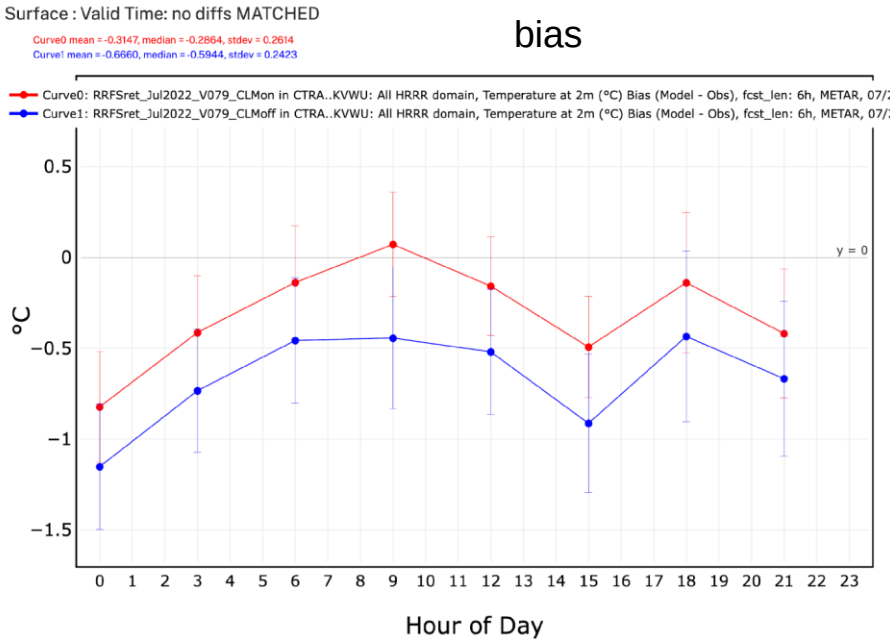


Summer RRFS retro, 21-27 July 2022

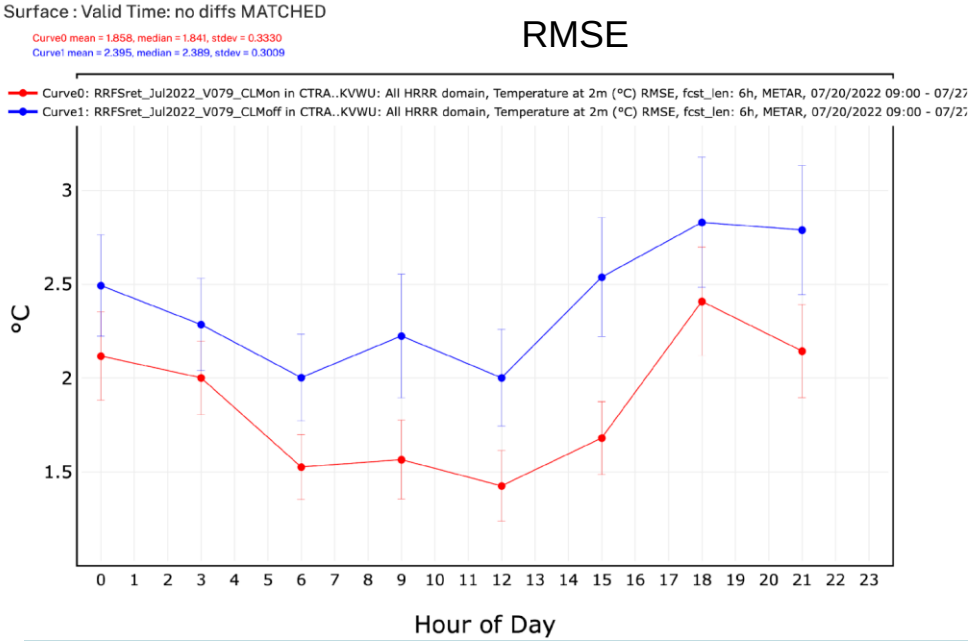
2-m temperature diurnal variations, 6-h forecast, lake stations

Red – with CLM-Lake
Blue – no CLM-Lake

bias



RMSE

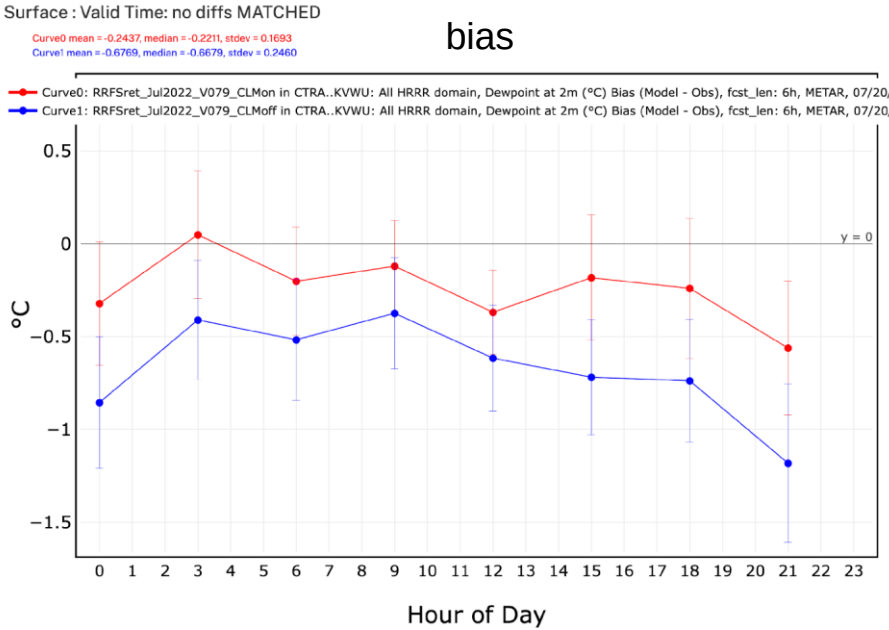


Summer RRFS retro, 21-27 July 2022

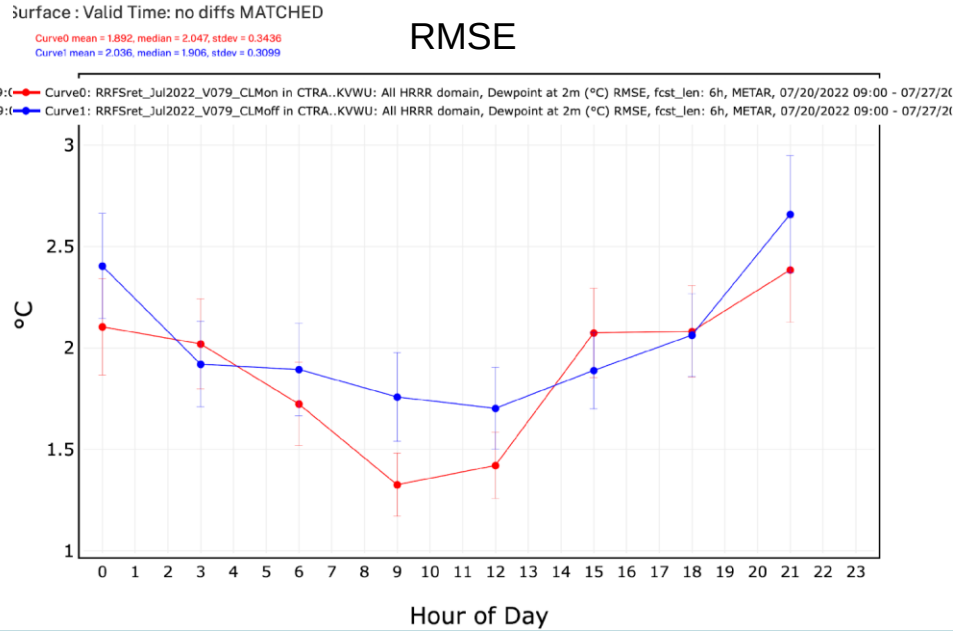
2-m dewpoint diurnal variations, 6-h forecast, lake stations

Red – with CLM-Lake
Blue – no CLM-Lake

bias



RMSE

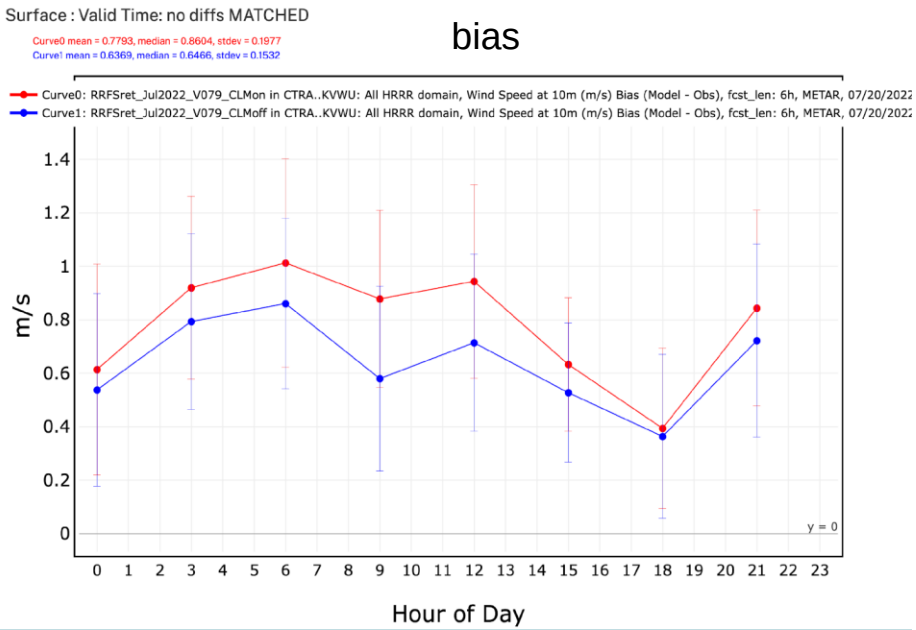


Summer RRFS retro, 21-27 July 2022

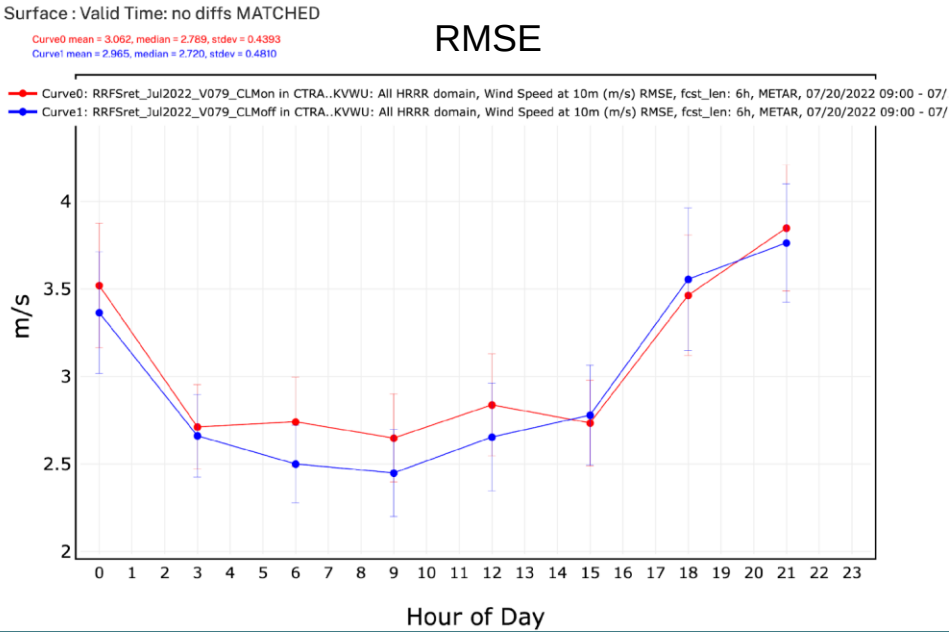
10-m wind diurnal variations, 6-h forecast, lake stations

Red – with CLM-Lake
Blue – no CLM-Lake

bias



RMSE

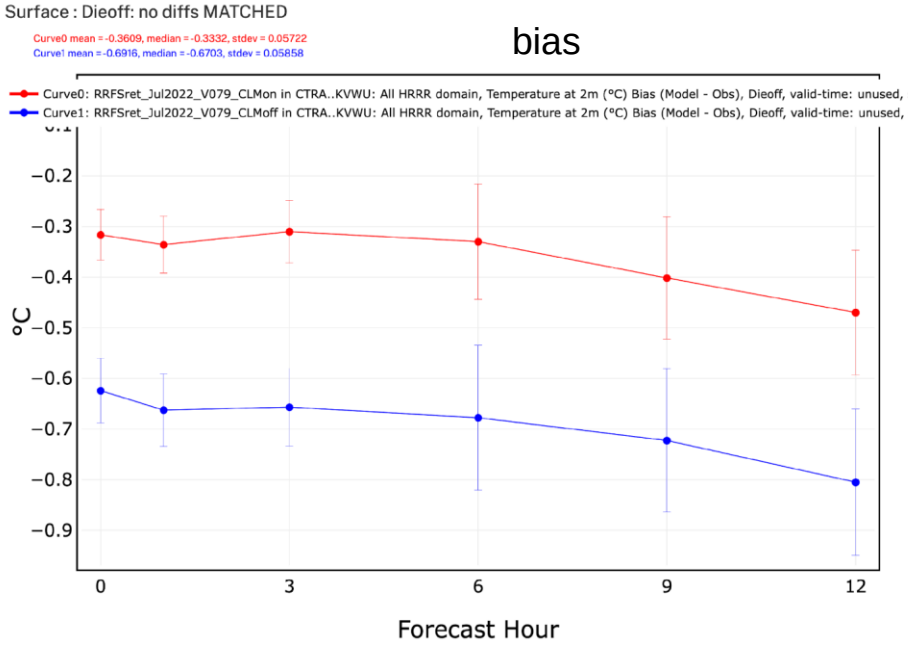


Summer RRFS retro, 21-27 July 2022

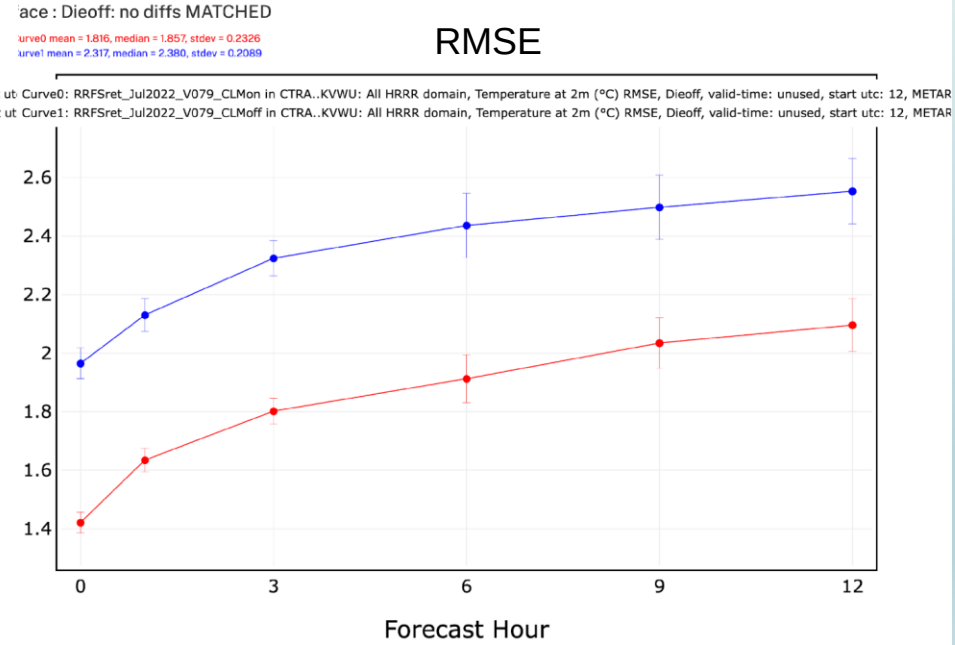
Red – with CLM-Lake
Blue – no CLM-Lake

2-m temperature die-off, lake stations

bias



RMSE

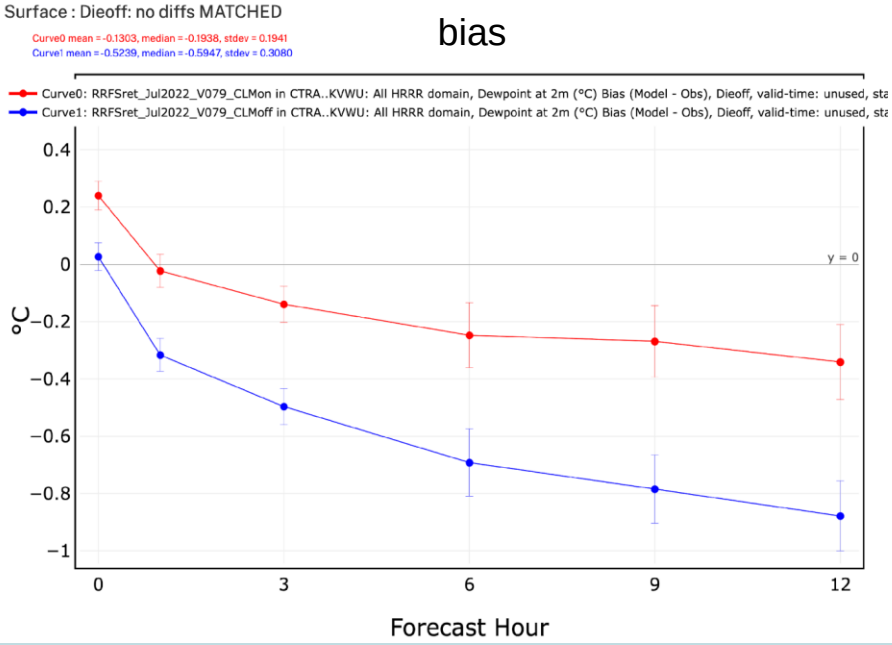


Summer RRFS retro, 21-27 July 2022

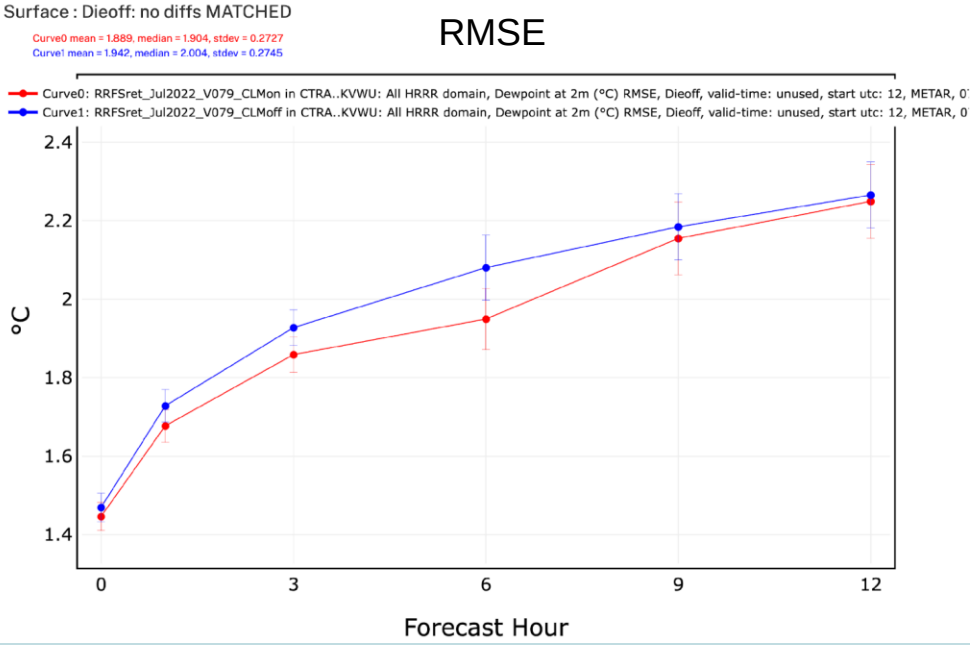
2-m dew point die-off, lake stations

Red – with CLM-Lake
Blue – no CLM-Lake

bias



RMSE

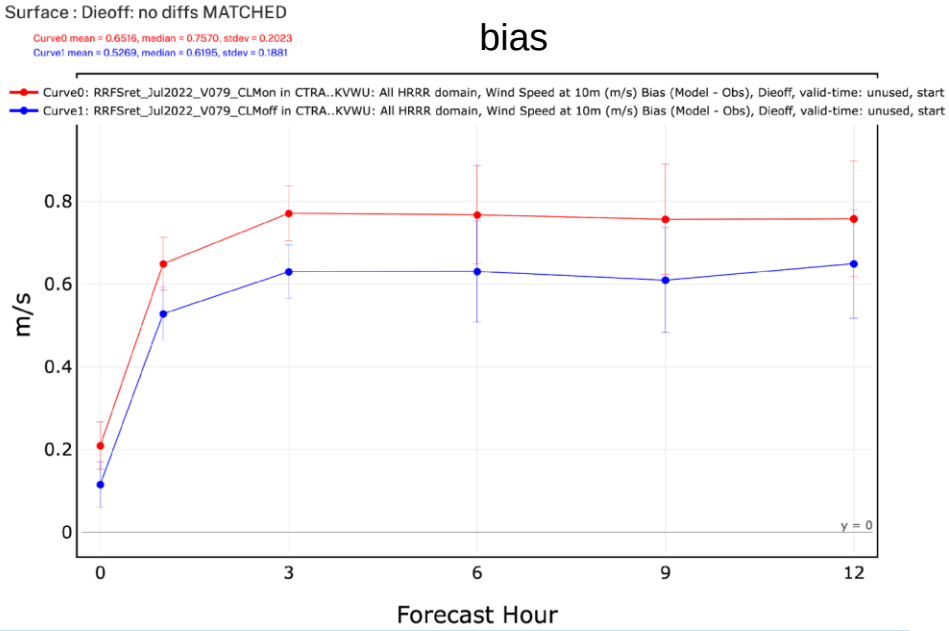


Summer RRFS retro, 21-27 July 2022

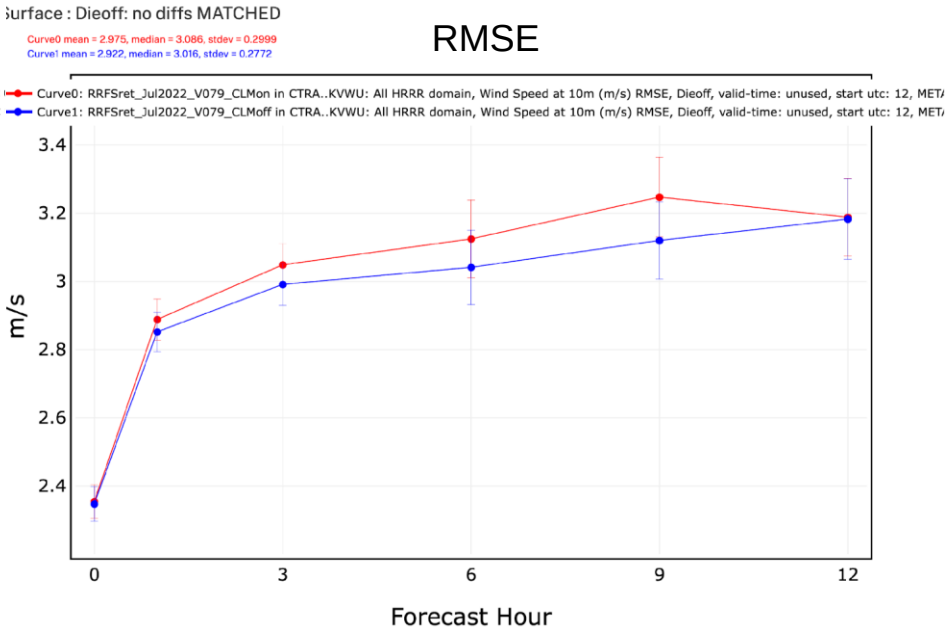
10-m wind die-off, lake stations

Red – with CLM-Lake
Blue – no CLM-Lake

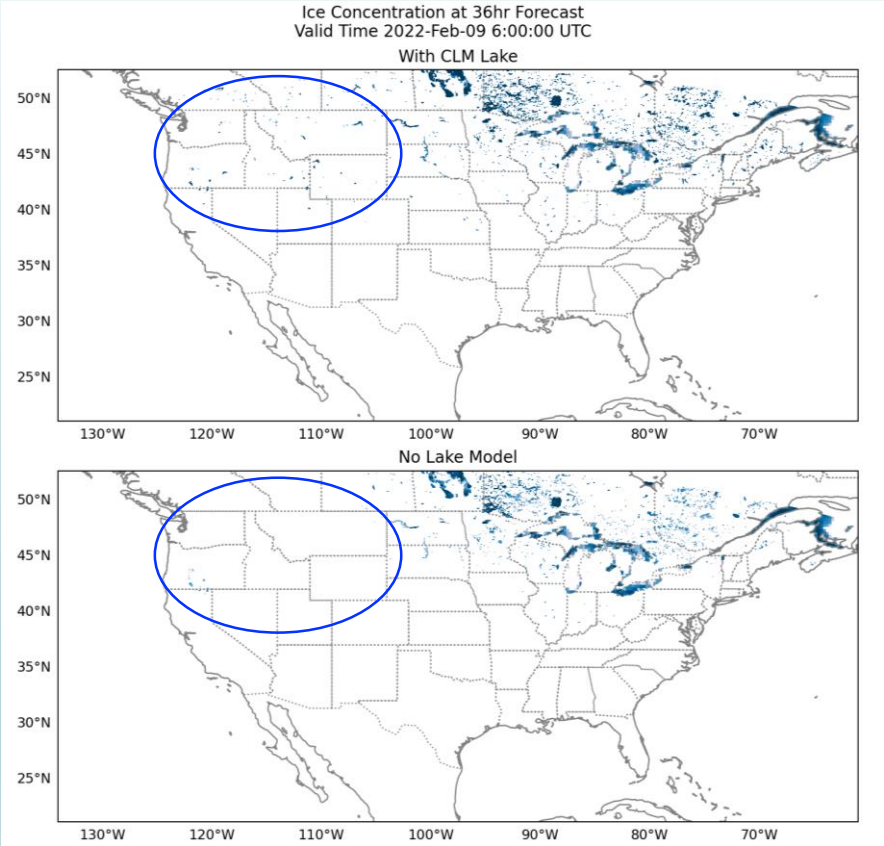
bias

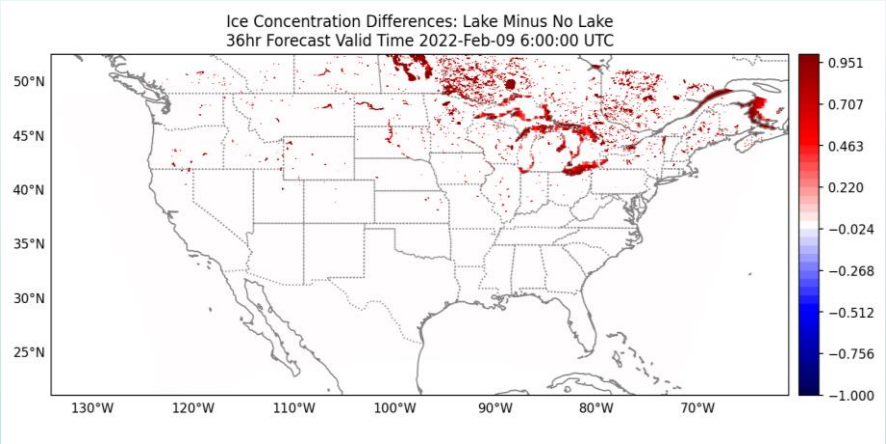


RMSE



Winter RRFS retro, 1-9 February 2022





- Without CLM-Lake ice is initialized from the global model based on the satellite information
- With CLM-Lake
  - lake ice is created in the CLM-Lake and evolves in the cycled RRFS
  - many small lakes are frozen after a week of cycling compared to global data
  - higher ice concentrations for most lakes

CLM-Lake in the real-time cycled RRFS

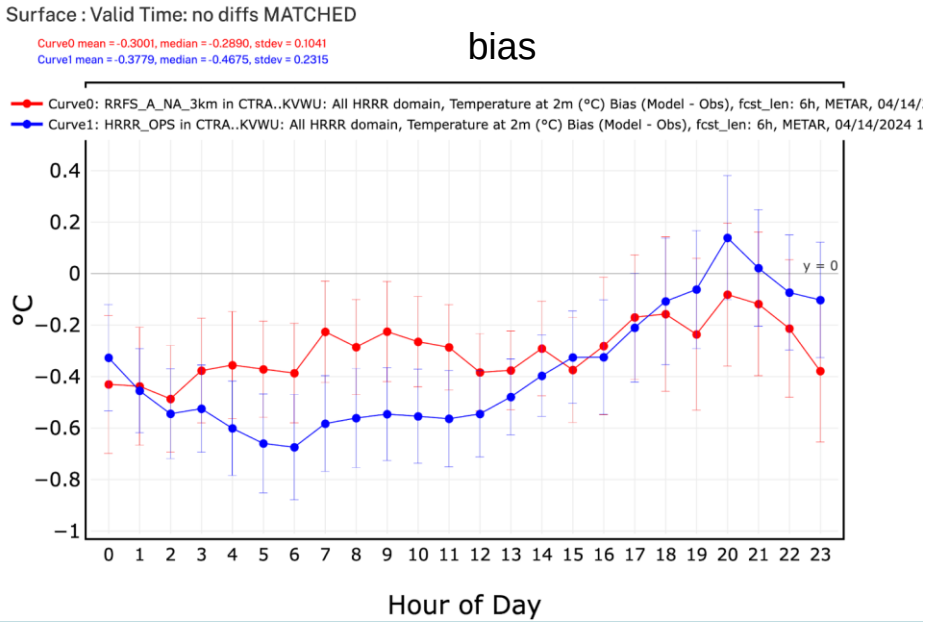
- The 1D CLM-Lake is implemented in the RRFS in January 2024
- Lake variables are evolving in RRFS for ~10-month
- Comparisons to the current NOAA operational regional model HRRR cycled since August 2018 for ~75 months

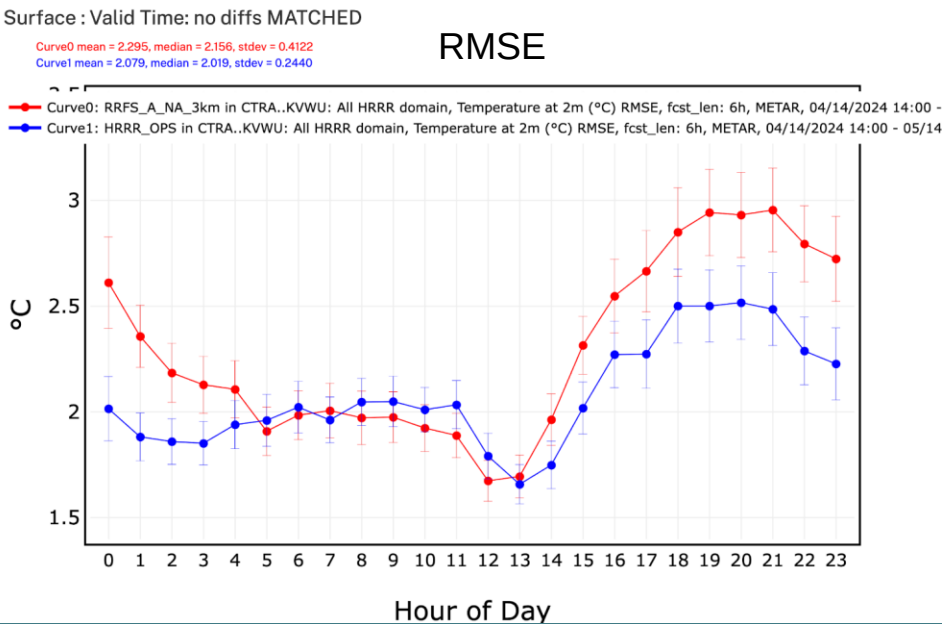
Real-time RRFS versus HRRR, both have CLM-Lake

14 April – 14 May 2024

Red – RRFS
Blue – HRRR

2-m temperature diurnal variations, 6-h forecast, lake stations



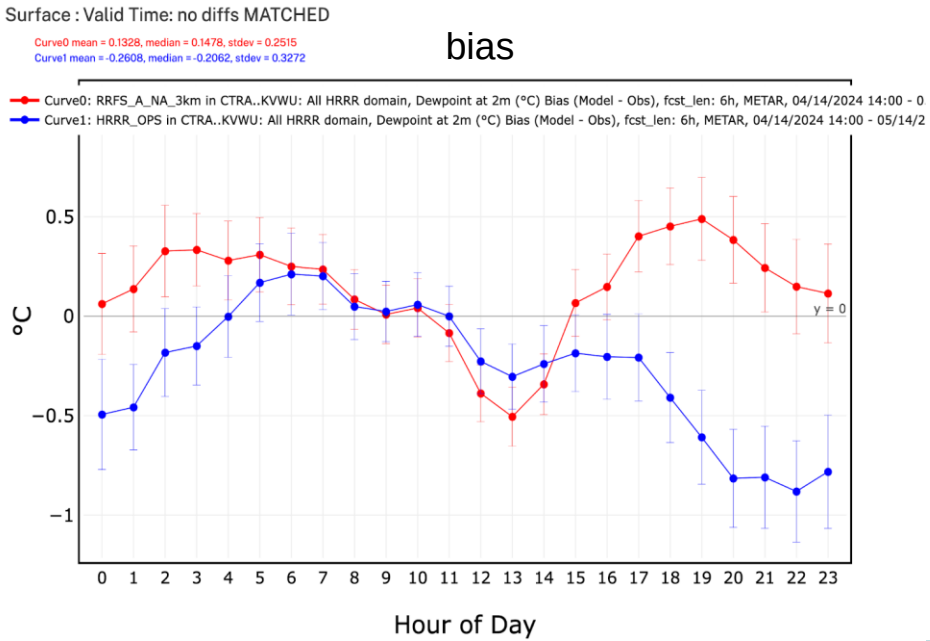


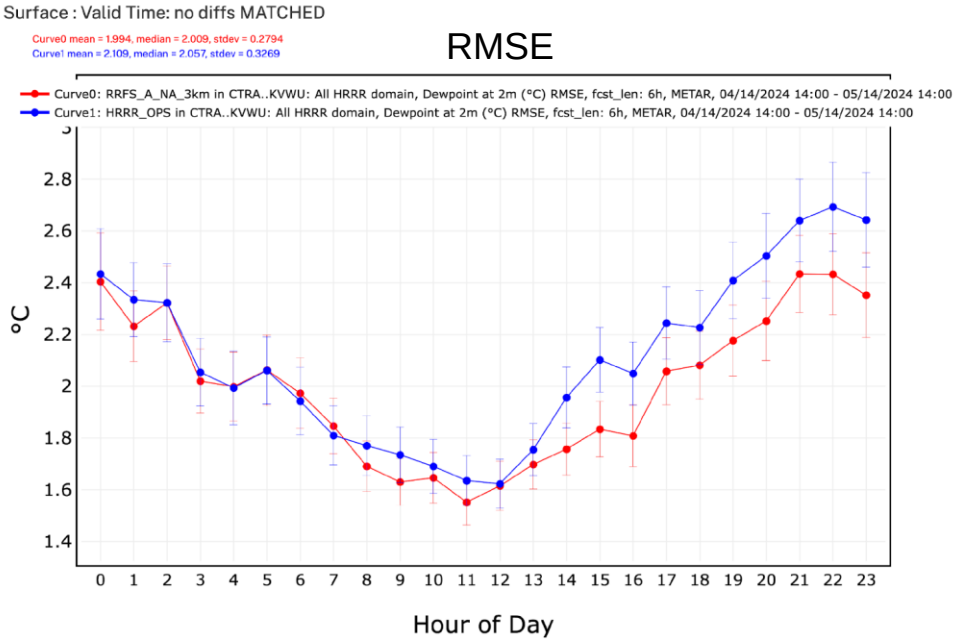
Real-time RRFS versus HRRR, both have CLM-Lake

14 April – 14 May 2024

Red – RRFS
Blue – HRRR

2-m dewpoint diurnal variations, 6-h forecast, lake stations



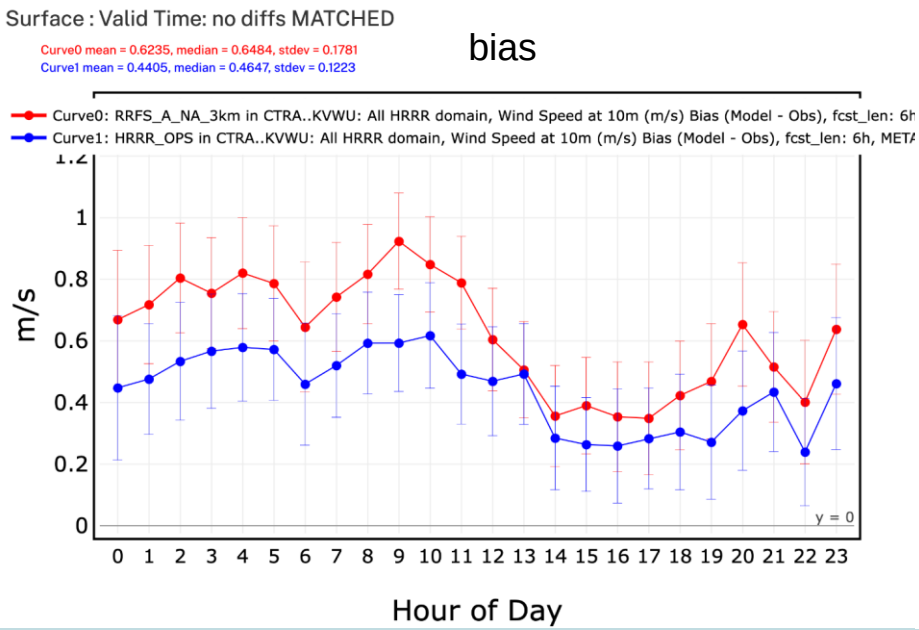


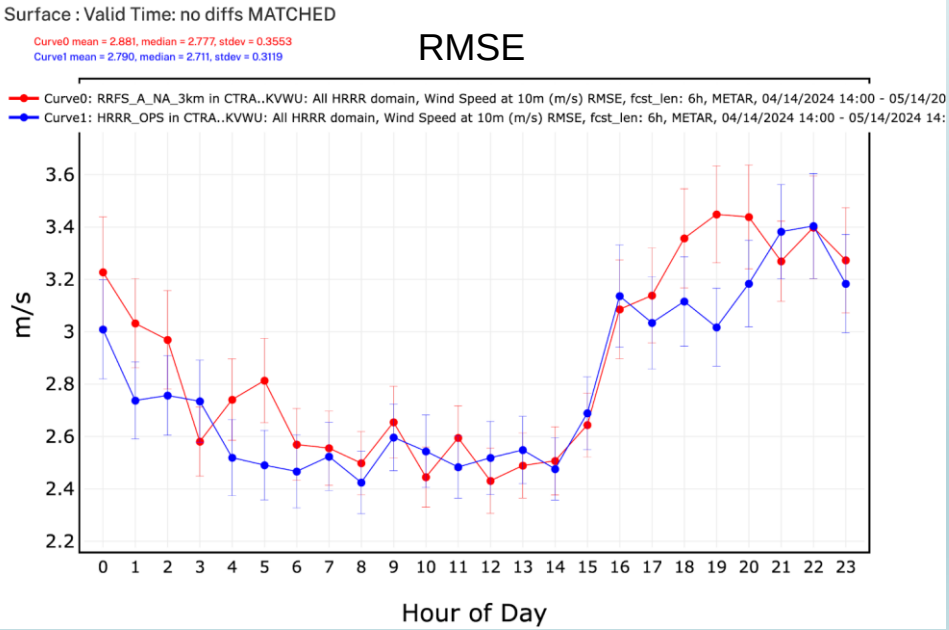
Real-time RRFS versus HRRR, both have CLM-Lake

14 April – 14 May 2024

10-m wind diurnal variations, 6-h forecast, lake stations

Red – RRFS
Blue – HRRR





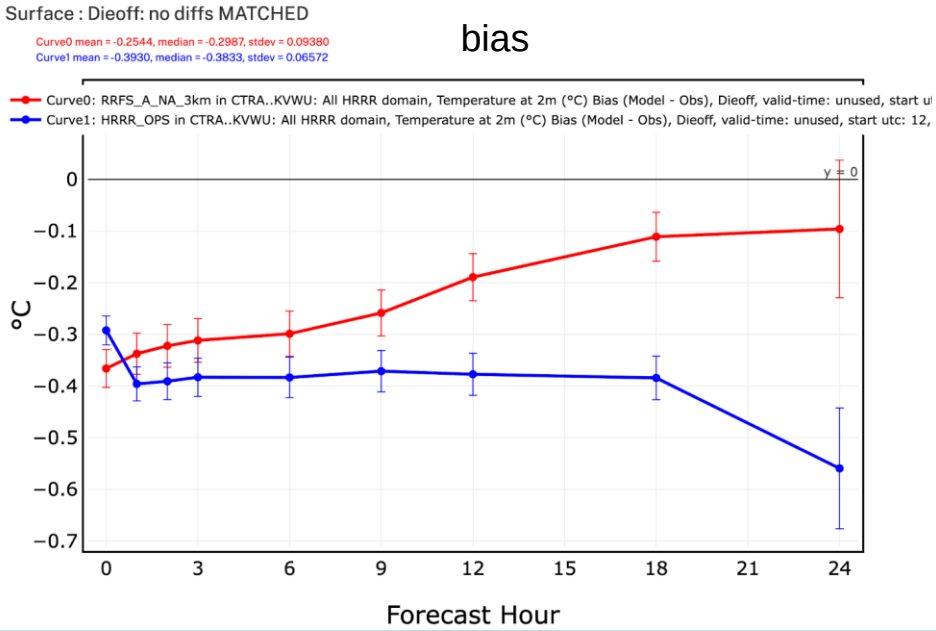
Real-time RRFS versus HRRR, both have CLM-Lake

14 April – 14 May 2024

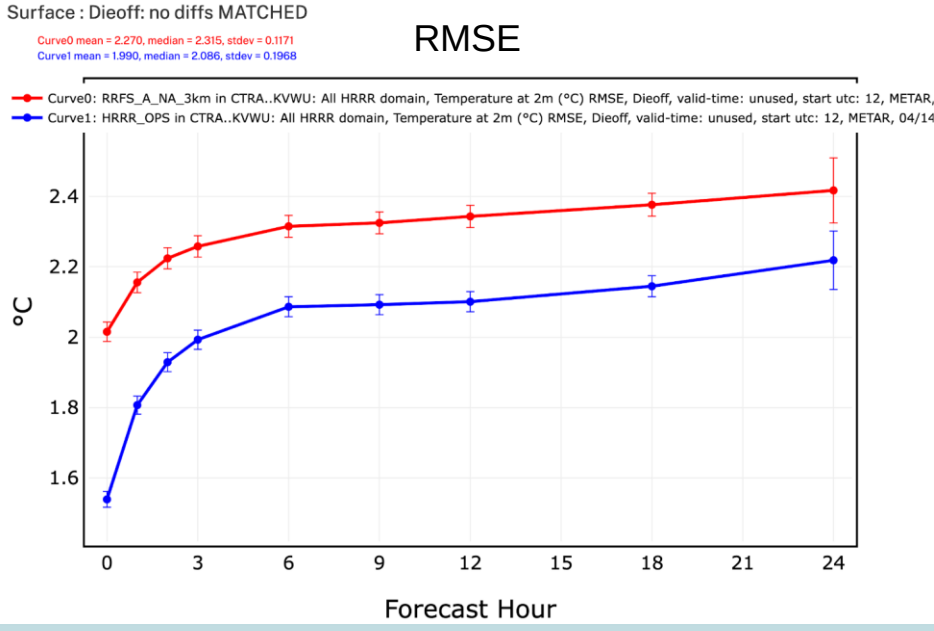
Red – RRFS
Blue – HRRR

2-m temperature die-off, lake stations

bias



RMSE



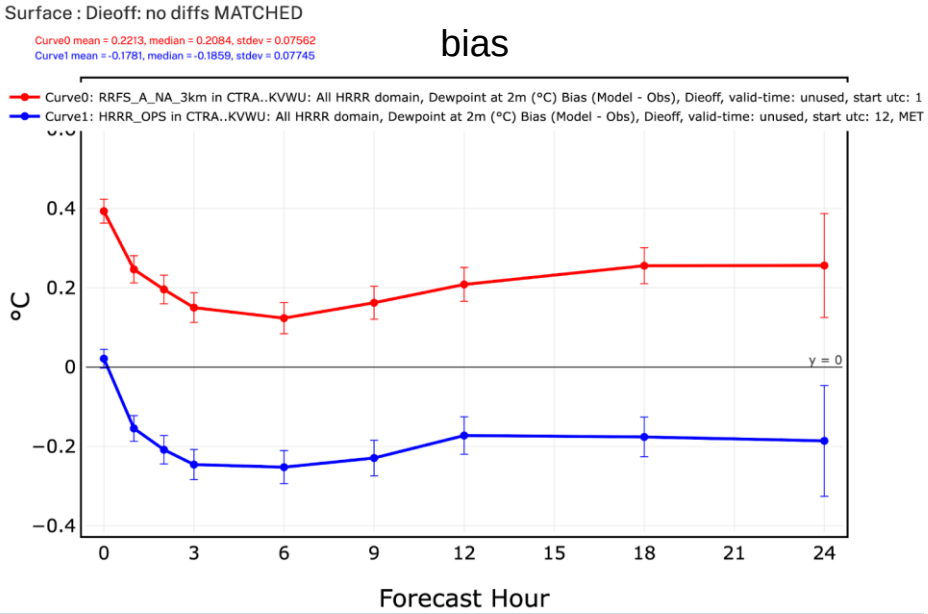
Real-time RRFSv1 versus HRRR, both have CLM-Lake

14 April – 14 May 2024

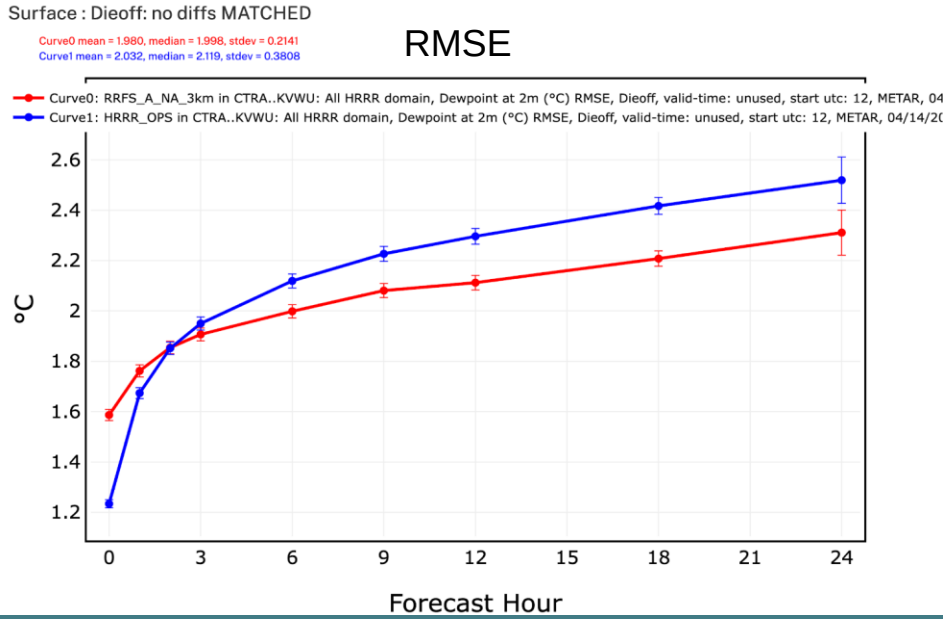
Red – RRFS
Blue – HRRR

2-m dew point die-off, lake stations

bias



RMSE



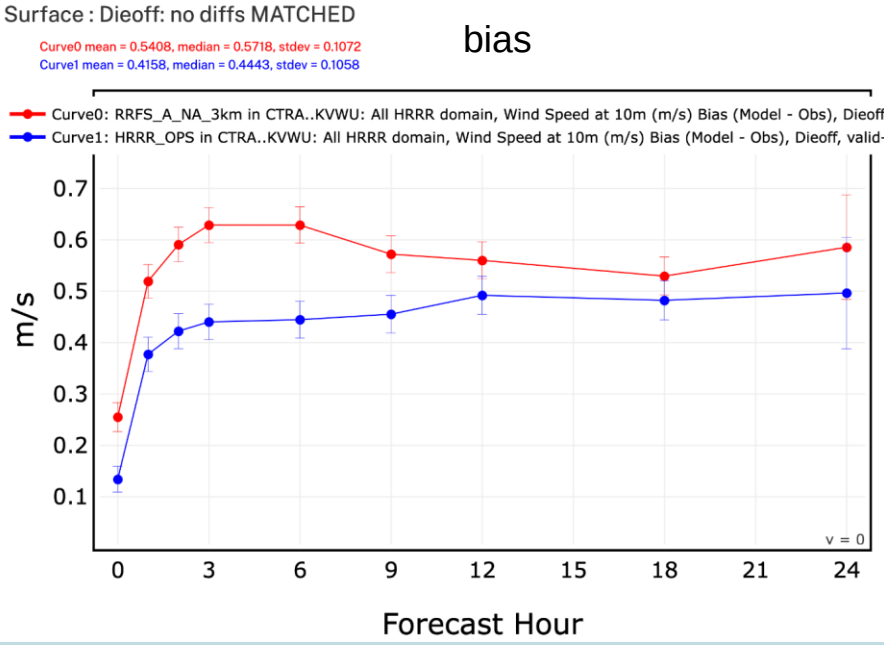
Real-time RRFSv1 versus HRRR, both have CLM-Lake

14 April – 14 May 2024

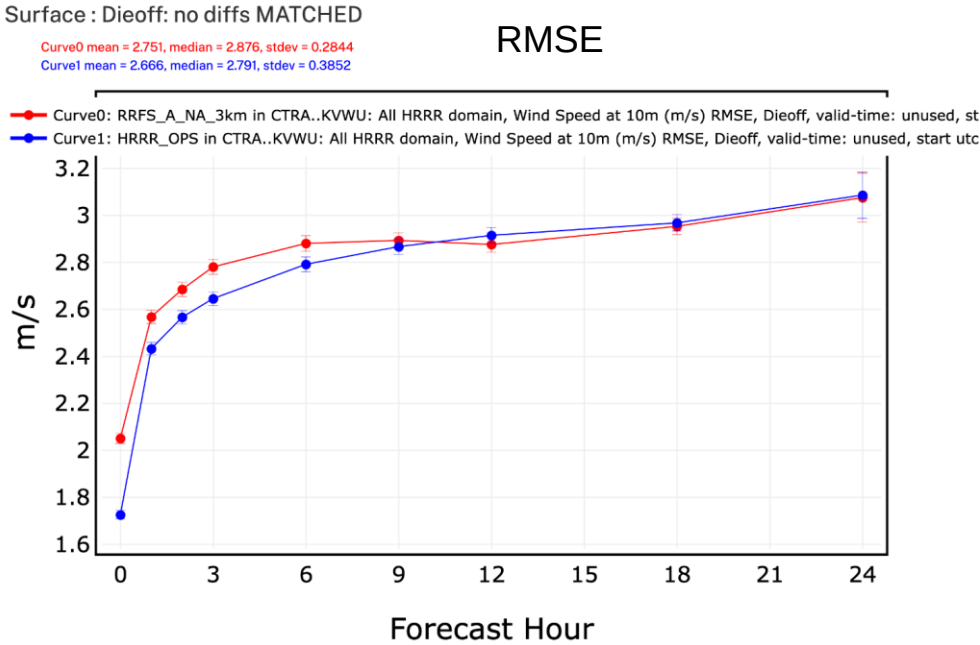
Red – RRFSv1
Blue – HRRR

10-m wind die-off, lake stations

bias

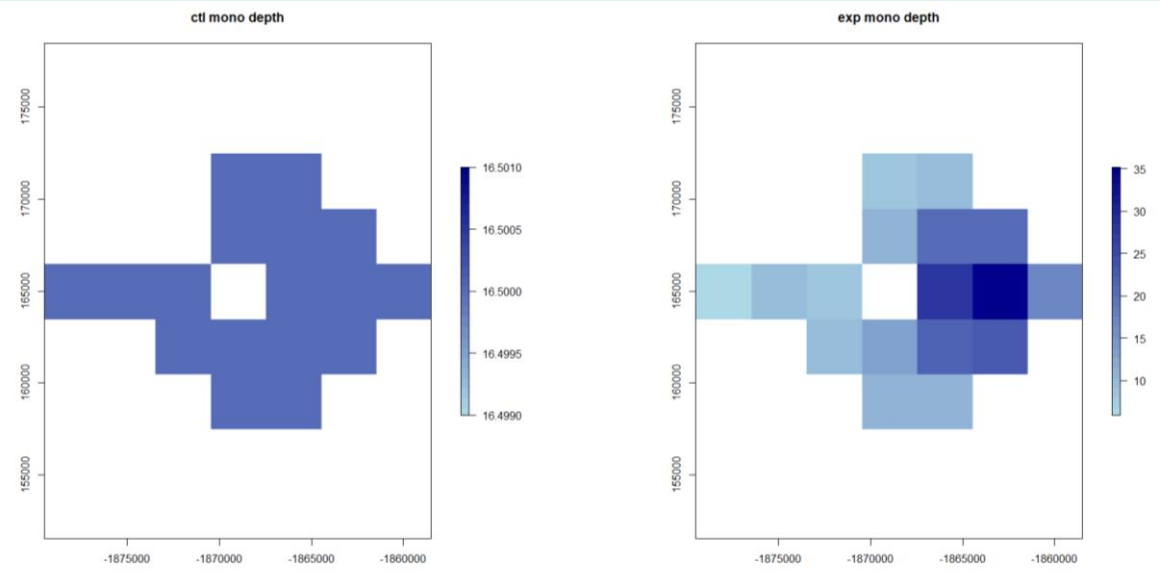


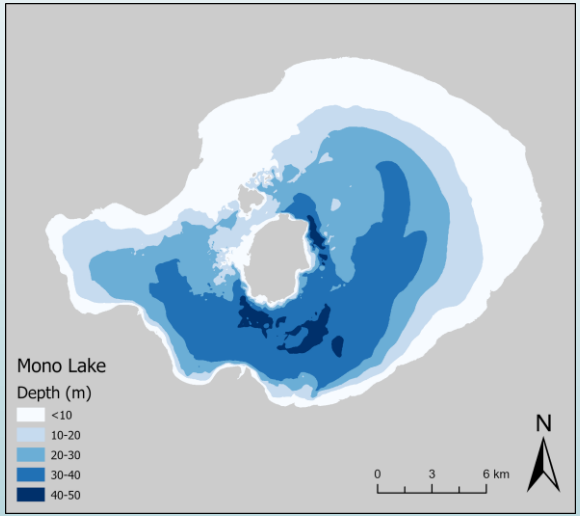
RMSE



High-resolution GLOBathy compared to GLDBv3

GLOBv3 Mono Lake GLOBathy





Khazaei, B., Read, L.K., Casali, M., Sampson, K.M, and Yates, D.N.,2022: GLOBathy, the global lakes bathymetry dataset. *Sci Data* **9**, 36 https://doi.org/10.1038/s41597-022-01132-9

Data from: Raumann, Christian G, et al. “Digital Bathymetric Model of Mono Lake, California.” *U.S. Geological Survey*, 2002, https://doi.org/10.3133/mf2393.
Map made by Eamon Espey, University of Michigan

Conclusions and future work

- CLM-Lake is available in the NOAA Unified Forecasting System
- Lakes' set-up in the domain requires preliminary work to remove larger lakes (>15,000 km^2), where 1D CLM-Lake is not capable to represent lake processes realistically
- Lake depths in the UFS are currently initialized from GLDBv3 data, constant depth for most lakes
- *Work underway* to replace GLDBv3 with the high-resolution GLOBathy information, variable depths for most lakes
- Lake variables are cycled controlled by atmospheric DA to evolve towards realistic balanced state (Benjamin et al. 2022)
- CLM-Lake improves surface predictions in the vicinity of the lakes
- RRFS (shorter cycling period) is compatible with HRRR for stations near lakes