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Alpine Catchment Snow Distributions, Mountain Winds, and AI Modeling

Ethan Gutmann

Kyle Sha, Rachel McCrary, Andy Newman, Jessica
Lundquist, Daniel Kirshbaum, Clinton Alden, Ju-Hye
Kim, Seth McGinnis, Lulin Xue, David John Gagne

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AI Models are revolutionizing NWP, but can they science?

- CREDIT AI Modeling
- Mountains need resolution : Meso-CREDIT
- Early Meso-CREDIT results show skill at 4 km
- Generalized training to work in “any” mountains
- Use of observed processes in mountains for evaluation mountain valley wind test
- Building a high-res hydroclimate reanalysis, but inconsistent observations in mountains!



Meso-CREDIT : A Mesoscale AI Weather Model



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Global AI-WP models in the news are mostly ~19–25km
(trained on ERA5 or IFS)

GraphCast, WeatherNext, AIFS, Pangu,...

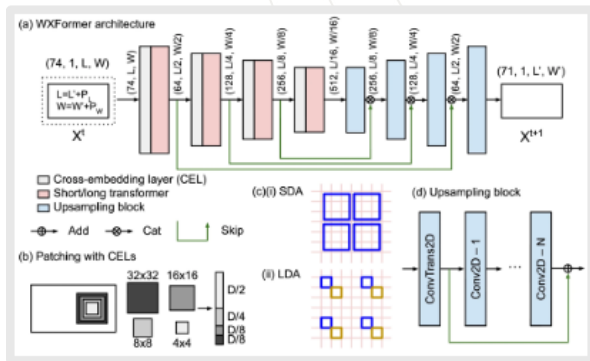
Can we use the >40yr 4km CONUS WRF simulations
(CONUS404) to simulate mesoscale processes?

CONUS 404 training variables:

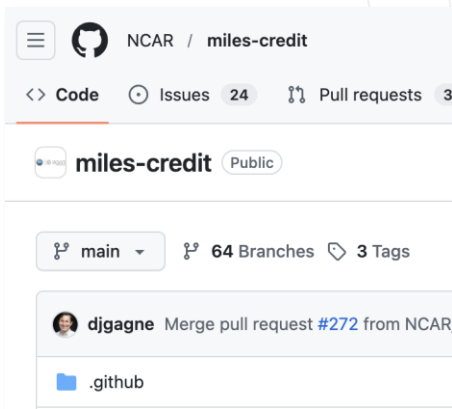
- **Prognostic upper air:** P, U, V, T, Q_tot (15 sigma levels)
- **Prognostic surface:** MSLP, SP, T2, TD2, U10, V10, PWAT
- **Diagnostic:** Precip, REFL, TCC, OLR, SWDOWN, GLW
- **Static:** HGT, land-sea mask, LU, VAR

ERA5 forcing “boundary” conditions in training (1980–2010)

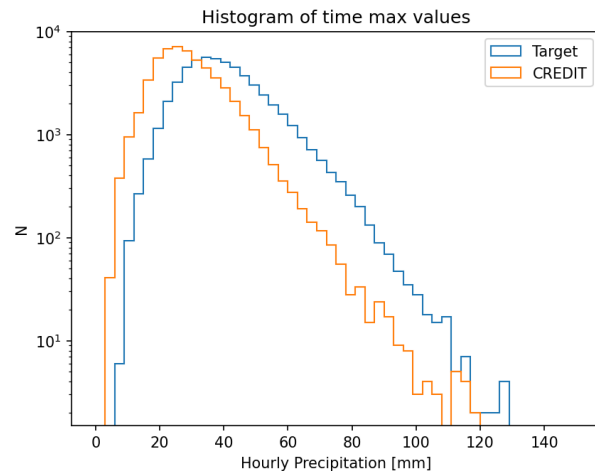
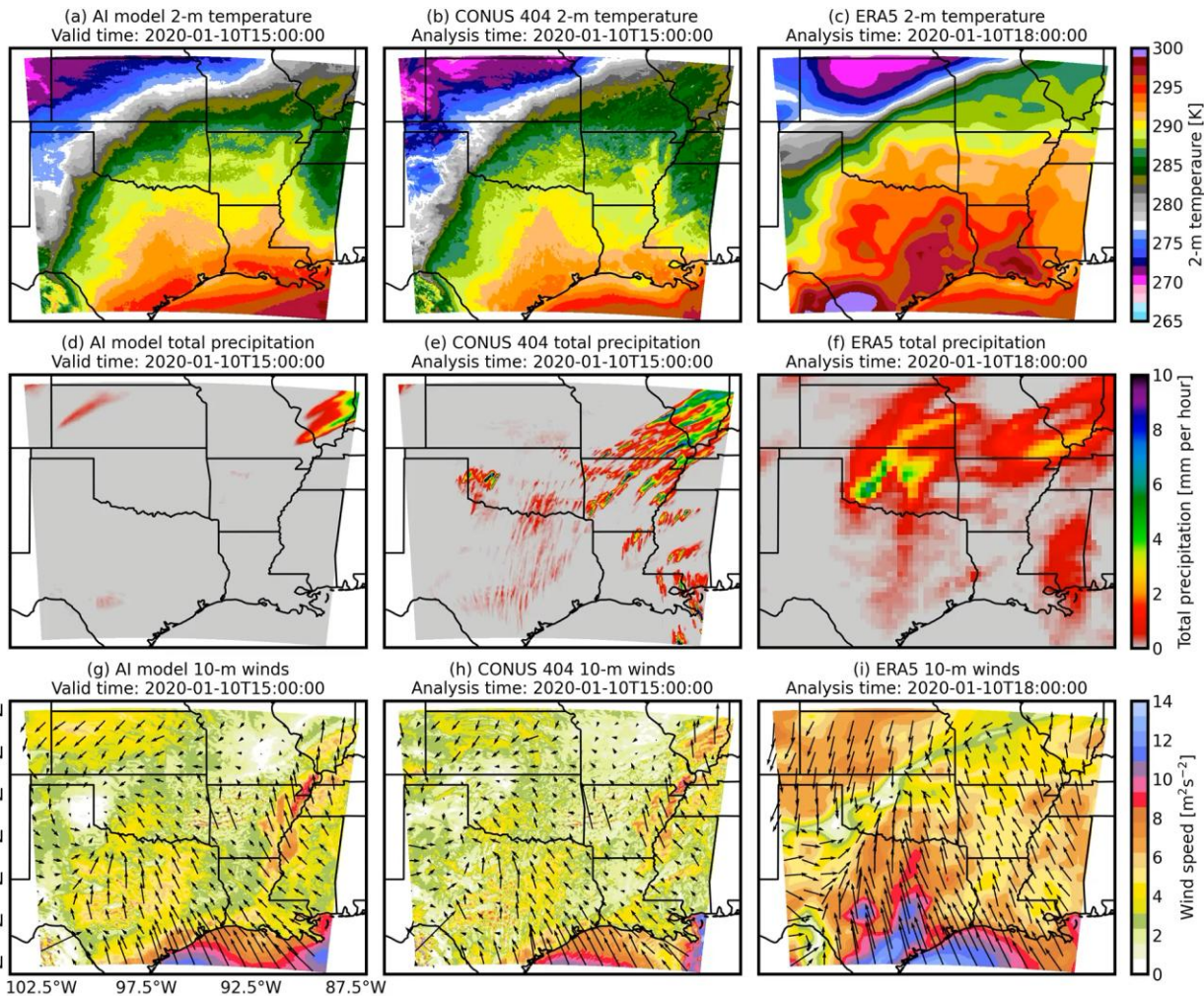
- **Upper air boundary conditions:** U, V, T, Q (11 pressure levels)
- **Surface boundary conditions:** MSLP, T2, U10, V10



CREDIT: Schreck et al. (2025)
Meso-CREDIT: Sha et al. (2026)



Comparisons of hourly AI forecasts (a, d, g), CONUS 404 (b, e, h), and 3-hourly ERA5 (c, i)
 Forecast initialization time: 2020-01-02T00:00:00 | Forecast lead time: 230 h | ERA5 init



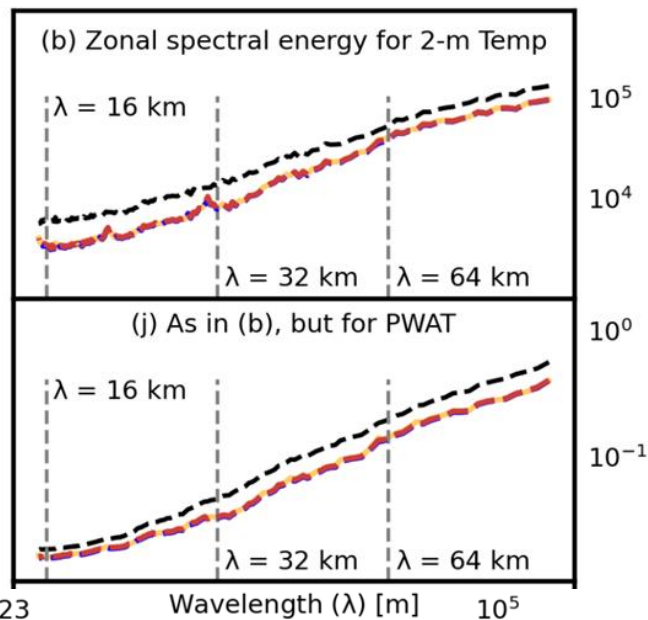
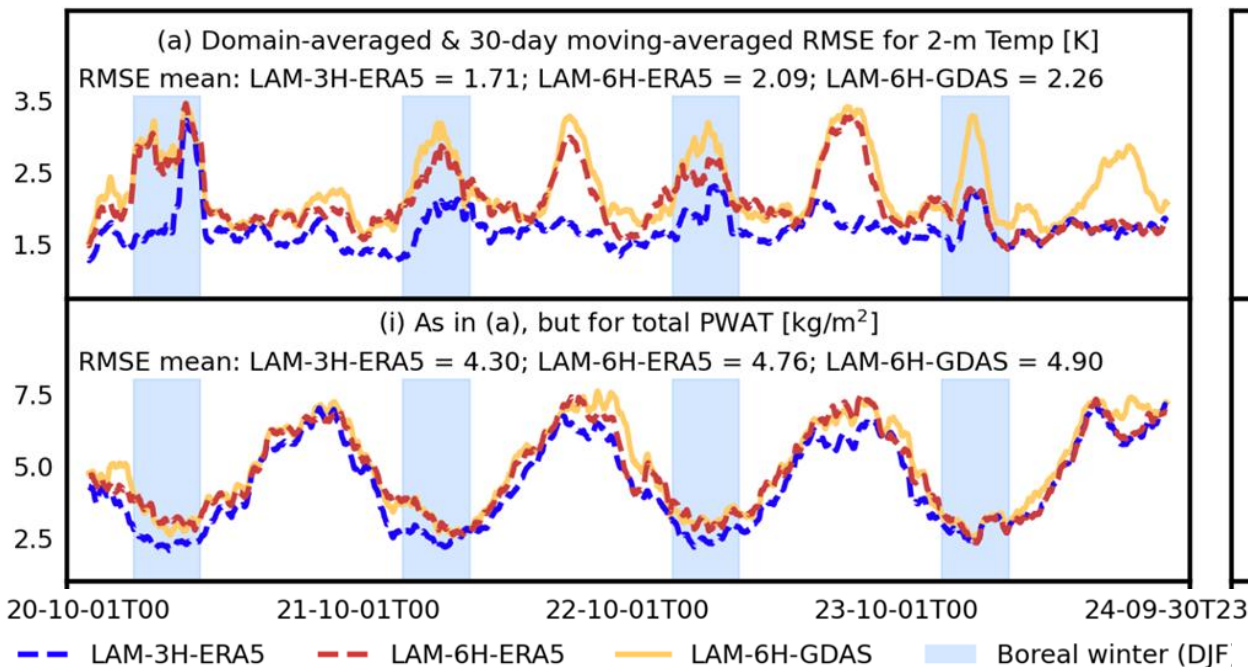
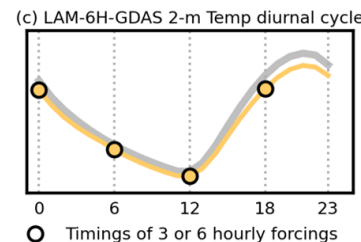
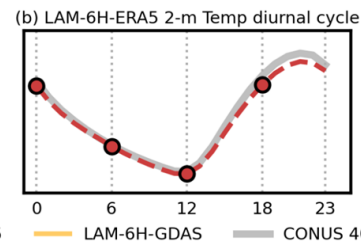
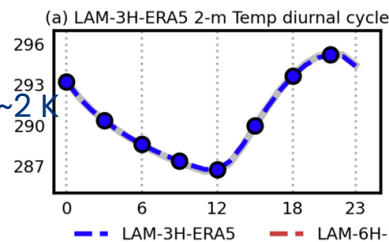
Able to produce hourly rainfall rates of 120mm/hr

Still biased low, working on adding diffusion model for precipitation

Multi-Year RMSE stability and Diurnal cycle (mostly) robust to forcing input

Domain-averaged RMSE:

- Long-term stable with low errors (e.g., ~ 2 K for T2)
- 3H-ERA5** > **6H-ERA5** $\sim$ **6H-GDAS**

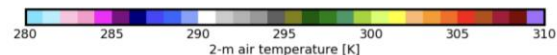
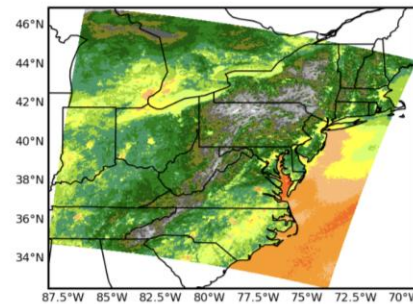
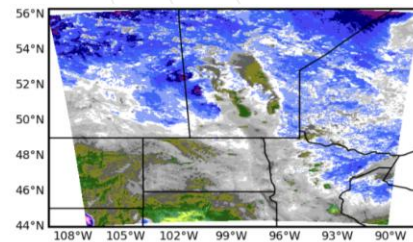
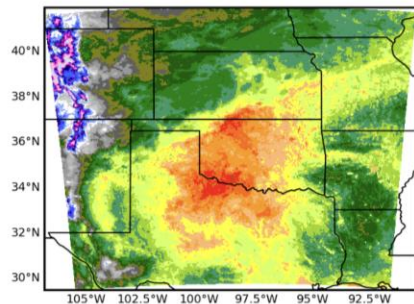
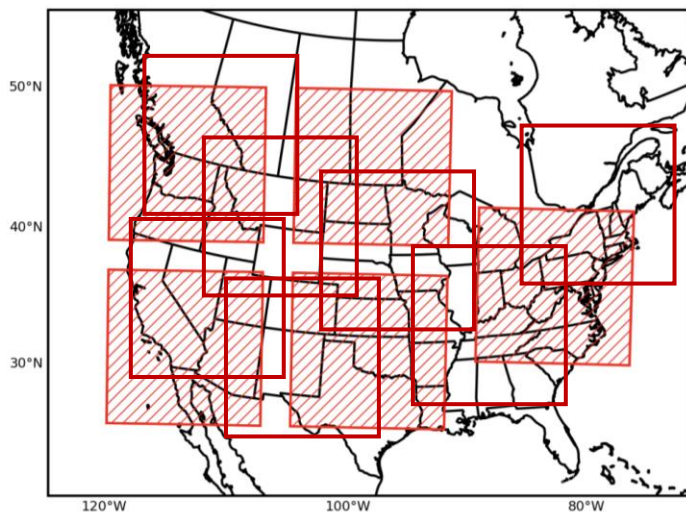
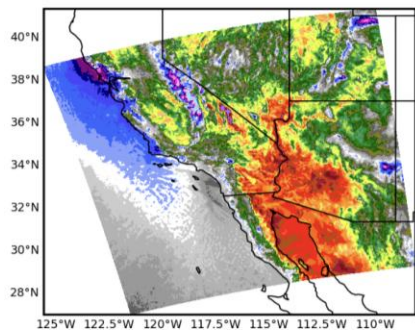
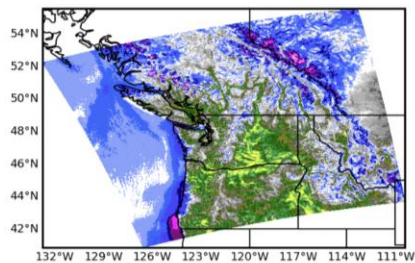


Generalizing an AI model for Alpine Catchments



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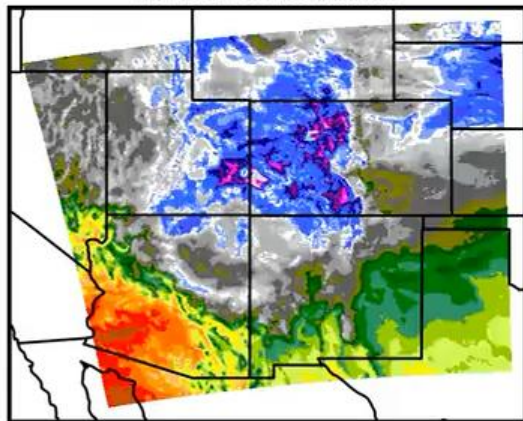
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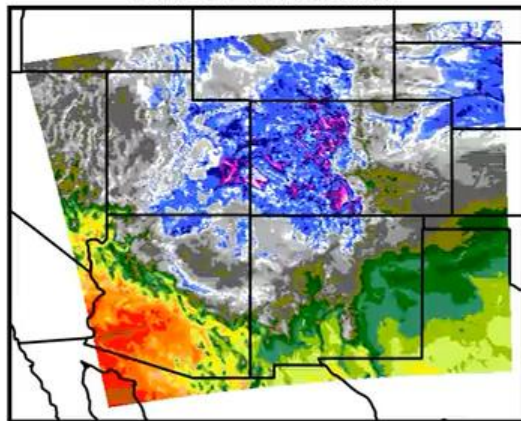
Example case of AI-based dynamical downscaling on 2020-01-01T01:00:00

Initialization time: 2020-01-01T00:00:00 | Iteration: 1 steps

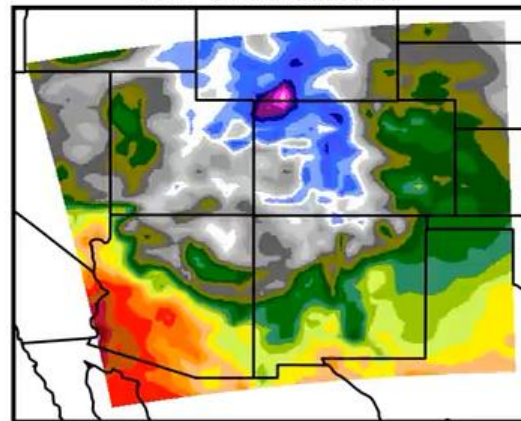
(a) AI Model 2-m Temp
2020-01-01T01:00:00



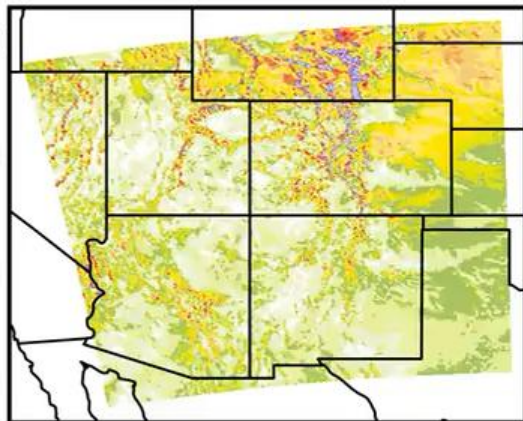
(b) CONUS404 2-m Temp
2020-01-01T01:00:00



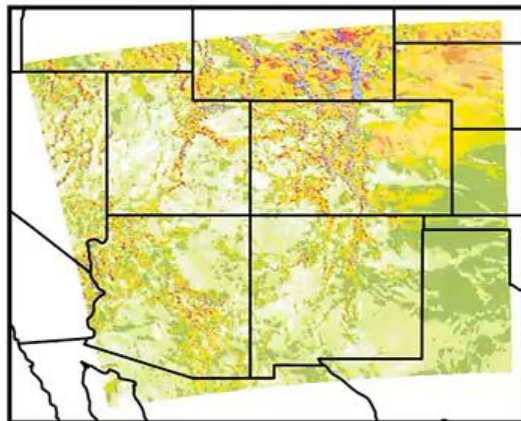
(c) Interp. ERA5 2-m Temp
2020-01-01T00:00:00



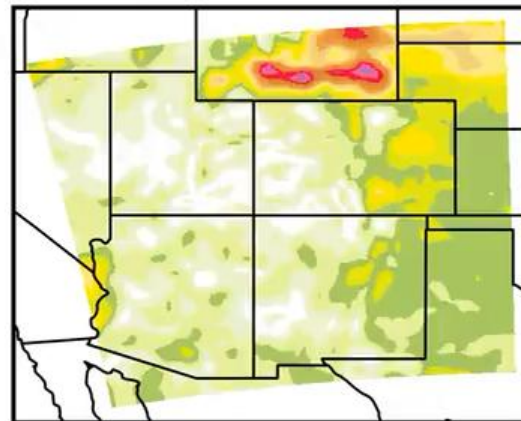
(d) AI Model 10-m Wind
2020-01-01T01:00:00



(e) CONUS404 10-m Wind
2020-01-01T01:00:00



(f) Interp. ERA5 10-m Temp
2020-01-01T00:00:00



290
280
270
260
250
2-m air temperature [K]

15.0
12.5
10.0
7.5
5.0
2.5
0.0
10-m wind speed [m/s]

Comparison with Alpine Observations

Combined field campaigns in the East River

Basin, CO

DOE SAIL

NOAA SPLASH

NSF SOS



Colorado State University X-band Radar



Twice-daily radiosonde



DOE Doppler Lidar

Rocky Mountain Biological Laboratory (RMBL)

Observed Diurnal Valley Wind

wind directions local valley relative

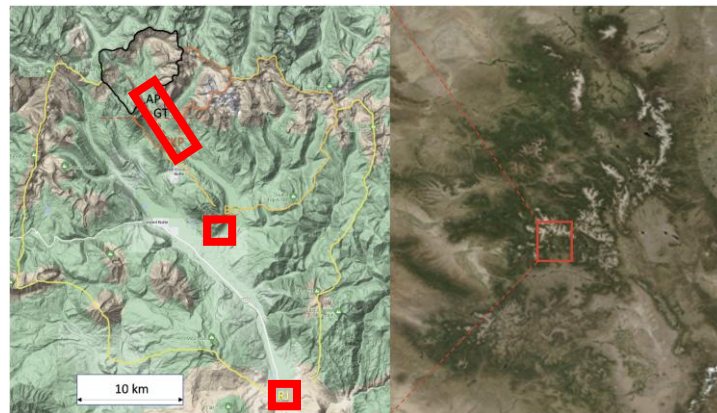
Strong diurnal cycle

Varies with season and site

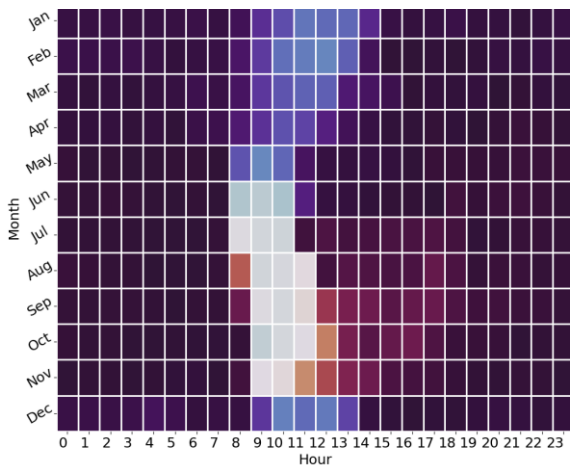
Kettle ponds: snow cover effects

Brush creek local slope heating

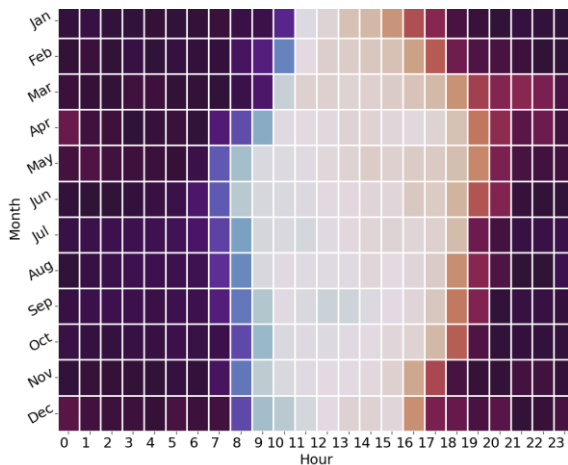
Roaring Judy open to upper level flow



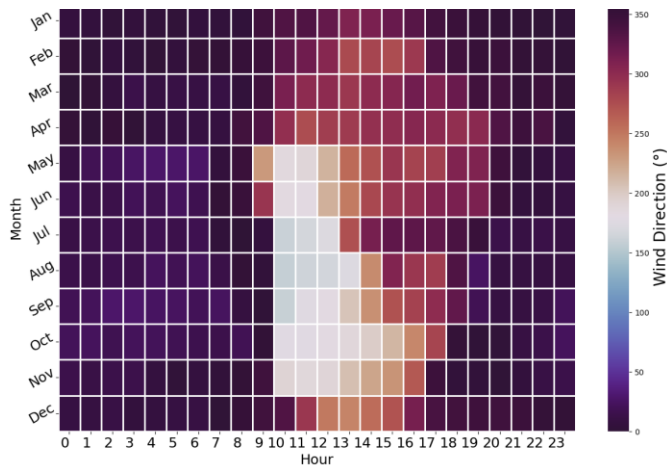
Kettle Ponds High Elevation



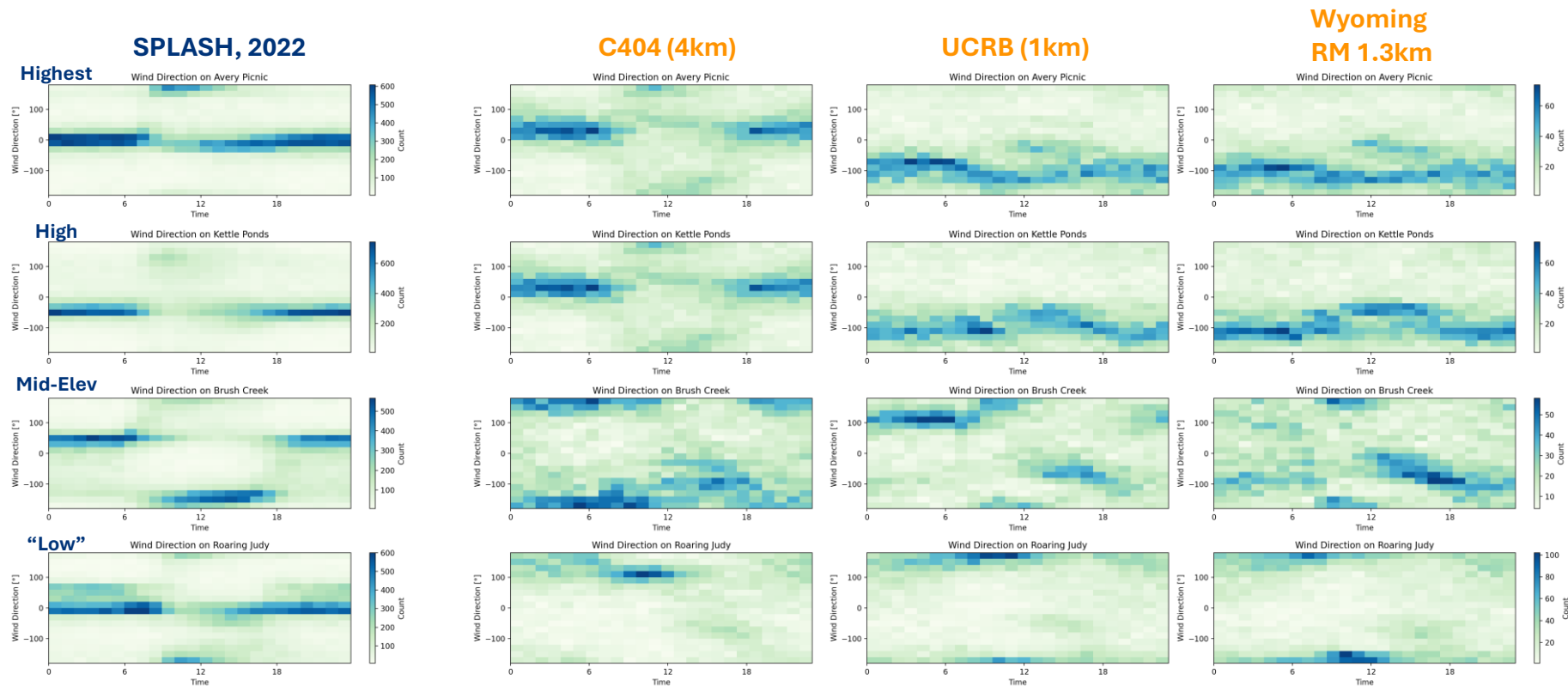
Brush Creek Mid-elevation



Roaring Judy “Low”-elevation



Diurnal cycle of wind direction from three simulations and SPLASH (four sites along the valley)



Meso-CREDIT : AI Mountain Winds



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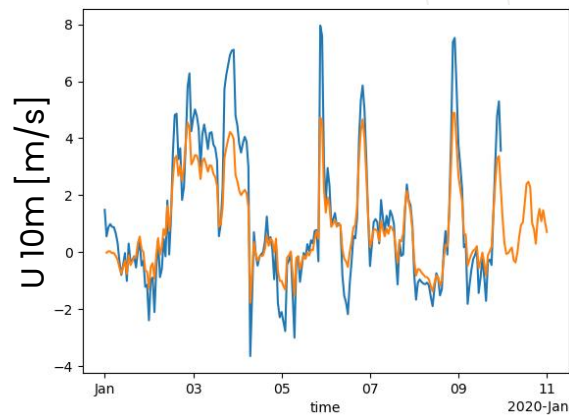
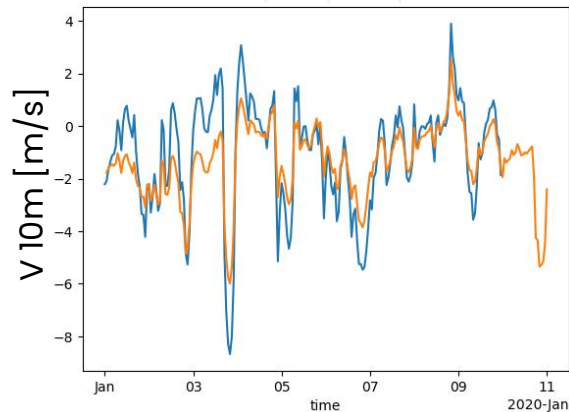
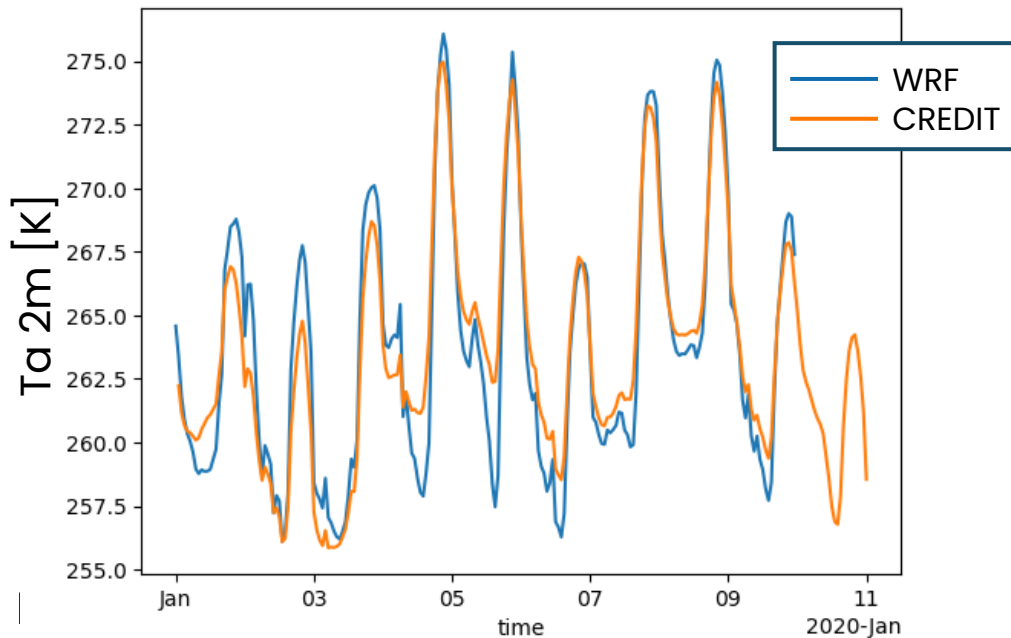
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Evaluation over the East River Basin

Current comparison limited to WRF

Will evaluate with SAIL/SPLASH/SOS field campaigns

CREDIT underestimates variability, excellent timing



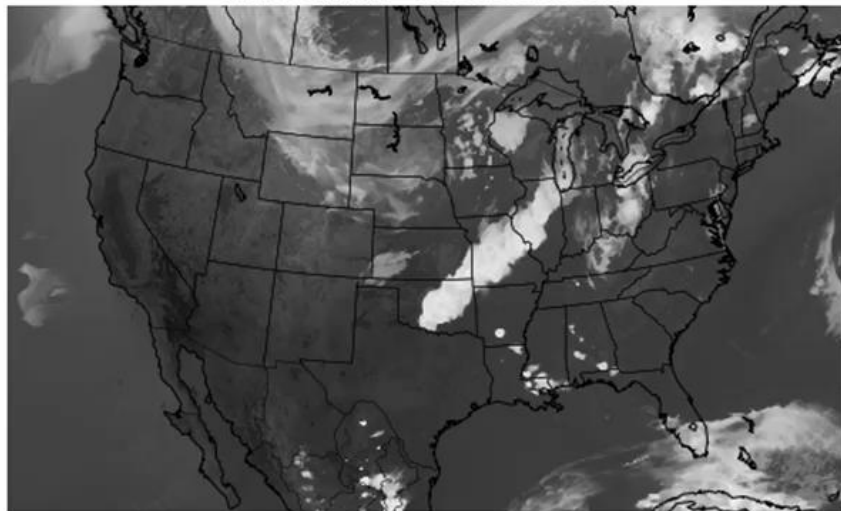
Beyond Training on a model



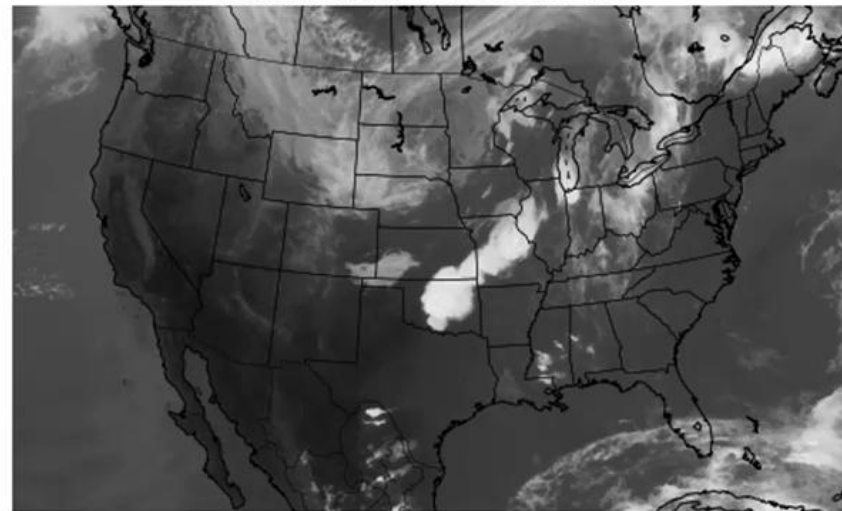
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WRF404 chanel4 - 2013-06-01 00:00:00

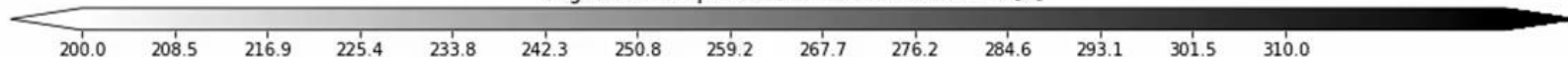


GOES14 chanel4 - 2013-06-01 00:00:00



Animation from Andreas Prein

brightness temperature of GOES14 channel 4 [K]



How do we merge sparse INARCH observations
in a **Alpine Catchment Reanalysis?**

The real world is complicated: reanalysis needed?



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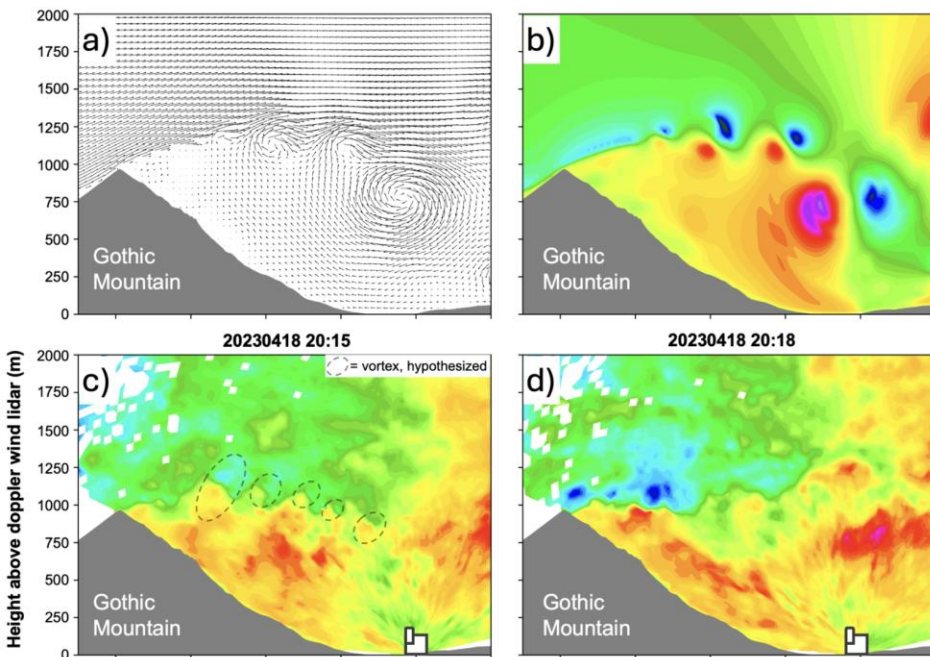
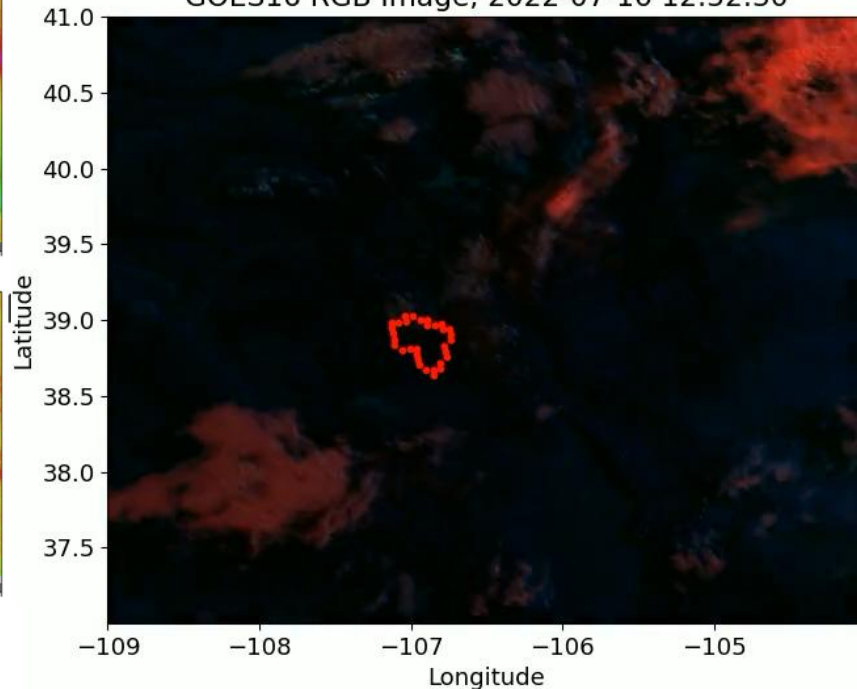


Figure by Eli Schwat

GOES16 RGB Image, 2022-07-16 12:52:30



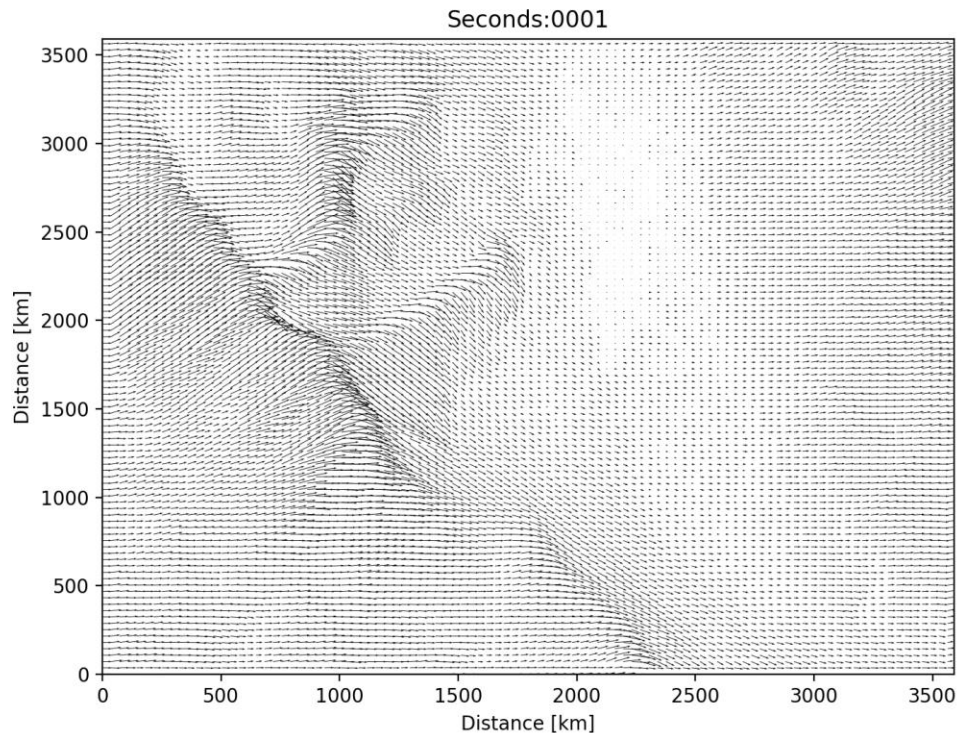
Wind Data for Alpine Snow Redistribution



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- Alpine regions are extremely complex and data sparse
- Models capable of simulating these regions are rare, expensive and may do more than you want, or not enough
- AI coding enables bespoke models for whatever you need
- Here:
 - 3-D non-hydrostatic turbulence model with immersed boundary
 - Multi-GPU native



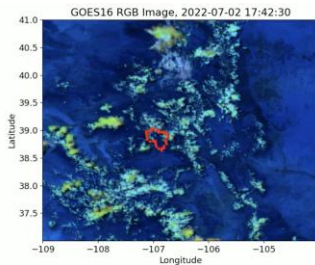
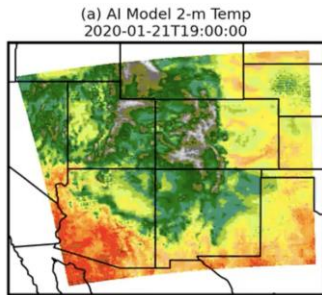
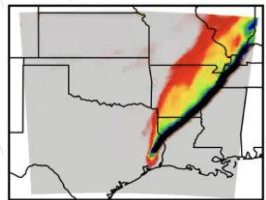
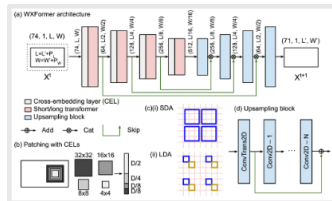
AI for Alpine HydroMet



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- “Convection Permitting” AI modeling is blossoming
- AI Mountain Met is plausible, but generalizing to enable scientific experimentation is not there yet
(More training is needed?)
- To surpass WRF (MPAS/AROME/CM1/...?) we need to train AI models on observations (or reanalysis)
- Alpine training data is limited, AI enables bespoke models



Supported by the NSF National Center for Atmospheric Research, and the DOE Atmospheric Systems Research (ASR) program