

Developing a Linear Inverse Model for Improved Model Guidance of CPC's Week 3-4 Temperature Outlooks

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Project Overview

- Goal: improvement of Week 3-4 Temperature and Precipitation outlooks
- CPC currently produces operational Temperature and Experimental Precipitation Week 3-4 outlooks
- Develop Linear Inverse Model (LIM) as model guidance for Week 3-4 temperatures (and, eventually, precipitation)
- Work with CPC to develop LIM in response to operational needs, transfer code, evaluate skill

Empirical model of dynamics: *Linear inverse model (LIM)*

S2S prediction involves the evolution of climate anomalies (*aggregates of weather, not individual weather events*), where non-linearities may largely be approximated as unpredictable noise.

Empirically model anomaly *evolution* with linear stochastically forced dynamics:

$$\frac{dx}{dt} = Lx + \xi$$

$x(t)$: series of **maps**, L : stable operator, ξ : white noise (also **maps**)

An “effectively linear” model – but *not* a linearization – of a nonlinear system

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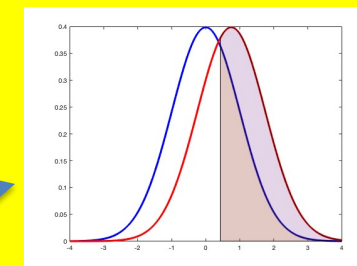
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An “effectively linear” model – but *not* a linearization – of a nonlinear system

- In a LIM, anomalies can growth and evolve through **eigenmode destructive/constructive interference** (*all modes are non-normal and stable*)
- Get L from covariance statistics (e.g., AR1), noise statistics from balance relation
- LIM is low-order model (prefiltered in EOF space), $O(10s)$ degrees of freedom
- Test assumption of linearity (“tau-test” : model is independent of training lag)
- **Forecasts:** $x(t + \tau) = \exp(L\tau)x(t)$ (ensemble-mean)
- **Categorical forecasts** determined from ensemble-mean PDF shift



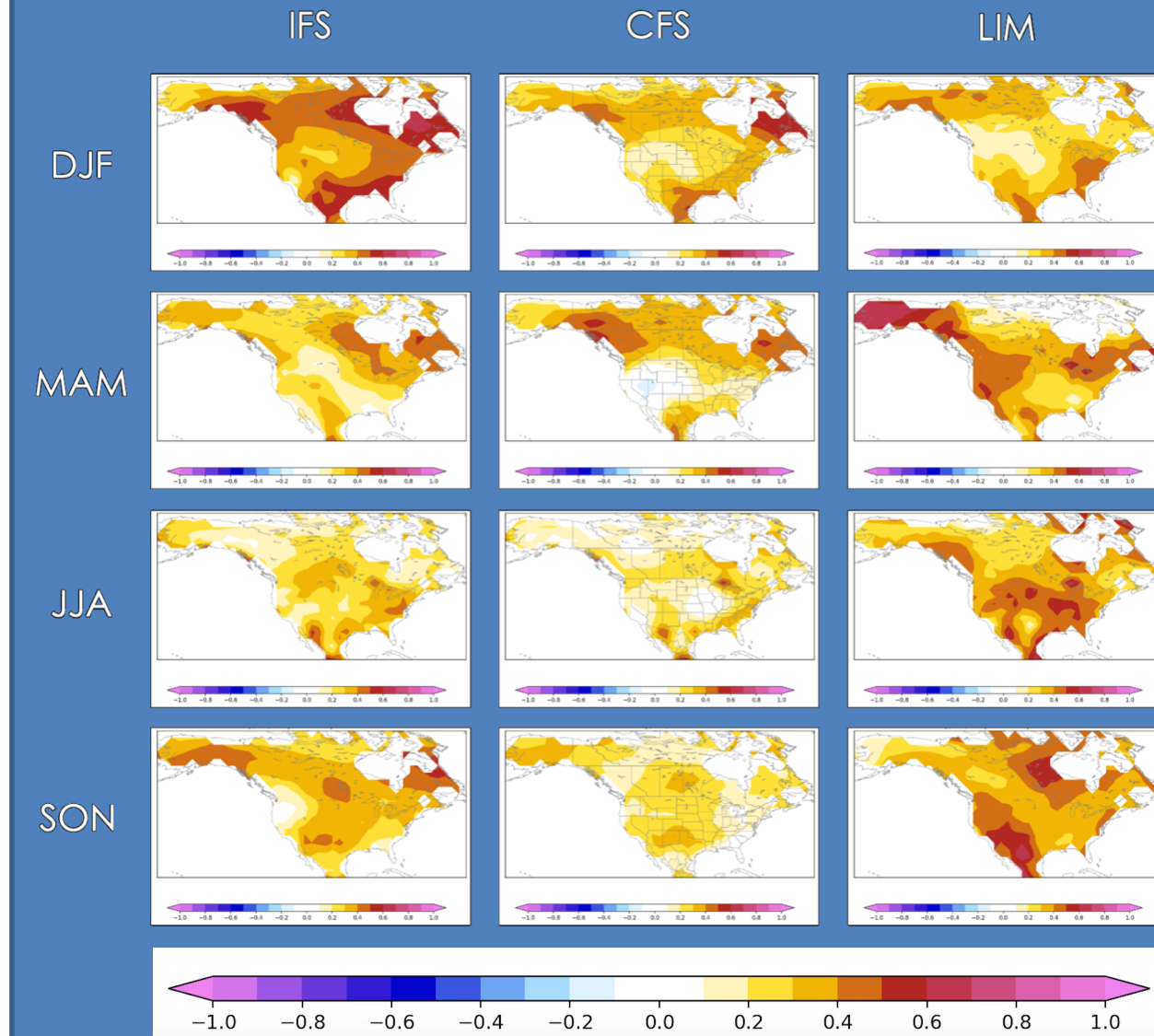
Year-round LIM design

- LIM state vector (listed in table) consists of weekly averaged anomalies drawn from JRA-55 reanalysis from 1979 – 2017, available from NCAR
- LIM computed in reduced EOF space (retaining about 60 – 90% variance)
 - Skill evaluation relative to full space
 - Remaining EOFs added back to forecast ensembles as unpredictable noise for probabilistic prediction
- We construct **12 LIMs, one for each month**, based on bimonthly data
 - EOFs also determined separately for each LIM
 - Linear transition for forecasts between models in first and last week of each month
- Hindcast skill ('79-'17) ten-fold cross-validated
- Real-time forecasts are 2017-present

Variable	Domain	PCs
Temperature at 2m	North America landmass	5
Pressure at mean sea level	20°N – 90°N	23
Geopotential height	500 hPa; 20°N – 90°N	14
Tropical heating	20°S – 20°N	23
Tropospheric streamfunction	700 hPa; 20°N – 90°N	15
Stratospheric geopotential height	10 hPa and 100 hPa; 30°N – 90°N	12

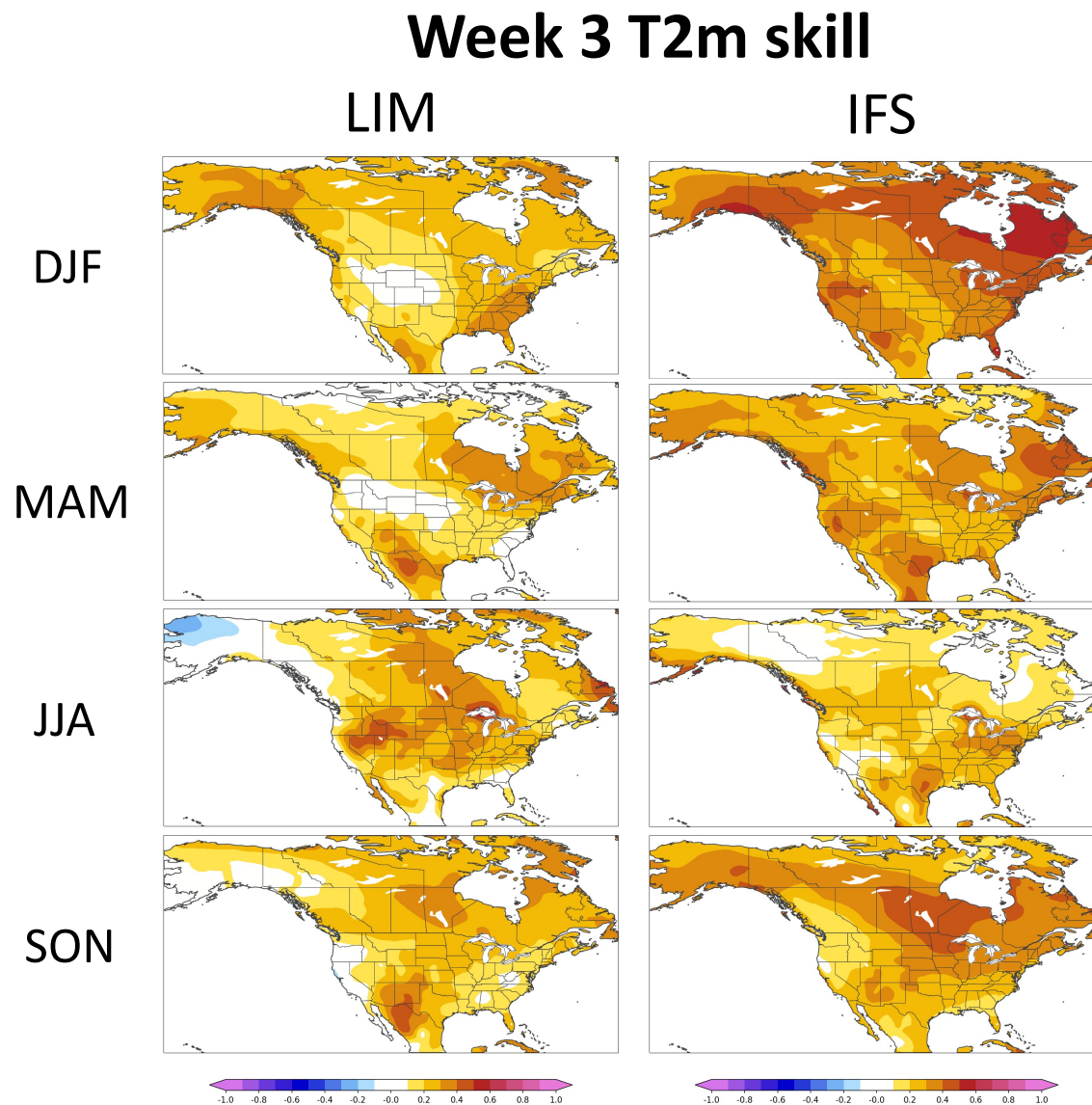
Weeks 3-4 LIM T2m skill is comparable to IFS/CFSv2

- By season, for the common hindcast period 1999-2010.
- Verified against JRA-55 2m air temperature
- All models bias-corrected by removing centered 30-day moving average error.
- IFS: IFS-CY43 (2017 operational model)
 - Output 2x per week
 - Horizontal res: Tco639/319 (16 km until day 16, 32 km beyond)



Week 3: IFS skill > LIM

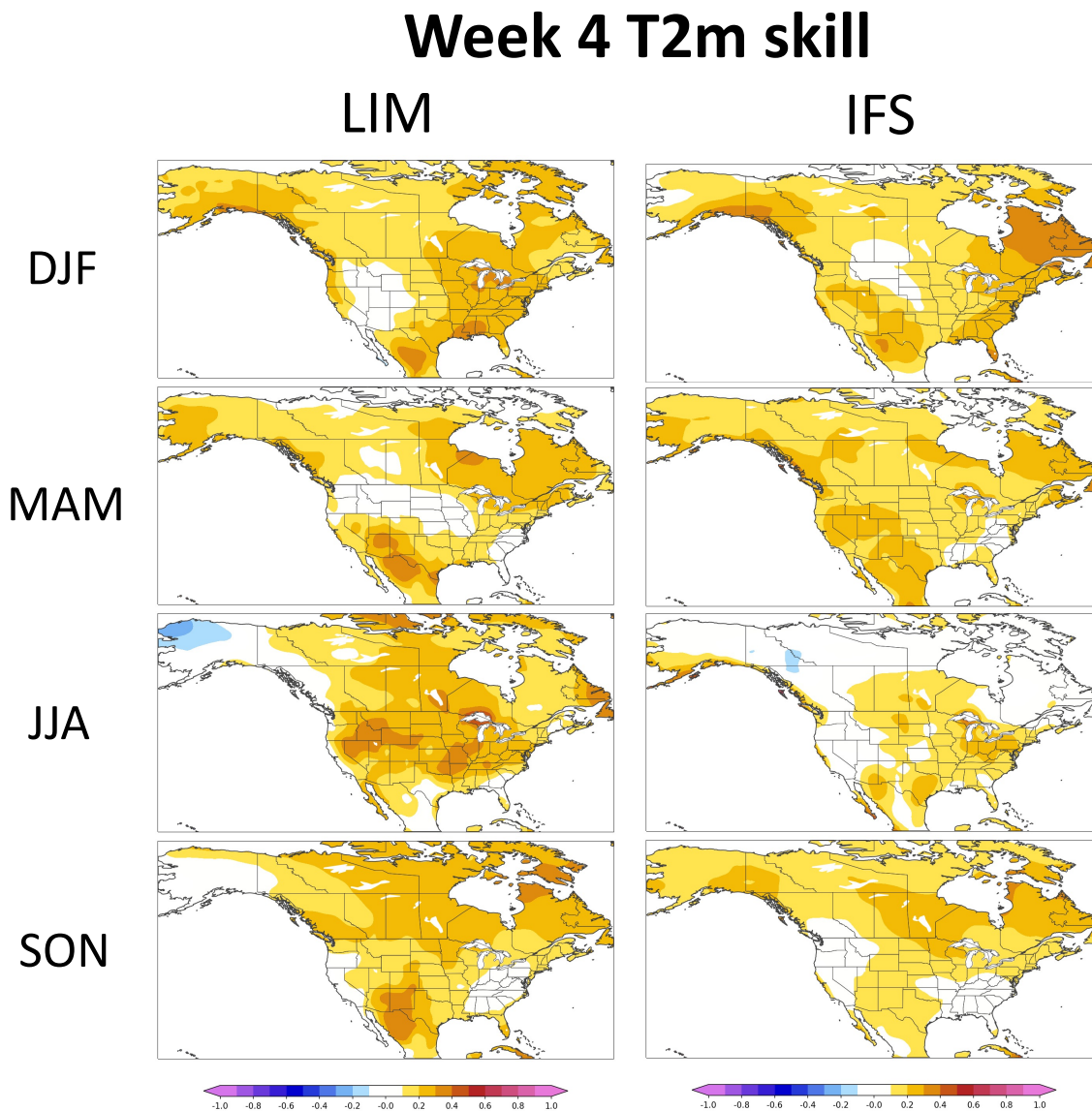
- By season, for the common hindcast period 1997-2016.
- IFS bias-corrected (leave-one-out)



Week 3: IFS skill > LIM

Week 4: LIM skill > IFS

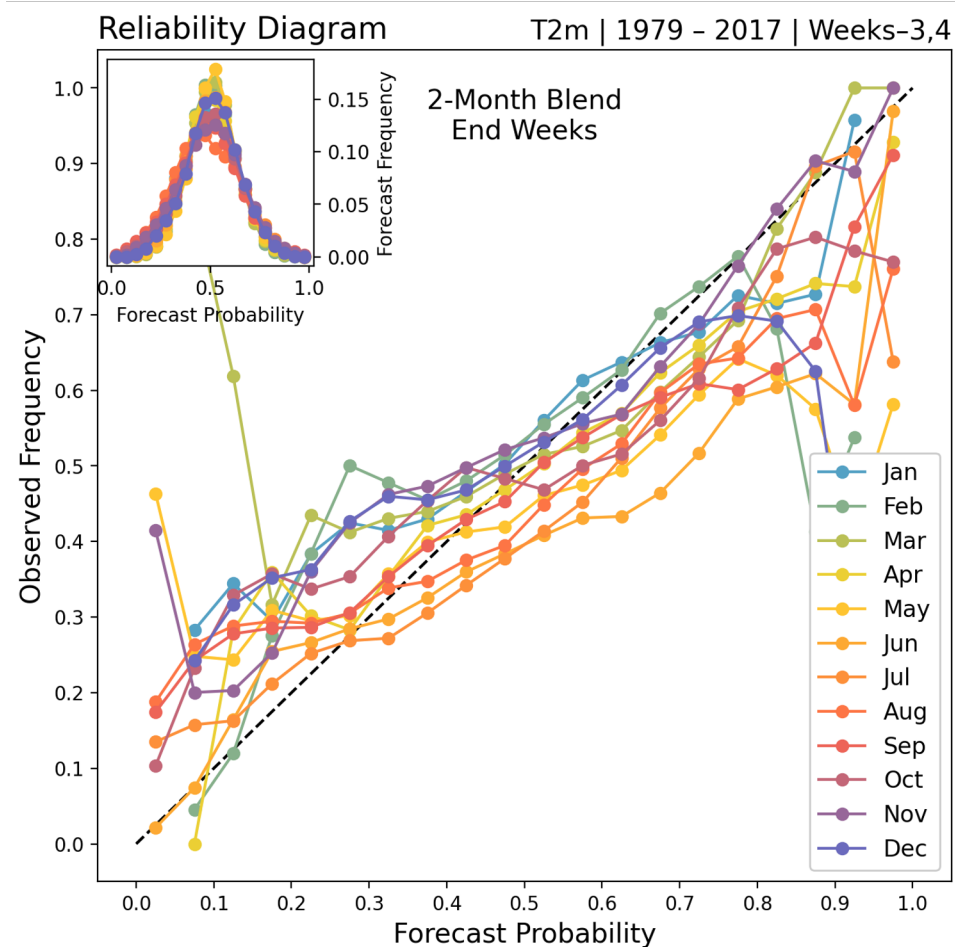
- By season, for the common hindcast period 1997-2016.
- IFS bias-corrected (leave-one-out)
- [Weeks 5-6 LIM skill is consistently better as well]



LIM probability forecasts (2-category) are reliable

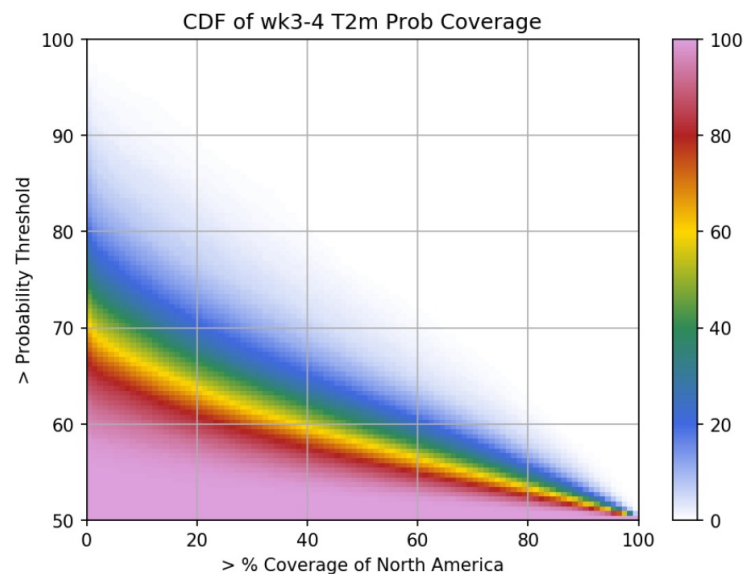
Reliability computed separately for each month's forecasts

Inset shows related sharpness for each month

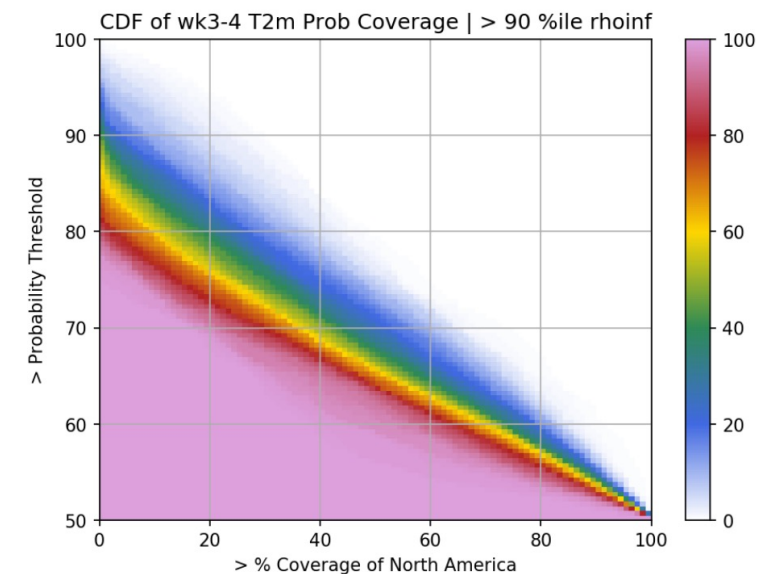


LIM identifies forecasts of opportunity

- “Expected anomaly correlation”: Use simple LIM signal-to-noise metric (e.g., Albers and Newman 2019, 2021) to *predict LIM skill at the time of forecast*
- Higher expected skill = higher probabilities.
- *On S2S time scales where mean skill is generally low, forecast confidence is crucial for actionable prediction*



Coverage (in percent) of North America where forecast probability reached specified threshold, for all LIM hindcasts, 1997-2016



Same except only when expected anomaly correlation was in the top decile of all forecasts

Operational LIM development

- LIM is an empirical-dynamical model, so our goal has been to develop the same products, generated by (physical) dynamical models, currently used by forecasters
 - including probabilistic forecasts, since LIM is an “infinite ensemble”
 - Goal is to support forecaster confidence in forecasts *when warranted*
- Typical forecaster sequence is:
 - Current tropical state (MJO) and forecast
 - Week 2 forecast recap
 - Weeks 3/4 500 mb heights, 2m temperature, probabilities
- Python code packages in github, allowing for future updates to be propagated to CPC
 - CPCLIM (real-time forecasts) will not be publicly released; current version is LIM v1.0
 - pyLIM (making LIMs) will (eventually) be publicly released, as part of “LIM tutorial” hosted by Georgia Tech
- Running in realtime (JRA-55 reanalysis runs 3 days behind), available to CPC forecasters but spring downtime (due to Python issues) disrupted routine use
- “Retrospective forecasts” since 2017 (after LIM training period) also now at CPC, available for comparison to other model guidance tools

LIM web interface at CPC

LIM Week 3-4 Forecast

<< Initialization: 10 September 2021 >>

Spatial Map

Variable	Anomaly	Probability
T2m	Init, Week 2, Week 3, Week 4, Weeks 3-4 obs obs obs obs	Week 2, Week 3, Week 4, Weeks 3-4 obs obs obs obs hit/miss hit/miss hit/miss hit/miss HSS RPSS
H500	Init, Week 2, Week 3, Week 4, Weeks 3-4	Week 2, Week 3, Week 4, Weeks 3-4
SLP	Init, Week 2, Week 3, Week 4, Weeks 3-4	Week 2, Week 3, Week 4, Weeks 3-4
Tropical Heating	Init, Week 2, Week 3, Week 4, Weeks 3-4	Week 2, Week 3, Week 4, Weeks 3-4

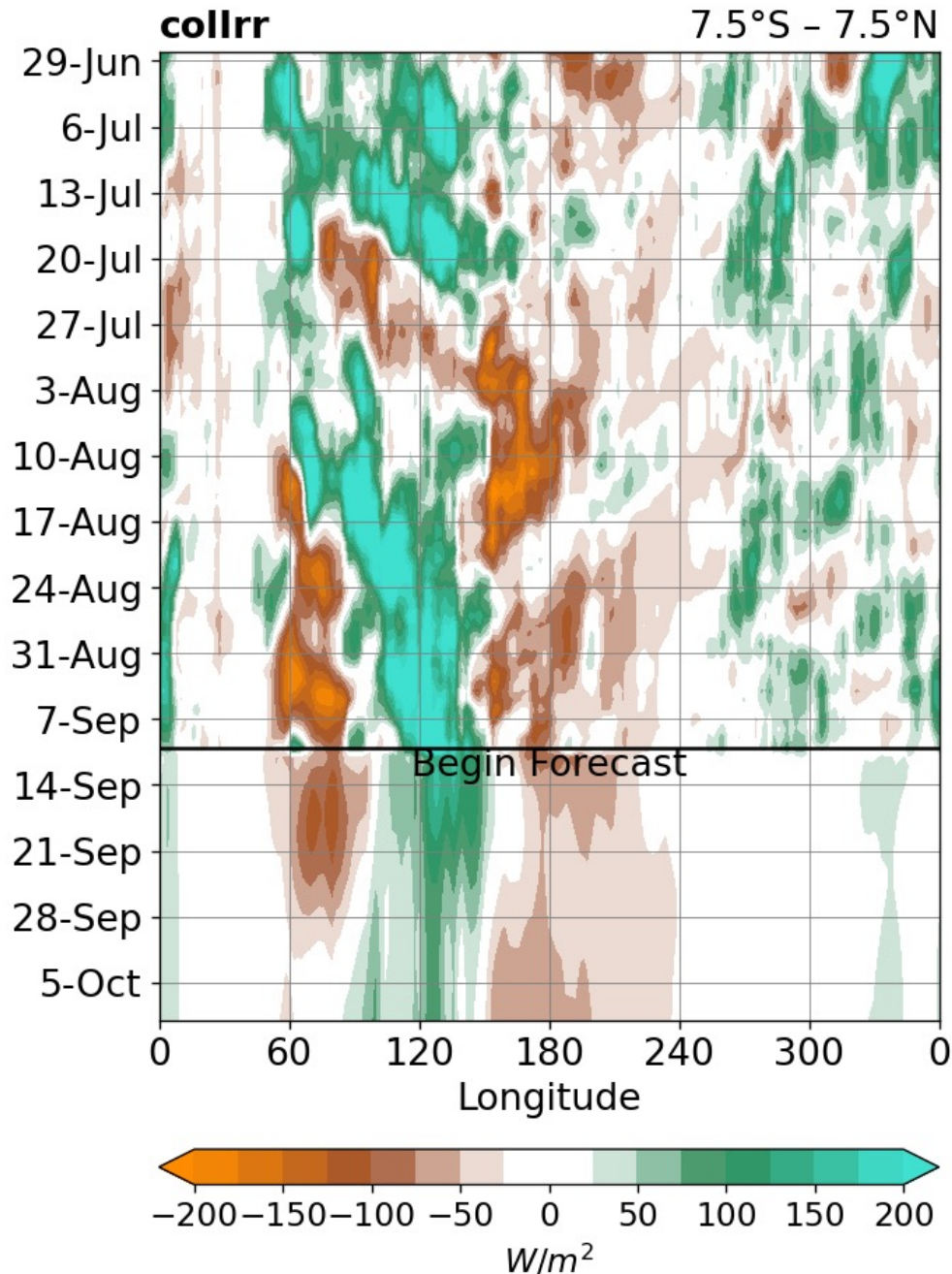
Hovmöller Diagram

H500	Tropical Heating
30°N - 50°N	7.5°S - 7.5°N

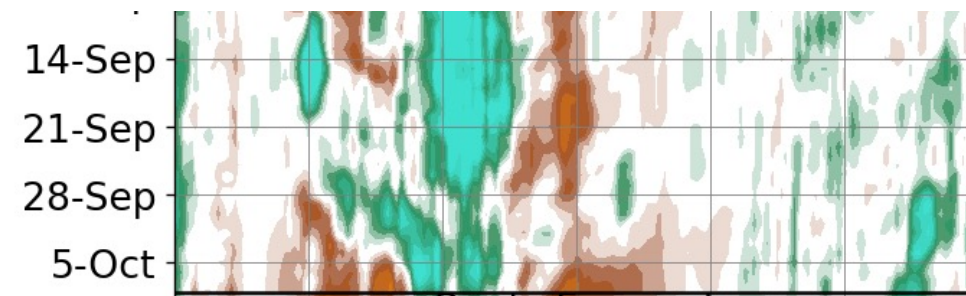
Time Series: Teleconnection Pattern

E. Atlantic	NAO	Scandinavia
E. Atlantic/W. Russia	PNA	TNH
E. Pacific/N. Pacific	Polar/Eurasian	W. Pacific

Equatorial
Hovmoller of
column-
integrated
tropical diabatic
heating

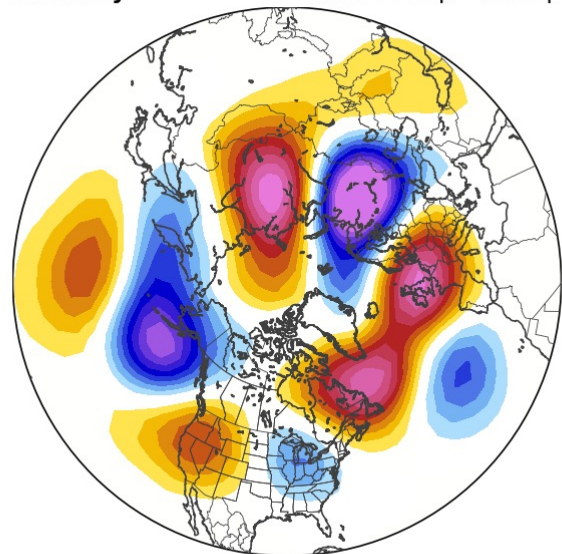


Verification



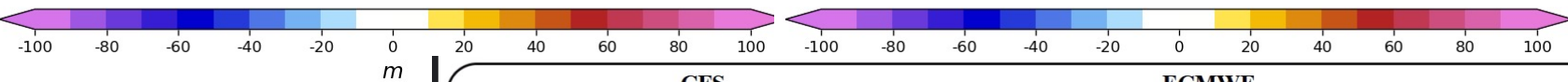
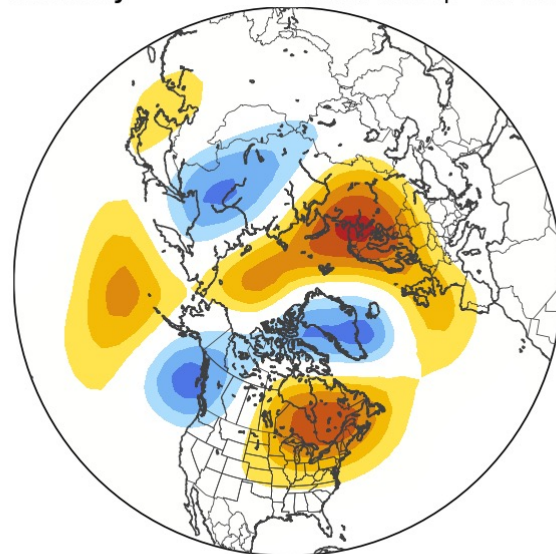
H500 Anomaly

Init: Fri 10 Sep 2021
Valid: 04 Sep - 10 Sep



H500 Anomaly

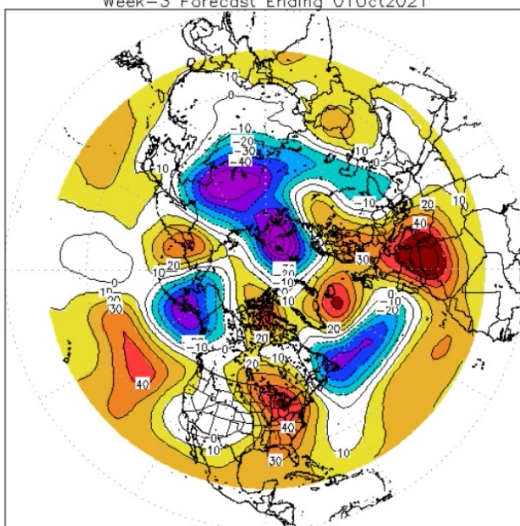
Init: Fri 10 Sep 2021
Valid: 25 Sep - 01 Oct



CFS

[Product Description](#)

CFS 500hPa Height Anomalies Issued 09Sep2021
Week-3 Forecast Ending 01Oct2021

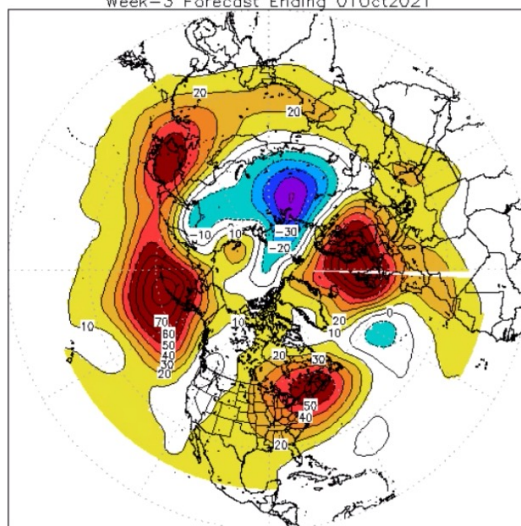


(meters)

ECMWF

[Product Description](#)

ECMWF 500hPa Height Anomalies Issued 09Sep2021
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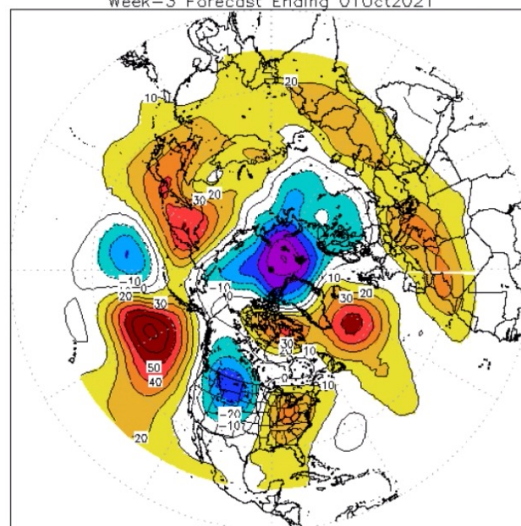


(meters)

JMA

[Product Description](#)

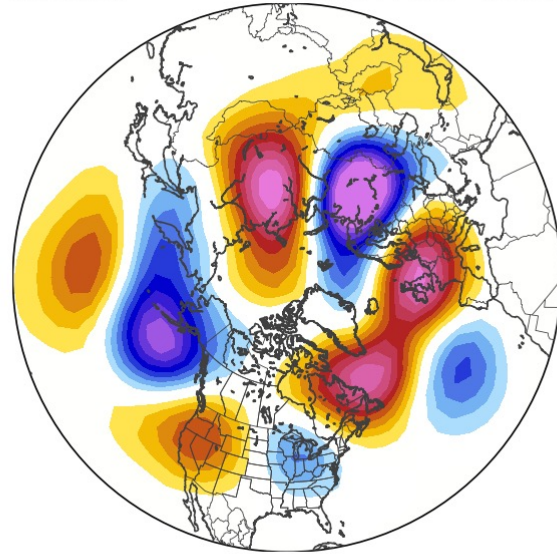
JMA 500hPa Height Anomalies Issued 08Sep2021
Week-3 Forecast Ending 01Oct2021



(meters)

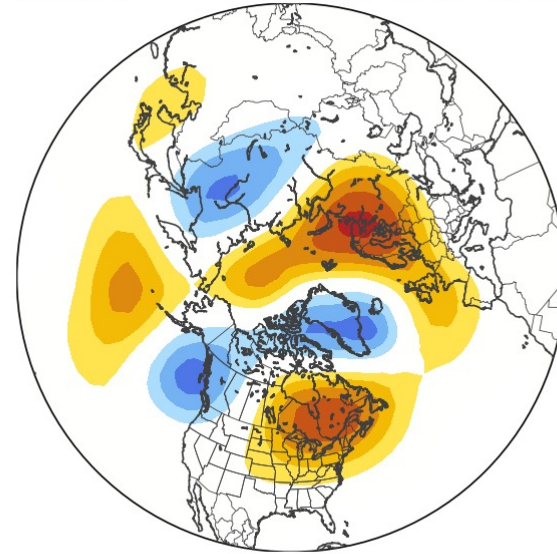
H500 Anomaly

Init: Fri 10 Sep 2021
Valid: 04 Sep - 10 Sep



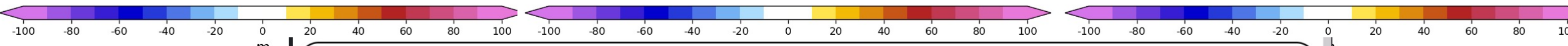
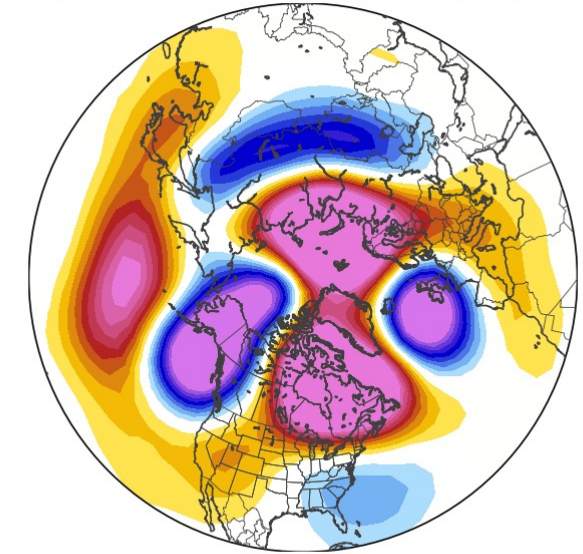
H500 Anomaly

Init: Fri 10 Sep 2021
Valid: 25 Sep - 01 Oct



H500 Anomaly

Init: Fri 01 Oct 2021
Valid: 25 Sep - 01 Oct

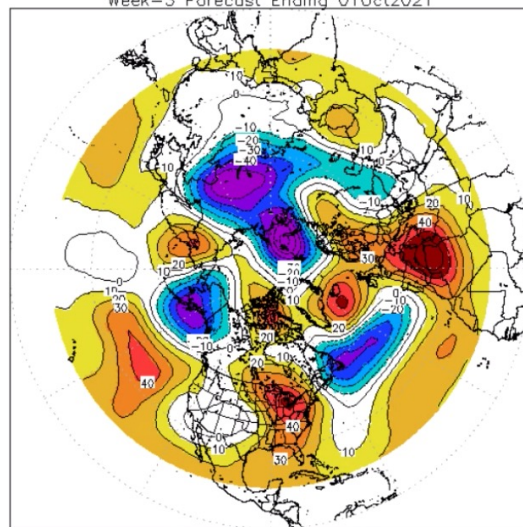


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CFS

[Product Description](#)

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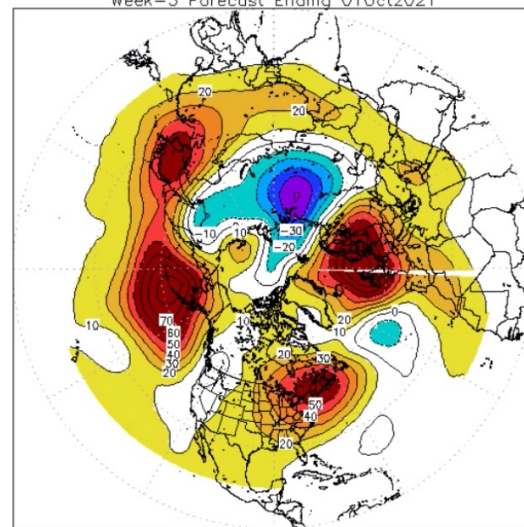


(meters)

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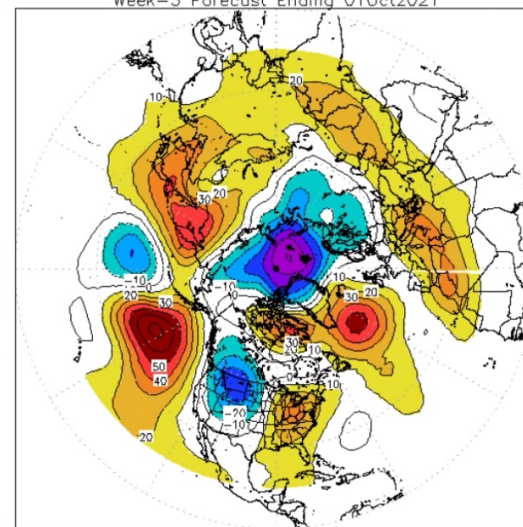


(meters)

JMA

[Product Description](#)

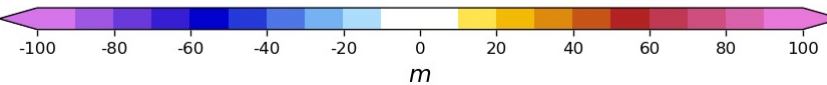
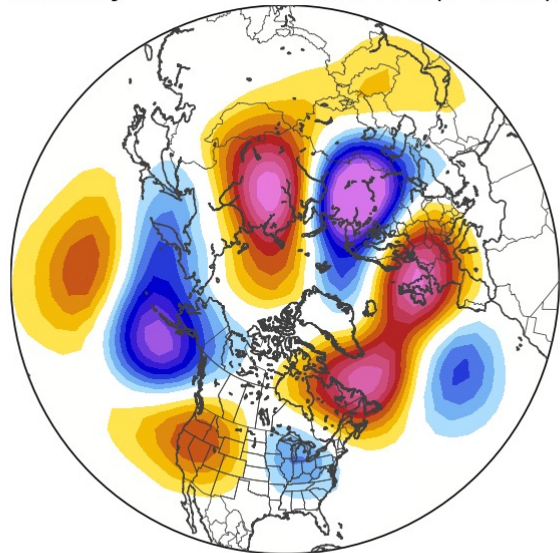
JMA 500hPa Height Anomalies Issued 08Sep2021
Week-3 Forecast Ending 01Oct2021



(meters)

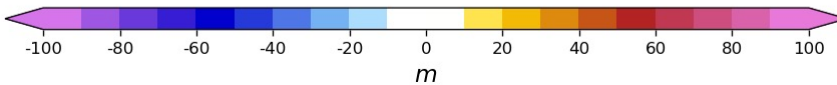
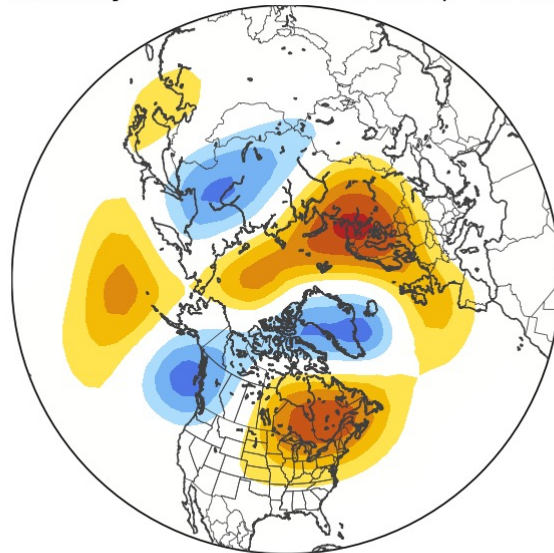
**H500
Anomaly**

Init: Fri 10 Sep 2021
Valid: 04 Sep - 10 Sep



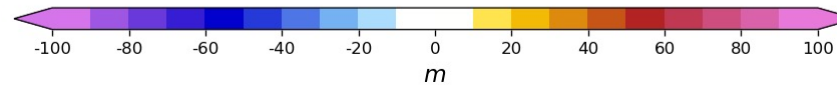
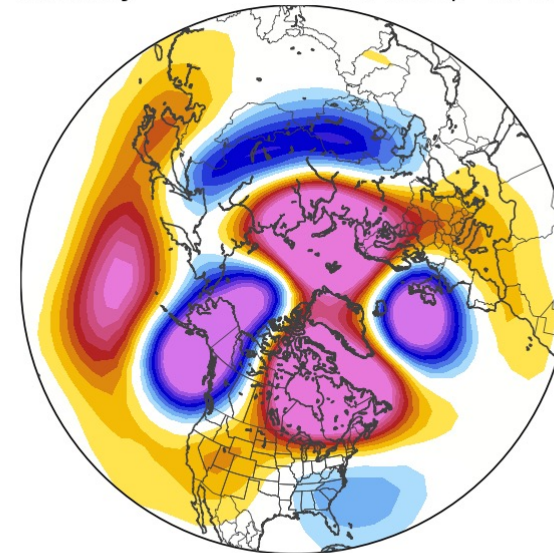
**H500
Anomaly**

Init: Fri 10 Sep 2021
Valid: 25 Sep - 01 Oct



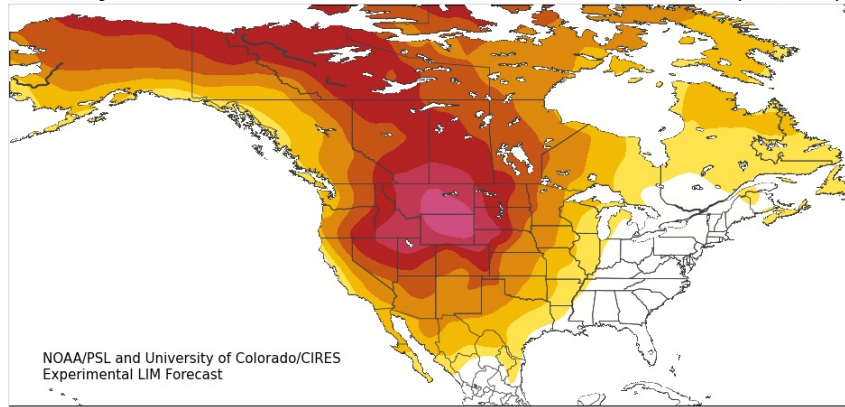
**H500
Anomaly**

Init: Fri 01 Oct 2021
Valid: 25 Sep - 01 Oct

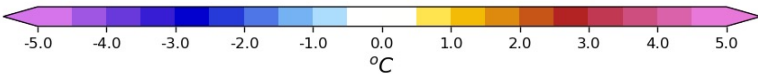


**T2m
Anomaly**

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Valid: 04 Sep - 10 Sep

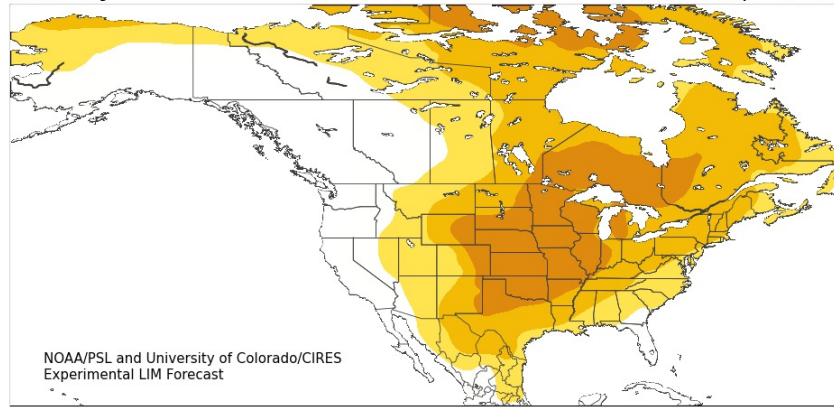


NOAA/PSL and University of Colorado/CIRES
Experimental LIM Forecast

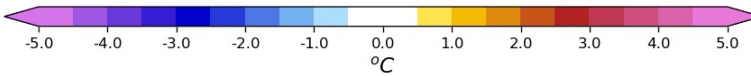


**T2m
Anomaly**

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Valid: 25 Sep - 01 Oct

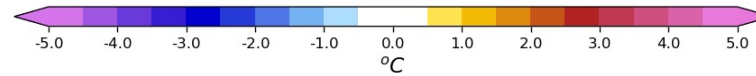
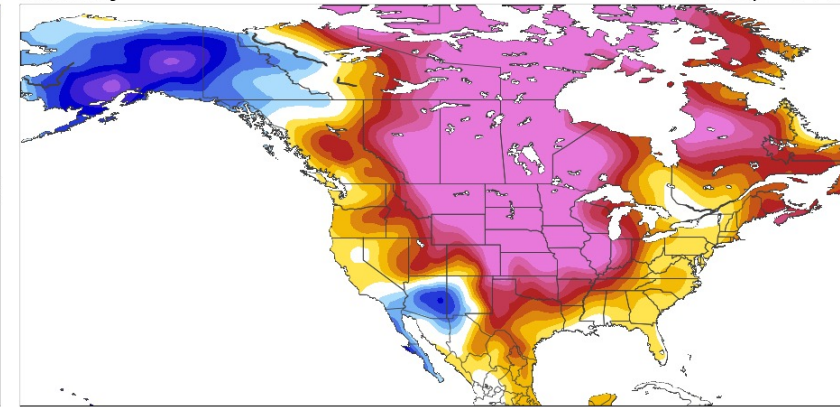


NOAA/PSL and University of Colorado/CIRES
Experimental LIM Forecast



**T2m
Anomaly**

Verification
Valid: 25 Sep - 01 Oct

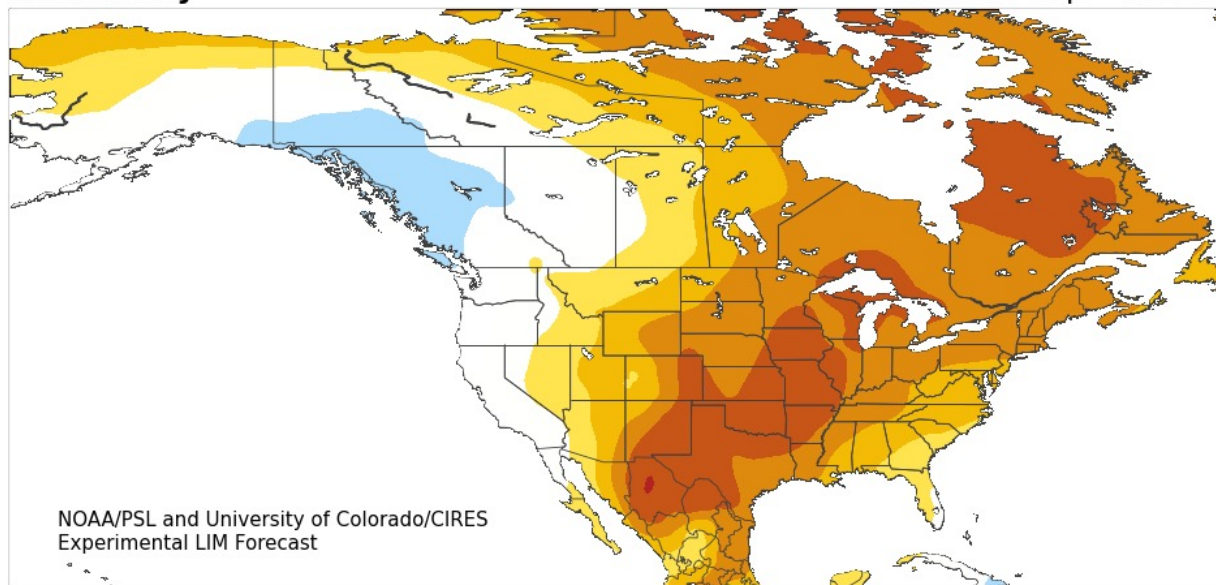


Final product: Weeks 3+4 probability for above/below median temperature

Note: we view LIM probabilities < 55% as “equal chances”

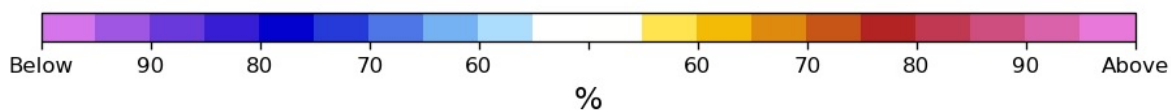
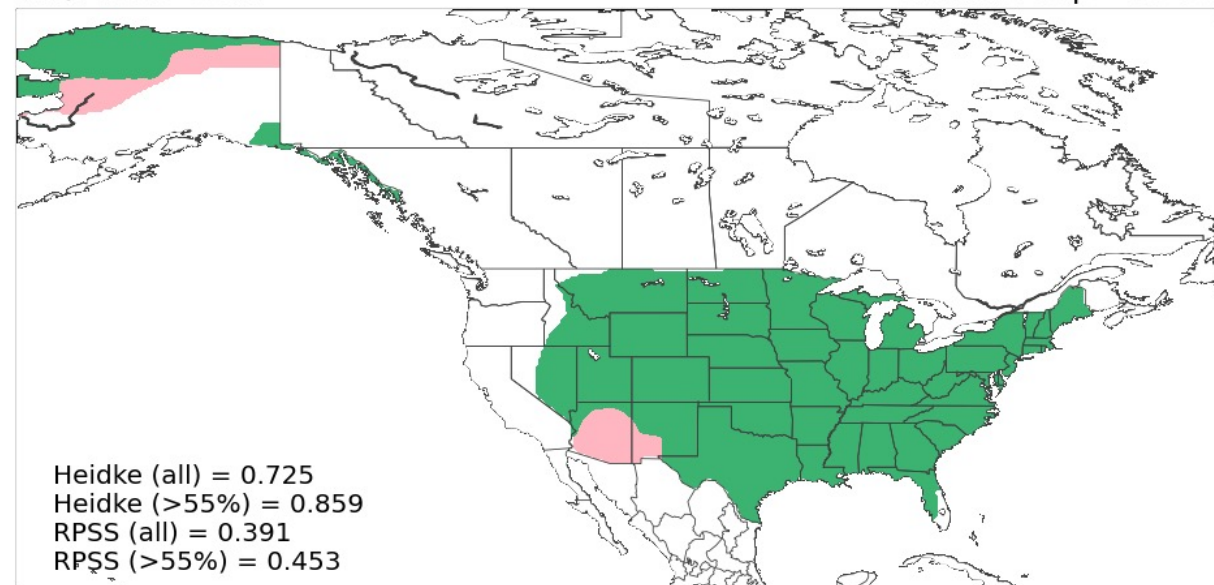
**T2m
Probability**

Init: Fri 10 Sep 2021
Valid: 25 Sep - 08 Oct



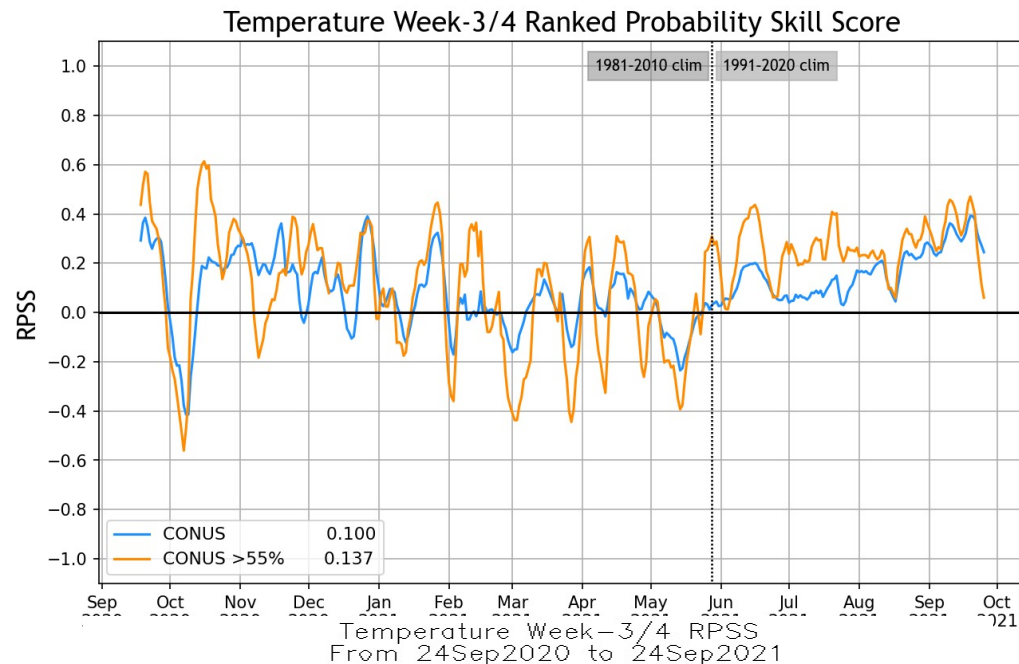
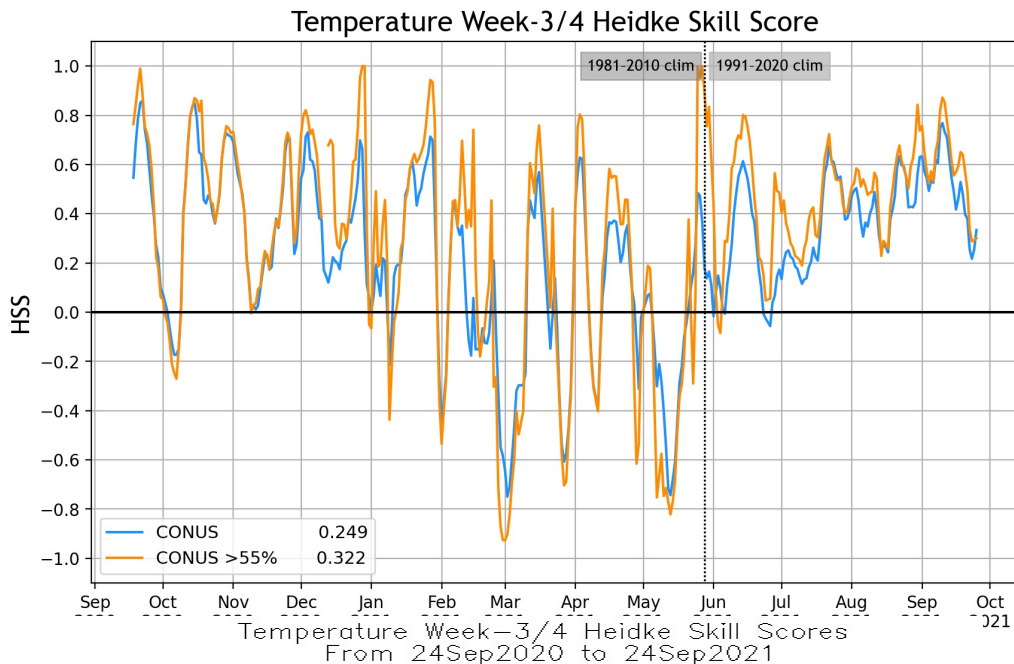
**T2m
Hit/Miss >55%**

Verification
Valid: 25 Sep - 08 Oct

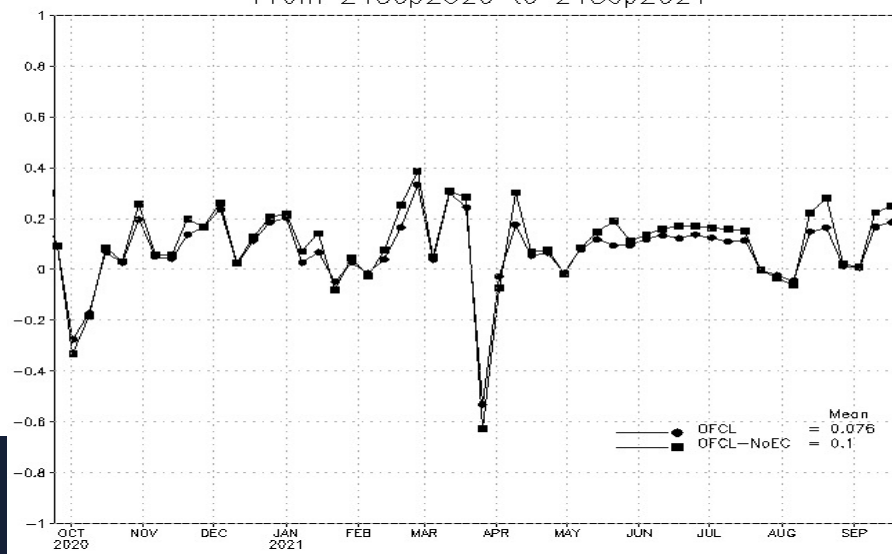
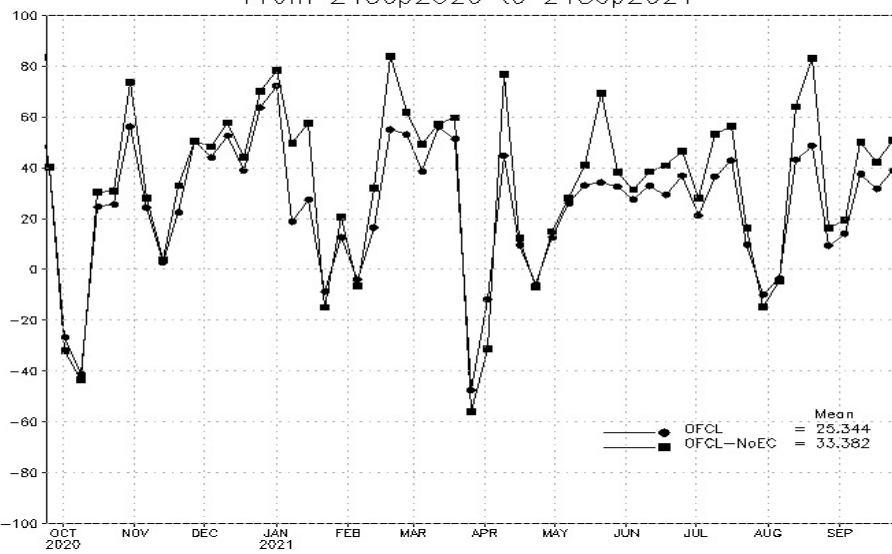


Real-time skill scores, October 2020 - September 2021

**LIM
(daily)**



**Official CPC
Forecast
(weekly)**



*Both verified against
CPC Global 2m
temperatures*

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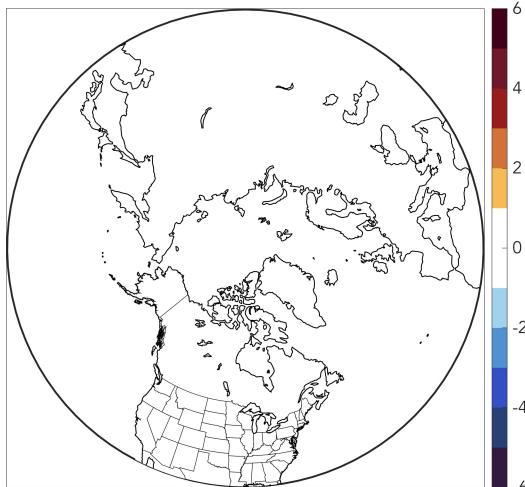
LIM 2.0 plans

- Output realtime LIM diagnostics to aid in model guidance of forecasts (Albers talk from Wednesday)
- Add “root zone” soil moisture to LIM state variables during warm season, which improves skill (Lillo talk from Tuesday)
- Better leverage LIM’s ability to identify forecasts of opportunity in an operational context (e.g., when can forecasters increase confidence and set higher probabilities?)
 - Relevant for planned tercile forecast categories
- Move on to precip...

LIM diagnosis of realtime sources of predictability, *at time of forecast*

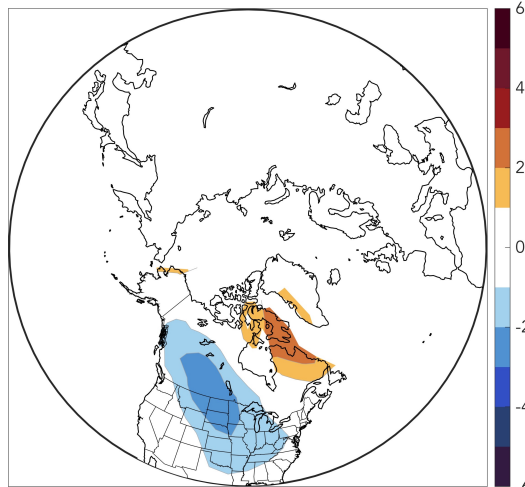
Internal space (no MJO),
largely unpredictable

LIM forecast weeks 3/4
Verif. dates 08-Feb-2021 - 21-Feb-2021



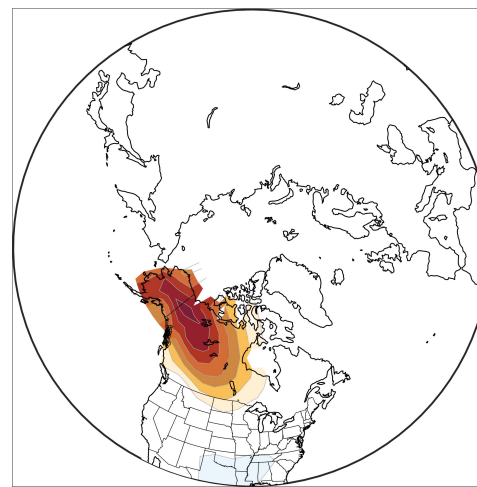
SST/stratosphere modes

LIM forecast weeks 3/4
Verif. dates 08-Feb-2021 - 21-Feb-2021



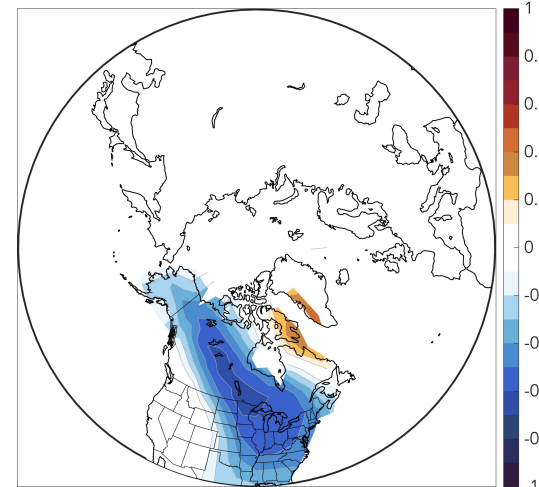
MJO mode

LIM forecast weeks 3/4
Verif. dates 08-Feb-2021 - 21-Feb-2021

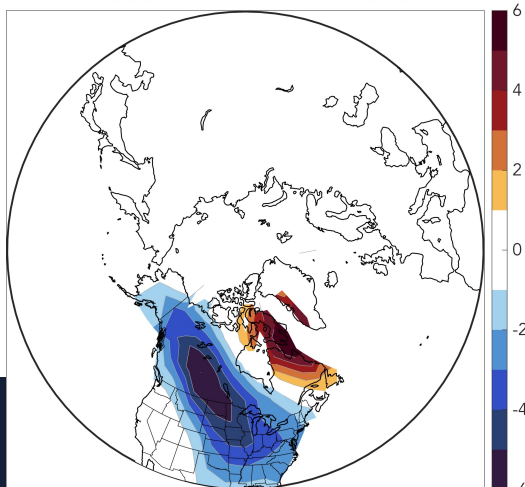


Stratospheric NAM mode

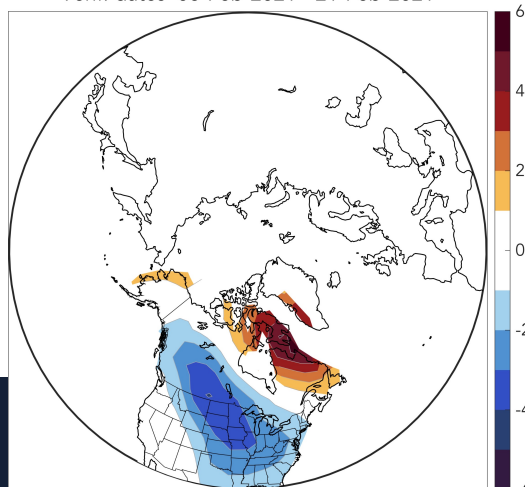
LIM forecast weeks 3/4
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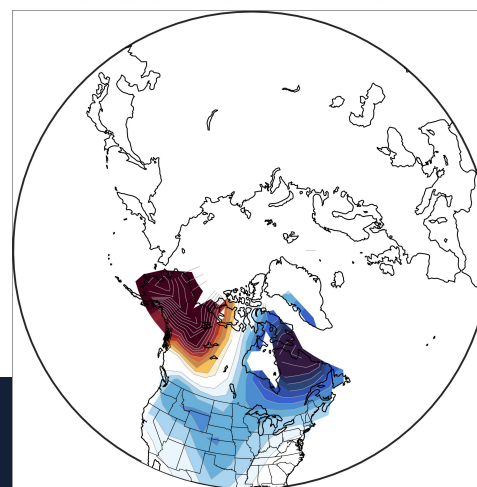
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Verif. dates 08-Feb-2021 - 21-Feb-2021



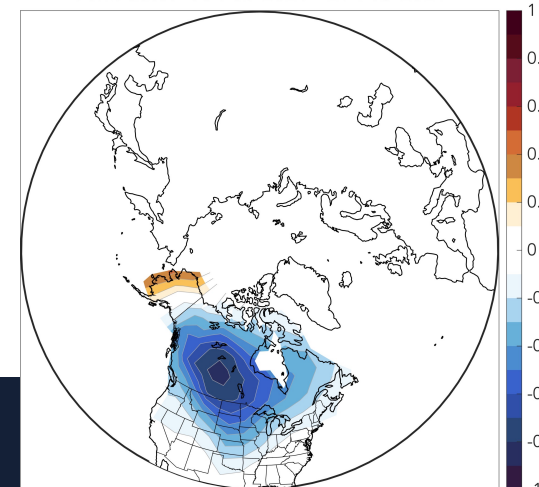
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Verif. dates 08-Feb-2021 - 21-Feb-2021



Verification (EOF truncated) weeks 3/4
Verif. dates 08-Feb-2021 - 21-Feb-2021



Verification (EOF truncated) weeks 3/4
Verif. dates 08-Feb-2021 - 21-Feb-2021



LIM Week 3-4
forecast for
2/8-2/21 2021

Verification
(observed 2-
week mean,
2/8-2/21 2021