PREDICTABILITY AND SKILL OF AN OPERATIONAL EMPIRICAL-DYNAMICAL MODEL FOR WEEKS 3-4 NORTHERN HEMISPHERE FORECASTS

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Empirical model of dynamics: *Linear Inverse Model (LIM)*

- If nonlinearities are mostly ***fast*** then on slower seasonal time scales, they are essentially ***unpredictable***.
- Some portion of these fast nonlinearities can be linearly parameterized to retrieve their ***slow*** aggregate effect.
- Empirical model for climate anomaly ***evolution*** with linear stochastically forced dynamics:

$$\frac{d\mathbf{x}}{dt} = \mathbf{L}\mathbf{x} + \mathbf{S}\eta$$

$\mathbf{x}(t)$ is the state vector at time t,

$\mathbf{L}$ is a stable linear operator, combining slow linear processes and linearly parameterizable nonlinearities

$\mathbf{S}\eta$ is white noise

Multivariate nonnormal linear dynamics

- The linear operator, $\mathbf{L}$, is obtained from covariance statistics of the state variables (e.g. AR1).
- Eigenmodes of $\mathbf{L}$ represent different oscillatory evolutions, with various periods and exponentially decreasing amplitude with time.
- Individual anomalies can grow and evolve through ***eigenmode constructive / destructive interference.***

LIM as a forecast model

- The LIM is a low-order model (prefiltered in EOF space) with O(10) degrees of freedom.
- Test assumption of linearity ("tau-test") – model is independent of training lag.
- The LIM is an ***infinite gaussian ensemble***
- **Forecast (ensemble mean):**

$$\mathbf{x}(t+\tau) = \exp(\mathbf{L}\tau)\,\mathbf{x}(t)$$

- **Categorical forecasts:**

  Forecast error, ε, is only a function of lead-time

  From the error covariance matrix, $\mathbf{E}$, we can form the gaussian PDF of the ensemble.

$$\mathbf{E}(\tau) = <\varepsilon\,\varepsilon^{\tau}> = \mathbf{C}(0) - \mathbf{G}\,\mathbf{C}(0)\mathbf{G}^{\tau}$$

- **Expected skill:**

$$\rho_\infty = \frac{s}{\sqrt{1+s^2}} \text{ where } s^2 = \frac{[\mathbf{G}\,\mathbf{C}(0)\mathbf{G}^{\tau}]_{ii}}{[\mathbf{E}(\tau)]_{ii}}$$

Objectives:

- Develop and operationalize a skillful sub-seasonal forecast model based on the statistics of the system.
- Identify "forecasts of opportunity" using the ***expected skill*** derived from the model signal-to-noise ratio.
- Extract the dynamical properties of the system from its observed statistics.

Sub-seasonal forecast models

LIM

- Cross-validated operator
- Variables are weekly-averaged coarse-grained 5-deg resolution, and truncated in EOF space (retaining about 60 – 90% variance)
- Trained on JRA-55 reanalysis from 1979 – 2017
- 12 seasonal $\mathbf{L}$ operators, each trained on a trimonthly period, with the EOFs truncation done accordingly.

Variable	Domain	PCs
Surface layer	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

ECMWF IFS-CY43

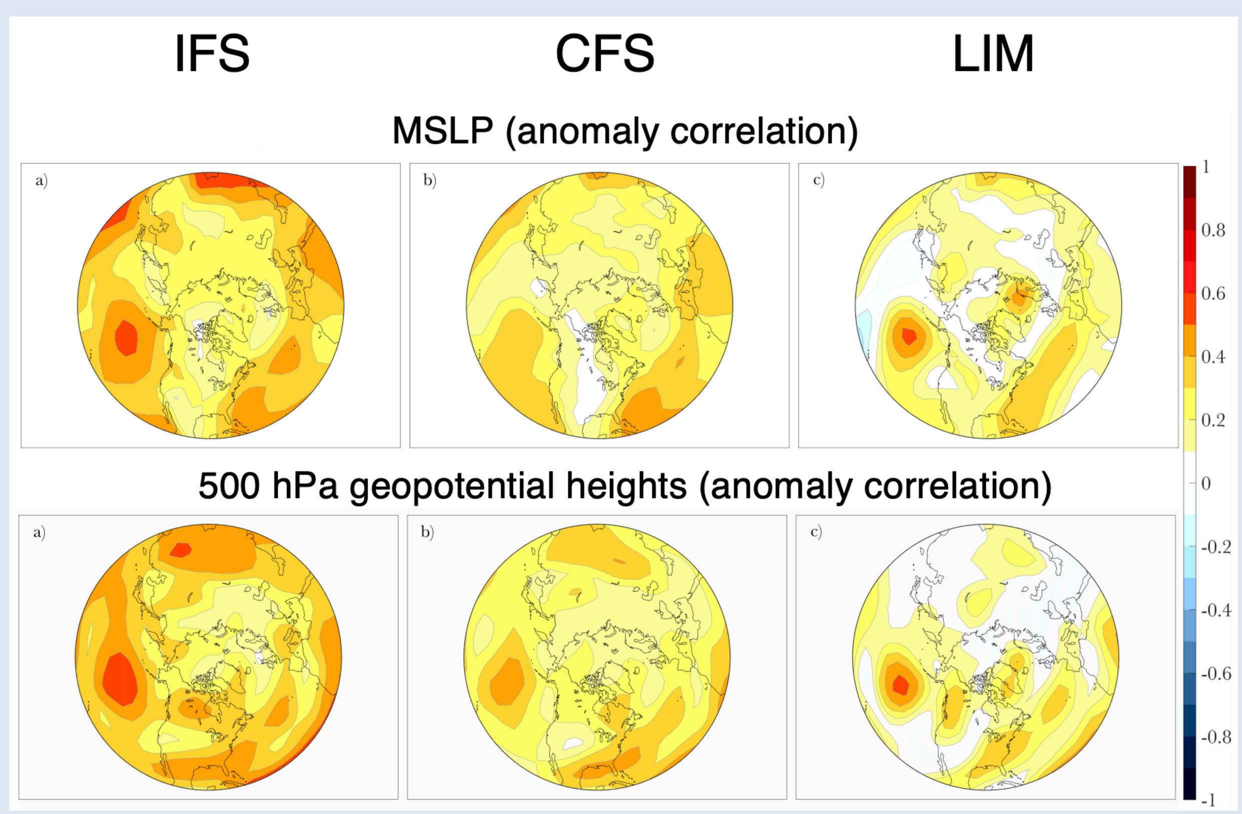
- 11 reforecasts
- Horizontal res: Tco639/319 (16 km until day 16, 32 km beyond)
- Years available: 1997 - 2016 (2017 model)

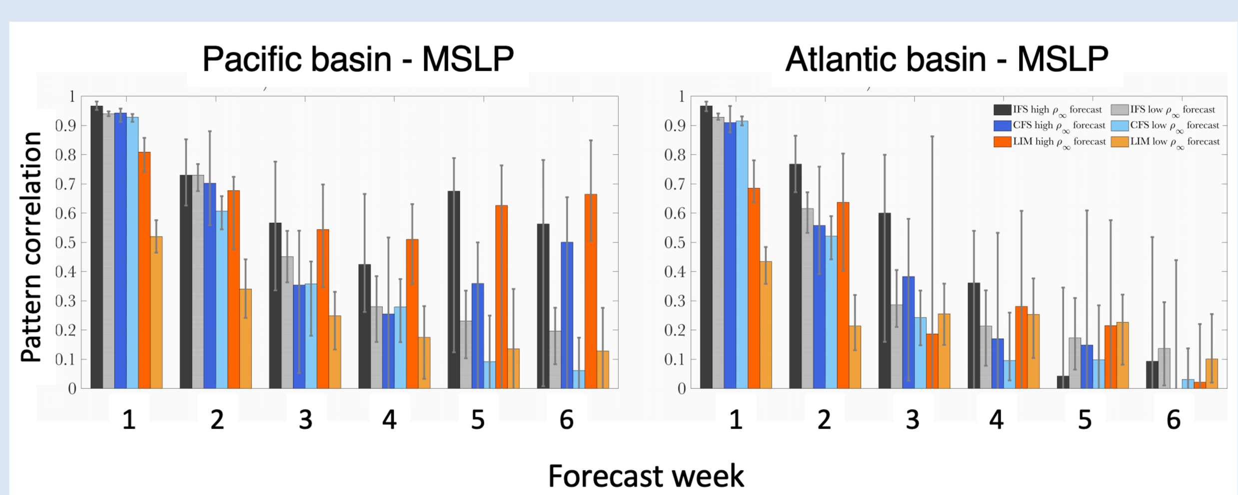
NCEP CFSv2

- 4 daily reforecasts x 4-day lagged ensemble (16 mem)
- Horizontal res: T126 (~100 km)
- Years available: 1999 - 2010

NH 500mb and SLP

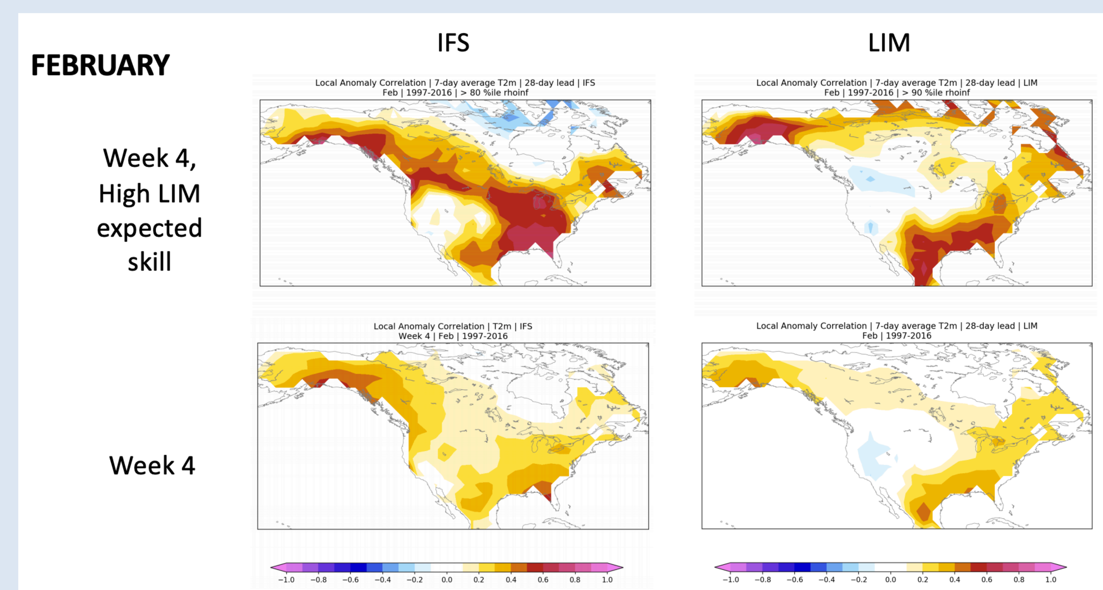
- All models share same regions of high skill in weeks 3-4, over the North Pacific and central Atlantic.
- LIM offers more skill over Scandinavia than IFS and CFS
- Using the ***expected skill*** derived from the LIM, can identify ***forecasts of opportunity*** in both the LIM itself as well as the IFS and CFS.

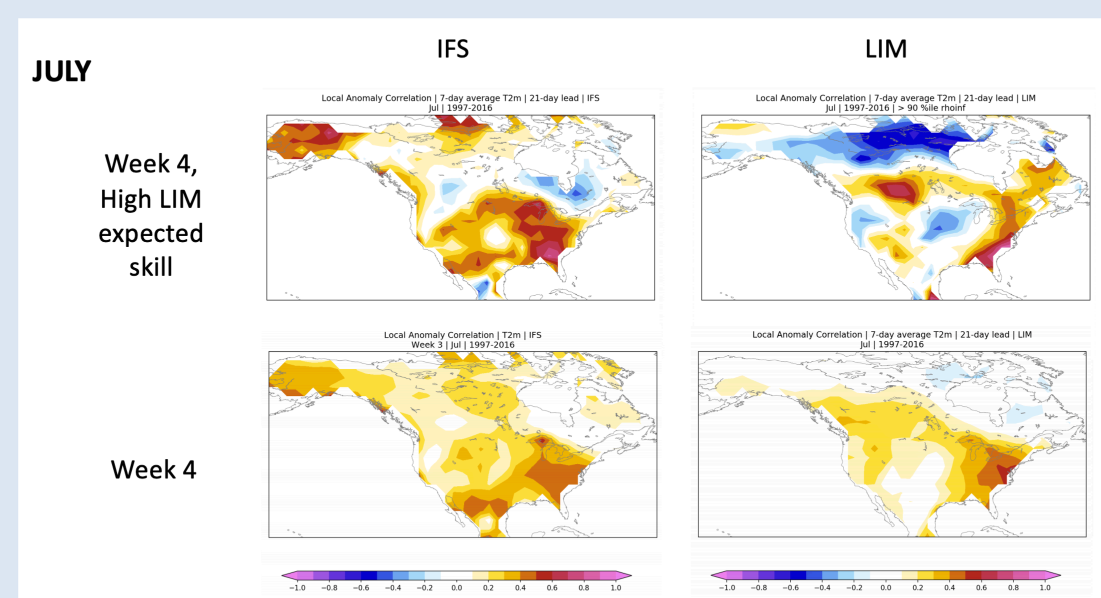


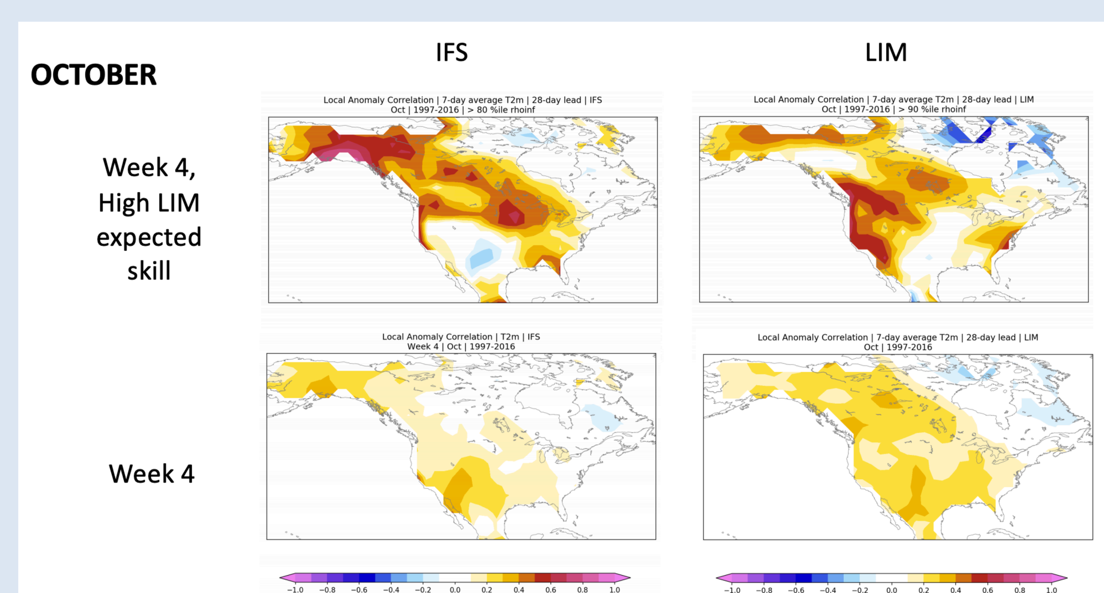


Stratify actual hindcast skill by whether LIM predicted skill value is high (top 10%) or low (bottom 90%)

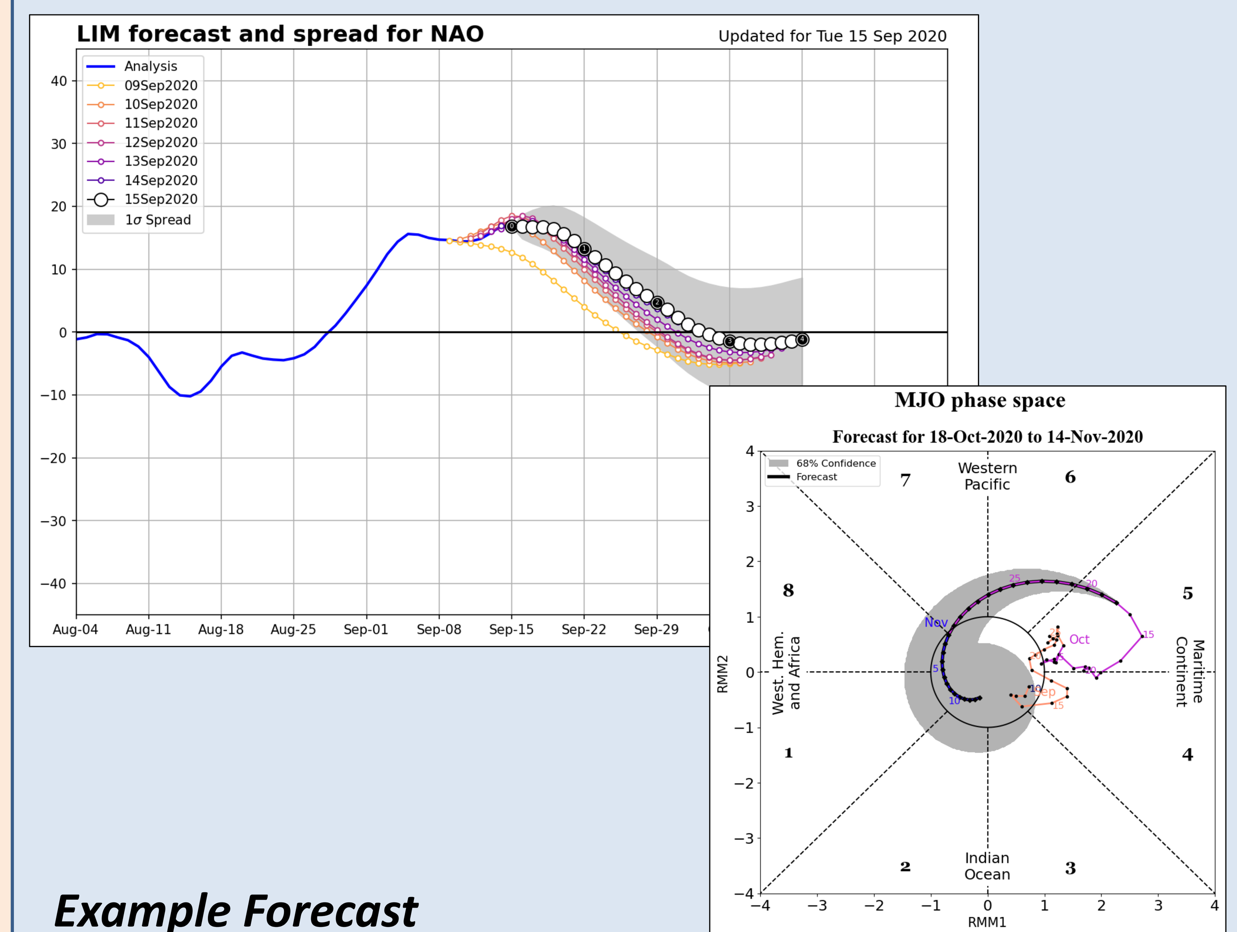
North America T2m



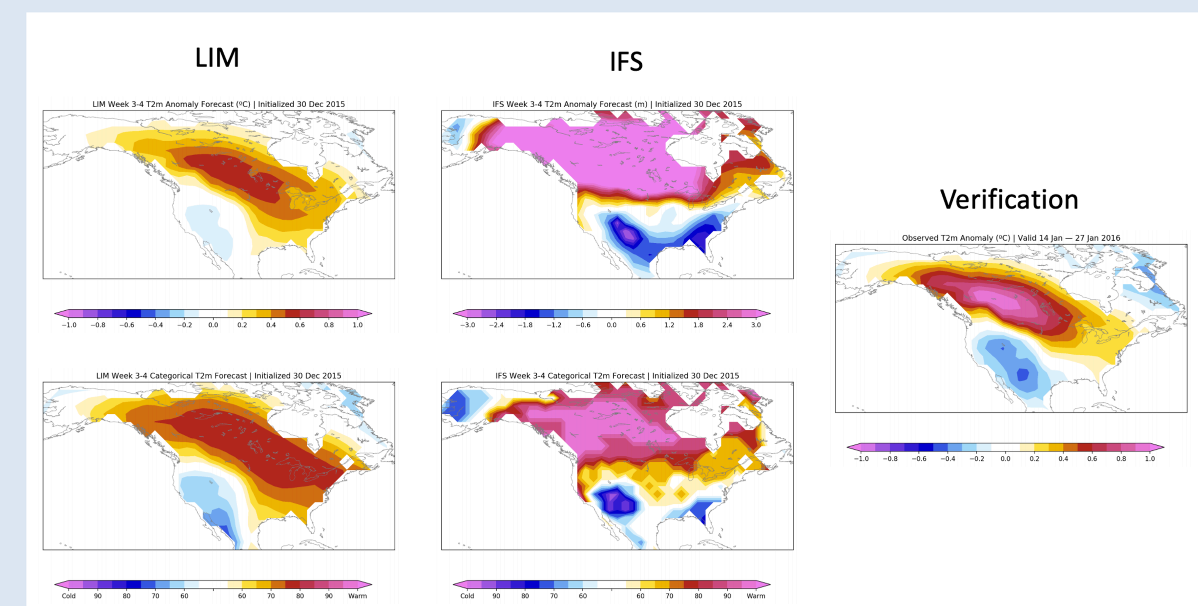




Forecast products and use

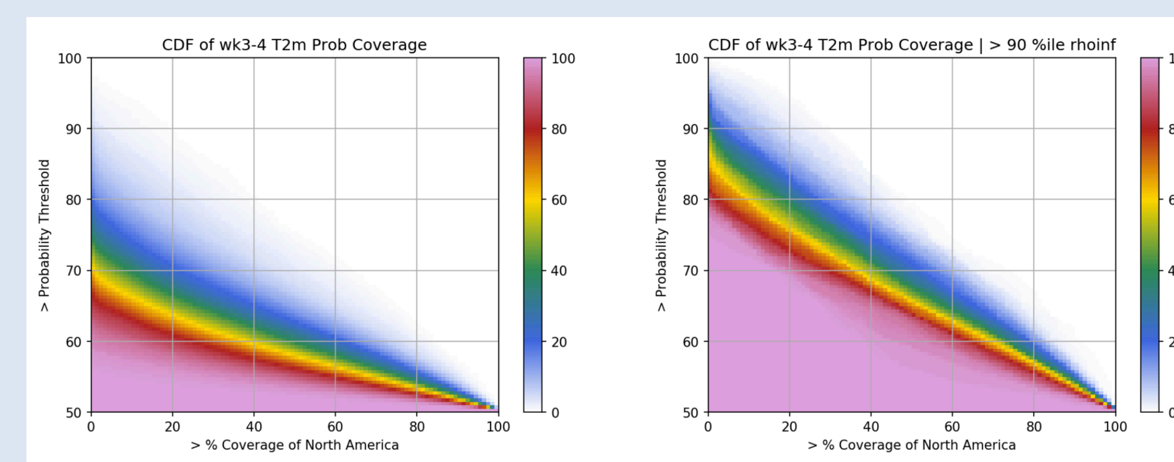


Example Forecast



LIM probabilistic forecasts and forecasts of opportunity

- Infinite ensemble creates robust distribution of magnitude and coverage of T2m probabilities across North America.
- Higher expected skill = higher probabilities.



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

Relevant References

- Albers and Newman (2019)
- Penland (1989)
- Winkler et al. (2001)
- Newman et al. (2003)

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