**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:

\[
\frac{dx}{dt} = Lx + S\eta
\]

\(x(t)\) is the state vector at time \(t\),
\(L\) is a stable linear operator, combining slow linear processes and linearly parameterizable nonlinearities
\(S\eta\) is white noise

**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**

<table>
<thead>
<tr>
<th>Model</th>
<th>Domain</th>
<th>PCx</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIM</td>
<td>North America landmass</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>20°N – 20°S</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>20°N – 50°S</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>20°S – 20°N</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>10–50°N</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>10–30°N</td>
<td>23</td>
</tr>
</tbody>
</table>

**Multivariate nonnormal linear dynamics**

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

**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.

**North America T2m**

- Fast nonlinearities are mostly unpredictable
- Inverse Model (LIM) 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.

**Forecast products and use**

- 4 daily reforecasts x 4-day lagged ensemble (16 mem)
- Horizontal res: T126 (~100 km)
- Years available: 1997 - 2016 (2017 model)

**Example Forecast**

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

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**Relevant References**

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

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

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