Was the blocking event that contributed to the February 2021 cold air outbreak over the central U.S. predictable on subseasonal timescales?

John R. Albers[1,2], Matthew Newman[1,2], Melissa L. Breeden[1,2] , Andrew Hoell[1] , Yan Wang[1,2] , Jiale Lou[1,2]

[1]NOAA Physical Science Laboratory, [2]CIRES University of Colorado Boulder

NOAA Physical Sciences Laboratory

CIRES — University of Colorado Boulder

Goal: Diagnose the potential subseasonal predictability of the winter 2021 North American severe cold air outbreak (CAO) and associated Pacific blocking event.

To do this, we use a linear inverse model (LIM) to construct a dynamical ('nonnormal') filter that decomposes subseasonal climate variability into distinct types of dynamical climate modes, including those that are predictable on subseasonal timescales (the MJO, ENSO, stratospheric processes), as well as those that represent synoptic variability that is not predictable on subseasonal timescales.

Linear inverse model (LIM):

- Empirical dynamical model that approximates chaotic atmospheric nonlinearity in terms of predictable linear dynamics (L) and unpredictable noise (ξ) with "coarse-grained" state vector (x):

$$\frac{dx}{dt} = Lx + \xi \qquad x = \begin{bmatrix} p \\ \Phi \\ H \\ \psi_T \\ \psi_S \\ SST \\ T_{2m} \end{bmatrix}$$

- Mean sea-level pressure (0˚-90˚N)
- Geopotential (500 hPa, 0˚-90˚N)
- Tropical heating (-15˚S-15˚N)
- Tropospheric stream function (750 hPa, 0˚-90˚N)
- Stratospheric stream function (combined 10 and 100 hPa, 30˚-90˚N)
- Tropical sea surface temperature (-15˚S-15˚N)
- 2m temperature (North America–land only)

- x consists of 7-day running mean anomalies of Japanese Reanalysis (JRA-55)
- L is constructed from 5-day lag covariances of x
- ξ represents rapidly decorrelating (<1 week) daily timescale (potentially nonlinear) synoptic variability that is unlikely to be predictable on subseasonal timescales
- ξ is observationally constrained (function of lag-zero covariance statistics)

LIM simulations:

- 2021 reforecasts with LIM trained on DJF 1979-2017 data and run with out-of-sample forecasts
- Ensemble reforecasts and climate simulations: 5,000 ensemble member LIM data denial experiments (initialized during Dec./Jan. 2020/2021)
- 2000-year LIM climate simulation

Building a 'nonnormal' filter

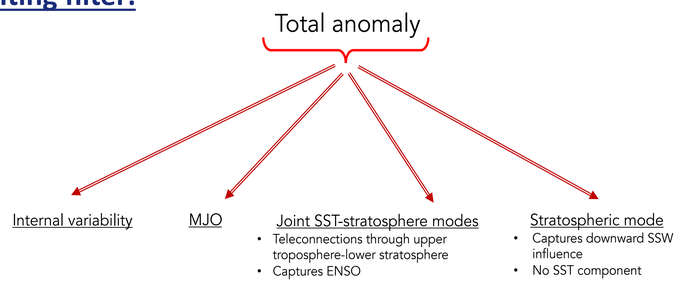
$$\frac{dx}{dt} = Lx + \xi$$

Eigendecomposition of L yields eigenmodes with 3 important characteristics:

1. Period/frequency of oscillation
2. e-folding decay time
3. Relative amplitude in each LIM state vector (x) variable

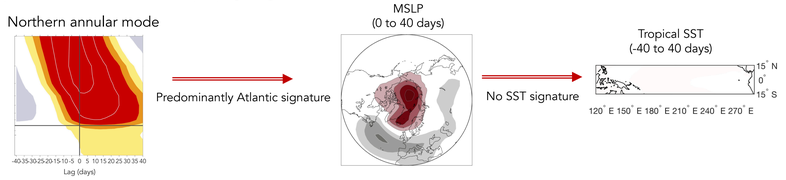
(Penland and Matrasova 2006, Albers and Newman 2021, Albers et al. 2022)

Resulting filter:



Example one: Stratospheric eigenmode

(captures SSWs and downward propagating NAM events)



LIM and ECMWF forecasts and JRA-55 observations of February 2021 CAO

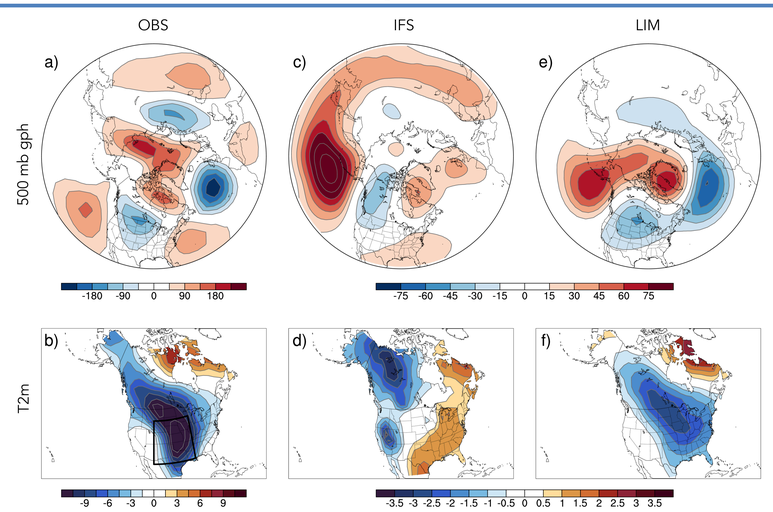


Figure caption: Two-week average 500 gph and 2m temperature for JRA-55 reanalysis (left column), ECMWF IFS forecast (middle column) and LIM forecast (right column).. The JRA-55 verification is shown for 8–21 Feb 2021. The LIM reforecast is initialized on 24 Jan 2021 and verifies 8–21 Feb 2021 The bias-corrected IFS forecast (model version CY47R1, operational 2021) is initialized on 25 Jan 2021 and verifies 9–22 Feb 2021.

Apply nonnormal filter to JRA-55 observations and LIM forecasts of February 2021 CAO

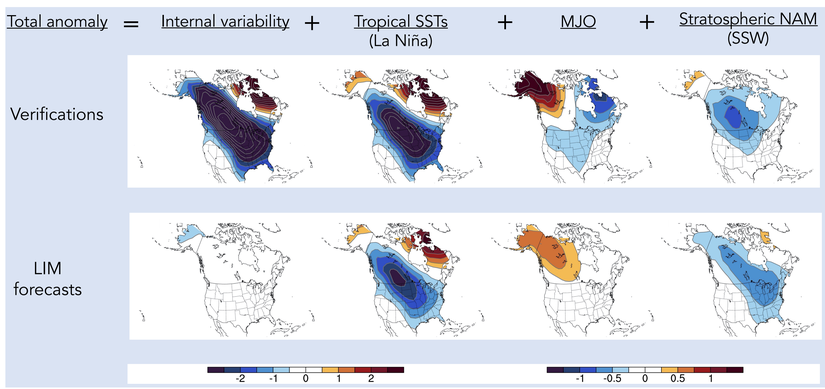


Figure caption: Two-week average 2m temperature with LIM nonnormal filter applied. Top row shows filtered JRA-55 reanalysis and bottom row shows Weeks 3-4 LIM forecast.

Severe CAO risk based on ensemble LIM forecasts

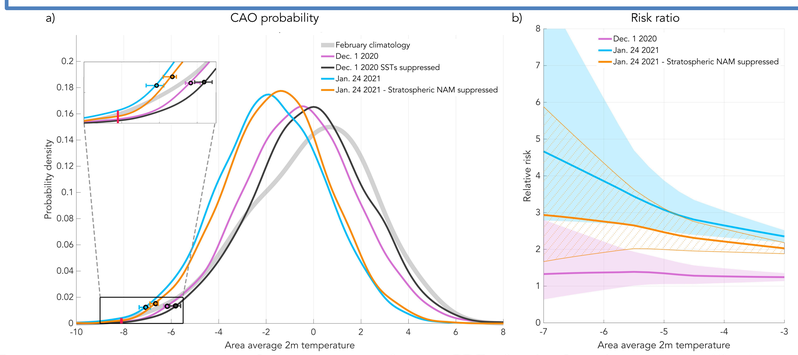


Figure caption: (a) Area average 2-m temperature forecast PDFs for the 2-week average verifications of four reforecast experiments (see legend for details). The thick gray curve denotes the climatological PDF for 5,000 two-week average periods randomly subsampled from all February 2-week periods between 1979 and 2017. The 95th percentile bootstrap confidence intervals are shown as whiskers. (b) The risk ratio for the same reforecasts, defined here as the probability CAOs of various magnitudes in each of the reforecast experiments 1, 3, or 4 relative to the probability of a CAO in reforecast experiment 2. The 95th percentile bootstrap confidence intervals are depicted via the shaded or hatched regions. Units in both panels are in degrees Celsius.

Characteristics of 'typical' severe CAO based on LIM climate simulation

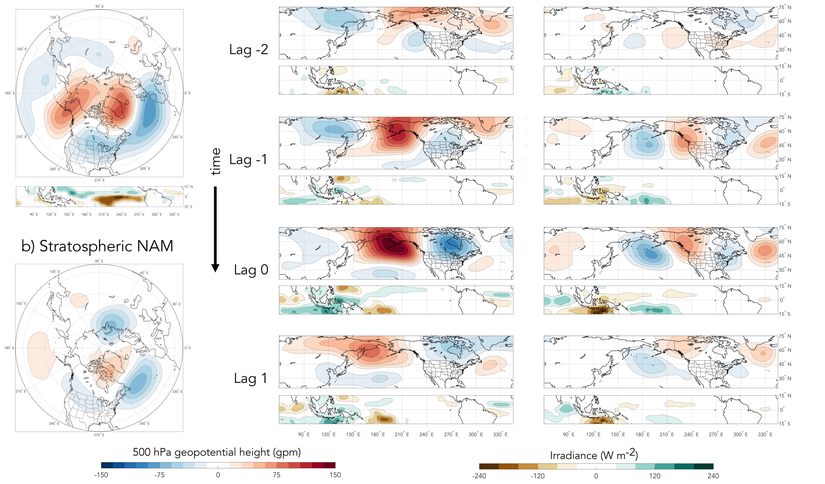


Figure caption: 500-mb gph and column integrated tropical irradiance composited from the most severe CAOs in a 3,000-yr LIM climate simulation (2-week area average temperature < 8.1°C). The anomalies are filtered to show: lag 0 composites of 500-mb gph and tropical irradiance related to (a) tropical SSTs, (b) downward propagating stratospheric NAM anomalies; and time-lagged composites of 500-mb gph and tropical irradiance related to (c) internal variability, and (d) the MJO.

Conclusions:

- Dynamical models suggested warm North American 2m temperatures until 2 weeks before CAO
- LIM suggested CAO at least 4 weeks in advance
- Predictable portion of 2021 North American CAO was due to SST-stratosphere modes (La Niña), with small contributions from SSW and MJO
- Risk of strong CAO was mildly increased on Dec. 1, 2020 because of La Niña
- Risk of strong CAO was 3-5 times as likely by Jan. 24 due to combined effects of La Niña and SSW

Reference: *Albers, John R., Matthew Newman, Andrew Hoell, Melissa L. Breeden, Yan Wang, and Jiale Lou. "The February 2021 cold air outbreak in the United States: A subseasonal forecast of opportunity." Bulletin of the American Meteorological Society 103, no. 12 (2022): E2887-E2904.*