



Feeling the Pulse of the Stratosphere: An Emerging Opportunity for Predicting Continental-Scale Cold Air Outbreaks One Month in Advance

Ming Cai

Department of Earth, Ocean, and Atmospheric Science

Florida State University

mcai@fsu.edu

Sources of Prediction Skill

- **NWP:** initial value problem. Rossby waves and baroclinic system => chaotic nature => inherent predictability (1-2 weeks).
- **NWP + lower boundary forcing: “forced” problems** Internal variability often is as large as the forced anomalies, particularly in the absence of large SST anomalies (e.g., non ENSO years) and over the regions where prominent atmospheric internal modes are present at all time scale => **the forecasts of the “forced” anomalies are indecisive.**
- **New Source:** Global mass circulation => The extratropics is connected to the tropics via stratosphere: => A much longer time scale.

The Needs for Predicting Cold Air Outbreaks at a Long Lead Time

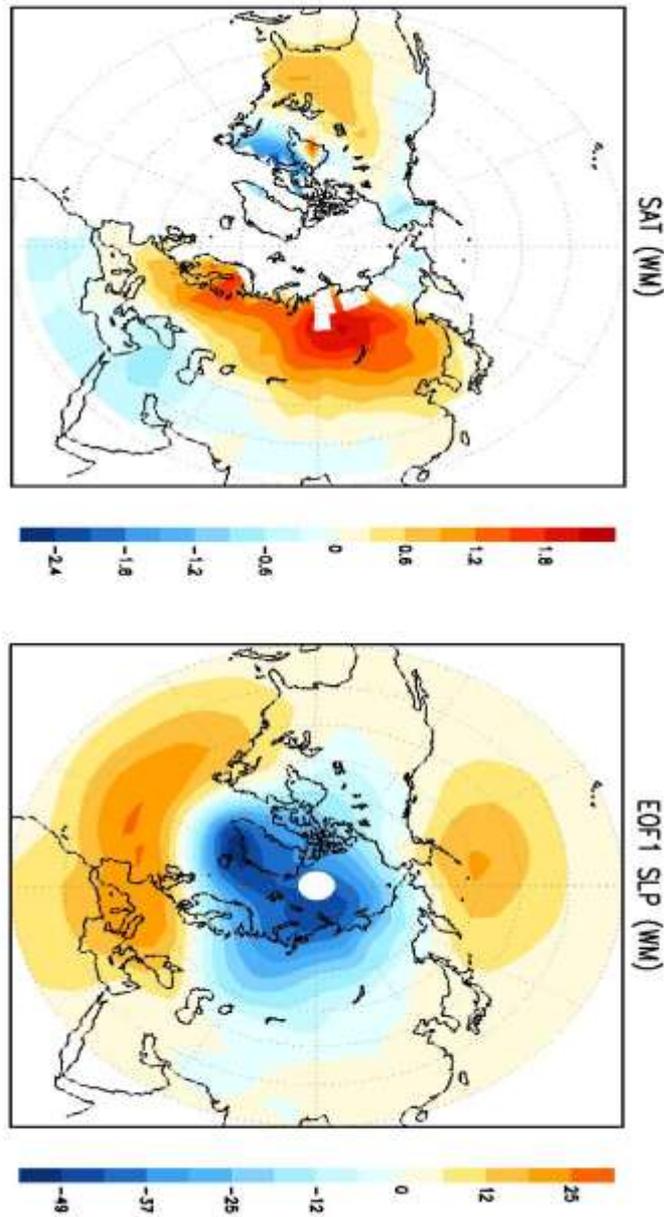
- Cold air outbreaks are frequently occurring extreme events with a large-impact area in winter seasons.
- Accompanied with cold air outbreaks are wintery storms (e.g., snow, frozen rain, high wind, icy/freezing).
- Forecasts of wintery storms at a long lead time help business and governments to prepare for potential threats to the society and business functioning (school/business closure, road/highway snow removal and deicing, flight cancellations, loss of agricultural products, etc.)

The minimum requirement to predict cold air outbreaks at a long lead time beyond the inherent 2-week limit of predictability for weather forecasts using operational models

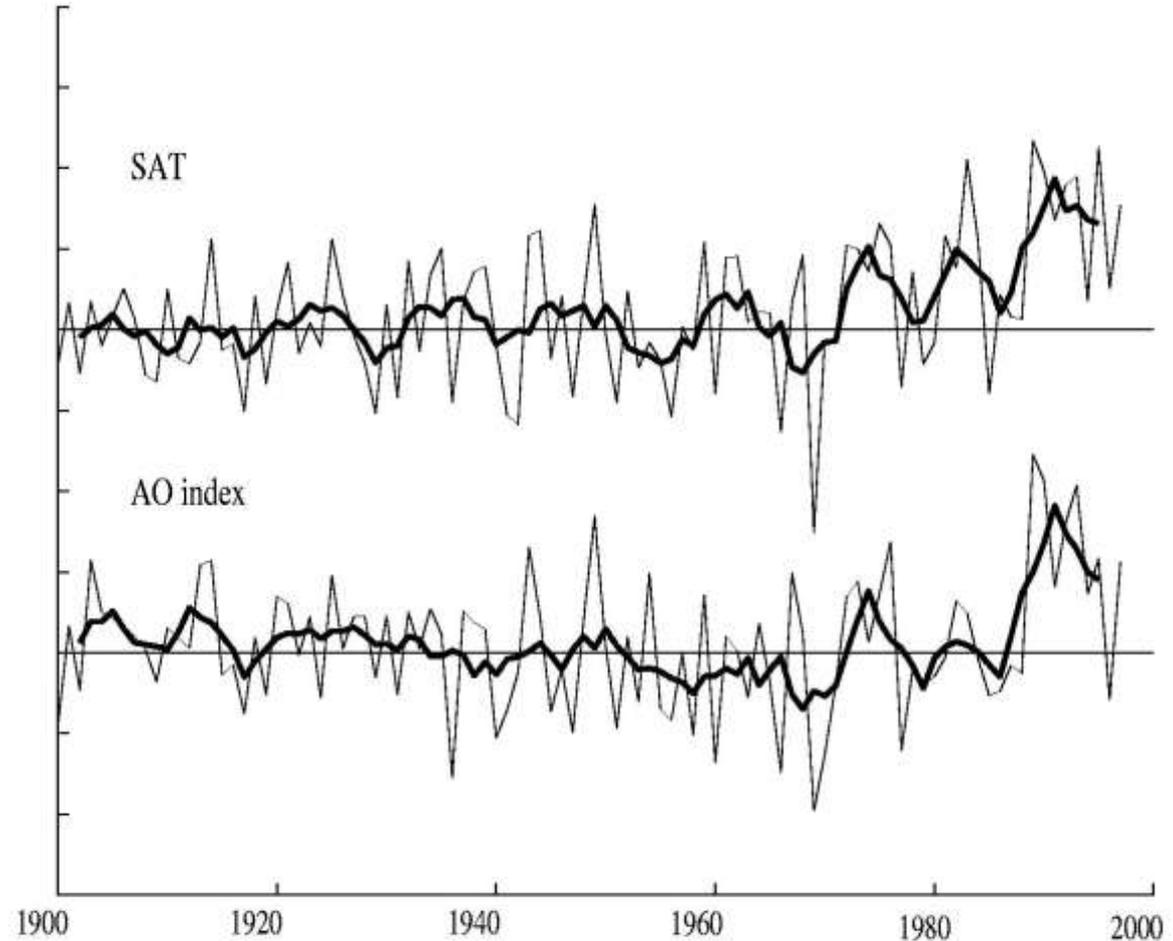
- Existence of robust diagnostic relations between some circulation indices and cold air outbreaks.
- The circulation indices that have robust diagnostic relationships with cold air outbreaks can be predicted by operational models at a long lead time with a reasonably good skill.

Key circulation indices that have good diagnostic relationships with (monthly or seasonal) mean temperature anomalies

AO and Seasonal Mean Surface Air Temperature Anomalies



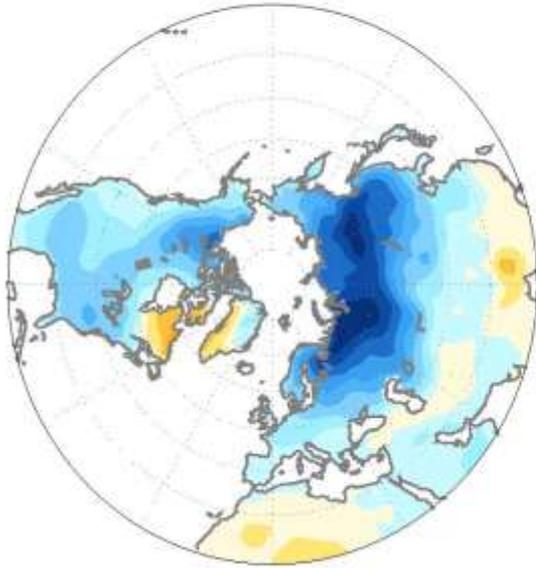
Seasonal Mean SAT



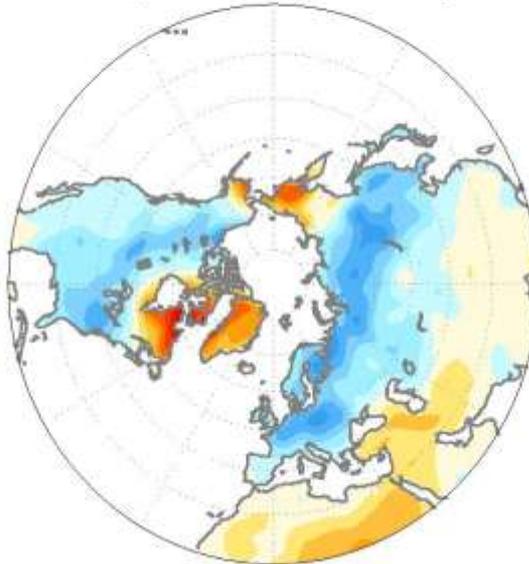
Thompson and Wallace (1998, GRL)

Stratospheric NAM and Winter Mean SAT anomalies

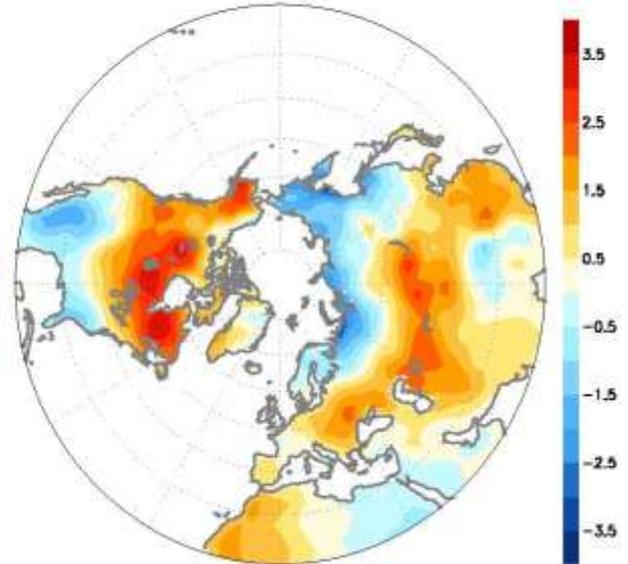
Days 1-60 following stratospheric anomalies



QBO easterly-westerly



ENSO (warm-cold)



Day 1-60 after
Stratospheric
Anomalies

Jan. only
17 Easterly versus
17 Westerly

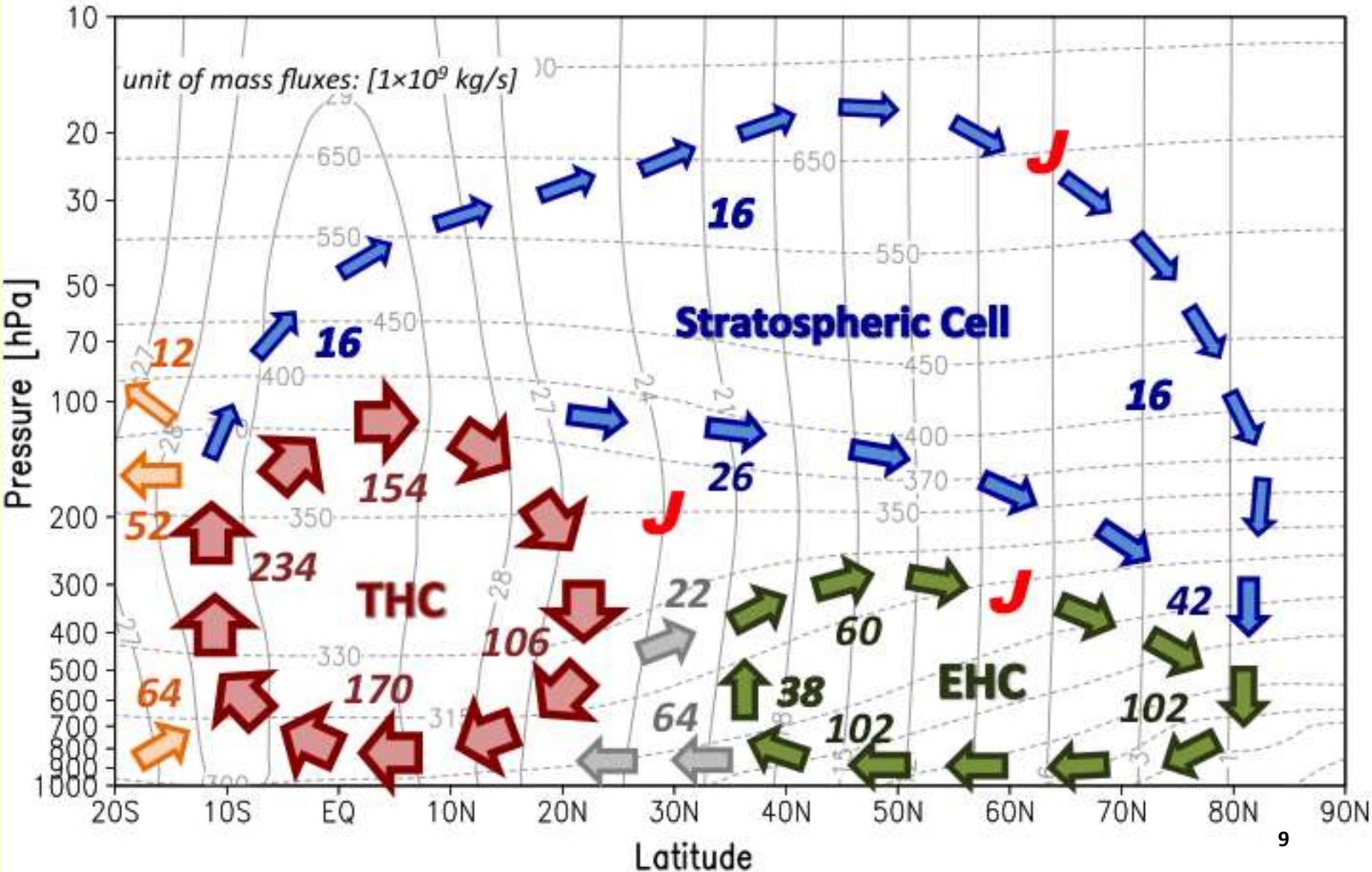
ENSO

$T(\text{negative NAM}) - T(\text{positive NAM})$
weaker_vortex - stronger_vortex
28 cases versus 31 cases

Thompson, Baldwin, and Wallace (JC,2002)

Meridional mass circulation indices and cold air outbreaks

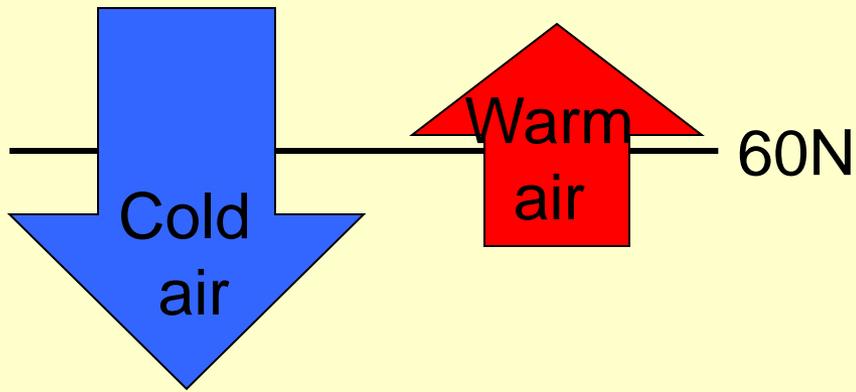
Mean meridional mass circulation in winter hemisphere (Cai and Shin 2014)



Mass circulation variability and cold air outbreaks in the mid-latitudes

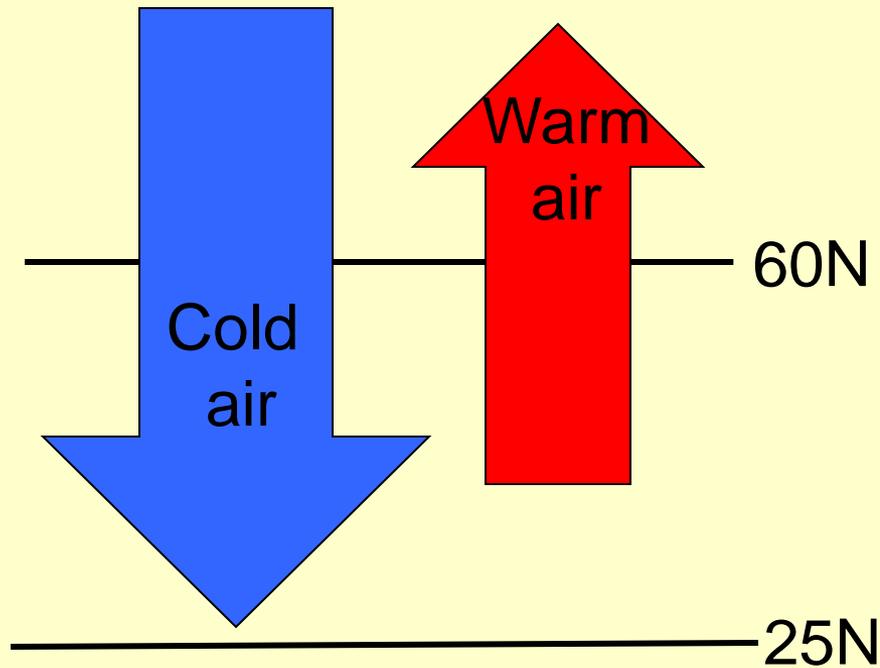
Weaker Meridional Mass
Circulation near surface

90N



Stronger Meridional Mass
Circulation near surface

90N

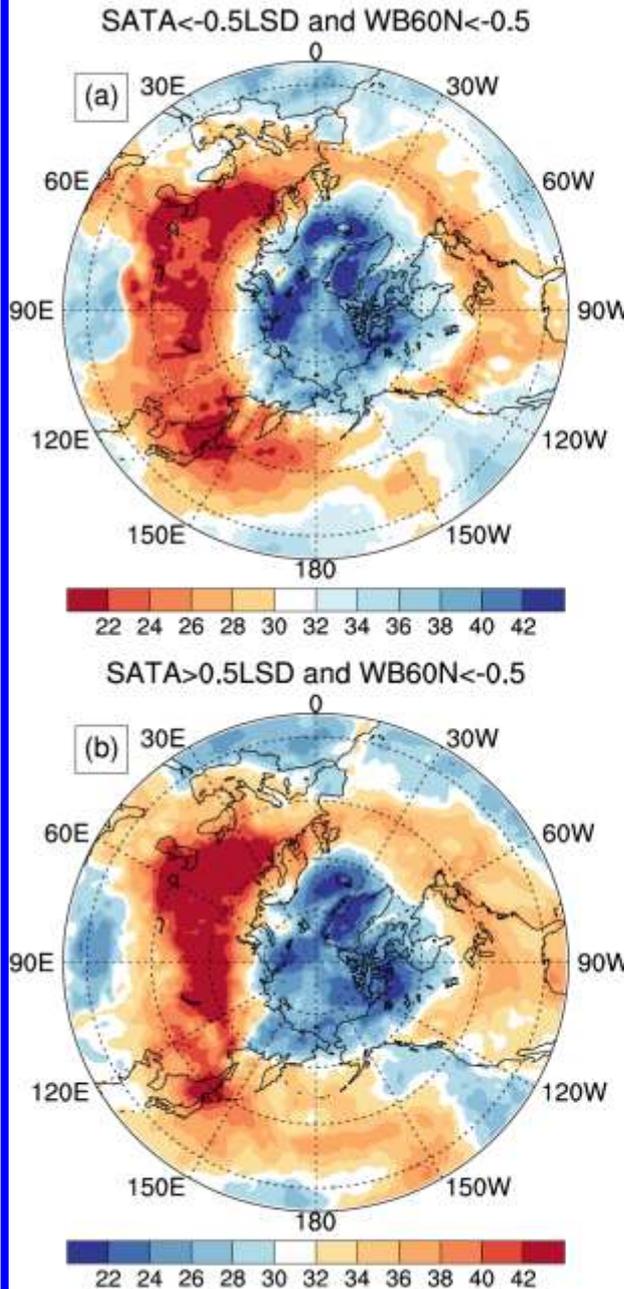


Less cold air outbreaks in
mid-latitudes
Coldness in high latitudes

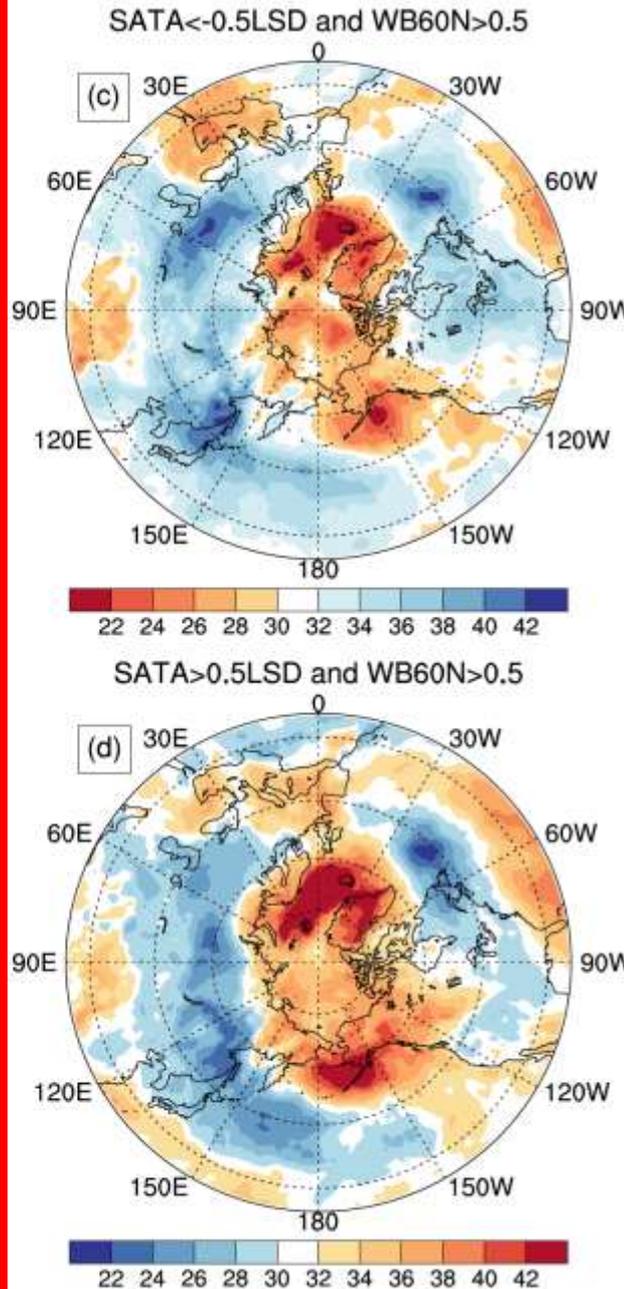
More cold air outbreaks in
mid-latitudes
Warmness in high latitudes¹⁰

Maps of Probability of $T > 0.5\text{LSD}$ or $T < -0.5\text{LSD}$

Weak Circulation



Strong Circulation



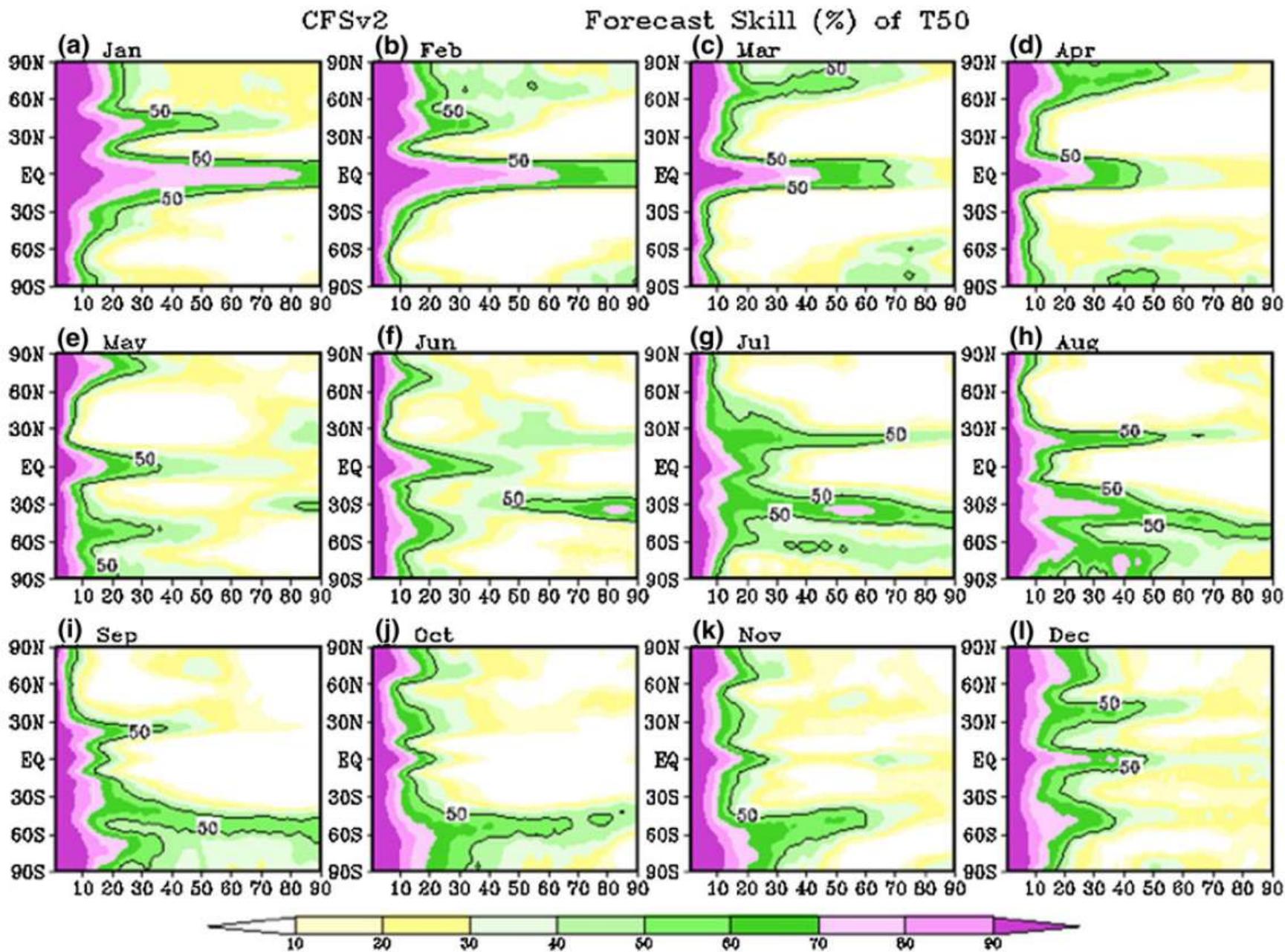
Occurrence
Prob of
 $T < -0.5\text{LSD}$

Occurrence
Prob of
 $T > 0.5\text{LSD}$

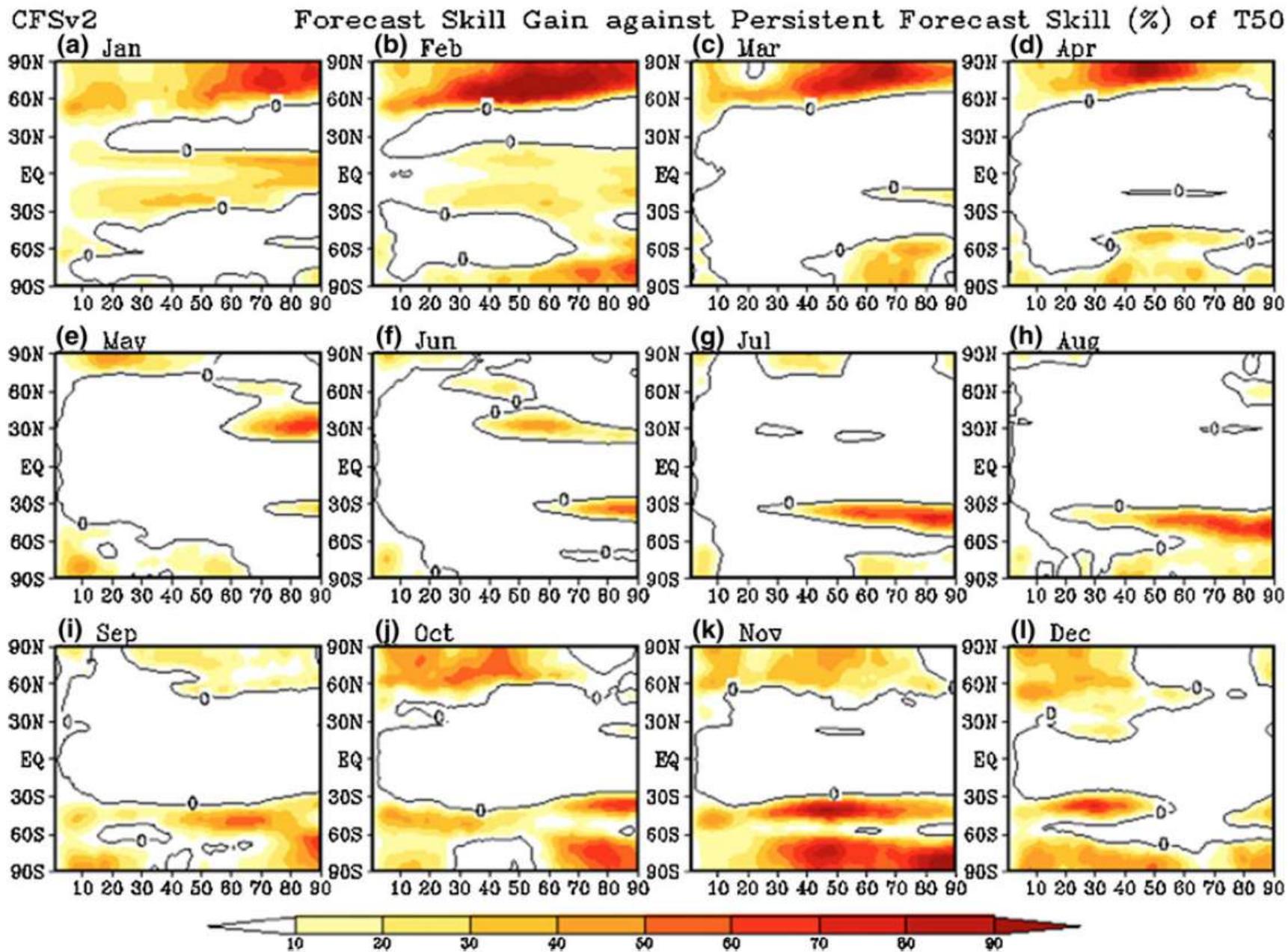
Key Findings of Yu et al. (2015)

- Variability of mass flux warm air branch is **synchronized** with that of cold air branch.
- **Lack of warm air into polar region** is accompanied by weaker equatorward advancement of cold air near the surface. As a result, the cold air mass is largely imprisoned within polar circle, responsible for general **warmness in mid-latitudes** and **below climatology temperature in high latitudes**.
- **Stronger warm air into polar stratosphere** is accompanied by stronger equatorward advancement of cold air near the surface, resulting in massive **cold air outbreaks in mid-latitudes** and **warmth in high latitudes**.
- Associated with a stronger mass circulation event are warm over Arctic and cold over the two major continents or one of the two continents is cold whereas the other is warm.

CFSv2 skill for zonal mean of T50 anomalies



Gain of CFSv2 over persistence forecasts



Key Findings of Zhang et al. (2013)

- The NCEP CFSv2 still has a remarkable skill in predicting mid-winter polar stratosphere warming events and the timing of the yearly final polar stratosphere warming in both hemispheres 3-4 weeks in advance. We also prove that the CFSv2 has a high prediction skill for winter polar stratosphere both in an absolute sense and in terms of gain over the persistence.
- The remarkable skill comes from the signal of systematic poleward propagation of thermal anomalies in the stratosphere associated with the global mass circulation variability (intensity/time scale).
- As long as the westward tilting of planetary waves in the stratosphere and their overall amplitude can be captured, the CFSv2 forecasts would still be very skillful in predicting zonal mean anomalies even though it cannot do so for the exact locations of planetary waves and their spatial scales.

Lab of Experimental Forecast for Cold Air Outbreaks (in real time)

(www.amccao.com)

What we do: We are making sub-seasonal forecasts for time periods of high probability of cold air outbreaks in Eurasia and North America 30-40 days in advance. We issue such forecasts on a weekly basis and this website is updated around Thursday each week.

Hybrid procedures of sub-seasonal forecasts for cold air outbreaks (lead time 20-40 days)

- Prognostic component: Dynamical predictions for mass circulation intensity into polar stratosphere derived from operational CFSv2 forecasts in real time plus forecasters' knowledge.
- Diagnostic component: Statistical “instantaneous” relationships between stratospheric circulation strength and surface temperature anomalies (downscaling).
- Products: Time periods of strong mass circulation events and cold air outbreaks

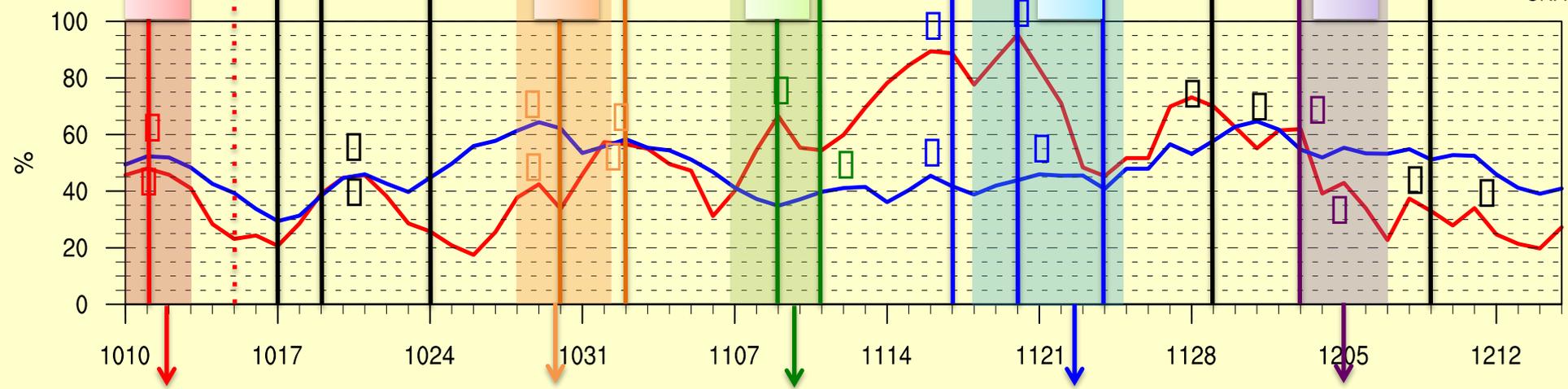
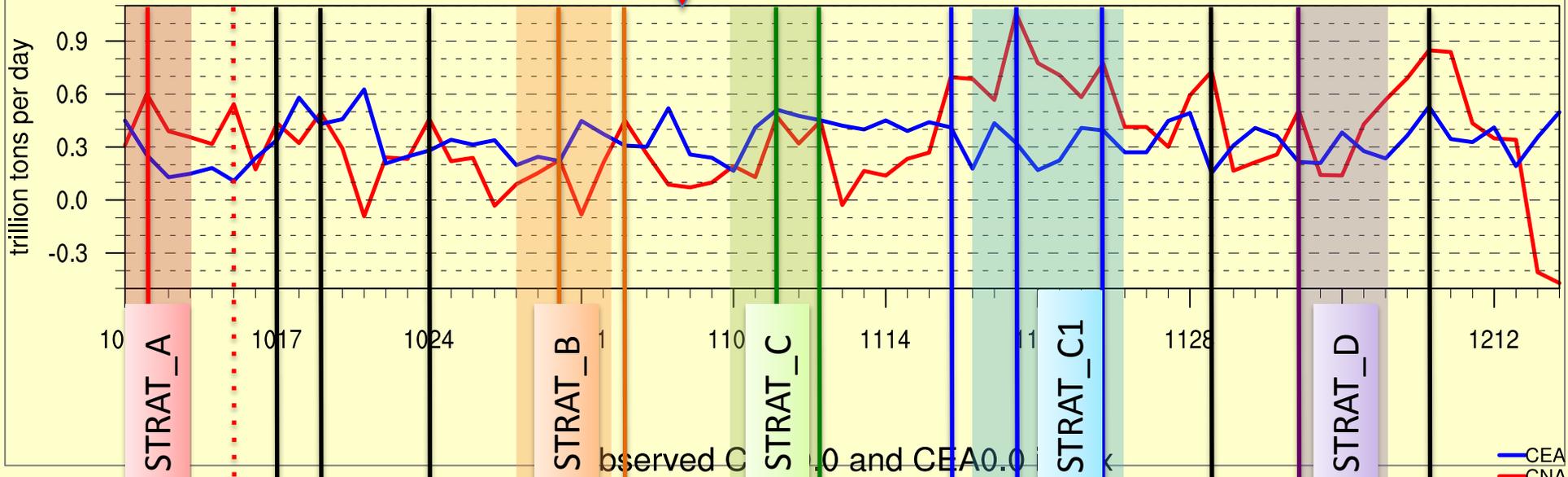
Summary of forecasts in 2014-15 winter

(www.amccao.com)

- Forecasted 15 strong circulation episodes: no false alarm forecasts and 13 of them took place within a range of our forecasts (2 for events after March 25, 2015: **one issued on 02/18 to occur in the last few days of March and first few days in April, a major event, and the other issued on 03/20 to occur between 04/16 and 04/22**).
- Average lead time is 30+ days.
- All forecasted stratospheric events are associated with cold air breaks within few days of the peak times of stratospheric events, covering a total of 38 round of cold air outbreaks over North America and Eurasia continents.
- We only missed 10 rounds of cold air outbreaks associated with 4 strong circulation events. Most of them were minor events and 6 were in the first two months of our forecast exercise.

Website Lunched (11/04/2014)

Observed Stratospheric Mass/Cold Air Trans. Into/Out of Arctic



Lead 9+ days
Named on 9/29

Lead 30+ days
Named on 9/29

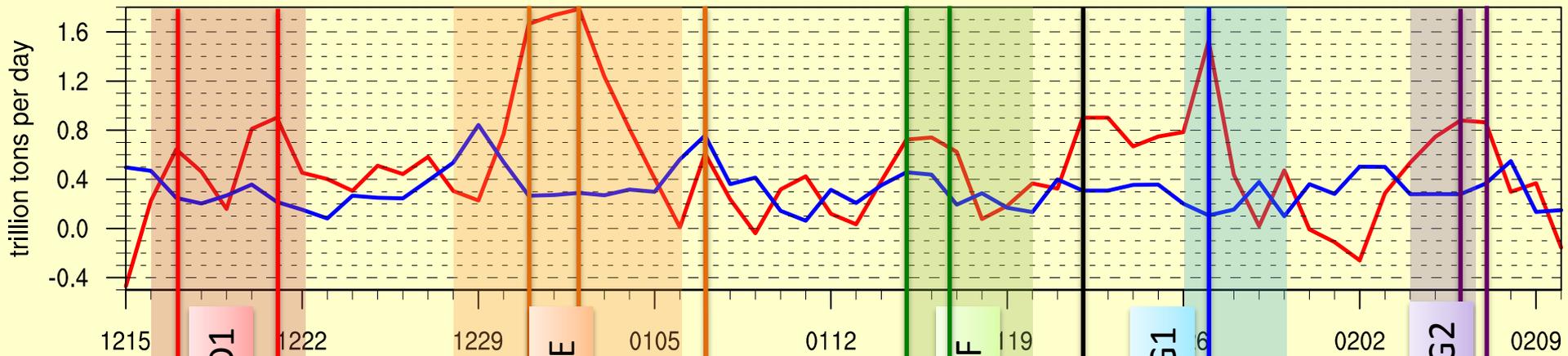
Lead 16+ days
First mentioned on 10/6
Named on 10/21

Lead 12+ days
First mentioned on 10/6
Named on 11/6

Lead 36+ days
Named on 10/28

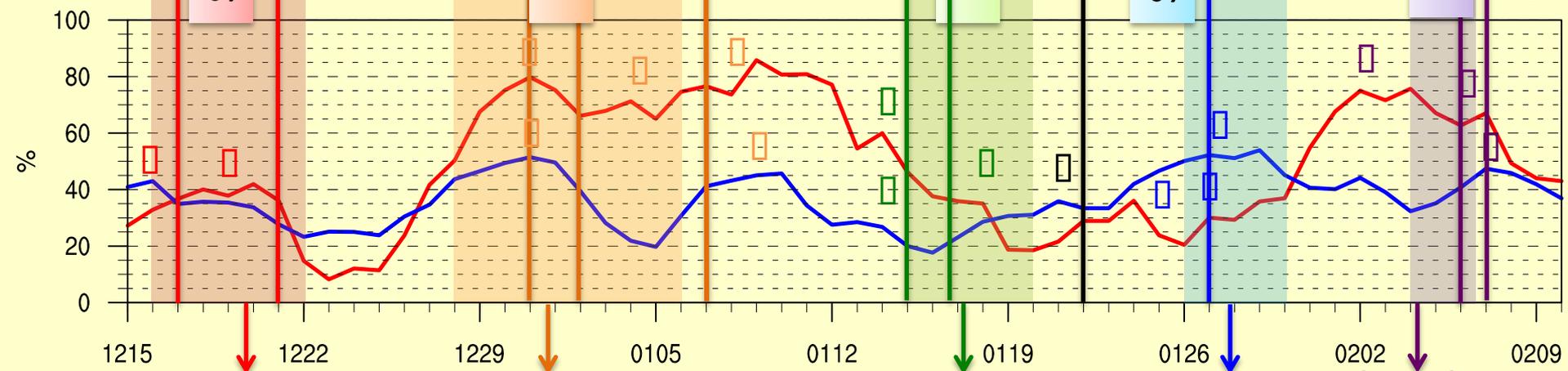
Observed Stratosphere Mass/Cold Air Trans. Into/Out of Arctic

COLD AIR
STRAT MASS



Observed CNA0.0 and CEA0.0 index

CEA
CNA



Lead 21+ days

Named on 11/25

Lead 45+ days

First mentioned on 11/6

Named on 11/13

Lead 41+ days

Named on 12/04

Lead 33+ days

First mentioned on 12/17

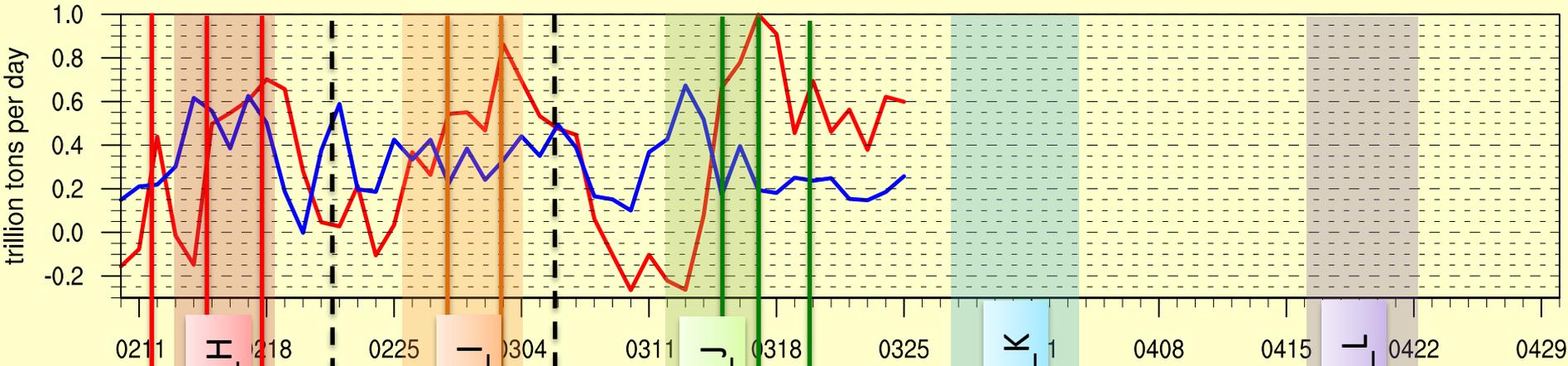
Lead 41+ days

First mentioned on 12/17

Named on 12/24

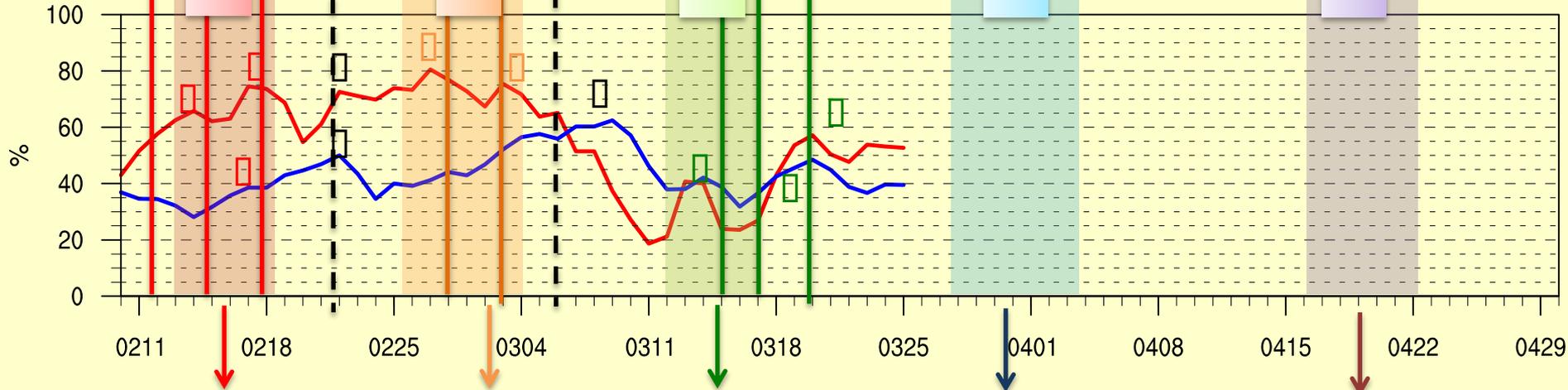
Observed Stratosphere Mass/Cold Air Trans. Into/Out of Arctic

COLD AIR
STRAT MASS



Observed NAO0.0 and CEA/CNA Index

CEA
CNA



Lead 33+ days
Named on 01/10

Lead 28+ days
Named on 01/29

Lead 28+ days
Named on 02/12

Lead 38+ days
Named on 02/18

Lead 27+ days
First issued on 03/20

Conclusions

- There exists an intrinsic connection between the amount of air mass transported into the polar stratosphere and the probability of the occurrence of massive, continental-scale cold air outbreaks in the Northern Hemisphere.
- Operational forecast models such as the NOAA CFSv2 is capable of predicting the air mass transported into the polar stratosphere with a good skill at a lead time longer than a month, although it cannot do so for tropospheric circulations.
- The combination of both factors leads to the creation of a hybrid (dynamical + statistical) paradigm that allows us, for the first time, to predict occurrences of massive cold air outbreaks one month in advance.