Environment Canada Environnement Canada

Canada

Contribution of Tibetan Plateau Snow Cover to Seasonal Prediction of the North American Winter Temperature

Zhiwei Wu and Hai Lin

Meteorological Research Division

Fall Seminar at CMC, Dorval QC, October 1, 2010

Extremely abnormal 2009/2010 winter

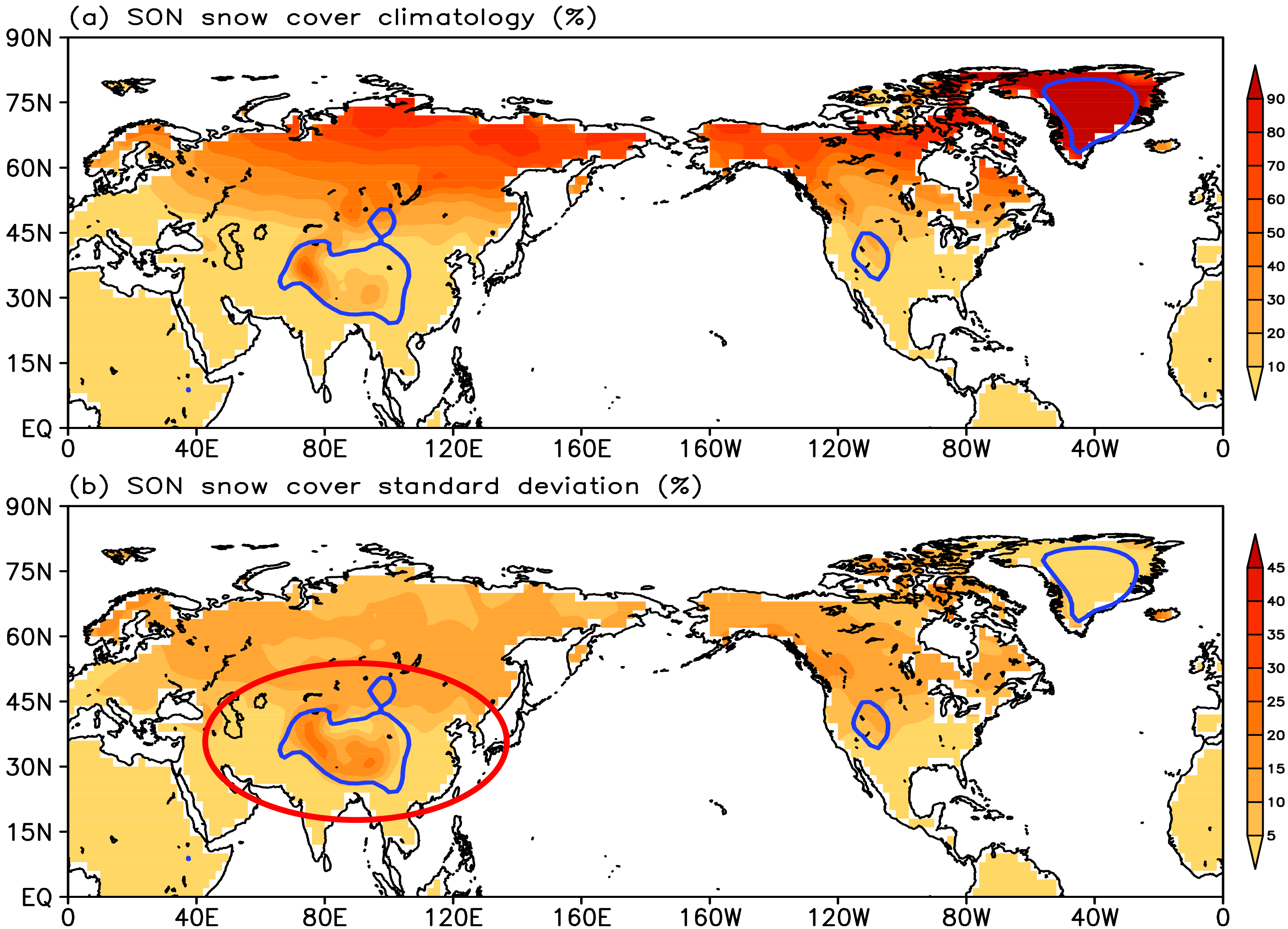
Canada USA

For instance, the 2009/2010 winter is noteworthy for the warmest and shortest one within the past decades in Canada and once-in-a-century snow storms over mid-Atlantic in 2009/2010 winter [*NOAA attribution team*, 2010]

Research Review

- The **El Niño and Southern Oscillation (ENSO)** is a primary predictability source for interannual variations of NA winter Ts (e.g., Ropelewski and Halpert 1986; Hurrell 1996; Sharbar and Khandekar 1996).

- As one of the most important patterns of atmospheric variability, the **North Atlantic Oscillation (NAO)** accounts for 31% of the hemispheric Ts interannual variance over the past 60 winters (Hurrell 1996).



Other lower boundary forcing mechanisms need to be investigated in order to further improve seasonal predictions. Of these, one of the most important is snow cover (e.g., Barnett et al. 1987; Robinson et al. 1993; Bamzai and Shukla 1999; Gong et al. 2007; and etc.).

TABLE 2. Lag-correlation coefficients of the east Asian snow extent time series.

Lag	r
1 week	0.65
2 weeks	0.37
3 weeks	0.22
4 weeks	0.09

(From Clark and Serreze 2000, Mon. Wea. Rev.)

Due to lack of persistence of the snow cover anomalies, Clark and Serreze (2000) suggested that the East Asian snow cover (105° to 150° E) was limited for short- to medium-range weather forecasting applications than for problems on longer timescales.

Question?

- Can the Tibetan Plateau (TP) snow cover influence the inter-annual time-scale climate of North America (NA)?
- If so, how does it work and to what extent does it contribute to the seasonal prediction of NA winter Ts?

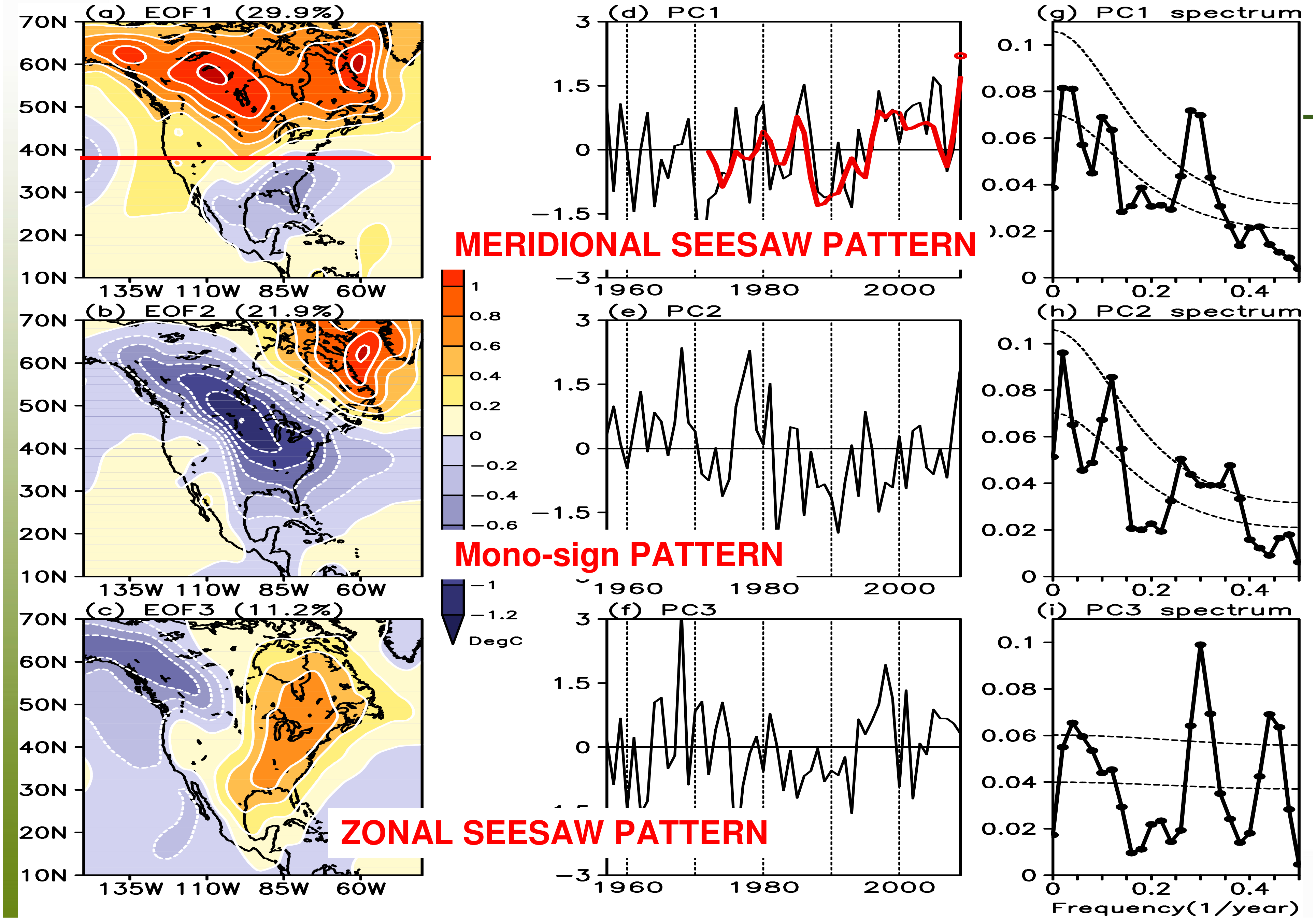
Data, model and methodology

- The European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year reanalysis data (ERA-40; Uppala et al. 2005) and the National Centers for Environmental Prediction (NCEP) reanalysis version 1 reanalysis data (NCEP-1; Kalnay et al. 1996)
- Monthly Northern Hemisphere snow cover data (1972-2009; in unit of %) gridded at 2.0° × 2.0° resolution, calculated with weekly snow cover data and programs from http://www.cpc.ncep.noaa.gov/data/snow/.
- The Met Office Hadley Centre's SST datasets gridded at 1.0° × 1.0° resolution (Rayner et al. 2003)

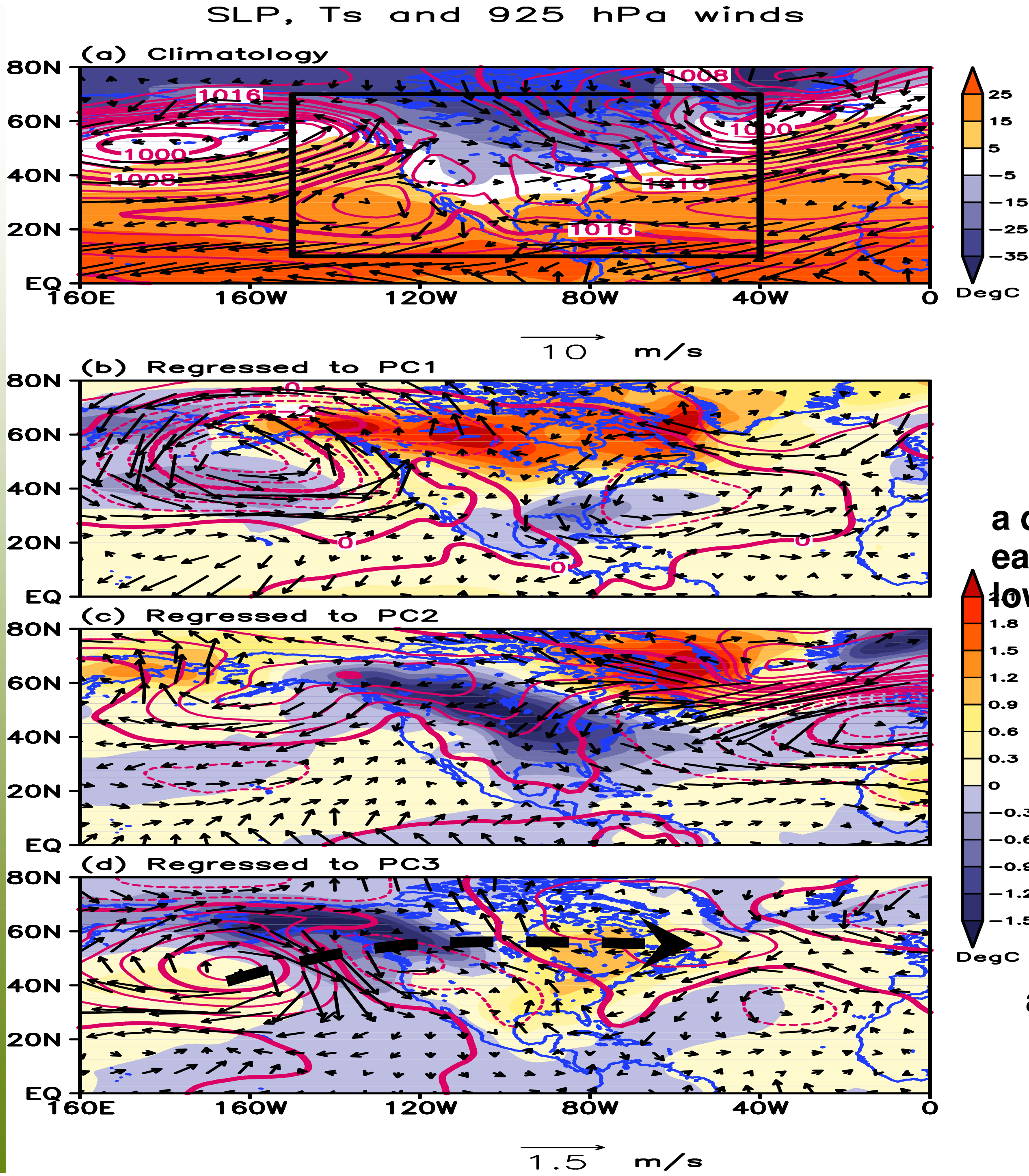
Data, model and methodology

- The output of the multi-model ensemble (MME) hindcast conducted with four dynamical models from Canadian Meteorological Center under the second phase of the Historical Forecasting Project (HFP2) is used in this study. The four models are the second and third generation atmospheric GCMs (**GCM2 and GCM3**) of the Canadian Centre for Climate Modelling and Analysis (CCCma) (Boer et al. 1984; McFarlane et al. 1992), a reduced-resolution version of the global spectral model (**SEF**) of Recherche en prévision numérique (RPN) (Ritchie 1991), and the Global Environmental Multiscale (**GEM**) model of RPN (Côté et al. 1998). The MME hindcast covers twenty four winters from 1969/1970 through 2002/2003.

Distinct principal modes of NA winter Ts variability



Dynamic structures and predictability sources of the three leading modes



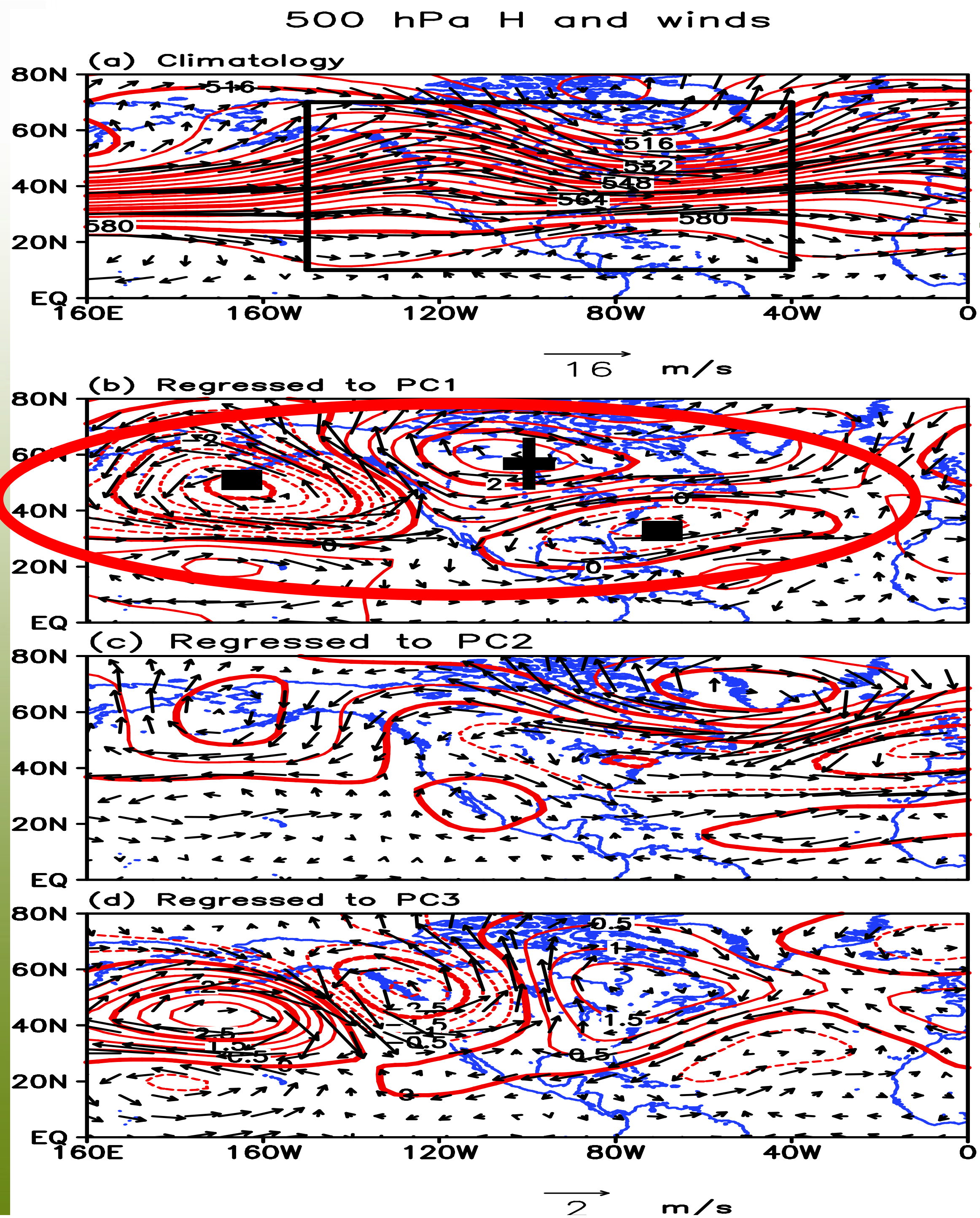
TNH

a deeper than normal and eastward shifted Aleutian low pressure system

NAO-like anomalies in SLP and 925 hPa winds over the North Atlantic

a wave train pattern

Canada



Tropical-Northern Hemisphere pattern (TNH) (e.g., Mo and Livezey 1986).

pronounced NAO-like anomalies

a notable wave train propagates from the northeastern Pacific to the eastern NA continent

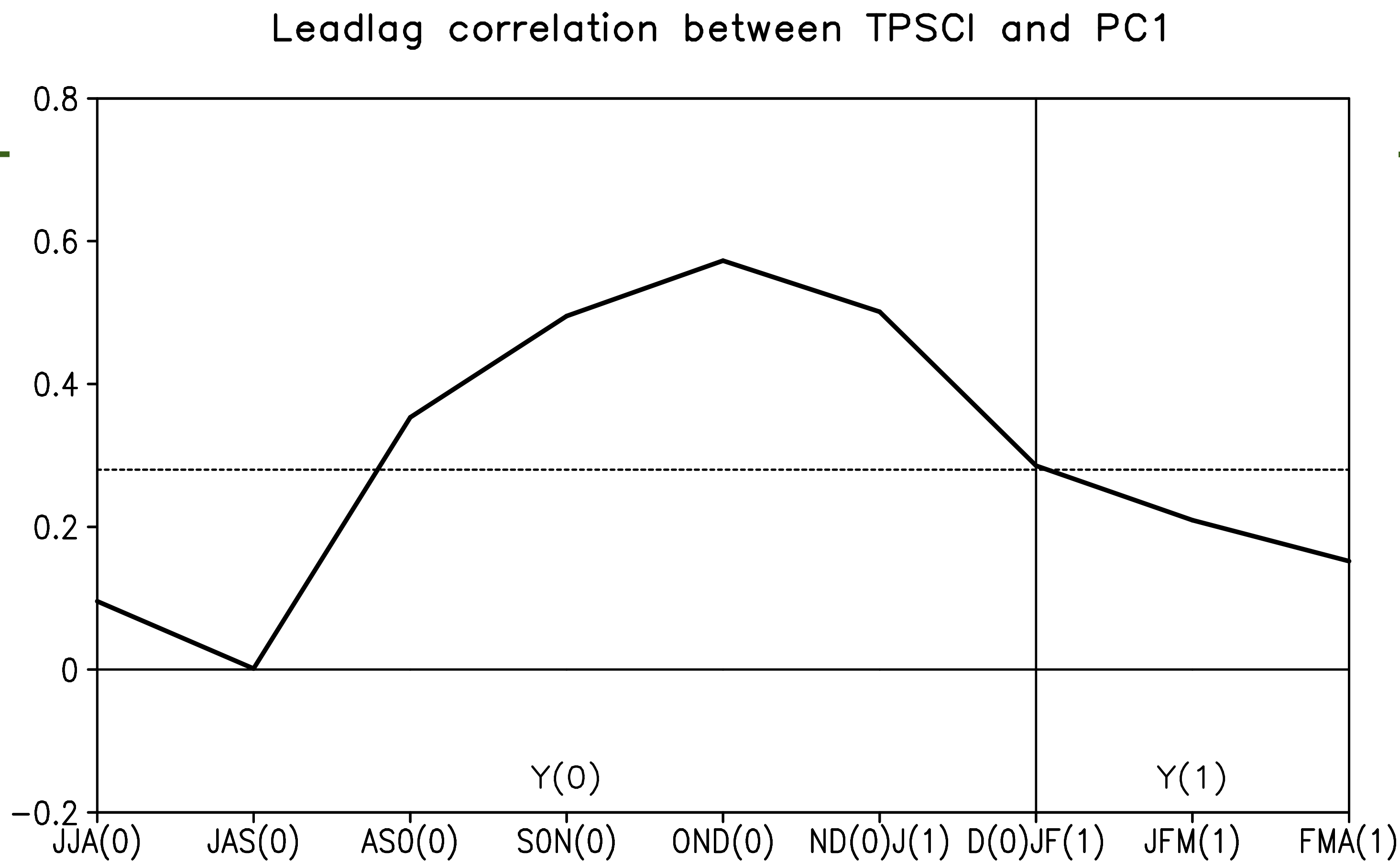
Canada

Table 1. Correlation coefficients between PCs and some major autumn potential predictability sources [a)]

PCs	Niño 3.4 index	NAO index	TP snow cover index
PC1	***0.42***	–0.07	***0.57***
PC2	–0.12	–0.2	***0.34***
PC3	0.19	–0.16	–0.1

The first mode is likely to be the most predictable mode and this study will focus on seasonal prediction of the first mode.

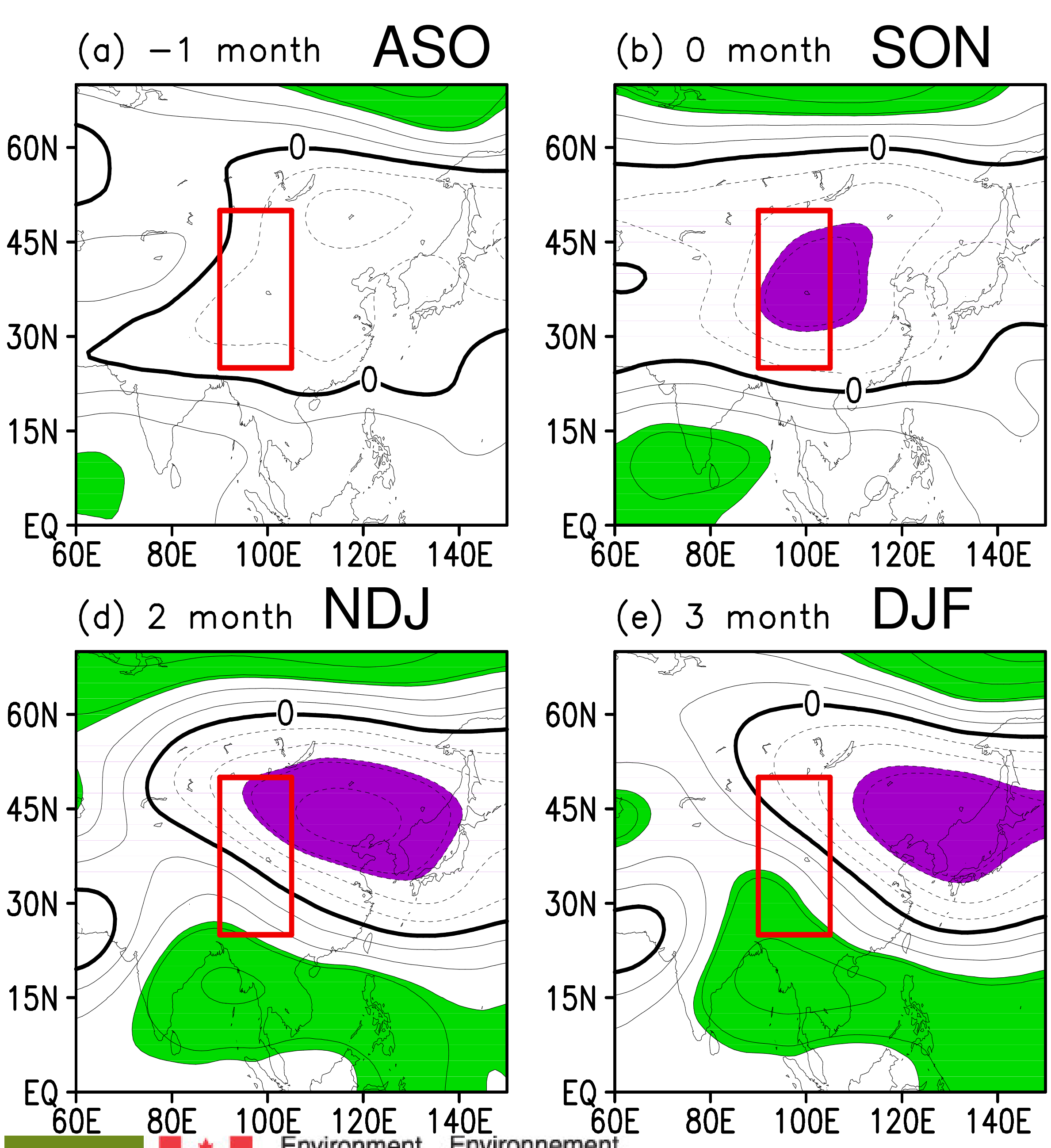
1. Can the TP snow cover persist from prior autumn to winter?



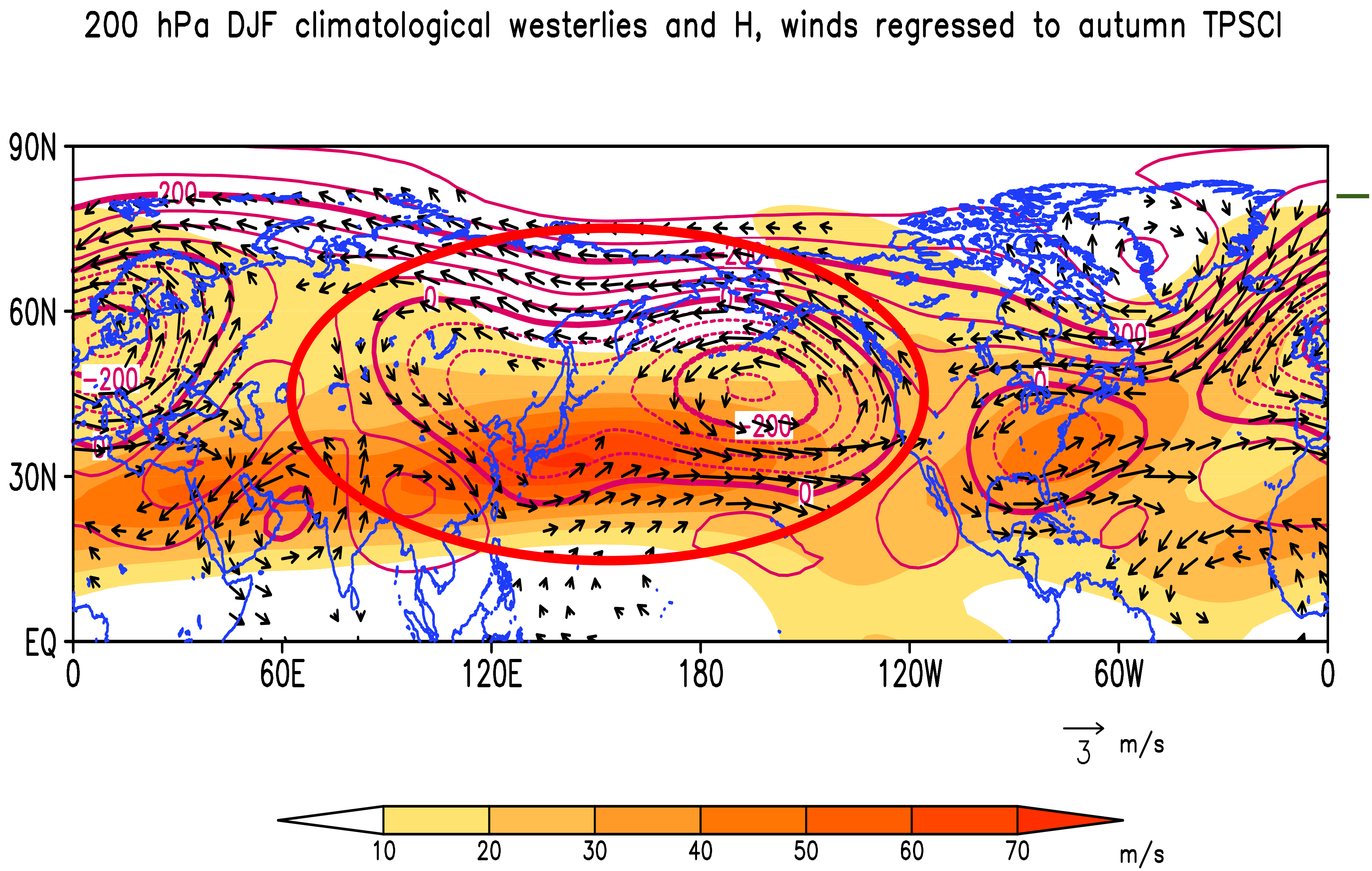
Thus, the TP snow cover yields a strong and persistent connection with the NA Ts leading mode, which makes it of seasonal prediction value.

2. How can the TP snow cover anomalies sustain from autumn through winter?

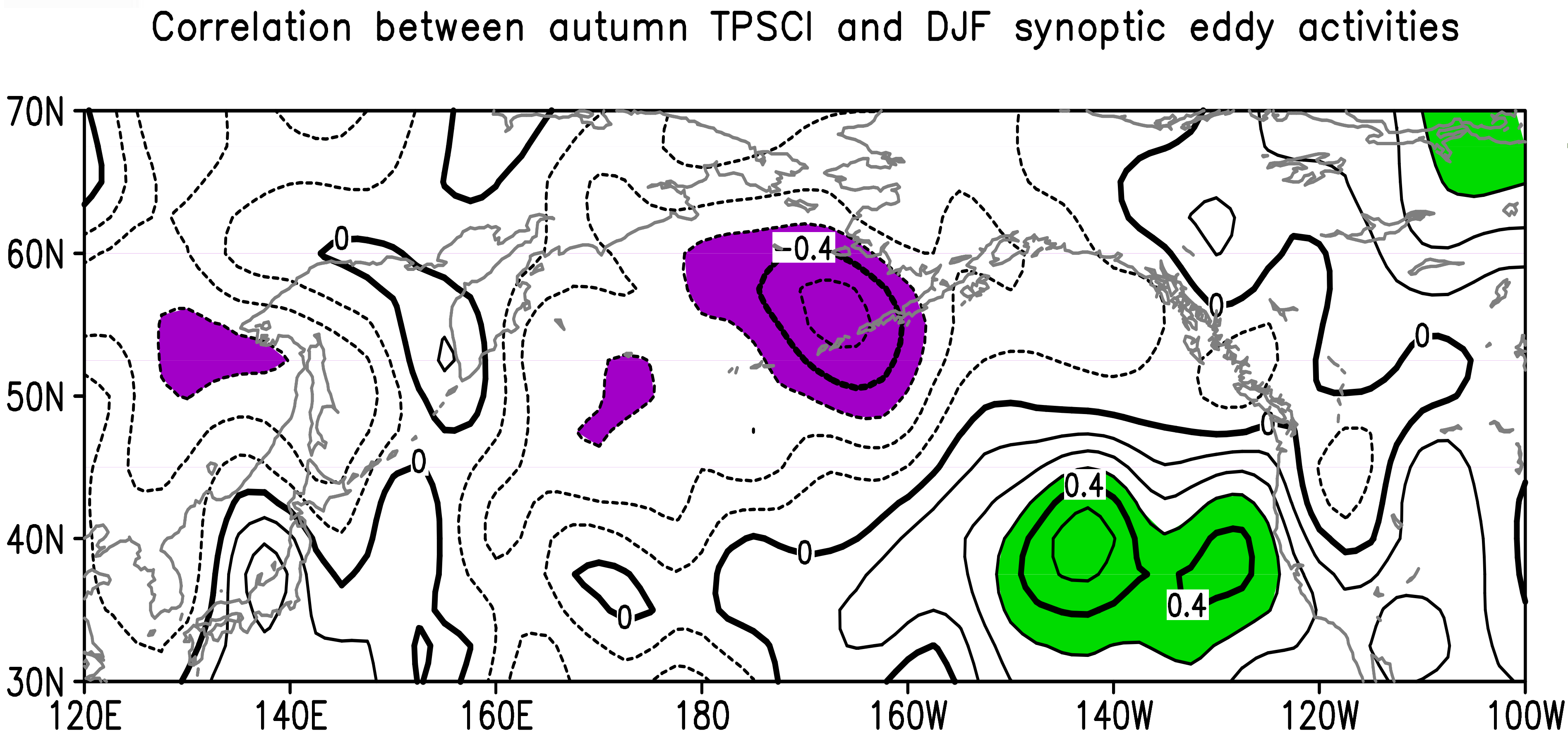
Leadlag correlation between H200 and autumn TPSCI



The excessive (reduced) snow cover usually favors low (high) H anomalies due to the sensible heating. On the other hand, low (high) H anomalies induced by enhanced (reduced) snow cover would produce increased (decreased) potential vorticity (Hoskins et al. 1985; Shaman and Tziperman 2005). Air advected toward such anomalies would experience anomalous vertical motions that would lead to increased (decreased) cloudiness and increased (decreased) precipitation in the region. This maintains the excessive (reduced) snow cover anomalies.



Such wind anomalies tend to shift the westerly jets more southward than normal.



Synoptic eddy activity is defined as the variance of the daily mean meridional winds at 300 hPa every winter season.

Such shift will suppress cold air activities in the northern domain and enhance those in the southern domain, which consequently favors a warm-north-cold-south winter coming into being over North America.

How can the autumn TP snow cover affect NA winter Ts?

Autumn TP snow anomalies

↓ Positive feedback between snow cover and atmosphere

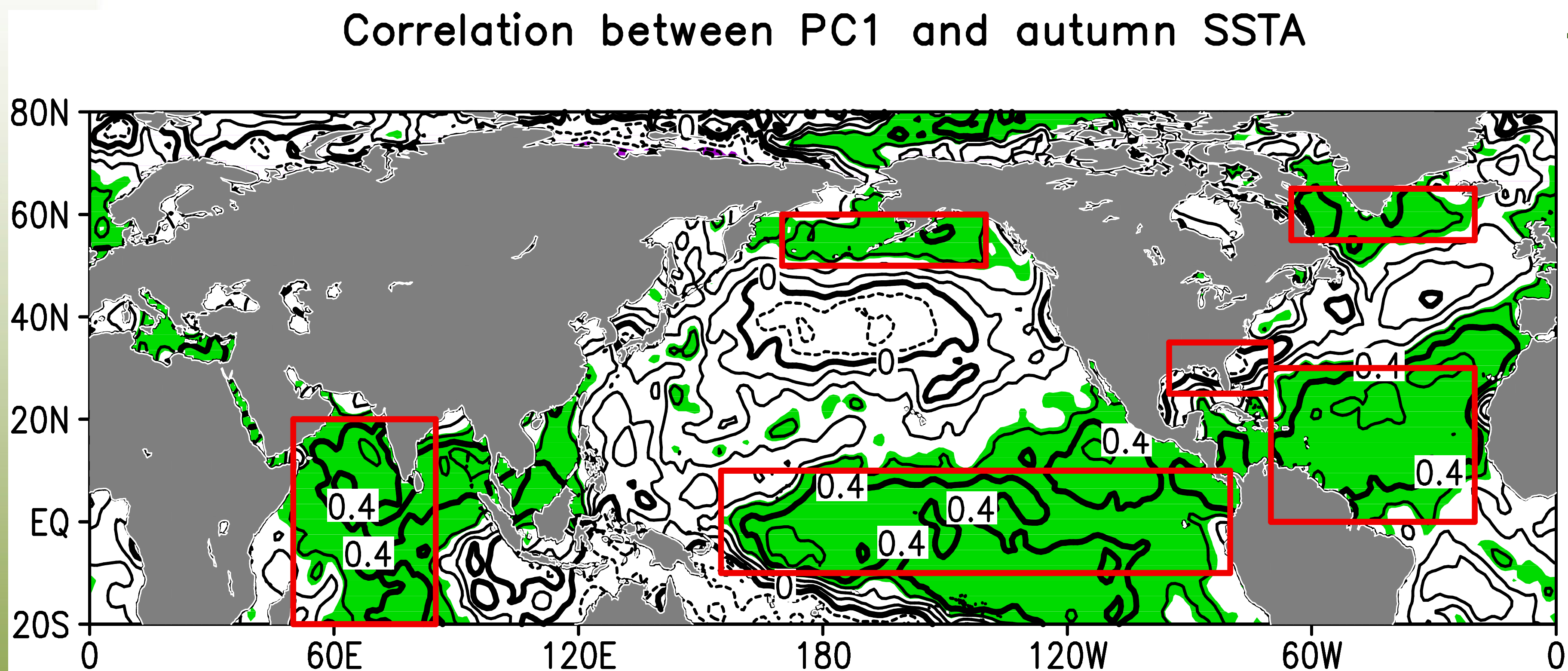
Persist through the winter

↓ Induce TNH teleconnection across North Pacific

Influence the NA Ts

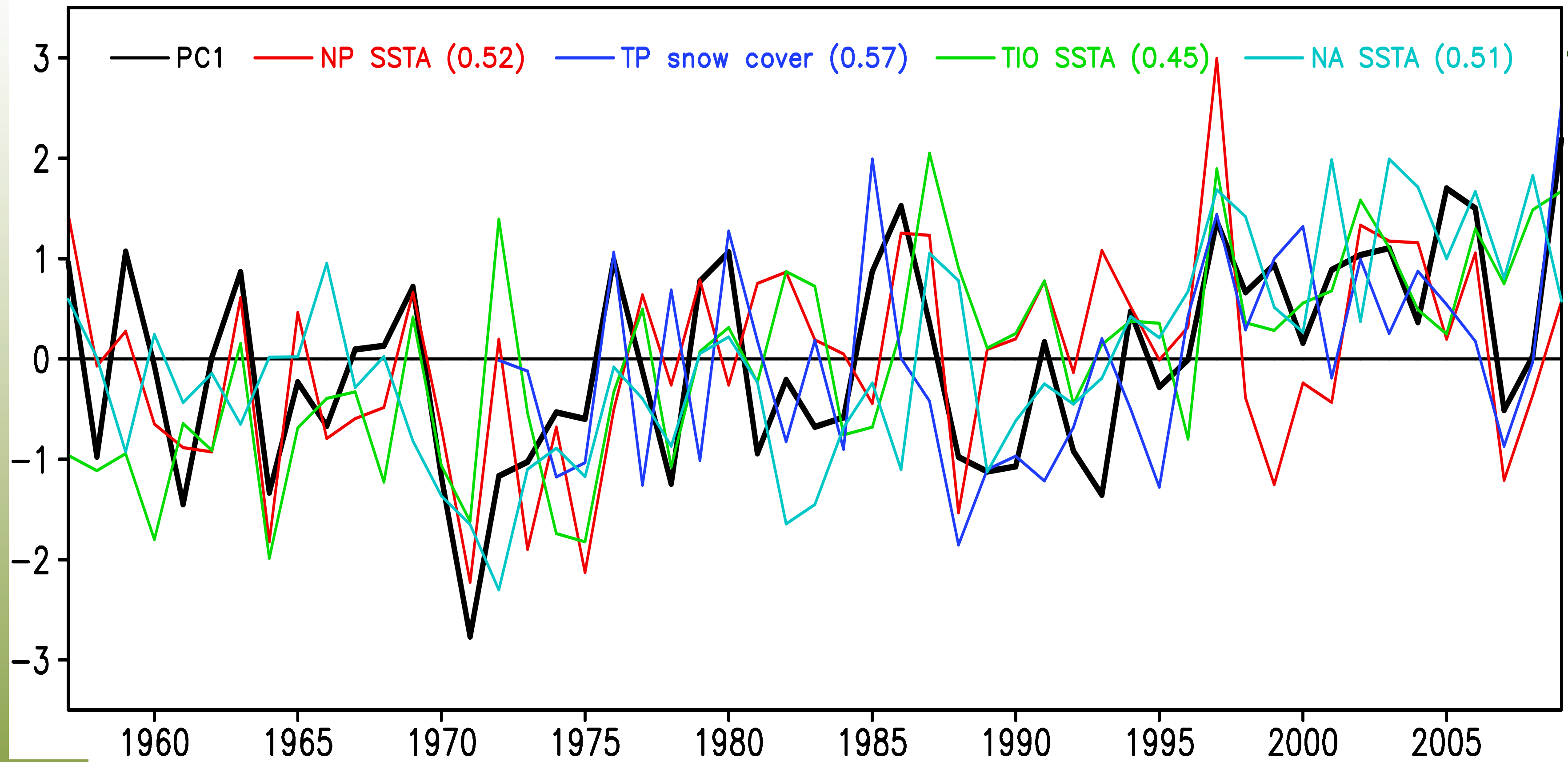
To what extent the autumn TP snow cover contribute to seasonal prediction of PC1

SST Predictors for PC1



If the SSTA in Pacific is considered to be an ENSO-related predictor, those in North Atlantic are regarded as the NAO-related predictor (Fig. 9), namely, a so-called tri-pole SST anomaly pattern, which was documented in previous studies (e.g., Rodwell et al. 1999; Pan 2005; Wu et al. 2009).

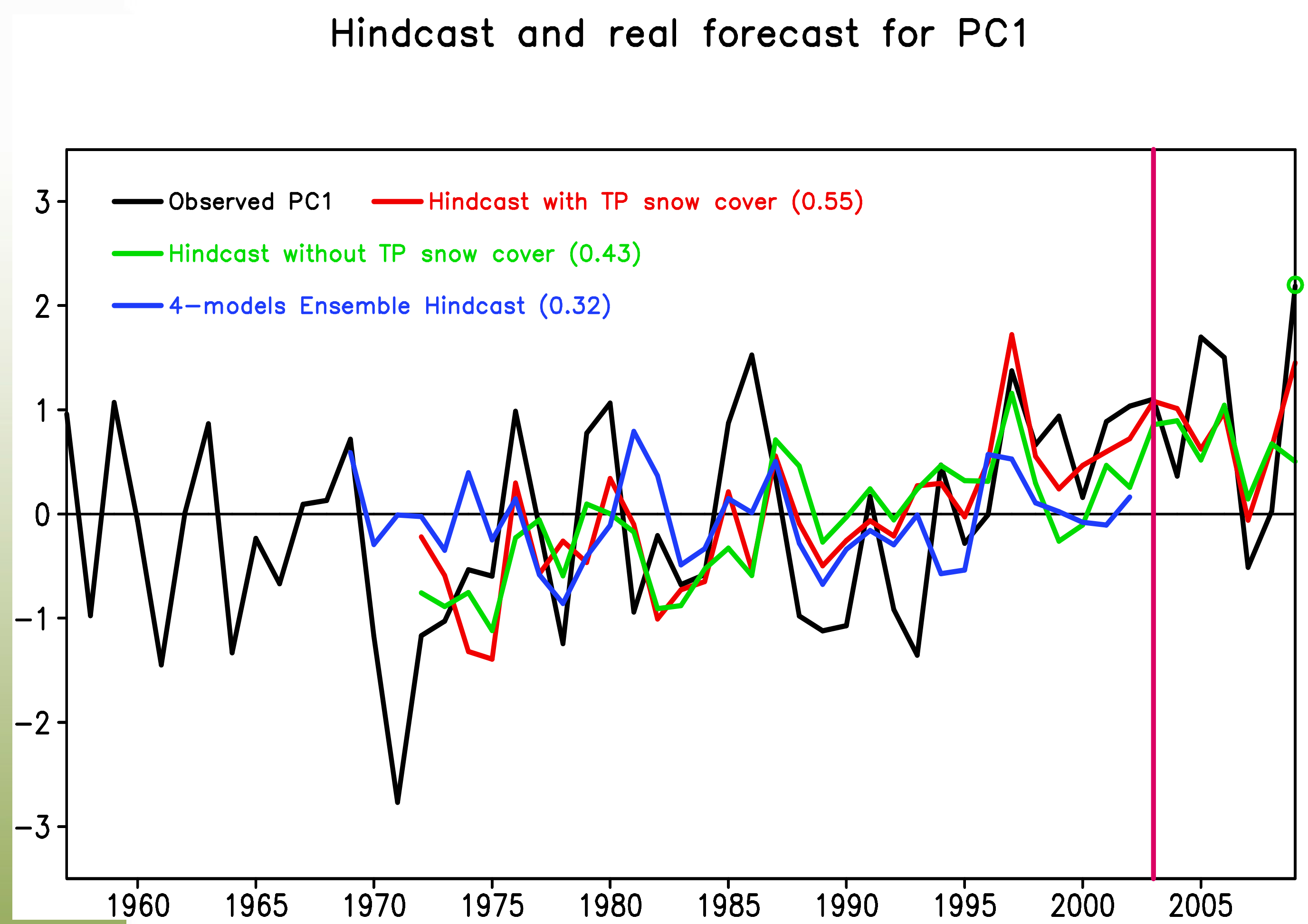
Predictors for the dominant mode of North American Ts



An empirical seasonal prediction model is developed using a linear regression method for the period of 1972-2009:

$$y = a_0 + a_1 g x_1 + a_2 g x_2 + a_3 g x_3 + a_4 g x_4$$

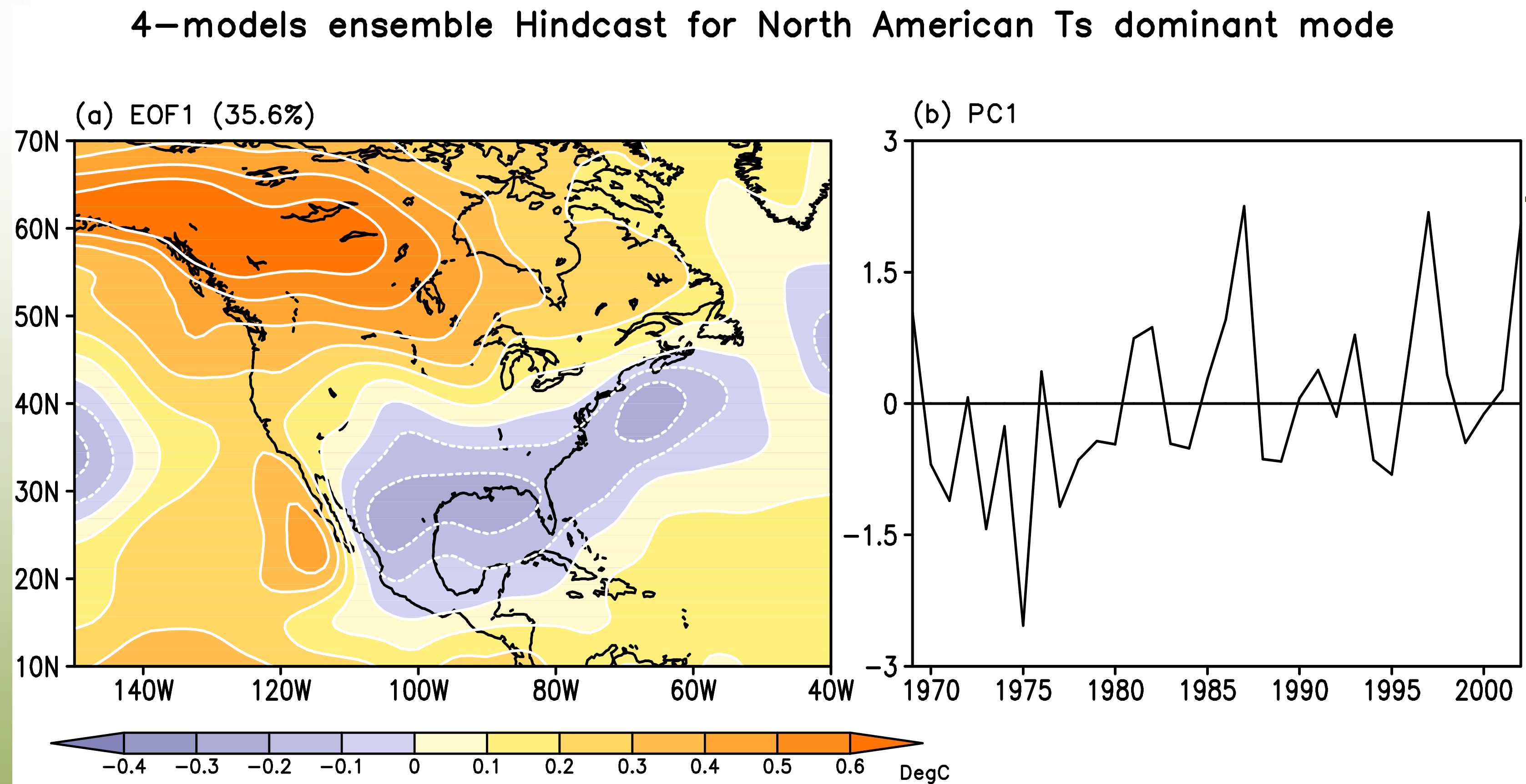
The relevant procedures are as following: The cross-validation method systematically deletes eight years from the period 1972-2003 (namely, years left out in 4 blocks of 1972-1979, 1980-1987, 1988-1995, and 1996-2003, respectively), derives a forecast model from the remaining years, and tests it on the deleted cases.



Comparison of the "leaving-eight-out" cross-validated hindcast PC1 made by the empirical model (with and without TP snow cover) and by the 4-models ensemble hindcast.

The correlation coefficient between the observation (black line in Figure 11) and the 32-year cross-validated estimates of the empirical model with (without) TP snow cover is 0.55 (0.43).

The extremely abnormal NA 2009/2010 winter, is realistically forecast.



In general, the MME hindcast of 4 dynamical models used here has a realistic performance in capturing the first mode of NA winter Ts (Fig. 12). The meridional seesaw pattern over the NA continent is well reproduced and the correlation coefficient between observed and hindcast PC1 is 0.41, exceeding the 95% confidence level. On the other hand, the MME of the dynamical models exhibits a worse prediction skill than the empirical model. One possible reason is that the TP snow cover influence may not have been adequately represented in the models. Our results thus propose a future direction for the dynamical model improvement.

Conclusion

- **The autumn TP snow cover anomalies can exert profound effects on the abnormal winter Ts over North America, which has never been noticed before.** The positive TP snow cover anomalies may induce a pattern similar to the negative phase of the TNH, with upper-troposphere negative geo-potential height anomalies over East Asia-western Pacific and contribute to the southward displacement of the subtropical jet stream and the storm track across North Pacific. This usually favors the occurrence of warm-Canada-cold-US winter over the NA continent. When the negative TP snow cover anomalies occur, the situation tends to be opposite.

Conclusion

- **Since the autumn TP snow cover shows only a weak linkage with ENSO and the tropical Indian Ocean SSTA (their correlation coefficient being 0.2), it may yield a new predictability source for the dominant mode of NA winter Ts.**

- **Based on the above results, an empirical model is established to predict PC1 of the NA winter Ts. Hindcast is performed for the 1972-2003 period, which shows a better prediction skill than the MME hindcast of 4 dynamical models. Since all these predictors can be readily monitored in real time, this empirical model provides a real time forecast tool and may facilitate the seasonal prediction of the NA winter climate.**

Conclusion

- **Our results indicate that the contribution of the preceding TP snow cover anomalies should be correctly taken into account in a dynamical model, which propose a future direction for the dynamical model improvement.**

Thank you!

Mechanism 1:

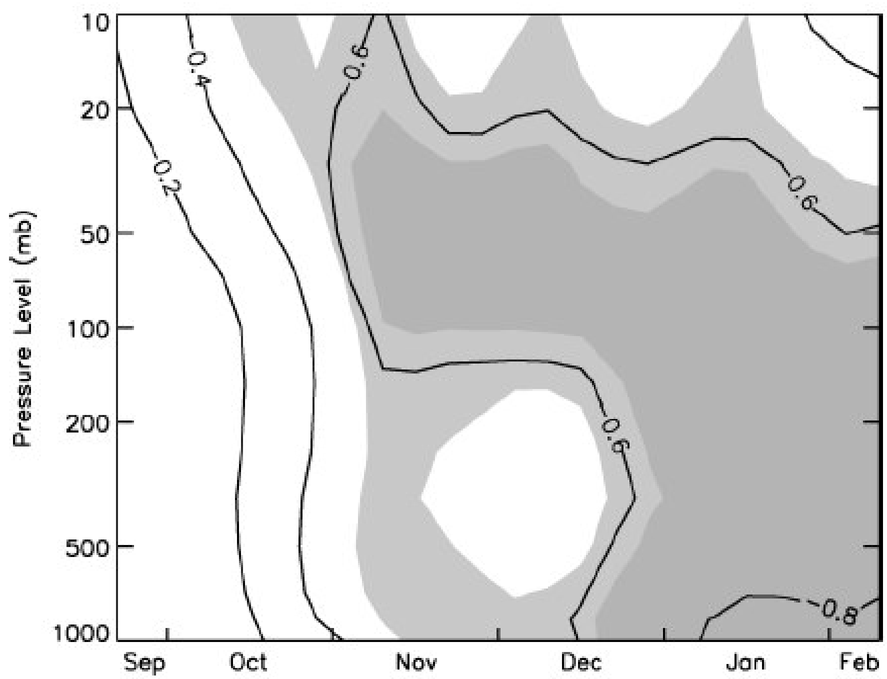


FIG. 9. Weekly evolution (horizontal axis) over the atmospheric column (vertical axis) of normalized 42-day rolling average hemispheric AO index response (SNO76–SNO88). Contours drawn at -2, -4, -6, -8 std dev. Light (dark) shading indicates 90% (95%) statistical significance.

(Gong et al. 2003, J. Climate)

Anomalously high Siberian snow increases local upward stationary wave flux activity, weakens the stratospheric polar vortex, and causes upper troposphere stationary waves to refract poleward. These related stationary wave and mean flow anomalies propagate down through the troposphere via a positive feedback, which results in a downward-propagating negative AO anomaly during the winter season from the stratosphere to the surface.

Mechanism 2:

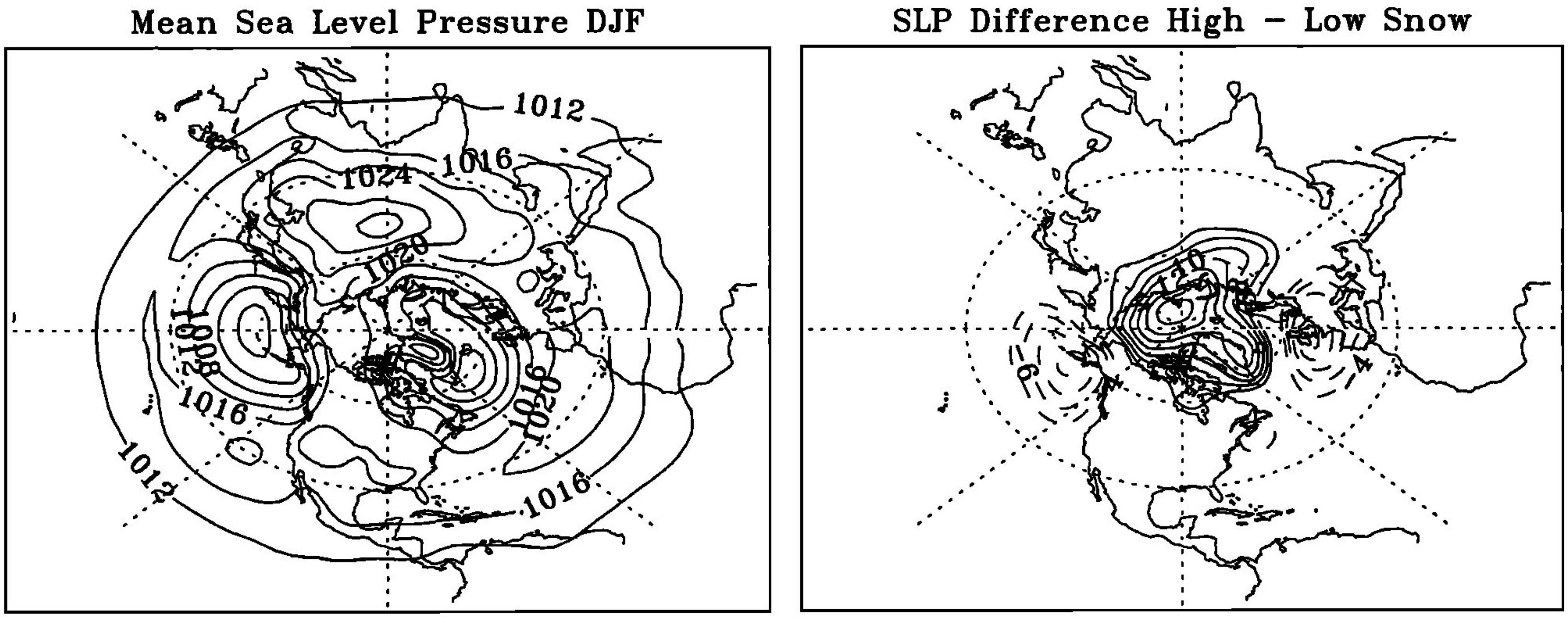
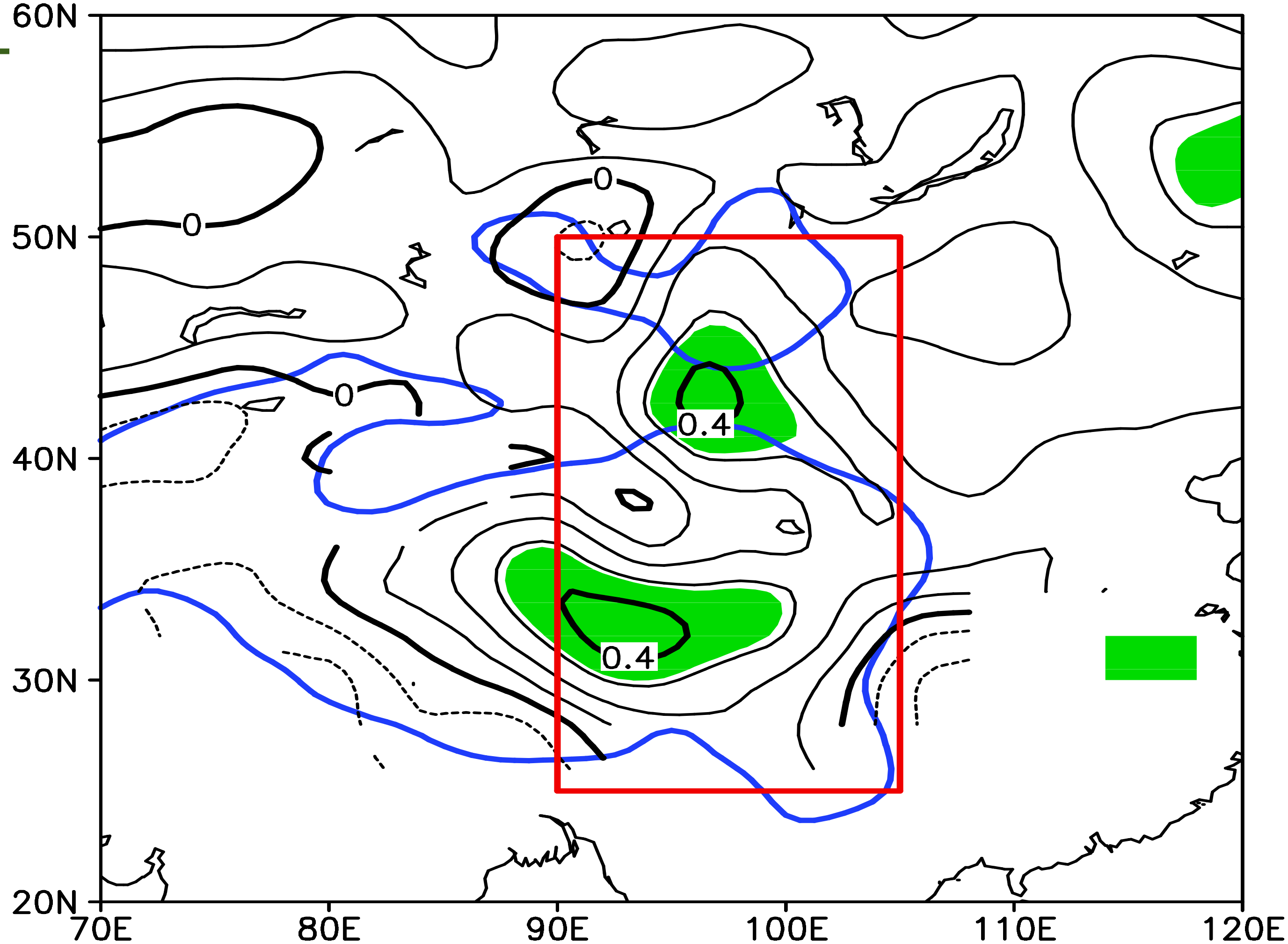


Figure 3. a) Mean sea level pressure for DJF. b) Sea level pressure difference between winters where preceding mean SON Eurasian snow cover were in highest 10% and winters preceding mean SON Eurasian snow cover were in lowest 10%. Figure closely resembles first EOF of DJF SLP (please refer to Fig. 3 in *Hurell* [1995] and Fig. 1 in *Thompson and Wallace* [1998]). Clearly evident is the expansion of the Siberian high north and west.

(Cohen and Entekhabi 1999, G.R.L.)

Correlation between PC1 and autumn TP snow cover



Data Combination

To get a longer time length covering the period from December 1957 through February 2010, the ERA-40 and NCEP-1 data are combined together. Since the NCEP-1 data may have systematic errors in the period before 1980 (Wu et al. 2005), we use the ERA-40 data for the period 1957-2001 and extend the data from December 2002 to February 2010 by using NCEP-1 data (Wang et al. 2010). To maintain temporal homogeneity, the 2002-2010 NCEP-1 data were adjusted by removing the climatological difference between the ERA-40 and NCEP-1 data. The autumn in this study refers to September-November (SON).