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Controlling factors of historical variation of winter Tibetan Plateau snow cover revealed by large-ensemble experiments

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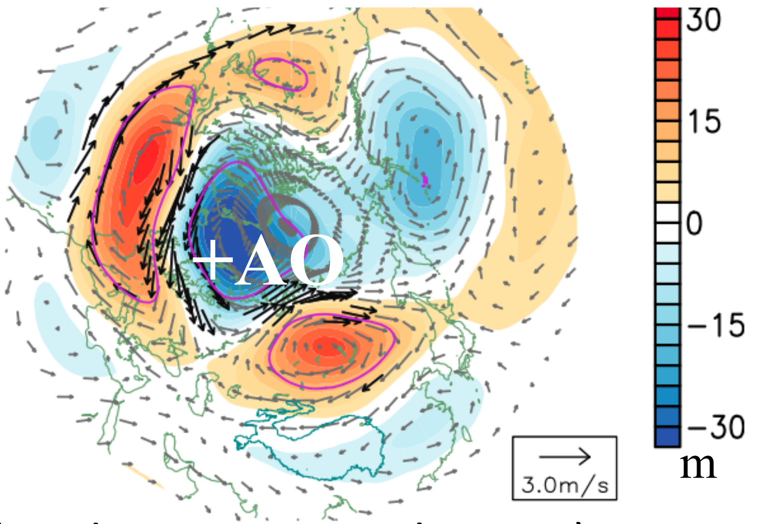
Review: factors that control TP snow cover

Arctic oscillation (AO)

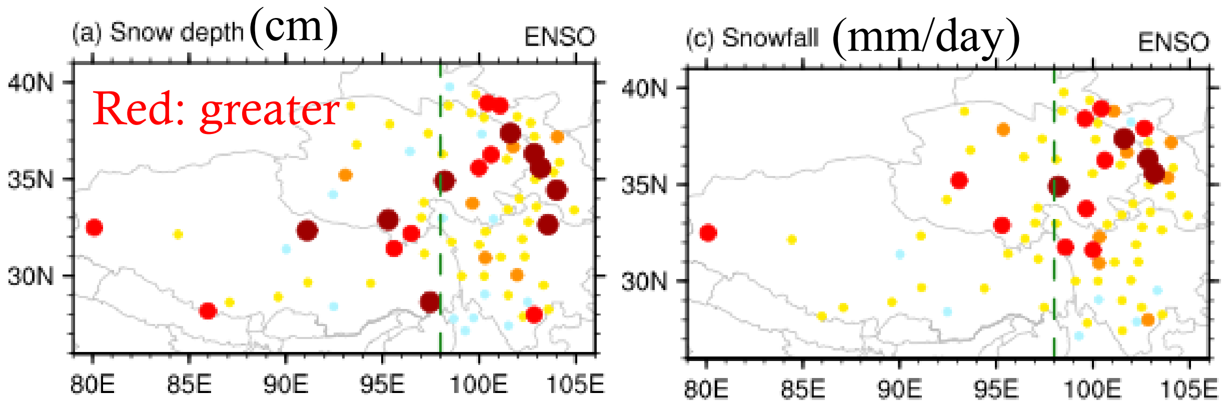
Circulation leading to high winter TPSC (250 hPa)



(Satellite data, Wang et al., 2018)
Arctic-TP snow connection:
In situ: Lu et al., 2008; Zhang et al., 2019.

El Niño-Southern Oscillation (ENSO)

Regressed winter parameters on Nino 3.4 index



Jiang et al. 2019

ENSO's impact:
Shaman et al., 2005 (in situ); Bao et al., 2019 (satellite)

- Observational measurements up to 48 years in previous studies
- This could limit the availability of strong AO and ENSO cases
- Combined impact of AO and ENSO remains unresolved

Objectives

1. To quantify impact of AO and ENSO on winter TP snow cover by using large ensemble simulations
2. To understand how historical global warming has modulated winter TP snow cover

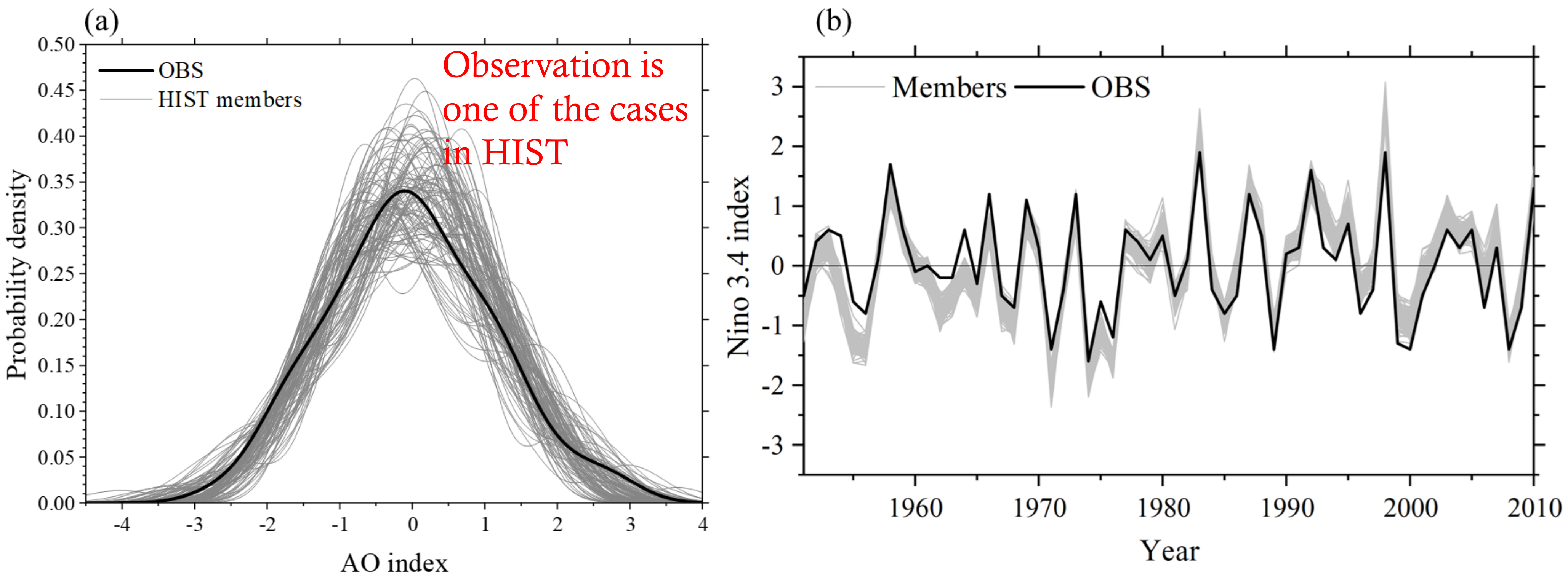
Data

	Data: January to March average	
Observation	**1982-2016**	• Snow-hydrologic parameters
Ensemble simulation	**HIST: 1951-2010** (Mizuta et al., 2016)	• Forced by using observed SST and external forcings • 60yrs ×100 ensemble members =6,000yrs
Ensemble simulation	**NAT: 1951-2010** (Mizuta et al., 2016)	• Forced by trend-removed observed SST. Other external forcings are fixed at pre-industrial status. • 60yrs ×100 ensemble members =6,000yrs

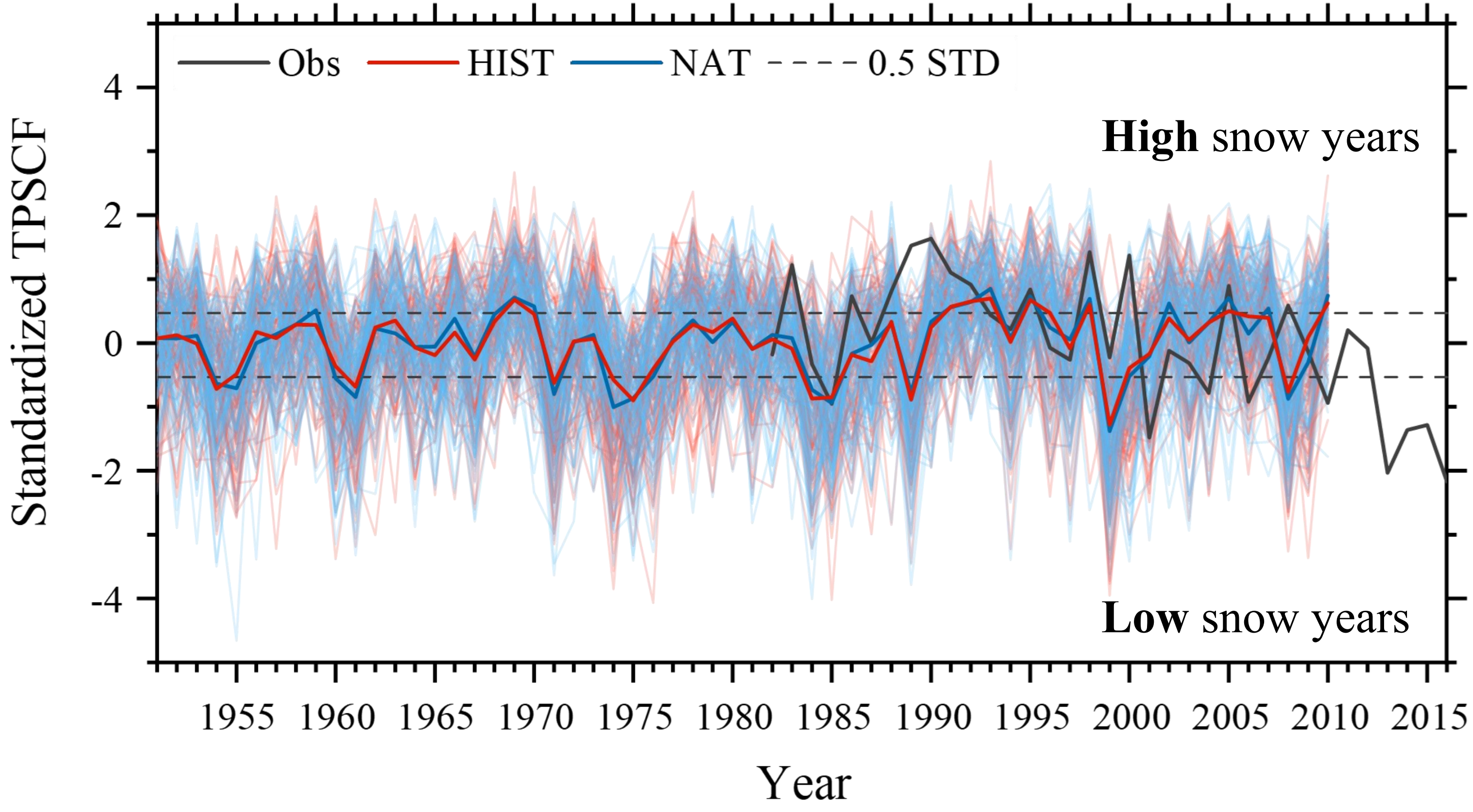
Indices

- **TPSC fraction (TPSCF):** the percentage of the snow-covered area over the TP higher than 3000 m.
- **AO and Nino indices:** calculated for each member in HIST following Wallace et al. (1981) and Ashok et al. (2007).

Comparison of AO and Nino indices between obs. and HIST

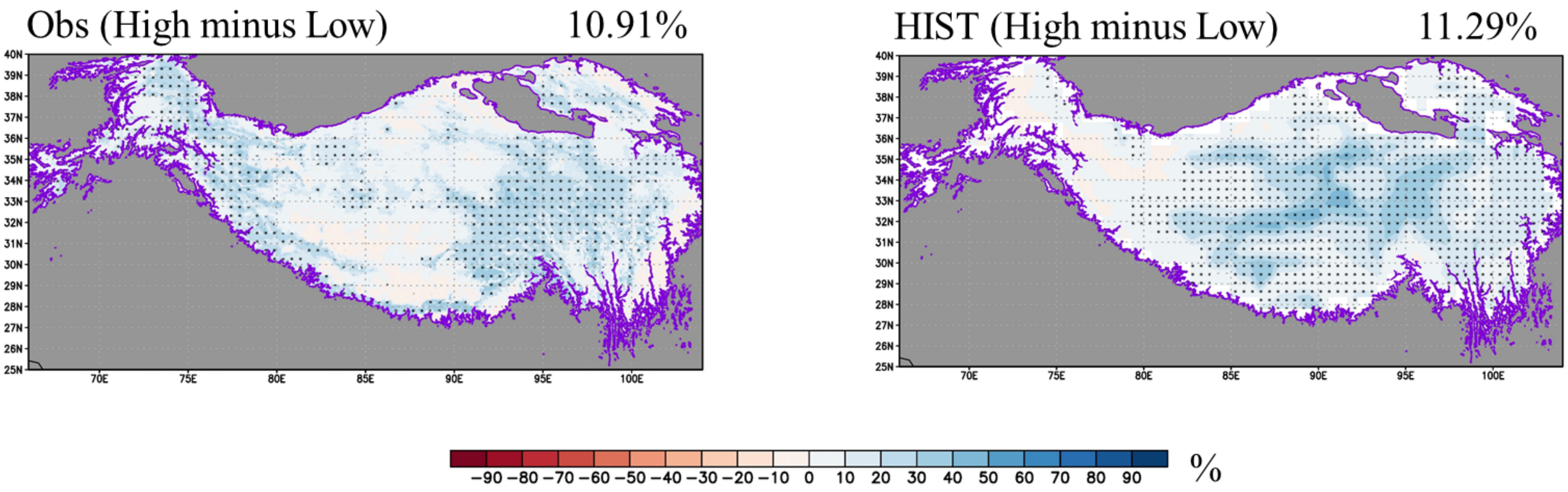


Interannual variation of TPSC (HIST and NAT)



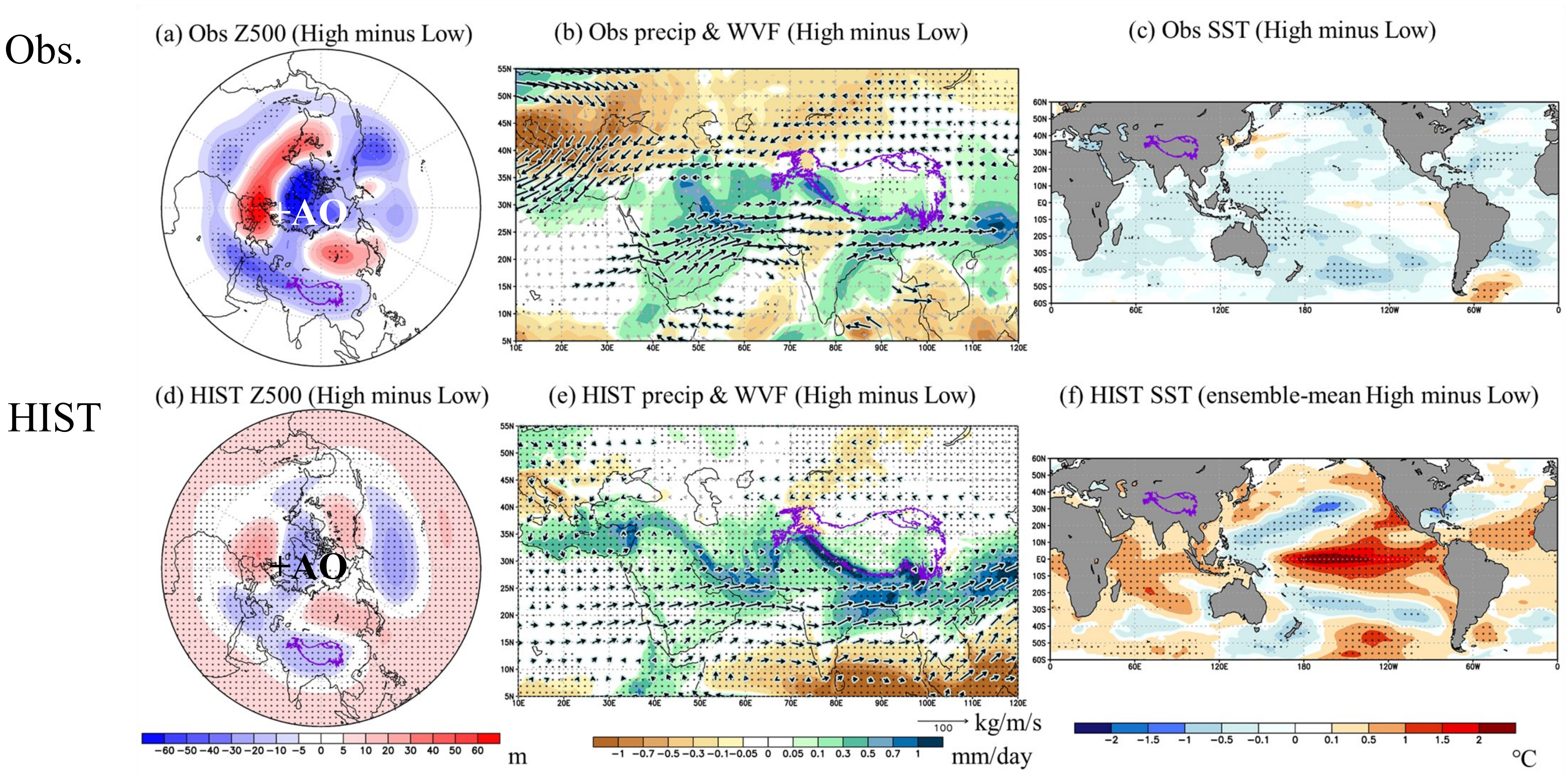
- A strong control of internal processes on TPSCF (r=0.11 for obs. and HIST-mean)
- Lower (e.g., 1961, 1985) and higher (e.g., 1969, 1995) shift of ensemble members, indicating SST's control also exist.
- Observed TPSCF has decreased since 2000s.
- Ensemble mean has no significant trend both HIST and NAT.

Composited TPSC (OBS and HIST)



- The range of simulated variation is reasonable.
- The bias is found in western TP where terrain is more complex
- Inadequacy of resolution in GCMs (model ~60km; OBS ~5km)

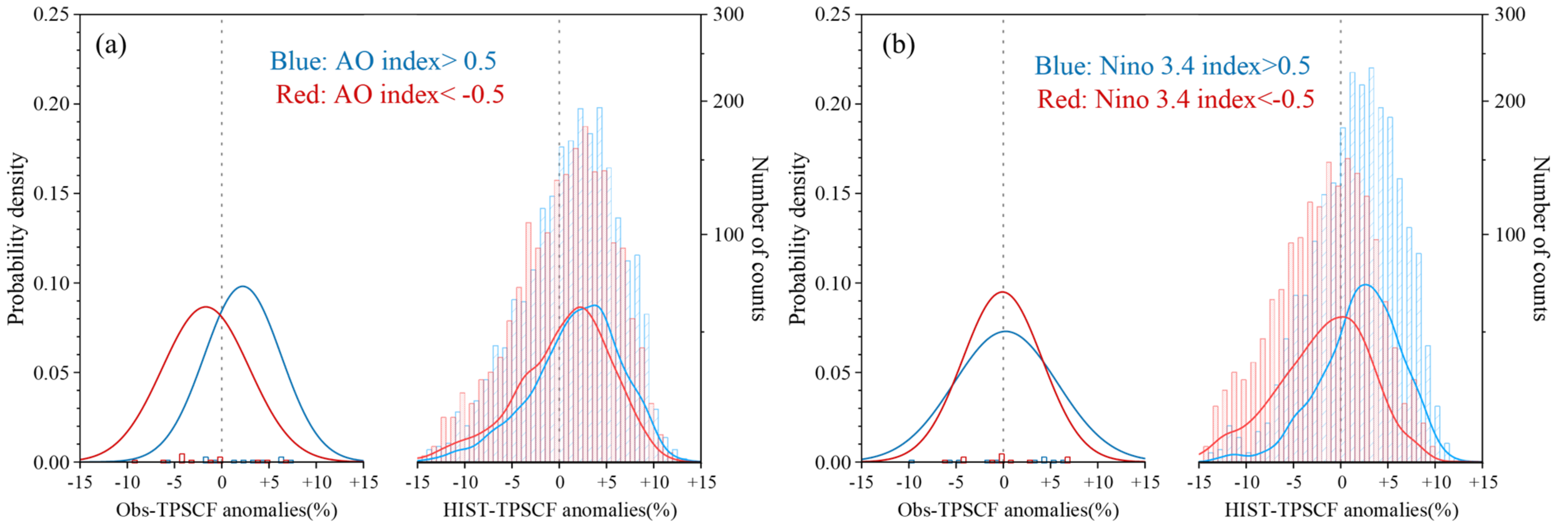
Composite circulation pattern (OBS and HIST)



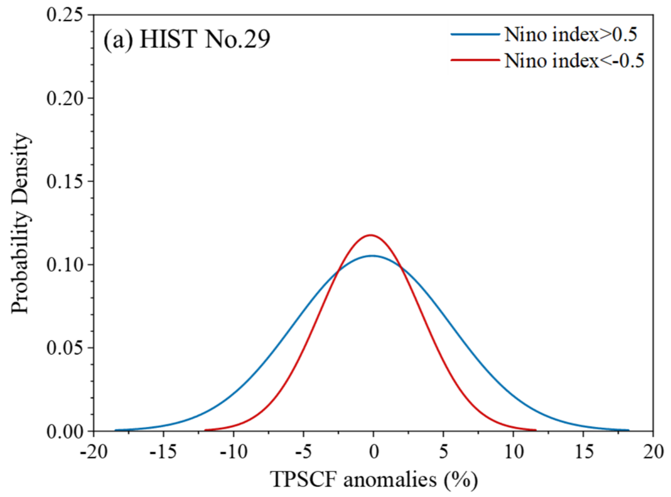
In high TPSCF year :

- Lower Z500 extends from Middle East to TP.
- Water vapor flux exhibits an enhanced cyclonic circulation around the TP, carrying more water vapor to TP
- The discrepancies of ENSO signal is found between observation and HIST.
- In HIST, the likelihood of + AO and El Niño corresponding to high TPSCF is confirmed.

The impact of AO and ENSO on TPSC

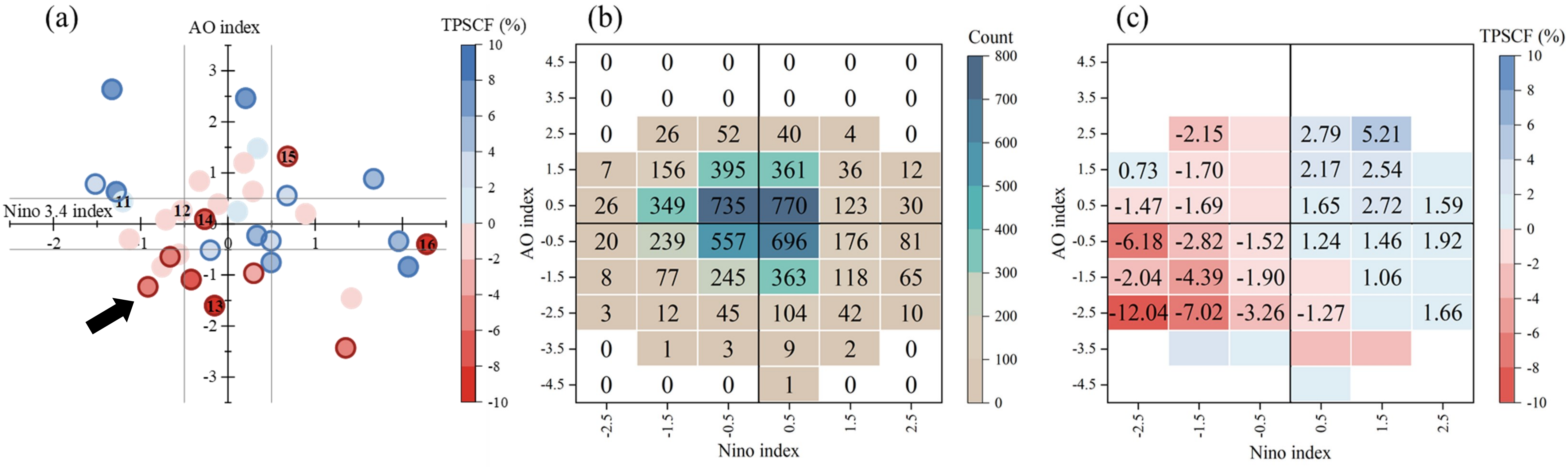


Few members



- Large-ensemble members reveals that TPSCF is sensitive to both AO and ENSO.
- The observations tend to reflect stronger linkage to AO and weaker linkage to ENSO owing to the limited number of cases.

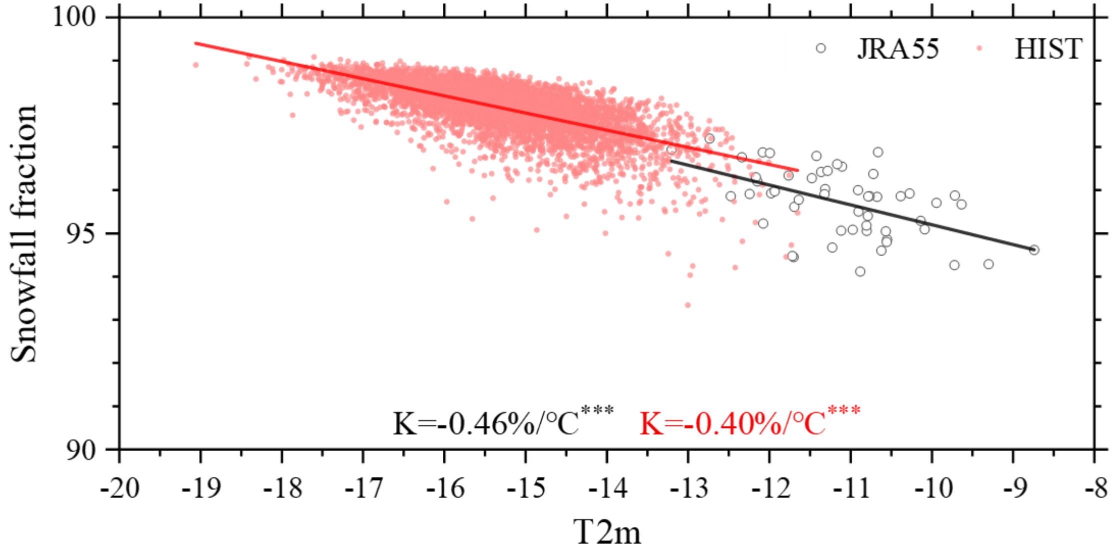
The impact of AO and ENSO on TPSC (joint)

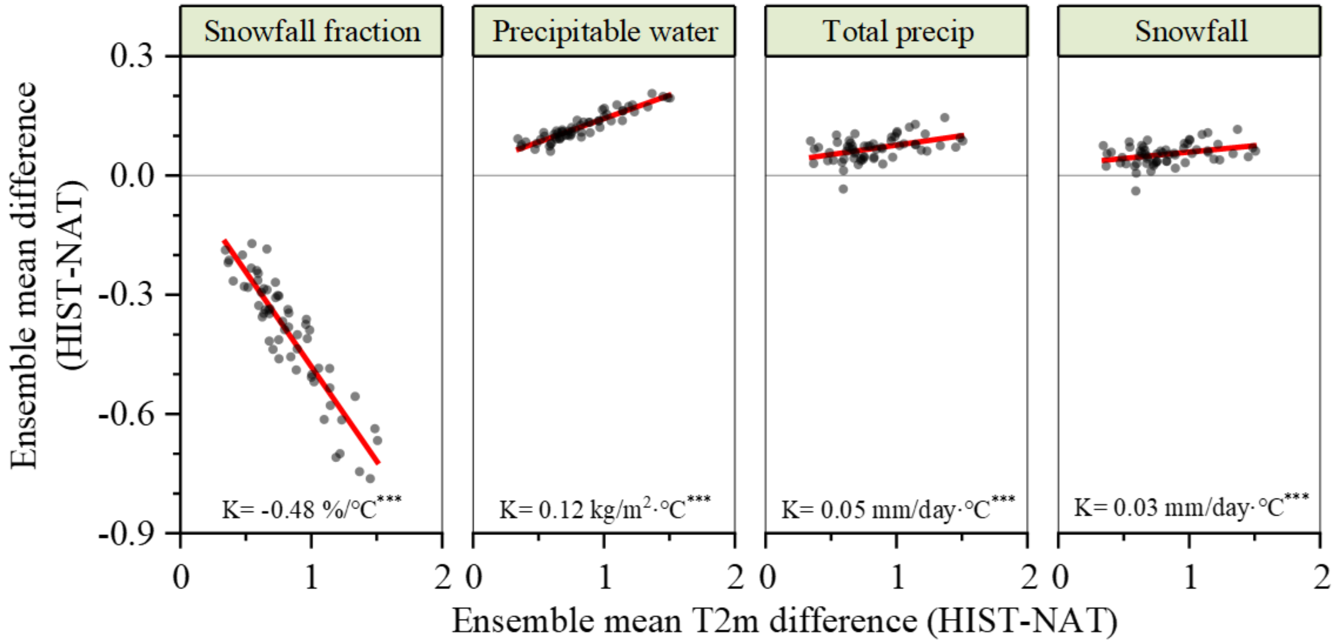


- Observed low TPSCF years appear slightly concentrated in the third quadrant (-AO & La Niña)
- Oceanic forcing (i.e., El Niño/La Niña) is considered to have greater influence than atmospheric internal variability (i.e., AO) on TPSCF.
- Observed recent decline of TPSCF is presumably not caused by AO or ENSO

The impact of global warming on TPSC

Mechanism: thermodynamical aspect





- Higher air temperature reduces the snow-to-rain ratio, which tends to reduce snowfall
- Raising temperature tends to increase TP winter precipitation
- As a result, the impact of historical global warming on TPSC is negligible in 1951–2010
- Recent decline of TP snow cover might due to light-absorbing aerosols, i.e., dust and black carbon (e.g., Sarangi et al., 2020)

Conclusion

- Observations tend to reflect stronger linkage to AO and weaker linkage to ENSO owing to the limited number of cases.
- Analysis of the large-ensemble members reveals that TPSCF is sensitive to both AO and ENSO, but with stronger impact from ENSO than AO.
- Historical global warming has reduced the snow-to-rain ratio, however, water vapor flux and precipitation have tended to increase.
- Owing to this compensating effect, the impact of global warming on TPSCF is negligible in the simulations till 2010.

Supporting information

Table 1. Comparison of JFM hydroclimatic parameters averaged over the TP region (>3000 m) between high and low TPSCF years for the observations and HIST. Values significant at the 95% and 99% level are denoted by ** and ***, respectively.

high years minus low years	Obs.	HIST
2-meter air temperature (°C)	1.59***	1.27***
Snowfall (mm/d)	N/A	0.16***
Precipitation (mm/d)	0.13**	0.17***
Snow/Precipitation (%)	N/A	0.34***
Convergence of WVF (10^{-5} kg/m^2/s)	0.23***	0.18***

Supporting information: ENSO's impact