Understanding the climatic trends around Antarctica since the mid-Holocene

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Background

- Antarctica and the Southern Ocean (SO) are cornerstones for global climate variability
- No clear global warming trends are detected in the Southern Ocean over the instrumental era (*cf.* Fig. 1)
- General oceanic cooling trend over the Holocene in the SO (Denis et al 2010, Hodell et al. 2001), although the exact trends over the last 6 kyrs are still not well understood
- Possible teleconnections between large changes in Tropical Pacific and SO (Pike et al. 2013)

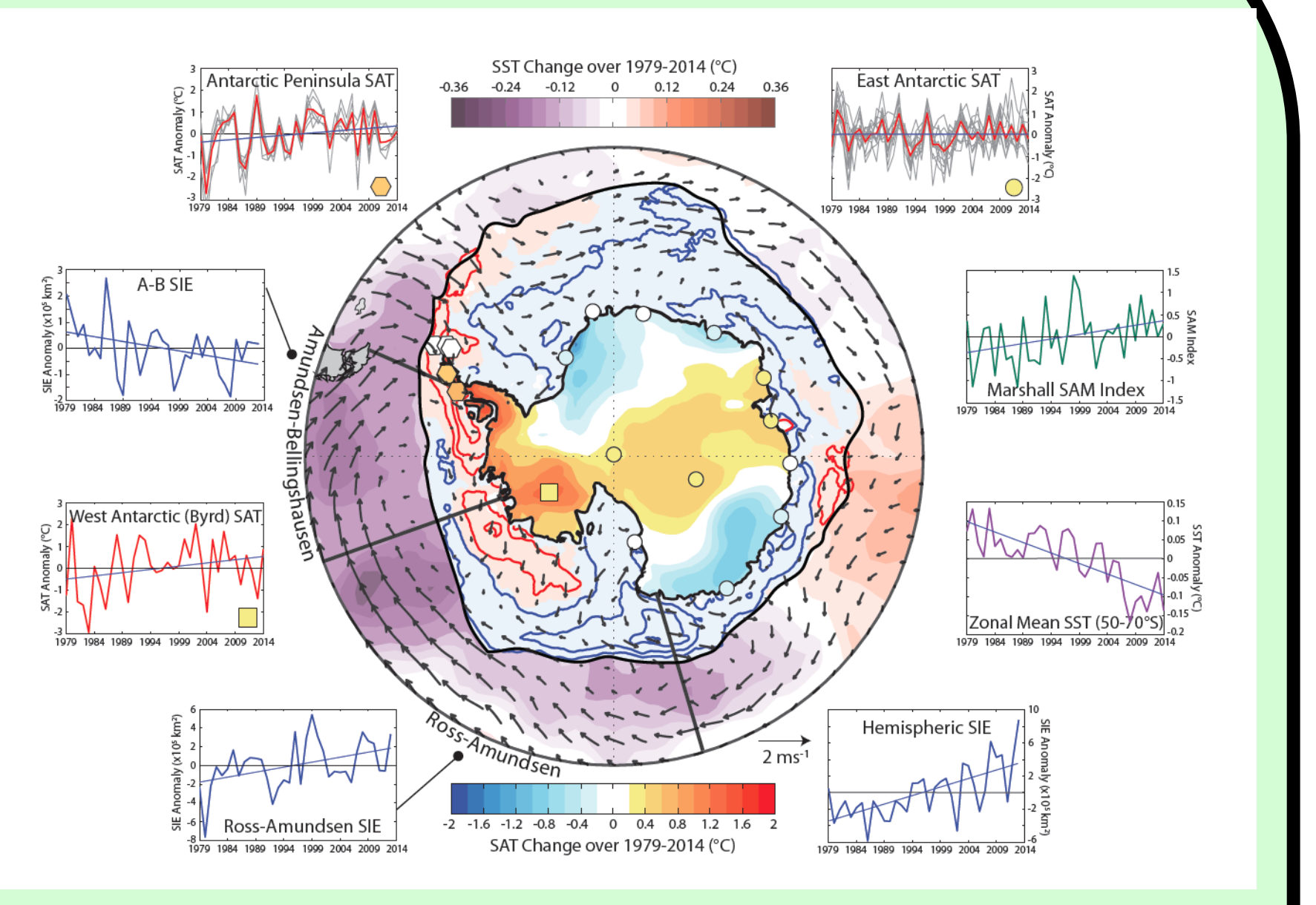

Fig.1: recent trends observed in Southern Ocean (Courtesy of WCRP Southern Ocean group lead by S. Gille and J. Jones)

Aim of this work

- Put recent changes in a longer time frame context *i.e.* the Holocene
- Add new oceanic data for SO covering the whole Holocene
- Understand the trend by use of AOGCM simulations to isolate associated **mechanisms**

Experimental design

Observational materials

- New $\delta^{18}O_{diatom}$ record, the first in the Indian sector of the SO (East Antarctic margin).
- $\delta^{18}O_{diatom}$ are regulated by glacial discharges (iceberg and brash ice discharge) and/or frontal melting of glaciers (Pike et al., 2013; Crespin et al., 2014): more freshwater inputs to the ocean leading to lower $\delta^{18}O_{diatom}$ values.
- We also consider two existing $\delta^{18}O_{diatom}$ records allowing a coverage around Antarctica (Fig. 2)
- Ice cores: we produce an EOF analysis (200 years resampling over the last 9 kyrs) from 10 Antarctic $\delta^{18}O$ ice cores (Dome F, EDC, WAIS, Byrd, Siple, James Ross, EDML, Vostok, Taldice, Law Dome).

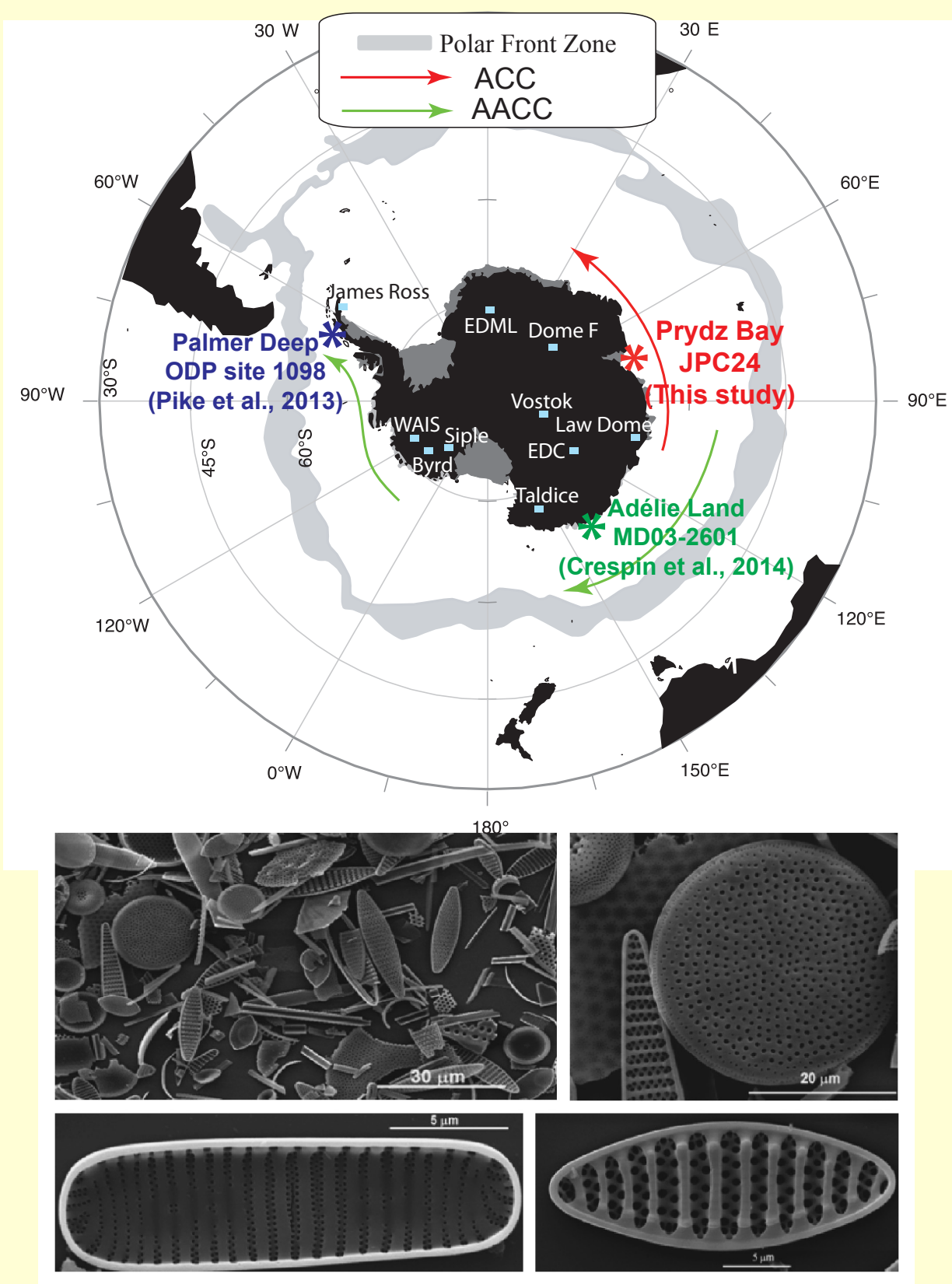

Fig.2: Location of analysed oceanic cores and ice cores used for the EOF as well as analysed diatoms.

Model simulations

We use the **IPSL-CM5A-LR** coupled model:

- Ocean ORCA2: 2°x(0.5-2°)
- Sea-ice LIM2: dynamic-thermodynamic
- Atmosphere LMDz: (1.875°x3.75°)
- Land model ORCHIDEE

We consider a 3-member ensemble of accelerated simulations including the changes in insolation over the last 6 kyrs. The insolation in these 600-yr simulations is accelerated by a factor of 10. We do not consider any changes in greenhouse gas concentrations.

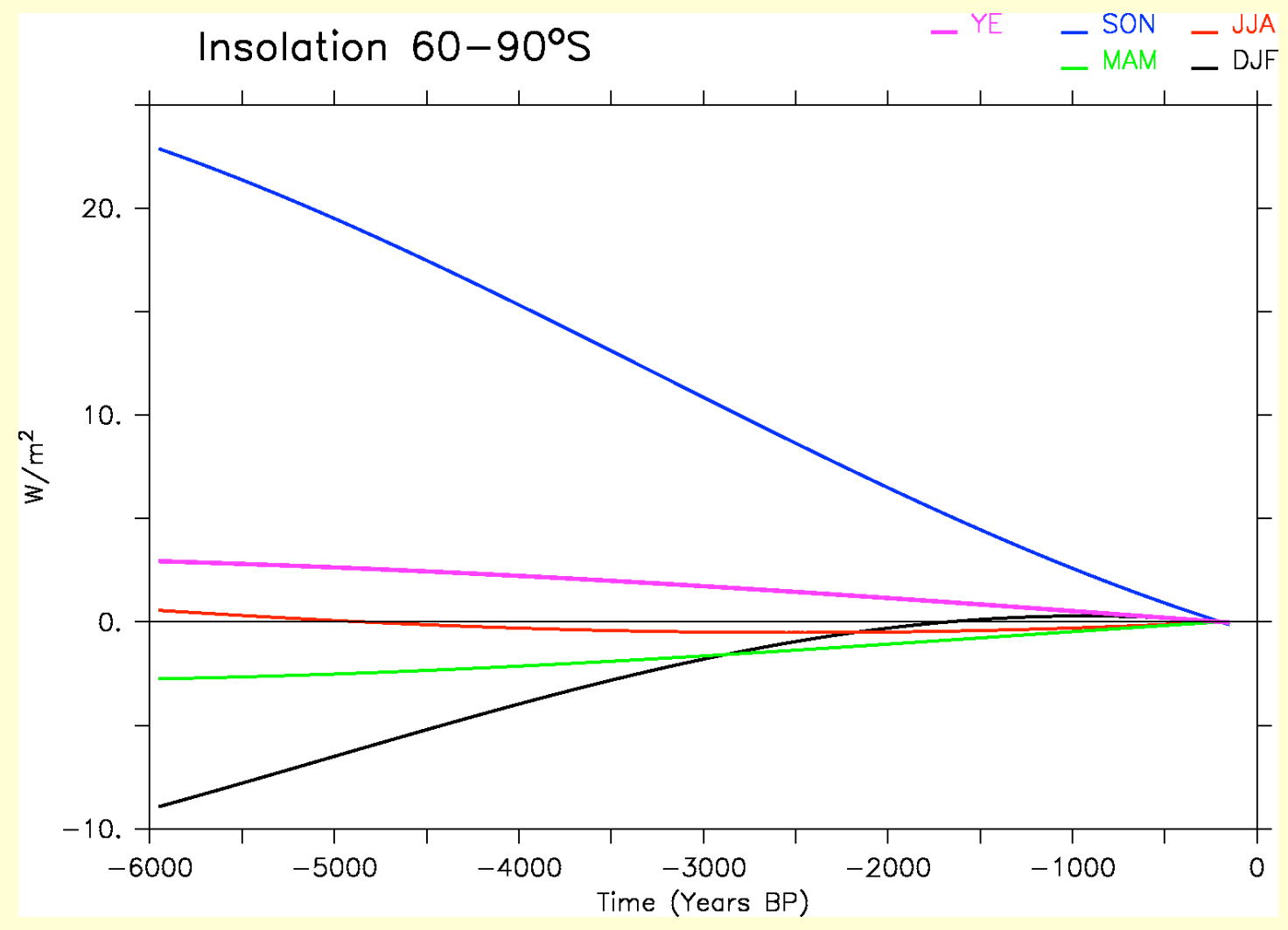

Fig.3: External forcings used in the simulations

	# Ensemble	Initial conditions	Forcing	Years of simulation
Control	1	Spin-up simulation	Preindustrial	1x1000
Accelerated Holocene	3	Start in 1850 every 10 years from a preindustrial simulation	Insolation accelerated 10 times	3x600

Table1: list of the simulations using IPSLCM5A-LR model

Model-data comparison

- We found positive trends over the Holocene for glacial discharges from $\delta^{18}O_{diatom}$ records at the three core locations (Fig. 3).
- This is in agreement with modelled temperature at the three sites considered (Fig. 4).

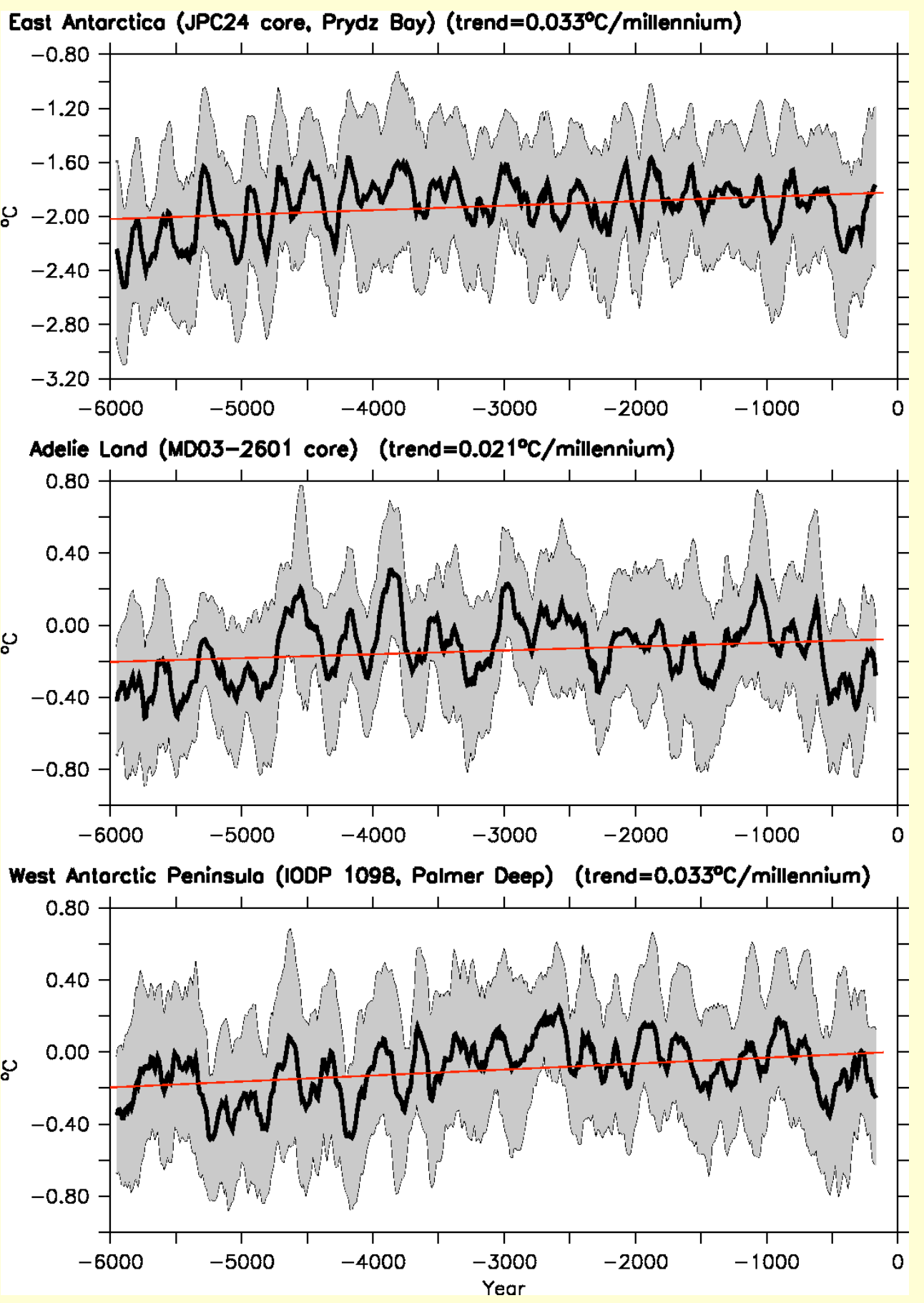

Fig.4: 2-meter temperature in the simulations at the three cores locations

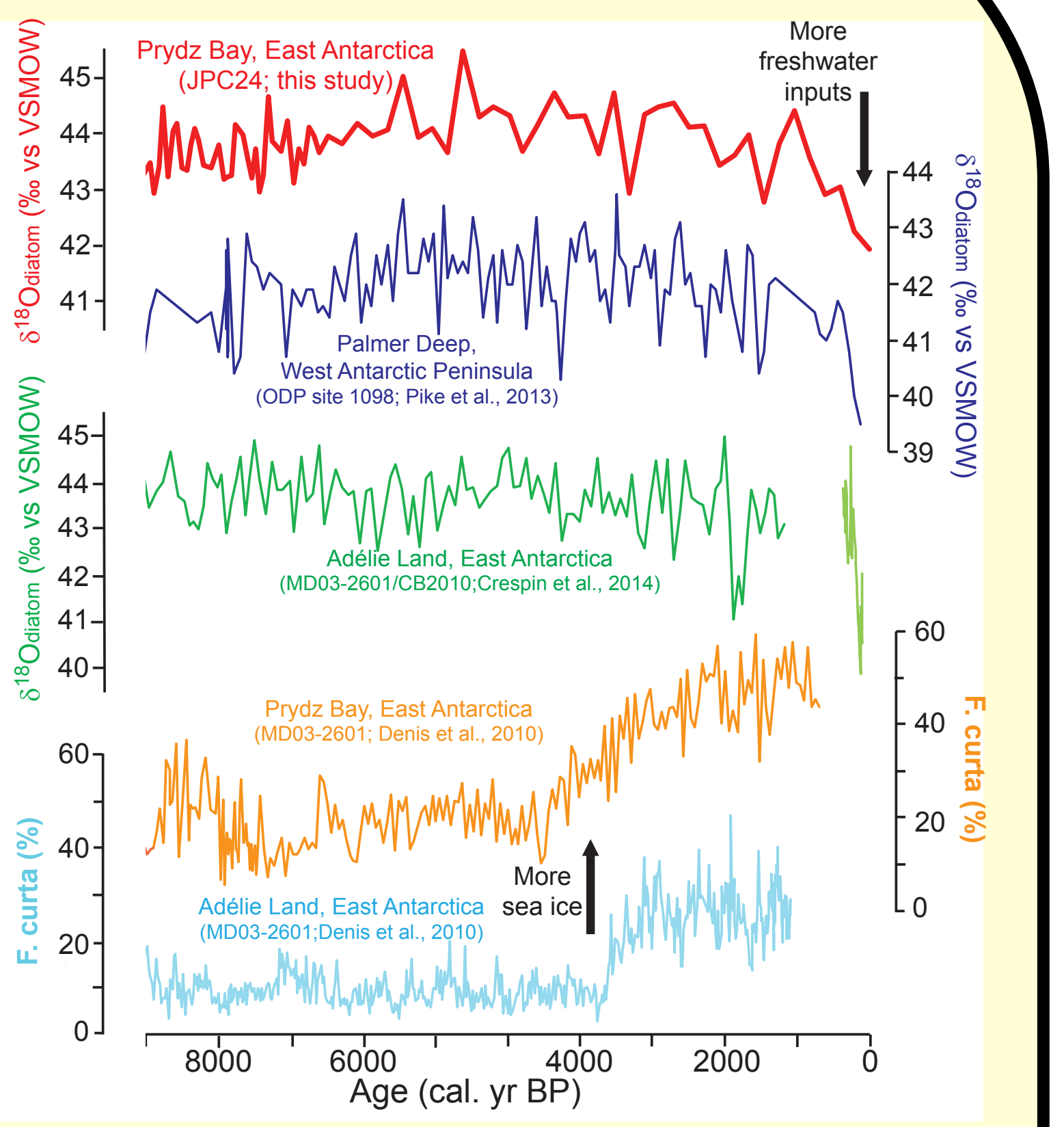

Fig.3: Measurements at the three cores considered.

- The simulated trend in the 3-member ensemble mean follow this warming in Austral summer as well as in winter (not shown).
- This can be surprising given that orbital forcing is negative in annual mean.
- We do not find any significant difference in simulated trends at the 3 core locations

Comparison with Antarctic records

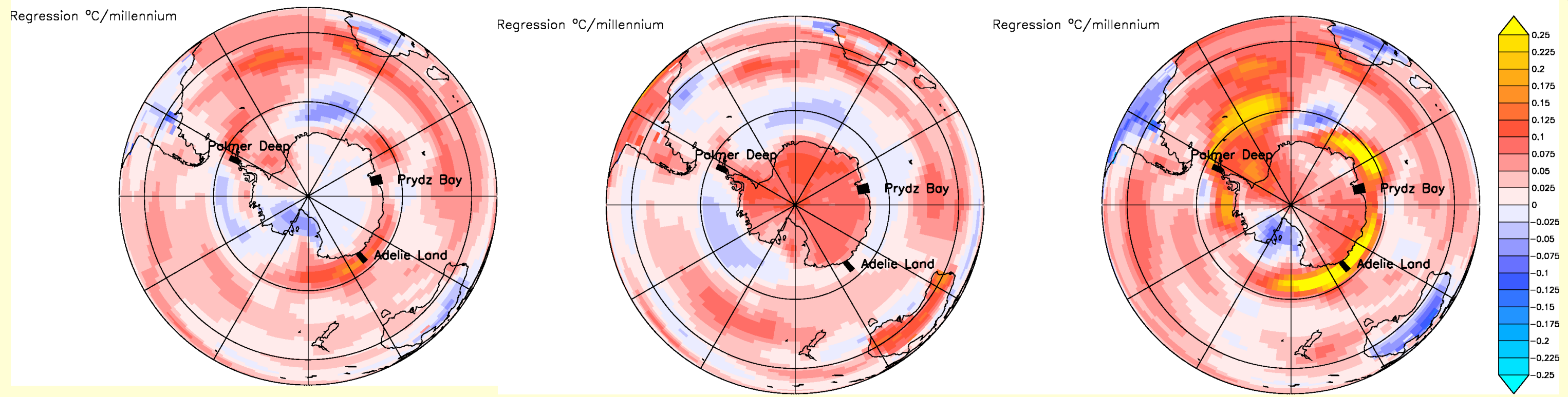

Fig.6: Map of temperature trends in simulated 3-member ensemble mean over the period 6-0 kyrs BP.

- Annual mean forcing trend is very weak but slighly negative over Antarctica in the simulation (Fig. 6).
- On the opposite, the temperature trend is positive in summer and winter indicating the key role played by spring for the annual trend (Fig. 6).
- Ice cores from Antarctica also indicate a cooling trend for annual mean temperature (Fig. 7).
- We notice an asymmetrical response to insolation over south of 60°S (Fig. 8).
- This is due to insulation effect from sea ice.
- While heat can be stored on the ocean in summer due to low sea-ice cover, the ocean is insulated from the atmosphere in winter due to ice cover, limiting the impact of negative trend in spring insolation.

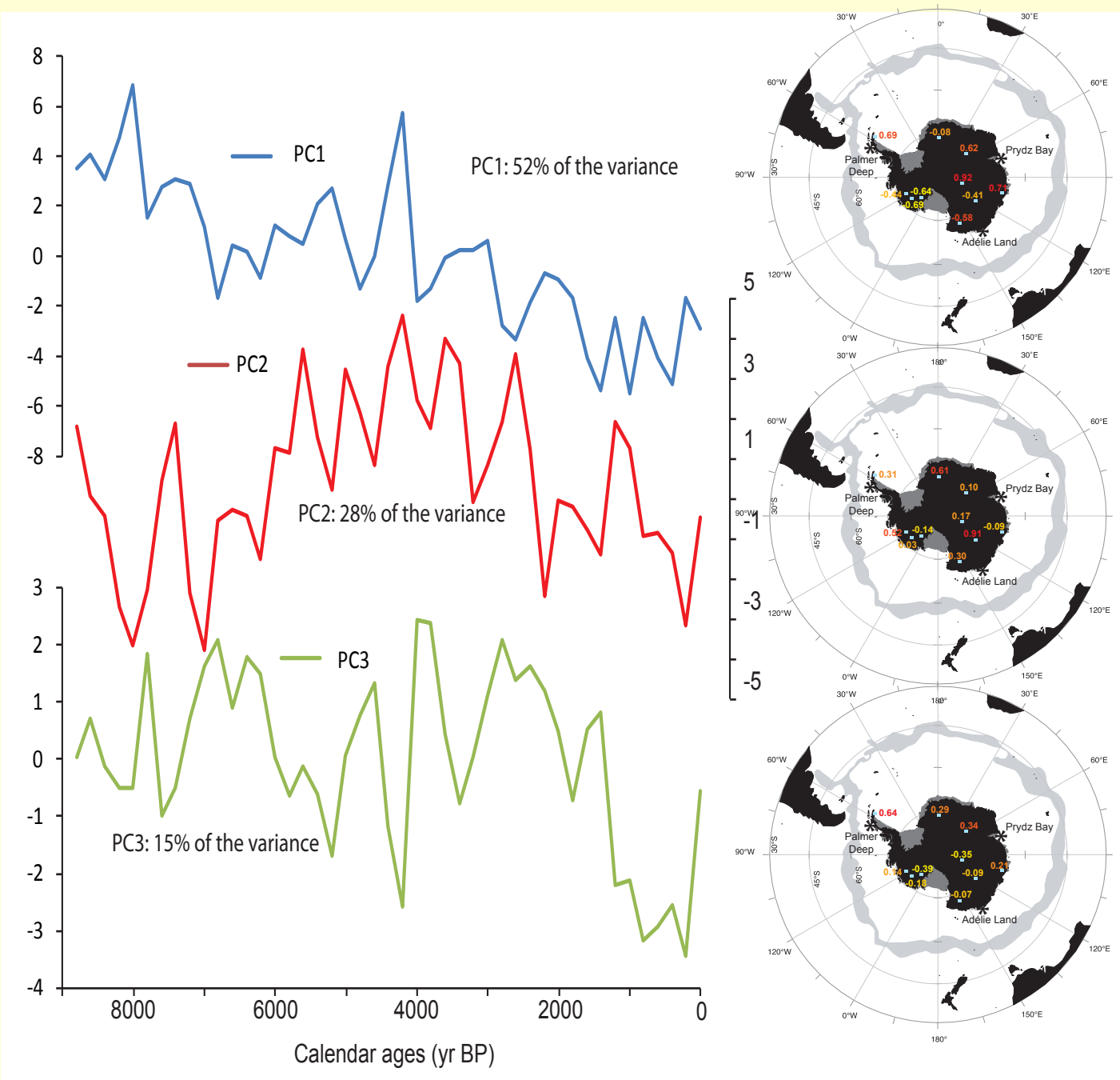

Fig.7: First three PCs from in $\delta^{18}O$ *in* Antarctica ice cores (proxy of annual mean temperature) and the associated EOF pattern.

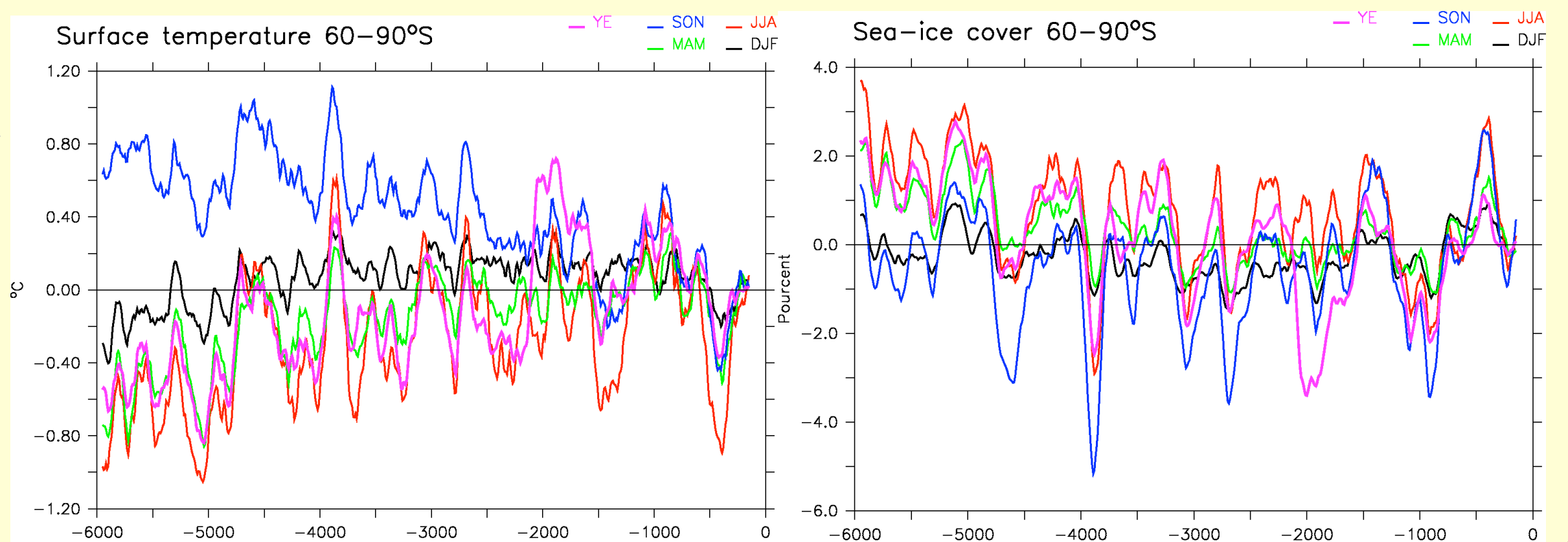

Fig.8: Time series of the simulated ensemble mean of surface temperature (left) and sea-ice cover (right) south of 60°S

ENSO influence?

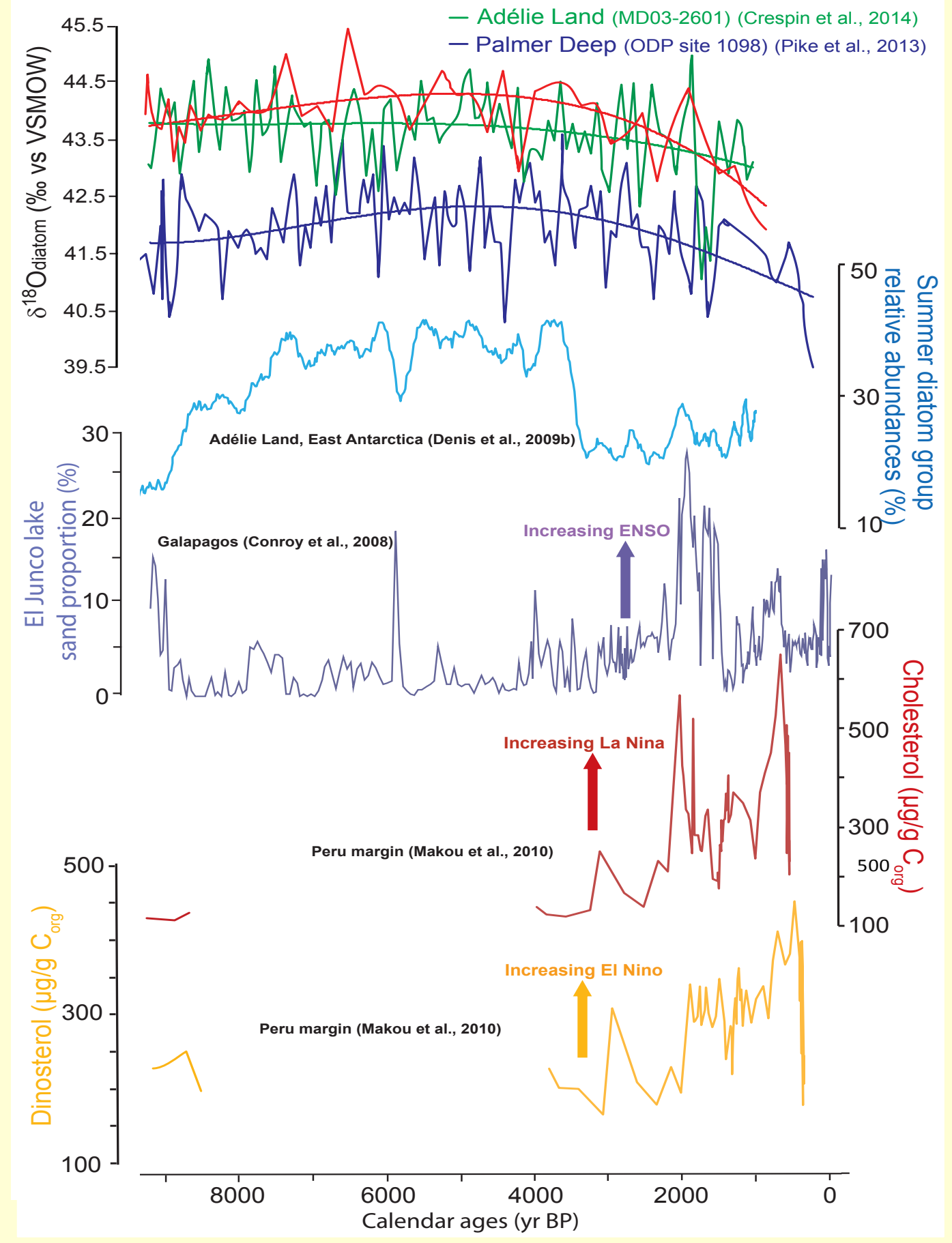

Fig.9: Southern Ocean and Nino/Nina records

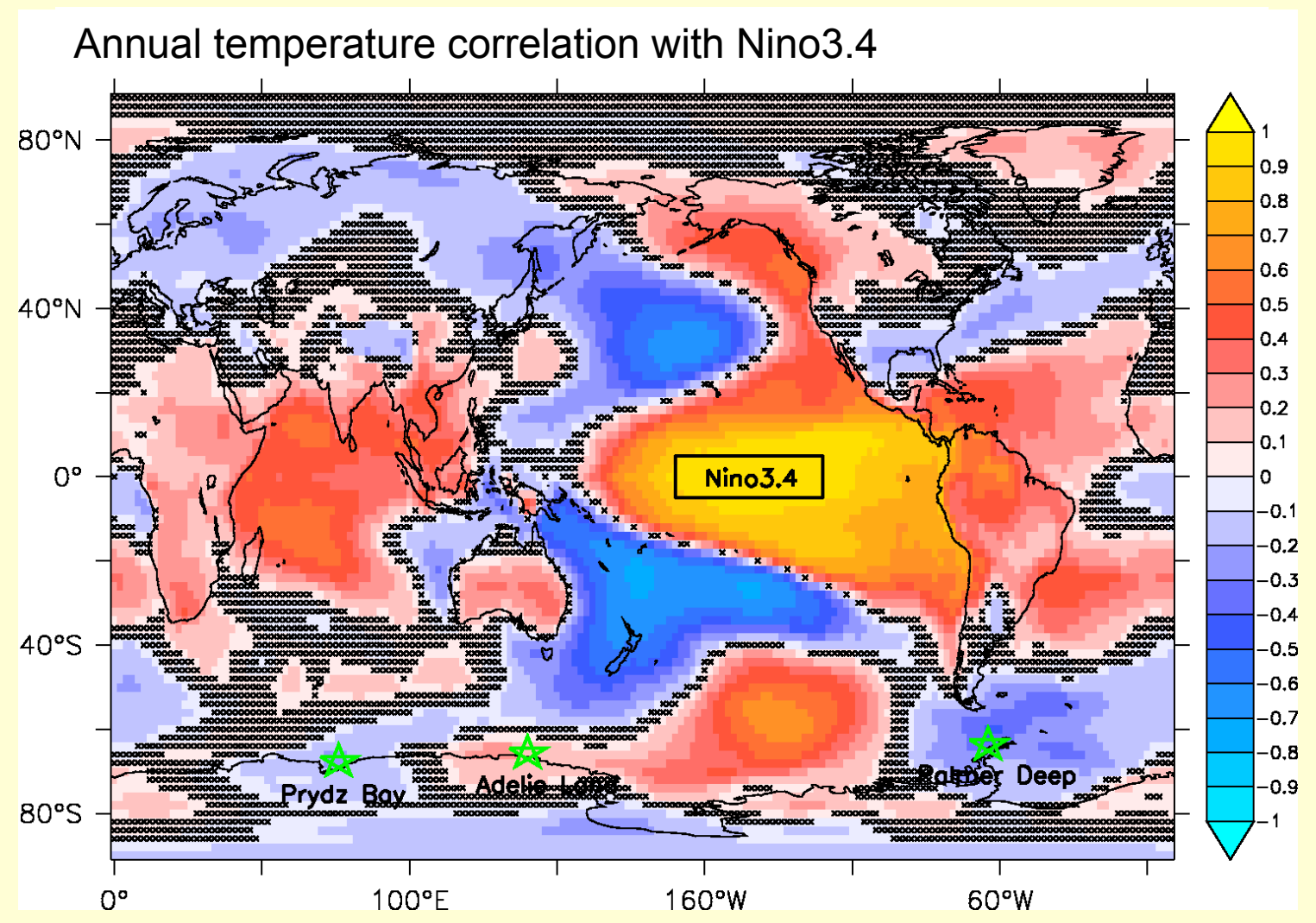

Fig.10: Correlation map of 2-meter temperature with Nino3.4 index using HadISST data over the 1870-2010 period

- Records from Galapagos indicate larger ENSO since 4 cal. kyr BP (Conroy et al. 2008).
- Diatom abundance from Adelie Land also show an abrupt shift at 4 cal. kyr BP (Denis et al. 2009).
- $\delta^{18}O_{diatom}$ records from Prydz Bay and Palmer Deep do show a larger trend from 4 kyr BP as well (Fig. 8).
- Has a change in ENSO property affected Antartica?
- Recent teleconnections may indicate different link between ENSO and the 3 sites (Fig. 10).
- Model simulations slightly support such changes (Fig. 11).

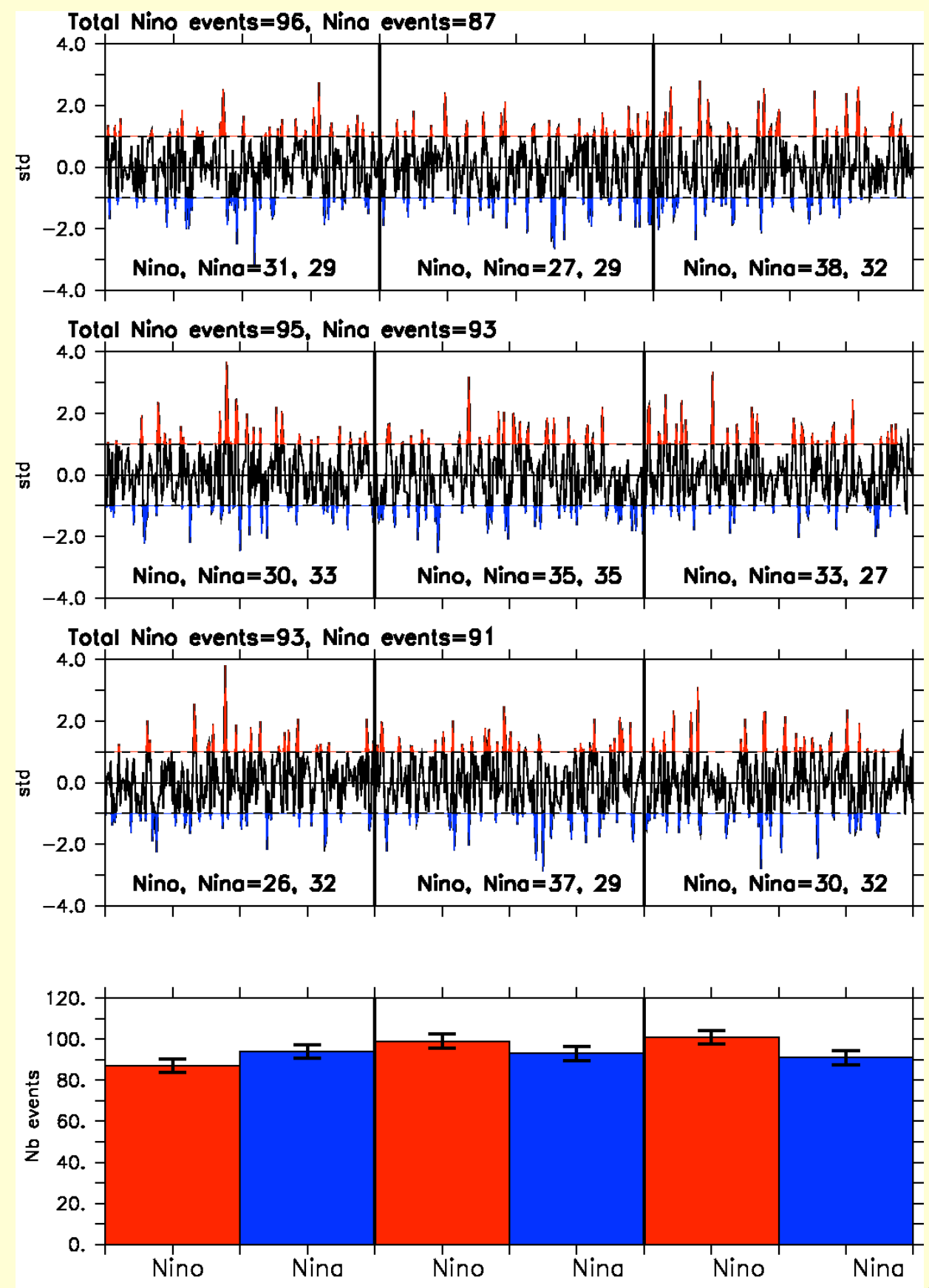

Fig.11: Evolution of SST in Nino3.4 box in the 3 simulations. The last panel show the number of events.

Discussions and conclusions

- New $\delta^{18}O_{diatom}$ record from Prydz bay show a positive warming trend over the Holocene.
- Strong seasonality differences between spring (diatom assemblages) and summer ($\delta^{18}O_{diatom}$).
- Agreement with model simulations in terms of temperature trends for the $\delta^{18}O_{diatom}$ records at the different core locations.
- Comparison with continental Antarctic ice core records: yearly mean has a cooling in model as well as in ice cores, but very strong difference in seasonal signal
- Spatial differences: Palmer Deep and Prydz Bay show similarities in trends but Adélie Land is different: due to change in ENSO frequencies over the Holocene (Pike et al. 2013).
- Coherent with recent ENSO observed teleconnections.
- Simulations also indicate possible weak increase in frequency.

Outlooks

- Non accelerated simulations. Useful to look at ENSO variability.
- Inclusion of other forcings (CO_2, CH_4).
- Ice sheet, ice shelf, ocean interactions necessary to simulatie potential abrupt changes.
- New data from Ross Sea where correlation with ENSO variability is strong.
- Analysing single species samples to produce $\delta^{18}O_{diatom}$ records at seasonal resolution (spring and summer signal in particular) given the strong seasonal disparity in insolation changes.

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