A posteriori adjustment of near-term climate predictions: Accounting for the drift dependence on the IC

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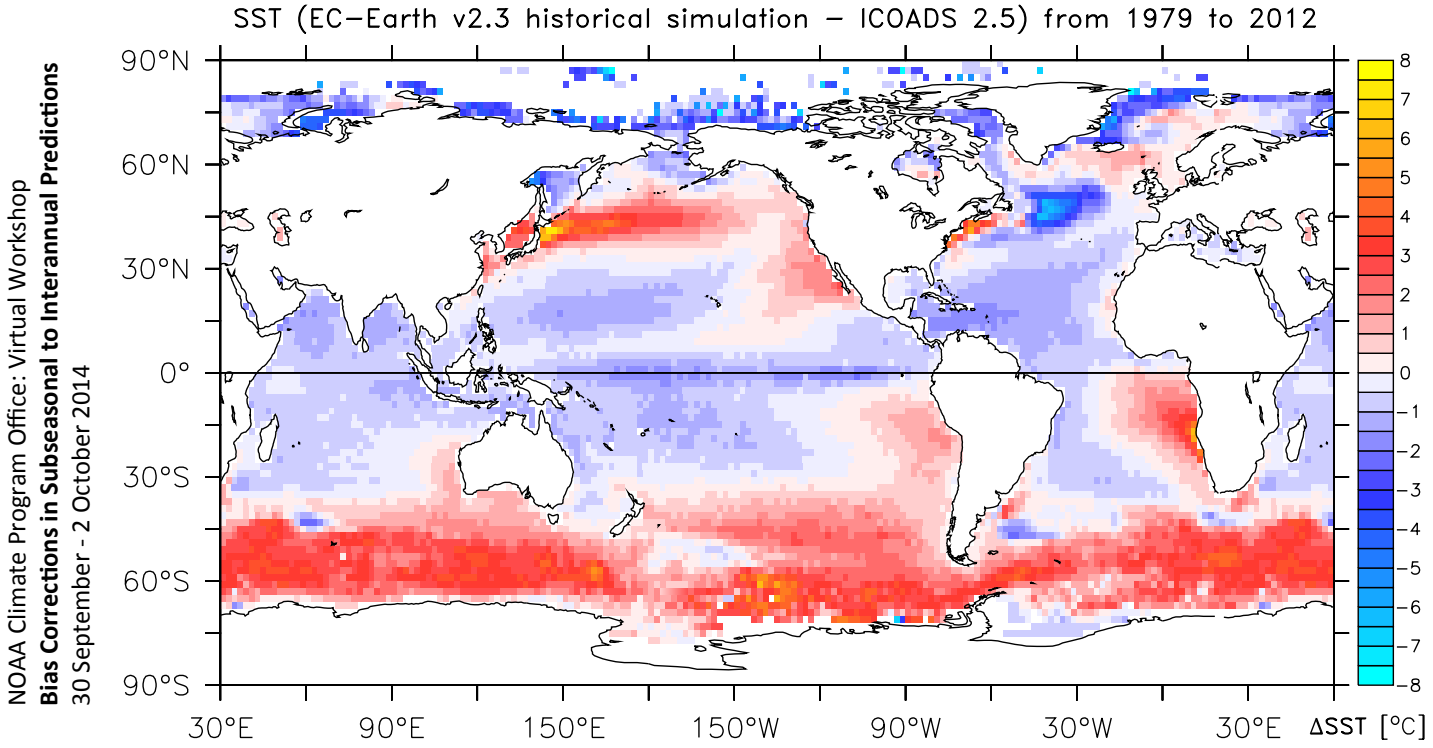


NOAA Climate Program Office: Virtual Workshop
Bias Corrections in Subseasonal to Interannual Predictions
30 September - 2 October 2014

- EC-Earth version 2.3

A global coupled climate model based on ECMWF seasonal forecasting system (http://ecearth.knmi.nl/) and we are using full-field initialization.

Atmospheric component:
IFS with T159L62 (up to 5 hPa)

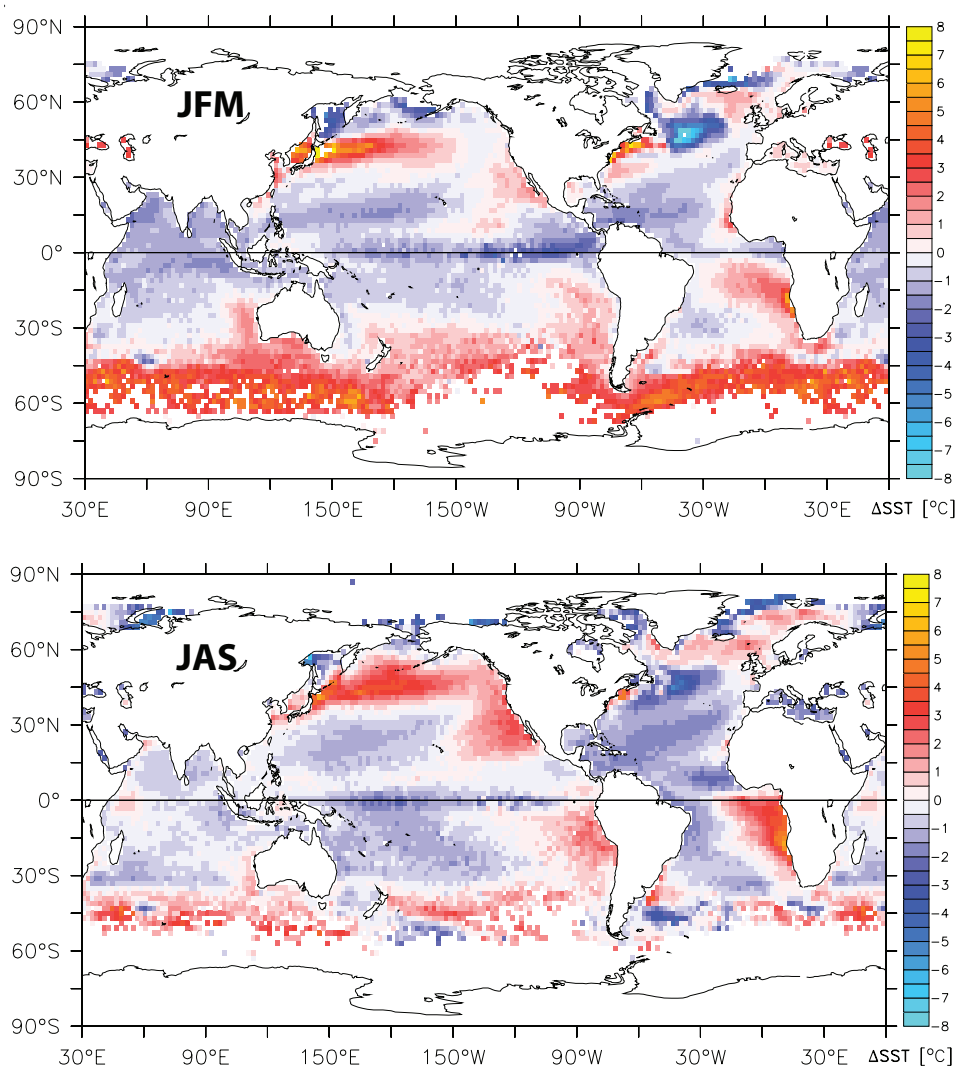
Ocean and sea ice component:
NEMO2-LIM2 in ORCA1L42

Land component: H-TESSEL in IFS

Global coupler: OASISv3 (3hrs)

Climate models are approximations with inherent sources of errors:

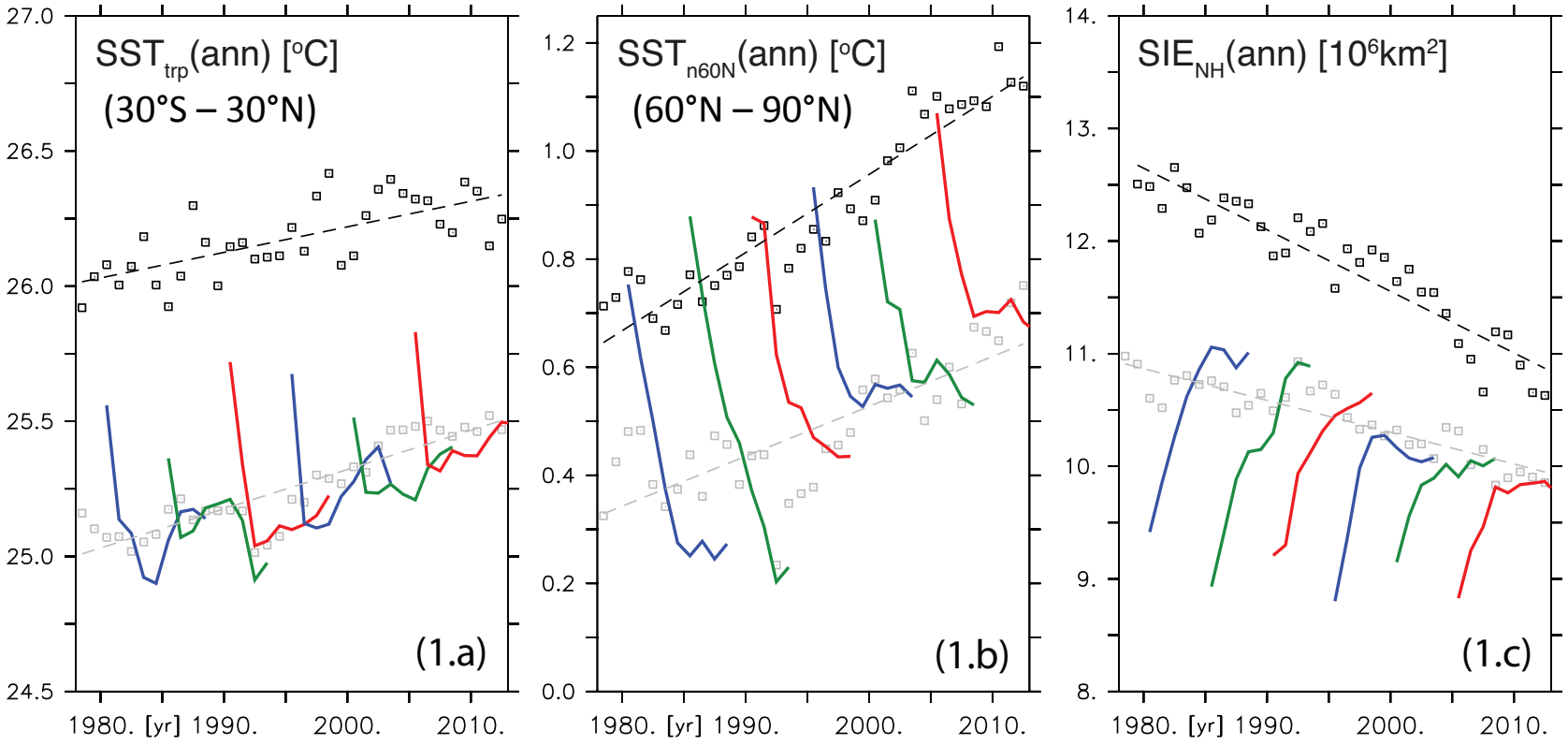
i) discretization errors,
ii) context errors (includes IC errors),
iii) scale representation errors
iv) process representation errors



ΔSST (EC-Earth v2.3 historical simulations – ICOADS 2.5) 1979–2012 seasonal means

⇒ **All models develop biases, i.e., forecasts require post-processing bias correction**

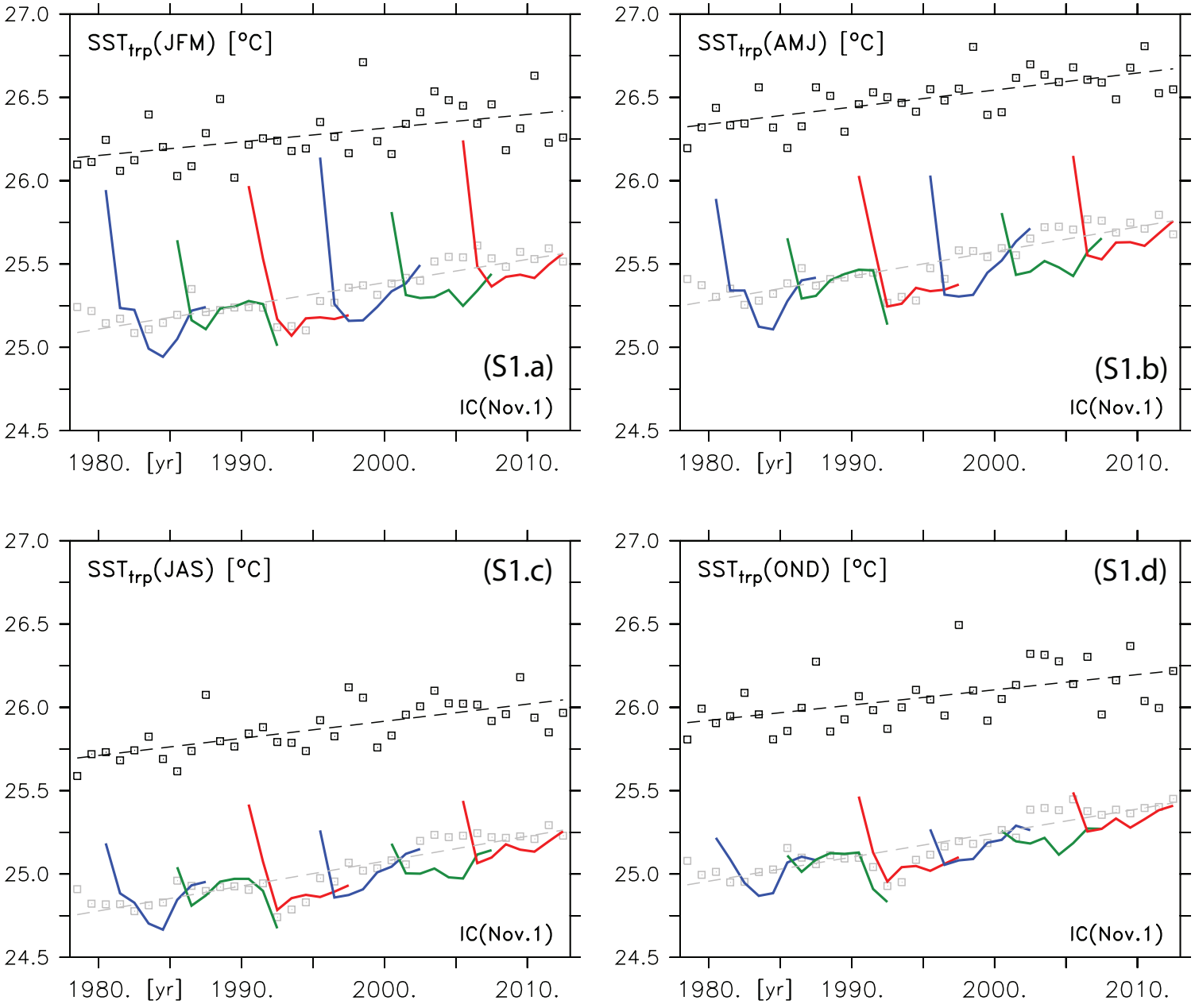
- Observational analyses: ERSSTv3b and NSIDC sea ice concentration
- Climate forecast system: EC-Earth2.3 (historical simulations, HIST, and decadal predictions initialized on November 1st, INIT, from 1979 to 2005)

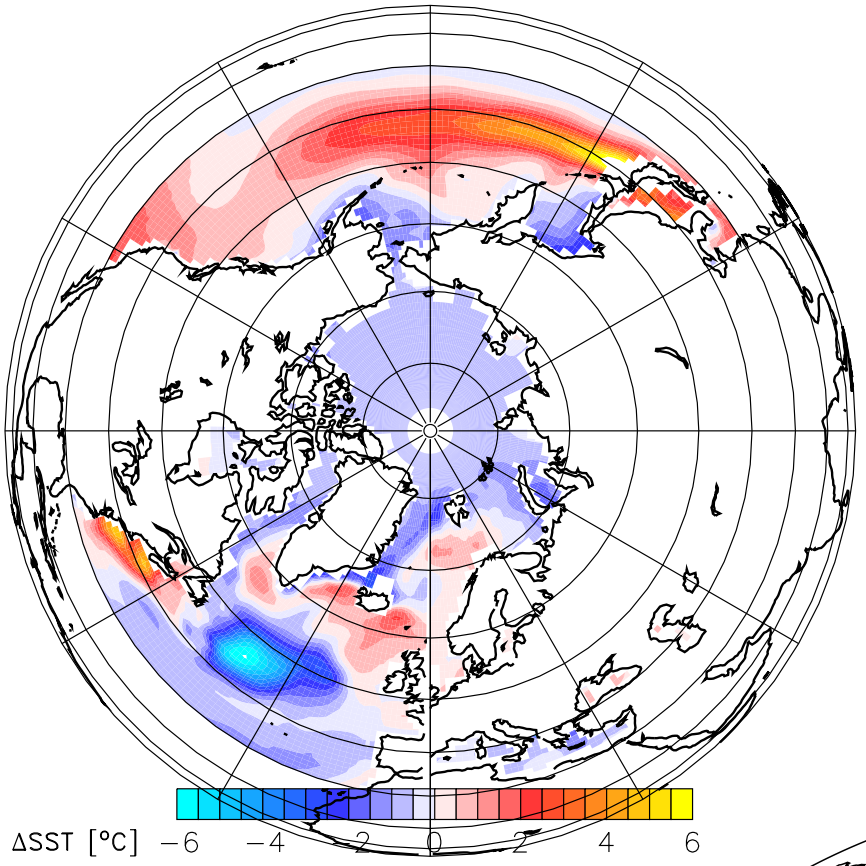


→ cold SST bias in the tropics is stronger than in the Arctic, but the SST bias tends to get smaller in the tropics and larger in the Arctic under a warmer climate

→ bias of the NH sea ice cover in HIST is reduced under a warmer climate.

Seasonal means of tropical SST (30°S – 30°N)

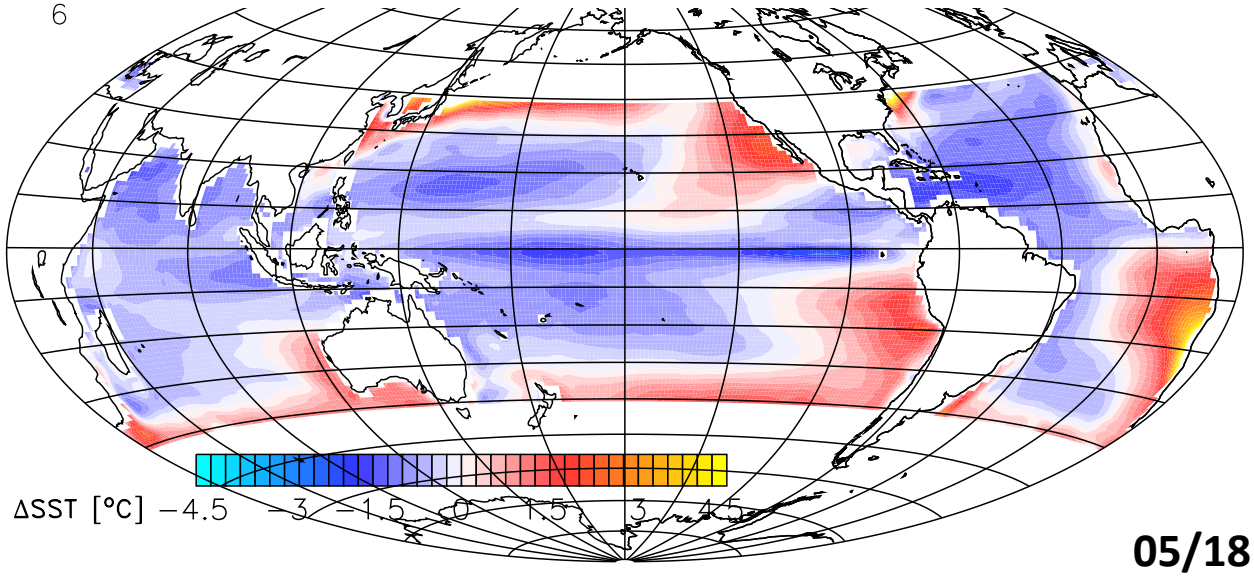


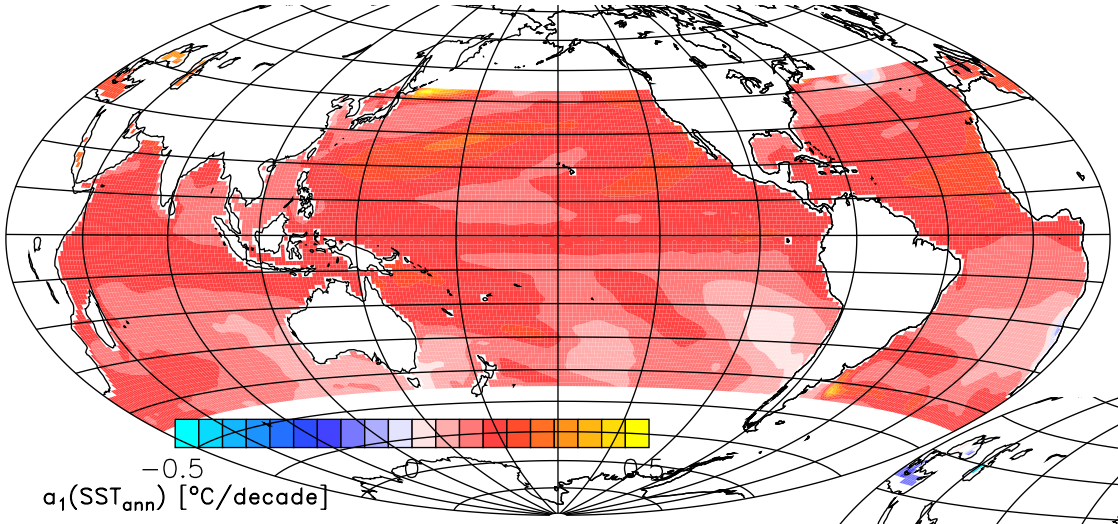


- Structure of mean SST bias (due to)

- radiative imbalance in the atmosphere
- inaccurate detachment (too far north) of the NH western boundary currents
- weak AMOC
- weak exchange between the surface and the deep Southern Ocean
- deficient mid-latitude clouds
....

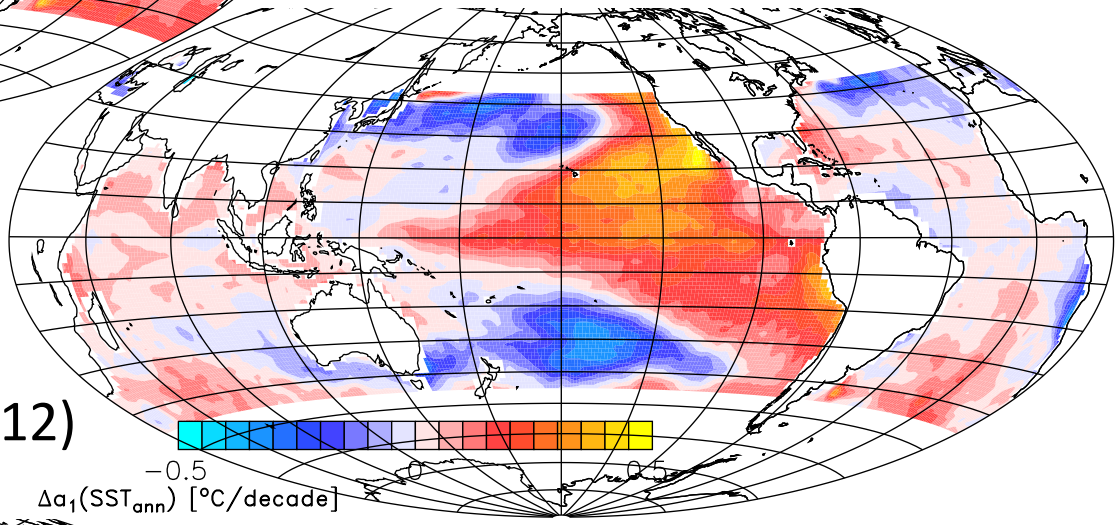
EC-Earth2.3 (1979-2012)
- ERSSTv3b (1979-2012)

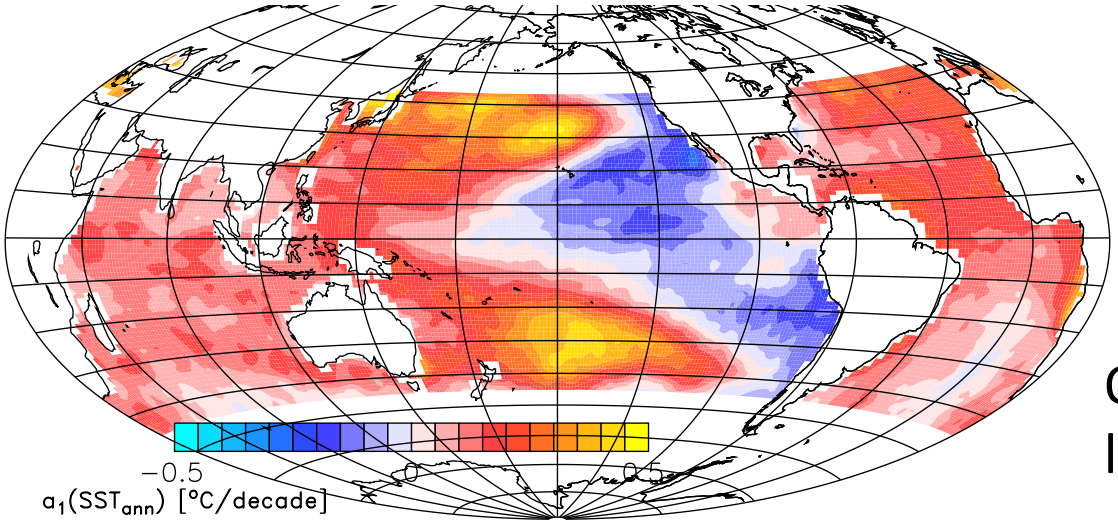




Hist. sim. EC-Earth2.3
lin. trend (1979-2012)

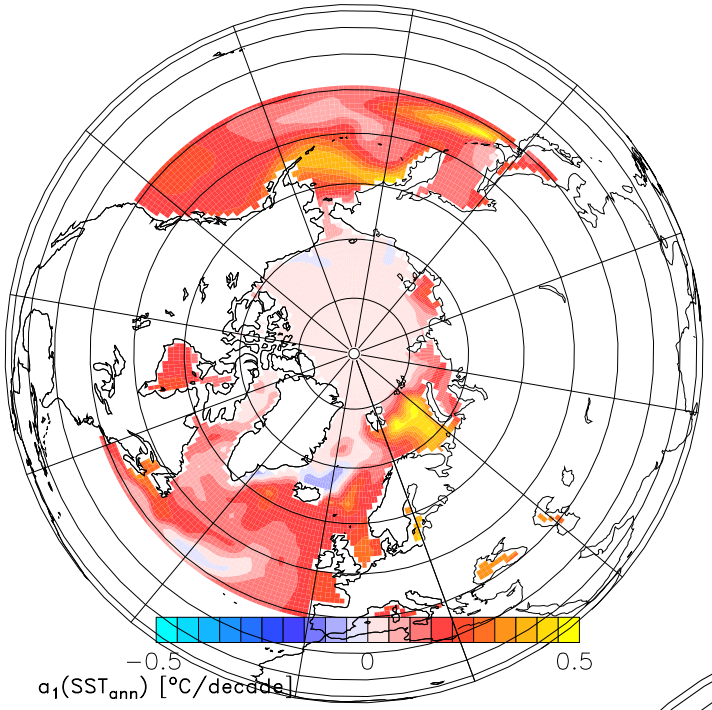
EC-Earth2.3
lin. trend (1979-2012)
- ERSSTv3b
lin. trend (1979-2012)



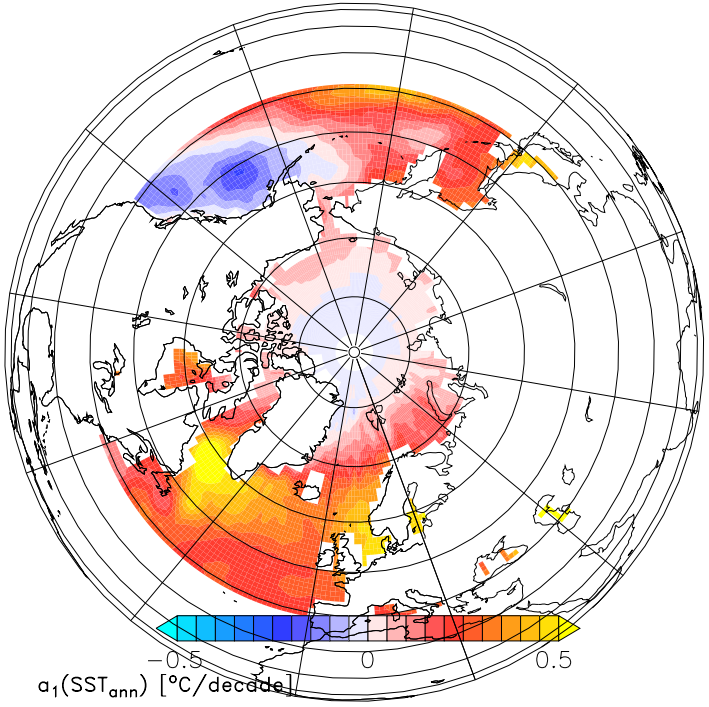


- Long-term trend (and natural variability) also exhibits significant biases

Obs. ERSSTv3b
lin. trend (1979-2012)

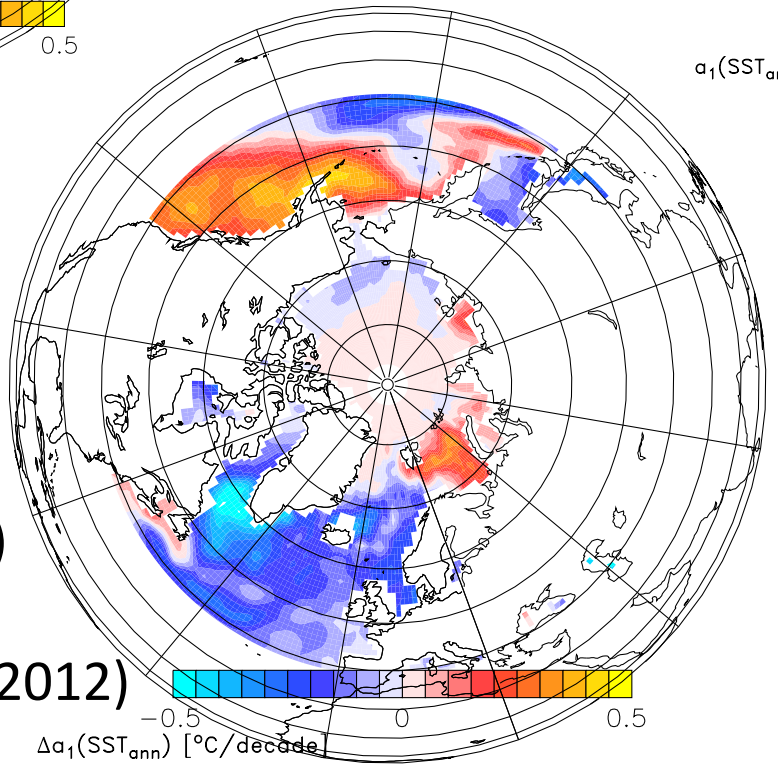


Hist. sim. EC-Earth2.3
lin. trend (1979-2012)



Obs. ERSSTv3b
lin. trend (1979-2012)

EC-Earth2.3
lin. trend (1979-2012)
- ERSSTv3b
lin. trend (1979-2012)



● IC bias correction method

Even with the best possible BC and IC, the model bias can still be larger than the climate signal one wants to predict

⇒ We use a set of hindcasts to estimate the development of the model error as a function of the start date i and the forecast time f

1) Mean (per-pair) bias correction method (I)

→ replaces the long-term mean (over i) of a model variable with the long-term mean of corresponding OBS at each forecast time f (or lead time l)*:*

$$m_{i,l} \equiv \overline{m_l} + m'_{i,l} \;\; and \;\; o_{i,l} \equiv \overline{o_l} + o'_{i,l},$$

$$m_{i,l} \longmapsto \hat{m}_{i,l} \equiv m_{i,l} - [\overline{m_l} - \overline{o_l}] = \overline{o_l} + m'_{i,l}.$$

m is the "raw" forecast, o is obs./reanalysis, i is the initial time (year), and l is the lead time

Some forecast systems, beside the mean bias, also exhibit a conditional bias in time; i.e., a forecast drift that is dependent on the start date i (e.g., the NH sea ice extent)

⇒ to account for errors in the forced climate response, a more general adjustment method assumes a linear dependence of the bias on the start date *I*

2) Trend bias correction method (II)

→ replaces a linear regression of the forecasts on *i* with the linear regression of the corresponding OBS on *i* at each forecast or lead time

$$m_{i,l} \equiv [a_l^{(m)} + b_l^{(m)} i] + m''_{i,l} \;\; and \;\; o_{i,l} \equiv [a_l^{(o)} + b_l^{(o)} i] + o''_{i,l},$$

$$m_{i,l} \longmapsto \tilde{m}_{i,l} \equiv m_{i,l} - \{[a_l^{(m)} + b_l^{(m)} i] - [a_l^{(o)} + b_l^{(o)} i]\}$$

$$= \hat{m}_{i,l} - [b_l^{(m)} - b_l^{(o)}][i - \bar{i}].$$

Trend bias correction includes the mean bias correction term, but it can also account for the systematic difference between the forecasted and observed long-term trends

However, even if there is no significant error in the long-term trend, there can be a different drift depending on the initial conditions

⇒ we see the need for a new postprocessing method that should incorporate the conditional sensitivity to the observed state of natural variability

3) The new IC bias correction method (III)

→ we propose that the dependence of the model drift and bias on the observed IC, should be taken into account as additional correction to the mean adjustment

However, instantaneous IC at the beginning of the first day in a month are too noisy for climate forecasting

⇒ we put forward assumption of a linear dependence of the model bias on the monthly mean obs in the 1st forecast month (lead month 0), $o_{i,l=0}$=a proxy for IC, as a simple approach to incorporate such conditional bias dependence on the IC

→ here implemented version of the IC bias correction method replaces the linear regression of the model forecasts on $o_{i,l=0}$ with the linear regression of OBS on $o_{i,l=0}$ for each forecast month (or lead time).

$$m_{i,l} \equiv [\alpha_l^{(m)} + \beta_l^{(m)} o_i^{(IC)}] + m'''_{i,l} \;\; and \;\; o_{i,l} \equiv [\alpha_l^{(o)} + \beta_l^{(o)} o_i^{(IC)}] + o'''_{i,l},$$

$$m_{i,l} \longmapsto \tilde{\tilde{m}}_{i,l} \equiv m_{i,l} - \{[\alpha_l^{(m)} + \beta_l^{(m)} o_i^{(IC)}] - [\alpha_l^{(o)} + \beta_l^{(o)} o_i^{(IC)}]\}$$

$$= \hat{m}_{i,l} - [\beta_l^{(m)} - \beta_l^{(o)}][o_i^{(IC)} - \overline{o_i^{(IC)}}].$$

Implemented: $o_i^{(IC)} \equiv o_{i,0}$

Other options:

$o_i^{(IC)} \equiv o_{i,-1}$

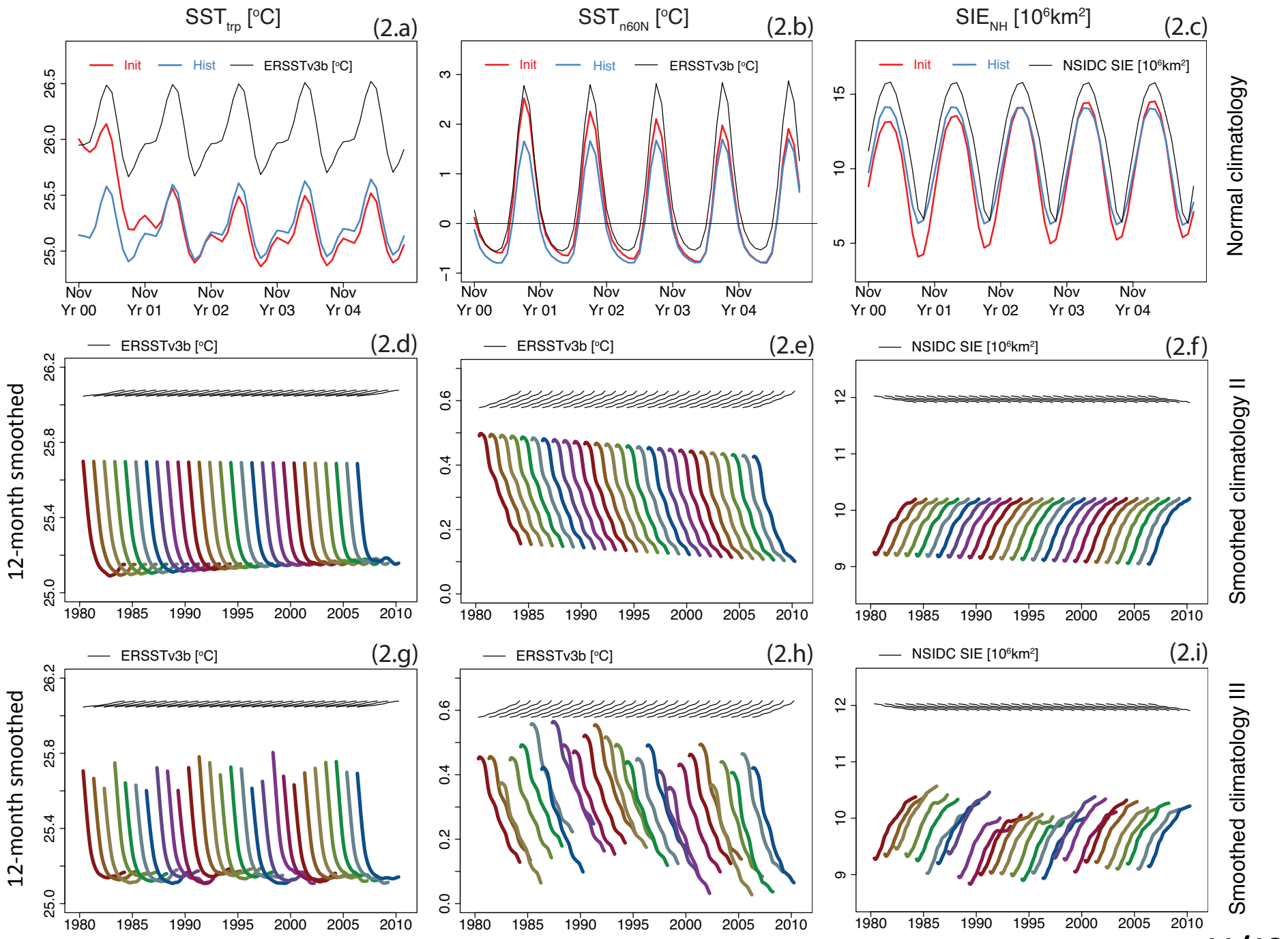
$o_i^{(IC)} \equiv (o_{i,0} + o_{i,-1})/2$

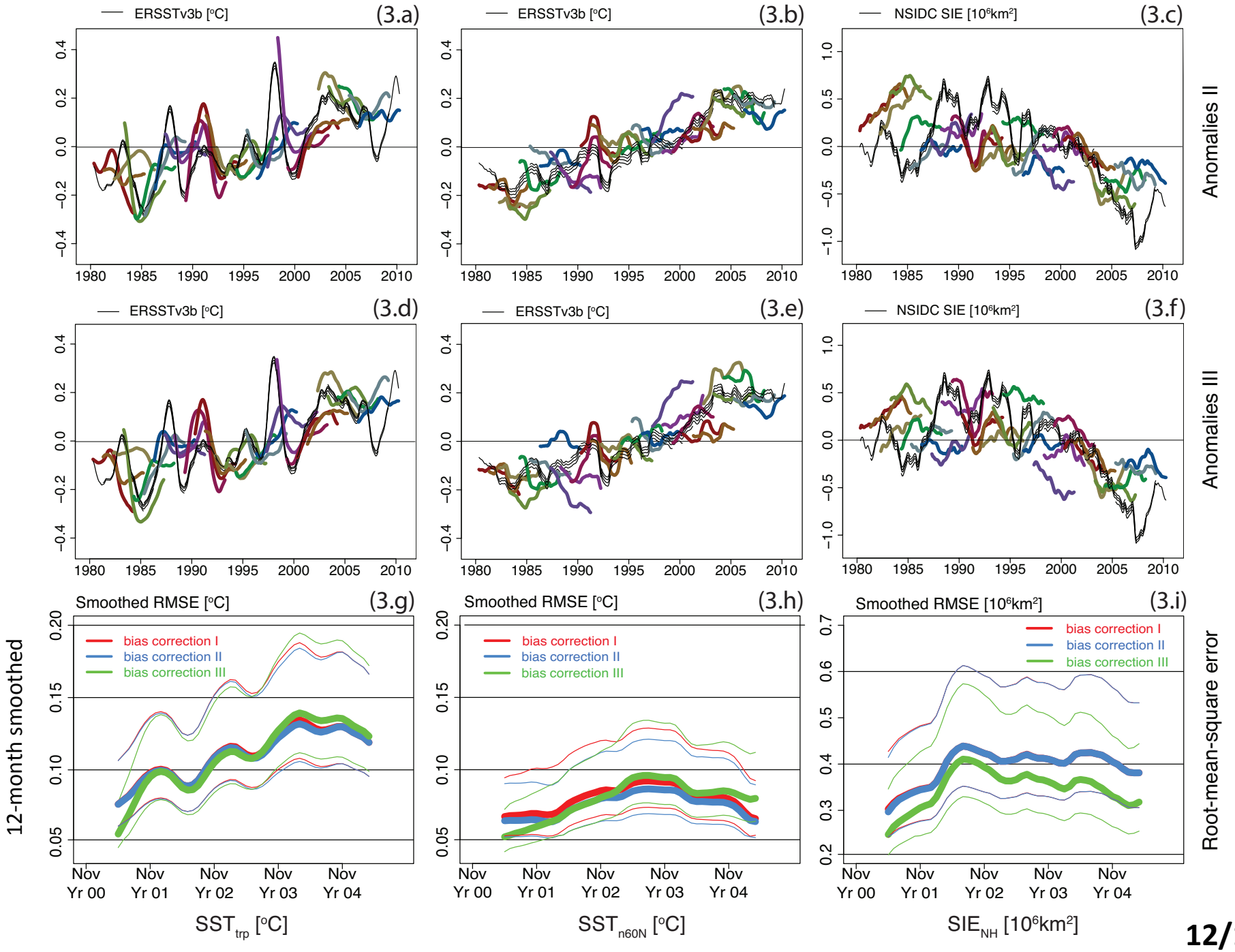
→ new IC method also incorporates the mean bias correction term but additionally contains a key linear dependence on a smoothed proxy for obs IC.

However, the IC bias correction method has a stronger dependence on the quality of obs than the mean and trend bias correction methods

⇒ we focus on the modern observational period since 1979 characterized with a high density of quality monthly surface obs that will enable us to establish the largest possible advantage of the IC bias correction method

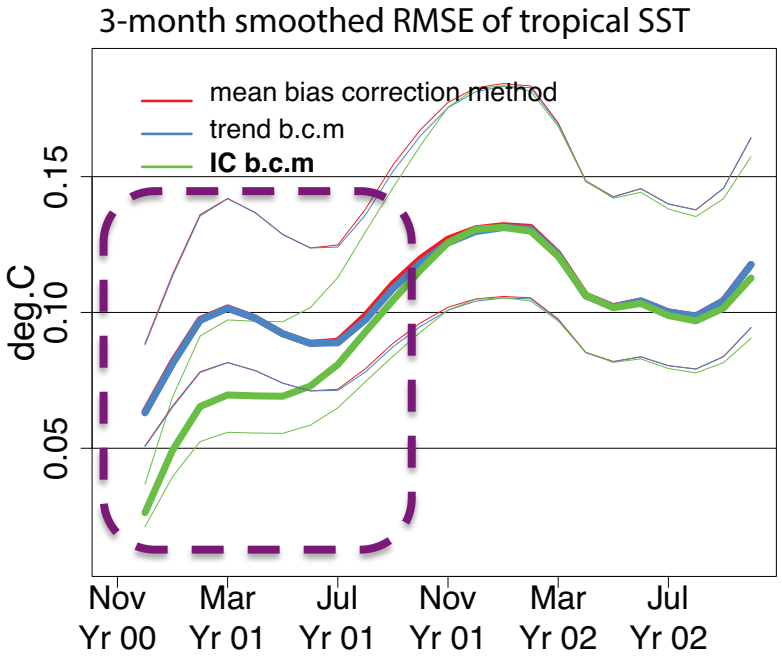
The states of the ocean and sea ice cover are among the main sources of climate predictability on seasonal to decadal time scales, hence we will firstly focus on large-scale SST indices and the NH sea ice extent.

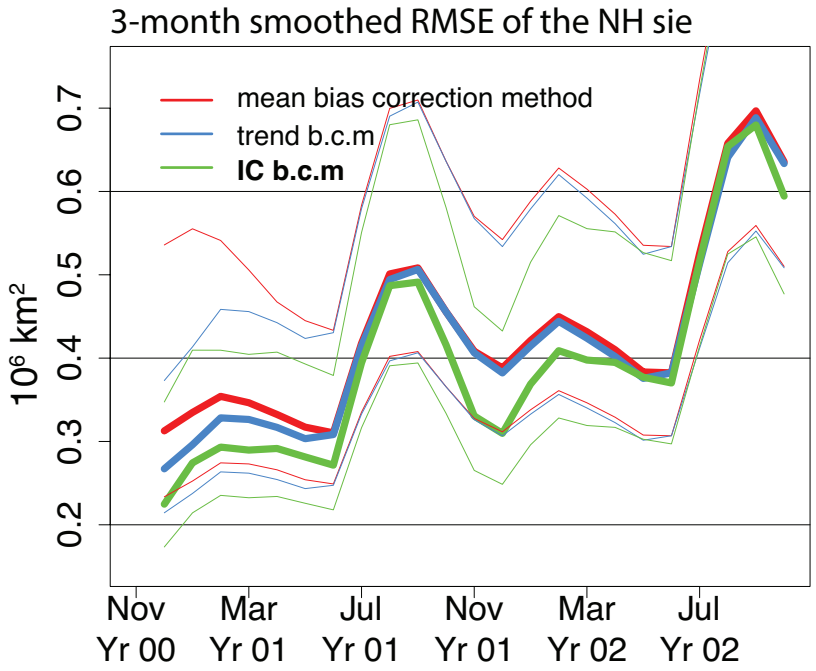

SST$_{trp}$ [°C]
(2.a)
Init
Hist
ERSSTv3b [°C]
SST$_{n60N}$ [°C]
(2.b)
SIE$_{NH}$ [10^{6}km^2]
(2.c)
NSIDC SIE [10^{6}km^2]
Nov Yr 00
Nov Yr 01
Nov Yr 02
Nov Yr 03
Nov Yr 04
Normal climatology
12-month smoothed
(2.d)
(2.e)
(2.f)
Smoothed climatology II
(2.g)
(2.h)
(2.i)
Smoothed climatology III

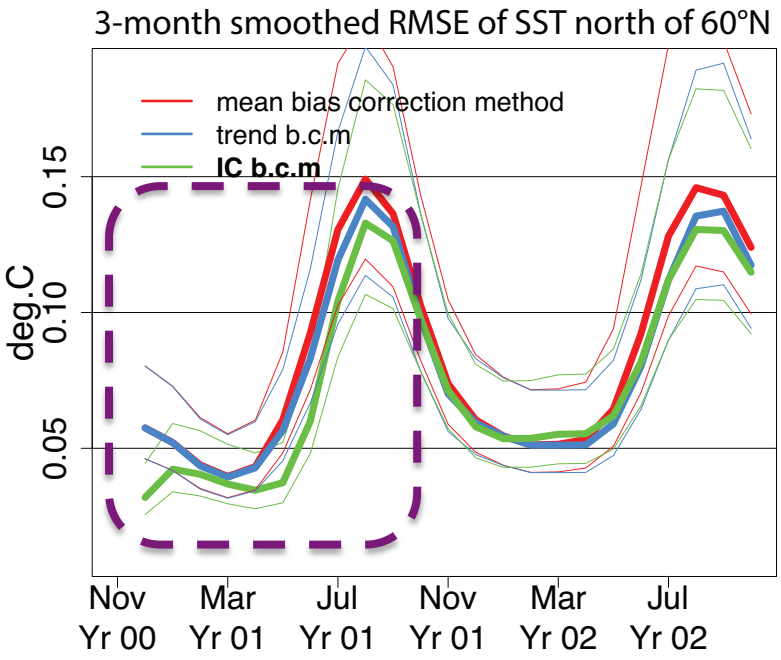

ERSSTv3b [°C]
(3.a)
ERSSTv3b [°C]
(3.b)
NSIDC SIE [10⁶km²]
(3.c)
Anomalies II
ERSSTv3b [°C]
(3.d)
ERSSTv3b [°C]
(3.e)
NSIDC SIE [10⁶km²]
(3.f)
Anomalies III
Smoothed RMSE [°C]
(3.g)
Smoothed RMSE [°C]
(3.h)
Smoothed RMSE [10⁶km²]
(3.i)
bias correction I
bias correction II
bias correction III
12-month smoothed
Root-mean-square error
Nov Yr 00
Nov Yr 01
Nov Yr 02
Nov Yr 03
Nov Yr 04
SST_trp [°C]
SST_n60N [°C]
SIE_NH [10⁶km²]

→ on *annual time scale* IC bias correction method shows mean improvement in the first year or so though not statistically significant at the 95% confidence level based on a χ^2 distribution.

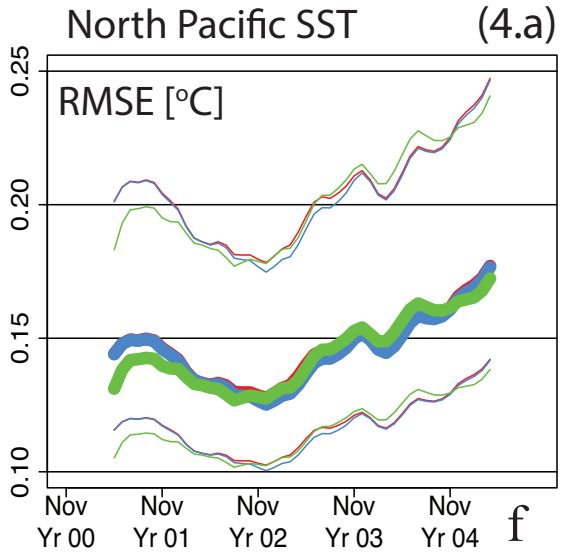
→ on *seasonal time scale* some climate indices due to the IC bias correction show statistically significant improvements over the first 3-4 months

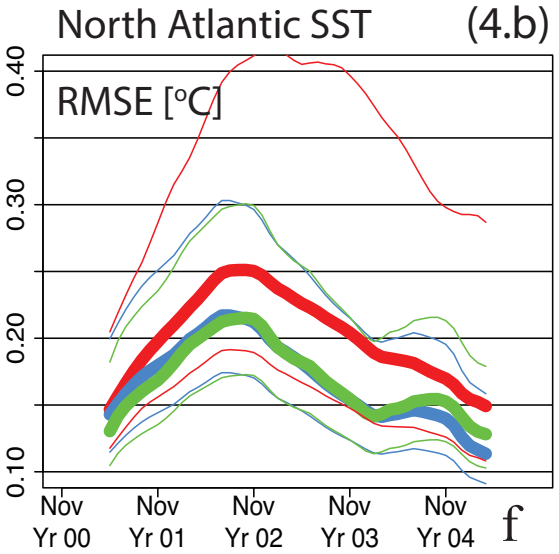


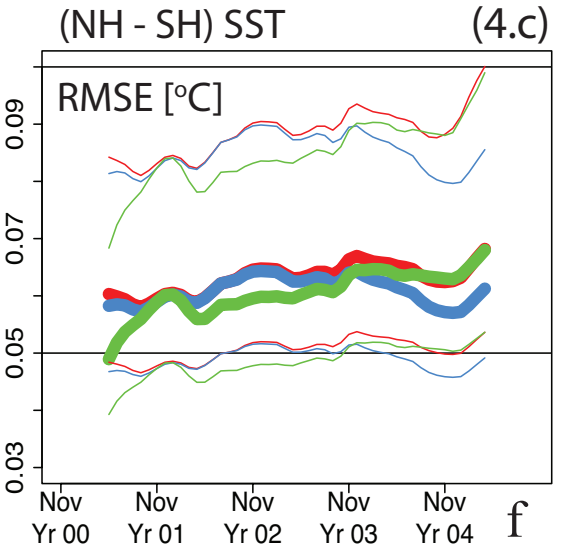


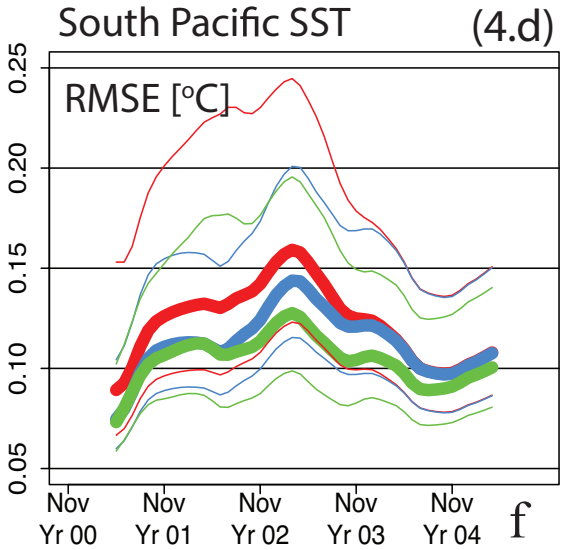


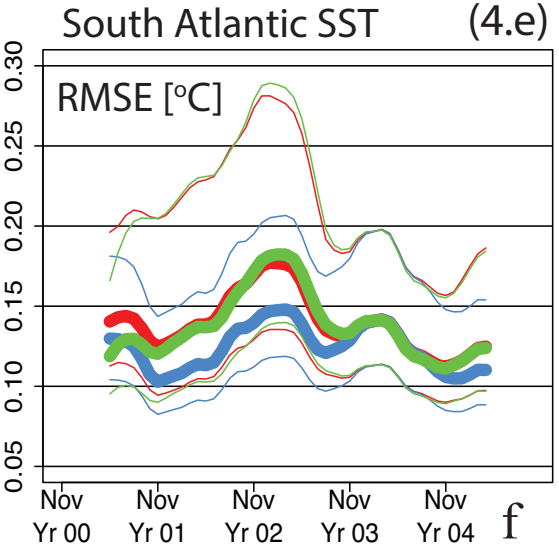
12-month smoothed RMSE for large-scale SST in various regions

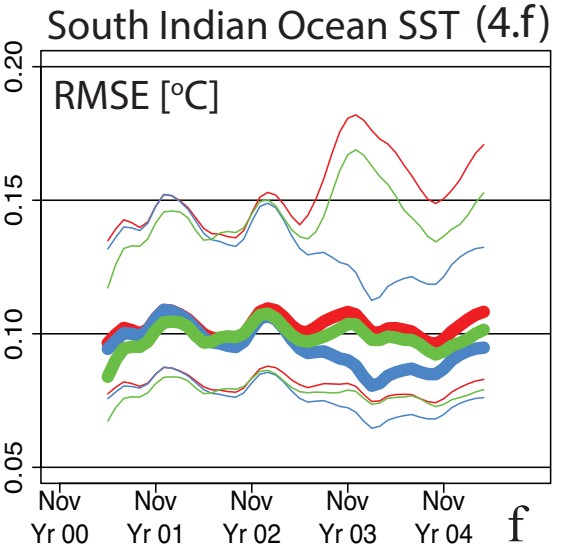








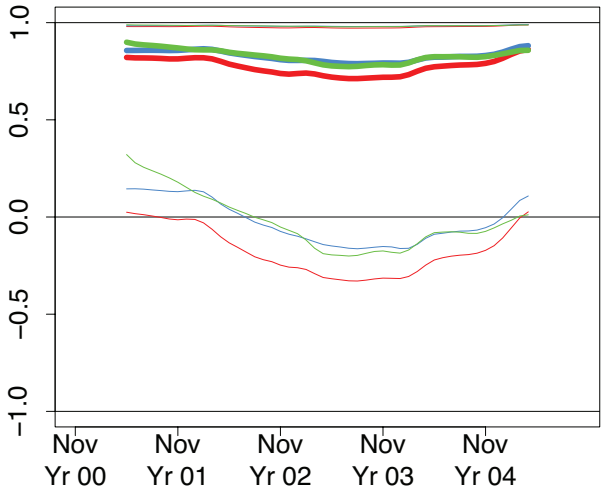




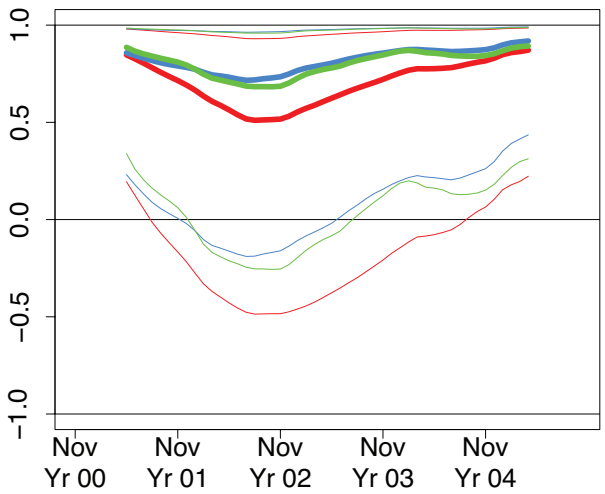
→ IC bias correction method improves or yields RMSE comparable with two established methods

12-month smoothed ACC for large-scale SST in various regions

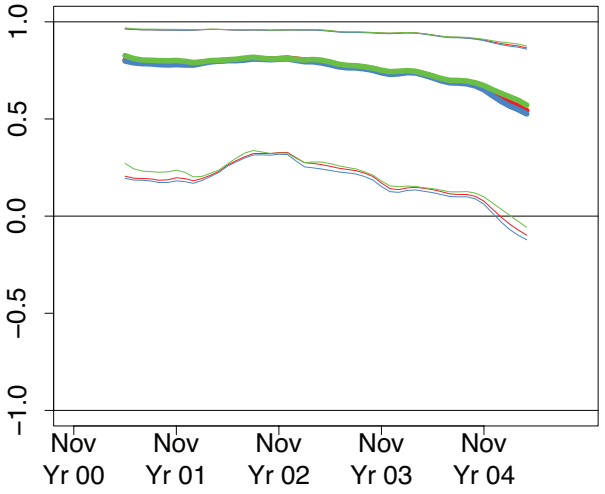
SST north of 60N = SST_{n60N}



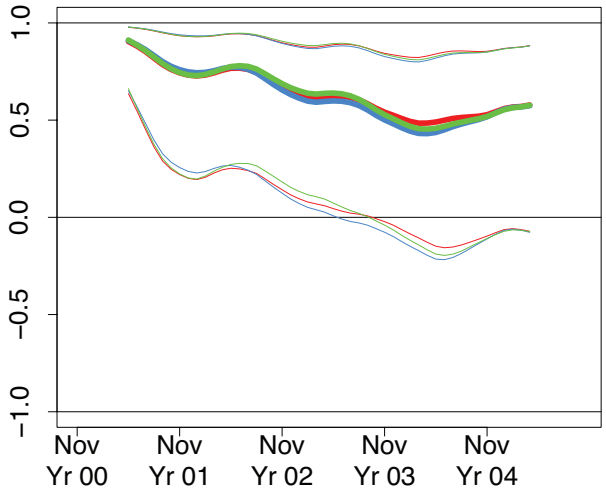
North Atlantic SST



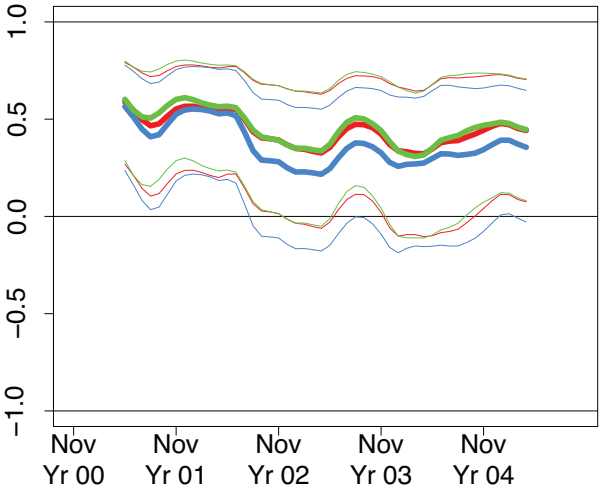
North Pacific SST



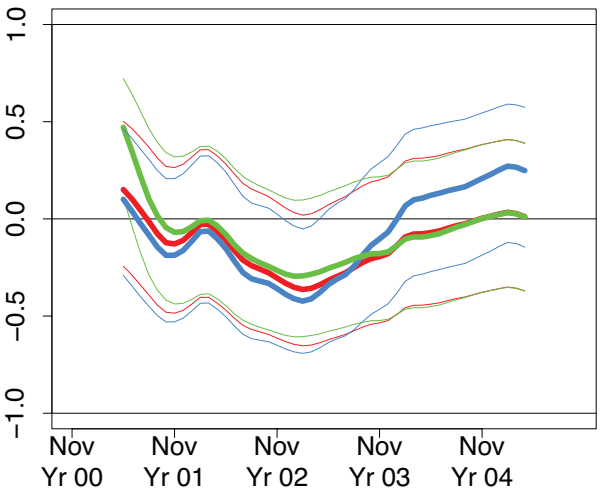
SST in tropics = SST_{trp}



South Atlantic SST

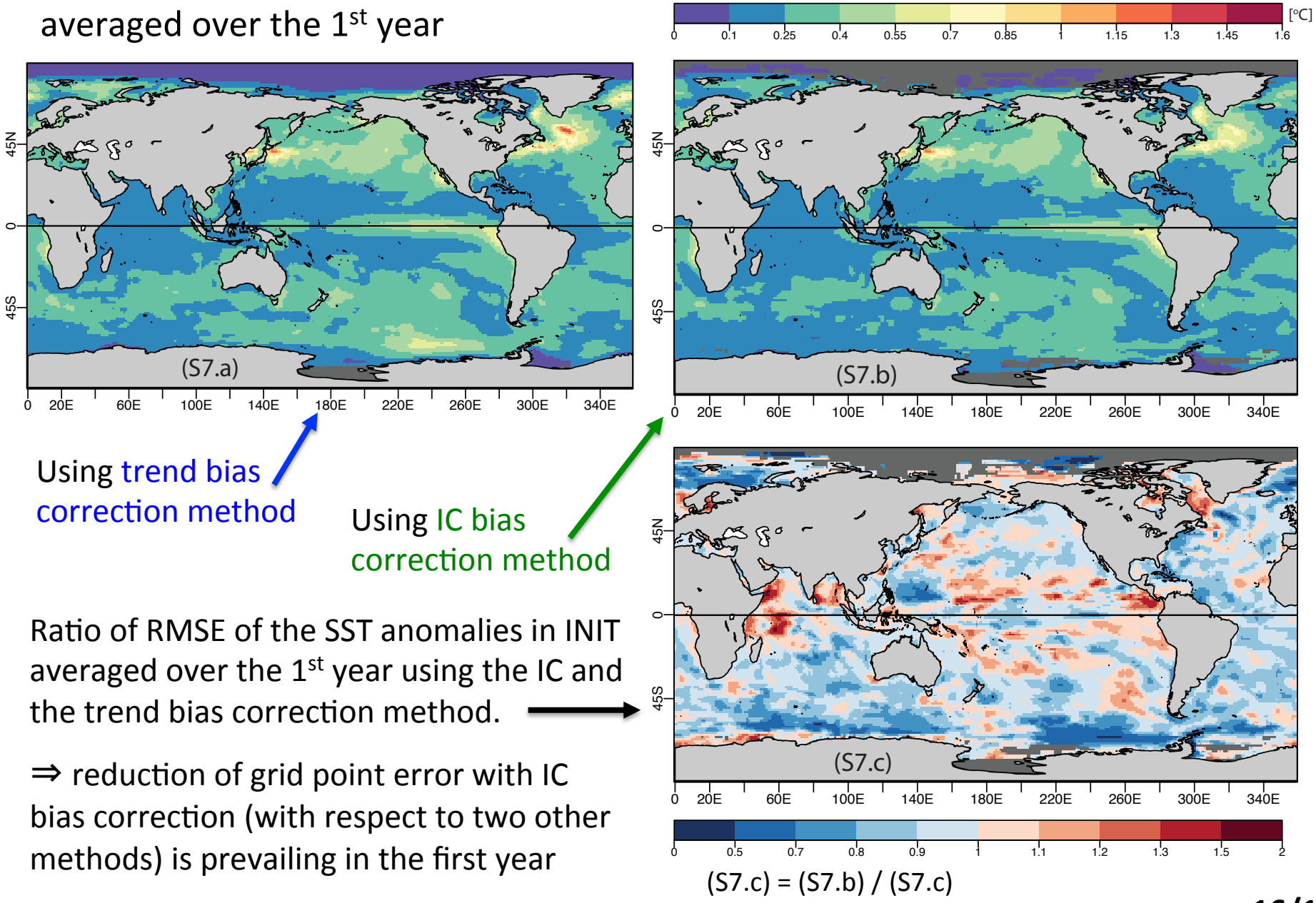


Southern Ocean SST



→ IC bias correction method improves or yields ACC comparable with two established methods

RMSE(x,y) of SST anomalies in INIT averaged over the 1st year



Using trend bias correction method

Using IC bias correction method

Ratio of RMSE of the SST anomalies in INIT averaged over the 1st year using the IC and the trend bias correction method.

⇒ reduction of grid point error with IC bias correction (with respect to two other methods) is prevailing in the first year

(S7.c) = (S7.b) / (S7.c)

● Summary and Conclusions

Proposed IC bias correction method for post-processing adjustment of climate forecasts takes into account the dependence of the prediction drift on the observed IC through linear regression in phase space of obs

Improvements in the deterministic forecast skill of ensemble mean after using IC bias correction, with respect to the two established methods, are shown from the first two seasons for some large-scale SST indices and up to 5 years for the NH sea ice extent

→ on seasonal time scale these improvements are statistically significant in the first 3 or 4 months for several examined climate indices

Instantaneous IC at the beginning of a month are too noisy for the application of IC bias correction method in climate forecasts on monthly and longer time scales

→ we use monthly mean obs in the first forecast month as a smoothed proxy

IC bias correction method has a strong sensitivity to the quality of obs

→ extending the hindcast archive deeper into the past may not benefit the prediction skill, but with a shorter verification period we could increase the uncertainty

- **Future directions**

Apply IC bias correction method to wider spectrum of large-scale climate indices and variables at grid-point resolution in different forecasting systems to further analyze its capability and limitation

Adapt IC bias correction method for use with anomaly initialization

Explore different options for temporarily smoothed proxy of obs IC