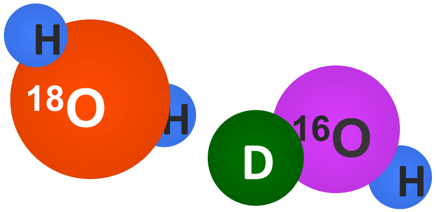


20^{th} century Isotope Reanalysis

Reproduction of isotopic time series in corals, tree-rings, and tropical ice cores

Kei Yoshimura (AORI, U-Tokyo)

1. An **<u>economic way</u>** to dynamically downscale an ensemble mean field
2. First **<u>direct</u>** comparisons with hisotrical isotopic proxy data

Stable Isotope Information: known as "Time capsule of climate"

- Much longer records than man-made observation
  - Oceanic sediment $\delta^{18}O$ (millions yBP)
  - Icesheet cores $\delta^{18}O$ ▪ δD (~800 kyBP)
  - Icecap cores $\delta^{18}O$ ▪ δD (~20 kyBP)
  - Speleothem $\delta^{18}O$ (~2000 yBP)
  - Treering $\delta^{18}O$ (~1000 yBP)
  - Coral $\delta^{18}O$ (~400 yBP)

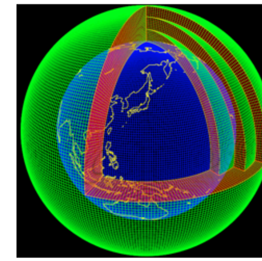
Still some difficulties in interpretation

NOAA: http://www.ncdc.noaa.gov/paleo/

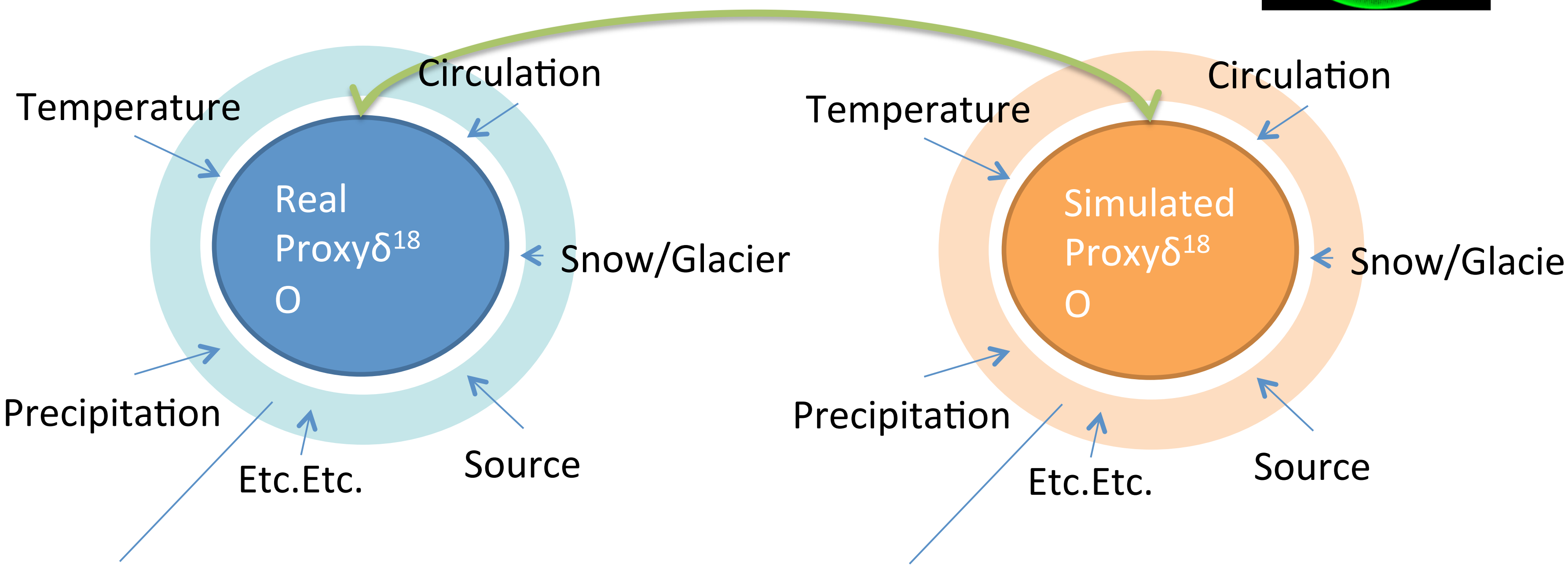
Forward Proxy Modeling Approach

Real World

Model World



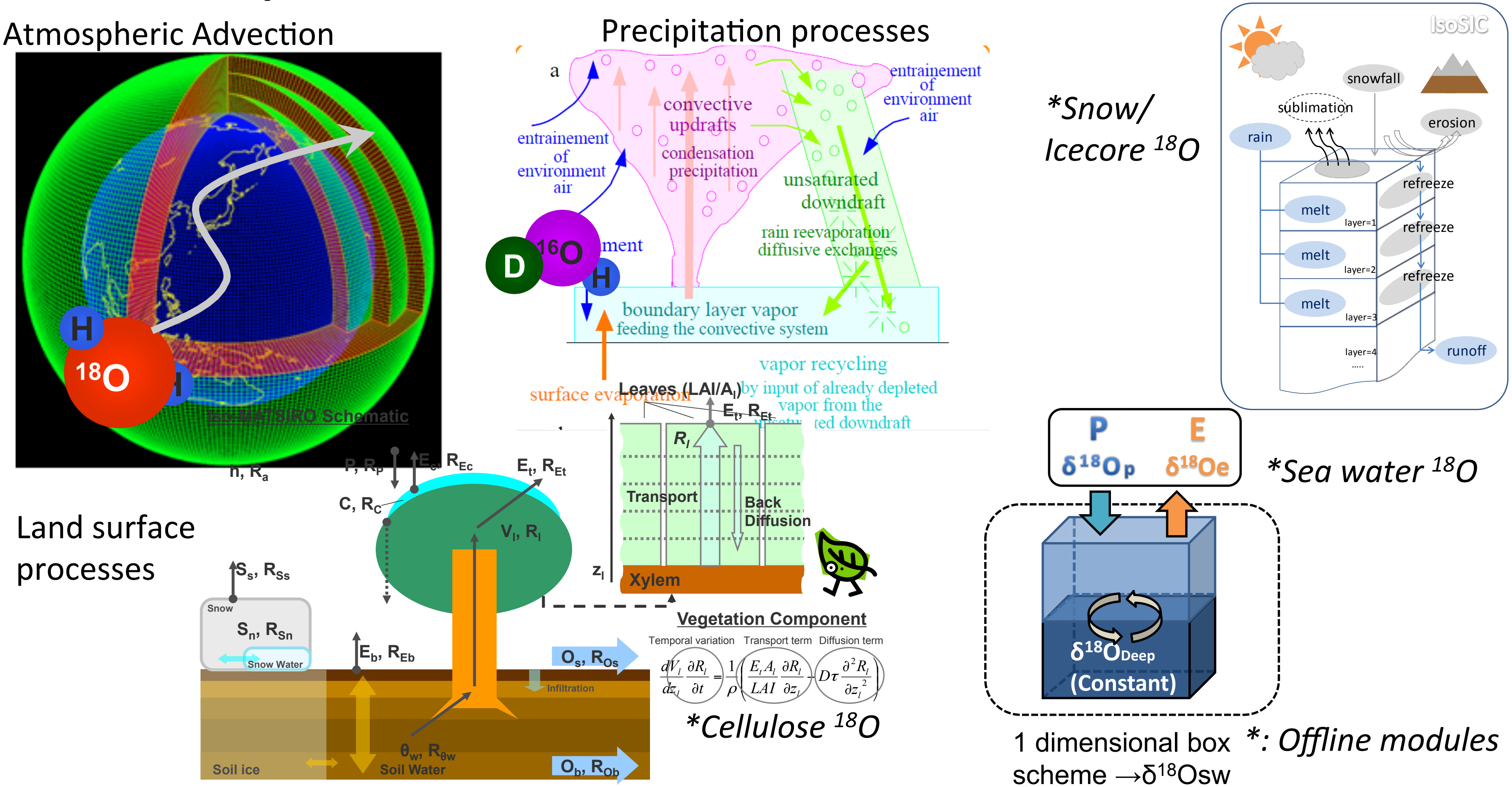
Evaluate the reliability of the Forward model.



The impact from each component is **not fully quantifiable**.

The impact from each component is **explicitly quantifiable**.

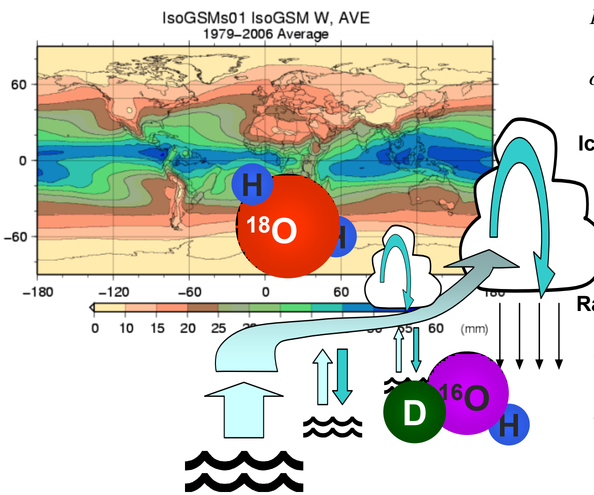
Forward modeling: Isotope-GCM/RCM and Offline Modules



$$\frac{dV_l}{dz_l}\frac{\partial R_l}{\partial t}=\frac{1}{\rho}\left(\frac{E_t A_l}{LAI}\frac{\partial R_l}{\partial z_l}\right)\left(D\tau\frac{\partial^2 R_l}{\partial z_l^2}\right)$$

- Incorporate water isotopes as passive tracers in models. Whenever water phase change takes place, isotopic water (HDO, $H_2^{18}O$) behave differently to ordinary water ($H_2^{16}O$).

Spectral Nudging:
Poor man's data assimilation



Surface evaporation (MJ79)

$$R_E = \alpha_{k\_mv}\frac{\alpha_e R_{sea} - hR_a}{1-h}$$

$$\alpha_{k\_mv} = \begin{cases}1-A & \cdots V<7(\mathrm{m/s})\\ 1-(B\times V+C) & \cdots V\ge 7(\mathrm{m/s})\end{cases}$$

Ice crystal formation (JM84)

$$\alpha_{eff} = \alpha_{k\_jm}\alpha_e$$

$$\alpha_{k\_jm} = \frac{S}{\alpha_e (D/D')(S-1)+1}$$

$$S = 1-0.003T \cdots T < -20^{\circ}C$$

Rain drop evaporation (S75)

$$m\frac{dR_r}{dm} = \beta(R_r - \gamma R_v)$$

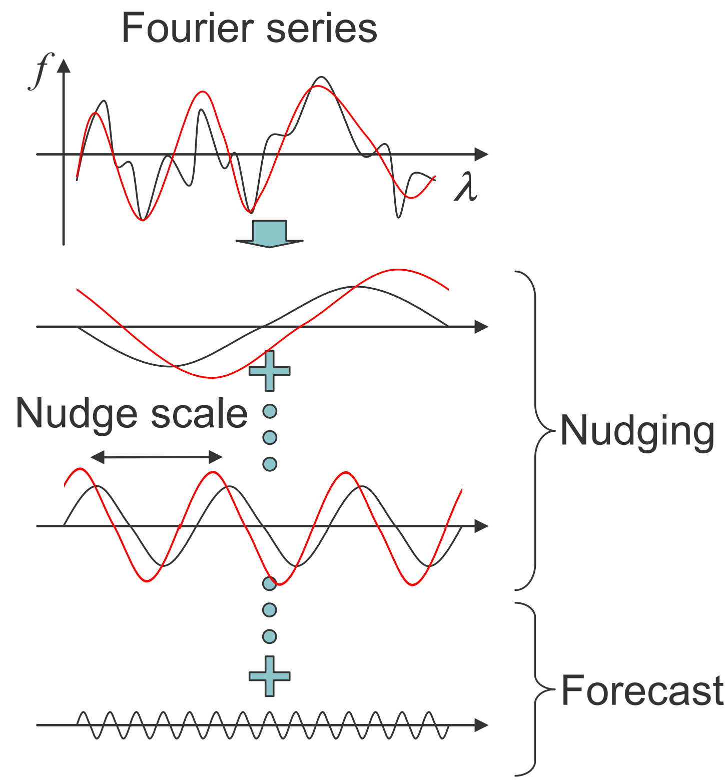
$$\beta = \frac{1-\mu}{\mu},\ \gamma=\frac{\alpha_e h}{1-\mu},\ \mu = \alpha_e (D/D')^n (1-h)$$

$$R_r = \varepsilon\left[(R_{r0}-\gamma R_{v0})(m/m_0)^\beta + \gamma R_{v0}\right] + (1-\varepsilon)R_{r0}$$

$$R_v = \left[q_0' + (m_0' - mR_r)\right]/q$$

IsoGSM

SIO/UT Isotopic Global Spectral Model

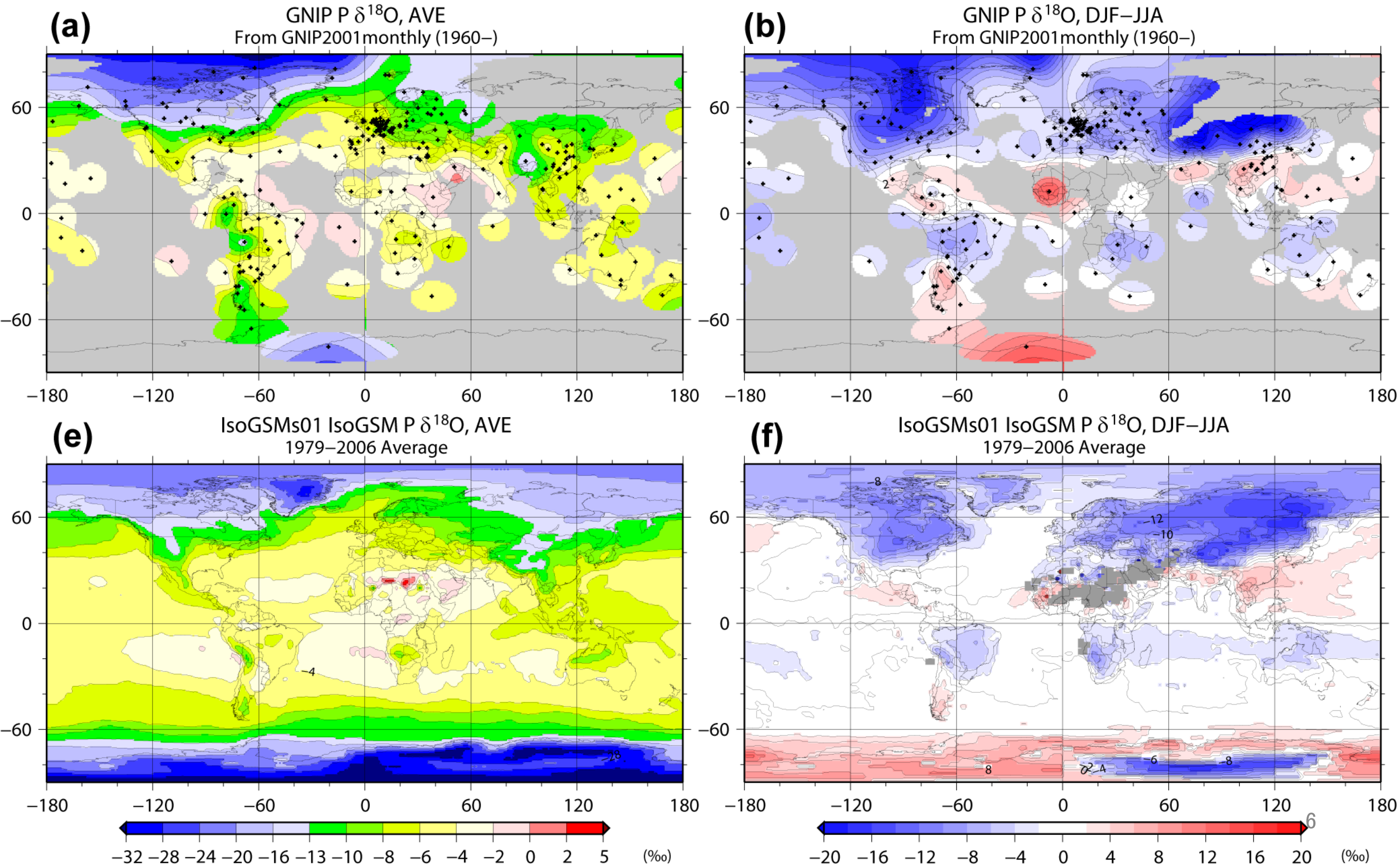


Use large scale (>1000km) winds to constrain dynamical field, so that the isotopic field is also constrained and reproduced in daily to inter-annual time scales.

Yoshimura and Kanamitsu, 2008; Yoshimura et al., 2008

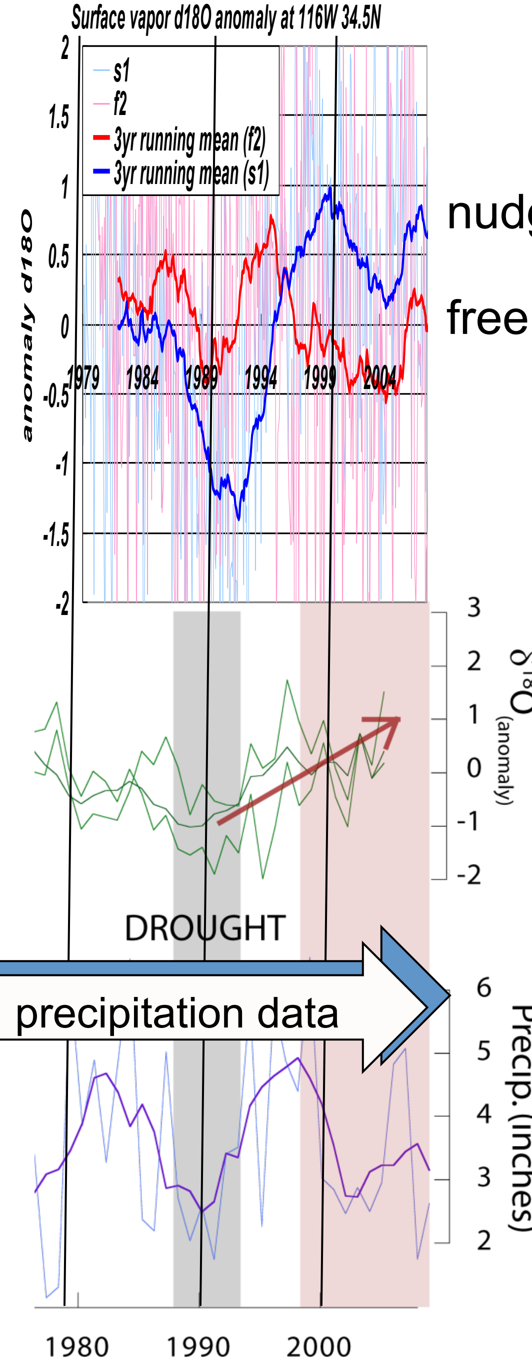
Yoshimura et al., 2008

Validation: Comparison in $\delta^{18}O$ in Precip



Comparisons with Proxies

Extension of simulation needed!!



nudged

free

δ18O Cellulos
(White Mts.)

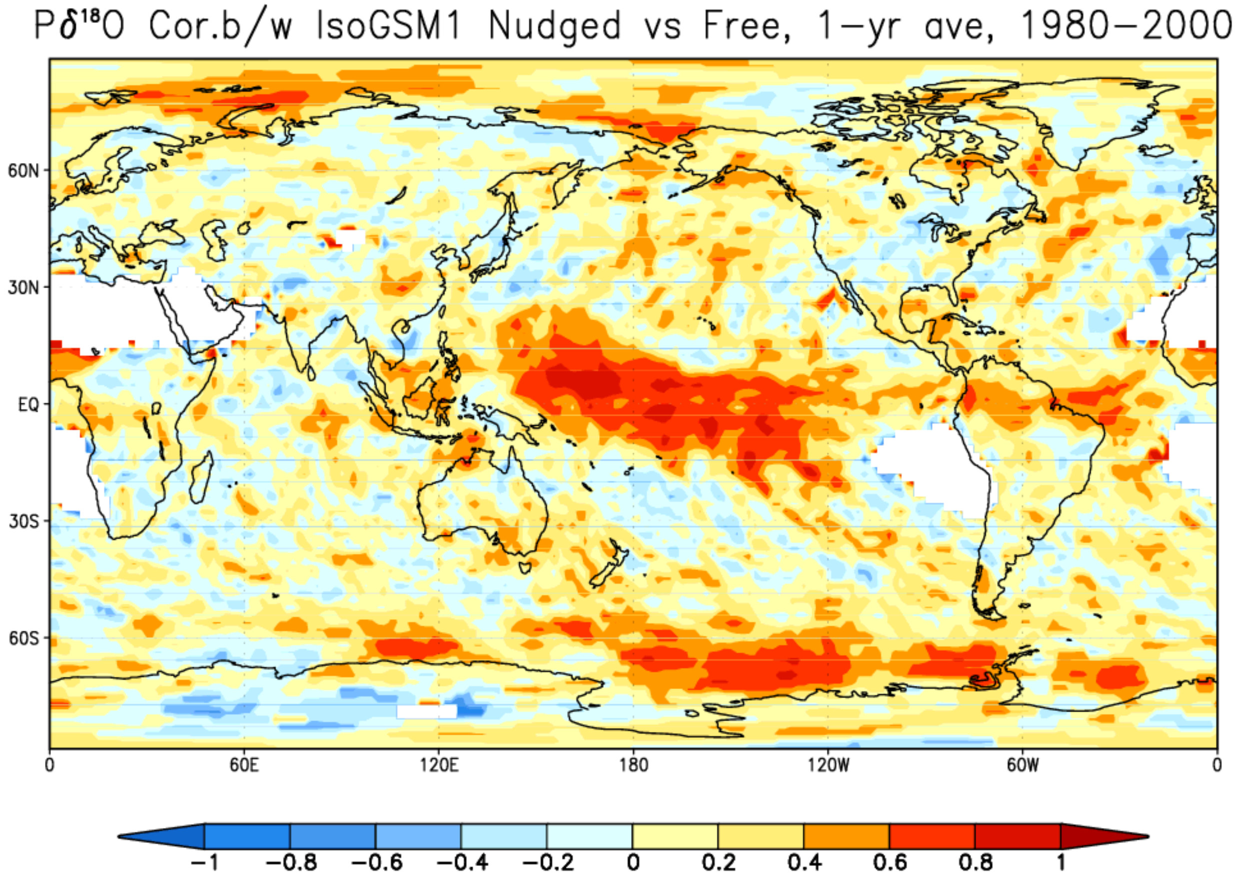
other proxy data (treerings/corals/etc)

precipitation data

Winter Pre(
(SE Califorr

Stott et al., prep
Kojima et al., submitted

Correlation b/w Nudged vs AMIP

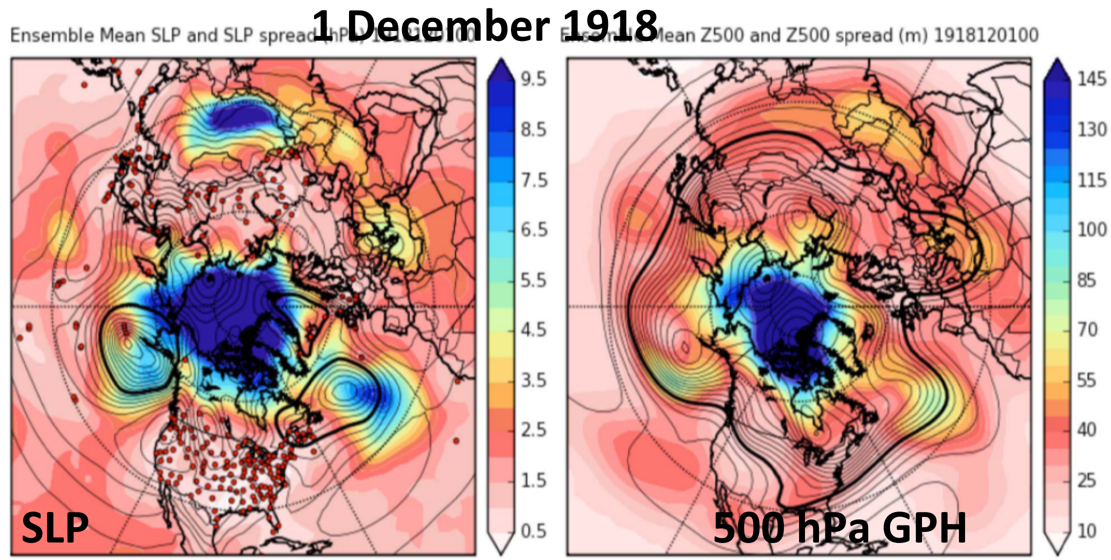


- Interannual variability in precipitation $\delta^{18}O$ is NOT constrained by SST except tropic regions.
  ➔ Atmospheric modes play independent roles for $\delta^{18}O$

20th century Reanalysis

(Compo et al., 2011)

- Using only **surface pressure data** historically recorded since 1870’s
- Ensemble Kalman Filter for data assimilation (56 member)
- T62L28 GFS with NOAH LSM



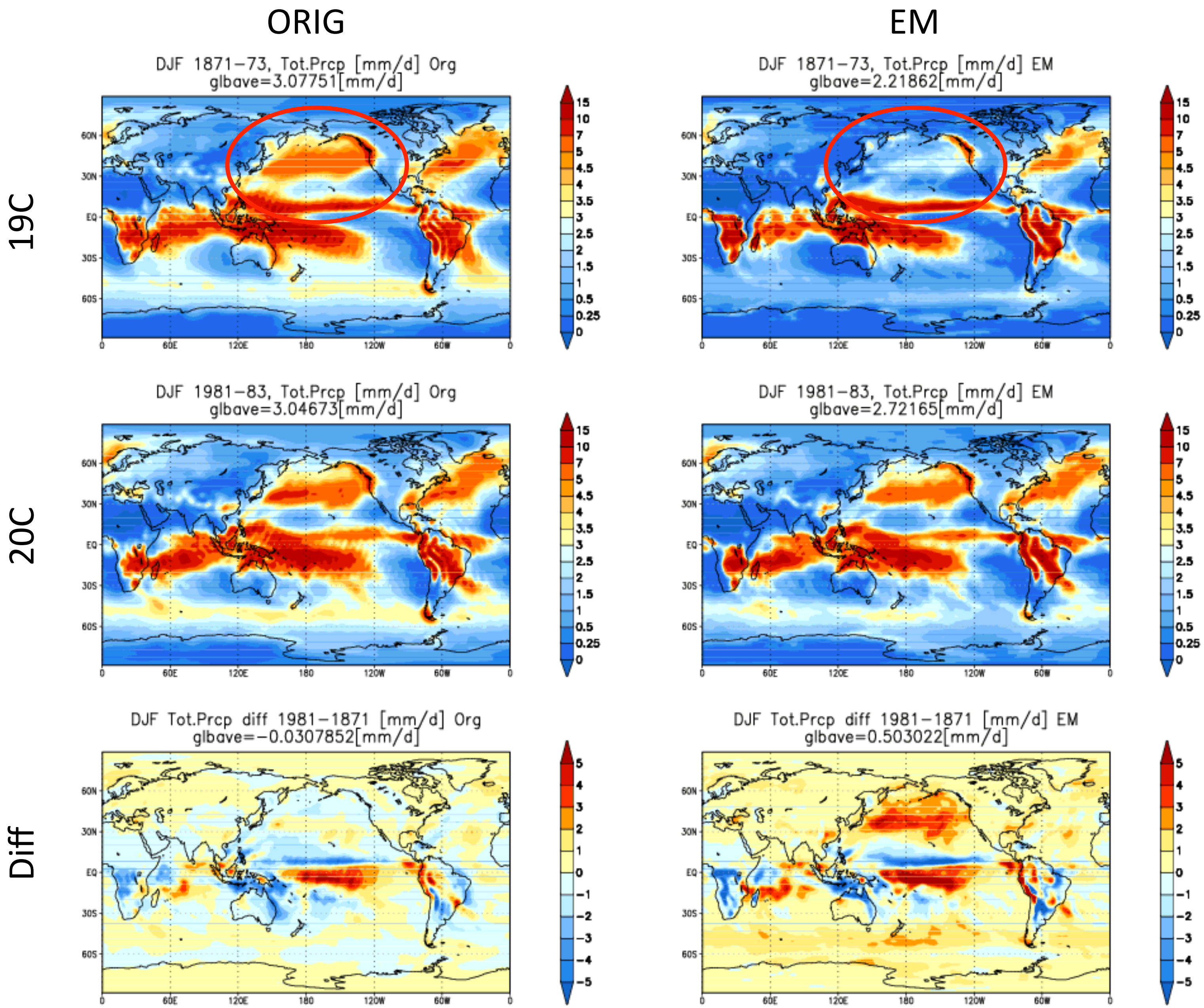
Whitaker et al. (2009)

- Reanalysis skill is comparable to current Day-3 forecast skill (Whitaker et al., 2009)
- **Ensemble Mean (EM) fields** are publically available.

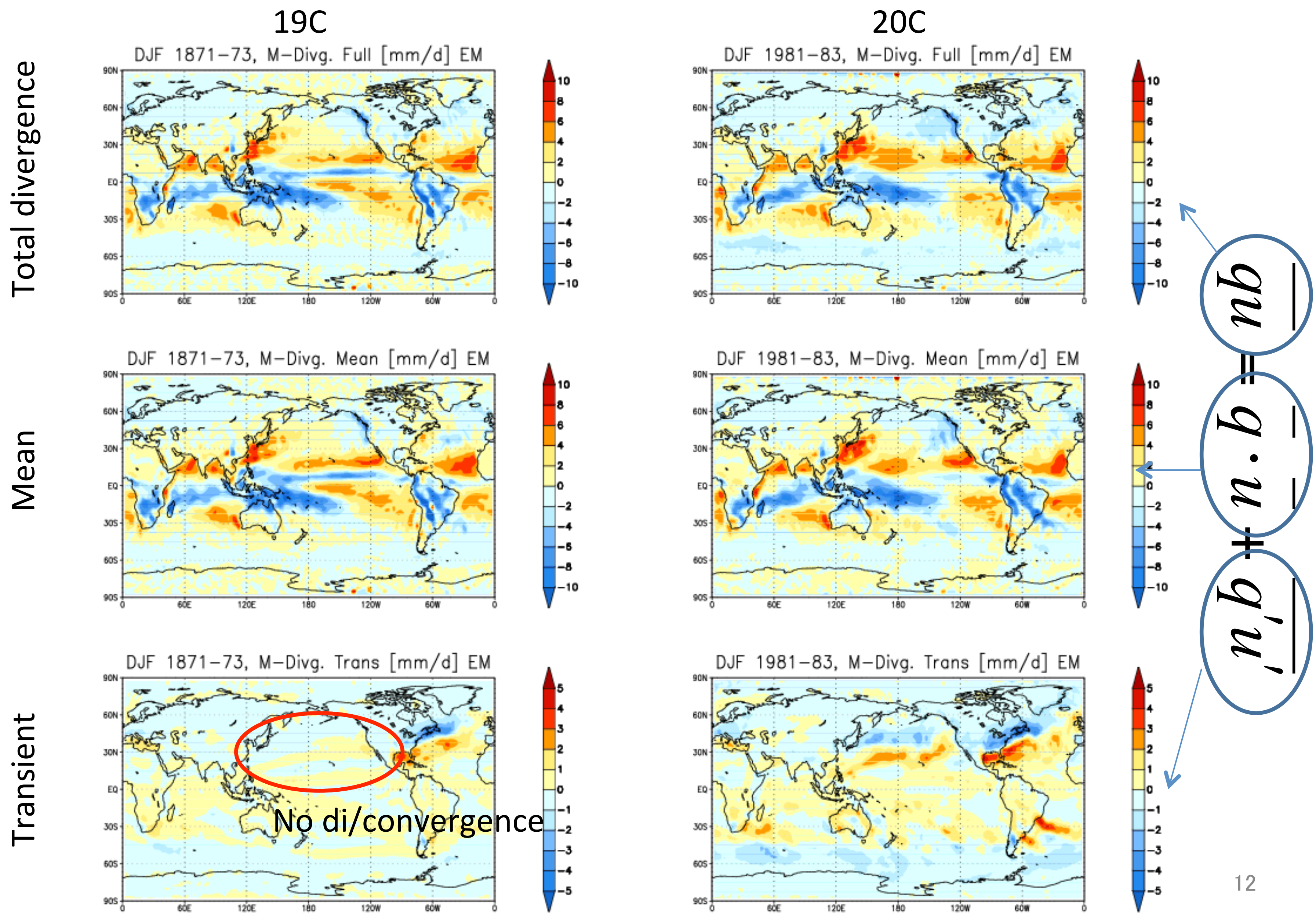
A Problem for *Poor man's Data Assim.*

Are the ***ensemble mean fields*** appropriate as lateral boundary conditions for spectral nudging?

NO!!


ORIG
EM
19C
20C
Diff
DJF 1871–73, Tot.Prcp [mm/d] Org
glbave=3.07751[mm/d]
DJF 1871–73, Tot.Prcp [mm/d] EM
glbave=2.21862[mm/d]
DJF 1981–83, Tot.Prcp [mm/d] Org
glbave=3.04673[mm/d]
DJF 1981–83, Tot.Prcp [mm/d] EM
glbave=2.72165[mm/d]
DJF Tot.Prcp diff 1981–1871 [mm/d] Org
glbave=–0.0307852[mm/d]
DJF Tot.Prcp diff 1981–1871 [mm/d] EM
glbave=0.503022[mm/d]

Transient component of moisture divergence is smoothed out in **EM**

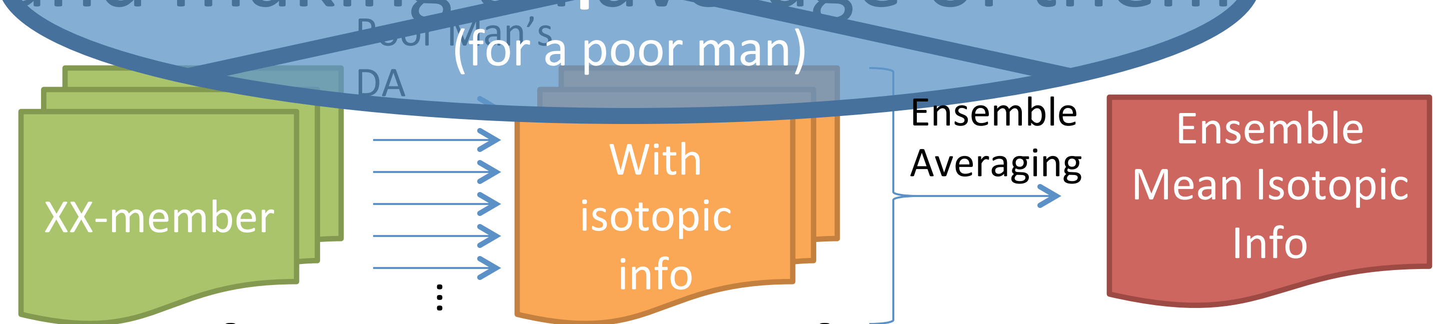


Straight forward remedy:

Downscale a single member many times and making an average of them

Too Expensive!!

(for a poor man)

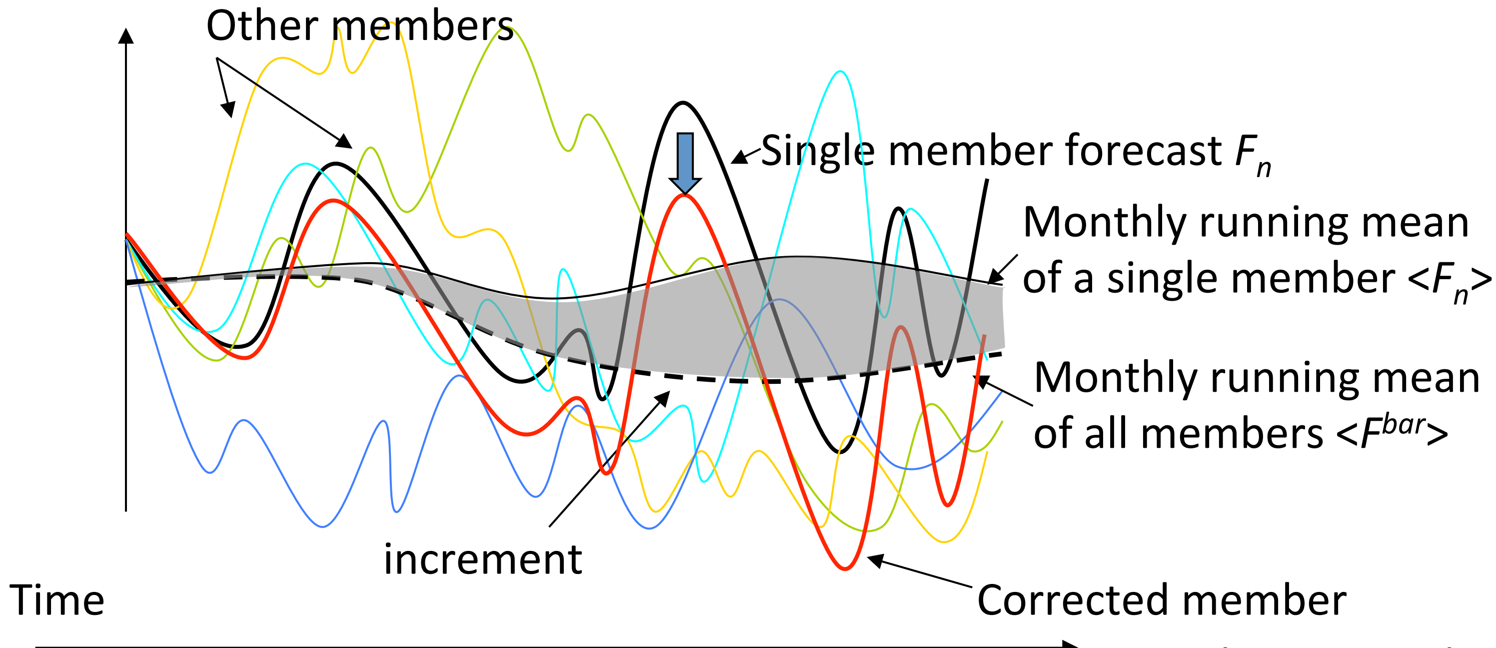


Is there any other way to reduce computation?

Modification of single member by ensemble mean increment (MS method)

$$F_n^{new} = F_n + \langle \overline{F} \rangle - \langle F_n \rangle$$

- where F is full field of physical variable, n is an ensemble member, bar indicates ensemble mean, and <> indicates running mean (e.g. one-month).
- The downscaling will be performed using F_n^{new} as a lateral boundary forcing.

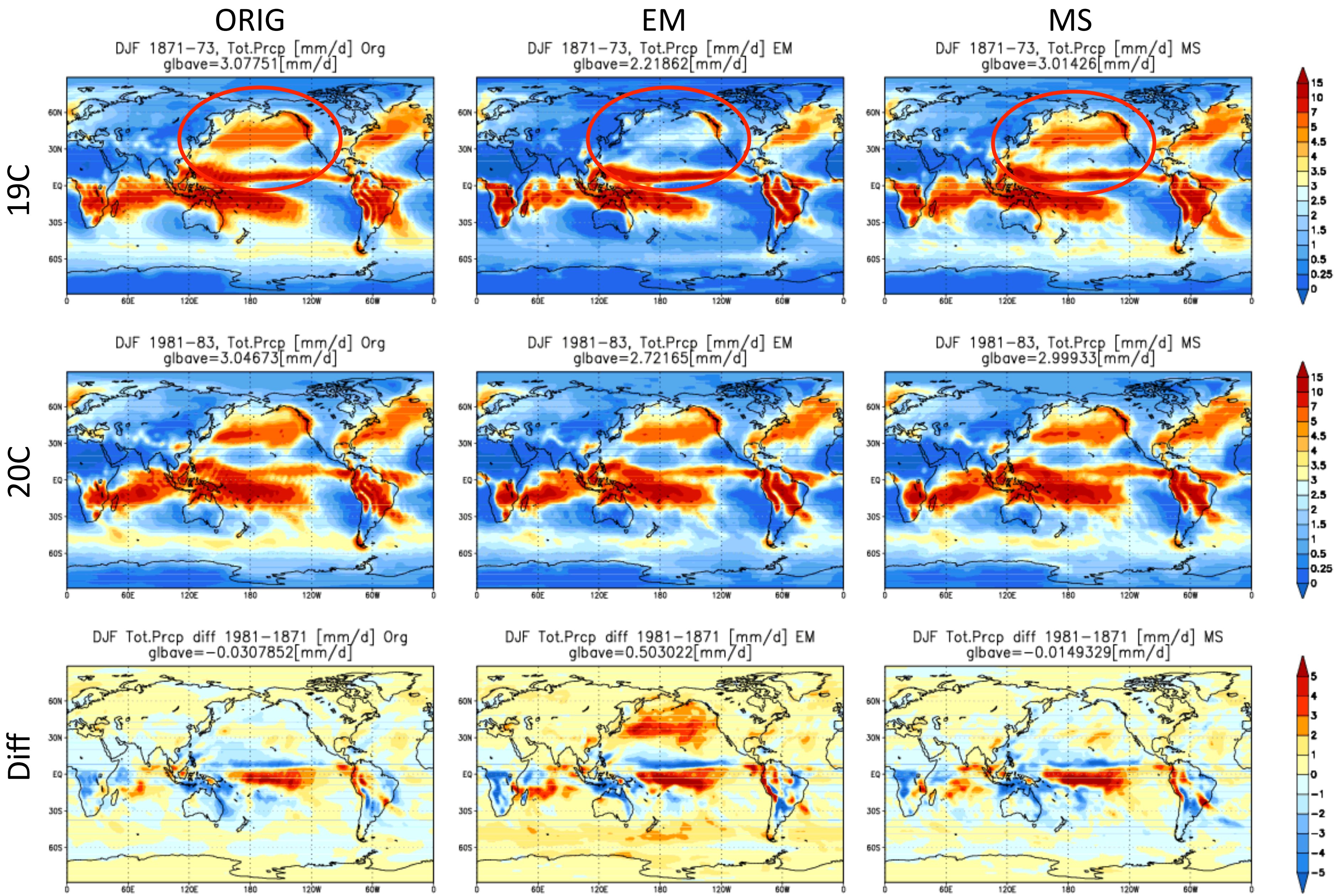


Yoshimura et al., in prep

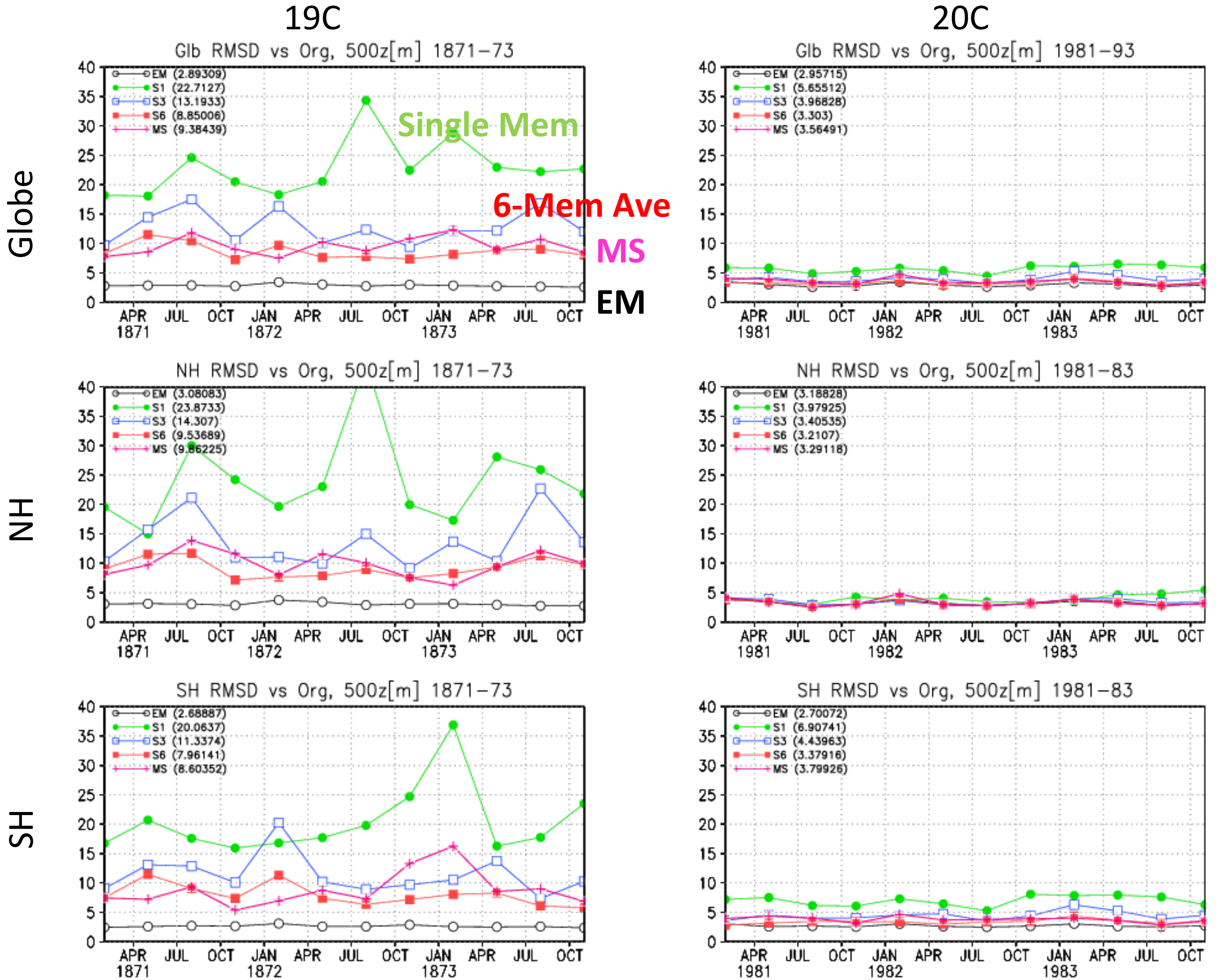
Specification of experiments

- Atmospheric Forcing: 20thC Reanalysis (Compo et al., 2011)
  - Also regarded as “truth”.
- Experiments: Different by the atmospheric forcings.
  - **EM: Ensemble mean is used.**
  - S1: Arbitrary chosen single member (run01) is used.
  - S3: Mean of the runs in which arbitrary chosen three single members (run01, run11, & run21) are used.
  - S6: Similar to S3, but 6 single members (S3 + run31, run41, & run51) are used.
  - **MS: Modified single member is used.**
- Periods:
  - 1871-2008 for EM and MS.
  - 1871-1873 and 1981-1983 for S1-S6.
- Model: IsoGSM with global spectral nudging (Yoshimura et al., 2008)

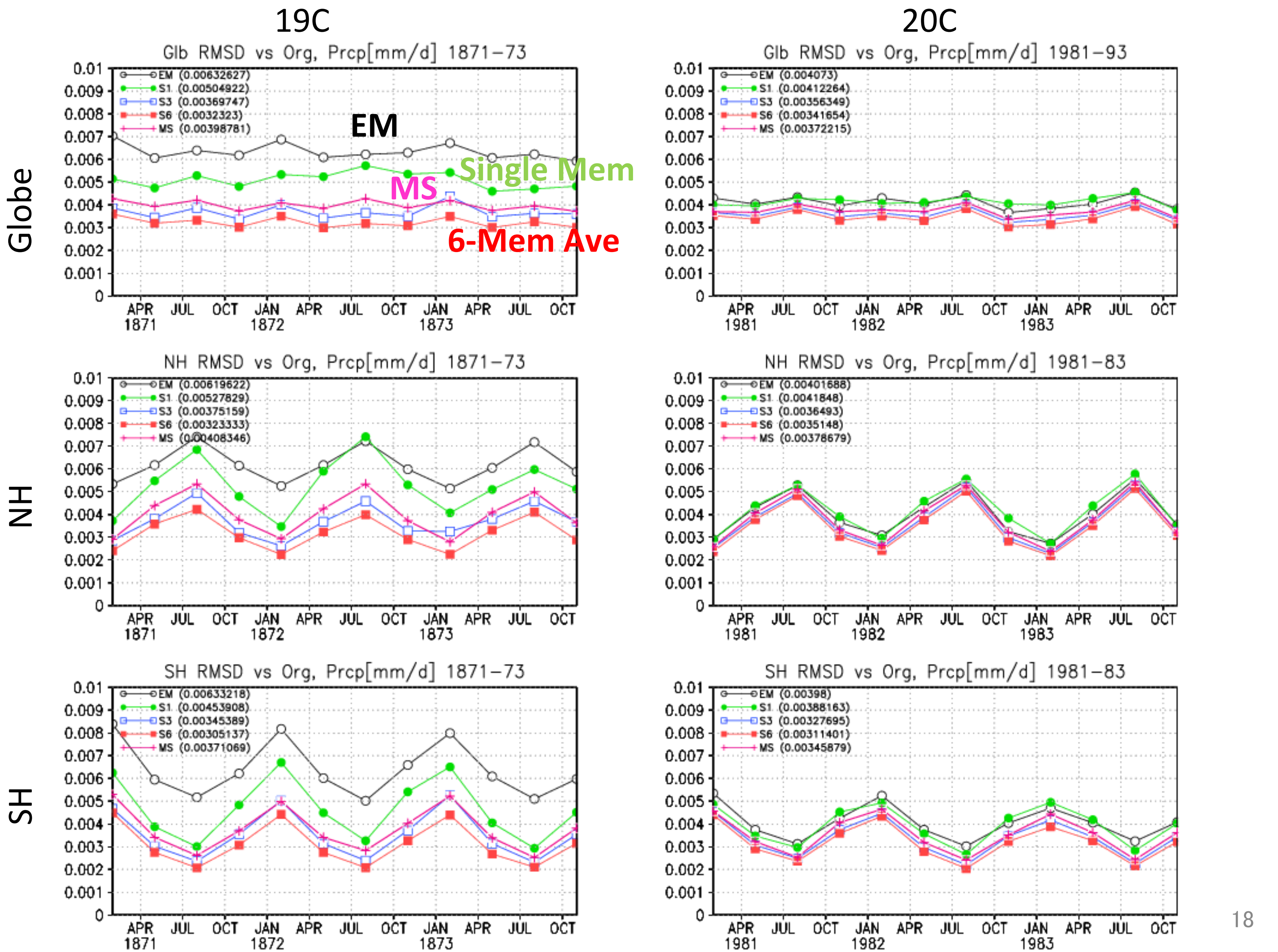
Seasonal mean precipitation with MS field



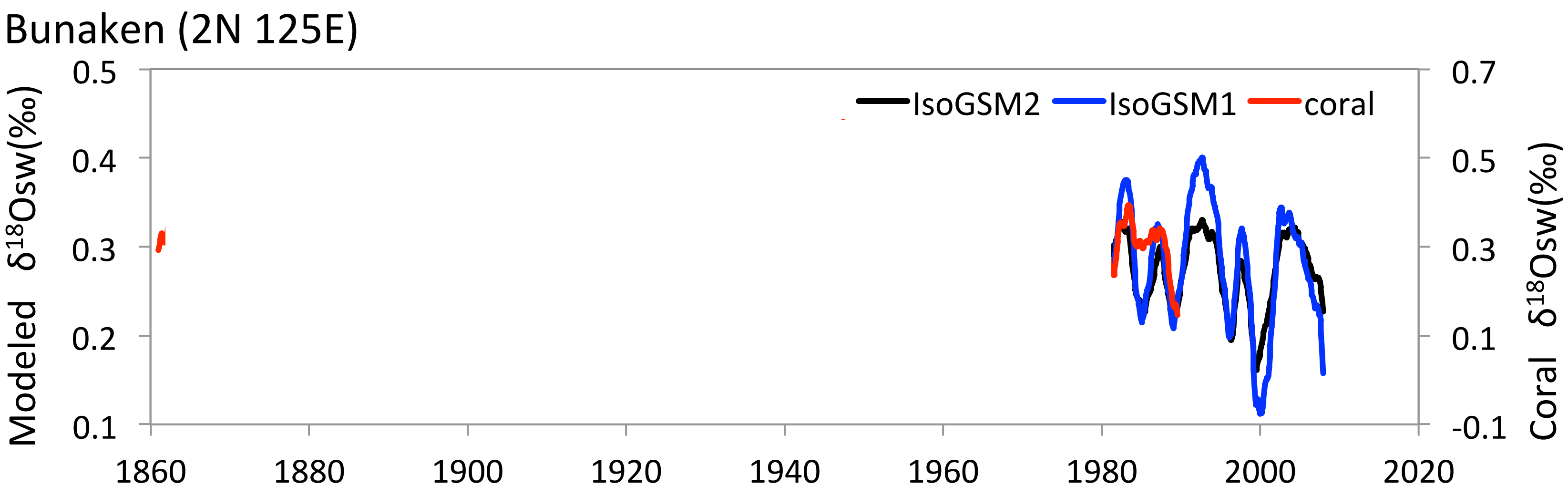
RMSD in 500Z against "truth"

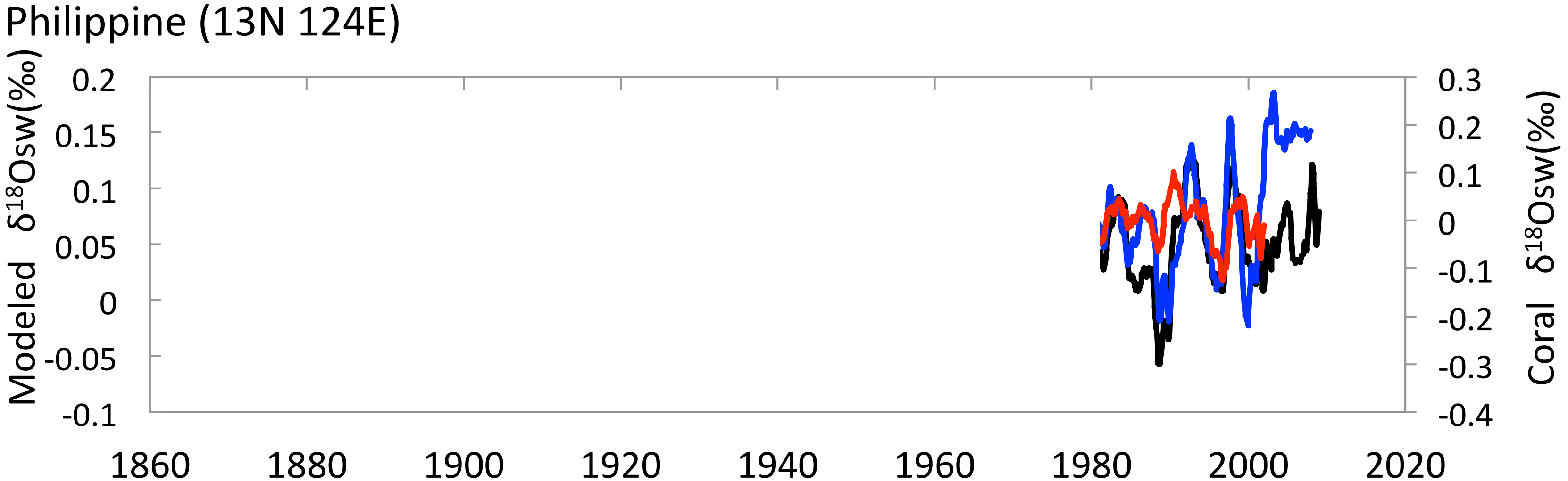


RMSD in Precipitation against "truth"



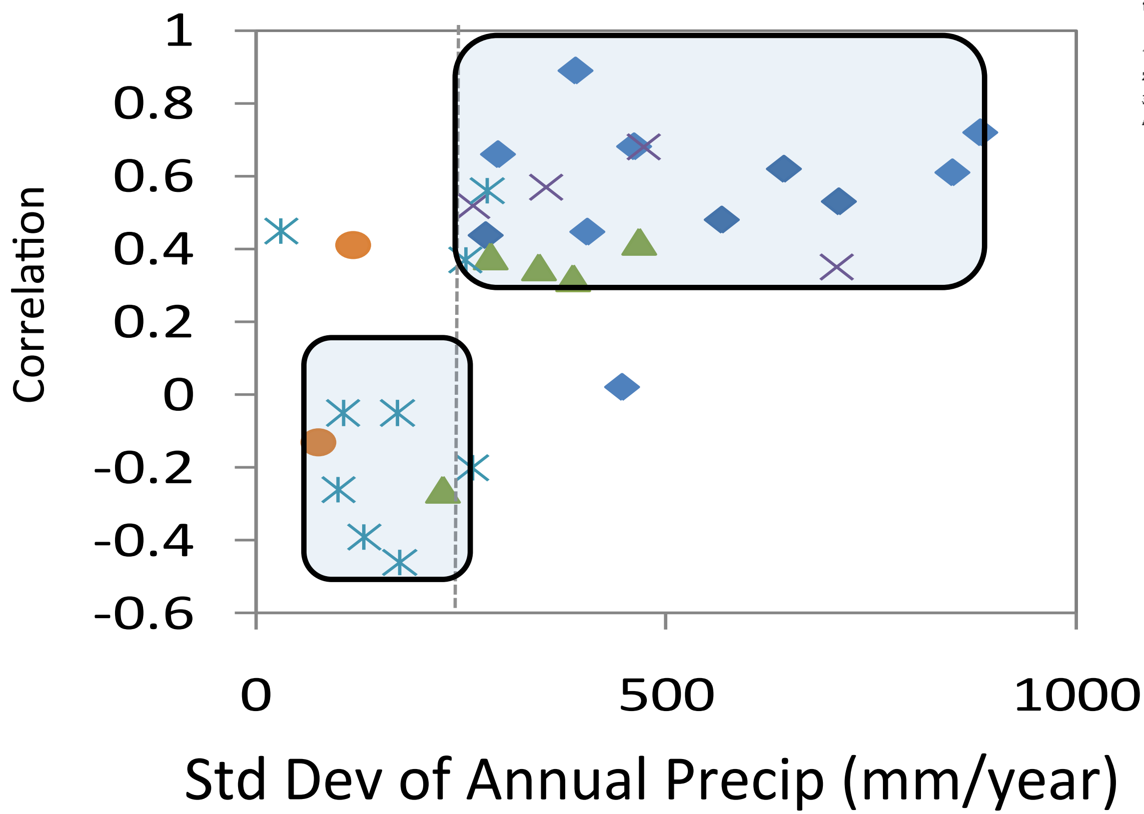
Seawater δ18O from Coral and Model

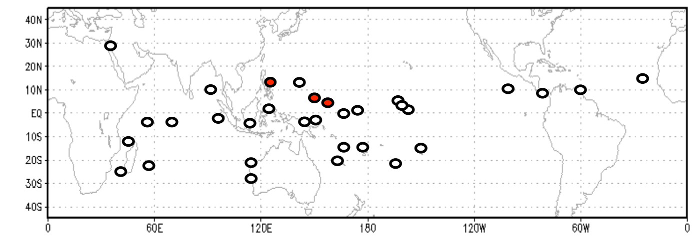


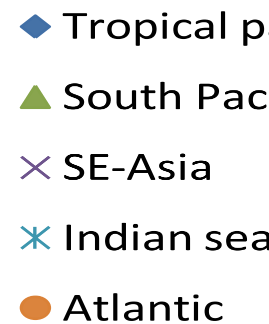


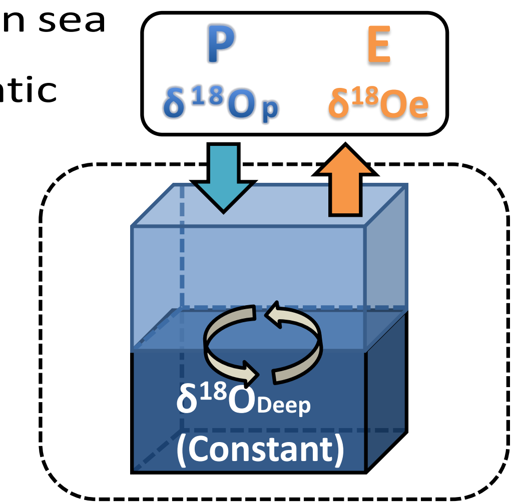
Yoshimura et al., in prep

Reproducibility of Interannual $\delta^{18}O_{sw}$ and Precip Amount









1 dimensional box scheme →δ^{18}Osw

Large Precip Variability

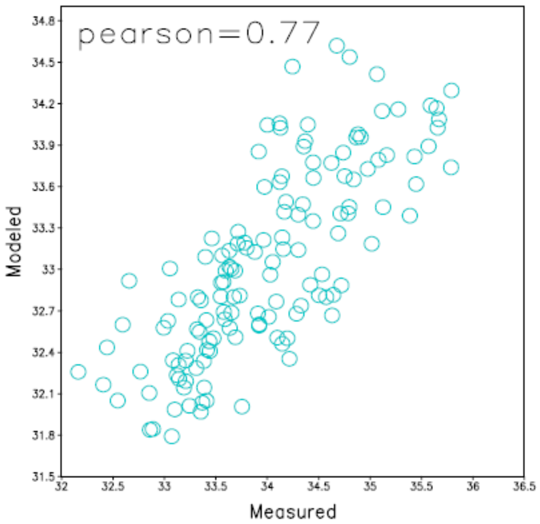
→ Local precipitation is recorded

Small Precip Variability

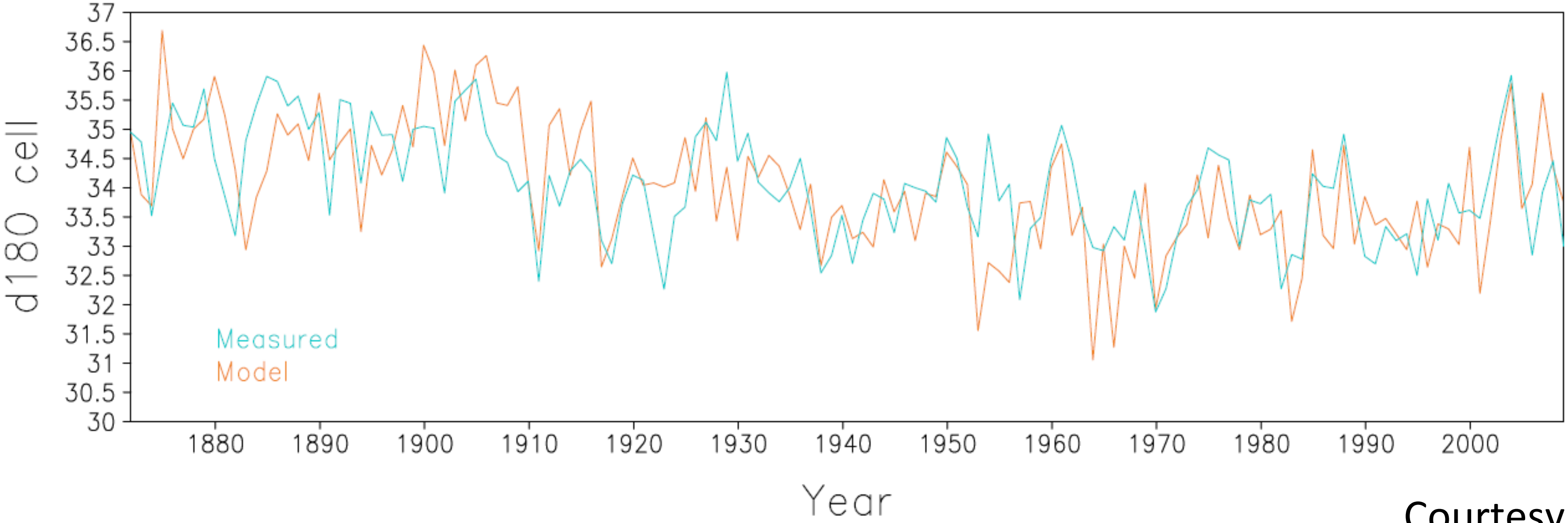
→ Other factors (current, river flow, etc) may play big roles.

Kojima et al., 2011.

Treering δ^{18}O in West US

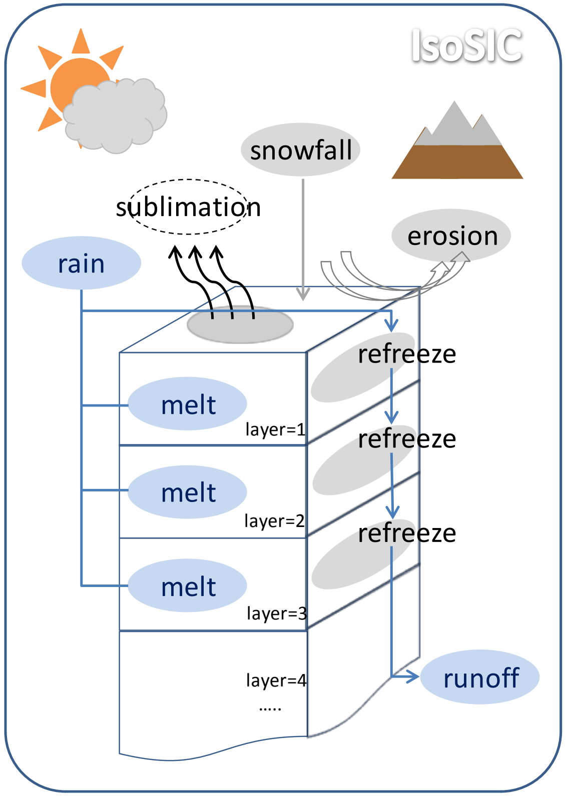


Measured values are composite of Bale 2010 and recent Stott and Rincon data. Model is based on Roden Model with met./iso inputs from Yoshimura 20c Reanalysis



Courtesy of L. Stott

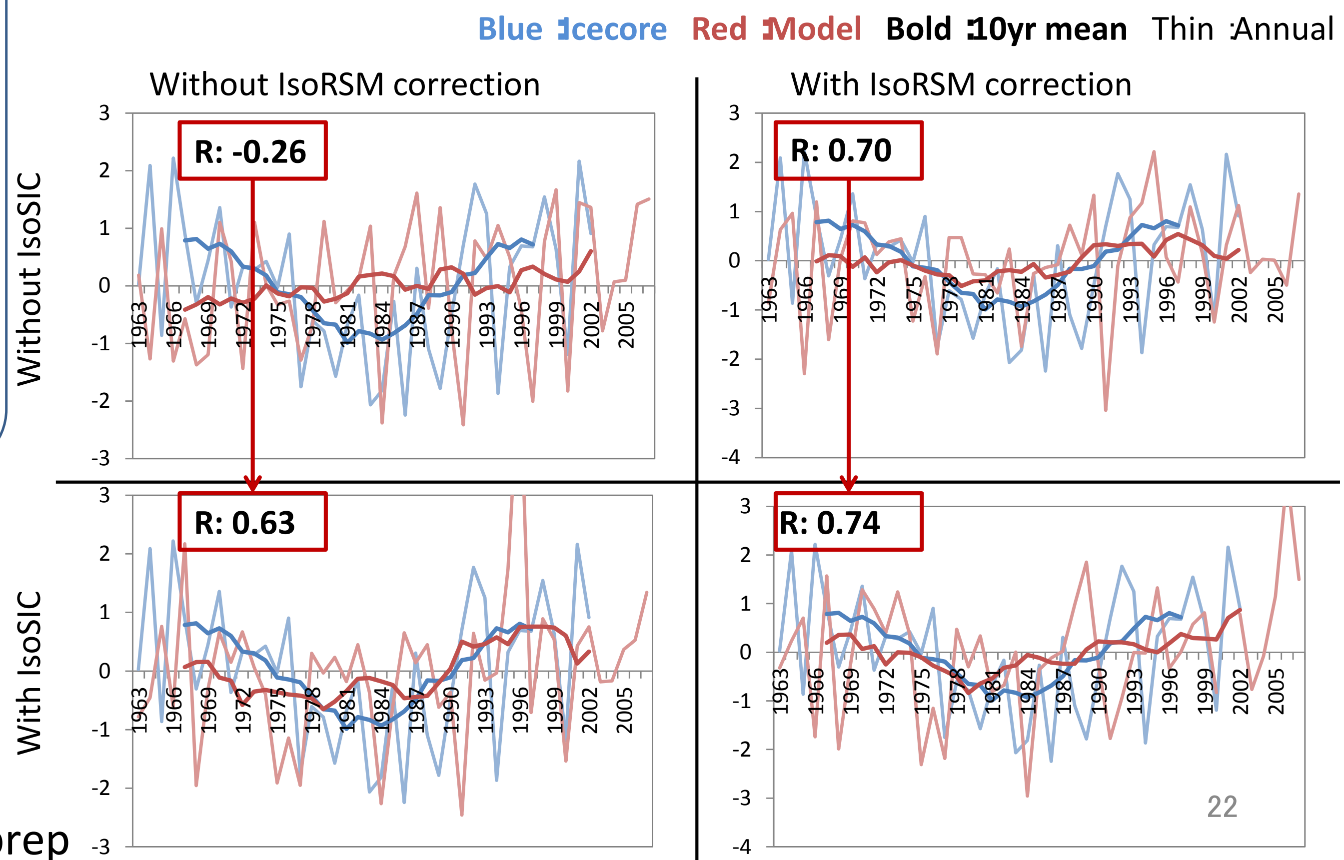
Isotope Simulator for Ice-cap Cores



To reproduce low-latitudinal icecore data, we need to consider both:

1. Complex topography
2. Detailed snow/Ice fractionation

Observation sites



Okazaki and Yoshimura, in prep

Summary

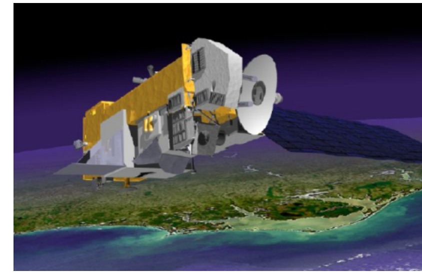
- First 20th century Quasi Reanalysis for Isotope is now available.
  - Global, 6-hourly, 180km-scale, 1871-2008.
  - Higher resolution can be provided upon request.
  - Usage from interdisciplinary communities is most welcome!
- A relatively economical way to dynamically downscale the ensemble mean fields is proposed. *Cost would be 1/6.*
- Though number is limited, comparisons with paleoclimate proxy data *show nice performance for 19th-21st centuries*.
- This effort helps to develop the "forward proxy modeling" approach to more comprehensively and more quantitatively interpret the proxy data.
- Moreover, this study may contribute for development of *the proxy-constrained (paleo) Reanalysis.*

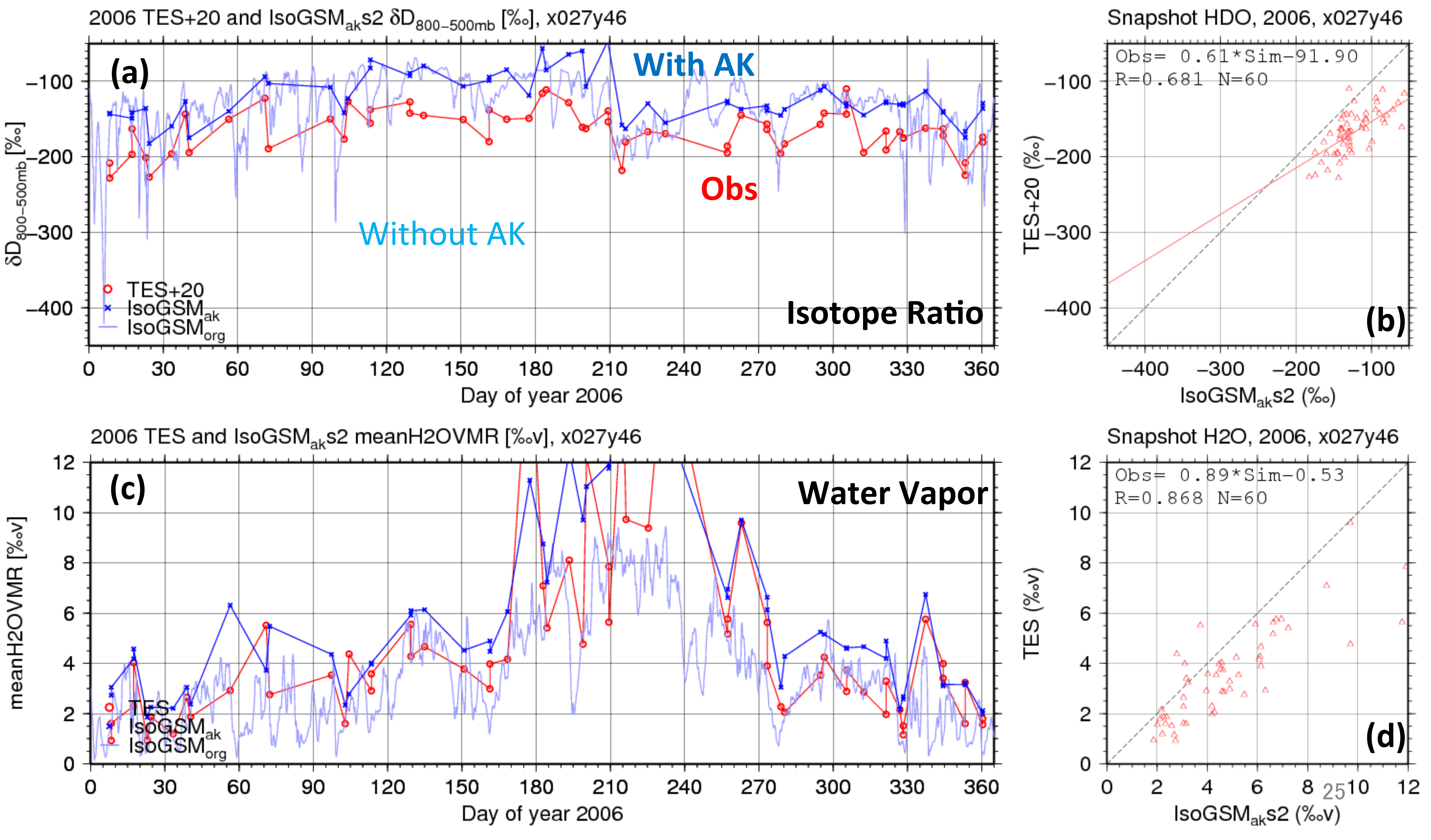
Thank you very much.

In memory of Kana
Dr. Masao Kanamitsu
（died 2011/8/17)

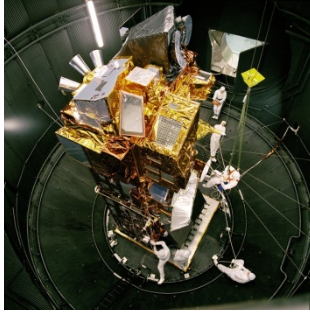
Acknowledge to:
M. Kanamitsu, G. Compo, N. Buenning,
L. Stott, M. Zhu, A. Okazaki, K. Kojima

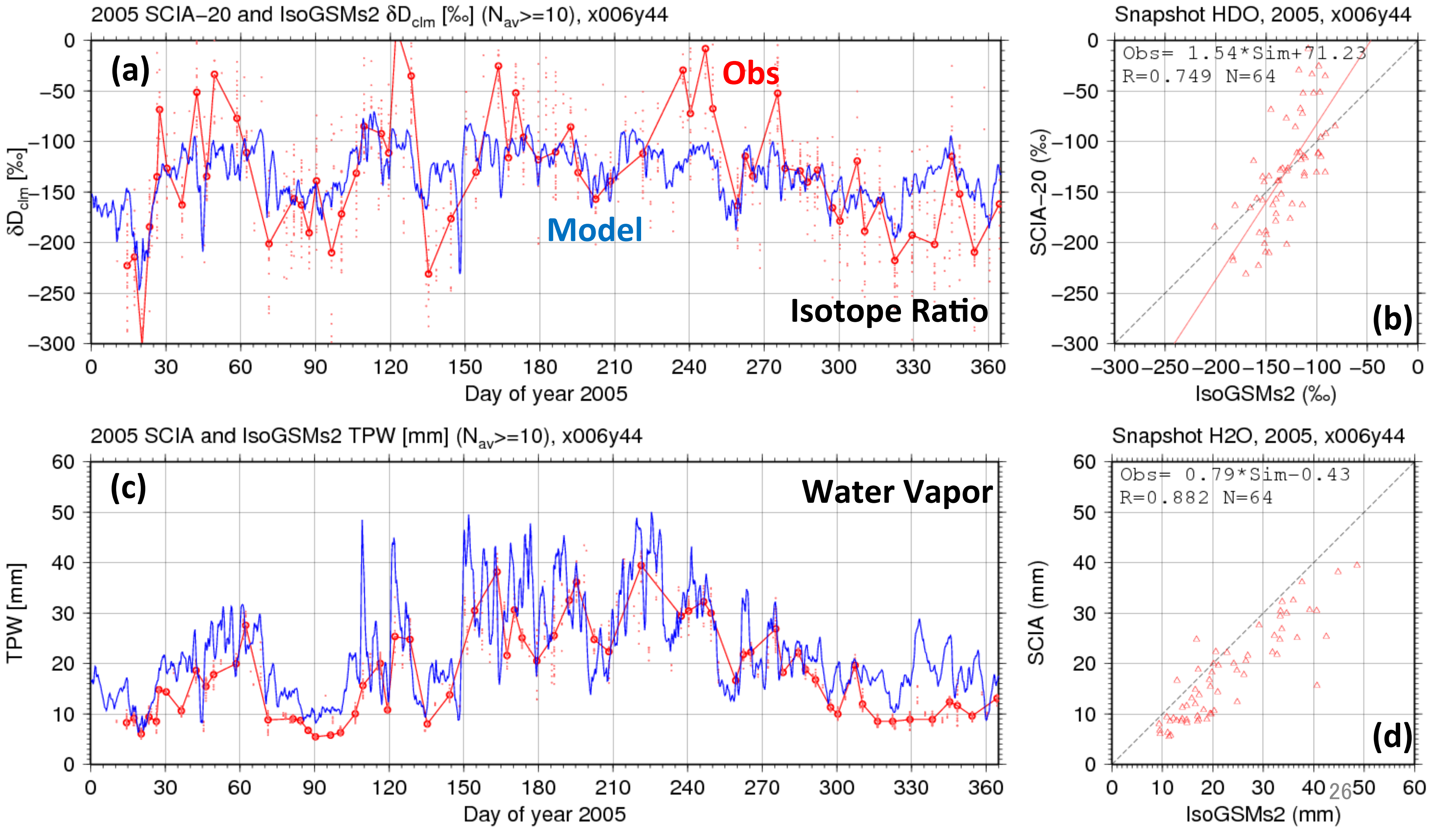
Short-term variability for TES



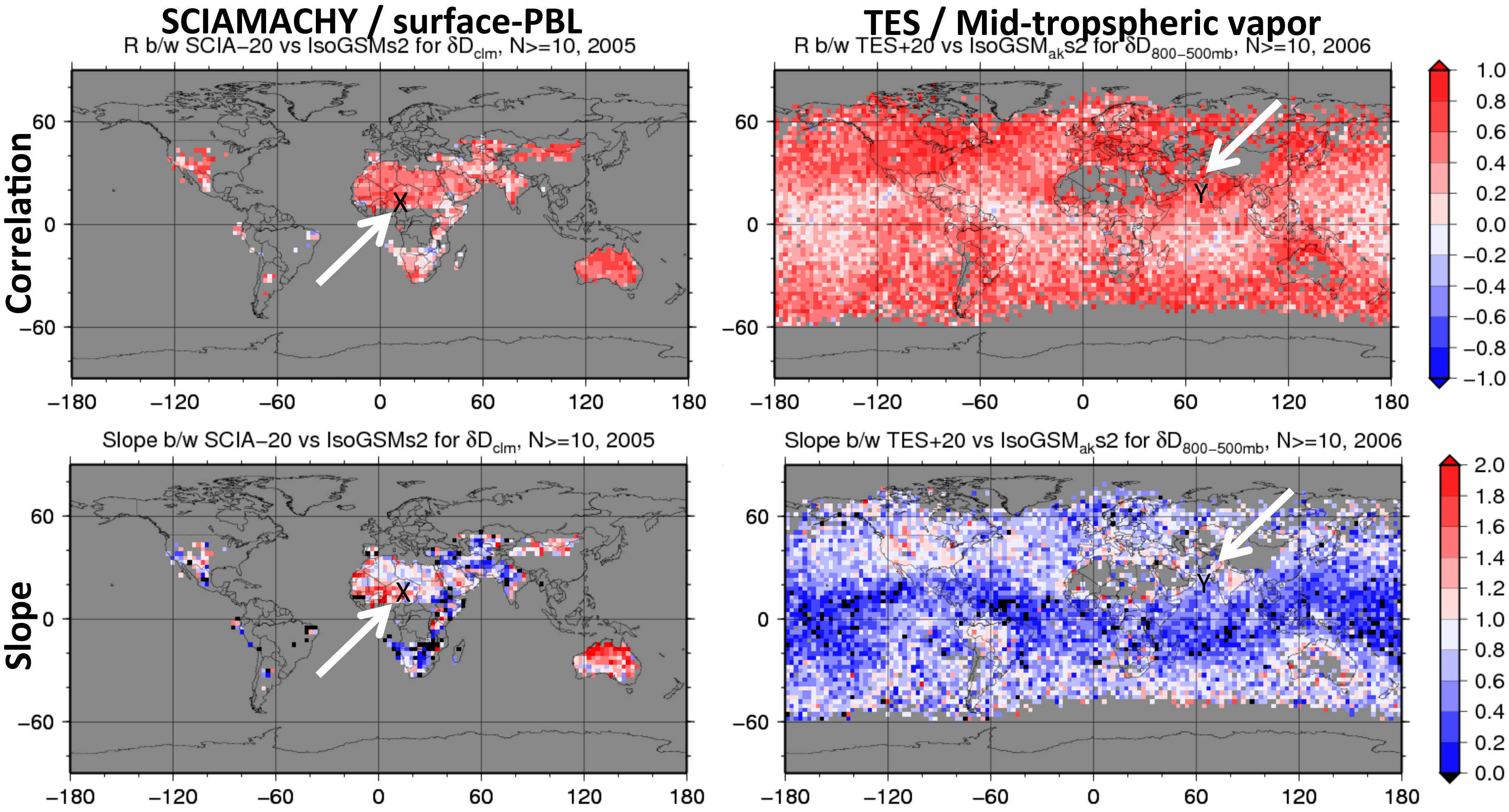


Short-term variability for SCIA





Correlation and Slope b/w RS & Model



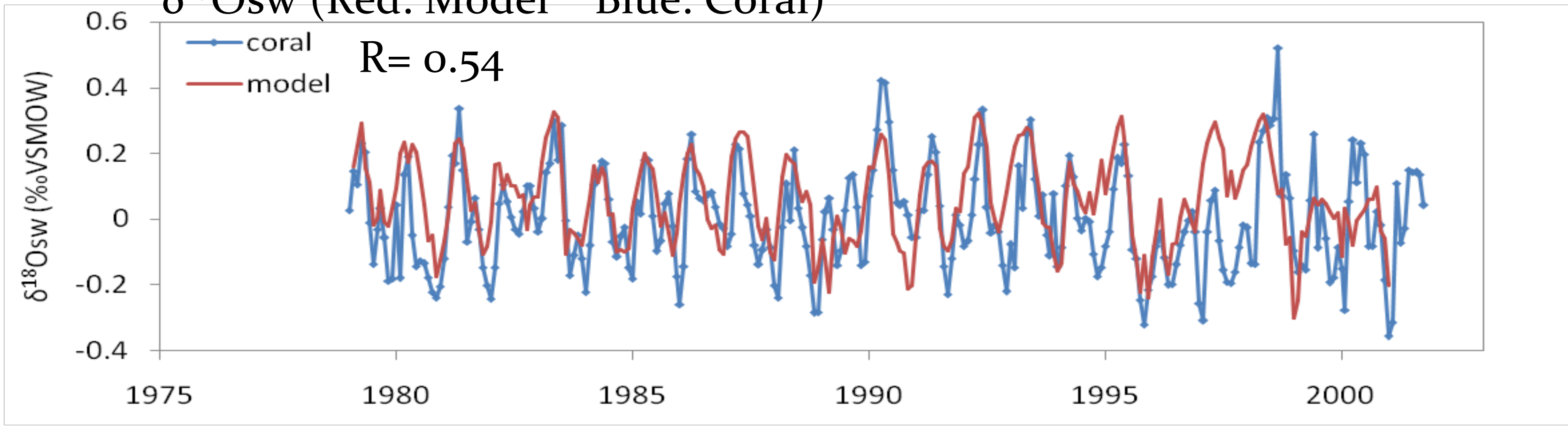
- Model's problematic vapor circulation can be corrected by data assimilation over desert lands (SCIA) and sub tropical oceans (TES).

Summary of Part 1

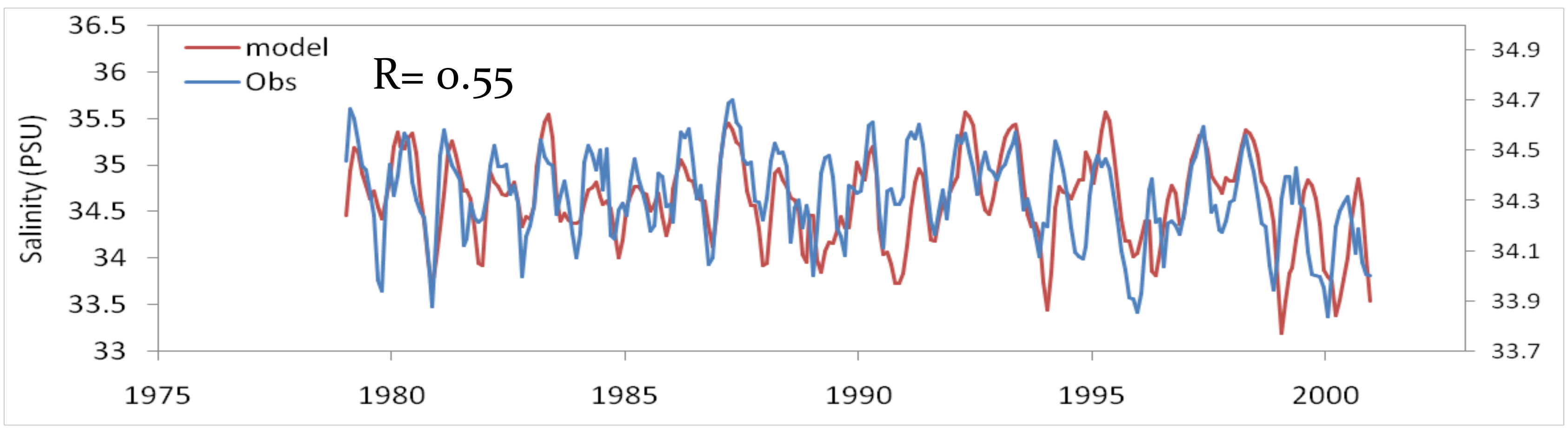
- Use of ensemble mean field as atmospheric forcings for downscaling study makes big shortcomings, particularly too small precipitation, when the spread of ensemble members is large.
- Downscaling of each single ensemble member is straightforward, but requires lots of resources and time.
- To avoid these problems, we propose a new method which modifies a single member field to have the same monthly skills as ensemble mean field (MS method) .
- Use of the MS method clearly improves skill than direct usage of a single member. About the same skill as when 3 members are directly used.

Seawater $\delta^{18}O$ from Coral and Model near Philippines

$\delta^{18}Osw$ (Red: Model Blue: Coral)



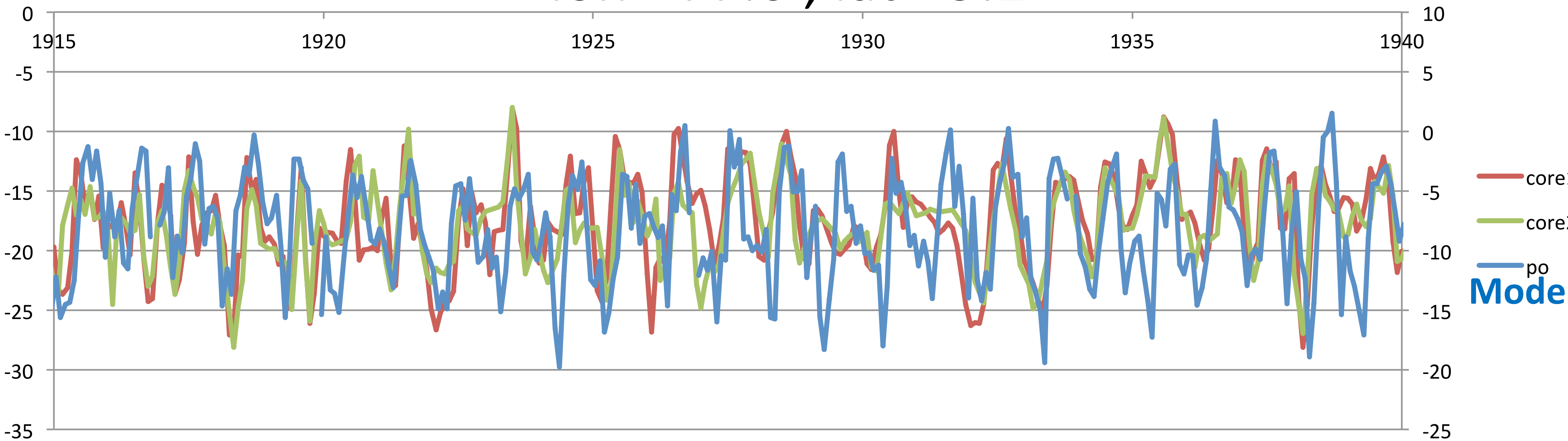
SSS (Red: Model Blue: SODA)

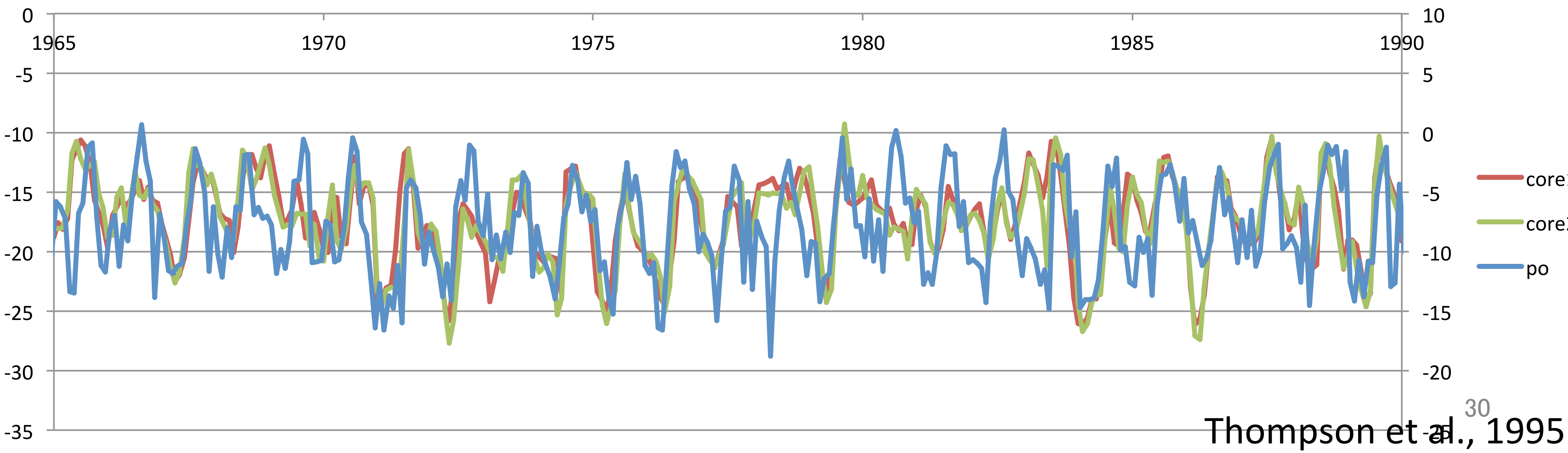


Kojima et al., submitted

Icecap $\delta^{18}O$ at Mt Huascaranm, Peru

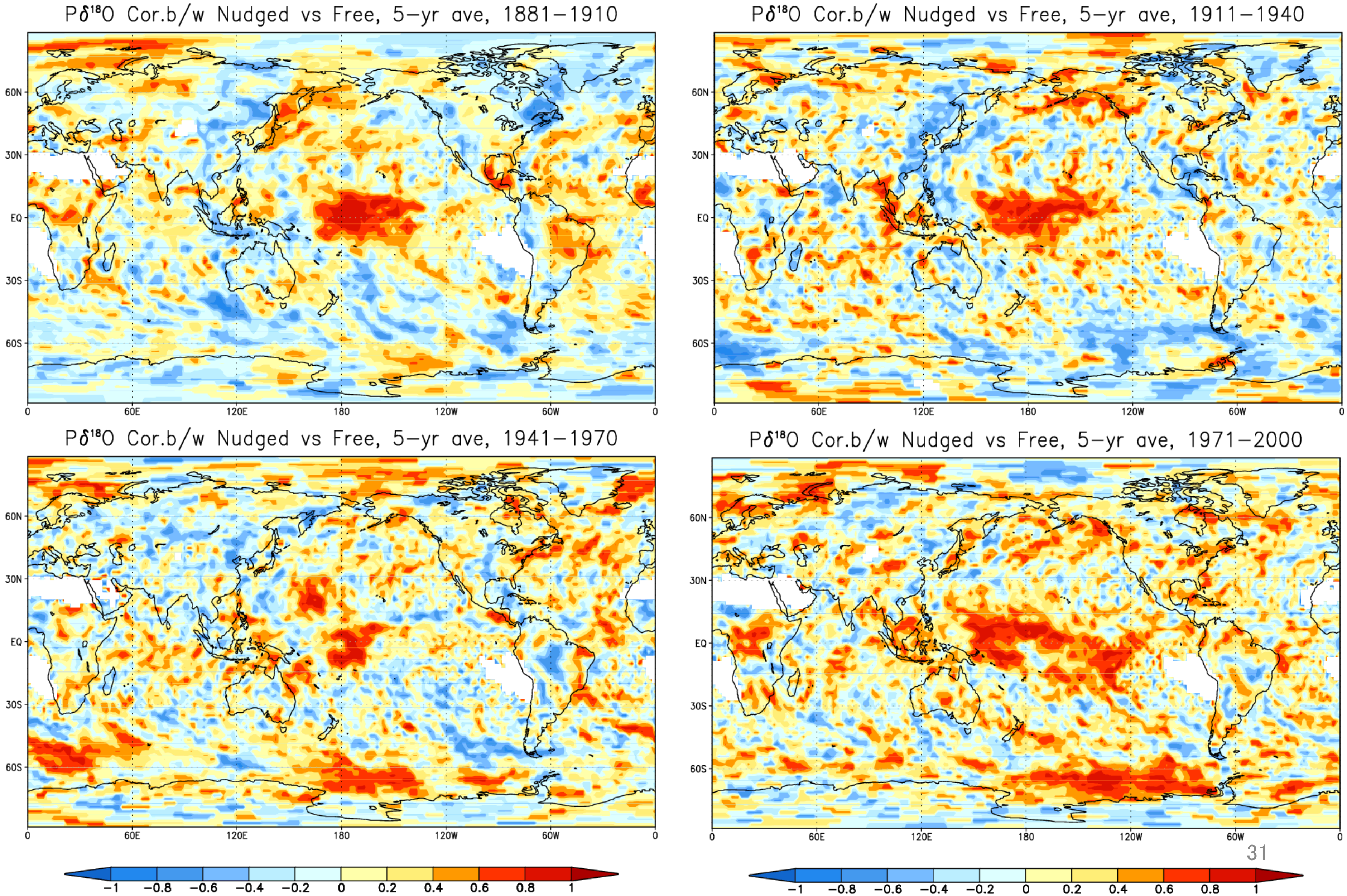
lon=-77.6 ; lat=-9.1



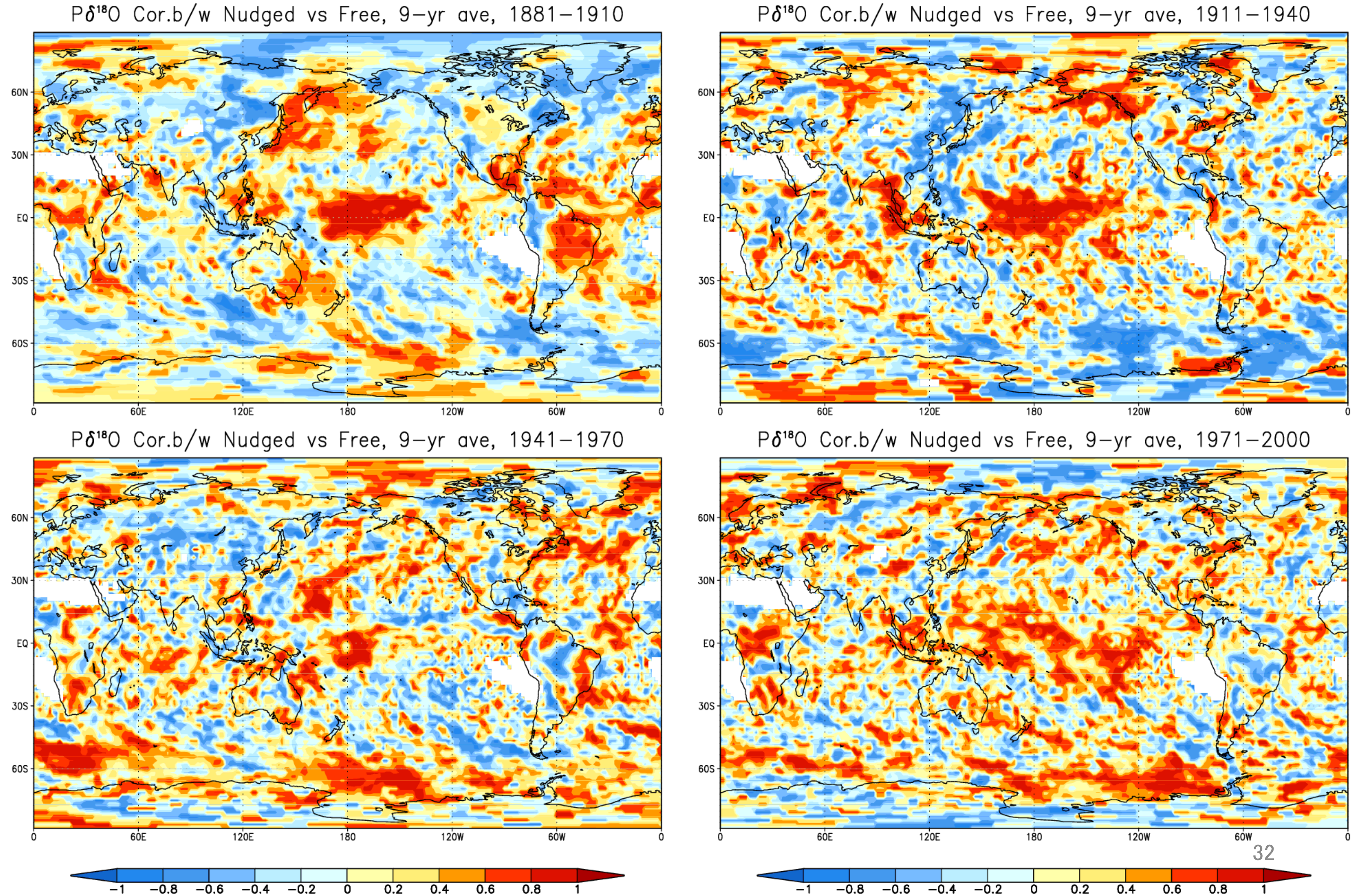


Thompson et al., 1995

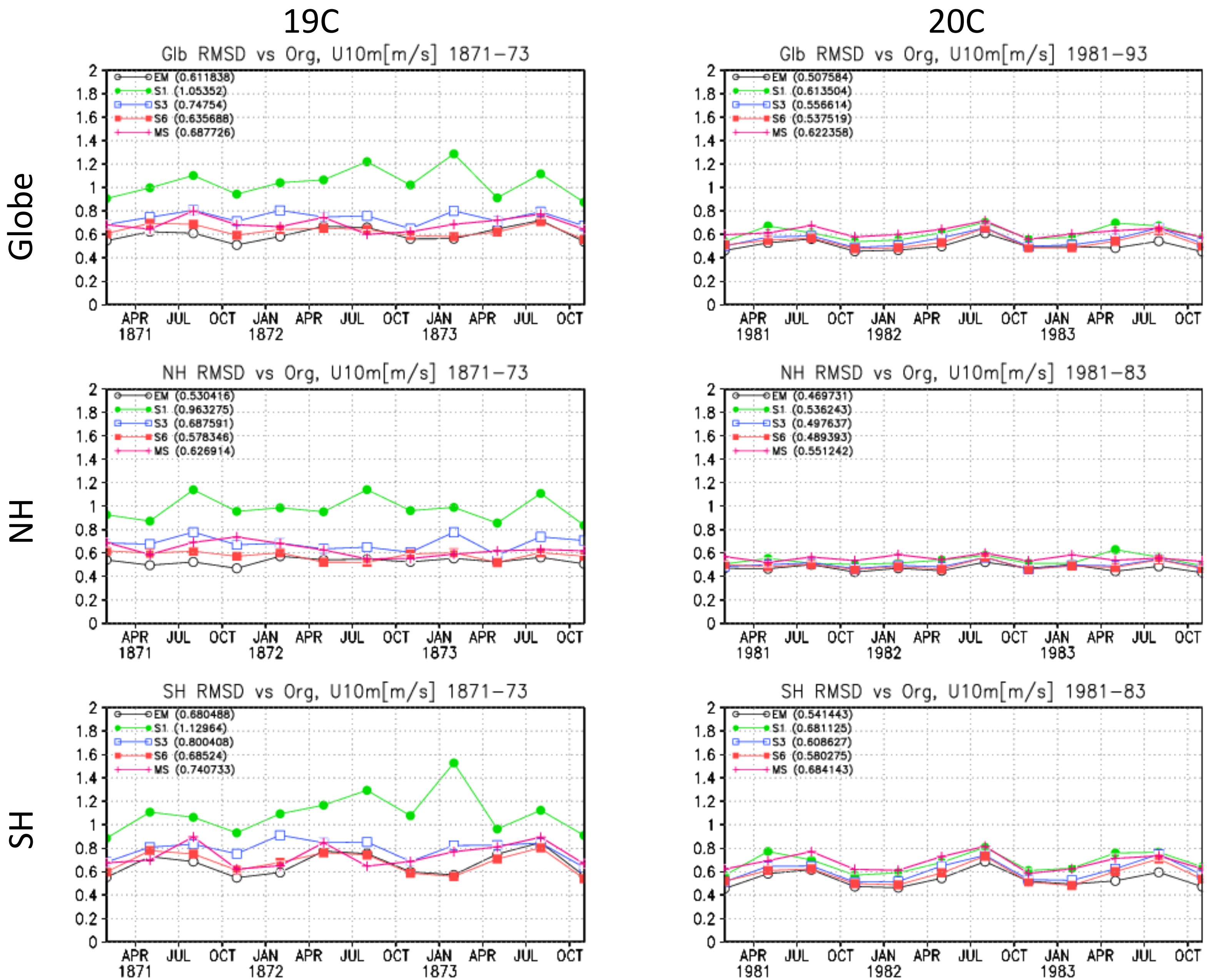
5-yr running mean correlation



9-yr running mean correlation



RMSD in Wind against “truth”



Long term global precipitation

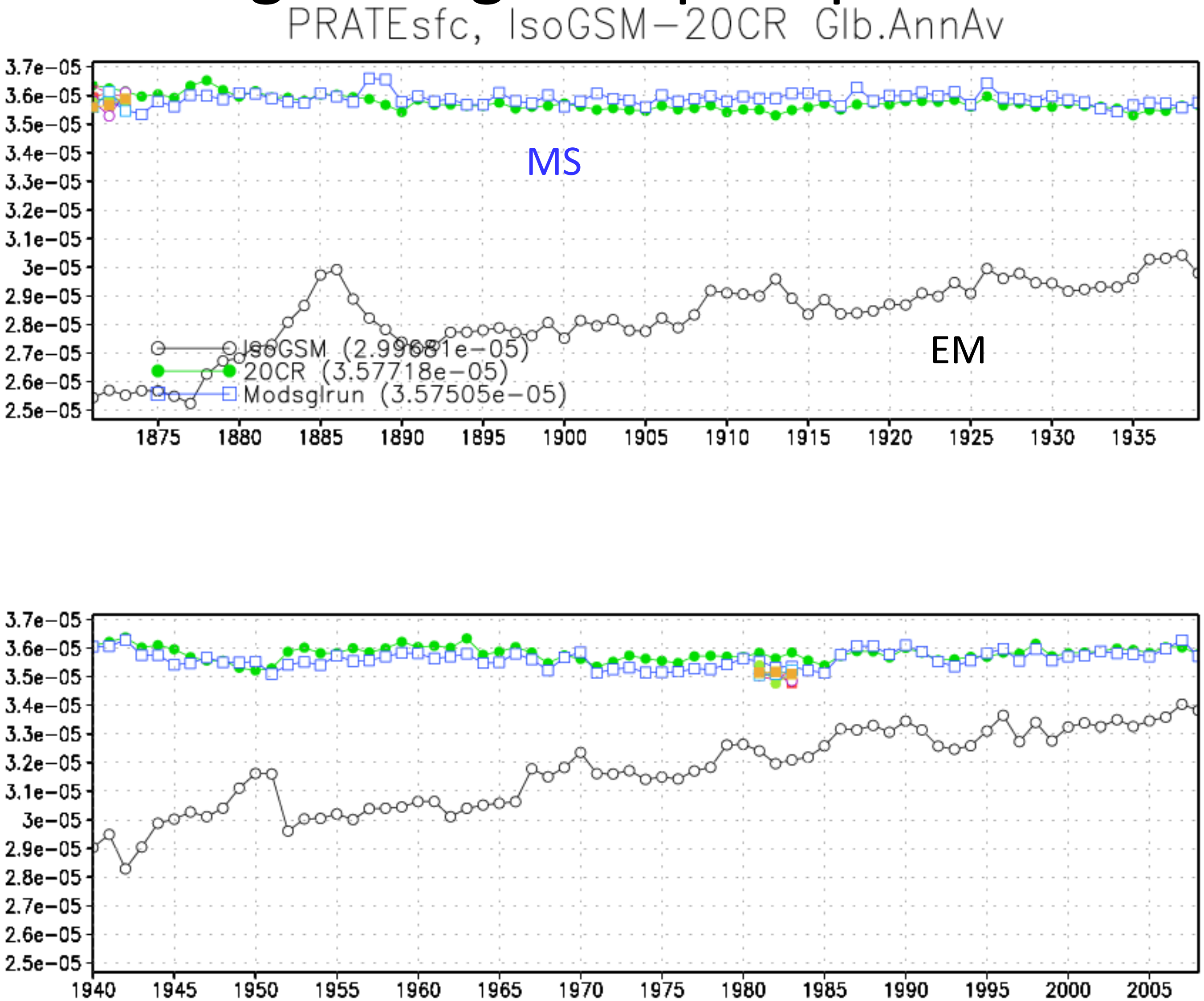
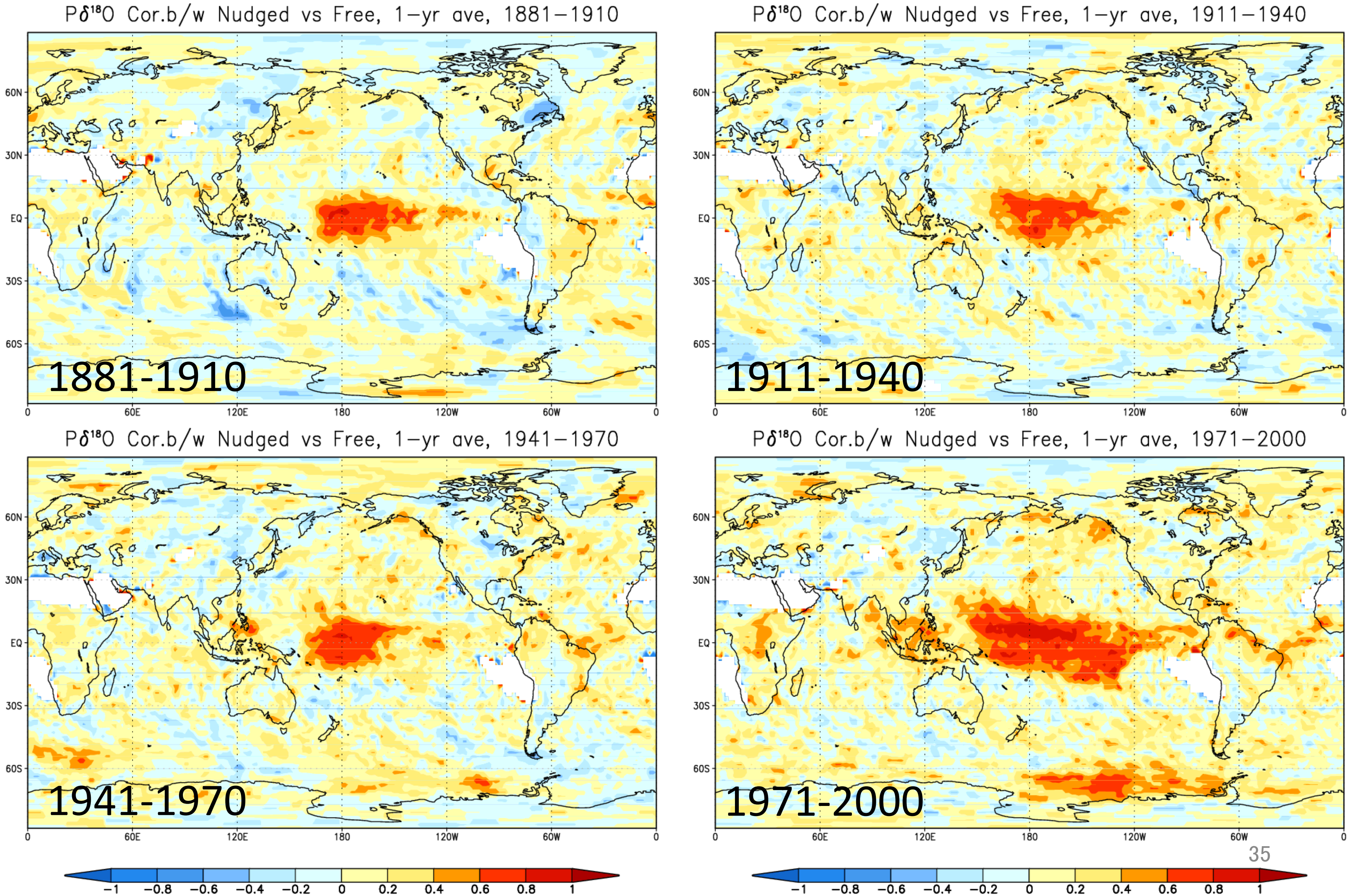


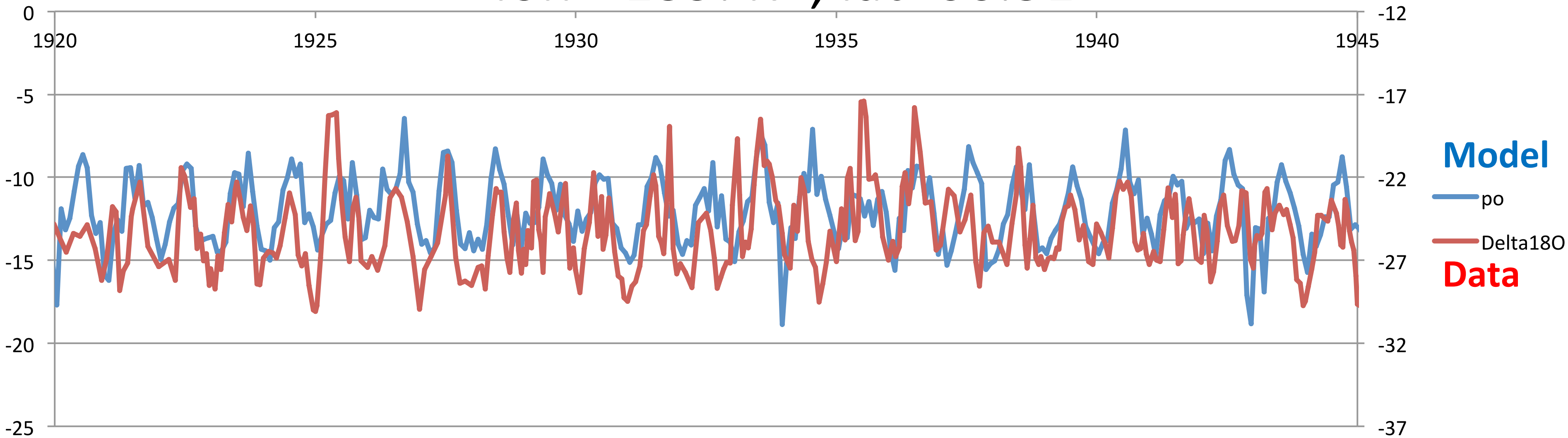
Figure 10: Global mean precipitation by each experiments from 1871 to 2008. Original 20th century Reanalysis (green), EM (black), and MS (blue) are shown for all period. Those runs with the direct use of single members (which consists S6) are shown only for 1871-73 and 1981-83.

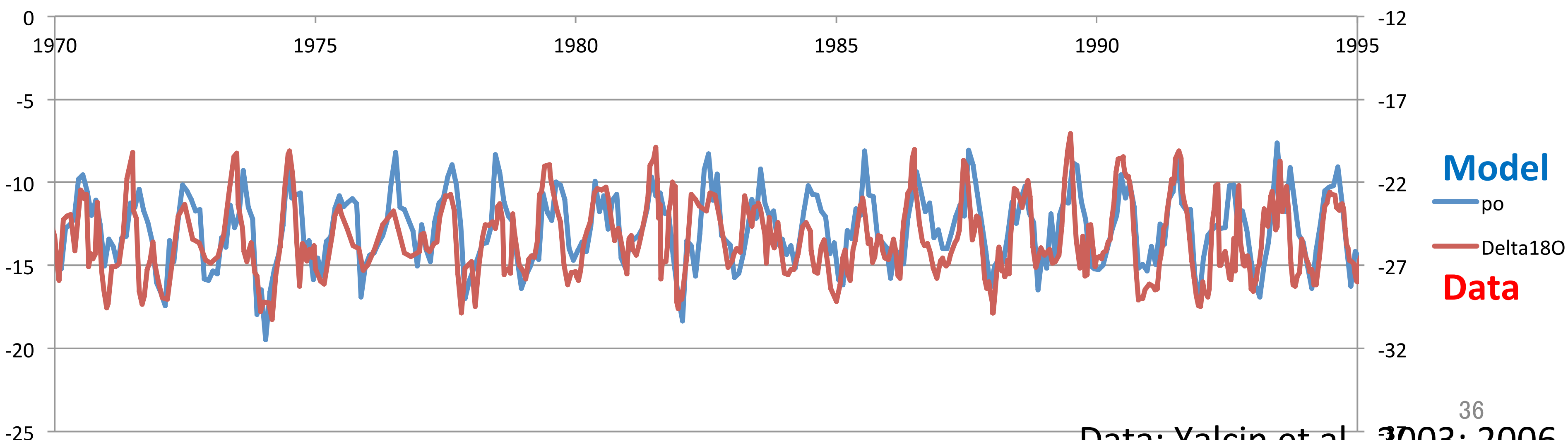
Nudged vs Un-nudged in Different Period



Icecore δ¹⁸O at Eclipse Icefield

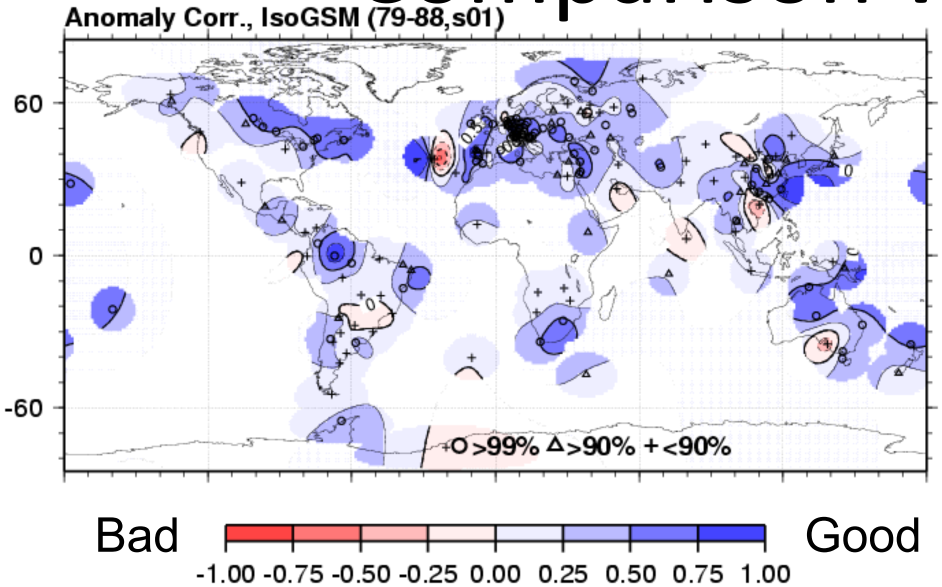
lon=-139.47 ; lat=60.51

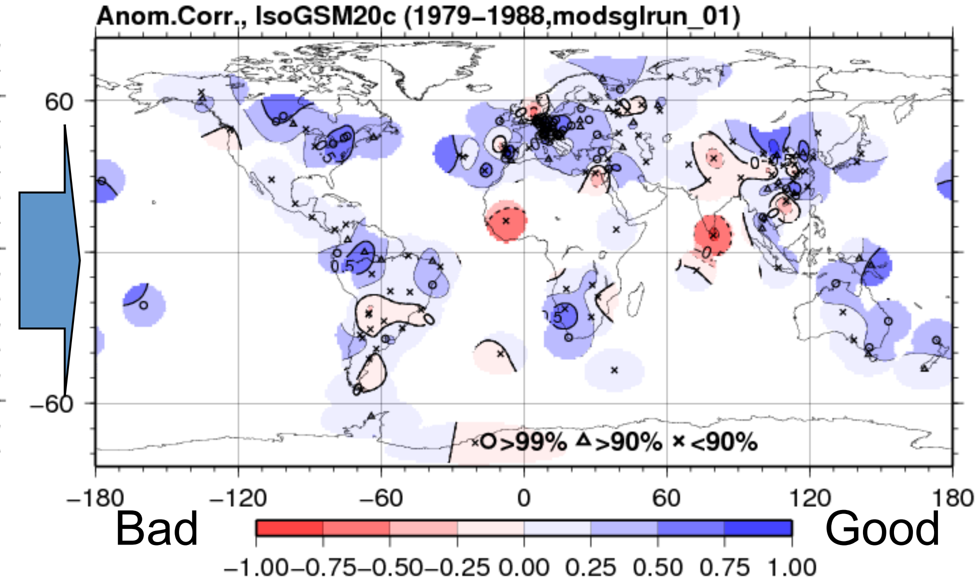




Data: Yalcin et al., 2003; 2006

Comparison with GNIP data

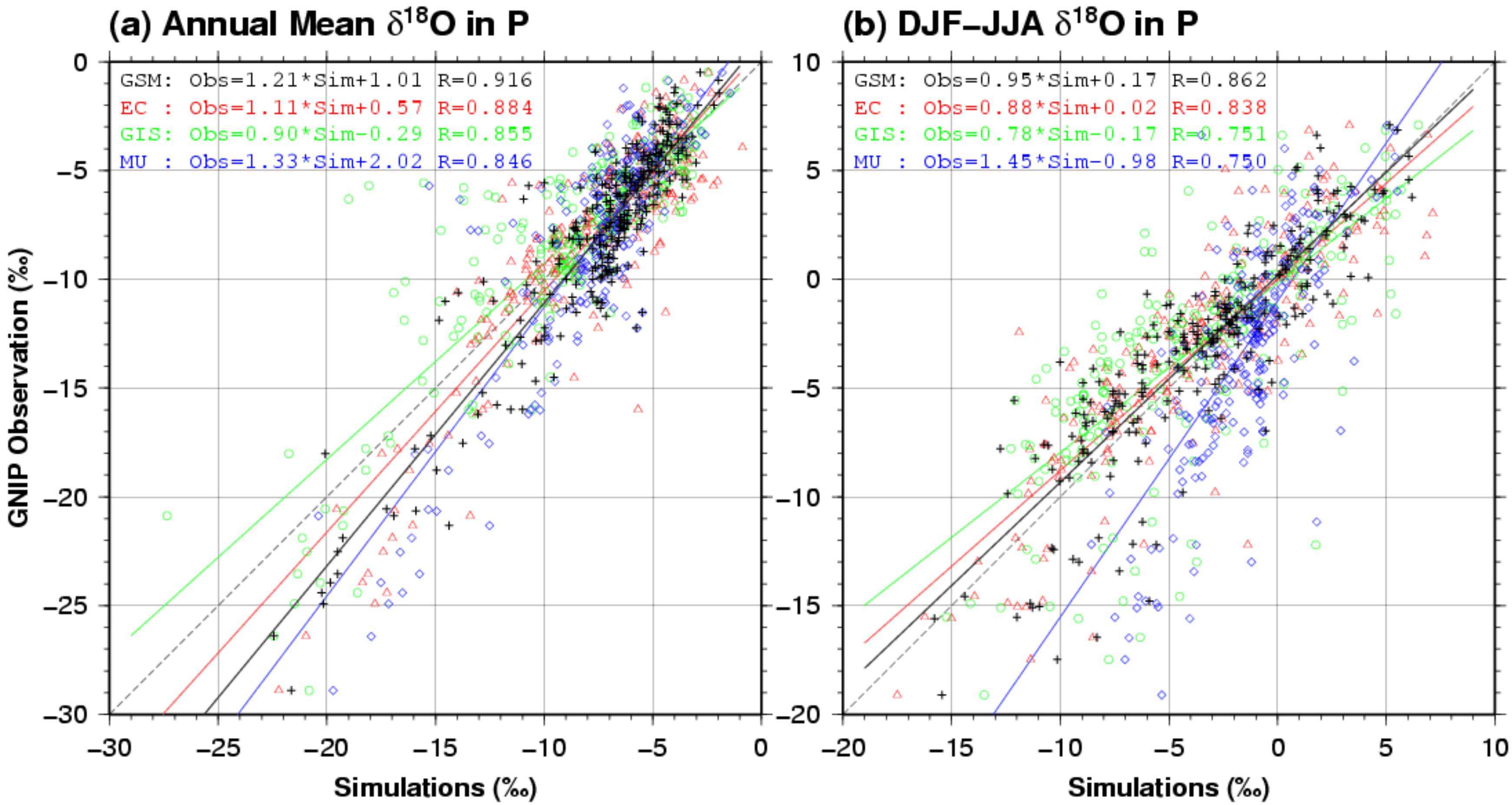




Number of GNIP sites where correlation is significant for 1980-1999					
		ECHAM	**GISS-E**	**IsoGSM-R2**	**IsoGSM-20C**
Correlation	**NH (210)**	**147**	**171 (81%)**	**174 (83%)**	**171 (81%)**
	Tropics (142)	**68**	**82 (58%)**	**96 (68%)**	<u>**105 (73%)**</u>
	SH (37)	**22 (60%)**	**18**	**25 (68%)**	**25 (67%)**
Anomaly Correlation	**NH (146)**	**13 (9%)**	**12**	**114 (78%)**	<u>**93 (63%)**</u>
	Tropics (67)	**9**	**12 (18%)**	**32 (48%)**	**34 (50%)**
	SH (29)	**1**	**3 (10%)**	**12 (41%)**	**12 (41%)**

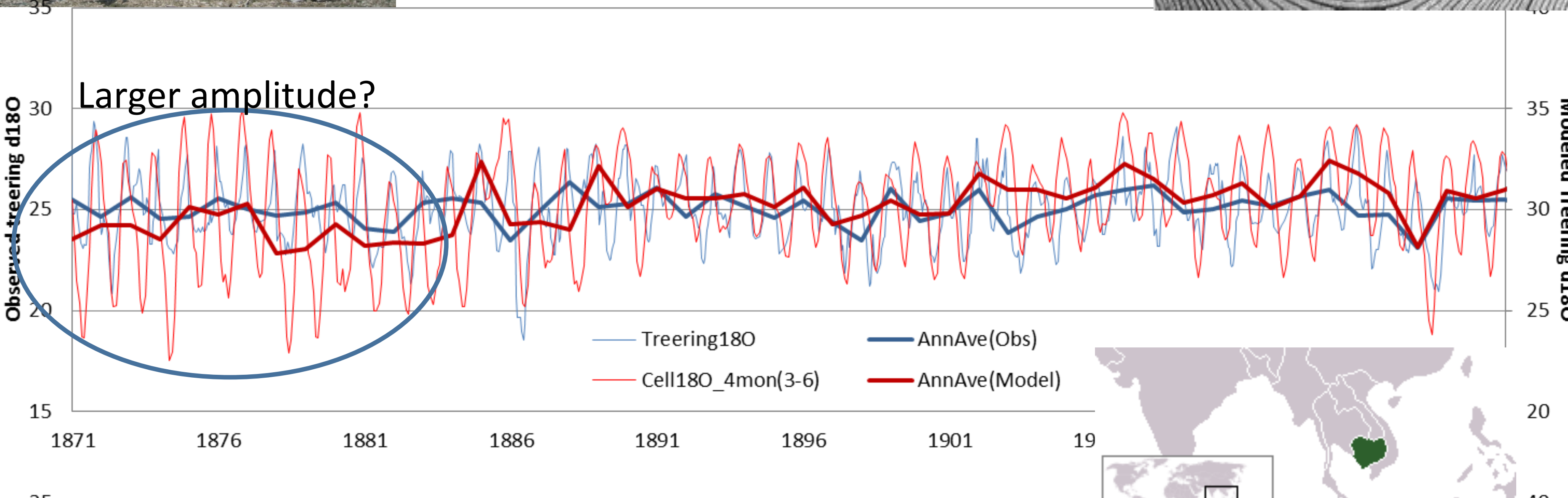
Yoshimura et al., 2008

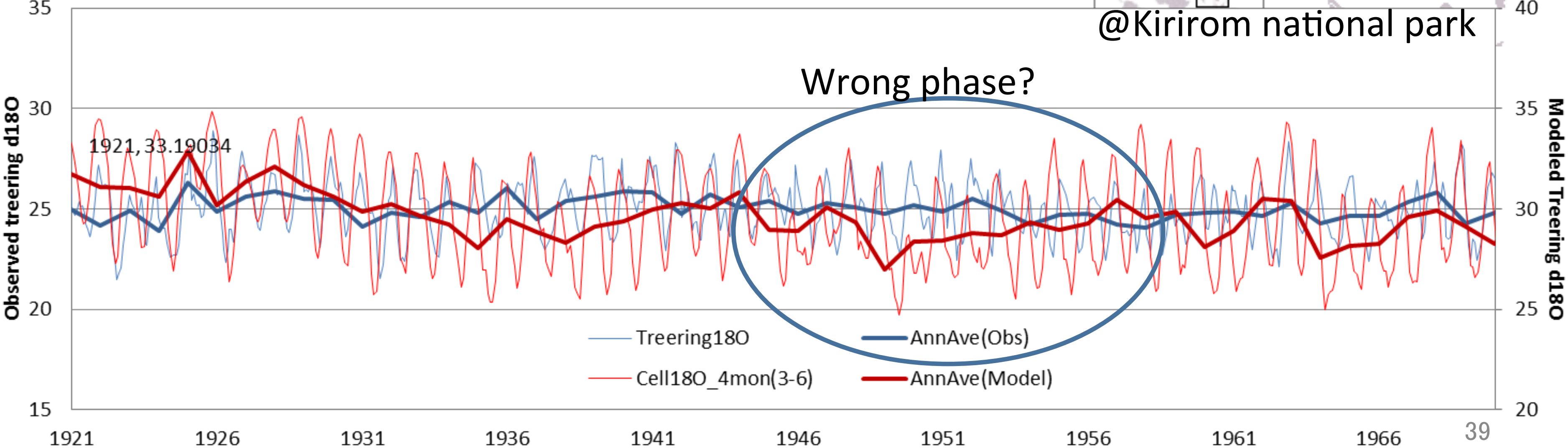
Validation: Comparison in $\delta^{18}O$ in Precip



- Many other validation studies available.
  Uemura et al., 2008; Abe et al., 2009; Frankenberg et al., 2009; Pfahl and Wernli, 2009; Schneider et al, 2010; Galewsky and Hurley, 2010; Yoshimura et al., 2010; Berkelhammer et al., 2011; Yoshimura et al., 2011; Pfahl et al., 2011; Welp et al., 2011; Zhu et al., 2012; etc.

Treering $\delta^{18}O$ in Cambodia





Data: Zhu et al., 2012

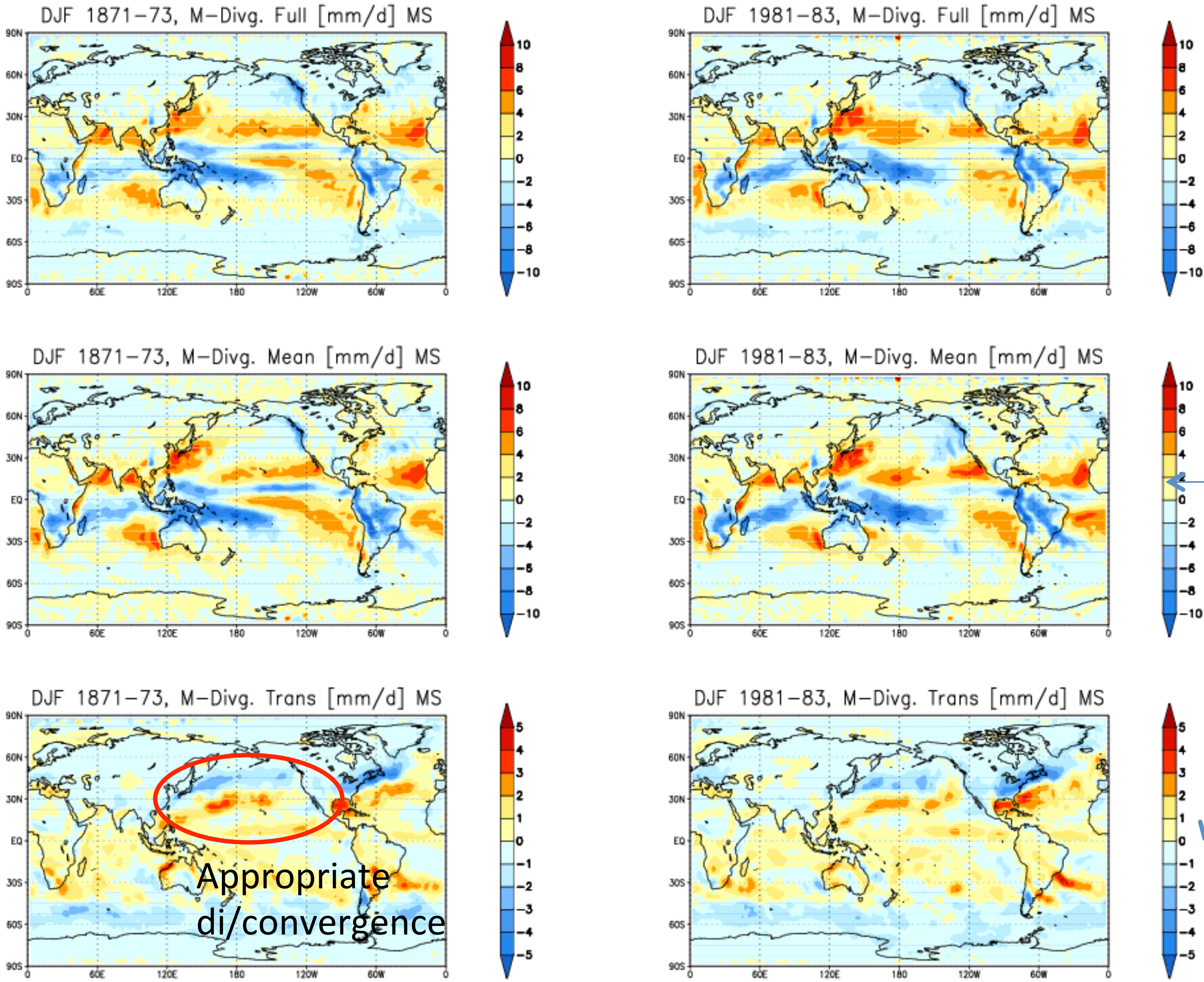
DJF mean of moisture divergence in **MS**

19C | 20C

Total divergence

Mean

Transient



$$\overline{nb} = \bar{n} \cdot \bar{b} + \overline{n'b'}$$