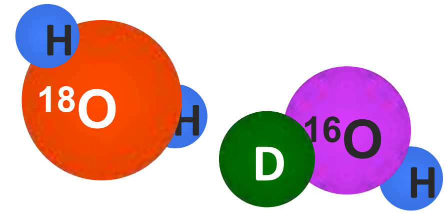


A 140-year long historical water isotope simulation with the 20th century reanalysis and its comparison with climate proxy data

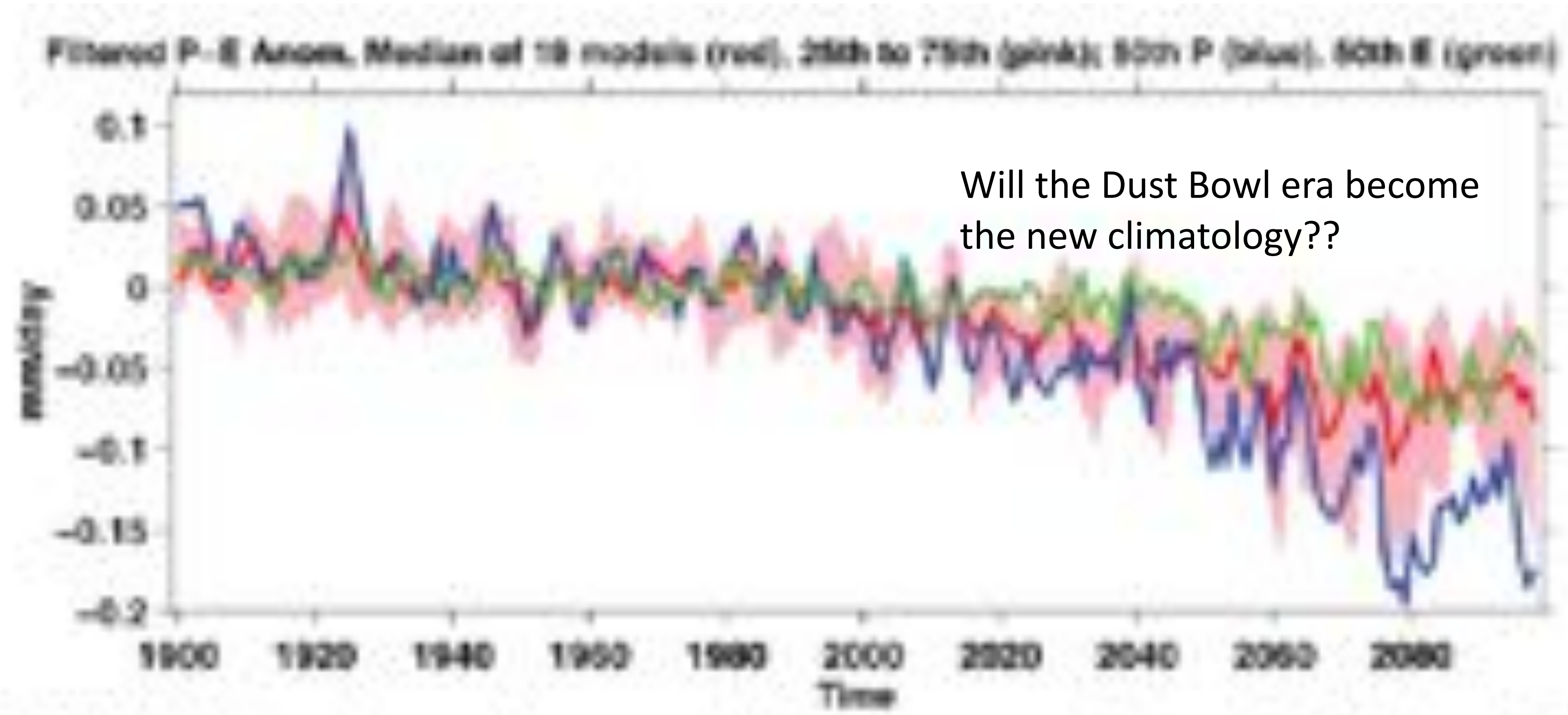
Kei Yoshimura[1], Lowell Stott[2],
and Masao Kanamitsu[3]

1: Atmosphere and Ocean Research Institute, University of Tokyo
2: Department of Geology, University of Southern California
3: Scripps Institution of Oceanography, UCSD

preliminary work

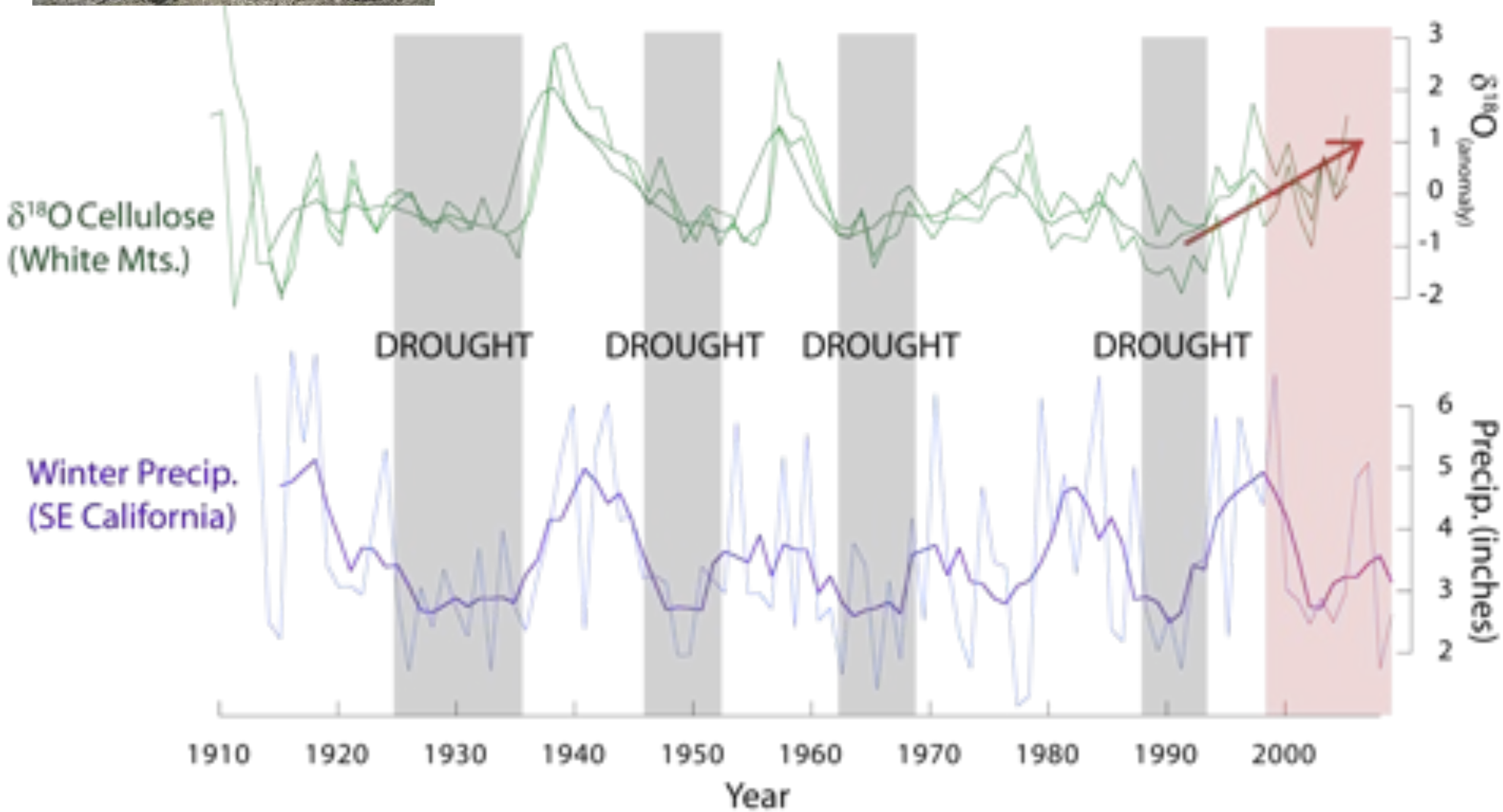
Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America

Seager et al., 2007



Bristlecone pine tree at SE CA

$\delta^{18}O$ in cellulose seems good indicator for historical drought events, but **not for the current drought**.



Berkelhammer et al., 2009; Stott and Yoshimura, in prep

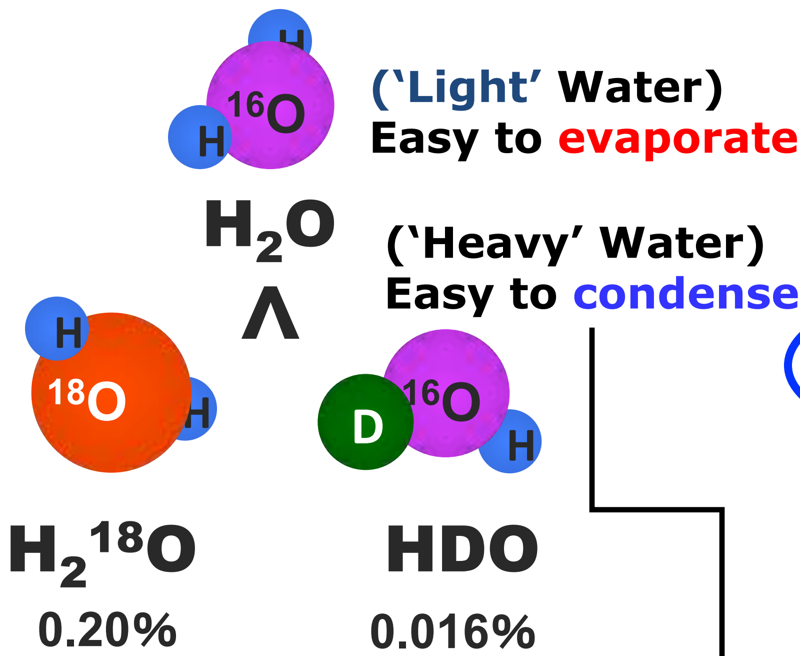
Motivation

- Specific:
  Is the current SW-US drought attributable to the global warming? Is the isotopic data able to tell the uniqueness of this event?

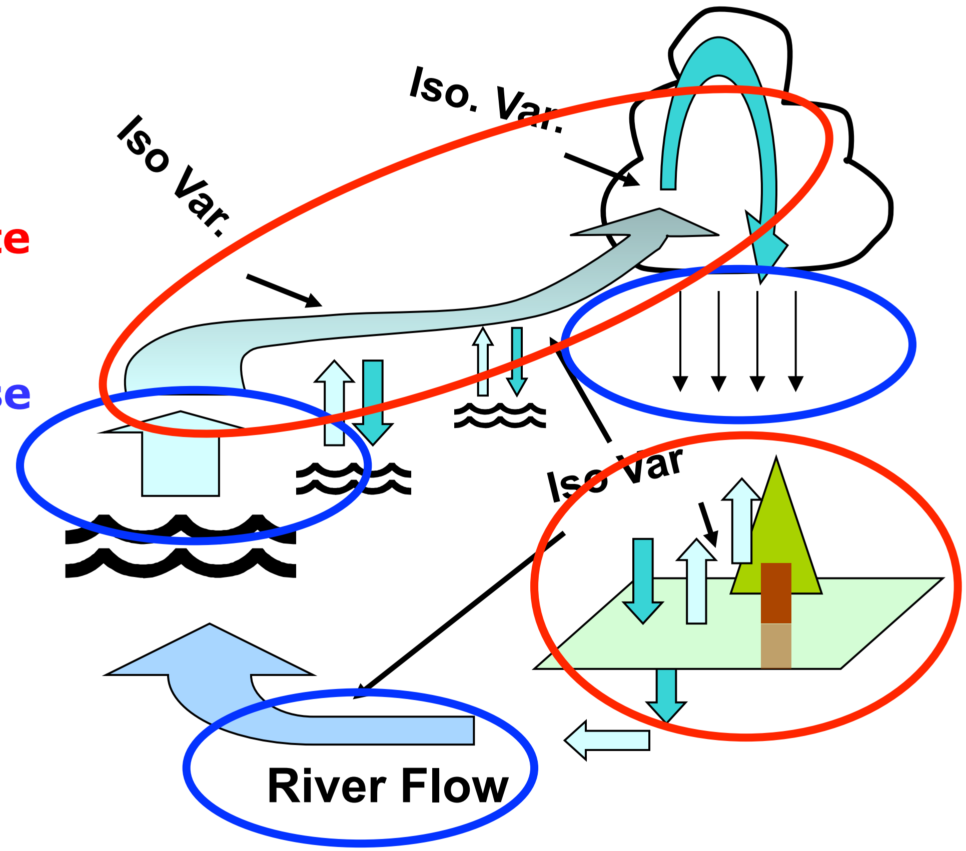
- General:
  How accurate are isotopic proxies to reconstruct the recent climate? Is there any change in the relationships?

Stable Water Isotopes and Hydrologic Cycle

- SWI have integrated records of phase changes during its transport.

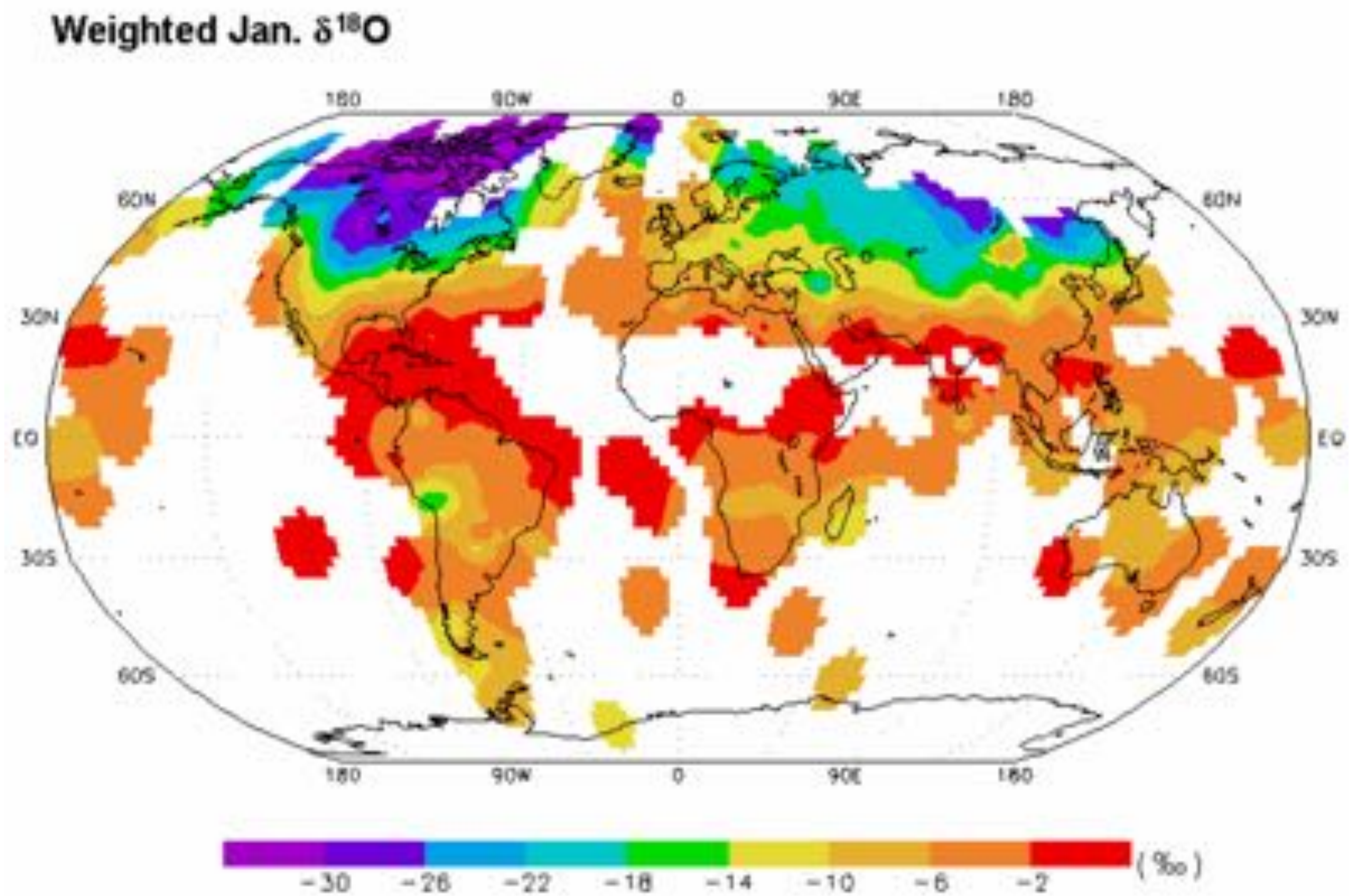


"Fractionation" causes large heterogeneity in time and space.



Recorded in:
ice core, coral, cellulose, etc.etc.

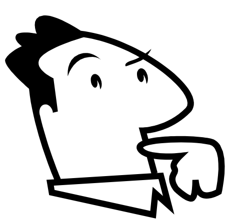
GNIP Observation (1960s-, WMO/IAEA)

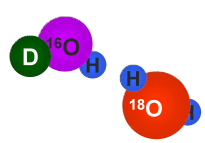


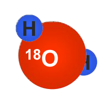
- Found good correlation between precipitation isotopes and surface temperature at mid-high latutude and precipitation amount at low latitude (Dansgaard, 1964). ➔ Justification for Paleoclimate reconstruction

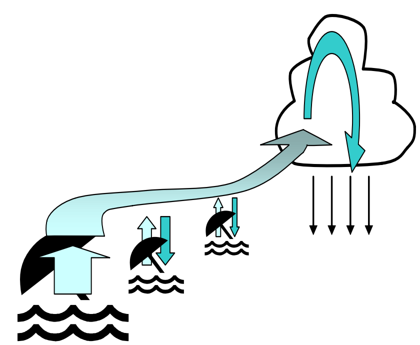
Isotopes are useful…

- To interpret past and current climate information from ice cores, corals, stalagmite, etc., in various spatial/temporal scales.
- To detect an erroneous hydrologic process in the model and/or evaluate the model / reanalyses in an integrated manner.



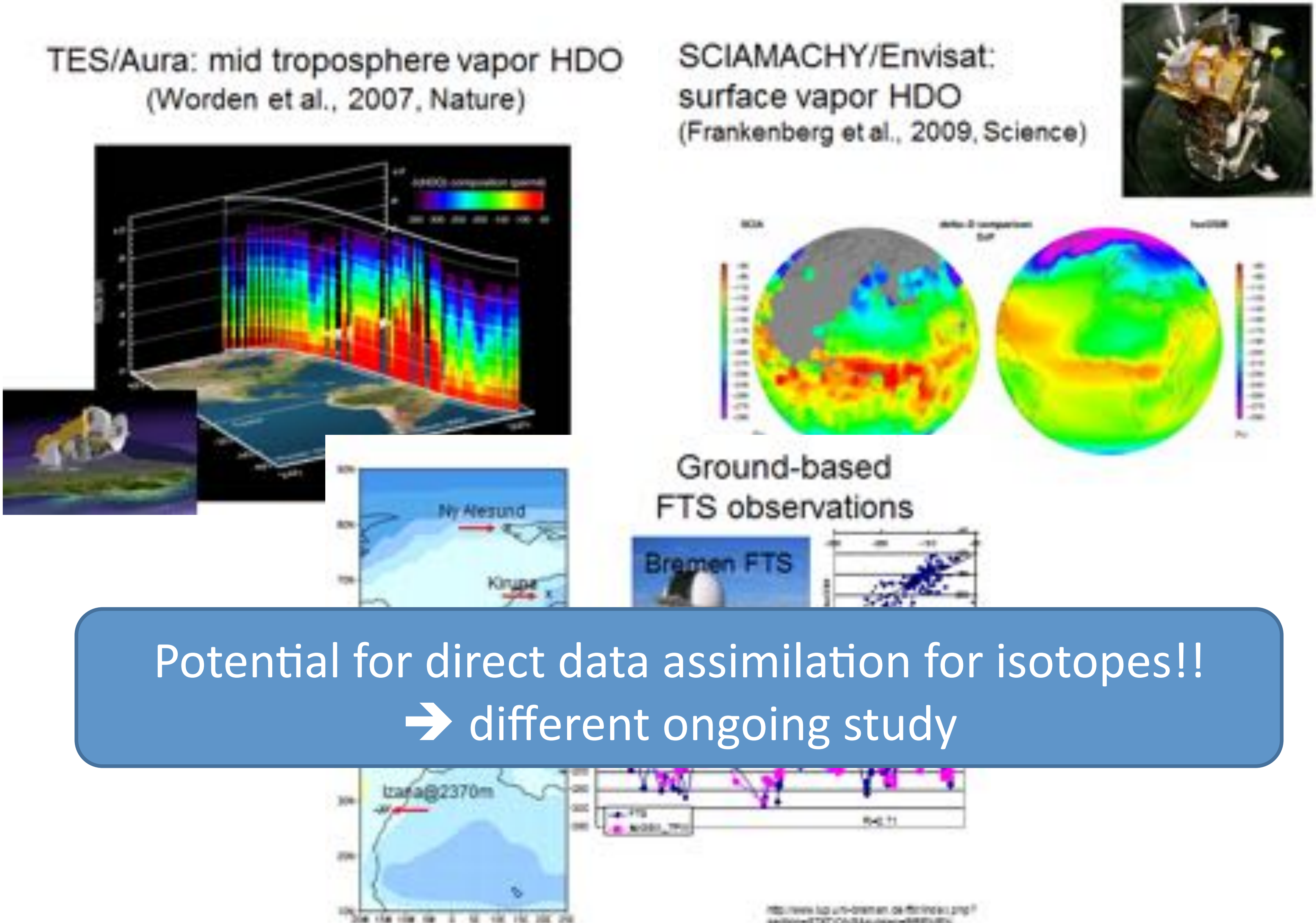






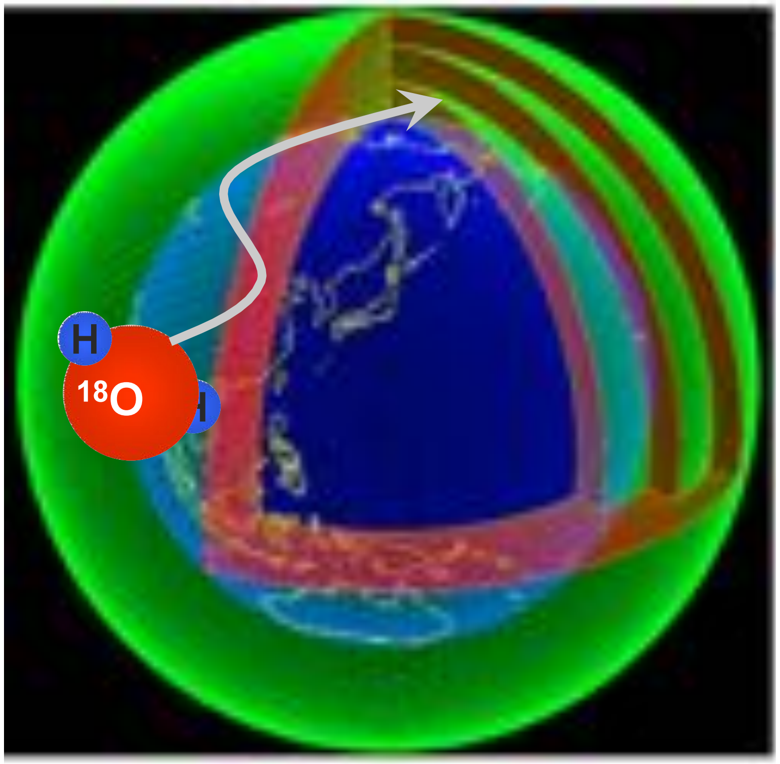
Isotope studies are *hot* these days

due to new remote sensing technology



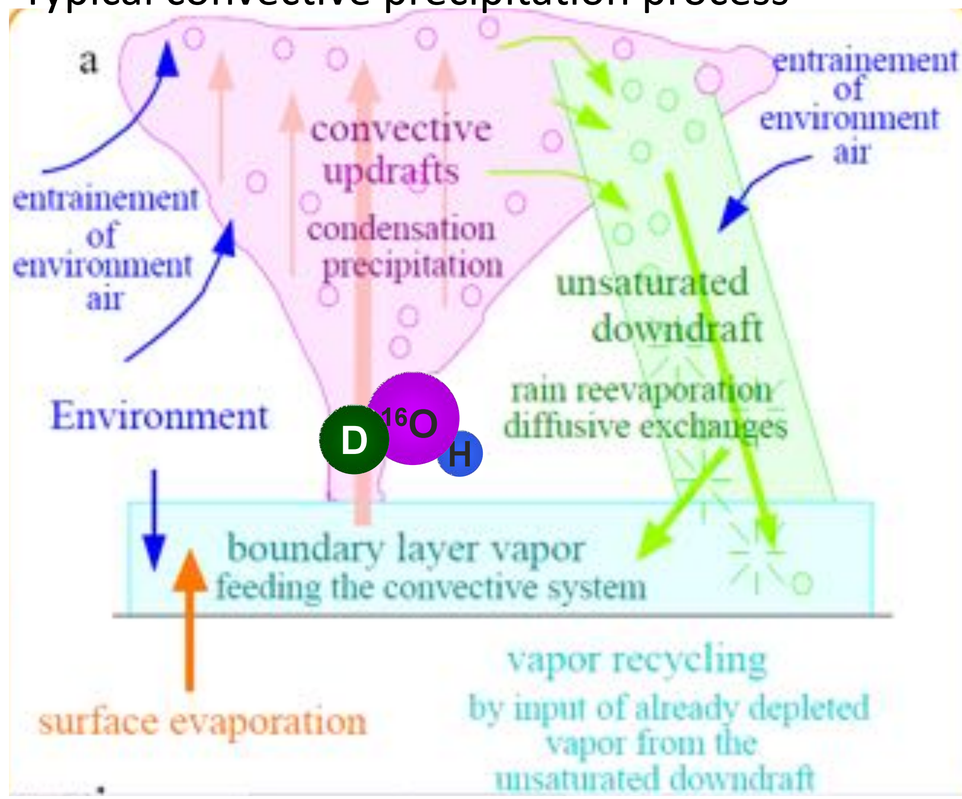
Potential for direct data assimilation for isotopes!!
➔ different ongoing study

Isotopes in GCM/RCM



Courtesy of JMA

Typical convective precipitation process



Risi et al. 2008

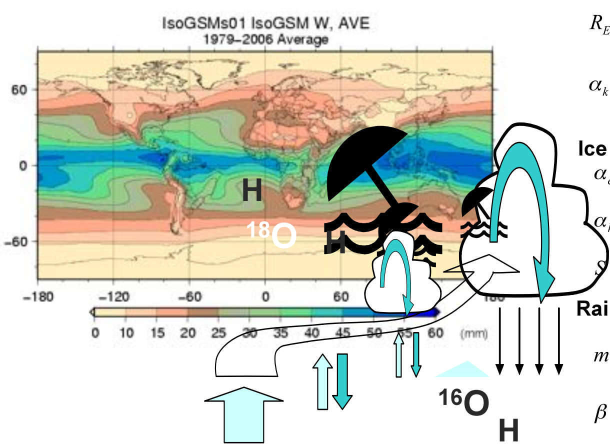
- Incorporate water isotopes as passive tracers in GCMs/RCMs. Whenever water phase change takes place, isotopic water (HDO, $H_2{}^{18}O$) behave differently to ordinary water (H_2O).

Previous works

Spectral Nudging + Isotope GSM

– *Poor man's data assimilation for isotopes* –

http://meteora.ucsd.edu/~kyoshimura/IsoGSM1



Surface evaporation (MJ79)

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

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

Ice crystal formation (JM84)

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

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

$$S = 1 - 0.003T \cdots T < -20°C$$

Rain drop evaporation (S75)

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

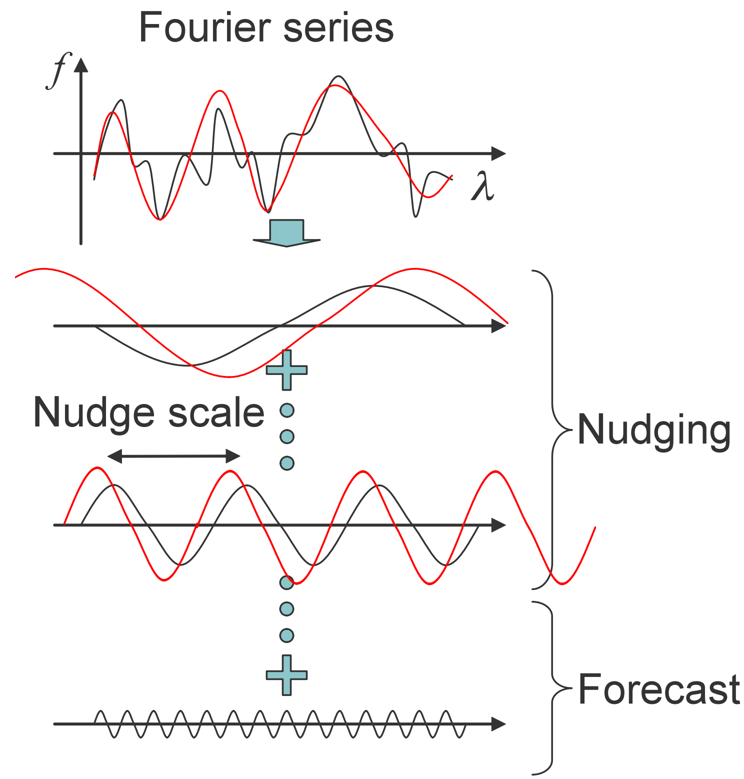
$$\beta = \frac{1-\mu}{\mu}, \gamma = \frac{\alpha_e h}{1-\mu}, \mu = \alpha_e (D/D')^n (1-h)$$

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

$$R_v = \left[q'_0 + (m'_0 - mR_r) \right] / q$$

IsoGSM

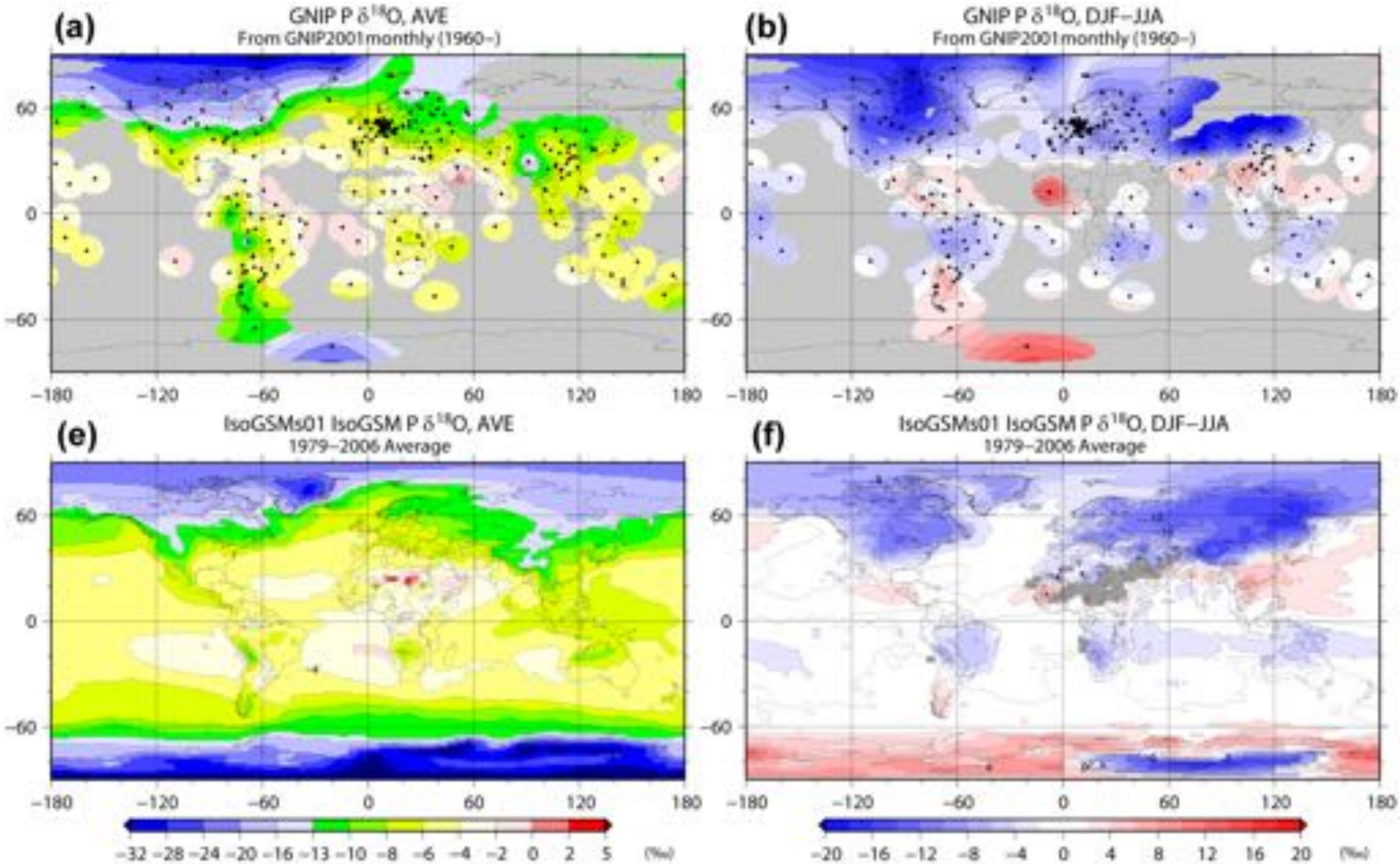
SIO/UT Isotopic Global Spectral Model



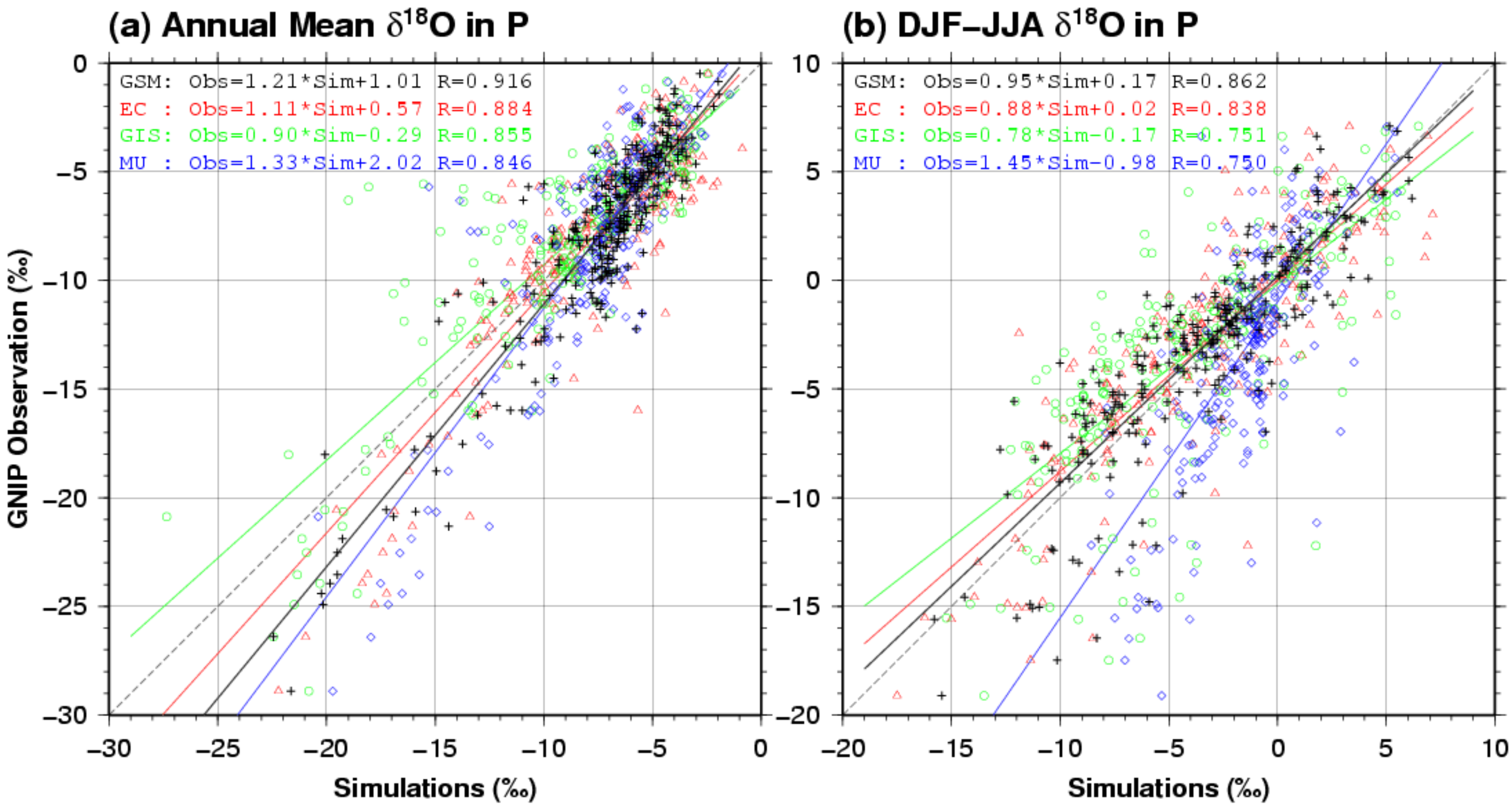
Use large scale (>1000km) winds from R2 to constrain dynamical field, so that the isotopic field is also constrained and reproduced in daily to inter-annual time scales.

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

Comparison with GNIP Climatology



Comparison with GNIP Climatology

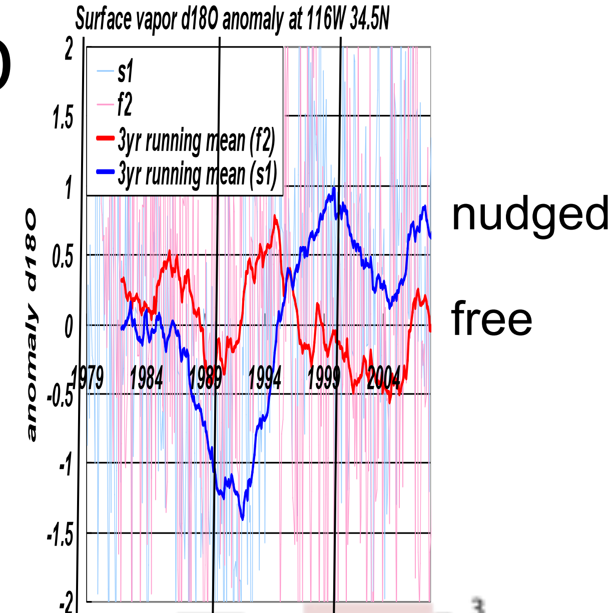


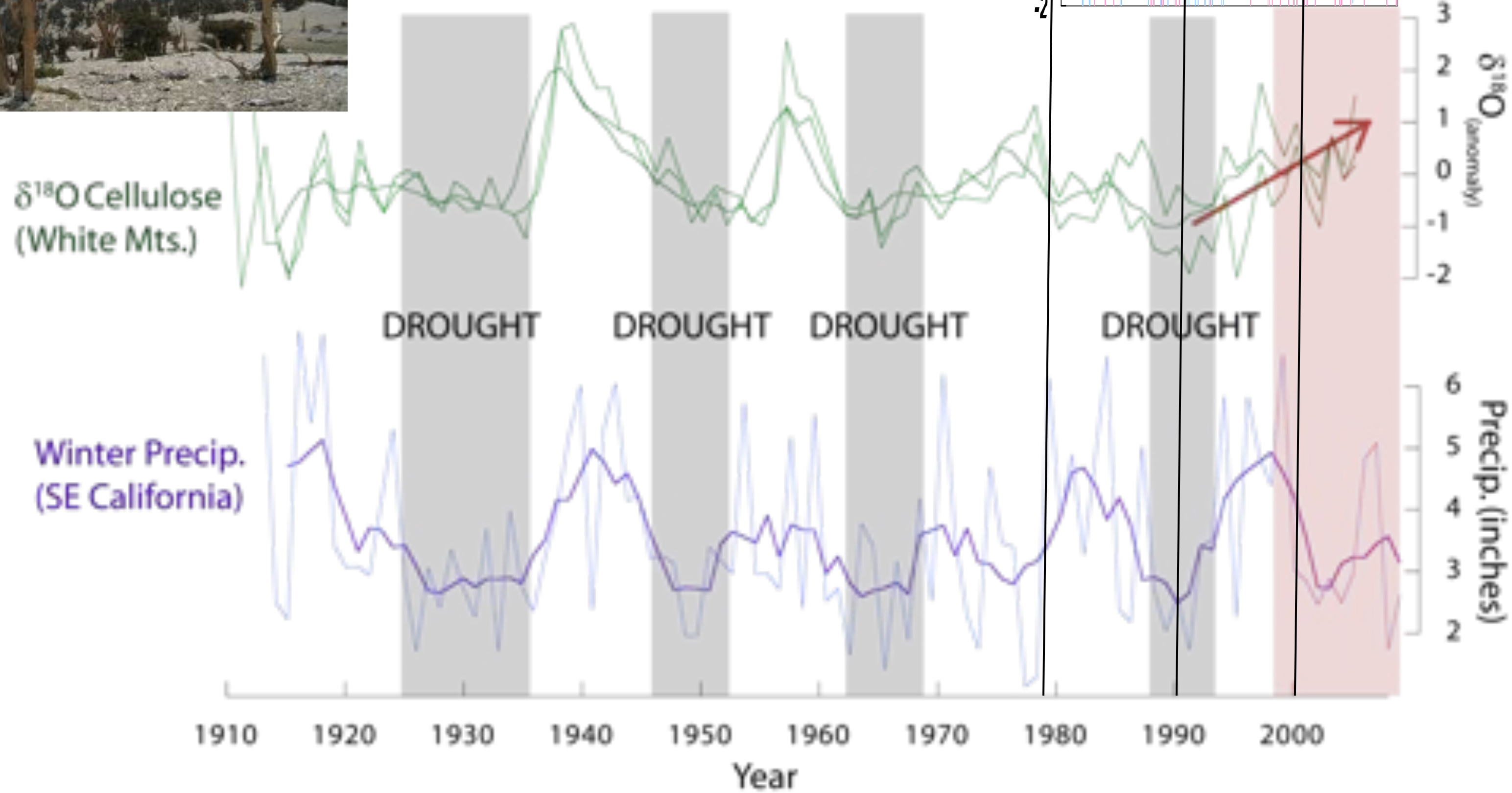
- Many other verification studies available.
  Uemura et al., 2008; Abe et al., 2009; Frankenberg et al., 2009; Pfahl and Wernli, 2009; Schneider et al, 2010; Galewsky and Hurley, 2010; Yoshimura et al., 2010, Berkelhammer et al., 2011; etc.

Comparison with Bristlecone $\delta^{18}O$

Extension of simulation needed!!

Bristlecone pine tree at SE CA

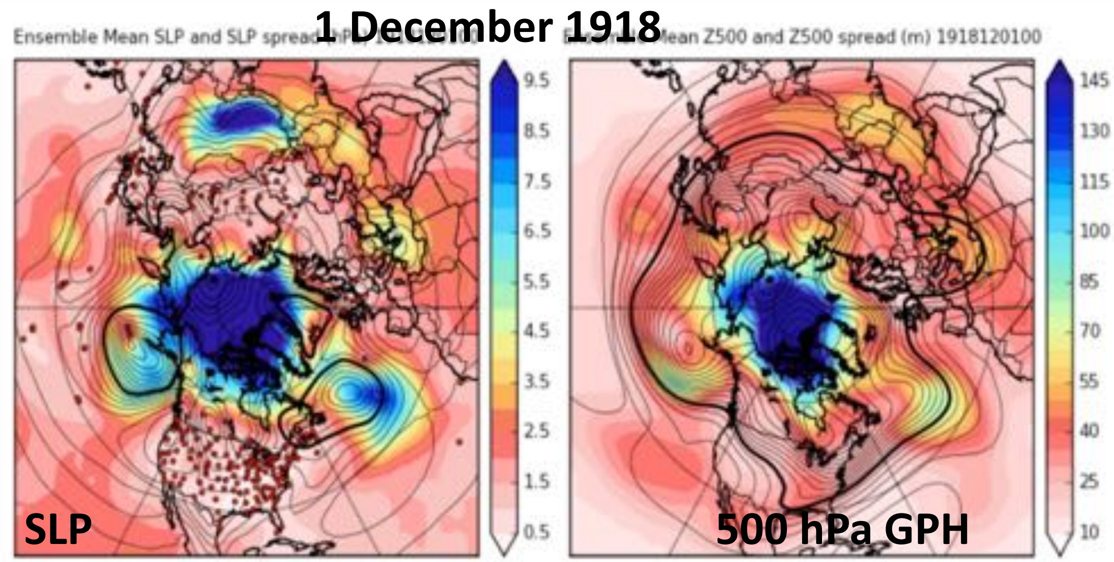




20th century Reanalysis

(Compo et al., 2010)

- 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)

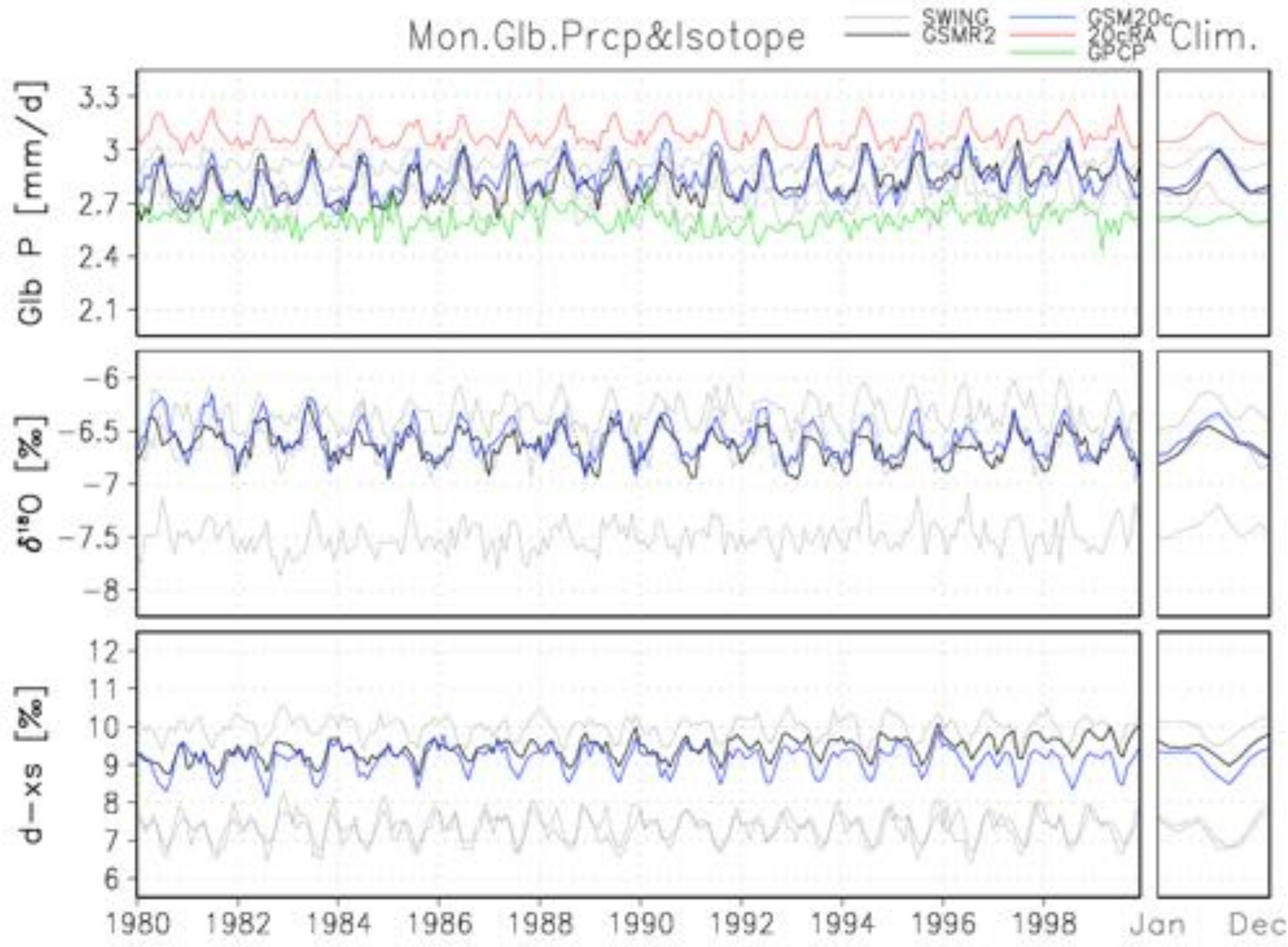
- Reanalysis skill is comparable to current Day-3 forecast skill (Whitaker et al., 2009)

Simulation Design

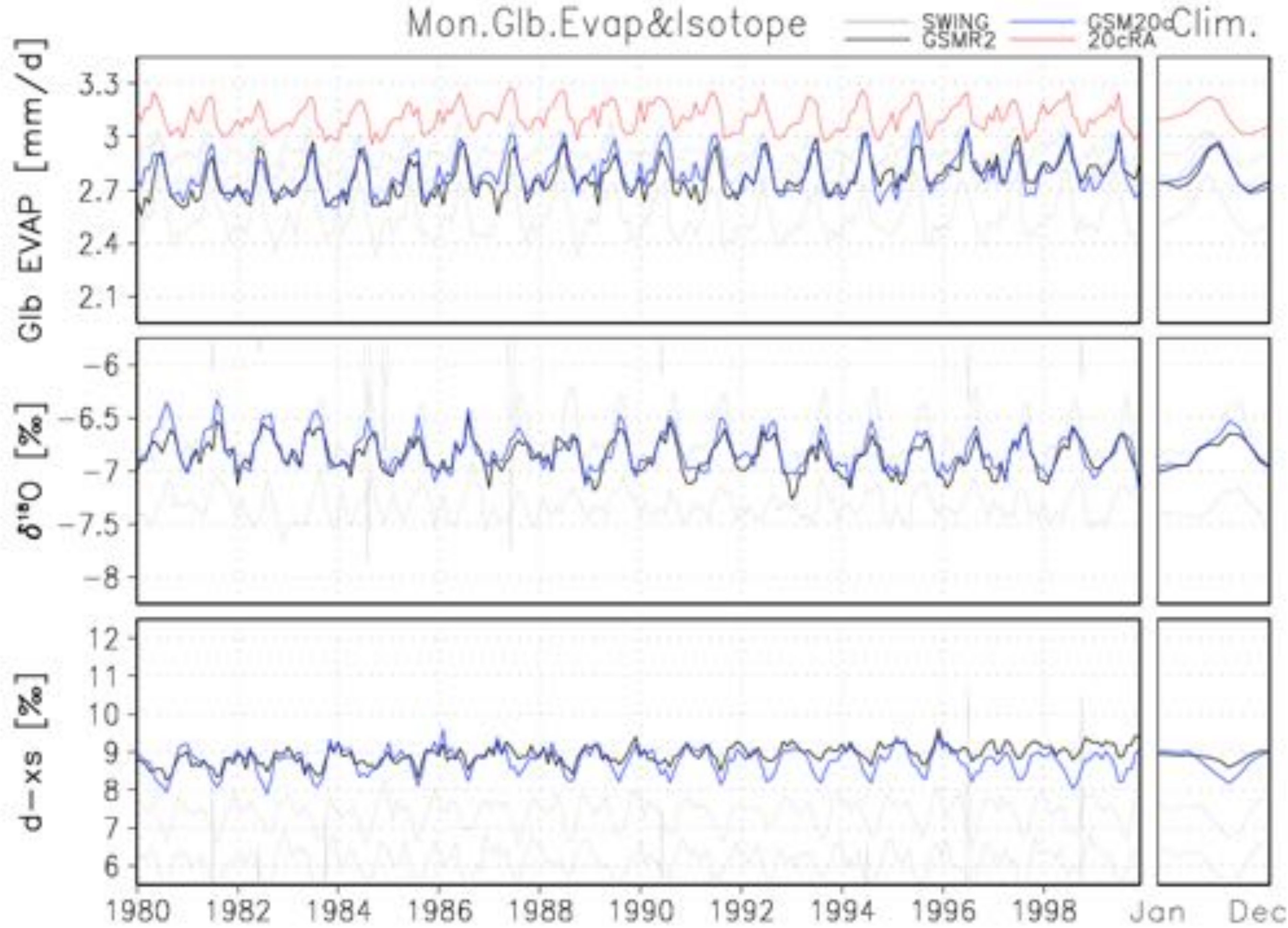
- Model: IsoGSM (Yoshimura et al., 2008) & River (Yoshimura et al., 2004) & Simple Biochem (Roden et al., 2000)
- Atmospheric forcing: 20C Reanalysis (Compo et al., 2010) spectral files, 6-hourly ensemble mean field
- Boundary forcing: HadISST
- Period: 1871-2008
  - Stream 1: 1871-1980
  - Stream 2: 1979-2008 (for comparison with Y08)

Results

- Performance in the recent decades (➔ poster available)
  - Comparison in global means with other global datasets
  - Comparison with GNIP monthly precipitation isotope data
  - Isotope signal related with AO
  - Isotope signal related with ENSO
- Comparison with >100-year proxy isotope data
  - Tree-ring cellulose $\delta^{18}O$ in Cambodia
  - Coral $\delta^{18}O$ near Philippines



Mon.Glb.Prcp&Isotope
SWING
GSMR2
GSM20c
20cRA
GPCP
Clim.
Glb P [mm/d]
3.3
3
2.7
2.4
2.1
δ18O [‰]
-6
-6.5
-7
-7.5
-8
d-xs [‰]
12
11
10
9
8
7
6
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Jan
Dec



Mon.Glb.Evap&Isotope
SWING
GSMR2
GSM20c
20cRA
Clim.
Glb EVAP [mm/d]
3.3
3
2.7
2.4
2.1
δ18O [‰]
-6
-6.5
-7
-7.5
-8
d-xs [‰]
12
11
10
9
8
7
6
1980
1982
1984
1986
1988
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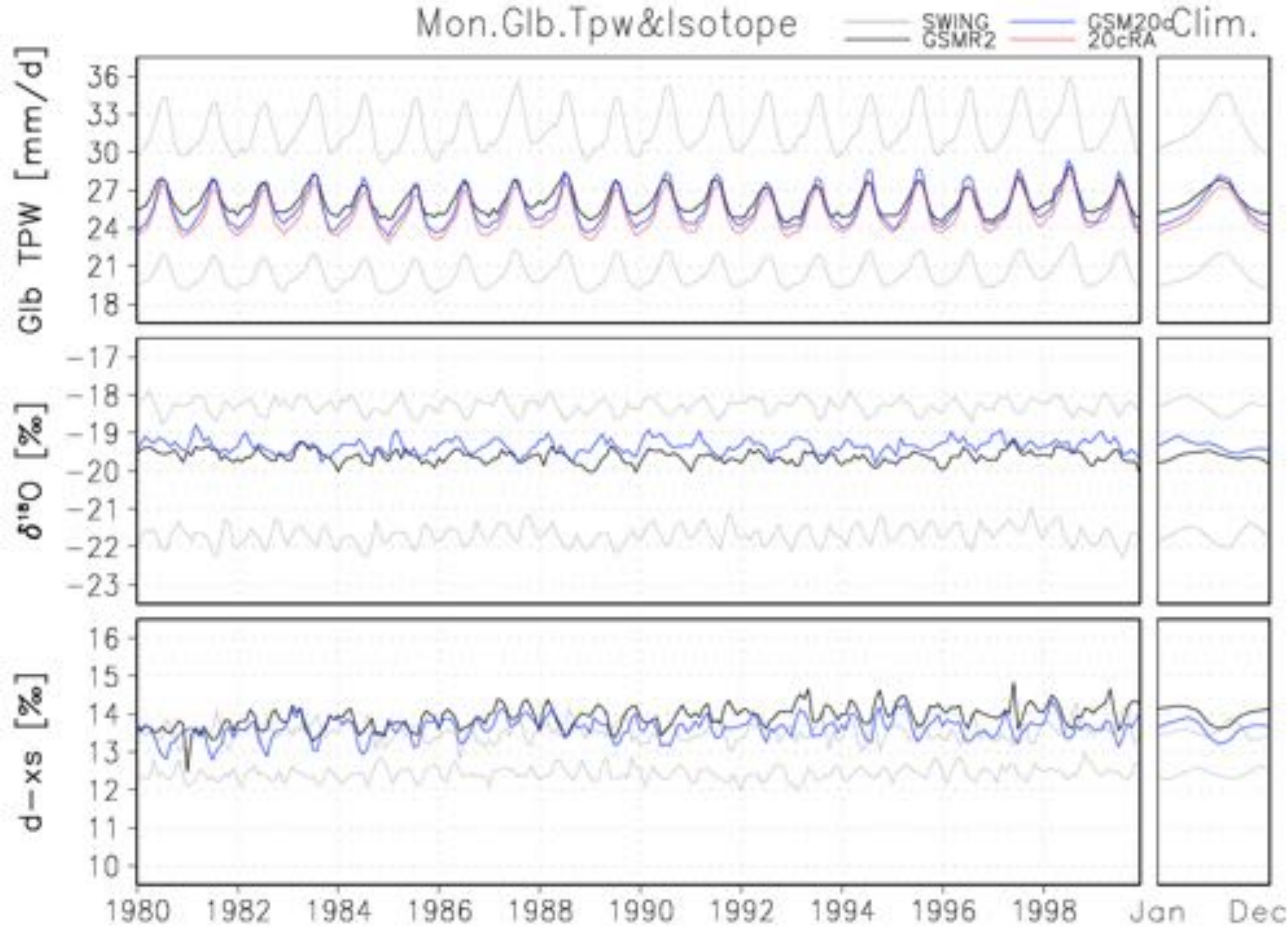
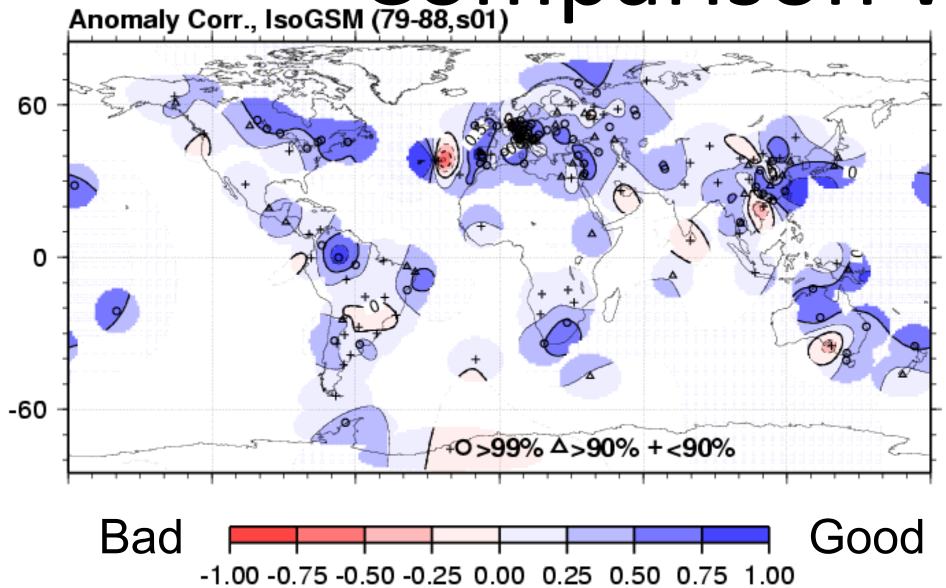
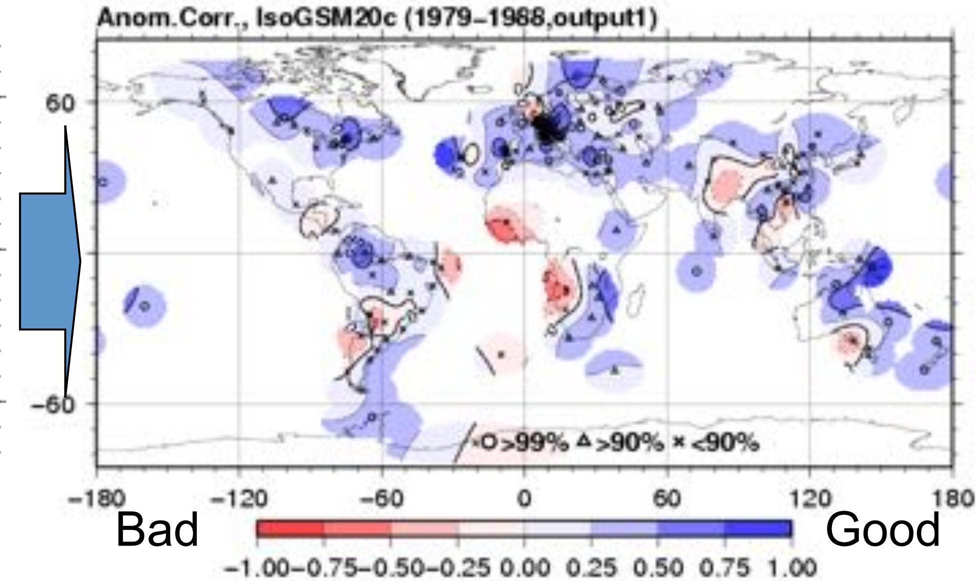
1992
1994
1996
1998
Jan
Dec



Mon.Glb.Tpw&Isotope
SWING
GSMR2
GSM20c
20cRA
Clim.
Glb TPW [mm/d]
δ18O [‰]
d-xs [‰]
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Jan
Dec

Comparison with GNIP data

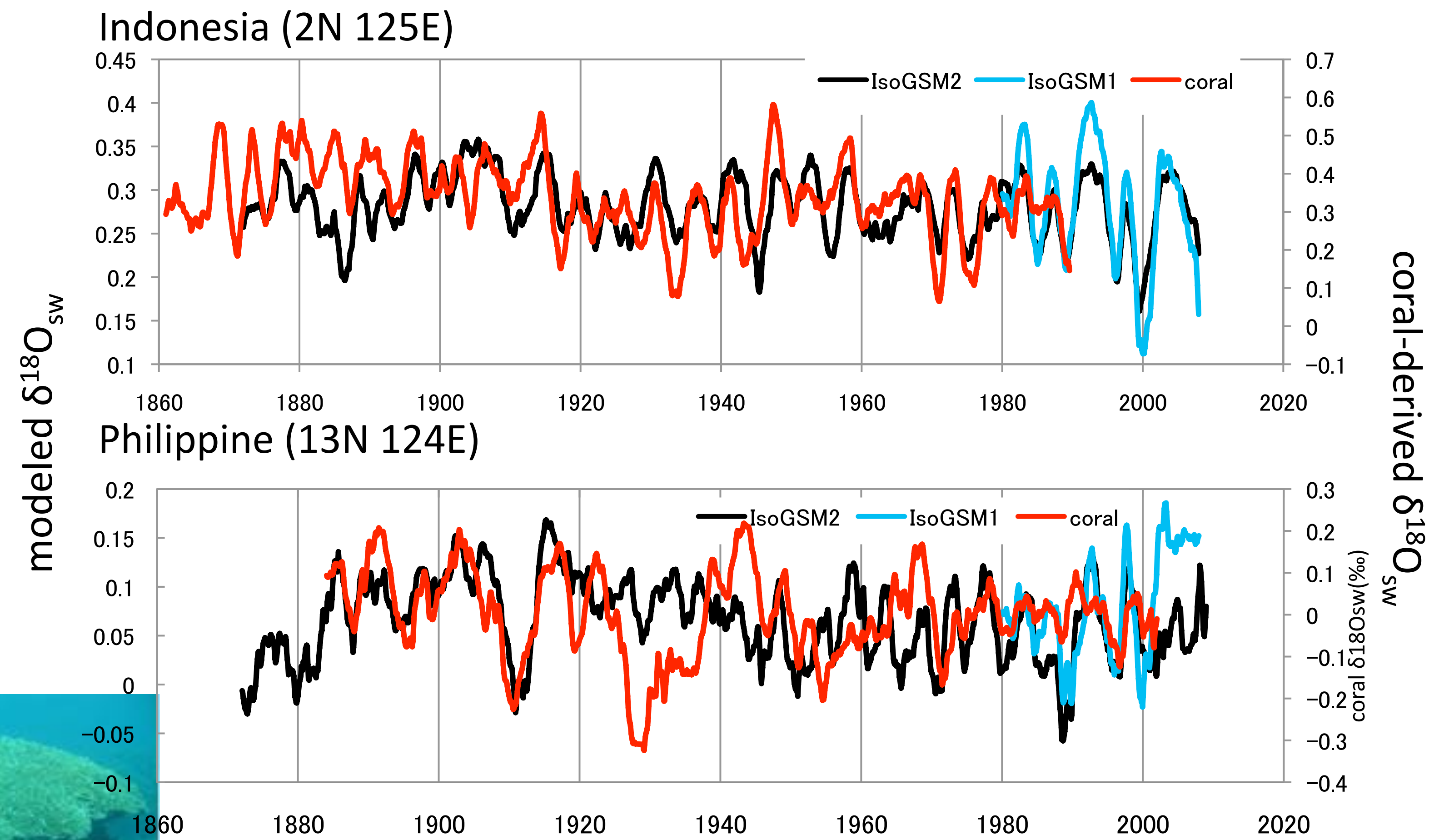


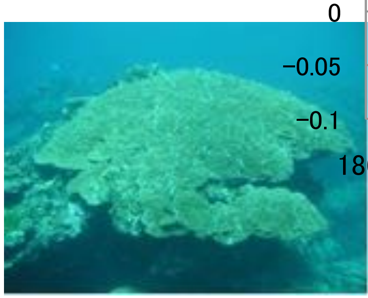


Number of GNIP sites where correlation is significant for 1980-1999

		ECHAM	GISS-E	IsoGSM-R2	IsoGSM-20C
Correlation	NH (210)	147	171 (81%)	174 (83%)	174 (83%)
	Tropics (142)	68	82 (58%)	96 (68%)	105 (74%)
	SH (37)	22 (60%)	18	25 (68%)	27 (73%)
Anomaly Correlation	NH (146)	13 (9%)	12	114 (78%)	93 (64%)
	Tropics (67)	9	12 (18%)	32 (48%)	28 (42%)
	SH (29)	1	3 (10%)	12 (41%)	11 (38%)

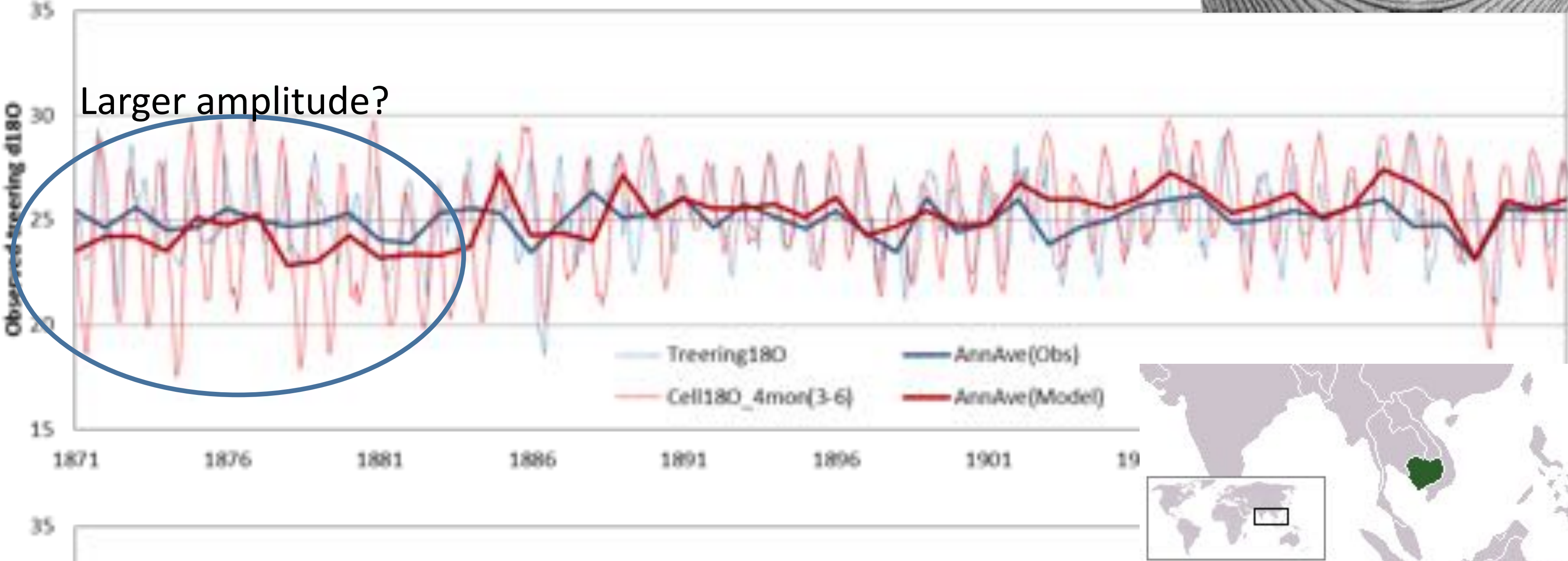
coral-derived $\delta^{18}O_{sw}$ vs. modeled $\delta^{18}O_{sw}$ (Annual average)

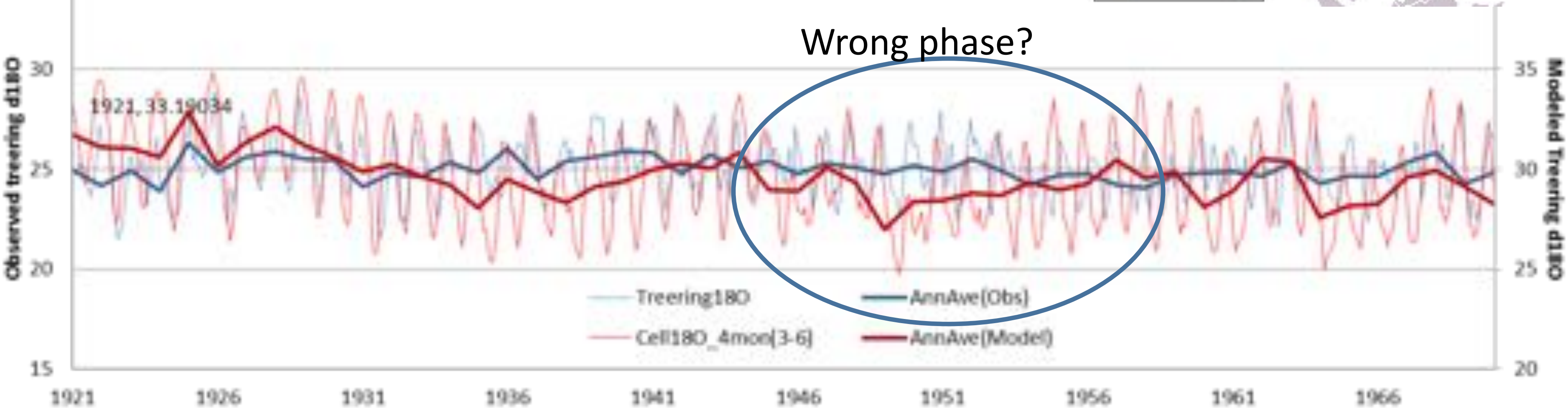




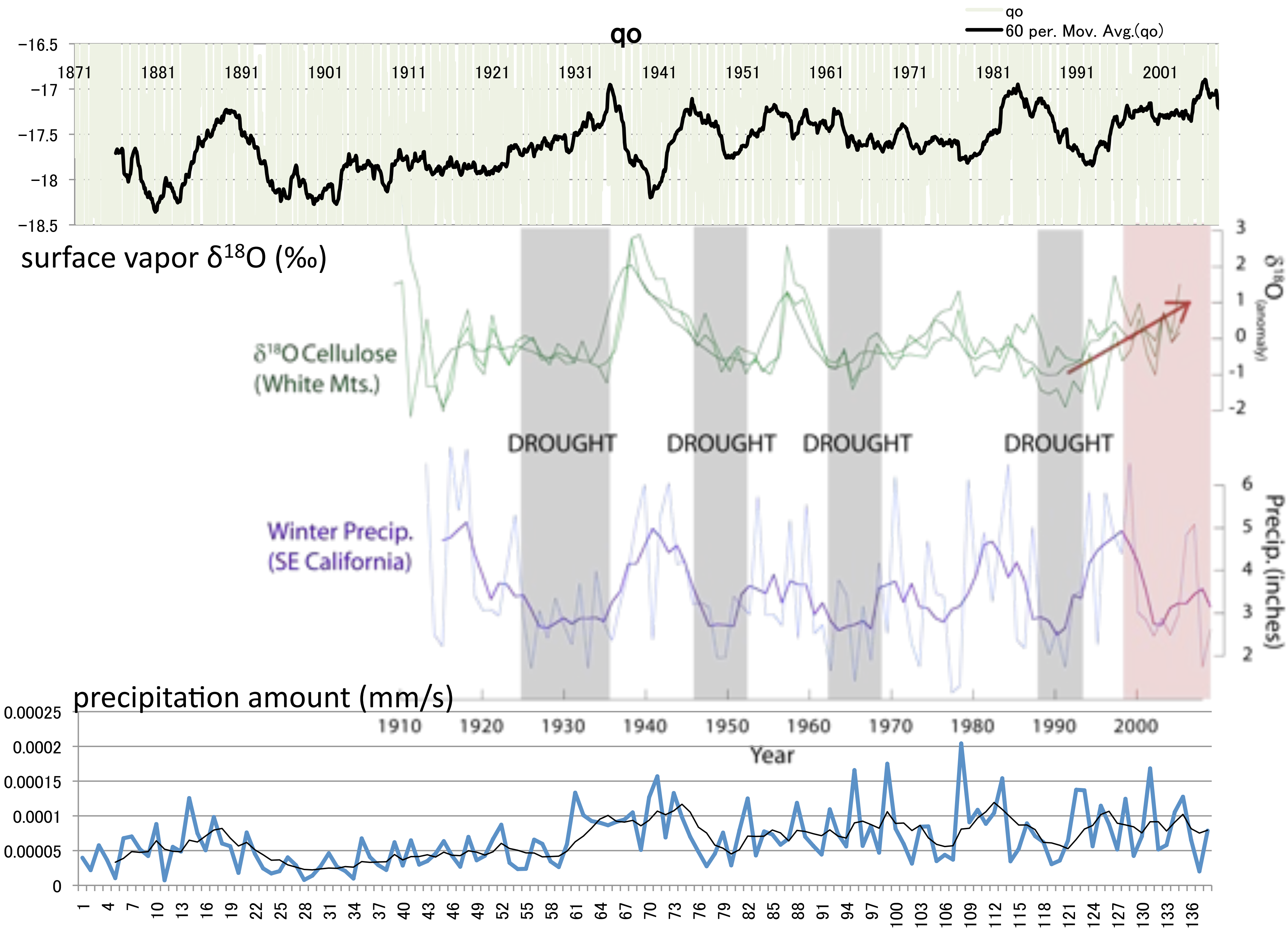
Kojima and Yoshimura, in prep

Cambodian Treering Cellulose δ^{18}O



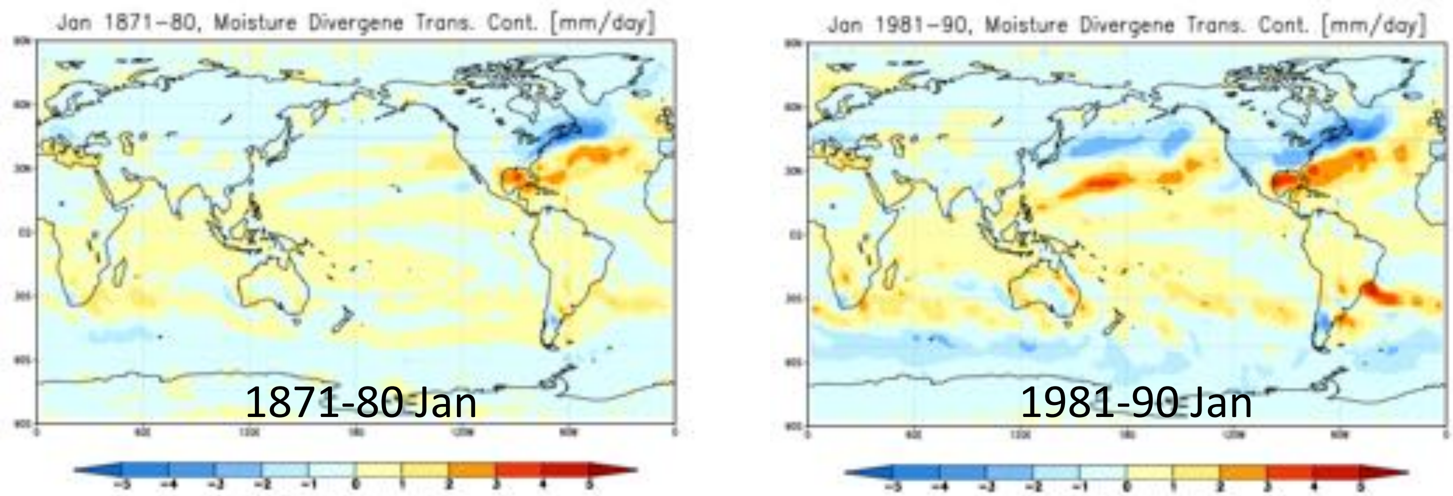


Comparison with Bristlecone δ18O (preliminary)



Issues

- Relationship between Bristlecone $\delta^{18}O$ and $\delta^{18}O$ in surface vapor remains unclear.
  - Limitation of Roden et al. (2000) biochem model?
- Did ensemble mean wind field properly work?
  - A single member run is necessary.

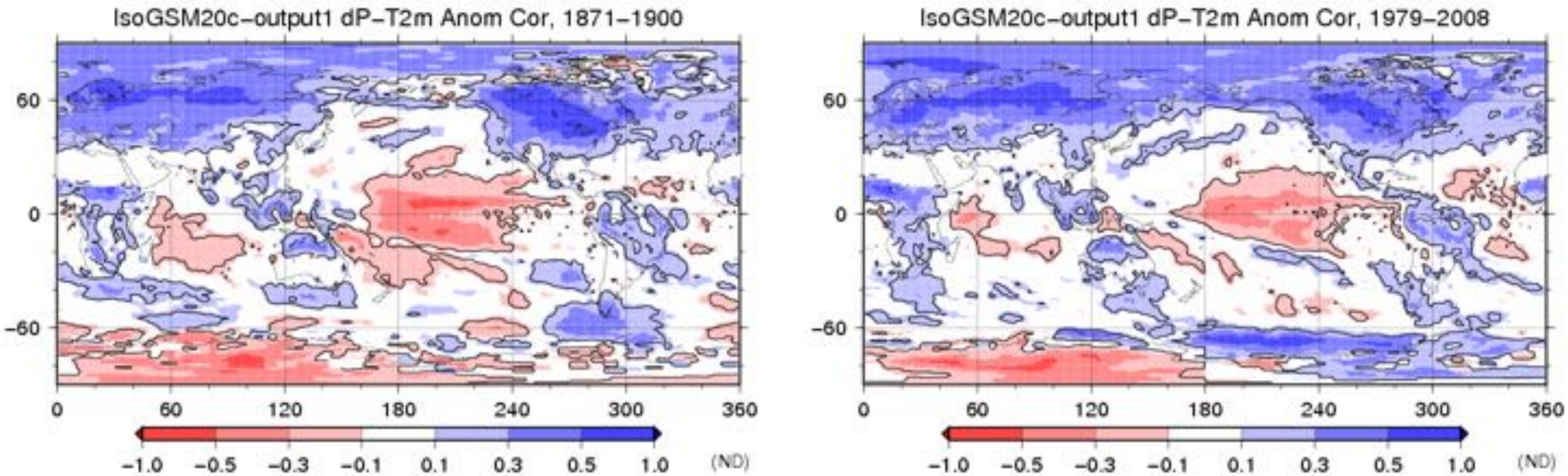


Monthly climatology of moisture divergence contribution from transient term

- More comparison/verification is needed.

Challenges

- Is climate proxy relationship changing?
  - More accurate and comprehensive climate reconstruction will be achievable.



Correlation between temperature and $\delta^{18}O$ in precipitation

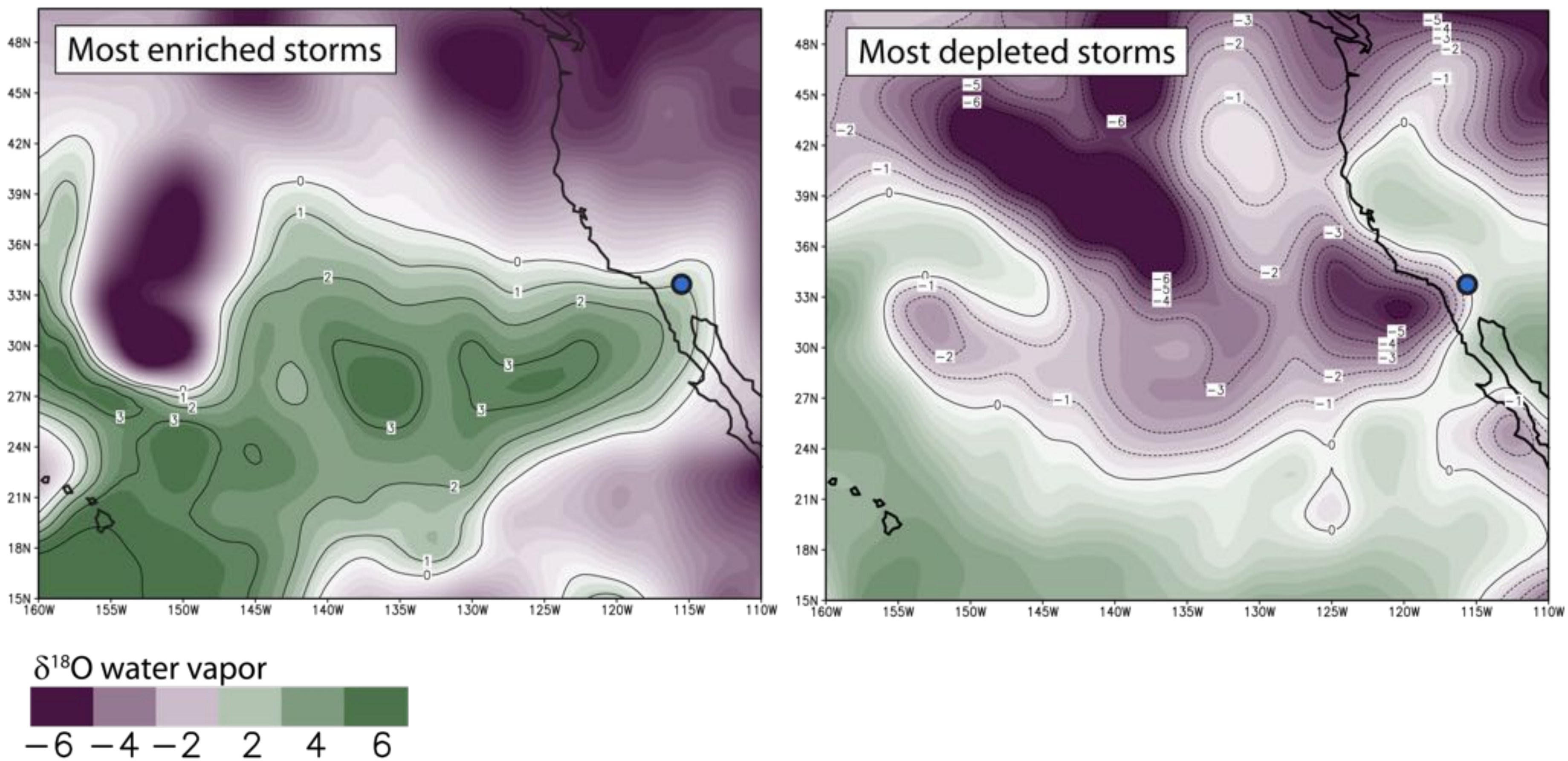
- A climate reanalysis with isotope information?
  - Simpler model is newly needed. But how?

Thanks for your attention.

Any Q&C, send email to keiyoshi08@gmail.com

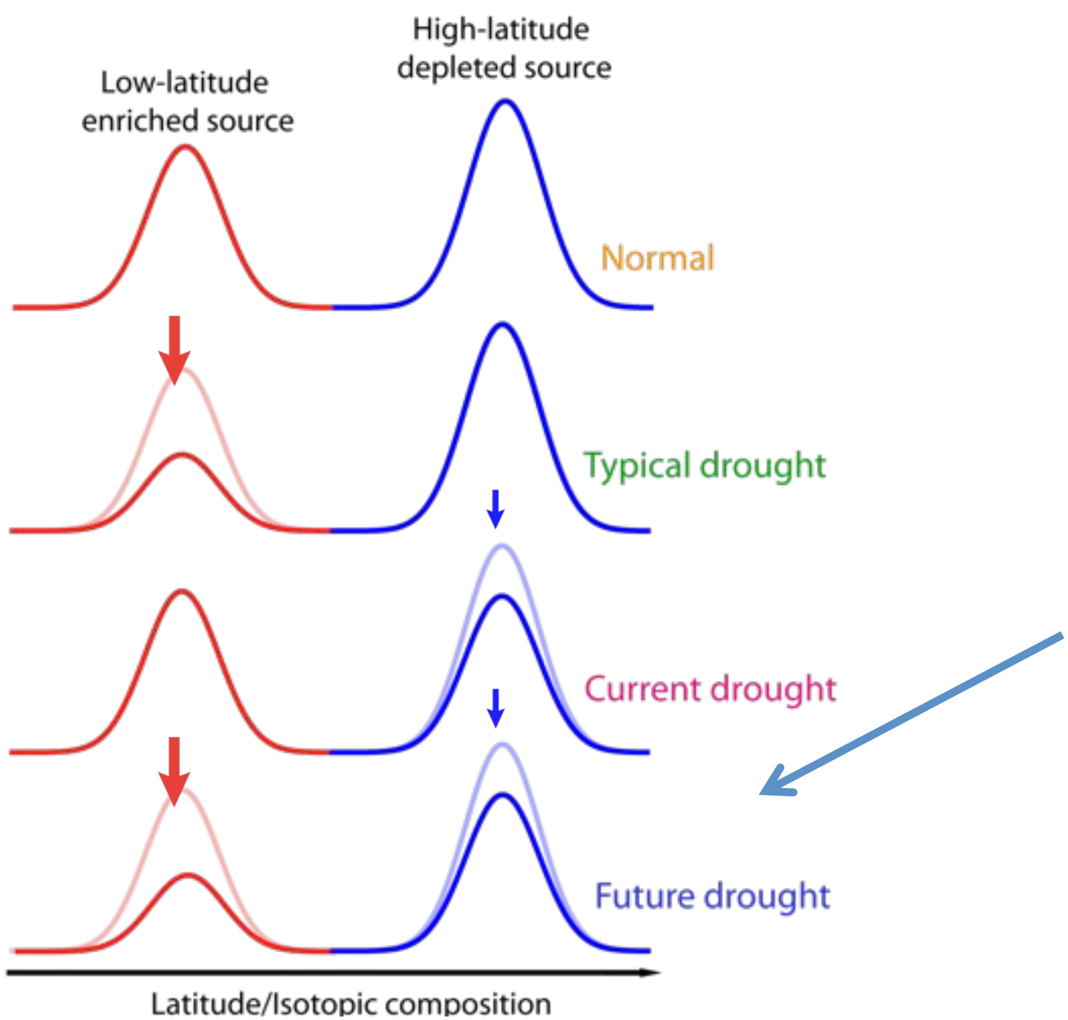
Model Simulates Individual Storms For the Past 30 Years

The most enriched isotopic events are associated with southwesterly flow tapping into a "heavy" vapor pool



Berkelhammer et al., prep.

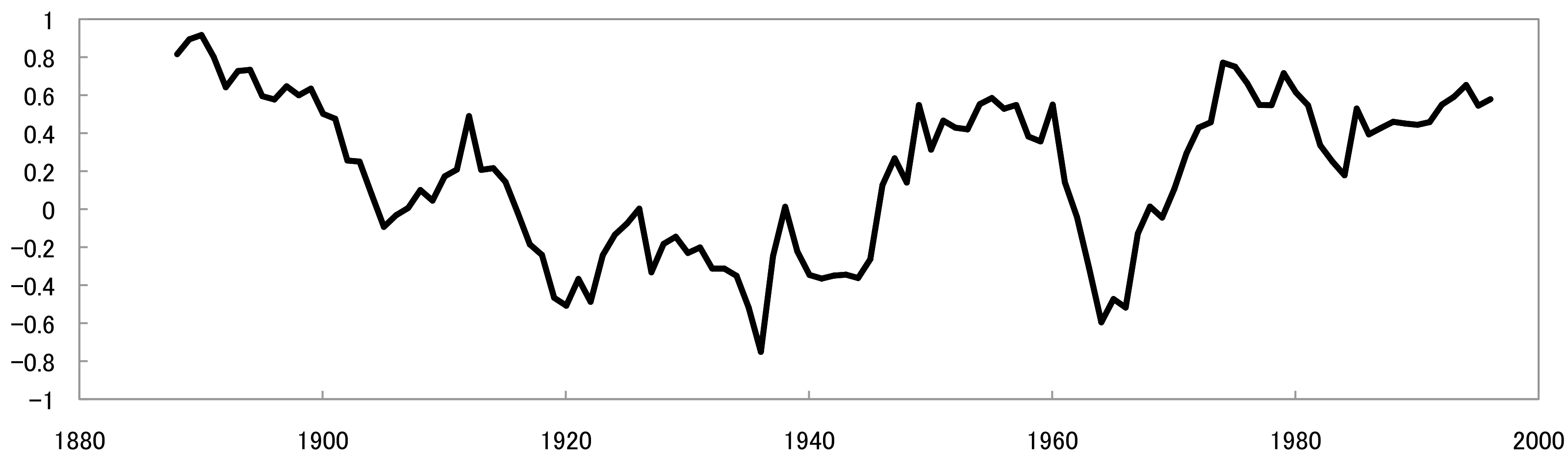
The Current Drought is Different



Open Questions:

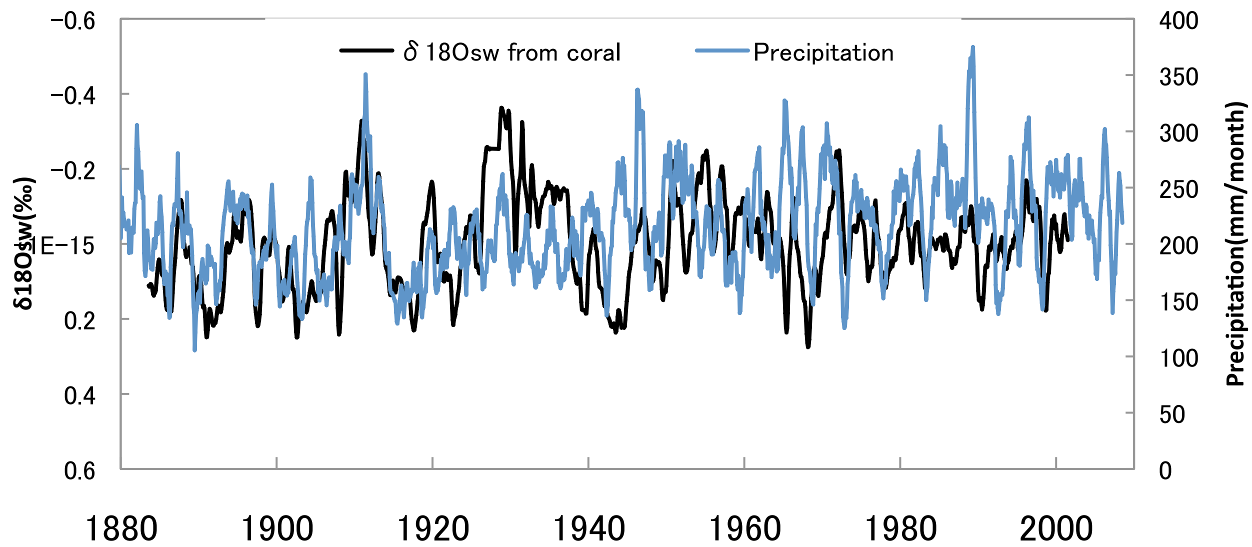
What implications do these ongoing changes have for aridity in the region?

Correlation between spring coral-$\delta^{18}O_{sw}$ (March to May) and previous season NINO34 (DJF)

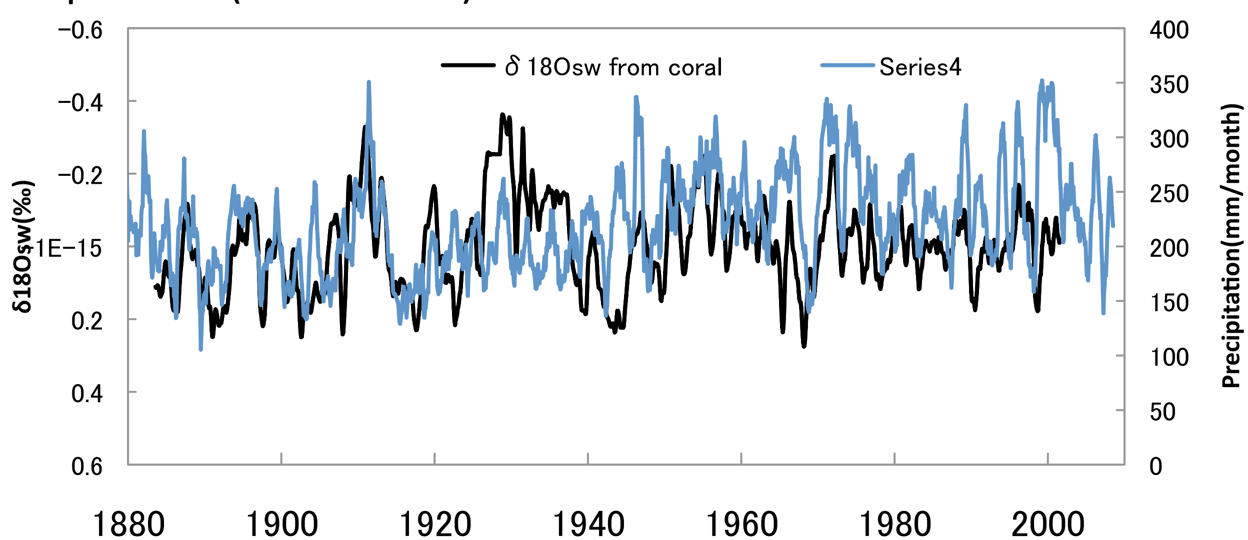


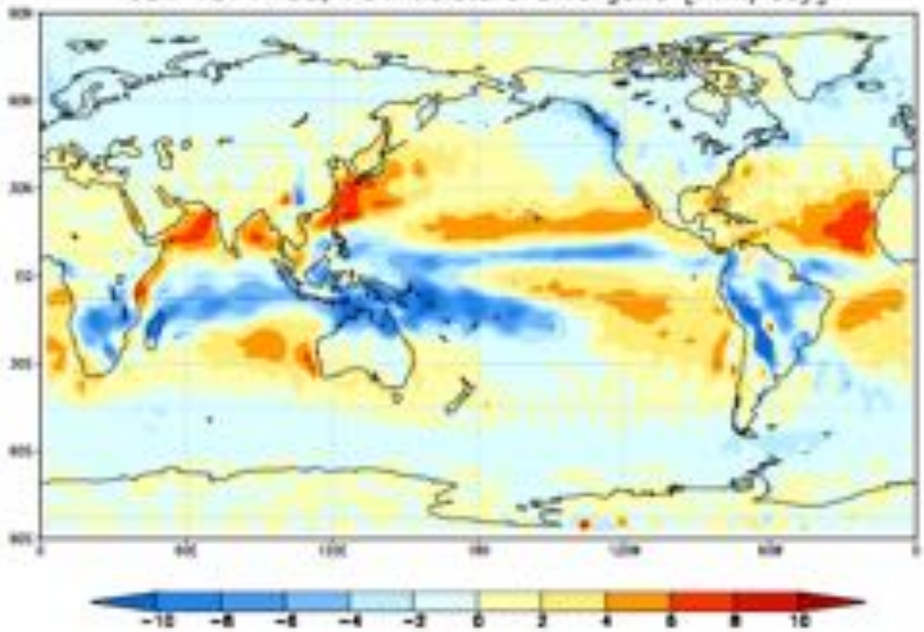
δ18Osw from coral vs. precipitation (1year running average)

IsoGSM precipitation

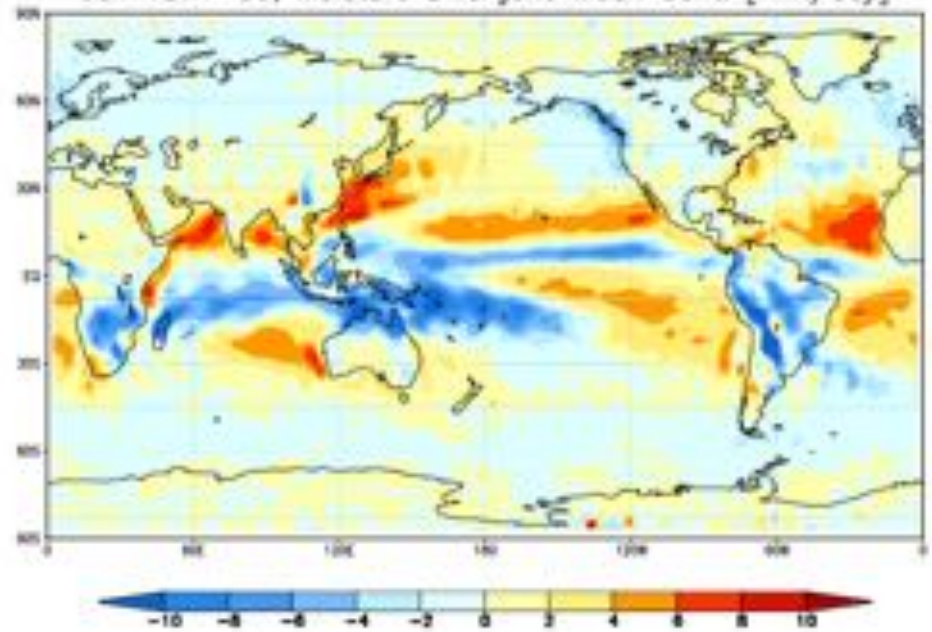


Local precipitation (1951~2000)

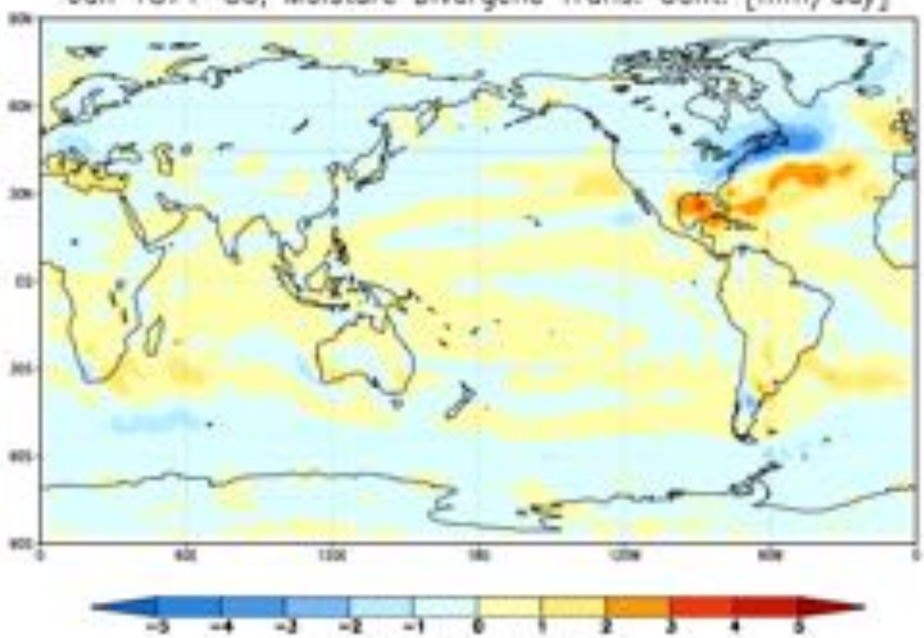




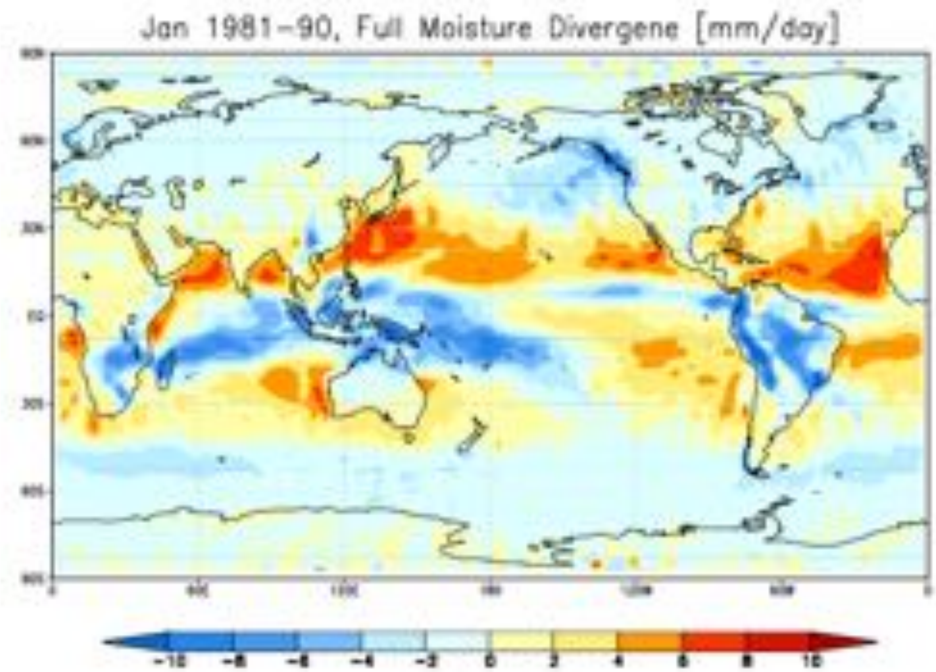
Jan 1871-80, Full Moisture Divergene [mm/day]

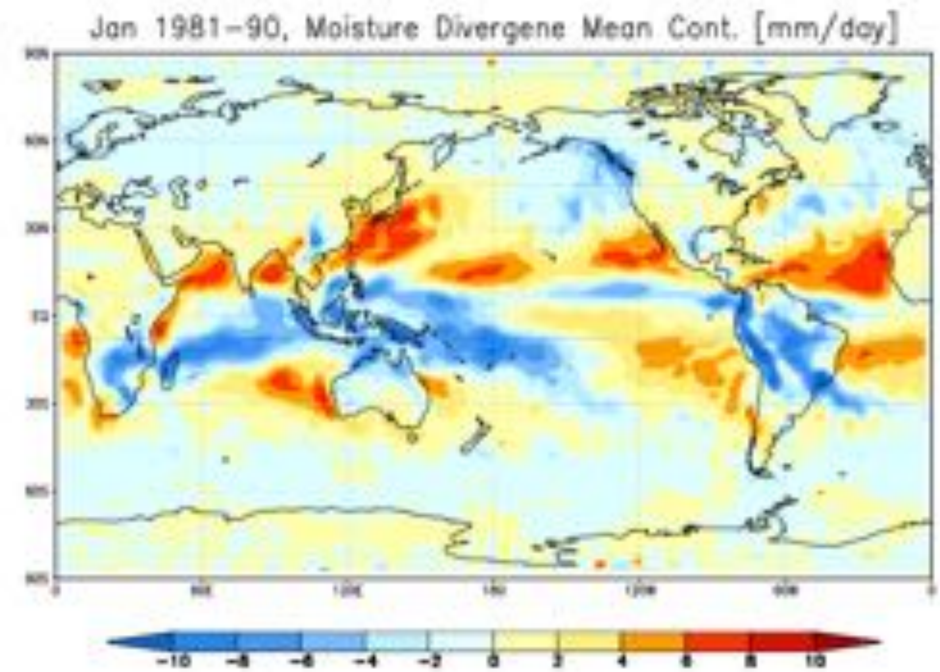


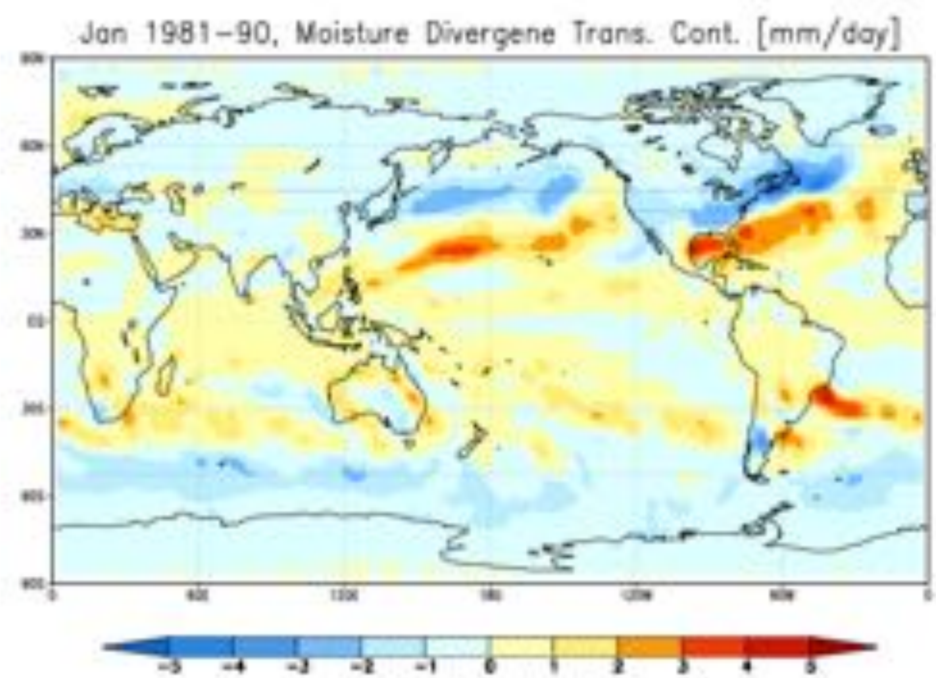
Jan 1871-80, Moisture Divergene Mean Cont. [mm/day]

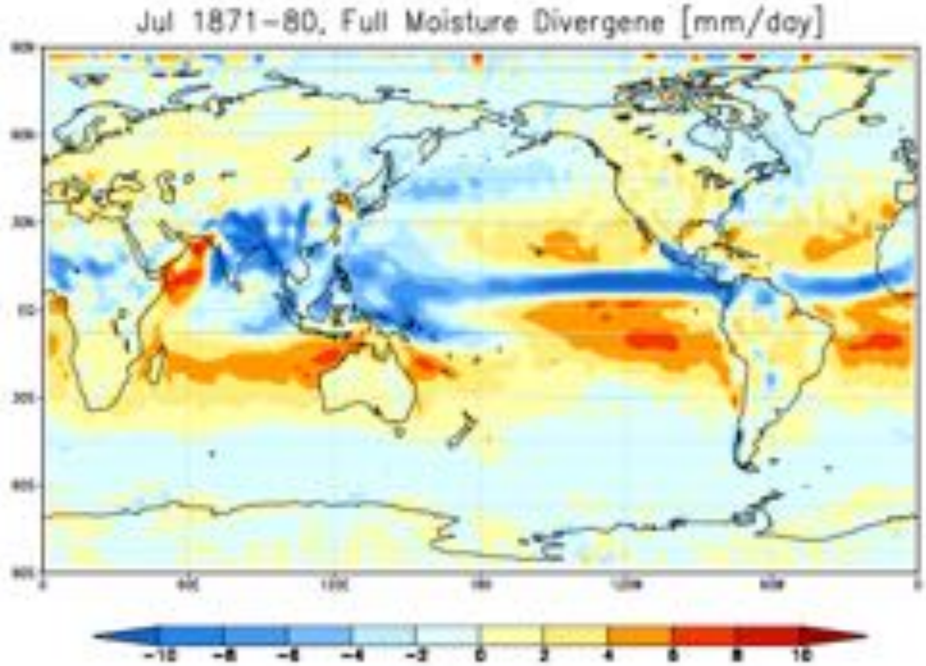


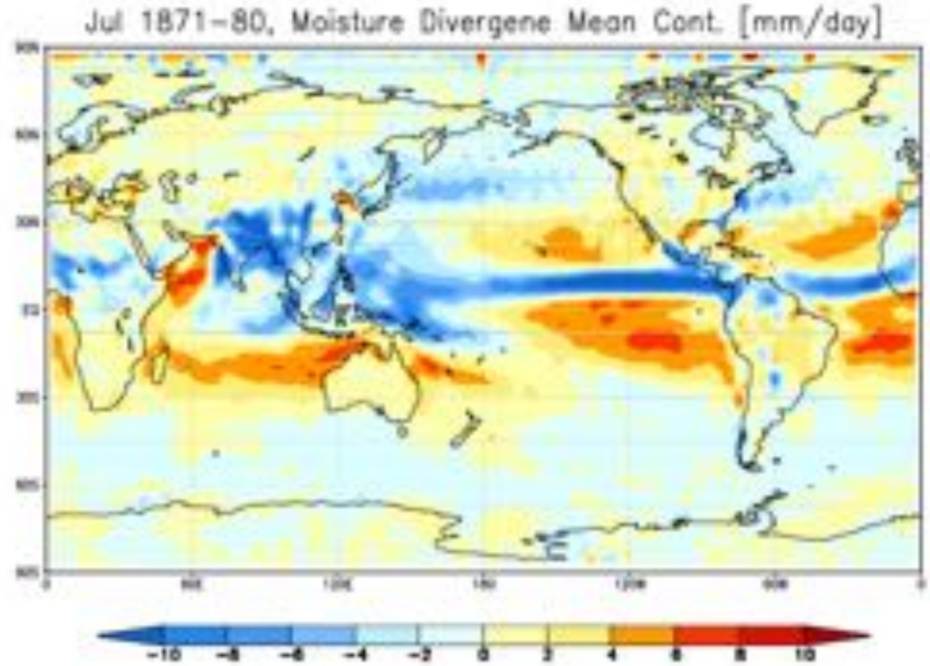
Jan 1871-80, Moisture Divergene Trans. Cont. [mm/day]

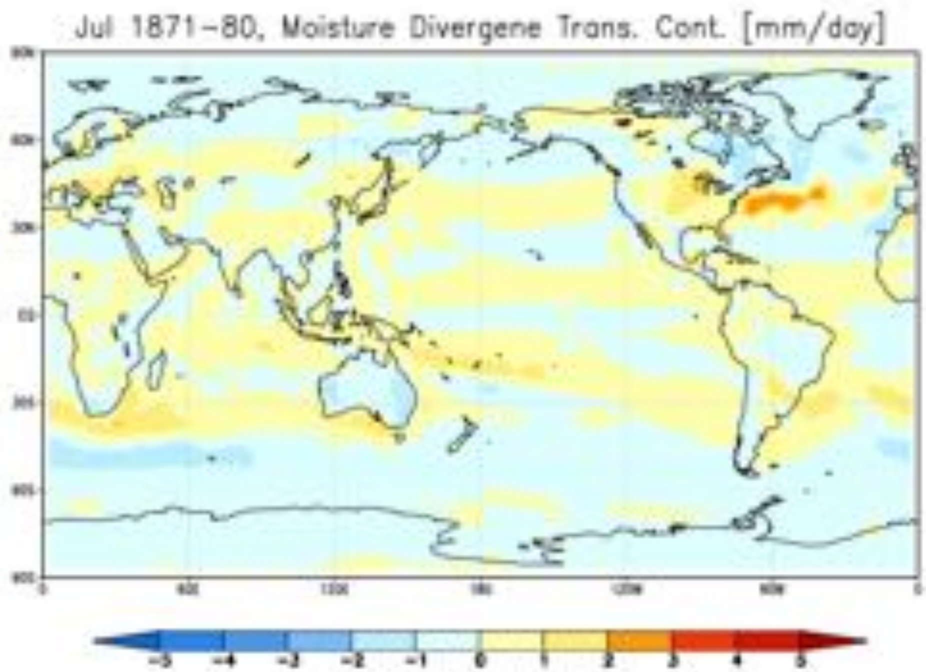

Jan 1981-90, Full Moisture Divergene [mm/day]
-10 -8 -6 -4 -2 0 2 4 6 8 10


Jan 1981-90, Moisture Divergene Mean Cont. [mm/day]
-10 -8 -6 -4 -2 0 2 4 6 8 10

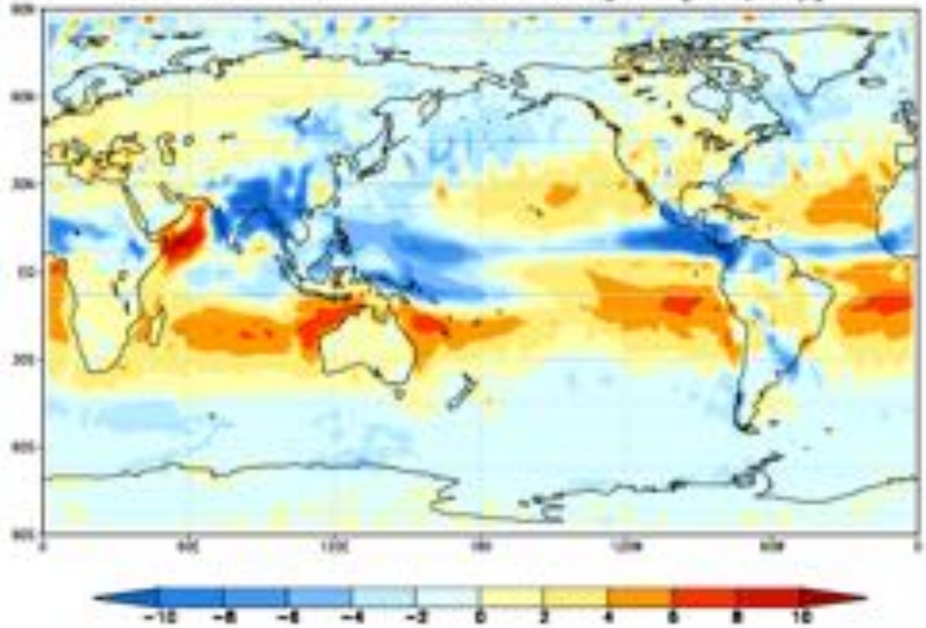

Jan 1981-90, Moisture Divergene Trans. Cont. [mm/day]
-5 -4 -3 -2 -1 0 1 2 3 4 5


Jul 1871-80, Full Moisture Divergene [mm/day]
-10 -8 -6 -4 -2 0 2 4 6 8 10

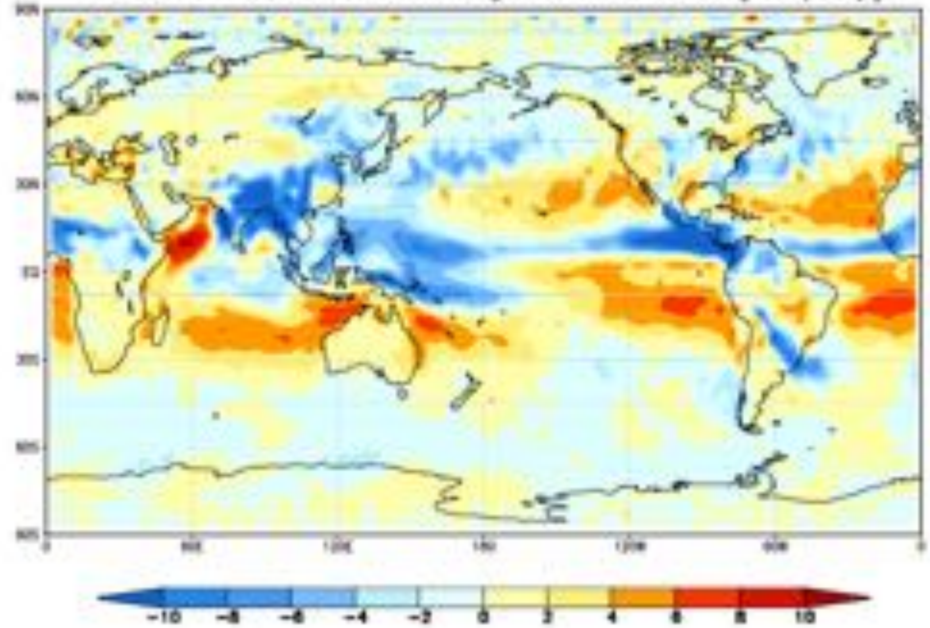

Jul 1871-80, Moisture Divergene Mean Cont. [mm/day]
-10 -8 -6 -4 -2 0 2 4 6 8 10


Jul 1871-80, Moisture Divergene Trans. Cont. [mm/day]
-5 -4 -3 -2 -1 0 1 2 3 4 5

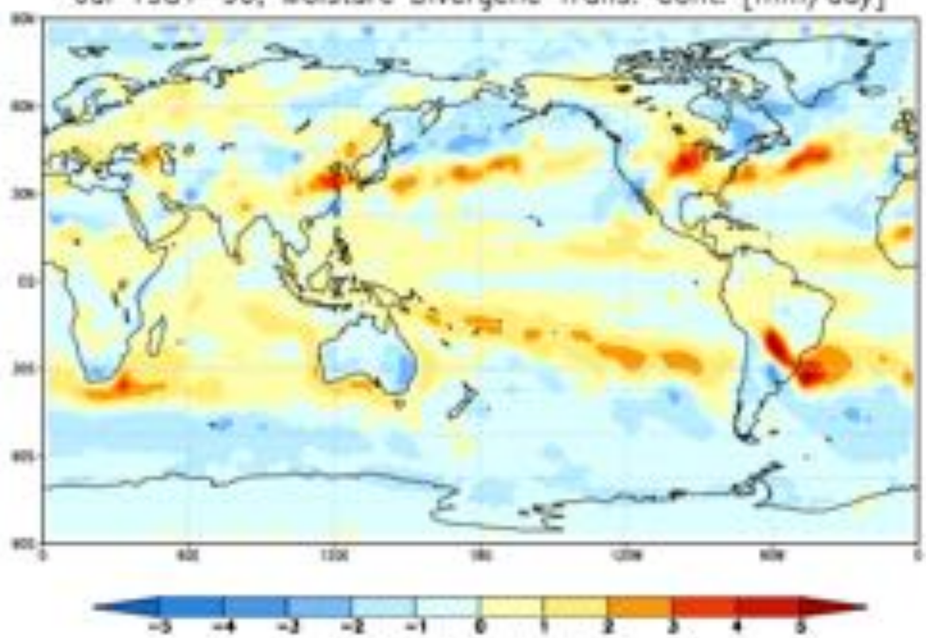
Jul 1981-90, Full Moisture Divergene [mm/day]

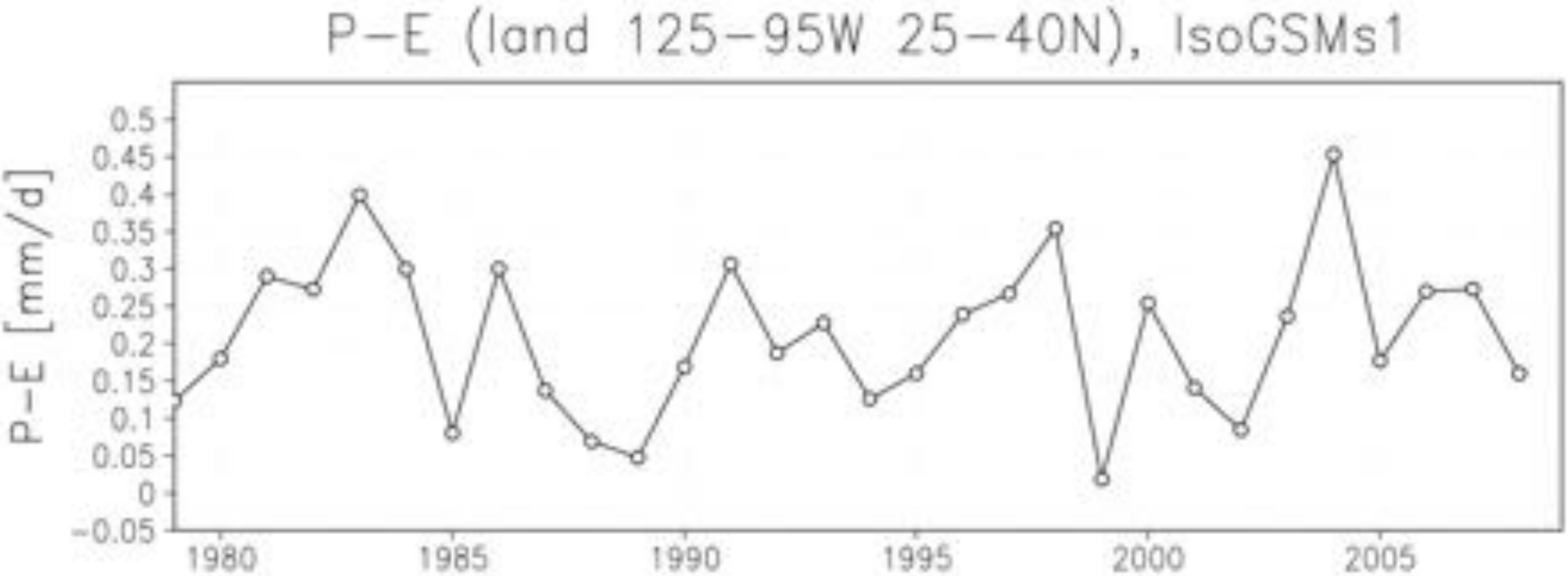


Jul 1981-90, Moisture Divergene Mean Cont. [mm/day]

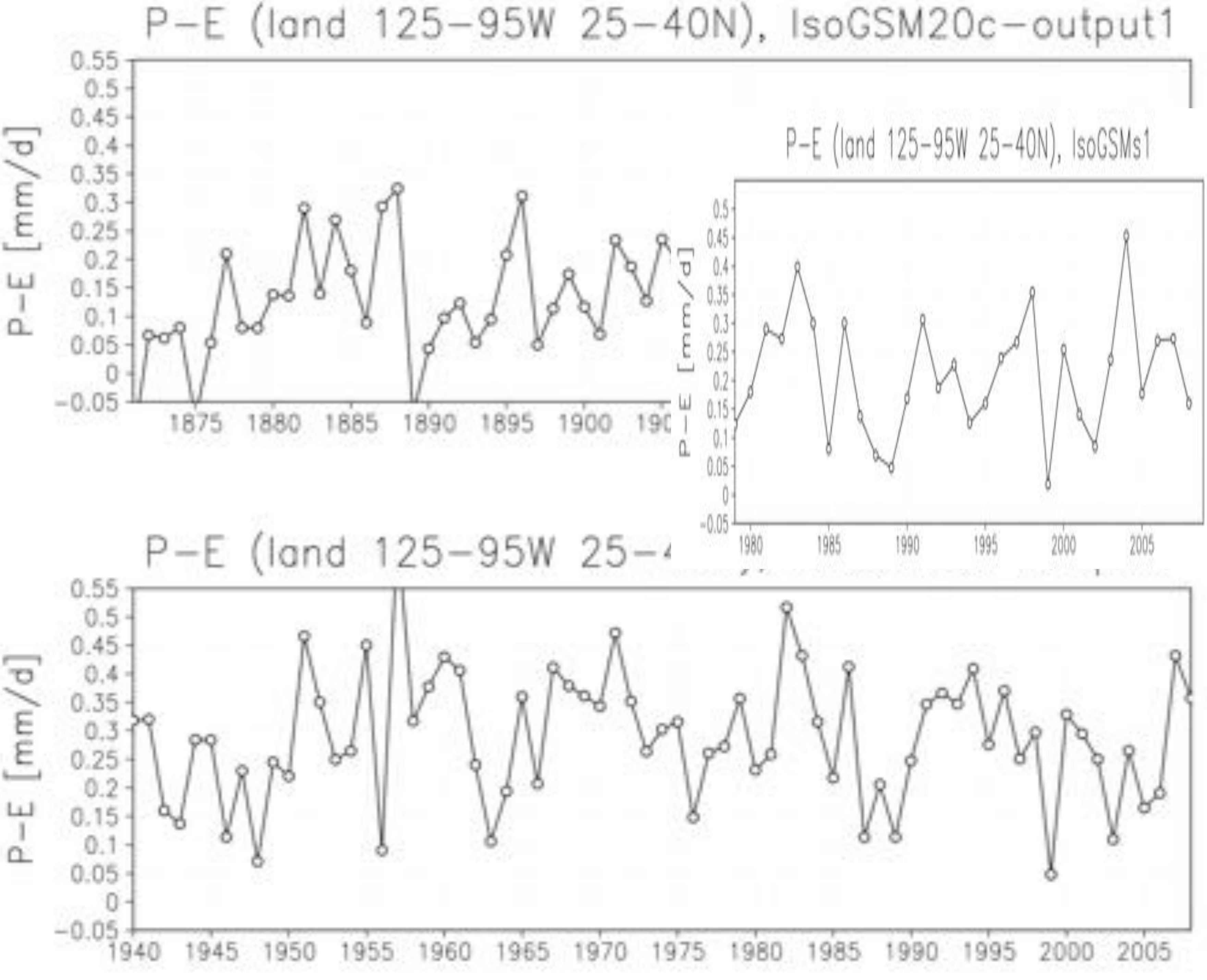


Jul 1981-90, Moisture Divergene Trans. Cont. [mm/day]





P-E (land 125-95W 25-40N), IsoGSMs1
P-E [mm/d]
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
1980
1985
1990
1995
2000
2005

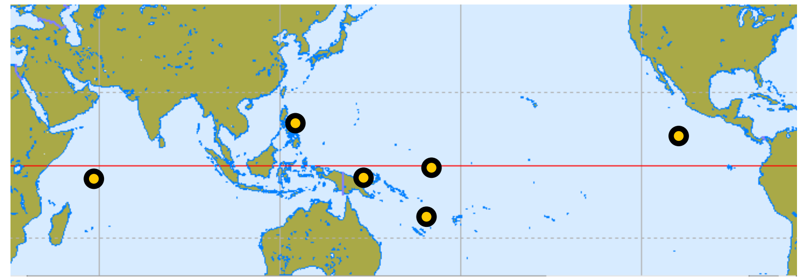


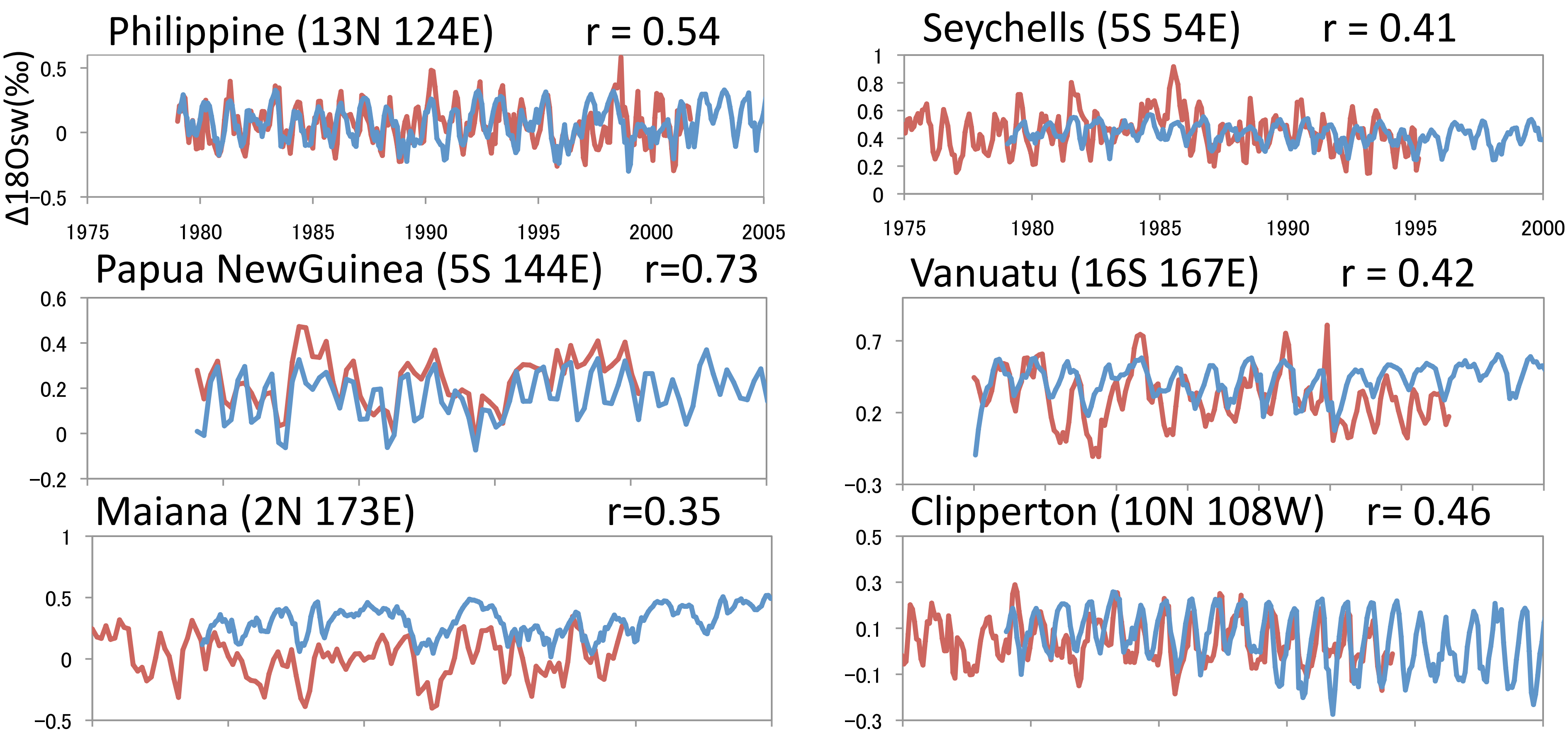
P−E (land 125−95W 25−40N), IsoGSM20c−output1
P−E [mm/d]
0.55 0.5 0.45 0.4 0.35 0.3 0.25 0.2 0.15 0.1 0.05 0 −0.05
1875 1880 1885 1890 1895 1900
P−E (land 125−95W 25−40N), IsoGSMs1
P − E [mm/d]
0.5 0.45 0.4 0.35 0.3 0.25 0.2 0.15 0.1 0.05 0 −0.05
1980 1985 1990 1995 2000 2005
P−E (land 125−95W 25−
P−E [mm/d]
0.55 0.5 0.45 0.4 0.35 0.3 0.25 0.2 0.15 0.1 0.05 0 −0.05
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005

Simulating sea water isotopes (1979-2009)

(Courtesy of Keitaro Kojima)

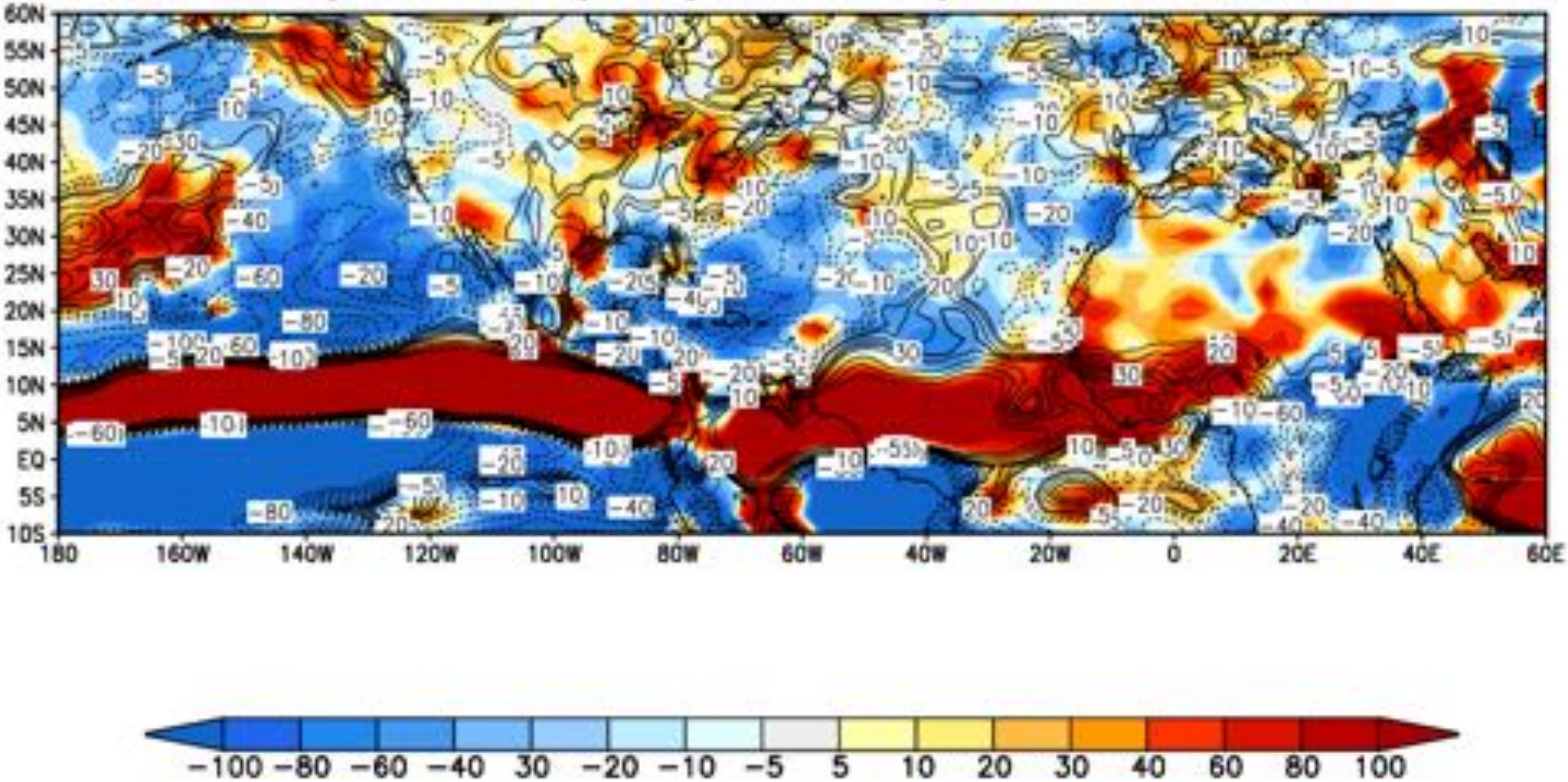
— : Model — : Obs (Coral)



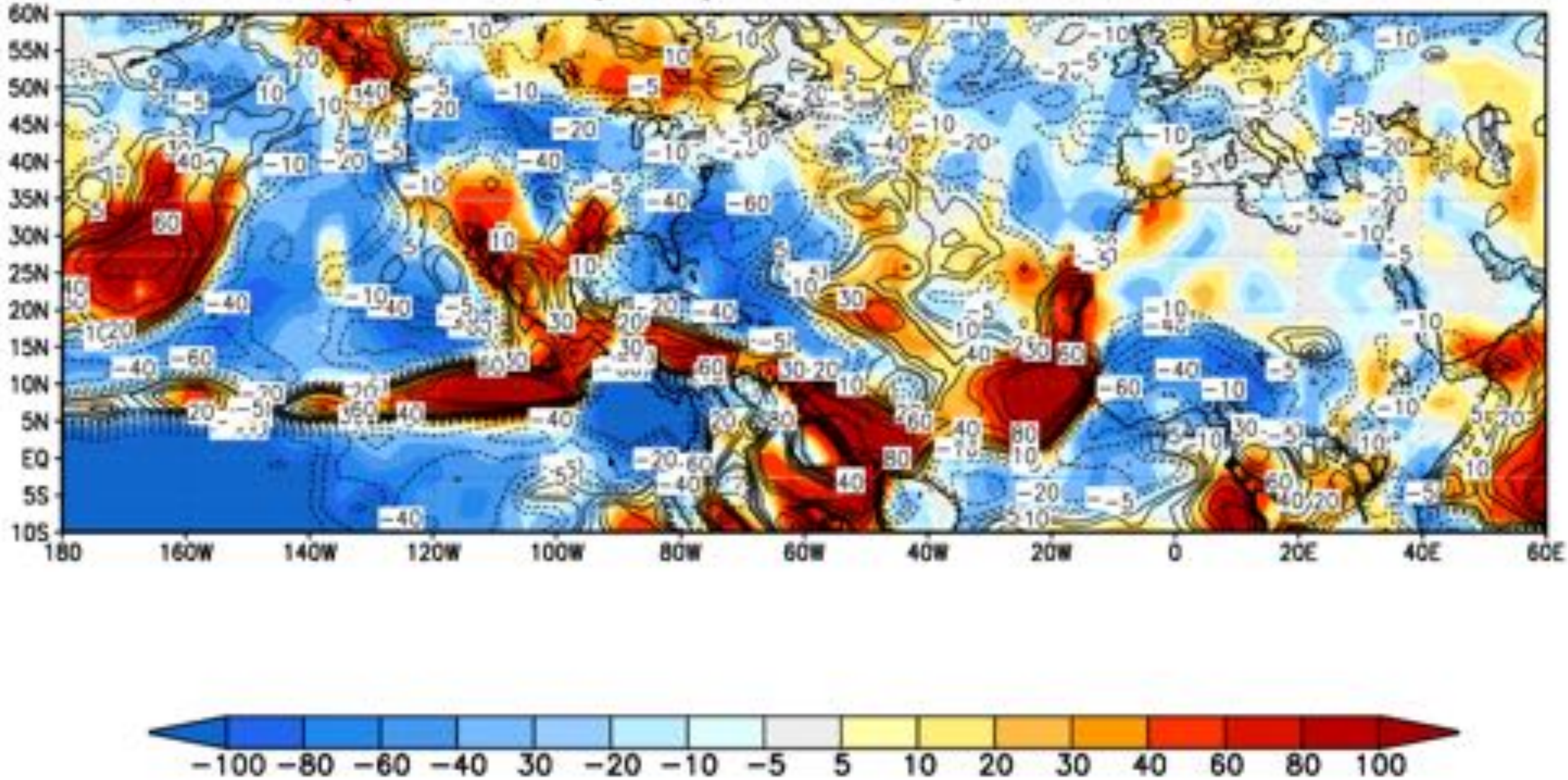


Better reproducibility (R=0.25~0.73) at humid climate sites

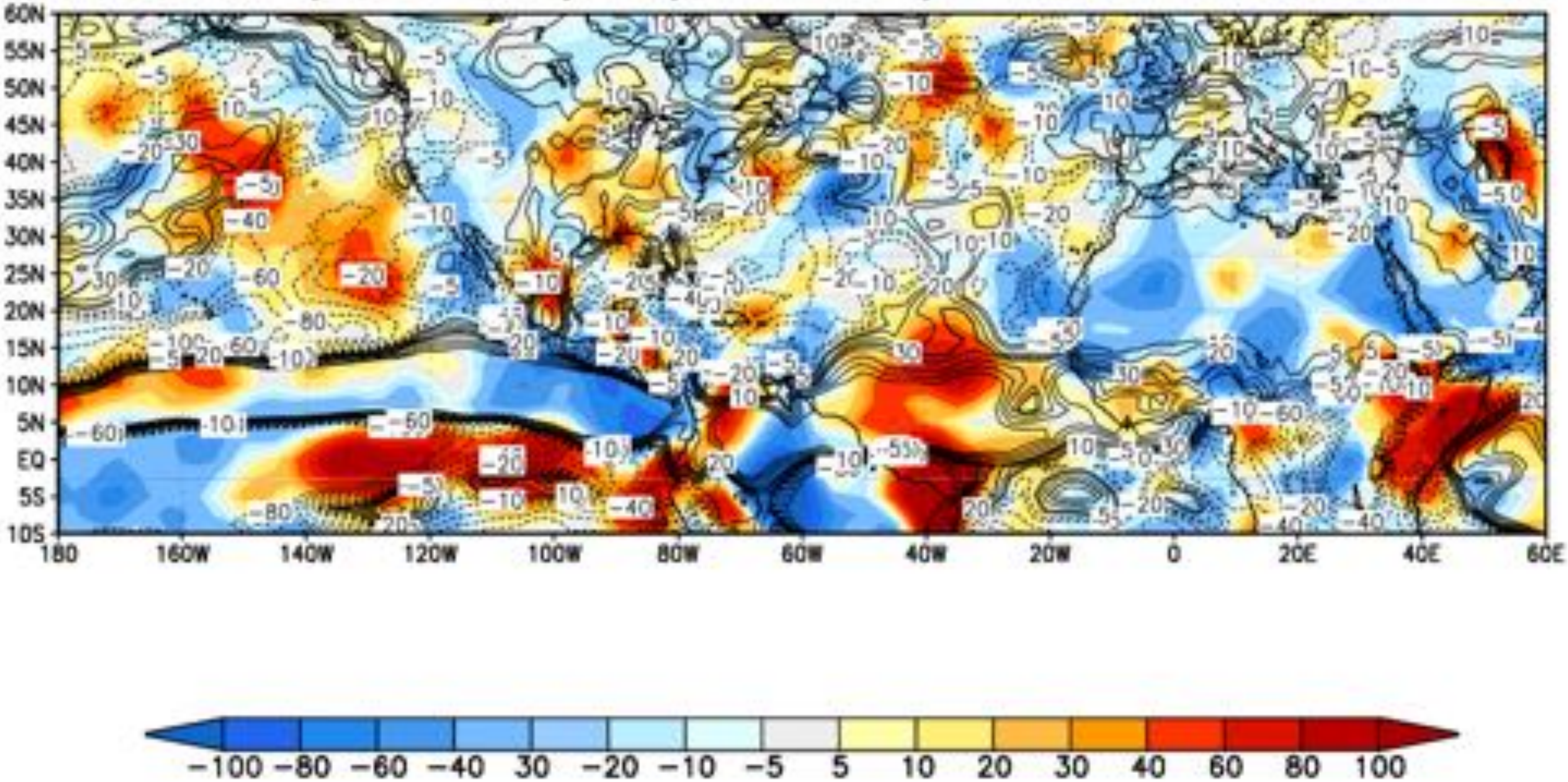
A Mean Circulation Contribution [1e−2 mm/d]
(2008−1999) − (1979−1998) Δa=0.0383766

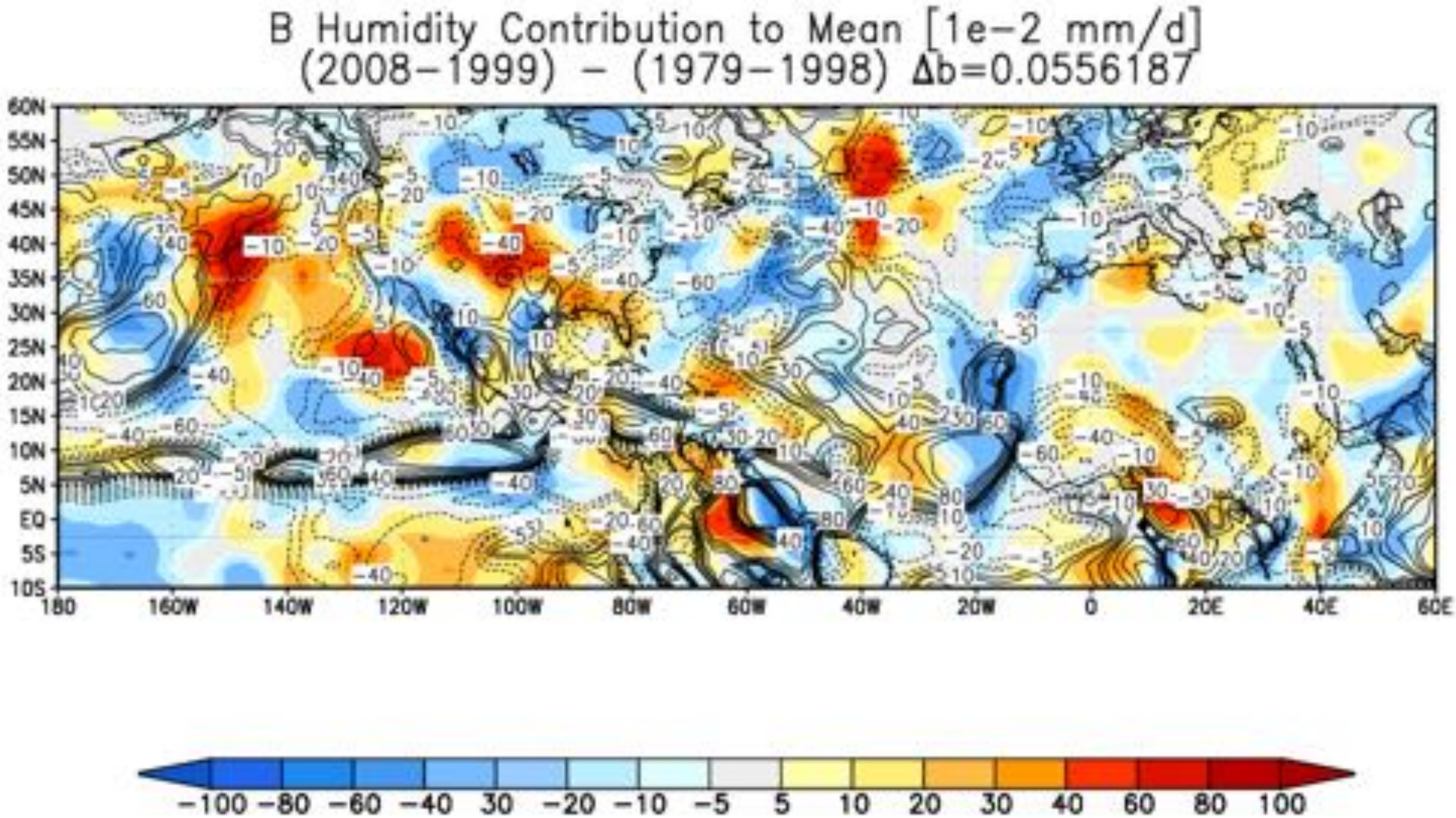


A Mean Circulation Contribution [1e−2 mm/d]
(2008−1999) − (1979−1998) Δa=0.221633

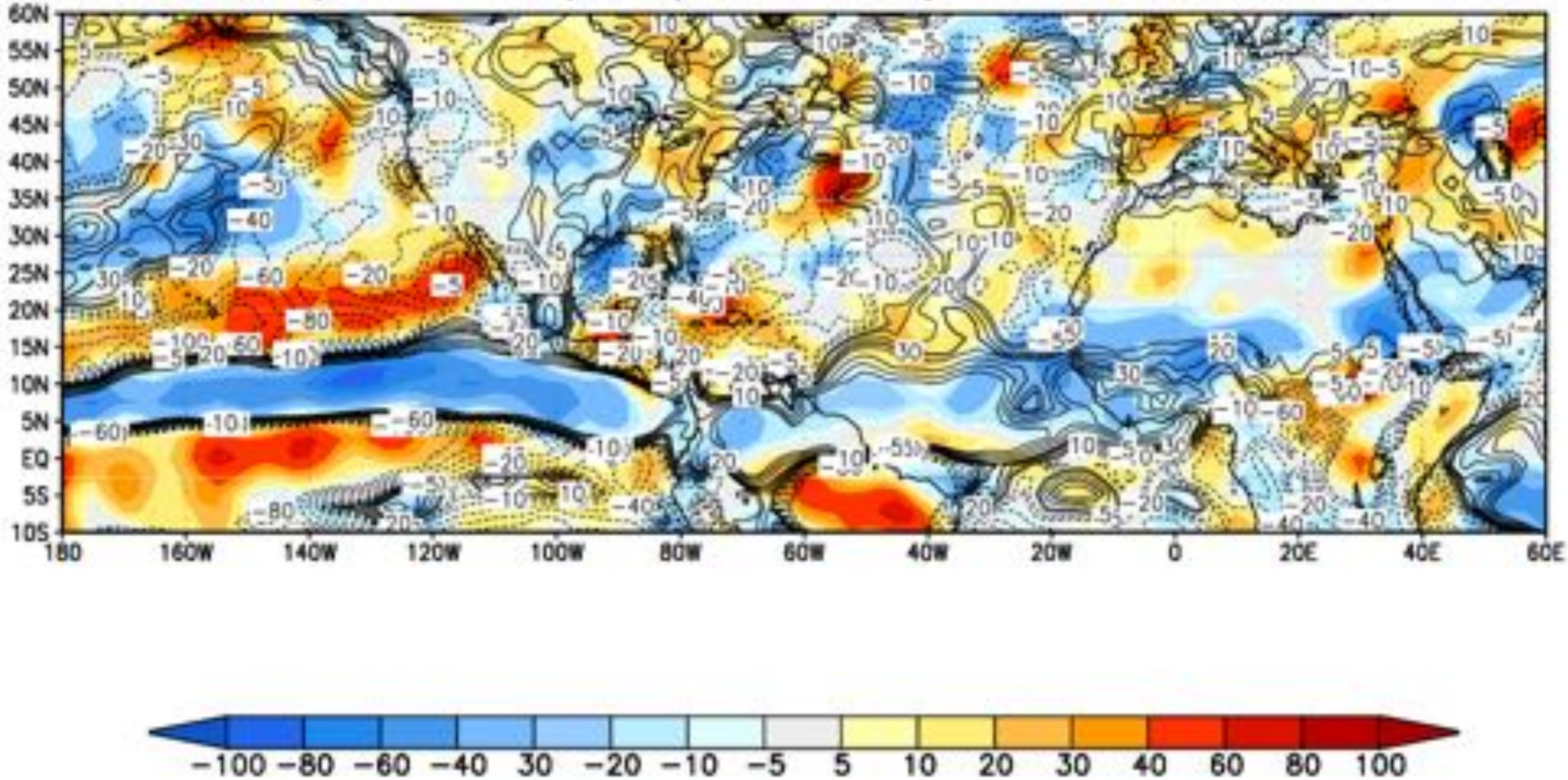


B Humidity Contribution to Mean [1e-2 mm/d]
(2008-1999) - (1979-1998) Δb=-0.0104005

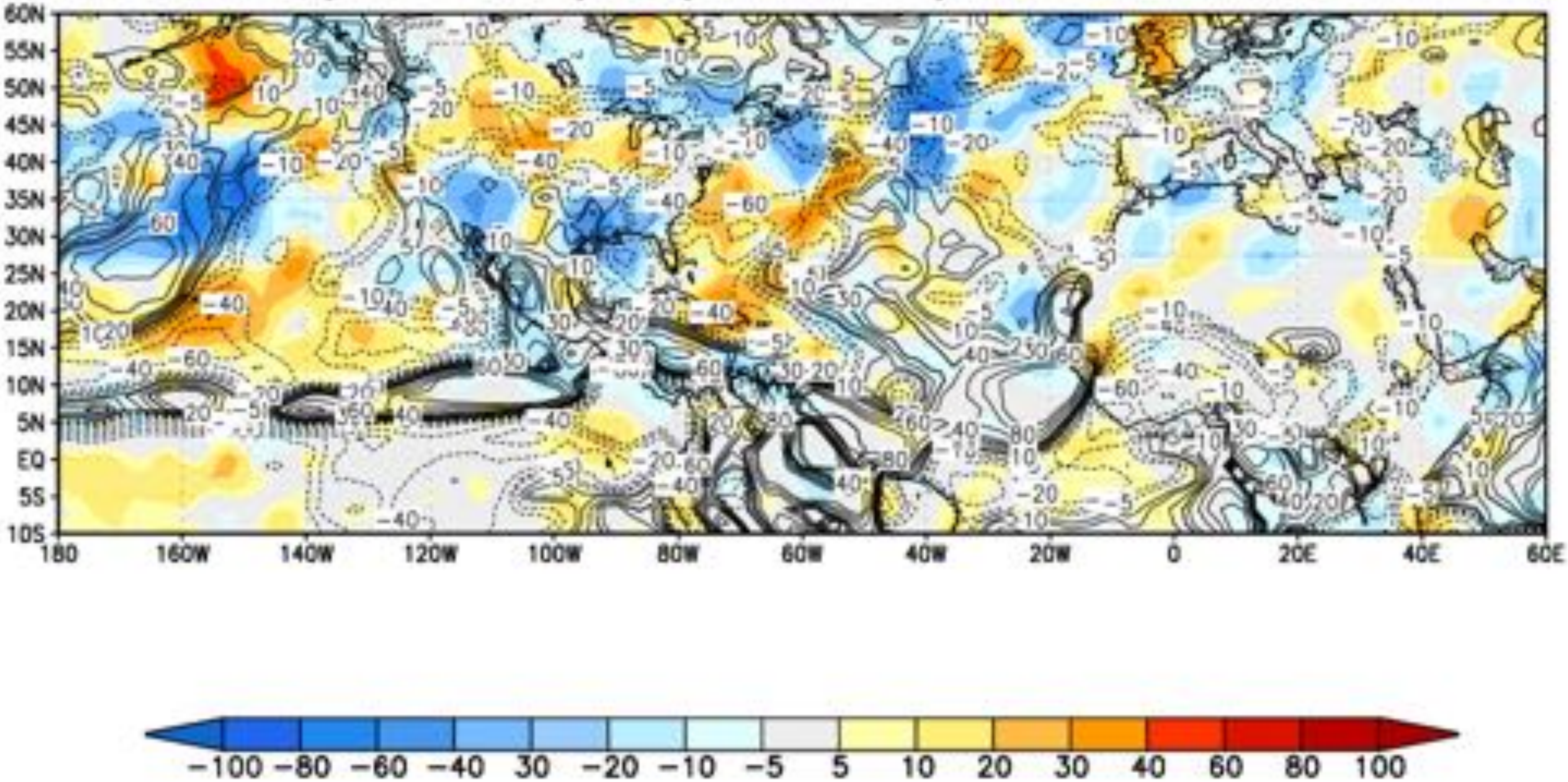



B Humidity Contribution to Mean [1e−2 mm/d]
(2008−1999) − (1979−1998) Δb=0.0556187
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
180
160W
140W
120W
100W
80W
60W
40W
20W
0
20E
40E
60E
−100 −80 −60 −40 30 −20 −10 −5 5 10 20 30 40 60 80 100

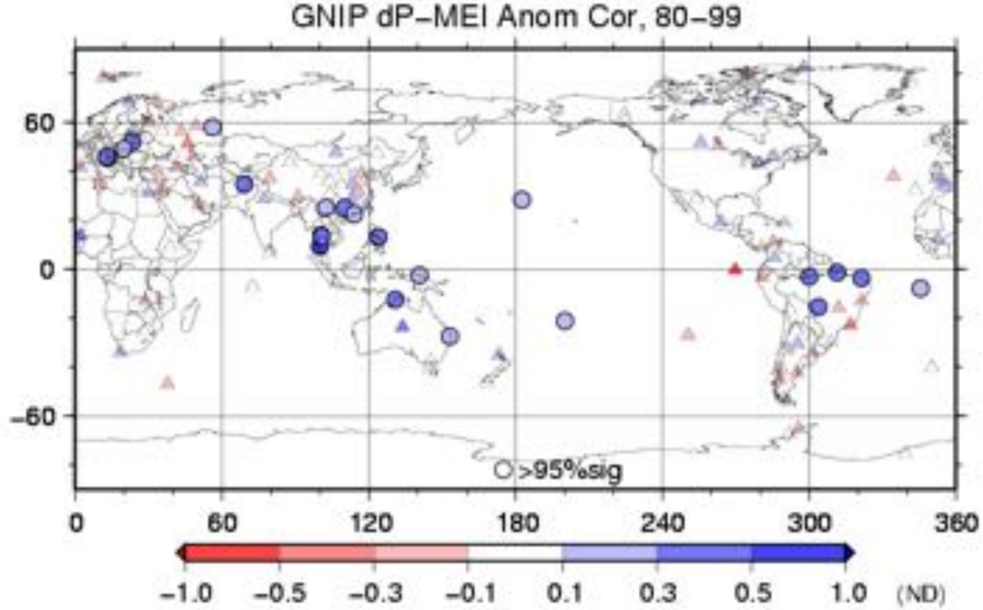
C Transient Contribution [1e−2 mm/d]
(2008−1999) − (1979−1998) Δc=−0.0222284

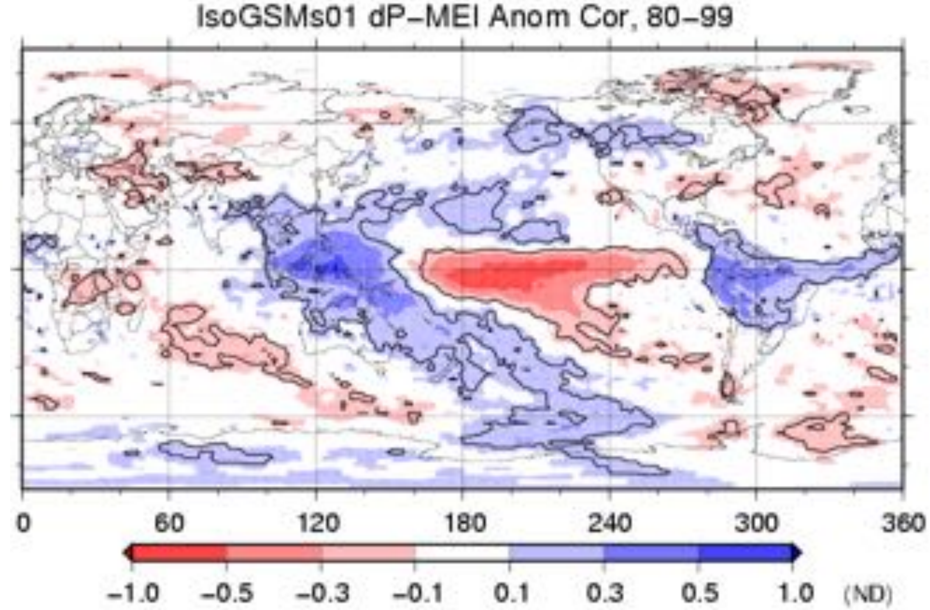


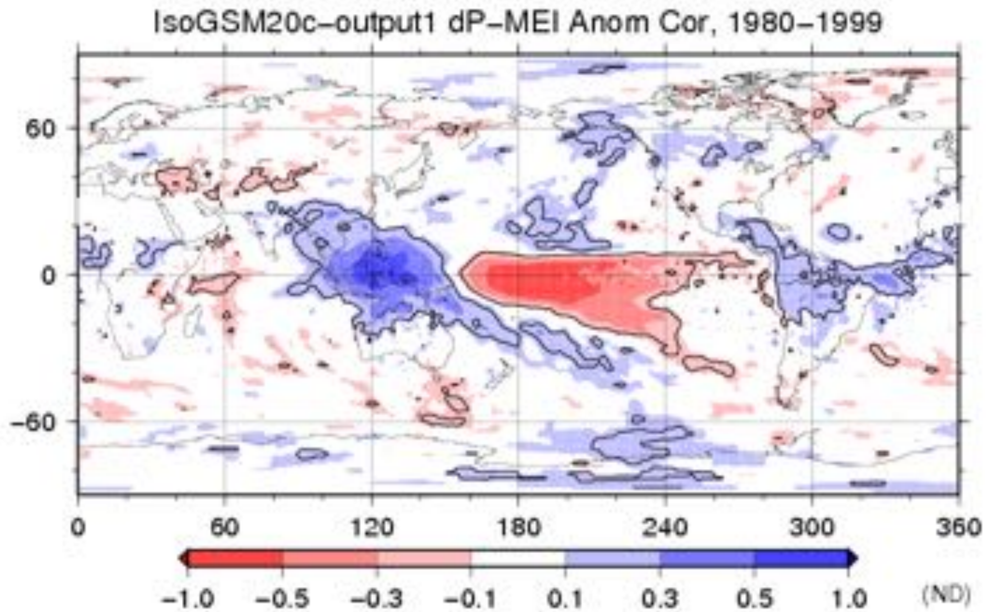
C Transient Contribution [1e−2 mm/d]
(2008−1999) − (1979−1998) Δc=−0.122065



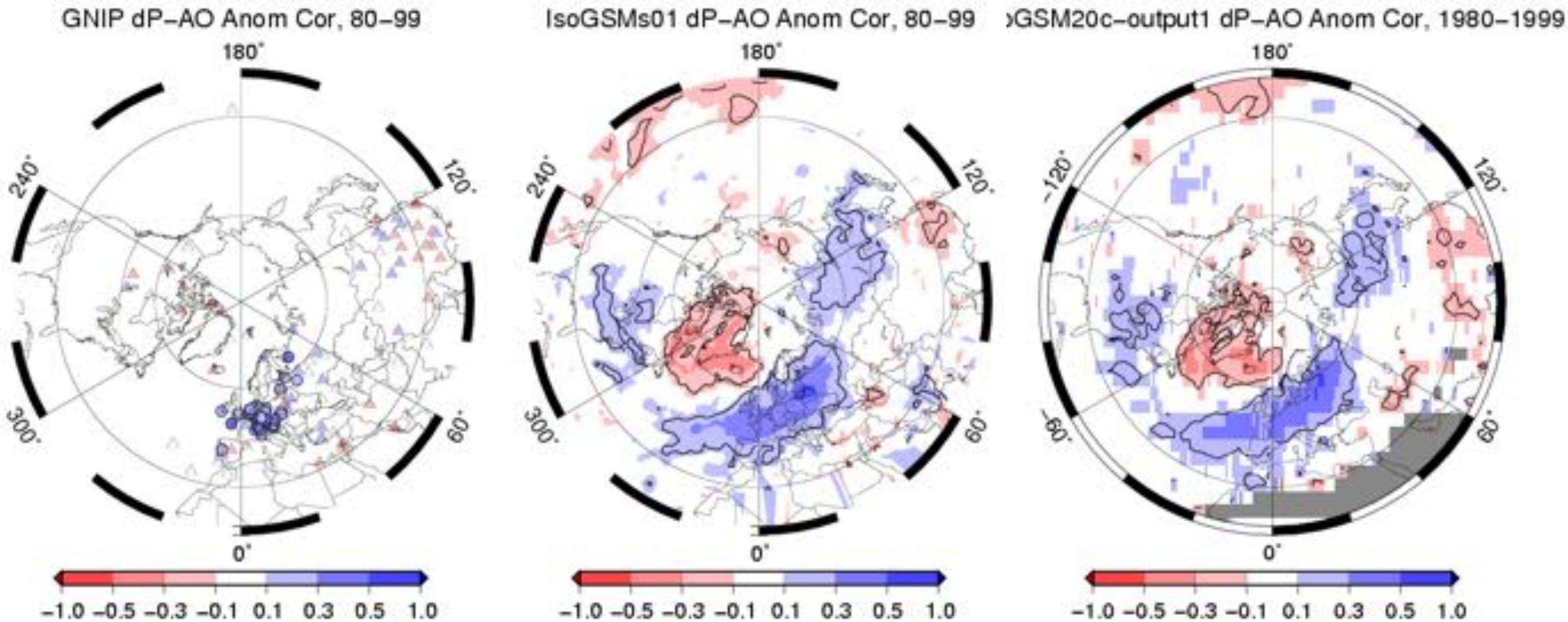
Correlation with ENSO

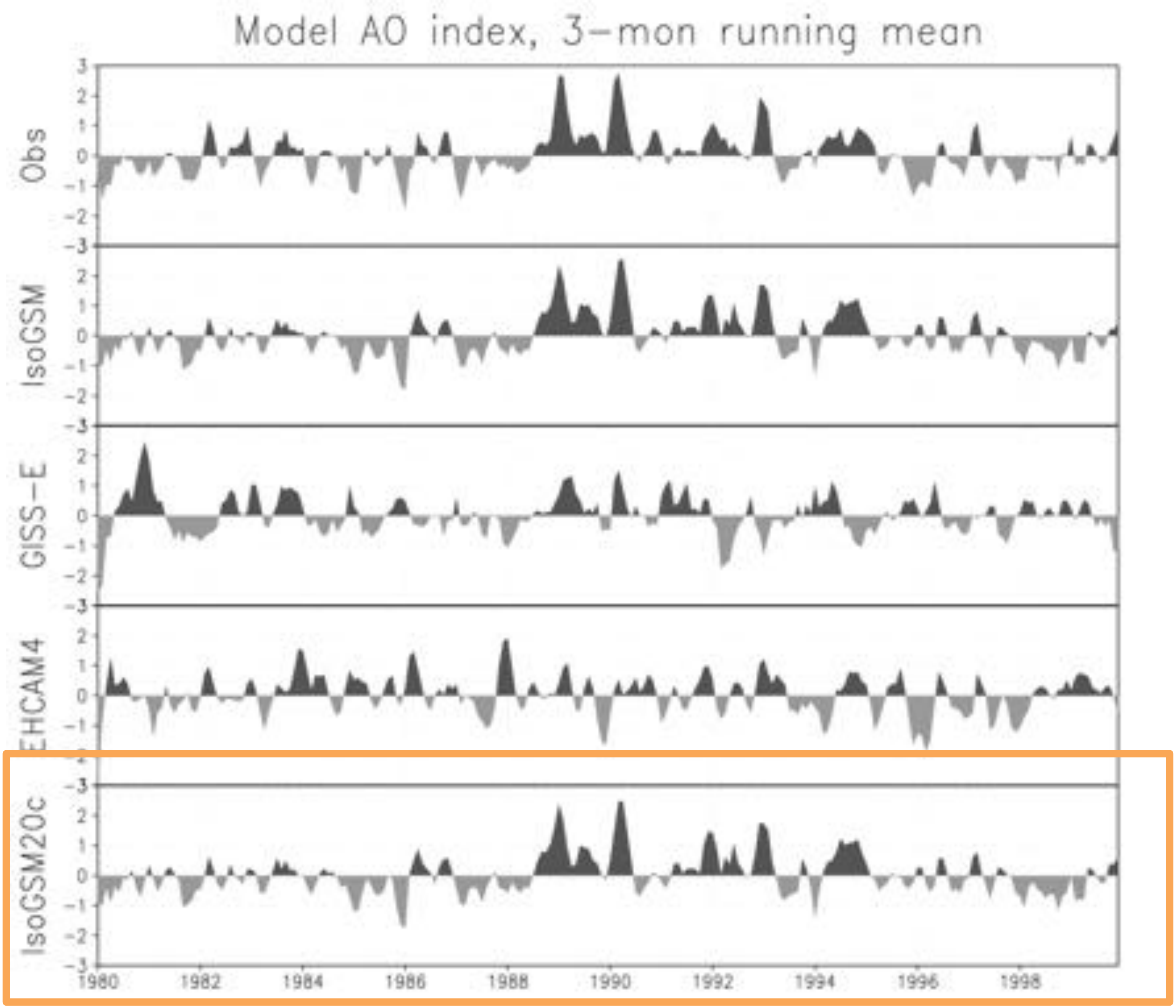




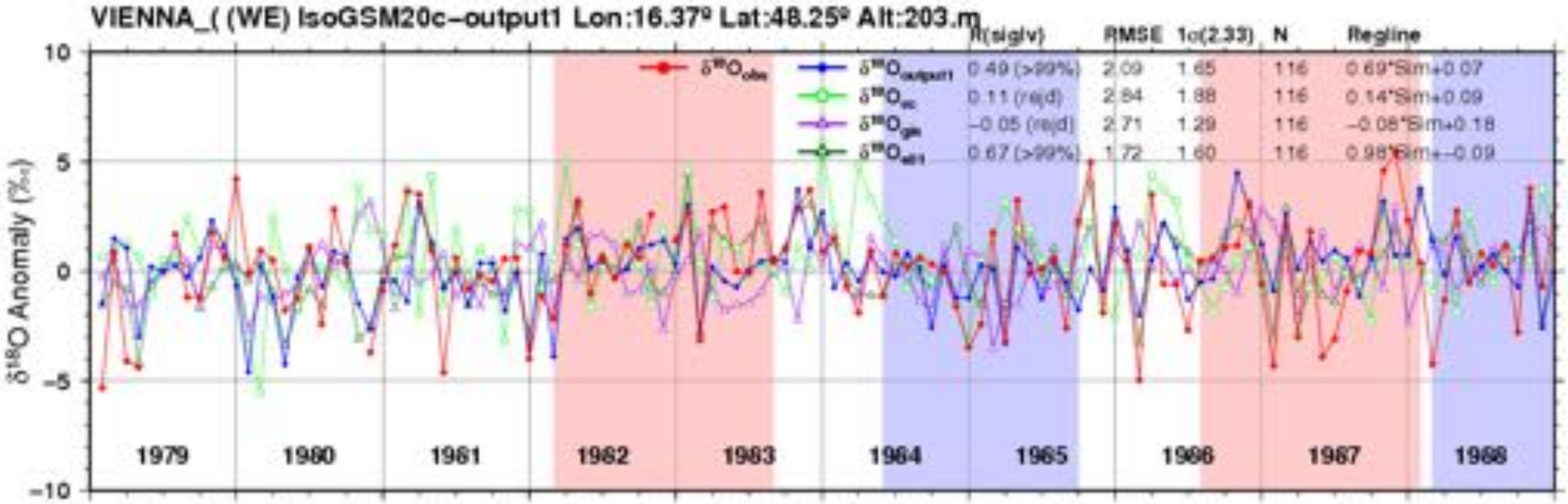


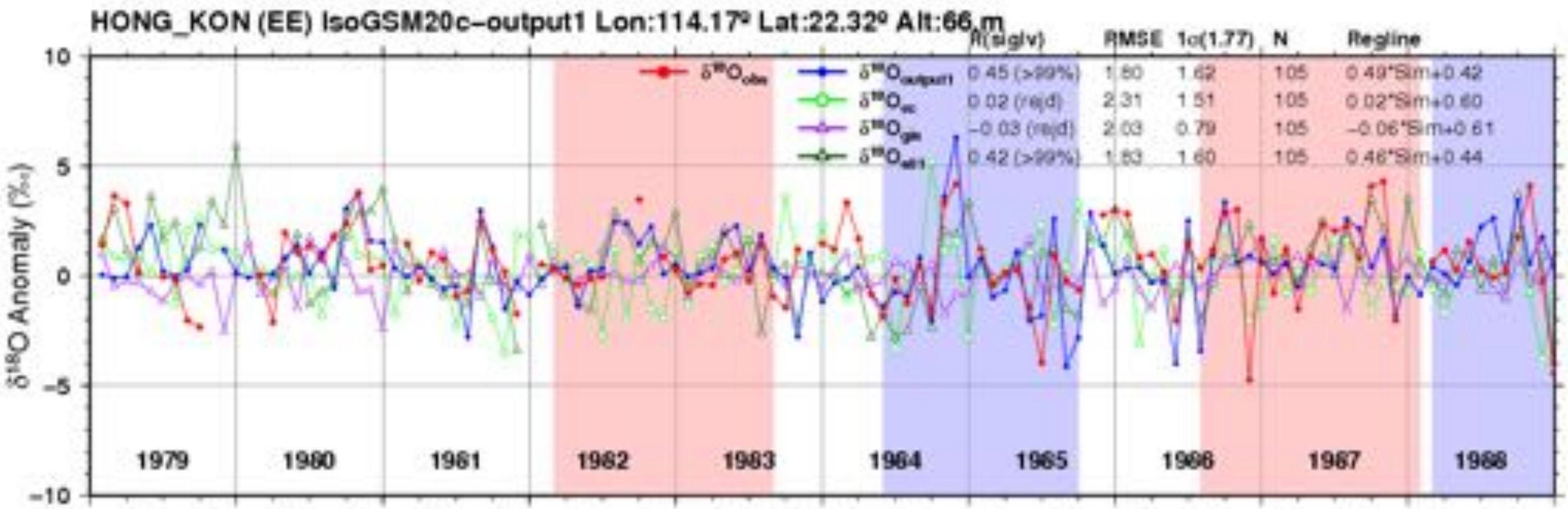
Comparison with AO

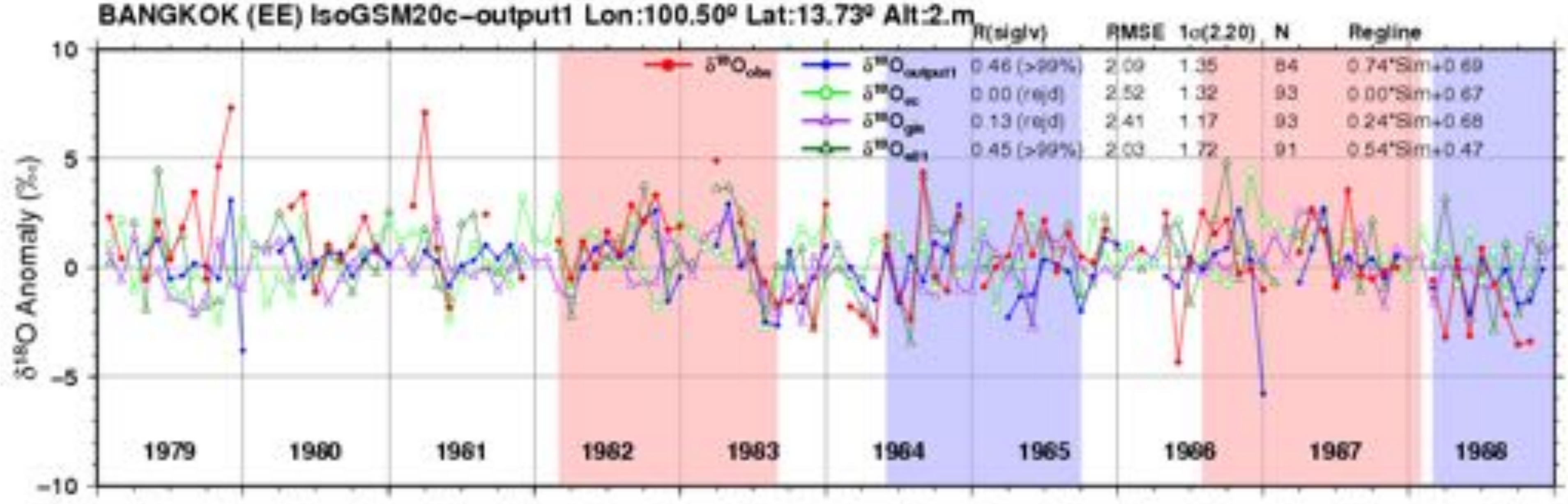




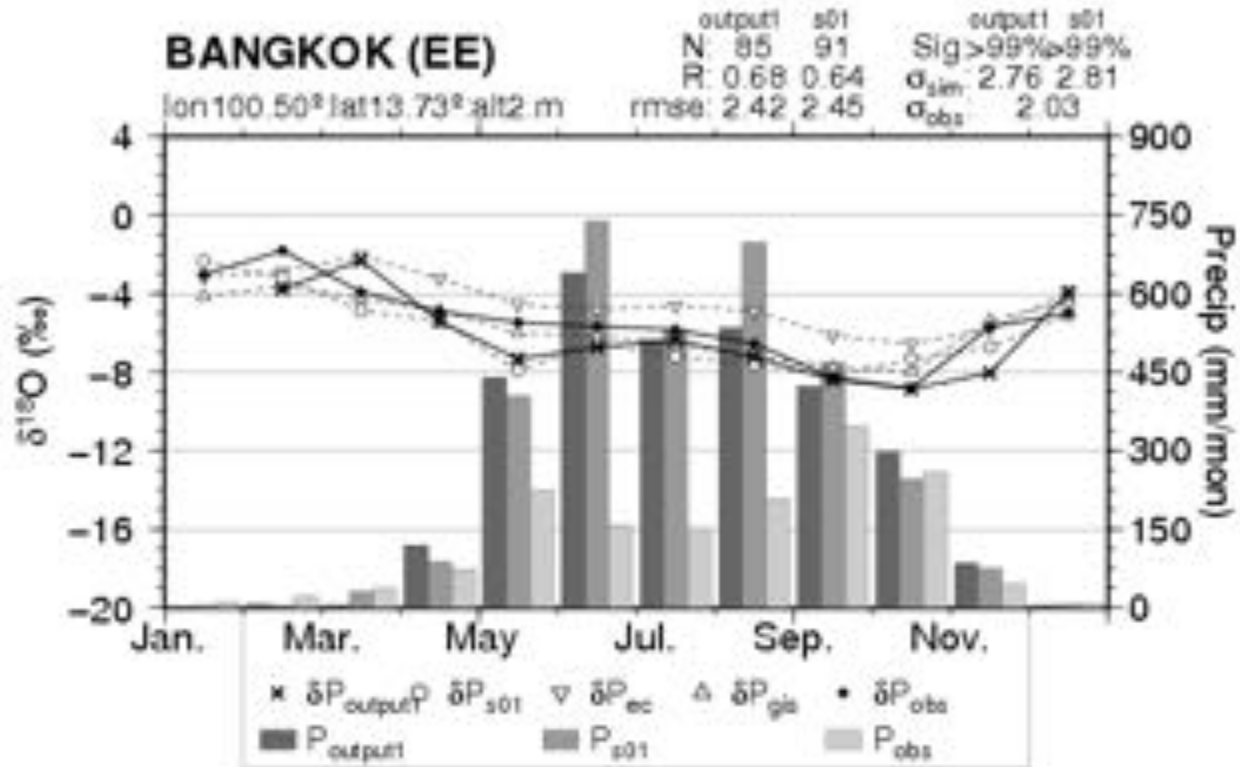
Model AO index, 3-mon running mean
Obs
IsoGSM
GISS-E
EHCAM4
IsoGSM20c
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998


VIENNA_((WE) IsoGSM20c-output1 Lon:16.37º Lat:48.25º Alt:203.m
R(siglv) RMSE 1σ(2.33) N Regline
δ18O obs
δ18O output1 0.49 (>99%) 2.09 1.65 116 0.69*Sim+0.07
δ18O sc 0.11 (rejd) 2.84 1.88 116 0.14*Sim+0.09
δ18O gis −0.05 (rejd) 2.71 1.29 116 −0.06*Sim+0.18
δ18O all1 0.67 (>99%) 1.72 1.60 116 0.98*Sim+−0.09
δ18O Anomaly (‰)
10
5
0
−5
−10
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988


HONG_KON (EE) IsoGSM20c-output1 Lon:114.17º Lat:22.32º Alt:66.m
R(siglv) RMSE 1σ(1.77) N Regline
δ18O obs
δ18O output1 0.45 (>99%) 1.80 1.62 105 0.49*Sim+0.42
δ18O sc 0.02 (rejd) 2.31 1.51 105 0.02*Sim+0.60
δ18O gis −0.03 (rejd) 2.03 0.79 105 −0.06*Sim+0.61
δ18O all1 0.42 (>99%) 1.83 1.60 105 0.46*Sim+0.44
δ18O Anomaly (‰)
10
5
0
−5
−10
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988

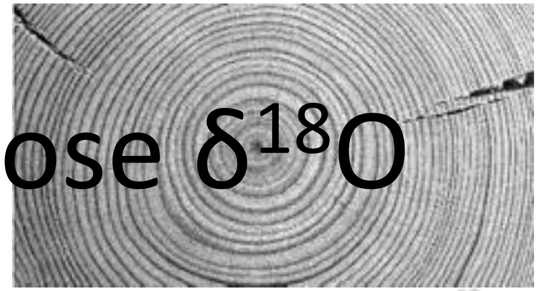


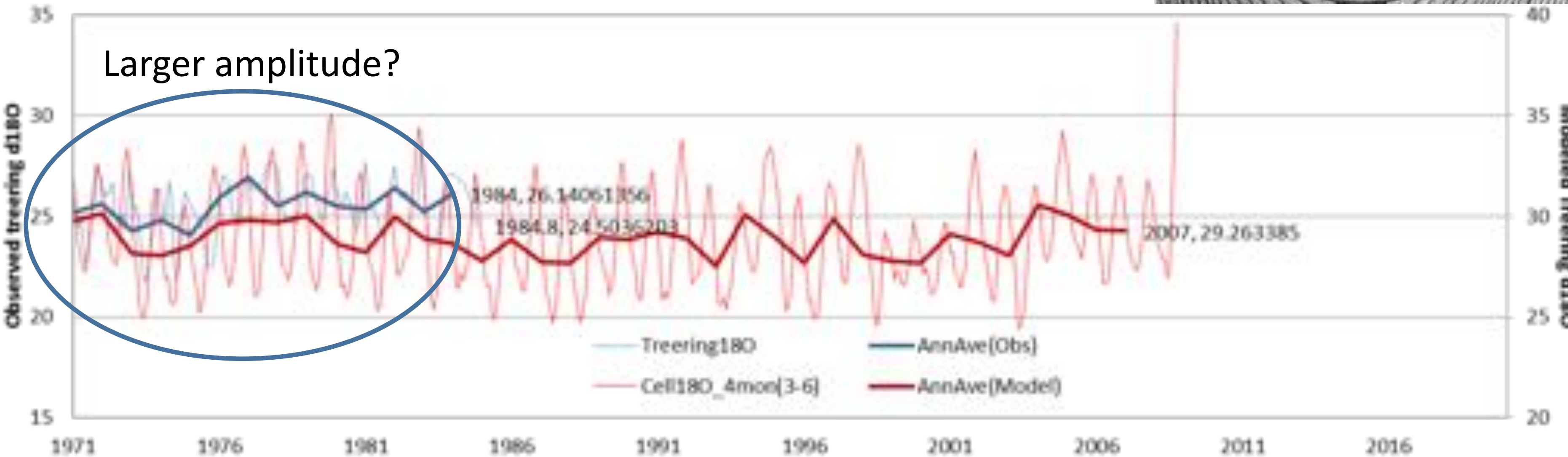
BANGKOK (EE) IsoGSM20c-output1 Lon:100.50º Lat:13.73º Alt:2.m
R(siglv) RMSE 1σ(2.20) N Regline
δ18O obs
δ18O output1 0.46 (>99%) 2.09 1.35 84 0.74*Sim+0.69
δ18O ec 0.00 (rejd) 2.52 1.32 93 0.00*Sim+0.67
δ18O gis 0.13 (rejd) 2.41 1.17 93 0.24*Sim+0.68
δ18O s01 0.45 (>99%) 2.03 1.72 91 0.54*Sim+0.47
δ18O Anomaly (‰)
1979 1980 1981 1982 1983 1984 1985 1986 1987 1988

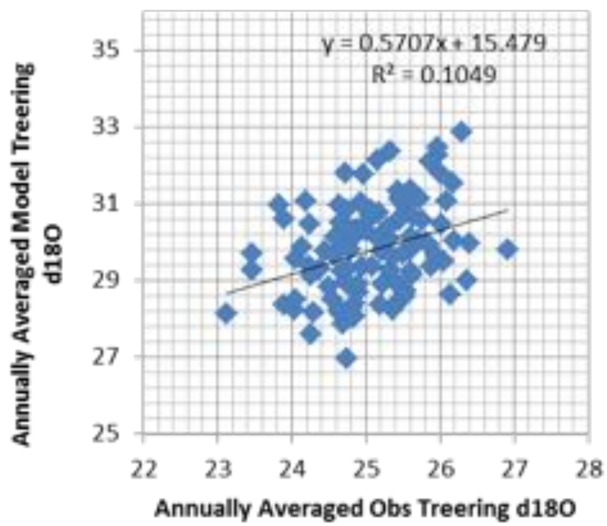


BANGKOK (EE)
lon100.50º lat13.73º alt2.m
output1 s01
N: 85 91
R: 0.68 0.64
rmse: 2.42 2.45
output1 s01
Sig >99% >99%
σsim 2.76 2.81
σobs 2.03
δ18O (‰)
Precip (mm/mon)
Jan. Mar. May Jul. Sep. Nov.
δP output1 δP s01 δP ec δP gis δP obs
P output1 P s01 P obs

Cambodian Treering Cellulose $\delta^{18}O$







R=0.324, >99% sig.