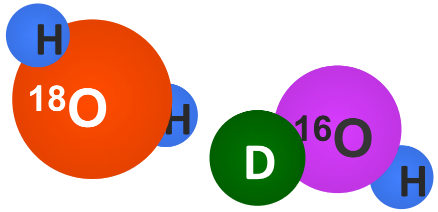


Development of Water Isotope Ratio Data Assimilation System with Ensemble Kalman Filter

Kei Yoshimura

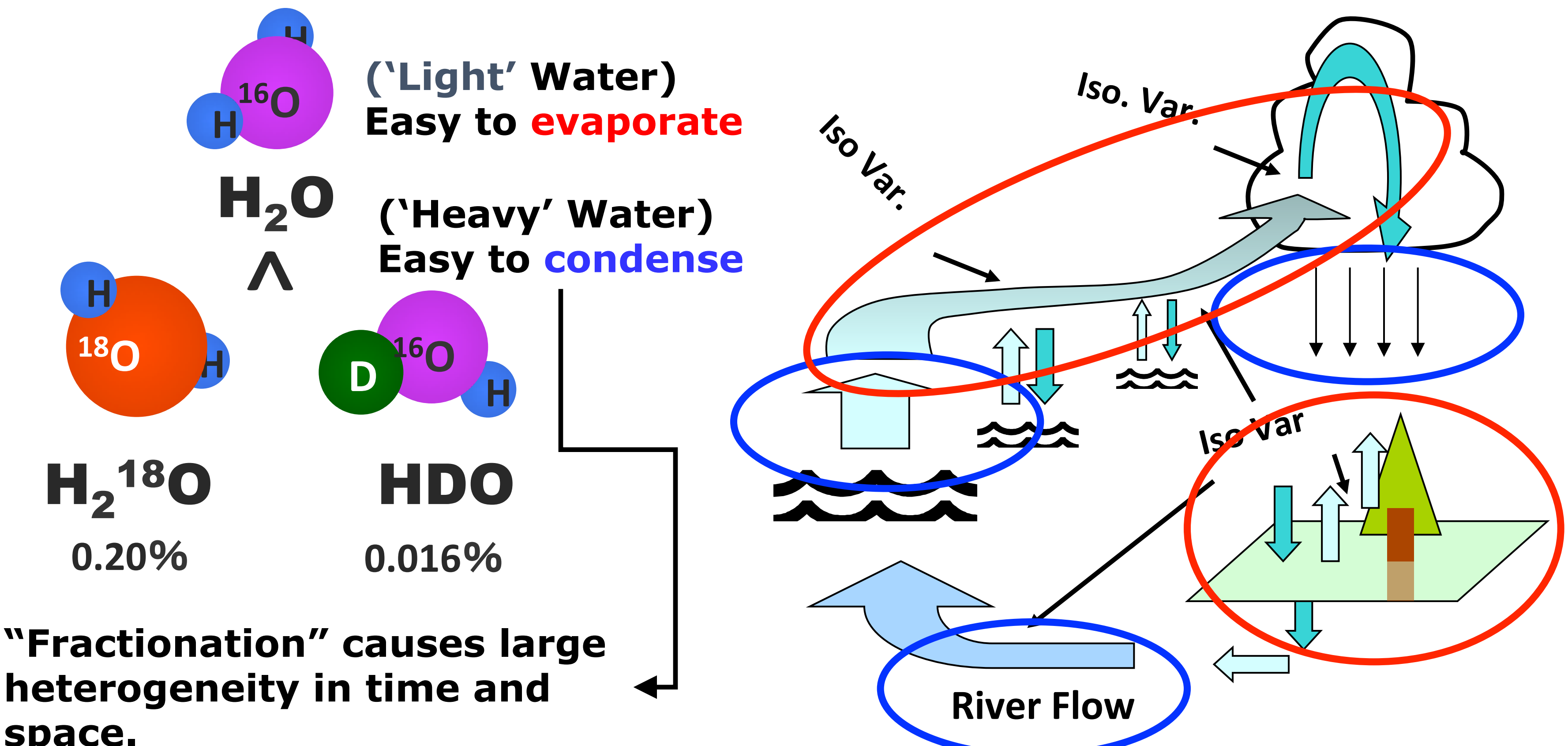
AORI, Univ Tokyo

Yoshimura, Miyoshi, Kanamitsu, 2013

Yoshimura, Miyoshi, Kanamitsu, 2014

Stable Water Isotopes and Hydrologic Cycle

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



LETTER

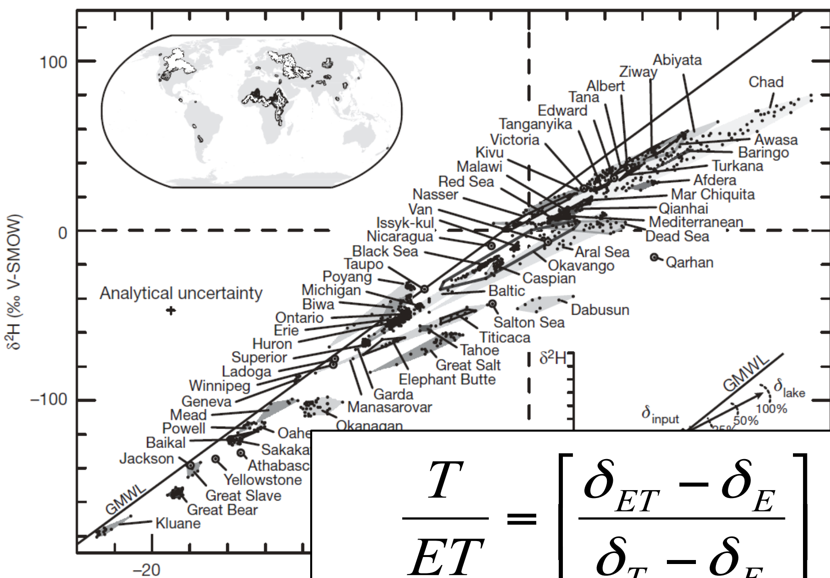
Jasechko et al., 2013

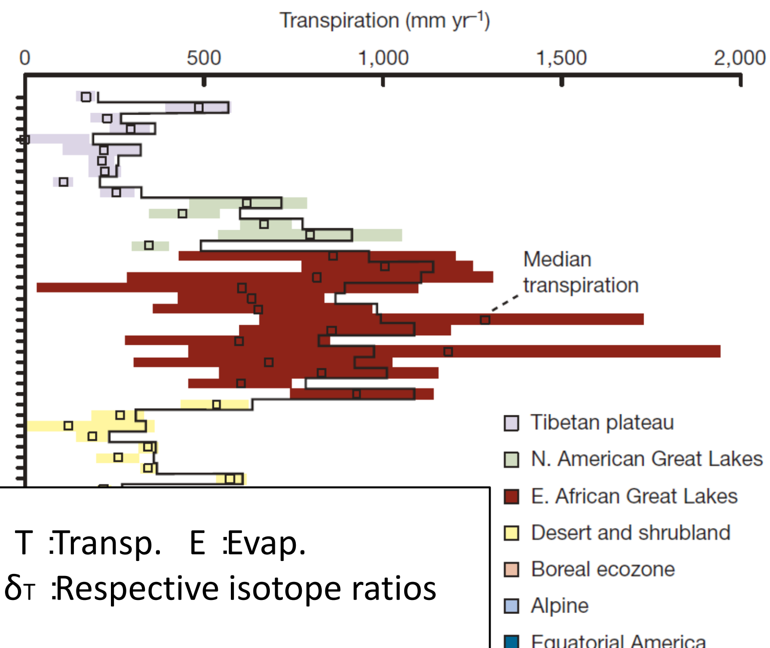
doi:10.1038/nature11983

Terrestrial water fluxes dominated by transpiration

Scott Jasechko[1], Zachary D. Sharp[1], John J. Gibson[2,3], S. Jean Birks[2,4], Yi Yi[2,3] & Peter J. Fawcett[1]

- Transpiration represents 80~90 % of terrestrial ET.

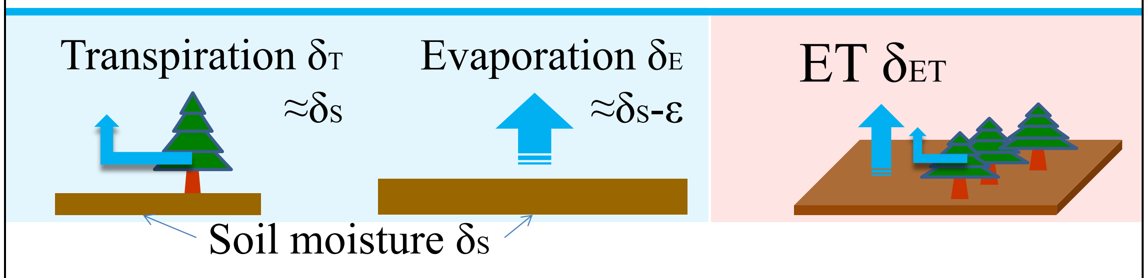




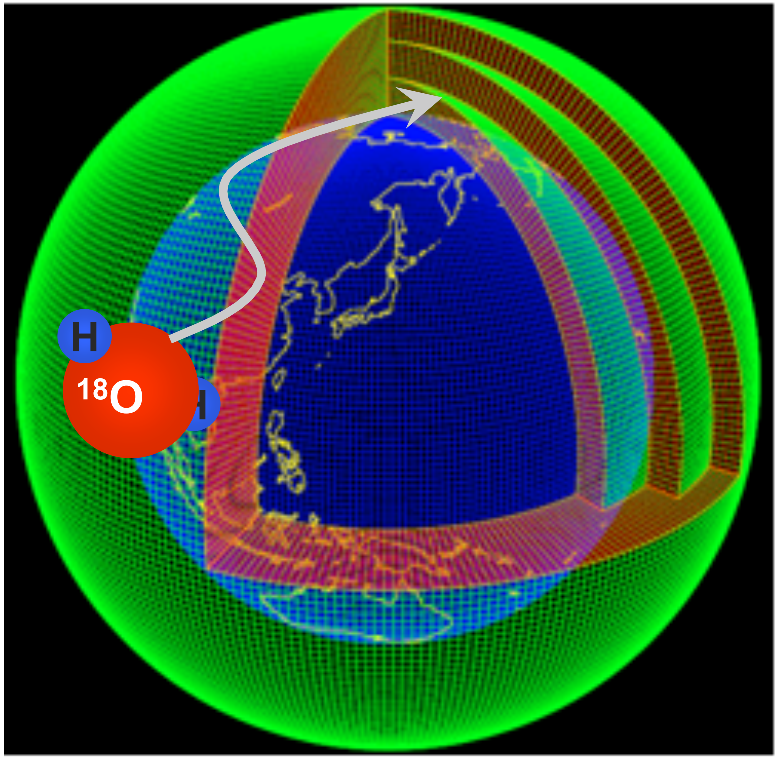
$$\frac{T}{ET} = \left[\frac{\delta_{ET} - \delta_E}{\delta_T - \delta_E}\right]$$

ET :ET T :Transp. E :Evap.

δ_{ET}, δ_E, δ_T :Respective isotope ratios

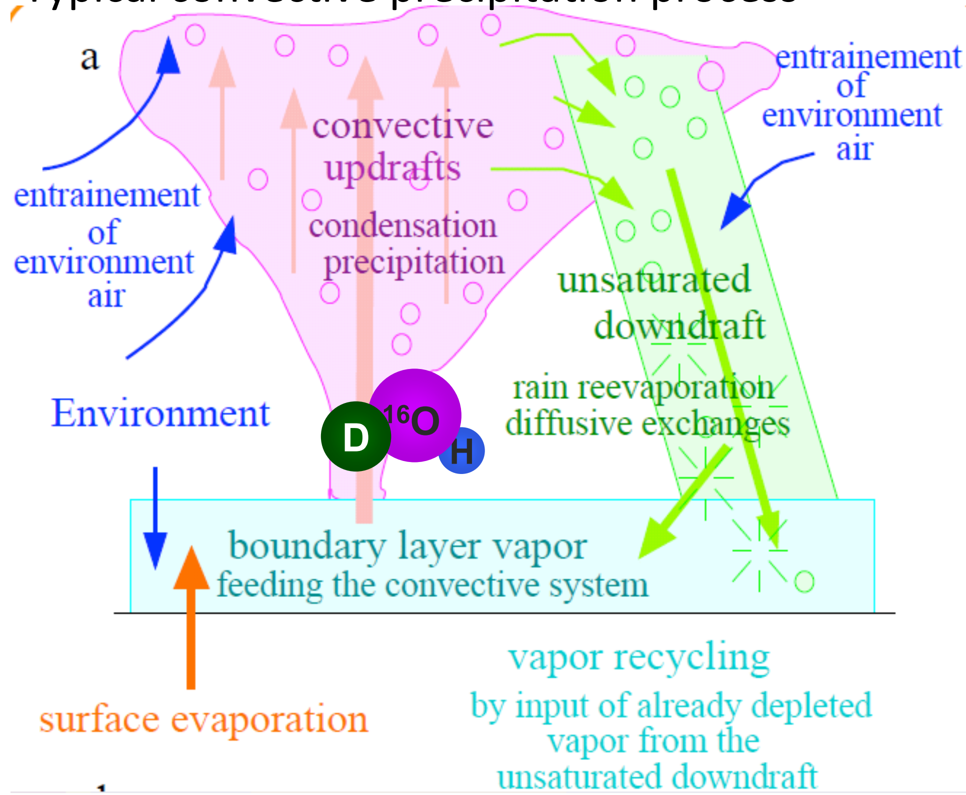


Isotopes in GCM/RCM



Courtesy of JMA

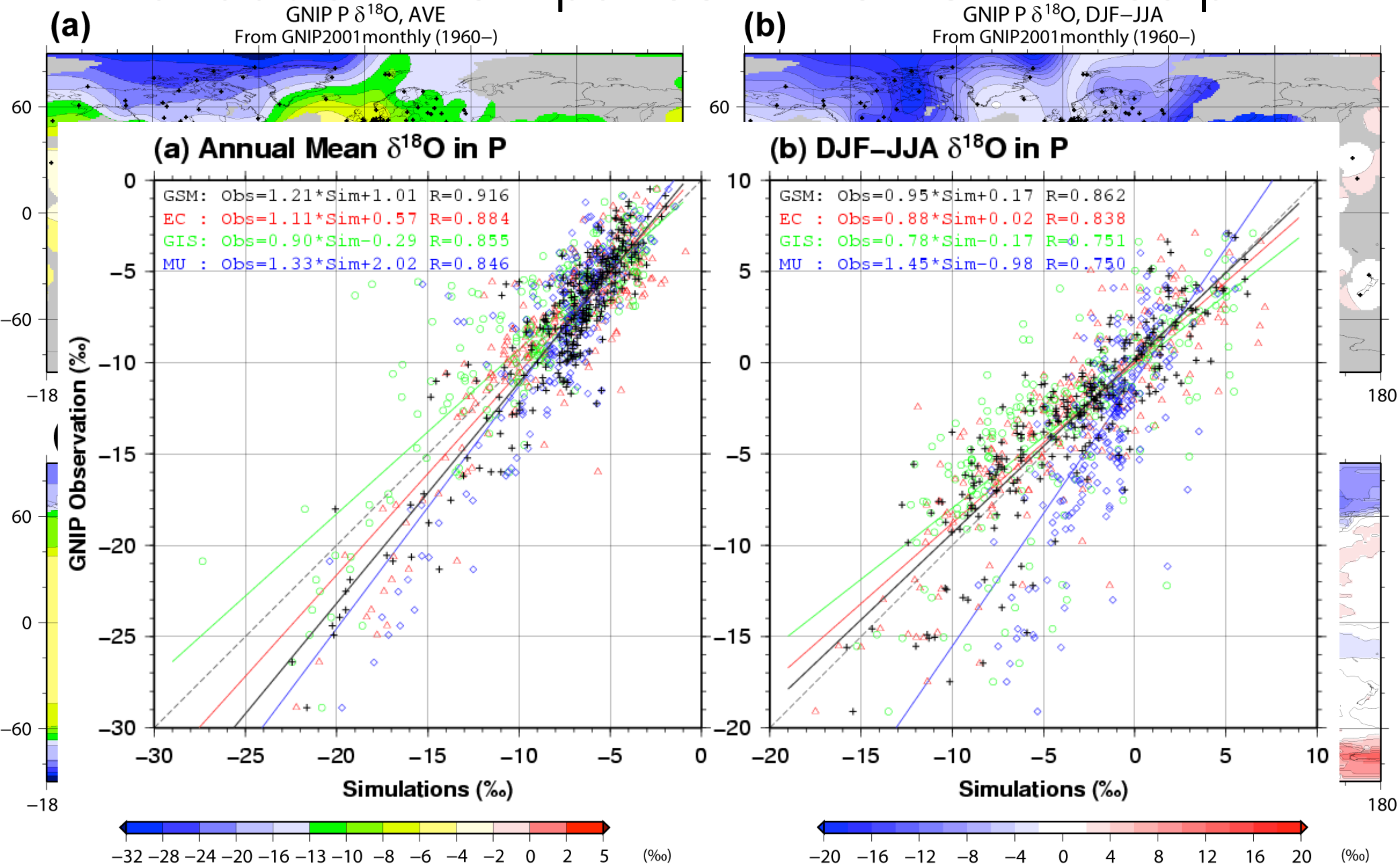
Typical convective precipitation process



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).

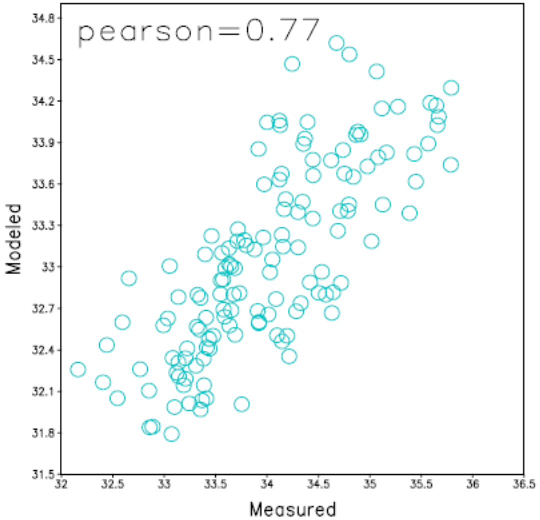
Validation: Comparison in δ18O in Precip



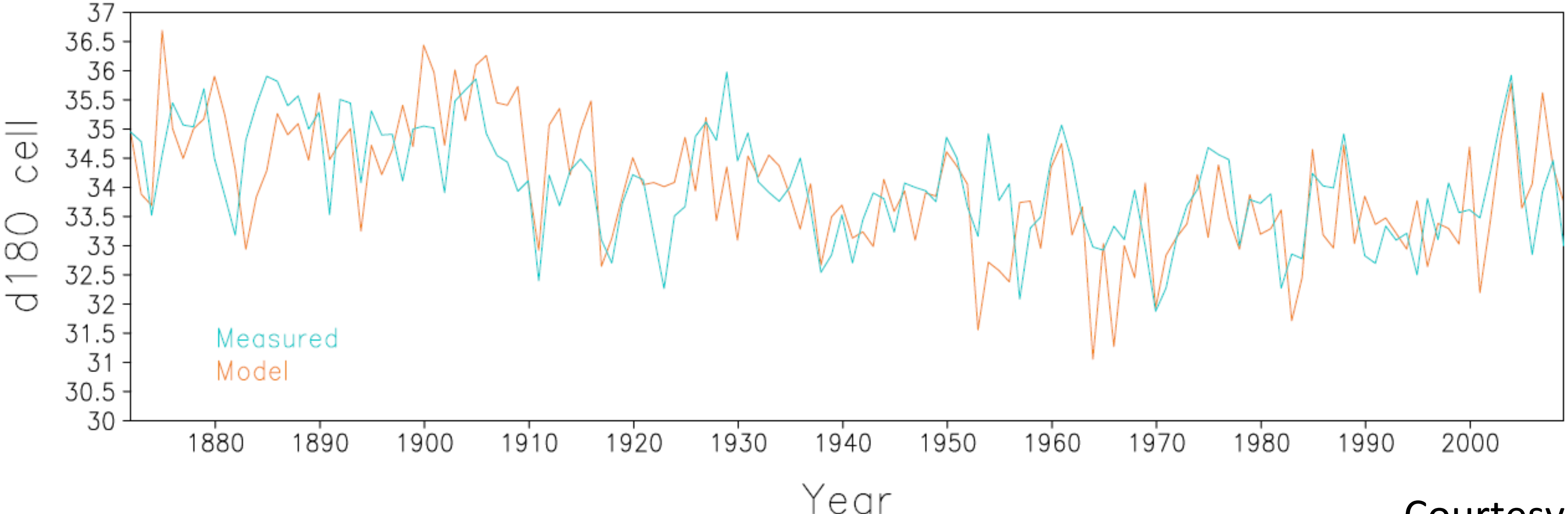
SWING-2

- Kick-off in 17-19 November 2008 in IAEA HQ; chaired by C. Sturm, K. Yoshimura & D. Noone.
- More isotopic AGCMs (at least 9) and 2 isotopic RCMs.
- Add nudging experiments to focus on only isotopic parameterizations and on more realistic reconstruction of isotopic variations.
- More focused on hydrologic cycle than climatology
- Endorsed by GHP/CEOP in 2008-2010

Forward Proxy Modeling of $\delta^{18}O$ in cellulose

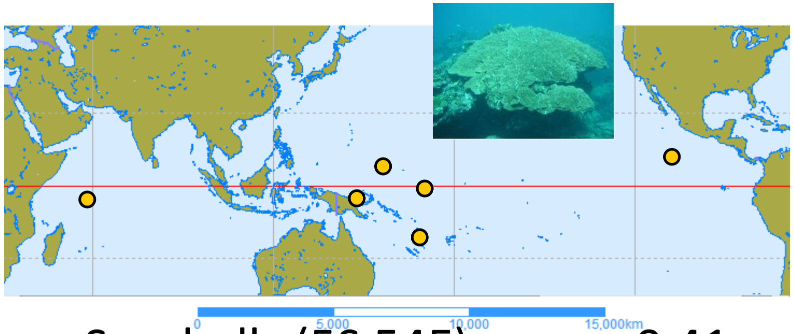


Measured values are composite of Bale 2010 and recent Stott and Rincon data. Model is based on Roden Model with met./iso inputs from Yoshimura 20c Rear

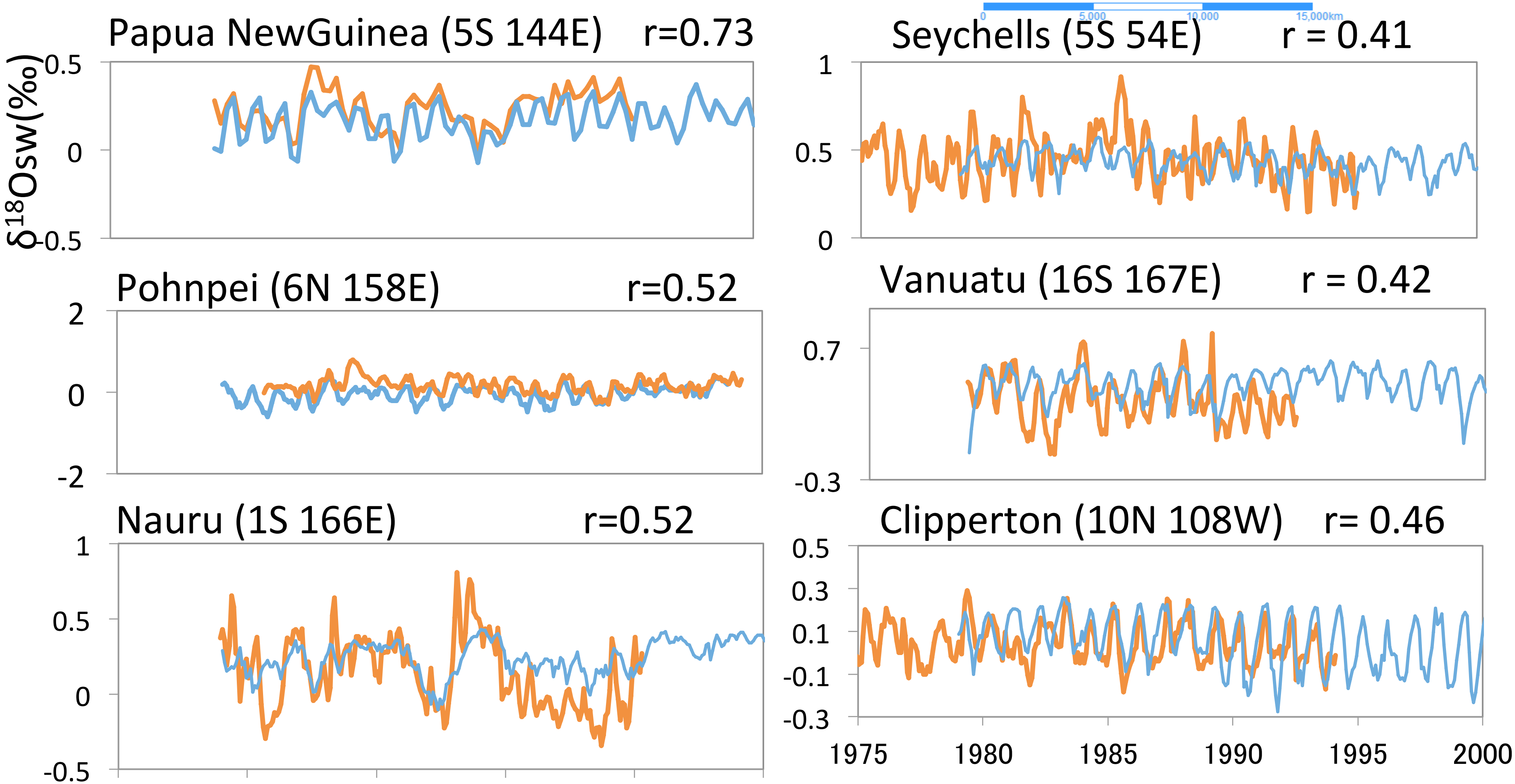


Courtesy of L. Stott

Sea water $\delta^{18}O$ derived from coral and model (temperature effect removed by Sr/Ca)



— :Model — :Coral record



$\delta^{18}Osw$ records are well reproduced both seasonally and inter-annually in various sites.

Courtesy of K. Kojima

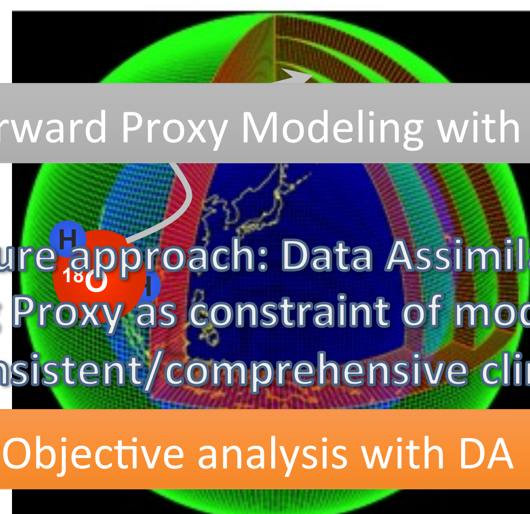
Way forward: Isotope Reanalysis

$\delta^{18}O$, δD

Conventional paleo-climatology
Empirical relationship between δ-T or -P.

Regression Analysis, etc

Ongoing approach: Forward proxy modeling
Proxy-Climate relationship may vary in space and time



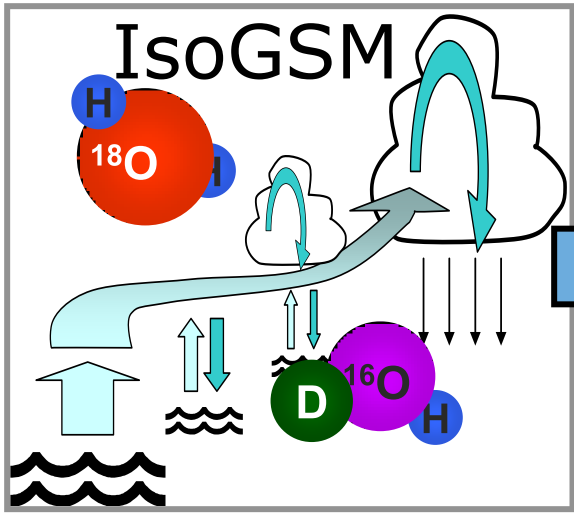
Forward Proxy Modeling with GCMs

Future approach: Data Assimilation
Using Proxy as constraint of model and
analyze consistent/comprehensive climate system

Objective analysis with DA

T, P, etc

Toward "Real" Isotope Reanalysis: Data Assimilation of Isotope

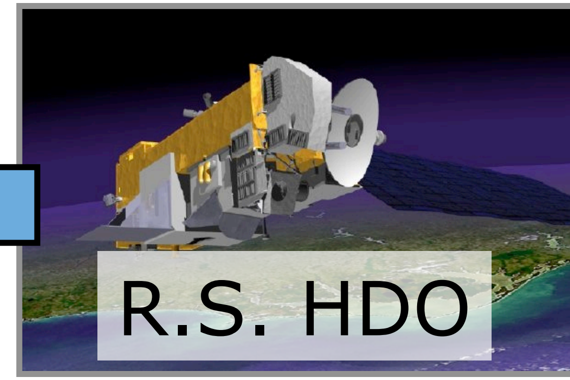


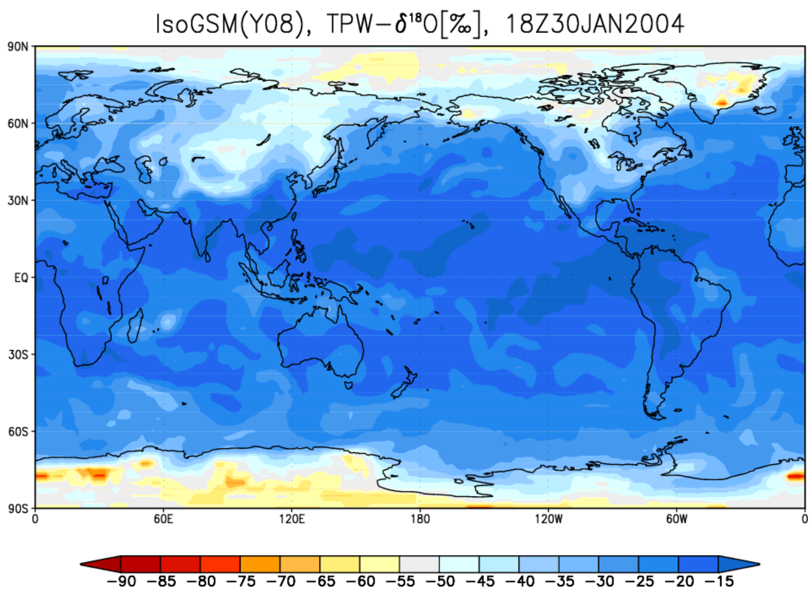
$$\mathbf{X} = [\mathbf{x}_1 \quad \cdots \quad \mathbf{x}_m], \quad \delta\mathbf{X} = \mathbf{X} - \overline{\mathbf{X}}$$

$$\mathbf{K} = \delta\mathbf{X}_f \mathbf{U}\mathbf{D}^{-1}\mathbf{U}^T (\mathbf{H}\delta\mathbf{X}_f)^T \mathbf{R}^{-1}$$

$$\mathbf{X}_a = \overline{\mathbf{X}_f} + \mathbf{K}(\mathbf{y}_o - \overline{H(\mathbf{X}_f)}) + \delta\mathbf{X}_a$$

LETKF

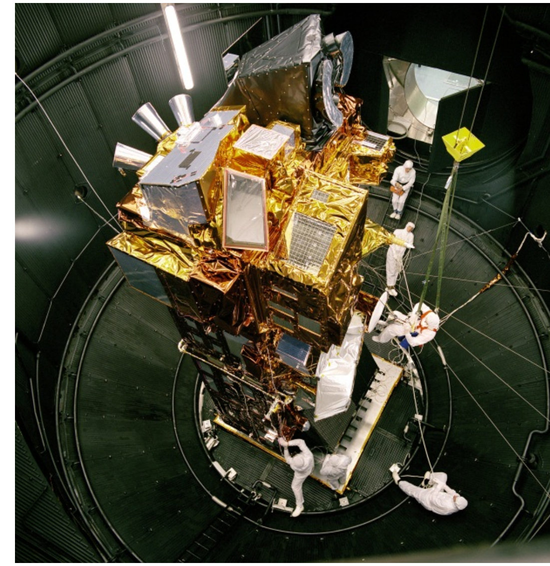


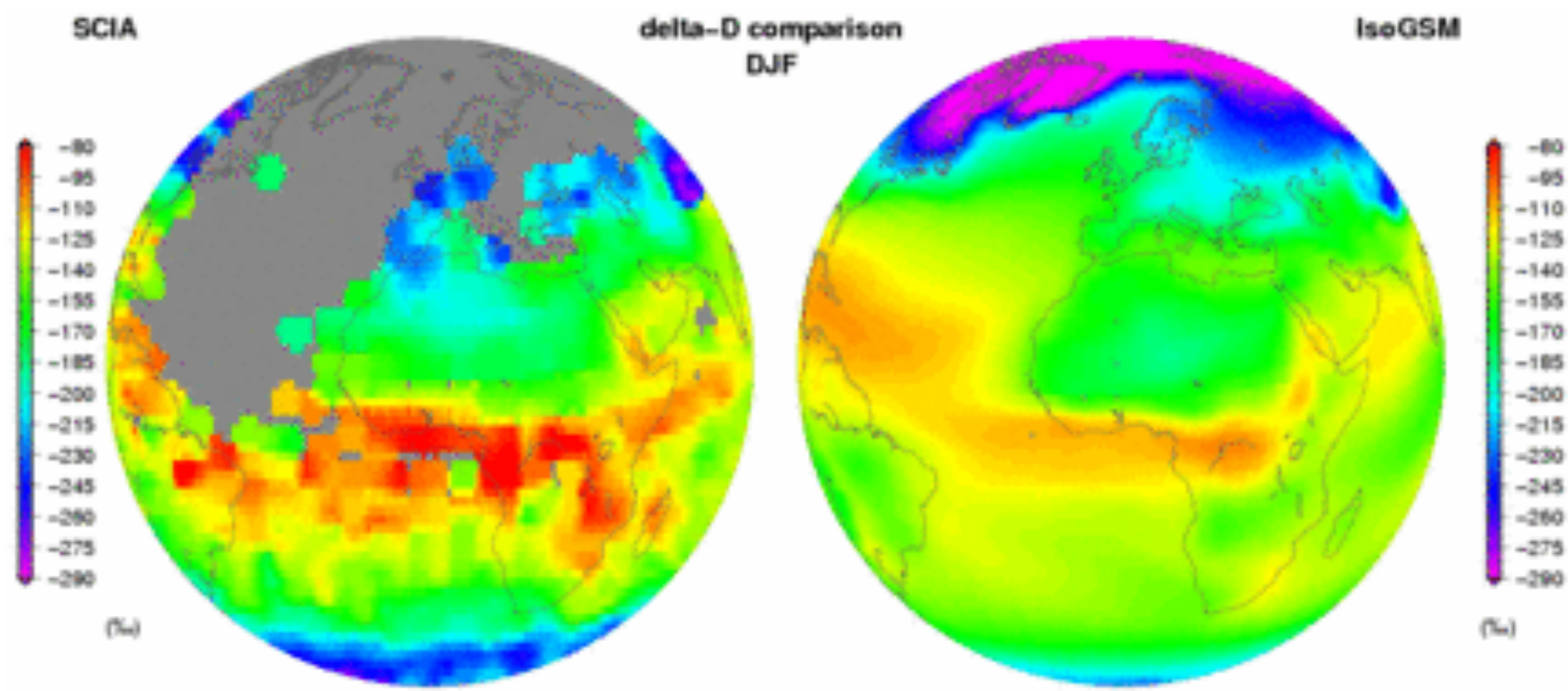


Targets:

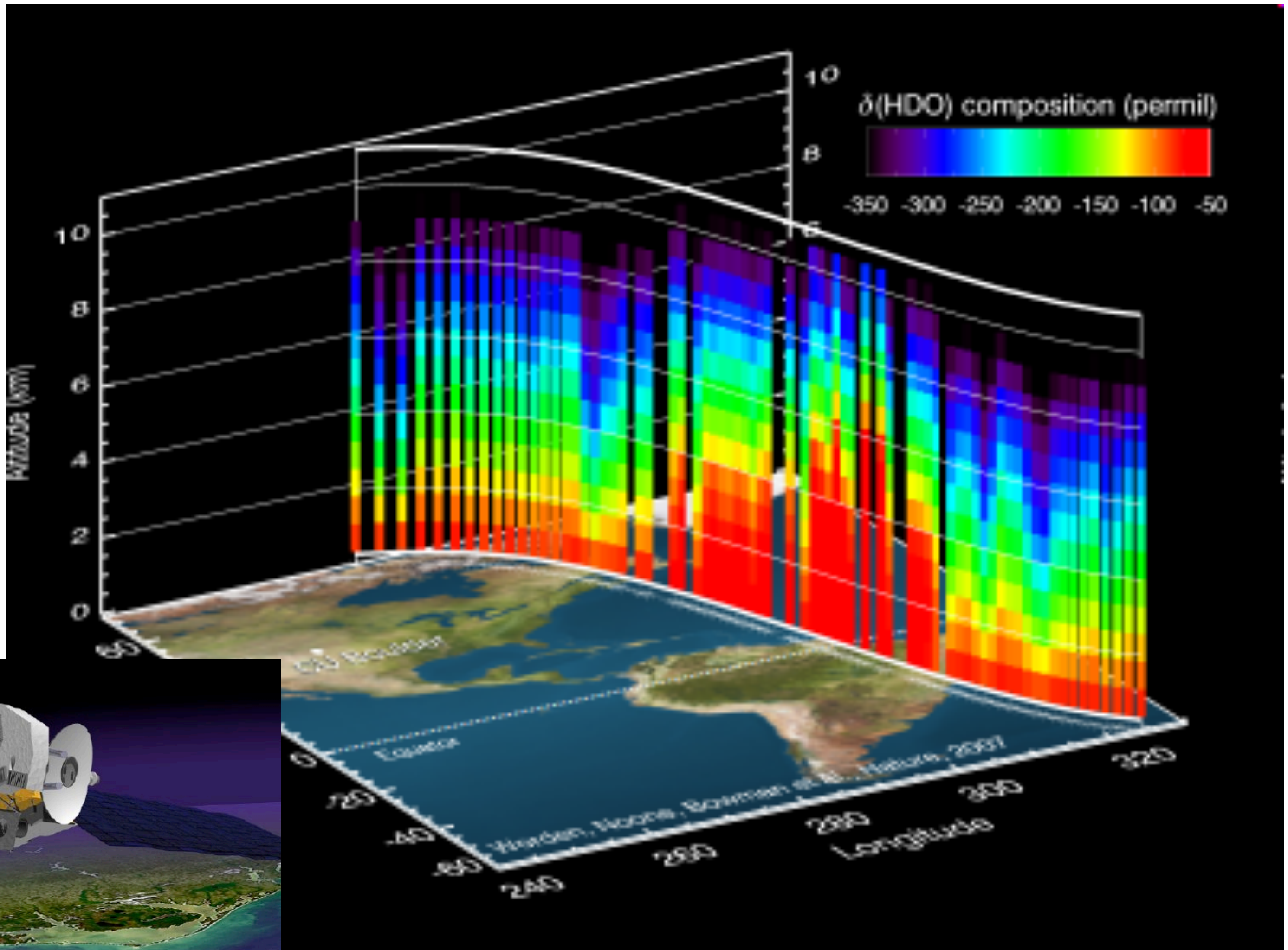
- ✓First global 4D analyses for vapor isotopes.
- ✓Accurate Precip. isotopes in fine resolution.
- ✓Possibility of improvement on other dynamical fields.

SCIAMACHY/Envisat: surface vapor HDO
(Frankenberg et al., 2009, Science)

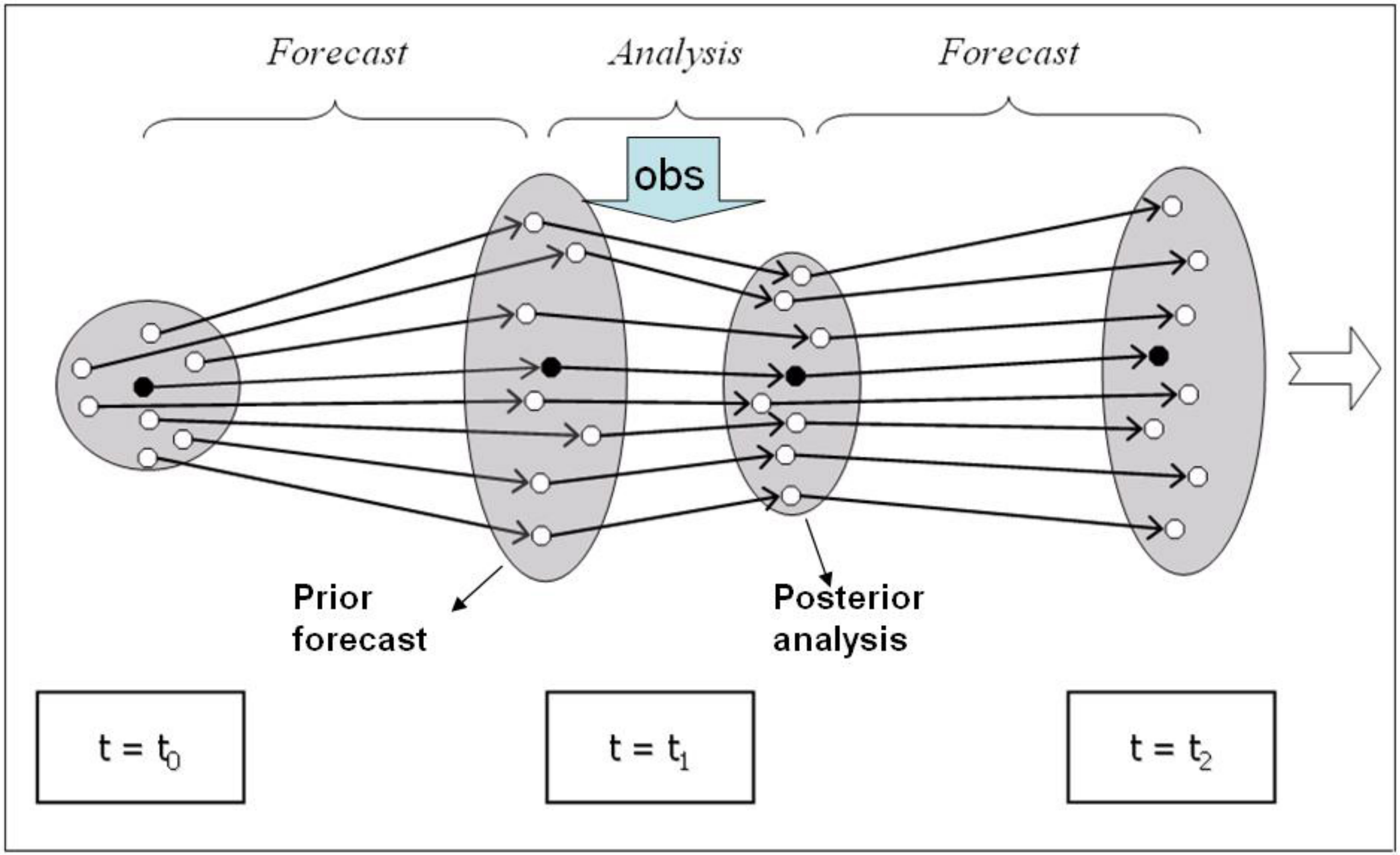




TES/Aura: mid troposphere vapor HDO (Worden et al., 2007, Nature)



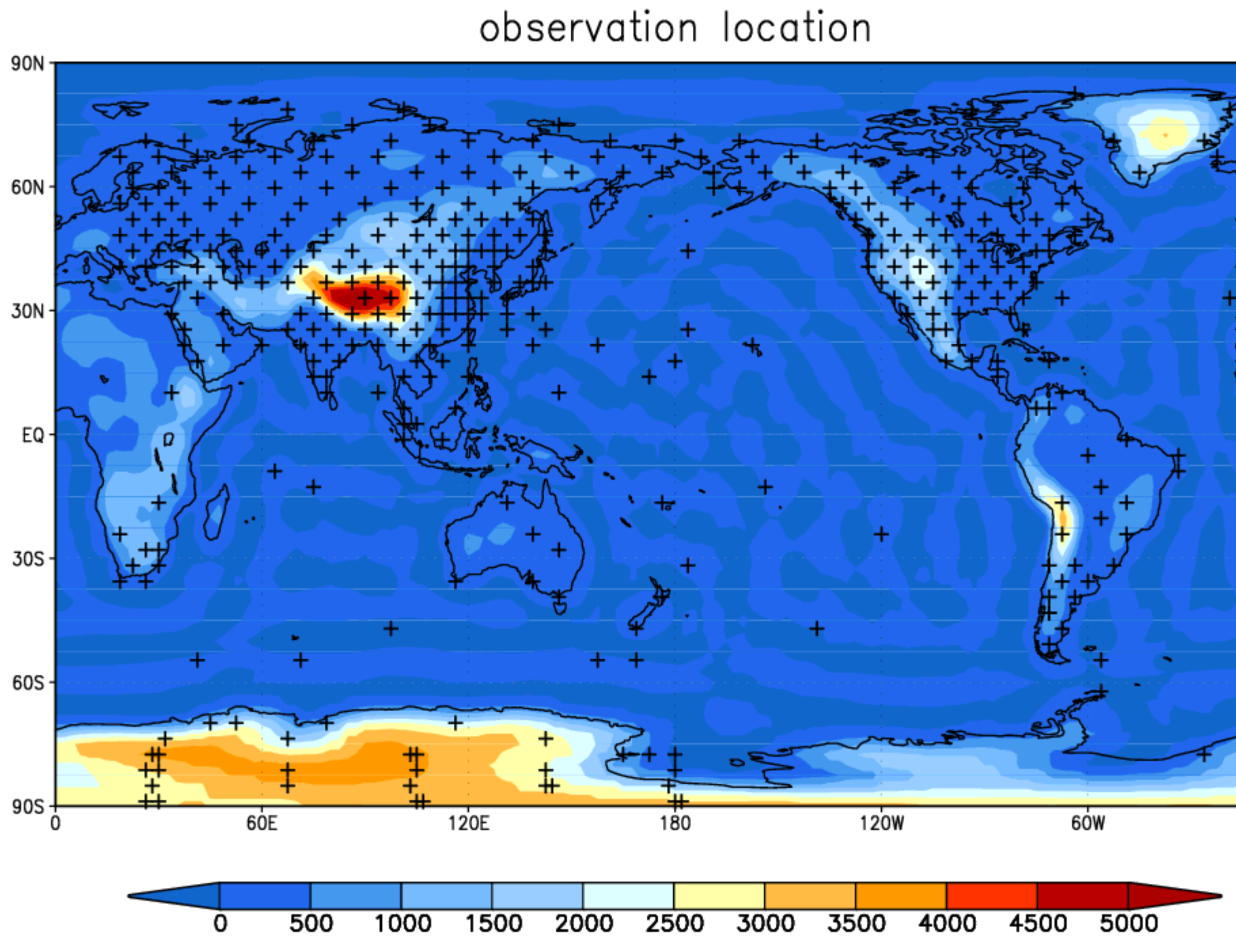
Local Ensemble Transformed Kalman Filter
(Miyoshi and Yamane, 2008)



（Aksoy 2003）

- Not only the assimilated variables, **but also other variables will be corrected** to be a consistent field.

Idealized Experiments (OSSE)

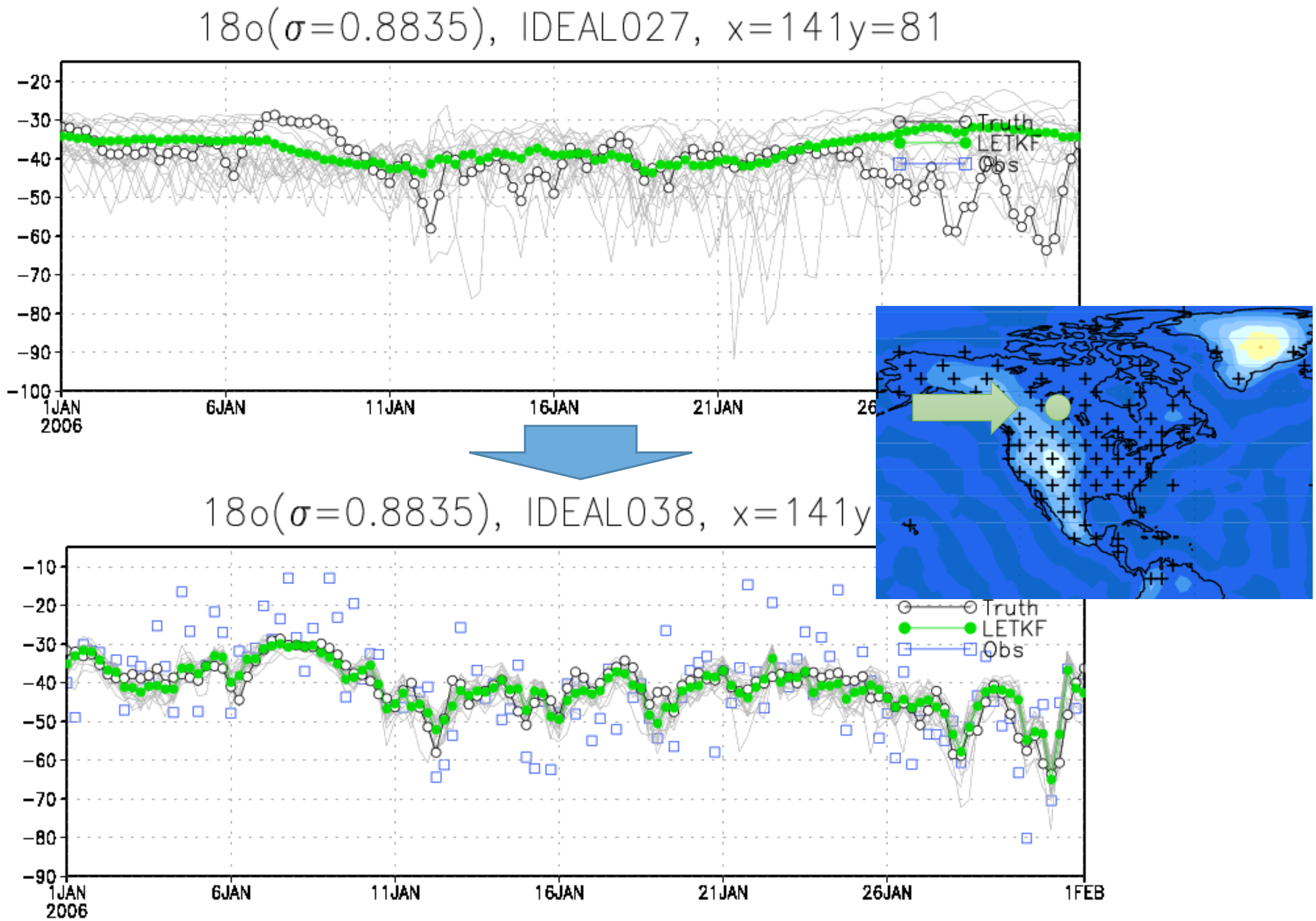


- Assume one realization of AMIP runs as truth.

Grid with denser observations, $\delta^{18}O$

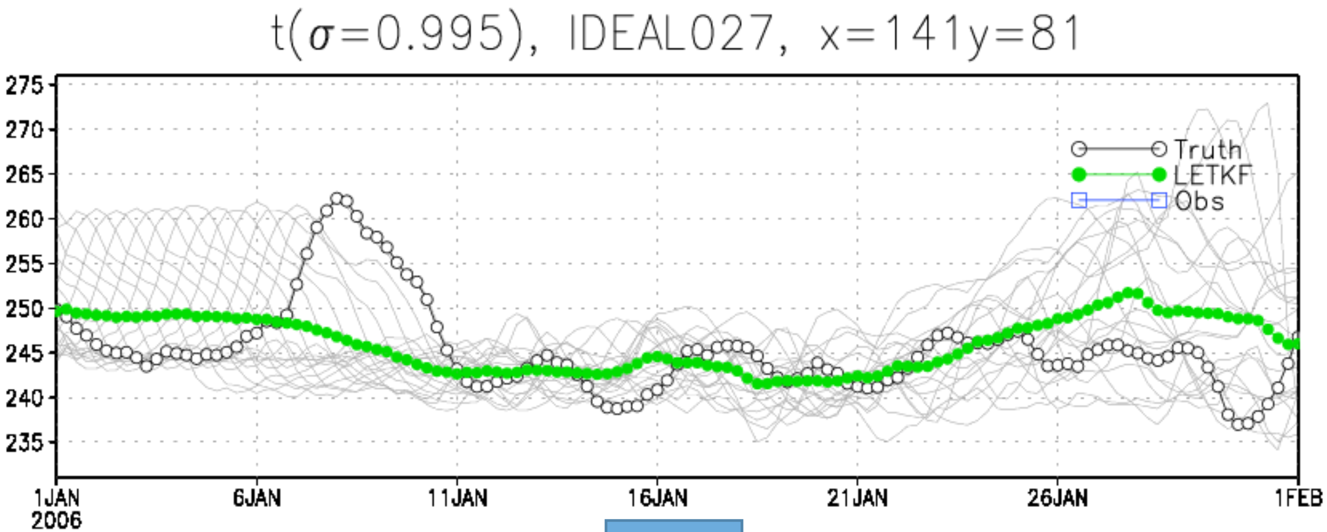
NoObs

DeltaOnly

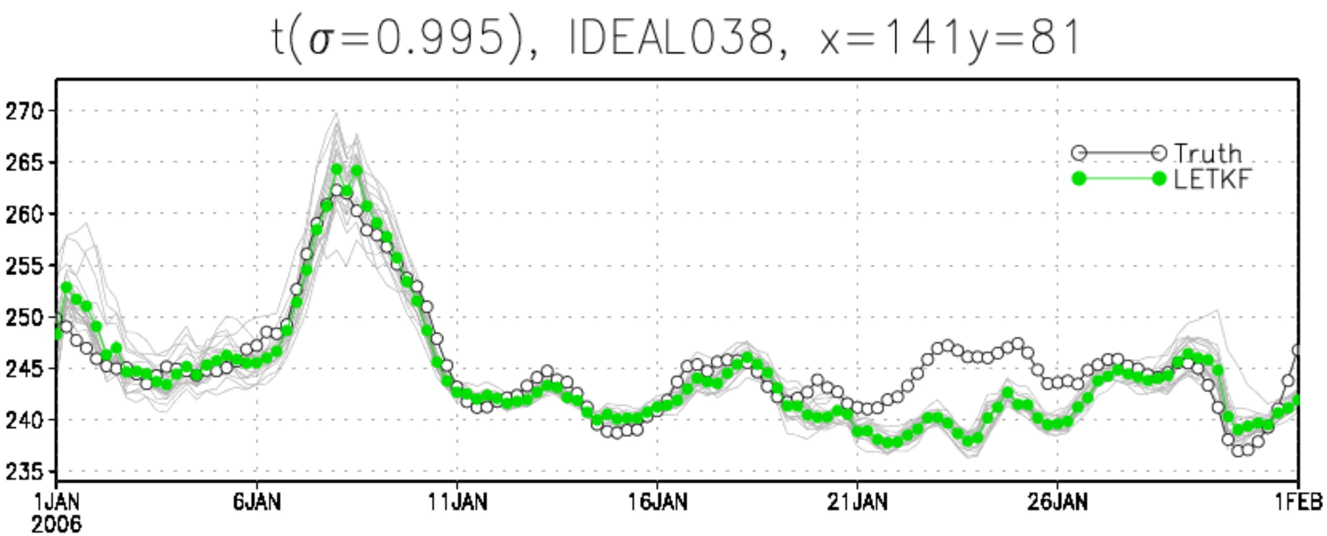


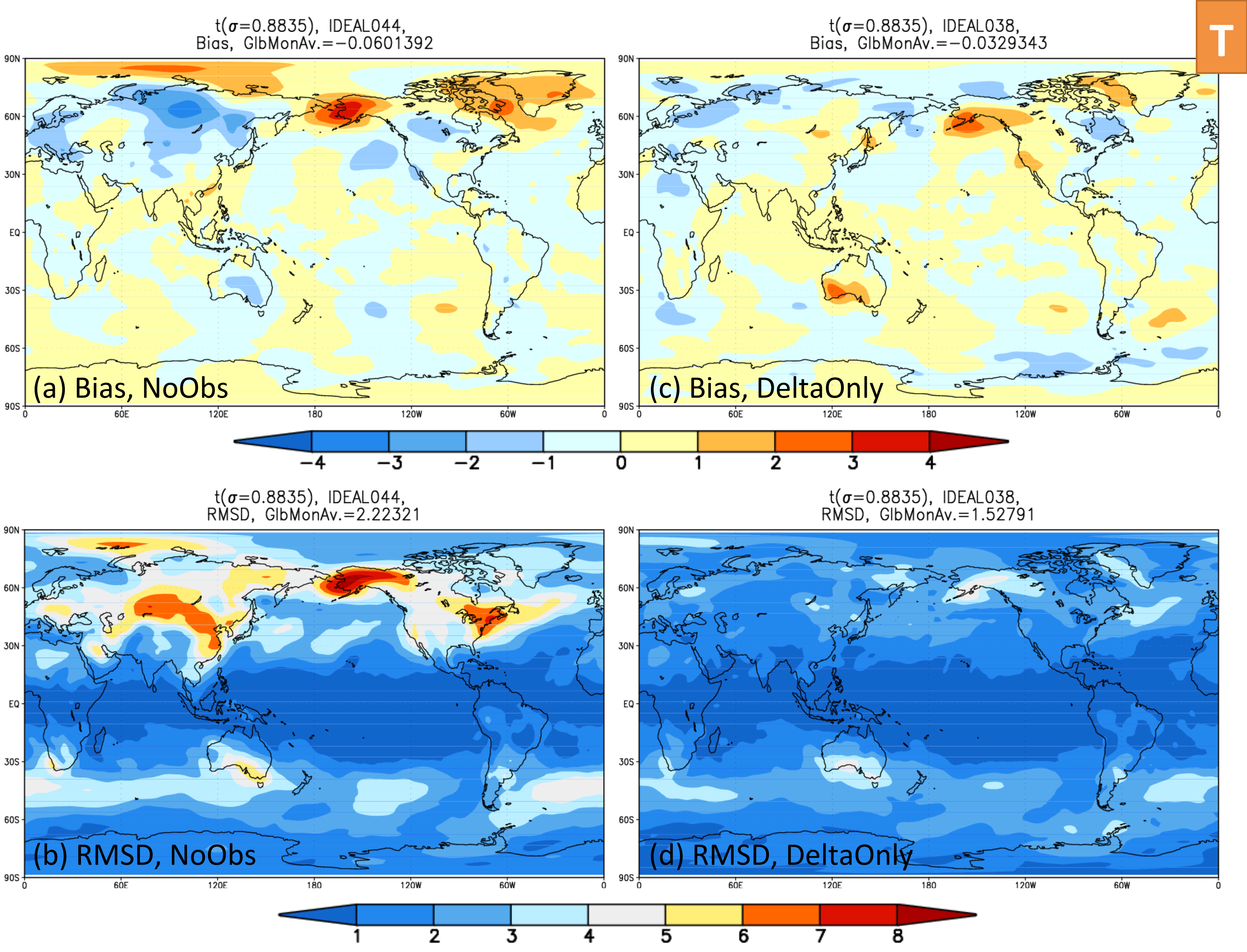
Grid with denser observations, T

NoObs

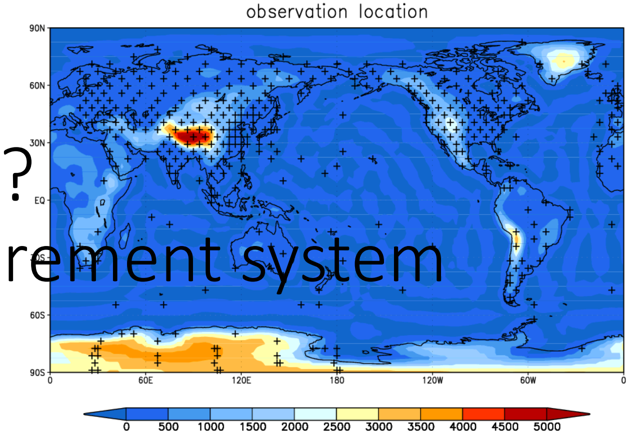


DeltaOnly




T
t(σ=0.8835), IDEAL044,
Bias, GlbMonAv.=−0.0601392
(a) Bias, NoObs
t(σ=0.8835), IDEAL038,
Bias, GlbMonAv.=−0.0329343
(c) Bias, DeltaOnly
−4 −3 −2 −1 0 1 2 3 4
t(σ=0.8835), IDEAL044,
RMSD, GlbMonAv.=2.22321
(b) RMSD, NoObs
t(σ=0.8835), IDEAL038,
RMSD, GlbMonAv.=1.52791
(d) RMSD, DeltaOnly
1 2 3 4 5 6 7 8
90N 60N 30N EQ 30S 60S 90S
0 60E 120E 180 120W 60W 0

What about more realistic situation?
Experiments with conventional measurement system



Global RMSD

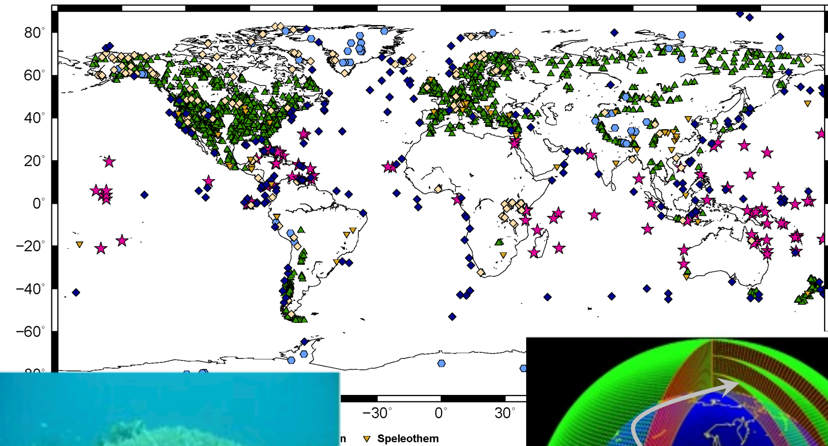
σ=0.995	U [m/s]	V [m/s]	T [K]	q [g/kg]	Ps [hPa]	$\delta^{18}O$ [‰]	δD [‰]
UVTq	1.33	1.30	0.40	0.42	1.04	0.98	7.23
UVTq+δD	**1.27**	**1.25**	**0.40**	**0.41**	**0.99**	**0.93**	**6.94**

σ=0.8835	U [m/s]	V [m/s]	T [K]	q [g/kg]		$\delta^{18}O$ [‰]	δD [‰]
UVTq	1.49	1.39	0.55	0.69		1.41	10.77
UVTq+δD	**1.42**	**1.34**	**0.53**	**0.68**		**1.35**	**10.35**

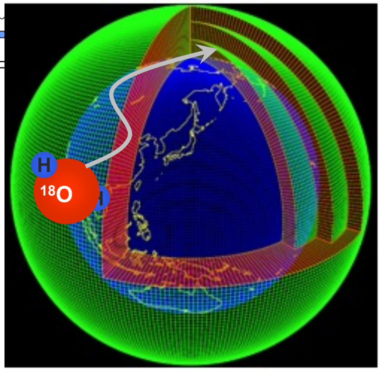
Ultimate goal: *Climate Reanalysis*

- Much longer records than man-made observation
  - Oceanic sediment $\delta^{18}O$ (millions yBP)
  - Icesheet cores $\delta^{18}O \cdot \delta D$ (~800 kyBP)
  - Icecap cores $\delta^{18}O \cdot \delta D$ (~20 kyBP)
  - Speleothem $\delta^{18}O$ (~2000 yBP)
  - Treering $\delta^{18}O$ (~1000 yBP)
  - Coral $\delta^{18}O$ (~400 yBP)
- Bridging data and physics, consistently!

Proxy_Sampling_Site_BC1000~AD2008



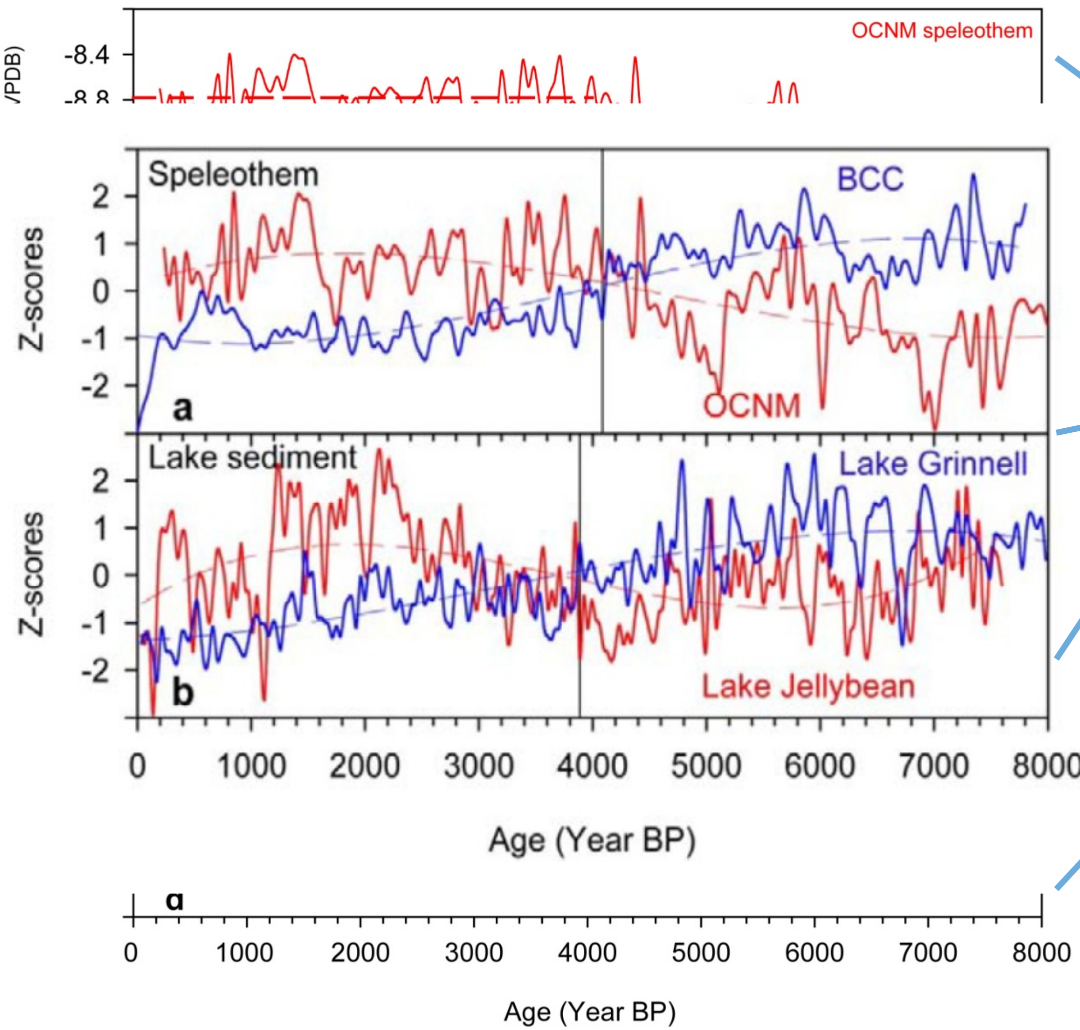
NOAA: http://www.ncdc.noaa.gov/paleo/

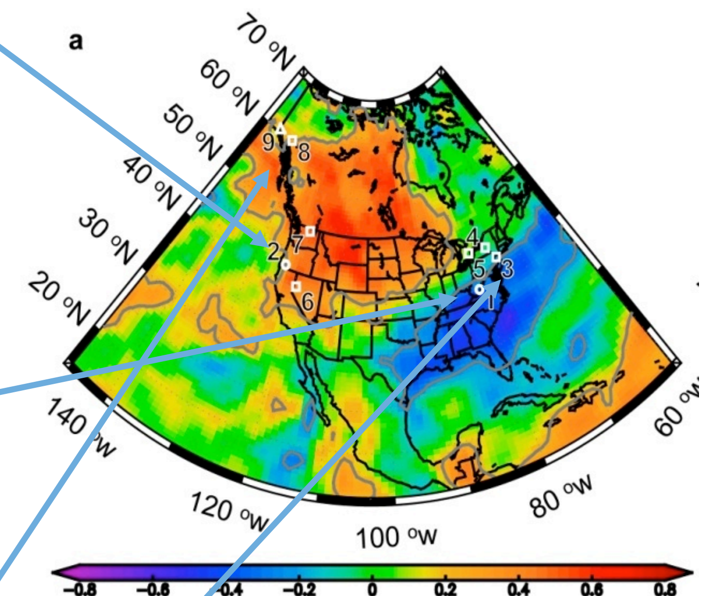


Summary

- Isotopic Data as input observation had positive impact on not only isotopic fields but also dynamical fields.
- (Selfish) suggestion for new observations:
  - Accuracy < Number of data
  - Temporal resolution < Longer data
  - Dense coverage < Sparse but equally distributed
- There is potential for dynamical constraint by isotopic proxy data for the past, but lots of technical obstacles exist.

Paired isotopic proxy data since 8,000yBP





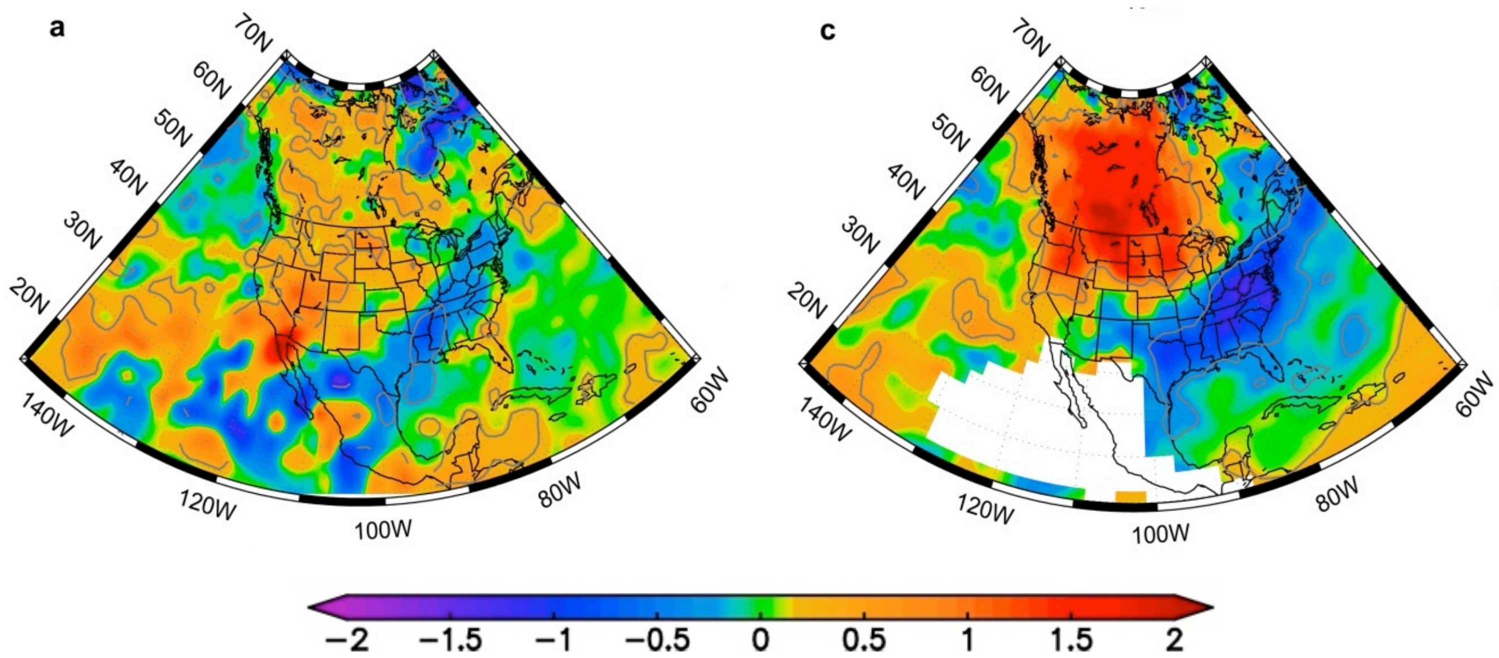
Liu et al., 2014, Nature Comm.

IsoGSM simulations

- Time-slice runs for MH and LH for 30 years, respectively.
- SST anomaly simulated by IPSL-CGCM was forced.

IsoGSM simulated precipitation $\delta^{18}O$ difference

LH minus MH (‰) PNA+ minus PNA-（‰）



Result (Global RMSE for $\delta^{18}O$, Wind, Temp, and Surface Pressure)