TES workshop in Boulder, Feb. 23-25, 2009

Nudged isotope AGCM simulation and its comparison with TES, SCIAMACHY and ground-based FTS isotope retrievals

Contents

- Model – Ground based FTS comparison
- Model – Satellite comparison (UT and PBL)
- Isotope Assimilation (plan)

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Collaborators:
TES (J. Worden, D. Noone)
SCIAMACHY (C. Frankenberg, T. Rockman)
Ground based FTS (M. Schneider, F. Hase, J. Notholt)

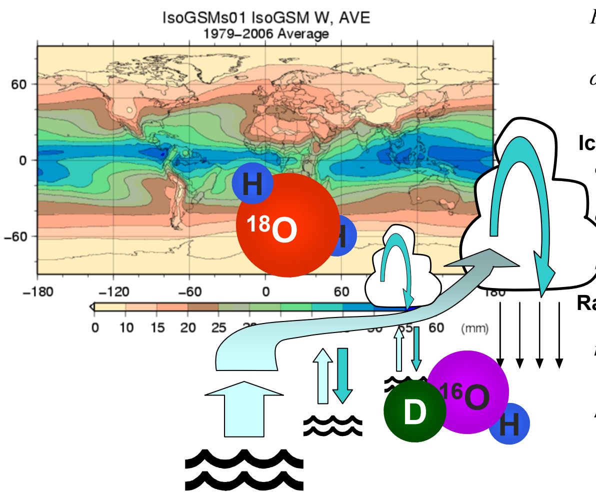
Issues in GCM vs RS comparison

- Timing (clear sky vs rainy)
- Space (vertical and horizontal)

- Significant difficulty:
  GCM’s time and “real” time is different!

A solution: Spectral Nudging

– Poor man's data assimilation –



Surface evaporation (MJ79)

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

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

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)

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

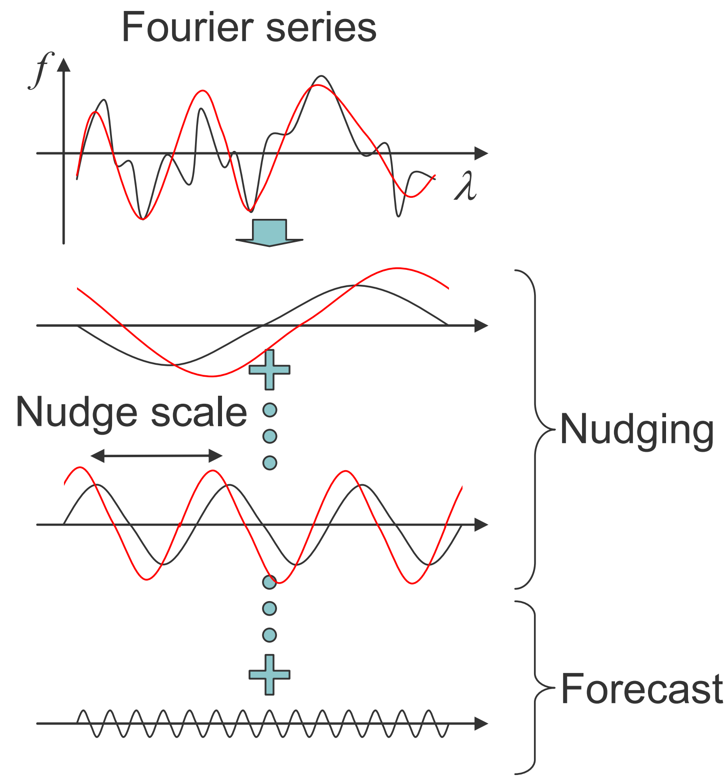
$$\beta = \frac{1-\mu}{\mu}, \ \gamma = \frac{\alpha_e h}{1-\mu}, \ \mu = \alpha_e (D/D')^n (1-h)$$

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

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

IsoGSM

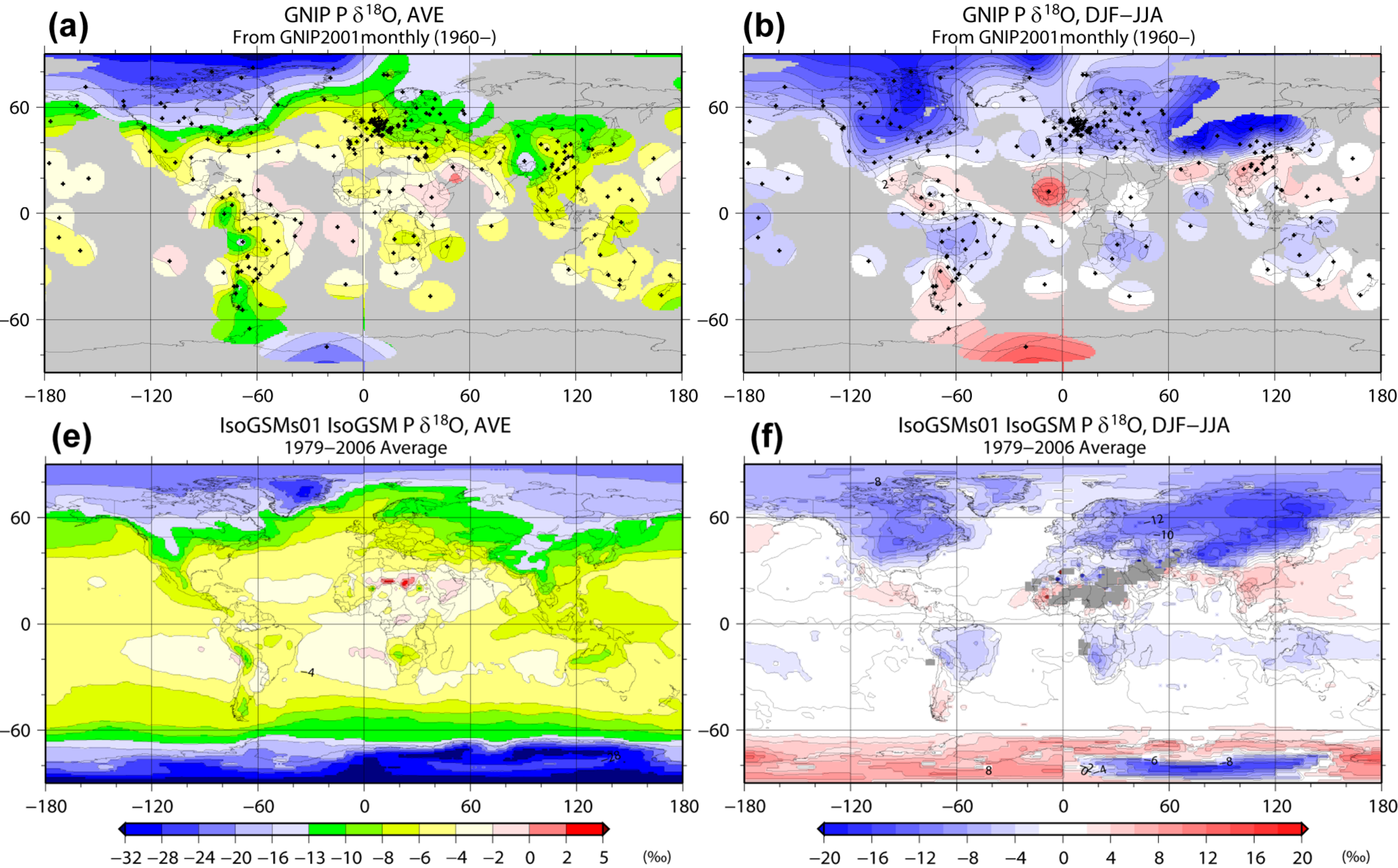
SIO/UT Isotopic Global Spectral Model



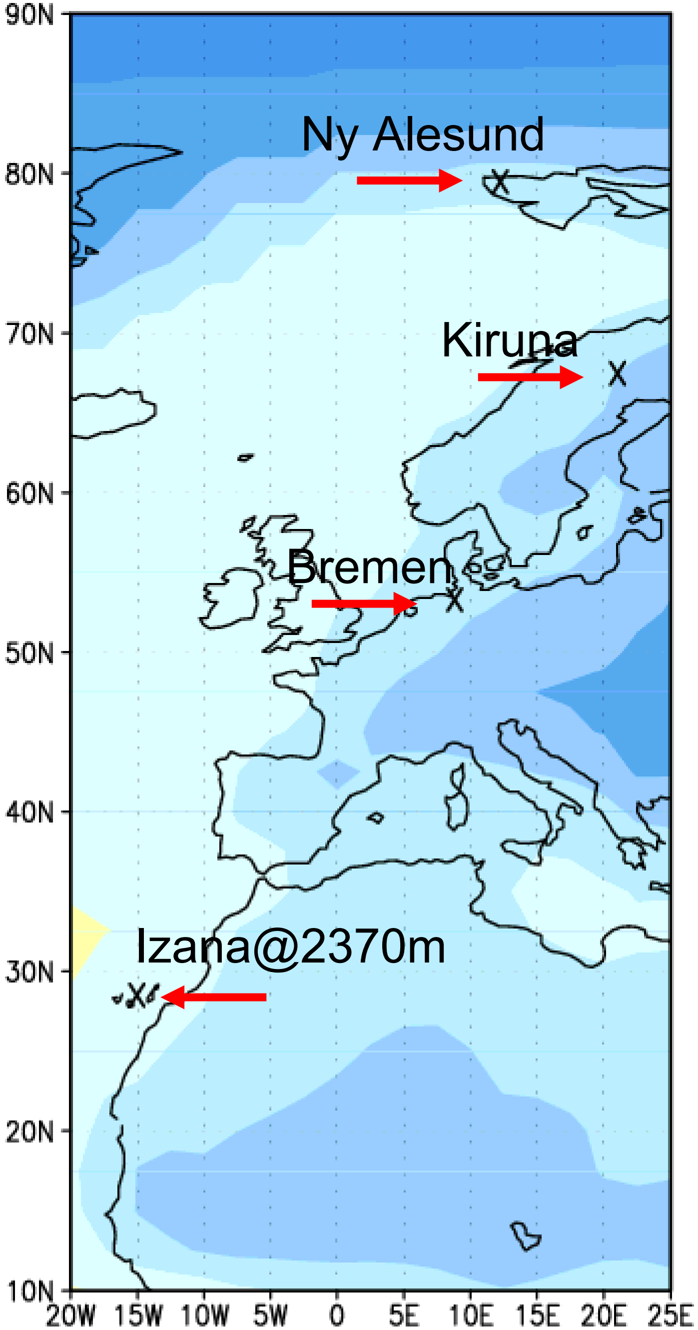
Use large scale (>1000km) winds to constrain dynamical field, so that the isotopic field is also constrained and reproduced in daily to inter-annual time scales.

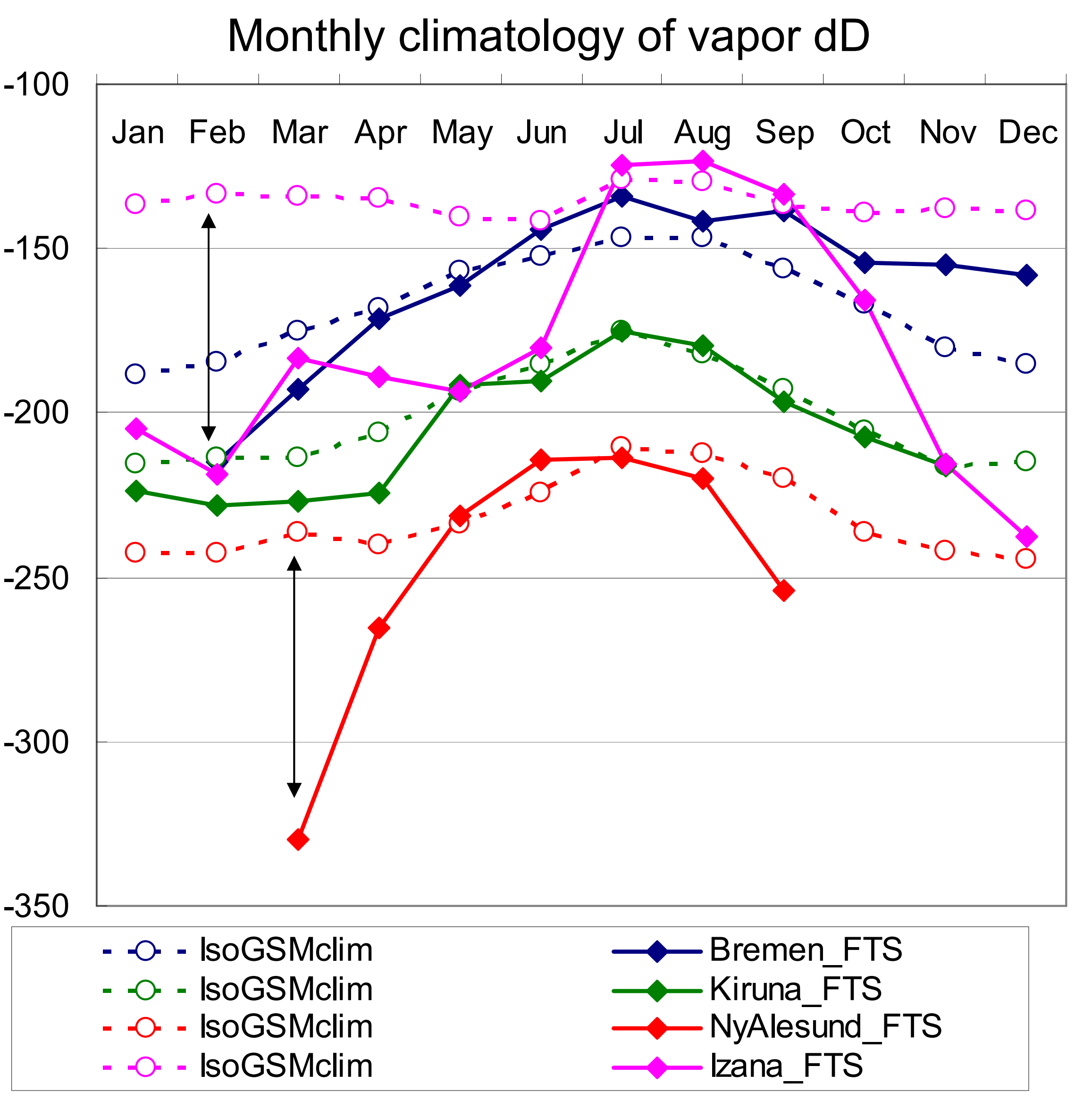
Yoshimura and Kanamitsu, 2008; Yoshimura et al., 2008

Comparison with GNIP Climatology
“Rainy sky integration”

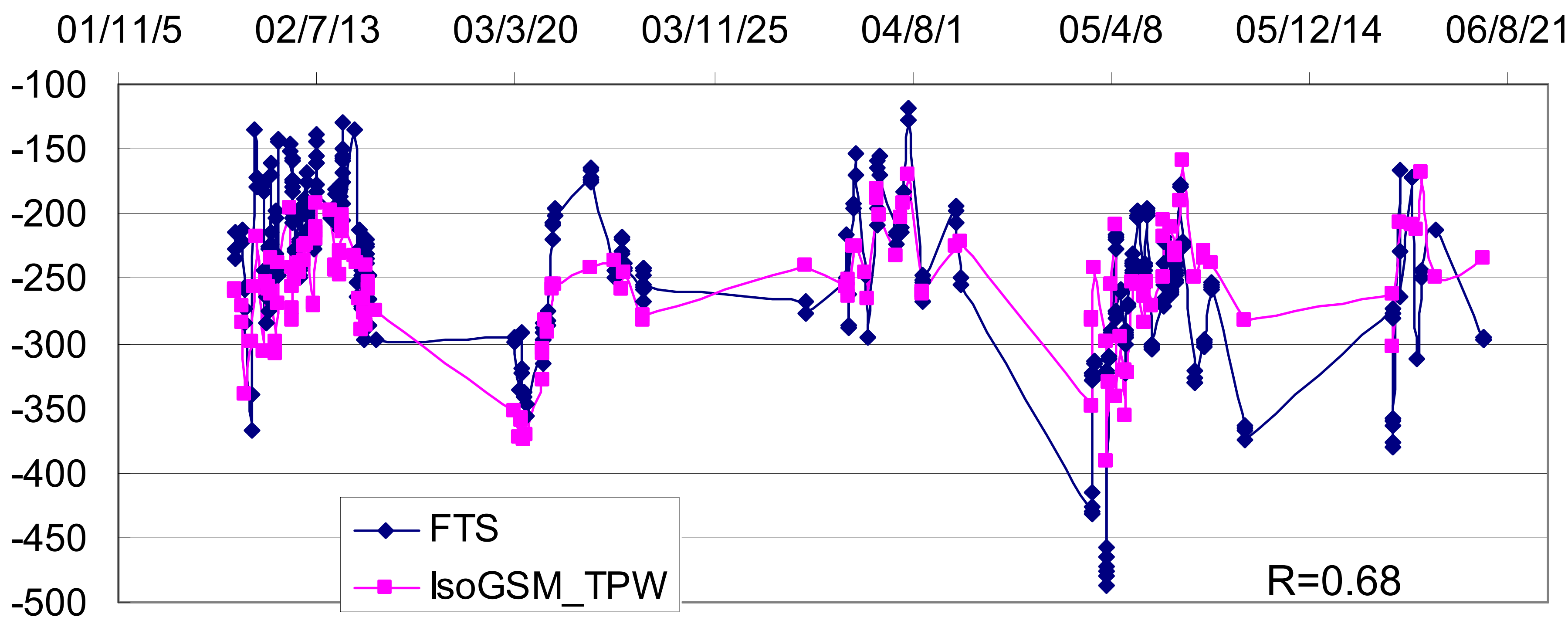


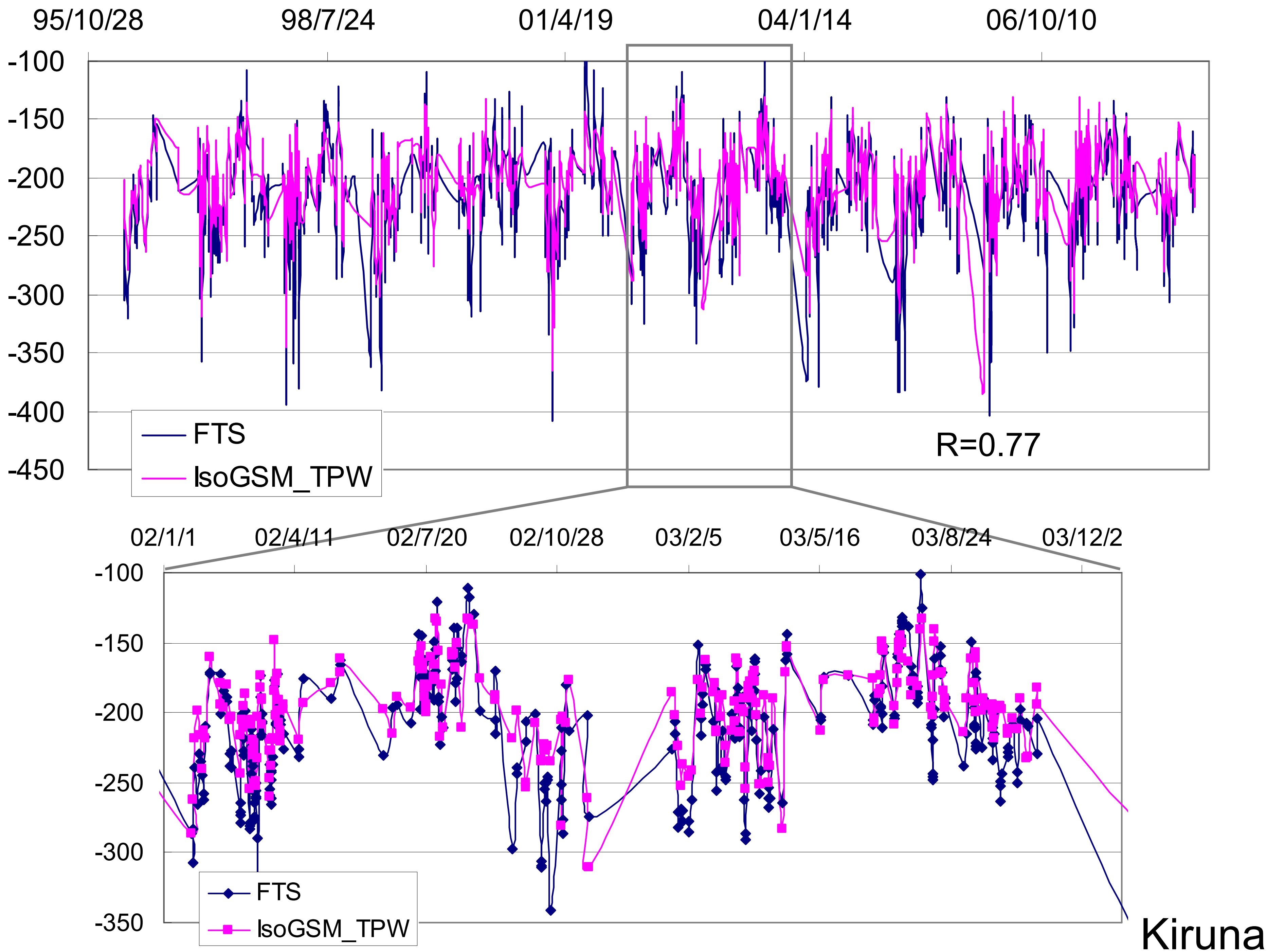
Comparison with FTIR Climatology
"Clear sky integration"



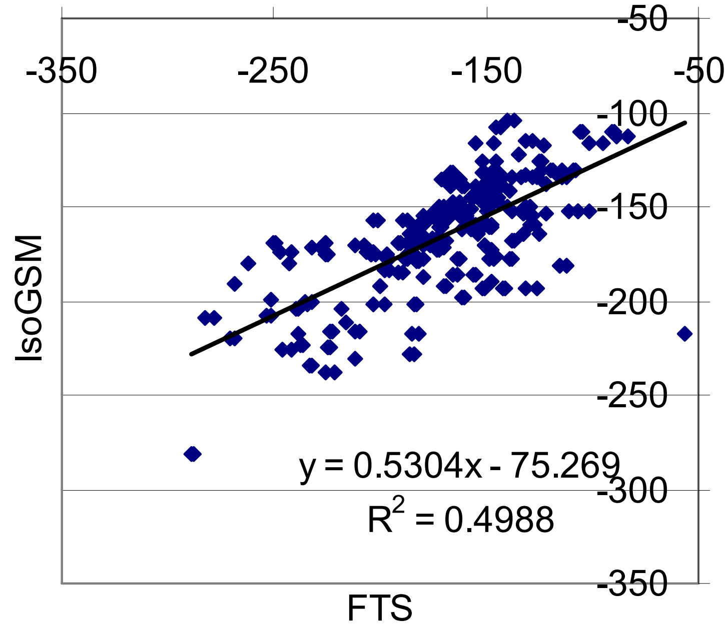


Collocated: Ny Alesund

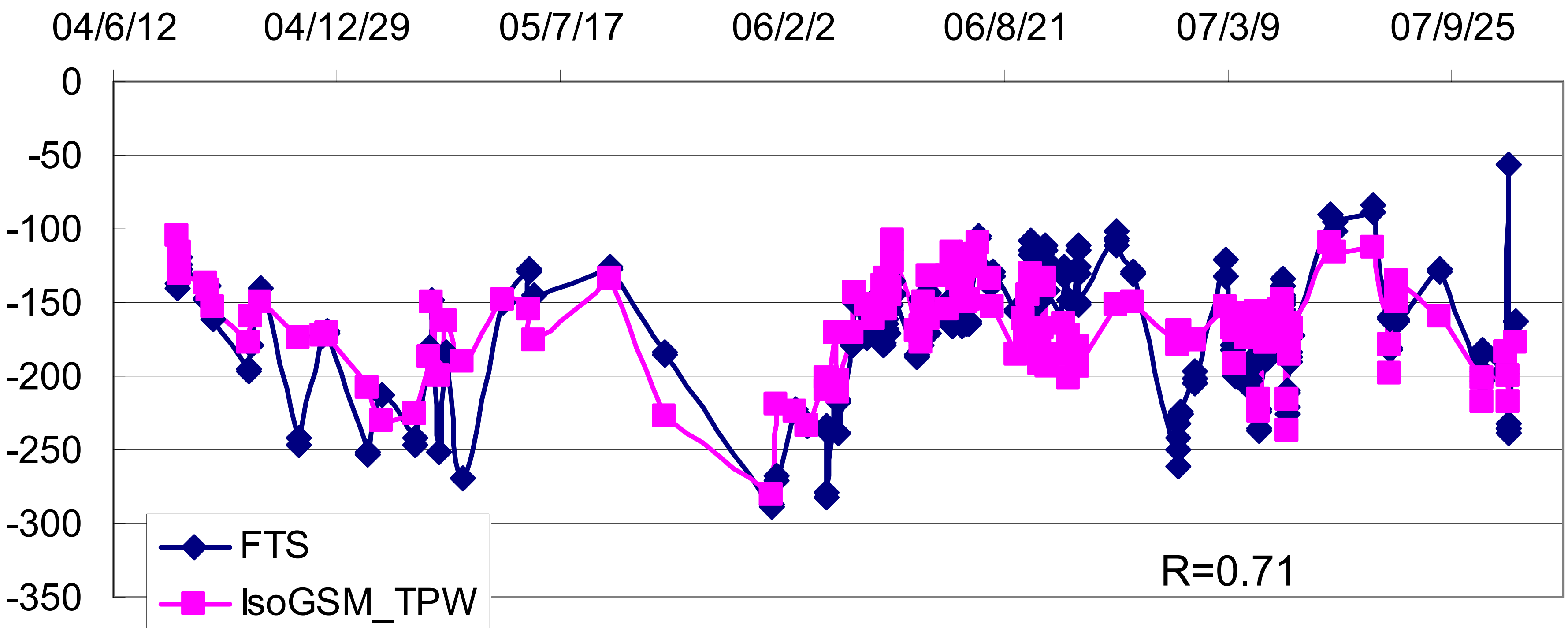



95/10/28
98/7/24
01/4/19
04/1/14
06/10/10
-100
-150
-200
-250
-300
-350
-400
-450
FTS
IsoGSM_TPW
R=0.77
02/1/1
02/4/11
02/7/20
02/10/28
03/2/5
03/5/16
03/8/24
03/12/2
Kiruna

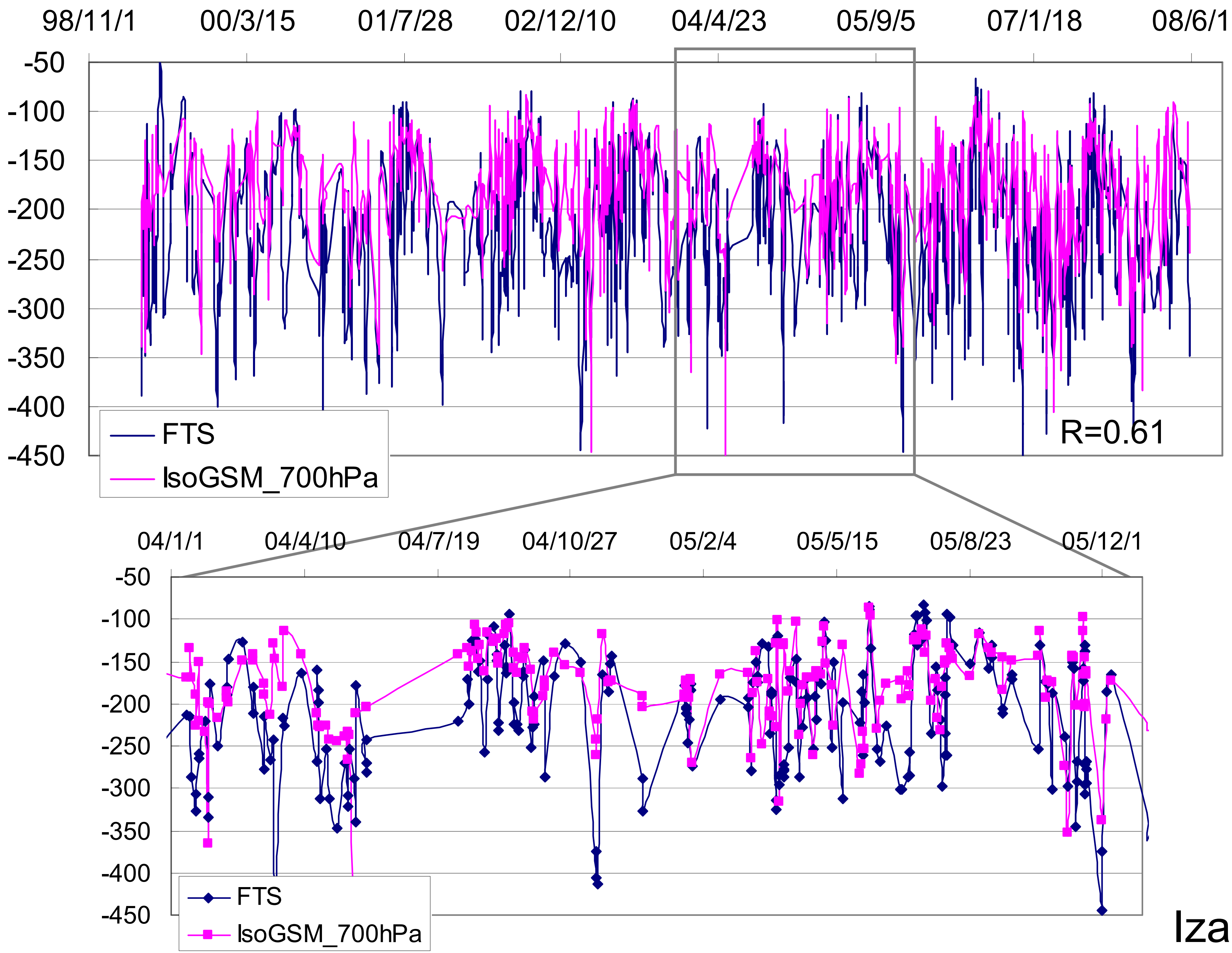
Bremen FTS



-350
-250
-150
-50
-50
-100
-150
-200
-250
-300
-350
IsoGSM
FTS
y = 0.5304x - 75.269
R^2 = 0.4988



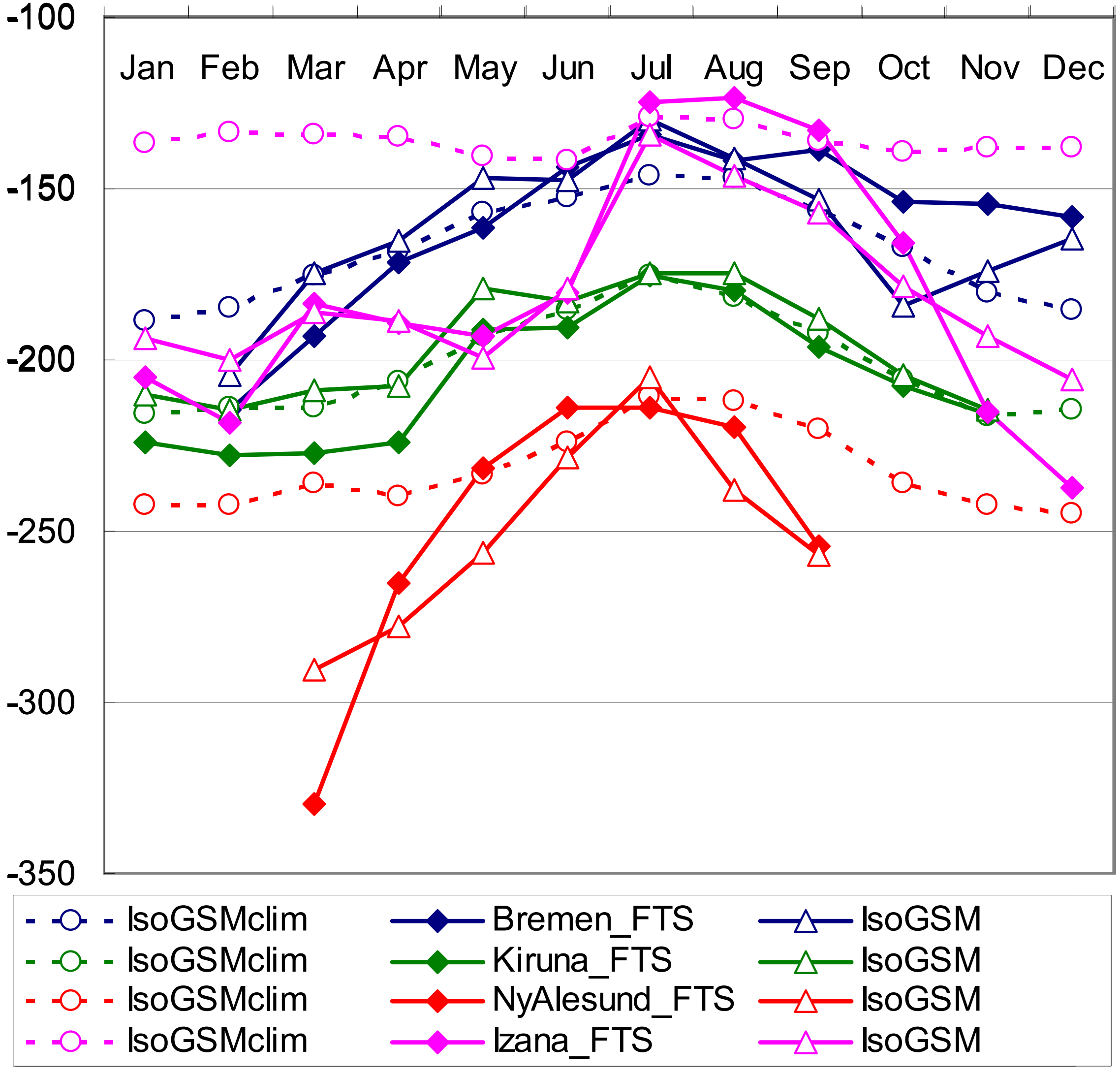
04/6/12
04/12/29
05/7/17
06/2/2
06/8/21
07/3/9
07/9/25
0
-50
-100
-150
-200
-250
-300
-350
FTS
IsoGSM_TPW
R=0.71



98/11/1
00/3/15
01/7/28
02/12/10
04/4/23
05/9/5
07/1/18
08/6/1
-50
-100
-150
-200
-250
-300
-350
-400
-450
FTS
IsoGSM_700hPa
R=0.61
04/1/1
04/4/10
04/7/19
04/10/27
05/2/4
05/5/15
05/8/23
05/12/1
-50
-100
-150
-200
-250
-300
-350
-400
-450
FTS
IsoGSM_700hPa

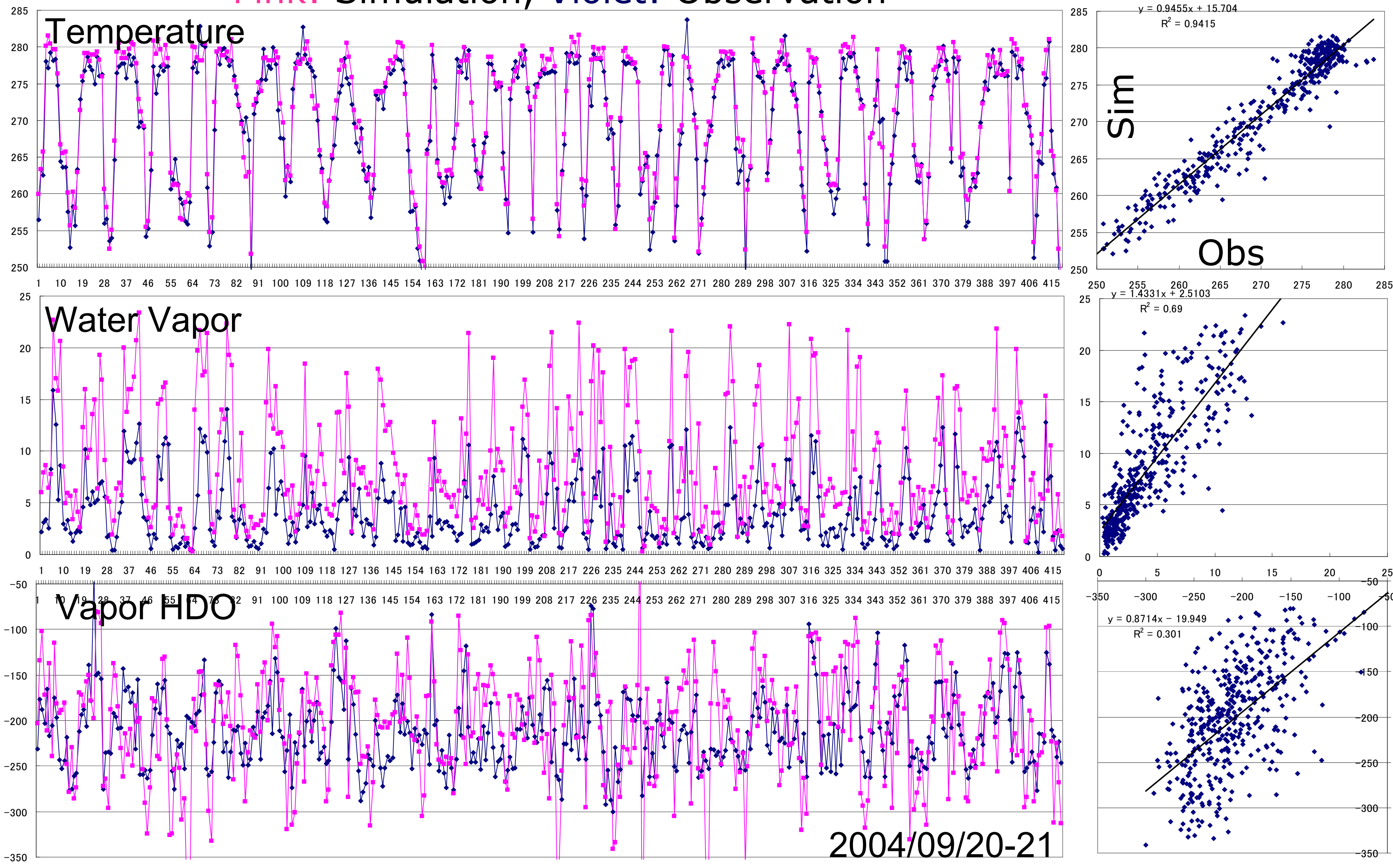
Izana

Collocated model vs FTS

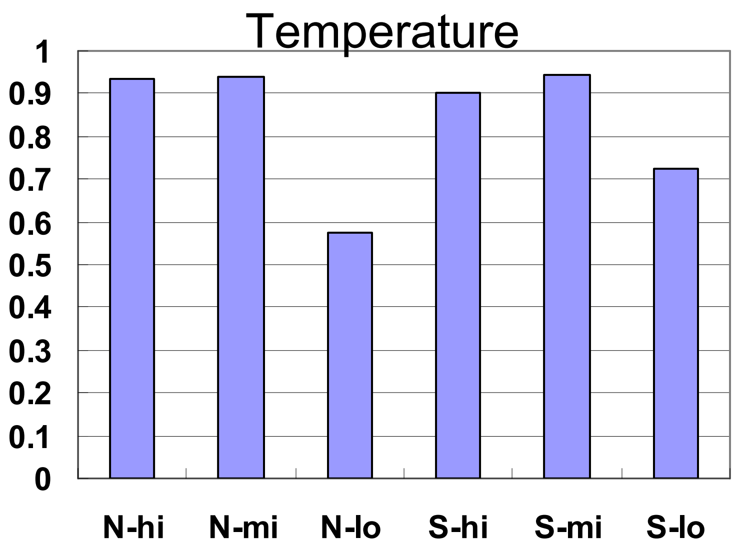


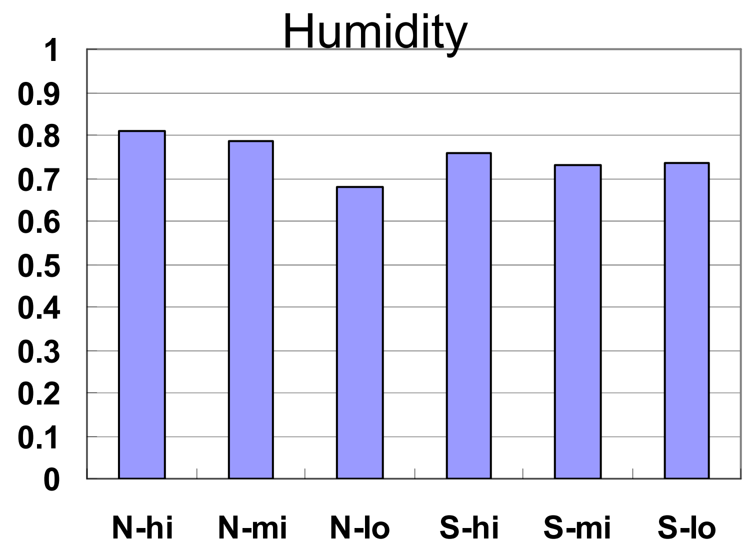
TES vs collocated-IsoGSM comparison

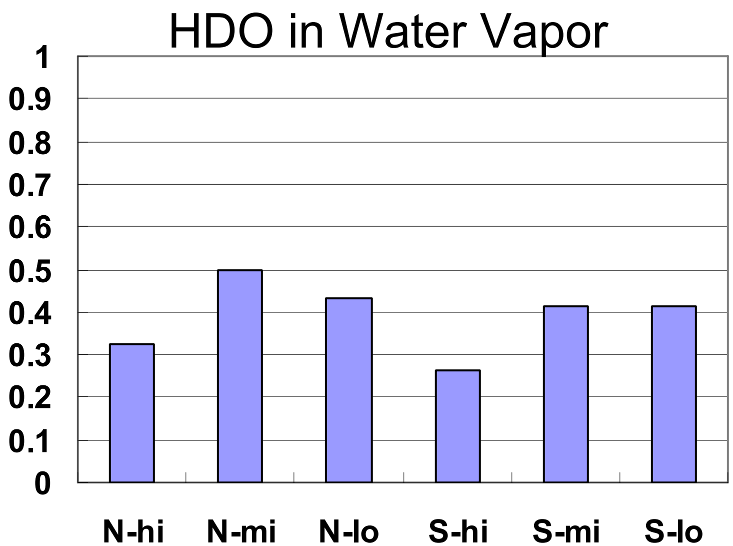
Pink: Simulation, Violet: Observation



Correlation b/w TES & IsoGSM
(averages of 2004-2007 monthly score)





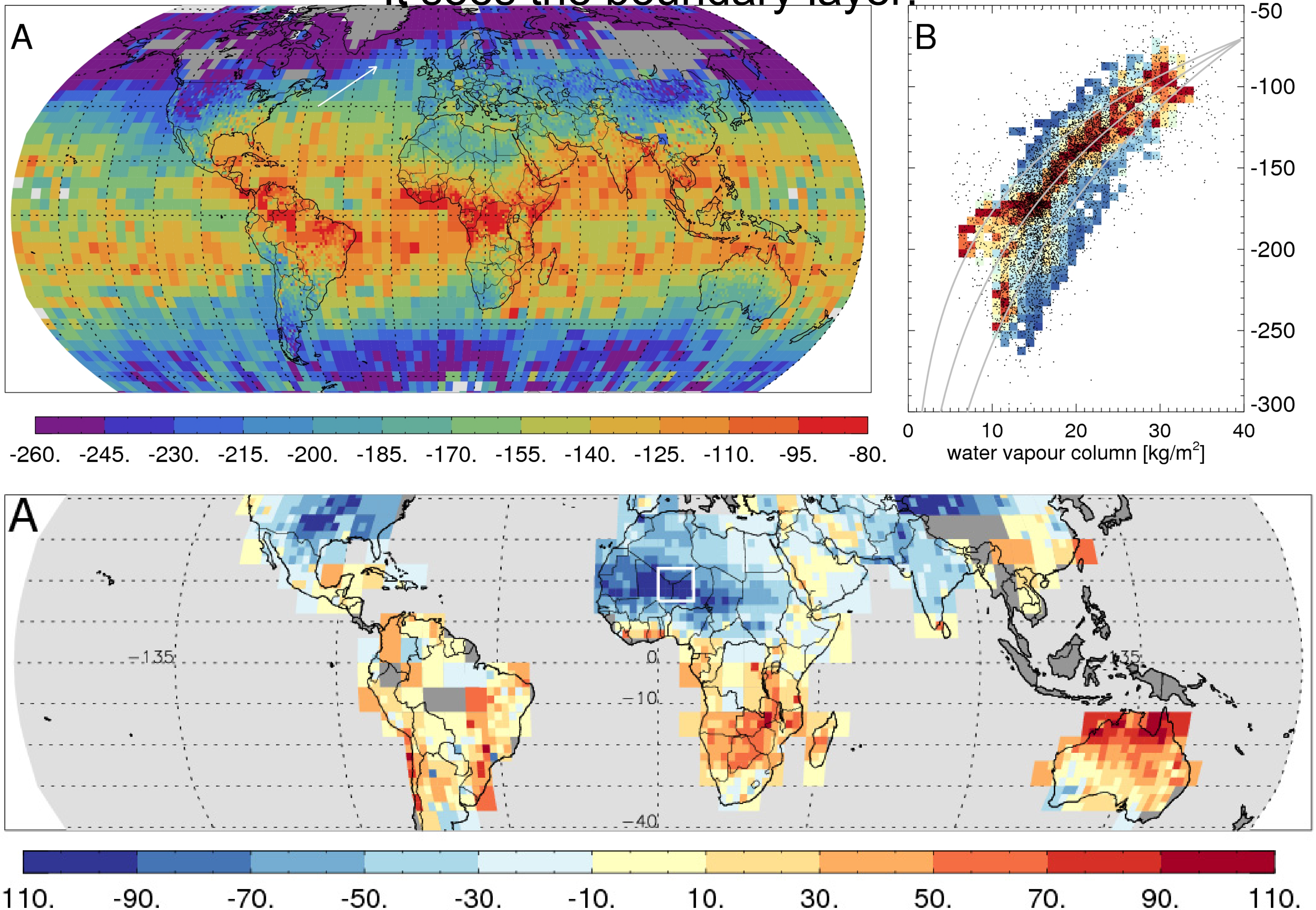


Accuracy order:

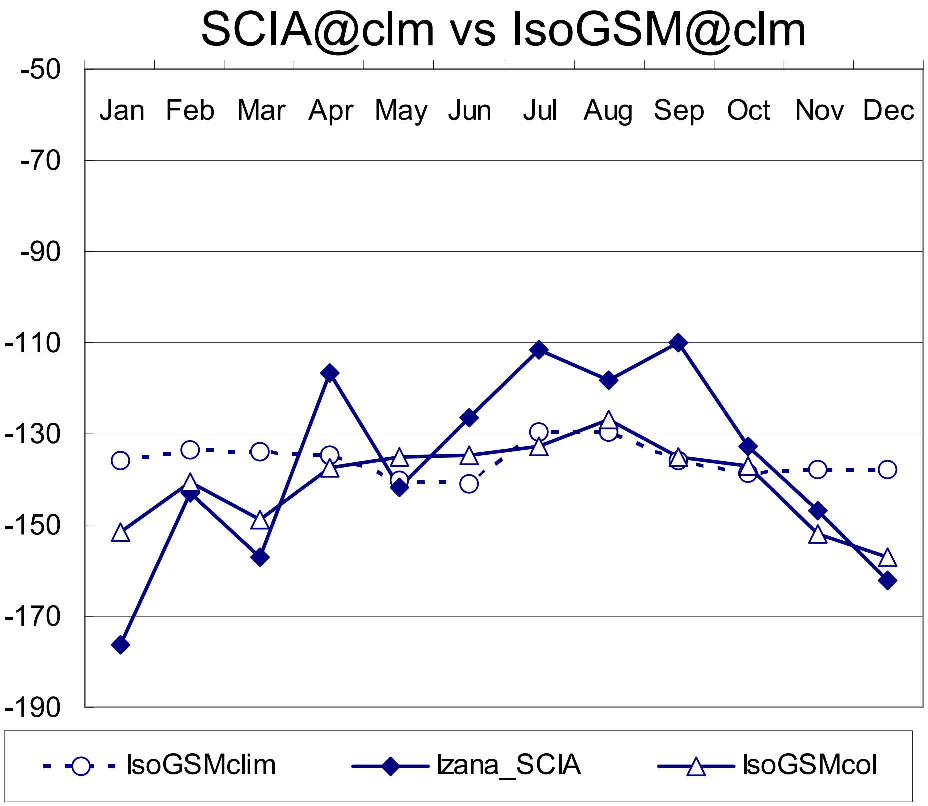
- T > Humidity > HDO
- For HDO
  - N-hemi > S-hemi
  - Mid > Low > High

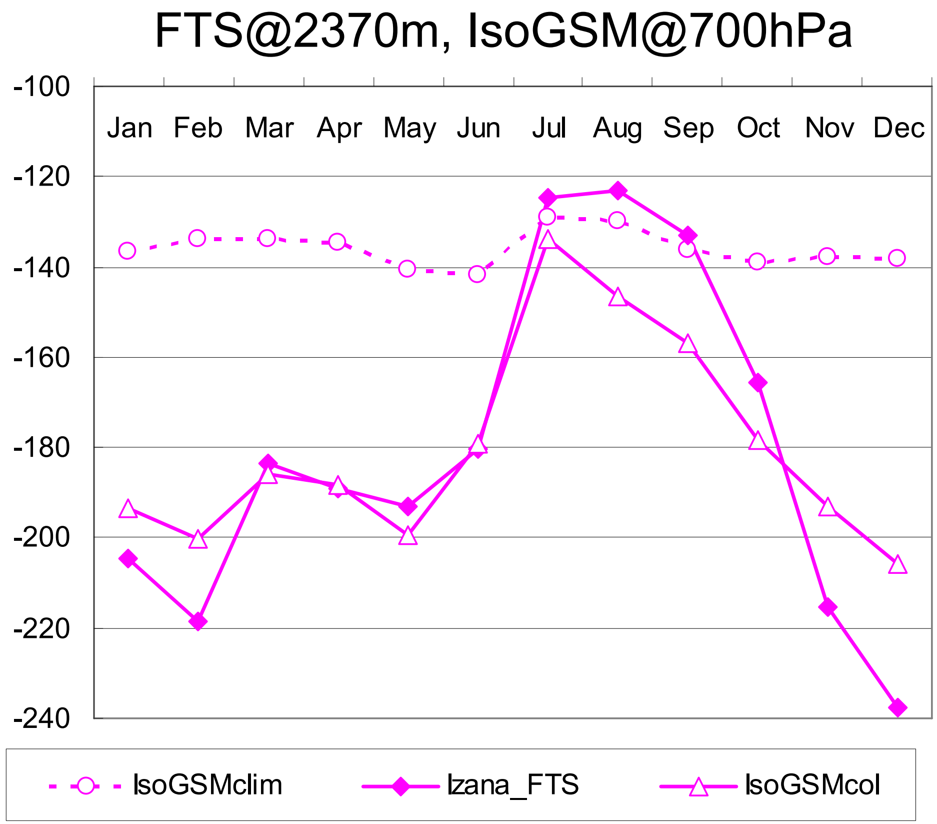
Yoshimura et al., in prep

SCIAMACHY HDO retrieval (Frankenberg et al., 2009)
It sees the boundary layer!



SCIA/FTS/collocated-IsoGSM comparison at Izana (left: SCIA vs Model, right: FTS vs Model)

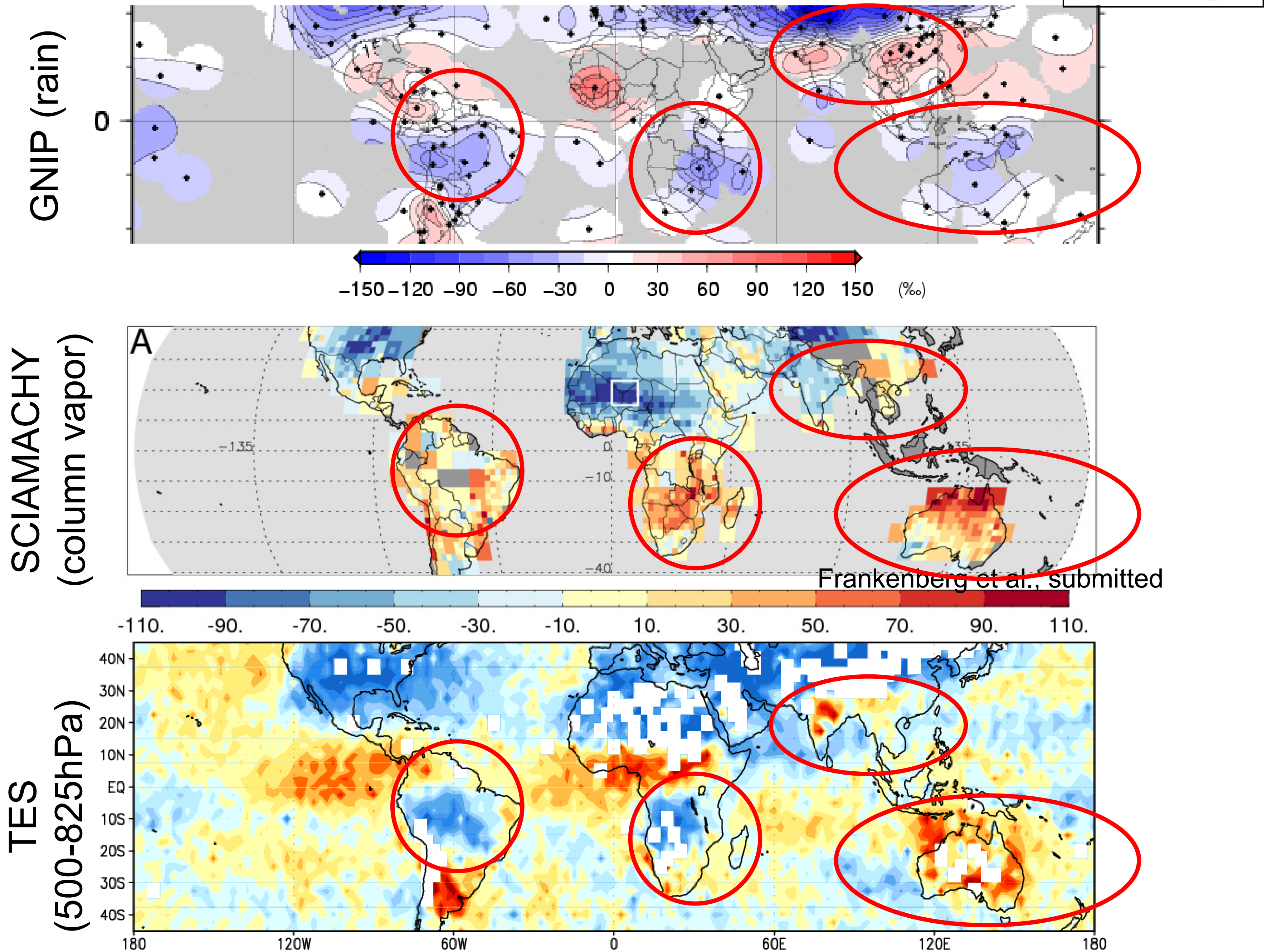


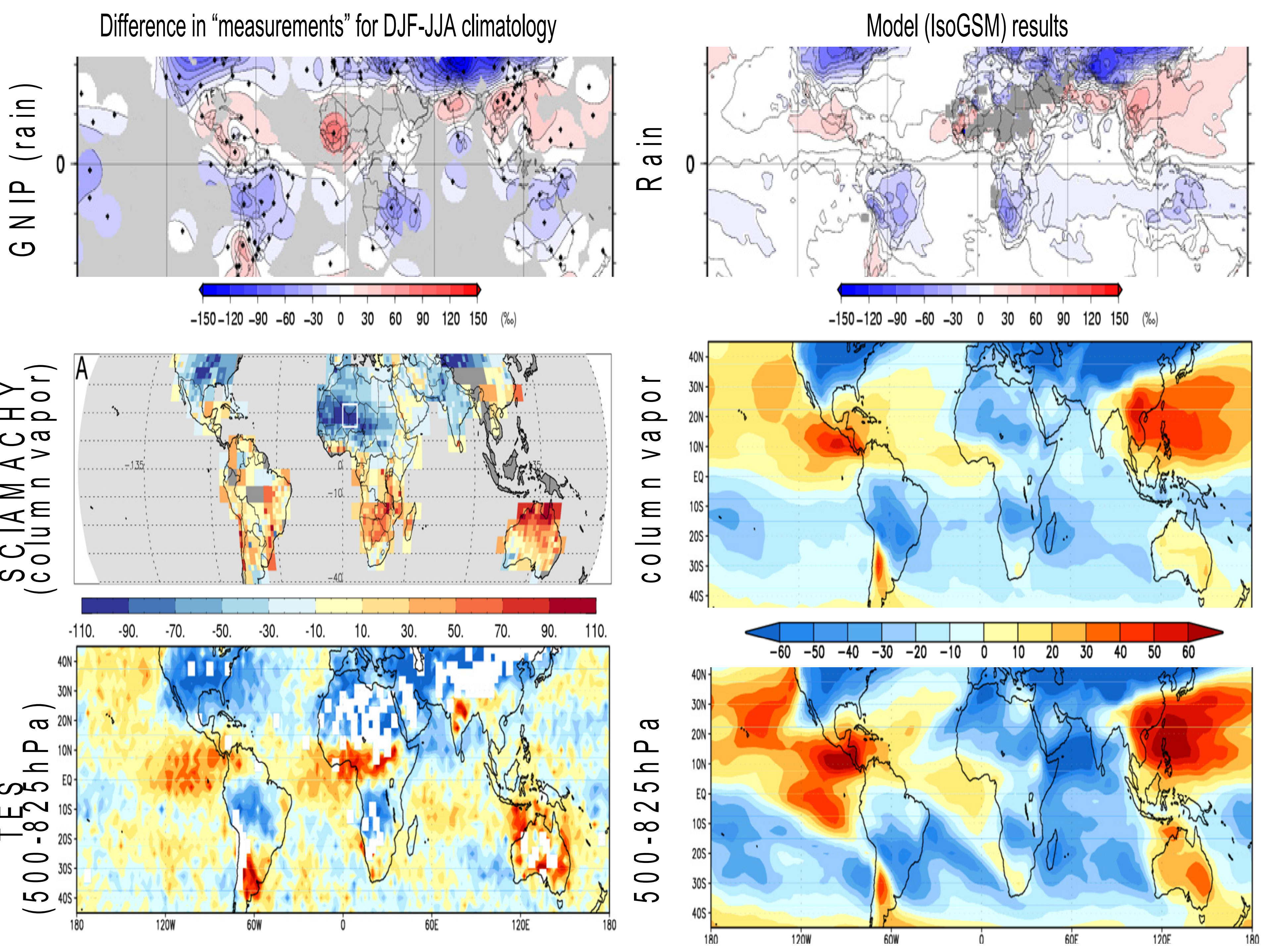


Yoshimura et al., in prep

Difference in “measurements” for DJF-JJA climatology

dD in H_2O



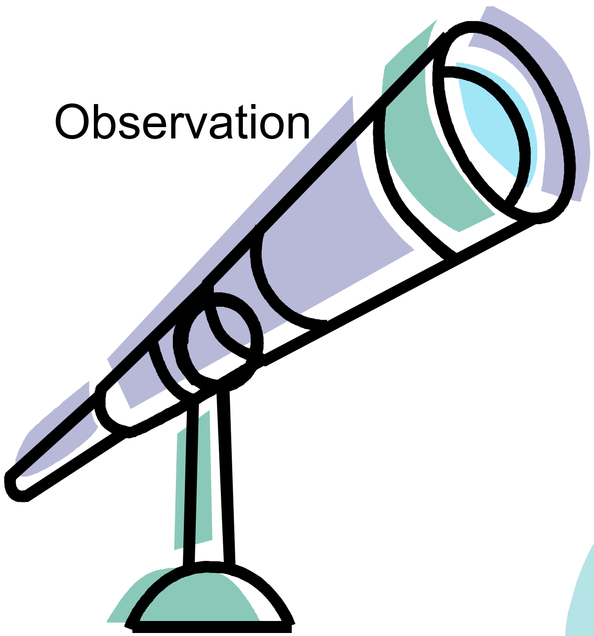


Difference in "measurements" for DJF-JJA climatology
Model (IsoGSM) results
GNIP (rain)
Rain
-150 -120 -90 -60 -30 0 30 60 90 120 150 (‰)
SCIAMACHY (column vapor)
column vapor
A
-110. -90. -70. -50. -30. -10. 10. 30. 50. 70. 90. 110.
-60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60
TES (500-825hPa)
500-825hPa
40N 30N 20N 10N EQ 10S 20S 30S 40S
180 120W 60W 0 60E 120E 180

Science: Assimilation of isotopes

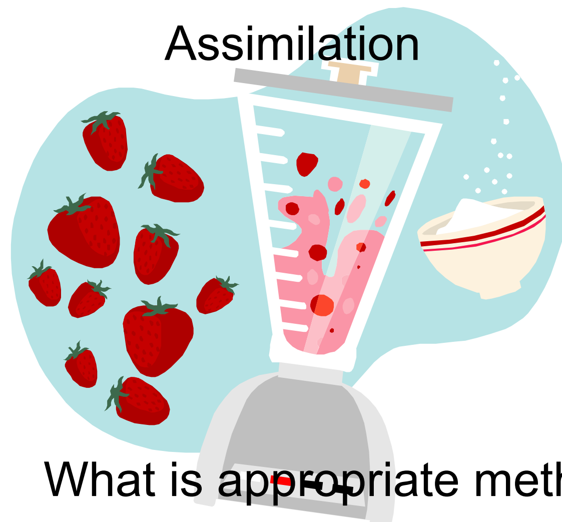
– *No longer a poor man!* –

Observation

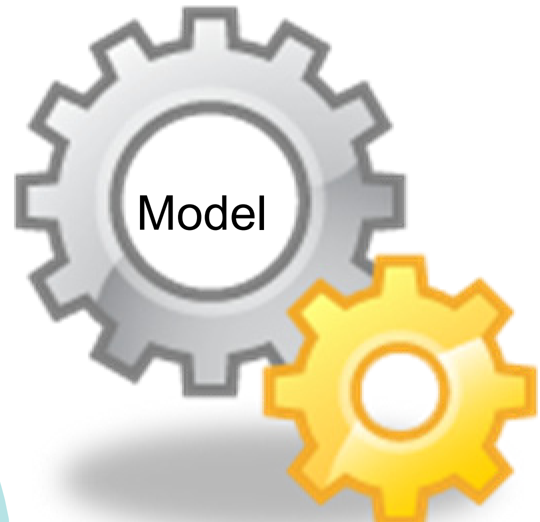


TES/Aura HDO
(Worden et al., 2007)
SCHIAMACHY
(Frankenberg et al., 2009)
FTS

Assimilation



What is appropriate method?



Model

IsoGSM
(Yoshimura et al., 2008)

- 1st Purpose: Make dD vapor analysis fields

How about EnKF?

- In comparison with variational methods:
  - Better than 3D-Var in general.
  - Adjoint model unnecessary. (needed by 4D-Var)
- Possibility to improve (influence) other thermo-dynamical fields (q, wind, T, etc.)
  → 2nd Purpose (for better weather analysis/forecast, maybe)
  (*c.f.*, wind field improvement by humidity assimilation; Liu et al., 2008)

General form of Kalman Filter

Forecast model

$$\mathbf{x}_{i+1}^{f} = M(\mathbf{x}_{i}^{a})$$

Forecast of error covariance

$$\mathbf{P}_{i}^{f} = \mathbf{M}\mathbf{P}_{i-1}^{a}\mathbf{M}^{T}$$

Kalman filter

$$\mathbf{x}_{i}^{a} = \mathbf{x}_{i}^{f} + \mathbf{K}_{i}\left(\mathbf{y}_{i}^{o} - H_{i}(\mathbf{x}_{i}^{f})\right)$$

Kalman gain

$$\mathbf{K}_{i} = \mathbf{P}_{i}^{f}\mathbf{H}_{i}^{T}\left(\mathbf{H}_{i}\mathbf{P}_{i}^{f}\mathbf{H}_{i}^{T} + \mathbf{R}_{i}\right)^{-1}$$

Analysis of error covariance

$$\mathbf{P}_{i}^{a} = \left(\mathbf{I} - \mathbf{K}_{i}\mathbf{H}_{i}\right)\mathbf{P}_{i}^{f}$$

$\mathbf{x}$: state in model’s world
$\mathbf{y}$: state by observation
$\mathbf{P}$: model error covariance
$\mathbf{R}$: obs error covariance
M, $\mathbf{M}$: model
H, $\mathbf{H}$: obs operator
$\mathbf{K}$: Kalman gain

Ensemble Kalman Filter
(Square Root Filter; SRF)

$\mathbf{x}$: state in model's world
$\mathbf{y}$: state by observation
$\mathbf{P}$: model error covariance
$\mathbf{R}$: obs error covariance
M, $\mathbf{M}$: model
H, $\mathbf{H}$: obs operator
$\mathbf{K}$: Kalman gain

$$\mathbf{X} = \begin{bmatrix} \mathbf{x}_1 & \cdots & \mathbf{x}_m \end{bmatrix}$$

Ensemble Matrix (small x means each ensemble member)

$$\boldsymbol{\delta}\mathbf{X} = \mathbf{X} - \overline{\mathbf{X}}$$

Ensemble perturbation (anomaly)

$$\mathbf{P}_f = (\mathrm{m} - 1)^{-1} \boldsymbol{\delta}\mathbf{X}\boldsymbol{\delta}\mathbf{X}^T$$

Perturbation → Model error covariance

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

Kalman gain

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

Ensemble analysis

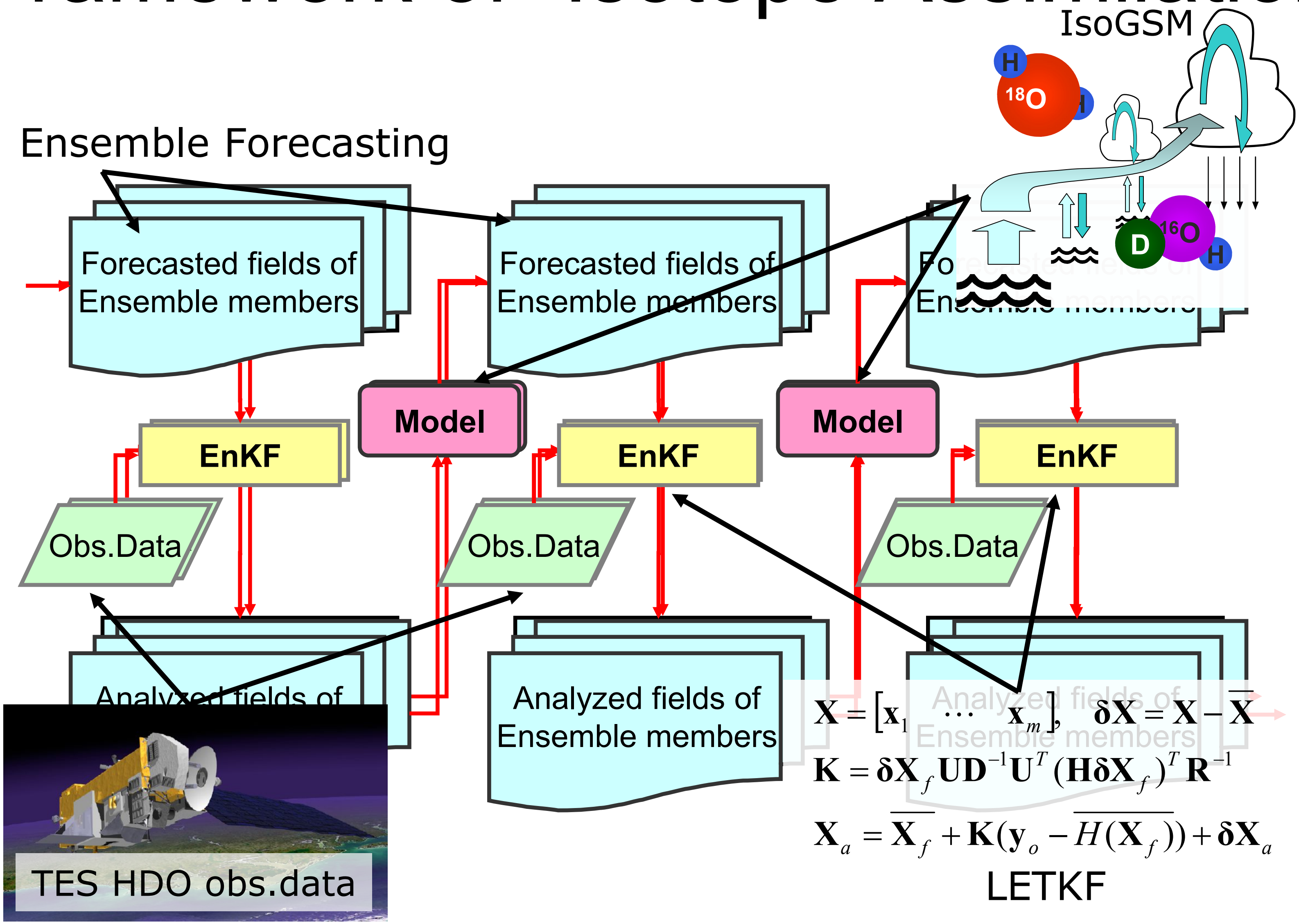
$$= \overline{\mathbf{X}_f} + \boldsymbol{\delta}\mathbf{X}_f [\mathbf{U}\mathbf{D}^{-1}\mathbf{U}^T (\mathbf{H}\boldsymbol{\delta}\mathbf{X}_f)^T \mathbf{R}^{-1} (\mathbf{y}_o - \overline{H(\mathbf{X}_f)})$$

$$+ \sqrt{m-1}\,\mathbf{U}\mathbf{D}^{-1/2}\mathbf{U}^T]$$

Eigenvalue decomposit

$$\text{where} \quad \mathbf{U}\mathbf{D}\mathbf{U}^T = (m-1)\mathbf{I} + (\mathbf{H}\boldsymbol{\delta}\mathbf{X}_f)^T \mathbf{R}^{-1} \mathbf{H}\boldsymbol{\delta}\mathbf{X}_f$$

Framework of “Isotope Assimilation”



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

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

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

LETKF

3rd Purpose: Estimate “required” accuracy and resolution of HDO measurement for “adequate” isotope assimilation