GOSAT データ利用ワークショップ
虎ノ門パストラル
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GOSAT TANSO-FTS TIR (Band 4) data analysis method

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GOSAT sensors

【Satellite】

- Mass, power ： Approx. **1650kg**, **3.3kw** - EOL
- Designed life span ： **5 years**
- Orbit ： Altitude **666km** , Orbit Inclination **98 deg**.
  Sun-Synchronous Sub-Recurrent Orbit

【TANSO-FTS】

- Spectral range
  - Band 1 ： **0.75μm～0.78μm** (O_2-A)
  - Band 2 ： **1.56μm～1.92μm** (CO_2 column)
  - Band 3 ： **1.92μm～2.08μm** (CO_2 , CH_4, cirrus cloud)
  - Band 4 ： **5.5μm～14.3μm** (CO_2 vertical profile, CH_4)
- Spectral resolution ： **0.2cm^{-1}**
- SNR ： **> 300**

CO_2 retrieval from spectrum data measured from space

<u>European group led by Dr. Chedin</u> 4A+TIGR+3R, MSU → 3I, N.N; AIRS+AMSU.

HIRS: Chedin et al., 2002a, 2002b, 2003a, 2003b,

AIRS: Crevoisier et al., 2004, Chevallier et al., 2005, Engelen et al., 2004, 2005

and

<u>AIRS group led by Dr. Chahine</u> AMSU, 4D-VAR

Chahine et al., 2008, 2005(VPD), Maddy et al. (2008), Aumann et al., 2005, Engelen et al., 2004

have successfully obtained global maps of CO_2 in the upper troposphere from the thermal infrared spectrum.

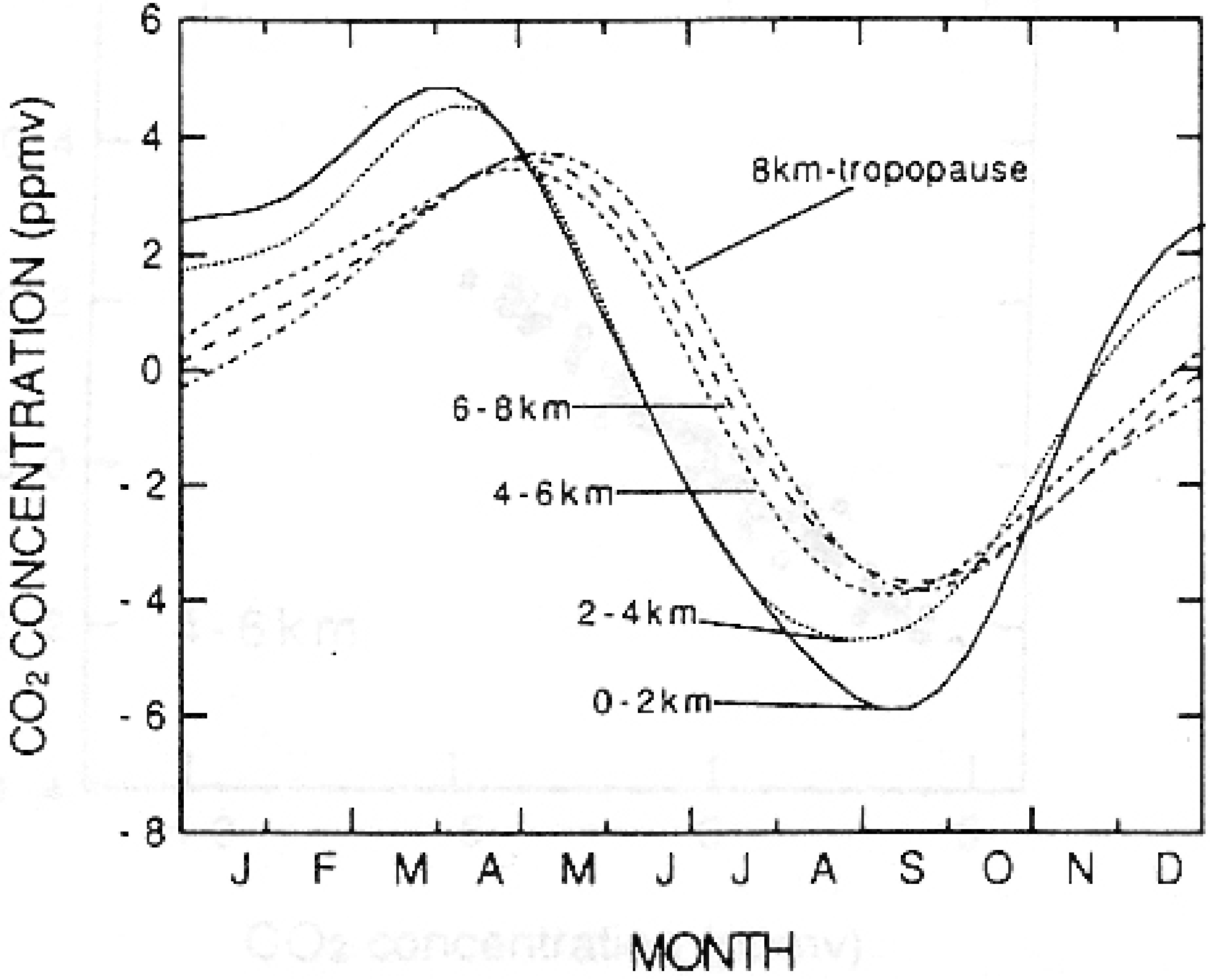
<u>Next target</u> :

Information on <u>vertical structure</u> of CO_2, particularly on CO_2 concentration in <u>PBL</u>

→ Synergetic usage of GOSAT FTS bands (SWIR, TIR) is effective ・・・ benefit of GOSAT sensors！

inter-annual variation of CO_2 at various height

Air craft obs. (in situ)



(Nakazawa et al., 1996)

Calculation of Jacobian

1. Optimization of layer thickness of "retrieval grid"

In order to obtain uniform sensitivity and retrieval error, layer thickness have to be optimized

→ Radiative transfer cal. at "full grid" (finest grid)
→ Determining layer thickness based on "Area value" of averaging kernel
→ "Linear-mapping" : "retrieval grid" ←→ "full grid"

2. Selecting retrieval channels

In order to reduce the effects of temperature estimation error, spectral channel that are used for retrieval have to be selected

→ Channel selection based on "Shannon information contents"

Optimal estimation retrieval

MAP (Maximum A *Posteriori* retrieval)

- Retrieval method based on Bayesian theory.
- Total retrieval error can be estimated .

- The (*i+1*)-th concentration, X_{i+1}, is

$$X_{i+1} = X_a + (K_i^T S_e^{-1} K_i + S_a^{-1})^{-1} K_i^T S_e^{-1} (Y - F(X_i) + K_i (x_i - x_a))$$

X_a: a *priori*; S_e: measurement error covariance; S_a: a *priori* covariance; Y: measurement spectra; F: forward spectra; K_i: Jacobian

- Total retrieval error is

$$\hat{S} = (S_a^{-1} + K^T S_e^{-1} K)^{-1}$$

[e.g., *Rodgers*, 2000]

"full grid" ⟷ "reduced grid"

- Liner-mapping between state (x) and retrieval (z) vectors is

$$x = Wz$$
$$z = W^{*}x$$

x : state vector
z : retrieval vector

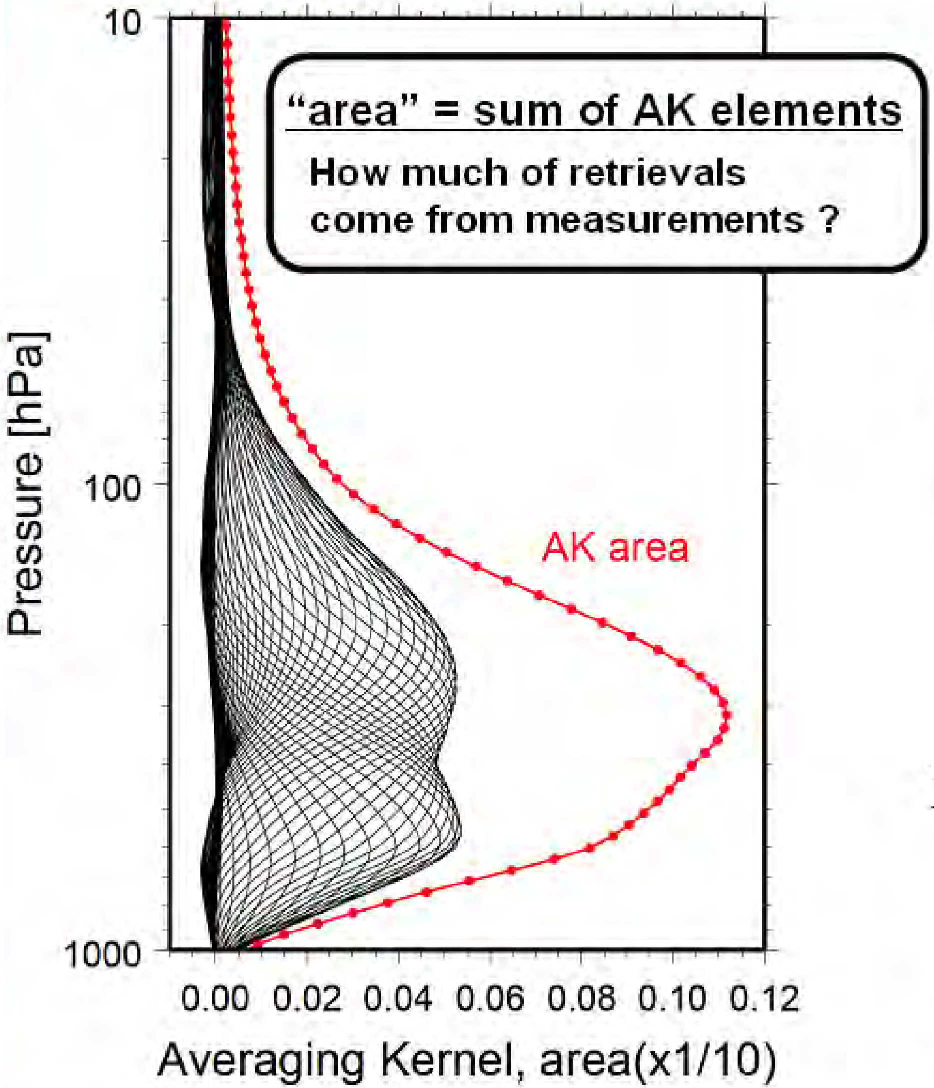
- The (*i+1*)-th concentration, X_{i+1}, is

$$X_{i+1}$$
$$= W^{*}X_{a} + (W^{T}K_{i}^{T}S_{e}^{-1}K_{i}W + (W^{*}SW^{*T})^{-1})^{-1}W^{T}K_{i}^{T}S_{e}^{-1}(Y - F(X_{i}) + K_{i}W(W^{*}x_{i} - W^{*}x_{a}))$$

- Total retrieval error is

$$\hat{S} = (W^{T}K^{T}S_{e}^{-1}KW + (W^{*}S_{a}W^{*T})^{-1})^{-1}$$

“full grid” ⟷ “reduced grid”



“full grid” (state vector)

radiative transfer & jacobian calculations

← Atmosphere between 1100 and 0.1 hPa divided into 110 layers.

↓

layers merged until sum of AK areas > 1

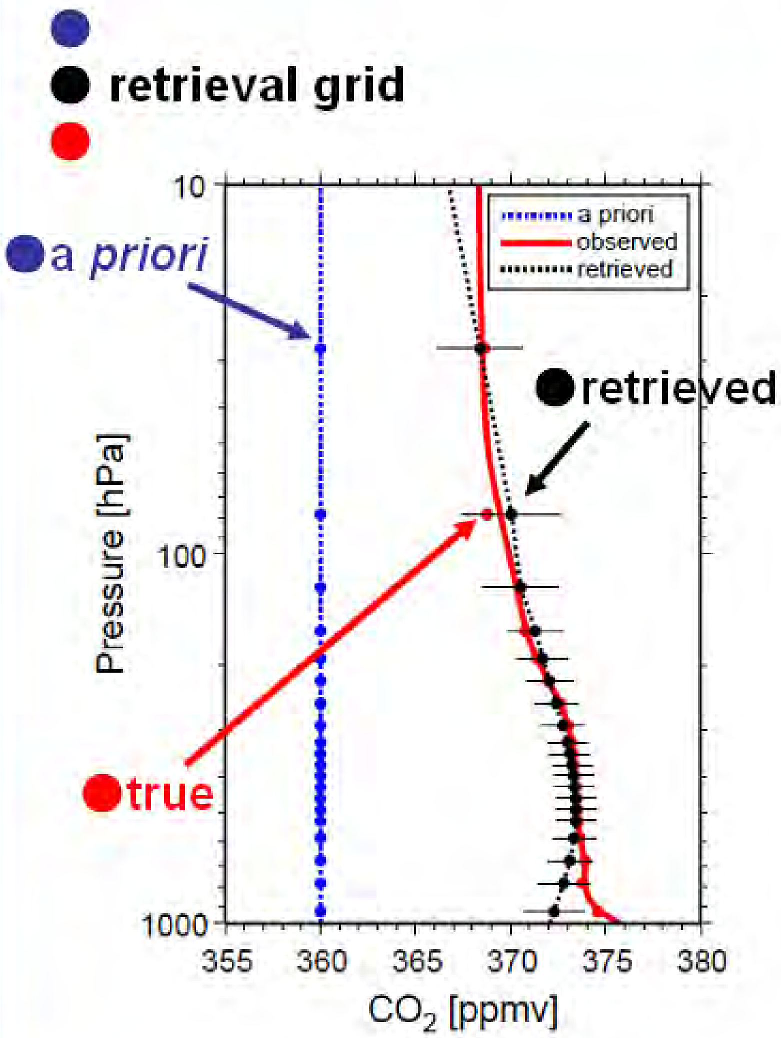
↓

“reduced grid” (retrieval vector)

CO_2 retrieval

← Coarser grid.
Grid inferred from AK area.

Retrieval without T uncertainties



simulations

30 pseudo-spectra with random noise of GOSAT/TANSO-FTS were computed for each season and latitude.

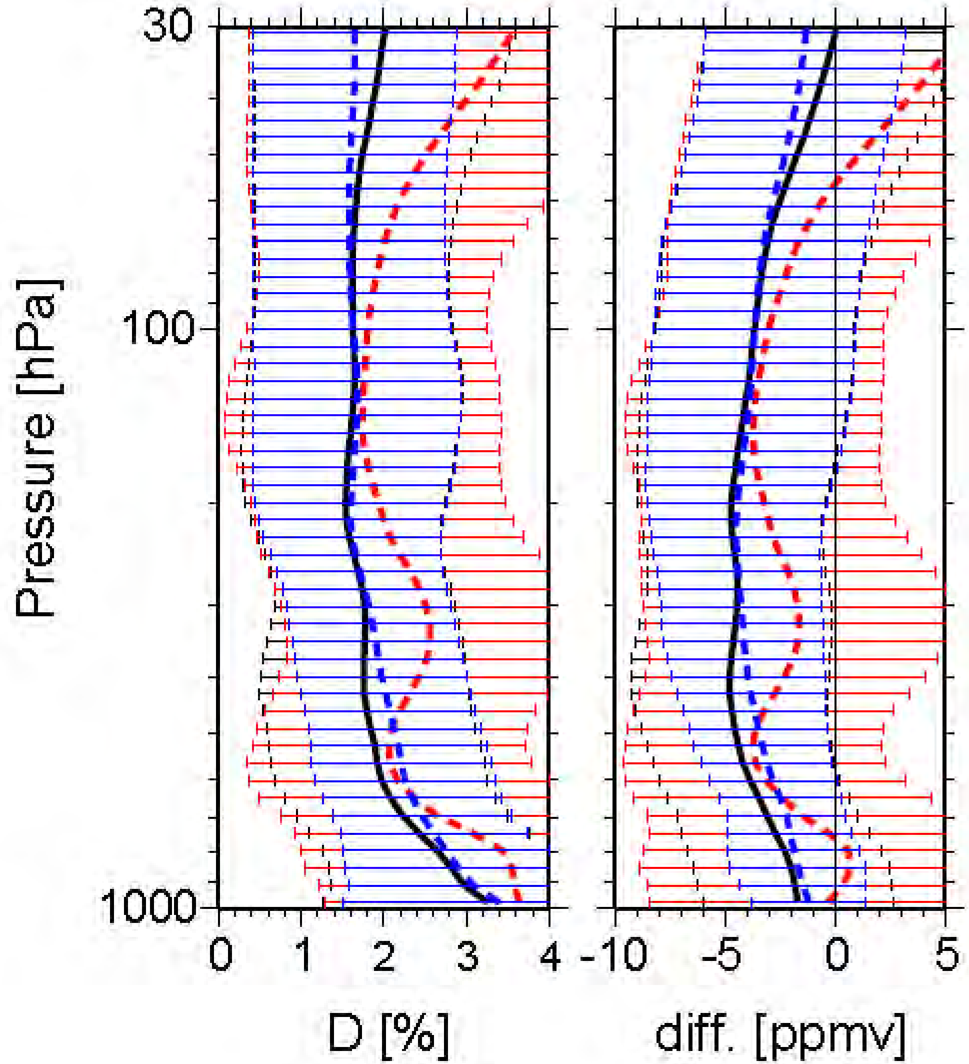
↓

Retrieval was performed,

- Sa (error covariance of a *priori*)
  - for diagonal elements,
    1) ±1% (diagonal)
    2) 1-σ of NICAM CO_2 from a *priori*
  - for non-diagonal elements,
    correlation between layers decreasing to 1/e at 30 hPa apart from each other

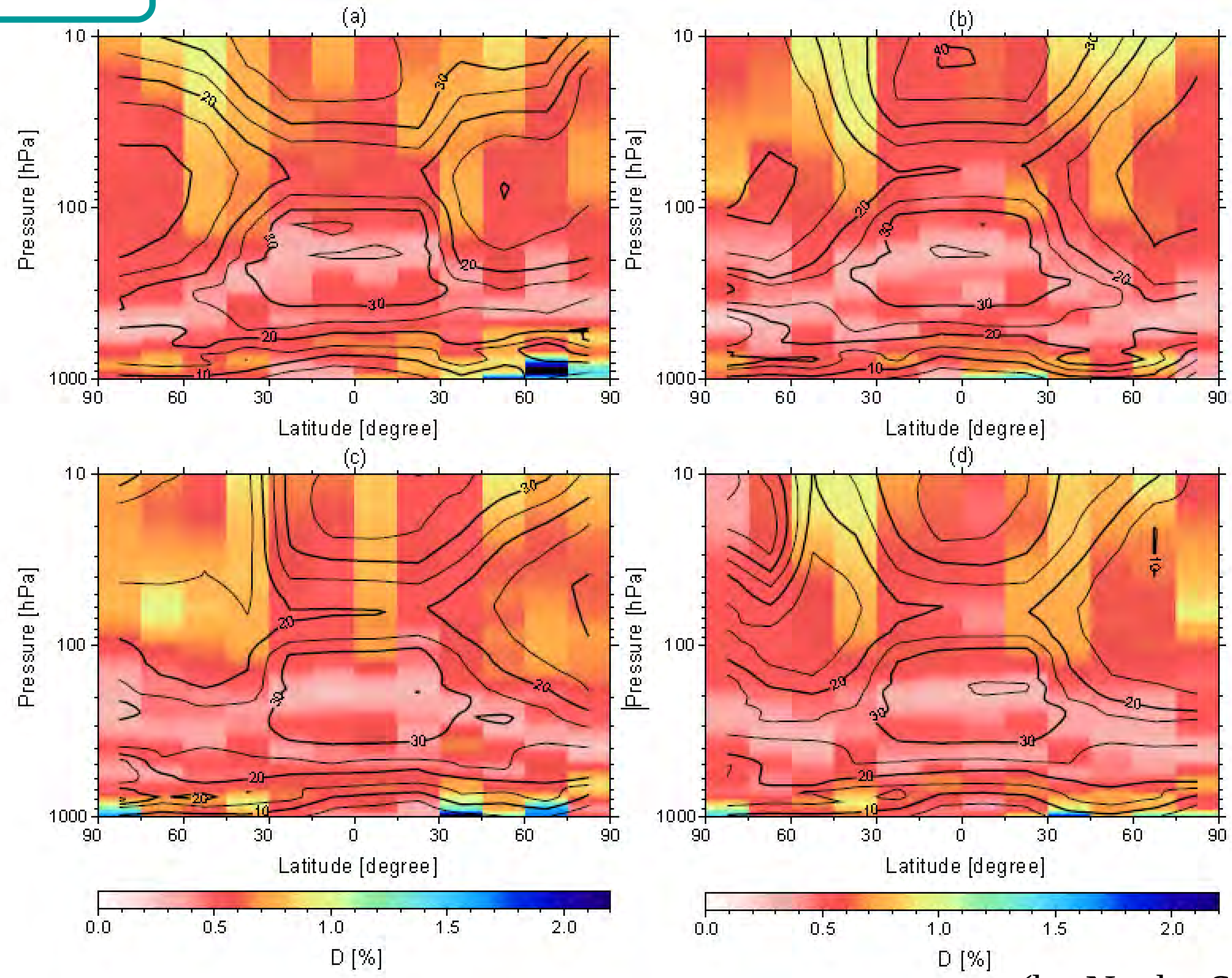
Center for Climate System Research, University of Tokyo

Error analysis

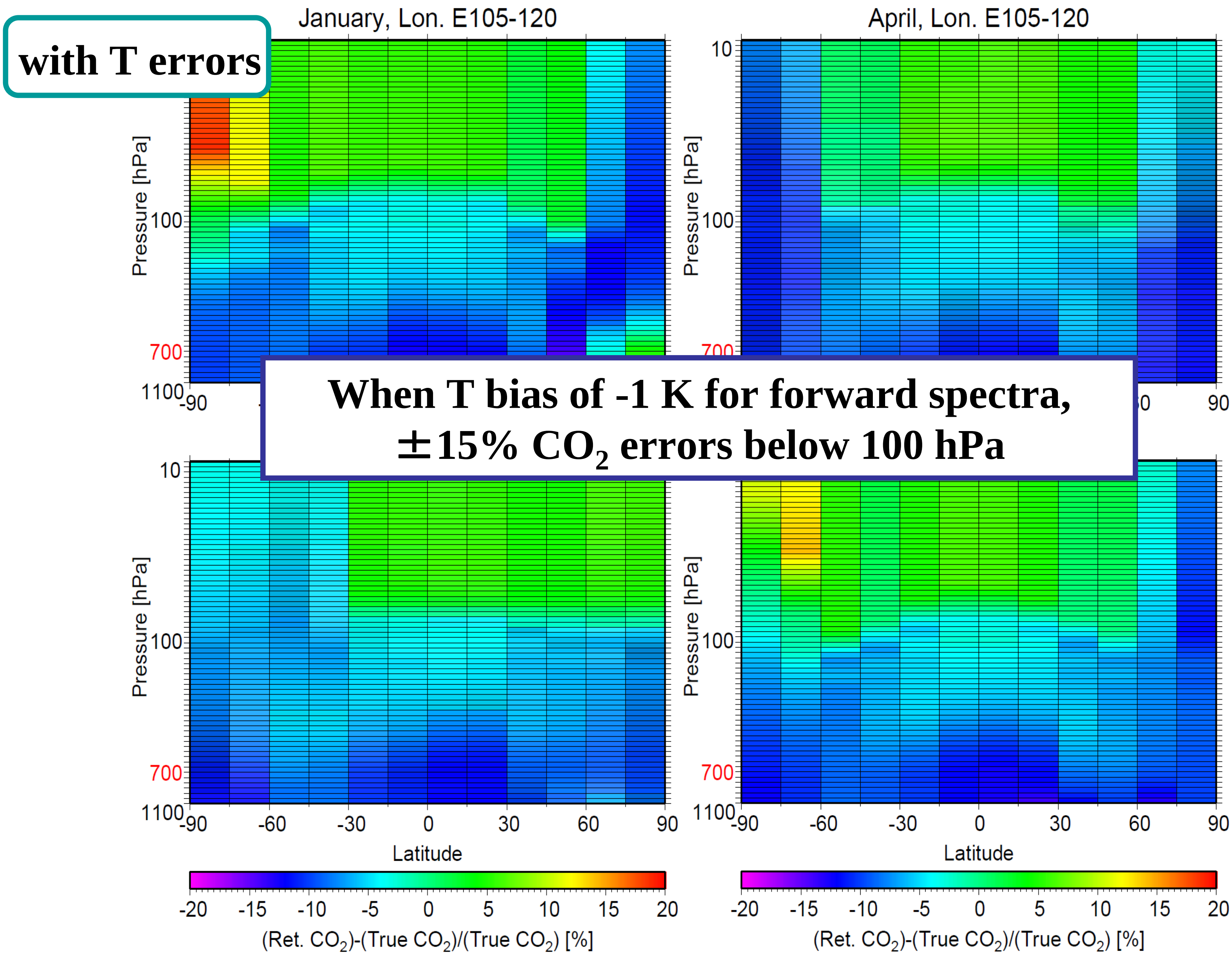


(by Naoko Saitoh)

no T errors



(by Naoko Saitoh)


with T errors
January, Lon. E105-120
April, Lon. E105-120
Pressure [hPa]
10
100
700
1100
-90
-60
-30
0
30
60
90
Latitude
-20
-15
-10
-5
0
5
10
15
20
(Ret. CO2)-(True CO2)/(True CO2) [%]
When T bias of -1 K for forward spectra,
±15% CO2 errors below 100 hPa

Retrieval channel selection

Appropriate retrieval channels should be selected to reduce the effect of T uncertainties on retrieved CO_2 concentrations.

- According to Shannon's information theory [*Shannon and Weaver*, 1949], information contents of CO_2 and temperature,

$$I = \frac{1}{2}\log_2\left|S_a\right| - \frac{1}{2}\log_2\left|\hat{S}\right| \qquad I = \frac{1}{2}\log_2\left|S_{temp}\right| - \frac{1}{2}\log_2\left|\hat{S}\right|$$

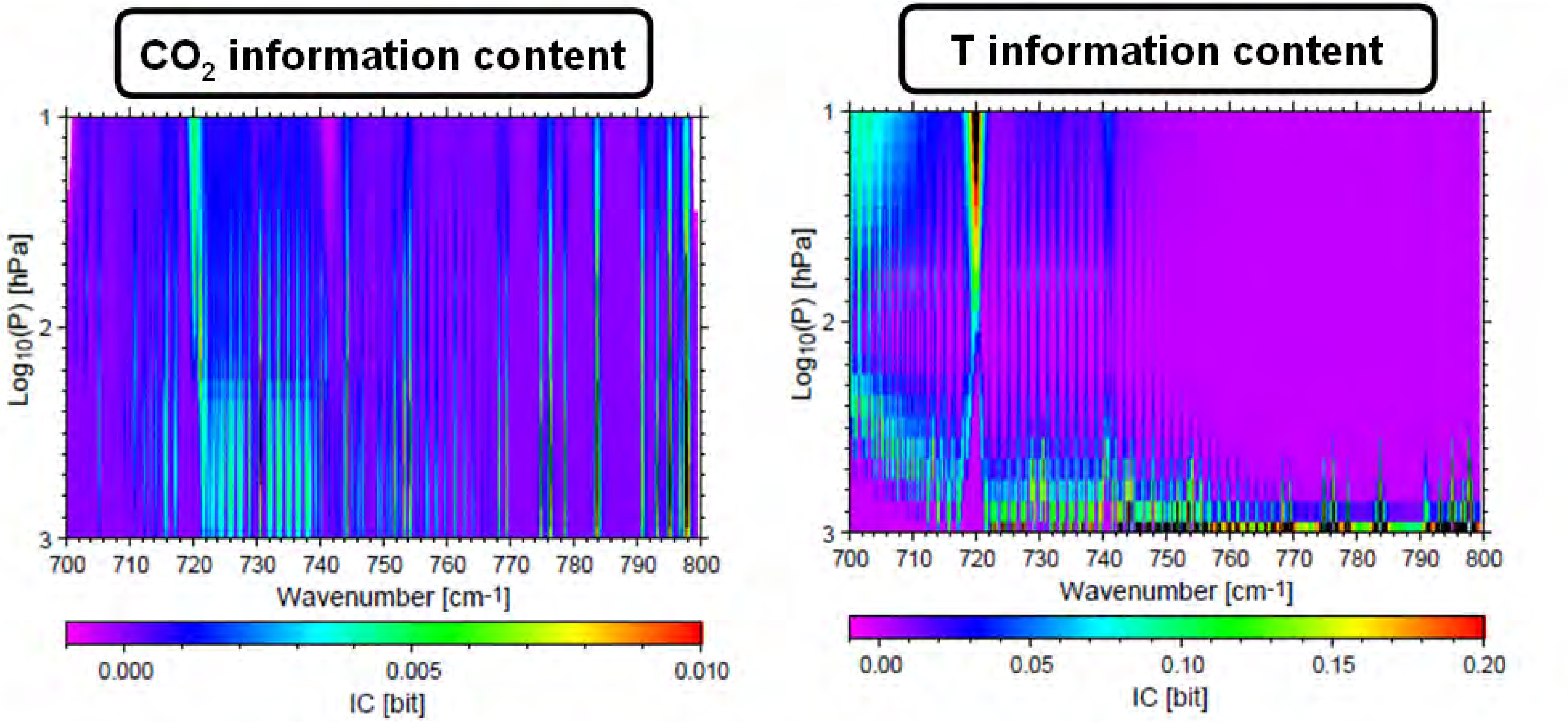
[e.g., *Rodgers* 1996; *Lerner et al.*, 2002]

- Temperature errors regarded as a measurement noise,

$$S_e = S_e + \underbrace{K_{temp} S_{temp} K_{temp}^T}_{\text{T random errors}}$$

[*Rodgers* 2000; *Ota*, 2006]

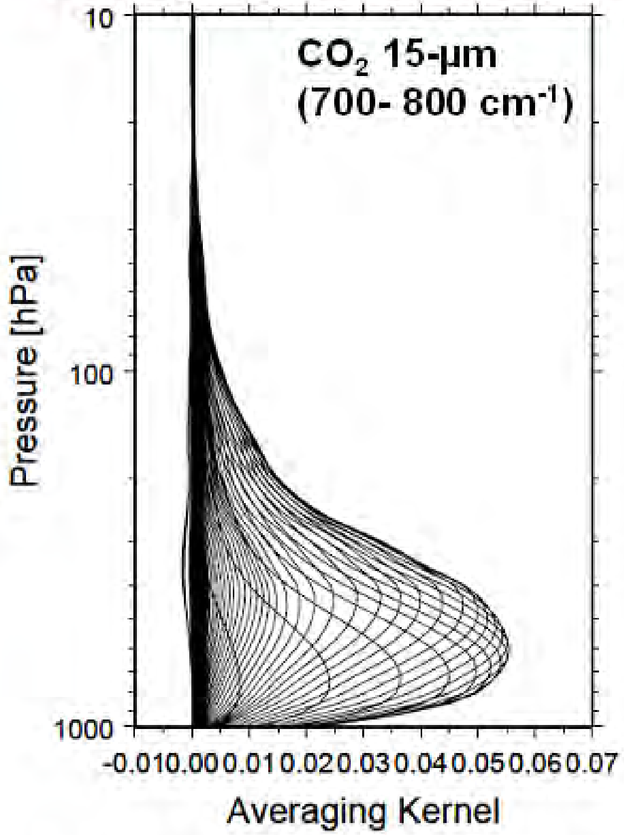
Channel selection based on IC



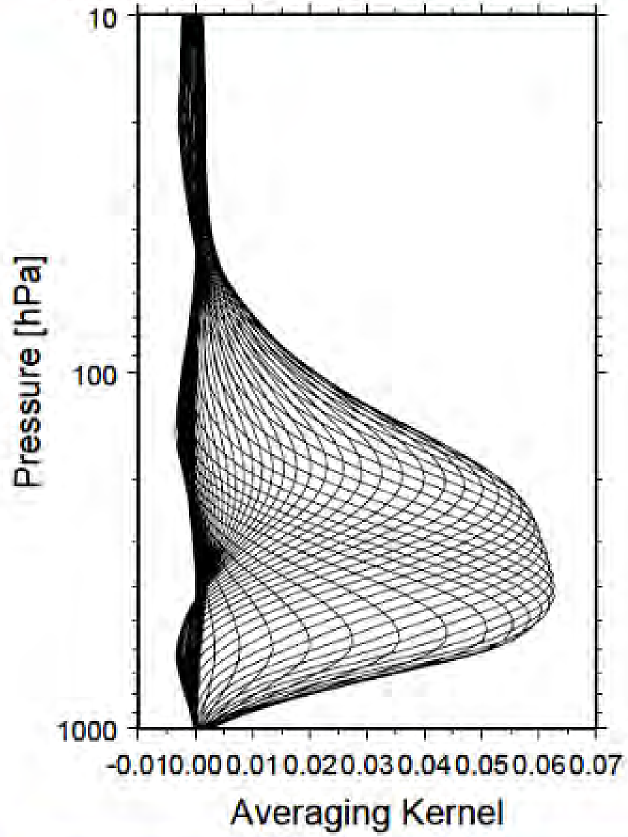
Channels sensitive to CO_2 are different from those to T.

Retrieval grid depending on latitude

averaging kernel at high lat.

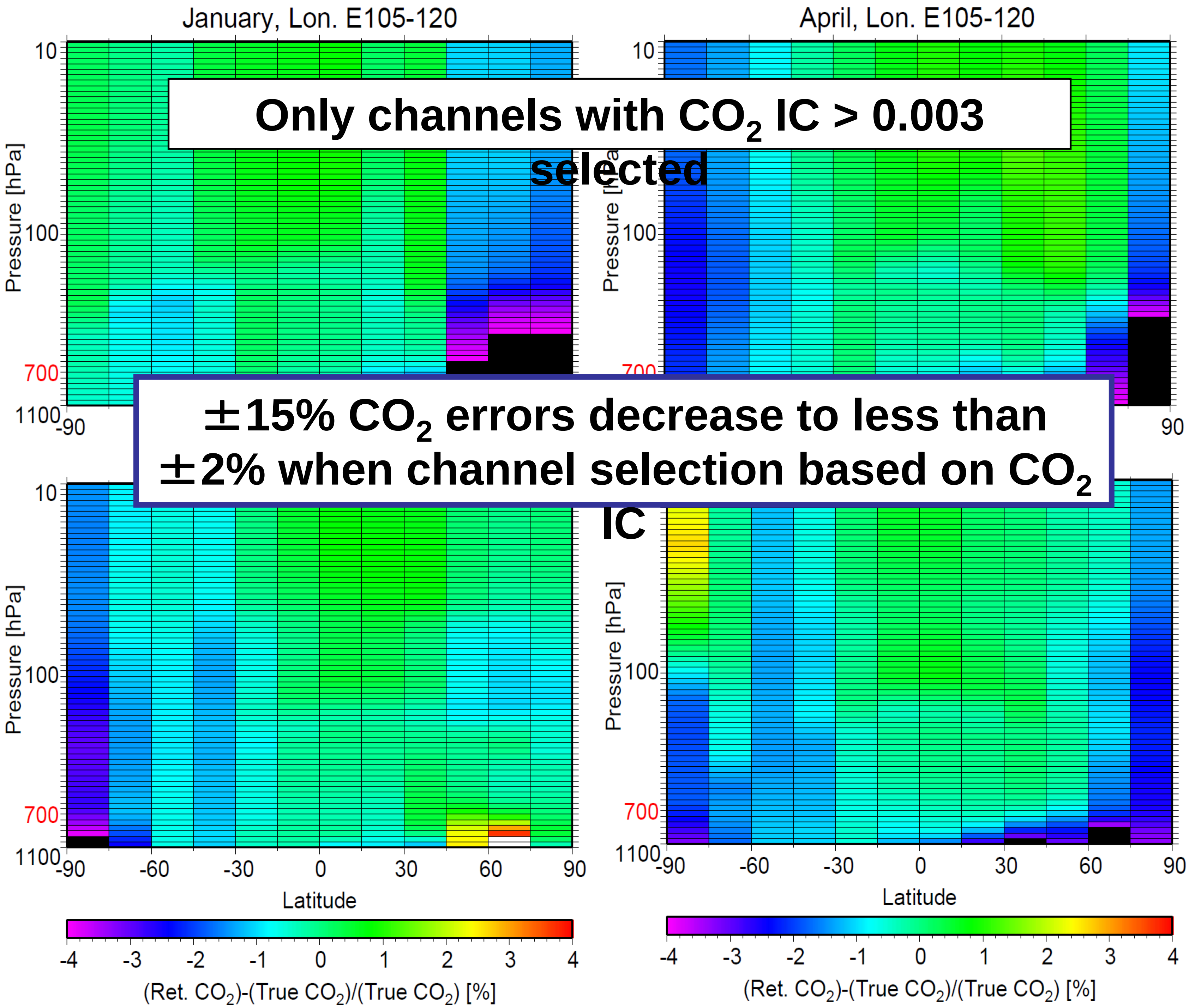


averaging kernel at low lat.



Spectra at low & mid-latitudes with large T gradient contain more CO_2 information than at high latitude. → **Retrieval grid depends on latitude (and season).**

Only channels with CO_2 IC > 0.003 selected



±15% CO_2 errors decrease to less than ±2% when channel selection based on CO_2 IC

In order to reduce the retrieval error down to 1 %, "averaging" is necessary

Assumption:

- Temp. estimation error : random
- CO_2 variation : systematic

(e.g., Engelen et al., 2002)

↓

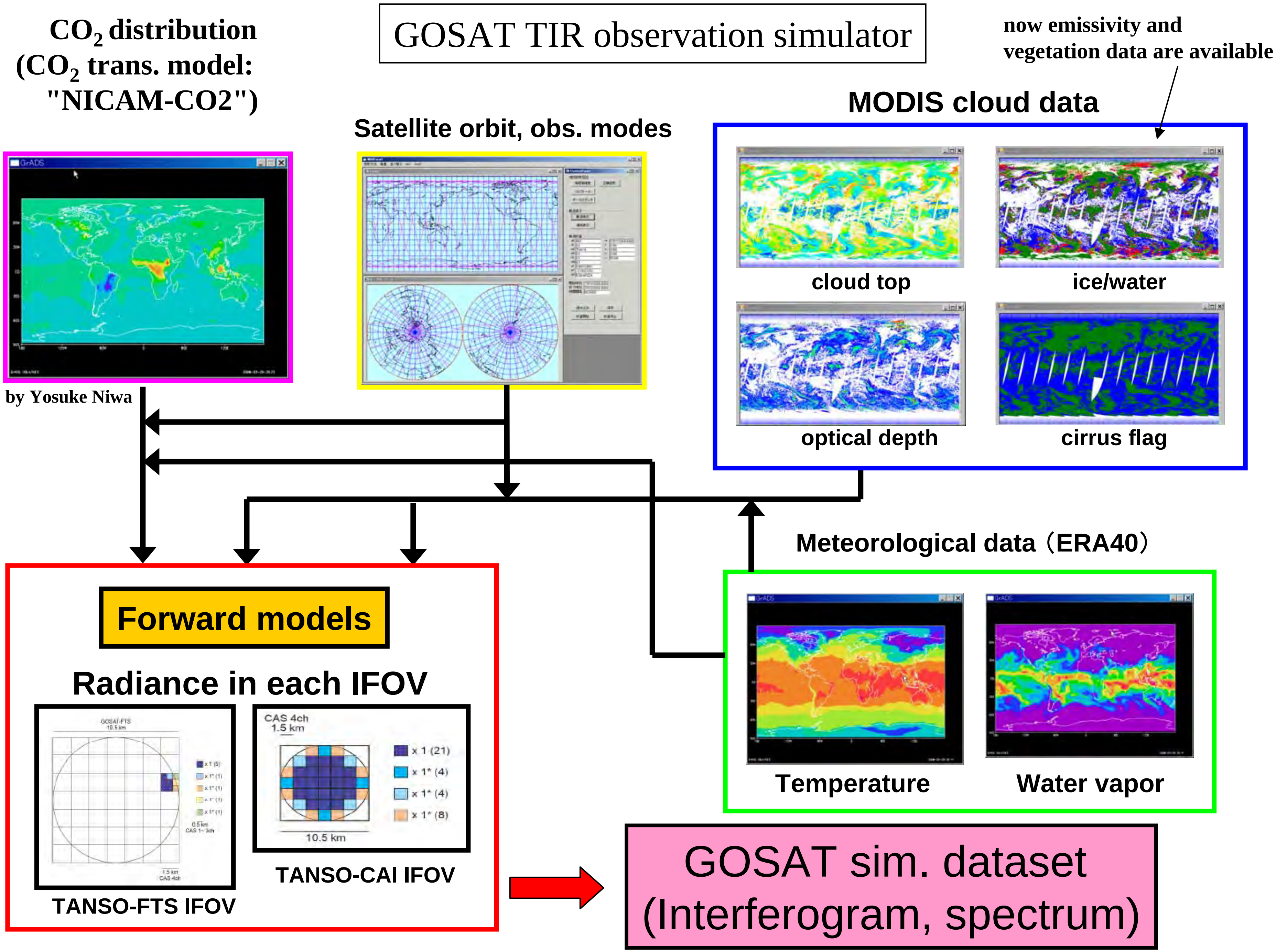
Averaging causes degradation of vertical and temporal structure of CO_2 distribution retrieved

Simulation:

How degraded by averaging even if the best performance of retrieval can be achieved.

↓

Convolving original profile with "Averaging Kernel", then averaging spatially and temporally.

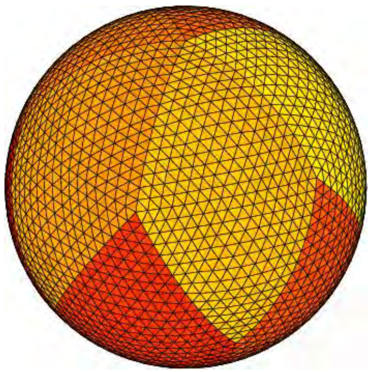

GOSAT TIR observation simulator
CO2 distribution
(CO2 trans. model:
"NICAM-CO2")
by Yosuke Niwa
Satellite orbit, obs. modes
MODIS cloud data
now emissivity and
vegetation data are available
cloud top
ice/water
optical depth
cirrus flag
Meteorological data（ERA40）
Temperature
Water vapor
Forward models
Radiance in each IFOV
CAS 4ch
1.5 km
x 1 (21)
x 1* (4)
x 1* (4)
x 1* (8)
10.5 km
TANSO-FTS IFOV
TANSO-CAI IFOV
GOSAT sim. dataset
(Interferogram, spectrum)

General circulation model: NICAM (Nonhydrostatic ICosahedral grid Model)-based CO_2 transport model (developed by Mr. Yosuke Niwa)

NICAM was originally developed by Prof. Satoh and Dr. Tomita

Advantages

- High-resolution
  - No polar problem
- Mass conservation
  - Tracer advection is consistent with continuity
  - Tracer masses are completely conserved without a mass fixer
- Easier to develop a nest generation inverse model



Icosahedral grid

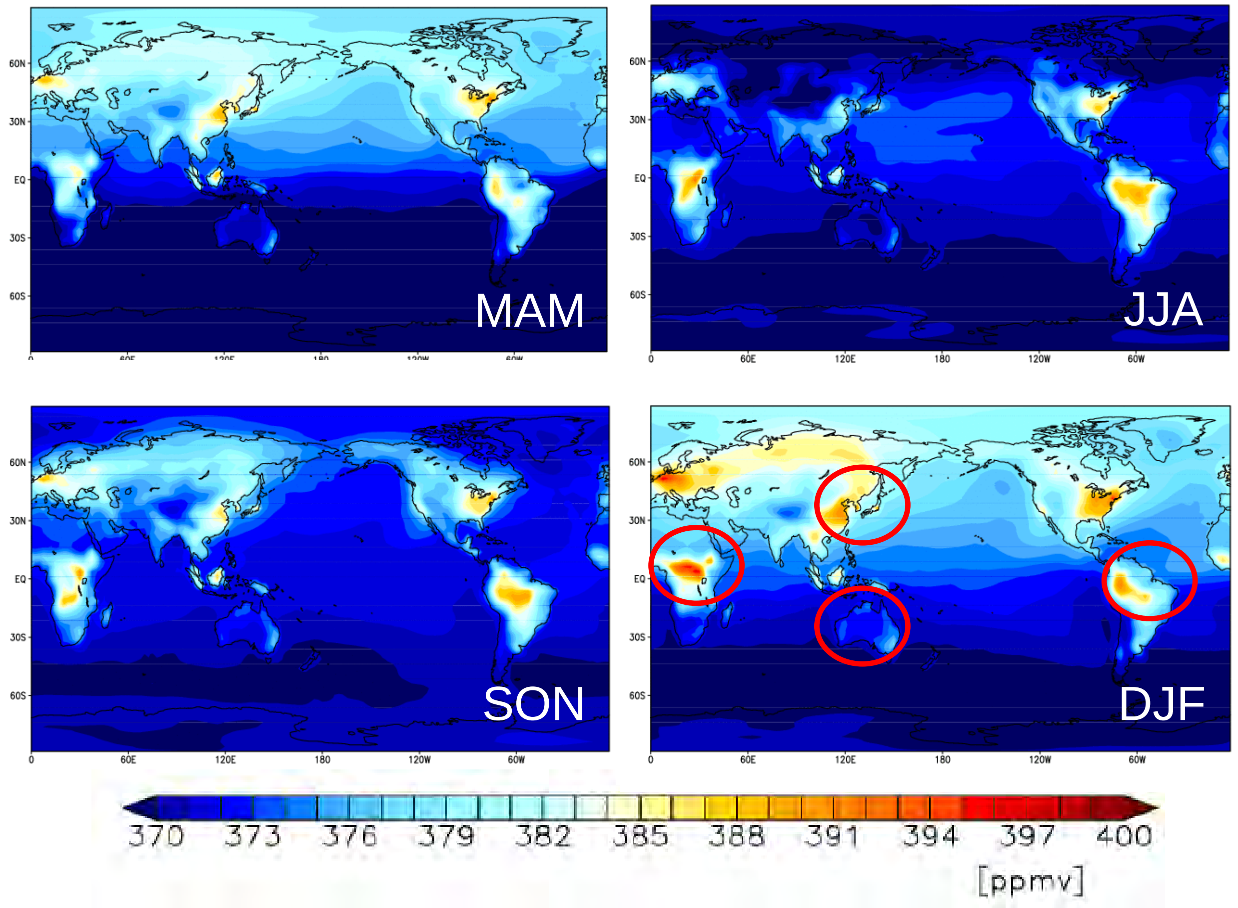
Schemes and setting parameters

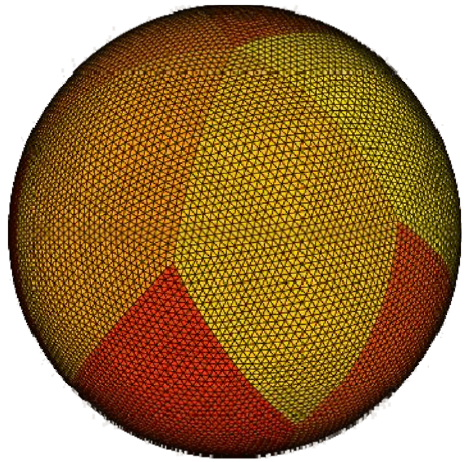
- Horizontal resolution: glevel-5 (dx~240km)
- Vertical layer: 54 layers
- Advection scheme : Miura2004 scheme (no limiter version)
- Cumulus convection scheme : simplified prognostic Arakawa-Schubert
- Vertical diffusion scheme : Mellor-Yamada 2 with modification by Smith (1990)

GCM based CO_2 transport mode, NICAM-CO_2

NICAM (Nonhydrostatic ICosahedral Atmospheric Model)

Seasonal variation of surface CO_2 concentration





NICAM grid
(glevel–5:dx~240km)

Surface fluxes

- NEP flux derived from CASA model
- Fossil fuel (CDIAC)
- Air-sea change (Takahashi et al., 2002)

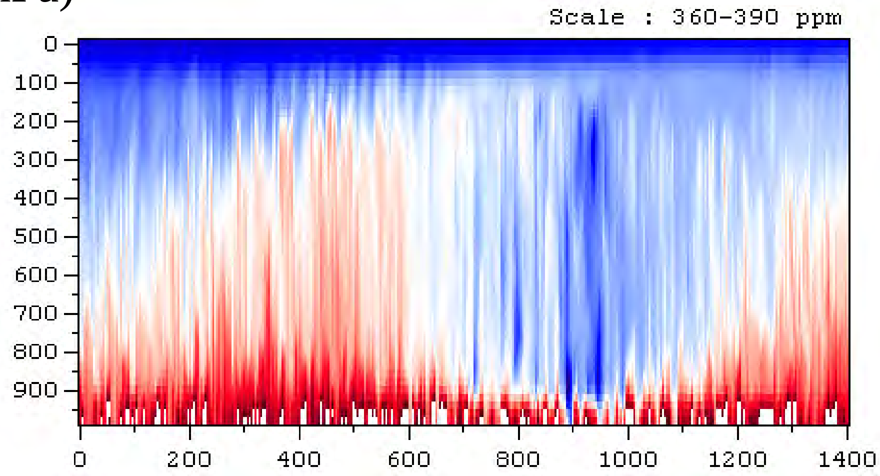
Original

CO_2 concentration (original)

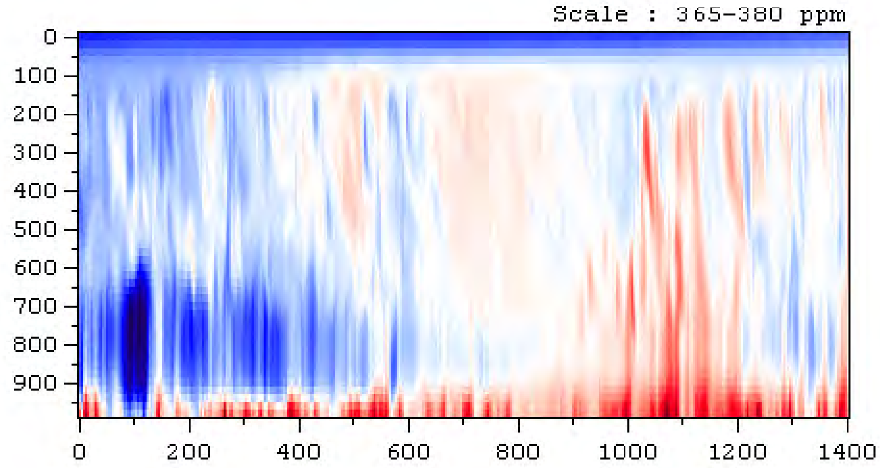
(4 times/day)

(hPa)

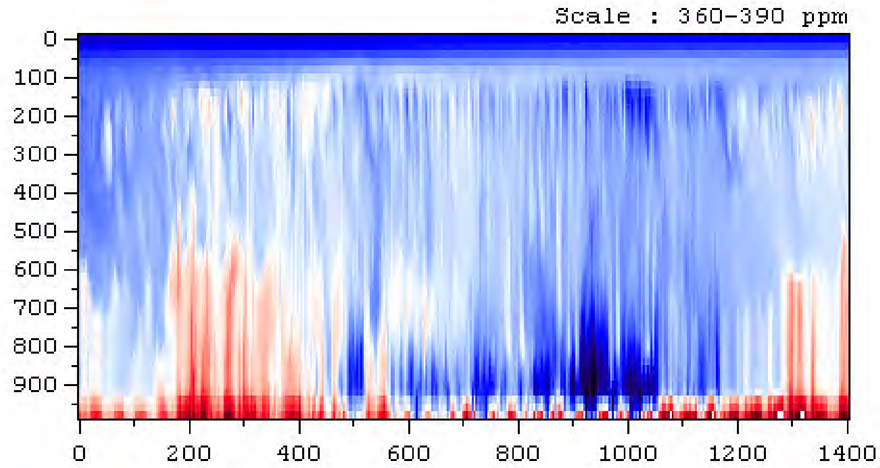
East Asia 35N 140E



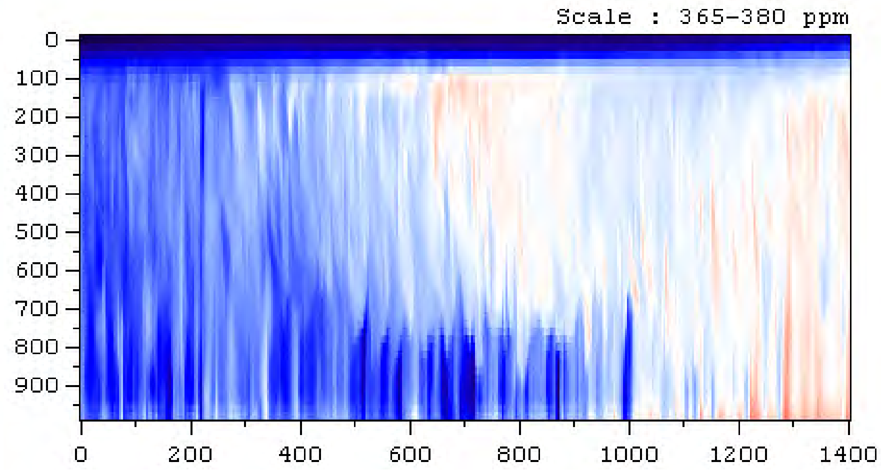
Amazonian forest 10S 45W



Mid-Africa (Nigeria) 10N 20E



Australia 20S 140E



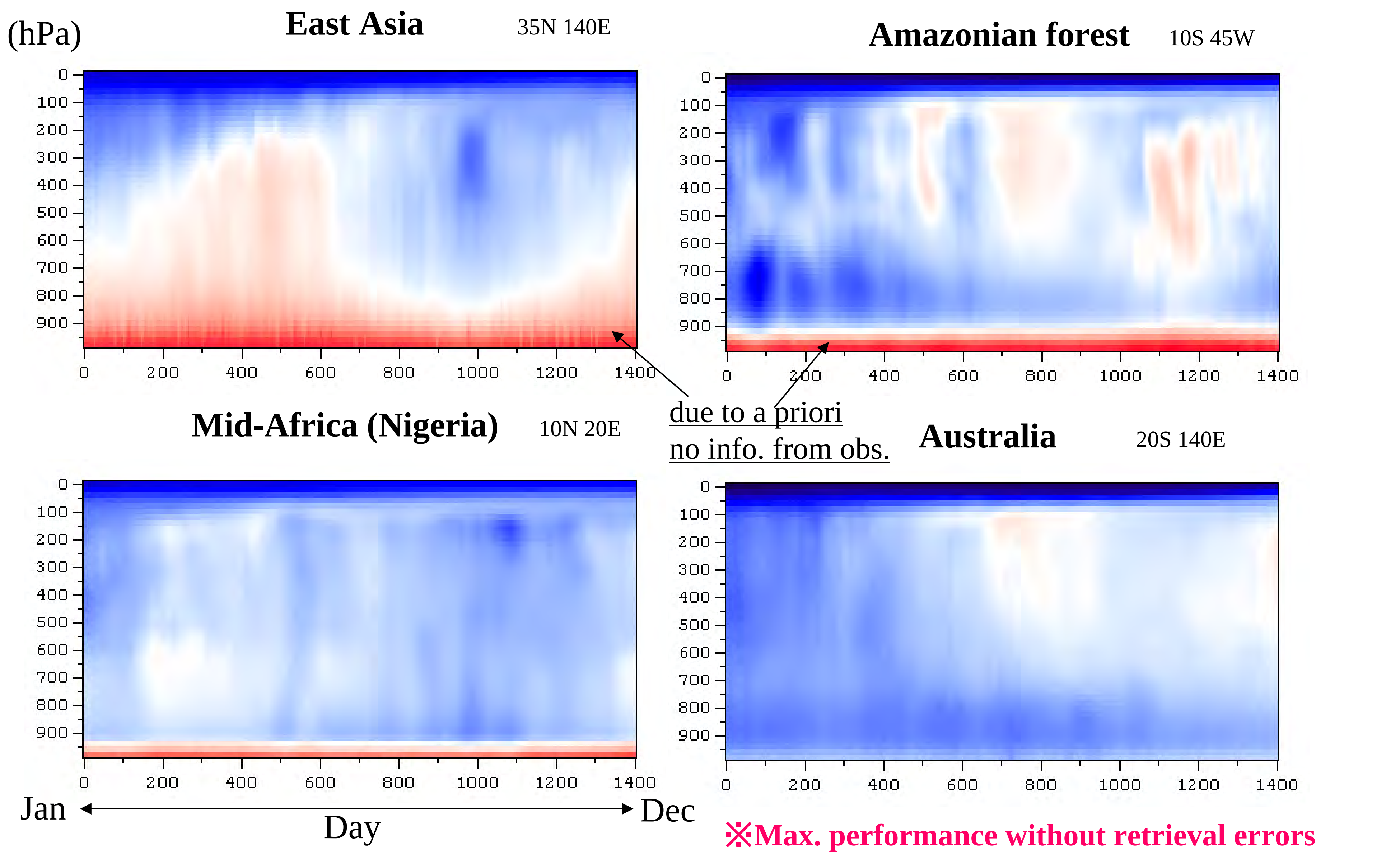
Jan ← Day → Dec

(Calc. : using NICAM-CO_2 by Y. Niwa)

Convolved with Averaging kernel before averaging ※

CO_2 concentration (retrieved-averaged)

(spatially averaged: 4.5° × 4.5° ; temporally: 15 days)



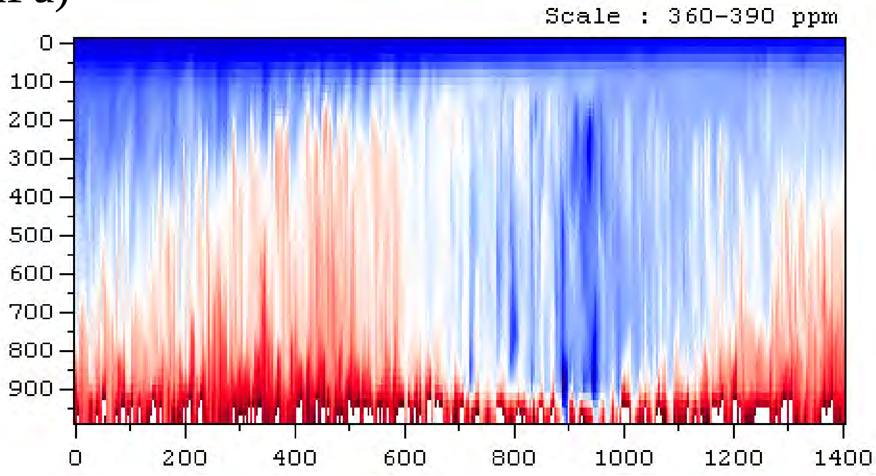
※Max. performance without retrieval errors

CO_2 concentration (original)

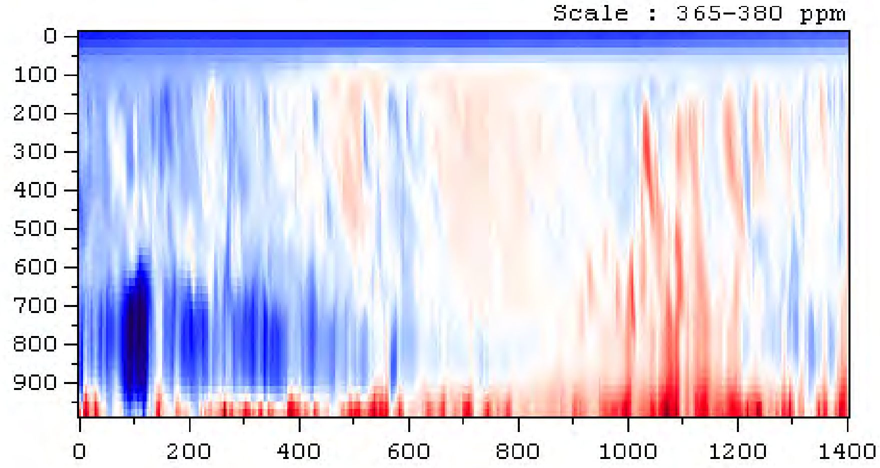
(4 times/day)

(hPa)

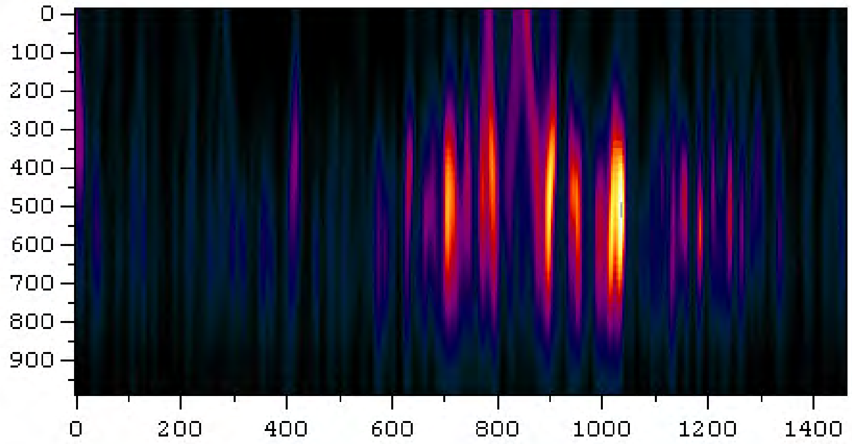
East Asia 35N 140E

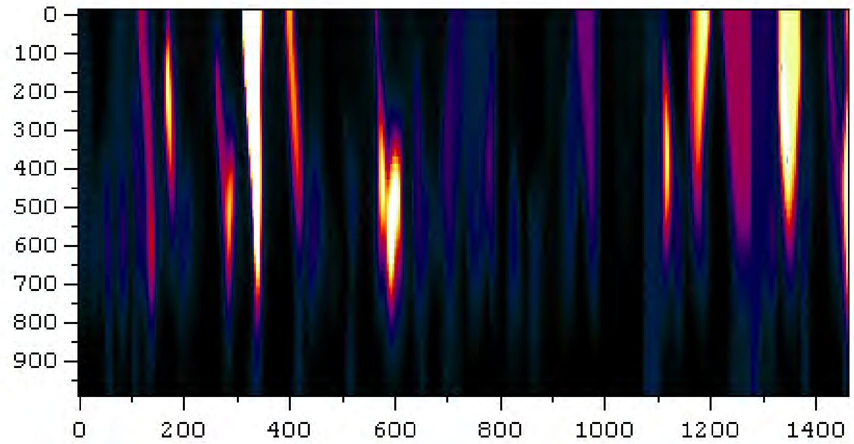


Amazonian forest 10S 45W



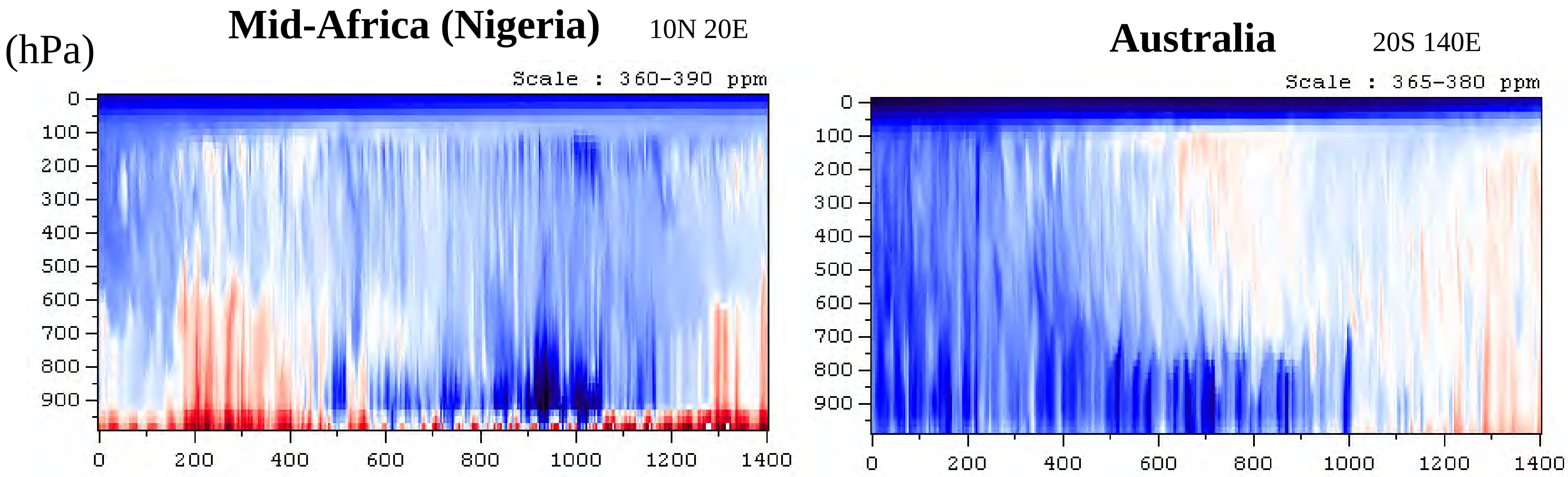
Cloud Fraction in GCM grids (NICAM-CO_2 model output)





Jan ← Day → Dec

CO_2 concentration (original) (4 times/day)



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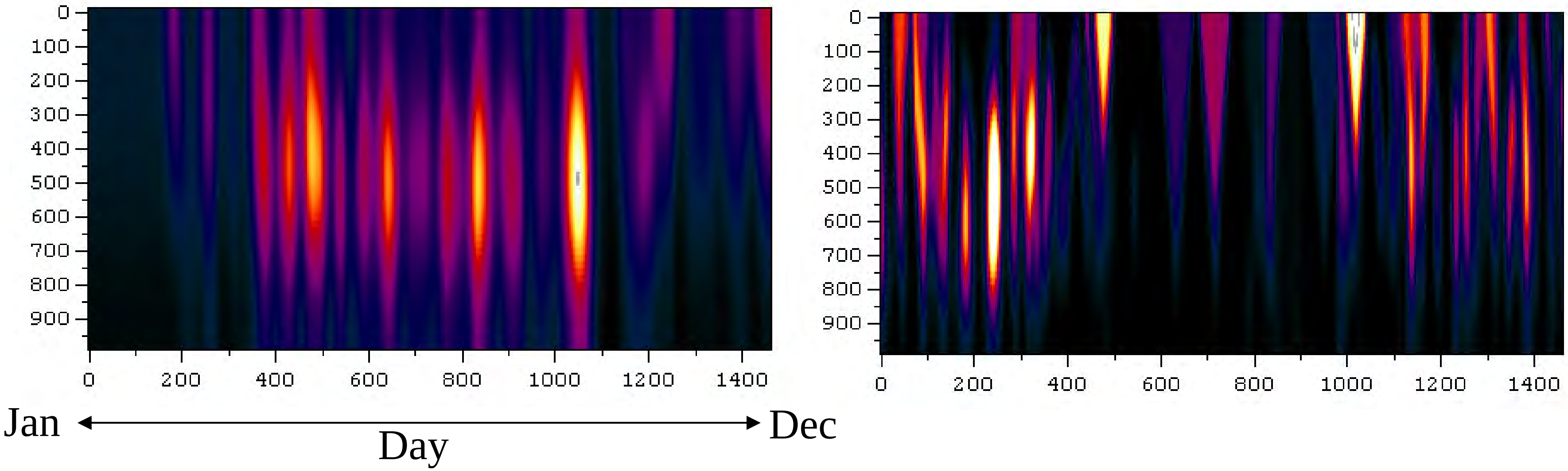

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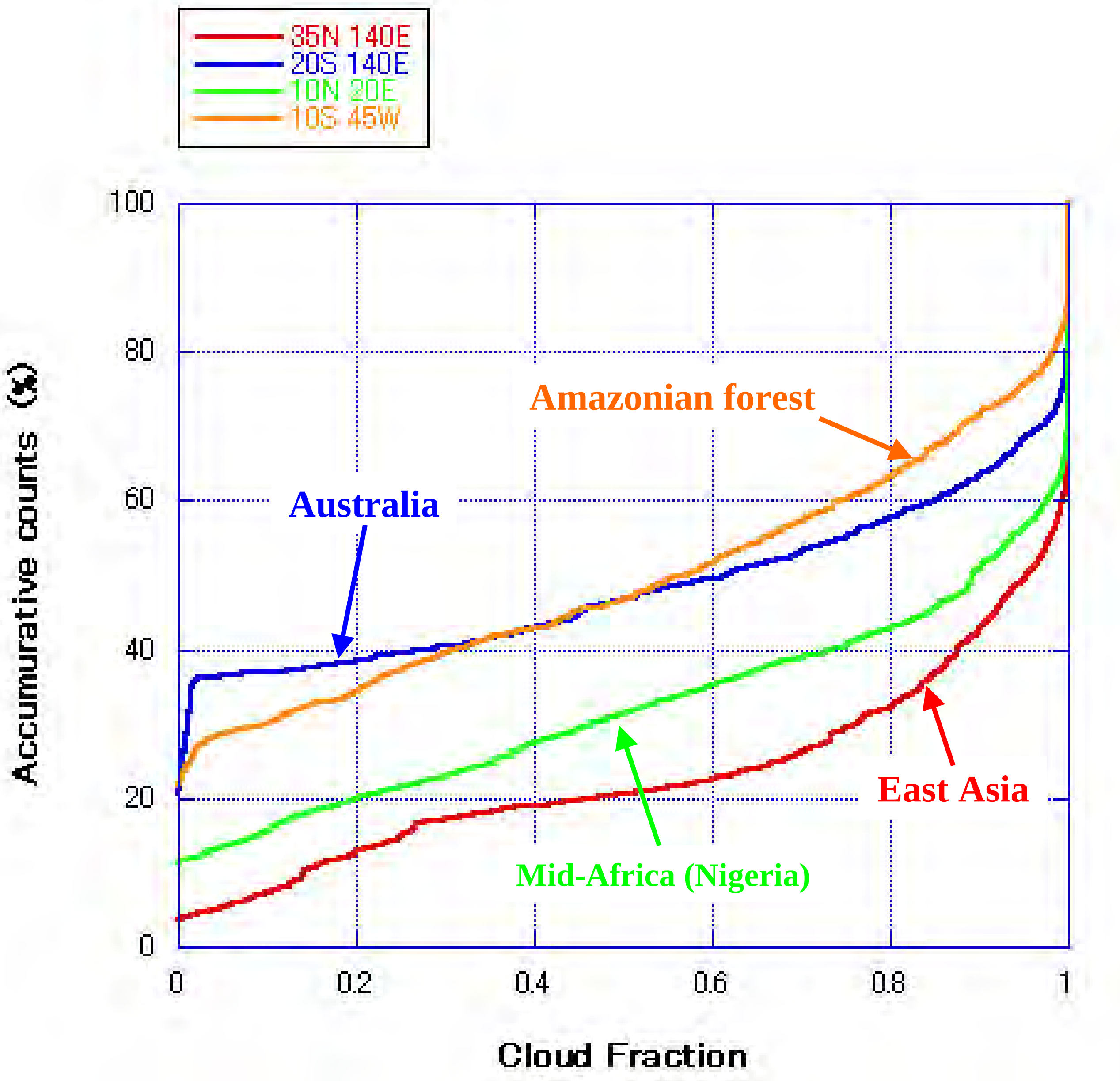


Cloud Frac. < 0.1
Eeat Asia : . 7 %
Mid-Africa : 15 %
Amazon : 30 %
Australia : 37 %

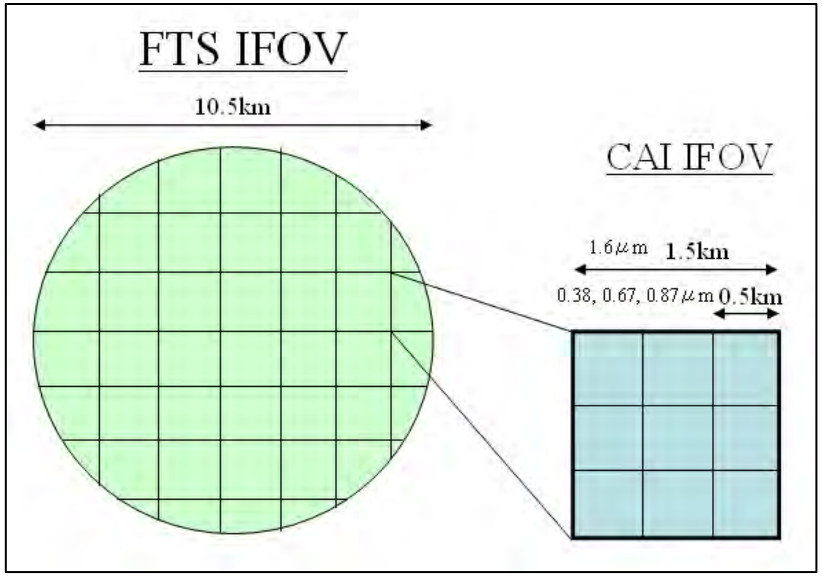
Cloud screening

	Band	IFOV	Cloud/aerosol properties
FTS	0.76 μm	10.5 km	Surf. Press., Cloud top height
	1.6 μm		CO_2
	2.0 μm		Cirrus clouds
	5.5-14 μm		Cloud top height, Opt. thickness (8-10, 11-13 μm), Ice/liquid water (11-13 μm) Cirrus clouds (11-13 μm)
CAI	380nm	0.5 km	Absorbing aerosols
	670nm		Optical thickness
	870nm		Optical thickness, Ice/Vegetation
	1.6 μm	1.5 km	Ice/liquid water

Day/Night

- Slicing method (Z, Frac. cov.)
- Split window method
- Cloud score approach
- Adiabatic lapse rate analysis based on the retrieve temp.

Fractional cloud coverage in FTS-IFOV can be estimated at ～1% resolution



Summary

Retrieval method

- Temp. data : Meteorological analysis data (sonde: land, MW: ocean)
- "Area value of averaging kernel" → layer thickness → uniform sensitivity and error
- "Shannon information contents" → channel selection → reduction temp. error

CO_2 distribution feature that will be retrieved by TANSO-FTS (TIR)

- What we want to retrieve with TANSO-FTS (TIR) is ･･･
- Degrading of fine structure due to spatially and temporally averaging was estimated
- Clear sky probability = ~10% or less
- Detailed simulations considering cloud coverage have been continued using GOSAT-Sim (TIR) for source/sink inversion of CO_2

Synergetic usage of GOSAT sensor data

- Cloud screening based on CAI, SWIR(2 μ m), and TIR
- Estimation of CO_2 in the boundary layer (PBL) : "Lower = column – upper"
- Usage of columnar data for retrieving profiles "as an additional constraint" or "scaling after retrieval"