JEJU IN KOREA

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HIDEKAZU MATSUEDA

METEOROLOGICAL RESEARCH INSTITUTE

Acknowledgements

For This Workshop

I greatly appreciate KMA and KRISS people for organizing this wonderful meeting,
as well as giving me an opportunity for presentation.
It's a great pleasure to meet all of the participants here in Jeju.

For Researches and Engineers

Professor Hisayuki Inoue at Hokkaido University in Japan,
for stating our observational programs.

Our colleagues, many JMA staffs as well as
co-workers in other Japanese Institutes of NIES and AIST,
for operating collaborative observations

Japan Airlines (JAL) and JAMCO engineers,
for their on going support of the JAL aircraft project

INTRODUCTION AND RECENT TOPICS FOR ATMOSPHERIC CARBON CYCLE RESEARCHES IN METEOROLOGICAL RESEARCH INSTITUTE (MRI), JAPAN

By
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Kazuhiro TUBOI, Yosuke NIWA, and Yousuke SAWA

Outline

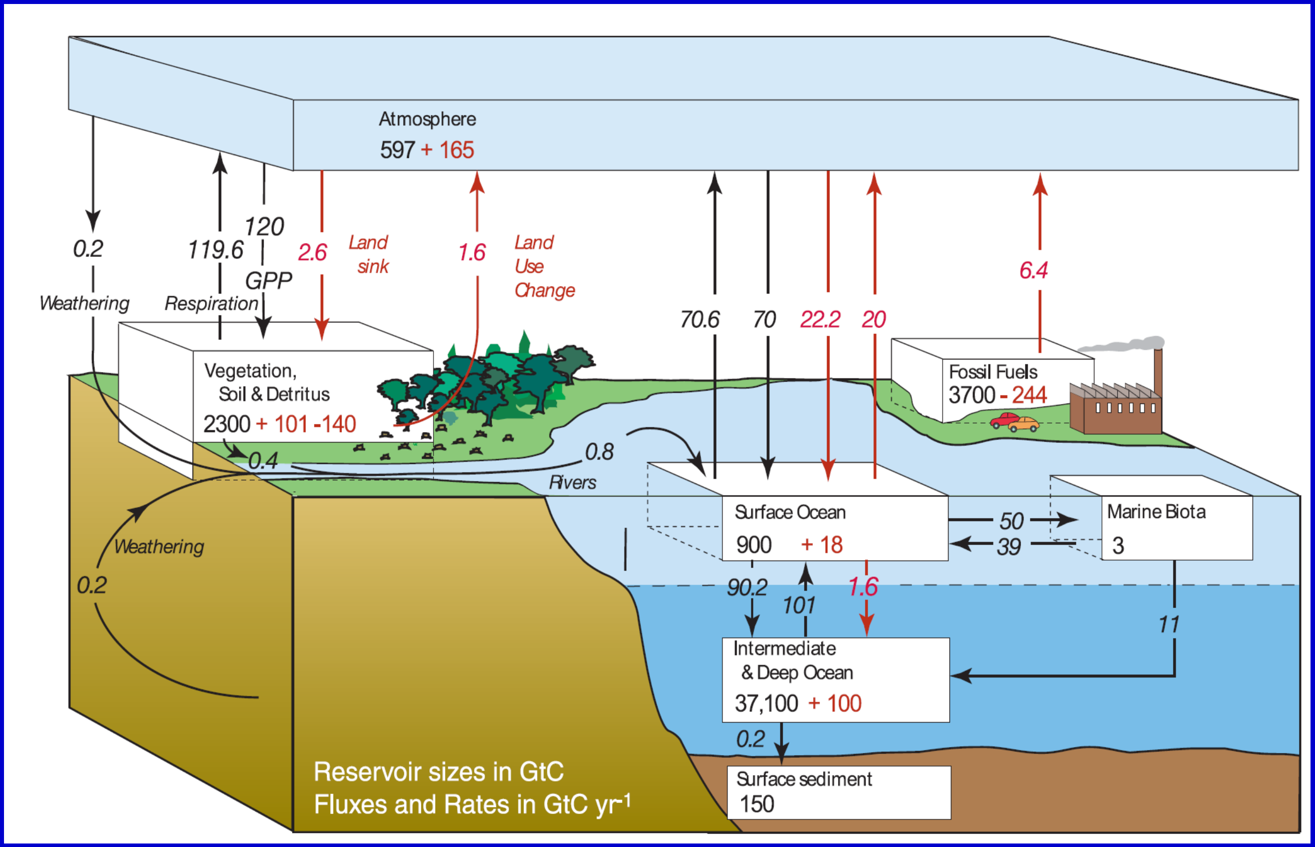
1) Introduction of the recent carbon cycle studies emphasizing the significance of atmospheric observations.

2) Brief overview of our MRI research activities.

3) Recent topics of JAL aircraft observation.

Global Carbon Fluxes [after IPCC 2008]

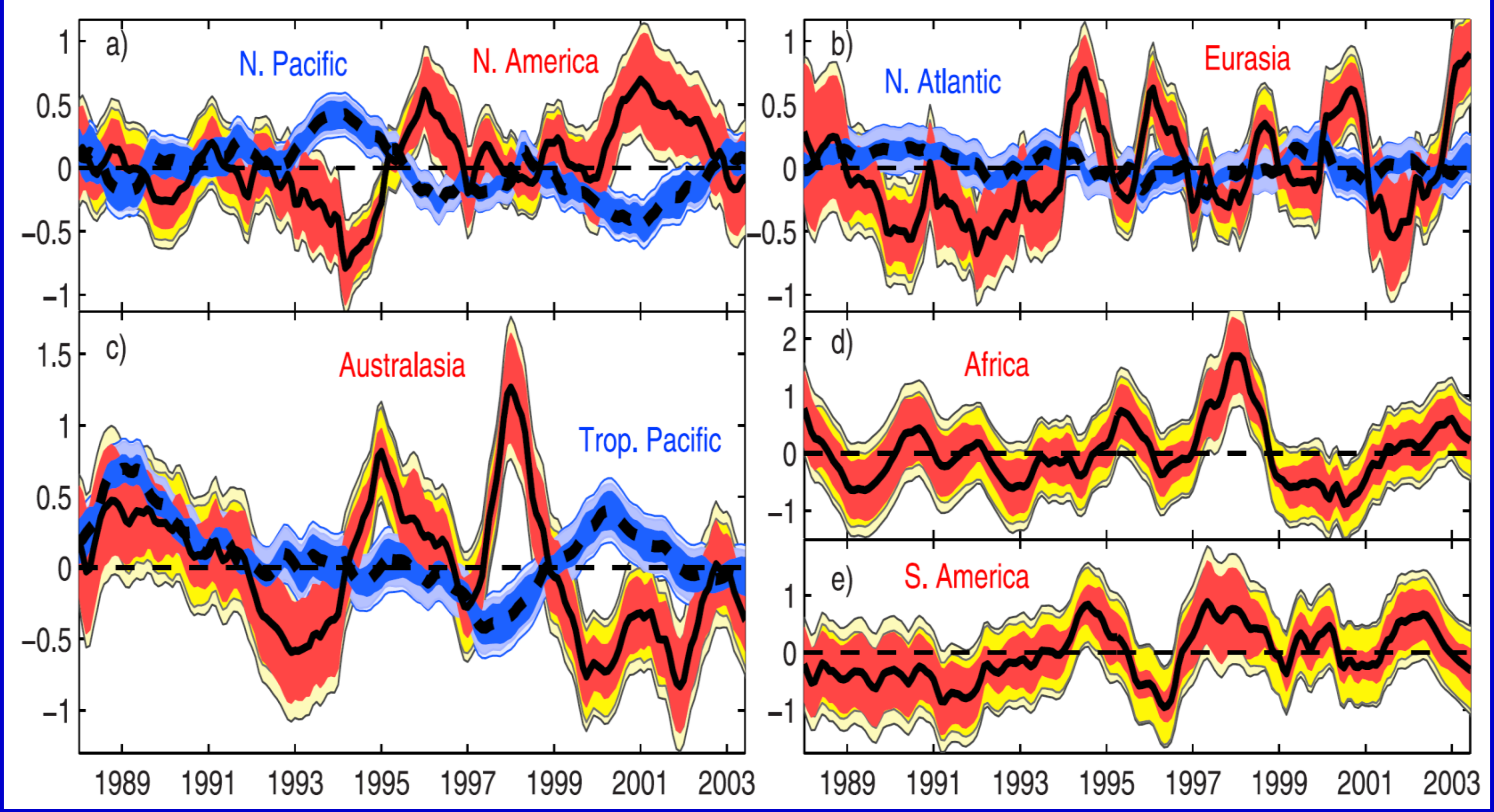
However, gross and net fluxes still have large uncertainties !



- In the IPCC report, the atmospheric CO2 accumulation is caused by the fossil fuel emissions increase, as well as by exchanges with the two other reservoirs, the land biosphere and the oceans.
- However, gross and net fluxes still have large uncertainties.
- Therefore, how well we can predict the future global warming depends greatly on how well we can understand the global carbon cycle, as shown in this figure.

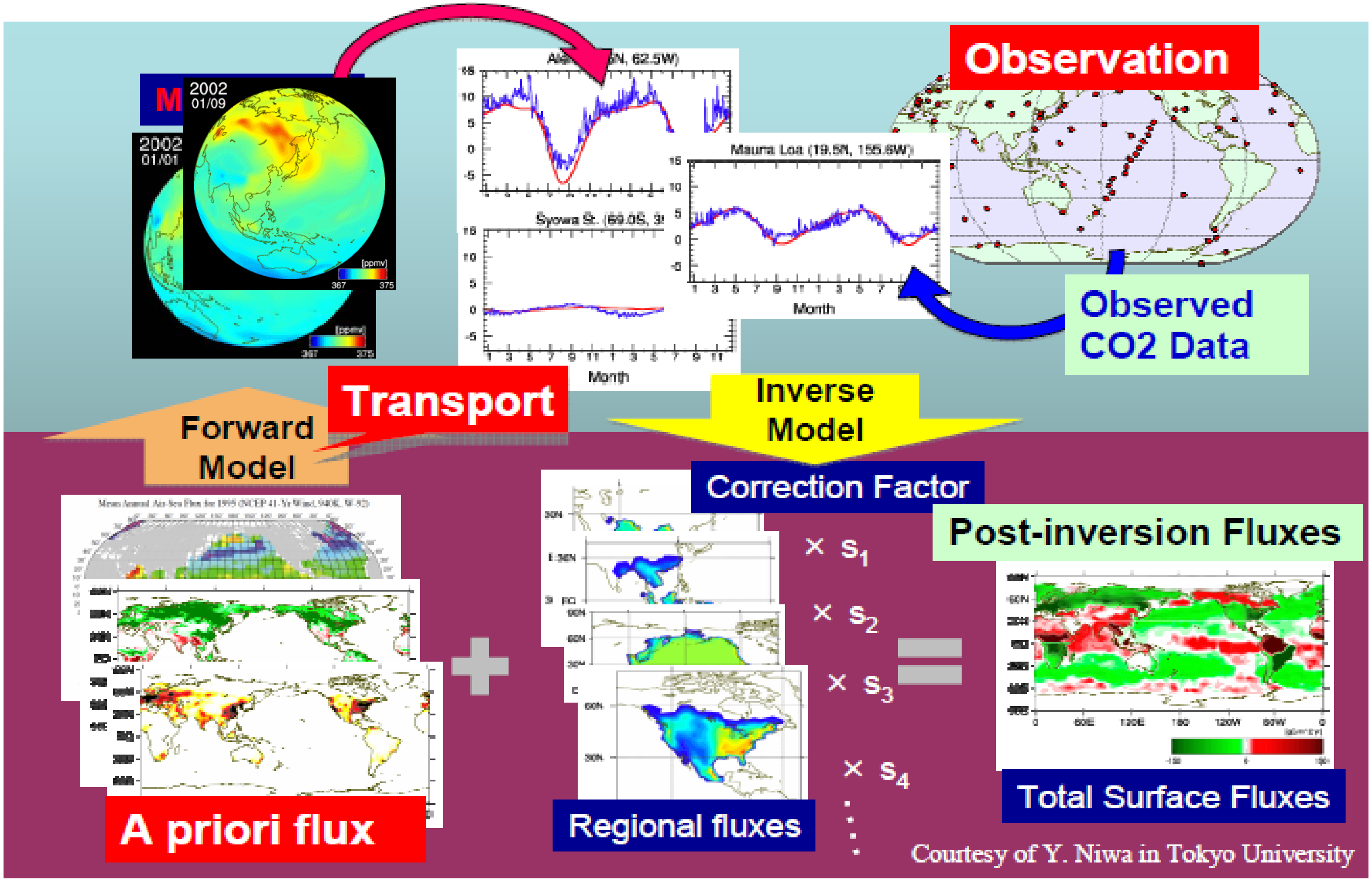
How well can inverse calculation constrain CO2 fluxes ?

Baker et al. (2006) GBC, 20, GB1002, doi:10.1029/2004GB001439



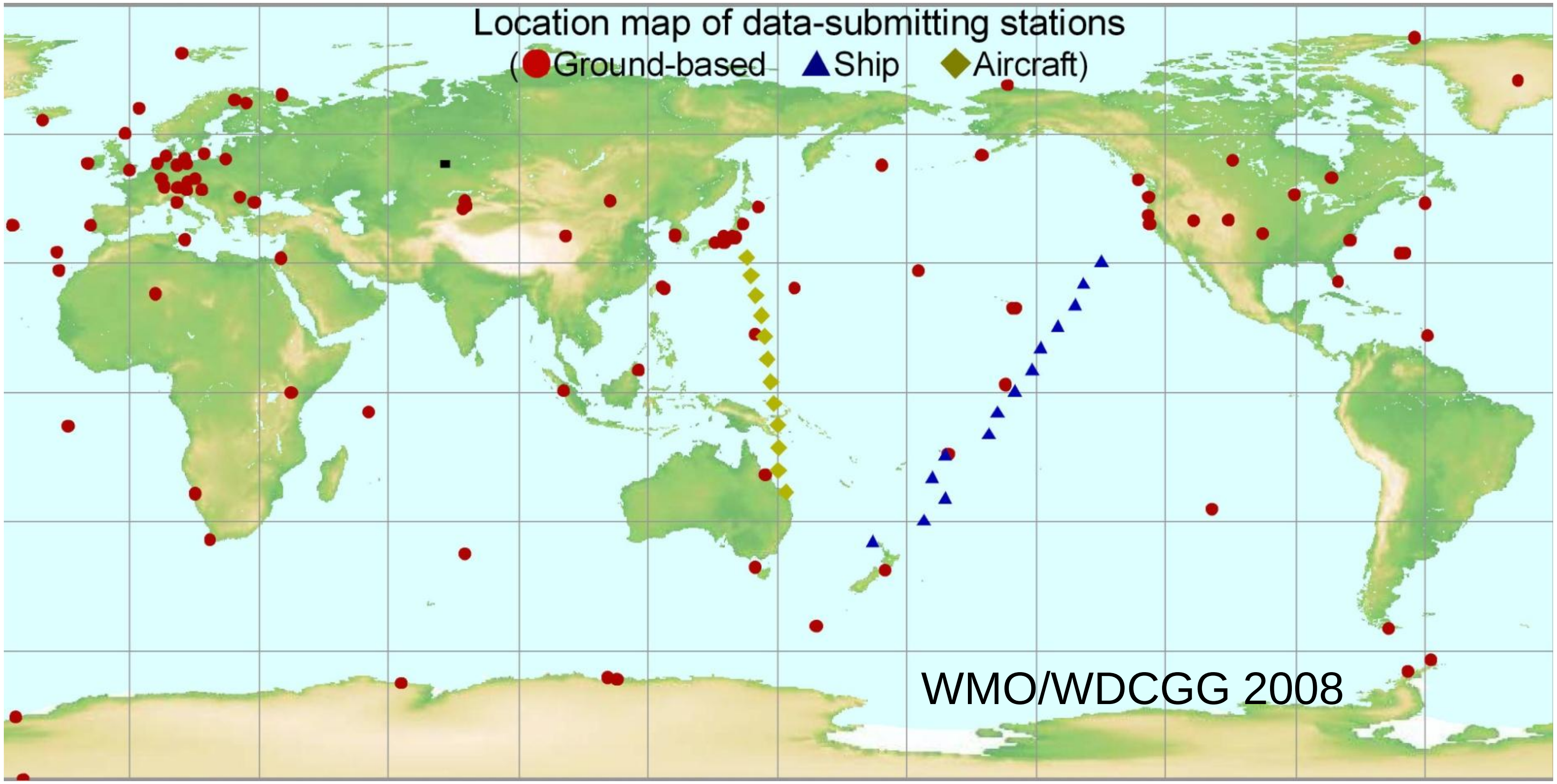
- This is a time for the question of how well we can constrain the regional CO2 fluxes.
- In the carbon cycle model community,
  various top-down inverse methodologies have been developed.
- Their results in this figure show a larger inter-annual variations in terrestrial ecosystem,
  but the model-to-model differences are still large.
- Thus, we have to improve the problems of the uncertainties in the inversion methods.

Basic Concept of Top-down Approach



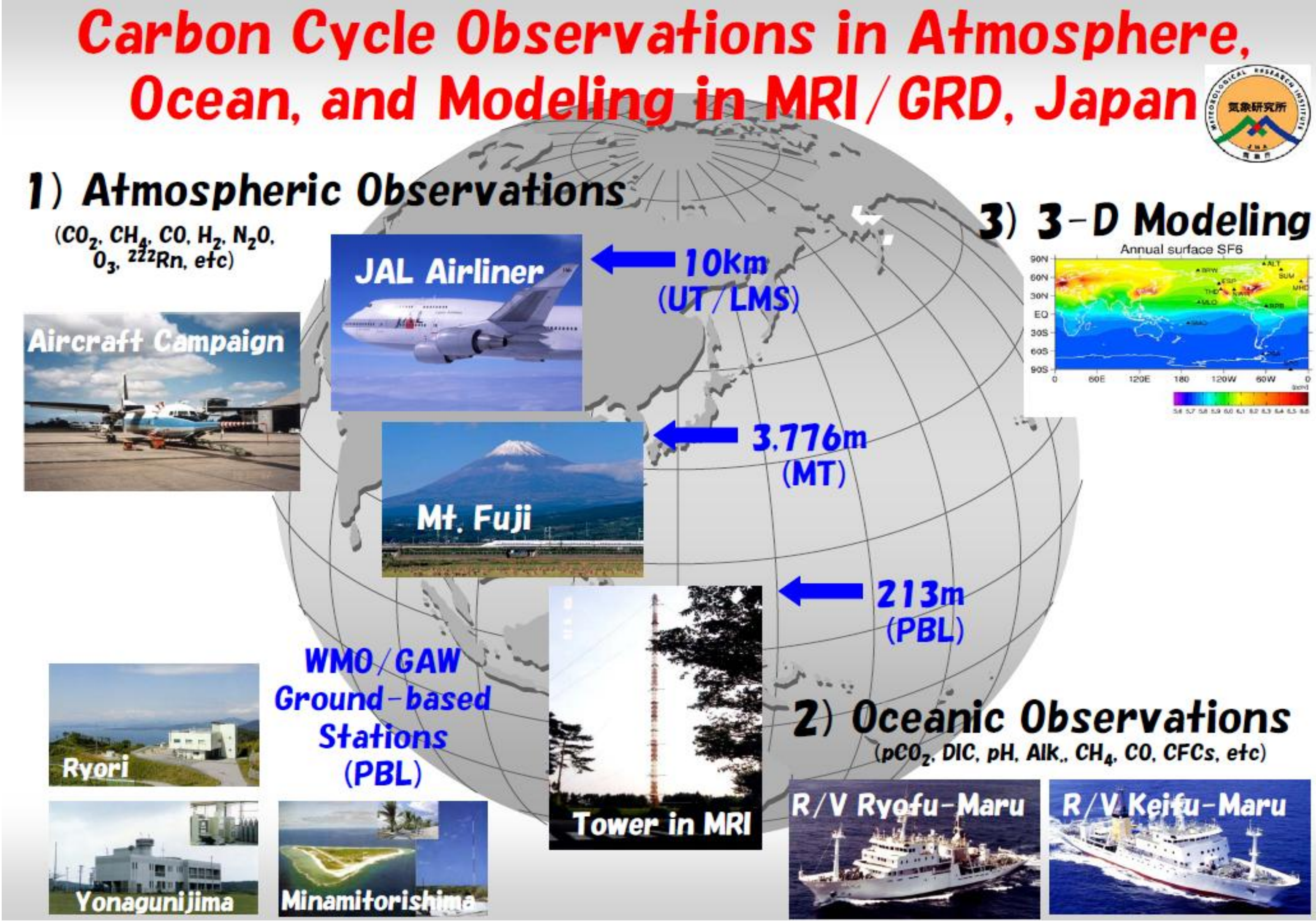
- Our current problems can be found, when we consider the basic concept of top-down approach.
- For the inversion, a priori fluxes are used by forward model to produce the simulated data.
- Their model data are fitted with the observations to obtain the post-inversion fluxes.
- Thus, the major uncertainties are associated with transport errors and sparse observations.

More observations and their Integration



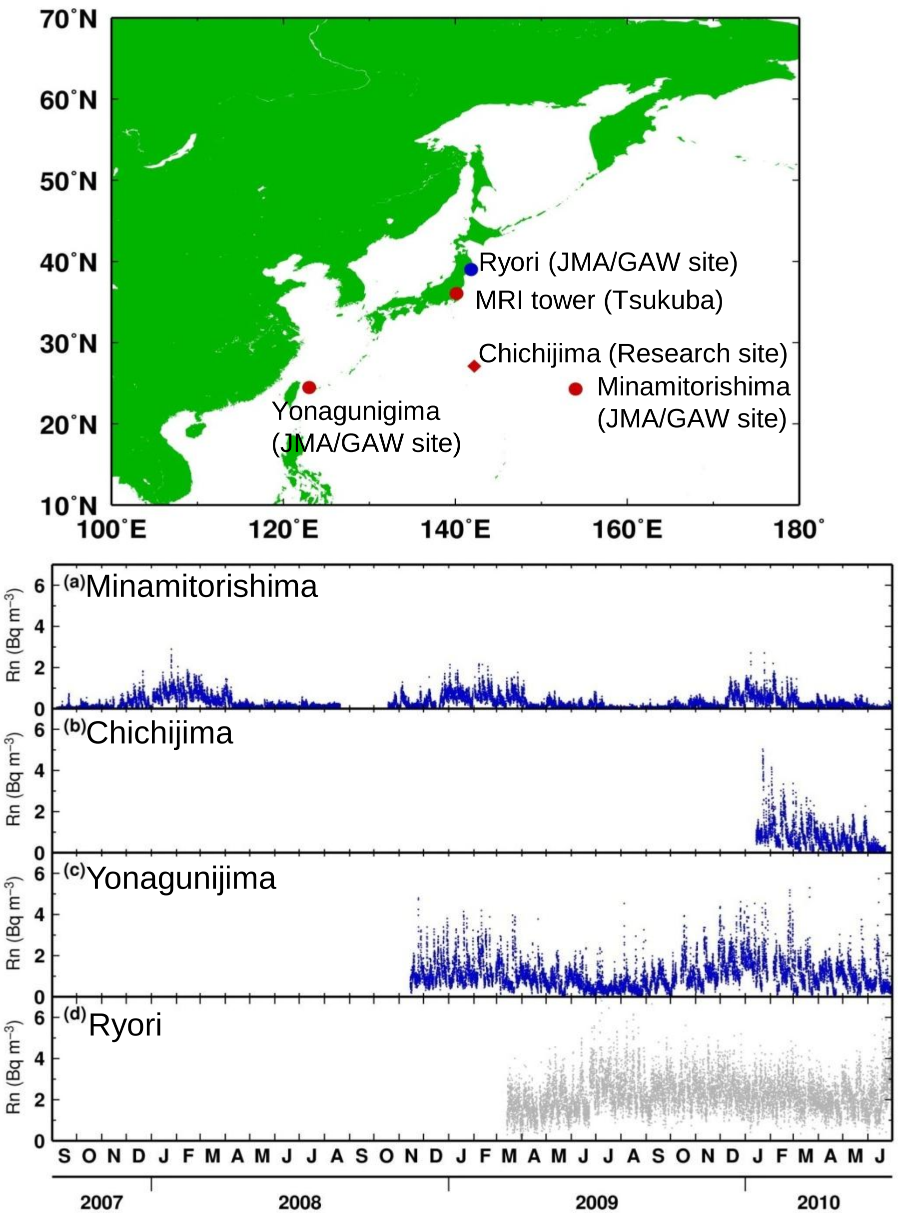
- Japan Meteorological Agency are operating the WMO/WDCGG data center to collect the measured data from all over the world, as shown in this map.
- However, this figure tells us that the geographical coverage of the observations is not sufficient to understand the global carbon cycle studies until now.

- More observations and their integration are strongly encouraged for the WMO/GAW activities, as they serve as an input for model validation and inversion flux estimate.



- Our MRI activities tightly connect to the WMO/GAW program for the international collaborative observations.
- We are using various observation platforms for the atmosphere and ocean observations.
- In the atmospheric field, JAL passenger aircraft, campaign aircraft, Mt. Fuji observatory and meteorological tower are operated for the 3-D observations for various greenhouse gases.
- In addition, 3 ground-based stations of the JMA-GAW also help our research observations.
- In the ocean field, 2 research vessels in JMA are used for the marine carbonate system in the western North Pacific.
- In the modeling field, the 3-D modeling is also very useful to evaluate the sources and sinks based on the observations.

Rn observation network



- As one of the MRI research programs, we started the atmospheric Rn measurements over the western North Pacific since 2007.
- In our Rn observation network, three Japanese GAW stations of Ryori, Yonagunijima and Minamitorishima are used.
- Chichijima is a research site for the campaign observation.
- This network is suitable for the study of Asian continental outflow.
- Later, details for this study will be presented by Mr. Tsuboi in MRI.

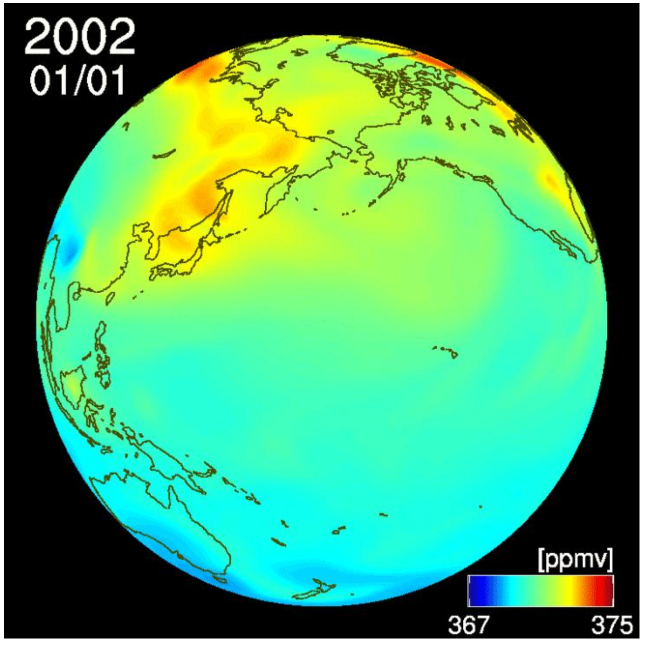
Not Cited !

(Unpublished)

3-D Transport Model

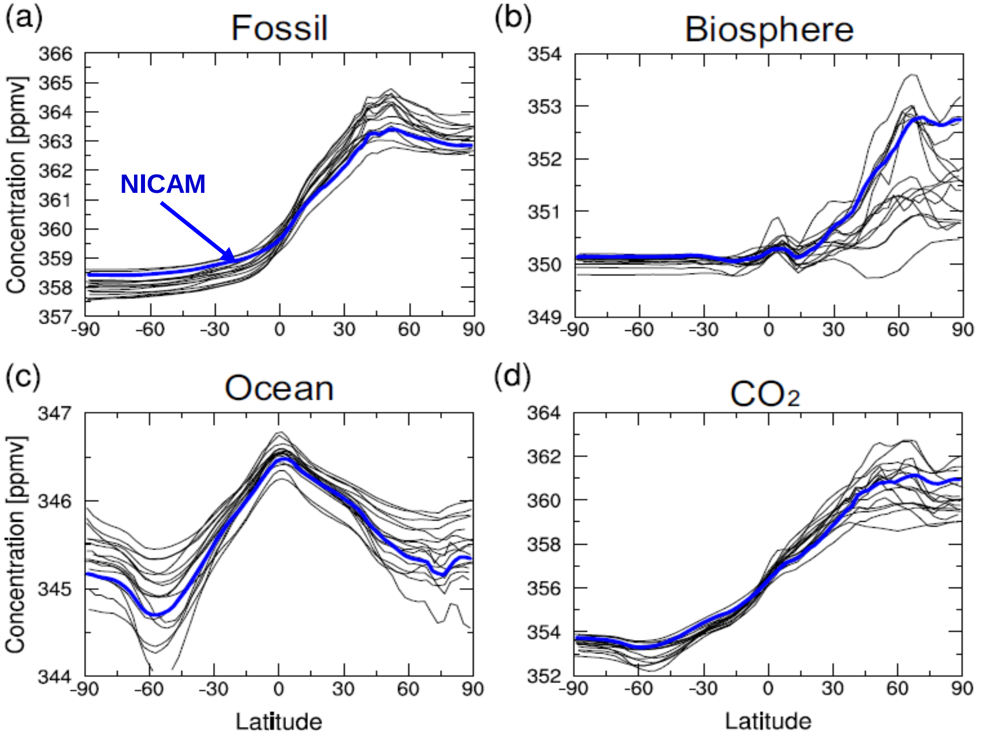
NICAM-TM

(NICAM based Transport Model)



Niwa (2010) Ph.D. thesis, University of Tokyo.

TranCom Model Intercomparison

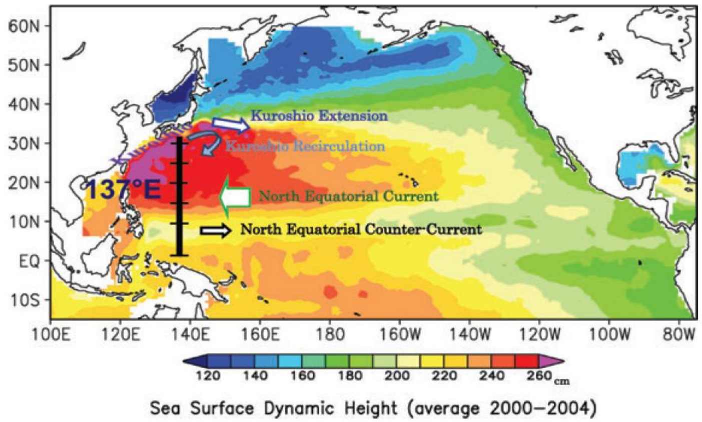


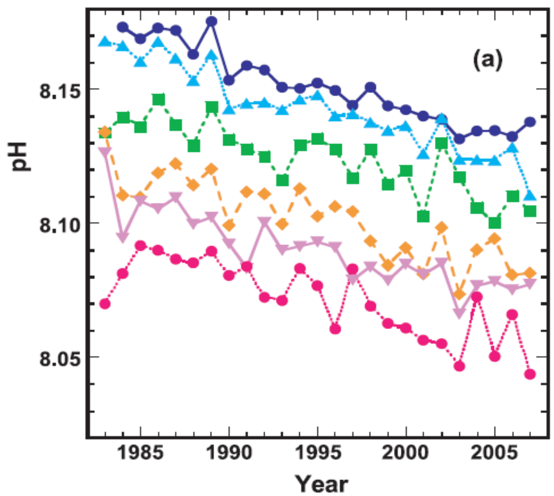
Patra et al. (2008) GBC, 22, GB4013, doi:10.1029/2007GB003081.

Law et al. (2008) GBC, 22, GB3009, doi:10.1029/2007GB003050.

- Recently, NICAM based transport model developed at University of Tokyo is introduced in our laboratory to advance our research activities in conjunction with various kinds of observations.
- This model was experienced in the international TranCom intercomparison project to evaluate its performance.
- Later, Dr. Niwa in MRI will present details of this model structure and its application studies.

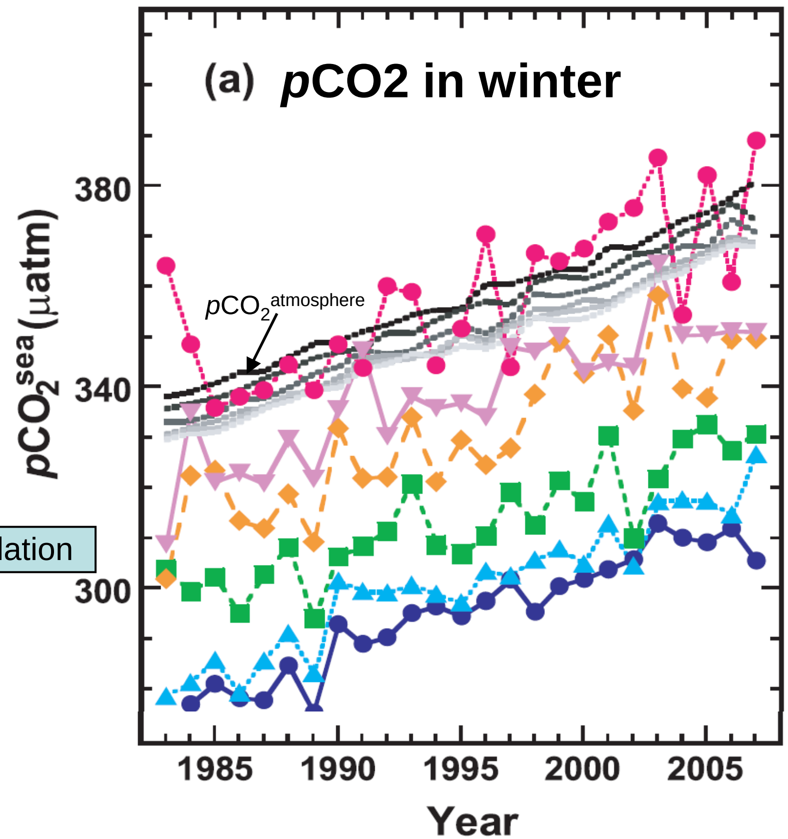
Long-term oceanic observation of pCO_2 in the surface sea water in the western North Pacific





pH calculation

Midorikawa et al. (2010) Tellus, in press.



- In our laboratory, ocean carbon cycle study stared in early 1980's, in order to get a very long observational record.
- In particular, long-term increases of partial pressure of CO2 are well captured, along this 137E observation line in the western North Pacific.
- From these data sets, we calculated a pH decrease due to ocean acidification, that is recently verified by very high-precision pH measurements in our laboratory

JAL Airliner Observation

Motivation

Until recently, campaign-style aircraft observations have been sporadic, due to limited opportunities and limited spatial and temporal coverage

Advantage

On the other hand, commercial airliners provide a significantly more powerful observational platform of regular observations for long periods of time over a large geographical space.

History of JAL Airliner Observation Instrumentations in Japan

Pioneer Period

(1984 ~ 1985)

Manual Sampling

Tohoku University

First Phase

(1993 ~ 2005)

Automated Air Sampling
ASE

MRI / JAL Foundation

Second Phase
(CONTRAIL-PROJECT)

(2006 ~)

Improved ASE

In situ CO2 Measurement
CME

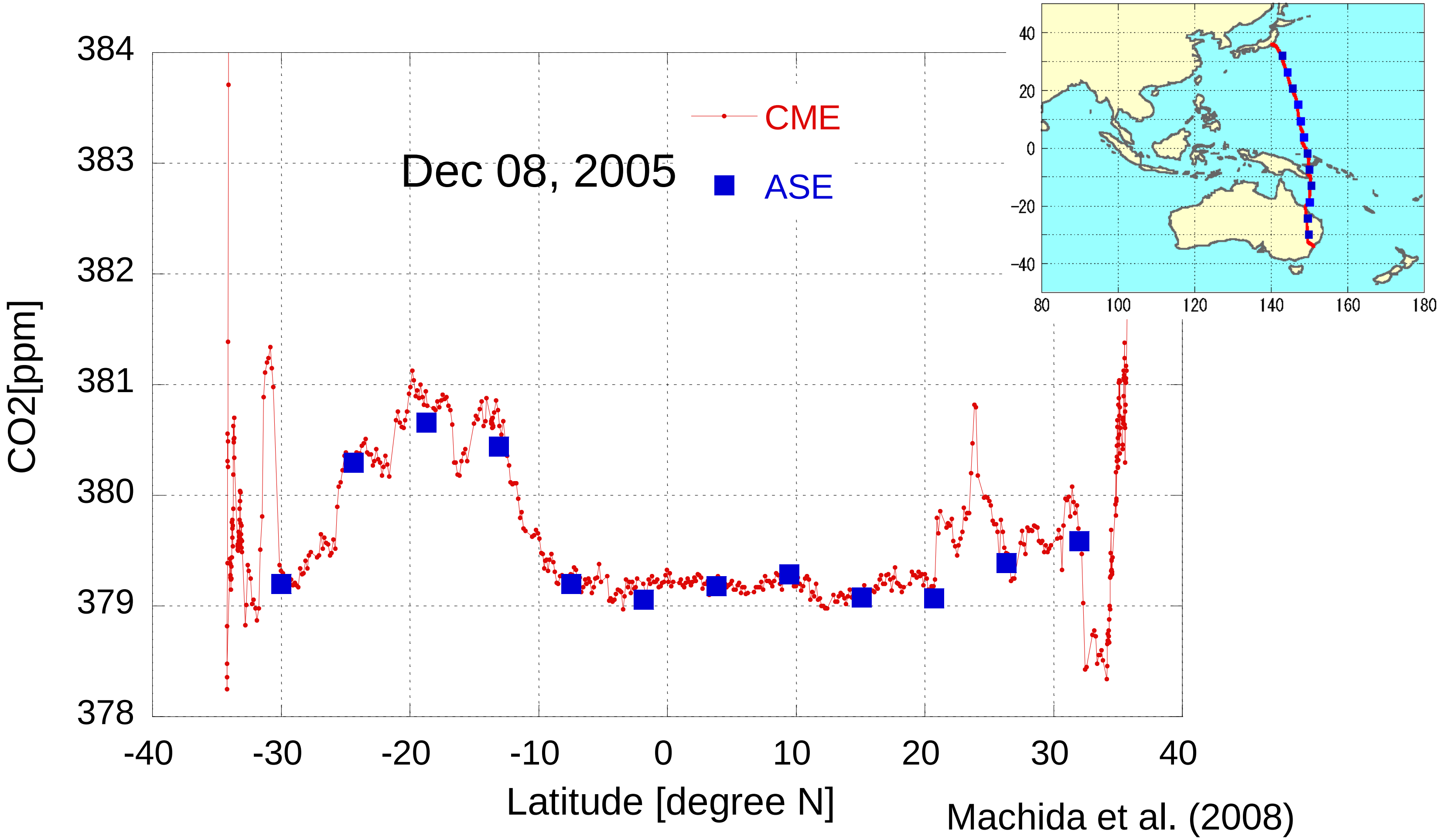
NIES / MRI

- Earlier pioneer observation in 1980s was made by a manual sampling equipment by Tohoku University.
- From1993, an automated air sampling system, ASE, was developed to largely improve the observation technique.
- From 2006, two new instrumentations of improved ASE and continuous CO2 measuring system (CME) were licensed and successfully installed on board the JAL aircraft.

Cargo in Boeing 747-400

- ASE and CME are installed in the forward cargo compartment under the cabin.
- After one flight, ASE are unloaded to measure trace gases in the laboratory.
- On the other hand, CME are operated for all flights during one to two months.

High-precision measurements from CME and ASE



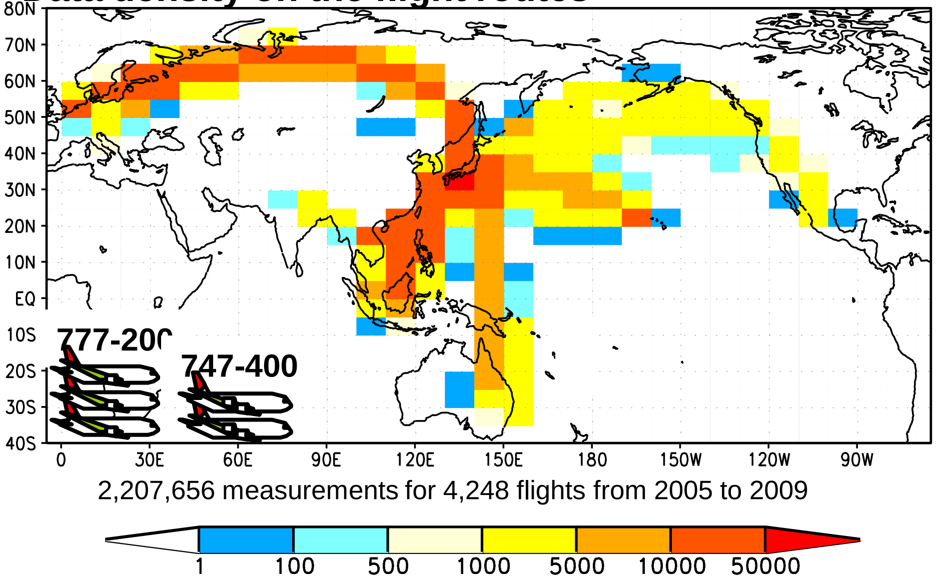
Machida et al. (2008)

- This is one example for the data measured by the both ASE and CME for the same flight.
- The precise CO_2 measurements from the ASE flask samples are well consistent to those from the CME.
- The ASE flask data are sparse,

 but the in-situ measurements from the CME can capture a very fine structure of CO_2 distribution.

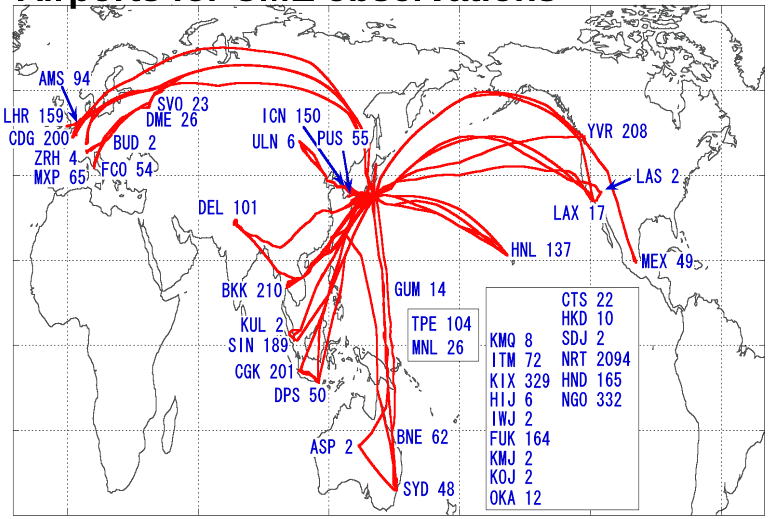
Worldwide high-resolution measurements collected from CME- CO_2

Data density on the flight routes



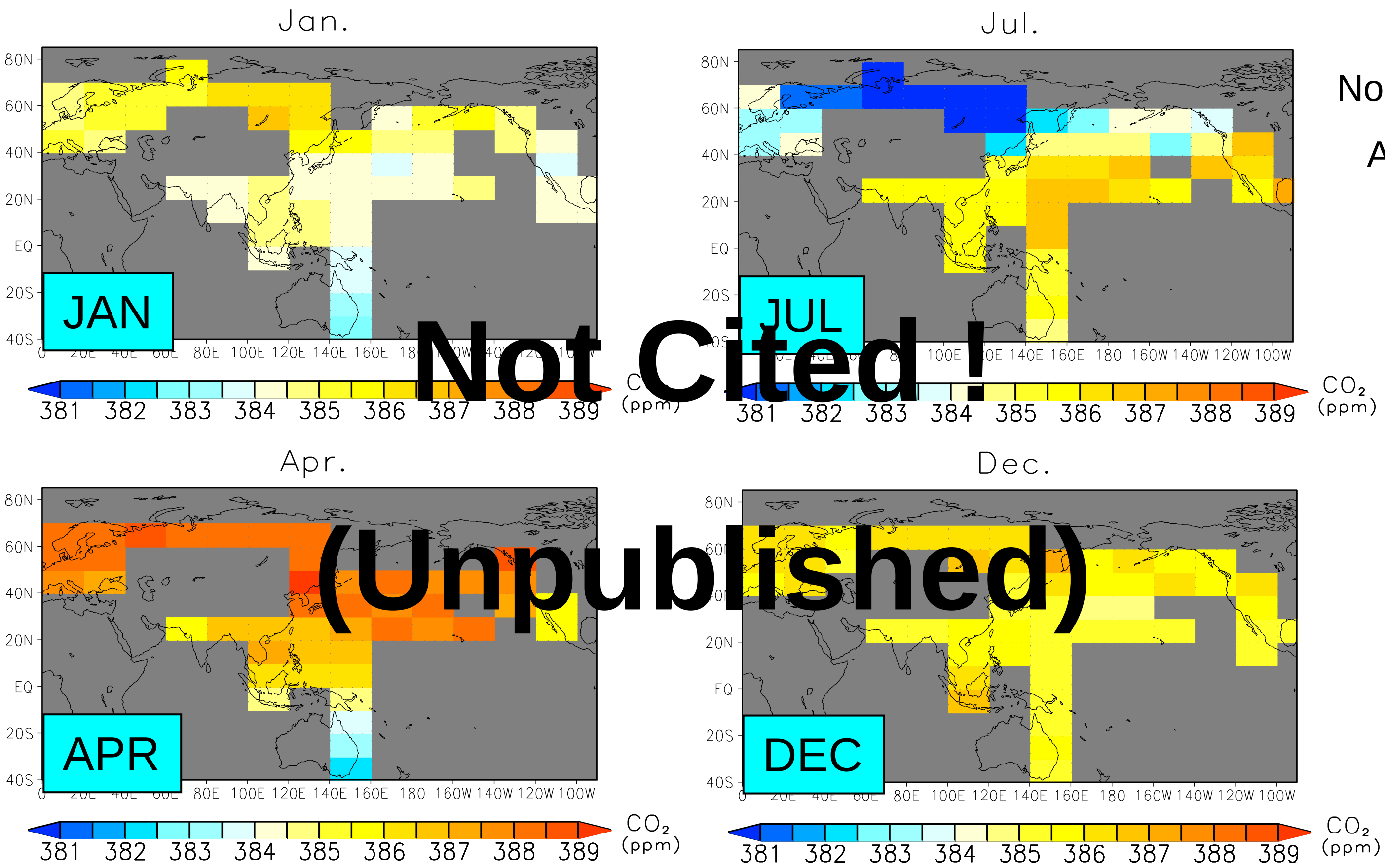
2,207,656 measurements for 4,248 flights from 2005 to 2009

Airports for CME observations



- The CME for in-situ measuring CO2 have been installed on five Boeing aircraft of B777 and B747.
- They are operated by JAL with regular flights to Europe, North America, Hawaii, Southeast Asia and Australia.
- For all of the flights, high-resolution data are collecting with 1 min for cruising flights and 10 sec for ascending and descending flights.
- For the past 4 years from 2005 to 2009, the total number of CO2 measurements is more than 2 million from more than 4000 flights. These huge data are enough to analyze global pictures of CO2 distributions over the world.

CO_2 seasonality in the upper troposphere between 8km and tropopause



Normalized

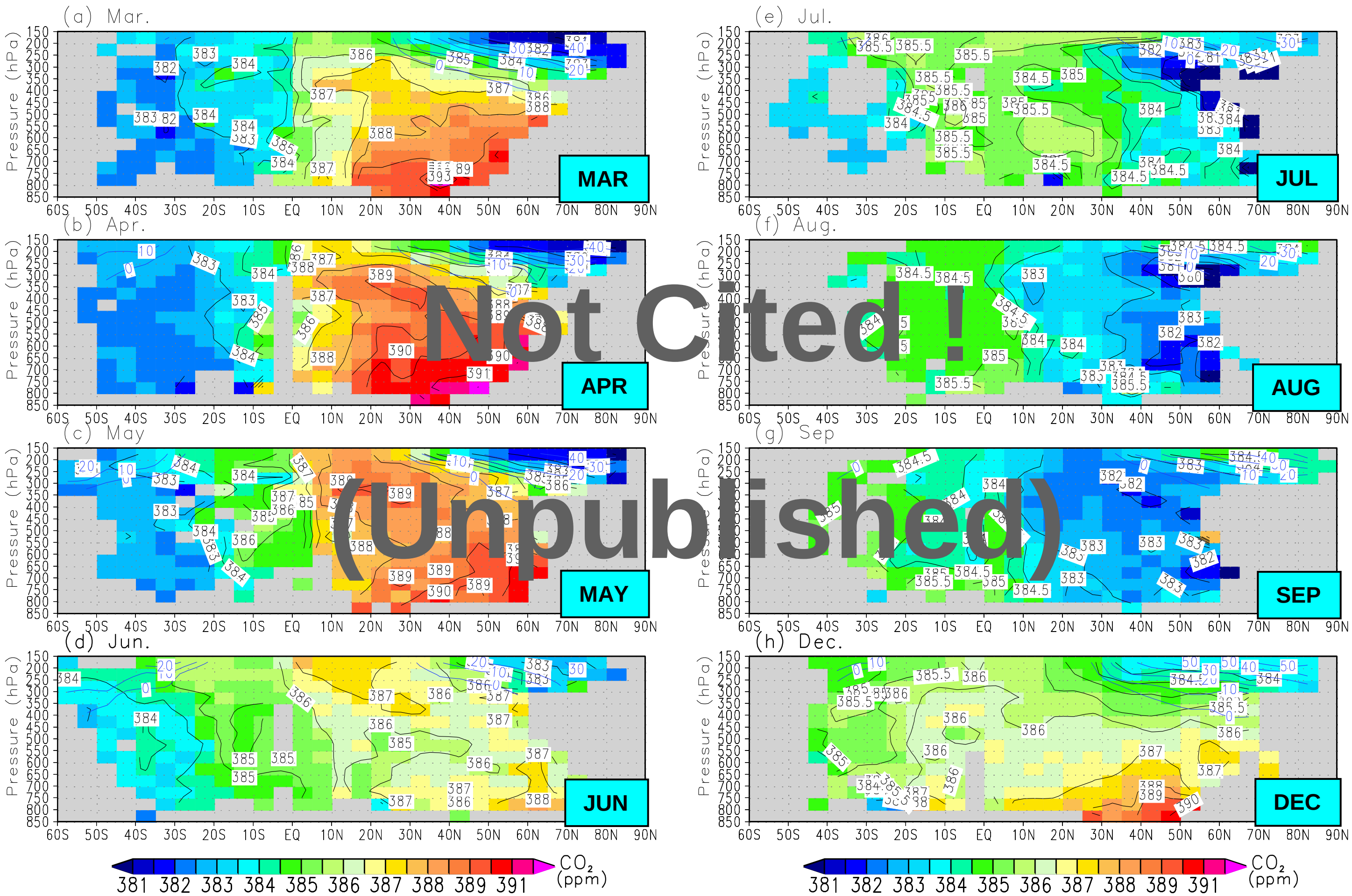
At 2008

Not Cited !

(Unpublished)

- From a lot of cruising flights, a climatology of monthly CO2 distributions in the upper troposphere is successfully created, as shown in these panels.
- These distributions reveal a clear seasonal change as well as latitudinal and longitudinal differences.
- One interesting feature in July is very low CO2 over the Siberia, indicating an active upward transport from the surface to the upper troposphere during summer.

Latitudinal cross section of CO_2 over the western Pacific

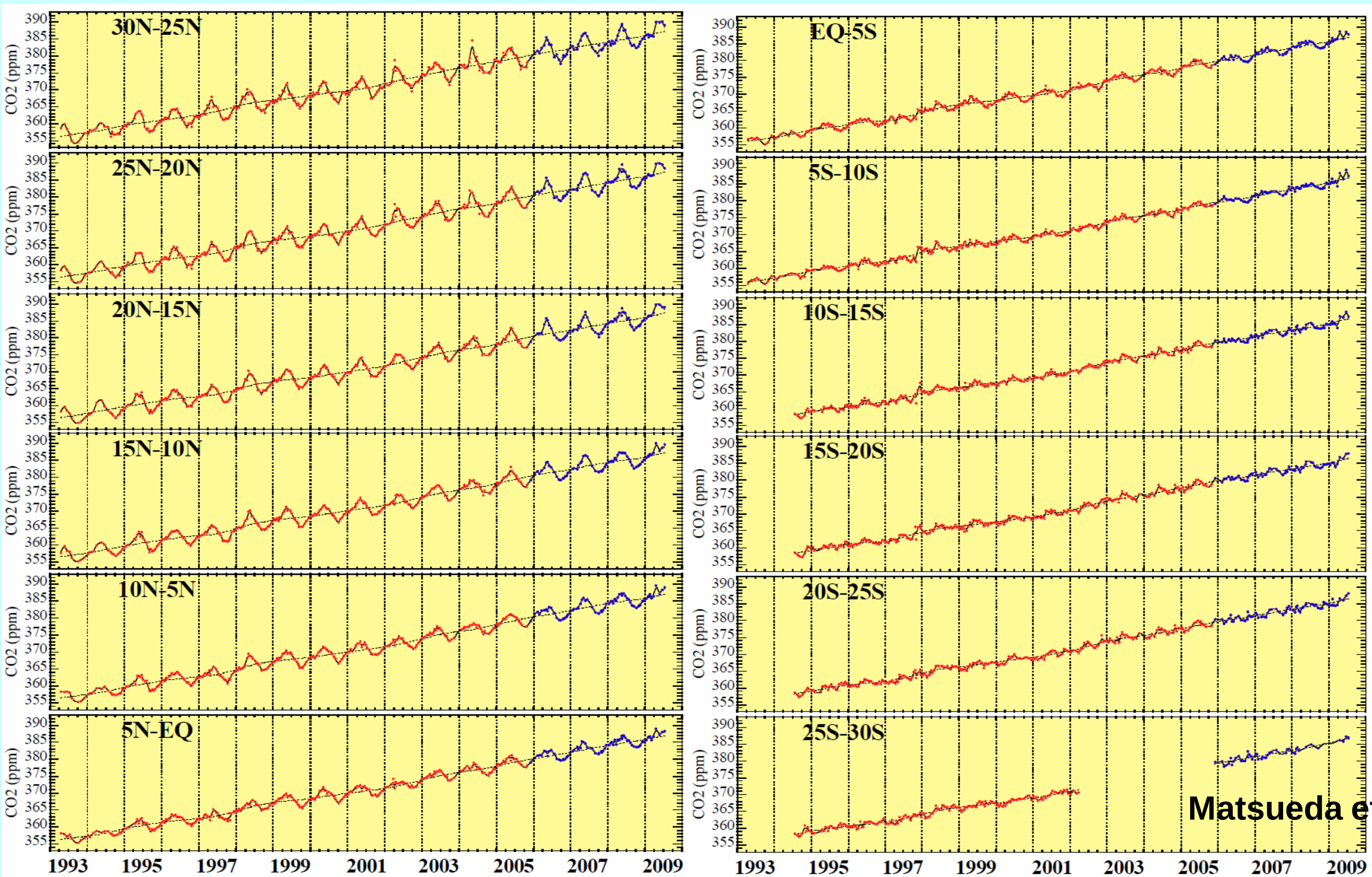


- When we further analyze all of the CO2 data including a lot of vertical profiles, 2-D distributions with equivalent latitude and pressure could be illustrated each month.
- As shown in these figures, we can well understand a propagation of the seasonality on a global scale.

- These CME-CO2 data are very useful to validate the 3-D model simulations as well as the satellite observations.

Long-term record of CO_2 at 10km between Japan and Australia

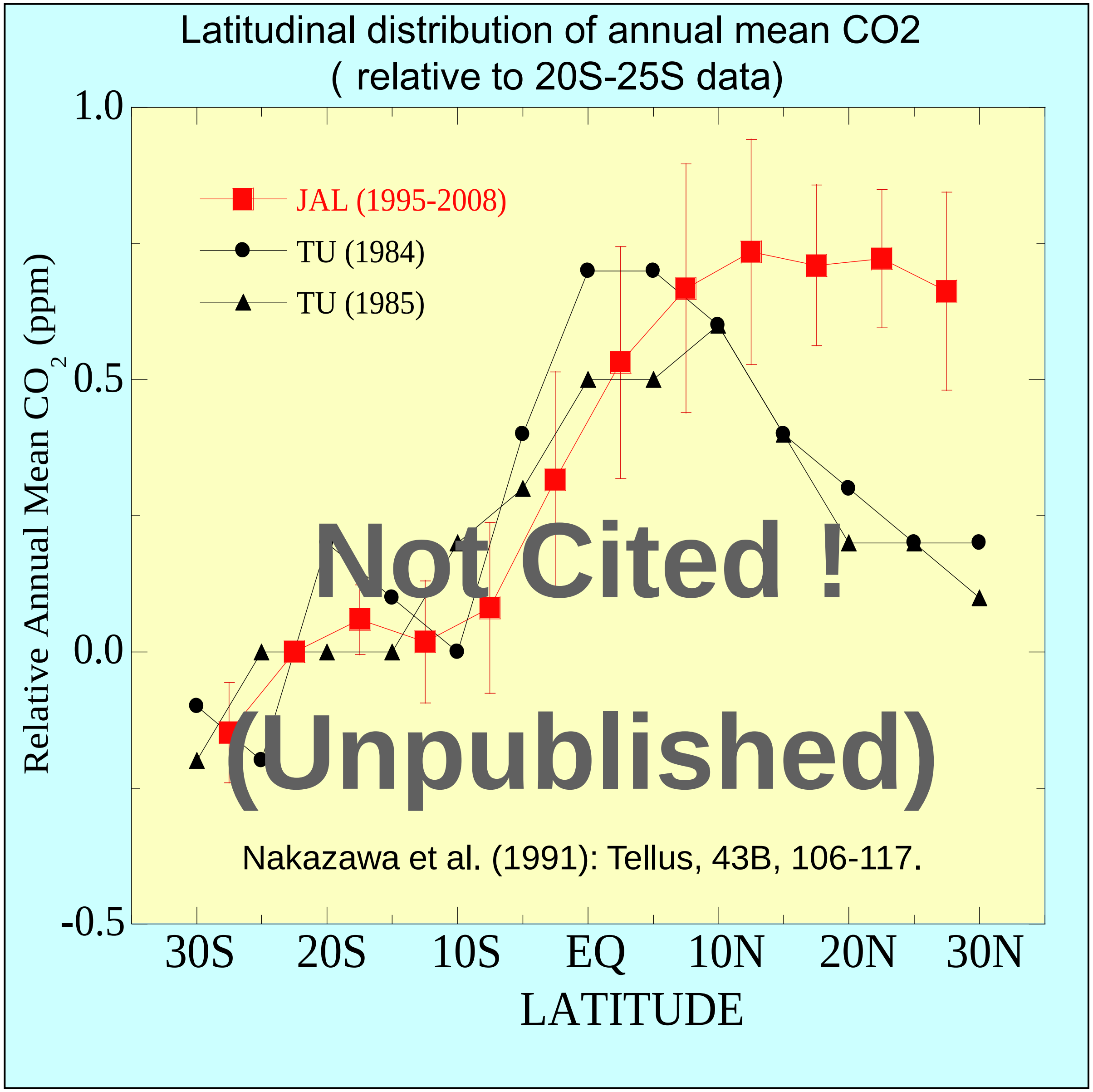
NH(30N-EQ) SH(EQ-30S)



Matsueda et al. (2008)

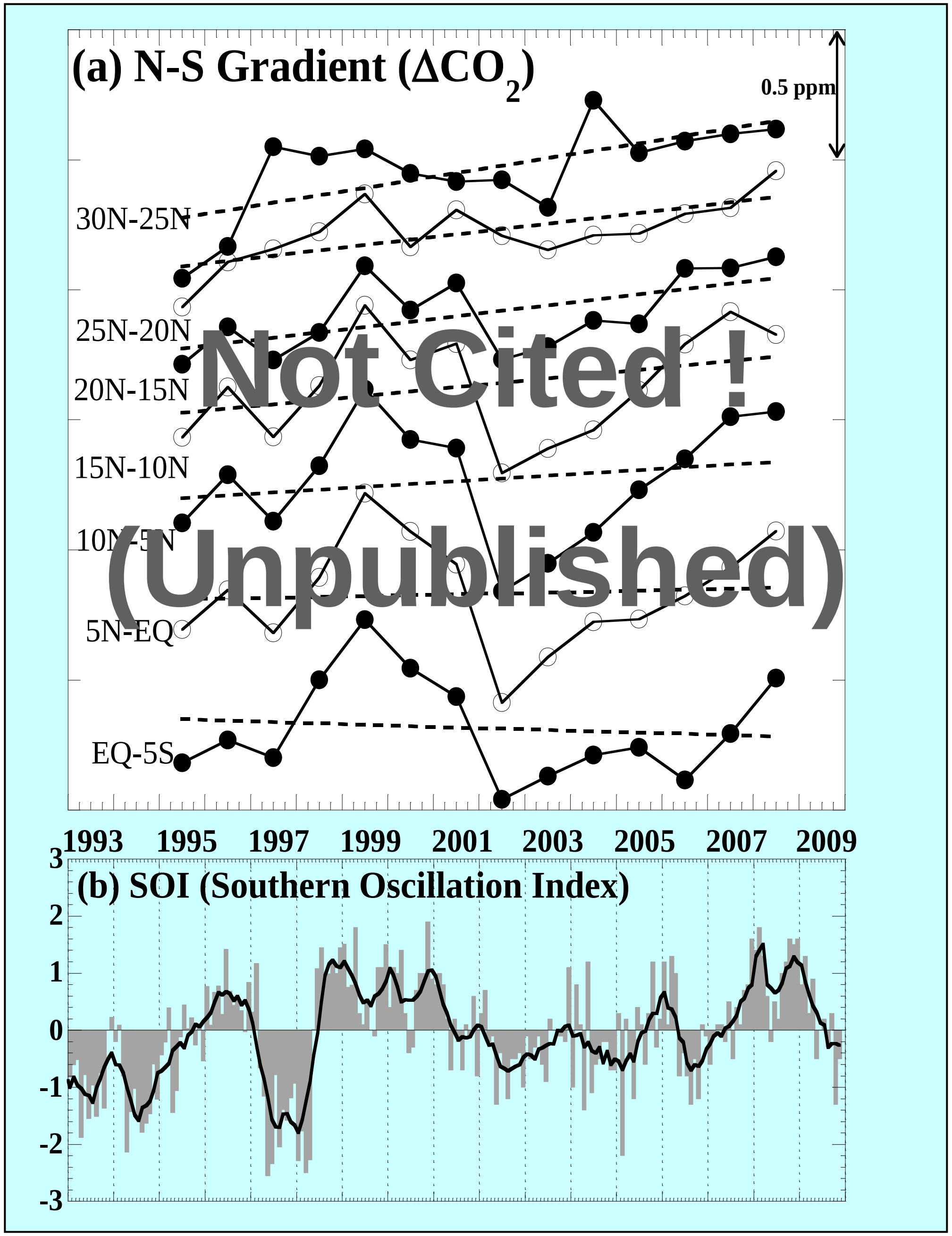
- The flask sampling observation with ASE started from April 1993, and have been continuing for more than 16 years.
- In this long CO2 record, a continuous increasing trend as well as a clear seasonal cycle are well defined.
- Today, I would like to introduce one new result from these ASE data analysis,
  focusing on the latitudinal CO2 distribution between 30N and 30S at 10 km altitude.

Comparison between recent and earlier data



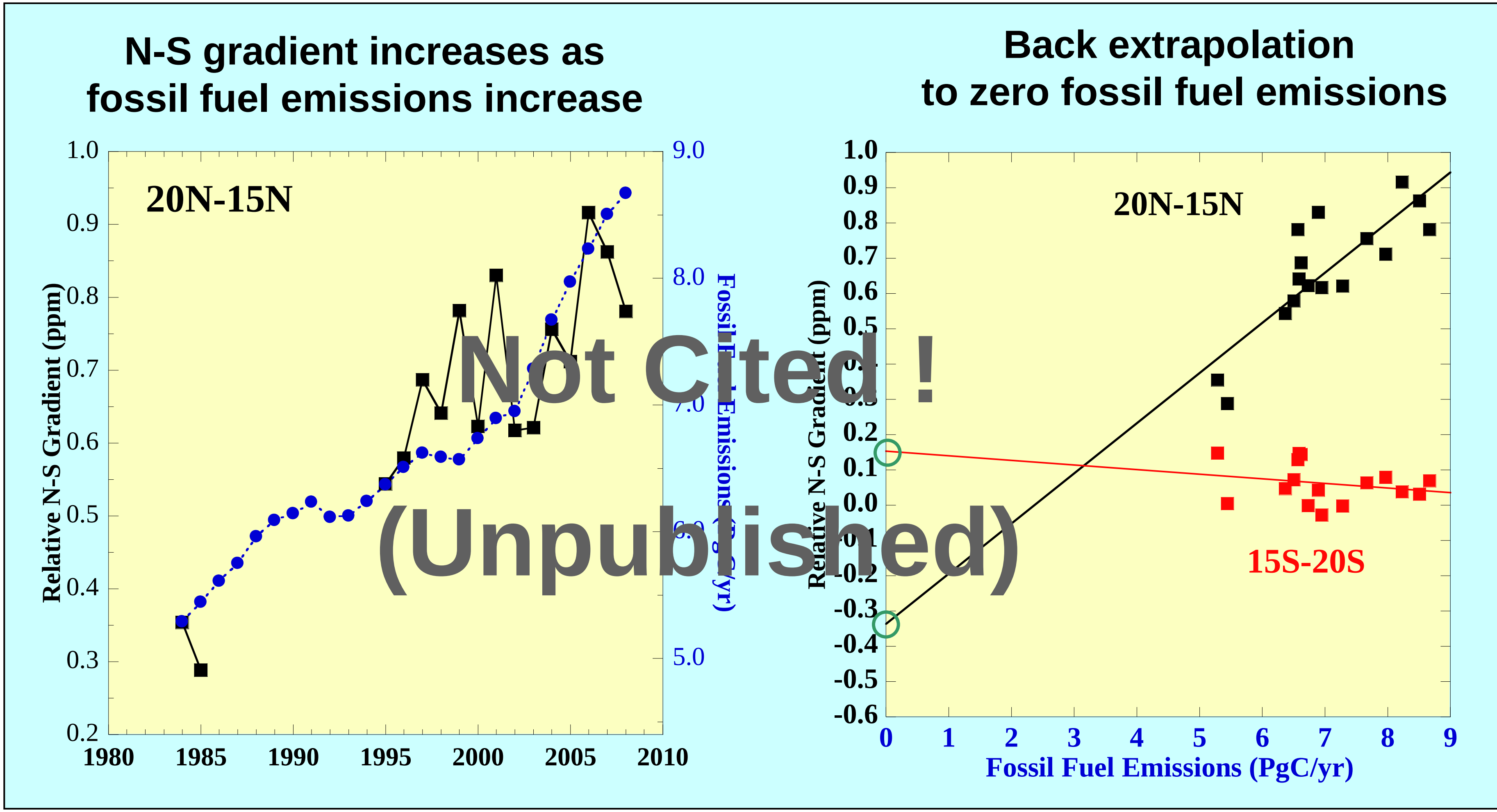
- About 25 years ago, Professor Nakazawa and his colleagues in Tohoku University collected CO2 data in 1984 and 1985 over the same flight route.
- When we compared the latitudinal distribution of the annual mean CO2 data, we found a remarkable difference of north-south distribution pattern between the earlier and recent data.
- This difference indicates a gradual change of CO2 latitudinal distribution during the past 25 years.
- This finding is achieved by high-precision measurements for a long period of time.

Time evolution of CO2 latitudinal distribution



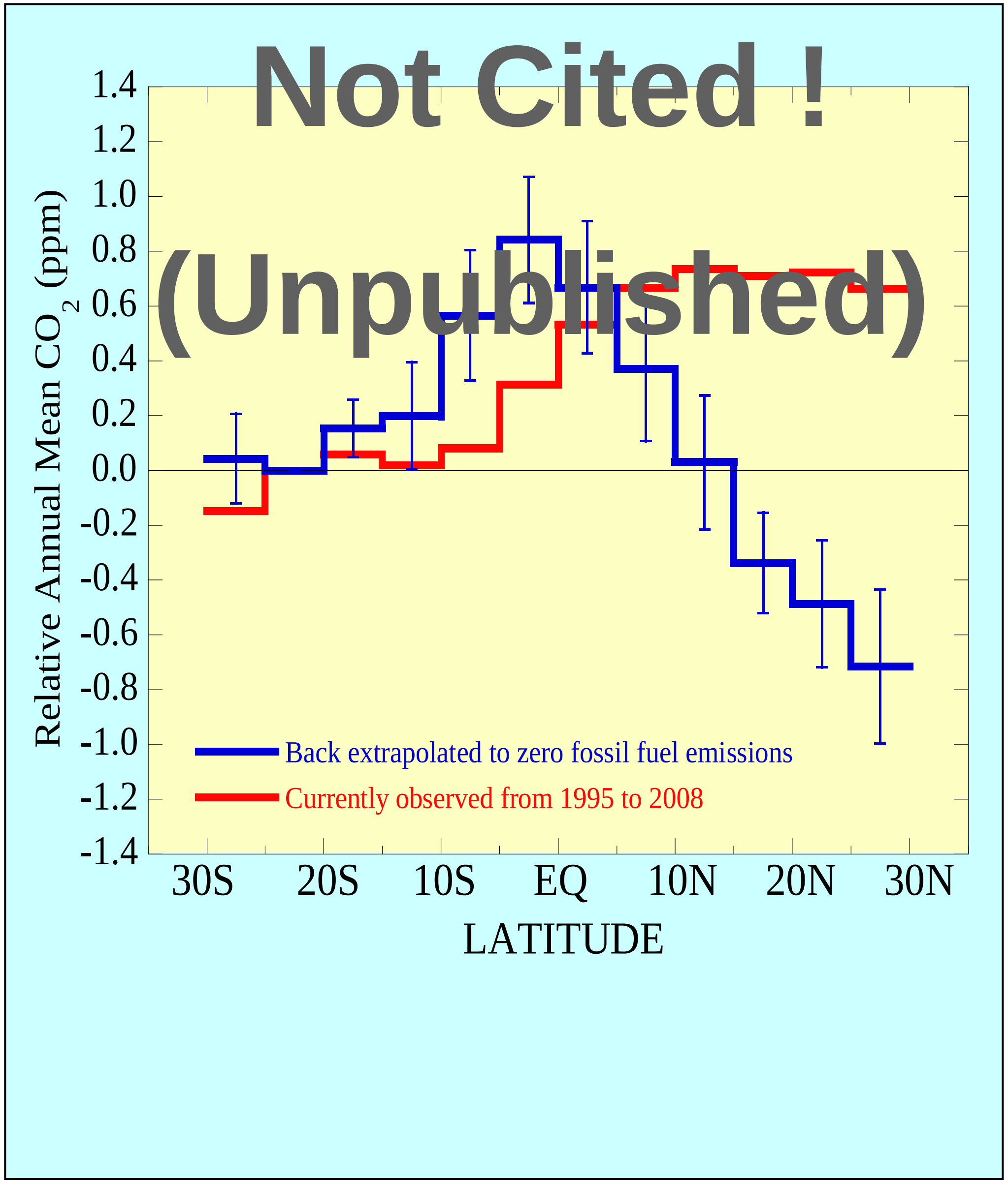
- This figure shows the temporal variation of the north-south gradient for each latitudinal band, that is defined as a difference of CO2 relative to the 20-25S latitudinal band.
- As you can see that, interannual variations of the gradients are well associated with the Southern Oscillation Index, indicating the ENSO-induced variability.
- In addition, it is clearly found the long-term increasing trends in the Northern Hemisphere.
- On the other hand, the gradients around equator show a slight decreasing trend.
- This is evidenced that the long-term gradient changes modified the CO2 distributions on a global scale.

N-S gradient change in proportion to fossil fuel emissions



- As shown in the left figure, we already expected that the north-south gradient increases, due to fossil fuel emissions increase in the Northern Hemisphere.
- When the N-S gradient change in proportion to fossil fuel emissions is linearly fitted, it gives us an intercept by back extrapolation to zero fossil fuel emissions, as shown in the right figure.
- This back linear-extrapolation can be applied for other all latitudes to construct the CO_2 latitudinal distribution at zero fossil fuel emissions.

Latitudinal distribution at zero fossil fuel emissions



- The blue line indicated a unique CO2 distribution extrapolated to zero fossil fuel emissions, but it is largely different from that currently observed.

- The extrapolated data show a negative north-south gradient with the Northern Hemisphere lower than the Southern Hemisphere, as well as a regional CO2 increase in the tropical regions.

- The negative gradient will be possibly explained by a southward transport in the ocean balanced by an atmospheric return flow,
  and/or a growing northern land sink.

- Although these causes are still under investigation at the present time,
  the question of what this unique distribution tells us about natural CO2 sources and sinks
  should be discussed furthermore to get a hint of the natural global carbon cycle with less human perturbations.

Summary

1) More observations are strongly required to reduce the uncertainties of inversion flux estimations as well as to improve the model transport for global carbon cycle studies.

2) Our MRI research activities in the atmosphere, ocean and modeling fields are performed based on various observation platforms combined with sophisticate model to contribute the WMO/GAW program.

3) JAL aircraft observations are very useful to provide unique data sets on a global scale, that were never seen before. In order to further continue this observation, encouragements and supports from all of you in the WMO/GAW community are greatly appreciated.