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Variability of carbon cycle and biological production in the North Pacific estimated from mapping of CO_2, alkalinity, and dissolved inorganic carbon

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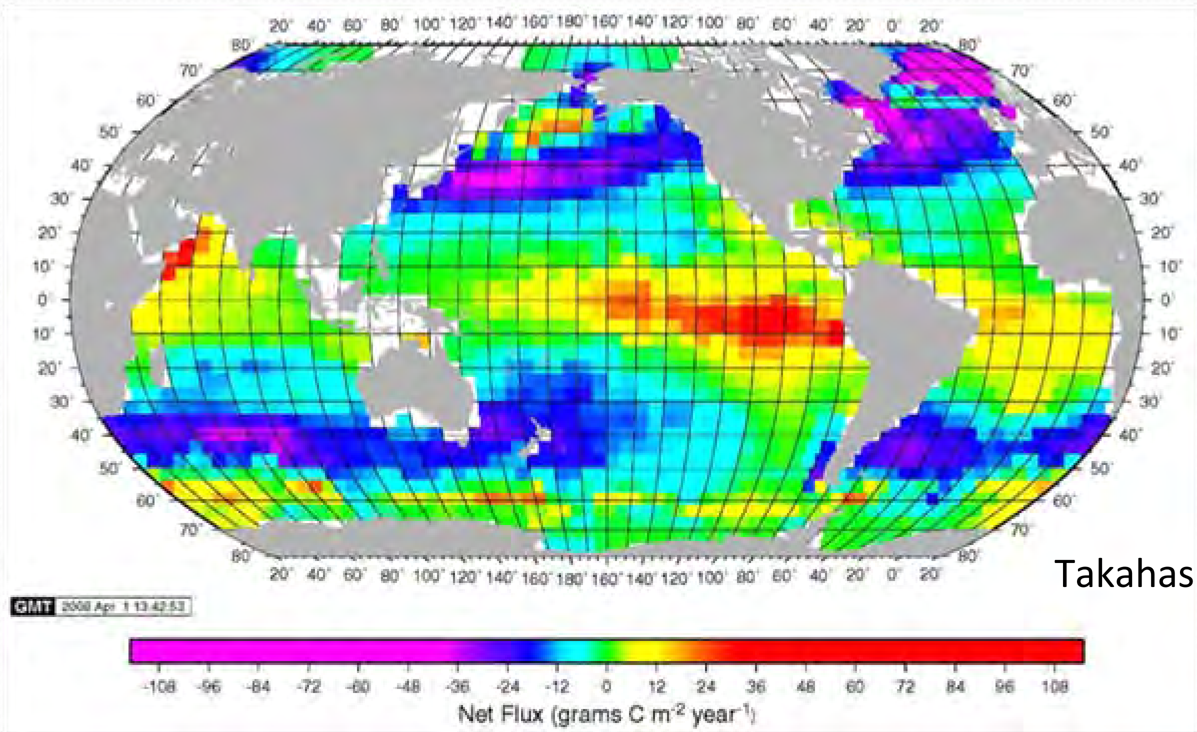
Funded by MOE (P.I. Y. Nojiri) and MAFF (P.I. T. Ono)

Bottom-up approach in ocean CO_2 sink by pCO_2 mapping



Takahashi et al. (2009)

- 3 million observations for 1970-2007
- Climatology (ref. year of 2000)
- grid cell 4° lat x 5° lon

Our goal is to reconstruct pCO_2 map
with **higher spatial resolution** and with **inter-annual variability**
by Self Organizing Map(**SOM**), a kind of **neural network**.

What is neural network?

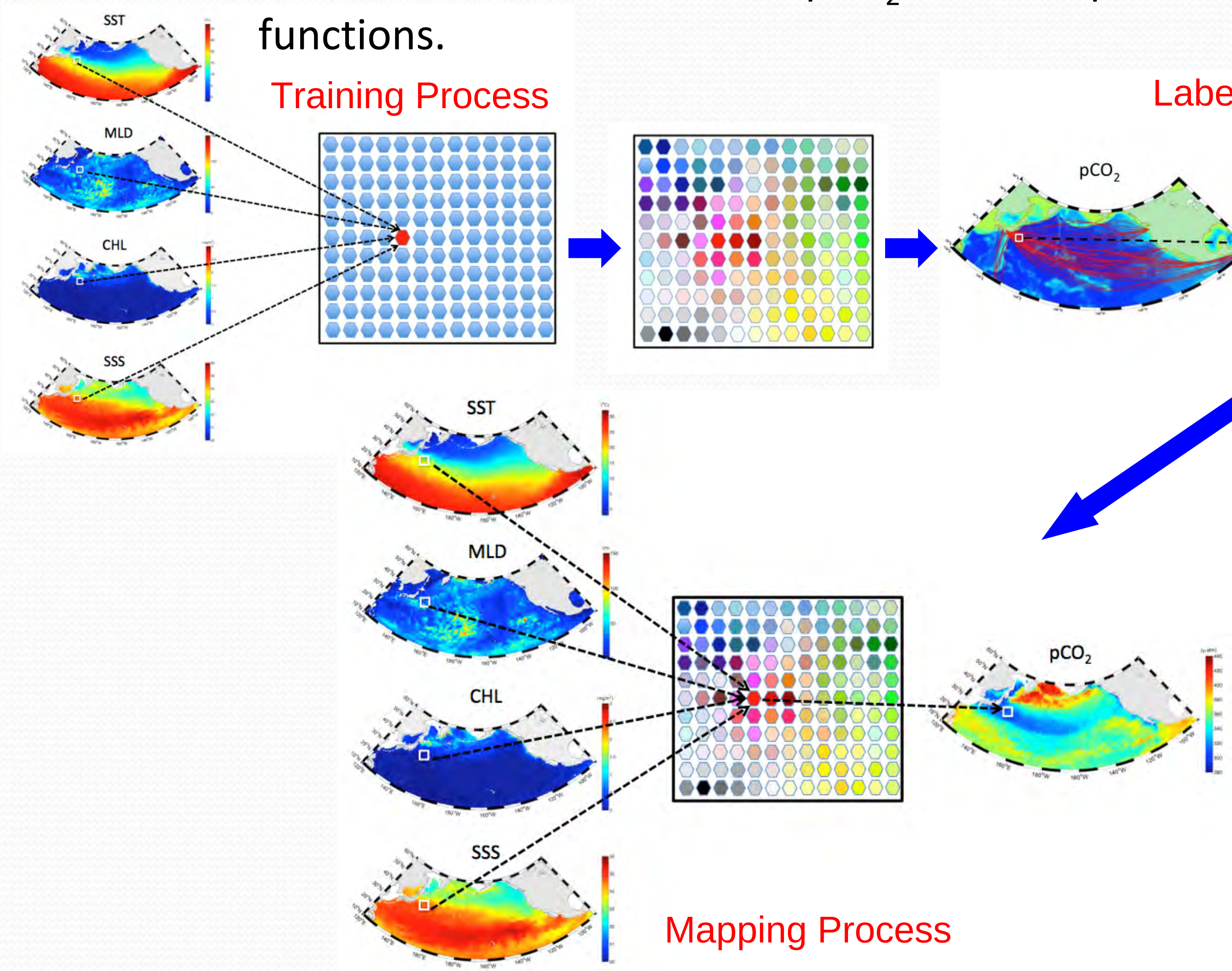
The term *neural network* reflects the method's conceptual connection to the functionality of a (human) brain.

- SOM is one kind of Artificial Neural Networks family of statistical analysis tools. This technique was first applied to estimate pCO_2^{sea} field in North Atlantic by Telszewski et al (2009).
- Method neglecting the temporal & spatial sparseness of the pCO_2 data
- Method able to provide robust basin-wide estimates of the inter-annual variability (*Telszewski et al.* 2009)
- Method allowing high resolution output
- Analysis of the North Pacific (10-60°N, 120°E-90°W) pCO_2 for 2002-2008.

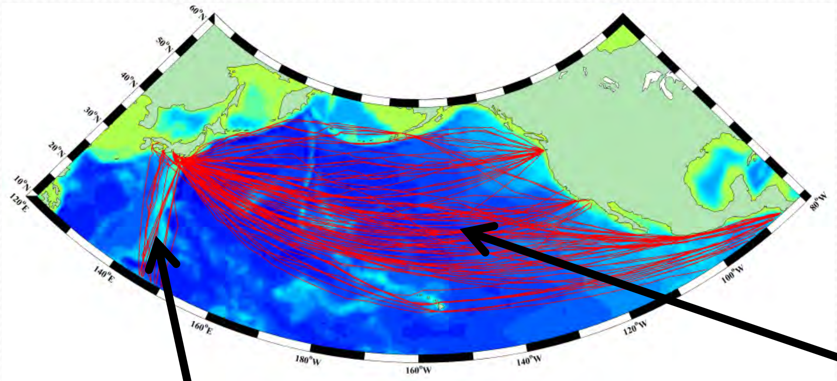
$$pCO_2^{sea} = f_{SOM}(SST, MLD, CHL, SSS) + \alpha (t - t_{ref})$$

Procedure of the SOM approach

Non-linear nature of surface pCO_2 can be expressed by SOM functions.



North Pacific pCO_2 Monitoring by NIES-VOS

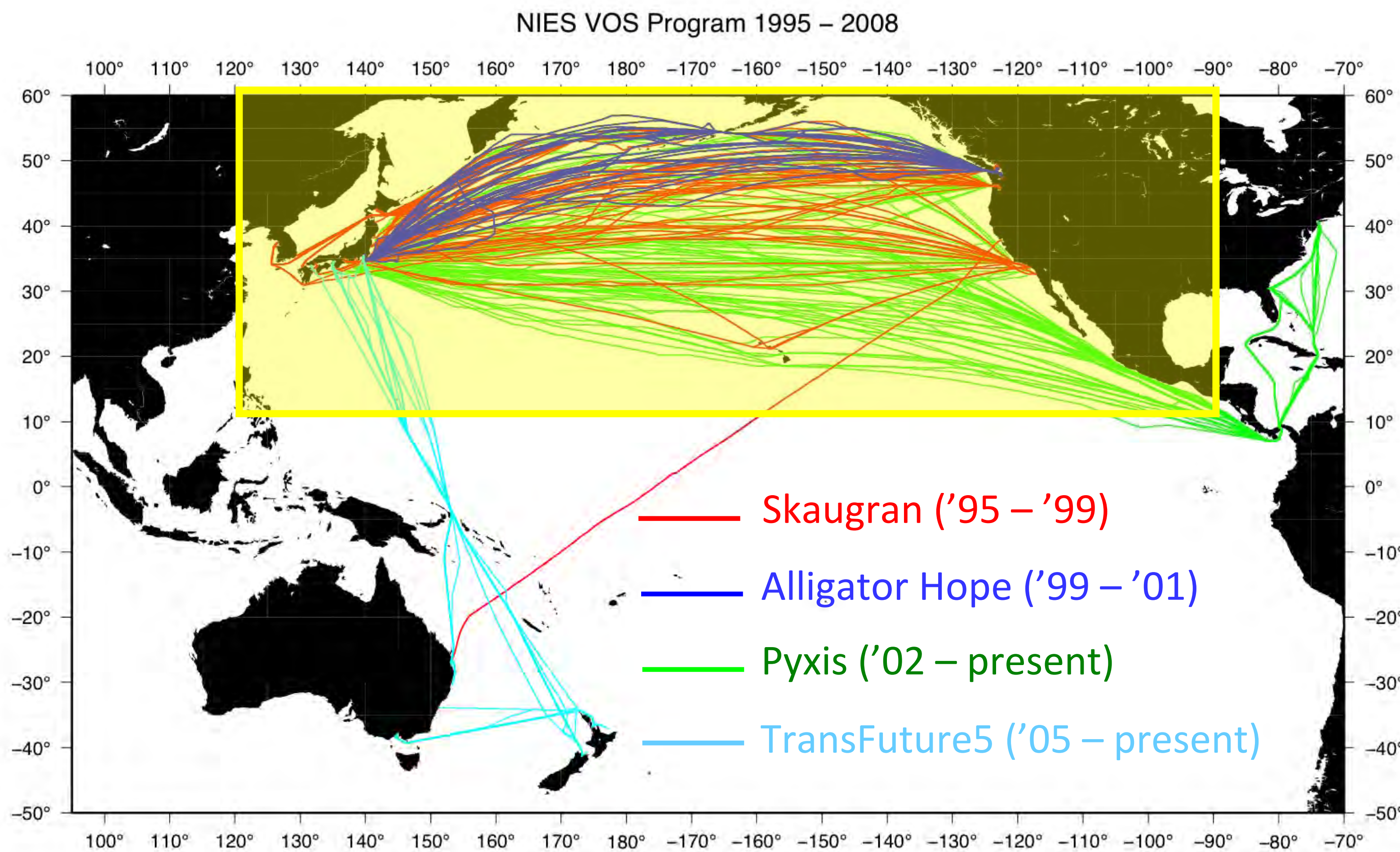


- **Labeling data**
- 48,374 daily, 0.25° x 0.25° averages
- water deeper than 500 meters
- each point co-located with SST, MLD, CHL and SSS

- **Trans Future 5**
- Japan – Australia – New Zealand
- 6 weeks return voyage
- Data available: Jun.2006 – Dec.2010 (submitted to SOCAT v.2)

- **Pyxis**
- Japan – USA (east or west coast)
- 5-8 weeks return voyage
- Data available: Jul.2002 – Dec.2010 (submitted to SOCAT v.2)

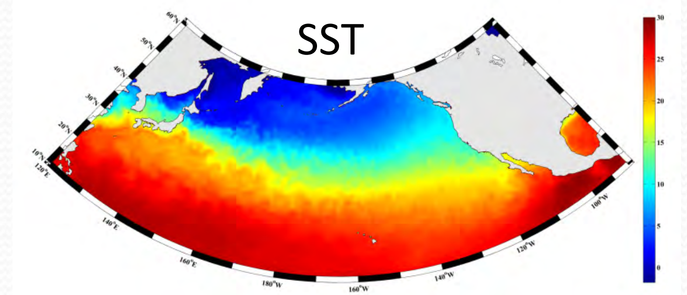
Achievement of NIES VOS for pCO_2 measurement



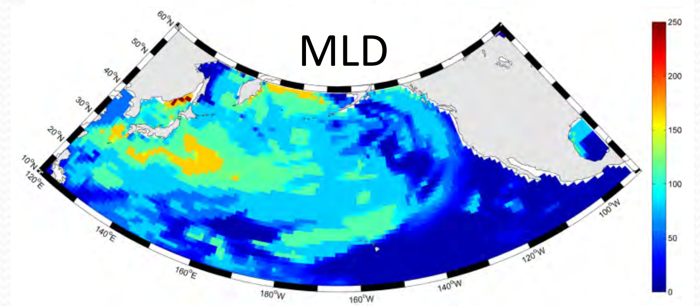
NIES pCO_2 measurement is enough intensive
to reconstruct North Pacific basin-scale pCO_2 distribution.

Parameters

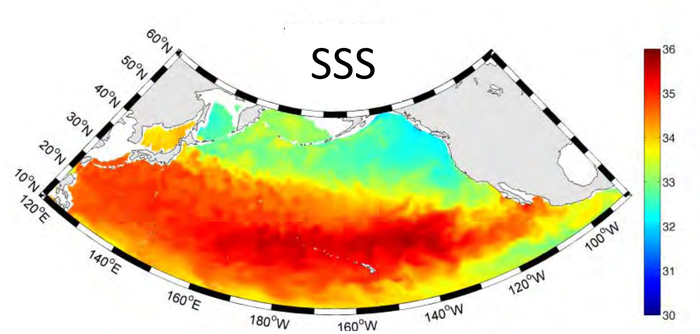
- **MGDSST, Office of Marine Prediction, JMA, Japan**
- Daily, 0.25° x 0.25° reanalysis
- Fits very well to *in situ* SST from SOCAT
- SSTs derived from satellite's infrared sensors (AVHRR/NOAA) and microwave sensor (AMSR-E/AQUA), and *in situ* SSTs (buoy & ship) are used in reanalysis.



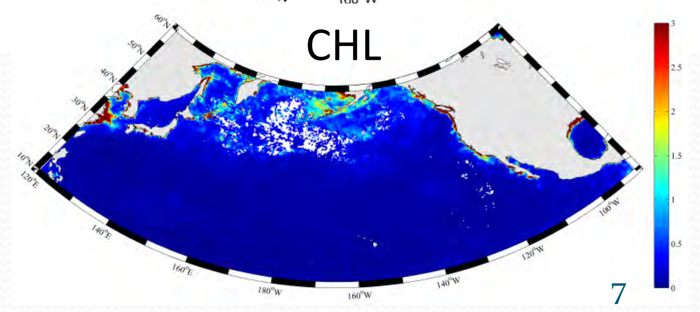
- **GLORYS, Mercator Research Centre, CNRS, France**
- Daily, 0.25° x 0.25° reanalysis
- NEMO ORCA025, 50 levels, ECMWF operational forcing are used as the results of OGCM.
- Data assimilated *in situ* temperature & salinity from Argo, XCTD/CTD, and NCEP real-time global SST.



- **MOVE/MRI.COM, MRI, Japan**
- 10-daily, 0.5° x 0.5° reanalysis
- System assimilates *in situ* SST & salinity profiles, and SSH anomaly from satellite altimeter into the dynamical model.

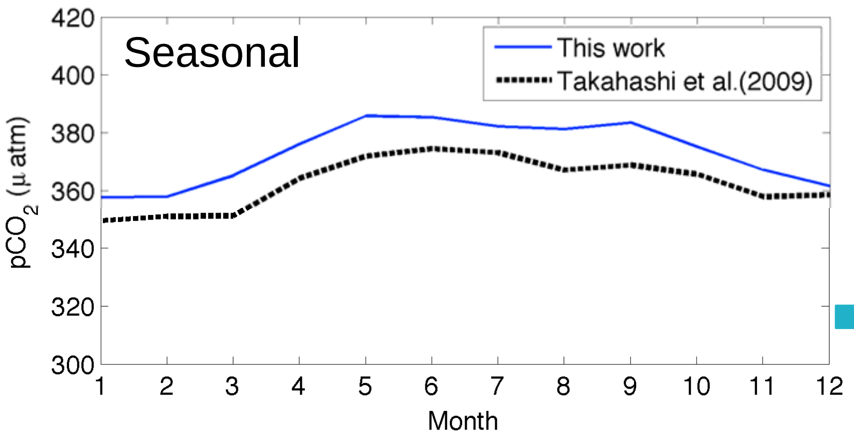


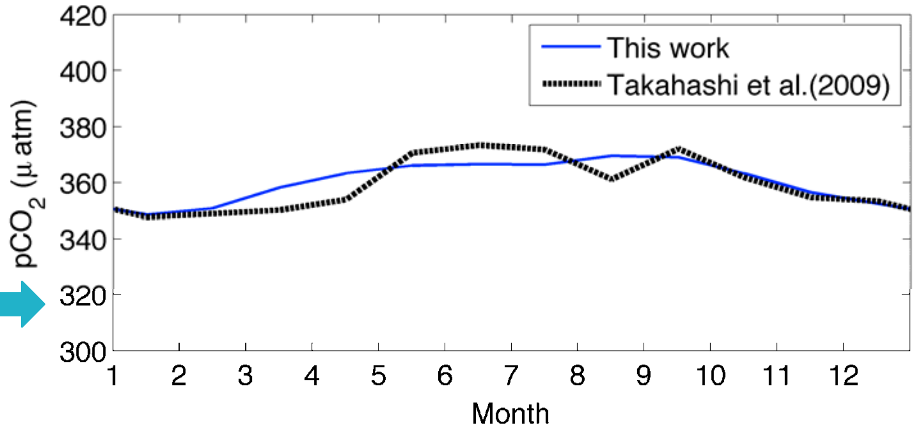
- **SeaWiFS/MODIS combined product, NASA, USA**
- 8-daily, 1/12° x 1/12°
- Coverage improved by filling the empty pixels with 2002-2008 weekly climatology.



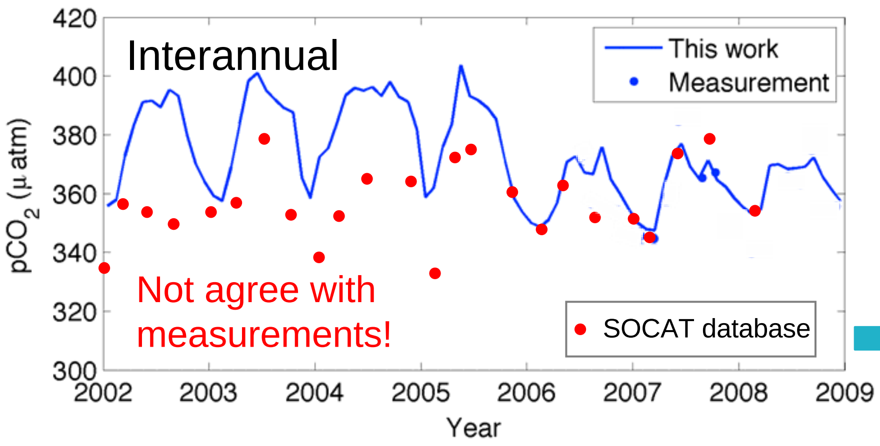
Use of Mercator MLD data set

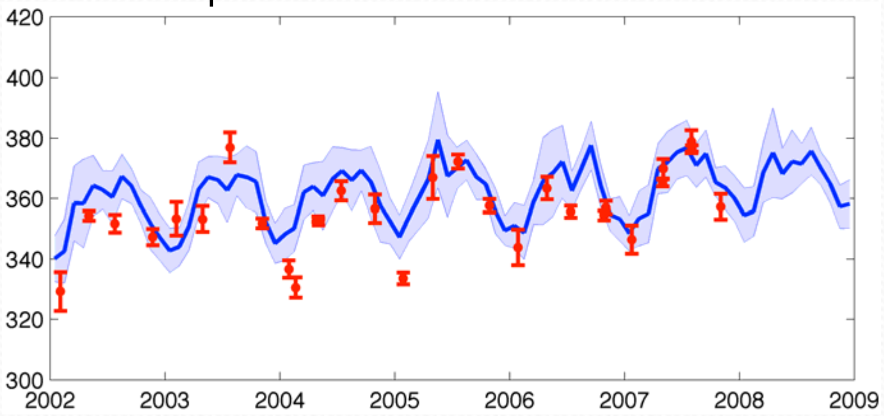
Consideration of secular increasing trend of pCO_2





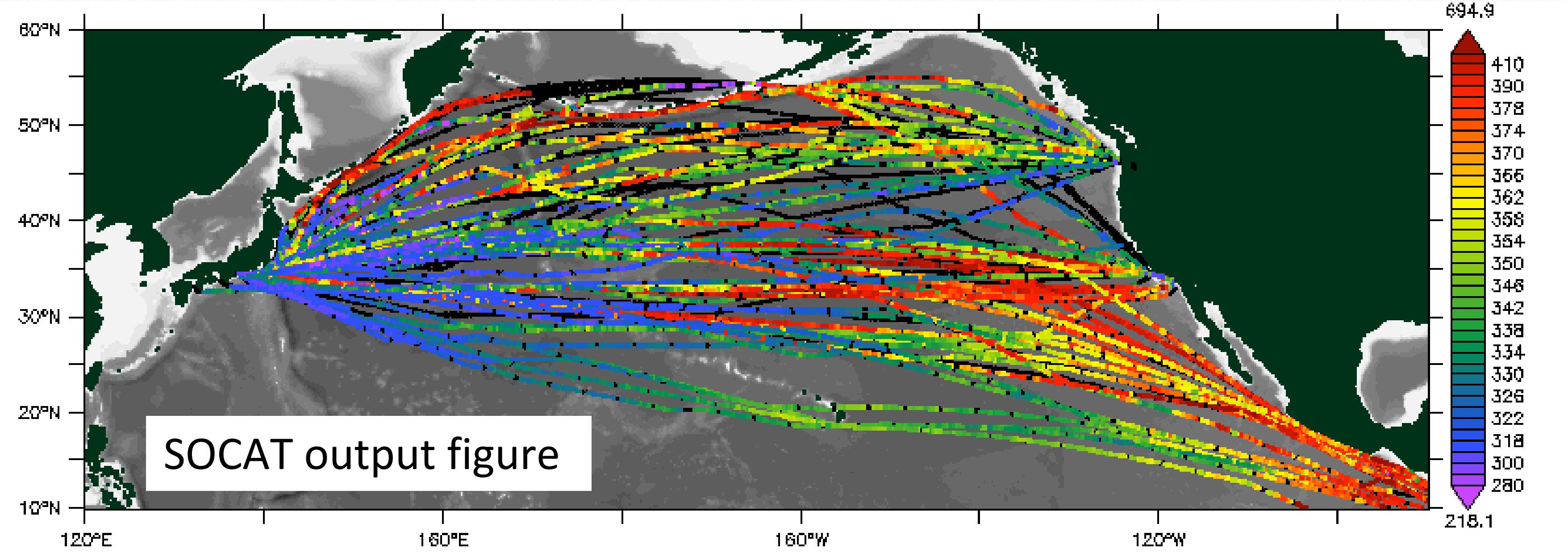
Comparison at Western Subtropical Pacific (15N, 137E), where JMA repeat observation record exits.





By changing MLD dataset, the pCO_2 estimate improves its seasonality and the interannual variation especially for the 2002-2005 period.

Results ~ monthly pCO_2 distribution



Winter: high pCO_2^{sea} at high latitudes
low pCO_2^{sea} at mid latitudes

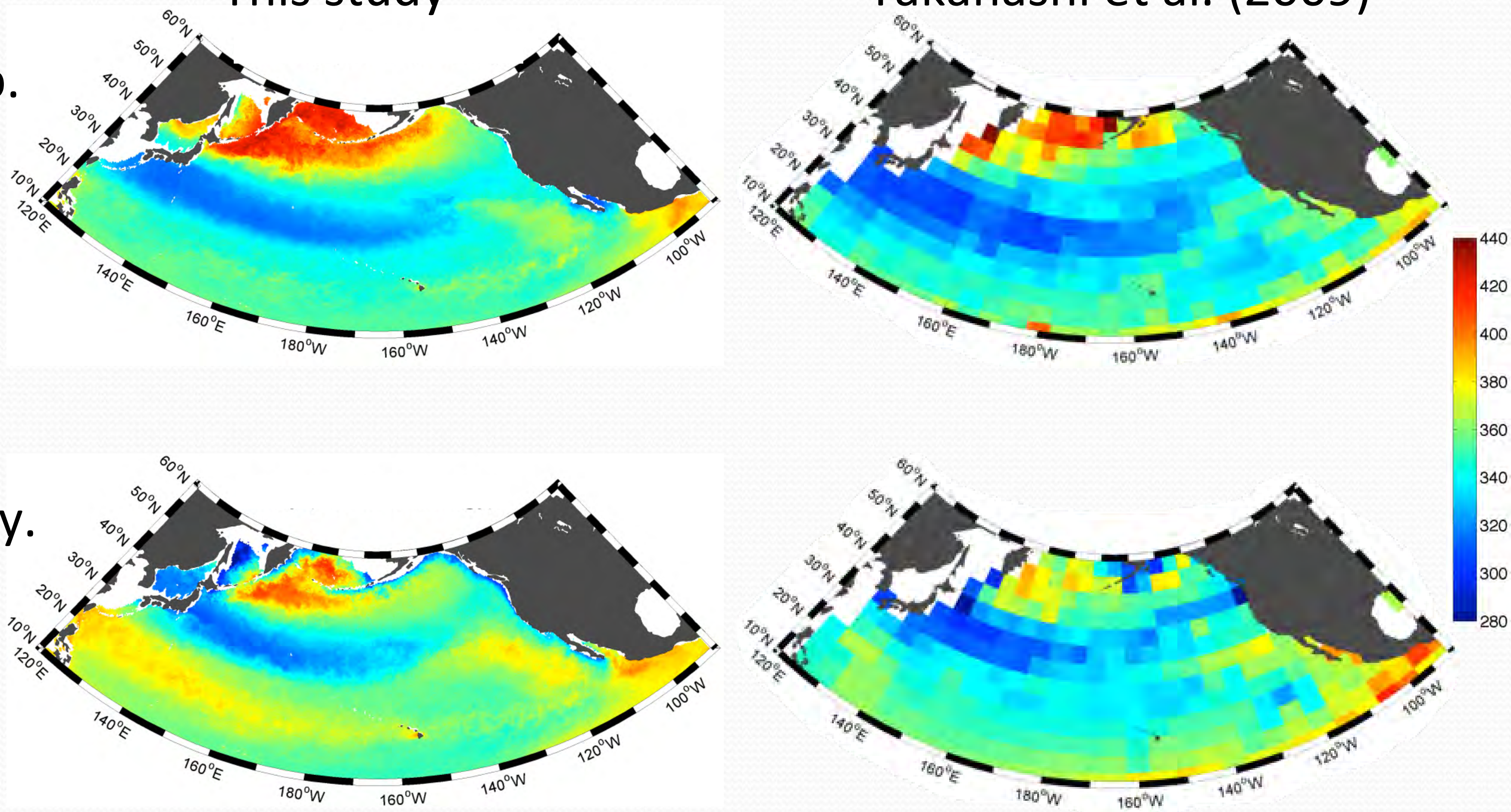
Summer: low pCO_2^{sea} at high latitudes
high pCO_2^{sea} at low latitudes

Climatological pCO_2 map ~ Winter & Spring~

This study | Takahashi et al. (2009)

Feb.

May.



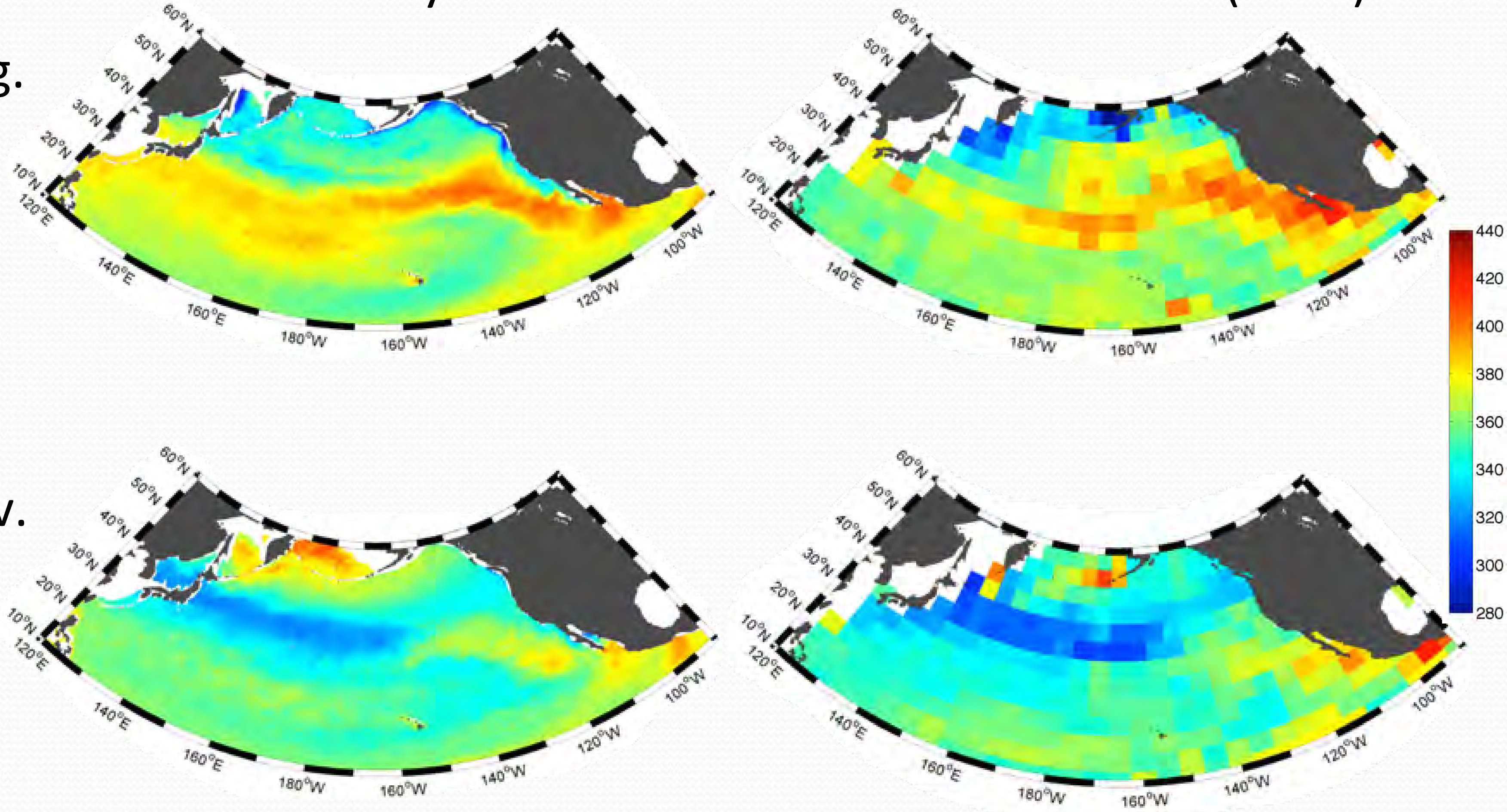
Surface pCO_2 mapping with inter-annual variability is used for DIC estimation, with learning data set as SST, SSS, MLD. CHL mapping is not necessary but Si and PO_4 climatology are used for carbonate chemistry calculation.

Climatological pCO_2 map ~ Summer & Fall~

This study | Takahashi et al. (2009)

Aug.

Nov.

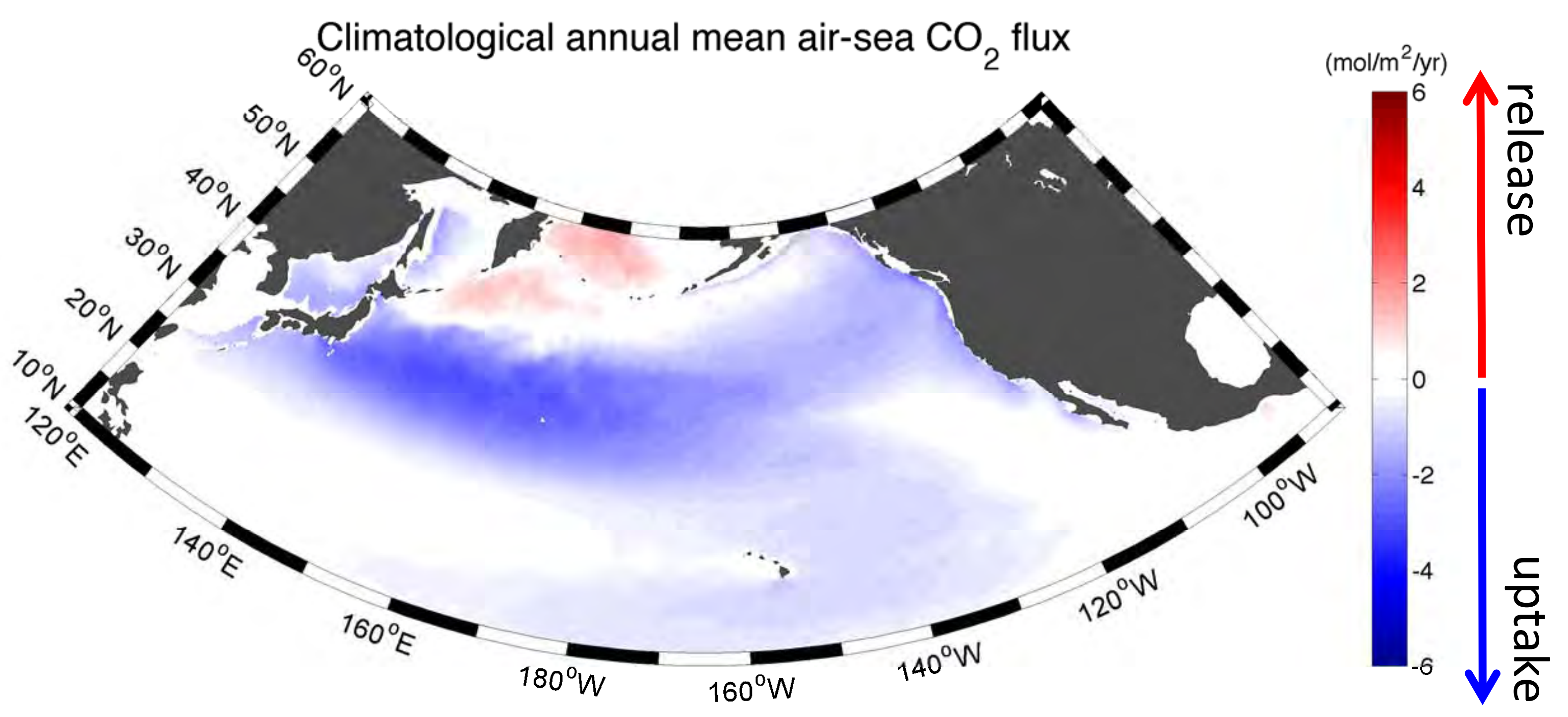


Surface pCO_2 mapping with inter-annual variability is used for DIC estimation, with learning data set as SST, SSS, MLD. CHL mapping is not necessary but Si and PO_4 climatology are used for carbonate chemistry calculation.

CO_2 flux in the North Pacific

flux = K • (pCO$_2^{sea}$ - pCO$_2^{air}$)

Gas transfer coefficient: Sweeney et al.(2007)
Wind dataset: CCMP (Cross-Calibrated, Multi-Platform) wind dataset



High-latitude: weak CO_2 source area
Mid-latitude: strong CO_2 sink area
Low-latitude: weak CO_2 sink or neutral area

Surface flux is used for correction in productivity analysis.

Summary and Conclusions for pCO_2 mapping

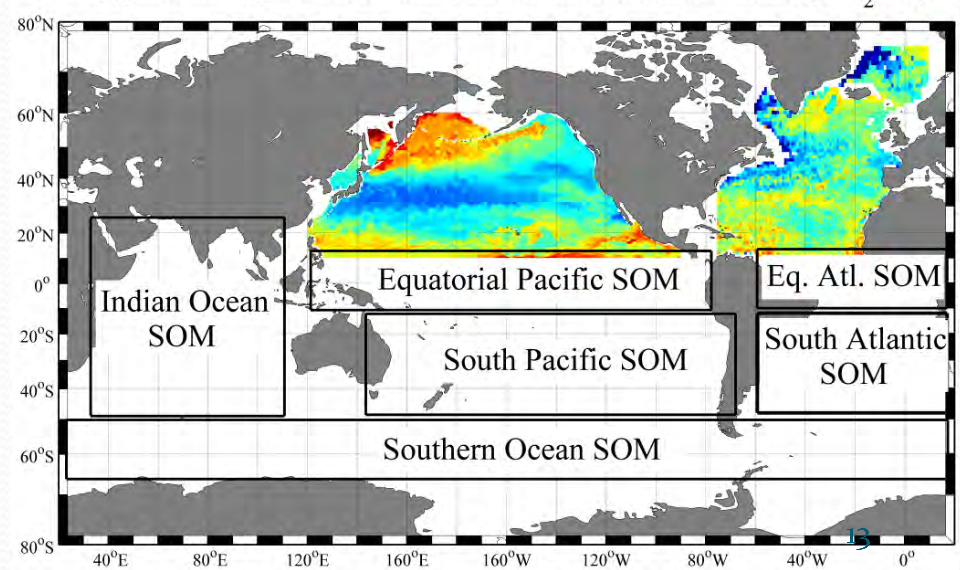
1. Best results obtained by SST, MLD, CHL and SSS as input parameters
   Root mean square error (RMSE) to NIES measurements; 17.8 µatm

2. SOM applicable to the entire basin, no need to divide into several regions
   SOM applicable for over several years

3. Annual mean oceanic CO_2 uptake for 7 yrs; 0.44 PgC/y with relatively small inter-annual variability

4. Future expansion to basins of global ocean with SOCAT pCO_2 dataset

Regional SOM parametrizations to be combined into the Global pCO_2 map



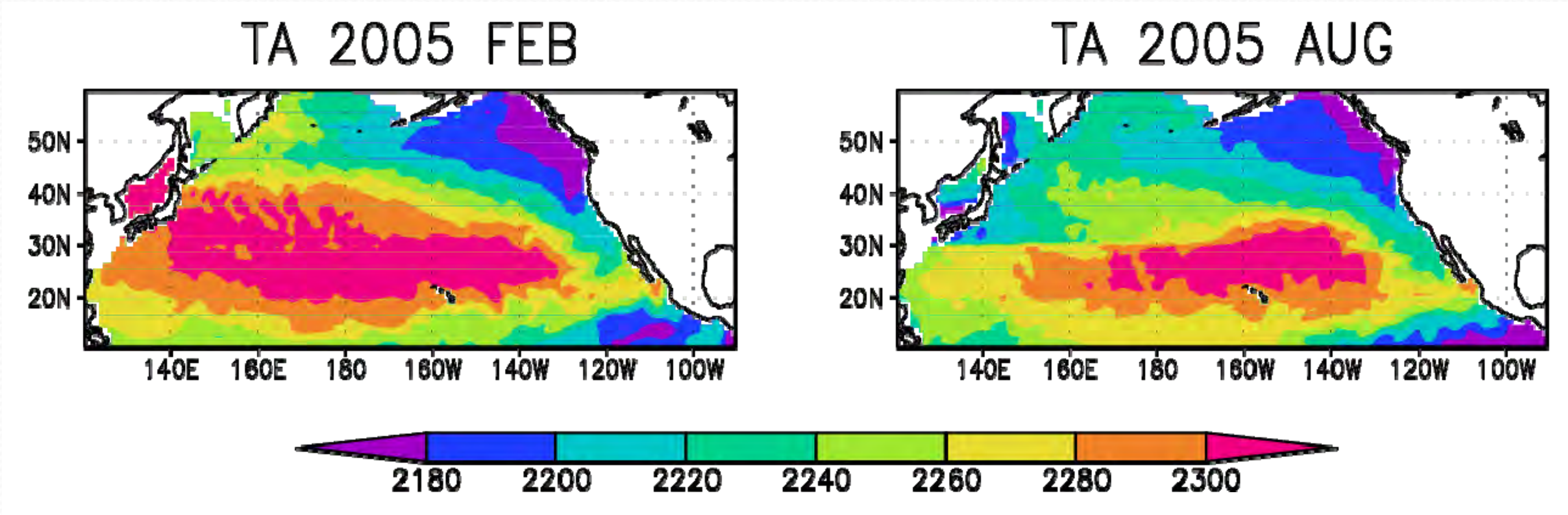
Application of pCO_2 mapping to estimate surface DIC

Dissolved Inorganic Carbon (DIC) is a straight forward carbon parameter of biological productivity.
Lee (2001) first applied pCO_2 mapping to net community productivity estimation for global ocean. Takahashi et al. (1997) global climatology was used.
Our new precise pCO_2 mapping with inter-annual variability is applicable for production of detailed distribution map of sea surface DIC.

It starts from alkalinity mapping with empirical eq. proposed by Lee et al. (2006).

Estimation of TA (Lee et al. 2006)

$$TA = a + b\,(SSS - 35) + c\,(SSS - 35)^2 + d\,(SST - 20) + e\,(SST - 20)^2\ [+ f\,(SST - 20)\ \text{Longitude}]$$

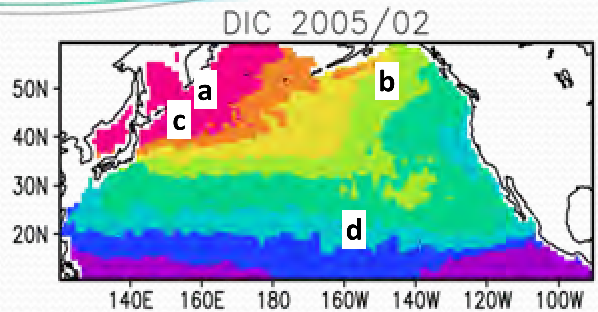


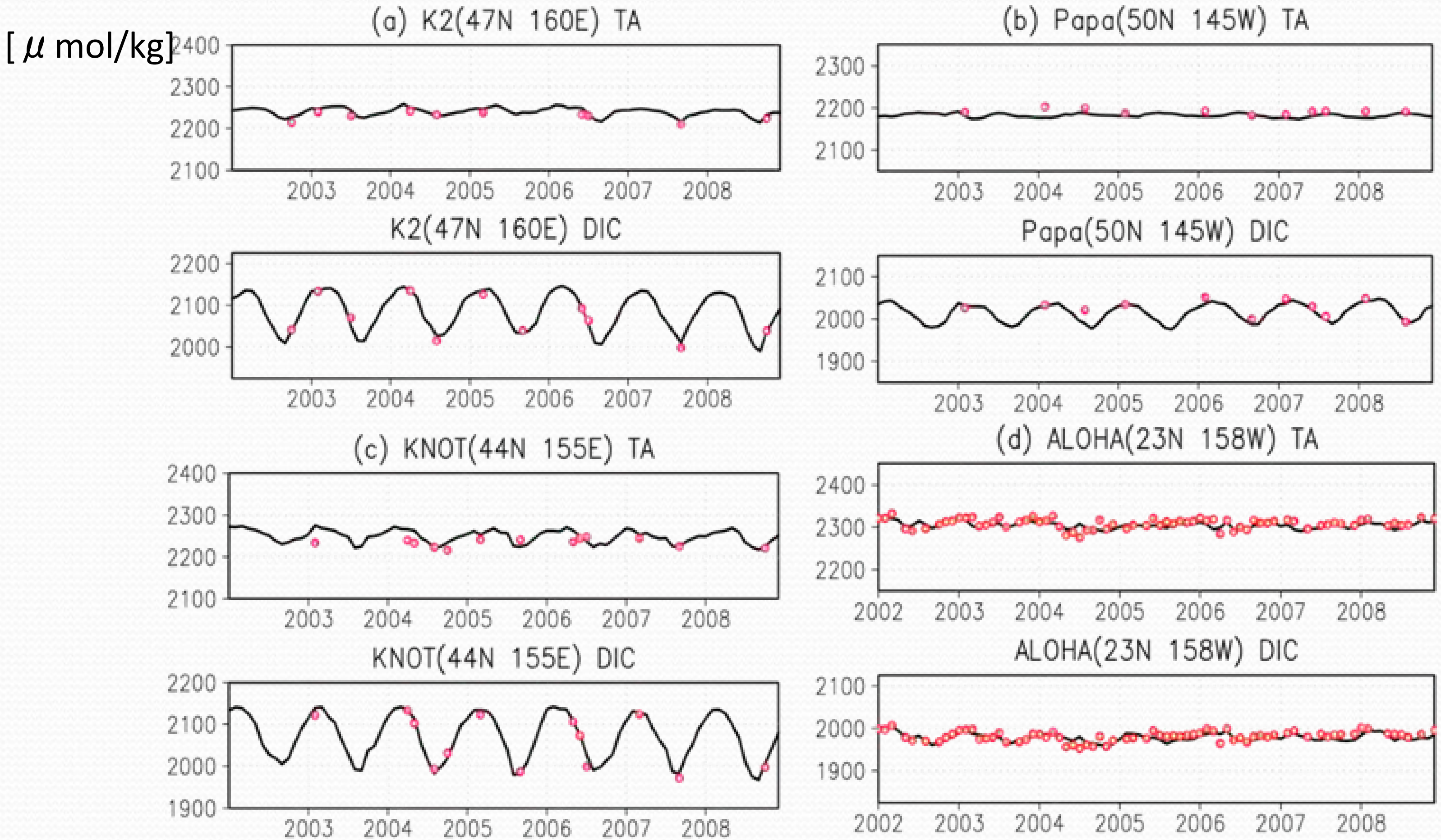
Comparison of estimated DIC at time series stations

Estimation of DIC, CO2SYS for MatLab (van Heuven et al. 2009)

pCO_2, TA, SST, SSS, PO_4, Si → DIC

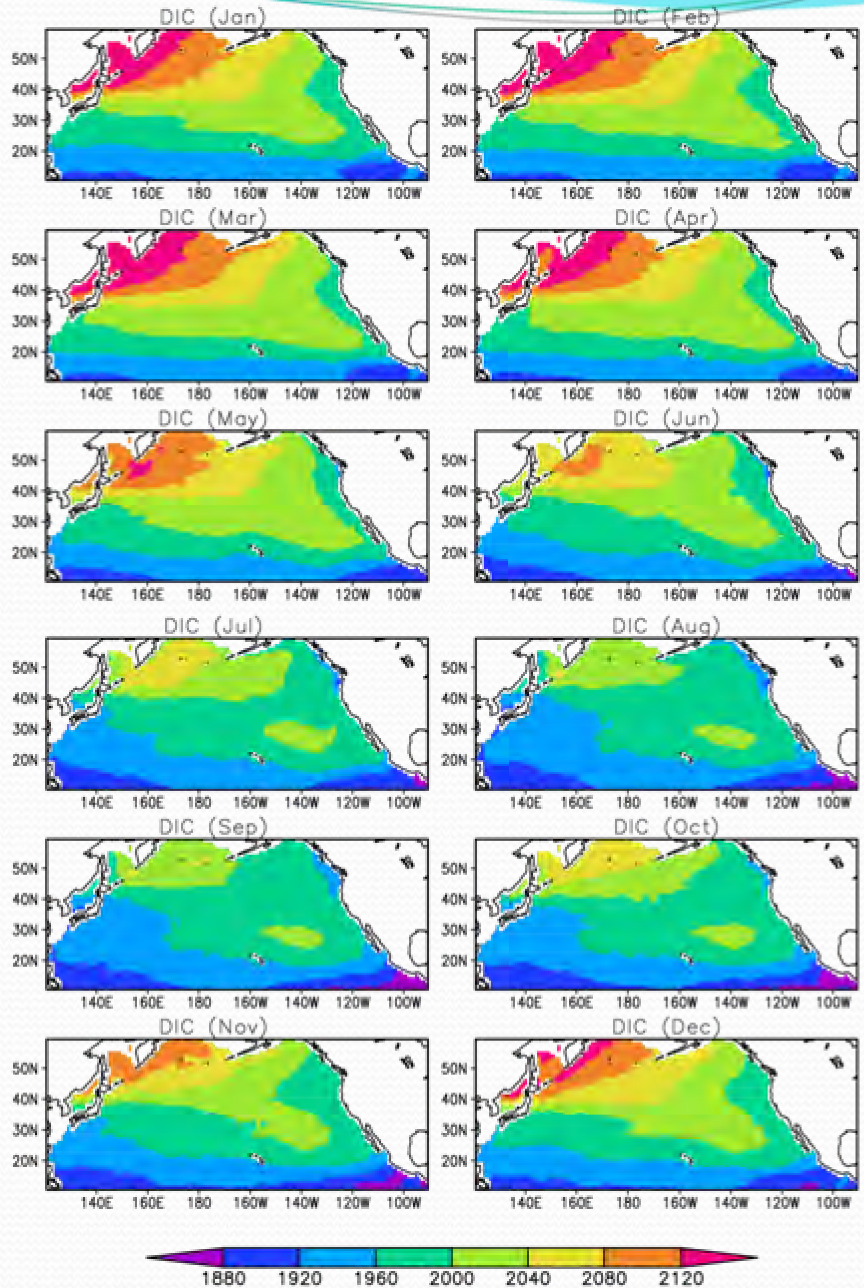
RMSEs of DIC for time series stations were 10.2 μmol/kg.





Monthly sea surface DIC averaged for 2002-2008

North-south and east-west difference in sea surface DIC distribution was well re-produced.



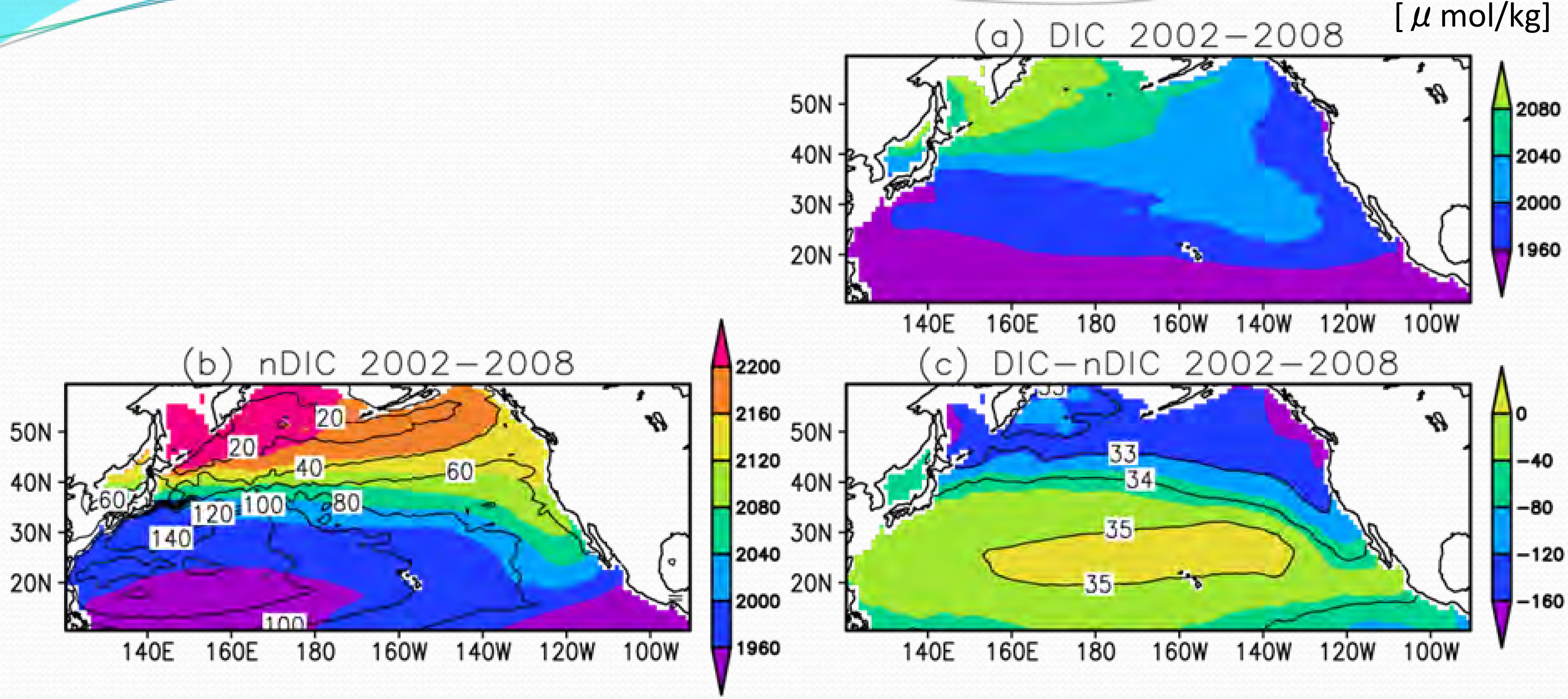
winter

spring

summer

autumn

7-year climatology of annual surface DIC distribution

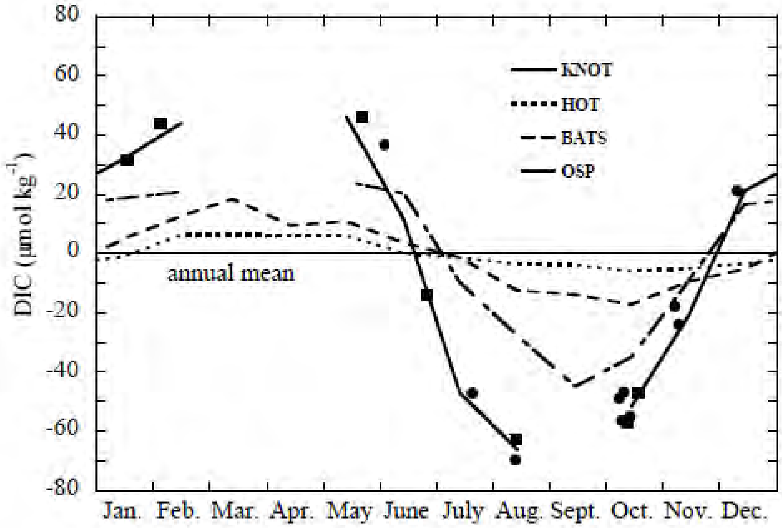


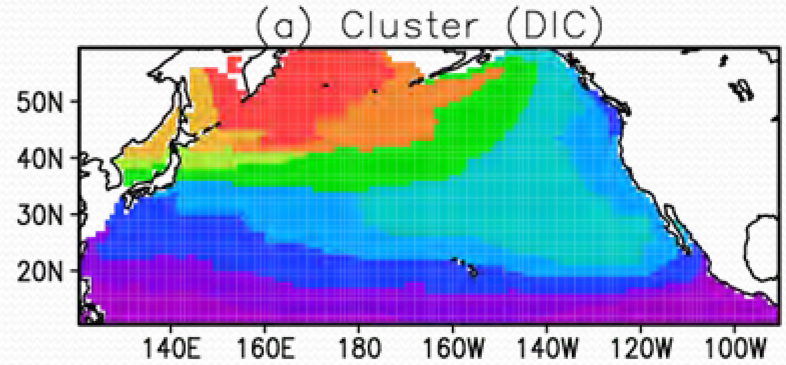
n-DIC (salinity normalized DIC) corresponds SSH (sea surface height) contour. →

Relationship with ocean circulation

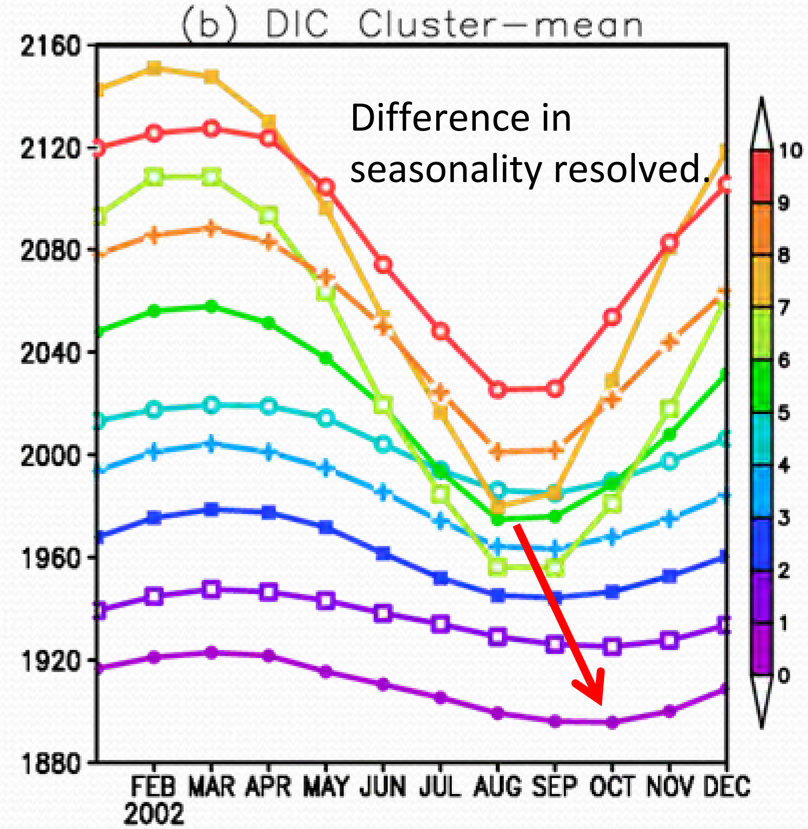
Contour: salinity distribution
Salinity is one of major controlling parameter for DIC.
Difference of DIC and n-DIC is the salinity component of DIC.

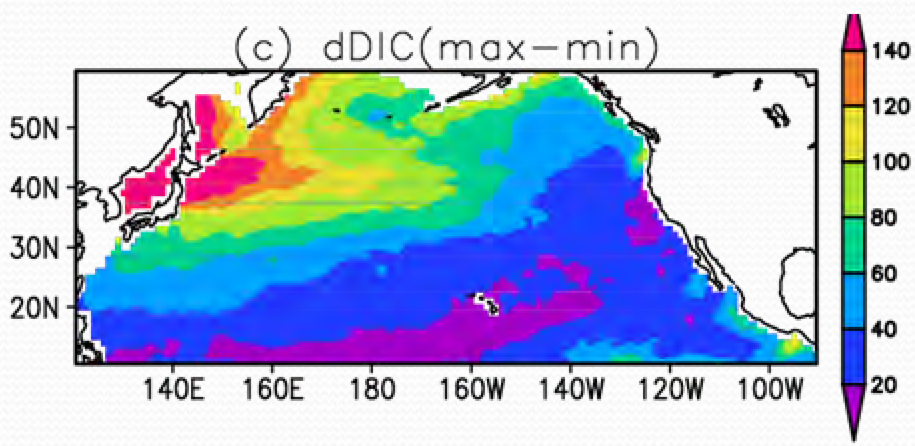
Areal difference in annual amplitude of surface DIC



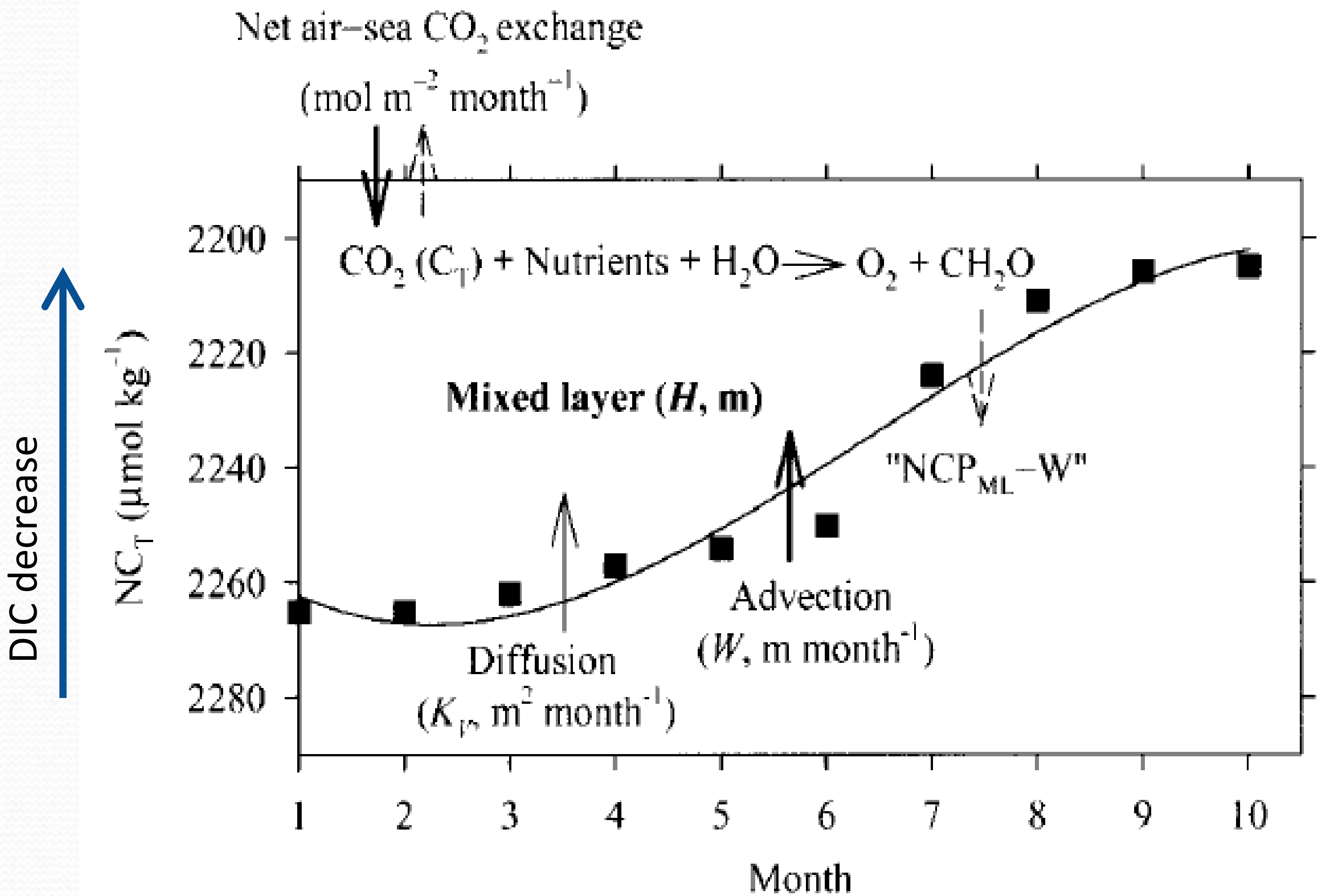


100-150 μmol/kg of DIC amplitude was deduced in North-West Pacific region. It well agrees with observation.





Mixed layer integration of ΔDIC in warming months to deduce NCP



Conceptual idea of upper thermocline integration of DIC change in warming months corrected with air-sea exchange, advection and diffusion to deduce net community productivity (NPP) proposed by Lee (2001).

Subtraction of salinity and flux components from upper thermocline ΔDIC in warming months

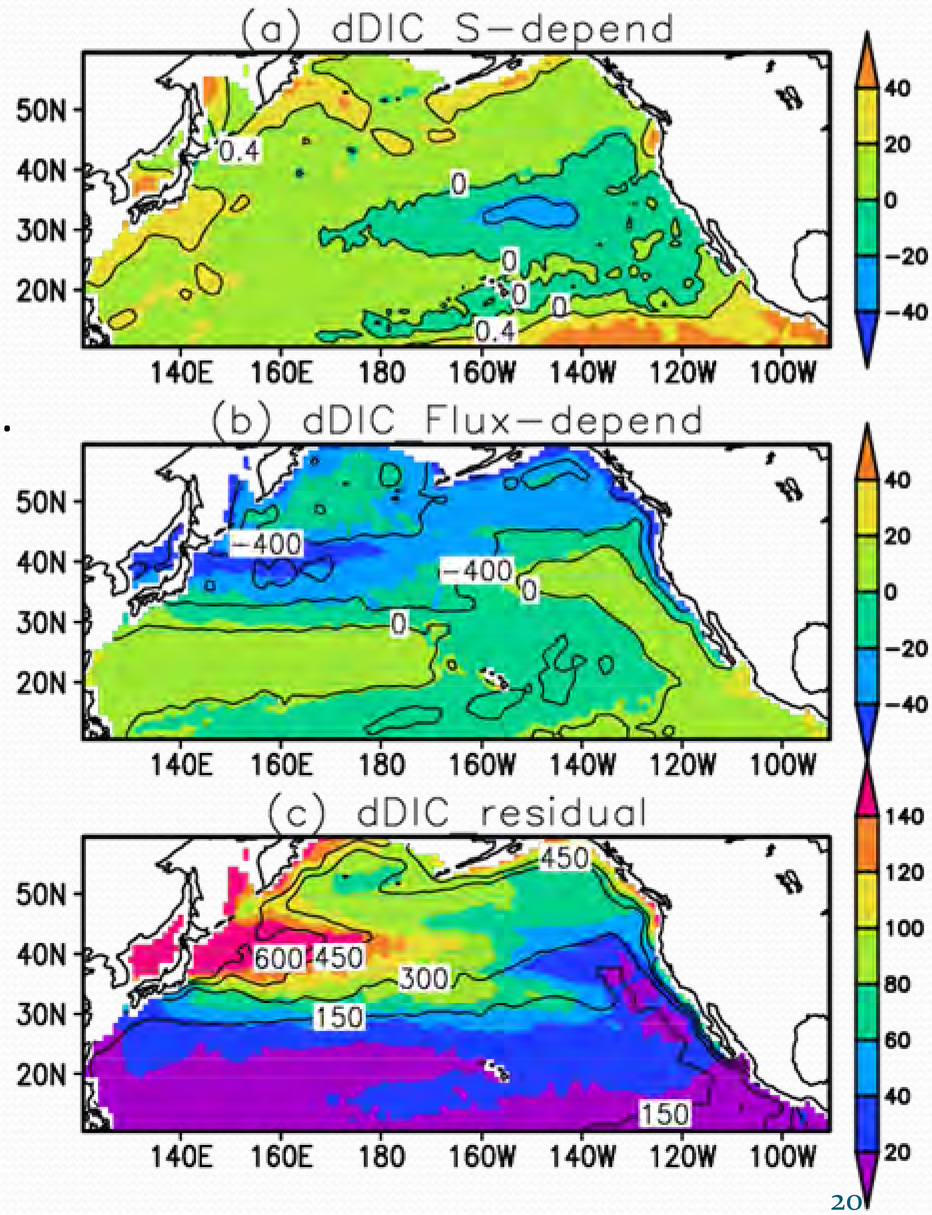
Advection component could be related with salinity component.

Salinity and flux (gas exchange) components of ΔDIC (max-min) should be subtracted to estimate the biological signal.

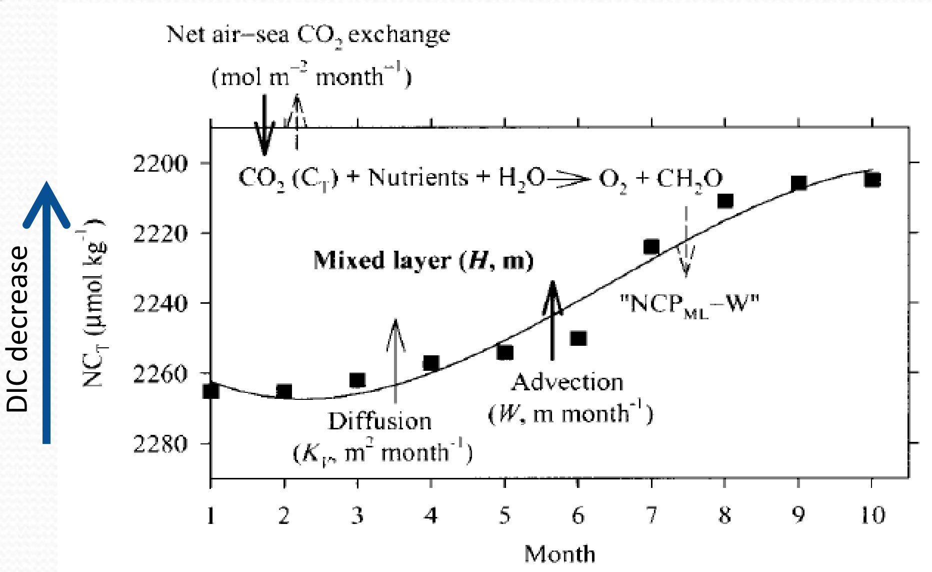
Residual ΔDIC can be compared with satellite PP.

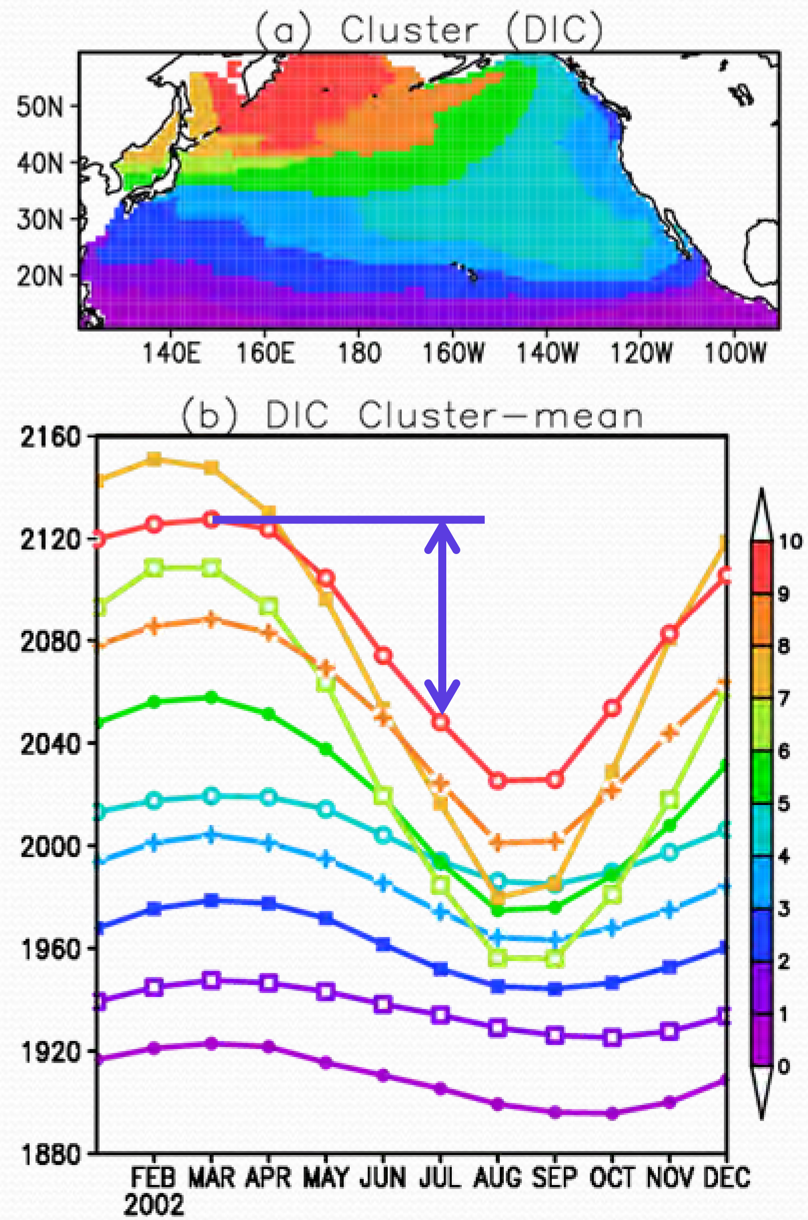
Contour is satellite derived productivity in warming months, converted to the unit in surface DIC change.

[μ mol/kg]



Estimating NPP from monthly ΔDIC for upper thermocline





Relatively accurate to integrate for months of developing stratification (4 months from March to July) neglecting diffusion effect.

Deduced NCP from monthly ΔDIC

NCP (t) =

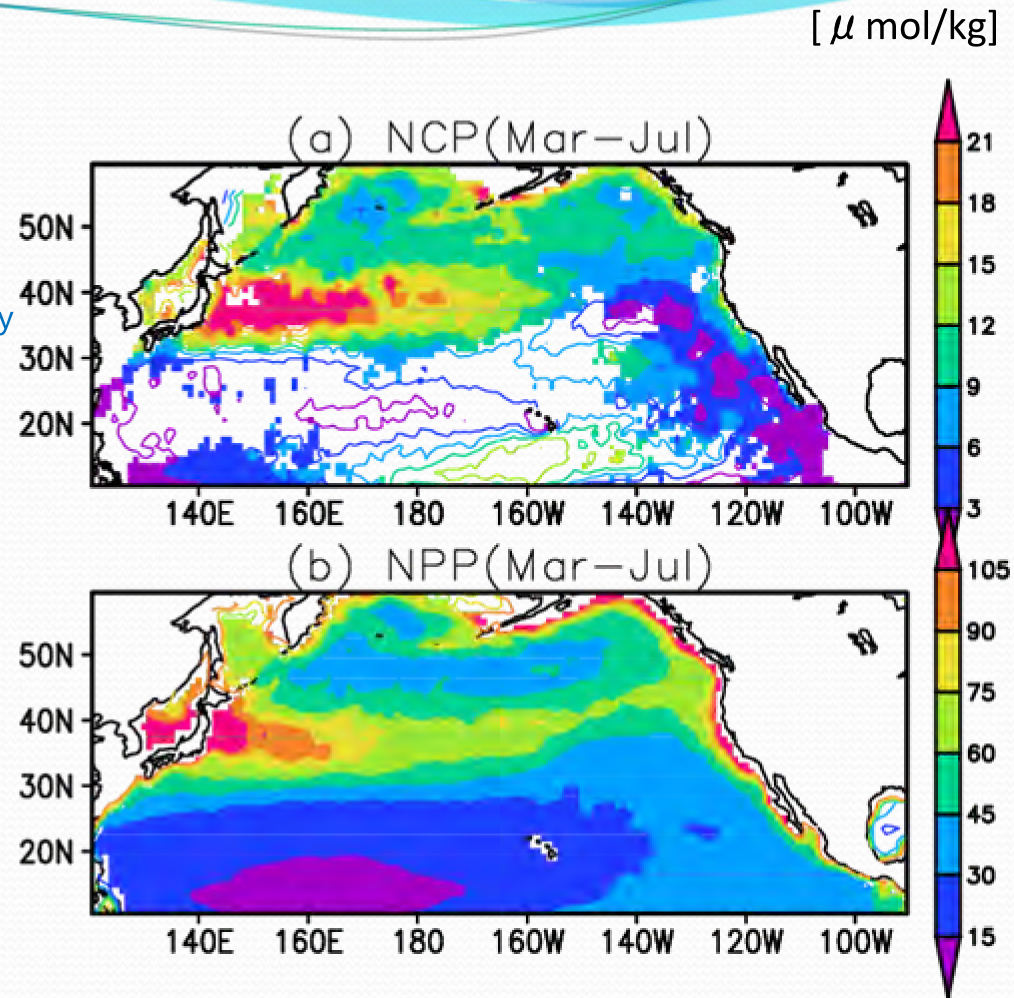
March – April – May – June - July

Area ･ MLD (t+1) ･ [nDIC (t) – nDIC (t+1)]
+ Area ･ pCO2_flux (t+1)

Upper thermocline integration of monthly DIC change. → Net Community Productivity estimation

"pCO_2-Alk-DIC mapping method"

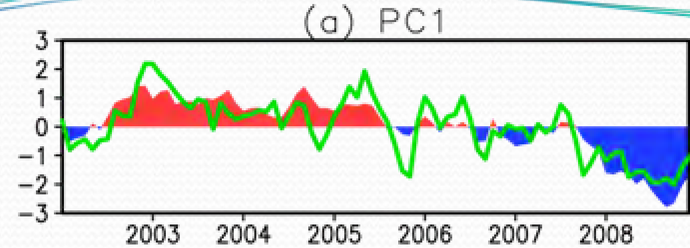
White area is less significant than colored area for the NCP estimation.



4 months integration of DIC change for NCP estimation by **mapping method** is well comparable with satellite NPP.

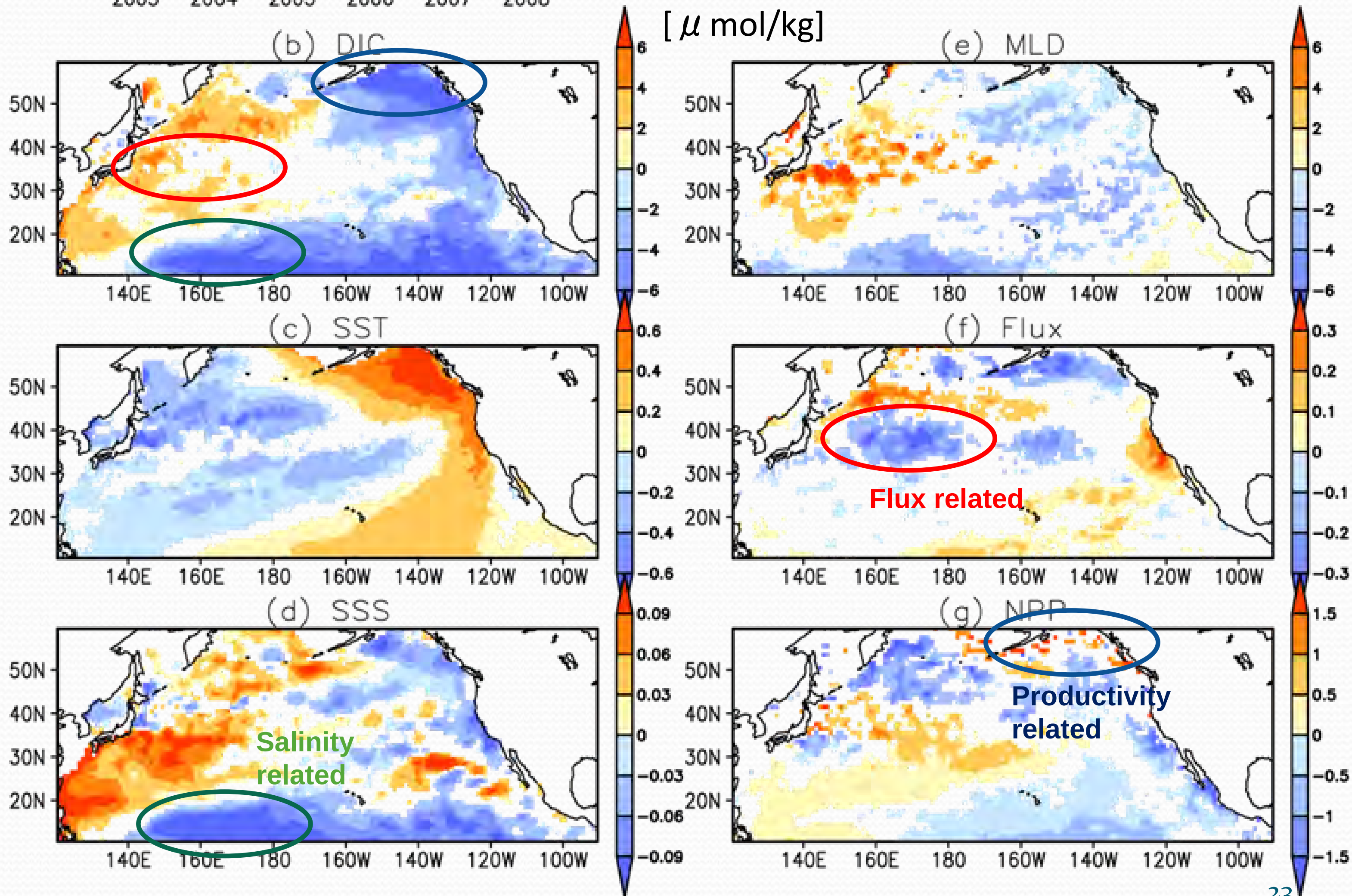
Ratio suggests distribution of *f*-ratio.

Inter-annual variation of surface DIC and parameters



Inter-annual variation of surface DIC mapping showed strong correlation with PDO (Pacific Decadal Oscillation).

Statistic shows various relationships of DIC anomaly with ocean parameters.



Summary and Conclusions for surface DIC mapping

1. Estimation of DIC distribution with high spatial resolution can be done using result of Neural Network pCO_2 mapping. Root mean square error (RMSE) to time series stations were 10.2 μmol/kg.

2. Reasonable adjustment of salinity component and flux influence to deduce NCP (Net Community Productivity) from upper thermocline integration of DIC change.

3. Signal of inter-annual variability related to PDO has been observed over the North Pacific (2002-2008).

4. Future expansion can be done without surface DIC measurement dataset (rare) but needs global pCO_2 dataset. Hopefully we will have the improved pCO_2 data set from next version of SOCAT.

NIES GHG Monitoring Network by 3D Observation

Acknowledgement:
NIES GHG observation, especially by volunteer ships and aircrafts, are supported by many people of commercial companies, port and airport authorities and technical staff.

Aircraft Routes

Ship Routes

Observation Sites