Promotion of International Database of Ocean Surface pCO_2 and Use for Basin Scale Estimation of Ocean CO_2 Sink and Sources (Abstract of the Final Report)

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1. Introduction

The global ocean is the largest natural CO_2 sink. There exists disequilibrium between ocean and atmosphere with lower pCO_2 of ocean surface than that of atmosphere. It is the driving force of the oceanic sink of atmospheric CO_2 and it accounts about 2.4 Gt C/year of natural sequestration of atmospheric CO_2. The understandings of the temporal and spatial change of the oceanic sink and source of CO_2 are important for model estimation of the future natural sink of CO_2, which could be significant for the necessary mitigation to ensure the safe stabilization level of atmospheric CO_2.

As the oceanic pCO_2 can only be measured by at sea observation by ship or buoys, global observation has been maintained by the international collaboration and Japanese institutions have been continuing important roles in the North and West Pacific regions. NIES (National Institute for Environmental Studies) is operating North Pacific oceanic pCO_2 observation by volunteer observation ships (VOSs) since 1995 as a part of global environmental monitoring project.

In 2007, an international database project was proposed by UNESCO/IOCCP (International Ocean Carbon Coordination Project) as SOCAT (Surface Ocean Carbon Atlas). It is the approach for effective global integration of ocean surface pCO_2 dataset and distribution to international scientists for analysis and modeling the ocean carbon cycles. The data centers have been established, settling core offices in Bergen University, Norway, and NOAA/PMEL (National Oceanic and Atmospheric Administration/Pacific Marine Environmental Laboratory), USA. On September 2011, the first version of SOCAT database was opened for public. The 2nd version of SOCAT has also been successfully opened for public in Sept. 2013. The current status of SOCAT is in the preparation phase of its 3rd version. NIES is taking important role in the data submission curator of the North Pacific region and has responsibility in the quality control and assurance of the data. This research program is contributing the NIES activity as a North Pacific hub in SOCAT program.

2. Research Objective

NIES ocean pCO_2 observation is one of major data contributors of SOCAT project.

This research program has been planned for supporting the NIES VOS observation of surface pCO_2 in the Pacific. It supports establishment of accurate calculation of ocean pCO_2 using CO_2 measurement and various auxiliary measurements for necessary quality control, like temperature, salinity, pressure and so on. It promotes a timely data submission of NIES pCO_2 observational dataset to SOCAT and also supports other Japanese institutes to submit pCO_2 data set, as a Pacific hub institute for SOCAT project.

The ocean surface CO_2 sink and sources are important components of ocean carbon cycle including physical and biological processes. This program also contributes data analysis using NIES dataset and also SOCAT database to estimate temporal and spatial variability of ocean surface pCO_2 in the Pacific using an up-to-date data analysis technique of neural network, which is suited for estimating non-linear relationship with ocean parameters and pCO_2. The application of neural network technique is to be expanded from North and Equatorial Pacific, where data coverage is enough, to South Pacific, where sparse observation has been done. For global estimation of ocean surface pCO_2, another scheme of neural network has also been tested. Mapping of dissolved inorganic carbon was established from the pCO_2 mapping as a direct indicator of biogeochemical cycling of CO_2 in the ocean surface.

3. Results and Discussion

(1) Pacific hub of international ocean pCO_2 database (SOCAT)

NIES has been continued the oceanic surface pCO_2 observation for North and West Pacific using VOSs servicing one between Japan and US since 1995 and one between Japan and Australia/New Zealand since 2006. The data treatment scheme has been improved by this research program with the recent improvements of on board auxiliary measurements for quality control of pCO_2 data. Installation of high precision temperature sensors to the water intake and equilibrators enabled to eliminate error from seawater temperature change during traveling in the pipe line and gave improvement of the pCO_2 data quality.

In NIES ocean pCO_2 data site (http://soop.jp), we uploaded photo of on board system and detailed specification of measurement items to give better understanding of the observation. In this year, we open the recent dataset by March 2014 observation to the web site. The data publication is quickest in institutes involving ocean surface CO_2 observation. The site includes data from atmospheric observation cargo ship in the South East Asian area.

The on board system of the north Pacific pCO_2 platform, M/S Pyxis, has already been very old and ship itself will stop operation in near future. We decided to change platform to other ship. The new ship is M/S New Century 2, operating between Japan and North America route. We finished the installation of ocean pCO_2 system by March 2014 and the observation will be resumed very soon.

SOCAT is activity to establish global ocean surface pCO2 database, uniformly quality controlled. Responsibility of quality control of each ocean area has been allocated to leading institute of regional observation. NIES has responsibility in the quality control in the North Pacific. During the period of this project, there were several events for SOCAT. In September 2011, 1st version of SOCAT had been public. By the end of 2011, dataset for 2nd version had requested to be submitted to the data management office. After the quality control, 2nd version had been public on June 2013. The data submission for 3rd version has been requested by the end of 2013. NIES submitted up-to-date data for each submission request. In 1st version of SOCAT, only North Pacific data had been

included from NIES observation, however, NIES added Oceania route data for 2nd and 3rd versions. For 3rd version, NIES submitted data by August 2013 (Figure 1). NIES is sharing data quality control in the North Pacific, north of 30 degree, including all dataset submitted by world institutes to SOCAT.

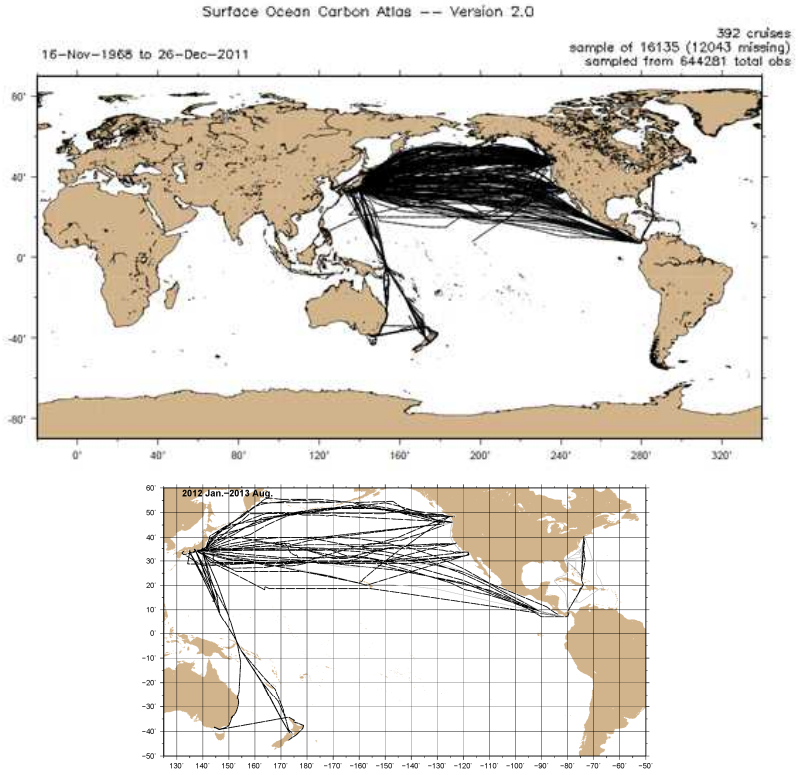

Figure 1. Cruise line map of pCO_2 data submitted from NIES in 2nd version of SOCAT (upper panel) and 3rd version of SOCAT (lower panel).

(2) Basin scale estimation of pCO_2 distribution with the neural network technique

It was found that Multiple Linear Regression (MLR) method, which is commonly applied for spatial interpolation of ocean surface pCO_2, is not necessarily suitable for basin-wide pCO_2 estimation, and suggested that recent artificial Neural Network (NN) technique, which is applicable for non-linear field such as pCO_2 variability, could be successful way to do it. We tried to evaluate temporal and spatial variability of pCO_2 using Self Organizing Map (SOM) type of NN in the basin-scale North Pacific pCO_2 estimation in this study. Estimation of North Pacific area using NIES VOSs dataset was the first step and then it was expanded to Equatorial and South Pacific, using SOCAT dataset. Finally the estimation includes Pacific sector of Southern Ocean, giving whole Pacific data analysis of ocean surface pCO_2.

The NN estimation uses basin wide mapping data of sea surface temperature (SST), sea surface salinity (SSS), mixed layer depth (MLD) and sea surface chlorophyll-a concentration (CHL). These mapping data sets are available from satellite observation and/or objective analyses. Equation includes location information as polar coordinates. Surface pCO_2 has impact of anthropogenic increase of atmospheric CO_2 concentration and it is added as a linear increasing term. Mapping process of the NN uses equation as follows;

$$pCO_2 = f_{som}(x, y, z, SST, SSS, MLD, CHL) + \alpha*(t-t_{ref}) \quad (1)$$

where, x, y, z are cos(Lat)* cos(Lon), cos(Lat)*sin(Lon), sin(Lon), α is atmospheric increasing rate and t_{ref} is reference year of 2005. Estimation was made for January 1998 to December 2008.

In Figure 2, distribution of data for the NN estimation process from the 2nd version of SOCAT database is shown. The data density in the North Pacific, north of 15 degree N is enough dense, however, Western South Pacific is the area of few observation. This lack of data could be the major cause of pCO_2 estimation.

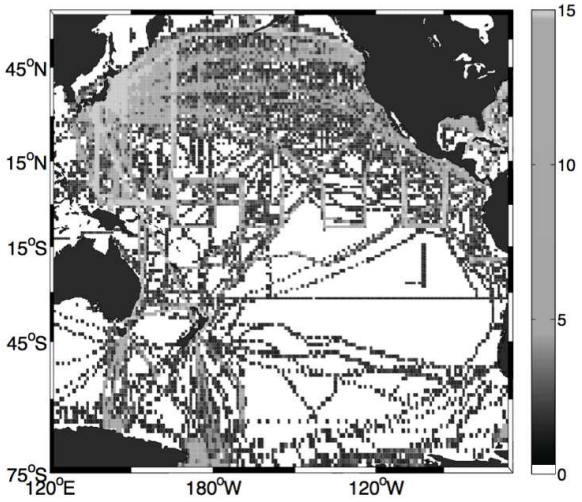

Figure 2. Distribution of data density for 1998-2008 (data number/month) used for neural network estimation of Pacific Ocean pCO_2 from the 2nd version of SOCAT.

The results (Figure 3) indicate general agreement with climatology given by Takahashi et al. (2009). In boreal winter, high pCO_2 is observed in the Northern North and low in mid latitude North Pacific of 20-40 degree N. In the eastern Equatorial Pacific has high pCO_2 more than 400 μatm.

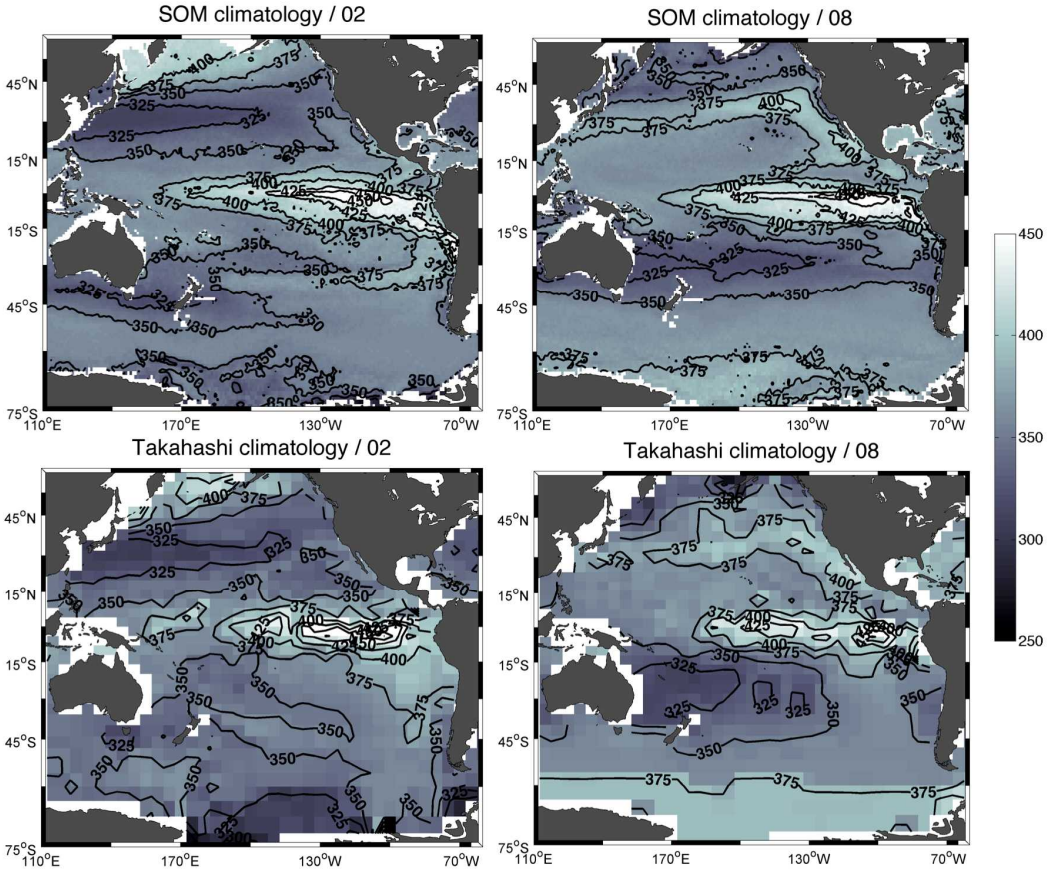

Figure 3. Estimated distribution of pCO_2 in the Pacific with Pacific sector of Southern Ocean, left panels: February, right panels: August, upper panels: results of this study as 1998-2008 climatology by neural network technique, lower panels: published climatology by Takahashi et al. (2009).

These are well recognized phenomenon by shipboard observation. Western South Pacific of 15-45 degree S has lower pCO_2 less than 350 μatm, however less observational data exists. The calculated difference of the two climatological maps is about 0.6 μatm. It has very small impact for the CO_2 flux calculation, however, the NN estimate has advantage in the information of inter-annual variation and also in high spatial resolution.

We investigated another NN scheme to expand the technique for global estimation of pCO_2. Back-Propagation method is the candidate of applicable NN technique to ocean pCO_2 estimation with global coverage, because of the less needs of computational power. As first trial, it was applied for estimating global ocean pCO_2 climatology. The results showed good agreement with the SOM estimated pCO_2 in the whole Pacific Ocean, shown above. The Back-Propagation method application including inter-annual variation is the next necessary step.

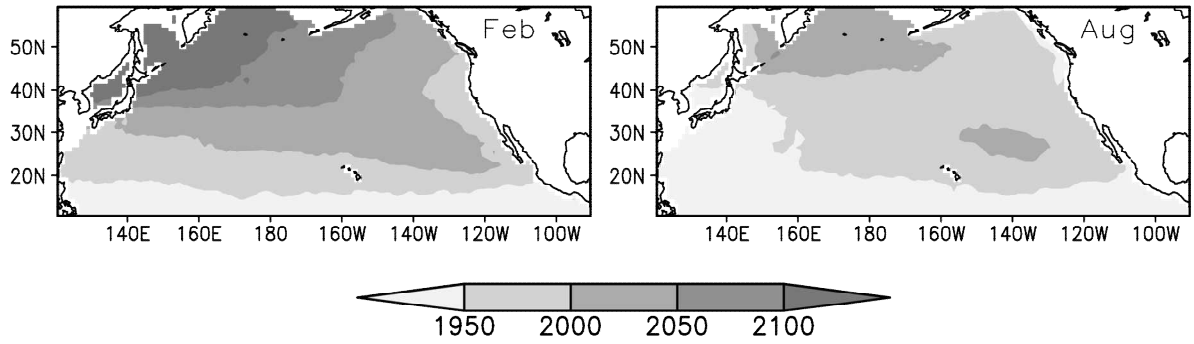

Figure 4. Estimation of dissolved inorganic carbon concentration (μmol kg^{-1}) in the surface water of North Pacific from pCO_2 map and empirical formula for surface water alkalinity, left panel: February, right panel: August.

Using the pCO_2 maps, mapping of DIC (dissolved inorganic carbon) in surface seawater was successfully done. DIC is a CO_2 parameter more directly interacts to biological uptake of carbon in the surface ocean than pCO_2. The summer month's DIC decrease in the surface water column is useful for estimating the net community productivity. Estimation of summer draw down of DIC indicates distribution of biological productivity in the North Pacific, which has good similarity with that estimated from ocean color satellite. The mapping scheme is very new and unique results suggesting the difference of these productivities or f-ratio in the surface water with high spatial resolution.

4. Conclusion

Owing to the activity of this program, ocean surface pCO_2 data from NIES VOS observation achieved very prompt manner in the release of the data set from web page. NIES contributed SOCAT activity for the 1st to 3rd versions in the quality control of submitted data set for North Pacific. Mapping of pCO_2 using NN technique was applied for whole area in the Pacific and global application is in trial. The DIC mapping using the NN results well demonstrated the distribution of biological productivity in the North Pacific, having relationship with the CO_2 uptake of the ocean.

Reference

1) T.Takahashi et al., Climatological mean and decadal change in surface ocean pCO_2, and net sea–air CO_2 flux over the global oceans, Deep Sea Res. II, 56, 554-577, 2009.