Promotion of Circulation and Use of Ocean Surface pCO_2 Data Set and Variability Analysis for Pacific Region (Abstract of the Final Report)

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1. Introduction

The global ocean is the largest natural CO_2 sink. Because the size is so huge, the time constant required for the equilibrium of the entire depth of the ocean about atmospheric and oceanic CO_2 is much longer than the history of the anthropogenic emission of fossil fuel by human beings. There exists disequilibrium between ocean and atmosphere with lower pCO_2 of ocean surface than the atmosphere. It is the driving force of the ocean about atmospheric CO_2 and it accounts about 2 Gt C/year of natural sequestration. The understandings of the temporal and spatial change of the oceanic sink and source 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.

The present oceanic sink and source of CO_2 can be estimated from the results of ocean surface pCO_2 observations, however, the observation coverage is not enough in terms of coverage for all oceans and for all seasons. Ocean pCO_2 can only be measured by in situ observation which uses research vessels or ships-of-opportunity with installing pCO_2 instruments on board. Recently, autonomous buoy observation has been challenged, however, it is not easily operated. These are why ocean pCO_2 data set can not have enough coverage against the global coverage of satellite based observations like sea surface temperature or chlorophyll-a.

The oceanic parameter has been observed by global network of developed countries for oceanic observation and Japan is giving important role for the global coverage, especially for Pacific. Japan should continue ocean surface pCO_2 observation for North and West Pacific regions and JMA (Japan Meteorological Agency) and NIES (National Institute for Environmental Studies) are keeping routine observations of the region for long years. The data treatment and distribution are necessary follow up activity of the observation for effective use of the data set by the global ocean scientists.

The global data integration was done by collaboration by the ocean CO_2 scientists and 'Takahashi map[1)]' is the famous contribution as the product of the data synthesis. Now the global data integration activity is concerned by the International Ocean Carbon Coordination Project (IOCCP) established by UNESCO/IOC (Intergovernmental

Oceanographic Commission) and ICSU/SCOR (Scientific Committee on Ocean Research). A new global frame work has been started to build ocean surface pCO_2 database compiling the available global data sets, which was named as SOCAT (Surface Ocean Carbon Atlas Project). This research program has been contributing to the new frame work.

2. Research Objective

The program collaborate the international ocean surface CO_2 data integration activity with the promotion of circulation and use of NIES ocean pCO_2 data set aiming the variability analysis of the Pacific oceanic pCO_2.

(1) Operational processing of NIES pCO_2 data set by the improved quick procedure, updating NIES ocean pCO_2 data set home page and submission to the pCO_2 global databases.

(2) Novel analysis of North Pacific pCO_2 distribution with high temporal and spatial resolution with a Neural Network technique.

3. Results and Discussion

(1) pCO_2 system inter-comparison

This activity was done related to the first research target for supporting global data integration of oceanic pCO_2. For dissolved inorganic carbon and alkalinity, bottled CRM (certified reference material) is very useful for comparison of inter-laboratory difference of the scale. However, ocean surface pCO_2 system uses running water, therefore, it can not be used the bottled water for a standard. Only way is to gather the pCO_2 systems in a same place and supply identical seawater and measure simultaneously. We call it as inter-comparison or inter-calibration. The 2003 inter-comparison was held in Japan using a huge indoor seawater pool of National Research Institute of Fishery Engineering and was very successful because of the stable pCO_2 of the pool with small temperature fluctuation.

The 2009 inter-comparison was again used the pool facility and 14 pCO_2 systems was gathered from the active institutions for pCO_2 measurement. 7 of the 14 were the buoy system, many of which were developed after the 2003 inter-comparison. The NIES underway systems were reliably operated and could be used for reference system. The NOAA (National Oceanic and Atmospheric Administration, US) underway system and similar system of NIO (National Institute for Oceanography, India) gave good agreement with the reference system and the agreement was better than 0.7 ppm. NIWA (National Institute for Water and Atmosphere, New Zealand) underway system also recorded good agreement. We can say the well trained institutes for underway pCO_2 already achieved the 1 ppm accuracy target, which is a great improvement from the 2003 inter-comparison. Buoy systems with NDIR (non dispersive infra-red photometer) sensors including NOAA and NIES systems showed a good accuracy approximately with 1 ppm, however, colorimetric systems showed much larger biases. For long term autonomous operation with a limited battery power supply, colorimetric buoy has an advantage than NDIR and it needs much more improvement of the operational accuracy.

(2) Processing of NIES pCO_2 data set and submission to the global databases

NIES has been continued the oceanic surface pCO_2 observation for North Pacific using 3 VOSs (volunteer observation ship) servicing between Japan and US/Canada from 1995 and started West Pacific observation by a ship servicing between Japan and Australia/New Zealand from 2006. The data treatment scheme has been improved by this research program and it was finished including recent cruise data. The data set has been submitted to CDIAC (Carbon Dioxide Information Analysis Center), which is existing database for all aspects of ocean carbon studies.

The SOCAT data base is the new mechanism to produce quality controlled ocean surface pCO_2 data set with proposed protocol by the data management office. We carefully followed the protocol and processed the quality check and quality assurance. We have organized the regional meeting of SOCAT mainly for Pacific regional activity in March, 2009 and February, 2010. The most laborious work was flagging of data set and we have been assigned as the responsible institute for North Pacific data quality control. We handled with all of submitted data sets for North Pacific and checked carefully according to the protocol of SOCAT. The SOCAT data base is now completed and has been opened for data contributors and will be opened to public in very near future.

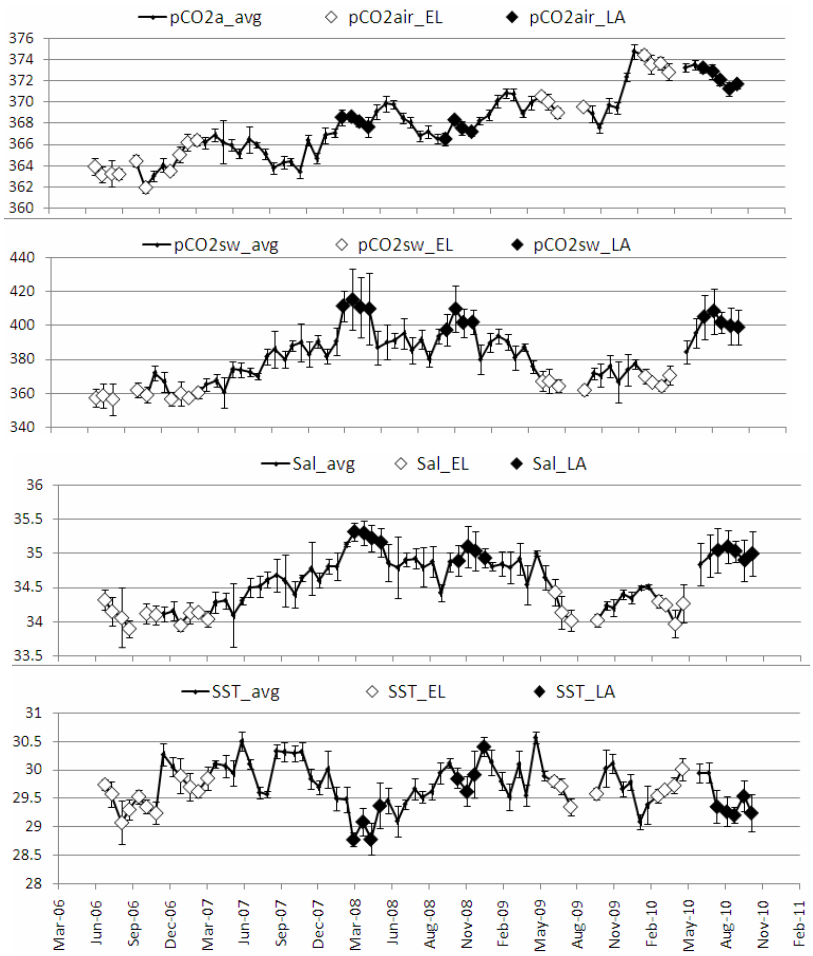

Figure 1 Observed results for Western Equatorial Pacific of 150ºE by M/V Trans Future 5 since 2006, atmospheric pCO_2 in µatm (upper panel), oceanic pCO_2 in µatm (second panel), sea surface salinity in psu (third panel) and sea surface temperature in degree C (bottom panel), black and open triangle indicates periods with larger of lower ΔpCO_2 plus or minus one standard deviation, respectively.

According to the processing of NIES pCO_2 observation data set, it was found the feature of pCO_2 change in the West Pacific region using data record more than four years of M/V Transfuture 5 from 2006. The annually averaged ΔpCO_2 (ocean minus atmosphere) for the observed area in the Western Pacific showed a clear spatial distribution of oceanic CO_2 sinks and sources. As the results of time series analysis, a clear feature of pCO_2 change in Western Equatorial Pacific revealed the relationship with ENSO, which has some similarity and dissimilarity with the well known phenomena in Eastern Equatorial Pacific. In Figure 1, time series of atmospheric pCO_2, oceanic pCO_2, sea surface salinity (SSS) and sea surface temperature (SST) are shown for equatorial region of 150ºE. To distinguish the time series change, marks were categorized for the period when oceanic ΔpCO_2 is larger than average plus one standard deviation and for the period when lower than minus one standard deviation. The black diamond shows data in plus period and open diamond data in minus period. It is clearly shown the close relationship with SSS and oceanic pCO_2 but less with SST. The relationship is the unique feature of Western Equatorial Pacific possibly affected with the seawater coming from central or

Eastern Equatorial Pacific. It is suggested the NO_2+NO_3 nitrogen with increasing the stronger La Nina phase but showing low concentrations in the weak La Nina and in El Nino phases. The amplitude of oceanic pCO_2 change in Western Equatorial Pacific in between La Nina and El Nino phases will be significant to contribute to the variability of atmospheric CO_2 concentration.

(3) North Pacific 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. The NN reflects the method's conceptual connection to the functionality of the human brain and this technique was effective for pCO_2 estimation in the North Atlantic. Therefore, 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. North Pacific is one of the oceans where pCO_2 measurement has been extensively done like North Atlantic so as to achieve enough learning for pCO_2 estimation in NN.

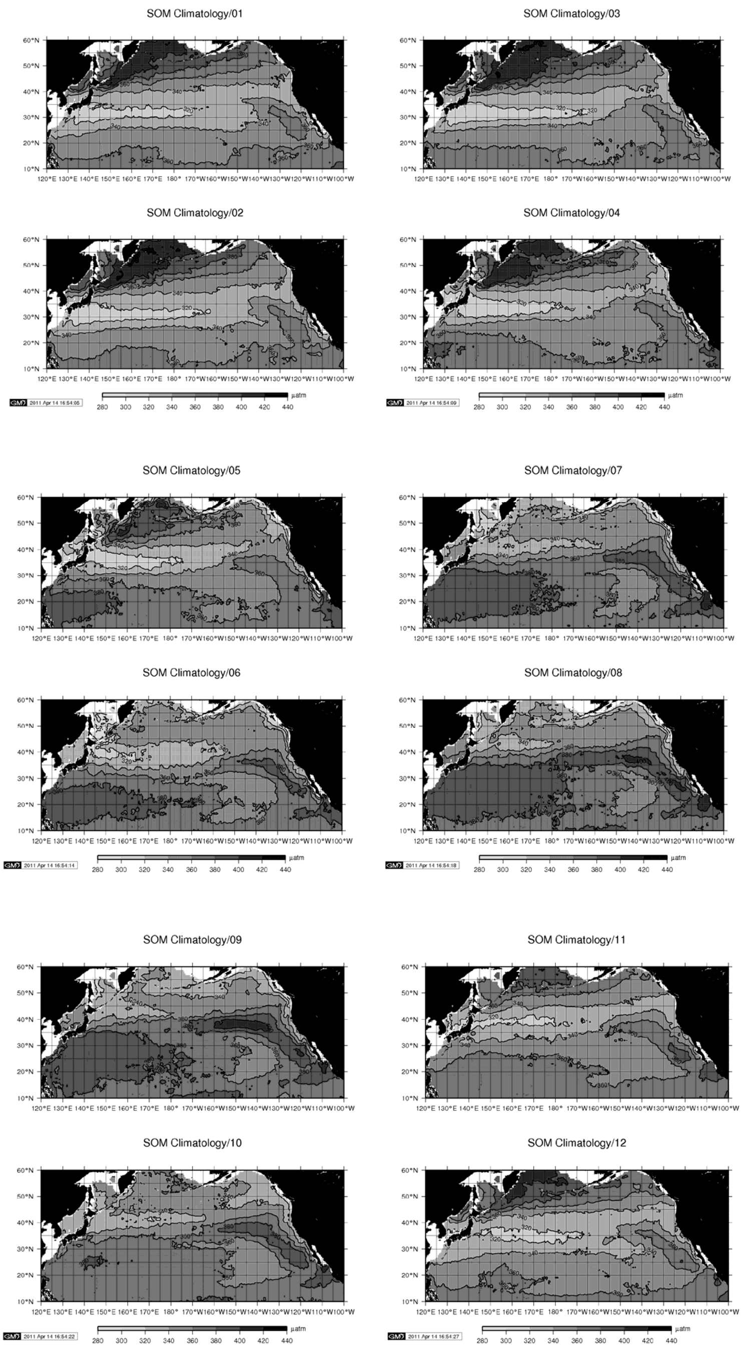

Figure 2 Climatological distribution of ocean surface pCO_2 for 2002-2008 estimated by the Neural Network technique.

The used training data set for the NN consists of 4 subsets, Sea Surface Temperature (SST), mixed layer depth (MLD), amount of phytoplankton pigments like chlorophyll a (CHL) and Sea Surface Salinity (SSS). Basin-wide SST data are analyzed by and obtained from the Office of Marine Prediction of the JMA. Merged satellite and in-situ data refer to as Global Daily Sea Surface Temperature (MGDSST) are analyzed at the Office of Marine Prediction of the JMA with 1/4 degree grid resolution and daily frequency on the near-real-time basis. The one of the Basin-wide MLD estimates is obtained from the Forecasting Ocean Assimilation Model (FOAM, Meteorological Office, Exeter, UK; http://www.nerc-essc.ac.uk/godiva) at daily frequency and 1° latitude by 1° longitude resolution. CHL data set comes from Level3 data product of SeaWifs mission from NASA. SSS datasets comes from JMA objective analysis of 0.5 degree resolution. All 4 products offer almost full basin-wide coverage for the North Pacific for the years 2002 to 2008. All parameters will be re-gridded onto a daily frequency and 0.25° latitude by 0.25° longitude resolution. The study area stretches from 10°N to 60°N and from 120°E to 90°W and is hereafter called the North Pacific. Therefore, the total amount of grids is 215,000,000.

The final products of this project used the above mentioned for ocean parameters but we started with other possible combination of ocean parameters and with longitude or Julian day as training data sets for simplicity in describing the east/west gradient of pCO_2 or time series change in the ocean basin. The reconstructed pCO_2 fields are shown in Figure 2 as the climatological mean distribution of each month for 2002-2008. The maps provide realistic distributions, such as high pCO_2 value over 400 μatm due to winter deep convection in high latitude by adopting MLD result. Biological draw down to give low pCO_2 less than 320 μatm in June distribution of off coast of Tohoku district and cooling effect decreasing pCO_2 in winter in Kuroshio extension zone are also provided. There are general agreement with climatology by Takahashi et al.[1], however there exist some dissimilarities.

The inter-annual variability in pCO_2 was analyzed with the estimated results from 2002 to 2008 especially for some ocean stations with repetitive research vessel occupations. In our NN estimation, there is general change of MLD up to 2005 and from 2006. In many regions in the North Pacific show increase of MLD from 2006 and it gives decrease of pCO_2 in sub-tropical stations but increase in the North Eastern Pacific. Unfortunately, the present NIES pCO_2 observation could not conclude whether the change is realistic, however, we hope we can confirm the results with SOCAT data base or some existing time series observation stations in the Pacific.

4. Conclusion

The data upload to global ocean surface pCO_2 databases from NIES cargo ship observation were accomplished for the new global pCO_2 database effort of SOCAT. The data analysis of the West Pacific cargo ship observation by a ship servicing from Japan to Oceania revealed the precise time series variations in Western Equatorial Pacific region, which suggested the relationship with ENSO variability. We produced the North Pacific pCO_2 distribution maps from 2002 to 2008 using the Neural Network technique and it was effective tool to estimate surface distribution of basin-wide oceanic pCO_2 field with high time and space resolutions.

Reference

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