Observations for Climate: Measurements of Surface pCO_2 on Ships

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The aim of this project is to quantify the regional sources and sinks of carbon dioxide in the ocean to help understand and predict climate trends, and provide the best available scientific information upon which international policies are based. NOAA investigators are collaborating with academic partners in the largest coordinated effort in the world in outfitting research and commercial vessels with automated systems which measure the carbon dioxide in surface waters and well as the overlying atmosphere in order to determine the direction and magnitude of the flux of CO_2 between the air-water interface. The project is a NOAA/CPO/COD funded partnership between 5 entities: AOML and its GOOS center, PMEL, LDEO, RSMAS and BIOS. It has close international interactions with similar efforts undertaken in Norway, Iceland, France, Germany, England, Australia, New Zealand and Japan. The tasks of each investigator range from data collection to data reduction and dissemination. There is currently an international effort (SOCAT) to gather all available surface pCO_2 data to which this project is the major contributor. The data has been used in an updated global air-sea CO_2 flux climatology, regional basin fluxes, sea surface CO_2 trend analyses, and new techniques to quantify fluxes such as self-organizing maps/neural networks.

The Underway pCO_2 System: A Community Effort

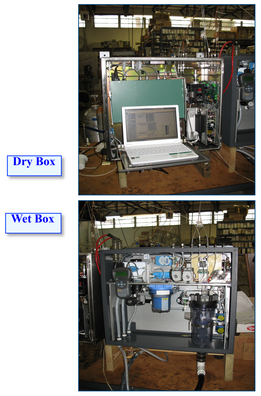

Figure 1. The underway pCO_2 system

There is a wide variety of pCO_2 measuring systems corresponding to a wide variety of purposes, each with their own advantages and shortcomings. This project's first challenge was to design an underway pCO_2 system able to meet the community's goal of being able to constrain the regional fluxes to 0.2 Pg C/year as recommended in Bender et al. (2002), which translates into measuring the atmospheric fCO_2 to within 0.1 µatm and the seawater fCO_2 to within 2 µatm (Bender et al., 2002). This work was done in coordination with the International Ocean Carbon Coordination Project (IOCCP) (www.ioccp.org) with the goal to meet the key climate monitoring principles of robust and uniform instrumentation which produces measurements that are traceable to standards .

The design and mode of operation of the system were decided upon by a large group of pCO_2 experts during a workshop held at the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami, Florida in 2002. The workshop was motivated by the need of the community to agree on requirements for autonomous systems in order to produce high quality and comparable data sets.

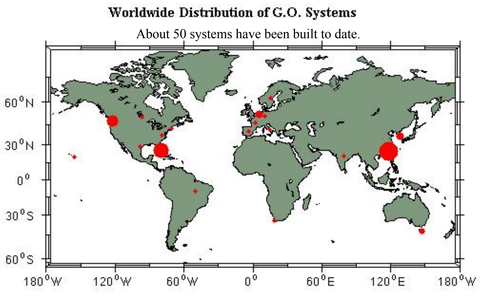

Figure 2. Worldwide distribution of our underway pCO_2 system

The system is designed to operate fully unattended with only routine maintenance in port. It was decided that the new system would be patterned after systems combining air–water equilibrators with an infrared analyzer for detection, which have been in use for over 40 years (Figure 1). Fifty units have been sold to date worldwide (Figure 2)

The project currently has 17 ships outfitted with an autonomous pCO_2 system (Figure 3). The type of ship involved in the operation range from research to merchant vessel and cruise liners. The nature of the shipping business is such that vessels are constantly taken out and being replaced, making this endeavor very costly and time consuming every time a system has to be moved and re-installed on another ship.

Each group in the project work in a different basin with PMEL mostly doing measurements in the Pacific, LDEO at the high latitudes and AOML and BIOS sharing the North Atlantic. Some areas like the South Atlantic and South Pacific are still not well covered and are difficult to logistically.

Our data is usually made public within six months of being collected and is accessible via major data centers such as CDIAC (http://cdiac.esd.ornl.gov/oceans/index.html).

We are also working in close collaboration with other groups worldwide in an effort to promote reciprocal data exchange, logistics support and contribute to a worldwide dataset.

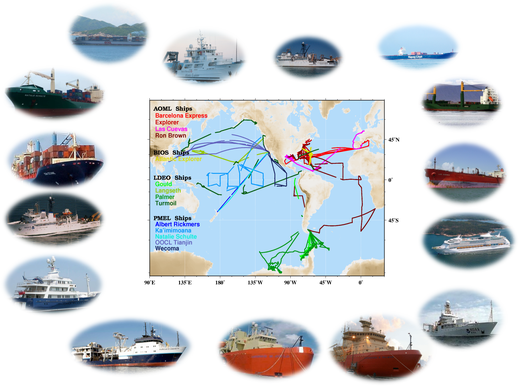

Figure 3. Tracks of the ships of opportunity having a pCO_2 system onboard in the year 2009.

Data Contribution

The data collected on board the ships of opportunity are used for a wide variety of research. The project is a major contributor to global surface pCO_2 dataset such as the one used in the Takahashi (2009) climatology (Figure 4).

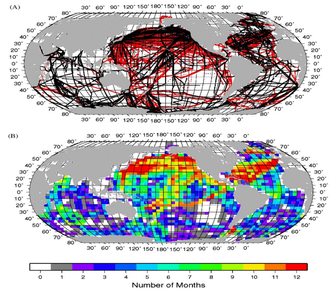

Figure 4. Maps of the pCO_2 measurements used in the Takahashi (2009) climatology (from Takahashi 2009)

The top map represents the sampling locations. The black dots indicate the measurements in the 0.94 M database used in Takahashi et al. (2002) and the red dots are new measurements added to the database (3.0 M). The bottom map represents the number of months in each 4º by 5º box area where at least one surface water pCO_2 measurement has been made since the early 1970s. White areas have no measurements.

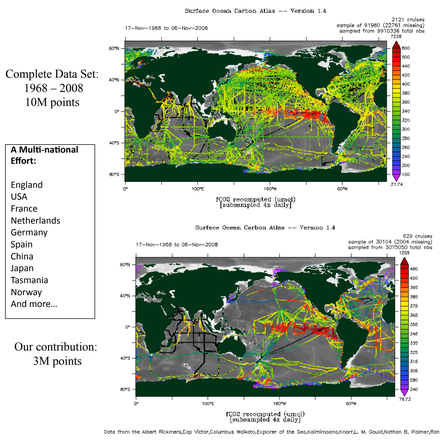

Figure 5. Map of all the surface pCO_2 measurements included in the SOCAT (version 1.4) database (top map) and those contributed by this project (bottom map)

All the data that has been obtained as part of this project are being contributed to the Surface Ocean CO_2 Atlas (SOCAT), which is a multi-national effort to produce a uniformly quality controlled dataset of surface pCO_2 measurements (http://www.socat.info). This publicly distributed compilation of about 8 million data points will be a major resource for scientific investigations and assessments. The data holding is more than twice as large as the currently used database maintained by Dr. Taro Takahashi and provides comprehensive assessments of data quality and procedures. This NOAA sponsored "pCO_2 on ships" effort is the single largest contributor to the *SOCAT* effort (Figure 5).

Data Products: Algorithms and Flux Maps

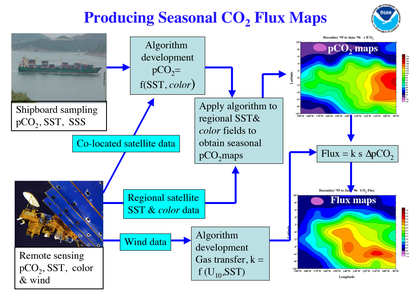

Figure 6. Diagram showing the steps for the production of flux maps

Our goal is to produce CO_2 flux maps by using our shipboard measurements of fCO_2, SST and SSS to develop algorithms that will enable us to use remotely sensed data to generate fCO_2 maps which, combined with wind data, will allow us to compute flux maps over the region (Figure 6).

We now have 3 vessels partially sailing through the Gulf of Mexico, a region which was greatly under-sampled until now. It is an important area for the coastal carbon budget of the contiguous United States.

We developed algorithms for the region with the following form:

$$\Delta fCO_2 = C + A*SST(ºC) + B*SSS(o/oo)$$

We use these algorithms to derive maps of the seasonal air-sea CO_2 flux in the region using remotely sensed SST, SSS and wind. Finally, we average our data set per month for the whole region, compute the net annual flux and compare it with the estimate by Takahashi et al. (2009), based on only two cruises and only summer data (Figure 7). Our results suggest the Gulf of Mexico is a weak sink for CO_2 with a net flux of -0.02 ± 0.03 mol C/m^2/year (or -0.38 Tg C/year) compared with Takahashi's estimate of a source of 0.21 mol C/m^2/year.

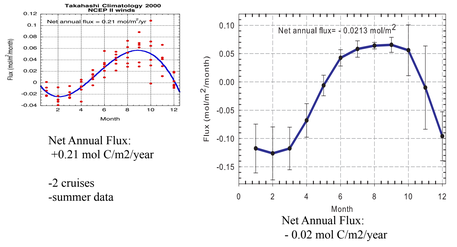

Figure 7. Comparison of seasonal fluxes for the Gulf of Mexico based on Takahashi (2009) data set (left graph) and our new data (right graph).

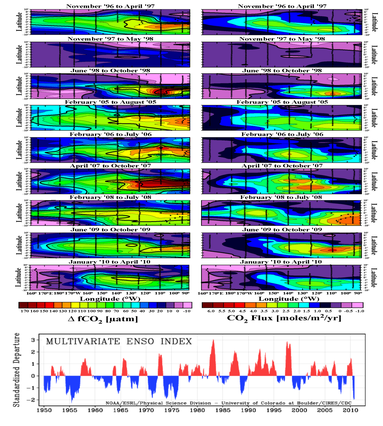

Figure 8. Time-Series of surface water fCO_2 levels in the tropical Pacific resulting from Ka'imimoana repeat observations from 1997 thru 2010. Recent ENSO Indices illustrate El Niño conditions in spring, 2010.

From 2007 to 2010, the Ka'imimoana collected fCO_2 data on about 20 cruises in the tropical Pacific. The results show weak seasonal and strong inter-annual variability of CO_2 fluxes from the oceans to the atmosphere. El Niño conditions persisted into early 2010, resulting in lower than usual ΔfCO_2 and CO_2 flux in the equatorial Pacific. Conditions returned to normal in May 2010, and La Niña conditions began in September 2010. Figure 8 is an update of Feely et al., 2006.

References

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- Feely et al., 2006, Decadal variability of the air-sea CO2 fluxes in the equatorial pacific ocean, J. Geophys. Res., 111(Co8S90), doi:10.1029/2005JC003129
- Takahashi et al., 2009, 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, v. 56, p. 554-557, doi:510.1016/j.dsr1012.2008.1012.1009.