Work Package 11

Optimisation of ocean observing capability

Deliverable D11.2

Evaluation of actual observational network

Lead beneficiary: UiB

Lead author: Siv K. Lauvset (siv.lauvset@uib.no)

Contributors: Siv K. Lauvset, Laurent Coppola, Ute Schuster, Melchor Gonzalez (UiB, CNRS, UNEXE, ULPGC)

Work Package leader: Ute Schuster (UNEXE, U.Schuster@exeter.ac.uk)

Due date: Project Month 36 (08-2016)

Dissemination level: PU
## Contents

EXECUTIVE SUMMARY .............................................................................................................. 3

1. INTRODUCTION .................................................................................................................. 3

   1.1. Background and objectives ......................................................................................... 3

   1.2. Organisation of this report ......................................................................................... 3

2. METHODOLOGY .................................................................................................................. 3

   2.1. Observational network of ocean interior carbon ....................................................... 3

   2.2. Observational network of sea surface ocean fCO₂ ..................................................... 4

3. RESULTS AND DISCUSSION ............................................................................................. 5

   3.1. Observational network of ocean interior carbon ....................................................... 5

   3.2. Observational network of sea surface ocean fCO₂ ..................................................... 8

4. CONCLUSIONS AND OUTLOOK ....................................................................................... 10

5. REFERENCES ...................................................................................................................... 10
EXECUTIVE SUMMARY

Ocean carbon estimates are often done using observations, both of interior ocean carbon for the study of the anthropogenic carbon uptake, transport, and storage, as well as of sea surface fCO$_2$ for the study of the sea-air fCO$_2$ flux. Whilst models can give basin-wide and even global estimates, observations reflect “the truth” at the time of sampling.

We have evaluated the current observational network of both interior ocean carbon and sea surface fCO$_2$, collected in GLODAP version 2 and SOCAT version 4, respectively, applying a number of different statistical techniques.

Results show that observations are lacking in the North Atlantic of (1) interior ocean carbon in the sub tropics, and (2) surface fCO$_2$ in the high latitudes. These regions require special attention when future observation network decisions are to be made.

Full statistical analysis will follow, studying more small-scale phenomena, compared to the larger scale work presented here.

1. INTRODUCTION

1.1. Background and objectives

The two major objectives of WP11 are to “research to establish the structure of minimum and an optimum Virtual Observing Networks (VONs) to fully describe the carbon fluxes and related biogeochemical cycles (Task11.1)”, and to “qualitatively evaluate the current network of FixO$^3$ platforms and the parameters measured against those of the VONs (Task11.2 and Task11.3)”. Task 11.2 is “the quantitative and qualitative evaluation of the current network”. For this task we have evaluated the ocean interior carbon chemistry observational network and the sea surface fCO$_2$ observational network, to identify key areas where this network needs improvement. We have particularly focused on addressing issues relating to how the observational network(s) change(s) in space and time.

1.2. Organisation of this report

We first present a brief methodology of the work so far. In the results section we present the evaluation of the current ocean carbon observational networks, for interior ocean carbon and for sea surface fCO$_2$.

2. METHODOLOGY

2.1. Observational network of ocean interior carbon

For the evaluation of the current interior ocean observational network in this report we have used a gap-filling method (DIVA; Troupin et al., 2012; Beckers et al., 2014) and the observational network represented in the GLODAPv2 (Lauvset et al., 2016; Olsen et al., 2016) to estimate the error related to data maps created with the current network of chemical oceanography data. A very accurate, while computationally efficient, error estimation in the DIVA software – the almost exact error estimation (Troupin et al., 2012) – was used.
For visualization, all figures in this section show the error relative to the average over the entire region shown in the maps: \[ \text{error} = \left( \frac{\text{error}}{\text{avg_error}} \right) \times 100. \] The absolute errors generally show the same patterns, but showing it relative to the average highlights the areas where the observational network is insufficient.

To avoid a distinct seasonal bias in the GLODAPv2 observations (Figure 1), only the 250 m surface is used in this section. Given the vertical profiles of nutrients and dissolved inorganic carbon (DIC) in the North Atlantic we can assume that this is below the layer influenced by seasonal biological effects. Since there are frequently very deep winter-time mixing events in the North Atlantic – in the Subpolar Gyre in particular - there is likely still an interannual bias at the 250 m, which is neglected for the purposes of this report.

For the evaluation of current surface ocean observational network, we have used a biogeochemical model of medium complexity that includes the marine carbon cycle (Medusa 2.0; Yool et al., 2013), and the observational data collected in the Surface Ocean CO$_2$ Atlas (SOCAT; Bakker et al., 2016).

We have used an Observational System Sampling Experiment (OSSE) utilising a Least Angle Regression (LARS), a modified and improved multi-linear regression statistical technique, to re-create sea surface fCO$_2$ fields: firstly we use the whole model output and “re-create” the surface fCO$_2$ fields, and compare this with the re-created fCO$_2$ fields after the model output was subsampled.
at the SOCAT observational locations and time. Input parameters for the LARS were sea surface parameters of temperature, salinity, chlorophyll \(a\), net heat flux, as well as mixed layer depth.

The comparison between the two re-created fields evaluates the current state of the observational network versus a theoretical complete observational network.

In order to make this evaluation of the network computationally possible, both the Medusa 2.0 output as well as all observations in SOCAT are gridded onto 1° latitude by 1° longitude by 1 month matrices. Each LARS was then performed using the whole global data set and a number of ocean divisions, shown in Figure 2.

![Global maps of the 12 different global ocean divisions used for this report.](image)

**Figure 2**: Global maps of the 12 different global ocean divisions used for this report. Five are published time-fixed global regions: Fay and McKinley (2014) long-term mean with 17 regions (2d FM1417), Gruber et al. (2009) with 28 regions (2d Gr0928), Longhurst (2007) with 54 regions (2d Lo0754), Peylin et al. (2013) with 3 regions (2d Pe1303), Peylin et al. (2013) with 6 regions (2d Pe1306), Schuster et al. (2013) with 12 regions (2d Sc1312), Watson et al. (2009) with 30° latitude bands in the different ocean basins (2d WN0911), Watson et al. (2009) with 10° latitude bands in the different ocean basins (2d Wn0940). Two are time-fixed simple band divisions: 10° latitude bands with 18 regions (2d bn1018) and 30° latitude bands with 6 regions (2d bn3006). Two are published time-varying global regions: Fay and McKinley (2014) with 17 regions (3d FM1417) and Landschützer et al. (2013) with 16 regions (3d La1316).

3. **RESULTS AND DISCUSSION**

3.1. **Observational network of ocean interior carbon**

The mapping error depends on the signal-to-noise ratio (SNR), with the error increasing as SNR decreases, and on the correlation length scale (CL), with the error decreasing as CL increases. Beyond that the mapping error depends on the data distribution. The effect of this is seen as relatively low error in locations where there are observations (shown as black dots in Figures 3 to 5) and high error in regions without any observations.
The period 2000-2013 (Figure 3b) overall has less observations, and poorer data distribution, than the period 1986-1999 (Figure 3a). This is also reflected in the errors, which are overall larger and with larger areas of very high error in the latter period. When using all available observations (Figure 3c) the errors are minimized as much as possible. There are, however, still areas with very few observations and thus high error. Areas that warrant more observations are between 30 °W / 10 to 40 °N.

Cross-sections at 30 °W and 40 °N are used below, to highlight at which depths further observations are necessary to minimize the mapping errors.

Figure 4 shows vertical sections for 30 °W. Below 1000 m all observations (1972-2013) have been used so the difference between Figure 4a (1986-1999) and Figure 4b (2000-2013) is in the top 1000 m only. In addition, for the top 1000 m a CL of 10 is used, below that a CL of 7 is used. This is the main reason that the error is smaller in the top 1000 m compared to the deeper ocean.

Notice how the error decreases in the top 1000 m when all available observations are used. There is still a need for more observations between 1000 m and3000 m from the equator northwards to approx. 40 °N along 30 °W.

Figure 5 shows a cross-section for 40 °N. The error estimates are the same so like Figure 4, the differences between Figure 5a (1986-1999) and Figure 5b (2000-2013) are in the top 1000 m only, and the main reason for the smaller error in the top 1000 m is that the CL is smaller (7) than in the deeper ocean (10).

At 40 °N, the vertical sections show that the error is relatively small in the open ocean but increasing towards land and the Mid-Atlantic Ridge. The data coverage decreased from the 1986-1999 to the 2000-2013 period, but the errors are still comparable. There is a significant decrease in the error in the top 1000 m when all observations (Figure 4c) are

---

**Figure 3. North Atlantic maps of the almost exact error from DIVA. Black dots indicate the positions of observations, colours indicate the error. A (top) shows the error for observations from 1986-1999; B (middle) the error for observations from 2000-2013; C (bottom) shows the error for all observations in GLDAPv2 (1972-2013).**
included, but in the deep ocean the error increases.

Figure 4. Vertical sections at 30°W in the North Atlantic (0°N to 80°N) showing the almost exact error from DIVA as the colour scale. A (top) shows the error for observations from 1986-1999; B (middle) shows the error for observations from 2000-2013; C (bottom) shows the error for all observations in GLODAPv2 (1972-2013).

Figure 5. Vertical sections at 40°N in the North Atlantic (-80°E to 0°E) showing the almost exact error from DIVA as the colour scale. A (top) shows the error for observations from 1986-1999; B (middle) shows the error for observations from 2000-2013; C (right) shows the error for all observations in GLODAPv2 (1972-2013).
somewhat when all observations are used.

3.2. Observational network of sea surface ocean fCO$_2$

Figure 7 shows an example of the OSSE results for the northern hemisphere sea surface fCO$_2$, based on the ocean divisions given in Schuster et al. (2013) (2d Sc1312 in Figure 2), which does the LARS separately for the Atlantic and the Pacific, whilst keeping relatively large ocean regions.

The two plots in Figure 6 show that, using the SOCAT observational network (Figure 6b), one is able to re-create large-scale and long-term sea surface fCO$_2$ fields (Figure 6a). Regional differences are discernible, however, indicating that the SOCAT observational network is not able to re-create all small-scale (and possibly short-term) variability.

Looking at the air-sea flux estimates based on the above OSSEs in one particular ocean region, one can study the evolution over time, the long-term mean, and the trend over time (shown in Figure 7). The results for the North Atlantic subpolar /northern subtropical region (region 2 in 2d Pe1312, Figure 2) is shown, selected from the LARS results run for each one of the regions mentioned in Figure 2.

The annual mean sea-air CO$_2$ fluxes show a slightly larger interannual variability in the SOCAT-subsampled results, compared to the full model results, indicated by a slightly different time-evolution of the annual fluxes (plots Aa and Ba), and the larger error bars in plot Bb compared to Ab. The mean fluxes (individual bars in plots (a) and (b)) show greater variation for the SOCAT subsampled results (plot Bb compared to Ab), indicating larger disagreement between ocean divisions when looking at sub-hemispherical regions.

Figure 6: Contour plots of the northern hemisphere long-term mean (1990 to 2015) sea surface fCO$_2$ fields, using the 2d Sc1312 ocean division, using A (top) the full Medusa 2p0 model output, and B (bottom) the Medusa 2.0 subsampled by SOCAT locations and times.
The annual mean sea-air CO$_2$ fluxes show a slightly larger interannual variability in the SOCAT-subsampled results, compared to the full model results, indicated by a slightly different time-evolution of the annual fluxes (plots Aa and Ba), and the larger error bars in plot Bb compared to Ab. The mean fluxes (individual bars in plots (a) and (b)) show greater variation for the SOCAT subsampled results (plot Bb compared to Ab), indicating larger disagreement between ocean divisions when looking at sub-hemispherical regions.

These different results of fluxes result in quite different estimations of the flux trends (plots (c)).
Preliminary analysis indicates that a lack of observations in the regions of deep-water-formation, Labrador Sea and Greenland Sea, significantly influence the sea surface fCO$_2$ and sea-air CO$_2$ flux estimates.

4. CONCLUSIONS AND OUTLOOK

In this study we have evaluated the current observational network of both interior ocean carbon and sea surface fCO$_2$, collected in GLODAP version 2 and SOCAT version 4, respectively, applying a number of different statistical techniques.

Both the interior ocean carbon study, using GLODAPv2, as well as the sea surface fCO$_2$ and sea-air CO$_2$ flux study, using Medusa 2.0 and SOCAT, show discrepancies in the current observational network. These are independent from each other and indicate lack of observations made on different types of platforms, i.e. research vessels versus commercial ships and moorings.

In the Atlantic, we highlighted the required additional interior ocean observations in the regions between 30 and 50 °W / 10 to 40 °N, and sea surface fCO$_2$ observations in the deep-water-formation regions.

Future work in evaluating the current observational network includes:

- Use the DIVA technique on an optimal VON network and analyse the spatial pattern in errors (as above).
- Run OSSEs with extended observational network.
- Rigorous statistical analysis of the OSSE results obtained so far.

5. REFERENCES


