1. TITLE

1.1 Data Set Identification

ISLSCP II Air-Sea Carbon Dioxide Gas Exchange

1.2 Database Table Name(s)

Not applicable to this data set.

1.3 File Name(s)

There are eight data files with this data set. This includes six compressed (.zip) and two comma-separated (.csv) files. The original files (files 1 and 4 below) were changed from space delimited format (.asc) to comma-separated format (.csv) by ORNL DAAC staff.

<u>**File Names:**</u>

1) **air_sea_d-pco2_5d_1995.csv**: Original data file submitted by the Principal Investigator in space-delimited format. This original data file contains monthly CO_2 partial pressure difference (delta-pCO_2) in seawater corrected to 1995 with ancillary data, and interpolated onto a 5 degree longitude by 4 degree latitude Earth grid. The data are longitude (LON), latitude (LAT), month (MONTH), sea surface temperature (SST), salinity (SAL), barometric pressure (PBARO), (PCO2_SW), (PCO2_AIR), and DELTA_PCO2. These data are used to calculate the ocean/air CO_2 flux. See Section 8.2 for complete file and compression information.

2) **air_sea_d-pco2_5d_1995.zip:** A point shape file of the lat/lon data from the file above. This also includes six files named **air_sea_d-pco2_5d_1995..xxx** where **xxx** is .dbf, .prj, .sbn, .sbx, .shp, and .shx.

3) **air_sea_d-pco2_5d_1995_12month.zip:** A polygon shape file of 12 months of data from the file in air_sea_d-pco2_5d_1995.csv. This also includes seven files named **air_sea_d-pco2_5d_1995_12month.xxx** where **xxx** is .dbf, .prj, .sbn, .sbx, .shx., .shp., and .xml.

4) **air_sea_co2flux_5d_1995.csv**: Original data file submitted by the Principal Investigator in comma-delimited format. This original data file contains monthly global ocean/air CO_2 fluxes for 1995 with ancillary data. Data are included for longitude (LON), latitude (LAT), month (MONTH), CO2 partial pressure difference (DELTA_PCO2), wind speed (WIND_SPD), sea surface temperature (SST), and CO2 flux (CO2_FLUX). These files are also interpolated onto a 5 degree longitude by 4 degree latitude Earth grid. See Section 8.2 for complete file and compression information.

5) **air_sea_co2flux_5d_1995.zip**: A point shape file of the lat/lon data from the file above. This includes six files named **air_sea_co2flux_5d_1995.xxx** where **xxx** is .dbf, .prj, .sbn, .sbx, .shp, and .shx.

6) **air_sea_co2flux_5d_1995_12month.zip**: A polygon shape file of 12 months of data from the file **air_sea_co2flux_5d_1995.csv.** This also includes seven files named **air_sea_co2flux_5d_1995_12month.xxx** where **xxx** is .dbf, .prj, .sbn, .sbx, .shx., and .shp, and .xml.

7) **air_sea_d-pco2_maps_1d.zip:** Contains 12 files (.asc) of monthly average ocean/air CO2 flux data for 1995. The files have been arranged on a 1 by 1-degree global grid by replication of original cell values.

8) **air_sea_co2flux_1d_1995MM00.asc**: Contains 12 files (.asc) of monthly average seawater-air pCO2 difference data. The files have been arranged on a 1 by 1-degree global grid by replication of original cell values.

   NOTE: The 5 x 4-degree files listed above (.csv files) were processed again by: filling in blank pixels along the coastlines using averaging of all the surrounding pixels, then expanding each pixel in a line 5 times, then copying each line 4 times. This preserved the original missing values of -999.9. Additionally, the 1-degree land mask was overlayed on the files, inserting the land (listed as -99.9) at a finer scale than the original 5 x 4-degree data. Thus, there are missing land data listed as -99.9, then additional missing data listed as -999.9. Sea ice is indicated by -888.8.

1.4 Revision Date of this Document

February 26, 2014

2. INVESTIGATOR(S)

2.1 Investigator(s) Name and Title

Taro Takahashi, Stewart C. Sutherland, Rik H. Wanninkhof, Richard A. Feely, Ray F. Weiss, David W. Chipman, Nicholas Bates, Jon Olafsson, Christopher Sabine, A. Poisson, N. Metzl, B. Tilbrook, Y. Nojiri , C. Sweeney.

2.2 Title of Investigation

Climatological mean net sea-air CO_2 flux and the sea-air pCO_2 difference over the global oceans.

2.3 Contacts (For Data Production Information)

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2.4 Data Set Citation

Takahashi, T., S.C. Sutherland, R.H. Wanninkhof, R.A. Feely, R.F. Weiss, D.W. Chipman, N. Bates, J. Olafsson, C. Sabine, A. Poisson, N. Metzl, B. Tilbrook, Y. Nojiri, and C. Sweeney. 2014. ISLSCP II Air-Sea Carbon Dioxide Gas Exchange. In Hall, Forrest G., G. Collatz, B. Meeson, S. Los, E. Brown de Colstoun, and D. Landis (eds.). ISLSCP Initiative II Collection. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, USA.

2.5 Requested Form of Acknowledgment

Users of the International Satellite Land Surface Climatology (ISLSCP) Initiative II data collection are requested to cite the collection as a whole (Hall et al. 2006) as well as the individual data sets. Please cite the following publications when these data are used:

Hall, F.G., E. Brown de Colstoun, G. J. Collatz, D. Landis, P. Dirmeyer, A. Betts, G. Huffman, L. Bounoua, and B. Meeson, The ISLSCP Initiative II Global Data sets: Surface Boundary Conditions and Atmospheric Forcings for Land-Atmosphere Studies, *J. Geophys. Res.*, 111, doi:10.1029/2006JD007366, 2006.

Gurney, K.R., R. M. Law, A. S. Denning, P. J. Rayner, D. Baker, P. Bousquet, L. Bruhwiler, Y.-H. Chen, P. Ciais, S. Fan, I.Y. Fung, M. Gloor, M. Heimann, K. Higuchi, J. John, T. Maki, S. Maksyutov, K. Masarie, P. Peylin, M. Prather, B.C. Pak, J. Randerson, J. Sarmiento, S. Taguchi, T. Takahashi and C.-W. Yuen, 2001: Towards robust regional estimates of CO_2 sources and sinks using atmospheric transport models. *Nature*, **415**, 626-630, Feb. 2002.

Takahashi, T., Sutherland, S. C., Sweeney, C., Poisson, A., Metzl, N., Tillbrook, B., Bates, N., Wanninkhof, R., Feely, R. A., Sabine, C., Olafsson, J. and Nojiri, Y. (2002). Global sea-air CO_2 flux based on climatological surface ocean pCO_2, and seasonal biological and temperature effects, *Deep-Sea Res. II*, **49**, 1601-1622.

3. INTRODUCTION

3.1 Objective/Purpose

The original purpose of generating these data was to characterize the distribution of the oceanic sink and source areas for atmospheric CO_2 and the magnitude of the net CO_2 flux across the sea surface.

3.2 Summary of Parameters

The climatological distributions of monthly net sea-air CO_2 flux have been estimated based upon the measured sea-air CO_2 partial pressure (pCO_2) difference, or ΔpCO_2, and wind speed, for the reference year of 1995. The data are provided in their original tabular format with associated ancillary data (e.g. sea surface temperature, salinity, pressure, etc.) and as monthly files on Earth grids.

3.3 Discussion

These estimates are based on approximately 1 million measurements made of pCO_2 in surface waters of the global ocean since the International Geophysical Year, 1956-59. Only the ocean water pCO_2 values measured using direct gas-seawater equilibration methods are used. Observations made in the equatorial Pacific between 10 degrees N and 10 degrees S during El Niño events have been excluded from the data set. Thus, the results represent climatological distributions under non-El Niño conditions. Since the measurements were made in different years, during which the atmospheric pCO_2 was increasing, these data were corrected to a single reference year (arbitrarily chosen to be 1995) on the basis of the following assumptions. Surface waters in subtropical gyres mix vertically at slow rates with subsurface waters due to the presence of strong stratification at the base of the mixed layer. This will allow a long contact time with the atmosphere to exchange CO_2. Therefore, their CO_2 chemistry tends to follow the atmospheric CO_2 increase. Accordingly, the pCO_2 measured in a given month and year is corrected to the same month of the reference year 1995 using changes in the atmospheric CO_2 concentration during this period. Oceanic pCO_2 measurements made after the beginning of 1979 have been corrected to 1995 using the atmospheric CO_2 concentration data from the

GLOBALVIEW-CO_2 database (2000), in which the zonal mean atmospheric concentrations (for each 0.05 in sine of latitude) within the planetary boundary layer are summarized for each month since 1979 to 2000. Pre-1979 oceanic pCO_2 data were corrected to 1979 using the annual mean trend for the global mean atmospheric CO_2 concentration constructed from the Mauna Loa data of Keeling and Whorf (2000), and then from 1979 to 1995 using the GLOBALVIEW-CO_2 database. Measurements for pCO_2 made in the following areas have been corrected for the time of observation; 45 degrees N, 50 degrees S in the Atlantic Ocean, north of 50 degrees S in the Indian Ocean, 40 degrees N, 50 degrees S in the western Pacific west of the date line, and 40 degrees N, 60 degrees S in the eastern Pacific east of the date line.

In contrast to subtropical gyres, surface waters in high latitude regions are mixed convectively with deep waters during the fall-winter seasons, and their CO_2 properties tend to remain unchanged from year to year reflecting those of deep waters, in which the effect of increased atmospheric CO_2 is diluted to undetectable levels as observed by Takahashi et al. (1997). Hence, no correction is necessary for the year of measurements.

These pCO_2 values adjusted to the reference year 1995 are binned into each of 750,000 pixels [= (72 pixels along the E-W direction) x (41 along the N-S direction) x (365 days)], which represent the global 5 degrees x 4 degrees (lon/lat.) grid for each day in a single virtual calendar year. Since pCO_2 measurements have been made only sparsely in each year, it is necessary to pool the data collected over 40 years into a single reference year in order to have a sufficient spatial and seasonal coverage over the global oceans.

The original files of ΔpCO_2 and air-sea CO_2 flux submitted by the Investigators have been used to create global maps of monthly ΔpCO_2 and air-sea CO_2 flux at their original spatial resolution. Because of the need to create a complete International Satellite Land Surface Climatology Project (ISLSCP) Initiative II data collection at a common spatial resolution, the ISLSCP II staff has also used the original data to create 1 degree by 1-degree maps by replicating the value of each 5 degrees x 4-degrees cell 20 times. This 1-degree product is provided as a ‘browse’ product and is not intended for scientific applications. Users should always consult and use the original data at their native spatial resolution for these applications.

4. THEORY OF ALGORITHM/MEASUREMENTS

Mean monthly global distributions of pCO_2 in surface ocean waters have been constructed using an interpolation method based on a lateral 2-dimensional advection-diffusion transport equation (Takahashi et al., 1995; Takahashi et al., 1997). The transport equation used for interpolation is:

$$dS/dt = K \nabla^2 S - \partial S/\partial x\ V_x + \partial S/\partial y\ V_y, \quad (1)$$

$$\text{and } \nabla^2 S = \partial^2 S/\partial x^2 + \partial^2 S/\partial y^2, \quad (2)$$

where S is a scalar quantity, V_x and V_y are the local surface water advective velocities, and K is the eddy diffusivity. The implied boundary conditions are that there is no material transport across the sea land interface or the air-sea Interface: on an orthogonal grid, $\partial S/\partial x = 0$ and $\partial S/\partial y = 0$ along the boundaries. The computational domain is joined at the prime meridian, so that the oceans are freely interconnected in the east–west domain. Singularities at the poles are avoided by the presence of the Antarctic continent in the south (80 degrees S) and the polar ice cap in the north (84 degrees N) which is treated as a land mass for the purposes of the interpolation.

The equation yields pCO_2 values for 5 x 4-degrees pixels where no observations exist, while it satisfies the observed values explicitly. The effects of vertical mixing and sea-air CO_2 flux are considered inherently embedded in the observed data. Therefore, the short-term behavior of surface water properties may be approximated using the lateral transport model without vertical mixing and gas exchange terms. For advective transport, the mean monthly surface flow field of Toggweiler et al. (1989) is used and, for diffusive transport, a constant value of 2000 m^2/sec is used. The equation has been solved iteratively using a finite-difference algorithm, in which the computational domains are joined at December 31, 1995, with January 1, 1995, and along the prime meridian to ensure continuity in time and space. The ocean-land boundaries are assumed to be reflective boundaries. Typically, several thousand iterations are necessary before solutions converge. Although the solutions give daily distributions, monthly mean distributions have been computed and used for flux calculations.

Net sea-air CO_2 flux, F, may be estimated using: $F = k.\ \alpha\ .\ (\Delta pCO_2)_{sea\text{-}air}$, where k is the CO_2 gas transfer velocity, α is the solubility of CO_2 in seawater (Weiss, 1974), and $(\Delta pCO_2)_{sea\text{-}air}$ is the sea-air pCO_2 difference. The sea-air pCO_2 difference is computed using the mean monthly pCO_2 values in surface waters obtained and the atmospheric pCO_2 computed using the zonal mean CO_2 concentrations in the dry atmosphere for 1995 reported by the GLOBALVIEW-CO_2 (2000). The climatological mean barometric pressure (Pb) (Atlas of Surface Marine Data, 1994) and equilibrium water vapor pressure (Pw) at climatological surface water temperature and salinity (World Ocean Database, 1998) are used for computing the atmospheric pCO_2 in the relationship: $(pCO_2)_{air} = (CO_2\ conc.)_{air} * (Pb - Pw)$. The net sea-air CO_2 flux in each pixel has been computed using the monthly mean ΔpCO_2 values thus obtained, and the Wanninkhof (1992) formulation (Eq. 1) for the effect of wind speed on the CO_2 gas transfer coefficient with the NCEP-41-year mean monthly wind speed at 0.995 sigma level over each pixel area.

5. EQUIPMENT

5.1 Instrument Description

These estimates are based on approximately 1 million measurements using direct gas-seawater equilibration methods for the pCO_2 in surface waters of the global ocean since 1957. Although the CO_2 concentration in equilibrated air was determined using various types of infrared gas analyzers and gas chromatographs, all these measurements are calibrated against the reference CO_2/air mixtures of known CO_2 concentrations that were determined by C. D. Keeling (Scripps Institution of Oceanography) using his manometric method. The atmospheric CO_2 concentration was also measured using infrared gas analyzers that were calibrated using the standard gas mixtures of C. D. Keeling.

5.1.1 Platform (Satellite, Aircraft, Ground, Person)

There are two sources of pCO_2 data in surface waters: those obtained for discrete water samples at each hydrographic station and those obtained semi continuously (several times per hour) using underway systems (e.g. ships). In our data treatment, observations made within a single day were binned into a pixel area to give a daily mean value. This averaging scheme has been shown to represent a spatial variation of pCO_2 in seawater even in areas of strong gradients such as the equatorial Pacific.

5.1.2 Mission Objectives

Various.

5.1.3 Key Variables

Various oceanographic variables.

5.1.4 Principles of Operation

Various.

5.1.5 Instrument Measurement Geometry

Not applicable to this data set.

5.1.6 Manufacturer of Instrument

Various.

5.2 Calibration

Although the CO_2 concentration in equilibrated air was determined using various types of infrared gas analyzers and gas chromatographs, all these measurements are calibrated against the reference CO_2/air mixtures of known CO_2 concentrations that were determined by C. D. Keeling (Scripps Institution of Oceanography) and later by Pieter Tans (CMDL/NOAA) using their respective manometric methods.

5.2.1 Specifications

Not available at this revision.

5.2.1.1 Tolerance

Not available at this revision.

5.2.2 Frequency of Calibration

Not available at this revision.

5.2.3 Other Calibration Information

Not available at this revision.

6. PROCEDURE

6.1 Data Acquisition Methods

Many of the observations used have been published in scientific journals and in technical reports. In addition, many unpublished data in the archives of the authors at the Lamont–Doherty Earth Observatory, the Scripps Institution of Oceanography, the Pacific Marine Environmental Laboratory (National Oceanic and Atmospheric Administration), and the Atlantic Oceanographic and Meteorological Laboratory (National Oceanic and Atmospheric Administration) have been used.

6.2 Spatial Characteristics

6.2.1 Spatial Coverage

Observations made in the equatorial Pacific between 10 degrees N and 10 degrees S during El Niño events have been excluded from the data set. Thus, the results represent the climatological distributions under non-El Niño conditions. The spatial coverage of the data sets is for most large global oceans. Data for smaller water bodies such as the Mediterranean Sea are not included.

6.2.2 Spatial Resolution

The sea-air pCO_2 difference values are binned into a total of 750,000 pixels (72 pixels along the longitude x 45 along the latitude x 365 days), which represent the global 5 x 4-degrees longitude and latitude Earth grid for each day in a single virtual calendar year. There is also a 1 by 1-degree product that has been created by the ISLSCP II Staff (see section 9.2.3 for more details).

6.3 Temporal Characteristics

6.3.1 Temporal Coverage

Approximately one million measurements using direct gas-seawater equilibration methods for the pCO_2 in surface waters of the global ocean since 1957. The sea-air pCO_2 difference measured in a given year was corrected to the reference year of 1995.

6.3.2 Temporal Resolution

Observations made in the equatorial Pacific between 10 degrees N and 10 degrees S during El Niño events have been excluded from the data set. Thus, the results represent the climatological distributions under non-El Niño conditions in each month in the reference year of 1995.

7. OBSERVATIONS

7.1 Field Notes

Not applicable to this data set.

8. DATA DESCRIPTION

8.1 Table Definition with Comments

Not applicable to this data set.

8.2 Type of Data

<table>
<tr><th>8.2.1 Parameter/ Variable Name</th><th>8.2.2 Parameter/ Variable Description</th><th>8.2.3 Data Range</th><th>8.2.4 Units of Measurement</th><th>8.2.5 Data Source</th></tr>
<tr><td colspan="5">File: air_sea_d-pco2_5d_1995.csv</td></tr>
<tr><td>LON</td><td>Longitude coordinate for the center of a 5 x 4-degree cell (long/lat.). West Longitudes are negative.</td><td>-177.5 degrees to 177.5 degrees</td><td>decimal degrees</td><td>Earth Grid</td></tr>
<tr><td>LAT</td><td>Latitude coordinate for the center of a 5 x 4-degree ell (long/lat.). South latitudes are negative.</td><td>-76 degrees to 80 degrees</td><td>decimal degrees</td><td>Earth Grid</td></tr>
<tr><td>MONTH</td><td>Month number</td><td>1 to 12</td><td>N/A</td><td>N/A</td></tr>
<tr><td>SST</td><td>Monthly Sea Surface Temperature, derived from 1 x 1-degree NODC World Ocean Database (1998).</td><td>-2.10 to 30.18</td><td>degrees C</td><td>NODC World Ocean Database</td></tr>
<tr><td>SAL</td><td>Monthly Salinity, derived from 1 x 1-degree NODC World Ocean Database (1998).</td><td>21.28 to 37.47</td><td>unitless</td><td>NODC World Ocean Database</td></tr>
<tr><td>PBARO</td><td>Monthly climatological mean barometric pressure, derived from 2 x 2-degree NCAR database.</td><td>983.10 to 1022.80</td><td>mb</td><td>NCAR</td></tr>
<tr><td>PCO2_SW</td><td>Monthly pCO_2 in surface water, corrected to 1995.</td><td>155.30 to 528.87</td><td>µatm</td><td>Computed</td></tr>
<tr><td>PCO2_AIR</td><td>Monthly pCO_2 in air corrected to 1995</td><td>340.90 to 366.13</td><td>µatm</td><td>Computed</td></tr>
<tr><td>DELTA_PCO2</td><td>Monthly seawater-air pCO_2 difference, calculated as PCO2_SW - PCO2_AIR</td><td>-199.58 to 181.61</td><td>µatm</td><td>Computed</td></tr>
<tr><td colspan="5">File: air_sea_d-pco2_5d_1995.zip: A point shape file of the lat/lon data from the file above.</td></tr>
<tr><td colspan="5">File: air_sea_d-pco2_5d_1995_12month.zip: A polygon shape file of 12 months of data from the file above.</td></tr>
<tr><td colspan="5">File: air_sea_co2flux_5d_1995.csv</td></tr>
<tr><td>LON</td><td>Longitude coordinate for the center of a c cell (long/lat.). West Longitudes are negative.</td><td>-177.5 degrees to 177.5 degrees</td><td>decimal degrees</td><td>Earth Grid</td></tr>
<tr><td>LAT</td><td>Latitude coordinate for the center of 5 x 4-degree cell (long/lat.). South latitudes are negative.</td><td>-76 degrees to 80 degrees</td><td>decimal degrees</td><td>Earth Grid</td></tr>
</table>

MONTH	Month number	1 to 12	N/A	N/A
DELTA_PCO2	Monthly pCO_2 difference, from 1).	-199.58 to 181.61	µatm	Same as above
WIND_SPD	Monthly Wind speed	0.775 to 15.598	m/sec	None given
SST	Sea Surface Temperature, from 1).	-2.20 to 30.18	degrees C	Same as above
CO2_FLUX	Monthly ocean/air CO_2 flux, corrected to 1995. Negative fluxes are into the oceans while positive fluxes are from the ocean to the air.	-1.29 to 3.26	mole C/m^2	940k Version
File: air_sea_co2flux_5d_1995.zip: A point shape file of the lat/lon data from the file above.				
File: air_sea_co2flux_5d_1995_12month.zip: A polygon shape file of 12 months of data from the file above				
Mapped Files **air_sea_co2fluxmaps_1d.zip, and air_sea_d-pco2_maps_1d.zip**				
d-pco2	Monthly seawater-air pCO_2 difference	-199.58 to 181.61	µatm	Original ΔpCO_2 file
co2flux	Monthly ocean/air CO_2 flux	-1.29 to 3.26 Sea Ice = -888.8	mole C/m^2	Original CO_2 flux file

8.3 Sample Data Record

air_sea_d-pco2_5d_1995.csv

```
LON,LAT,MONTH,SST,SAL,PBARO,PCO2_SW,PCO2_AIR,DELTA_PCO2
2.5,0.0,1,27.97,34.29,1010.7,383.21,345.28,37.93
7.5,0.0,1,28.14,32.11,1010.6,373.00,345.09,27.91
47.5,0.0,1,26.67,35.33,1011.8,375.27,346.65,28.62
52.5,0.0,1,27.05,35.34,1011.9,375.09,346.40,28.69
57.5,0.0,1,27.57,35.28,1011.5,379.61,345.87,33.74
```

air_sea_co2flux_5d_1995.csv

```
LON,LAT,MONTH,DELTA_PCO2,WIND_SPD,SST,CO2_FLUX
172.5,-76,1,-134.370,6.626,-0.104,-888.8
177.5,-76,1,-156.840,7.307,-0.377,-888.8
-177.5,-76,1,-120.980,7.493,-0.548,-888.8
-172.5,-76,1,-141.270,7.203,-0.705,-888.8
-167.5,-76,1,-50.900,6.608,-0.778,-888.8
```

8.4 Data Format

The original data file **air_sea_d-pco2_5d_1995.csv** has a total of 9 columns while the **air_sea_co2flux_5d_1995.csv** file has a total of 7 columns. Both files have 21,109 total rows. A value of –888.8 is used in the CO2_FLUX column in the file **air_sea_co2flux_5d_1995.csv** to indicate the presence of sea ice.

The file format for the map files consists of numerical fields of varying length, which are delimited by comma and arranged in columns and rows. All values in these files are written as real numbers. Land cells are given the value –999.9 and the value -888.8 indicates sea ice.

The files in the **air_sea_co2fluxmaps_1d.zip** and **air_sea_d-pco2_maps_1d.zip** are at a resolution of 1 x 1-degree and thus have 360 columns by 180 rows. All values in these files are written as real numbers. These maps were created from the original 5 x 4-degree maps, and the original missing values of -999.9 are preserved. Additionally, the ISLSCP II 1.0-degree Land/Sea Mask was overlaid on the files, inserting the land (listed as -99.9) at a finer scale than the original 5 x 4-degree data. Thus, there are missing land data listed as -99.9, then additional missing data listed as -999.9. Sea ice is indicated by -888.8 in the CO_2 flux files.

These files are all gridded to a common equal-angle lat/long grid, where the coordinates of the upper left corner of the files are located at 180 degrees W, 90 degrees N and the lower right corner coordinates are located at 180 degrees E, 90 degrees S. Data in the files are ordered from North to South and from West to East beginning at 180 degrees West and 90 degrees North.

WARNING: The 1 x 1-degree map product is for browse use only. These data files were created from the original 5 x 4-degree files, and are not interpolated between the original 5 x 4-pixels. Use these data with caution and always refer to the original tabular data files for specific information.

8.5 Related Data Sets

See http://daac.ornl.gov/ISLSCP_II/islscpii.shtml for additional ISLSCP II data sets. Also, http://ingrid.ldgo.columbia.edu/ for more related data sets at the Lamont Doherty Earth Observatory. The ISLSCP II data collection contains Sea Surface Temperature and Sea Ice Concentration data sets that the user may find useful.

9. DATA MANIPULATIONS

9.1 Formulas

9.1.1 Derivation Techniques/Algorithms

The pCO_2 value in seawater was obtained using the CO_2 concentration, the water vapor pressure at the equilibration temperature and the pressure of equilibrated gas (which is commonly equal to the barometric pressure). It was corrected to the seawater temperature using the difference between in situ and equilibration temperatures and the isochemical temperature effect on seawater pCO_2 of 4.23% C^{-1}. The atmospheric pCO_2 was obtained using the local mean monthly value of CO_2 concentrations in dry air over respective pixel areas using the data of Keeling and Whorf (2000) before 1979, and then from 1979 to 1995 using the GLOBALVIEW-CO_2 database with mean monthly barometric pressure, and water vapor pressure at seawater temperature. The sea–air pCO_2 difference, ΔpCO_2, was computed by subtracting it from the oceanic pCO_2 value.

Many of the observations used have been published in scientific journals and in technical reports. In addition, many unpublished data in the archives of the authors at the Lamont–Doherty Earth Observatory, the Scripps Institution of Oceanography, the Pacific Marine Environmental Laboratory (National Oceanic and Atmospheric Administration), and the Atlantic Oceanographic and Meteorological Laboratory (National Oceanic and Atmospheric Administration) have been used.

9.2 Data Processing Sequence

9.2.1 Processing Steps and Data Sets

See Takahashi et al. (2002).

9.2.2 Processing Changes

None.

9.2.3 Additional Processing by the ISLSCP Staff

The original data files submitted were the ASCII tables, at a resolution of 5 x 4-degrees. The ISLSCP II modified the original latitudes from the original 0 degrees to 360 degrees convention to a –180 degrees to 180 degrees longitude convention. Sea ice cells with an original value of –999.9 were replaced with a value of –888.8. Every cell in the **air_sea_d-pco2_5d_1995.csv** and the **air_sea_co2flux_5d_1995.csv** files was assigned to its corresponding location on a global 5 x 4 (long/lat) Earth grid using the latitude and longitude coordinates that were provided. Individual monthly files were created and written to the ASCII format. ORNL DAAC staff also created shape files from these data.

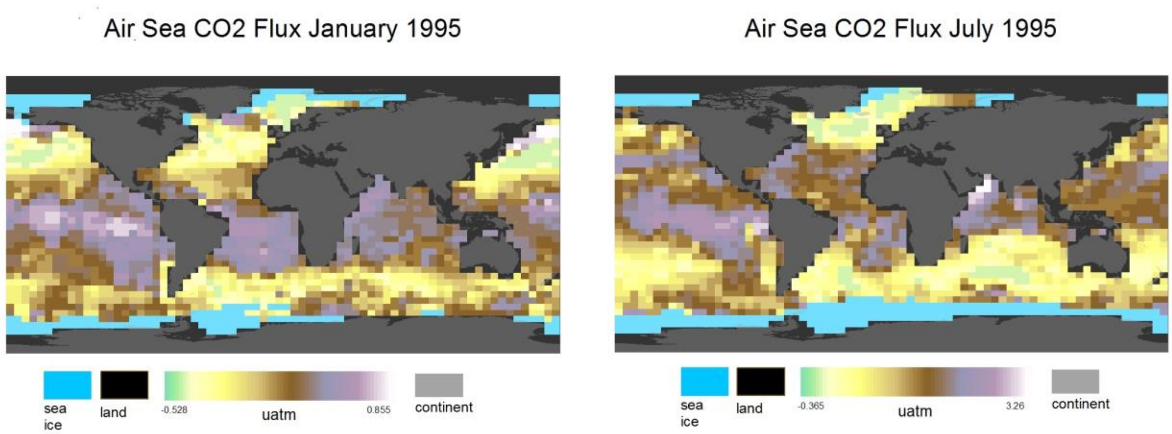

Figure 1. Images created by ORNL DAAC staff depicting two months of data from the air_sea_co2flux_5d_1995.csv data file.

The ISLSCP II staff also took the 5 x 4-degree files listed above and created 1 x 1-degree versions by replicating each 5 x 4-degree cell 20 times. Cells near coastlines that did not match the ISLSCP II land/sea mask were added by using averaging of all the surrounding ocean pixels, then expanding each pixel in a line five times, then copying each line four times. This preserved the original missing values of -999.9. Additionally, the ISLSCP II 1.0 degree Land Mask was overlaid on the files, inserting the land (listed as -99.9) at a finer scale than the original 5 x 4-degree data. Thus, there is missing land data listed as -

99.9, then additional missing data listed as -999.9. Sea ice is indicated by a value of -888.8 in the CO_2 flux files.

WARNING: The 1 x 1-degree map products are for browse use only. These data files were created from the original 5 x 4-degree files, and are not interpolated between the original 5 x 4-pixels. Use these data with caution and always refer to the original tabular data files for specific information.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

The data set represents measurements made at locations and times that were dictated by ship tracks without mathematical regularity. A computational method is needed to interpolate these observations discretized in a 5 x 4-degree x 365 day grid to construct global pCO_2 distribution maps in surface ocean waters. For this purpose, a finite-difference algorithm based on a lateral two-dimensional transport model (See Section 4.0) is used. In the interpolation scheme, all pixel values based on observations are explicitly satisfied, and those in pixels that have no observations are computed.

9.4 Graphs and Plots

See http://ingrid.ldgo.columbia.edu.

10. ERRORS

10.1 Sources of Error

The sea-air CO_2 flux values provided in this data set are subject to two sources of errors: 1) biases in ΔpCO_2 values interpolated from relatively sparse observations, and 2) errors due to uncertainties in the gas transfer coefficient estimated on the basis of the wind speed dependence.

Possible biases in ΔpCO_2 differences have been estimated by Takahashi et al. (2002) using sea surface water temperatures (SST) as a proxy. The monthly SST in each pixel was computed using the SST values measured concurrently with pCO_2 and the same interpolation scheme used for obtaining the global distribution of ΔpCO_2. This was compared with the climatological SST value given in the World Ocean Database (1998), and the global mean of the differences was computed. The global mean SST estimated on the basis of our data and methods has been found to be 0.28 ± 1.64 degrees C greater than the climatological mean SST. Using the mean effect of SST on seawater pCO_2 observed over the global ocean (3.5% per ^oC), we estimate that the SST difference corresponds to about 3 µatm or 30% error in ΔpCO_2. Therefore, the estimated global sea-air CO_2 flux is subject to a systematic error of up to 30%.

The reliability of the wind speed dependence on the CO_2 gas transfer coefficient has been significantly improved as a result of the recent GASEX98 study reported by Wanninkhof and McGillis (1999). Eq. (1) of Wanninkhof (1992) used to generate this present data set is consistent within about ± 20% with their eddy correlation flux measurements conducted over the North Atlantic. Hence, the estimated fluxes are subject to this level of uncertainty.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Not available at this revision.

10.2.2 Confidence Level/Accuracy Judgment

The 1x1-degree map products are for browse use only. These data files are not interpolated between the original 5 x 4-pixels. Thus the data is very "blocky", and values at specific pixels are not exact. Use this data with caution and always refer to the original tabular data files for specific information.

10.2.3 Measurement Error for Parameters and Variables

The sensitivity of the interpolated ΔpCO_2 values to the number of observations made along ship's tracks has been tested by eliminating a measurement from every 10 observations. The interpolated values obtained with 90% of the full database have been compared with those computed using 100% of the database. The effect of this reduction on the interpolated ΔpCO_2 is small with a mean difference of 0.01 ± 2.2 µatm and is independent of latitude. Therefore, the estimated ΔpCO_2 values over the global oceans are not sensitively affected by the number of measurements made along the ship's tracks.

10.2.4 Additional Quality Assessment Applied

The quality of the measurements themselves is excellent, but it is not possible to measure air-sea flux directly, rather pCO_2 in the water. There are two main sources of error in the fluxes: (1) the extrapolation and interpolation of the measurements to a regular grid for each month, from decades of point measurements; and (2) uncertainty in the air-sea gas exchange coefficients and their dependence on wind speed, which is used to calculate fluxes from the pCO_2. The quality of the gridded estimates has been evaluated by Rik Wanninkhof (wanninkhof@aoml.noaa.gov) and by Richard Feeley (feely@pmel.noaa.gov), among others. The spatial coverage of the measurements varies substantially in both space and time. For example, there are many measurements over all seasons in many years in the North Atlantic, much fewer in the South Pacific and the Southern Ocean in winter. El Niño periods have been intentionally and systematically omitted from the analysis.

A recent calculation compared estimates of air-sea gas exchange derived from atmospheric CO_2 measurements using 16 different tracer transport models found broad agreement with the Takahashi estimates in most ocean regions (Gurney *et al* , 2002). The only major exception to this agreement was over the Southern Ocean and adjacent regions of the southern parts of the Atlantic, Pacific, and Indian Oceans. Inversions of the atmospheric CO_2 data using all 16 models found a weaker sink in these regions relative to the surface water pCO_2 based estimates.

The method used to grid the pCO_2 data is as follows: (1) each measurement of pCO_2 in the ocean (taken over a 30-year period) is "adjusted" to 1995 conditions to account for the steady accumulation of CO_2 in the atmosphere and surface oceans due to fossil fuel combustion. (2) the time-adjusted pCO_2 values are then extrapolated in space and time by advecting and diffusing them along mean ocean current streamlines. This is perhaps the most controversial part of the algorithm. Individual measurements made in particular months and locations are moved both forward and backward in time, assuming that they conserve pCO_2. So they are taken to represent large areas of ocean, and the motion of the water is assumed to be correctly represented on a 5 x 4-degree grid. There is also diffusion so the "influence" of each measurement spreads out in space as it gets farther from the point where the measurement was taken. (3) These advected and diffused pCO_2 estimates are averaged onto the 5 x 4-degree grid for each month. Although the 5 x 4 grid used cannot represent some of the major but fine oceanographic features such as the Gulf Stream and the various equatorial currents in the Pacific, the observations do not allow finer spatial resolutions. Finally, the gridded pCO_2 maps are used to estimate air-sea CO_2 fluxes, by applying maps of climatological wind speeds and apply an equation for the dependence of the gas exchange coefficient to wind speed. Several such relationships have been tested, and the one used in the present data set is based on the work of Wanninkhof (1992). Assuming the wind speeds are correct, and the pCO_2 maps for each month are correct, Takahashi estimates about 20% uncertainty in the global fluxes just from uncertainty in the gas exchange calculation.

The data set given in this file yields an annual global ocean net CO_2 uptake flux of 2.2 Pg-C in 1995. This is consistent with an estimate of 2.0 ± 0.6 PgC yr^{-1} obtained totally independently on the basis of the changes of the atmospheric oxygen and CO_2 concentrations observed during the 1990s (Keeling et al., 1996; Battle et al., 2000).

11. NOTES

11.1 Known Problems with the Data

No known problems are reported at this revision.

11.2 Usage Guidance

Users should always consult the original data files for their research. The 1-degree version of this data set created by the ISLSCP II staff is not intended for scientific applications.

11.3 Other Relevant Information

The 1995 flux values show that the Atlantic Ocean is the largest net sink for atmospheric CO_2 (39%); the Southern Ocean (22%) and the Indian Ocean (22%) the next; and the Pacific (11%) the smallest. The large sink flux of the northern oceanic areas is attributed to the intense biological drawdown of CO_2 in the high latitude areas of the North Atlantic and arctic seas during the summer months. This is also due to low CO_2 concentrations in upwelling deep waters, which are, in turn, caused primarily by the short residence time of the North Atlantic Deep Waters. The small uptake flux of the Pacific can be attributed to the combined sink flux of the northern and southern subtropical gyres is roughly balanced by the source flux from the equatorial Pacific. The equatorial Pacific CO_2 source flux may be totally or partly eliminated during El Niño events. This effect alone could increase the global ocean uptake flux up to 0.6 Gt-C/yr during an El Niño year.

12. REFERENCES

12.1 Satellite/Instrument/Data Processing Documentation

None.

12.2 Journal Articles and Study Reports

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Wanninkhof, R. and McGillis, W. M. (1999). A cubic relationship between gas transfer and wind speed, *Geophys. Res. Let*., 26, 1889-1892.
World Ocean Database (1998) Version 2, the National Oceanographic Data Center, NOAA, Washington, D. C.

13. DATA ACCESS

13.1 Contacts for Archive/Data Access Information

The ISLSCP Initiative II data are available are archived and distributed through the Oak Ridge National Laboratory (ORNL) DAAC for Biogeochemical Dynamics at http://daac.ornl.gov.

13.2 Contacts for Archive

E-mail: uso@daac.ornl.gov
Telephone: +1 (865) 241-3952

13.3 Archive/Status/Plans

The ISLSCP Initiative II data are archived at the ORNL DAAC. There are no plans to update these data.

14. GLOSSARY OF ACRONYMS

CMDL	Climate Monitoring and Diagnostics Laboratory (NOAA)
CO_2	Carbon Dioxide
DAAC	Distributed Active Archive Center
ISLSCP	International Satellite Land Surface Climatology Project
GSFC	Goddard Space Flight Center
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanic Data Center
ORNL	Oak Ridge National Laboratory
pCO_2	CO_2 Partial Pressure
ΔpCO_2	CO_2 Partial Pressure Difference