README FILE

Global sea-air CO_2 fluxes determined from a ΔpCO_2 climatology and monthly anomalies in SST and wind

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This global monthly sea-air CO_2 flux product is an updated version of CO_2 fluxes (PAR_CLIM) submitted to RECCAP (http://www.globalcarbonproject.org/reccap/products.htm). Two significant changes were made compared to the original version:

1. The trend in sea-air CO_2 fluxes due to rising atmospheric CO_2 levels is included. This trend is determined for each grid cell using the output "CO_2-only run" from the NCAR/CCSM-3 ocean model.
2. When observations were missing in the Cross Calibrated Multi-Platform (CCMP) winds used, the simulated winds from this product were incorporated to avoid spatial and temporal data gaps.

In the area outside of CCMP winds coverage (78°S - 78°N), wind data were interpolated from adjacent cells to calculate CO_2 fluxes.

Introduction

This file describes the method and data used to create the global monthly sea-air CO_2 flux product. In this approach we use the monthly sea-air CO_2 flux climatology from Takahashi et al. (2009) as the basis to estimate interannual variability in sea-air CO_2 fluxes. We apply subannual relationships between sea surface temperature (SST) and partial pressure of CO_2 in surface water (pCO_{2SW}) from this climatology to estimate the monthly pCO_{2SW} for the other years from the sea surface temperature anomaly compared to the SST for reference year 2000. Details can be found in Lee et al. (1998) and Park et al. (2006, 2010a, 2010b).

In equation form we derive the surface water pCO_2 for each month ($pCO_{2SW\,ym}$):

$$pCO_{2SW\,ym} = [pCO_{2SW\,2000m} + (\delta pCO_{2SW}/\delta SST)_{2000m} \times \Delta SST_{ym-2000m}]$$

where *ym* is the year and month, and subscript *2000m* refers to the month in 2000.

The flux in turn is determined from:

$$F_{ym} = k_{ym}\, K_{0\,ym}\, \{pCO_{2SW\,ym} - pCO_{2AIR\,2000m}\} = k_{ym}\, K_{0\,ym}\, \Delta pCO_{2\,ym}$$

The solubility $K_{0\,ym}$ is determined from monthly SST and climatological salinity estimates using the solubility equations of Weiss (1974). We estimate the monthly gas transfer velocity, k_{ym} from the second moment of monthly mean wind speed and the gas transfer coefficient:

$$k_{ym} = 0.251 \times \langle U_{10\,ym}{}^2\rangle\, (Sc_{ym}/660)^{-0.5}$$

where $\langle U_{10\,ym}{}^2\rangle$ the second moment of the wind at 10m above sea surface representing the variance of the 6-hourly wind speeds for each grid cell over *ym*, and Sc is Schmidt number. The coefficient (0.251) is determined from the bomb ^{14}C inventory in the ocean according to Sweeney et al. (2007). In the polar regions where sea-ice forms seasonally, k_{ym} was multiplied by (1–f), where f is the fractional sea-ice cover.

Details on inputs used in this product

1. The time period covered is from 1990-2009

2. The basis ΔpCO_2 climatology is that of Takahashi et al. (2009). The data is obtained from www.ldeo.columbia.edu/res/pi/CO2/carbondioxide/pages/air_sea_flux_2009.html. This product is at monthly resolution on a 4˚ by 5˚ grid.

3. For each grid cell optimum subannual relationships are created to determine $(\delta pCO_{2SW}/\delta SST)_{2000m}$. Optimum subannual pCO_{2SW}-SST relationships are made from at least three consecutive monthly values according to the annual patterns of pCO_{2SW} and SST in each grid cell. Details can be found in Park et al. (2010a, 2010b)

4. The SST's are the NOAA Optimum Interpolation (OI) Sea Surface Temperature (SST) V2 processed from 1990 onward. The monthly $1^o \times 1^o$ data (180 × 360) is binned and averaged onto a $4^o \times 5^o$ grid. The original data source is: http://www.cdc.noaa.gov/data/gridded/data.noaa.oisst.v2.html

5. The wind speed is the 6-hour (4 times a day) Cross Calibrated Multi-Platform (CCMP) winds processed from 1990 onward. The analysis uses all wind data within each $4^o \times 5^o$ grid cell for one month, from which the second moment $\langle U_{10\,ym}^2 \rangle$ is derived. Access to the data in native format and important background information on the product can be found at: http://podaac-www.jpl.nasa.gov/dataset/CCMP_MEASURES_ATLAS_L4_OW_L3_0_WIND_VECTORS_FLK

6. The monthly fractional sea-ice cover values for each $4^o \times 5^o$ grid cell are obtained from the NCEP/DOE reanalysis 2 surface ice concentration fields (ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis2/gaussian_grid/). The original data are re-gridded to a $4^o \times 5^o$ grid and averaged for each month in each grid cell. Following the convention in Takahashi et al. (2009) each grid cell is regarded as a sea-ice-free area when the ice cover value is less than 0.1. In the case that the ice cover value is over 0.9, we assume that each grid cell has 10% ice-free open water (f = 0.9) because of leads and polynyas where CO_2 is exchanged across the sea-air interface (Takahashi et al., 2009).

7. For the central and eastern Equatorial Pacific (10^oS–6^oN, 165^oE–280^oE (= 80^oW)) there are sufficient data to derive time period specific equations updated and extended through 2009 from those of Feely et al. (2006). They provide unique algorithms between pCO_{2SW}-SST for El Niño and Non-El Niño periods for three different time periods. Mean atmospheric pCO_2 values for estimating ΔpCO_2 in each grid cell of the central and eastern Equatorial Pacific are obtained from GLOBALVIEW-CO2, 2009.

Considering the fluxes due to atmospheric CO_2 increase

The basic assumption of this approach is that surface pCO_{2SW} increases at the same rate as the atmosphere. Therefore, global sea-air CO_2 fluxes estimated from this approach do not include fluxes caused by atmospheric CO_2 increase. Here, we estimate the fluxes owing to atmospheric CO_2 increase using the results of NCAR CCSM-3 model (Doney et al., 2009a and 2009b) with CO_2-only run for the period of 1987-2006. These model outputs are produced by repeat annual physical forcing and rising atmospheric CO_2. In each $4^o \times 5^o$ grid cell, the trend in ΔpCO_2 is computed by a linear regression with deseasonalized monthly values using a harmonic function. CO_2 fluxes caused by atmospheric CO_2 increase are only calculated in the grid cells that have significant increase or decrease trends in ΔpCO_2 ($p<0.05$). All grid cells with no significant trends assume that pCO_{2SW} increases at the same rate as atmospheric CO_2, that is, ΔpCO_2 is constant year-to-year. These "CO_2-only" fluxes are added to CO_2 fluxes from the empirical model using subannual relationships between SST and pCO_{2SW} and interannual changes in SST.

Comparison with other model results

This global sea-air CO_2 flux product is based on ocean measurements. Therefore, undersampling error of 0.2 Pg C yr^{-1} from ΔpCO_2 climatology proposed by Takahashi et al. (2009) and riverine flux input of 0.45 Pg C yr^{-1} should be added to global fluxes for comparison with other model results.

Data

NETCDF file 'fgco2_1990_2009_mon_PAR_CCMP.nc' has monthly fields at 1^o by 1^o of sea-air CO_2 flux from 1990 to December 31, 2009. The structure for the monthly CO_2 flux product on 1^o by 1^o degree grids for the .nc file is:

```
dimensions:
    lat = 180 ;
    long = 360 ;
    time = UNLIMITED ; // (240 currently)
variables:
    float lat(lat) ;
        lat:units = "degrees_north" ;
        lat:actual_range = "-89.5 89.5" ;
        lat:axis = "y" ;
        lat:coordinate_defines = "center" ;
    float long(long) ;
        long:units = "degrees_east" ;
        long:actual_range = "0.5 359.5" ;
        long:axis = "x" ;
        long:coordinate_defines = "center" ;
    float time(time) ;
        time:units = "months since 1990-01" ;
        time:actual_range = "1990-01 2009-12" ;
        time:delta_t = "0000-01" ;
        time:axis = "t" ;
    double fgCO2_CLIM(time, lat, long) ;
```

```
            fgCO2_CLIM:long_name = "CO2 flux" ;
            fgCO2_CLIM:units = "mol/m2/yr" ;
            fgCO2_CLIM:cell_methods = "time:mean" ;
            fgCO2_CLIM:missing_value = "-9.999e+02" ;
      double fgCO2_ANTH(time, lat, long) ;
            fgCO2_ ANTH:long_name = "CO2 flux with the effect of atmospheric CO2
increase" ;
            fgCO2_ ANTH:units = "mol/m2/yr" ;
            fgCO2_ ANTH:cell_methods = "time:mean" ;
            fgCO2_ ANTH:missing_value = "-9.999e+02" ;

// global attributes:
            :title = "Monthly sea-air CO2 fluxes" ;
            :source = "Park et al., 2010, Tellus 62B & CCMP winds" ;
            :source2 = "For the effect of atm CO2 increase, Doney et al., 2009" ;
            :reference = "http://www.aoml.noaa.gov/ocd/gcc/TGeunHaFlux" ;
```

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