A multiyear, global gridded fossil fuel CO_2 emissions data product evaluation and analysis of results

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Methodology

We are using the **Fossil Fuel Data Assimilation System (FFDAS)** which has a dynamical model at its core based on the modified Kaya identity

$$F = Pgef$$

F = emissions,
P = areal population density
g = per capita economic activity
e = energy intensity of economic activity
f = carbon intensity of energy consumption

Data assimilation is applied to constrain components of Kaya with a number of observational operators.

In the current version of FFDAS we treat two sectors, **a power generation** sector and **"other"** sector (sum of industrial, resid, comm, and trans)

For more details see Rayner et al. 2010 and Asefi et al., 2014

Advantages of data assimilation to downscaling techniques:

- Process-based dynamical model at core
- Smoother spatial distribution
- The ability to integrate the range of observations
- The ability to include **prior uncertainty** and estimate **posterior uncertainties**
- Ability to perform at different spatial and temporal scales

Dataset

National emissions: National and global FFCO2 are constrained by $FFCO_2$ **sectoral** emissions reported by International Energy Agency (IEA) for 1997 to 2010 time period. **National prior uncertainties** are *objectively* estimated based on recent analysis by Macknick 2011.

Nightlight: A new unsaturated **radiance calibrated** nightlight product is generate by NOAA-NGDC that is inter-calibrated and gas flares are removed [Elvidge et al., 1999; Ziskin et al., 2010; Elvidge et al., 2009]. This dataset is used to create nightlights at 0.1°x0.1° grid resolution for 1997-2010.

Population: Gridded population density dataset provided by LandScan Global Population Database (30 arc sec resolution, 2000-2010) and 1995 and 2000 data from the Gridded Population of the World - GPW.v3 (0.04° resolution) are combined to create a time-series population density dataset at 0.1° resolution for 1997-2010 [Asefi et al., 2014]

Power plant emissions: We have built upon and improved existing power plant emissions database (CARMA) [Ummel, 2012].
- locations & emissions improved via national datasets and GE search.
- A multivariate regression model generates imrpoved emissions and uncertainties for each individual power plant [Gurney and Coltin, manuscript in preparation].

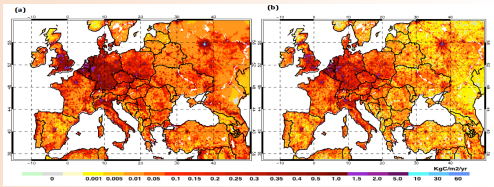

Figure 1 shows comparison of FFDAS total fossil fuel CO2 emissions when (a) power plant emissions are not allocated to power plant location but distributed by nightlights and population and **(b)** power plant emissions are allocated to power plant location.
Units: kgCm-2yr-1
Separate estimation of the electricity generation at geocoded points, reduces the amount of emissions spread into the populated and lighted areas within a given country.

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Introduction

There is a growing need, from both carbon cycle science and policymaking communities for quantification of global fossil fuel CO_2 (FFCO2) emissions at fine space/time resolutions. Atmospheric CO_2 inversion/assimilation and carbon budget studies rely on accurate quantification of $FFCO_2$ emissions to quantify biosphere and ocean exchange. Resolved $FFCO_2$ emissions are equally important to climate policy as a means to baseline emissions, guide mitigation efforts, and assess progress on reductions.

We have built a high-resolution global $FFCO_2$ emissions data product and uncertainties for the years of 1997 – 2010 using a combination of in situ and remotely sensed data in a fossil fuel data assimilation system (FFDAS).

Previous datasets:

Traditionally global population and nightlights have been used as a spatial proxy used to **downscale** national emissions to generate global fossil fuel CO_2 emission data.

CDIAC [Marland and Rotty, 1984; Boden et al., 1995]: monthly fossil fuel CO2 emissions (1950 to 2010). Distributes the national totals into 1°x1° grid cells according to population density.

EDGAR [Olivier et al., 2005]: annual estimates on a 0.1°x0.1° grid (1990 to 2010). Distributes national emissions with a variety of spatial proxies ranging from population density to specific point source location maps.

ODIAC [Oda & Maksyutov, 2011]: estimates of fossil fuel CO2 emissions on a 1x1 km grid (1980 to 2007), combines downscaling of national emissions using satellite observations of nighttime lights and a geocoded estimation of power plant CO2 emissions.

PKU [Wang et al., 2013] estimates of fossil fuel CO2 emissions at 0.1° x 0.1° resolution for 2007, combines bottom-up data sources (province/state level fuel consumption) with downscaling (using a combination of CO emission inventories or population as spatial proxies.)

Results

Comparison to Vulcan

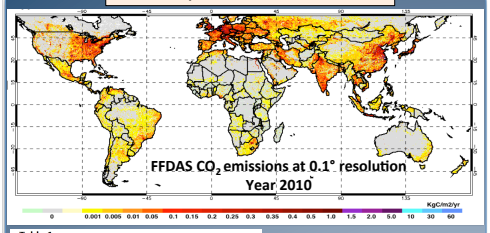


Table 1

	Other sector	ffdas (all sectors)
Resolutions	Correl	Correl
0.1	0.48	0.86
0.2	0.67	0.88
0.3	0.76	0.90
0.4	0.81	0.91
0.5	0.84	0.92
1	0.91	0.95
2	0.94	0.97
3	0.96	0.98
4	0.97	0.99

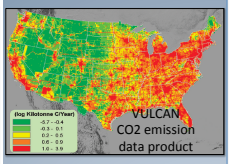
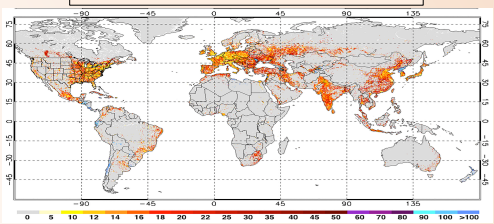


Table 1 shows the comparison of FFDAS with the Vulcan (a state-of-the-art bottom-up approach to fossil fuel emissions quantification) data product for the US domain [Gurney et al., 2009]. Spatial correlation between the FFDAS results and Vulcan exceeds 0.8 at the 0.1° resolution. As the spatial resolution is decreased, the spatial correlation increases. Much of the high spatial correlation of the total emissions is due to near perfect correlation of power plant emissions while for the "other" sector, the spatial correlation value is 0.48. This will improve in the future by further sectoral division of FFDAS to roads, residential, commercial and industrial.

Posterior Uncertainties



Posterior uncertainties associated with the total fossil fuel CO2 emissions (expressed as percentage standard deviation).

Short term trend analysis

emissions anomalies reflecting subnational impacts of the Global Financial Crisis

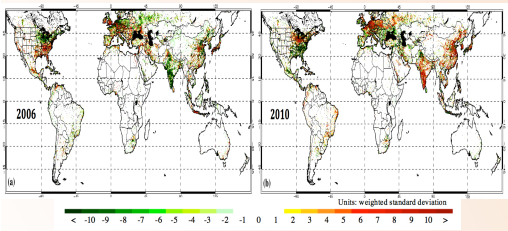


Figure 4. Annual FFCO2 anomalies for two years, 2006 and 2010, that bracket the Global Financial Crisis (GFC). In the year 2006, negative emission anomalies are present in much of the northern half of the eastern US and throughout northern Europe, India and eastern China indicating values greater than the long-term mean trend. Positive anomalies, by contrast, appear in the southern half of the eastern US and parts of southern Europe. In 2010 however, the spatial pattern of these anomalies reversed.
The GFC occurred during the period spanning 2006 to 2010 [Peters et al., 2011]. The observed subnational spatial patterns of negative and positive emissions anomalies may, therefore, be a reflection of the subnational impacts of the GFC.

Conclusion

We have significantly advanced the Fossil Fuel Data Assimilation System (FFDAS), first described by Rayner et al. [2010] for global, high-res fossil fuel CO2 (FFCO2) emissions estimation.

We have **improved the observational constraints**, extended the system to a sector-based treatment and generated a complete time series of emissions from 1997 to 2010.

The FFDAS v2.0 comparison to the Vulcan data product in the U.S. shows **improved performance** over the FFDAS v1.0.

Long-term trends show considerable sub-national spatial structure in the United States, China and India. These three countries show different long-term trends and nighttime light and population trends reveal decoupling of population and emissions.

Analysis of **shorter term variations reveal sub-national spatial structure** such as the Global Financial Crisis in 2008/2009 with widespread negative anomalies in emissions across the US, Europe, and Japan. 2010 shows a recovery with the US marked by a North-South division in the eastern half of the country.

All data can be downloaded from http://hpcg.purdue.edu/FFDAS/

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