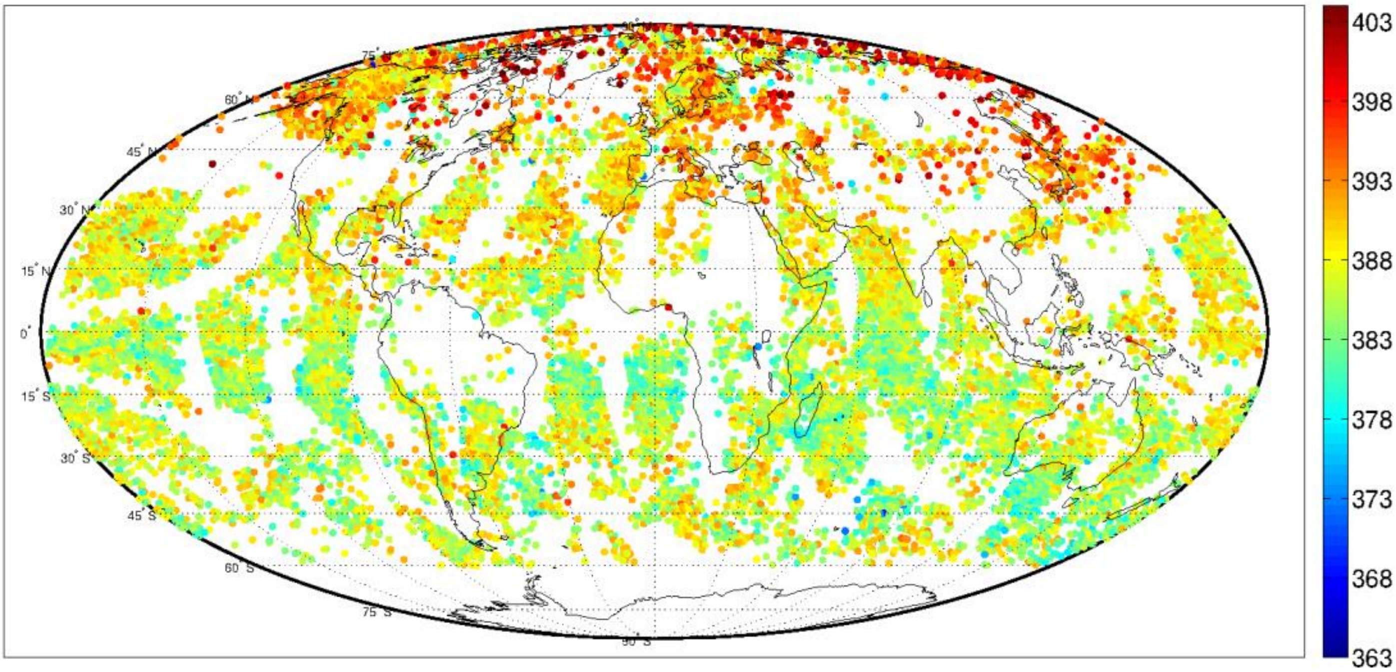
Spatio-temporal Analysis of CO_2 Emissions

Project Goal

Monitoring and reporting of CO_2 emissions has a decisive impact on the negotiations of global climate change. However, the current system refers to non-standardized national reports based only on industry specific statistics. This results in non-verifiable estimates of national CO_2 emissions. The project goal was therefore to identify alternative methods to make global CO_2 emissions quantifiable and objectively verifiable.



Atmospheric CO_2 centration in ppm for January 2009

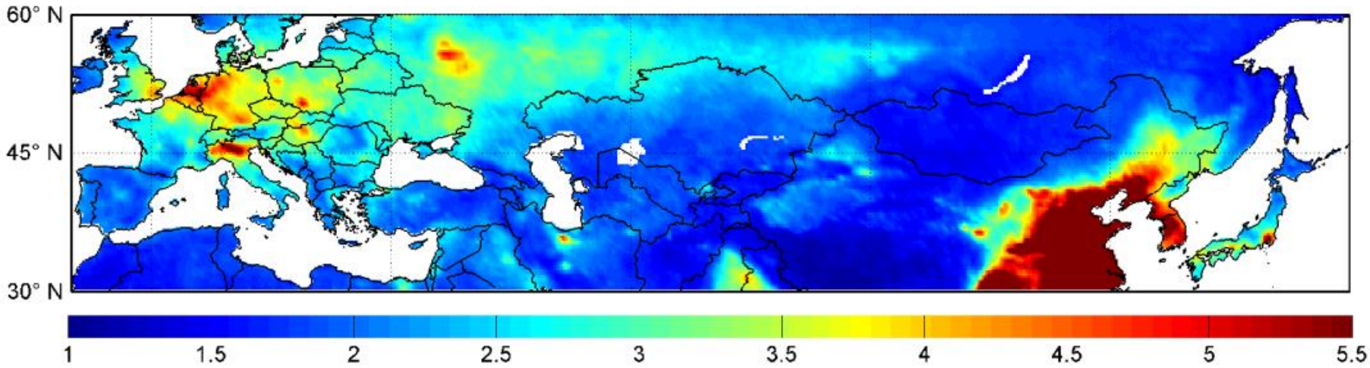
Data Selection

The main data set used includes measurements of CO_2 surface concentration obtained by the Greenhouse Gases Observing Satellite (GOSAT). The data was collected in two week intervals as 90 km² footprint measurements from 2009 until 2012. The spatial dimension of the study area covered the majority of Europe's and Asia's landmass.

Challenges

The first challenge addresses a common problem in spatio-temporal analysis: data complexity. High dimensionality in space and time quickly leads to bottlenecks in computing power when running the model. To circumvent this, suitable approaches for the approximation of the space-time covariance function are needed.

The second task was the development of a model framework for CO_2 concentration, which allows a space-time prediction of the data set with very low data density and also utilizes the space-time auto correlation structure within the data. The main challenge to be solved in practice is the determination of carbon sources and sinks from the concentration data. The model should therefore be able to quantify how much CO_2 has been emitted by mankind and separate how high the variation in CO_2 surface concentration is due to terrestrial vegetation. The calculations necessary to achieve this require thorough modelling of the global CO_2 cycle.



Model estimate of human CO_2 emission in January 2009

Model Framework

Approximation Approaches

In order to deal with the problem of high dimensionality, a comparative study was carried out. It analyzed the approaches to approximate the space-covariance function with respect to the trade-off between predictive power and computational requirement. The most efficient approach was the combination of covariance tapering and Fixed-Rank Kriging Approximation. For the space-time interpolation of the CO_2 concentration data, a Linear Mixed-Effects model with space-time varying coefficients was used, because it captures spatio-temporal dynamics of the process by modelling the space-time covariance function. By using spatial random fields that move according to time, the dependency can also be modelled as varying in space and time.

Interference of carbon sources and sinks

This model integrates the entire CO_2 cycle: it includes the seasonally varying vegetation process, as well as the seasonally changing dependency structure between CO_2 concentration and vegetation with a negative CO_2 balance in the summer months and CO_2 emission during the winter. Through application of the model framework and the corresponding space-time correlation structure of the covariate data, human CO_2 emission is quantifiable. The above figure illustrates the hotspots of CO_2 emission in urban industrial areas, especially apparent in China and North Korea.

Project Outcome

An alternative to the existing approach of monitoring and reporting CO_2 emissions was developed. It is capable of efficiently mapping the CO_2 concentration process globally and the whole terrestrial CO_2 cycle based on objective satellite measurements of CO_2 emissions. A comparative study showed that the model results were largely consistent with the reported emissions (UNFCCC) within European countries, but differed widely for countries such as China and North Korea. This indicates an error (intentional or not) in the currently implemented reporting system.