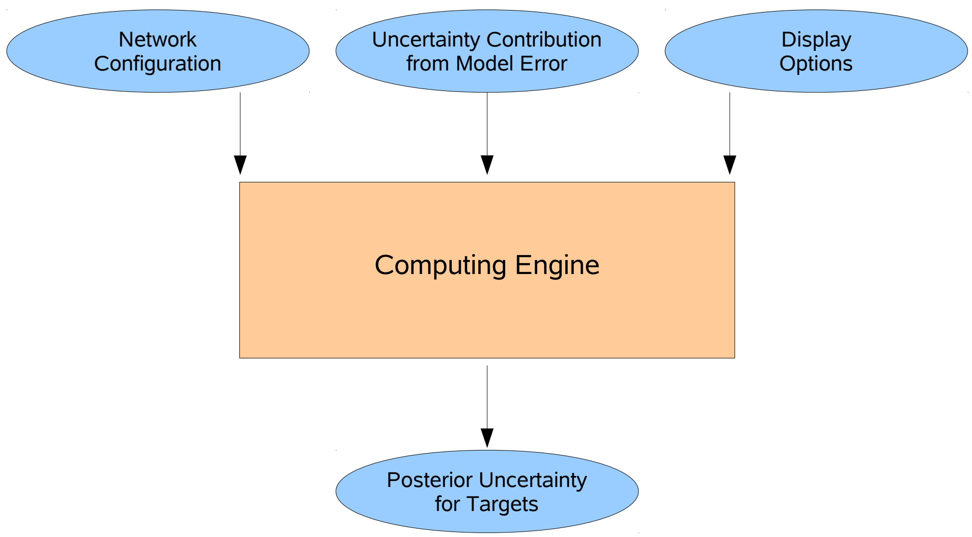
Network Designer
User's manual 2.0



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March 14, 2012

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1 Summary

This document describes the usage of version 2.0 of *Network Designer*, an interactive tool accessible through a web interface via `http://imecc.CCDAS.org`. *Network Designer* is based on the Carbon Cycle Data Assimilation System (CCDAS, *Kaminski et al.* [2003]; *Scholze* [2003]; *Rayner et al.* [2005]; *Scholze et al.* [2007]). CCDAS is built around the Biosphere Energy Transfer HYdrology scheme (BETHY, *Knorr* [2000]; *Knorr and Heimann* [2001]), a global model of terrestrial vegetation. For details on CCDAS we refer to `http://CCDAS.org`.

Network Designer applies quantitative network design techniques as described by *Kaminski and Rayner* [2008] to evaluate networks for observing the carbon cycle. Such an observational network is composed by the user of three different observational data types: flask samples of atmospheric CO_2, continuous samples of atmospheric CO_2, and eddy covariance measurements of the land-atmosphere flux of CO_2. The user selects the respective sampling locations and, for each location, an uncertainty for the combined effect of observational and model error.

For a given network, *Network Designer* then approximates the posterior uncertainties that CCDAS would deliver for two types of carbon fluxes, Net Primary Production (NPP) and Net Ecosystem Production (NEP), aggregated over three regions, namely Europe, Russia, and Brazil. In addition, *Network Designer* is able to display the uncertainty reduction in NEP on a global map for the chosen network relative to no observational network.

2 Revision History

The following revisions have been made to the software:

- Version 1.0 Demo version to assess uncertainty in European sink (NEP) for a flask sampling network.
- Version 1.1 Inclusion of NPP as second type of target quantity and integrals over three regions for both NEP and NPP.
- Version 2.0 Inclusion of two further data types (continuous, and eddy flux), user-defined model error, various display options, including a map of posterior uncertainty.

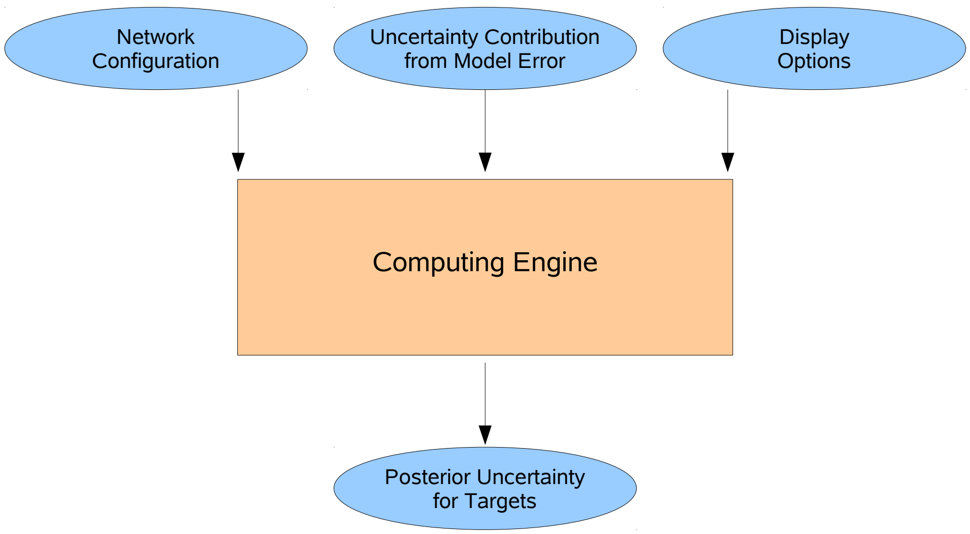

Figure 1: Flow of information in *Network Designer*

3 Usage

The flow of information through *Network Designer* is illustrated by figure 1. The inputs and outputs are denoted by ovals, and the processing step by a rectangular box. The access is arranged through a web-interface (via `http://imecc.CCDAS.org`) that contains from top to bottom:

1. the results table,
2. the uncertainty reduction map (optional, default not shown),
3. the network map (optional, default shown),
4. the network definition table (optional, default shown),
5. the specification table for uncertainty due to model error,
6. the display options table, and
7. a set of action buttons.

Network Designer is operated in three steps

1. specifying input (configuration of network, specification of uncertainty contribution to target quantity from model error, and selection of display options),

2. running computing engine, and

3. analysis of results.

In the following subsections we describe the three steps.

3.1 Specifying Input

3.1.1 Network Configuration

Network Designer provides a default network configuration. The current configuration is shown on the network map in the browser window. Green symbols indicate sites whose observational constraints are active, i.e. which are included in the calculation of posterior uncertainty in the target quantities. Red symbols indicate those sites of the network that are deactivated. The form of the symbols indicate the type of observation: circle (O) denotes atmospheric flask sampling, cross (X) denotes continuous atmospheric sampling, and plus (+) denotes eddy flux measurement.

You can change this configuration either via the network definition table through the web-interface or by editing the network configuration file on your machine.

For each site there are two things you can modify. You can activate or deactivate the site in the network, and you can specify a data uncertainty $\sigma(d)$ that reflects the combined effect of observational $\sigma(d_{\text{obs}})$ and model error $\sigma(d_{\text{mod}})$:

$$\sigma(d)^2 = \sigma(d_{\text{obs}})^2 + \sigma(d_{\text{mod}})^2 \tag{1}$$

This corresponds to the specific case of Equation 3 in *Kaminski and Rayner* [2008] where data uncertainties for different sites are uncorrelated. The other assumption here is that uncertainties in the model and the observational process are uncorrelated.

The unit of the data uncertainties depends on the data type. For flask and continuous samples of atmospheric CO_2 it is ppmv, for eddy flux measurements it is gC/m^2/day (where gC stands for grams of carbon).

You can add/remove rows in the network definition table via the “Add ...” and “Remove site(s)” buttons. For the two atmospheric data types the tool provides a list of sites from which you can choose. Within *Network Designer* the link from the terrestrial biosphere model to the atmospheric observations (i.e. the so-called observation operator) is provided by an atmospheric transport model. Flask samples are simulated as monthly mean concentrations by the transport model TM2 [*Heimann*, 1995], and continuous observations as daily means by the transport model LMDZ [*Hauglustaine et al.*, 2004]. The respective simulation periods are 21 years.

For the flux measurements, you can place a site over any vegetated BETHY grid cell. This observational type is modelled by hourly means of CO_2 fluxes over 21 years. The button “Add Eddy Flux Site” opens a table into which you enter the site coordinates. Via these coordinates the tool will identify the corresponding 2 by 2 degree land grid cell. The tool returns an error if the coordinates miss the vegetated grid cells. Otherwise the tool opens up another table that displays the (up to three) plant functional types (PFTs) that populate the corresponding BETHY

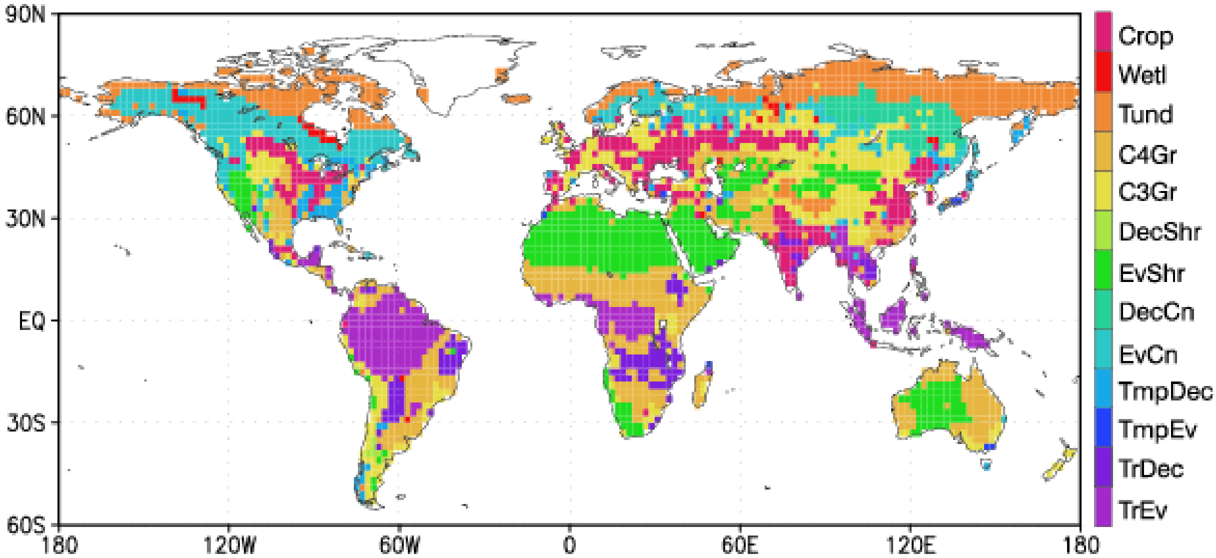

Figure 2: Distribution of the dominant CCDAS Plant Functional Type (PFT) per gridcell, PFT labels are given in Table 1, taken from *Rayner et al.* [2005]

grid cell, and their default fractions of coverage (see table 1 for a list of CCDAS PFTs and figure 2 for a map of the dominant PFT). You can now modify these fractions. If the sum of the fractions exceeds 1, the tool will return an error message. Further, you can choose a name for the site and the data uncertainty. In this procedure the only role of the coordinates is to define the climate at the site. Any two sites over the same grid cell will share the same climate. Hence, it is not problematic, if the location of your intended site is not within a BETHY land grid cell: You can just choose a land grid cell with similar climate. In its current setup, to limit the response time, the tool accepts up to 100 flux sites.

For editing the configuration locally on your machine, use the "Save" and "Upload" buttons. The "Save" button allows to save the actual network to a local file. Note that the file also records the entries of the results table (see section 3.3). This is an example of a network configuration file:

```
MLO | yes | flask | 2.0 | -155.58 | 19.53
SPO | yes | flask | 2.0 | -24.8 | -89.98
Sibiria | yes | flux | 5.0 | 60.0 | 60.0 | 642 | 9 | 0.52 | 5 | 0.48 | 0 | 0.0
MHD | yes | cont | 10.0 | -9.9 | 53.33
#==================================================
#          RESULTS
#
# Sigma NPP/NEP [GtC/yr]
#
# NPP Europe    0.14
# NPP Russia    0.35
# NPP Brasil    0.49
# NEP Europe    0.13
# NEP Russia    0.37
# NEP Brasil    0.32
#
#==================================================
```

Table 1: Plant Functional Types (PFTs) defined in CCDAS and their abbreviations, taken from *Rayner et al.* [2005]

PFT No.	PFT Name	Abbreviation
0	Not vegetated	
1	Trop. broadleaved evergreen tree	TrEv
2	Trop. broadleaved deciduous tree	TrDec
3	Temp. broadleaved evergreen tree	TmpEv
4	Temp. broadleaved deciduous tree	TmpDec
5	Evergreen coniferous tree	EvCn
6	Deciduous coniferous tree	DecCn
7	Evergreen shrub	EvShr
8	Deciduous shrub	DecShr
9	C3 grass	C3Gr
10	C4 grass	C4Gr
11	Tundra vegetation	Tund
12	Swamp vegetation	Wetl
13	Crops	Crop

Comment lines must start with a "`#`" as first character. Each row corresponds to a site, and the entries within a row are separated by "`|`". Within a row, the first column contains the name of the site with the geographical coordinates in columns five and six. The second column specifies whether the site is used in the computation of the target quantities ("`yes`" or "`no`"), the third indicates the type of observation, and the fourth the associated uncertainty. For the sites with atmospheric data types ("`flask`" and "`cont`") it is only allowed to alter columns 2 and 4. The flux site has a few additional columns. Column seven is an indicator for the grid cell, column eight is the number of the first PFT and column nine its fraction, column ten the number of the second PFT and column eleven its fraction, column twelve the number of the third PFT and column thirteen its fraction. A number "0" for the third PFT means there are only two PFTs at the chosen site.

3.1.2 Uncertainty contribution to target quantity from model error

The output of *Network Designer* (see section 3.3) are uncertainties $\sigma(y)$ of target quantities y simulated within CCDAS. They are computed via Equation 8 of *Kaminski and Rayner* [2008]:

$$\sigma(y)^2 = \sigma(y_{\text{perfect}})^2 + \sigma(y_{\text{mod}})^2, \tag{2}$$

where $\sigma(y_{\text{perfect}})$ quantifies the uncertainty in y under the assumption that the CCDAS model (BETHY) can simulate y perfectly (without any error), while $\sigma(y_{\text{mod}})$ quantifies the uncertainty resulting from errors in the simulation of y, i.e. the contribution from model error. The tool offers two types of target quantities: Net Ecosystem Production (NEP), i.e. the net CO_2 flux between the atmosphere and the biosphere and the Net Primary Production (NPP) of the biosphere. The two fluxes are related via

$$\text{NEP} = \text{NPP} - \text{RES}, \tag{3}$$

where RES is the heterotrophic respiration from the soil. $\sigma(y_{\text{mod}})$ can be specified by the user, as a (spatially fixed) percentage of NPP in the table "Uncertainty contribution to target quantity from model error".

3.1.3 Display Options

The user can determine three aspects of the page layout. For the network definition you can select between the table, the map, or both. In the map you can activate a zoom over Europe. You can further include, as an additional result, a global uncertainty reduction map (see section 3.3). This map can be provided with dynamic labels or with fixed labels, which is convenient for comparing the effects of several networks.

3.2 Computing

Once your network is configured you use the "Compute" button to invoke the computing engine. This also updates the network map. The computation approximates a CCDAS run over 21 years with the observational constraints specified by the network configuration. Note that any network modification that was executed by the "Add ...", "Remove site(s)" or the "Upload" action buttons automatically invokes the computing engine.

3.3 Analysis

The results table shows approximated posterior uncertainties for a set of target quantities, i.e. it quantifies the uncertainty in inferring the target quantities from the observations in the specified network within CCDAS. As mentioned the tool provides NEP and NPP as target quantities in the form of long-term averages over the 21 year CCDAS integration period. Both are specified in units of GtC/yr, where GtC stands for Gigatons (i.e. 10^{15} grams) of carbon. For both quantities we display the uncertainties of spatial integrals over three regions, namely Europe, Russia, and Brazil.

A further optional output is a map (see section 3.1.3 for display options) that displays the uncertainty reduction afforded by the network, i.e.

$$1 - \frac{\sigma(y)}{\sigma(y_{prior})}, \tag{4}$$

where $\sigma(y_{prior})$ denotes the uncertainty in the target quantity without any observational constraint, i.e. an empty network configuration file.

References

Hauglustaine, D. A., F. Hourdin, L. Jourdain, M. A. Filiberti, S. Walters, J. F. Lamarque, and E. A. Holland, Interactive chemistry in the Laboratoire de Météorologie Dynamique general circulation model: Description and background tropospheric chemistry evaluation, *J. Geophys. Res.*, *109*, doi:10.1029/2003JD003,957, 2004.

Heimann, M., The global atmospheric tracer model TM2, *Technical Report No. 10*, Max-Planck-Institut für Meteorologie, Hamburg, Germany, 1995.

Kaminski, T., and P. J. Rayner, Assimilation and network design, in *Observing the continental scale Greenhouse Gas Balance of Europe*, edited by H. Dolman, A. Freibauer, and R. Valentini, Ecological Studies, chap. 3, Springer-Verlag, New York, 2008.

Kaminski, T., R. Giering, M. Scholze, P. Rayner, and W. Knorr, An example of an automatic differentiation-based modelling system, in *Computational Science – ICCSA 2003, International Conference Montreal, Canada, May 2003, Proceedings, Part II*, *Lecture Notes in Computer Science*, vol. 2668, edited by V. Kumar, L. Gavrilova, C. J. K. Tan, and P. L'Ecuyer, pp. 95–104, Springer, Berlin, 2003.

Knorr, W., Annual and interannual CO_2 exchanges of the terrestrial biosphere: Process-based simulations and uncertainties, *Glob. Ecol. Biogeogr.*, *9*(3), 225–252, 2000.

Knorr, W., and M. Heimann, Uncertainties in global terrestrial biosphere modeling: 1. A comprehensive sensitivity analysis with a new photosynthesis and energy balance scheme, *Glob. Biogeochem. Cycles*, *15*(1), 207–225, 2001.

Rayner, P., M. Scholze, W. Knorr, T. Kaminski, R. Giering, and H. Widmann, Two decades of terrestrial Carbon fluxes from a Carbon Cycle Data Assimilation System (CCDAS), *Global Biogeochemical Cycles*, *19*, doi:10.1029/2004GB002,254, 2005.

Scholze, M., Model studies on the response of the terrestrial carbon cycle on climate change and variability, Examensarbeit, Max-Planck-Institut für Meteorologie, Hamburg, Germany, 2003.

Scholze, M., T. Kaminski, P. Rayner, W. Knorr, and R. Giering, Propagating uncertainty through prognostic CCDAS simulations, *J. Geophys. Res.*, *112*, doi: http://dx.doi.org/10.1029/2007JD008642, 2007.