Science meeting report:

ICOS CP Network Design workshop

Amsterdam, 27 June 2014

Application reference no: 5466

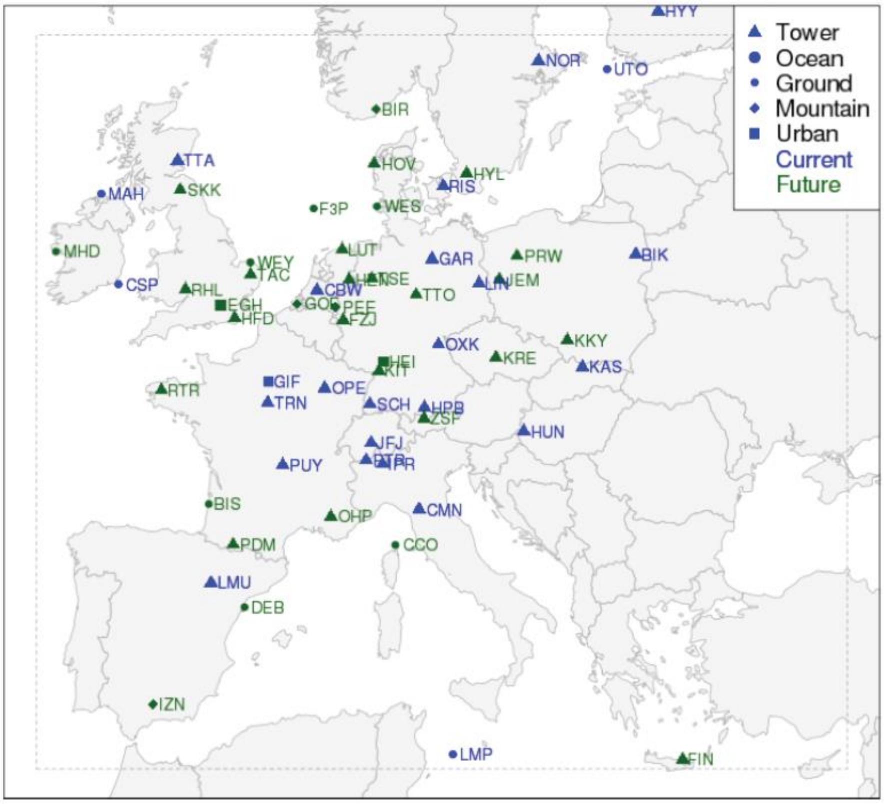

Table of Contents

ICOS Carbon Portal Network Design workshop, Amsterdam, 27 June 2014

ICOS, the Integrated Carbon Observation System, is a newly-started European research infrastructure (RI) with the mission to enable research on the greenhouse gas budgets and its perturbations in Europe and adjacent regions. ICOS is in the strategic roadmap of ESFRI (European Strategy Forum for Research Infrastructures) for Europe as one of the required Research Infrastructures. ICOS will provide the long-term observations required to understand the present state and predict future behavior of the global carbon cycle and greenhouse gas emissions.

ICOS' major task is the collection of high-quality observational data at ground-based measurement stations that are operated with a long-term (15+ years) perspective. The stations are run as national networks in the RI member states. When fully deployed, ICOS RI will receive data from 80-100 stations located in more than 15 countries. The measurement data are quality controlled and processed at shared Thematic Centers (TCs), operated by experts on Atmospheric, Ecosystem and Marine observations and data processing, and a Central Analytical Laboratory.

The Carbon Portal is the data platform of ICOS, envisioned as a place where all data produced within ICOS station network can be discovered and accessed, and where the scientific community can post elaborated data products that are obtained from ICOS data. All relevant ICOS data and ancillary data sets from external sources will be published and be accessible through the facilities of the Carbon Portal. The Carbon Portal will provide easily accessible and understandable science and education products for all users, ranging from experts to stakeholders and the general public.

One of the more urgent needs identified from user surveys undertaken in the setup and construction phase of the carbon portal is guidance in the design of the (atmospheric) network. Several countries are now developing their observations network and would like some assistance in evaluating potential locations and choices in measurement setups (sampling heights etc.). This workshop was meant to further identify the user needs and to discuss a way forward in providing this assistance and to select possible tools that the CP can adopt and eventually further develop.

The workshop started with a series of targeted presentations on the subject that are summarized in this report.

The detailed minutes of the meeting are still open for discussion among the participants so cannot be shared at the moment of writing this report. However all discussion material is accessible through the meeting website at the following URL:

http://icos-nl.wikidot.com/cp-networkdesign

Discussion paper

Some comments and questions to network design for atmospheric monitoring in ICOS RI

Ingeborg Levin, Institut für Umweltphysik, Heidelberg University, June 12, 2014

What are the main questions to be answered by ICOS RI from the perspective of

- Observers
- Modellers
- Politicians & the public

1. Observers:
    - What are the signals that we are interested to monitor at the measurement stations (e.g. clean marine or continental reference levels (coastal, high mountain), large scale "natural" ecosystem fluxes, regional scale managed ecosystem fluxes, fluxes from urban areas, fluxes from industrial areas, others)?
    - What is the main (e.g. 80%) footprint of the station, possibly depending on height a.l.g.?
    - Can one station serve to monitoring more than one influence area?
    - How accurate and compatible do observations need to be?
    - How can different source influences be separated within one single record or combining different trace substances?
    - Others …
    -

   Practical:
    - How to choose optimal (national) sites from a suite of M out of N potential (M<<N) stations, and, at the same time, serve best the goal of optimal European coverage?
    - What are the best height levels to sample (vertical resolution)?
    - What is the best strategy for discrete/integrated sampling (e.g. of isotopes) for source apportionment?
    - Others …

2. Modellers:
    - How can we monitor all major European fluxes with an optimal (i.e. cost effective) network of observations?
    - What are the optimal height levels to be sampled?
    - How well do recent models perform at the individual stations?
    - Which additional observations are needed to validate model performance (e.g. mixing height, radon or other transport tracers, …)?
    - Which additional tracers must be implemented in the models for (carbon, others?) source apportionment?
    - How accurate do model-derived flux estimates need to be?
    - Which spatial and temporal resolution of a priori emissions inventories are required for forward or inverse modelling?
    - How dependent are the model results from a priori information?
    - How do observational biases translate into biases of the estimated fluxes?

3. Politicians & public (Stakeholders):
    - What is the advantage of the top-down approach (compared to the currently applied bottom-up (UNFCCC) reporting praxis)?
    - What is the accuracy of current national bottom-up inventories?
    - What is the accuracy of national inventory estimates from current and future top-down

estimates based on the ICOS atmospheric observational network?

- How accurate can emissions changes be estimated from a top-down approach?
- What is the perspective of this approach for the next 5-10 years (i.e. for 2020, when e.g. Germany committed itself to 40% GHG emission reductions wrt. 1990)?

Agenda of the meeting

Friday 27 June - morning

Chair *Alex Vermeulen*

0830 - 0900	*walk in*
0900 - 0915	Introduction - Alex Vermeulen
0930 - 10:00	Network design study within ICOS-INWIRE: current status - Christoph Gerbig
1000 - 1030	Potential of ground based networks of CO2 measurements for the monitoring of natural and anthropogenic fluxes at the continental scale - Gregoire Broquet
1030 - 1100	*Tea/coffee break*
1100 - 1130	Surface CO2 flux in weekly temporal resolution over the globe inferred from the CONTRAIL dataset - Shoichi Taguchi
1130 - 1200	Inverse modeling of CH4 and N2O emissions for verification of national inventories - current status and challenges - Peter Bergamaschi
1200 - 1230	An interactive tool to analyse the benefit of CO2 flask concentration and CO2 eddy-flux measurements in determining terrestrial CO2 sources and sinks - Marko Scholze
1230 - 1330	*Lunch at the venue*

Friday 27 June - afternoon

Chair *Ingeborg Levin*
Rapporteur *Alex Vermeulen*

1330 - 1500	Discussion
1500 - 1530	*Tea/coffee break*
1530 - 1600	Wrap-up and conclusions

Summary of the presentations

Introduction - Alex Vermeulen

In this introduction a short overview of the Carbon Portal and its role in ICOS was presented. Furthermore Ingeborg Levin gave an introduction to the discussion paper as the basis for the questions to be addressed at the workshop.

Network design study within ICOS-INWIRE: current status - Christoph Gerbig

In this presentation the results of work performed within several current and recent projects (ICOS PP, ICOS Germany, ICOS InWire, InGOS and GeoCarbon) was presented. Quite some of the discussion items from the discussion paper were addressed in the talk, translated into the following questions:

- How accurate and compatible do observations need to be?
- How to choose optimal (national) sites from a suite of M out of N potential (M<<N) stations, and, at the same time, serve best the goal of optimal European coverage?
- How can we monitor all major European fluxes with an optimal (i.e. cost effective) network of observations?
- How do observational biases translate into biases of the estimated fluxes?

As there is an important cost benefit relationship between the number of stations in the network and the goals for compatibility (bias, precision) of the measurements, this question was central in this presentation. The most important word of caution however is that the outcome of this kind of analysis is very dependent on the model chosen for the evaluation and also strongly depends on basic assumptions used, like for example correlation times and distances assumed. Also it is important to note that often practical and logistical arguments can prevail over theoretical optimal solutions.

The answers to the questions above were answered using the WRF-Stilt inversion framework as operated by MPI-BGC in Jena. It was shown that the answers depend on the desired resolution in time and space of the optimized fluxes. Also for the different greenhouse gases the results vary as we have different uncertainties in the prior flux estimates that we need to improve upon.

The study shows that in the chosen model setup and framework, when using the future ICOS atmospheric network, the current compatibility demands can be relaxed if only seasonal and countrywide fluxes need to be retrieved at the desired uncertainties, assuming that the model systems are bias free, which they are obviously not at this moment. However, if we wish to obtain regional (10x10 km^2) fluxes at monthly time-scale then the current compatibility goals for the atmospheric observations are necessary conditions. This will, however, require a vast improvement in the model systems. Also a much denser network will be required to completely cover the area of interest, next to the needed extension towards under-sampled regions like Southern and Eastern Europe.

In a second part of the talk it was shown that the current models can capture relatively well the influence of strong local point sources at relatively small distances, which would allow to use information from stations in less ideal non-background areas.

Potential of ground based networks of CO2 measurements for the monitoring of natural and anthropogenic fluxes at the continental scale - Gregoire Broquet

Two atmospheric inversion studies here provide insights on the potential of present and future CO2 and 14C atmospheric concentration measurement networks for monitoring natural and anthropogenic CO2 fluxes in Europe based on state of the art inversion systems. The inversions shown here were based on Observing System Simulation Experiments (OSSE) using synthetic data.

First, the potential of ICOS-like CO2 networks for the inversion of the CO2 Net Ecosystem Exchange is assessed with an inversion system controlling these fluxes at 0.5° horizontal and 6-hour time resolution, using an atmospheric transport model, and a prior estimate of the NEE from a vegetation model. The inversion configuration is evaluated against independent data when assimilating actual measurements from the CarboEurope-IP network, using 10 to 15 sites, over a 6 year period. The OSSEs indicate 50% and 66% uncertainty reduction compared to the prior information at the European and monthly scale in July and December respectively, when using 23 sites (an approximation of the present ICOS network), resulting in ~ 43 $TgCmonth^{-1}$ (resp. 26 $TgCmonth^{-1}$) uncertainty in July (resp. December). At the local – 1 month scale, this yields 30% to 60% uncertainty reduction in the core part of the network (in Northern France, Benelux and Western Germany) down to 1.4gC/m2/day uncertainty. Tests with extended networks with 50 and 66 sites reveal far larger impact of these extensions at the local scale and for central European countries, where the most critical part of the extension should occur, than for other national or European budgets. These tests are generally highly promising regarding the ability to monitor natural fluxes at the country scales throughout Western and Central Europe. Assuming a decreased uncertainty from transport model or from the prior estimates reveals to be more critical than the extension of the network in areas where the network is already dense.

The second set of experiments assesses the potential of existing or far denser (e.g. assuming each ICOS site would monitor 14C) networks of 14CO2 measurements for a large scale monitoring of anthropogenic emissions of CO2 in Europe. The inversion is based on a global transport model at ~3° resolution and controls country scale monthly budgets. The initial configuration is optimistic regarding the ability to filter the signature of anthropogenic emissions in 14CO2 measurements, ignoring that from natural fluxes. However, special care has been taken to quantify the impact of uncertainties in the emissions and concentrations at scales higher than these solved by the coarse transport and inversion systems since this underlies the main limitations of large scale approaches. The tests generally indicate some high potential for monitoring high emitting regions in Eastern France, Benelux and Western Germany but rather low uncertainty reduction for the largest part of Europe. Experiments using continental scale transport modelling at higher resolution are needed to refine these challenging results for large scale approaches since the signature of anthropogenic emissions strongly increases at 0.5°-1° resolution.

Surface CO2 flux in weekly temporal resolution over the 1 globe inferred from the CONTRAIL dataset - Shoichi Taguchi

In this global study it was shown that increments from areas with large emissions from North Eastern U.S.A can be picked up by measurements over Europe by commercial aircrafts like performed in the CONTRAIL project. Using the high resolution STAG atmospheric transport model an inversion system was setup for 64 regions on the globe. Clear evidence was found that misfits between modelled and observed concentrations could be explained by updates of emissions at regions with high ecosystem exchange.

Inverse modeling of CH4 and N2O emissions for verification of national inventories - current status and challenges - Peter Bergamaschi

In this presentation results of the inverse modeling of European CH_4 and N_2O emissions, performed in the framework of Nitro-Europe, were presented, including also first, preliminary CH_4 results from the InGOS project. The inversions use the (limited but growing) European network of 10-20 stations using four different model systems. Three inverse models yield higher total CH_4 emissions from North-Western and Eastern Europe compared to bottom-up emissions reported to the UNFCCC, while one model is close to the UNFCCC values. For The UNFCCC CH_4 inventories, relatively low uncertainties are reported (on the order of 20-25 % per country), which is smaller than the difference between UNFCCC and EDGAR for several countries. Especially, CH4 emissions from fossil fuels appear to be very uncertain, and could be potentially underestimated. On the other hand, however, due to potential common systematic errors in the transport models, conclusions on the total emissions derived in the flux inversions should be drawn with extreme caution and require more detailed analyses of the performance of the transport models The model validation performed in InGOS, comparing the important parameter Boundary Layer Height in the models with observations demonstrates the need to further improve the models. Also the use of tracers like ^{222}Rn and especially vertical gradients of this gas, with the now improved ^{222}Rn emission estimates for Europe will be a powerful tool to evaluate and improve model performance and reduce the biases introduced by these models in inverted fluxes due to errors in the vertical mixing and transport.

An interactive tool to analyse the benefit of CO2 flask concentration and CO2 eddy-flux measurements in determining terrestrial CO2 sources and sinks - Marko Scholze

In this talk an interactive software tool was presented that allows to evaluate the value of observations from either CO2 exchange fluxes, atmospheric flask and/or continuous concentrations of CO2 on the error reduction of estimates of the net CO2 exchange fluxes at the global grid scale. The software tool is based on a CCDAS (Carbon Cycle Data Assimilation System) framework. One of the main features of CCDAS is that the model will update fluxes by adjusting parameters in the parameterization of the biospheric CO2 exchange fluxes in order to minimize the mismatch between observations and modelled values. The system works on a global scale and distinguishes 13 Plant Functional Types (pft) and optimizes 57 process parameters of which 3 are dependent on PFT.

The tool uses observational measurement uncertainties as an input and based on these it evaluates the improvement, defined as the reduction in uncertainty relative to the a-prior uncertainty without observational constraint, of simulated NEP and NPP over three regions (Europe, Russia and Brazil) over a period of 20 years. It is also possible to look at global NEP uncertainties at 2 x 2 degree resolution.

Some theoretical networks were tested consisting of just atmospheric flask sites, just flux sites, just continuous atmospheric sites and a combination of flux and flask sites. The tool suggests that the last combination seems to work best. An unbalanced flux network with underrepresentation of important PFT’s would result in bad results. In this setup a continuous atmospheric network performs only well in the region that it covers. The results for a network with a combination of a flask and continuous concentration measurement network was not shown. A larger number of PFT's would require a substantial increase in the flux network.

Summary of the discussions

In order to answer the question which network is needed for ICOS and to say how many stations are needed, at which locations, which components should be measured at which frequency and which precision and measurement compatibility demands should be required, it should first be clear what the objectives of ICOS actually are. And there we have a problem not to get trapped in an endless loop because what we can do and are doing now will actually limit what we will be able to achieve. And the available resources are limited.

The rationale behind ICOS is to provide the observations needed to monitor the state of the carbon cycle in Europe. That is clear.

Historically the emphasis of the ICOS network has been on determining the carbon balance of natural vegetation, with again an emphasis on forests for the ecosystem (flux) observations and on background locations for the atmosphere, all strongly focused on CO2 only. However anthropogenic impacts on climate through the greenhouse gas balance extend to other gases and environments. Capturing this in detail would require to extend and modify the network drastically. Societal interest in the overall greenhouse gas balance of Europe including the anthropogenic influence in emissions related to land use changes, water surfaces and urban environments is an important incentive to widen the ICOS scope. And there are also good scientific arguments to not study just a part of the system but to take a holistic view on the system including the human influences, as they cannot be separated in the observations and all need to be interpreted together.

Also science and its models are evolving and need to be further developed. For example increased spatial resolution of atmospheric transport models makes stations as receptor points in the grid better represented and now allows (and even requires) that stations can be closer to large sources and sinks. We also learned that these models can have significant biases due to errors in for example vertical mixing that can be evaluated using additional passive tracers like ^{222}Rn or SF_6. All this requires additional observations at different locations.

In order to go beyond expert knowledge and practical conditions (current network, costs, and logistical arguments) we need 'objective' tools to define the best network that would fulfill the requirements that follow from the scientific objectives. The state of the art (data assimilation) models are the best tools for that, as long as we keep in mind continuously the limitations of these models. And in using these models we can also build in some of the limitations by using the existing network as the basis, taking into account cost constraints, limits on precision and biases (in observations and models).

Nice is also that the network will allow to test and improve these same data assimilation systems so that the information and the quality of the information we get from the networks will increase with time. Which again will lead to possibilities to improve the network design. Care should be taken of course to guarantee also the continuity of the network but within practical limitations the network should be a dynamical system that evolves in accordance with the knowledge that it provides.

The presentations at the workshop are good illustrations of the analyses that we can make today for the current and possible future networks. It will be essential to use the information from these analyses in setting up of the national networks and to keep on performing these analyses also in the future using the best available models and new observational data.

The ICOS Carbon Portal can assist as the natural place where the data from the networks can be stored, retrieved, viewed and distributed and where the models can retrieve the observational data and contribute their (Level-3) results on retrieved overall budgets and flux estimates, as well as accumulated footprints of emission sensitivity and flux uncertainty reduction maps for possible and existing stations in the network.

Specific recommendations from the workshop

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- Test potential atmospheric measurement sites first by installing simple (Picarro) observations for a few months to get an idea of the concentration variations at the site: pre-setup measurements. No extensive target and calibration measurements are needed, just a sampling line, a pump and a Picarro G2401 instrument. This approach is currently taken by ICOS Germany (German Weather Service).
- 14C sampling and analysis is expensive, so first we should limit the observations to a selected few sites and learn how diurnal variations look like (high frequency sampling, short campaigns) and what the seasonal variation is (low frequency, long campaign), before deploying into the whole network. A dedicated working group will develop this strategy: Ingeborg Levin, Wouter Peters, Felix Vogel, Gregoire Broquet, Sanam Vardag, Marc Delmotte.
- A working group will make a design for tools for the CP for users to explore the uncertainties in fluxes of CO2 with current and future network(s); Christop Gerbig, Gregoire Broquet, Alex Vermeulen and Marko Scholze.
- Work is needed on further improving transport models and including additional tracers and getting more/better and assimilating PBL height measurements, a follow-up for InGOS and ICOS Inwire is recommended, where this should be an important part of the work.
- A task force for evaluation policyrelated questions is needed. Should be led by JRC and should involve EEA, IASA, ICOS HO.

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Financial information

Room, audiovisuals:	€ 1 080
Catering+meals:	€ 1 662
Total cost	**€ 2 742**

ESF Grant	€ 2 500
InGOS contrib.	€ 242
Total Budget	**€ 2 742**