WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

WMO Greenhouse Gas Monitoring Infrastructure: An Emerging Tool to Support Mitigation Action under the UNFCCC and the Paris Agreement

Toward an operational GHG Monitoring Infrastructure

Lars Peter Riishojgaard, WMO Secretariat

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

The work presented here includes contributions from:

WMO Joint Study Group on Greenhouse Gas Monitoring (SG-GHG):
Michel Jean, Chair, Greg Carmichael, Vice-Chair
Tuula Aalto, Erik Andersson, Daniele Biron , Manola Brunet , Kevin Cossel, Paul Counet, Han Dolman, Bruce Forgan, Pierre Friedlingstein, Tobias Fuchs, Alistair James Manning, Yasjka Meijer, Joe Melton, Frank Muller-Karger, Lucia Perugini, Vincent Henri Peuch, Chao Ren, Paolo Ruti, Yosuke Sawa, Ariel Stein, Kiyoto Tanabe, Toste Tanhua, Matt Tully, Jocelyn Turnbull, Sara Venturini , Alex Vermeulen, Anya Waite, Salah Zeinab, Xingying Zhang, Xiaochun Zhang

SG-GHG Task Team members *(in addition to names listed above)***:**
Toshinori Aoyagi, Antonio Bombelli, Gabrielle Canonico, Christa Marandino, Meghan Cronin, Mark Dowell, Richard Engelen, Warren Joubert, Andrea Kaiser-Weiss, Frank-Thomas Koch, Dagmar Kubistin, Werner Kutsch, Jan Newton, Yosuke Niwa, Osamu Ochiai, Michel Rixen, Zeinab Salah, Emmanuel Salmon, Mike Smit, Hiroshi Suto, Colm Sweeney, Tuula Aalto, Felix Vogel, Anya Waite.

May 2022 WMO GHG Monitoring workshop *(in person):* Stephen Briggs, Pep Canadell, Greg Carmichael, Philippe Ciais, David Crisp, Phil DeCola, Han Dolman, Mark Dowell, Yana Gevorgyan, Akihiko Ito, Vincent-Henri Peuch, Joanna Post, Anthony Rea, Stephen Sitch, Mike Smit, Vijay Soni, Martin Steinbacher, Colm Sweeney, Claire Treat, Alex Vermeulen, Brad Weir, Xingying Zhang, Wenjian Zhang

July 2022 GHG Modeling Workshop *(online):* Arlyn Andrews, Toshinori Aoyagi, Brendan Byrne, Frédéric Chevallier, Phil DeCola, Richard Engelen, Akihiko Ito, Anna Karion, Liangyun Liu, Kimberly L. Mueller, Osamu Ochiai, Lesley E. Ott, Jeff Privette, Nobuko Saigusa, Yosuke Sawa, Hiroshi Sudo, Colm Sweeney, Brad Weir, James R. Whetstone, John Worden, Nan Zhang, Peng Zhang, Xingying Zhang, Xiaochun Zhang

WMO Secretariat staff:
Lars Peter Riishojgaard, Oksana Tarasova, Kenneth Holmlund, Jitsuko Hasegawa, Bonnie Galvin, Zoya Andreeva, Sergio Moreno, Bin Qu

Problem Statement *(I)*

Anthropogenic emissions of greenhouse gases (primarily CO2, CH4 and N2O) are the primary drivers of currently observed climate change;

Paris Agreement approved in 2015 as part of the UNFCCC, following on to the Kyoto Protocol, aiming to hold the increase in global mean temperature well below 2.0^{o} C (preferably 1.5^{o}), via reduction of GHG emissions;

This is not a simple and straightforward proposition!

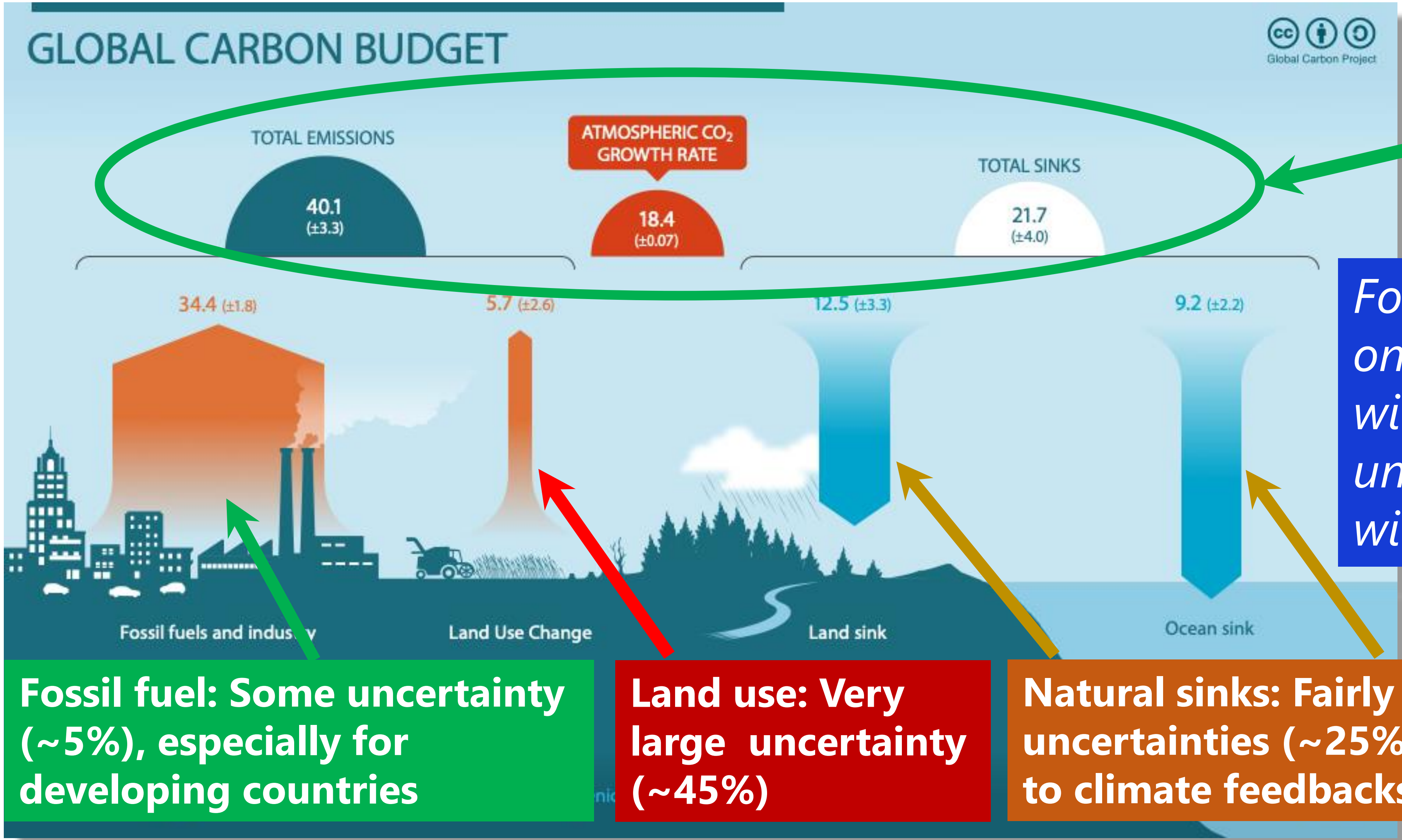
It is not simple from a policy perspective, and it is not simple even from a scientific perspective;

Greenhouse gas concentrations are influenced also by natural processes, some of which add and remove far more GHGs than anthropogenic processes;

This means that successful mitigation must be based on monitoring and understanding of GHG concentrations and all GHG fluxes, whether natural or anthropogenic.

How well do we understand the CO_2 fluxes ?

(Graphic by the Global Carbon Project)



Top level global budget is well understood

Focusing our efforts only on the areas with low uncertainties (green) will not work!

Fossil fuel: Some uncertainty (~5%), especially for developing countries

Land use: Very large uncertainty (~45%)

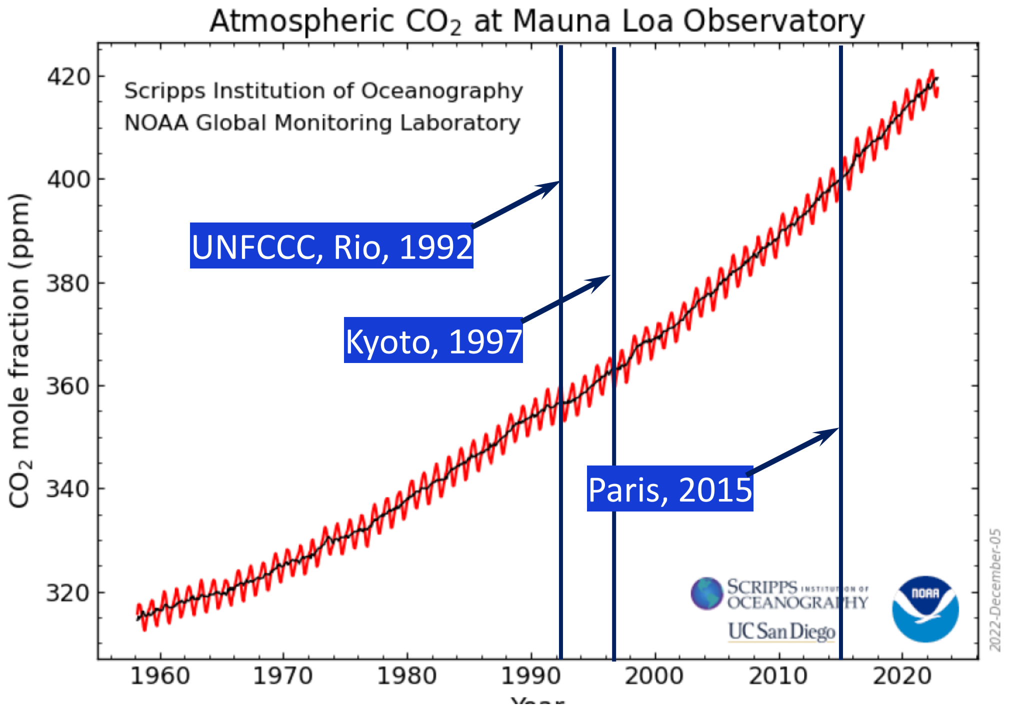
Natural sinks: Fairly large uncertainties (~25%); subject to climate feedbacks

Problem Statement *(II)*

- The Paris Agreement focuses on GHG *emissions* and on tracking these via development of accurate *emission inventories;*
- ”Emissions” can be negative as well as positive, and the standards for negative emissions, used for carbon offsets and carbon credits are relatively poorly regulated and ineffectively monitored;

The climate responds to the atmospheric ***GHG concentrations****, not to what we claim to be doing to reduce or offset our GHG emissions;*

So far, neither UNFCCC (1992), the Kyoto(Protocol (1997) nor the Paris Agreement (2015) has had any impact on the steady rise in CO2



Two basic ways to monitor how Greenhouse Gas concentrations change:

(much more comprehensive analysis in 2022 US National Academies Report on GHG Emissions Information)

Bottom up *(used e.g. by IPCC TFI)*

Based on local estimation, modeling of individual sources and sinks of carbon;

Advantages

- High level of standardization (IPCC);
- Detailed, sector-specific information;
- Can provide very accurate estimation of anthropogenic ***emissions***;
- Relatively low cost; relying on existing economic data and process modeling;

Disadvantages

- Time lag;
- Focuses on annual totals;
- Requires good national statistics;
- Country specific information on emission factors is not applicable in all countries;
- Works best for anthropogenic ***emissions***.

Top down *(still not widely used)*

Based on systematic observations of atmospheric carbon (or GHGs) over extended periods of time, combined with **modeling/data assimilation;**

Advantages

- Global coverage;
- Can accommodates many different scales;
- Applies to all GHG sources and sink; provides estimates of *net* ***fluxes*** rather than of emission;
- Allows for spatial mapping;
- Improved/faster timelines in ***flux*** estimates;

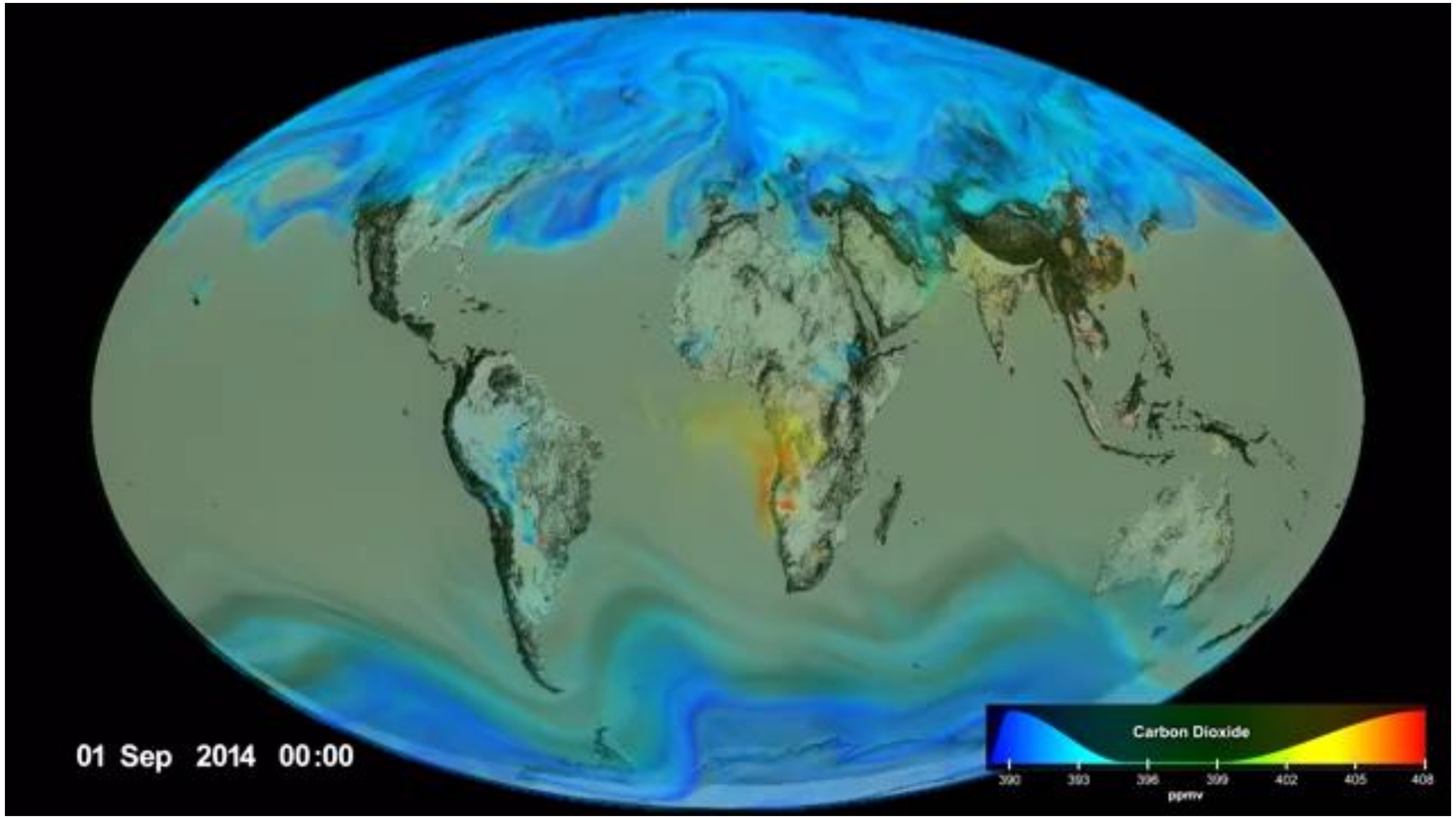
- **Disadvantages**
  - Relatively high cost (requires global coverage of observations, comprehensive Earth system modeling/assimilation framework);
  - Net ***fluxes*** cannot easily be discriminated to the level of individual sectors;

How can we improve our understanding of the processes controlling GHG concentrations?

*By monitoring the behavior of GHGs using via **top-down** approach similar to the one that has led to success in weather prediction and climate monitoring:*

Currently GHG monitoring not done this way

- **Near-real-time international exchange of all greenhouse gas observations**, both from satellite and surface;
- Modeling and assimilation systems running **continuously** to convert observational input into *coherent, optimized estimates of greenhouse gas concentrations and fluxes;*
- Framework for direct intercomparison of model output and verification against independent data;



NASA Goddard Space Flight Center

Workshop organized by WMO, May 2022 - "The case for a coordinated GHG Monitoring Infrastructure"

- More than 20 experts in person; 80 online participants, including representatives from NASA, NOAA, NIST, JAXA, NIES, JMA, CMA, ESA, European Commission, UNFCCC,…
- Surface- and space based observing systems;
- Ocean carbon;
- Land surface observation and modeling;
- Cryosphere;
- Modeling, data assimilation;
- Program and project managers and coordinators;
- WMO Members and their staff;

Following this Workshop, WMO, with a broad group of stakeholders, is developing a concept for top-down, internationally coordinated routine global Greenhouse Gas Monitoring Infrastructure (GGMI)

Main elements:

- Integrated observing system for greenhouse gases (surface- and space-based) building on existing capabilities;
- Earth system modeling with data assimilation tracking CO_2, CH_4 and N_2O concentrations;
  - Coupling with ocean and land biosphere models (level of refinement still TBD);
- Timely international exchange of all observations and relevant model data;
- Common approach to quality assurance , intercomparison of model output.

Relevant experience of WMO

- Observational data requirements, network design, regulatory approaches, mechanisms for sustainable funding for observations (GBON and SOFF);
- Systems and protocols for real time international exchange of observations and model output;
- International collaboration on intercomparison and quantitative assessment of model output;
- Co-sponsor of GCOS (observations) and WCRP (research, modeling);
- Greenhouse gas monitoring as a research activity since1975 (GAW), modeling since 2015 (IG3IS);

The WMO World Weather Watch as a paradigm

Many of the elements of the GGMI already exist or are being developed

- building on GEO Carbon Strategy, Copernicus Reports (2015, 2017, 2019), US National Academy of Sciences Report (2022)

Several countries and international organizations investing in carbon monitoring capabilities:

- Surface-based observations
- Space-based observations
- Modeling
- Data assimilation

Elements to be strengthened:

- Observational data coverage;
- Sustainability of funding (obs.);
- Routine exchange of observations;
- Routing modeling/data assimilation
- Agreement on metrics of skill
- Routine model output intercomparison

OCO-3 Orbiting Carbon Observatory

GLOBAL ATMOSPHERE WATCH

Copernicus Europe's eyes on Earth

TCCON total carbon column observing network

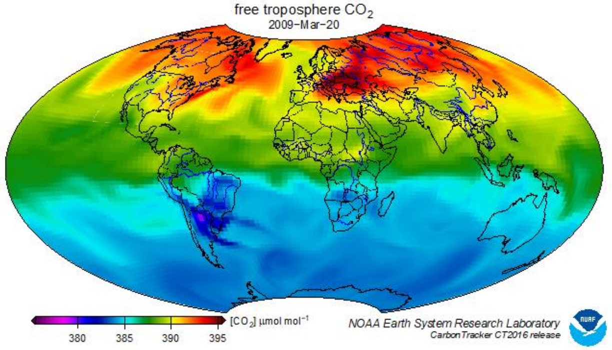
ICOS Integrated Carbon Observation System

GOSAT-2 PROJECT AT THE NATIONAL INSTITUTE FOR ENVIRONMENTAL STUDIES

NASA Carbon Monitoring System

TANSAT

Global Carbon Project



INTERNATIONAL OCEAN CARBON COORDINATION PROJECT IOCCP

Primary GGMI output

- Time-continuous global fields of **3D GHG (initially CO2, CH4 and N2O) concentrations**;
- Consolidated, top-down, **monthly estimates of *net* GHG fluxes at a global 100 by 100 km resolution** (initial target, to be increased as capabilities develop);
- Source attribution is not the primary initial target but will be develop as capabilities grow to include e.g. isotope measurement and co-emitted species;

Intended users of GGMI output

- Parties to the Paris Agreement (i.e. countries);
- Various public and private entities who are are responsible for reporting on and verifying their emissions;
- Participants in regulatory and voluntary carbon markets;
- The scientific community working on GHG Budgets;
- IPCC, as input to emissions pathways and future climate scenarios;

Role of GHG monitoring in the UNFCCC and the Paris Agreement

(as of now there is no role; Paris Agreement does not include observation-based monitoring!)

The Rio UNFCCC text anticipates potential changes; *the Conference of the Parties (COP) shall (art. 10):*

(d) Promote and guide, in accordance with the objective and provisions of the Convention, the development and periodic refinement of comparable methodologies, to be agreed on by the Conference of the Parties, inter alia, for preparing inventories of greenhouse gas emissions by sources and removals by sinks, and for evaluating the effectiveness of measures to limit the emissions and enhance the removals of these gases;

- IPCC Task Force on Inventories recognizes atmospheric observations as a valuable complement to bottom-up approaches;
- 20222 GCOS Implementation Plan inc

WMO believes that the data from this sy

- Global Stocktake;
- Work programme for urgently scaling
- IPCC Assessment Reports;
- National Inventories;
- Enhanced Transparency Framework;
- ….

In order for GHG monitoring to be able to provide authoritative data to Parties, it must be conducted

- Openly - with participation from all interested Parties;
- Transparently – with free and unrestricted access to all input and output data;
- Using documented (preferably published) methodologies and algorithms:

Next steps

- ***WMO International Greenhouse Gas Monitoring Symposium in Geneva, January 30 –February 1, 2023;***
- Global Greenhouse Gas Monitoring program development proposal being prepared for 19th World Meteorological Congress in June 2023;
    - Executive Council in Feb/March 2023 is part of the process; documents shared with you on January 25;
- Next, we will development a full implementation plan, hopefully in collaboration with many of you;
- Potentially dedicated meetings later in the year on (i) Exchange of observational data, (ii) Data management, (iii) Protocols for model/assimilation runs, exhange of output, (iv) Metrics of skill; (v) GHG exchange processes;...