Response to Scientific Review of CarbonTracker
for NOAA's Climate Working Group

NOAA Earth System Research Laboratory
Global Monitoring Division

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1. Background

The review of NOAA's Climate Research and Modeling program in March 2008 concluded that a detailed, scientific review specific to the CarbonTracker program was warranted. In direct response to this conclusion, the NOAA Earth System Research Laboratory convened a panel of carbon cycle and modeling experts on 16 September 2008 to conduct a scientific and technical review of the CarbonTracker (henceforth, CT) program. The review panel delivered its report on 28 September 2009 (http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/review_files/CT.review%2020090928.pdf). This document details the CT response to that review.

2. Review findings and recommendations

The review panel was gracious in its praise of CT's progress to date. In addition to their compliments, the major findings of the review panel were:

- **F1.** CT is understaffed;
- **F2**. CT should expand its use of computing resources;
- **F3**. CT should benefit from other NOAA modeling efforts, specifically the prognostic carbon models of GFDL and the meteorological state estimation of NWS;
- **F4.** The presentation of CT results should emphasize its native scale of estimation instead of higher-resolution 1˘x1˘ maps;
- **F5**. CT should assimilate other CO_2-relevant data such as eddy covariance fluxes and remote observations of the sea-surface;
- **F6**. The CT inversion system is limited by a 5-week estimation window, by its use of assumed fossil fuel emissions, and by difficulty in estimating true uncertainties; and
- **F7**. CT should not be oversold as an emissions verification tool.

The panel made three broad recommendations for the CarbonTracker program:

R1. NOAA should consider CT as a prototype of an integrated earth system analysis that links observations, modeling, prediction, and dissemination of results;

R2. In the near term there should be an increase in personnel (3x) and computing resources (10x) for CT, and this expansion should include efforts to integrate with and benefit from other NOAA carbon, climate, and weather modeling programs; and

R3. NOAA should pursue a major expansion of its greenhouse gas observation network.

Finally, the panel identified four perspectives from which to view CarbonTracker's role within NOAA:

P1. As a device for carbon cycle diagnosis and analysis;

P2. As a platform for rationalizing enhancements to the observation network;

P3. As a development testbed for earth system model components; and

P4. As a tool for research into the changing carbon cycle.

3. NOAA/ESRL response

The response by NOAA/ESRL and the CT team to comments by the CarbonTracker review panel and the CRM review panel comprises specific enhancements in the CT2009 and upcoming CT2010 releases of the CarbonTracker product, ongoing developments of the CT program, and two broader initiatives: the creation of a NOAA Carbon Cycle Research Plan, and attempts to increase the CT budget.

NOAA Carbon Cycle Research Plan In February, 2009, representatives from NOAA's PMEL, AOML, and GFDL gathered at ESRL to begin work on a coordinated plan for observations, analysis, and modeling for NOAA carbon cycle research. This emerging document is seen as a way of directing NOAA carbon cycle research, by coordinating observational programs, sharing modeling resources, and collaborating on analysis efforts. This plan should help to address panel findings **F2**, **F3**, and **F5** above, by providing a framework for sharing analysis products like the pCO_2 air-sea flux maps being generated at AOML and PMEL, and by sharing model products between GFDL and ESRL. Furthermore, it promotes the across-laboratory vision for using contemporary atmospheric CO_2 observations to evaluate and constrain climate models (**P3**, above), and recommendation **R1** involving the creation of an integrated earth system analysis. A draft of the plan is being circulated among the authors this summer, with broader circulation within NOAA anticipated for this fall.

FY11 Budget Increase A funding alternative including a significant increase for greenhouse gas observations and modeling at ESRL was proposed to NOAA for FY2011. This alternative was successful through the entire planning process at NOAA and the Department of Commerce, and was included in the FY2011 President's Budget. The additional funds, pending Congressional approval, will be devoted to increased atmospheric CO_2 observations, to data management efforts, and to increased manpower for CT modeling. This is a direct response to **F1**, **R2**, and **R3** above.

Collaborations with academic institutions We have a vigorous program of active collaborations with academic institutions. We have trained researchers from U Wisconsin, U Michigan, Colorado State University, UC Irvine, Berkeley, Oregon State, and Penn State University to work with CT results and models. Numerous proposals have been generated with several notable successes already leading to postdoctoral position advertisements. The increased scrutiny of CT results has proven invaluable for identifying CT strengths and weaknesses (**F6**), and in the absence of direct funding increases, these collaborations are essential for addressing the finding **F1** of personnel shortages. It should be noted that these collaborations do not directly address NOAA's CT development priorities, since they are generally funded to use the existing CT platform as an analysis tool.

Collaborations within government The CarbonTracker effort is seen as a notable success for the North American Carbon Program (NACP), and CT team members are strongly involved with NACP activities. The Department of Energy has shown significant interest in collaborating on CO_2 modeling, and CT members have active accounts on supercomputers at Sandia National Labs and Oak Ridge National Labs. The current CT implementation does not scale well to using large numbers of CPU cores, but establishing the ability to exploit expanded computing resources is a high priority for CT development (*cf*. recommendation **R2**).

International collaborations In addition to the domestic partners from academia and government mentioned above, the CT program has generated significant interest from international collaborators. Due to its use of regional high-resolution transport, the CT framework lends itself to other implementations. To date, the CarbonTracker Europe (Wageningen University) and CarbonTracker Asia (Korean Meteorological Agency) efforts have been most prominent. Regional CT simulations for China, Canada, New Zealand, and Brazil are all currently underway. This community of collaborators is promoted by the philosophy of complete openness within the CT project at NOAA, and having these partners indirectly addresses panel findings **F1** and **F6**.

CT2009 release The October 2009 release of the CT product incorporated several significant changes in response to review panel concerns. We emphasized the ecoregion-scale estimation scheme by presenting "patch" flux maps as the primary visualization tool; we developed documentation pages specifically aimed at describing the ecoregion flux estimation scheme, and rolled out several

documentation upgrades on uncertainty estimation and the effects of design decisions in our inversion scheme. These enhancements address finding **F4** directly, and begin to address finding **F6**.

OGP – GCC sponsored research Two research proposals for CT development were funded by NOAA's Global Carbon Cycle program. The first, led by Wouter Peters, Kevin Schaefer, and John Miller of the University of Colorado Cooperative Institute for Research in Environmental Sciences (CIRES), Wageningen University, and the National Snow and Ice Data Center, aims to introduce a new terrestrial model into the CT framework, and to explore the direct assimilation of eddy covariance data. This effort directly addresses finding **F5**, and by entraining external partners (Peters and Schaefer), helps to address recommendation **R2**. The second piece of sponsored research is led by Andy Jacobson, also of CIRES, and is an attempt to create a new air-sea flux model driven by pCO_2 observations extrapolated using remote observations of the sea surface. This product begins with GFDL ocean modeling and an air-sea flux inversion generated at the Princeton-GFDL cooperative institute. It builds on observations collected by AOML and PMEL, as well as analyses and modeling efforts at those institutions, thus addressing findings **F3** and **F5** above.

CT2010 efforts A major revision to the CT inversion scheme is planned during FY2011. The CT product will be generated using a multi-model ensemble of two land models and two ocean models. The ocean models both use *in situ* pCO_2 observations to drive flux variability, and one of them uses GFDL assimilated ocean currents. The land models are both tuned to eddy covariance flux observations and other terrestrial carbon cycle constraints. This variety of input data being used to generate prior fluxes goes a long way towards addressing finding **F5** above. The creation of a multi-model ensemble also requires a review of CT's parameter model, and will most likely involve an improvement to the current scheme of estimation scaling factors in a 5-week estimation window. By including multiple land and ocean models, a fuller picture of the true uncertainty should emerge. Both of these developments address finding **F6**.

FIM We are beginning to evaluate the new NOAA FIM (Flow-following, finite-volume icosahedral model) for use in global tracer studies. This model platform is strongly tied to NWS model development, and includes GFS model physics packages and uses GFS analyses as initial conditions. In collaboration with other divisions at ESRL, an ensemble Kalman filter for weather data assimilation has been ported to the FIM, and the exciting possibility of joint carbon-weather assimilation is now conceivable. This model bridges ESRL and NWS efforts, giving a direct means of addressing finding **F3** and recommendation **R2**. As a potential platform for integrated weather-CO_2 analysis, it addresses recommendation **R1**. Its online tracer transport also provides a means of dramatically increasing the resolution of atmospheric modeling—potentially to 15km scales—and provides a way of better exploiting NOAA computing resources (finding **F2**). By involving a larger NOAA community, this effort also helps to address the personnel shortage identified in finding **F1**.

We take issue with finding **F7**. While CT is currently far from a tool that can be used to verify emissions at a regional scale, we strongly believe that global carbon analysis of this sort is required to identify shortcomings in our understanding of the carbon cycle, including the role of anthropogenic emissions, especially on sub-continental scales. Indeed, at the largest of scales, CT is already a tool for demonstrating (in)consistency of fossil fuel emissions estimates and surface CO_2 exchange with observed atmospheric growth rates. As our models of fluxes and atmospheric transport improve, and as the observational network becomes more complete, the scales at which atmospheric inversions provide constraints on emissions will become smaller. Our belief is that atmospheric verification of CO_2 emissions will be crucial to mitigation efforts, and we need to have tools like CT now to identify modeling and observational shortfalls which limit the utility of the atmosphere to inform policy.

4. Summary

By vigorously pursuing external collaborations with federal, academic, and international partners, the CarbonTracker program is ensuring that there will be increased resources available in the future. While these resources are not dedicated to CT development, this diverse set of collaborations provides a base for improving models and assimilation techniques. At the same time, we are working hard to justify increased direct funding and to coordinate carbon cycle research across NOAA laboratories and have succeeded so far in getting such funding included in the President's FY2011 budget. CarbonTracker continues its program of annual product releases, with incremental improvements to observations and modeling techniques. We remain committed to openness, with the conviction that scrutiny of our product by a wide community will provide the feedback necessary to understand the limitations of our analysis and guide its improvement.