2.4 STATUS OF CURRENT CAPABILITIES AND FUTURE DIRECTIONS FOR CARBON CYCLE DATA ASSIMILATION

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1. INTRODUCTION

Biogeochemical “sinks” in the oceans and terrestrial biosphere currently absorb nearly half of the CO_2 emitted by fossil fuel combustion, but the sink processes are not yet well understood. Our inability to predict changes in biogeochemical processes (e.g., sink saturation or reversal) is currently one of the leading sources of uncertainty in projections of changing climate in the 21st century. Diagnostic modeling and data assimilation is an important way to test quantitative hypotheses about global biogeochemical responses to climate variability and change, and has emerged as a major research focus in carbon cycle science. This effort is analogous to the interaction between meteorological analysis and climate modeling, in which operational experience with forecasting leads to improved physical representations for longer-term simulations. We present examples of diagnostic data assimilation into process-based models of carbon cycling in the ocean, on land, and in the atmosphere.

2. OCEAN CARBON

Ecosystem and biogeochemical models are embedded in physical ocean models, which simulate fluid dynamics, temperature, salinity, and other state variables. Assimilation of a rich suite of observations (e.g., sea-surface dynamical height, temperature, and wind speed from spaceborne sensors and profiles of temperature and salinity by telemetry from autonomous samplers), into physical ocean models allows hindcasting with unprecedented accuracy. Models of ocean carbon cycle processes include air-sea gas exchange, ecosystem dynamics, and transport of nutrients and other biogeochemical constituents in the oceans. Marine ecosystem process models have been developed using many years of in-situ observations and experimental work at a suite of intensive timeseries stations. In forward simulations driven by analyzed weather and satellite data are able to capture many features of available observed variability of air-sea CO_2 flux (Fig 1), and have been used to construct multidecadal reanalyses of the marine carbon cycle (Fig 2). Future capabilities will include near-real-time assimilation of ocean color to constrain the ecosystem model, sea-surface winds measured by scatterometer to estimate

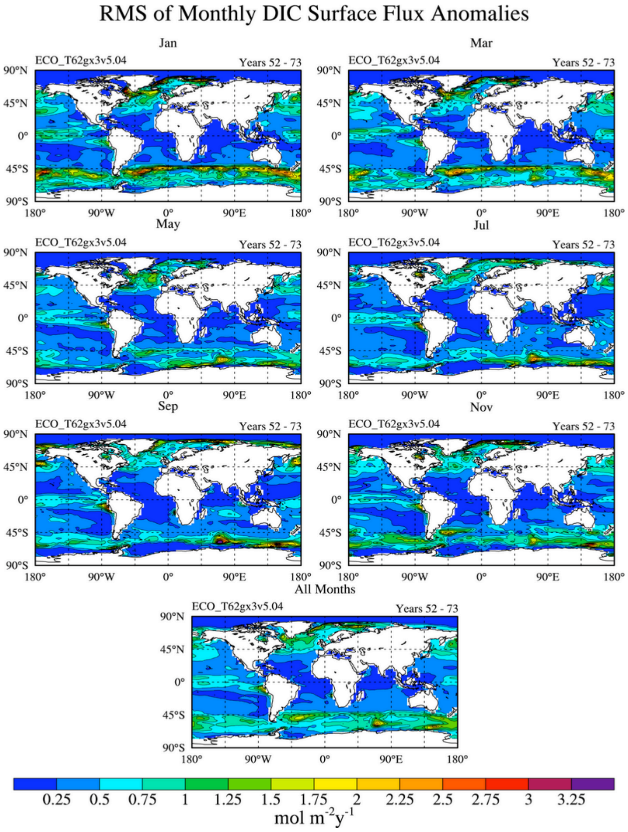

Figure 1: Interannual variability of air-sea CO_2 fluxes from a reanalysis using CCSM-POP.

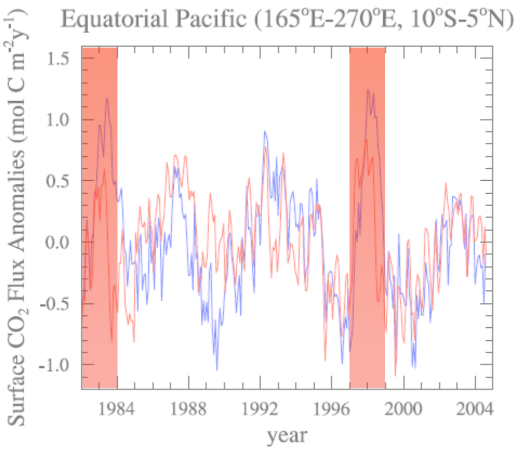

Figure 2: Evaluation of analyzed air-sea flux anomalies in the tropical Pacific, compared

atmospheric CO_2 and other tracers to constrain large-scale sources and sinks.

3. TERRESTRIAL CARBON

Terrestrial carbon cycle models include photosynthesis and respiration; seasonal phenology; allocation, nutrient cycling, and decomposition; biomass burning and wildfires, disturbance and succession; land use and land cover change. Each of these biogeochemical processes at the land-surface has been studied at various scales by networks of eddy covariance measurements, field experiments, and ecosystem manipulations. Biogeochemical models have been driven by spectral vegetation imagery from spaceborne sensors and analyzed weather to construct gridded global reanalyses of past variations in these fluxes on a 1° x 1.25° grid for each hour, and compared to local observations. The interaction of climate variability with these processes produces very large variations in net carbon sources and sinks from year to year, which are coherent over large areas and lead in turn to measurable anomalies in CO_2 and other trace gases at a network of observing sites around the world.

4. ATMOSPHERIC CO_2

Atmospheric carbon cycle processes included in tracer transport models are advection, convection, turbulence, and reactions of carbon gases. A rich suite of observations from both in-situ and spaceborne platforms is also available for comparison to the predictions of such

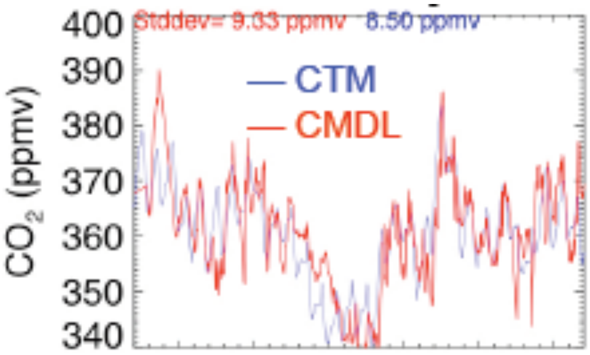

Figure 3: Hourly [CO_2] for July 2004, simulated and observed at 396 m over Wisconsin.

boundary condition to atmospheric tracer transport models and evaluated by comparison of the resulting concentration variations to observations (Fig 3).

Estimation theory and methods have been developed over decades in meteorological and other geophysical data assimilation research and are now being applied to state and parameter estimation in carbon cycle science. Regional sources and sinks of CO_2 can be estimated by inversion of the tracer transport operator through variational or ensemble data assimilation methods. Future observational data constraints on such calculations will be enhanced by a much denser network of in-situ stations and also by dedicated satellite missions to estimate column CO_2, beginning in 2008.

Future capacity for carbon data assimilation will include near-real-time estimation of model parameters, state variables, and model error from multiple observational data streams into fully-coupled nonlinear models of the biogeochemical processes involved. These Earth-system data assimilation efforts will lead to improved understanding of coupled climate-biogeochemical processes and better confidence in climate models.

5. ACKNOWLEDGEMENTS

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