**Airborne Eddy Flux Measurements for Validation of Regional Carbon Flux Estimates from Satellite Data**

Global distributions of greenhouse gas (GHG) sources and sinks, principally CO2 and CH4, and characterization of the processes that control them, comprise a key uncertainty in projection of future carbon-climate interactions and, hence, climate prediction (US Carbon Cycle Science Plan, 2011; NASA Strategic Plan, 2011). NASA has invested strongly in space missions (ACOS/GOSAT, OCO-2) and programs (CCE, CMS, EV-S1) to address these issues, and appears poised to pursue them further in the future (ABOVE, GEDI, EV-S2, OCO-3, PACE, ASCENDS). Very little information, however, is available to evaluate global source/sink inversions from space data. For example, current OCO-2 validation includes Level 2 (CO2 mixing ratio) products but does not address experimental validation of the inferred fluxes that are the fundamental mission driver [Crisp et al., Adv. Space Sci., 2004]. Bottom up and top down estimates (including forest inventories) don’t match well, even for relatively well-sampled areas like North America. Bottom-up vegetation flux models vary widely among themselves, and their response to climate forcing is apparently limited and not adequately tested. Flux tower data are notoriously local site-specific with large spatial variability. Furthermore, requirements for CMS treaty-relevant monitoring, reporting, and verification or Reducing Emissions from Deforestation and Forest Degradation are likely to be extremely stringent compared with current research-level uncertainties and very difficult to quantify on a regional scale. All of this points to an emerging need for NASA to develop a capability for direct validation/evaluation of GHG surface fluxes, which can be most directly obtained regionally via airborne eddy covariance measurements.

The eddy covariance flux measurement technique is well established, but historically NASA has had limited involvement in these measurements. Flux tower measurements, e.g., AmeriFlux, have been valuable in characterizing fluxes over a range of surfaces, but sub-regional variability makes them difficult to compare to grid-scale fluxes as inferred from space data. The use of aircraft is necessary to bridge the flux representation scale from about a kilometer or less, as measured from towers, to tens or hundreds of kilometers in a global model. Airborne eddy covariance provides a method for direct flux computation over regional scales under suitable conditions. NASA employed eddy covariance measurements from several of their aircraft in the 1980s and 1990s for tropospheric chemistry studies, but that facility has waned in recent years.

The potential for new deployment of relatively inexpensive instrumentation for GHG flux measurements is enabled by new commercial off the shelf (COTS) instruments using advanced laser detection methods (Los Gatos Research (LGR), integrated cavity output spectroscopy/ICOS). These and similar COTS instruments (Picarro, Inc.) have been demonstrated to have high precision, stability, and ruggedness previously attainable only with highly specialized research equipment. Airborne systems for CO2 flux are in use by several groups and CH4 has only recently been tested. Development of a GHG flux measurement package requires integration of the trace gas analyzer(s) with a gust probe system for measuring vertical wind velocity on a suitable aircraft. We have identified the NASA Wallops Sherpa as a good potential platform given its substantial payload capacity and ability to fly low and slow as required for best eddy covariance measurement. The instrumentation and know-how for the gust probe system is available from several groups including NASA Langley. While the instrumentation is relatively turn-key by design, implementation for airborne eddy covariance is a sophisticated endeavor requiring a range of specialized experience – something that NASA is uniquely situated to provide.

The initial objective of this effort is to build a NASA airborne system for eddy covariance measurements of regional GHG fluxes and to use this system to obtain flux data for a range of ecosystem states and land use regions. Such measurements are needed to evaluate CO2 and CH4 top-down and bottom-up source/sink estimates, including: validation of top-level OCO-2 products and other space-based GHG missions, evaluation and improved parameterization of biogeochemical flux models, and application in airborne science campaigns of opportunity. Near-term targets for deployment include OCO-2 validation and Arctic boreal process studies (ABOVE, CARVE follow-on) possibly through Earth Venture-Suborbital 3 (EV-S3 expected in 2018). Eventually, the GHG system could become a key component in a NASA CMS validation strategy including fugitive emissions from energy exploration and production. The ultimate payoff will be to establish NASA as the leading US institution for integrated carbon cycle science, from space measurements to earth system modeling to data assimilation, with quantitative assessment of uncertainties using the best available validation methodology.

The airborne GHG flux measurement facility would provide a new tool for NASA Earth Sciences. The future development path for the eddy flux system could expand to instrumentation for other atmospheric chemical species and possibly aerosol, for which surface flux information is needed. For example, a flight series to quantify vegetation emission fluxes of isoprene (CH2O) and other ozone precursors under varying environmental conditions would help to constrain our understanding of air pollution sources and the effect of reduction policies, which is part of the science motivation for the Tropospheric Emissions: Monitoring of Pollution (TEMPO) space instrument. Many other potential airborne science and application missions can be envisioned.