Final Report

Biosphere-Atmosphere Interactions

A NASA Earth Observing System (EOS) Interdisciplinary Science (IDS) Investigation
1991-2000

Principal Investigator‡

Inez Y. Fung
Center for Atmospheric Sciences
University of California, Berkeley
307 McConne Hall, MC 4767
Berkeley, California 94720-4767
phone:  (510) 643-9367, 643-8336
fax:   (510) 643-9377, 643-9980
email: ifung@uclink4.berkeley.edu

Co-Investigators

J. A. Berry Carnegie Institution of Washington
G.J. Collatz Goddard Space Flight Center
R. DeFries University of Maryland
A.S. Denning Colorado State University
R.E. Dickinson Georgia Institute of Technology
C.B. Field Carnegie Institution of Washington
S.O. Los Goddard Space Flight Center
P. Matson Stanford University
H. Mooney Stanford University
D.A. Randall Colorado State University
P.J. Sellers Johnson Space Flight Center
C.J. Tucker Goddard Space Flight Center
S.L. Ustin University of California, Davis
P. Vitousek Stanford University

‡ Responsibilities for the Principal Investigator have rotated from P.J. Sellers/H. Mooney to D.A. Randall (1996) to I. Fung (1998)
Background and overview

Our NASA Earth Observing System- Inter-Disciplinary System (EOS-IDS) team has played a central role in advancing earth system science understanding the past decade. “Biosphere-Atmosphere Interactions” is an EOS-IDS team selected in the original competition in 1991. At the suggestion of NASA management, the team resulted from the merger of Piers Sellers’ group in global scale modeling and observations and Harold Mooney’s group in local-scale biophysical and biogeochemical processes. Principal investigator responsibilities, initially in the hands of Piers Sellers, transferred to Dave Randall in 1996, and rotated to Inez Fung in 1998.

The focus of our work the past 10 years has been atmosphere and biosphere exchanges of energy, water, carbon, and other trace constituents at all space and time scales. The exchanges are dependent on and, in turn, alter the states of the biosphere and the atmosphere. The ten years of research of our IDS project has resulted in tremendous progress in the study of biosphere-atmosphere interactions. The progress has come from global and multi-temporal satellite and in situ observations of ecosystem variations, and the modeling of the biophysics and biogeochemistry on scales compatible with global climate models. Satellite observations have been fundamental to our research.

The research of the IDS team has integrated the diverse scales and approaches of the Sellers and Mooney groups into single-framework investigations. The global-scale multi-temporal NDVI observations is a major team product, and has served as the starting point for the biophysical and biogeochemical modeling of different aspects of biosphere-atmosphere interactions. Satellite data are required to understanding the spatial and temporal variability of biospheric processes, and the modeling studies have stimulated an exploration of their consequences on climate and atmospheric composition.

We have used the 1981-1999 advanced very high resolution radiometer to represent global variations in photosynthetic capacity and related variables through time. The same AVHRR data, augmented by Landsat data, have been used to produce improved descriptions of land cover. The unique contributions of satellite data enabled us to simulate biosphere-atmosphere interactions with unprecedented accuracy and realism. Our work is continuing, as we incorporate improved satellite data streams from the Terra Platform into our studies of biosphere-atmosphere interactions through a partial continuation of our previous work. We are presently working to make the transition to MODIS, MISR, and ASTER data as we continue our studies into the new millennium. Satellite data will continue to be a fundamental component of our biosphere-atmosphere interaction research. It is impossible to capture the spatial and temporal complexity of the biosphere which our advanced coupled models require without using satellite data.
Major Accomplishments of the IDS project “Biosphere-Atmosphere Interactions”

- Global distributions of land surface properties have been derived from satellite observations for use in GCM studies of energy and water exchange [Defries and Townshend, 1994; Sellers, 1995; Sellers et al., 1995].

- We have produced a global 20-year time series of NDVI by merging and intercalibrating observations across different instruments on different polar orbiters [Loš, 1993 and 1998; Malmstrom et al., 1997]. We have succeeded in significant reductions in errors in the NDVI so that the time series can be used to assess interannual variations in vegetation at the global scale [Tucker and Nicholson, 1999].

- We have led the development of a third generation SVAT model SiB2 for incorporation into atmospheric GCMs [Randall et al., 1995 and 1996; Sellers et al., 1996b; Sellers et al. 1996c]. SiB2 incorporates realistic biophysics and links the transpiration of water with the assimilation of carbon. A unique feature of our approach is the a priori incorporation of satellite information into the model formulation and data stream.

- We have developed a new global biogeochemical model CASA that is forced by, inter alia, satellite observations of photosynthetically active radiation and employs distribution of FPAR from NDVI [Potter et al., 1993; Field et al., 1995].

- We have developed a new approach for more realistic characterizing, from satellite observations, land surface variations as a continuum rather than by discrete biomes [Defries et al., 1995; DeFries et al., 1999].

- We first hypothesized that climate variability is a non-negligible contributor to variations in annual imbalances in CO$_2$ net flux [Dai and Fung, 1993]. Using the NDVI time series and an inverse model, we showed that an early growing season at high latitudes is directly observed by the NDVI [Myneni et al., 1997] and is corroborated by analysis, via tracer transport modeling, of the changing seasonal cycle of atmospheric CO$_2$ in the Northern Hemisphere [Randerson, et al. 1999].

- Using SiB2-GCM, we showed that vegetation variability (based on 1981-1990 NDVI) may contribute to the variability in the physical climate [Bounoua et al., accepted in Journal of Climate].

- Using the SiB2-GCM, we showed, for the first time, that direct effects of increased CO$_2$ on vegetation physiology will lead to a relative reduction in evapotranspiration over the continents, with associated regional warming and drying over that predicted for conventional greenhouse warming effects, particularly in the tropics (Figure 1) [Sellers et al., 1996; Bounoua et al., 1999].

- Using the SiB2-GCM, we showed that covariation of seasonally varying CO$_2$ fluxes and the height of the planetary boundary layer contributes to a positive CO$_2$ effect.
concentration in the PBL in the annual mean, even when fluxes cancel in the annual mean (the rectifier effect) [Denning et al., 1995 and 1999]. This finding has significant implications for the magnitudes of CO₂ sources and sinks inferred from atmospheric CO₂ measurements in the PBL.

- Using CASA, we have produced the first global model of C¹³ exchange with the biosphere and first calculation of the isotopic disequilibrium due to the long residence time of carbon in the biosphere [Fung et al., 1997]. The long residence time suggests that C4 vegetation takes up a non-trivial fraction anthropogenic CO₂ [Fung et al., 1997] and that CO₂ fertilization is not the only mechanism responsible for the uptake [Randerson et al., 1999].

- In collaboration with Dickinson’s IDS team, we have participated in the inclusion into GCM climate simulations the effects of nitrogen controls on photosynthesis and hence the water and energy cycles (Dickinson et al., 2000).

- We have initiated modeling of aspects of biosphere-atmosphere interactions other than energy, water and carbon exchange. These include the cycles of oxygen¹⁸ in CO₂ [Ciais et al., 1997; Peylin et al., 1999], mineral aerosols [Tegen and Fung, 1994; Tegen and Fung, 1995; Tegen et al., 1996], and iron [Fung et al., 2000].
Table 1. Major tools and infrastructure developed by the Sellers/Mooney-Randall-Fung IDS team “Biosphere-Atmosphere Interactions” 1991-1999.

<table>
<thead>
<tr>
<th>Description</th>
<th>Reference</th>
<th>Comments</th>
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<tbody>
<tr>
<td>NDVI</td>
<td>20-year time series</td>
<td>[Los, 1993 and 1998; Los et al., 1994]</td>
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<tr>
<td>Biospheric properties from satellite obs</td>
<td>Global vegetation distribution; FPAR; albedo</td>
<td>[Sellers et al., 1995 and 1996b; Defries and Townsend, 1994]</td>
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<td></td>
<td>Continuous fields</td>
<td>[Defries et al., 1995 and 1999]</td>
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<td>Precipitation anomalies</td>
<td>Global, 100-year gridded time series</td>
<td>[Dai et al., 1997]</td>
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<td>Photosynthesis model</td>
<td>Coupled photosynthesis – stomatal conductance model for C₃ and C₄ plants</td>
<td>[Collatz et al., 1991 and 1992]</td>
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<td>CASA</td>
<td>Biogeochemical model</td>
<td>[Potter et al., 1993; Field et al., 1995]</td>
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<td>GCM-SiB2</td>
<td>CSU GCM with SiB2 interactive</td>
<td>[Sellers et al., 1996a and 1996b; Randall et al., 1996]</td>
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<td>Atm tracer transport model</td>
<td>Global, derived from GISS 1997 GCM</td>
<td>[Fung et al., 1983 and 1999]</td>
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<td>CO₂ fluxes</td>
<td>Global, monthly, derived from NDVI and temperature</td>
<td>[Fung et al., 1987]</td>
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<td></td>
<td>Global, monthly, derived from CASA</td>
<td>[Field et al., 1995]</td>
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<tr>
<td>C-13 distributions</td>
<td>Derived from SiB2-GCM and CASA</td>
<td>[Fung et al., 1997]</td>
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Graduate Students and Postdoctoral Fellows Trained

Training graduate students and postdoctoral fellows is fundamental to higher education and our EOS-IDS project has been no exception. Table 2 lists the various students which have received M.S. and Ph.D. degrees supported by our project and also identifies the postdoctoral fellows with whom we have been associated.

Table 2. Graduate students and post doctoral fellows trained under the Sellers-Randall_Fung EOS-IDS Project.

<table>
<thead>
<tr>
<th>name</th>
<th>position</th>
<th>affiliation</th>
<th>degree</th>
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<tbody>
<tr>
<td>Kevin Schaefer</td>
<td>graduate student</td>
<td>Colorado State University</td>
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<tr>
<td>Scott Denning</td>
<td>graduate student</td>
<td>Colorado State University</td>
<td>PhD</td>
</tr>
<tr>
<td>Scott Denning</td>
<td>postdoctoral fellow</td>
<td>Colorado State University</td>
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<td>Algou Dai</td>
<td>graduate student</td>
<td>Columbia University and NASA/GISS</td>
<td>Ph. D.</td>
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<tr>
<td>Ina Tegen</td>
<td>postdoctoral fellow</td>
<td>Columbia University and NASA/GISS</td>
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<tr>
<td>Sietse O. Los</td>
<td>graduate student</td>
<td>Free Univ. Amsterdam &amp; NASA/GSFC</td>
<td>Ph. D.</td>
</tr>
<tr>
<td>Pierre Friedlingstein</td>
<td>graduate student</td>
<td>Louis XVI Univ. of France and GISS</td>
<td>Ph. D.</td>
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<tr>
<td>Chris Potter</td>
<td>postdoctoral fellow</td>
<td>NASA/Ames</td>
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<tr>
<td>Pierre Friedlingstein</td>
<td>postdoctoral fellow</td>
<td>NASA/GISS</td>
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<tr>
<td>G. James Collatz</td>
<td>postdoctoral fellow</td>
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<tr>
<td>Alan Townsend</td>
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<td>Ph. D.</td>
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<tr>
<td>Amy Austin</td>
<td>graduate student</td>
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<td>Ph. D.</td>
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<tr>
<td>Anne Ruimy</td>
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<tr>
<td>Carolyn Malmstrom</td>
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<tr>
<td>Christopher Still</td>
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<tr>
<td>Greg Colelo</td>
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<td>Gregory Asner</td>
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<tr>
<td>James Randerson</td>
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<td>Jason Neff</td>
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<td>Joerg Kaduk</td>
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<td>Laurie Osher</td>
<td>graduate student</td>
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<td>Ph. D.</td>
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<tr>
<td>Manuel Lerda</td>
<td>graduate student</td>
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<tr>
<td>Matt Thompson</td>
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<td>Ted Schuur</td>
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<td>Wei Fu</td>
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<tr>
<td>Xia Li</td>
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<td>Sharon Hall</td>
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<td>Ph. D.</td>
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<tr>
<td>Kevin Gurney</td>
<td>graduate student</td>
<td>UC Santa Barbara/Colo. St. University</td>
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<tr>
<td>Lara Prihodko</td>
<td>graduate student</td>
<td>UC Santa Barbara/Colo. St. University</td>
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<td>William Riley</td>
<td>postdoctoral fellow</td>
<td>Univ. Calif. Berkeley</td>
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<tr>
<td>Lahouari Bounoua</td>
<td>postdoctoral fellow</td>
<td>University of Maryland</td>
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</tbody>
</table>
Our research project has been very active publishing scientific papers. Approximately 230 papers have been published as of June 2000. A bibliography of these follows.


Fung: Biosphere-Atmosphere Interactions


DeFries, R.S., J.R.G. Townshend, and M.C. Hansen, Continuous fields of vegetation characteristics at the global scale at 1-km resolution, *Journal of Geophysical Research-Atmospheres*, 104 (D14), 16911-16923, 1999b.


Fung: Biosphere-Atmosphere Interactions


Sellers, P.J., M.D. Heiser, and F.G. Hall, Relations Between Surface Conductance and Spectral Vegetation Indices At Intermediate (100m2 to 15km2) Length Scales, *Journal of Geophysical Research-Atmospheres*, 97 (D17), 19033-19059, 1992c.


Fung: Biosphere-Atmosphere Interactions


Thompson, M.V., and P.M. Vitousek, Asymbiotic nitrogen fixation and litter decomposition on a long soil-age gradient in Hawaiian montane rain forest, Biotropica, 29 (2), 134-144, 1997.


