Final Report

Biosphere-Atmosphere Interactions

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

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‡ 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 [Lo*s*, 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].

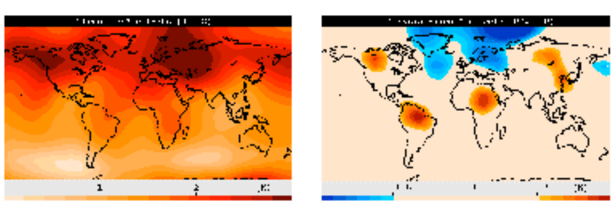

Figure 1. Increases in surface air temperature (K) in a $2xCO_2$ atmosphere: (left): due to radiative effects alone; (b) due to plant physiology feedbacks. (from Sellers et al., 1996a)

- 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

concentration in the PBL in the annual mean, even when fluxes cancel in the annual mean (the rectifier effect)[Denning et al., 1995 and1999]. This finding has significant implications for the magnitudes of CO_2 sources and sinks inferred from atmospheric CO_2 measurements in the PBL.

- Using CASA, we have produced the first global model of C^{13} 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 CO_2 [Fung et al., 1997] and that CO_2 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 oxygen^{18} in CO_2 [*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.

	Description	**Reference**	**Comments**
NDVI	20-year time series	[Los, 1993 and 1998; Los et al., 1994]	Distributed via GSFC website
Biospheric properties from satellite obs	Global vegetation distribution; FPAR; albedo	[Sellers et al., 1995 and 1996b; Defries and Townshend, 1994]	Distributed via ISLSCP CD ROM
	Continuous fields	[Defries et al., 1995 and 1999]	
Precipitation anomalies	Global, 100-year gridded time series	[Dai et al., 1997]	Distributed via GISS website together with Hansen's temperature anomalies
Photosynthesis model	Coupled photosynthesis – stomatal conductance model for C_3 and C_4 plants	[Collatz et al., 1991 and 1992]	Basis for biophysics parameterization in land surface models
CASA	Biogeochemical model	[Potter et al., 1993; Field et al., 1995]	Available from authors
GCM-SiB2	CSU GCM with SiB2 interactive	[Sellers et al., 1996a and 1996b; Randall et al., 1996]	
Atm tracer transport model	Global, derived from GISS 1997 GCM	[Fung et al., 1983 and 1999]	Available from authors
CO_2 fluxes	Global, monthly, derived from NDVI and temperature	[Fung et al., 1987]	Distributed via GISS website
	Global, monthly, derived from CASA	[Field et al., 1995]	Available from authors
C-13 distributions	Derived from SiB2-GCM and CASA	[Fung et al., 1997]	Available from authors

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.

name	position	affiliation	degree
Kevin Schaefer	graduate student	Colorado State University	
Scott Denning	graduate student	Colorado State University	PhD
Scott Denning	postdoctoral fellow	Colorado State University	
Aigou Dai	graduate student	Columbia University and NASA/GISS	Ph. D.
Ina Tegen	postdoctoral fellow	Columbia University and NASA/GISS	
Sietse O. Los	graduate student	Free Univ. Amsterdam & NASA/GSFC	Ph. D.
Pierre Friedlingstein	graduate student	Louis XVI Univ. of France and GISS	Ph. D.
Chris Potter	postdoctoral fellow	NASA/Ames	
Pierre Friedlingstein	postdoctoral fellow	NASA/GISS	
G. James Collatz	postdoctoral fellow	NASA/GSFC	
Alan Townsend	graduate student	Stanford University	Ph. D.
Amy Austin	graduate student	Stanford University	Ph. D.
Anne Ruimy	postdoctoral fellow	Stanford University	
Carolyn Malmstrom	graduate student	Stanford University	Ph. D.
Christopher Still	graduate student	Stanford University	
Greg Colello	postdoctoral fellow	Stanford University	
Gregory Asner	postdoctoral fellow	Stanford University	
James Randerson	graduate student	Stanford University	
Jason Neff	graduate student	Stanford University	
Joerg Kaduk	postdoctoral fellow	Stanford University	
Laurie Osher	graduate student	Stanford University	Ph. D.
Manuel Lerdau	graduate student	Stanford University	Ph. D.
Matt Thompson	graduate student	Stanford University	M.S.
Ted Schuur	graduate student	Stanford University	Ph. D.
Wei Fu	postdoctoral fellow	Stanford University	
Xia Li	graduate student	Stanford University	
Sharon Hall	graduate student	Stanford University	Ph. D.
Kevin Gurney	graduate student	UC Santa Barbara/Colo. St. University	
Lara Prihodko	graduate student	UC Santa Barbara/Colo. St. University	
William Riley	postdoctoral fellow	Univ. Calif. Berkeley	
Lahouari Bounoua	postdoctoral fellow	University of Maryland	

Journal Articles Published

Our research project has been very active publishing scientifc papers. Approximately 230 papers have been published as of June 2000. A bibliography of these follows.

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Bounoua, L., G.J. Collatz, P.J. Sellers, D.A. Randall, D.A. Dazlich, S.O. Los, J.A. Berry, I. Fung, C.J. Tucker, C.B. Field, and T.G. Jensen, Interactions between vegetation and climate: Radiative and physiological effects of doubled atmospheric CO2, *Journal of Climate*, *12* (2), 309-324, 1999.

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