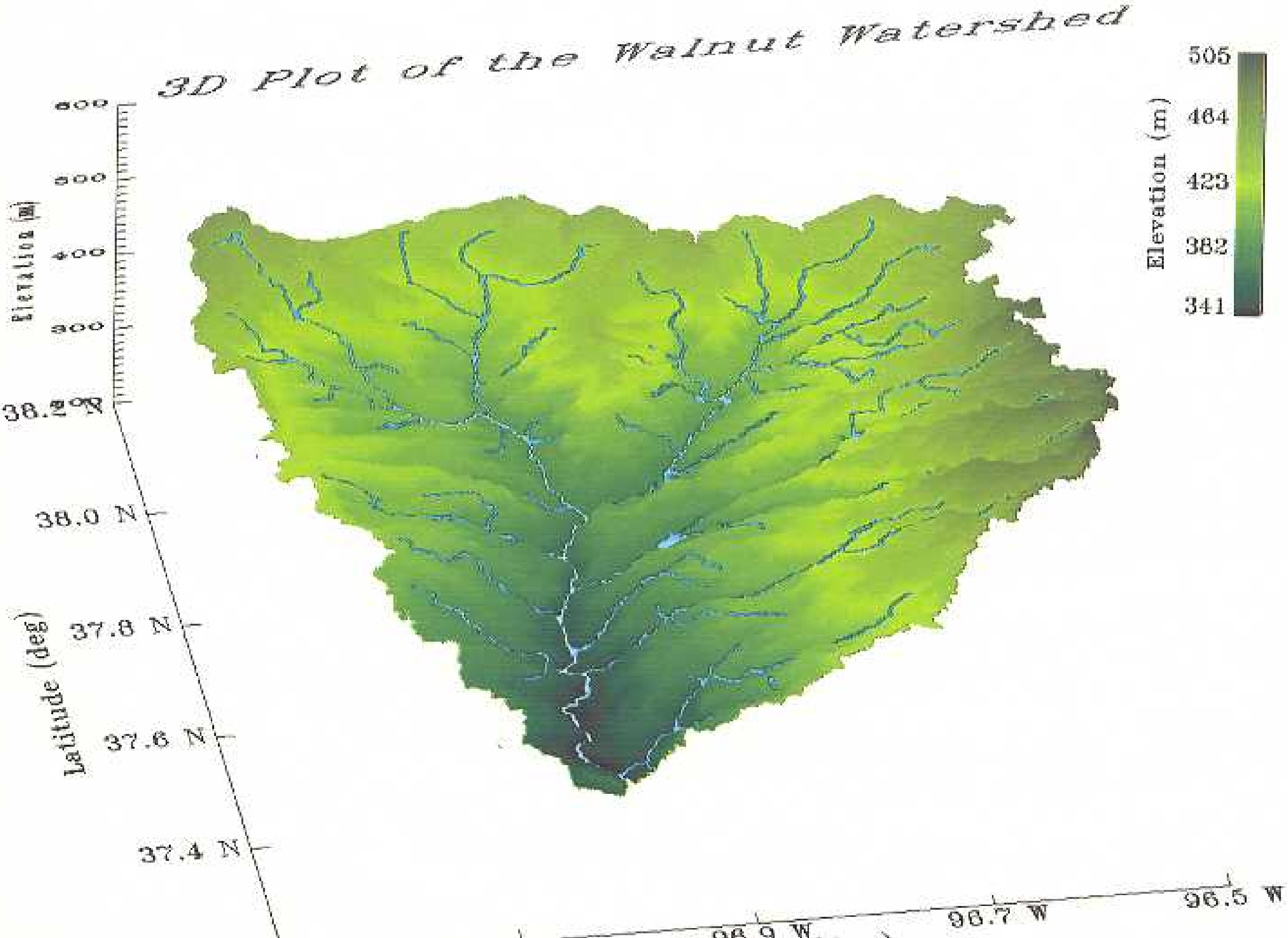
Overview and Implementation of CASES

The Cooperative Atmosphere-Surface Exchange Study



"Natural systems have rhythms and progressions over time that strongly influence, if not dictate, the characteristics of individual components. Long-term observations are required to formulate meaningful, testable hypotheses that describe and predict environmental responses to changing conditions."

- adapted from Freckman and Elliott, 1995

Foreword

This document describes the Cooperative Atmosphere-Surface Exchange Study (CASES), a multidisciplinary observation facility being developed in south central Kansas. Section 1 provides general information on CASES, its goals, evolution of the concept, and why CASES is timely and unique. Section 2 reviews interdisciplinary scientific issues addressable by a CASES type project. Section 3 describes the CASES facility and discusses implementation activities.

CASES was conceived and nurtured through brainstorming sessions among a broad cross section of the scientific community. From a series of planning meetings in Tulsa, Wichita, Boulder, and Washington D.C., the concept of a long term facility to study atmosphere-surface exchange processes slowly emerged and crystallized. A small group of scientists, chosen by their peers to represent them, are taking the lead in trying to implement the CASES site. For their past and continuing efforts, special thanks are extended to Richard Cuenca (OSU), Claude Duchon (OU), Robert Grossman (CU), Bruce Hicks (NOAA), Margaret LeMone (NCAR), James Moore (UCAR), Dennis Ojima (CSU), Roger Pielke Sr. (CSU), Lawrence Tieszen (Augustana), and Marvin Wesely (ANL). Without their dedication and that of their respective working groups, little progress would have been achieved. Appreciation is also expressed to William Blumen (CU) who has been a strong advocate and continuing contributor to CASES from the very start.

The CASES scientific community is very grateful to Argonne National Laboratory, and particularly Harvey Drucker, Christopher Reilly, and Marvin Wesely, for stepping forward with a substantial commitment of resources to initiate boundary layer aspects of the CASES facility. For past and hopefully continuing support, deep appreciation is also expressed to Dave Farrell and Frank Scheibe (DoA); Chandrakant Bhumralkar, Mike Coughlan, Dan Fread, Joe Friday, William Hooke, Mike Hudlow, Lee Larson, Jim Rasmussen, John Schaake and Alan Thomas (DoC); Ted Cress, Peter Lunn and Norm Rosenberg (DoE); Harry Lins (DoI); Jim Arnold, Bob Murphy and Ming Ying Wei (NASA); Bob Gall and Bob Serafin (NCAR); Doug James, Steve Nelson, Pam Stephens, and Ken Van Sickle (NSF); and Rick Anthes and Bill Pennell (UCAR).

Without the vision and conviction of all mentioned above, and many others who go unmentioned, we would not be on the verge of implementing this important long-term observing facility. May their wisdom be recognized in the years to come.

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(CASES)

Executive Summary

A Cooperative Atmosphere-Surface Exchange Study (CASES) site is being established to enable scientists to observe, understand and model linkages among the atmosphere, hydrosphere and terrestrial biosphere on time scales from minutes to years. CASES will also serve as a focal point to provide field experience for students of the natural sciences. The location of the CASES site is the upper Walnut River watershed north of Winfield, Kansas which is within DoE's well instrumented ARM/CART research area. Here, boundary layer profilers will be deployed coincident with the natural boundaries of the watershed. Such positioning simplifies efforts to close the surface water balance since the net runoff can be measured at one point. This, in turn, also helps verify other atmosphere/surface linkages. Surface flux and radiation data obtained within the watershed, in conjunction with WSR-88D radars, satellite data, stream gages, soil moisture data, topographic and land use data, surface meteorological data, biophysical data, and atmospheric-hydrologic-ecologic models, will allow for detailed descriptions of surface-atmosphere linkages and exchange processes between the watershed and the atmosphere. The CASES site will provide scientists with opportunities to pursue a broad range of interdisciplinary research including, for example:

* observing and documenting linkages between the atmosphere, hydrosphere, and biosphere

* testing parameterization schemes in weather and climate models

* refining representation of soil moisture in precipitation prediction

* determining effects of mesoscale motions on surface-atmosphere fluxes

* defining the role of land heterogeneity in boundary layer models

* developing and testing distributed hydrologic models

* developing procedures for scaling small basin hydrology to synoptic/climate scales

* fine tuning WSR-88D precipitation algorithms

* exploring multi-parameter radar techniques

* testing and improving satellite algorithms and optimizing integrated remote sensing techniques

* quantifying CO_2 fluxes between the atmosphere and the biosphere

* educating students to collect and analyze observational data

CASES will provide the infrastructure that is required to carry out both long term and episodic field campaigns that are associated with surface-atmosphere exchange processes. Among the facilities and services provided will be a minimum "critical mass" complement of instruments that will be operated continuously during the lifetime of CASES, with supporting power, phone, and data management services. Instrument maintenance and site management will be available to ensure that the services provided will be used in an efficient manner. The facility will be available to individual investigators or groups of investigators who will use the instruments in place or deploy additional ones which would complement the existing array for their specific research needs.

CASES evolved from meetings among a broad cross section of the university community and representatives of Argonne National Laboratory, the Atmospheric Radiation Measurements (ARM) Program, the Global Energy and Water cycle EXperiment (GEWEX) Continental scale International Project (GCIP), the United States Weather Research Program (USWRP), the Agricultural Research Service (ARS), the National Aeronautics and Space Administration (NASA), the National Center for Atmospheric Research (NCAR), the National Severe Storms Laboratory (NSSL), the National Weather Service (NWS), the United States Geological Survey (USGS). Once fully established, CASES is projected to have a minimum lifetime of three years with possible continuance for the duration of ARM-CART. Periodic evaluation of the facility will determine its longevity.

CASES is being initiated in FY 96 with Argonne National Laboratory assuming a lead role by establishing an atmospheric boundary layer facility in the Walnut River Watershed in Kansas. The boundary layer facility will be equipped to provide surface-based observations of the vertical profiles of temperature, humidity, and wind and of the air-surface exchange rates of heat, moisture, and momentum over the southern half of the CASES area. A continuous view of atmospheric processes will be provided with sufficient detail to enable significant advances in the description, understanding, and modeling of the planetary boundary layer. The facility will be particularly suited for studies of evolution of the planetary boundary layer, areal averages of air-surface exchange, wave motions in the nocturnal boundary layer, and characterization of the low-level wind speed maximum in the stable boundary layer. The facility also provides the necessary foundation for the interdisciplinary studies previously mentioned.

A joint Argonne/NCAR/NOAA CASES project office has been established at NCAR to continue developing funding resources for CASES; identify, coordinate, and facilitate research opportunities for the scientific community; and to establish an operational data management scheme addressing all aspects involved in providing access to continuously collected observations relating to the CASES site. Funding to fully implement the CASES facility is being pursued via standard and internal proposals which have/will be submitted to DoA, DoC, DoD, DoE, EPA, DoI, NASA, and NSF.

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1. INTRODUCTION

CASES (Cooperative Atmosphere-Surface Exchange Study) is a multi-year, interdisciplinary effort to investigate linkages among the atmosphere, hydrosphere and terrestrial biosphere. The complex interactions among these components of the earth's ecosystem manifest themselves in the fields of meteorology, hydrology, climate, ecology and chemistry, and challenge current capabilities to understand, simulate and predict many aspects of our environment on time scales from minutes to years. Advances in observation, analyses, and numerical modeling techniques suggest that **timely progress can now be achieved** in understanding and modeling these linkages. By bringing scientists from different disciplines together, enabling them with modern observation systems, and facilitating the availability of data, **CASES is designed to help this happen.**

1.1 Goals

The **Goals** of CASES are to:

1) **quantify** the exchange of energy, moisture, and trace chemical species that link the earth and its vegetation to the atmosphere on a variety of temporal and spatial scales;

2) develop techniques to properly **represent** these linkages in numerical models;

3) **identify** the relative importance of these linkages to atmospheric, hydrospheric, and biospheric processes; and

4) **examine** applicability to similar biomes worldwide.

CASES will also serve as a focal point to provide students with field experience in the natural sciences. There has been an increasing realization that an insufficient number of students are being trained to take and analyze observations, understand the instruments involved, and deal with problems of data quality and representative sampling (Serafin et al., 1991).

1.2 Motivation

The sciences of meteorology, climate, hydrology, ecology, and environmental chemistry have made great progress in understanding specific processes of the Earth system through disciplinary studies. It has now become evident that future breakthroughs in understanding the Earth as a system will come from studying interrelationships of processes linking these disciplines on a wide spectrum of space and time scales.

Inhibiting progress toward these interdisciplinary goals are current models linking atmosphere-hydrosphere-biosphere systems, which remain incapable of adequately describing, simulating, and predicting processes which define and control our planet's complex ecosystem. Furthermore, there are no multi-disciplinary data sets with the necessary detail, length of record, and diversity of scales to test and improve these models.

CASES provides an opportunity to develop the needed multi-disciplinary data sets and test the representativeness of physical processes in numerical models designed to simulate and predict our environment.

Expanded Discussion: Deficiencies in understanding exchange processes between the Earth and its atmosphere have become significant limiting factors to applying knowledge in the fields of meteorology, climate, hydrology, ecology, and environmental chemistry to real world problems. Integration of these disciplines calls for a common framework of information gathering and exchange to test the representation of respective processes in numerical models, either explicitly or through parameterization (CEES/IGPO 1994, CEES/USWRP 1992, CEES/USWRP 1994, GEWEX 1992, GEWEX 1993, NASA/NRC 1994, WMO 1994). Not only must the meteorology be understood to better understand the complex biogeochemical processes taking place between the atmosphere and surface, but surface and subsurface processes as well must be better understood to improve weather forecasts and climate models (Beljaars et al 1994).

Over the past decade a number of field experiments have been conducted which have brought together atmospheric scientists, hydrologists, ecologists, chemists, and remote sensing scientists. These include HAPEX- MOBILHY, FIFE, EFEDA, HAPEX-Sahel and BOREAS, experiments which have focused on different ecosystems having the potential for significant impact in the global system and resulting climate. Importantly, all have all been brief, intensive field campaigns, generally capturing a few months of the growing season, but not offering the interannual or interseasonal comparisons needed for more comprehensive studies.

The most recent experiment in this series is the Boreal Ecosystem-Atmosphere Study (BOREAS) conducted in the boreal forest of Canada during 1994 and 1996. At the BOREAS project review in winter 1995, it was decided that a high priority for further experimental work in the boreal forest should focus on long-term measurement of fluxes and balances in contrast to the short-term intensive field campaigns conducted in 1994. Data from the one long-term site in BOREAS revealed significant carbon fluxes for the Black Spruce species were occurring during parts of the year not covered by the intensive field campaigns.

Longer-term studies, in general, are needed to evaluate inter-seasonal and inter-annual responses of the coupled hydrology, soil moisture, ecosystem and boundary layer, and to ensure capture of a region's widely varying weather regimes and longer term climatic conditions. Study areas should be well positioned within a surrounding domain that is sufficiently instrumented to provide supporting data on synoptic and mesoscale atmospheric conditions and have relatively easy access to ensure optimal use by the scientific community. None of the field experiments listed above met all these criteria.

Over the last several years, the frequency and resolution of observations over the central United States have greatly increased as a result of wind measurements from the National Weather Service (NWS) demonstration Profiler network, radial wind and reflectivity data obtained from WSR-88D Doppler radars, and more numerous automated surface stations. The Department of Energy has capitalized on these developments by establishing the Atmospheric Radiation Measurement (ARM)

Program's Clouds and Radiation Testbed (CART) in Oklahoma and Kansas, to conduct research on improving treatments of cloud radiation forcing in climate models. This facility increases the density and variety of observations even further so that the atmosphere above Oklahoma and Kansas is now observed routinely in greater detail than any other comparably sized region on earth.

However, the lowest data level of the demonstration profiler network is 500 meters above the surface, data from surface stations are often unsuitable for research due to location and/or accuracy, and WSR-88D radars are tightly controlled by operational constraints. Thus, despite the high data density, current observations are insufficient to adequately observe and describe surface and boundary layer processes and their linkages at the earth-atmosphere interface.

The distribution of soil water content, evaporation and transpiration is tightly coupled to the structure and evolution of the atmospheric boundary layer. An accurate hydrological representation of the land-surface system is critical for improving models of the boundary layer and land-atmosphere coupling at all spatial and temporal scales and over heterogeneous domains. Long-term descriptions of land use and fluxes also enable assessments of the coevolution of surface characteristics and climate.

In addition, most current or planned national and international programs have overlapping objectives to better understand surface-exchange and/or boundary-layer processes. For example:

> The Global Energy and Water Cycle Experiment's (GEWEX) Continental-Scale International Project (GCIP) proposes to go upscale from well-documented flows in smaller stream basins to flows in the area of a GCM grid square in order to represent the water cycle on a continental scale. Although progress has been made modeling smaller watersheds, such as the Little Washita (~500 sq. km.), the bridge to continental scale models is large and many issues remain unresolved regarding the constancy of processes across the spectrum of scales (CEES, 1994).
>
> The U.S. Weather Research Program (USWRP) needs boundary layer and surface data for studies on the initiation and maintenance of convective storms, quantitative precipitation forecasting, evolution of fronts, and cyclogenesis. Data sets are also required to develop and verify radar/satellite precipitation and surface-process retrieval algorithms and their application to flood and water resource issues (Emanuel et al 1995).
>
> Experiments with well-specified environments, boundary layers and cloud cover are needed for the International Satellite Cloud Climatology Project, ISCCP. This has been reinforced by the expressed need for air-surface interaction data for model verification (e.g., Project for Intercomparison of Land-Surface Parameterization Schemes (PILPS), and the National Academy report on the role of terrestrial ecosystems on global change (NASA/NRC, 1994)).
>
> The International Geosphere-Biosphere Program seeks to enlarge its focus from a local ecosystem to a region (NAS 1994). There is a need also to document the spatial and temporal evolution of trace species (NAS 1994).

No single program has funding to deploy and operate all the instrumentation it requires. Indeed, the documents of each program imply a hope that some of the necessary measurements will be handled by one of the other programs.

1.3 Community Response

Under the sponsorship of DoA, DoC, DoE, DoI, NASA, and NSF, meetings were held to discuss and evaluate whether the aforementioned needs could be filled and, if so, to develop a course of action. Participants included a broad cross section of the university community and representatives of Argonne National Laboratory, the Atmospheric Radiation Measurements (ARM) Program, the Global Energy and Water cycle EXperiment (GEWEX) Continental scale International Project (GCIP), the United States Weather Research Program (USWRP), the Agricultural Research Service (ARS), the National Aeronautics and Space Administration (NASA), the National Center for Atmospheric Research (NCAR), the National Severe Storms Laboratory (NSSL), the National Weather Service (NWS), the United States Geological Survey (USGS).

Emerging from these meetings was **enthusiastic support for establishing a Cooperative Atmosphere-Surface Exchange Study (CASES) site**, within the ARM-CART research area, to provide a facility for scientists to study the complex linkages of meteorology, hydrology, climate, ecology, and chemistry, and to serve as a focal point to provide field experience for students of the natural sciences. CASES will provide important data not currently collected on exchange processes, and simultaneously satisfy many of the needs of the fore-mentioned national and international programs.

CASES is being initiated in FY 96 with Argonne National Laboratory assuming a lead role by establishing an atmospheric boundary layer facility in the Walnut River Watershed in Kansas. The boundary layer facility will be equipped to provide surface-based observations of the vertical profiles of temperature, humidity, and wind and of the air-surface exchange rates of heat, moisture, and momentum over the southern half of the CASES area. A continuous view of atmospheric processes will be provided with sufficient detail to enable significant advances in the description, understanding, and modeling of the planetary boundary layer.

A CASES project office, jointly sponsored by Argonne, NCAR, and NOAA has been established to initiate and coordinate research using the Argonne Boundary Layer Facility and to pursue funding to instrument the entire CASES area. These efforts are being attempted via standard or internal proposals submitted from interested scientists to DoA, DoC, DoD, DoE, DoI, EPA, NASA, and NSF. Once fully established, CASES is projected to require a minimum lifetime of three years to acquire the necessary interseasonal and interannual data sets. Periodic evaluation of the facility will determine its eventual longevity.

CASES will be the first facility to unify efforts of the meteorology, climate, hydrology, ecology, chemistry, and education communities in both short- and long-term interdisciplinary research.

2. Scientific Basis for CASES

A general form of the surface energy balance can be represented:

$$Rn = H + LE + G$$

where Rn is the net radiation at the surface, and H, LE, and G are the sensible, latent, and soil heat fluxes, respectively, into or away from the surface.

A general form of the surface water balance can be represented:

$$P = R + S + E$$

where P is the precipitation, R is the runoff, S is the soil water storage, and E is the water lost or gained through phase change at the surface.

While these relationships appear simple, they are actually quite complex. They form the framework within which important components of atmospheric, hydrospheric, and biospheric processes must be studied. Embodied within each of these terms are variables which are very difficult to measure over large areas. Nevertheless, the challenge confronting modelers of all environmental sciences is how best to formulate the various fluxes in numerical simulations. **CASES aims to provide state-of-the-art answers** to these questions.

The following sections discuss the scientific basis for CASES in more detail.

2.1 Linkages Between the Atmosphere, Hydrosphere, and Terrestrial Biosphere

Understanding the three-way interactions between the atmosphere, hydrosphere and terrestrial biosphere through land surface-atmosphere exchange processes is critical to understanding regional and local scale weather, climate and water basin hydrology. Terrestrial ecosystem-hydrologic-atmospheric interactions refer to exchanges of heat, moisture, momentum, trace gases and aerosols between land surfaces and the overlying air. These exchanges represent a dynamically coupled system which evolves as a result of interactions among its components. Terrestrial biospheric processes, hydrological partitioning, and terrain heterogeneity control fluxes of water, energy, and radiatively active trace gases (e.g., CO_2, CO, CH_4, NO_x, N_2O) and these fluxes perform important roles in determining mesoscale weather and climate by modifying energy gradients, circulation patterns, atmospheric chemistry, and cloud formation. The weather, in turn, influences biospheric and hydrospheric processes.

The importance of these interactions between the terrestrial biosphere, the hydrosphere and the atmosphere is now well accepted (Bolle et al. 1985, Dickinson 1986, Bolin and Cook 1983, Crutzen and Andreae 1985, Crutzen 1988, Matson and Ojima 1990). However, it has been largely in the last decade that the magnitudes of atmospheric and/or land cover impacts have become generally accepted, due mainly to concern about the effects of greenhouse gases and aerosols (Charlson and Wigley, 1994; IPCC 1992) and an increasing awareness of more localized land cover effects on regional climate

(Dirmeyer, 1994; Loveland et al., 1991; Pielke, 1995). Additional evidence comes from Beljaars et al. (1994) and others, who have demonstrated that variations in soil water content can significantly impact model simulations of weather and climate.

Climate, in turn, affects terrestrial ecosystem dynamics and hydrological inputs and outputs at the land surface. Changing climate and land surface properties affect this three-way interaction and modify the terrestrial biosphere. The manner in which changes in terrestrial ecosystems affect these interactions through changes in ecological processes is not well understood.

A. Focus on the Atmosphere

The vertical structure of the daytime atmospheric boundary layer is critically dependent on the partitioning of net radiation into sensible and latent turbulent heat flux, and ground heat conduction (for a summary of these feedbacks, see e.g., Pielke, 1995). A deeper boundary layer results when more of this radiative energy is realized as sensible heat flux. When vegetation is present, the response of leaf conductance to atmospheric conditions represents a rapid feedback between the biosphere and the atmosphere. The passage of a cloud during daylight, for example, will significantly reduce net radiation with stoma apertures responding within minutes. The removal and emission of chemicals at the surface are regulated by many of the same processes that affect heat and moisture flux, although the chemical and physical properties of the chemicals must also be considered (Hicks and Matt, 1988; Wesely, 1989: Foken et al., 1995).

The drying of the near surface soil and the depletion of deeper soil moisture as a result of transpiration represent other, slower feedbacks with the atmosphere, varying over days to a few weeks. When vegetation becomes water stressed, for instance, stoma will close to conserve the remaining water, so that a larger fraction of the net radiation is realized as sensible heat flux. Precipitation represents a short-term feedback that can quickly replenish the soil moisture, as well as provide shallow liquid water layers on the vegetation. The water available for short-term reinsertion into the atmosphere also depends on surface and subsurface runoffs which are also dependent on precipitation rate, soil water content, precipitation type, etc.

Seasonal interactions include feedbacks between increases in biomass during the growth season which will modify the partitioning of latent and sensible heat fluxes. Nutrient limitations can also constrain biomass growth, particularly in moist environments (Schimel et al. 1994; Parton et al. 1993). It has been shown that the increase of mean temperature in the spring in the eastern United States is interrupted as vegetation leafs out. Also, drought conditions over the eastern United States are apparently perpetuated by the reduced transpiration from the water-stressed vegetation. Clearly there is a two-way feedback in which ecosystem development responds to the microclimate, and the ecosystem characteristics in turn affect the surface fluxes of heat, moisture, and trace gases.

Another important influence of the land surface on the atmosphere occurs through modification of the surface albedo. For example, desertification of the Sahel region of Africa may have resulted from excessive grazing by domesticated goats of the darker vegetation such that a larger fraction of the solar radiation is reflected back into space. It has been suggested that the Rajastan Desert in India has resulted from the same mechanism.

Recently, there have been several field programs designed in part to explore short-term (out to seasonal scale) atmosphere-terrestrial ecosystem interactions. These include the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE) in eastern Kansas (Sellers et al. 1992a; Betts and Beljaars 1993), the Hydrologic Atmospheric Pilot Experiment and Modelisation du Bilan Hydrique (HAPEX-MOBILHY) in southwest France (Andre et al. 1989b; Noilhan et al. 1991), the HAPEX-Sahel in Niger in central Africa (Gash et al. 1991), the Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS) in the Amazon region of Brazil (Shuttleworth 1985; Wright et al. 1992; Gash and Shuttleworth 1991), and the Boreal Ecosystem-Atmosphere Study (BOREAS) in Manitoba and Saskatchewan in Canada (Sellers et al. 1996). A goal of the programs is to explore atmospheric-terrestrial ecological interactions for different major biomes.

CASES will complement these efforts by permitting both short and long-term measurements with a focus on the interactions. Among the linkages understood the least are interactions between the biosphere and atmosphere. Currently, land surface characteristics are specified for use in meteorological and hydrologic models, while ecological models use prescribed climate data. The CASES site in the Walnut watershed will permit fundamental studies of these interactions on a spectrum of time and spatial scales.

B. Focus on the Hydrosphere

To close the land branch of the hydrologic cycle, four components must be considered: (a) precipitation, (b) the time rate of change of surface and subsurface water storage, (c) evaporation, and (d) the divergence of horizontal water transport in the surface and subsurface layers. The largest component of the hydrologic cycle over land is precipitation. As time scales become shorter than one week, the spatial and temporal distribution of precipitation becomes increasingly important.

The National Weather Service is about to complete the deployment of a national Doppler radar network - NEXRAD (WSR-88D). These radars have enhanced capabilities to estimate precipitation compared to radars used for the last 35 years. Nevertheless, performance evaluation to date suggests there is still room for improvement in the WSR-88D precipitation algorithms. Questions have surfaced about range biases, the generality of the radar-rainfall relationship, and the radar's ability to detect and quantify freezing rain, sleet, snow and hail events (Smith and Krajewski 1995).

Continuing efforts are needed to improve satellite derived precipitation estimates which have suffered from a lack of well defined in-situ areal precipitation measurements. Algorithms to derive precipitation from satellite data have been developed (Janowiak 1992; Richards and Arkin 1981) but estimates fall short of desired performance levels. Optimizing techniques for estimating precipitation will require an integration of satellite, radar, and gage observations. The distribution of soil water content is another hydrologic variable which could benefit from improved satellite algorithms. Of particular interest is the linkage between soil water content at the surface and its subsurface profile as a function of time during the growing season and in days following precipitation events. A well instrumented site is needed to provide ground truth for satellite and airborne sensors.

CASES will provide an excellent opportunity for integrating satellite, radar, and gage information and optimizing the performance of the NEXRAD network. The location of CASES places its center under the umbrella of four different WSR-88D radars at ranges varying from 50 to 210 km and in a climatic region which experiences a broad spectrum of precipitation events. With a deployment of supplemental rain gages, the CASES facility will provide an unprecedented data set for fine tuning the new radar system's capability to measure precipitation. Toward this end, exploratory polarimetric measurements have shown promise and can also be tested here. In addition, the measurement of streamflow at a number of nested gaging stations in the area will enable the observed runoff to be compared with the areal precipitation, providing an independent check of WSR-88D derived precipitation fields.

Closely connected to the occurrence of precipitation are the response characteristics of the watershed on which the precipitation is falling. Improved warnings of flash floods require that better rainfall observations and predictions be coupled with hydrologic models of runoff production on the basin scale. Once precipitation has reached the earth's surface, surficial processes such as infiltration, soil moisture flow, evaporation, transpiration, and runoff become primary players in subsequent redistribution of the water substance. One of the main obstacles in understanding surficial processes is the high spatial variability of surface features and hydrological factors. Integrating and linking these variables across the spectrum of relevant scales remains an outstanding challenge. Current parameterizations representing the hydrological processes of runoff, infiltration, soil moisture distributions, and evaporation/transpiration from bare and vegetated surfaces, have been developed from hillslope and small basin data. It is unknown whether these parameterizations are scale invariant and applicable to much larger river basins.

The Walnut Watershed, which comprises the CASES site, represents a unique set of conditions that will enable researchers to better understand hydrologic processes. The size of the Walnut Watershed (4800 sq. km.) is particularly useful as it approaches the grid size used in many weather and climate models. This represents a scale in which there has not been sufficient observations for valid model parameterizations. In addition, the Walnut River basin of the CASES site is similar in terrain and vegetation to the intensively studied Little Washita River watershed in Oklahoma, but is an order of magnitude larger, thereby providing opportunities for scaling inter-comparisons.

C. Focus on the Terrestrial Biosphere

Climate and atmospheric deposition of nutrients affect ecosystem processes such as primary production and decomposition. These, in turn, feed directly back into climate and atmospheric systems by modifying fluxes of water and "greenhouse" gases such as CO_2, CO, CH_4, NO_x and N_2O. This class of interactions that result in immediate changes in hydrological and climatic properties can be referred to as "direct feedback effects". Examples of these processes include: (1) net C fluxes via plant production and decomposition; (2) biogenic trace gas exchange controlled by nutrient cycling processes such as denitrification, nitrification, leaching, methanogenesis, and biomass combustion; and (3) water and energy fluxes via evaporation, transpiration, run-off, and run-on. These processes are sensitive to changes in the environment and have relatively fast response times (days to years, Schimel et al. 1991, Ojima et al. 1991).

Ecological processes operating over longer time frames determine community structure, disturbance regimes, and other biotic interactions which indirectly affect biogeochemical and ecophysiological fluxes to the atmosphere and the hydrosphere. These interactions constitute the "indirect feedback effects" between natural ecosystems and the hydrological and climatic systems. Although less understood, they may just as important as shorter term processes in their influence on atmospheric and hydrological dynamics and subsequent changes in ecosystem properties. These effects result from changes in processes affecting ecosystem development which alter ecosystem structure (Ojima et al. 1991).

Modifications of biophysical characteristics of the land surface caused by a shift from forest to savanna-woodlands or grasslands or a shift from C_4 tallgrass prairie to C_3 wheat croplands are examples of changes of indirect ecological feedback to the atmosphere and the hydrosphere (Salati 1986, Eagleson 1986). Changes in the structure of vegetation alters the roughness and albedo of the land surface and can potentially modify local, regional, and global scale climate through changes in albedo, humidity, soil moisture, evaporation, transpiration, and ground-level wind patterns (Dickinson 1986, Sellers 1986, Pielke and Avissar, 1990).

At the CASES site, land use changes have resulted in the interesting juxtaposition of two major land cover classes, 1) intensive agriculture dominated by wheat and pasture fields and 2) rangelands which still retain characteristics of native prairie. The effect of this ecosystem conversion by agriculture produces a CASES site which has a natural grassland ecosystem dominated by C_4 species and a derived system dominated by C_3 species in a system of very low diversity (i.e., wheat). These two photosynthetic systems are of special interest and importance in the Great Plains (see Tieszen, 1994) because their distributions are largely climatically controlled in natural systems (Tieszen et al., 1979) and because they respond differently to various environmental factors (see Ehleringer and Monson, 1993) including CO_2 concentrations, temperature, nitrogen availability, and water stress. These ecological interactions modifying fluxes of water and carbon also are important feedbacks to atmospheric phenomena, including mesoscale weather patterns and the evolution of climate patterns.

The replacement of C_4 grassland by wheat, a C_3 species, over large spatial areas results in substantially different phenological patterns of NDVI (Normalized Differential Vegetation Index, a surrogate for green biomass) with significantly earlier onsets of greenness in wheat and C_3 pastures (see Reed et al., 1994, for phenology interpretations from NDVI and Tieszen et al., 1995, for grassland interpretations). Schwartz (1994) suggests that the onset of greenness is significantly related to the increase in atmospheric humidity and nighttime warming. The causal relationship which is implied, suggests that vegetation conversions which affect phenology (C_4 to C_3) should have marked effects on regional weather and climate via changes in the transfer of latent and sensible energy.

The linkages between weather/climate and land use, the alteration of natural phenological patterns, and changes in the magnitudes of leaf area index and greenness need to be understood to assess coevolution of weather/climate-ecosystem patterns in the Great Plains. CASES will facilitate such studies by providing the necessary detailed data sets to examine, verify, and parameterize these linkages.

2.2 Modeling the Systems and Their Linkages

A. Atmospheric Models

Numerical weather prediction (NWP) models, used for either short- or long-term predictions, have neither the temporal nor spatial resolution required to adequately describe the interaction between the troposphere and the earth's surface. This interaction occurs within the planetary boundary layer (PBL), which is quite variable in depth, ranging from a few hundred meters to a few kilometers in depth, responding to the diurnal cycle of solar heating as well as to larger-scale dynamics and forcing (Stull, 1995a). Beljaars (1995) has noted, based on his work with the European Centre for Medium Range Weather Forecasts (ECMWF) model, that "The impact of the boundary layer in models is particularly felt after a few days of integration when accumulated surface fluxes contribute substantially to the heat, moisture and momentum balances of the atmosphere."

Atmospheric boundary layer (ABL) simulation has been shown to exhibit a strong degree of sensitivity to soil moisture conditions as well as to parameterization of soil hydraulic properties (Ek and Cuenca, 1994; Cuenca et al., 1996). The variety of ABL and GCM simulation models tested in the PILPS program yielded a wide scatter of results for annual latent and sensible heat fluxes, monthly soil moisture content, and runoff. Variations in predicted soil moisture content and runoff were apparently caused by differences in calculating water balance and soil water transport. With regard to the role of soil moisture in surface resistance parameterizations (Dickinson et al., 1993; Sellers et al., 1986; Pan and Mahrt, 1987), variations in soil moisture also caused differences in partitioning available energy into latent and sensible heat fluxes, thereby affecting the computed annual evapotranspiration.

The characterization of surface fluxes in atmospheric models has been limited to simple representations where most aspects of the soil and vegetation are prescribed. Stomatal conductance responds to atmospheric inputs of solar radiation, temperature, relative humidity, precipitation, carbon dioxide concentration, and to soil inputs of temperature and moisture. Such models are discussed in Avissar and Verstraete (1990), Andre et al. (1989a, Beljaars and Holstlag (1991), Clark and Arritt (1995), Bonan et al. (1993), Chen and Avissar (1994), Collins and Avissar (1994), Manqian and Jinjun (1993), Pitman (1994), Schadler et al. (1990), and Segal and Arritt (1992). These soil-vegetation parameterizations include BATS (Biosphere-Atmosphere-Transfer Scheme; Dickinson et al. 1986), SiB (Simple Biosphere scheme; Sellers et al. 1992a), SiB2 (Sellers et al. 1996) and LEAF (Land-Ecosystem-Atmosphere Feedback scheme; Lee et al. 1993).

An illustration of the form in which these modeling components are used in atmospheric models is shown in Figure 1.

These soil-vegetation schemes have been most extensively used in general circulation and mesoscale models. In most cases, only one vegetation and soil characterization is used for each horizontal model grid interval. Such a representation, based on averaged conditions, is presumed to represent the net effect of the landscape within that grid cell. Some newly considered approaches attempt to represent the landscape variability that may exist within a grid cell. One of these approaches includes the use of a mosaic of patches where subregions within a model grid are evaluated separately and the resultant grid-averaged heat, moisture, and momentum fluxes obtained by a fractional weighting

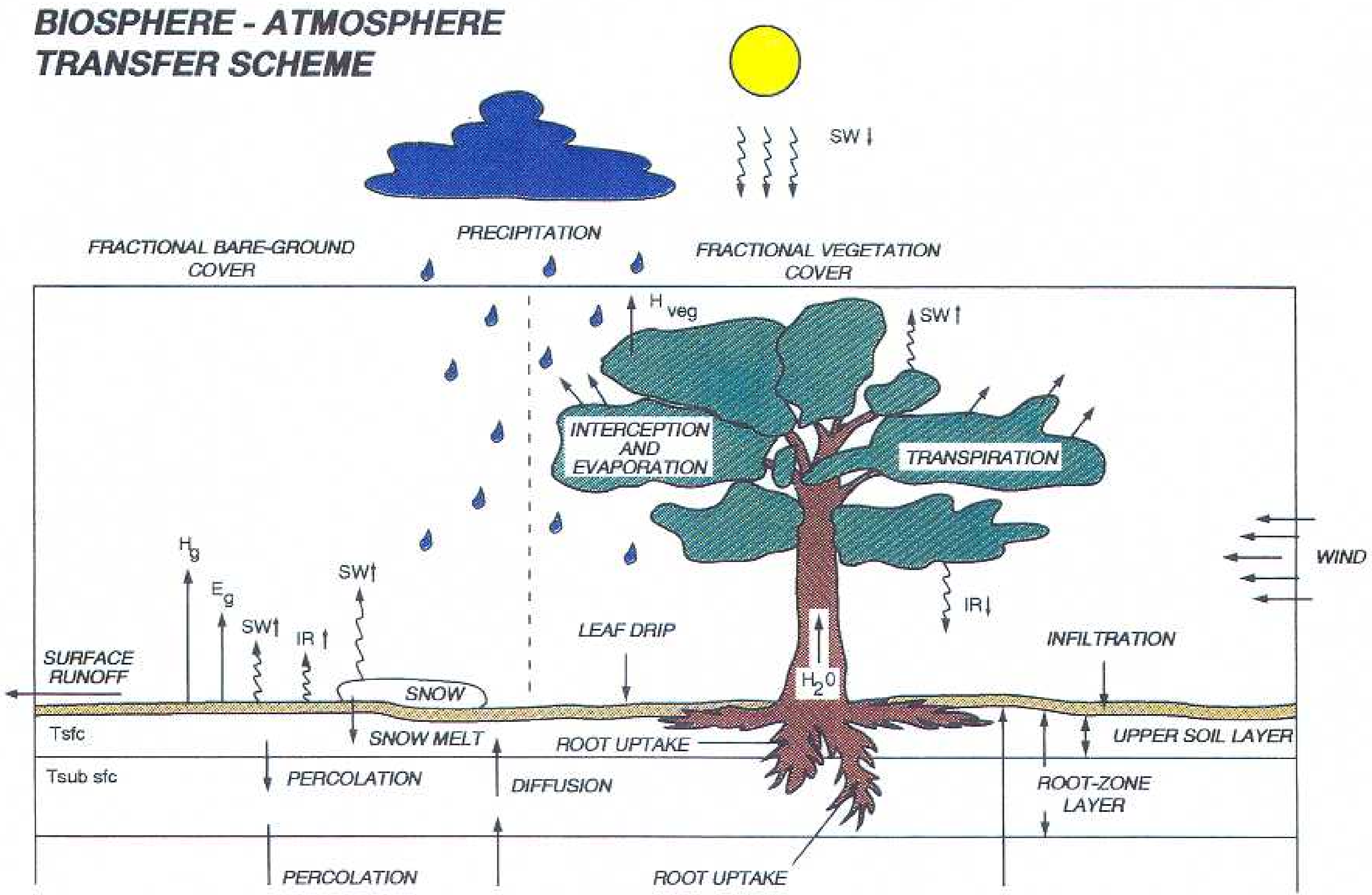


Figure 1. Schematic showing components of the biosphere-atmosphere transfer scheme.

of the subregion fluxes (e.g., Miller 1994, Koster and Suarez 1992, Bonan et al. 1993, Pleim and Xiu 1995, Pitman 1994, Avissar and Pielke 1989, Collins and Avissar 1994, Li and Avissar 1994). Another approach uses a statistical-dynamical formulation in which the response to surface properties is assumed to vary with a specified statistical distribution (Avissar 1992).

The inability to formulate coupled land-surface/atmospheric boundary-layer processes that occur on scales smaller than those resolved by numerical weather prediction models can significantly degrade overall model performance. Subgrid scale processes, such as transport of heat and moisture between the land-surface and the atmosphere, must be parameterized from model-resolved variables. Furthermore, recent studies show that errors in such parameterizations may be even larger than earlier expected (e.g. Smith et al, 1992; Kubota and Sugita, 1994; Sun and Mahrt, 1995a,b; Godfrey and Beljaars, 1991; Stull, 1994; Ek and Cuenca, 1994; Beljaars, 1995; Cuenca et al, 1996; and others). Equally important, boundary-layer clouds are inferred from grid-averaged values (e.g. Slingo, 1980, 1987; Ek and Mahrt, 1991; and others), but failure to predict the subgrid fraction of boundary-layer cloud cover leads to major errors in the surface energy budget and fluxes to the atmosphere, which has important implications for large-scale modeling (Garratt et al, 1993; Garratt, 1994; Browning, 1994).

The generation of fluxes by unresolved subgrid mesoscale motions must also be considered (e.g. Bougeault et al, 1991; Mahfouf et al, 1987; Segal et al, 1988; Pinty et al, 1989). Numerical simulations suggest that heterogeneous landscape patterns, such as irrigated and non-irrigated land, snow and snowfree ground, etc., can produce atmospheric circulations that are as strong as sea breezes (e.g., Anthes, 1984; Zeng and Pielke, 1995). The resultant fluxes of energy and trace gases due to these mesoscale circulations has yet to be adequately considered in larger-scale models.

Garratt (1992) emphasized two aspects that are central to improve modeling of the PBL. These are i) the presence of clouds within the PBL and ii) the nature of the underlying surface. The emphasis is on the acquisition of long data records to provide quantitative evaluations of turbulent fluxes of sensible and latent heat at the surface, which represent an important source of moist available energy for atmospheric circulation and momentum diffusion. As Garratt notes in the concluding paragraph of his book, "The most promising strategy for improving a given parameterization scheme is to study carefully the performance of that scheme in a particular GCM and to compare simulations both with observations and with results from small-scale PBL models." This theme applies to all numerical model studies.

The establishment of the CASES site directs attention to the observational needs which must be met to provide the guidance and verification data required for the development of physically sound parameterization schemes that will have positive influences on NWP model performance.

B. Hydrologic models

Operational models in hydrology include those that cover the unsaturated zone from the soil surface to the water table, groundwater aquifer models, surface runoff models and open channel hydraulic models. Physically based models for components of the hydrologic cycle include parameterizations for canopy interception, infiltration, evapo-transpiration, snowmelt, interflow, overland flow, channel flow, unsaturated subsurface flow and saturated flow in groundwater aquifers.

The model scenarios important for flood forecasting and potential control include single-event rainfall-runoff models, continuous stream-flow simulation models and flood hydraulics models.

The HEC-1 (Hydrologic Engineering Center) rainfall-runoff model is a standardized model which has been developed by the U.S. Army Corps of Engineers (Feldman, 1981). The program develops discharge hydrographs in response to historical or simulated rainfall events over the basin. Calibration can be made for unit hydrograph and loss rate parameters as well as channel routing parameters. The primary objective of the HEC-1 model is generation of the flood hydrograph. Longer term processes such as evaporation, transpiration, and soil moisture are not modeled. Basins can be divided into subbasins using HEC-1 and flow routing used to simulate the overall basin response. Model results include generation of hypothetical storm runoff, snowmelt runoff, dam safety applications and flood damage analysis (DeVries and Hromadka, 1992).

The National Weather Service FLDWAV program simulates unsteady flow for flood wave simulation based on solution of the one-dimensional St. Venant equations (Fread and Lewis, 1988). It is capable of simulation of unsteady flow conditions in dendritic (tree-shaped) waterways subject to backwater effects including flood forecasting, dam breach analysis by overtoppping or piping failure, inundation mapping, and representation of flow structures such as levees and gates (DeVries and Hromadka, 1992).

The hydrologic response unit (HRU) concept has been used to scale segments of a watershed with similar soil texture, topography, land use, vegetation and geological features (e.g. soil depth). The use of a GIS framework is particularly useful in delineating watershed and HRU boundaries. Physically-based hydrologic process models are applied to each HRU to simulate the response of the land surface to precipitation and atmospheric forcing through evaporation and transpiration (Leavesley et al., 1983).

Continuous streamflow simulation models are more complex than the HEC-1 model in that they must simulate watershed behavior between storm events and the processes of soil moisture depletion, evaporation, transpiration, and subsurface saturated and unsaturated flow must also be modeled. Lumped parameter models such as the Modular Modeling System (MMS), which divides the basin into hydrologic response units (HRUs), and distributed parameter models such as the Systeme Hydrologique European (SHE), which divides the watershed into rectangular grid points, fall into this class (Leavesley et al., 1983, 1995; Abbott et al., 1986a, 1986b).

MMS provides a framework for incorporation of various process models as well as model calibration and verification (Leavesley et al., 1995). MMS is a dynamic modeling platform which allows for development and addition of new hydrologic process models within a structured framework which is required for communication between the various process modules. The additional hydrologic processes simulated by such models require supplemental input data including atmospheric forcing, stomatal response functions, and soil hydraulic parameters. Models of this type can be applied to a wide range of hydrologic problems such as water resources planning, impacts of changes in land-use, groundwater transport and contamination, and erosion and sediment transport.

Both distributed and lumped parameter hydrologic models can make use of topography, surface and subsurface conditions described in geographic information system (GIS) data bases. Different data sets are co-located through the application of GIS and each data set is represented by an overlay. The information contained in a GIS can be used to separate regions for application of different types of hydrologic simulation models and for retrieval of physical conditions or properties over the region of interest. The information contained on multiple overlays can be used to determine relationships between various parameters within a basin or study area and can also be used to set initial or boundary conditions for hydrologic and atmospheric simulation models (Lee et al., 1993; Maidment, 1993).

Current operational flash flood guidance models do not accurately represent the spatial and temporal variability of predicted or observed precipitation. Operational models, usually run every 6 hours, take 6 hr precipitation forecasts and partition the rainfall equally over time and space into the basin being forecast. Observed precipitation is accounted for similarly although the models can be run more frequently in "flood" situations. Improvements can be made in modeling when and where the precipitation is falling. This is particularly important in convective situations where large amounts of rain can fall over small areas in short time intervals.

Operational runoff predictions are usually based on gaging curves which have been derived from historical data for each river, with land-surface characteristics and conditions included only implicitly. There is a need to incorporate high resolution depictions of land-surface characteristics, which have become available in recent years, into operational models.

Next generation hydrologic models are now being developed to use NEXRAD rainfall estimates in real time with high resolution depictions of land-surface characteristics. By providing detailed data sets, including high resolution gage and NEXRAD rainfall estimates, CASES will help resolve the appropriate temporal resolution needed for flash flood modeling based on precipitation characteristics and the spatial scale of the flash flood forecast. The nested basins within the Walnut watershed will provide an important testbed to refine and calibrate the modeling of distributed runoff and the conversion of runoff to streamflow by various routing methods.

C. Terrestrial ecosystem models

The modeling of terrestrial ecosystems involves short-term responses of vegetation and soils to atmospheric effects, and longer-term evolution of species composition, biome dynamics, and nutrient cycling associated with landscape and soil structure changes (Ojima et al. 1991; Schimel et al. 1991). The assimilation of carbon from vegetation growth, and its subsequent release during decay has been a focus of these models (Schimel et al. 1990; Parton et al. 1993). However, the manner in which land use properties influence biospheric fluxes of CO_2 remains an outstanding problem (Schimel, 1995).

The modeling framework of these simulation tools have generally involved empirically-based logic statements, which, while frequently based on fundamental biophysical concepts, are not expressed as differential equations. The spatial scales of these simulations have ranges from patch sizes to biome scales. These models, particularly when applied on the smaller spatial scales, include a stochastic component to represent unpredictable random inputs from the atmosphere and interactions within the vegetation such as a falling tree. An illustration of the framework of terrestrial-ecosystem models is shown in Figure 2.

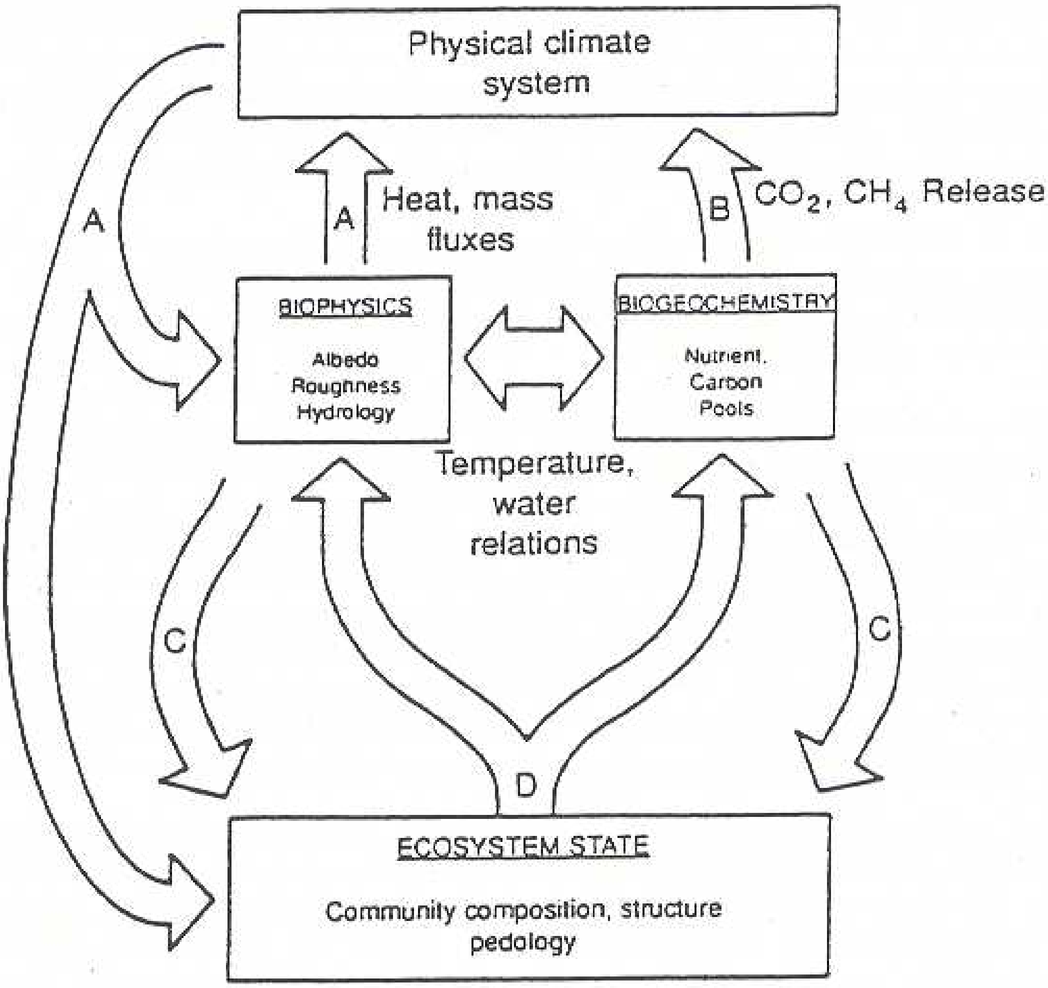


Figure 2: Climate-ecosystem model hierarchy. Interactions between climate and ecological models operating at different spatial or temporal scales needed for prediction of regional ecological response to climatic effects of rising concentrations of greenhouse gases and to direct physiological effects of elevated atmospheric CO_2.

These models require atmospheric inputs such as temperature, relative humidity, net radiation, and precipitation, to integrate their formulations forward in time. Output from nearby climatological stations have been used as the needed boundary conditions for these models when applied on the patch up to the regional scale. However, mean annual changes in regional precipitation and temperature patterns have little relevance to plant productivity and decomposition rates, when these changes take place unevenly throughout the annual cycle or geographical region. Ecosystem development is more sensitive to events as first frost occurrence, duration of wet or dry seasons, timing of thaw out, and beginning of the wet season, which are not well represented in average values of climatic parameters. These characteristics are crucial cues or constraints on processes such as germination, growth initiation, senescence, and mortality. Climate or weather patterns need to be expressed in daily, weekly, or at most, monthly time frames to capture and help predict these biotic processes.

On the global scale, output from general circulation models have been used to estimate potential changes of biome type in response to hypothesized climate change scenarios using, for example, the concept of a Holdridge diagram. More recent representations of equilibrium vegetation distributions are also available (Nielson, 1993).

Ojima et al. (1991) evaluated ecosystem sensitivity to the temporal and regional resolution of climate change (changes in annual mean climate vs. seasonally varying changes) by driving a regional ecosystem model with general circulation model (GCM) climate output. Using a grassland model developed for the North American Central Grasslands region (CENTURY, Parton et al. 1987), simulations of aboveground net primary productivity and soil organic carbon for 72 sites across the region were made. Climate change was applied in two ways: (1) monthly basis, where monthly changes in temperature (T) and precipitation (PPT) were based on monthly GCM output, and (2) annual basis, where annual changes in T and PPT from GCM output were applied uniformly across the year. The growing season climates that resulted from applying climate change at these two temporal resolutions differed substantially.

The complexity of the interactions between weather, climate, and biotic systems is tremendous. Understanding their linkages is an enormous challenge which has been hampered by both technological limitations and the lack of sufficient and spatially explicit data sets of carbon flux. The CASES research facility can provide a comprehensive set of carbon flux data and isotopic information to examine the fluxes and budgets for carbon in selected well-defined land cover classes within a thoroughly instrumented watershed of the Great Plains. This will improve our understanding and modeling of the terrestrial biosphere and its linkages to the atmosphere and hydrosphere.

2.3 Summary

The atmosphere, hydrosphere, and biosphere are coupled, interactive systems. It is no longer sufficient for one component to be studied using prescribed inputs from the other two. They must be studied together over extended time periods. The CASES site will enable scientists to pursue a broad range of interdisciplinary research including for example:

* observing and documenting linkages between the atmosphere, hydrosphere, and biosphere

* testing parameterization schemes in weather and climate models

* refining representation of soil moisture in precipitation prediction

* determining effects of mesoscale motions on surface-atmosphere fluxes

* defining role of land-surface heterogeneity in boundary layer models

* developing and testing distributed hydrologic models

* developing procedures for scaling small basin hydrology to synoptic/climate scales

* fine tuning WSR-88D precipitation algorithms

* exploring multi-parameter radar techniques

* testing and improving satellite algorithms and optimizing integrated remote sensing techniques

* quantifying CO_2 fluxes between the atmosphere and the biosphere

* educating students in the collection and analyses of observational data

CASES represents a unique opportunity for scientists and students of the environmental sciences.

3. Experimental Strategy

To address the scientific challenges outlined in the previous section, the following experimental strategy will be followed.

3.1 Guiding Philosophy

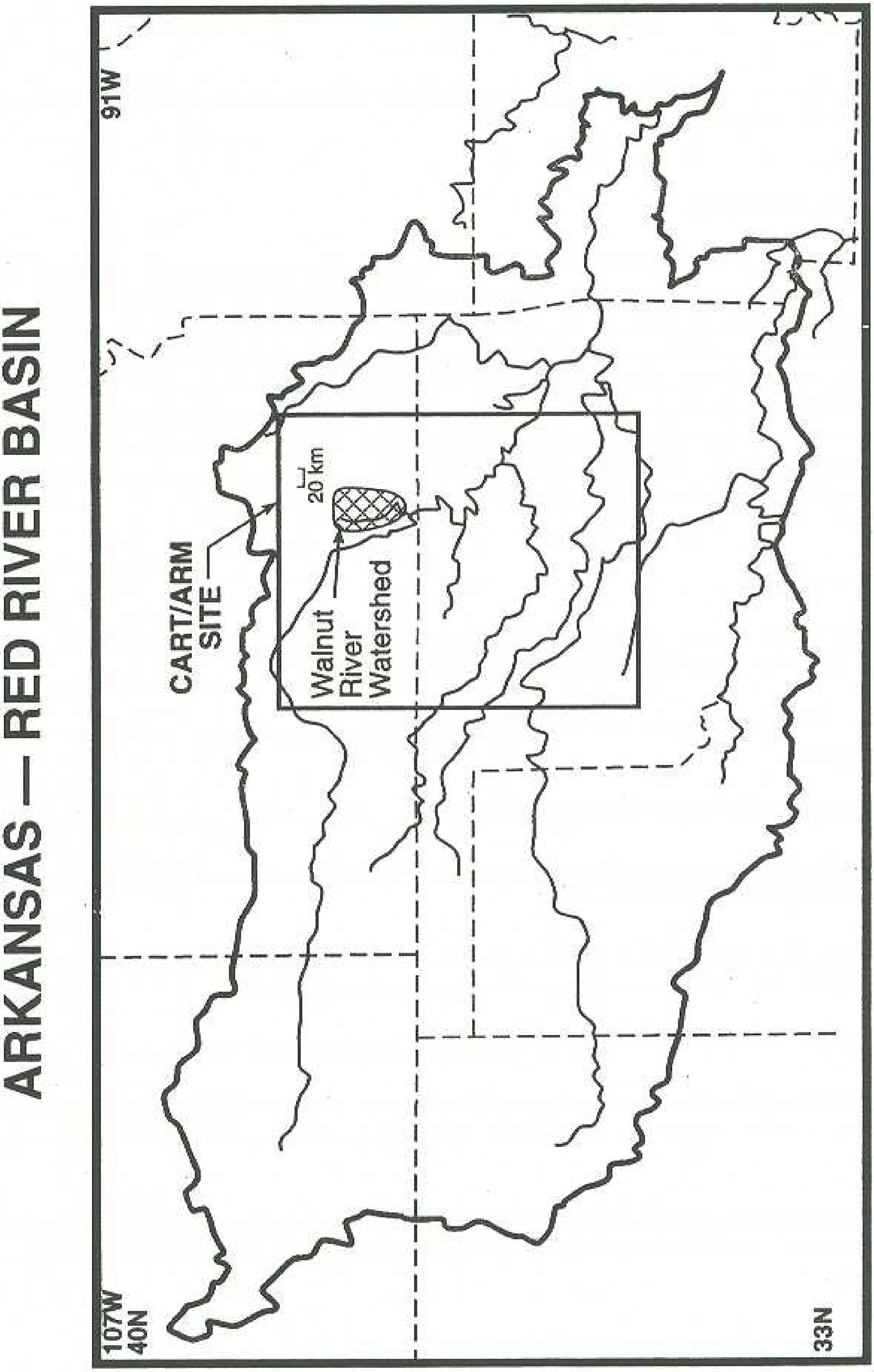
The design of CASES has evolved from a collaborative effort among university scientists, federal agencies, and national programs with similar scientific interests. The CASES design positions boundary layer instrumentation such that it coincides with the natural boundaries of a watershed. Such positioning simplifies efforts to close the surface water balance since the net runoff can be measured at one point. This, in turn, also helps verify other atmosphere/surface linkages. Thus, the boundary layer instrumentation, in conjunction with satellites, WSR-88D radars, stream gages, soil moisture data, topographical and land use data, surface meteorological data, biophysical data and coupled atmosphere-biogeochemical models, will allow for a detailed observation and description of event-driven, interseasonal, and interannual surface-atmosphere exchange processes.

3.2 Site Description

The CASES site is located in the upper Walnut River watershed, north of Winfield, Kansas (see Figure 3). This watershed was chosen for the following reasons:

- It is within the ARM-CART site, thereby ensuring comprehensive atmospheric data on the mesoscale.
- Shape, size and land use patterns are compatible with boundary layer design considerations.
- The boundary layer array will be essentially congruous with the watershed boundaries, thereby facilitating hydrologic research.
- It is an order of magnitude larger in area than the Little Washita watershed, thus allowing for critical scaling issue comparisons to be made between the two.
- Low level research flights over the majority of the region are possible.
- Hydrologically, it is considered a reasonably tight watershed, with minimal leakage into the substrata; and the stream bed is relatively stable which increases the reliability of stream gage data.
- It includes the headwaters of the Walnut and Whitewater rivers, thereby minimizing differencing errors which can effect water balance studies conducted on river segments between stream gages.

Figure 3



ARKANSAS — RED RIVER BASIN

- It is located in the NE portion of the Arkansas River basin in a region that receives about 34 inches of precipitation annually. This should ensure several good cases of significant runoff events and periodic wet/dry cycles every year.
- It has WSR-88D coverage from Wichita, Topeka, Tulsa, and Vance AFB, which will allow testing and intercomparisons of precipitation estimation algorithms at various ranges.
- It has an annual average snowfall of 14 inches, providing some opportunity to examine WSR-88D snow measuring capabilities.
- It has 5 established gaging stations at various points along the Walnut river, providing a historical data base.
- It has 8 USGS precipitation stations which report via satellite in real time, providing a historical data base.
- It was the optimum location which met the majority of joint requirements as outlined by the meteorology, climate, hydrology, ecology, and chemistry communities who participated in the planning of CASES.

3.3 The CASES Facility

CASES is envisioned to provide the infrastructure required to carry out long term and episodic field campaigns associated with surface-atmosphere exchange processes. Among the facilities and services provided would be a minimum "critical mass" complement of instruments, operated continuously during the lifetime of CASES, with supporting power, phone, and data management services. Instrument maintenance and site management will be available to ensure that the services provided will be used in an efficient manner. The facility will be available to individual investigators or groups of investigators who would either use the instruments in place or deploy an additional suite of instruments to complement the existing array. These investigators will be responsible for obtaining funding to deploy any additionally desired instrumentation. Mechanisms for data collection and archiving from the supplemental instrumentation will be in place but would also require funding from the PI(s).

A. Long Term Instrumentation: As part of the implementation process (see section 3.4), modeling studies will provide guidance as to the preferred number and location of long term instrumentation. At this time, the following instruments are envisioned to eventually be part of the CASES site:

- 6 boundary layer profilers with RASS
- 6 mini-sodars co-located with profilers
- 6 ceilometers co-located with the profilers

* 10 surface flux stations each adapted for 10 multiplex soil water/heat content instruments and 3 replicate precipitation measurements. Also, Carbon Dioxide and Monoxide measurements.

* 20 surface meteorological stations with DCP satel. uplink, each adapted for 3 replicate precipitation and soil water/heat content.

* 3 stream gages with DCP satel. uplink (bringing total to 8)

* 1 humidity profiler at central site

Six boundary layer (915 MHz) wind profilers, with virtual-temperature profiling (RASS) capability at half-hour intervals are envisioned to encompass the watershed. These will be used to observe the vertical structure of the atmospheric boundary layer (ABL) over the site. In conjunction with surface measurements and other methods to measure water vapor, they will also allow description of the horizontal advection of heat, moisture, and momentum. Characterization of the changing ABL is a critical component in understanding air-surface exchange processes.

Six mini-sodars, co-located with the profilers will be used to provide air flow data between 10 and 200m, a region the 915 MHz profilers have trouble resolving.

Six ceilometers, deployed in conjunction with the wind profilers, will be used to measure cloud base and better define the top of the boundary layer.

Ten flux stations, to provide eddy-correlation fluxes of heat, moisture, momentum, CO, and CO_2. Measurements of the water and energy budgets will include precipitation, evaporation, soil heat/water content (2-3 m depth), ground water level, solar radiation, net longwave radiation, sensible heat flux, and latent heat flux. Ten soil heat/water content measurement sites within the footprint of each flux tower down to a depth of approximately 1.5 m, depth increment 15 to 30 cm, will be distributed to evaluate the spatial variability of this parameter. Three replicate precipitation measurements at distances of 100m and separated by 120 degrees will also be made.

The flux stations will be situated according to land use as defined by a GIS (Geographical Information Systems) analysis of surface properties. Both ecologists and meteorologists recommend that half be placed in the grassland that generally characterizes the eastern half of the CASES area, and the remaining half placed according to farming practice in the cropland that generally characterizes the western half. Prior experience suggests that ten is about the minimum number needed to represent the different surface types and provide sufficient areal coverage. Evaluation of this number will be part of the implementation process. These stations will characterize the near surface atmospheric environment, the earth boundary layer, and fluxes between the two.

Twenty surface meteorological stations, to get representative surface fields of temperature, insolation, humidity, wind, precipitation, and soil water/heat content. For hydrological/ecological purposes, each site will be surrounded by 3 replicate measurements of precip, and soil water/heat at a distance of 100 meters, separated by 120 degrees.

Surface data aid in the determination of horizontal advection for the long-term budgets and investigations of nonhomogeneous boundary layers, and enhance investigations of the role of the surface and planetary boundary layer in the dynamics of fronts, storm initiation, etc. They also provide mesoscale and microscale data needed for WSR-88D algorithm testing and hydrologic modeling.

Three additional stream gages are proposed between Augusta and Winfield: one each on the two major creeks to the east which feed the main stem of the Walnut, and one on the main stem between the two creeks. This will create four additional sub-basins in the southern half of the Walnut, facilitating hydrologic scaling and modeling studies.

Long-term, continuous **humidity profiles** need to be collected in conjunction with the profiler sites. However, affordable, accurate humidity profiling techniques remain elusive. The use of serial radiosondes, a tethered balloon, or an instrumented kite (or a combination) at these sites will be weighed against the cost of continuous profiling of humidity through remote sensing. More detailed humidity budgets will probably be the focus of episodic experiments. The CASES site could serve as an ideal testbed for developing and testing new humidity profiling techniques such as combining ground based GPS receivers with independent data and/or models.

B. Deployment

Figures 4 and 5 show the schematic locations of most of the proposed instrumentation for the CASES site. In Figure 4, the upper Walnut watershed, north of Winfield and east of Wichita, is heavily outlined. Type and location of various instrumentation is indicated by the colored circles as defined in the Legend. Black letters within the colored circles indicate existing or soon to exist instrumentation. White letters indicate instruments which will hopefully be obtained in the future.

Figure 5 shows 10 surface flux stations distributed throughout the basin in a manner which would reflect appropriate representation of component ecosystems. The 20 meteorological stations would be deployed more uniformly. Decisions on final site locations and numbers will be coordinated with numerical modeling simulations of the watershed and evaluations of site density contributions.

3.4 Implementation

A. The Argonne Atmospheric Boundary Layer Facility

CASES is being initiated in FY 96 with the establishment of the Argonne National Laboratory (ANL) Atmospheric Boundary Layer Facility (ABLF) in the southern half of the CASES site. The ABLF will be equipped to provide surface-based observations of the vertical profiles of temperature, humidity, and wind and the air-surface exchange rates of heat, moisture, and momentum. A continuous view of atmospheric processes will be provided with sufficient detail to enable significant advances in the description, understanding, and modeling of the atmospheric boundary layer.

Figure 4

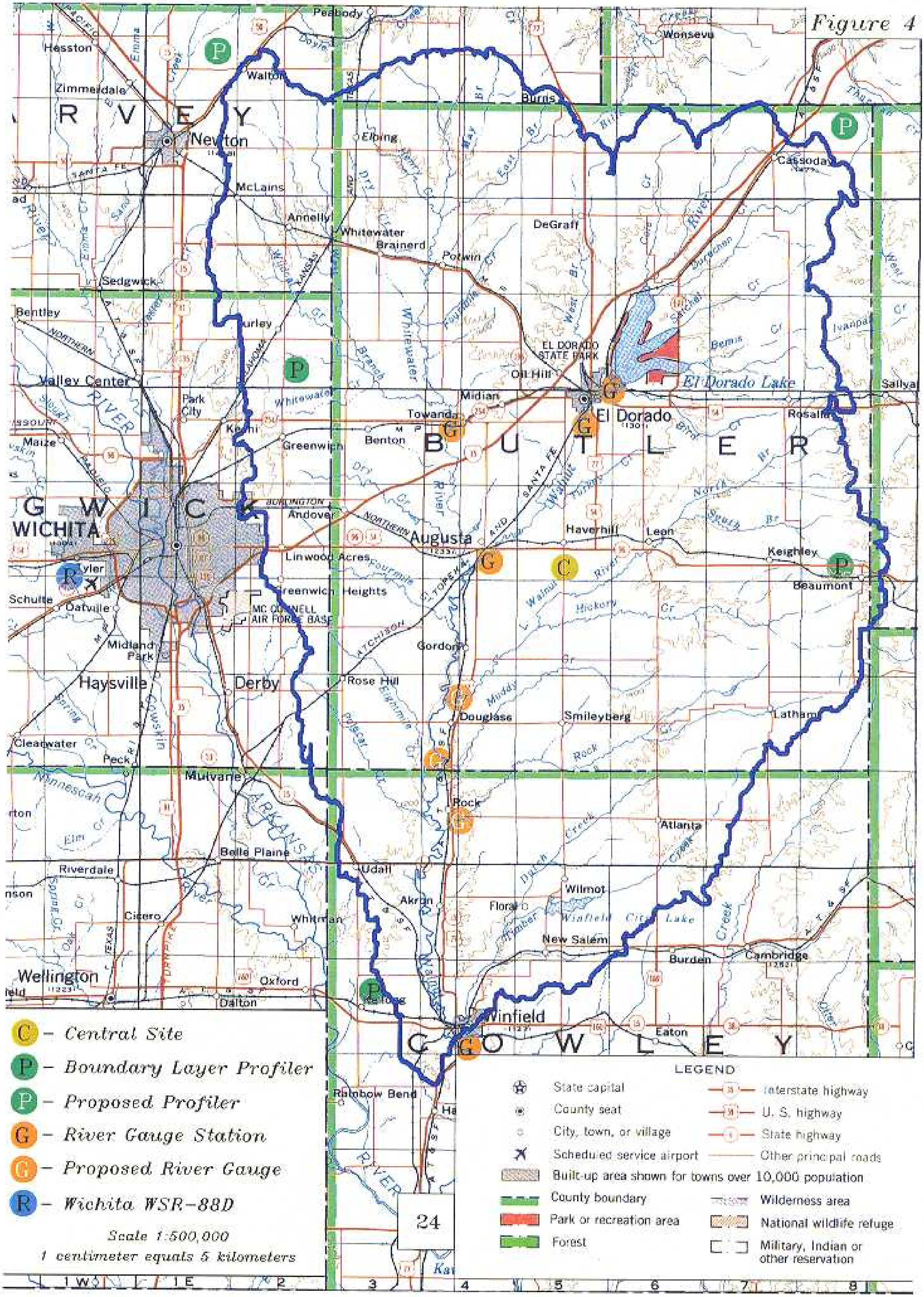
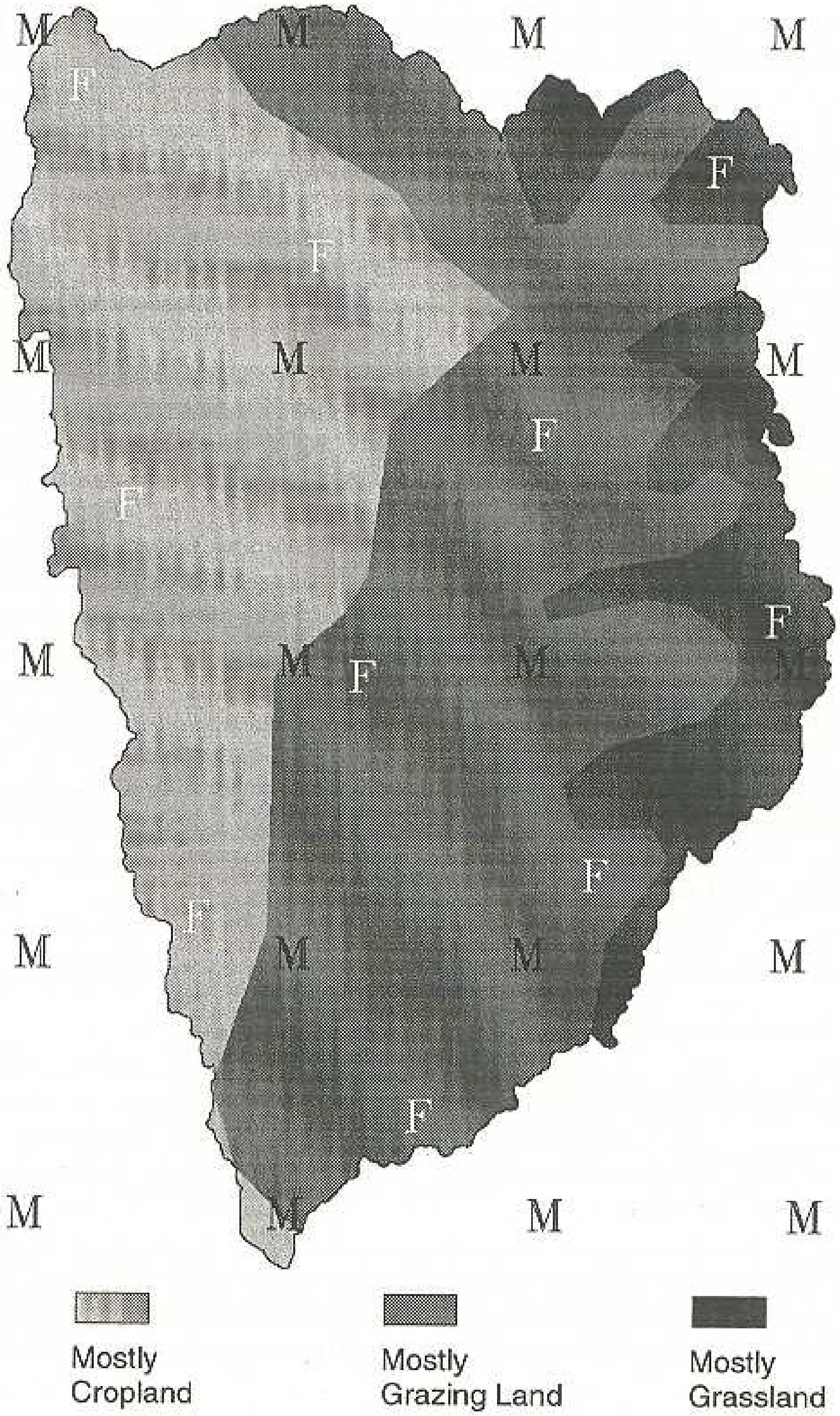

C – Central Site
P – Boundary Layer Profiler
P – Proposed Profiler
G – River Gauge Station
G – Proposed River Gauge
R – Wichita WSR-88D
Scale 1:500,000
1 centimeter equals 5 kilometers
LEGEND
State capital
County seat
City, town, or village
Scheduled service airport
Built-up area shown for towns over 10,000 population
County boundary
Park or recreation area
Forest
Interstate highway
U. S. highway
State highway
Other principal roads
Wilderness area
National wildlife refuge
Military, Indian or other reservation
HARVEY
SEDGWICK
BUTLER
COWLEY
Newton
WICHITA
El Dorado
El Dorado Lake
EL DORADO STATE PARK
Augusta
Winfield
Walnut River
Whitewater River
Arkansas River
Winfield City Lake
Wellington
Derby
Haysville
Towanda
Douglass
Rock
Cassoday
Beaumont
Burns
Wonsevu
Peabody
Andover
Udall
Oxford
Mulvane
1 W
1 E
2
3
4
5
6
7
8

Figure 5
Example of Proposed Deployment of Long-Term Surface Stations

F - Flux *M - Meteorological*



The equipment (and variables observed) at the Argonne Boundary Layer Facility as currently planned includes the following: (1) three 915-MHz radar wind profilers (RWPs) and radio acoustic sounding systems (RASS) (wind speed, direction, virtual temperature profiles); (2) three minisodars (wind and turbulence profiles); (3) one lidar ceilometer (cloud base height); (4) one balloon-borne sounding system (wind, temperature, moisture profiles); (5) five surface flux stations (surface sensible and latent heat, momentum flux, ground heat storage); (6) five soil sampling stations (soil moisture, soil temperature); (7) one satellite data receiver-processor; (8) one data hub at a central location on site for data collection; and (9) one (extra) instrument pad at the central site to facilitate deployment of supplemental instrumentation during episodic experiments.

During FY 1995, efforts at Argonne were focused on planning, coordination with CASES, acquisition of a workstation to serve as part of the data hub, and acquisition of one 915-MHz RWP-RASS. One existing 915-MHz RWP-RASS existing at Argonne was evaluated and modified for installation at the Walnut River Watershed. These two systems and a 915-MHz system independently supplied by the ARM program will be installed during 1996 at the vertices of a triangle drawn over the southern half of the CASES site, and the three systems are expected to begin producing data by summer or early fall of 1996. Efforts are also underway to install and begin operation of an eddy correlation system available at Argonne for measuring fluxes of heat, moisture, momentum, and possibly carbon dioxide within the array during 1996. Satellite data receiving-processing capabilities already exist at Argonne for polar orbiting satellites, and routine data collection for evaluation of non-dimensional vegetative indices will begin as surface data collection begins. In FY 1996, work will include adaptation of minisodars (item 2) existing at Argonne and installation in the ABLF; acquisition of surface flux stations (item 5); and site preparation involving leases, equipment installation, data communications, and related tasks. Methods of exchanging data with the ARM program will be developed. Overall, Argonne plans to complete the ABLF during FY 1998.

B. Coordinated Proposals

Using the ABLF as a nucleus, implementation of the entire CASES facility will be approached via coordinated proposals designed to:

1. Analyze data from the ABLF.
2. Demonstrate viability of the ABLF.
3. Demonstrate feasibility of achieving scientific goals.
4. Demonstrate applicability over the entire CASES site.
5. Obtain multi-year measurements of surface-atmosphere exchange processes over the entire CASES site.

The first effort is embodied in an experiment planned for 15 April-15 June, 1997 called CASES-97, which will address the first three objectives listed above. CASES-97 consists of an original core experiment that has been joined by a number of complementary experiments focusing on one or more of the objectives. Though each is self-contained, all can benefit from coordination with the others. Principal investigators and instrumentation come from several agencies and universities (see Table).

Scientists planning to participate in the CASES 97 core experiment (CASES-97-1a) include:

Margaret A. LeMone, NCAR, who will work with Robert Grossman, CU, on budgets and PBL diurnal variation, and with Richard Coulter, Marv Wesely, and others at Argonne to evaluate profiler data.

Robert L. Grossman, University of Colorado, who will (a) work with LeMone on budgets and PBL diurnal variation, and with Coulter on the effects of regional surface characteristics on surface exchange. (b) use conditional sampling to estimate the effect of entrainment events on the near-surface (3-m) fluxes

Richard Coulter and Marv Wesely, Argonne National Laboratory, who will work with LeMone and Grossman on evaluation of the profiler data.

Roger Pielke, Colorado State University, who will (a) run a version of RAMS to aid in the design of the field campaign, (b) run an operational version as an aid to forecasting during the field program; (c) produce surface-property data sets and analysis products with complete data for post-analysis (both budgets and diurnal variation), with Zeng; (d) produce surface-property datasets to be used along with meteorological datasets for parameterization testing, with Grossman, LeMone, and Zeng; (e) run a version of RAMS to identify the minimal long-term deployment needed to optimize instrumentation of the CASES site.

Xubin Zeng, University of Arizona, who will (a) evaluate a land surface scheme (BATS) coupled with the boundary layer scheme in NCAR climate model (CCM3) with an emphasis on soil moisture, surface temperature, equivalent potential temperature in the boundary layer, and boundary layer top entrainment interactions (with Grossman, LeMone, Pielke, Coulter), and (b) investigate the feasibility of using aircraft to document the effects of mesoscale eddies on boundary layer fluxes.

As part of CASES 97, related studies in hydrology, surface-layer processes, boundary-layer physics, and precipitation measurement, are planned by the following scientists:

Bruce Hicks (NOAA/ARL), Marvin Wesely (Argonne) and Robert Grossman (CU) who plan to use tower and NOAA twin aircraft data to study air-surface exchanges in conditions of patchy surface wetness.

Larry Mahrt (Oregon State Univ.), Jielun Sun (CU) and Robert Grossman (CU), who plan to (a) study the differences between the windy, weakly stratified and very stable, weak wind nocturnal boundary layers, (b) investigate proper use of surface temperature in bulk flux formulas, and (c) study effects of entrainment events on surface fluxes.

Richard Cuenca (Oregon State Univ.), who plans to determine the relationship between the predominant length scales of soil moisture content, soil hydraulic properties and precipitation and whether or not one or more of these length scales is affected by seasonality. Instrumentation includes a combination

Table: Experiments Proposed for CASES-97

Experiment	PI's	Affiliation	Times	Objectives
CASES-97-1a	R. Grossman M. LeMone R. Pielke X. Zeng M. Wesely R. Coulter	CU NCAR CSU Ariz. Argonne Argonne	May 1997 (five, 24-h fair-wx IOPs)	(a) Perform budgets of PBL heat, moisture, momentum (b) Quantify effect sfc properties on PBL evolution (c) Test BATS and CCM3 PBL scheme and link them (d) Test techniques to examine mesoscle eddies (e) Evaluate Argonne Boundary Layer Facility instrumentation, what measurements really needed for (a) and (b) using model, or just observations
CASES-97-1b	B. Hicks R. Grossman M. Wesely	NOAA/ARL CU Argonne	15 Apr-31 May[b] (up to 10 fair-wx IOPs)	Use tower and aircraft data to study air-surface exchanges in conditions using patchy surface wetness
CASES-97-1c	L. Mahrt J. Sun R. Grossman	Ore. State CU CU	Same as 1a	(a) Determine effect entrainment events on sfc fluxes (b) Investigate effects winds vs radiation on nocturnal PBL (c) Investigate use of sfc radiation temp in bulk formula for fluxes in nonhomogeneous terrain
CASES-97-1d	R. Cuenca	Ore. State	April 1 -->[a] (incl. 3-4 week IOP w/ soil moist. sampling coord w/radar PIs)	Determine relevant length scales for soil moisture content, soil hydraulic processes, and precipitation
CASES-97 2a	J. Wilson E. Brandes D. Zmic J. Vivekanandan C. Duchon V. Chandrasekar	NCAR NCAR NSSL NCAR Oklahoma CSU	15 April-15 June (emph rainy wx)	(a) Improve existing WSR-88D rainfall estimation (b) Evaluate dual-polarization rainfall estimation
CASES-97-2b	C. Duchon M. Stewart	Oklahoma WSFO/Wichita	April 1-->[a]	Investigate a space and time adaptive Z-R relationship for WSR-88D
JETEX-97	R. Arritt M. Segal	Iowa State Iowa State	May (4 fair-wx IOPs with S to SW geost. wind late aftenoon to after sunrise)	(a) Investigate the interaction of the low-level jet with boundary-layer processes and turbulent exchange. (b) Evaluate contamination of wind profiler data by birds
LLJ(tentative)	T. Parish A. Rodi	U. Wyo.	May o.k. (30-40h flt time, fair wx, night)	Evaluate use of differential GPS to infer horizontal pressure gradient, to get isallobaric part of ageostrophic wind associated with low-level jet (LLJ)
CENTURY Model	D. Ojima	CSU	n/a	Run CENTURY model with historical and CASES-97 data to study ecosystem controls on water, carbon, and other trace gases.

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[a] Signifies some observations will be taken longer-term (2-3 years +)
[b] NOAA Twin Otter, 15 April-15 May; Wyoming King Air 1-31 May

of automated and manual time domain reflectometry sites for soil moisture content, distributed tension infiltrometer measurements for soil hydraulic properties, and a rain gage network for precipitation.

James Wilson, Edward Brandes and Jothiram Vivekanandan (NCAR), Dusan Zrnic (NSSL), and V. Chandrasekar (Colorado State Univ.) who plan to deploy NCAR's S-Pol radar and evaluate dual-polarimetric data in conjunction with WSR-88D data to determine potential improvements in precipitation estimation and hail detection algorithms. Will cooperate with Duchon, Stewart, and Cuenca.

Claude Duchon (Univ. of Oklahoma) and Michael Stewart (Scientific Operations Officer at the WSFO in Wichita), who plan to evaluate WSR-88D precipitation estimation algorithms, addressing such issues as range biases and modifications to the Z-R relationship.

Ray Arritt and Moti Segal (Iowa State), who plan to use the data from this experiment, along with data they will collect on larger scales, to study the interaction of boundary-layer processes with regional scale dynamics in the evolution of the low-level jet.

Tom Parish and Al Rodi (Univ. of Wyoming), who tentatively plan to use Wyoming King Air measurements to study evolution of the low level jet.

Dennis Ojima (Colorado State Univ.), who plans to use the CENTURY model to assess ecosystem controls on water, carbon, and other trace gas fluxes into the atmosphere. The impacts of changes in climate on land use at the CASES site will be evaluated relative to changes in H_2O, and N exchange with the atmosphere. An eddy accumulation system is planned for the CASES site to measure C and H_2O exchange and determine the biospheric controls on C and H_2O fluxes from different land cover types. Linkages between the atmosphere, hydrosphere, and biosphere will be evaluated using an integrated model of the coupled systems.

Cross-cutting scientifically, the objectives of CASES-97 can be divided generally into fair-weather (CASES-97-1) and rainy-weather (CASES-97-2) goals. The fair-weather goals are to: (a) document effects of surface wetness on atmospheric planetary boundary layer (PBL) diurnal evolution incorporating PBL and surface data into observational analysis and numerical simulations using the Regional Mesoscale Atmospheric Modeling System (RAMS); (b) document the relevant length scales for soil moisture content and hydraulic processes; (c) test the representation of PBL, surface-process, and subsurface evolution parameterization schemes (e.g., the Biosphere-Atmosphere Transfer Scheme, BATS); and (d) use the analyses to evaluate the ABLF profiler data. The rainy- weather goals are to test existing and alternative WSR-88D precipitation-estimation algorithms and to explore use of dual-polarization information as a means for further improvements in precipitation estimation techniques.

The three wind profilers (minisodars plus 915 MHz wind profilers) with RASS that represent the first-stage deployment of the ABLF will serve as the instrumentation nucleus for CASES-97. If all the proposals of the PIs in the table are successful, additional instrumentation will include 11 surface flux stations (8 PAM IIIs requested from the NSF Deployment Pool, one flux tower operated by ARM/CART, one flux tower from Argonne National Laboratory, and one flux tower from NOAA. Each of the flux towers will sample heat, moisture, and momentum fluxes using the eddy-correlation technique, net radiation, incoming solar radiation, and the standard meteorological variables (wind, temperature, humidity, precipitation). At least two flux towers (Argonne, NOAA) will provide estimates of ozone and CO_2 fluxes, and at least two (Towanda, one PAM III) will have soil moisture profiles. CLASS radiosondes will be collocated with the profilers (for soundings at 1.5-h intervals for five 24-hour IOPs), and two aircraft (the NOAA Twin Otter and the Wyoming King Air) have been requested for daytime PBL observations (the King Air may also be requested for nighttime observations of the low-level jet, see Table). The NSF S-band POLarimetric (S-POL) radar will be deployed near the Wichita WSR-88D Doppler radar. 35 rain gages will be deployed in the Towanda sub-basin and another 25 will be distributed throughout the remainder of the Walnut watershed. During a 3-4 week period, soil moisture measurements will be taken at 25-30 locations within the Towanda sub-basin every 1-2 days for comparison to the soil-moisture profiles taken at the Towanda flux station. On the larger sale, JETEX-97 has requested collocation of Integrated Sounding Systems (ISSs) with the NOAA 404-MHz wind profilers at Jayton, Texas, Vici, Oklahoma, and Haviland, Kansas.

Numerical models will be used extensively by several of the PIs in the course of their data analysis. Pielke's runs of RAMS (CASES 97-1a) will be used to aid in siting the surface flux stations as well as to aid in deciding on whether or not to have an IOP. After the experiment, RAMS data will be used to evaluate PBL budgets of heat, moisture, and momentum through the diurnal cycle, for comparison with those derived from observations alone. Zeng will be using CASES-97 data to test the Biosphere-Atmosphere Transfer Scheme (BATS), the PBL scheme used in the NCAR Community Climate Model CCM3, and to link the two schemes. Hicks et al. will use a version of RAMS developed at NOAA/ARL as an aid in interpretation of their results. In JETEX-97, the PIs seek to improve the ability of the NCAR/Pennsylvania State University MM5 mesoscale model to replicate the low level jet. Dennis Ojima of Colorado State University will be conducting runs using the CENTURY model to assess ecosystem controls on water, carbon, and other trace gases into the atmosphere, using historical data from the CASES area, and CASES-97 data, in preparation for more ambitious measurements later on. Cuenca will work with Dennis Lettenmaier of the University of Washington to incorporate length-scale information into hydrologic models, and with Larry Mahrt and Michael Ek of Oregon State to incorporate results into the OSU Coupled Ocean Plant Soil (CAPS) model.

Additional scientists may become involved as planned CASES 97 activities are confirmed.

C. Future Activities

A more ambitious and extended field phase (CASES 98) is envisioned for Fall of 1998 through Spring of 1999 . Preliminary thoughts are that this experiment would include an expansion of the profiler array, flux, and meteorological stations to encompass the entire CASES site. A continuation and expansion of the CASES 97 foci to include an interseasonal component is planned. A national planning meeting in the late Fall of 1997 would be an appropriate forum for the presentation of preliminary results from CASES 97, obtaining guidance for CASES 98, and entraining additional scientists interested in pursuing research as part of CASES.

3.5 Data Management

The development and maintenance of a comprehensive and accurate data archive is critical to meeting the scientific objectives of CASES. The project has been designed as a multi-agency sponsored, multi-disciplinary program with potentially many different investigators and varied instrumentation over several years. An integrated data management activity is central to providing a consistent high quality database that is easily accessible throughout the lifetime of the program and beyond. The CASES data management philosophy is to make the completed dataset available to the research community as soon as possible. This will permit resolution of the interdisciplinary research objectives in a timely fashion and permit access by a broader community.

CASES has proposed that the following data protocols be followed by all participants.

* Ensure open access to all CASES datasets. This requires a data management strategy that facilitates data exchange and investigators taking responsibility for making data available. Exceptions to this policy will be considered only for PIs bringing strictly experimental sensors or facilities to the field.

* All investigators participating in CASES must agree to promptly (within 6 months of end of a field campaign) submit data to the CASES Project Office to facilitate data processing (if needed), archival and distribution. Quality controlled datasets must be submitted to the archive in a useable format with sufficient documentation to allow easy access and understanding by others. Certain datasets will be collected continuously over the lifetime of the CASES site. These data will be provided routinely (once per month, if possible) to the CASES Project Office for inclusion in the data archive.

* Ensure that the CASES dataset is comprehensive by acquiring appropriate data from NOAA, NASA, DOE-ARM, GCIP, etc. that might be conducting programs in conjunction with or of interest to CASES.

* The CASES Project Office, in conjunction with UCAR's Office of Field Project Support and Argonne National Laboratory, will assume responsibility for developing and implementing an integrated data management strategy.

* CASES data processing, quality control, validation ,archival and dissemination functions will be distributed among several sites and be the responsibility of several investigators, depending on the types and sources of data. The Project Office will coordinate these activities to minimize duplication and maximize availability of quality datasets.

* The CASES Project Office will gather a list of needs and requirements for datasets to address the different facets of CASES. For example, a special dataset that contains measurements needed by boundary layer modelers could be prepared synthesizing relevant radiation, aircraft, satellite, surface, soil and hydrology data that would be useful in initialization and validation studies. Similar derived datasets for ecology, atmospheric chemistry and hydrology will be prepared.

* The CASES Project Office will work with existing National data archive centers as much as possible to prepare a rich dataset for research and analysis. Contact has been made with the National Climate Data Center, the ARM Project Archive at Oak Ridge National Laboratory and the National Center for Atmospheric Research to assure data access interoperability.

3.6 Science Education

Field observation programs can provide exciting opportunities for students to learn about science. These can range from merely stimulating the scientific curiosity of middle and secondary school students, to providing hands-on experience for undergraduate and graduate students to learn about instrumentation, sampling problems, measurement errors, data collection, analysis and interpretation. The long-term and episodic components of CASES offer some unique possibilities in this regard.

First, CASES is multi-disciplinary, involving meteorology, climate, hydrology, ecology and chemistry. The fact that our environment acts as a system in which each component influences every other component is an important lesson for both students and teachers to learn at all levels of education. CASES will present an opportunity to observe these interactions occurring in a dramatic way when, for example, a thunderstorm passes through the Walnut River watershed in the midst of a dry period during the growing season. The influence of this event on stream flow, water quality, air quality, vegetation, and practically every land and atmospheric variable would be easily seen in data gathered using the proposed instrumentation. With data collected throughout the year, there will be opportunities to observe a spectrum of interesting events.

Second, physical measurements will be made using both standard and state-of-the-art instrumentation. Thus, university students will have the opportunity for hands-on experience collecting data themselves and/or observing how data are collected. Understanding the idiosyncrasies of instrumentation and the limitations of the data acquired are important to balance perceptions gained from the use of computers which generate seemingly "perfect" data. There has been a growing realization in the past few years that too few college science students either appreciate the important role that observational data play in the geophysical sciences or graduate with even a minimal appreciation of the limitations of environmental measurements (Takle, 1989; Atlas et al. 1989, Serafin et al. 1991). CASES can help remedy this situation by providing an incentive for faculty and students to engage in field studies either as part of a course of study or as thesis research. Various levels of student involvement will be possible ranging from short-term non-funded research projects, to summer employment, to discipline specific and multi-disciplinary research assistantships.

A third attribute of CASES is that it is a longer-term field effort. This allows time for developing a substantial educational component which can improve science education in middle and high schools. To enhance science literacy among secondary students and teachers, a long-term field facility with episodic experiments can serve as a classroom-in-the-field for observing scientific activities and a field-in-the-classroom for examining data from those activities and determining their physical meaning. Programs are envisioned in which students and teachers visit field observational sites, scientists and graduate students visit schools, and data sets collected in field projects are made available for classroom study by students and teachers.

What makes all this possible is the ease with which field data can now be brought into classrooms at all education levels using current data communications. Unidata, a branch of UCAR, whose mission is to empower U.S. schools and universities with the ability to access and utilize data streams, has the capability to effect such a distribution. With color display monitors and well-trained teachers to provide guidance, students can quickly grasp salient environmental interactions occurring in the Walnut River watershed. Educational materials (i.e., study guides, problems to be solved) will have to be designed to take advantage of the dynamic physical data that will be available.

Finally, it is critical to the success of any field program that there be a clear understanding of its objectives by the affected land owners, business people, and the general public, and that there be sustained good will between these groups, scientists, and other individuals connected to field projects. Thus, CASES will develop an outreach program where project personnel with sound communication skills can talk to both organizations and the general public through service club meetings, town council meetings, and the media.

3.7 Project Management

A joint Argonne/NCAR/NOAA CASES project office, consisting of a project director and a computer programmer, has been established within the Mesoscale and Microscale Meteorology division of NCAR. The primary roles of the office at this time are to: continue developing funding resources for CASES; identify, coordinate, and facilitate research opportunities for the scientific community; establish an operational data management scheme addressing all aspects involved in providing access to continuously collected observations relating to the CASES site; and to develop three-dimensional graphics to depict the data streams.

Experiment planning and logistics have been and will continue to be coordinated by the CASES project office in conjunction with the national scientific community through participation in planning meetings, workshops, and working groups. Additional coordination with Argonne National Laboratory, UCAR's Office of Field Project Support, federal agencies, and other research programs is ongoing.

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