Coupling Observations and Research in the Air Resources Laboratory: The ARL Multi-Tiered *Atmospheric Coordinated Observations and Research Network (ACORN)* Integrated Monitoring Array

Summary. The Air Resources Laboratory has been a long-time leading advocate of the principles of ***Coordinated Observations and Research***. This research philosophy is known by some as "Integrated Monitoring." ***ACORN*** represents a new approach to environmental research and prediction in which measurements are not limited to tracking changes in the characteristics of some environmental systems, but are also matched with the requirements for specifically designed scientific studies of factors that lead to more sound explanations of the causes of those changes. From the aspect of climate, weather air quality and ecological research, its objective to improve the capability to detect changes in the atmospheric environment and to improve predictions of such changes, with emphasis on the interaction between the atmosphere and the land surface and the biosphere. ***Coordinated Observations and Research*** implies a more focused coupling of measurements with theory to enhance the analysis and prediction research efforts being conducted by NOAA in compliance with its Strategic Plan. This in turn requires an effort to further utilize NOAA's long-term observing programs along the lines of a traditional scientific approach. It is through coordinated sets of observations, coupled with analytical investigations of cause-and-effect, that understanding can be improved at a more rapid pace, ultimately leading to more accurate prediction of future changes. The observations reveal the details of the true behavior of atmospheric phenomena and also provide for research on a continuous or nearly continuous basis, involving both NOAA's surface networks and satellites The suite of NOAA observations constitutes a complementary subset of other national observational programs, such as are led by NASA, NSF, USDA, and DOE, but the ARL surface networks are unique in that they cover much of the U.S. and obtain continuous data. It is the analysis and prediction aspects of the ***ACORN*** approach that constitute the heart of ongoing research. It is this aspect that differentiates ***ACORN*** from classical monitoring of status and trends.

Over the last two decades, ARL has organized a number of collaborative and interconnected monitoring networks, which together constitute an organized measurement and analysis approach to predict future changes in the coupling of the atmosphere-terrestrial biosphere system. This assembly of networks and research makes up the ***ACORN*** integrated monitoring network.

The components of ***ACORN*** start with ISIS – the Integrated Surface Irradiance Study – and end with AIRMoN – the Atmospheric Integrated Research Monitoring Network. There are several sub-components of these arrays, such as (the ISIS level 2) SURFRAD – the SURface RADiation network, but in combination the ARL monitoring system constitutes the nation's only truly integrated measurement system for permanent recording of past changes in the atmosphere-terrestrial ecosystem linkage and for extrapolating into the future. NOAA's satellite observations supply broader spatial coverage from the top of the atmosphere, but with less finer detail than the surface measurements. The two systems are complementary, each filling in scientific information voids where the other can not.

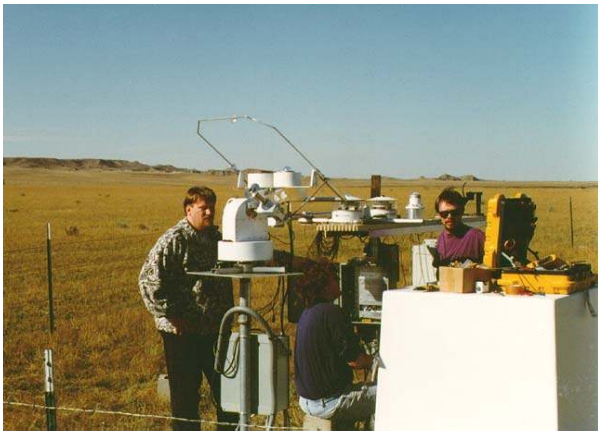
Scientific justification. The theme underlying ARL's network operations is the coupling of the earth's surface and the atmosphere. The magnitude and process of this coupling are quantified in terms of fluxes – rates of exchange of specific quantities such as heat, water, and various trace quantities like CO_2 and air pollutants. The driving force of the earth as a dynamic, life-supporting planet is radiation received from the sun. ARL's network operations therefore start with measurements of solar radiation received at the earth's surface.

Note that the stations of the SURFRAD network constitute much of the first phase of the Climate Reference Network, which has been initiated through collaboration between NESDIS/NCDC (Asheville, NC) and ARL/ATDD (Oak Ridge, TN).

There are four fundamental reasons that the ***ACORN*** array is constructed in its present form. First, a basic tenet of integrated observing concepts is that not all stations need to make every measurement with the sampling protocols necessary for every purpose. To do so would be prohibitively expensive. Therefore, ACORN is constructed as a nested network, with some stations using more advanced systems than others. Second, the next generation of prognostic models will require observational data on the surface fluxes of heat, moisture, and momentum to benchmark the air-surface exchange formulations on which they rely and to serve as a basis for diagnosing model performance related to precipitation, evaporation, humidity, etc. To this end, ACORN includes a component reporting surface fluxes, in real time. Third, ARL scientists concur whole-heartedly with the current belief that satellites offer promise that is yet to be fully realized, but further believe that in order to extend satellite observations ground truth is critical. This attitude comes from direct experience with the use of ground-based observations to verify satellite observations of surface shortwave and UV irradiance, and just as importantly, the development of inversion algorithms to retrieve information on atmospheric properties. Moreover, the World Climate Research Program in recognition of the importance of surface radiation for atmospheric research, has strongly emphasized the need for longterm surface irradiance observations to validate satellite determinations of these quantities. ISIS and SURFRAD in particular offer a unique set of surface radiation observations for checking the calibrations and performance characteristics of satellite sensors. Fourth, and in some contexts most important, ARL endorses strongly the need for long-term observations at the surface where people and other living organisms are actually affected by the environmental characteristics of climate and are impacted by its change. Attributing changes in any property to greenhouse effects or to other climate change forcing factors requires candid examination of the roles of other influences. This necessarily mandates concurrent measurement of other variables, as is inherent in the overall philosophy of ***Coordinated Observations and Research*** to which the ARL mission ascribes.

ISIS (Level 1). The Integrated Surface Irradiance Study measures the incoming radiation from the sun, with emphasis on the direct beam, the radiation scattered and absorbed by the atmosphere and its constituents, and the components of radiation that are especially harmful to living organisms. ISIS therefore measures direct and global shortwave surface radiation, plus surface UV radiation in the broad wavelength band that is biologically important. Table 1 lists the sites of the ISIS network. A detailed description of ISIS and access to processed data from the ISIS Level 1 network can be found at www.atdd.noaa.gov/isis/isis_frame.htp.

The issues being addressed by ISIS relate to the solar radiation incident at the surface, for purposes such as the detection of changes in cloud cover, trends in atmospheric turbidity, and assessment of the change



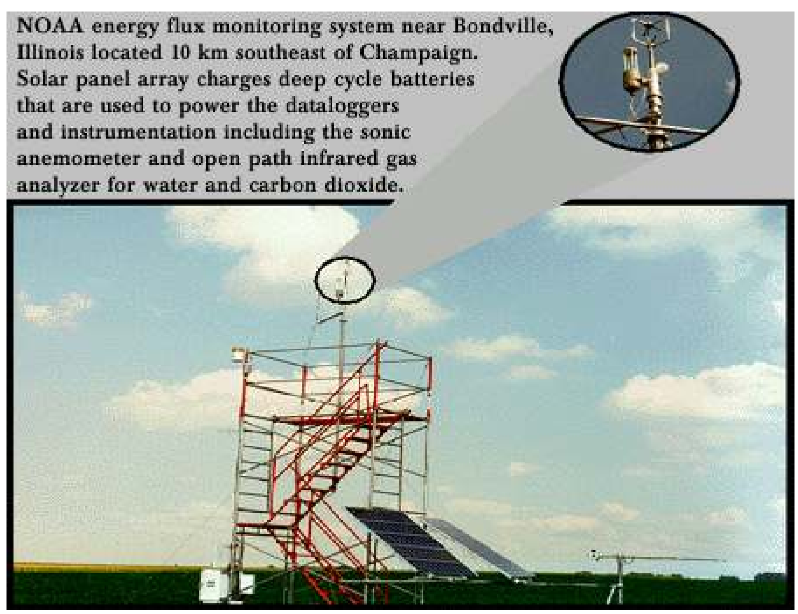
Setting up a SURFRAD site – Fort Peck, MT.

in UV radiation (which affects all exposed living organisms).

The UV component of ISIS deserves special mention. Surface UV radiation remains difficult to measure. As a contribution to the national multi-agency UV monitoring program, ARL operates, as a collaborative venture with NIST, the national Central UV Calibration Facility. ARL also co-chairs (with NASA) the task team organized by the US Global Change Research Program to coordinate the national UV measurement program.

Hourly data from all Level 1 sites are transmitted routinely to NCDC (Asheville), from where they are further submitted to the World Radiation Data Center in St. Petersburg, Russia. The UV components of this data set are routinely employed by the National Weather Service to benchmark the forecasts of UV Index, now operational.

SURFRAD (Level 2). The motions of the lower atmosphere are largely governed by the rate of heat input at the surface. To obtain the necessary information and to help generate the understanding to interpret the relevant data, ARL operates a smaller subnetwork of ISIS where measurements are made of upwelling longwave and shortwave components of surface radiation as well as downwelling. From this perspective, the emission of thermal radiation (infrared) from the surface must be accounted for to obtain a complete measure of the radiant energy heating and cooling process. Therefore, this SURface RADiation network (SURFRAD; see www.srrb.noaa.gov/surfrad/surfpage.htm) includes measurements of infrared radiation to the surface radiative flux suite. Since cloud cover is a crucial consideration, steps are currently being taken to augment SURFRAD stations with automated all-sky cloud cover sensors. Table 1 identifies the SURFRAD stations of the ISIS array. The specialized surface radiation balance data produced by SURFRAD are available at http://www.srrb.noaa.gov/surfrad/

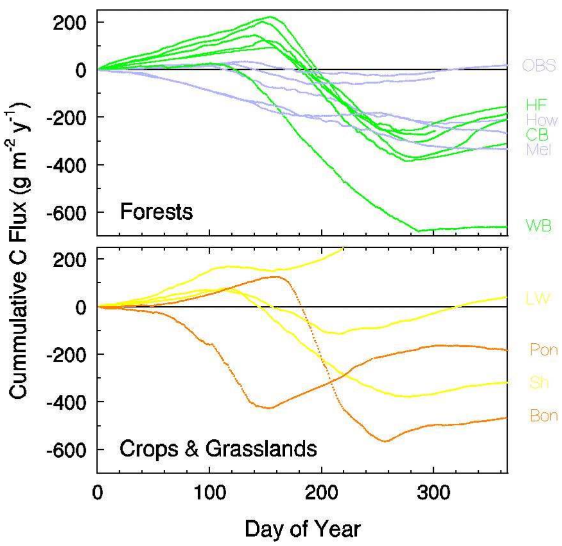


NOAA energy flux monitoring system near Bondville, Illinois located 10 km southeast of Champaign. Solar panel array charges deep cycle batteries that are used to power the dataloggers and instrumentation including the sonic anemometer and open path infrared gas analyzer for water and carbon dioxide.

SURFRAD data are currently being used to evaluate algorithms for interpreting satellite data, to monitor changes in high-level cloud, and to provide regionally-specific input data for national hydrological models. The Eta model now being run operationally is routinely tested by comparison against SURFRAD data.

Surface Energy Balance (Level 3). The next generation of mesoscale models must necessarily include more precise descriptions of the coupling between the earth and the atmosphere, as quantified in terms of the eddy fluxes of sensible and latent heats, and of momentum. ARL is actively establishing a network subset of full energy balance monitoring stations to complete the overall scheme of relevant observations . Stations currently operational are at Oak Ridge, Tennessee, Bondville, Illinois, and Fort Peck, Montana. Installations at Goodwin Creek, Mississippi, and at Davis, West Virginia, are being planned.

The data from these stations are being used to test and develop improved mesoscale models, for weather forecasting purposes. The next generation of numerical forecast models will necessarily involve improved depictions of air-surface exchange, for which this array of surface stations will provide the requisite "ground truth."



Sequestration of carbon by forests and other vegetation, for many AMERIFLUX sites: WB (Walker Branch), LW (Little Washita), and B (Bondville) are ARL locations.

The CO_2 Sequestration Network, and Ameriflux (Level 4). In addition to the eddy flux components of the surface heat balance, the augmented SURFRAD stations also measure fluxes of carbon dioxide. These measurements provide a direct quantification of the sequestering of atmospheric CO_2 in the terrestrial biosystem, and the water exchange data serve similarly in hydrological studies of the water balance of the atmosphere-biosphere system.

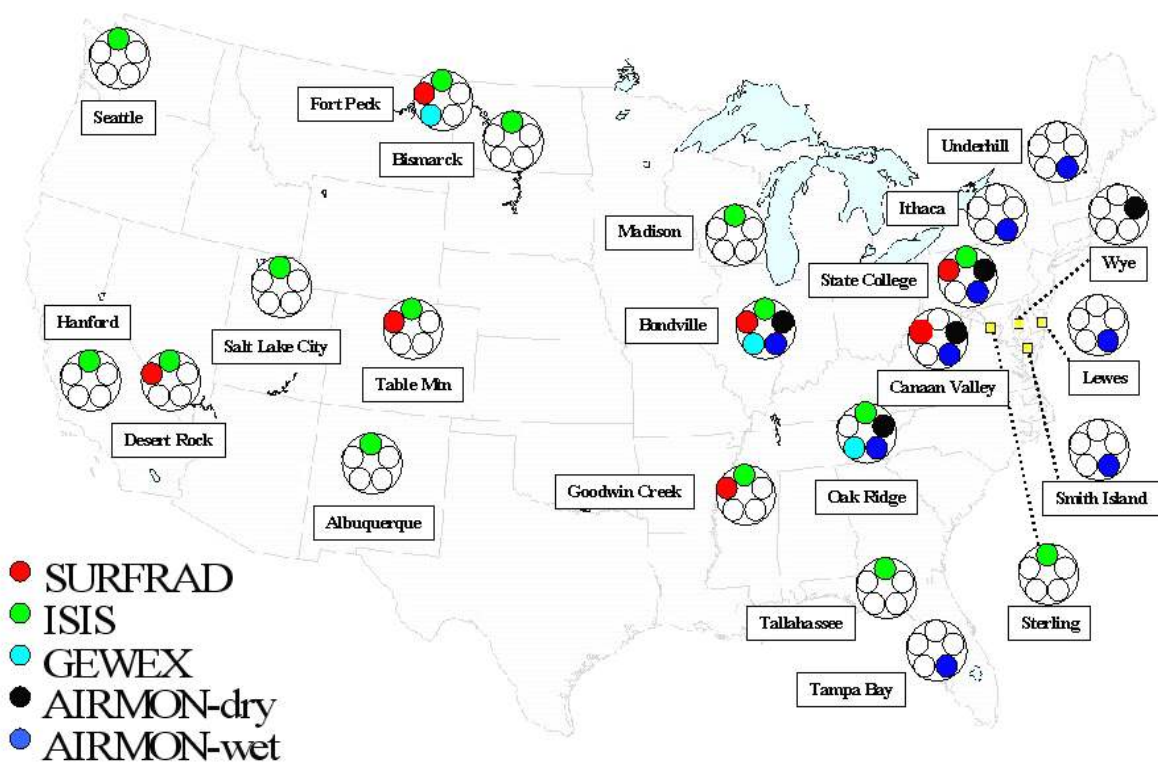
It is important to note that all ACORN measurements of the surface energy balance produce direct measurements of the surface carbon dioxide exchange rate. Thus, ARL already has an extensive record of CO_2 surface exchange information, and is directly involved in the national ("AMERIFLUX") and international ("FLUXNET") networks now being set up to address the CO_2 air-surface exchange question on a wide-spread, internationally cooperative basis. ARL was an organizer of the international workshops from which FLUXNET evolved. Table 1 identifies the stations where total energy balance data are being obtained under the overall CORe activity. FLUXNET and AMERIFLUX details are to be found at http://www.daac.ornl.gov/FLUXNET/fluxnet.html

AIRMoN-dry (Level 5). The ability to measure some of the suite of air-surface exchange variables (radiative and eddy fluxes) leads into one of the more extensive parts of the ARL coordinated observations program – the Atmospheric Integrated Research Monitoring Network (see www.arl.noaa.gov/research/programs/airmon.html). AIRMoN has been established to develop methodologies for monitoring the rates of deposition of air pollutants to natural landscapes. This deposition occurs in two forms – dry and wet. Dry deposition is by the gravitational settling of particles and by the turbulent exchange of trace gases (and of particles too small to sediment in a turbulent atmosphere). Wet deposition is occasioned by precipitation – it entails the scavenging of pollutants by clouds and the washout of pollutants by raindrops falling from clouds. ***AIRMoN-dry*** is the dry deposition part of the overall AIRMoN program, described in detail at http://www.arl.noaa.gov/research/programs/airmon.html

In AIRMoN-dry, measurements are made of the concentrations of selected pollutants in air, and of the atmospheric and surface variables that together control the efficiency associated with the turbulent exchange of these pollutants and their capture by the surface. The focus is on sulfur and nitrogen species, these being the key chemicals targeted by current Federal regulations. Table 1 also lists the stations of AIRMoN, both dry and wet (see below).

Methods for measuring dry deposition of airborne pollutants are not yet well developed. AIRMoN serves as the network in which new approaches are tested, and site-specific requirements are addressed. For example, it is currently apparent that deposition in coastal and urban areas is an important issue, hence it is expected that AIRMoN will move in related directions with a change in its site distribution. In accord with the driving principles of integrated monitoring, sites are selected where the data are most needed.

AIRMoN-wet (Level 6). The wet deposition part of the overall AIRMoN program (see Table 1) operates as a sub-network of the National Atmospheric Deposition Program (NADP; http://nadp.sws.uiuc.edu), the largest atmospheric deposition network in North America. In accord with the overall ARL monitoring philosophy, AIRMoN-wet is designed as a research sub-network of NADP, using more refined sampling protocols and exploring methodologies for accurately monitoring the deposition of quantities that NADP's existing protocols do not address well. A key chemical in this



category is ammonium. It is for this reason that AIRMoN-wet stations are predominantly in coastal regions, since it is near the coasts that nitrogen deposition is seen as a major issue and it is AIRMoN-wet that best addresses this issue. A description can be found at www.arl.noaa.gov/research/programs/airmon-wet.html. Data access is through NADP, via http://nadp.sws.uiuc.edu/airmon/GetAMdata.asp

As in the case of AIRMoN-dry, the present network operates as a research activity to develop improved methods for measurement that are then available for wider application.

Envoi. The ARL observational array is constructed to support and orient research that is necessary to assess changes in the atmospheric environment, to correctly attribute the causes of such change, to improve the next generation of forecast models, to facilitate the increased use of satellite data, to assess the benefits of pollution control actions, and to guide the development of new regulations to help reduce pollution impacts on the total environment. In every aspect, the ARL activity follows the scientific approach that couples research (understanding and prediction) and field measurement (physical evidence) in a manner that illustrates the advantages of ***Coordinated Observations and Research*** as presently conceived.

Table 1 ARL *ACORN* Locations

(lat, long)

	Level 1 ISIS (1)	Level 2 SURFRAD	Level 3 Energy Balance	Level 4 CO_2 SN	Level 5 AIRMoN-dry	Level 6 AIRMoN-wet
Albuquerque, NM	35.05, 106.62					
Bismarck, ND	46.77, 100.77					
Tallahassee, FL	30.38, 84.37					
Madison, WI	43.13, 89.33					
Salt Lake City, UT	40.77, 111.97					
Desert Rock, NV	36.62, 116.02	36.62, 116.02				
Hanford, CA	36.31, 119.63					
Seattle, WA	47.68, 122.25					
Bondville, IL	40.05, 88.37	40.05, 88.37	40.05, 88.37	40.05, 88.37	40.05, 88.37	40.05, 88.37
Sterling, VA	38.98, 77.47					
Goodwin Creek, MS	34.24, 89.87	34.24, 89.87				
Fort Peck, MT	48.31, 105.10	48.31, 105.10	48.31, 105.10	48.31, 105.10		
Table Mountain, CO	40.13, 105.24	40.13, 105.24				
Oak Ridge, TN	35.96, 84.29		35.96, 84.29	35.96, 84.29	35.96, 84.29	35.96, 84.28
Ithaca, NY						42.40, 76.66
Oxford, OH*						39.53, 84.72
Lewes, DE						38.77, 75.10
Smith Is., MD						37.98, 76.03
Underhill, VT						44.53, 72.87
Tampa Bay, FL						27.83, 82.50
State College, PA	40.79, 77.95	40.72, 77.92			40.79, 77.95	40.79, 77.95
West Point, NY*					41.35, 74.05	
Whiteface Mtn, NY*					44.39, 73.86	
Argonne, IL*					41.70, 88.37	
Panola, GA*					33.63, 84.18	
Sequoia, CA*					36.58, 118.75	

Howland, ME*	45.17, 68.77	
Huntington Forest, NY*	44.98, 74.25	
Wye River, MD	38.75, 76.00	
Apache Junction, AZ*		33.47, 111.47
Lilley Cornett Woods, KY		37.08, 82.99
Caribou, ME		46.88, 68.02
Newton, MS		32.34, 89.16
Great Plains Apiaries, OK		34.98, 97.52
Cottonwood, SD		43.95, 101.86
Beeville, TX		28.47, 97.70

* Station recently closed because of lack of funding.