An Assessment of Observational Research Facilities and Future Needs

Authors:
Robert Serafin – National Center for Atmospheric Research (NCAR), Chair
Karyn Sawyer – NCAR/Earth Observing Laboratory (EOL), Principal Investigator
Jim Huning, Facilities Coordinator – University Corporation for Atmospheric Research (UCAR) and Lower Atmospheric Facilities Oversight Section (GEO/ATM), National Science Foundation (NSF)
Cliff Jacobs, Head – UCAR and Lower Atmospheric Facilities Oversight Section (GEO/ATM), National Science Foundation

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Will Bolton – Sandia National Laboratory

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Dennis Baldocchi – University of California at Berkeley
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Bob Weller – Woods Hole Oceanographic Institute

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Steve Williams (co-chair) – NCAR/EOL
Mark Bradford (co-chair) – NCAR/EOL
Steve Worley – NCAR/CISL/SCD
Ethan Davis – UCAR/UNIDATA

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Preface

This study was undertaken in order to create an information catalog and description of instruments, systems, and facilities that are useful for research in the atmospheric and related sciences. This report and the attendant data base are expected to serve research and educational needs for years to come through regular updates and continuing attention to quality control. An additional goal is that the information contained herein on unmet observational needs, will assist in long range planning for the development of next generation instruments and facilities.

For a period of more than two years the study required the dedication of more than 60 experts, scientists and engineers, representing a wide range of scientific and technical disciplines. We extend our deep thanks to all the subcommittee members and co-chairs for their hard work and commitment to the completion of this task. We also express thanks to the hundreds of individuals and organizations who took the time to provide information and to enter it into the data base, which now contains more than 1100 entries and continues to grow daily.

We also express thanks to the National Science Foundation for its visionary leadership and financial support. Lastly the study required considerable administrative support. Sara Metz did a wonderful job in attending to all administrative needs: arranging for telecons, meetings and travel, coordinating the activities of seven subcommittees, and documenting all that took place. Her support has been central and crucial to the completion of this work.

- Robert Serafin, Chair
- Karyn Sawyer, Principal Investigator

Executive Summary

Beginning in 2005, the Earth Observing Laboratory (EOL) of the National Center for Atmospheric Research (NCAR), acting under sponsorship from the National Science Foundation (NSF)'s UCAR and Lower Atmospheric Observing Facilities (LAOF) program office, conducted a community-wide assessment of atmospheric science observing facilities and instrumentation. The Assessment considered facilities across government agencies, universities, national laboratories and the private sector. Facilities were considered at all stages of development up to and including completion and community use. The product from the Assessment is a web-based database containing pertinent information about research facilities and instruments, where they reside, some technical specifications, means for gaining access to the facility for research, persons to contact for further details, and if applicable, their stage of development relative to deployment-ready condition.

A Steering Committee, chaired by former NCAR Director Bob Serafin, was formed to lead the process. Seven Subcommittees were formed to assess facilities in: airborne platforms, airborne measurements, in-situ surface and surface-atmosphere exchange, surface-based remote sensing, solar measurements, satellite data, and emerging technology. An eighth Data Support Subcommittee provided technical support for web site organization, database development and data input.

The Steering Committee and Subcommittees conducted their work over two years meeting several times and holding teleconferences as information was gathered from the community and as the database was developed and refined. In September 2007, a community-wide workshop was held at NCAR in Boulder, Colorado to get final community input and discussion of the database. The workshop attendees also identified important unmet observational needs for advancement of earth system science. A final presentation was made to the NSF by the Chairman and Steering Committee members during late November 2007.

Principal Recommendations:

1. The database must be maintained on a continuing basis to add new and important facilities and to update existing entries, so that the information contained in it will be current and of maximum value to the community as a reliable reference source.

2. An Editorial Board will be named with NSF advice to meet once per year to examine the database for accuracy and completeness, and to resolve any data entry/data accuracy or other issues that may come up during the year. The Board will be comprised of participants from the initial committees who will serve on staggered terms to ensure continuity of experience and germane points-of-view in the maintenance and furtherance of the database. This Board will have 16 members and will be managed by NCAR/EOL. The Board will conduct a

major review of the database every five years and will update the information as appropriate.

3. The Editorial Board will update the Facilities Assessment Report as needed – possibly as often as once per year.

The database resides at NCAR/EOL (http://eol.ucar.edu/fadb/). Consistent with the principal recommendations listed above, work will continue to populate the categories with new, reliable and high-quality information. NSF and NCAR/EOL will work together in the future to keep the database current and to ensure the validity of its entries.

The Final Report of the Steering Committee will be available through the NCAR/EOL website at http://www.eol.ucar.edu, and articles introducing the database to the community will appear in BAMS and other appropriate publications during the first quarter of 2008

1. Introduction

Emerging instrument technologies in atmospheric and solar science offer improving capabilities for new discoveries and knowledge. New ideas for intensive observational field experiments and longer-term climate studies benefit from instrument miniaturization, greater portability, and autonomous operations, but also place an increasing demand on current atmospheric and solar science facilities and instrumentation. In times of limited science funding, strategic planning and community partnerships become vital in order to plan for appropriate investments in new capabilities, and to facilitate the sharing of available resources. To address these issues, a comprehensive review of facilities and technologies was needed to identify existing capabilities and gaps in scientific measurement capabilities and other salient issues.

1.1 Rationale

Complex observational field campaigns are increasingly a prominent part of atmospheric sciences. Drawing on decades of investment of billions of dollars to improve observational capabilities, field experiments are now being designed and executed using a plethora of instruments types, platforms capabilities, and complex cyberinfrastructure which turn data bits into new knowledge. But how does the community stay abreast of evolving instrument and platform capabilities across a wide spectrum of centers, universities, Federal agencies, and the international science community. Lack of widely available knowledge about the full spectrum of observing capabilities reduces the productivity of scientists and perhaps limits the effectiveness of field campaigns to achieve their stated science objectives. Discovery of the best instrument and/or platform to make an observation can be a daunting task for even the most experienced observational scientists. To assist in overcoming this challenge NSF, working with the community, funded this study. It is believed that the outcome from the effort has the potential to improve scientists' productivity, the effectiveness of field campaigns, and to enhance collaborations among community members.

This is not the first time the community has identified a lack of a centralized source of information on observing facilities. NSF employs external panels to assist the agency in improving its stewardship responsibilities. One such panel found that:

"Currently there is no mechanism to inform the entire atmospheric sciences community of the availability of platforms and sensors, except aircraft, that are not part of the NSF base-funded pool or available through NSF."

"UCAR and Lower Atmospheric Facilities Oversight Section (ULAFOS) could take the lead in establishing an informal inventory of platforms and sensors. The current lack of federal coordination encourages substantial redundancy in sensor systems and platforms." The COV's rationale was to:

- Rationalize the development of new sensor systems and the acquisition of new platforms;
- Increase the awareness of prospective users of the existence of these systems;
- Enable the development of research programs that could benefit from these resources;
- Highlight major gaps and redundancies in community assets;
- Improve interagency cooperation in the support and development of facilities using the NSF Interagency Coordinating Committee for Airborne Geosciences Research and Applications (ICCAGRA) structure
- Provide guidance for removal of facilities no longer used/cost effective/technically adequate
- Inform the direction of the ATM Mid-size Infrastructure investments

Since 2005, the Earth Observing Laboratory (EOL) of the National Center for Atmospheric Research (NCAR) acting under sponsorship and guidance from the National Science Foundation's UCAR and Lower Atmospheric Observing Facilities (LAOF) Program Office conducted a community-wide assessment of atmospheric science observing facilities and instrumentation. This assessment considered facilities across government agencies, universities, national laboratories, some international organizations, and private companies. The assessment looked at a wide range of technologies including currently available instrumentation and systems under development. Expertise was drawn from within the atmospheric science community to assist with the assessment. This broad community participation facilitated the identification of potential partnerships for sharing multi-purpose facilities and instrumentation for the greatest community benefit.

Based on the results of this assessment, an NSF-sponsored workshop was held in September 2007 to discuss gaps in atmospheric science measurement capabilities and how resource sharing and strategic investments that will increase both availability and capability of future instrumentation may fill these gaps. Emerging technologies for new observation capabilities, miniaturization, or autonomous operation are a major element of the assessment.

1.2 Goals

The goals of the assessment study were to:

1. Establish a web-based resource that provides descriptive information of atmospheric science facilities and instrumentation in a consistent, easy-to-read format as a resource for the broad atmospheric science community.

2. Organize and implement a workshop to comment on the committee work and to revise as necessary the overview paper before journal submission. The workshop will provide an additional opportunity to augment the facilities assessment study with overlooked measurement facilities or gaps in capabilities. Attendees will be by invitation.

3. Prepare an overview paper suitable for submission to the Bulletin of the American Meteorology Society (BAMS) or another journal of equivalent stature. The paper will describe the study process, contents of the database, means for access to the database, and future needs,

It was anticipated that the outcome of the committee work, including input from the workshop, would be documented and distributed widely to enhance community awareness both of the existing atmospheric facilities as well as new and emerging capabilities. The study's outcomes were expected to assist NSF in strategic planning and budgeting for future instrumentation and observational facility development

1.3 Subcommittee Structure

NCAR formed a Steering Committee that assessed the status of national and some international atmospheric science facilities and provided broad oversight to the facilities assessment study. The Steering Committee, with NSF advice, selected subcommittee membership from the community at large, and supervised their activities including the development of a project plan outlining schedule, deliverables, and regular reporting to NSF. The structure and membership are shown below.

Chair, Steering Committee
Robert Serafin - NCAR

Principal Investigator
Karyn Sawyer – NCAR/EOL

NSF Oversight
Jim Huning, Facilities Coordinator – UCAR and Lower Atmospheric Facilities Oversight Section (GEO/ATM), National Science Foundation
Cliff Jacobs, Head – UCAR and Lower Atmospheric Facilities Oversight Section (GEO/ATM), National Science Foundation

Airborne Platforms Subcommittee Co-Chairs
Bruce Albrecht – University of Miami - Rosenstiel School of Marine and Atmospheric Science (RSMAS)
Jeff Stith – NCAR/EOL

Airborne Measurements Subcommittee
Edward Browell – NASA Langley Research Center, Science Directorate
Al Cooper – NCAR/EOL

In-situ Surface and Surface-Atmosphere Exchange
Peggy LeMone – NCAR/ESSL/MMM
Mary Anne Carroll – University of Michigan, Dept. of Atmospheric, Oceanic, and Space Sciences; Dept. of Chemistry; Program for Research on Oxidants: PHotochemistry, Emissions, and Transport (PROPHET)

Surface-Based Remote Sensing Subcommittee
Steve Rutledge – Colorado State University, Dept. of Atmospheric Science
Junhong Wang – NCAR/EOL

Solar Measurements Subcommittee
Jeff Kuhn – University of Hawaii at Manoa, Institute for Astronomy
Hector Socas-Navarro – NCAR/ESSL/HAO

Satellite Data Subcommittee
Bill Emery – University of Colorado, Dept. of Aerospace Engineering Sciences
Phil Arkin – University of Maryland, Earth System Science Interdisciplinary Center (ESSIC)

Emerging Technology Subcommittee
David McLaughlin – University of Massachusetts at Amherst
Walt Dabberdt – Vaisala Corporation

Data Support Subcommittee
Steve Williams – NCAR/EOL/Computing, Data and Software Facility
Mark Bradford – NCAR/EOL/ Computing, Data and Software Facility

1.4 Process

In the spring of 2005, Roger Wakimoto, Director of NCAR's Earth Observing Laboratory, asked Bob Serafin, NCAR Director Emeritus, to chair a community-wide effort to establish a comprehensive catalog of available observational research facilities and instruments. Serafin agreed and several subsequent discussions took place with Wakimoto and Cliff Jacobs at NSF.

It was immediately obvious that a comprehensive assessment of technologies and the attendant science applications would require a community effort with many experts from diverse fields and that the effort and costs would scale linearly with the number of participants.

An early planning meeting was held at NCAR on August 2, 2005. The agenda for this meeting and the participants are found in Appendix B. The objective of the meeting was to organize the assessment study and identify the next steps for submission of a support proposal to NSF. Several decisions were made:

1. The work would be done by several subcommittees.
2. The topical areas for each subcommittee would be selected according to instrument/observing system type and not by science areas served.
3. Provisional subcommittee topical areas were established.
4. Potential co- chairs for the subcommittees were suggested.

5. Co-chair commitments should be obtained prior to proposal submission so that they could be included in the proposal to NSF.

Following this meeting Serafin contacted and received commitments from subcommittee co-chairs who would also serve as members of a study-wide Steering Committee. A meeting of the steering committee (by teleconference) took place on October 11, 2005 and at this meeting there was general concurrence on the process and on a schedule for conducting the assessment. Cliff Jacobs participated in the teleconference to provide NSF guidance and his thoughts on what the assessment objectives should be.

The proposal was submitted by Karyn Sawyer as PI in December 2005. It was viewed favorably by NSF and NCAR was notified that funding was likely. Initial funding arrived officially in late summer of 2006 with the second increment arriving in FY 2007.

NSF's early positive response was sufficient for the Steering Committee (SC) to continue its work in the interim. An SC meeting was held in Spring 2006. At this meeting the SC decided on revisions to the subcommittee titles and responsibilities. These were: Airborne Measurements, Airborne Platforms, Data Support, Emerging Technology, Satellite Data, Solar Measurements, Active & Remote Sensing (later renamed Surface-Based Remote Sensing), and Surface Fluxes and Soils (later renamed In-Situ Surface and Surface-Atmosphere Exchange). It was understood that there would be some overlap among subcommittees. It was decided that there would be a separate subcommittee for emerging technologies but that other subcommittees might also address this issue from a more narrow perspective consistent with their respective purviews. Potential subcommittee membership was discussed. Steering Committee co-chairs made recommendations for populating their committees and possible participants were identified and agreed upon.

At this meeting there was considerable discussion of web site and database organization. The actual design of the database, means for its access, user interfaces, search capabilities, etc. would be the responsibility of a small subcommittee led by Mark Bradford and Steve Williams at NCAR/EOL.

Following this meeting invitations were extended to subcommittee members and the subcommittee membership was established. During the Summer and Autumn of 2006 the subcommittee co-chairs worked with their committee members to discuss formats and contents of the database. Members of the Data Support Subcommittee took part in these discussions and implemented changes to the proposed database formats. Formats were customized to some degree based upon unique needs of the subcommittees. The subcommittees also identified people and organizations whose facilities should be included in the database. Much of the work was done via email but the subcommittees all had at least one face-to-face meeting.

On November 17, 2006 the Steering Committee held a conference call to review all of the work to date, to make modifications to the process and to develop a revised schedule for completion of the survey. Serafin visited NSF on November 30, 2006 to report on progress and to receive input from NSF.

In March 2007 a request was submitted to a broad cross section of the community based upon progress to date, recommendations of the subcommittees, and NSF input. Entries into the database were already arriving because of word-of-mouth communications among interested parties.

In late spring of 2007, the subcommittees held another round of face-to-face meetings to review the entries into their respective databases. Obvious omissions were identified and the subcommittees assigned responsibilities for direct person-to-person contacts to solicit input for the database. A second, broader, request was also sent to the community.

In June of 2007, the Steering Committee met again to decide on final steps for completion of the study. All Steering Committee members reviewed the status of their subcommittees, identified remaining issues and made recommendations for completing their work. Action plans were agreed upon. It was decided to dovetail the autumn assessment workshop with the NSF Facility Users' Workshop. This would provide the best opportunity to get broad community participation in the busy fall season. Moreover, because of the complementary nature of the two workshops, each would benefit from the other. The Steering Committee agreed that a student assistant should be hired to focus on filling missing information in many database entries, and an existing EOL student was subsequently assigned to do this work. The schedule for completion of the work was established. A preliminary agenda for the workshop was established and preferred dates were selected.

In July 2007, Serafin met with the EOL staff responsible for planning the workshops that would be held on September 23-28, 2007. The agendas for each were established.

On September 23-26, 2007, the NSF Facilities Users' Workshop was held and the NSF Facilities Assessment Workshop (FAW) followed immediately on September 27-28. The workshops were well attended with many people attending both as had been encouraged. The agendas for each workshop are found in Appendix C. The principal goals of the FAW were to 1) describe the database and its contents and 2) to identify high-priority unmet community needs. This second goal was common to each workshop. Each of the subcommittee reports below discusses and describes these unmet needs.

The last steps for completion of the study were to complete two reports. The first, this report, will be published on the assessment web site. The second is to be published in The Bulletin of the American Meteorological Society and the AGU's EOS, as a short informational article. The Steering Committee visited the NSF for a final debriefing session in November 2007. A principal recommendation is that an editorial board be established to provide oversight to ensure that: 1) high quality of the database is maintained; 2) that the database remains current; and 3) that the database meets user needs and remains relevant.

2. Database Structure and Access

Design and implementation of the Facilities Assessment database and its World Wide Web interface was performed in the NCAR/EOL Computing, Data, and Software Facility, with input and feedback from all subcommittees. Members of the Data Support subcommittee participated in the meetings of the other subcommittees, and collated requests for database fields. Certain fields were seen to be common among all of the subcommittees, and these were factored out into a general "Resource" data type. Similarly, a general "Contact" data type was defined for collecting personal contact information. The remaining fields were collected into "Detail" types, specific to a certain type of resource, e.g. Airborne Platform or Satellite Instrument. The resource types were generally aligned with the subcommittees, though several subcommittees were associated with multiple resource types.

To guard against accidental deletion of information, it was decided that the ability to directly edit or delete a resource entry would be restricted to subcommittee members. Members of the community would have the ability to submit new entries, or to submit corrections to existing entries, but these revisions would not be immediately published online. Instead, a subcommittee member would view the submitted entry and approve it before it becomes visible to all users. To facilitate this, subcommittee members were given additional permissions on the database site: to view "unpublished" entries and to change entries' "published" status. Also, both the submitter of the entry and the person responsible for the resource are listed. The site software sends e-mail notifications to subcommittee co-chairs when new or revised entries are submitted in their area of interest; the co-chairs may then either review the new entries themselves, or forward the notification to an appropriate subcommittee member. Since older entries are not deleted except by explicit action of a subcommittee member, it is possible to review the history of a resource, or revert to an older version. As a further safeguard against accidental deletion or corruption of information, the database is periodically saved in a Structured Query Language (SQL) format.

It is necessary to create an account on the site and log in before one may list existing entries or submit new entries. The site uses e-mail addresses as account names, to ensure that account holders can be contacted. Initial passwords are generated by the site software and sent to the registered e-mail address; users may change their passwords on the site at any time, or generate a fresh password if they forget or misplace their passwords. By requiring a verifiable e-mail address for use of the site, and requiring approval of new entries, we hope to forestall the illicit use of the site for the generation and propagation of "spam" and "phishing" e-mail. A further benefit is that entry submitters can be contacted for clarification or updating information they have submitted.

The decision to require an account for browsing or reading the site's information was based on the fact that individuals' and organizations' contact information, potentially including names, addresses, e-mail addresses, and telephone numbers, is displayed. This is of obvious benefit to the potential users of listed facilities, but if available without restriction, contact information could be collected by search engines and e-mail address harvesters with possible negative consequences. A possible compromise for future development would make general information available to site visitors without accounts, but require an account to submit information or to view contact information.

Visitors to the site may view a listing of all available resources, or they may restrict the listing to a single resource type (e.g., Emerging Technologies). Within the listing, visitors may specify the order in which the entries should be presented, and provide one or more search terms to narrow the focus of the listing. In addition to viewing database entries, visitors may submit suggestions to a "suggestion box", and report problems with individual entries via a web form.

The database site, located at http://www.eol.ucar.edu/fadb/, was opened for testing and development in December, 2006. Its availability was announced to the scientific community in March, 2007. As of mid-October, 2007, nearly 500 accounts had been registered on the site, representing over 300 institutions, and over 1,000 unique resources had been entered.

The site is implemented using "Ruby On Rails" technology, with a MySQL database back end, hosted on a Linux server at NCAR/EOL. It is presently not hosted in a high-availability environment, and is therefore subject to occasional outages for system maintenance or other issues. Questions regarding the site and its status may be directed to webmaster@eol.ucar.edu.

3. Topical Database Contents

3.1 Airborne Platforms

Description and Process

A detailed list of specifications for aircraft performance (Table 1) and scientific support for research (Table 2) was developed by the Aircraft Platforms Subcommittee, and used to develop the web based database.

Table 1: Aircraft Parameters

- Aircraft type
- Payload (not including required crew).
- Range (with full and reduced payload)
- Ceiling (with full and reduced payload)
- Endurance at typical cruse profile (with full and reduced payload)
- Aircraft capability: IFR, VFR, Known icing
- Special Flight Manual restrictions if any.
- Typical range of airspeeds for research applications
- Summary of runway operating requirements
- Minimum/typical flight crew requirements—number of seats available
- Type of airworthiness certificate and operating restrictions

Table 2: Research capabilities

- **Research History of aircraft**
  - Intended use of aircraft (e.g. boundary layer measurements, cloud sampling, air chemistry, etc.)
  - Summary of Past projects
  - Types of measurements made in previous projects
  - References
- **Description of aircraft data system and data handling**
  - Capacity, formats, time synchronization
  - Real time aircraft communication system description (e.g. satellite communications, etc.)
  - Description of available software for processing and viewing aircraft data
- **Ground support facilities (air-conditioning and heating, ground power availability, etc.)**
- **Power available for research use**
  - Amount and type of power (e.g. 400 Hz, 60 Hz, 28 V, etc)
  - Location of power (cabin, fuselage, etc.), number (type?) of receptacles.
- **Approximate cooling/heating capacity of cabin**
- **Description of rack space available for research instruments**
- **Description of available inlets**
- **Description (size, weight capacity, etc.) of available hard points for external mounting of instruments or inlets**
- **Description of external pods for instruments**

At the time of the Facilities Assessment Workshop, 26, airborne operators had participated, representing some 32 different aircraft (Table 3).

Table 3: Summary of Airborne Platforms

Light single	light twin	small turboprop	large turboprop	light jet	larger jet	helicopter	extreme high altitude	UAS
DOE/NOAA Cessna 206	Duchess/ALAR	Batelle G-1	NOAA WP-3D (2)	NOAA Citation II	NOAA G-IV	Duke Jet Ranger	NASA ER-2	ALTAIR/NASA-NOAA
NOAA Lake Amphibious	NOAA Aero_commander (2)	CIRPAS Twin Otter	NSF/NCAR C130	WMI Lear	NASA DC-8		NASA WB-57F	Ikhana/NASA
		NOAA Twin Otter	NASA P-3 B		NSF/NCAR G-V			
		NOAA Turbo_commander	NRL -P3 (3)					
		NASA Twin Otter						
		UW/NSF King Air						
		WMI Cheyenne II (2)						
		NRL- King Air (2)						

Unique Characteristics

The majority of the entries are for aircraft operated by federal agencies. Three universities responded as operators of research aircraft (including one helicopter). Only one private company responded (with 3 aircraft), while none of the remote sensing/aerial mapping commercial providers responded despite the inherent capability of the airborne platforms to accommodate atmospheric measurements in addition to imagery products. A wide diversity of capability exists in the various platforms represented in the list, with most aircraft focused on a specific type of payload (carrying a radar, or boundary layer payload), while a few (e.g. the NSF aircraft, CIRPAS aircraft, and NASA, NOAA) are adapted to a wide variety of airborne applications).

Of the various types of aircraft in Table 3, the most common were the turboprop aircraft (large and small). Several of the aircraft in this category have limited capacity for research payloads. Therefore, although there is ample capacity in terms of aircraft that might be available for research, this does not translate into an oversupply of capacity for research in this category. There were only two entries in the light jet category, and these had rather limited capacity for general purpose research missions. In addition to the diversity of research capability, there is limited payload interoperability, especially from one operator to another.

An issue that was raised at several points in this process relates to support for small projects and education. Resources are currently focused on supporting multiple investigators, “big science” deployments from a few centralized facilities. One concern is that this limits facility availability for small, focused studies, instrument testing and education of the next generation of airborne scientists.

3.2 Airborne Measurements

Description and Process

Because there are many airborne instruments that make similar measurements, the Airborne Measurements Subcommittee classified instruments into those measuring the same or closely related atmospheric properties. The outline that follows presents the measurements according to this classification scheme. In many cases, the instruments were not yet in the database, so we have used knowledge of the instruments in this assessment (rather than basing it only on those in the database). We expect the database to continue to evolve so that the representation of instruments will be more comprehensive. Of course, if instruments appear there that we have not considered, we may need to revise this assessment.

We classified instruments broadly into these categories:

1. State Parameters
2. Cloud Physics
3. Atmospheric Chemistry
4. Airborne Remote Sensing
5. Aerosols
6. Specialty Inlets
7. Other

Our description of airborne instrumentation will follow that outline. We also include some assessment of each measurement capability in this section. Where weaknesses are significant, they also appear in a subsequent section of this report.

State Parameters

As used here, the term "state parameters" refers to those properties needed to characterize the thermodynamic and kinematic state of the atmosphere, and also the measurements needed to determine the location, motion, and orientation of the aircraft. The basic sensors (with the exception of humidity sensors) are not entered into the database; for information, consult the web pages of operators of research aircraft. These omitted measurements are standard on all research aircraft, but especially at high airspeed they are difficult so we include some discussion of them here.

Pressure

The measurement often utilizes static ports and transducers similar to or identical to those provided by the aircraft manufacturer. This measurement has become more significant with the advent of high-accuracy GPS measurements of altitude, which now make it possible to measure "D-values" (the difference between the pressure altitude and the geometrical altitude) with high precision if high precision can be attained for the pressure measurement. This has imposed new needs for calibration and for determination of influences of airflow on the pressure measurement from research aircraft. Uncertainty associated with the pressure measurement has become the dominant contribution to uncertainty in measurement of D-values. Reduction of that uncertainty could make such measurements extremely useful in studies of mesoscale and storm dynamics.

Temperature

Conventional measurements are made by resistance-wire thermometers, often mounted in anti-iced housings. Many of these standard probes used on commercial aircraft, especially heated ones, have response times of 1-s or slower and so are too slow for many research applications. Widely used solutions to this problem, using unheated probes, have recently become more difficult because some of the standard sources of these probes have discontinued manufacturing them. A problem may arise in the future if alternate sources cannot be found, and it may be necessary to develop custom replacements.

A significant issue related to the measurement of temperature is that sensing wires exposed to the airstream become wet in clouds, and the evaporative cooling that results from dynamic heating of the air in contact with the wet sensor then causes the measurement to be too low in cloud. This limitation makes it difficult to determine the buoyancy of cloud parcels and affects efforts to study mixing processes in clouds by reference to thermodynamic mixing diagrams. Potential solutions include radiometric measurement of temperature (which is difficult with the needed response time) or use of special housings that prevent wetting of the sensor. Because this weakness in temperature measurement hinders many studies in cloud physics and dynamics, it is a serious weakness of most airborne platforms.

At high speed, other aspects of temperature measurement also become significant, including the need for accurate determination of the “recovery factor” (describing the effect of airspeed on the temperature measurement) and assessment of the possible dependence of that recovery factor on Mach Number. This is one of many examples that will occur in this report where a good calibration facility (able to expose sensors to high speed) would be a valuable addition to community capabilities.

Humidity

Sensors include chilled-mirror hygrometers, hygrometers that measure absorption of various wavelengths of light including that at the Lyman-alpha line, systems that make similar measurements using tunable diode lasers or microwave absorption, sensors that dissociate water molecules and detect fluorescence from the resulting excited molecules, sensors that detect the change in capacitance of elements with humidity, and sensors that measure the difference between the wet-bulb and dry-bulb temperature. The chilled-mirror devices provide a good standard reference (provided that the pressure in the sensing chamber is known or controlled), but often encounter limitations at low dewpoint and are slow to respond to changes. Another weakness is that, while there are many techniques for measuring humidity with fast enough response to support measurements of fluxes or to document other fine structure in the humidity field, most of these are either poorly documented, still under development, or dependent on technology that is becoming difficult to support (the older “Lyman alpha” sensors). There is need for a standardized, tested, system with fast response that can be used for measurements of water-vapor fluxes at all levels of the atmosphere, and these sensors would benefit from testing and intercomparison in a community test/calibration facility.

Aircraft Position and Motion

Two types of systems are used to determine the aircraft position and motion, inertial navigation systems and global positioning systems. Because inertial systems have high short term resolution while global positioning systems have good absolute accuracy, these systems are often used together, sometimes with complementary filters that combine the low-frequency response of a global positioning system with the high-frequency response of an inertial system.

Weaknesses that affect the use of such information for determining wind are inaccuracies in the determination of heading or pitch. Errors in heading are often the dominating source of error in wind-sensing systems.

Air Motion Relative to the Aircraft

Wind is conventionally measured from research aircraft from the vector sum of the aircraft motion relative to the ground and the air motion relative to the aircraft. The latter is usually measured by a gust probe of some type, sometimes mounted on a boom ahead of the aircraft. Other of the systems use pressure differences measured at different points on a blunt object, sometimes the radome of the aircraft. This measurement is usually the responsibility of the operator of the research aircraft, and information on gust systems is available on their websites.

Sounding Systems

There are two sounding systems in common use from aircraft, the NCAR GPS dropwinsonde system and the JPL Microwave Temperature Profiler (MTP). The soundings they provide are in high demand. For the dropwinsonde, ability to repeat launches with higher frequency, automation of the dispenser, and increased ability to launch over land would increase the utility of the system. In some cases, the need for operators to load sondes presents a safety issue. All these changes would be aided by development and use of a smaller sonde (such has been used for the NCAR Driftsonde). We see this as a high priority, especially for the NSF-supported aircraft.

There is also an unmet potential to deploy additional sensors on dropsondes, e.g., for chemical species, electric field, or to sample hydrometeors. Especially in a severe storm environment, this may be a valuable way to collect information otherwise difficult to measure from research aircraft.

Cloud Physics

Cloud Droplet Concentration and Size Distribution

Instruments in common use to measure the cloud droplet size distribution include optical particle-counting probes (like the standard Forward Scattering Spectrometer Probe and modifications or updates to it), experimental holographic imaging probes, probes that use laser diffraction, and sensors based on phase-Doppler interferometry. In addition, impactors have been used with various schemes to preserve the craters formed upon impact for subsequent analysis or to view the impact on the surface with video cameras.

The automated optical-counting probes provide a convenient means of measuring the droplet size distribution with adequate spatial resolution (0.1 s) for many uses. However, the sizing inaccuracies, uncertainties in definition of the sample volume, and dependence of sizing on airspeed for higher-speed aircraft have been hindrances in studies that need high-resolution determination of the cloud droplet size distribution (e.g., to study the development of that size distribution leading to rainfall or the effects of entrainment on the droplets). There is a remaining need for a measurement that has high size resolution and a well-defined sample volume and that remains valid on high-speed aircraft. Some developments now underway (like the phase-Doppler interferometer) hold promise for meeting those needs but have not yet become widely available. Until measurements of the cloud-droplet size distribution are improved, this will remain a limitation that hinders progress in understanding several fundamental questions in cloud physics involving how the droplet size distribution evolves in clouds.

Drizzle and Ice Concentration and Size Distribution

Instruments that measure the concentration and size distribution of precipitation and precipitation-embryo hydrometeors include various optical-array probes (including those that provide imaging as hydrometeors pass through the probe, like the 2DC and 2DP probes) and instruments that preserve images of the hydrometeors after being triggered by their passage (e.g., the CPI). As for cloud droplets, these instruments provide good automated detection of hydrometeors and have become standard in cloud-physics research. Some serious uncertainties remain in regard to sample volumes of these probes, especially for smaller sizes (<50 um), and these uncertainties often lead to differences among probes that are greater than their assessed accuracies. While promising new techniques have become available, continued assessment of the accuracy of these measurements (and of older instruments) is needed. In addition, data processing for the imaging probes continues to be a gap in measuring capabilities. Many researchers, especially those new to the use of these probes, would benefit from further attention to this need.

Liquid Water Content

Probes to measure liquid water content in clouds include the hot-wire instruments (where liquid-water content is measured by the cooling produces on an exposed heated element) and evaporators that measure the water content after vaporization of the condensed water. The PVM provides a measurement of liquid water content by using the relationship between appropriately selected scattering properties of the cloud droplet spectrum and the liquid water content, so it provides measurements that integrate over a large part of the drop size distribution while maintaining a large sample volume. The size distributions from cloud-droplet spectrometers (and, with assumptions, other hydrometeor spectrometers) also can be integrated to obtain the liquid water content. An excellent addition to capabilities in this regard is use of the counterflow virtual impactor to separate hydrometeors from the airstream, vaporize them, and detect the resulting vapor content. This style of evaporator removes the need of other evaporators to provide high power in order to evaporate the particles that are sampled. In addition, there are detectors like icing probes that use accretion on exposed elements to detect the supercooled-water content in clouds.

Our assessment is that the capabilities provided by this set of probes are adequate for many studies. The gap not filled well by the available instruments is that associated with precipitation, where available instruments provide inadequate sample volume to provide adequate measurements of rain-water content or to assess higher moments of the size distribution like that associated with radar reflectivity.

Cloud-Active Aerosols

We use the term “cloud-active aerosols” to refer to those aerosols (including CCN, ice nuclei, and giant nuclei) that have controlling roles in the formation of hydrometeors in clouds.

CCN spectrometers have been developed that can determine the full supersaturation spectrum of cloud-condensation nuclei with spatial resolution adequate for most studies, and others that are simpler to replicate and operate can determine the CCN activity at one or a few selected supersaturations. The weakness in these capabilities is that the former are complicated, expensive to replicate, and require a dedicated operator and researcher for their use, while the latter do not provide good coverage of the full supersaturation range needed to assess CCN activation in clouds. A remaining unmet need is that for a standardized, tested, replicable instrument for common usage on research aircraft.

Instruments to measure ice nuclei remain quite specialized, and specific instruments are sensitive to only a limited number of nucleation modes. It would be useful to have routine measurements of ice nuclei on research aircraft, but development of such an instrument remains a research project. At present, the measurement of ice nuclei requires a dedicated instrument and associated specialist to operate it.

Giant nuclei are poorly measured with most airborne aerosols spectrometers because they provide inadequate sample volume for measurements of the low concentrations that can still have significant effects on precipitation development in clouds. This weakness is sometimes addressed by special impactors exposed to the airstream, but analysis of the results from such collected samples are often tedious.

Atmospheric Chemistry

Measurements used for studies in atmospheric chemistry are usually characterized by the need to combine many different measurements in order to constrain reaction rates, understand the importance of various reaction paths, and test the results for consistency.

Table 4: Some examples of trace-gas measurements made in support of atmospheric chemistry

NO, NO2, NOx, NOy
O3
OH
HOx/ROx
H2SO4
DMS/DMSO, DMSO2
CO
CO2
N2O
HNO3
CH4
CH2O
Isoprene
CFCs, HCFCs, HFCs
PAN
SO2
O2/N2 ratio
Various others or multi-component systems

In most cases, more than one airborne instrument is available to make each of these measurements. The result is that comprehensive packages of sensors can be assembled for experiments in atmospheric chemistry. However, the desired payloads are so large and heavy that usually compromises are required and experiments must focus on those measurements thought most important for their research topics. In many cases, smaller and more autonomous instruments would relieve these problems and permit the assemblage of more comprehensive sets of measurements.

Aerosol Measurements

Concentration and Size Distribution

Suitable instruments are now available for the measurement of total aerosol concentration and aerosol size distribution; see, for example, the entries for condensation-nucleus counters and for aerosols spectrometers like those that use mobility analysis. Accumulation-mode and larger aerosols are detected and sized effectively by the available light-scattering instruments like the UHSAS. The many instruments available provide good capabilities for covering aerosol particles in the size range from a few nm to larger than one um. The more serious difficulty in measuring aerosols from aircraft, especially those that operate at high speed, is providing a suitable sample of the ambient air to instruments that operate in the cabin. Sampling through an inlet and usually leads to losses to the sides of the inlet that vary with aerosol size, and there are additional size-dependent losses in the lines connecting such inlets to aerosol-measuring instruments in the cabin. Furthermore, the samples are usually transported at speeds slower than three-stream airspeed, and in a high-speed aircraft and the associated dynamic heating can volatize components or even the entire particle. Some special inlets like the low-turbulence inlet have been designed to minimize losses from impaction, but the design and testing of good general-purpose inlets remains an important need for airborne studies of aerosols.

Radiative Properties

A number of instruments, often called nephelometers or aetheolometers, determine the ensemble light-scattering properties of the aerosol population. There are some more specialized instruments that measure the distribution of light scattered from single particles, and some specialize in detection of absorbing particles like soot or black carbon. A relatively new instrument, the SP-2, measures the size and some properties of individual soot particles, and so provides an important new measurement for tracking carbon-aerosol plumes and for studying absorbing particles

Chemical Composition

The Aerosol Mass Spectrometer (AMS), now available for and flown on many different research aircraft, has become an important tool for characterizing the chemical composition of individual particles. The measurement is limited to "non-refractory" composition, that portion that vaporizes quickly at a temperature of 600C or less; refractory material like sea salt and mineral dust may not be detected. There are commercial sources for AMSs, and some of these commercial instruments have been flown one on research aircraft. A related instrument, the "Particle Analysis by Laser Mass Spectrometry" or PALMS instrument, has been used in high-altitude aircraft. [note: good summary of available instruments: http://cires.colorado.edu/jimenez/ams.htm]

Aerosol collectors

Collections from aircraft have been made by diverse collectors, including filter samplers, cascade and other specialized impactors that provide some size discrimination, impaction on electron-microscope grids, etc. The chemical composition of collections of aerosol particles or of individual particles is often determined from the samples collected in these ways. In the past, filter samples were used to measure ice nucleus concentration, but this technique is seldom used now because the modes to which the method is sensitive are not thought to be the most important modes of ice nucleation.

Aerosol sampling inlets

The inlet is of critical importance when in-cabin instruments are used to measure aerosol properties, because particles larger than about 1 um tend to be lost to impaction on curves in the inlet or tubing and because small (ca. 0.01 um) particles are lost to Brownian collection at the walls of the inlet, tubing, and instrument. Both losses are enhanced significantly when the flow is turbulent. In addition, for a high-speed aircraft, the dynamic heating associated with slowing the airflow from the high airspeed of the aircraft to the low airspeed typically used in processing instruments causes a temperature increase that can be 20 degC or more, and this heating has the potential to volatize parts of the particles. Several studies of the efficiency of inlets have emphasized that inlet technology is in need of systematic study and improvement to minimize these problems.

One approach to this problem has been the Low-Turbulence Inlet (LTI) developed by Wilson and collaborators. In this inlet, a strong vacuum pump exhausts the boundary layer from the inside of the tube, and so inhibits the formation of turbulence. The LTI has been shown to have significantly improved transmission efficiency compared to conventional inlets, at least for some sizes.

Other samplers attempt to maintain isokinetic flow, in which the flow speed is reduced by gradual expansion of the inlet diameter at a rate designed to avoid boundary-layer separation. Simple Reynolds-number considerations, however, indicate that such inlets will develop turbulence that interferes with the design concept of preventing separation. Other strategies try to maintain fast flow, with minimum bends, to the location of the sampling instrument, in order to minimize losses to the inlet and tubing.

An important technique often used for sampling aerosols and cloud hydrometeors is that of the counterflow virtual impactor (CVI). In this instrument, a flow opposing the approaching airflow is sent through permeable material in the walls just inside the inlet, so that approaching particles encounter a sudden decelerating force. Particles that are large enough move through this region into the interior of the inlet, where a sample flow smaller than that of the counterflow is drawn to a detecting instrument. Smaller particles are carried around the inlet and don't enter the sample. The result is that the CVI can provide a sample of particles or hydrometeors all larger than some limiting size, and that limiting size can be varied by changing the flow rates. The instrument can be used to, for example, sample ice crystals, evaporate them, and study the residue for ice nucleating ability, or to collect the residues for detailed analysis, or to measure the condensed water content in a cloud provided by all hydrometeors larger than s specified size.

Remote Sensors

X-band and C-band radars (precipitation radars)

Centimeter-band radars, especially specialized X-band Doppler radars, are in use to measure reflectivity from precipitation and air motion. C-band is sometimes used for surveillance radars mounted in nose cones because of the superior ability of C-band to penetrate precipitation without attenuation. However, X-band radars are more commonly used for rotary-scanning (in antennas mounted on the tail of the aircraft) because the antenna size needed for good angular resolution is more practical. Examples include the "ELDORA" radar operated by the NCAR on the NRL P3 and the radars on the NOAA P3s equipped for hurricane surveillance. The NOAA aircraft also employ surveillance radars that help the air crew determine flight paths along which to collect the higher-resolution Doppler measurements from the tail-mounted radars.

These systems are aging and will become difficult to support in the future. Maintenance and continued operation of these systems will become difficult unless refurbishment or replacement programs are undertaken during the coming decade.

W- and K-band radars (cloud radars)

K-band or W-band radars can detect low-reflectivity regions (such as may be present in early stages of cloud development, before precipitation is present) with high angular resolution while still using antennas small enough to be practical on an aircraft. The Wyoming Cloud Radar (WCR), developed over the last >15 years, is a good example. That radar provides Doppler measurements as well as reflectivity and has been used to define the fine-scale structure of, e.g., marine Sc clouds with high precision. Other mm-wavelength radars have been flown on research aircraft, and other systems are under development.

Lidars

Aerosol backscatter and/or cloud physics lidars

Several simple backscatter lidars have been used from aircraft to locate cloud boundaries, aerosol layers, wave structures, and other structures revealed by discontinuities in aerosol populations. A recently developed example is the Wyoming Cloud Lidar. The Scanning Aerosol Backscatter Lidar, formerly operated by NCAR, was also used in many experiments, usually to assist in tuning flight plans to encounter aerosol layers.

Differential absorption lidar

Lidar can also be used to measure the number concentration of trace gases via the "DIAL" (differential absorption lidar) technique, in which two wavelengths are transmitted, one centered on a wavelength where the trace gas has high absorption, and the other located at a nearby wavelength outside the absorption feature. The intensity scattered back to the detector passes through any intervening absorbing material twice, so the ratio of the intensity detected at the two wavelengths can be used to determine the number concentration of the trace gas. Several DIAL systems included in the database detect constituents including water vapor and ozone, and systems for the detection of more difficult constituents (including CO2) are being considered.

Wind lidars

Lidar techniques can also be used to measure wind, either in scanning or fixed systems. One fixed-system application is that to measure wind (perhaps vector wind) at a fixed location displaced from the aircraft. Such "velocimeters" usually use the motion of particles through an interference pattern created ahead of the aircraft to determine the airspeed of the aircraft at a location displaced from the airframe. The significant advantage of such systems is that they are not subject to distortion of the wind field as the aircraft approaches, so they provide valuable calibration information for other wind-sensing systems.

3.3 In-Situ Surface and Surface-Atmosphere Exchange (ISSSAE)

Description and Process

Measurements under this heading are included from ground, ocean, or ship-based in-situ measurements of aerosols, radiation, meteorological variables including surface and boundary-layer fluxes, trace gas ambient levels and fluxes from surface towers, buoys or tethered instruments, as well as relevant measurements in soil, vegetation and fresh and ocean water. Since “networks” are explicitly listed as part of our charge, there is some overlap with the Surface-Based Remote Sensing Group.

The In-Situ Surface and Surface-Atmosphere Exchange (ISSSAE) subcommittee had two full meetings, on 31 August 2006 and 30-31 May 2007. Between meetings, the two co-chairs were in frequent communication. At least one of the co-chairs attended the full Assessment Steering Committee Meetings.

Breadth

At the first meeting, ISSSAE came up with sets of key words for the database in the fields of meteorology, climate, radiation, aerosols, soils, vegetation, ocean measurements, and atmospheric chemistry. The number of categories grew so large that our questionnaire design changed from drop-down lists (that would have been optimum for an easy search capability) to blanks to fill in. As a result of repeated conversations between the co-chairs, the category “Measurements/Networks” was expanded to include an option to fill out extra information for “tower groups” to include information on tall towers as well as the standard 10-m meteorological towers, and two new categories, “Ships” and “Calibration Facilities” were added.

At the second meeting, we realized that an exact parallel with airborne measurements (“platforms” and “measurements” should require the categories, “Surface platforms” and “Surface measurements” for land, and “ships” and “ocean measurements” for the ocean. Because of this, and the confusing overlap between the committees’ areas of responsibility (which had actually kept some from entering data), we felt that dividing the database according to subcommittee structure should be replaced by a simpler structure, and only one questionnaire with options to capture the special features the questionnaires currently have. This was suggested because the number and breadth of facility/instrument types was unique to our subcommittee. Further information appears in the report from the second meeting, in Appendix D.

Size of the Job

Given the large number of categories, and associated large number of submissions needed, the Sub-Committee sought ways to to partition and assign the work. At the first meeting, we asked member Scot Loehrer to populate the database with the 432 networks he had documented on a Joint Office for Science Support website over the last decade with funding from GEWEX/GAPP and other sources. We felt this would minimize the work for the network providers updating the entries and thus increase the chance for a response. We recommended broadcast emails to large groups such as appropriate parts of AGU, PIs for NSF or NASA directorates, AMS, or the UCAR Members, hoping this would streamline the job.

In anticipation of the labor required for reviewing the anticipated volume of replies, Carroll and LeMone met with Serafin, Metz, and Sawyer to figure out ways to streamline the approval process. It was decided to have two questions – identity of the person submitting the questionnaire and the relationship of that individual to the responsible contact person. If the responsible person and the contact person were the same, then the entry would be accepted.

By the time of the second meeting in May, the anticipated volume of entries had not materialized. Our research showed this to be normal: large broadcast questionnaires typically get poor response because of the sheer number of surveys and the likelihood that large emails are often intercepted by spam filters. Survey experts indicate that filling out a questionnaire has to be both easy for the person filling it out and worth their time. Personal contact and follow-up have proven to be effective in improving response rate. Thus, after the second meeting, the committee recommended that we:

- Change the request letter to make it more relevant to the recipient
- Avoid use of the word “survey”
- Provide the option to supply a web address instead of filling out the questionnaire
- Hire someone to populate the database by
  - Making individual requests
  - Mining web sites (listed in the Appendix D)
  - Following through on requests
- Simplify the database by making the language more uniform, changing organization, etc.

A student tasked to this work during the summer of 2007 has performed many of these functions. In particular, he has found and emailed people associated with the 420+ “networks” on the database requesting updated information. This effort had such good yield that LeMone and Carroll requested that he take over the “approval” function as well. After the June 2007 Assessment Committee meeting, LeMone contacted scientists at NCAR to make sure that NCAR instruments were represented.

Unique Characteristics

<u>*Entries*</u>

Of the entries submitted to the Facilities database, the ISSSAE is responsible for a significant fraction. As of late September 2007, more than 450 measurements/networks on the database, along with 13 instruments, one ship, and three calibration/validation facilities.

The networks on the database are diverse. Many are operated by the federal government for weather forecasting (e.g., NOAA), agriculture (USDA), or fire weather agencies or multiple agency sponsors. The Departments of Transportation of most, if not all, states operate or have access to weather information along highways, especially in sites subject to hazardous conditions, such as high winds, fog or icing (39 listed). States, counties, and cities operate several air quality networks (63 listed), and there are 37 coastal networks listed. In addition, several cities and regions have flood-alert networks of rain- and stream-gauges (31 listed), and several universities operate mesonets for meteorological, air-pollution or agricultural research. In the private sector, there are two entries for railroads taking weather measurements along their tracks, and there are networks operated by television stations (~50). Many factories and power plants observe emissions, but these data are rarely made available.

While most of the networks fit our expectation of a numerous fixed stations scattered over an area, many do not. The Texas Tech Stick-Net is a transportable network that can be deployed in 1-3 minutes. Some universities operate instrumented storm-chase vehicles (not yet on the database). The NCAR Integrated Surface Flux System (ISFS) operates a network of 9 surface-flux towers that can be used for field campaigns as part of the NSF Deployment Pool.

Database Structure

The four categories related to ISSSAE are "Surface In-Situ Measurements/Networks", "Instruments," "Ships," and "Calibration or Validation Facilities." As noted previously, we added questions so that we could know who the submitter of the data was and his/her relationship to the person responsible for the entry to streamline the approval process.

The questionnaire for Surface In-Situ Measurements/Networks was difficult to develop. As a result of Scot Loehrer's efforts populating the first 432 entries, we knew what to expect. Thus:

- We added whether the network contained fixed, mobile, or portable instruments.
- To simplify the questionnaire (and improve chances for a response), rather than having someone enter attributes of all the sites, we asked for
    - Parameters at most stations
    - Parameters at limited stations
- We asked about archives
- We have "tower groups" that request heights of measurements and heights of towers

"Instruments" was such a diverse category that:

- Drop-down menus or lists were used only for generic categories
    - Instrument type (radiation, chemistry, aerosol, or other)
    - Measurement type (meteorological, hydrological, soil, vegetation, or chemical)
    - Purpose (research, emergency response, climate monitoring, forecasting, education, or other)
    - Chemical phase (gas or aqueous)
- We allowed the instrument supplier to list the variables measured
- We asked for the measurement technique

- “Quality” was assessed in two ways
    - o Through asking for the purpose
    - o Through asking for “instrument maturity”

“Ships” questions were created by modifying the aircraft questionnaire, and adding questions appropriate to people actually living on the ship.

“Calibration or Validation Facilities” has only generic questions common to all resources.

3.4 Surface-Based Remote Sensing

Description and Process

High altitude instruments

In this survey of ground-based upper atmosphere remote sensing instruments, both optical and radio technologies are included. We surveyed passive and active instruments. The instruments measure upper atmosphere temperature, winds, gravity wave structures, and ionosphere densities, electron temperature, and ion temperatures. About 200 instruments are listed.

Regarding passive optical instruments, the survey includes all sky cameras (for gravity waves and auroral monitoring), Michelson interferometers (for mesosphere temperature), spectrometers and spectrographs (airglow intensities, rotational temperatures in the mesosphere), photometers (auroral and airglow emission intensities), temperature imagers (rotational temperature in the mesosphere), Fabry Perot Interferometers (mesosphere and thermosphere neutral winds and temperatures), For the active optical instrument, the survey covers lidars (Sodium, iron, potassium, multi-metal, and Rayleigh system). These systems measure parameters ranging from upper atmosphere temperature, winds, air density, sodium, iron, and other metal constituencies

Passive radio instruments included in the survey are riometers (height integrated ionosphere electron counts) and MF/HF swept frequency receivers (auroral radio emission).

Active radio instrument are mostly radars. The survey includes MF radars (mesosphere winds), meteor radars (mesosphere winds), incoherent scatter radars (ionosphere parameters, electron and ion temperatures, ion density, ion drift), coherent scatter radar array (large scale ion drift map), frequency agile radar (mesosphere winds, plasma irregularities), Julia radar (equatorial spread-F and E), and ionsondes (ionosphere profile).

Lidars

A list of U.S. lidar researchers was compiled from the web site (http://www-rab.larc.nasa.gov) maintained by the NASA Langley and the International Committee on Laser Radar Studies. This was expanded using contributions published in the proceedings of the International Laser Radar Conference held in Nara, Japan in July of 2006, a search for lidar web sites, and investigators known to panel members. An email was sent to the researchers on this list requesting that they post a description of their instruments on the FASC web site.

A wide variety of lidar instruments are include in the US inventory. These include sytems designed to measure mesospheric metals, temperatures and winds. Raman and DIAL systems to profile water vapor and ozone including statospheric ozone. Aerosol backscatter lidars to used track aerosol plumes and deliniate a wide variety of atmospheric structure. Coherent and inchorent Doppler lidars to measure wind velocities. Additional lidar research is proceeding on a variety of specialized fronts including systems to profile carbon dioxide, systems to detection biological warfare agents and even to track honey bees trained to sense explosives.

Wind Profilers

Wind profilers measure the horizontal wind from near the surface to the low- or mid-troposphere. The measurements are dependent on the humidity and temperature gradients in the atmosphere and dependent on the radar's operating frequency. The four operating frequencies of wind profilers used in the United States are 915, 404, 449, and 50 MHz. The 915-MHz wind profilers are also called boundary layer radars because they have the lowest height coverage usually up to 4 km above the ground. The license to operate radars in the 404-MHz band has been eliminated and all profilers operating at 404-MHz will either have to be turned off or converted to 449-MHz within the next couple of years. Terminating the 404-MHz license is world-wide due to the SARSAT search and rescue satellite program operating in this frequency band. The NOAA wind profilers located in the central U.S. are being converted from operating at 404 MHz to 449 MHz. There are a few 50-MHz wind profilers in the continental U.S. and these radars are sometimes called ST radars because they observe winds in the Troposphere and lower Stratosphere.

Two methods were used to collect information about wind profilers operating in the continental United States. First, personal knowledge of university researchers using wind profilers in their work provided about 10% of the entries in the database. The second source of information came from the NOAA Multi-Agency Profiler (MAP) database which is part of NOAA's Meteorological Assimilation Data Ingest System (MADIS) (http://madis.noaa.gov). The MAP database not only provides information about wind profilers that are operating around the world, but the database also contains quality controlled data sets that are in a common ASCII format.

In the late 1980s and early 1990s, NOAA constructed and operated the NOAA Demonstration Network of 404-MHz wind profilers in the central United States. During this time, NOAA spent considerable effort in developing a database of wind profilers operating around the world and formed the Cooperative Agency Profiler (CAP) database. The CAP database was a voluntary and unfunded program that collected profiler data from any operator that would ‘push’ or ‘get’ their data to NOAA, where NOAA quality controlled the data, and made the data available to forecast models and to the world via a web page. NOAA also developed the Meteorological Assimilation Data Ingest System (MADIS) which included many meteorological instruments. The wind profiler database is included in MADIS but is now called the NOAA Multi-Agency Profiler (MAP) database.

The goal of MADIS is (from the web page http://madis.noaa.gov): "The Meteorological Assimilation Data Ingest System (MADIS) is dedicated toward making value-added data available from the National Oceanic and Atmospheric Administration's (NOAA) Earth System Research Laboratory (ESRL) Global Systems Division (GSD) (formerly the Forecast Systems Laboratory (FSL)) for the purpose of improving weather forecasting, by providing support for data assimilation, numerical weather prediction, and other hydrometeorological applications."

The Multi-Agency Profiler (MAP) database is project within NOAA Oceanic and Atmospheric Research (OAR) with cooperation with the NOAA National Weather Service (NWS). Wind profiler data that are provided for the database voluntarily without any support from NOAA. Many owners of the wind profilers do not have the resources to support new field campaigns and may not be able to provide data to the research community. Also, since NOAA has an interest in maintaining the relationships with these wind profiler owners, the manager of the MAP program Patty Miller (Patricia.A.Miller@noaa.gov) has been added as either the first or second contact in the NCAR database for each profiler in the MAP database. Contact information for the owners of the wind profiler is also in the database, but researchers may wish to contact both the owners and the MAP manager to obtain fully comprehensive information.

mm-wave radars

The identification of millimeter wavelength cloud radars for inclusion on the NSF Facilities Assessment of Surface-Based Remote-Sensors entailed the following. A preliminary list of radars known to the committee member was compiled. The second stage involved internet searches for pertinent systems that were not already included on the list. A final search was performed via email correspondence with other lead scientists in the field of cloud radar research. The necessary details for each system were obtained either through web-based information pages or through direct correspondence with the individual instrument mentors of each system.

Millimeter radars are unique measurement platforms in a number of ways. Based on their wavelength and typical specification, they are optimized for observing cloud and light precipitation and are therefore able to detect small hydrometeors in the atmosphere that might otherwise be missed by longer wavelength radars. Moreover, attenuation of the radar signal through clouds is minimal, allowing for coincident observations of multiple cloud layers. Dopplerized radars are able to associate a radial motion with all identified atmospheric hydrometeors. Additionally, Doppler spectra measurements provide a detailed view of hydrometeor distributions and fall speeds within a radar observation volume. In short, millimeter-wavelength cloud radars are able to provide a detailed view of clouds and cloud particles throughout the depth of the troposphere.

Ground-based sounding system

The ground-based sounding system surveyed in the "Surface-based remote sensing" committee includes radiosonde (both operational and research), tethersonde, driftsonde and ballooning systems. The dropsonde system was left to the "Airborne measurements" committee. The sounding system instruments were identified and characterized by three steps. (1) The initial list was first compiled based on the committee member's personal knowledge. (2) Then an email was sent to eleven people who to the best of the committee member's knowledge have sounding systems to request more information on their systems. (3) A web search was conducted to further populate and refine the list. In addition, the email sent to all instrument mentors by the FASC also results in more sounding systems added into the database.

Radiosondes are just one of many, but perhaps the most common, amongst the various sounding systems surveyed. A radiosonde is an expendable, balloon-borne device that makes in-situ measurements of pressure, temperature, humidity and wind profiles from the surface to stratosphere, and transmits the data to a ground-based receiving and processing station. The research radiosonde system also measures other atmospheric parameters, such as other trace gases, atmospheric electricity and cloud properties. The applications of radiosonde data include input for weather prediction and air pollution models, local severe storm, aviation, and marine forecasts, climate change research, ground truth for satellite data, and characterization of thermo-dynamical and wind profiles for scientific field experiments. The tethersonde is a balloon with a line attached to the ground and carrying sensors at different altitudes to make high-solution sampling of the atmosphere in the boundary layer. A special type of sounding is also used to measure the 3-D electric field in clouds. This sonde is known as an EFM (Electric Field Meter) sounding, which is carried aloft by a helium balloon, along with a standard radiosonde. This sounding technology is maintained at NOAA's National Severe Storm Laboratory (www.nssl.noaa.gov). All sounding systems make active, in-situ measurements of the atmosphere and are very important for calibrating and validating both ground-based and space-borne remote sensing instruments.

Weather radars

Many weather radars (defined here as wavelengths of X, C and S band) were included in the survey. These instruments span those associated with national facilities such as the CSU-CHILL and NCAR S-pol radars, to those maintained by universities and various federal laboratories. Two radar networks maintained for operational purposes are not yet in the database, NEXRAD and Terminal Doppler Weather Radar (TDWR), both of which have considerable research applications. There are 47 TDWR radars located in the U.S., the majority near major airports. TDWR radars operate at C-band. One impressive characteristic of these radars in their high resolution data, provided by a 0.55 degree beamwidth antenna (http://www.ll.mit.edu/AviationWeather/TDWRflyer.html). NEXRAD, (Next-Generation Radar) consists of 158 S-band Doppler radars operated by the National Weather Service, an agency of NOAA. These radars, also known as WSR-88D's, provide reflectivity and Doppler velocity through two basic scanning modes, the clear air mode (maximum elevation angle of 4.5 degrees) and a precipitation mode (maximum elevation angle of 19.5 degrees). So-called Level II data are available from NOAA/NCDC. Level II data are most suitable for research applications (http://www.roc.noaa.gov/).

Lightning measurements

The National Lightning Detection network (NLDN) detects cloud-to-ground lightning throughout the contiguous U.S. Information provided includes location and time of the cloud-to-ground strike, peak current, flash polarity and number of strokes in the flash (multiplicity). The NLDN is operated and maintained by Vaisala (www.vaisala,com). A lightning spherics array is also operated and maintained by Los Alamos National Laboratory (www.lanl.doe.gov). The LASA network detects total lightning in the western and southern Great Plains region. The World Wide Lightning Location Network (webflash.ess.washington.edu) is a lightning detection network that detects spherics from lightning flashes in the 3-30 kHz portion of the electromagnetic spectrum. It provides estimates of lightning flash locations world wide. Approximately 25 sensors are deployed along the Earth's surface to comprise this network. Lightning Mapping Arrays (LMA's) are in operation at NASA's Kennedy Space Flight Center in Florida, in central Oklahoma and in southern Texas. These networks are comprised of roughly 10 VHF radio receivers that use GPS timing to triangulate the location of VHF energy bursts associated with lightning channels. From LMA data, the 3-D structure of lightning discharges can be measured.

Microwave, millimeter-wave, and infrared radiometers

A list of passive microwave and millimeter-wave radiometers, and infrared radiometers was compiled. These instruments basically measure down-welling radiance as a function of frequency and/or angle. From the radiance measurements, various atmospheric quantities are derived and include Precipitable Water Vapor, Cloud Liquid Path, low-altitude temperature profiles, and coarse-vertical resolution water vapor profiles. The basic radiance measurements are also useful for climate studies. Currently, in the United States, the Department of Energy's Atmospheric Radiation Measurements Program operates and maintains a data archive of data from several microwave, millimeter wavelength, and infrared radiometers. Data from these instruments have been one of the cornerstones of the ARM program. There are several research institutions that have developed microwave and millimeter-wave radiometers, and include JPL, NASA-GSFC, DRI, and the University of Colorado. A single commercial firm, Radiometrics Inc. has developed radiometers that have been sold around the world. The principal source of infrared atmospheric-profiling radiometers is through the University of Wisconsin and their cooperative agreements with a Canadian firm-BOMEM.

Unique Characteristics

Before the survey, the SBRSS established the following common format for the database:

- Resource *(name, description, availability, request procedure, web site, status, references, remarks)*
- Responsible and secondary contacts
- Details *(facility type, location, variables, archive data availability)*

The committee agreed that the format should be simple and focus on pointing the users to the right locations to obtain more information, rather than exhausting the database with a lot of detailed information. During the preparation for the survey, three unique questions were raised in the committee:

- *Do we identify manufactures of instruments?* The committee though that where appropriate this information ought be included, is useful to the users and does not constitute and does not constitute endorsement.
- *What do we do about the quality assessment of each instrument?* The committee chose not to specify any quality assessment (accuracy, errors or biases) in the database because they vary too much and are hard to reach consensuses.
- *What do we do with experimental, vulnerable, and not-US systems?* We decided to include experimental and under-development systems and label than as such in a "Status" column in the database. This avoids judgment on our part regarding inclusion of these systems but identifies them to interested users. The non-US systems were included if there was a US PI involved. This would apply to systems purchased abroad or joint development efforts. The decision was not to make any judgments on the issue of vulnerable systems. We simply included the systems that are in operation and made no statement about their future.

As of November 26, 2007, there are a total of 360 entries made in seven instrument categories described above. The unique characteristics of each category are presented above in details. The entries include both individual instruments and networks. The attendees at the breakout session of the September NSF Facility Assessment workshop were very helpful in identifying instruments that need to be added to the database. These instruments include the NEXRAD network, TDWR radars, the National Lightning Detection Network (NLDN), and several VHF Lightning Mapping Arrays that are operating around the country (at the University of Oklahoma, University of Alabama-Huntsville, Texas A&M and Kennedy Space Center). The breakout had a major discussion on lidars, both existing systems that need to be added, and new lidar-based instruments that should be developed. The breakout attendees will submit a list of lidar platforms that need to be added to the database. Two mobile Ka band radars at Texas Tech and solars need to be added. There are also commercially available microwave, rain profiling radars that provide measurements of rain rate that are missing the database.

3.5 Solar Measurements

Description and Process

The Solar Measurements Subcommittee believes that a good start has been made in populating the database. As of the end of September, 2007, there are 81 unique solar measurement entries, accounting for 9% of the database entries.

Initially, the solar measurements subcommittee sent requests to add entries to the database, to the solar physics community via community newsletters (e.g. SolarNews). The response to this request was muted. The subcommittee then took the step of creating skeleton entries for those facilities and archives of which it was aware. To assist with this, additional subcommittee members were recruited. Having identified the facilities, the principle investigators, or other responsible parties, were contacted by the subcommittee and asked to verify and update the information. This was the most successful tactic, raising the number of entries from a few to the greater than 80 it now contains. In addition, a significant fraction of the responsible parties updated the information.

The solar measurements database entries are intended to include PI class or higher facilities which make their data available to the community. The subcommittee limited entries to those that were directly related to the Sun. Included are US ground based, US space based, and US archive facilities, as well international facilities meeting the same criteria. This has resulted in several NSF study-related areas being missed. Facilities in the areas of magnetospheric and heliospheric physics are not included as solar measurements, and are not included elsewhere in the database.

In reviewing the solar measurements entries, the subcommittee finds that while there are still a large number of facilities not represented, that the database at this time does fairly represent the community investment. The entries are approximately evenly divided between space-based and ground-based. Facilities of a wide range of sizes are included. The subcommittee has reviewed all of the entries, but only at a high level, to consider whether they met the criteria laid out above. There has been no examination to determine whether all of the detailed information included is correct. Initial examination of the entries shows there are substantial inconsistencies from entry to entry, both in the format and in the level of detail. For example, some space based facilities have separate entries in the database for each instrument. The primary reason for this is each has a separate principle investigator. However, other facilities are listed only once, and the suite of instruments is listed within the facility description.

The level of detail in each entry is something that must be examined, either by the existing, or a future, subcommittee. The detail needed will be determined in part by how NSF chooses to use the information. Uniformity of the detail will be one component needed to make this a usable database for the community. However, one must recognize that outside of specific instrument and data parameters, there can be a level of subjectivity. For example, one might assume that facility expected lifetime is a key element of the database. It is difficult to determine the accuracy of a facility lifetime, as this can be driven by an irreplaceable consumable, scientific, or even political considerations.

The subcommittee has only recently started to pursue archive facilities for inclusion in the database and are likely under-represented. It is clear that we have only scratched the surface for international facilities entries, and a large number are likely missing. In particular, non-European facilities are under-represented.

3.6 Satellite Data

Description and Process

The first task of the Satellite Data Subcommittee was to identify the appropriate missions and instruments for sources of the relevant satellite data. Initially a "strawman" list of sensors on U.S. and international platforms was generated, and this list continues to grow. We then defined a suite of descriptive parameters that would cover the capabilities of the space borne instruments, and defined the characteristics of the resulting data products. We also discussed how these data access, including locations of data archives and the methods for data retrieval.

Both of these activities were consistent with the primary recommendation of the NRC's Decadal Study on Earth Science and Applications, which called for renewed investment of all private and public sectors into Earth observing systems from space. This study also points out that between 2006 and the end of the current decade, the number of operating Earth observing space missions will decline dramatically, with NASA sensors alone decreasing by about 40 percent (Figure 1). This emphasizes the need to catalog both the Earth observing satellite systems, and information related to data archives and distribution. Information on the coverages and accuracies of the space borne instruments is also important.

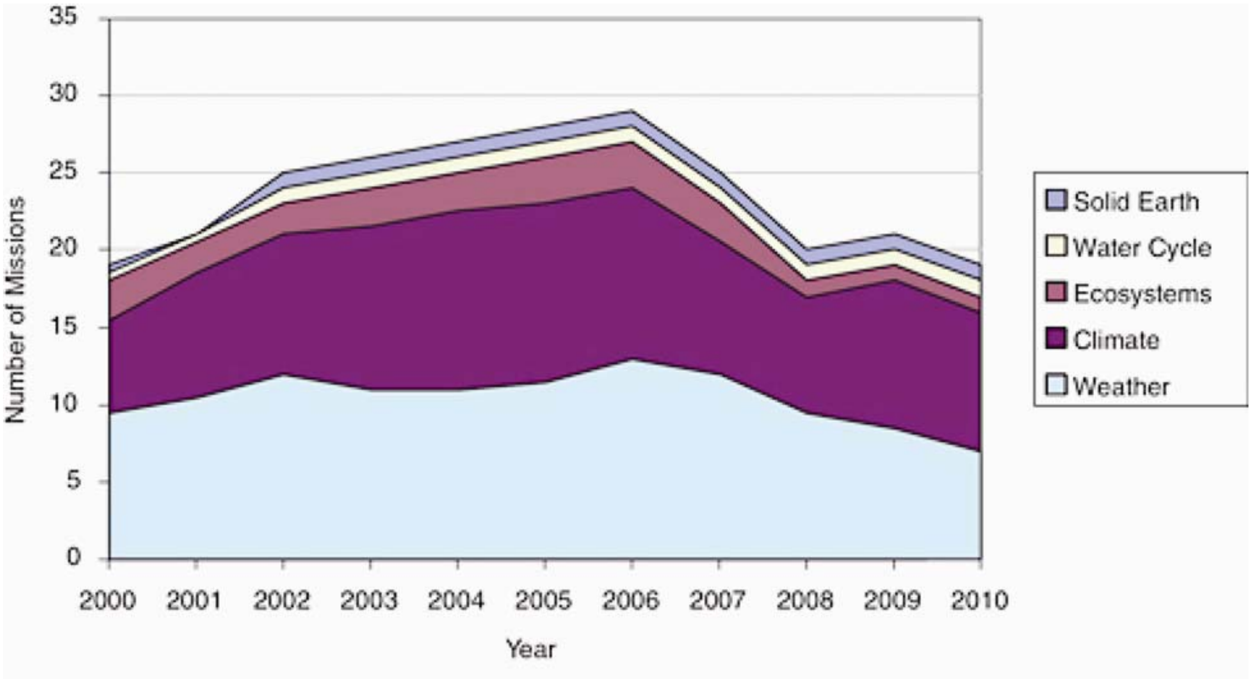


Figure 1: Number of U.S. space-based Earth observation missions in the current decade. An emphasis on climate and weather is evident, as is a decline in the number of missions near the end of the decade. For the period from 2007 to 2010, missions are generally assumed to operate for 4 years past their nominal lifetimes. Most of the missions are deemed to contribute at least slightly to human health issues, so health is not presented as a separate category. SOURCE: Information from NASA and NOAA Web sites for mission durations.

We were unable to uniformly cover some very important issues such as the calibration of each of the sensors due to lack of historical information, or to include links to other data sets in the facilities database. We recognize that by their basic nature satellite systems are large-scale and costly and are not generally controlled by a single PI or even a group of individuals. Generally satellite programs are government-initiated and government-sponsored efforts, which have many missions including weather forecasting. Having started with an emphasis on weather monitoring, environmental satellites have evolved to measure a wide range of atmospheric, oceanic and land surface processes. In addition, smaller satellites specifically focused on limited mission objectives have been and are now flying, so it is important to be aware of them when considering this database.

Because many of the satellite programs do not have a single point of contact the satellite group working on this database was responsible for populating a large portion of the list. This was good in the sense that we could complete the task, but it was problematic because we were not necessarily the most knowledgeable people to populate this resource table. We were forced to rely on information content from sometimes outdated and inactive web pages and also had to occasionally determine specifics for particular instruments from incomplete information. For this and other reasons the reader should be aware that some of the information in the database might not be as accurate as we would have liked. In ideal circumstances, a responsible individual possessing specific instrument expertise provided the missing information. Unfortunately that happened in fewer than 10% of the cases. We hope that people will continually update and correct entries in this table to improve its overall content above.

We believe that the future involvement of the larger satellite remote sensing community is very important and constitutes an important way in which we can markedly improve the quality of the database. There will be an “oversight committee” or “editorial board” that will act as a filter for all entries into the database. We believe that this editorial board will have a “rolling” membership so that there is both continuity in the process and new members bringing new ideas to the process. Continued outreach is required to increase the number of individuals involved in developing the database. Simultaneously, more people will be using the database. This use of the database will expand, in turn increasing interest to the activity and the number of people involved into the process.

Unique Characteristics

For each satellite instrument, entries include a brief description, availability, request procedure, web site, status, and contact information. Instrument details include measurement type, platform, orbit, altitude, inclination, repeat cycle, scan pattern, variables measured, wavelength range, number of discrete bands, and swath width. A start and end date are also included to provide information on temporal coverage. Separate entries are shown in cases where instruments acquire data at multiple spatial resolutions.

3.7 Emerging Technologies

Description and Process

Scope of the inventory and technology classification

The scope of the technologies surveyed and inventoried by the Emerging Technology Subcommittee includes new systems (collection of components/ technologies) and new system-level concepts; instruments; and critical sub-systems (e.g. sensors, processors). Since the technical maturity of emerging technologies can range from basic exploration, through different degrees of technology demonstrations, through operations involving different types of users, the subcommittee chose to adopt the Technology Readiness Level (TRL) as a uniform metric for objectively characterizing the maturity of the technologies in the database.

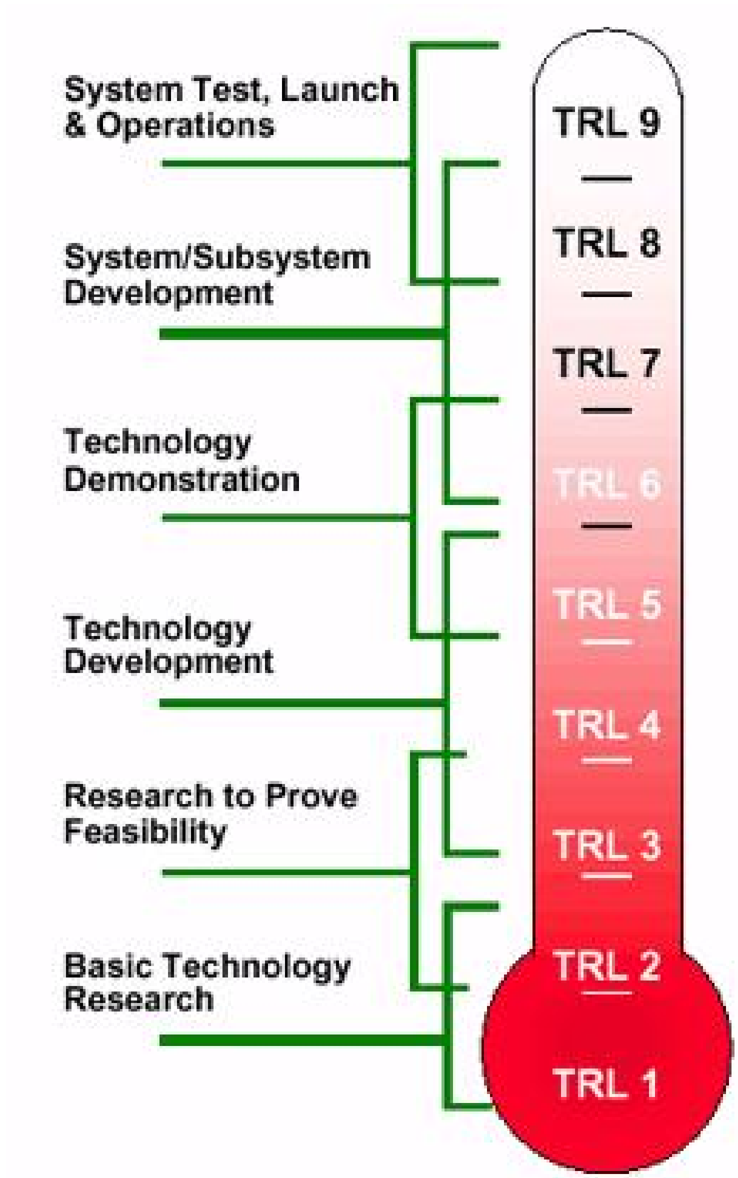


Figure 2: Technology Readiness Level (TRL) is a measure used by some United States government agencies (e.g. NASA and DoD) and many of the world's major companies (and agencies) to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating those technologies into a system or subsystem. Generally speaking, when a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and testing increasingly similar to the real application environment. Once the technology is sufficiently proven, it can be incorporated into a system/subsystem. The following TRL definitions are adapted from the DoD definitions (DOD (24 July 2006), *Defense Acquisition Guidebook*) by the Emerging Technologies Subcommittee (a part of the NSF Facilities Assessment Study) for application to atmospheric technologies.

Table 5: Technology Readiness Levels for Atmospheric Research and Operational Applications

Technology Readiness Level	Description
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Example might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high fidelity' laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, involving the demonstration of an actual system prototype in an operational environment, such as in an aircraft or other vehicle or in a ground-based application. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and 'field qualified' through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended application to determine if it meets design specifications.
9. Actual system 'field proven' through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

Whereas TRLs 1-9 describe the maturity of an invention, the subcommittee also believed it would be valuable to assign a measure of the degree to which an invention has been accepted by the community (i.e. a measure of innovation). These Community Adoption Levels (CAL) represent a new concept developed by the Emerging Technology Subcommittee of the NSF Facilities Assessment Study.

“Community Adoption Levels” (CAL) for technologies that have reached TRL 9.

CAL 0: Technology achieved nominal expectations in actual environment but did not offer significant cost or performance advantages and is no longer being pursued.

CAL 1: Technology is being actively pursued by its developers and possibly a few others but has not received significant community support. Additional development may be needed to transition to an operational system.

CAL 2: A quasi-operational version of the technology is in place supported on a best efforts basis by user groups/agencies and has achieved more than sporadic adoption.

CAL 3: A formally operational system with ongoing support has been put in place by at least one sponsoring agency and is enjoying significant use by the community.

CAL 4: Technology has been adopted as a core technique by the community with broad sponsorship of operational systems.

For the purposes of this study, technologies that have achieved levels of CAL 2 and higher are not considered emerging.

The subcommittee developed the following “Emerging Technology Watch List” as a way to categorize the various technologies in the database and to track gaps between the database entries and those technologies on the horizon. This watch list is based on the experience and knowledge of the members of the subcommittee, and it was shared with the wider community during the Facility Assessment Community workshop.

Emerging Technology Watch List

- Radar Signal processing algorithms & technologies & techniques (e.g., hydrometeor classification/dual-pol & range-Doppler mitigation algorithms; data acquisition subsystems that are <TRL9, radar networks)
- GPS science applications & techniques
- Synthetic gas tracers
- New Laser developments & light sources (e.g., diode, smaller cheaper, robust, eye safe, tunable, better beam quality, higher power, room temperature, narrower line width (more capable – enabling; smaller low cost - disruptive)
- Spectroscopic instruments
- Solid state sensors (chemicals to sense trace gasses,
- Absorption from cell-phone networks
- MEMS (micro electromechanical) devices
- Piggybacking on existing platforms (e.g. commercial aircraft routes, ground transportation)
- Range imaging
- High range-resolution optics (pulse compression, FMCW, …)
- Efficient optical beam steering

- Microsat arrays (GNSS occultation, cross-link occultation, SAR/interferometry from microsat)
- Optical Isotopic ratio techniques
- Particle/aerosol/cloud measurements
- Nanoparticle measurement
- New detection technology: CCD chips, eye-safe IR
- Sense & respond networks, adaptive arrays, distributed sensor networks
- Micro-fluidics – laboratory on a chip
- Long-duration balloons
- Disdrometers for real-time hydrometeor classification
- Superconductivity detectors – detect gaseous compounds, radioactive devices, toxic gasses
- Supersensitive quantum sensors (quantum dots; entangled photons)
- Integrated system of existing instruments and systems
- Emerging active remote sensors
- Emerging passive remote sensors
- Emerging in-situ sensors

On-line form

Recognizing that the task of survey and inventory of emerging technologies would be different from that of established technologies, the subcommittee developed a customized version of the on-line form which is shown in Appendix E to this report. The specialized form has a number of pull-down menus that guide technology developers through the process of entering in the kinds of information needed to characterize a wide range of technologies having a wide range of maturity.

Unique characteristics of the ET database

Entries in the Emerging Technology database were reviewed as of 25 September 2007. At that point, there were twenty-five non-duplicative entries covering a number of categories on the watch list. The entries include a mixture of new or emerging technologies and technology concepts, as well as some component technologies. Of the individual entries (listed below), seven are for radar systems, eleven relate to lidar or optical-based systems and three describe adaptive sensing networks.

These are the existing entries in the Emerging Technology database:

- 2-micron CO2 DIAL profiling system
- Adaptive Radar Network
- Adaptive Sensor Array (ASA)
- C-Band dual-polarization radar
- CO2 Laser Absorption Spectrometer
- Community Airborne Platform Rem Sens Suite (CAPRIS)
- Compact Microwave Radiometer Network
- Difference-frequency-generation (DFG)-based absorption spectroscopy
- Difference-frequency generation laser source

- Global Ozone Lidar Demonstrator
- GVR (183 GHz radiometer for water vapor and cloud liquid water)
- GSR (Scanning mm-wavelength radiometer for Arctic water vapor and clouds)
- IR Spectroscopic Techniques
- Intra-pulse Quantum cascade laser spectrometers
- Isotopic Radio Analysis
- Ka-band mobile Doppler radar
- Multiple Fields of View (MFOV) lidar
- Modular profiling network
- NO-XP radar
- Off-axis Intra-Cavity Optical Spectroscopy (ICOS)
- Polarization & Multiple Fields of View (MFOV) lidar
- Pulse Doppler Lidar
- Quantum Cascade lasers
- Wide Angle Imaging Lidar
- X-band dual-polarimetric radar network

4. The Future

4.1 Unmet Needs and Recommendations

4.1.1 Airborne Platforms

The committee's assessment of how effectively the current fleet can satisfy the future needs of the scientific community identified the following areas where these needs are not fully met:

Sampling capabilities in hazardous regions

Sampling in areas near the surface under high wind regions continues to be problematic. In addition to turbulence, salt spray over ocean surfaces provides another hazard to aircraft. Related to this issue is a lack of aircraft that can make hurricane eye-wall penetrations at low levels. Another gap in the fleet is the lack of an aircraft for thunderstorm penetrations and an inadequate capability for making cloud electrification studies. A third area where the fleet is deficient is in the capability to sample in Polar Regions. There is limited capability for doing so in some accessible areas of the Antarctic, but there is no capability for sampling over remote areas despite scientific interests in doing so.

Long endurance platforms

There is a lack of platforms that can make long endurance flights (range > 8000 km and/or endurance > 12 hours) in the boundary layer and at high altitudes (>20 km). There are many scientific questions that could be addressed with such capability.

Other needs

In addition to a lack of platforms for addressing scientific needs, it was noted that some of the aircraft available are incapable of supporting needed measurements since they lack hard points, data systems, inlets etc. Thus it may be possible to extend the capability of the fleet by modifying and upgrading existing aircraft to meet specific measurement needs.

Another critical need identified at the Users Workshop is the education of future observational scientists. An important benefit of university-developed airborne platforms is the opportunity presented by a university degree program where students can obtain knowledge and skills in the areas of instrument development, data analysis, flight and field program direction, and leadership in airborne system development. Workshops and field program exposure are also important components of the educational mix, but do not replace the benefits obtained through university facility involvement.

Instrument development requires flight testing for assessing instrument performance, calibration and determining deployment readiness. These tests must be completed prior to deployment on science programs where instrument performance is essential – there is no second chance. Investigators do not want to be faced with troubleshooting equipment during a funded science study and the instrument must be producing reliable, calibrated measurements. The flight testing process is often iterative and the very nature of the airborne sampling environment cannot be duplicated in the laboratory. Piggybacking on larger multi-investigator airplanes may not give some investigators enough freedom especially in the testing and development phases of instrument development. Smaller aircraft may be more productive in facilitating testing since they can be more easily deployed.

The Role of Unmanned Aircraft Systems (UAS)

The Federal Aviation Administration has recently adopted new terminology for the Unmanned Aerial Vehicle (UAV), which are now known as Unmanned Aircraft Systems (UAS). UASs are not well represented in the initial version of the database, with only 2 platforms entered, both Medium Altitude/Long Endurance. Platforms with the required characteristics do exist, although some need to be further developed to accommodate research infrastructure, and more need to be entered in the database. Several in-depth reviews of UAS technology and scientific needs have been done elsewhere and the results are available on the web. These include:

- A recent (2004) interagency UAS workshop, described at http://uas.noaa.gov/workshops/workshop1/index.html
- A NASA UAS Arlington Workshop report from July 2004: http://geo.arc.nasa.gov/uav-suborbital/
- The NOAA UAS home page, which includes links to a Civil UAS symposium http://uas.noaa.gov/ http://cauas.colorado.edu/

UAS technology has developed with extraordinary speed since the early 1990's based on several technological developments, including: low-cost, highly capable microproccessors; relatively low-cost composite primary aircraft structure; and the Global Positioning System, that enables precise navigation with low cost and in small packages compatible with a broad range of flight vehicles. The technologies of autonomous and remotely operated aircraft have been developed to an unprecedented degree as the result of government investments to achieve important military capabilities. Therefore, UAS could be viewed not as an emerging technology but rather an emerging capability that will be increasingly available to support research and scientific needs.

UAS place special requirements on instruments and payload systems, as instruments and payload systems must be capable of autonomous or remote operation. Frequently, the payload volume and power is limited, placing a premium on miniaturization and low-power requirements. These characteristics also benefit piloted research aircraft.

To realize the potential benefits of UAS for scientific research, several current issues must be successfully addressed. These include: 1) UAS must have relatively easy access to airspace, comparable to access currently available to occupied/piloted aircraft. Achieving this goal will require cooperative efforts of UAS proponents (e.g., UAS manufacturers and potential users) and governmental regulatory agencies (e.g., Federal Aviation Administration) to develop technologies and regulatory accommodations to allow airspace access with a level of safety comparable to occupied/piloted aircraft. When this issue is resolved, the utility of UAS vehicles for research will expand considerably. Thus, the schedule for UAS implementation is driven by resolving these problems more than it depends on the existence of UAS platforms. 2) UAS must provide capabilities not currently available from existing systems at a cost that is affordable for the application.

The availability of highly capable multiple aircraft for large field projects is a major area of concern, due to scheduling and support requirements. A serous mismatch exists between available aircraft and their deployment pool capability available to support research programs. In NSF and most other federal agencies that operate the national fleet (NOAA, ONR, NASA, DOE) the amount of funding for research flight hours has been relatively flat in recent years. Quite often there are many more viable scientific proposals than can be realistically funded. This may be one reason why the private sector is not widely represented in research aviation. The acquisition of new federal platforms, however, seems to be continuing (about 5 new platforms net to the national fleet in the last 3 years) with no matching increase in the net size of the relevant agency's funding for flight support. It is critical that operational funding be provided in order for these new platforms to be used effectively.

The need for better coordination of the national research fleet was identified as a major area of emphasis. Improved coordination is needed in the following areas, for example:

- Acquisition of new platforms. It was clear from a review of the available aircraft, that they are often put into research service without adequate consideration for the existing resources and the scientific need.

- Common standards for certification of payloads are not well standardized across aircraft operators, which makes it very difficult to use instrumentation on multiple-payload missions.

- Common policies for the safe implementation of certain research systems (e.g. dropsonde releases, lidar operating rules, etc.) do not exist, resulting in a mismatch in operating limitations among the platforms.

- Much more could be done to encourage the sharing of common resources among the fleet. (These resources include instrumentation, data systems, and calibration facilities.)

4.1.2 Airborne Measurements

The preceding discussion and the database show that an extensive set of instruments are available for making many measurements in support of atmospheric research. A few gaps in these capabilities were mentioned in the preceding, but this section contains a more comprehensive discussion of important needs for measurements that are not met by instruments now available or soon to be available.

State Parameters

- There is an important opportunity to measure pressure perturbations, in support of studies of mesoscale or synoptic-scale studies, if the accuracy (or even relative accuracy) of the pressure measurement can be improved to perhaps 0.1 hPa. GPS measurements now are available at the height resolution corresponding to this pressure uncertainty, making it important to improve the accuracy of measured pressure to these limits also.
- Studies of cloud buoyancy and entrainment are hindered by inability to make good measurements of temperature in cloud. An accuracy of perhaps 0.2 C or better for measurements in cloud (generally not possible now except from the slowest aircraft) would be an important advance. Radiometric techniques hold promise of providing this measurement.
- Some temperature sensors long used as standards are not being manufactured any longer, and this poses a problem for continuation of these standard measurements of temperature (esp. with good time response).
- It would be valuable to improve dropsondes systems by developing a smaller sonde, supporting a higher frequency of drops and more sondes in the air at once, and negotiating (perhaps with the FAA) a way of releasing sondes over greater portions of continental regions.
- Although there are good candidate instruments, the measurement of humidity in the UTLS remains problematic. Further study and calibration of instruments for measurement of humidity at the ppm level would be valuable. There are also weaknesses in high-time-response measurements of humidity suited to flux

measurements, partly related to unavailability of sources (Lyman-alpha lamps) long used for this measurement.

Cloud Physics

- Hydrometeor size distributions often have inadequate resolution to support desirable studies. There are promising new approaches now being deployed or developed, but careful study and calibration of those instruments is an unmet need. Measurements of concentrations of drizzle drops or small ice crystals (at sizes of perhaps 50 um) are difficult to make reliably with the instruments commonly available (perhaps with the exception of the SID).
- Many standard cloud-physics instruments do not work well at high airspeed, and continued development and study of such instruments at speeds typical of research jets is needed.
- A standardized, widely available measurement of CCN concentration, especially over a range of supersaturations, would be a valuable addition to commonly available instrumentation if it could be deployed routinely with only modest attention.
- Similarly, a standardized and widely available instrument for the measurement of ice nuclei would have substantial use. The instruments available cover only parts of the possible nucleation modes and sizes of particles, so further attention to this measurement seems appropriate.
- Sampling of “giant” aerosol particles is hindered by the low sample rates of most standard instruments.

Remote Sensing

- The important capabilities provided by the standard X-band Doppler radar systems need to be retained in the face of aging equipment and platforms that will become hard to maintain.
- Multiple-wavelength radar measurements from the same platform would be a valuable capability for the inferences possible via comparison of reflectivity at different wavelengths.
- It would be valuable to implement a scanning capability for the mm-wavelength radars.
- The many sophisticated remote sensors for trace gases that have been developed at NASA laboratories would be valuable components of NSF-supported experiments also, if a mechanism could be developed to provide NSF-supported investigators access to those facilities.

Atmospheric Chemistry

- To facilitate assembly of more comprehensive measurements in support of atmospheric chemistry, it would be valuable to continue to develop smaller instruments that operate autonomously in cases where state-of-the-art accuracy or sensitivity is not essential. Instruments capable of measuring several trace-gas species simultaneously also serve the same end.

Atmospheric Radiation

- Measurements that characterize spectral irradiance with good wavelength resolution are available from some specialized instruments now, especially some supported by NASA, but they need to be available as a common component of the field experiments of NSF-supported investigators. On the NSF-supported aircraft, measurements of long-wavelength radiation (thermal radiation) are mostly unavailable now and are needed with good spectral resolution.
- Many regard some of the commercial broad-band radiometers often used on research aircraft as questionable, and a study or new development project is needed to determine how serious this problem is.

Other

- There is interest in measurements made very close to the ocean surface, perhaps by a towed body below a research aircraft.
- Development and characterization of inlets for aerosol sampling, especially at jet-aircraft speeds, is a serious unmet need leading to critical uncertainties in studies of aerosols.
- There is need for greater attention to testing and calibration facilities. Perhaps an appropriate facility could be developed to meet the needs of many groups.
- Instruments to support studies of atmospheric electricity (including field mills and hydrometeor-charge detectors) have not been maintained, and this is now an important need of the atmospheric-electricity community.
- Most users of measurements from research aircraft find that the accuracy and precision of the measurements is inadequately characterized for their purposes. Comprehensive characterization of the uncertainty in measurements from research aircraft is needed, and such characterization would also be valuable as plans are made to improve such measurements.

4.1.3 In-Situ Surface and Surface-Atmosphere Exchange

Unmet Scientific Needs – General Remarks

At first look the presence of more than 450 networks in the U.S. implies that our needs for mesoscale weather observations are met. For example, the distribution of surface stations in the map in Figure 2 below implies a wealth of weather observations in California. But the wealth is not evenly distributed, and a closer look at networks here and elsewhere indicates that quality is uneven. Different networks have different purposes, so not all networks are optimum for any given application. For example, Road Weather Information System (RWIS) sites are installed along portions of highways with high potential for hazardous conditions, rather than the “representative” locations needed for weather-forecasting applications. Furthermore, some networks have better QA/QC and maintenance procedures than others; and some networks are falling into disrepair due to lack of funding. Data formats vary and important metadata on siting and instrument height are often missing. Siting criteria can vary, even for the same application. Finally, some networks have limited accessibility (e.g., registration and/or free required) or are inaccessible to most (or all) of the community. For example, some state DOTs do not release road surface temperature.

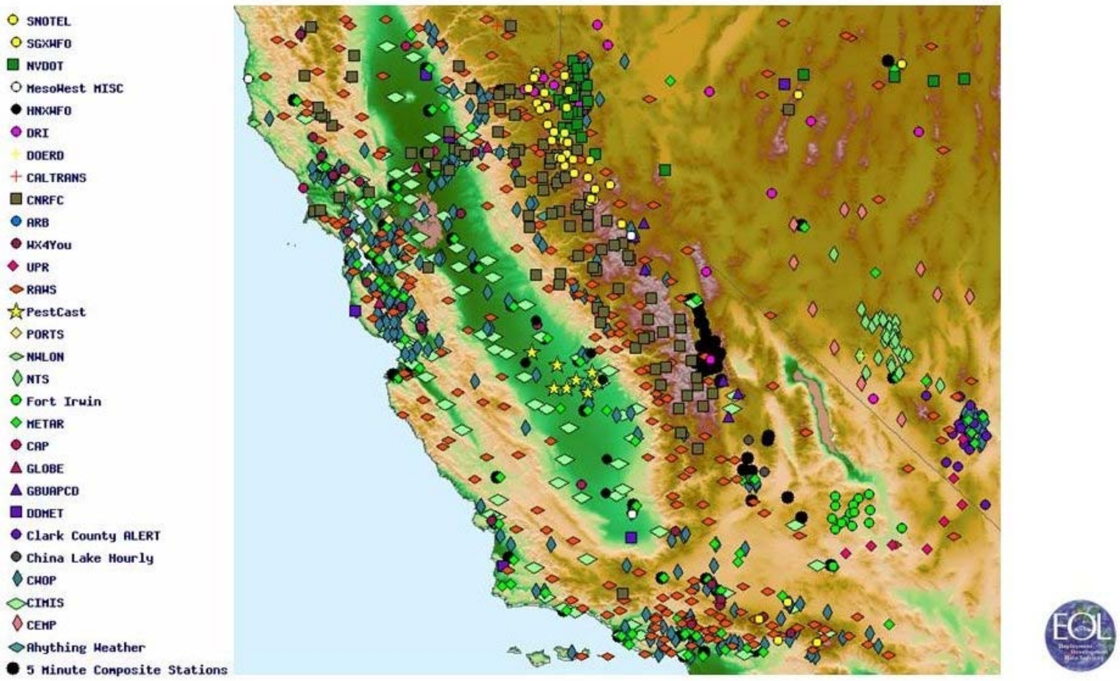


Figure 2. Observational networks in California, compiled for the T-REX experiment. Courtesy of Scot Loehrer.

Good metadata, QA/QC, instrument and siting standards, and a common data format could at least partially meet our data needs for some applications. Fortunately, this need is widely felt and responses are emerging. MesoWest (http://www.met.utah.edu/mesowest/), operated out of the University of Utah, and MADIS (http://madis.noaa.gov), operated out of NOAA ESRL, collect data from a number of networks, put them in common format, and provide a modest amount of QA/QC and metadata to the user. The next major advancement required for some research uses of the network data is the development of centralized access to the more detailed metadata (e.g., instrumentation, sensor heights). Some state climatologists are linking the state networks (e.g., South Carolina and Iowa) to improve data quality and provide a common format. The Federal Highway Administration's (FHWA) Clarus initiative (http://www.clarusinitiative.org/) is designed to integrate state surface transportation weather systems into a unified system for weather observation and forecasting. The roughly 2200 Remote Automated Weather Stations (RAWS, http://www.fs.fed.us/raws/) are operated jointly by several agencies for air-pollution, fire-weather and research applications. AIRNow (http://airnow.gov), maintained by EPA, NOAA, and the National Park Service, in partnership with tribal, state, and local agencies, has led to increased quality of the member observational networks not only for weather, but for air pollution (e.g. ozone and particulate matter). Many regions are developing collectives of the coastal networks in their areas (e.g., the Gulf of Mexico Coastal Ocean Observing System, http://ocean.tamu.edu/GCOOS/). These collectives are all part of the larger US Integrated Ocean Observing System (IOOS) and Global Ocean Observing System (GOOS). Finally, NOAA is developing the Multi-Network Metadata System. (http://mi3.ncdc.noaa.gov/) which currently focuses on the federal networks with plans for including non-federal networks in the future.

Some types of network still have obvious gaps. The network for soil moisture, in Figure 2, is one example. Because of the demonstrated importance of soil moisture to weather forecasting, NOAA/NCEP is developing the North American Land Data Assimilation System (NLDAS, Mitchell et al. 2004), which will compute soil moisture and temperature profiles from historical weather data (up to ~1-2 years) and combine this information with vegetation data into the operational numerical weather prediction model (Mitchell et al. 2004). For research purposes, a High Resolution Land Data Assimilation System (HRLDAS, Chen et al. 2007) provides similar information down to a resolution of 1 km. This solution works as long as the soil profiles are reliable; observations will still be needed as these systems develop.

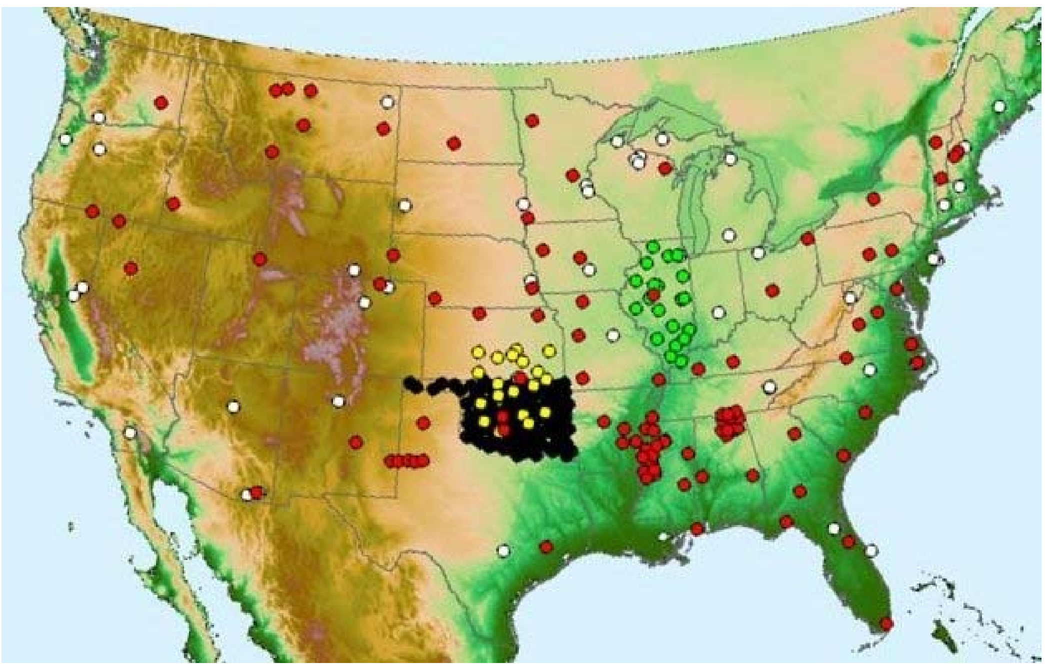


Figure 3: Soil-moisture networks in the U.S. The black dots represent the Oklahoma Mesonet, the green dots, the Illinois state water survey; Yellow is ARM/CART; white dots: AmeriFlux sites; red dots: USDA/NRCS Soil Climate Analysis Network. Source: Scot Loehrer

Needed Measurements

The list of networks is extensive; and, armed with supplementary information from Web sites of the major providers, we have made some tentative conclusions. However, the lists for “Instruments,” “Ships,” and “Calibration/Validation Facilities” are known to be incomplete. In fact, we estimate we have entries on less than 5% of available Surface In-Situ Instruments. Thus the assessments that follow are largely based on the 24-26 September 2007 NSF Facilities Users’ Workshop. Because most people attending the meeting were involved in weather and climate, nitrogen and carbon cycle, and boundary-layer meteorology, the conclusions drawn represent these communities reasonably well. However, scientists studying aerosols and ocean processes were less well-represented. This is reflected in less-specific and comprehensive findings for these areas. The conclusions for soil and vegetation are probably intermediate, since several people had an interest in these areas, but few were experts.

Water

Knowledge of the cycling of water in all three phases is vital to understanding the weather and climate system, and water has strong linkages to the nitrogen and carbon cycles as well as other aspects of the dynamic Earth System. Whether precipitation is in the form of rain, snow, ice pellets, freezing rain, or hail impacts transportation and public safety. The needs are summarized below.

- Water vapor measurements, especially through the atmospheric boundary layer.
    - Expand GPS surface sensor networks.
    - Improve instrumentation, data quality assurance, and metadata for surface networks, and create common data formats.
- Precipitation
    - Improve technology for measuring snow
    - Make more disdrometers available for research.
    - Develop capability to distinguish among types of precipitation

Other meteorological measurements

- Good wind measurements in boundary layer are particularly important for monitoring and reacting to toxic releases. Major urban areas are being instrumented, but this effort needs to continue for other high-risk areas.
- Temperature measurements, important for weather prediction, can be improved through strategic placement of surface temperature sites.

Aerosols

Aerosols affect Earth's radiation budget both directly and through their effects on the radiative properties and evolution of clouds. Aerosols deposited on snow or ice change the surface energy budget and contribute to more rapid snowmelt. Aerosols affect visibility and human health. Surface-based technologies continue to evolve on measuring important properties of aerosols (composition, radiative properties, size distribution), their deposition rate, and their effect on snow and ice. These efforts should continue.

Mercury was of particular interest, because of its potential health effects, and the amount being released from coal plants and wildfires. Existing measurements need to be documented, and the evolution of mercury compounds in the atmosphere studied.

Trace Gases

Numerous measurements are needed to better understand the Earth System, including the carbon and nitrogen cycles, their interaction, and their interaction with the water cycle. We need to understand how carbon is stored, the effects of changing agricultural practices. We need to understand the role of nitric acid, sulfuric acid, and ammonia in ocean acidification.

The needs can be divided into two categories, trace-gas measurements needed, and where they are needed.

What

The list of needed measurements varies with the problem, including capability of measuring CO_2, methane, non-methane carbon, VOCs (especially the highly reactive biogenic compounds such as sesquiterpenes), oxygenated VOCs (OVOCs), ozone, NOx, NOy, HOx, PAN and other organic nitrates, short-lived intermediate components of the C, N, and HOx cycles, NH_3, and DMS. Fast-measurement and flux-estimate capability is needed for many of these compounds, with grab samples adequate for others. In particular, longer-term measurements of many compounds are needed to address many pressing scientific questions.

Where

- Over the oceans (they cover 70% of Earth's surface)
- In extreme-weather environments (squall lines, fronts, tropical cyclones), to see how important air-sea transfers from these events are.
- The wake of tropical cyclones, to how air-sea trace-gas fluxes vary in the cool water left behind after the winds mix the upper ocean
- Coastal and tidal regions, including CO_2 with ^{13}C and ^{14}C isotopes
- In cities (exist air-pollution, health and homeland security concerns)
- Over diverse regions (to obtain a complete picture)
- In as well as above-canopy

Boundary Layer and Turbulence Measurements

Boundary-layer processes carry water vapor, aerosols, and trace gases between the surface and the free atmosphere. We need to know more about small-scale processes so that they can be represented as sub-grid scale processes in numerical weather forecast models and large-eddy simulations. Near the surface, horizontal heterogeneity and small eddies make measuring fluxes and high-frequency fluctuations difficult, particularly at night, when fluctuation amplitudes and eddies are even smaller. Measurement challenges involve faster instruments, smaller instruments, difficult-to-measure variables, and strategies for measuring fluxes in complex terrain. Some specific challenges include:

- Measurement of fluxes of heat, moisture, momentum, and trace gases,
    - In complex regions, including complex terrain, riparian zones, vegetation canopies and urban regions.
    - In situations with high humidity or falling precipitation
- Measurement of fluctuating pressure and correlations between pressure and other variables.

- Measurement of temperature, passive scalars, momentum, and pressure at scales sufficiently small that turbulence at scales smaller than typical for large eddy simulations can be studied.
- Accurate characterization of the surface energy budget, including over snow.

Surface Measurements

What goes on at the air-surface interface is critical for weather and climate research, as well as understanding biogeochemical cycles.

Over the ocean

Air-sea fluxes are complicated by the presence of waves, which are not uniquely related to the local environment. Predictions of air-sea fluxes of heat, momentum, and gases can be improved by including the effects of surface wave processes, surfactants, and bubbles. High-response instruments and mitigation of (or avoiding) salt-contamination effects are needed. Exchanges in foul as well as fair weather need to be explored.

- Ship platforms need to be maintained, and other types of platforms, such as buoys and oil-drilling platforms, should be explored.
- Deployable buoys could be useful in hurricanes or hurricane wakes.

Over land

<u>Soil and Vegetation Measurements</u>

Variability in soil conditions and vegetation create heterogeneity in areas that are otherwise uniform. Accounting for surface processes improves prediction of convective precipitation. The surface energy budget and trace-gas exchanges are affected not only by the moisture in soil, but by the amount and type of vegetation and the stage in its life cycle.

The number of soil-moisture measurements routinely taken is small (Figure 2). NSF/NCAR through the NSF Deployment Pool, provide some instrumentation for computation of heat flux into the soil. Other instrumentation is generally supplied by individual PIs. Likewise, surface-based measurements of soil properties such as NDVI, LAI, canopy height, and vegetation type are left to PIs.

Long-Term Observations

As atmospheric scientists have reached across disciplinary boundaries to study interactions between the atmosphere and the surface, the need for longer-term observations has grown. Typically, the length of an NSF-sponsored field deployment is a few months. This is entirely appropriate for studies that emphasize boundary-layer processes, cloud evolution, or the development of storms and tornadoes. However, studies of carbon uptake and nitrogen exchange, the water cycle, or aspects of climate change need to extend to a year or more (NRC 2007: Strategic Guidance for the National Science Foundation's Support of the Atmospheric Sciences).

Such deployments have happened in the past, but the likelihood of deployment is lower, since there are competing shorter-term projects. The SHEBA deployment lasted a year. The FIFE deployment was episodic, with three deployments over three years.

Recommendations

Support or join effort at improving existing networks

Well-distributed and long-term observations are needed for numerous applications. Using present networks is cost-effective if the measurements are good quality. Good-quality measurements can be fostered in a number of ways.

- Informal collaborative mesonets
- PI(s) requesting funding to help "beef up" an existing mesonet instead of purchasing a new one.
- EOL Scientists assistance for PI(s) who want to purchase or "beef up" an existing network, by helping with data system and purchase decisions, and training PI(s) and their colleagues.

Develop strategies to enable long-term observations

Many long-term research deployments already exist, and some are emerging. PIs should be made aware of the options and encouraged to use them. Among the present options are the DOE ARM facilities, LTERS, the Oklahoma Mesonet, and the Illinois State Water Survey Network. Others appear in the database. In the future, NEON should offer opportunities for long-term observations and collaboration. While EOL does not typically support long-term deployments, there are private companies that will deploy instruments under contract, provide quality control, and calculate derived products.

Exercising present networks led to improved quality even without financial incentives. If PIs write a little financial support for needed networks into their proposals, it would provide an additional means to improve the nation's current capability.

The Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) is looking at other strategies. USGS has agreed to work with CUAHSI to develop an equipment loan program on a pilot basis, to provide the CUAHSI community access to instruments stored at the USGS Hydrologic Instrument Facility in Mississippi. The two institutions would also cooperate in instrument development, procurement, and testing. Additionally, the CUAHSI Biogeoghemistry and Geophysics working groups are working to identify instruments needed to enhance the current suite of hydro-meteorological instruments. Finally, a CUAHSI Hydrological Observatory, if developed, would provide a home for long-term observations.

Use models and remote sensing to "fill in" data where possible

Currently, initial soil moisture fields for NWP or research-model integrations are developed using land-data assimilation systems that use historical in-situ, precipitation, and satellite-derived radiation data. These models are not perfect, so continued development is needed, and with it, robust soil measurements, particularly in geographical areas and in situations when the land-data assimilations do not work well. Models in this mode, more traditional OSE and OSSE modes, etc., can be used to identify where observations are needed both for model improvement and operations.

Similarly, analysis of satellite data could be used to identify and fill important holes in the network.

Involve community in identifying important undersampled geographic regions

When a geographic area or important region is not represented, a critical mass of the community should be involved in selecting the highest-priority site on the basis of scientific relevance.

Encourage NCAR/Private Sector/University Partnerships in developing needed technologies

This recommendation, similar to one made in NRC (NRC 2007: Strategic Guiodance for the National Science Foundation's Support of the the Atmospheric Sciences.), would stimulate technology development in needed areas.

4.1.4 Surface-Based Remote Sensing

Excellent discussions were held at the Facilities Assessment Workshop regarding needs for new observing technologies in the area of surface-based remote sensing. There was a strong sentiment from the group that we lack the means to provide economical and efficient dual-Doppler scanning at a wavelength that is not to subject to attenuation, perhaps C-band (given all the tradeoffs involved). The retired NCAR CP3-CP-4 platforms were mentioned in this vein.

A clear need was identified for rapid scan, high resolution, compact, mobile radars to study small scale circulations, including the fine scale nature of tornadoes. This radar would be W-band, or perhaps have dual-wavelength capabilities, such as W and Ka band combined. It was also recommended that an investigation be done regarding the military's use of portable S-band radar systems to determine possible applications to meteorology.

There is a strong need to develop remote sensing techniques to sample aerosols, particularly biogenic aerosols, atmospheric carbon dioxide and thermodynamic properties. A lidar for detecting CO2 was also identified as a clear need. In an expanded sense, there is a clear need to develop in-situ and remote sensors to detect and quantify trace gases, including application in urban meteorology and homeland defense applications. These devices may include small instrument packages that may go on radiosondes and dropsondes. New instruments to map boundary layer fluxes are needed as well.

There was considerable discussion about expanding lidar technologies, including a mobile lidar for measuring water vapor. There was also a strong recommendation that surface based meteorological radars be merged with lidars (in one platform) to provide simultaneous radar-lidar measurements. A heterodyne Doppler lidar for wind, thermodynamic and the measurement of water vapor profiles was also identified as a need. Parallel with this need is the emphasis on 3-D radiometric measurements of water vapor.

Multi-frequency, mobile profilers (say a combination of S-band and 915 MHz) are lacking in our instrumentation arsenal.

Future developments, in addition to calibration and cost reduction, may focus on the application of a network of radiometers for tomography, especially for profiling of cloud liquid water and water vapor.

All new instruments need to be supported with resources to provide calibration references/techniques, and quality control procedures. It makes no sense to pay for a new instrument and then not provide adequate support. The group also discussed the NSF Deployment Pool and the need for a mechanism to regularly determine the optimal mix of instruments that should be part of the Deployment Pool.

4.1.5 Solar Measurements

The subcommittee identifies four key unmet needs in the current instrumentation database. The general science and technique goals are the following:

1) Long-term synoptic (~11 years) observations of photospheric and chromospheric magnetic fields. This should be done ideally with high spatial resolution (sub-arcsecond) either from the ground or space, with accurate spectro-polarimetry (~10^-3) to derive vector magnetic fields. Instrumentation and calibration procedures should be stable enough to allow for consistent measurements during a time period of the order of the solar cycle. The SOLIS project is a first step in this direction but with only one station its capabilities are very limited and the data are gappy. This subcommittee believes that an expansion of the project to build a network of SOLIS stations would lead to major scientific breakthroughs, particularly in the fields of dynamo theory and global magnetic coupling between the photosphere and chromosphere.

2) Quantitative measurements of coronal magnetic fields. This should be done via infrared (between 1 and 4 microns) Zeeman spectro-polarimetry complemented with observations of Hanle-effect sensitive lines. Better radio frequency observations would also be helpful for coronal diagnostics. These measurements should be carried out with a spatial resolution comparable to TRACE images, up to 1.5 solar radii from the limb. A dedicated telescope with coronagraphic capabilities will be required to address this issue and it should be operational for a period of time spanning ~20 years.

3) Advances in high-order adaptive optics now permit ground-based observations at the diffraction limit for large-aperture telescopes (~4 meters) in the visible and near-infrared. Such high-resolution observations will allow for the first time direct comparisons with new realistic MHD numerical simulations of dynamic interactions between convecting plasma and magnetic fields. Since smaller structures evolve on faster time scales, the time cadence of these observations should be higher than present day observations, typically of the order of a few seconds.

4) Flexible, experiment-oriented, general-purpose ground-based spectro-polarimetry. Most of the current solar instrumentation is highly specialized with the goal of optimizing spatial resolution, polarimetric sensitivity, etc. However, groundbreaking discoveries often arise from new ideas that require a test bench where to perform experiments with innovative optical set-ups. Such an instrument should be flexible enough to accommodate a wide range of configurations, allowing for different compromises between spatial/spectral resolution, signal-to-noise ratio, time cadence, combinations of spectral domains, etc. It is important to bear in mind that this observing mode is a testing platform for new ideas and as such poses a higher risk of failure than traditional well-established set-ups.

Recommendations

<u>The need for long-term solar observations</u>

The sun changes on time scales from microseconds to millions of years. In particular, the sun undergoes a cycle of activity that typically spans 11 years. During the solar activity cycle, the number of sunspots increases and decreases as does the number and strength of the flares and coronal mass ejections (CMEs) that disrupt technology vital for daily life on earth. Figure 1 shows a plot of the number of sunspots over the last 125 years, and demonstrates the considerable variability in the number and size of the sunspots in a given cycle. In order to understand this variability and, ultimately, predict the activity that affects society, it is essential that the sun be monitored on a continual and long-term basis that spans many activity cycles.

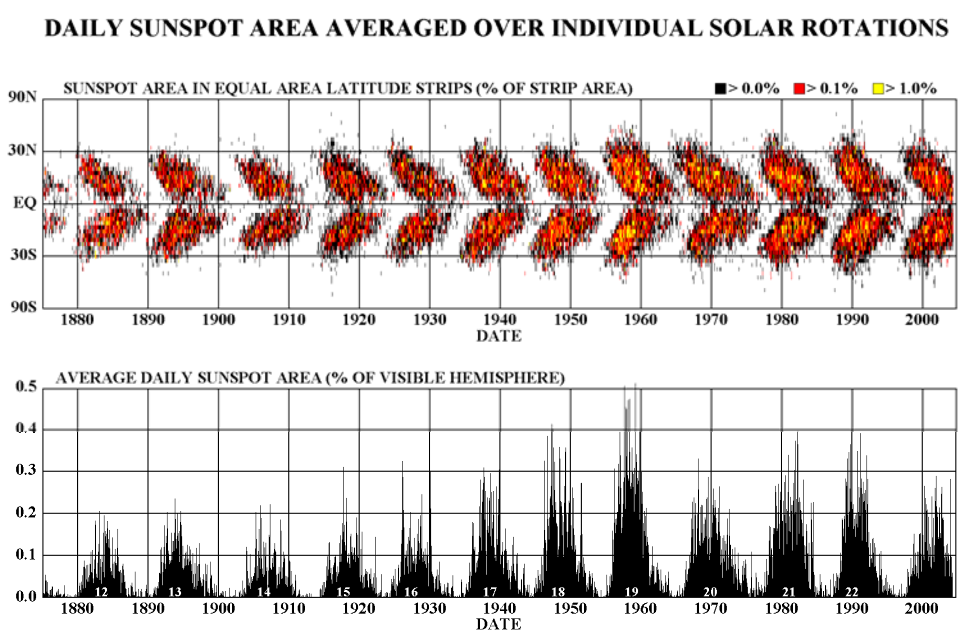


Figure 4: The number of sunspots as a function of time (bottom panel), and latitude and time (upper panel).

There are a number of programs that provide long-term solar coverage, known as synoptic observations in the solar community. Several programs provide full-disk measurements of the line-of-sight solar magnetic field in the photosphere; these observations now span 35 years and cover three solar cycles. Modern developments in technology, particularly space missions, have provided synoptic observations of intensity at various heights in the solar chromosphere, as well as images of the distribution and dynamics of the material in the solar corona. These data sets now cover 12 years, a single cycle of solar activity. Judging from the record of sunspot numbers shown in Figure 1, observations covering at least ten solar cycles are required to sample the recent range of solar activity. In addition, the sun underwent an extended period of about 40 years in the early 17th century during which essentially no sunspots were present (the so-called Maunder Minimum), suggesting that even longer observations are needed.

The activity on the solar surface must originate from processes below the photosphere, a region inaccessible to remote sensing with electromagnetic radiation. Fortunately, the sun is filled with sound waves that can be used to infer the properties of the solar interior. This field, known as helioseismology, has provided information about the motions of the plasma inside the sun that has the potential to predict solar flares, and can also be used to detect large sunspots on the far side of the sun before they rotate onto the earthward side. Modern continual helioseismic observations have been obtained only since 1995 and cover just one cycle at this point.

Thus, solar physics demands synoptic observations to fully understand the processes underlying the activity that increasingly affects our society as technology advances. Reliable support for synoptic observations from funding agencies such as the NSF is typically difficult to obtain because of the long-term commitment of funds it represents and because of the continual pressure for new and increasingly expensive facilities. However, the value of synoptic programs in solar physics for society cannot be overstated and it is thus vital that existing synoptic programs continue.

We thus recommend that, specifically:

- The Global Oscillation Network Group (GONG) program, the only ground-based helioseismology program that can be used for space weather prediction, should continue.
- The SOLIS program, a vector magnetic field instrument, should continue and be expanded into a network to provide continual full-disk vector magnetic field maps.
- A space-based coronagraph should be developed and launched as soon as possible to replace the LASCO instrument aboard SOHO. This new coronagraph should be designed for a lifetime of at least 20 years.

The need for continuous full-disk vector magnetic field measurements

The solar magnetic field is a vector quantity, but most magnetic field observations are sensitive only to the component along the line of sight between the observer and a point on the sun. These longitudinal magnetic field measurements are valuable, but there is much more information contained in the full vector field. In addition, models of the magnetic field in the corona are substantially more realistic when extrapolated from a vector boundary condition.

Currently, vector magnetic field data are episodically obtained only in active regions where the field is strong and the topology is complex. There are few full-disk observations (see Fig. 2 for an example), and they are neither continual nor long-term.

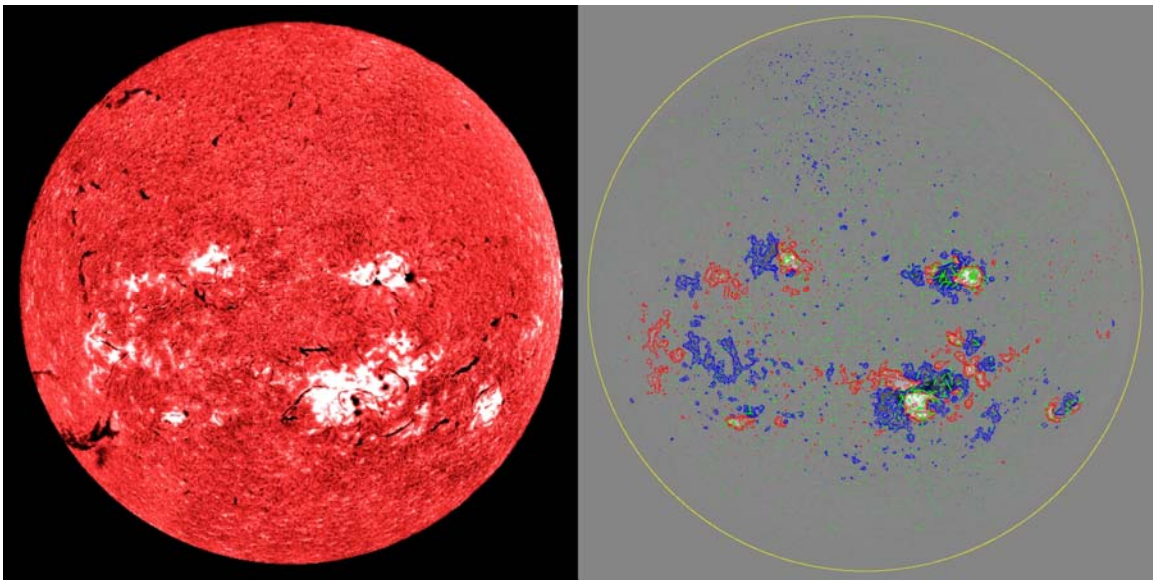


Figure 5: Left: Hα solar image. Right: vector magnetic field image. Data from the SMART project, Kyoto, Japan.

Continual vector magnetograms are required to track the temporal variation of the filed topology before, during, and after flares. Long-term observations will allow us to investigate how the direction of the field changes over the solar cycle, which could provide more clues about the nature of the dynamo mechanism underlying the activity cycle. In addition, the extrapolations of the surface field into the corona will be greatly improved by long-term continual full-disk magnetic field measurements. These extrapolated fields are used to predict the interplanetary magnetic field at the earth, where they interact with the terrestrial field and cause geomagnetic storms. The extrapolated field models would also benefit from vector measurements in the chromosphere, where the filed is approximately force–free.

We thus recommend that, specifically

- The SOLIS instrument at NSO should be used as the basis of a distributed network of vector magnetographs. This network should be deployed as soon as possible, and operated for at least two solar cycles.
- Instruments to obtain full-disc vector magnetic fields in the chromosphere should be developed, and operated in a long-term synoptic mode.

Measuring coronal magnetic fields

We believe that the dynamic structure of the solar corona, illustrated in the EUV TRACE image here, is fundamentally controlled by magnetic fields. This has been our "dark energy" problem as these fields have, until recently, not been readily measurable. Proof of a predictive understanding of how energy is released in the corona and how coronal mass is ejected and accelerated into the heliospheric environment depends on knowing these fields. It is clear that longstanding solar coronal problems will be advanced if we can obtain routine coronal magnetometry. We see several approaches to providing these data and are aware of three programs that have complementary strengths and which, overall, will satisfy this need

- The highest spatial resolution and greatest magnetic sensitivity will be obtained with the Advanced Technology Solar Telescope (ATST) in its coronagraph operation mode. This was our first priority for delivering occasional high resolution and magnetically sensitive coronal field measurements.
- Above active regions and in the low corona, microwave gyrosynchrotron observations can yield magnetic field and plasma diagnostics. We believe the Frequency Agile Solar Radiotelescope (FASR) may provide magnetic plasma diagnostics in active regions with greater temporal and potentially higher spatial resolution than optical/IR Zeeman techniques.
- At low spatial resolution the large-scale magnetic field is needed synoptically to understand the dynamics of the solar corona. A moderate aperature dedicated telescope, operating in the near IR with the FeXIII emission line should provide these data. One possible instrumental solution for this is the proposed COSMO facility.

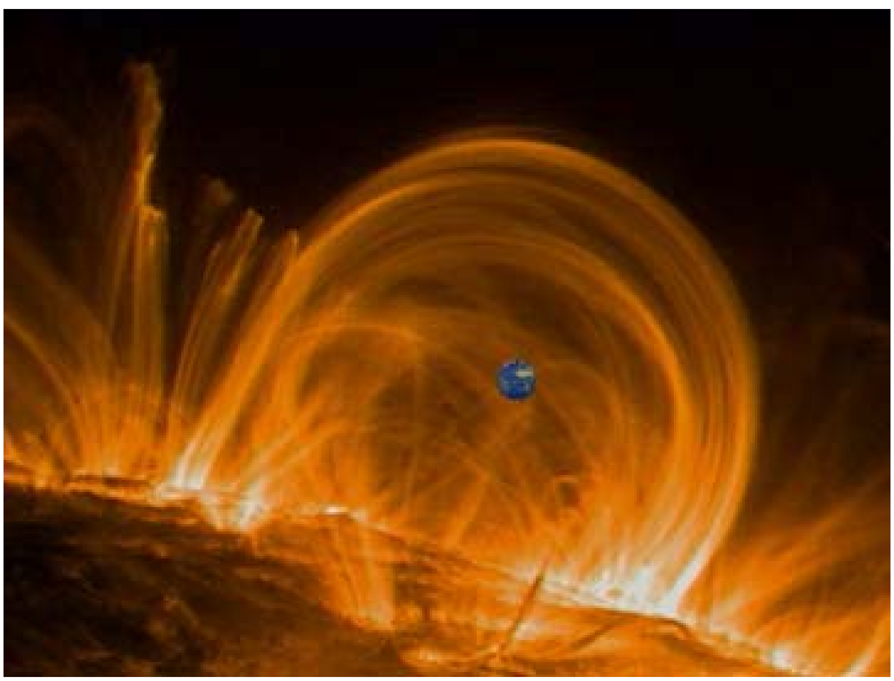


Figure 6: EUV TRACE image illustrating the dynamic structure of the solar corona.

4. Fundamental Physical Scale Photospheric Magnetometry

The dynamics of magnetic fields in the photosphere on length scales that sample the fundamental physics depend on adaptive optics technology, and will also benefit from infrared technology. The image below of a sunspot is a consequence of the complicated interaction of small scale magnetic fields with convection in the cool neutral layers of the photosphere. We require magnetometry at a spatial resolution that samples the important structure revealed in this adaptive optic sunspot image (courtesy T. Rimmele). The committee believes these data will be generated by the Advanced Technology Solar telescope and endorses the need to rapidly deploy this instrument.

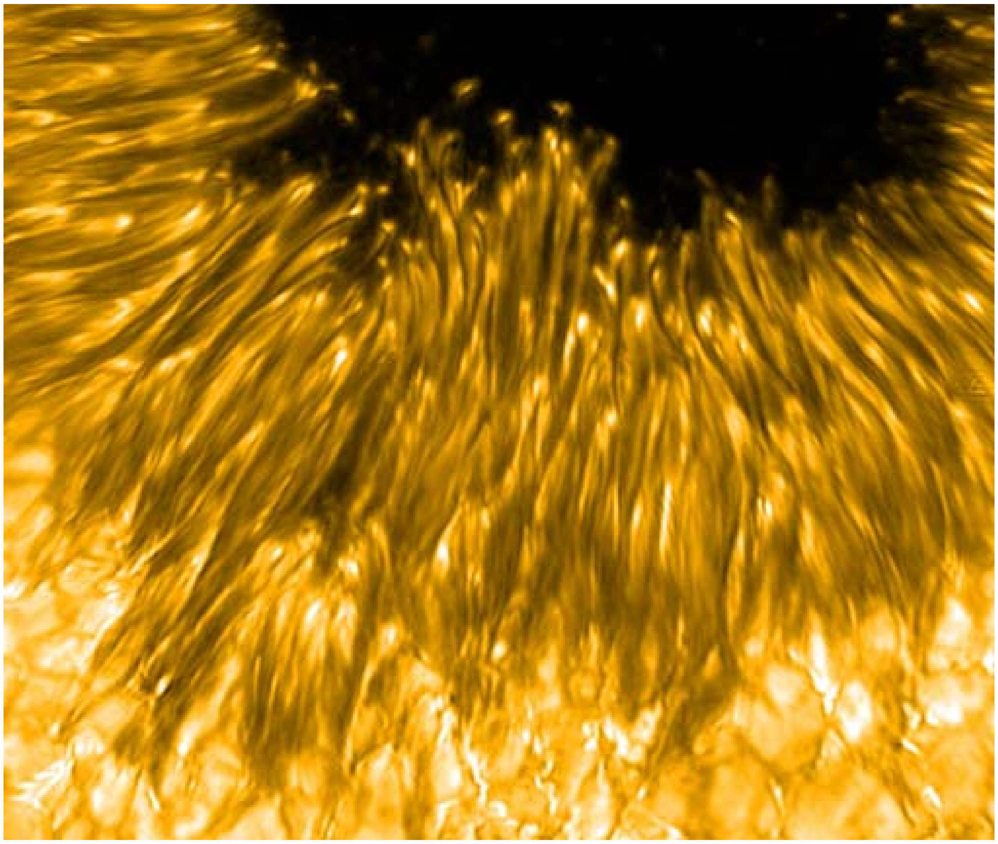


Figure 7: Adaptive optic sunspot image (courtesy T. Rimmele).

4.1.6 Satellite Data

As stated by the National Research Council's "National Imperatives for the Next Decade and Beyond (2007)" (http://www.nap.edu/catalog.php?record_id=11820)

> "Earth observations from satellites and in situ collection sites are critical for an ever-increasing number of applications related to the health and well-being of society. The committee found that fundamental improvements are needed in existing observation and information systems because they only loosely connect three key elements: (1) the raw observations that produce information; (2) the analyses, forecasts, and models that provide timely and coherent syntheses of

> otherwise disparate information; and (3) the decision processes that use those analyses and forecasts to produce actions with direct societal benefits."

Further the NRC committee recommended that

> "The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth science and applications."

This committee made many other specific recommendations, all recommending new satellite missions in Earth Science. While a change in national funding strategy is needed to bring these new missions to fruition, our efforts are concerned with the location and use of existing satellite data. The Satellite Data Subcommittee unequivocally endorses the NRC's recommendation.

While this has been an NSF sponsored activity we believe that NASA and possibly other foreign space agencies should be interested in this database. They may be willing to provide additional guidance and perhaps possible future funding to the project. We think that the project should do all it can to publicize the activity and spread the word to people who should be interested in this collection of information. We believe that this is a unique collection of useful information of which many other agencies could and should take advantage.

4.1.7 Emerging Technology

At the time of the September 2007 Facilities Assessment Workshop, approximately 25 entries in the emerging-technology section of the database were received, reviewed and accepted. Several issues became apparent in the course of discussions with the other subcommittees and their respective database entries; these are described below.

Although there appears to be broad support for the use of TRLs in conjunction with emerging technologies, there is **uneven self-reporting of the TRLs** by the various resource contributors. For example, one contributor might report a technology at the TRL-4 stage while another contributor might describe the same technology as TRL-6. The ET Subcommittee did not attempt to resolve this issue, but believes that the relative positioning on the TRL scale is a useful indicator, and that the database user should anticipate some variance in how the TRL levels have been assigned by the resource contributors. It should also be noted that the uncertainty in the TRL assignments is expected to decrease as the TRLs become larger, and there should be little uncertainty once the CAL levels have been reached.

The ET Subcommittee underestimated the **difficulties associated with actually getting resource entries** from many of the busy emerging technologists. Personal contacts (email and telephone) were made to approximately two dozen technologists who had developed instrumentation known to be a promising emerging technology, yet most of these contacts did not yield resource entries. Several steps were identified by the ETS to encourage the submission of entries to the database for these important developing technologies, including:

- More use of students to fill out the resource questionnaire through live telephone conversations with the developers, and
- Engaging students (particularly those in the atmospheric or engineering sciences) to take intellectual ownership of the challenge. It was felt that students who appreciated the value of the technology would be more motivated to successfully contact the developers and obtain their inputs.

For some technologies, technology developers may be **reluctant to disclose their technology** too soon so as not to jeopardize their intellectual property rights or their chances to be first to publish. Commercial companies and perhaps others are also reluctant to disclose based on competitive advantage concerns.

Cross-referencing emerging technologies with entries in the other technology categories in the database is a concern. A cursory review of the database contents indicates that emerging technology entries have in many cases been submitted to other technology areas. The objective will be to include those entries in the ET area, while retaining the entry in the area where it was originally submitted.

A number of recommendations have been identified by the subcommittee. The subcommittee strongly recommended a policy that the **TRL/CAL metric** employed in generating the Emerging Technology database be adopted by all seven subcommittees. We appreciate the challenge and workload this may present to the other subcommittees, but believe that many of the entries represented in many of the other databases may also have a component that could place a particular technology in the Emerging category as well. A way to simplify the process for the non-ET subcommittees might be for them to use a coarser-grained TRL classification: for example, TRL determinations falling within the 1-3, 4-6, 6-8, and 9+CAL categories could be established by each of the subcommittees. Using this approach, a mechanism needs to be established to cross-link technologies that have TRL/CAL levels below the TRL9/CAL3 level, so that they could also be included in the Emerging Technology database. Given the resources, the ETS recommends that a student assistant take on this task, as well as the task of cutting and pasting the technology descriptions into the Emerging Technology format. The subcommittees or the submitter of the entry would also be given the option of completing the Emerging Technology form if they chose to do so. The TRL/CAL status indicators, of course, would need to be updated from time to time, and there would need to be a mechanism established for doing this. One suggestion was that an **electronic "tickler"** letter could be emailed to each of the developers, perhaps on a yearly basis.

4.2 Database Maintenance and Evolution

4.2.1 In-Situ Surface and Surface-Atmosphere Exchange

Modifications to the Web Site

The ISSSAE Sub-Committee's interim report (Appendix D) recommended reorganizing the web site since aligning categories along the sub-committee structure has made it difficult for some people to figure out the appropriate category for data entry. For example, many atmospheric-chemistry instruments are used both on aircraft and at the surface. We recommended one questionnaire, so that the entry could be cross-referenced where appropriate. The categories would be "platforms" and "instruments" for "land", "sea", and "air", and remote sensing as a subcategory of instruments, with the Calibration/Validation Facility still a separate category. Nomenclature and acronyms would be defined and consistent. Details are in Appendix D.

Other recommendations are to:

- Add mapping capability
- Continue to improve search engine
  - List of acronyms and synonyms (e.g., ARM and Atmospheric Radiation Measurements will both get you to the right place)
  - Enable the search to also identify the relevant web sites
- Under all appropriate categories, have question about whether a PI can bring instrument to plug in (this should be added to "Measurements/Networks"
- Under all appropriate categories, invite statement on educational-outreach activities/opportunities.

If the major overhaul doesn't occur, then there are some alternative recommendations to help solve some of the problems we encountered, namely:

- Put statement on home page providing guidance to the user on how to select a category.
- Implement cross-referencing. So that "airborne" chemistry instrument that is used on land populates the land instrument category.
  - Add question to airborne questionnaire: Is this instrument used at the surface over land? Ocean?
  - Add question to surface instrument questionnaire: "Is this instrument used on aircraft?"
- Add new category "observatories" or "land-based platforms" (An example of a land-based platform is Elk Mountain).

Complete the assessment of trace-gas and aerosol measurements at the universities, government agencies, national laboratories, and the private sector

Characterizing needs in atmospheric chemistry and aerosols is currently not possible except in a generic sense since there are so many trace gases and techniques and investigators out there. Working from lists of people engaged in atmospheric-chemistry field programs like MILAGRO will locate scientists who know the benefits of collaborations, as well as working through NSF program officers and using earlier approaches.

Shift composition of Editorial Review Board in proportion to needed information and input

Our job is not over. While some subcommittees have only a small number of entries left, for others the job of populating parts of the database is far from done. Thus we recommend shifting the composition of the Editorial Review Board to reflect where the work is needed most. For ISSSAE, the need is particularly great in atmospheric chemistry and marine meteorology.

Hire staff that matches the job

As noted in the foregoing, response to surveys now requires personal contact and follow-through, rather than broadcast emails. Many have mentioned students with the relevant knowledge. A more senior supervisor with similar knowledge would help.

An additional job for this person would be to mine web sites for data on networks, as noted in our interim report.

Identified Omissions

There are several known deficiencies on the ISSSAE part of the database. Ocean coverage is incomplete, although there are five buoy networks listed under Measurements/Networks and one ship (Explorer of the Sea). Likewise, the Instruments category is significantly underpopulated. Of the 13 listed, most are for chemical measurements.

4.2.2 Surface-Based Remote Sensing

Efficient ways for users to identify instruments in the database need to be developed. Key words are available now but there was interest in having an interactive map, that when the user clicked on the map, it will show all instruments in a specific category (input by the user) within a specified radius. This is particularly relevant for ground surface based platforms, within and not within network configurations. The future of the data maintenance and evolution depends on by whom and for what the database is going to be used. It would be very useful to track users' applications of the database.

4.2.3 Satellite Data

We view this database as information on satellite instruments and the data they collect to be used as a guide to the resultant satellite data and data products. Users of this database won't find the detailed comments about instrument characteristics that they would on the individual web pages but they can get a pretty good idea of what is available in terms of overall satellite data that has been collected over the past three decades.

4.2.4 Emerging Technology

Identified Omissions

After reviewing the database entries at the Facilities Assessment Workshop, the subcommittee members and meeting attendees discussed possible gaps in the areas covered. Several such gaps in known, specific technologies – as opposed to "unmet measurement needs" or general categories of technology – were identified. These are listed below, with some annotation:

- UAS-deployed platforms & instruments [ETS defers to the Airborne Platforms Subcommittee, which has relevant expertise; they may wish to use the Emerging Technology database entry form to submit their UAS information.]
- Polarimetric radar hydrometeor classification algorithms [These algorithms likely fall at a Community Acceptance Level that is at the fringes of what is considered to be "emerging" (CAL 2+).]
- Small very low cost satellite networks (for example, "CubeSat")
- Total carbon (C_y) detector
- High peak power mid-IR laser sources [This was identified more as a technology needed to facilitate desirable measurements and is not, to the best of the committee's knowledge, an emerging technology.]
- Cross-link radio occultation measurements
- High sensitivity ceilometers as boundary layer profilers
- "CAPSonde" – commercial aircraft-deployed dropsondes
- Emerging disdrometers (impact & optical)
- Intelligent vehicle sensor systems
- SensorNet, UrbaNet, NYCityNet
- NEON (National Ecological Observatory Network)
- Scintillometers
- Holographic ice particle imaging system
- Multi-function phased array radar (MPAR)
- High power fiber-optic laser-based lidars
- Miniaturization concepts (e.g., for further development of trace gas sensors)
- Expendable electric field mill (e.g. radiosonde application)
- Soil moisture sensors

In addition to creating the list of gaps in the database entries, the subcommittee identified likely principal investigators or resource people for each of the gap technologies. Each of these people will be contacted by a member of the subcommittee and will be encouraged to submit an entry to the Emerging Technology database.

At the 28 September 2007 meeting of the Facilities Assessment Steering Committee, it was agreed that the gap list would be added to the published database; names of the developers and their institutions would not be published. Adding the gap list to the database would provide two benefits: (1) to alert the community to these developments, and (2) to encourage the developers to submit resource entries.

4.3 Principal Recommendations

At its final meeting, the Steering Committee agreed on three principal recommendations:

1. The database must be maintained on a continuing basis to add new and important facilities and to update existing entries, so that the information contained in it will be current and of maximum value to the community as a reliable reference source.

2. An Editorial Board will be named with NSF advice to meet once per year to examine the database for accuracy and completeness, and to resolve any data entry/data accuracy or other issues that may come up during the year. The Board will be comprised of participants from the initial committees who will serve on staggered terms to ensure continuity of experience and germane points-of-view in the maintenance and furtherance of the database. This Board will have 16 members and will be managed by EOL. The Board will conduct a major review of the database every five years and will update the information as appropriate.

3. The Editorial Board will update the Facilities Assessment Report as needed – possibly as often as once per year.

Appendix A – Subcommittee Structure

NCAR formed a Steering Committee that assessed the status of national and some international atmospheric science facilities and provided broad oversight to the facilities assessment study. The Steering Committee, with NSF advice, selected subcommittee membership from the community at large, and supervised their activities including the development of a project plan outlining schedule, deliverables, and regular reporting to NSF. The structure and membership are shown below.

Chair, Steering Committee
Robert Serafin - NCAR

Principal Investigator
Karyn Sawyer – NCAR/EOL

NSF Contacts
Jim Huning, Facilities Coordinator – UCAR and Lower Atmospheric Facilities Oversight Section (GEO/ATM), National Science Foundation
Cliff Jacobs, Head – UCAR and Lower Atmospheric Facilities Oversight Section (GEO/ATM), National Science Foundation

Airborne Platforms Subcommittee
Bruce Albrecht (co-chair) – University of Miami - Rosenstiel School of Marine and Atmospheric Science (RSMAS)
Jeff Stith (co-chair) – NCAR/EOL
Al Rodi – University of Wyoming
Dave Jorgensen – NOAA
Cheryl Yuhas – NASA
Mike Poellot – University of North Dakota
Will Bolton – Sandia National Laboratory

Airborne Measurements Subcommittee
Edward Browell (co-chair) – NASA Langley Research Center, Science Directorate
Al Cooper (co-chair) – NCAR/EOL
Bill Brune – Pennsylvania State University
Tony Clarke – University of Hawaii at Manoa
Al Gasiewski – University of Colorado at Boulder
David Fahey – NOAA
Kenneth Jucks – Harvard-Smithsonian Center for Astrophysics
Haflidi Jonsson – Naval Postgraduate School

In-situ Surface and Surface-Atmosphere Exchange
Peggy LeMone (co-chair) – NCAR/ESSL/MMM
Mary Anne Carroll (co-chair) – University of Michigan, Dept. of Atmospheric, Oceanic, and Space Sciences; Dept. of Chemistry; Program for Research on Oxidants: PHotochemistry, Emissions, and Transport (PROPHET)
Jay Famiglietti – University of California at Irvine
Dennis Baldocchi – University of California at Berkeley
John Ogren – NOAA
Chuck Long – Pacific Northwest National Laboratory (PNNL)
Scot Loehrer – NCAR/EOL
Bob Weller – Woods Hole Oceanographic Institute

Surface-Based Remote Sensing Subcommittee
Steve Rutledge (co-chair) – Colorado State University, Dept. of Atmospheric Science
Junhong Wang (co-chair) – NCAR/EOL
Qian Wu – NCAR/ESSL/HAO
Ed Eloranta – University of Wisconsin at Madison
Ed Westwater – University of Colorado at Boulder
Rit Carbone – NCAR/ESSL/TiiMES
Chris Williams – University of Colorado
Matthew Shupe – NOAA
Tom Ackerman – University of Washington

Solar Measurements Subcommittee
Hector Socas-Navarro (co-chair) – NCAR/ESSL/HAO
Jeff Kuhn (co-chair) – University of Hawaii at Manoa, Institute for Astronomy
K.S. Balasubramaniam – National Solar Observatory Sacramento Peak
Doug Biesecker – NOAA
Frank Hill – NSO Tucson
Therese Kucera – NASA
Dave Turner – University of Wisconsin at Madison
Bill Livingston – NSO Tucson

Satellite Data Subcommittee
Bill Emery (co-chair) – University of Colorado, Dept. of Aerospace Engineering Sciences
Phil Arkin (co-chair) – University of Maryland, Earth System Science Interdisciplinary Center (ESSIC)
Bob Evans – RSMAS/MPO
North Larsen – Lockheed Martin
Bruce Barkstrom – NOAA NCDC
Melba Crawford – Purdue University
Diane Evans – Jet Propulsion Laboratory

Emerging Technology Subcommittee
David McLaughlin (co-chair) – University of Massachusetts at Amherst
Walt Dabberdt (co-chair) – Vaisala Corporation
Mike Hardesty – NOAA
Chet Gardner – University of Illinois at Urbana-Champaign
Thomas Yunck – Jet Propulsion Laboratory
Greg McFarquhar – University of Illinois at Urbana-Champaign
Linnea Avallone – University of Colorado at Boulder
Alan Fried – NCAR/EOL (ex-officio member)

Data Support Subcommittee
Steve Williams (co-chair) – NCAR/EOL
Mark Bradford (co-chair) – NCAR/EOL
Steve Worley – NCAR/CISL/SCD
Ethan Davis – UCAR/UNIDATA

Appendix B – August 2005 Planning Meeting Agenda and Participants

Agenda – August 2, 2005 Planning Meeting

1. Introductions and purpose of the Meeting and Review the Agenda (15 Minutes)
2. Remarks from Cliff Jacobs on NSF's perspectives (20 minutes)
3. Examine the draft charge from NSF and suggest changes (45 Minutes)

(Break)

4. Discuss the topical partitioning (~ 90 Minutes)

- Airborne Platforms: piloted a/c, UASs, balloons
- Remote Sensing: radar, lidar, wind profiling, passive remote sensing of meteorological, and oceanic and chemical parameters
- Non-Mobile Networks (both urban and rural): ARM, OK Mesonet, California air quality monitoring
- In Situ measurements: chemical, meteorological, air-sea
- Mobile Networks
- Solar Observations
- Non-standard Instrumentation (w/attendant PI or operator)
- Satellite Remote Sensing

(Lunch)

5. Nominate potential chairs of the subcommittees for topics (i.e., the Oversight Committee) (~ 60 minutes)
6. Determine what the database should include (30 Minutes)
5. The Next Steps (30 Minutes)

Adjourn

Attendee List – August 2, 2005 Planning Meeting

Karyn Sawyer
Bob Serafin
Jeff Stith
Jorgen Jensen
Al Cooper
Al Fried
Steve Williams
Roger Wakimoto
Mike Coffey
Bob Harriss
Brian Ridley
Tom Horst
Peggy LeMone
Jim Wilson
Scott Spuler
Rit Carbone
Greg Holland
Sara Metz

Appendix C – Workshop Agendas

NSF Facilities Users' Workshop – Agenda

<u>Sunday, 23 September 2007</u>
(Rocky Mountain Municipal Airport, Foothills Lab, Marshall Field Site)

1300 - 1700 Open House / Facilities Demonstrations (Directions)

1300 - 1600 - Tour of NSF/NCAR GV, NSF/NCAR C130, UWY King Air
1430 - 1630 - Tour of SPOL at Marshall Site
1500 - 1700 - Tour of REAL, ISS, TRAM, GAUS at Parking Lot, Foothills Lab I
1500 - 1700 - Tour of Design and Fabrication Workshop at Foothills Lab 1, ground floor

<u>Monday, 24 September 2007</u>
(UCAR, Center Green I)

Session I: Informational Session (especially for students and new users)

0730 Start of Registration and Continental Breakfast

0800- 0830 Facility Request Process - How does it work?
James Huning/Brigitte Baeuerle

0830-0930 Field Project Planning, Operations and Data Services
Jim Moore/Mike Daniels

0930-0945 Break

0945-1045 RICO - From Dinner Napkin to Publication
Robert Rauber

1045–1145 NSF Facilities, Capabilities and Plans (EOL, U. of WY, CSU)
Roger Wakimoto, Al Rodi, Steven Rutledge

1145–1215 Airborne Instrumentation Certification: Process and User Responsibilities
William Cooper, Al Rodi

1215–1315 Lunch Break
(incl. opportunities for additional questions reg. Session I)

Session II: Setting the Stage

The keynote speakers were asked to provide their personal opinion on what science questions should command resources and how will answers to these questions make a difference?

1315–1325 Workshop Opening and Goal Setting
Roger Wakimoto

1325–1335 Welcome by NSF Representative & NSF Expectation of Workshop Outcome
Cliff Jacobs

1335-1340 Welcome by NCAR Director
Tim Killeen

1340–1425 Scientific and Societal Challenges for the next 20 years
Alexander MacDonald

1425–1510 Mesoscale Observing Challenges - One Perspective with Emphasis on the Urban Zone
Walt Dabberdt

1510–1525 Break

1525-1610 Opportunities and Challenges in Atmospheric Composition Research
William Brune

1610–1655 Science, Data, You and the Future: A Variation on the "Three Little Pigs". Which little Pig will you be?
Raymond McCord

1655–1715 Facilities Assessment Panel Activities
Robert Serafin

1715–2000 GV Movie followed by Reception
Vanda Grubisic

<u>Tuesday, 25 September 2007</u>
(UCAR, Center Green I)

Session III: SCIENCE

Each breakout session will be asked to identify observational needs, gaps and prioritize needs. Questions to be addressed include:
What are the outstanding science questions and key hypotheses in this area?

What facilities are needed to address them?
What kind of observations would make a difference?
Can we make these observations right now? If not, what is needed?

0730 Ongoing registration and Continental Breakfast

0800–1100 Breakout Sessions A1 through A6 with Break at 9:15 am

- Group A1: Aerosol and Cloud Chemistry
  Chairs: Dave Rogers, Chris Cantrell

- Group A2: Mesoscale Dynamics with Focus on High Impact Weather
  Chairs: Chris Davis, Josh Wurman

- Group A3: Boundary Layer and Turbulence (incl. surface/atmosphere interactions)
  Chairs: Tom Horst, Jielun Sun

- Group A4: Water Cycle
  Chairs: David Kingsmill, Steven Rutledge

- Group A5: Air Pollution (urban, biomass burning)
  Chairs: Frank Flocke, Linnea Avallone

- Group A6: Upper Troposphere/Lower Stratosphere
  Chairs: Laura Pan, Mark Zondlo

1100-1115 Break to change room set-up

1115–1215 Plenary - Short (10 min) presentations from each breakout session A
Chair: Linda Miller

1215– 1315 Lunch Break

1315– 1615 Breakout Sessions B1 through B5 with Break at 2:30 pm

- Group B1: Fundamental Questions in Cloud Physics
  Chairs: Robert Rauber, Jorgen Jensen

- Group B2: Carbon and Nitrogen Cycle incl. Biological Impacts on the Atmosphere
  Chairs: Elizabeth Holland, Barry Huebert

- Group B3: Large-scale and Long-term Characterization (satellite validation incl. radiative transfer and budgets)
  Chairs: John Braun, tbd

- Group B4: Weather Prediction and Usefulness for Forecasting
  Chairs: David Parsons, Howie Bluestein

1605-1620 Break to change room set-up

1620–1700 Plenary - Short (10 min) presentations from each breakout session B

1700–1715 Impressions of First Day and Expectations for Session IV
Cliff Jacobs

<u>Wednesday, 26 September 2007</u>
(UCAR, Center Green 1)

Session IV: FACILITIES PERSPECTIVE

0730 Continental Breakfast

0800–1000 Breakout Sessions C1 through C3
Questions to be addressed:
How well do existing facilities and instruments match scientific needs identified?
What new facilities/instruments/capabilities are needed?
What role should NSF play in creating these new facilities?

- Group C1: NSF Airborne Facilities
  Al Rodi, Jeff Stith

- Group C2: Ground-based and Airborne Radars & Lidars
  V. Chandrasakar, Jothiram Vivekenandan

- Group C3: Ground-based Remote and In-Situ Observations
  Steve Cohn, Allen White

1000-1030 Break

1030 - 1200 Breakout Sessions D1 through D4

- Group D1: Emerging Technologies and New Developments (continues through Lunch Break)
  Walt Dabberdt, Alan Fried

- Group D2: Educational Opportunities related to Facilities & Field Campaigns
  Bart Geerts, Pat Kennedy

- Group D3: Satellite Communications (continues through Lunch Break)
  Chris Webster

- Group D4: Interagency Collaborations
  Robbie Hood, James Huning

1200 -1300 Lunch Break

1300–1410 Plenary- Short (10 min) presentations from each breakout session C and D
Chair: Linda Miller

1410–1430 Break

1430-1600 Breakout Sessions E1 through E5

- Group E1: Data Quality Control and Quality Assurance
  Junhong Wang, Scott Loehrer

- Group E2: Real-time Data Acquisition and Display
  Charlie Martin

- Group E3: Data Cataloging, Browsing and Distribution
  Mark Bradford

- Group E4: Visualization and Analysis Tools
  Don Murray, Chris Burghart

- Group E5: Data Formats, Long-term Archive and Stewardship
  Steve Williams

1600-1615 Break to change room set-up

1615–1705 Plenary - short (10 min) presentations from each breakout session E
Chair: Linda Miller

1705-1715 Closing Remarks
Cliff Jacobs

NSF Facilities Assessment Workshop – Agenda

<u>Thursday, 27 September 2007</u>
(NCAR Foothills Lab/UCAR Center Green 1)

7:30am Registration
Continental breakfast

8:15am Welcome
Cliff Jacobs
Bob Serafin
Roger Wakimoto

8:45am Disperse into breakout groups

9:00am Breakout Groups – by Assessment Subcommittee

Subcommittee co-chairs will lead sessions and present information contained in the Assessment database entries. Discussion will focus on what are <u>unmet</u> measurement capability needs, based on what was heard at the NSFUW and questionnaire results. Breakout groups will each develop a report to deliver to the Assessment Workshop in the afternoon plenary session.

Group A: Airborne Measurements (Cooper, Browell)
Group B: Airborne Platforms (Albrecht, Stith)
Group C: Emerging Technology (Dabberdt, McLaughlin)
Group D: In-situ Surface and Surface-Atmosphere Exchange (LeMone, Carroll)
Group E: Surface-Based Remote Sensing (Rutledge, Ackerman)
Group F: Satellite Data (Emery, Arkin)
Group G: Solar Measurements (Kuhn, Navarro)

10:15am Break

10:30am Breakout group discussions continue
Breakout groups develop reports for the afternoon plenary session

12:00pm Lunch

1:00pm Plenary – Group report presentations

1:00-1:30pm Group A – Airborne Measurements
1:30-2:00pm Group D – In-situ Surface and Surface-Atmosphere Exchange
2:00-2:30pm Group E – Surface-Based Remote Sensing

2:30pm Break

2:45pm Group report presentations continue

2:45-3:15pm Group F – Satellite Data
3:15-3:45pm Group G – Solar Measurements
3:45-4:15pm Group B – Airborne Platforms
4:15-4:45pm Group C – Emerging Technology

4:45pm Open discussion

5:15pm Day One wrap-up remarks – Bob Serafin

5:45pm Reception, in the CG1 lobby
[Attendees who are not subcommittee members are free to go but may stay for Friday's morning sessions if they like.]

Friday, September 28, 2007

8:30am Continental breakfast

9:00am Subcommittees meet separately to discuss findings

10:30am Break

10:45am Subcommittees develop rough drafts of findings

12:00pm Lunch
Remarks – Cliff Jacobs

1:00pm Steering Committee meeting
(Subcommittee members may stay but are not required)

Review subcommittee drafts
Discuss next steps
Writing assignments for Assessment report
Develop Workshop report for the web

2:45pm Break

3:00pm Steering Committee discussions continue

4:30pm Closing remarks – Karyn Sawyer

5:00pm Adjourn

Appendix D – In-Situ Surface and Surface Atmosphere Exchange Subcommittee Preliminary Report

Preliminary Report: In-Situ Soil and Surface Atmosphere Exchange Sub-Committee
of the
NSF Atmospheric Science Facilities Assessment Committee
DRAFT – 31 May 2007

1. Introduction

The charge of the NSF Atmospheric Science Facilities Assessment Committee is to lead "an assessment of the current status of the national and international atmospheric science facilities," to provide a forum for the community for the development of community partnership, and to develop a database populated with "resources" for use by the community. As used here, a "resource" is a platform, a network, or an instrument. Finally, the activities will be used to identify gaps in the current infrastructure. The In-Situ Soil and Surface Atmosphere Exchange Sub-Committee (ISSSAE) focuses on the ground, ocean, of ship-based measurements of aerosols, meteorological variables including surface and boundary layer fluxes, trace gases, trace-gas fluxes, from towers, buoys, or tethered instruments, as well as relevant measurements in soil, vegetation, and fresh and ocean water. This document is based on the ISSSAE subcommittee's discussions, the database, and the referenced sources.

The database is evolving, and far from complete in its structure and capability as well as in its content. This interim report thus focuses on suggestions for improvement of our procedures and suggestions for the database before drawing any preliminary conclusions about the U.S. observational infrastructure. The last set of impressions is based primarily on supplementary materials.

2. Survey Response and Corrective Actions

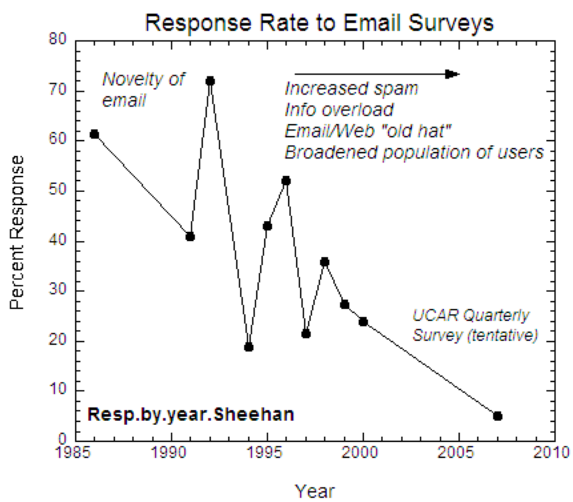
2.1 Response
Thus far, the response to the survey has been minimal. As shown in the Table, most of the database represents the "Networks" extracted by Scot Loehrer from the database he developed for the last 10 years with funding from various sources, most recently the GEWEX Americas Prediction Project. Only 77 responses have been received that weren't necessarily submitted by sub-committee members (e.g., the Solar Measurements Subcommittee did submit a small number). The invitation to populate the database was sent to 817 people. Assuming all of the 77 responses were from "outside" the committee structure yields a response rate of around 10%. Emerging Technology sent their survey to 572 addresses, and received 12 responses, a response rate of 2%.

Table: Facilities Database as of 31 May 2007.[1]

Category	Number
Total number of entries (includes revisions)	569
Scot Loehrer Networks database	432
Junhong Wang GPS Ground-Based Remote Sensing	9
Satellite Initial Spreadsheet	51
Remainder (includes some submissions from Solar)	77

[1]Date from fadb database, courtesy of Mark Bradford

The low response rate is consistent with a trend that is reflected in Figure 1. Looking at the reasons for poor response rate, Sheehan (2001) identified the time in recent history as an important factor. The early high response rate was attributed to the novelty of the computer and a relatively small community on-line. With time, that novelty has gone away, computer usage has become more widespread, and the combination of heavy email traffic and increase in spam has contributed to surveys being left unanswered or filtered out of inboxes altogether. Finally, people are receiving requests to complete surveys much more frequently than in the past . With heavy email traffic, roughly half of the response to an on-line survey is within hours; and 97% of the response is within two week (supersurvey.com). Computer capability has been a perpetual problem.



Response rate to on-line surveys, based on data from Sheehan (2001). Except for 2007 point, which is from Bob Henson of UCAR (personal communication 2007).

2.2 Improving response

There are well-known ways to improve survey response. High "salience" or relevance to the responder is very important. Survey length is also quoted as being important – people getting 50 emails a day aren't eager to spend the 10-15 minutes or longer needed to fill out a detailed questionnaire. Finally, personal contact and follow-up have proven effective in increasing response rate. Indeed, other subcommittees have (e.g. Solar Measurements) or are planning (e.g., Aircraft Platforms) to contact resource providers personally. Email follow-up can also modestly increase survey response (25% according to Sheehan and Hoy 1997).

The remedy for this situation is not straightforward for the ISSSAE. The relative difficulty of our job is illustrated by the fact that there are 434 entries (432 from Loehrer + 2 instrument entries) under the categories represented by ISSSAE, and only 135 entries represented by the remaining six sub-committees. Furthermore, there is one category (ships) under ISSSAE purview that was not even considered in early planning. We recommend the following steps be taken to populate the database:

- Sell the survey by focusing on the *measurements* as well as the *instruments* and *platforms.* Many scientists going into the field will find it useful to scan the database for where 'background" data are available when they are planning field campaigns (salience)
- Avoid using the word "survey" to the degree possible, especially in the email subject line. This could reduce the chance of "turning people off" and could increase the chance to get through spam filters. "Database" is the recommended substitute.
- Provide the option to supply a web address only (and leave the task of populating the database to database staff. (thus vastly reducing questionnaire length). The committee had taken two steps in the first round to make things easier for responders: entering preliminary information (Loehrer's 432 items) and noting in the invitation letter that the entries are started to make their work easier. This resulted in a response of about 10 out of 80 – higher than the overall average response but not by much.
- Hire a student (or group of students) to populate the database by mining web sites provided from the survey or other sources, request further information when needed, and seek approval when the data entry is completed. (personal follow-through).   Potential web sites appear in the Appendix.

3. Database

The database structure and interface serves two masters, instrument/facility operators who enter information and users who search for information about measurements, instruments, and/or facilities. The interface must make it easy for operators to enter and revise their information, while avoiding the need to enter the same information more than once. Users need an interface that makes it easy to search the database and filter the results, providing either summary or detailed results via an intuitive interface. Below are some attributes the sub-committee considers important.

3.1 Uniform and clearly-defined terminology

3.1.1 Implement clear general categories

Currently, the database contents are different for different applications ("resource types"), e.g., Current Airborne Measurements vs. Ground-based Remote Sensor. ISSSEA recommends that the database administrator work with the sub-committee chairs to harmonize the database structure and terminology. As a straw man for discussion, the following terminology is suggested:

Measurement:	a geophysical parameter of interest
Instrument:	a device or system for obtaining measurements
Platform:	a facility where instruments are operated (e.g., a fixed ground site, an airplane, a ship, a satellite)
Network:	an integrated collection of platforms
Operator:	a person or organization responsible for a network, platform, or instrument

Each entry in the database contains information on one or more of these categories.

3.1.2. Include common definitions of terms

The need for uniform terminology extends to subcategories. For example, in some entries, a 3 m platform is considered to be a tower (and thus the measurements would be noted as tower measurements). In most cases, measurements made at 3 meters would be considered to be surface measurements. However, searching the current database for tower measurements would include such surface measurements and thus be unproductive. **The ISSSAE Subcommittee strongly recommends that instructions that include "common definitions" adopted for the purpose of the database be provided.**

3.1.3 Provide access to definitions of terms or acronyms

The user interface for entering data into the database should anticipate questions that operators might have, and should provide an explanation of any database field through some simple mechanism. For example, holding the mouse pointer over a field labeled "Type" should provide an explanation, with examples, of what "Type" means in this particular context. In order to maximize the usability for interdisciplinary studies, a convenient way to obtain explanations of acronyms or specialized terminology should be an integral feature of the user interface.

3.2 Balance detail with durability

The committee discussed the pros and cons of requiring detailed information for each resource and concluded that limiting the information requested to data considered to be "durable" and providing a link to the authoritative page (original source) would yield a database that would be more useful to the community and one that could feasibly be maintained/sustained. "Durable" data are data that are unlikely to change in a 3-5 year time period. In addition, there was considerable discussion regarding the "minimal" information required to make the database of interest and useful to all users in the atmospheric sciences community. In this instance, "useful" implies both a fully searchable database and one that contains, at a minimum, resource information considered to be "critical" by users.[1] The committee emphasized the need for staff to

[1] Discussion regarding the utility of the database (see "salience" as addressed in Section 2) raised the issue of whether or not the database should focus on measurements or on instruments/platforms. The vast majority of database entries to date associated with the ISSSAE Subcommittee's focus and the effort as a whole – are in the

maintain / sustain the database, even if the contents are limited to “durable” or stable data.

There was some disagreement as to whether “critical information” includes details regarding the instrument or technique used to make a particular measurement or if solely listing the geophysical quantity measured is sufficient. This was especially the case for the resources currently included in the “Measurements (network, tower, buoy)” resource category. It was thought by some ISSSAE Subcommittee members that requesting information of individuals submitting data for networks regarding the instruments used would be prohibitively taxing. Moreover, it was thought that most users will not seek details regarding instruments used for general meteorological observations. It was suggested that users seeking greater detail should independently approach the responsible resource contact for additional information.

On the other hand, some ISSSAE Subcommittee members noted that the intention of this facilities assessment was the creation of an inventory of platforms and instruments and thus details regarding instruments or techniques used to make measurements are “critical information”. In addition, there was some concern that users from the atmospheric chemistry community would also want to be able to search by instrument or technique.

3.3 Provide Flexibility

One way to address the detail vs durability question is through flexibility. Under this scenario, the database would tolerate incomplete or general entries. For example, it would be possible to specify that most platforms in a network make a particular set of measurements, but that some platforms might make a more extensive set of measurements and others might make fewer measurements. Operators should not be daunted by requirements for providing detailed information. A guiding principle should be that it is better to have incomplete information than none at all. In some cases, such as a specialized atmospheric chemical analyzer, detailed information about an instrument may be required for users of the database, while in other cases, such as a network of soil temperature sensors, it may be sufficient to indicate what measurements are made without specifying the particular instruments being used.

3.4 Streamline filling out database

From the foregoing, the chances of response increases with ease in entering data into the database. The following suggestions address this.

3.4.1. Harmonize questionnaire so that all people entering data start at same place

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“Measurements (network, tower, buoy)” category. Here the focus is clearly on measurements (in fact, there are no questions regarding instruments / techniques used in the associated database questionnaire). Many of the ISSSAE Subcommittee members thought that the majority of database users would be interested in searching the database for a specific geophysical variable. It was thought that the database might especially be useful for users seeking to expand beyond their own expertise when embarking on interdisciplinary efforts.

With the current database configuration, some users desiring to enter data aren't sure where to start, and/or find the present organization along subcommittee lines to be artificial and confusing. **Hence the sub-committee strongly recommends harmonizing the questionnaire (as opposed to having separate questionnaires for different resources).** It was suggested that the questionnaire begin with general information (perhaps with a reassuring statement that your entry will be linked with all other appropriate categories) and then branch off according to the type of platform, instrument or measurement.

3.4.2. Prevent necessity for repeated entries of the same information

A key concept for organizing the database is that information should only need to be entered once, for example, the operator of a number of platforms or instruments should only need to enter their contact information once, and for subsequent entries should only have to click their name on a list (or some other convenient approach). Likewise, once the characteristics of an instrument have been entered, they should not need to be entered again for some other platform. It should be possible to make an entry for a variant of an instrument or platform by selecting the base type of the entry (e.g., a Twin Otter airplane or an Eppley PSP pyranometer) and then describing how this particular instance differs from the base type.

Similarly, an individual having a resource that falls into more than one category, should have the ability to enter information into the "in situ instrument" questionnaire and then simply list instruments used in the "measurements (network, tower, buoy) questionnaire and have the geophysical quantities measured automatically show up in the relevant fields in that questionnaire, thus eliminating the need to repeatedly enter the same information and requiring only minor revisions to represent the configuration in which the instrument is being used.

3.4.3. Cross-link entries

The Subcommittee strongly recommends that all entries be linked in a manner that allows transferability of data throughout the database. Ideally, this would be coupled with automatic field filling and/or popups from which users can select information already entered (by themselves or others) and would thus remove the need to repeatedly enter the same information (a current issue that is considered to prohibit the participation of many members of the community). Such cross-linking would also make the database fully searchable.

3.4.4. Facilitate entries for commercial instruments (e.g. Eppley PSPs)

The Subcommittee discussed the value of staff entering information into the database for commercial instruments that are routinely used. The data fields could include a link to the manufacturer's web site (e.g., www.eppleylab.com) and would include basic information regarding the instrument and all variables that can be measured. Individuals submitting information regarding a resource could select the instrument from a popup menu (thus ensuring uniform naming) and relevant data fields would be automatically populated. These fields could then be edited to reflect the configuration in which the instrument is being used. Finally, a search by instrument name would yield a list of links for associated entries that would include contact name and location. This would meet the needs of users interested in learning who owns these instruments and their availability and/or where the related measurements are being made.

3.5 Implement Search Capability

Users of the database have a variety of interests in the data. One user might be interested in identifying potential sites for collocating instruments or providing ancillary data. Another user might be interested in identifying gaps in the spatial distribution of a measurement, or obtaining a list of the measurements being made on a particular platform. Common features of user needs include searching and filtering the data by a flexible selection of criteria (Boolean AND/OR, partial string matching). Any field in the database (e.g., measurement, instrument, operator, instrument) should be available for use in building search/filter criteria. It should be able to specify the geographical region for a search by a number of means, including place names ("Minnesota", "U.S. Midwest", "Pacific Ocean"), center and radius of a circle ("within 1000 km of Pellston, MI"), and by selecting a region on a map with a mouse. Finally, it should be easy to progressively narrow a search, e.g., "first show me all places measuring soil moisture in Alaska", then "show me which of these sites where methane is also measured".

3.6 Install Simple button to report problems

A common aspect of the interfaces for both data entry and retrieval is an easy mechanism to report problems or ask for help. Prompt responses by the database administration team to problem reports and help requests will encourage operators to persevere in the often tedious and thankless task of contributing to the database. Users who report broken links or out of date information will be encouraged to do it again if they know that their reports are used to maintain the perishable information in the database. This requires a significant commitment in terms of staffing to both respond promptly to problem alerts and to remedying the problems.

3.7 Reorganize home page

If the home page of the database has an outline of facilities and measurements, the sub-committee came up with the following organization that removes the artificial dependence on committee structure. It is recognized that any entry may be under one than one heading.

Platforms

- Mobile
  - Aircraft
  - Ship
  - Buoy
  - Tower
- Transportable
  - Tower
  - Radar
  - Lidar
- Fixed

Instruments

- In-situ
- Remote

Geophysical Variables

Networks

- Ship/Buoy
- Land-based
- Air
    - Aircraft
    - Balloons/sondes

4. Trends

Even though the database is far from populated, the committee identified a few important trends related to the facilities assessment effort.

4.1 Unification or collaboration of networks

The "networks" web site (http://www.eol.ucar.edu/projects/hydrmetnet) developed by Scot Loehrer shows a trend toward various combinations of mesonetworks. The two best-known examples are the two large "networks of networks", Meso-West, operated out of the University of Utah, and MADIS, operated out of the Earth System Research Laboratory of NOAA. On the smaller scale, State Climatologists in some states are building collaborations between mesonets within their state (e.g., South Carolina and Iowa). Such efforts have led to better quality control (providers can easily find out data quality through comparison with adjacent sites) and uniform format, which simplifies access.

4.2 Synergistic activities to improve measurement capability

Programs such as the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) are involved in activities related to the Facilities Assessment. For example, USGS has agreed to work with CUAHSI to develop an equipment loan program on a pilot basis, to provide the CUAHSI community access to instruments stored at the USGS Hydrologic Instrument Facility in Mississippi. The two institutions would also cooperate in instrument development, procurement, and testing. Additionally, the CUAHSI Biogeochemistry and Geophysics working groups are working to identify instruments needed to enhance the current suite of hydro-meteorological measurements.

4.3. Deteriorating mesonets

Maintaining mesonets is expensive. As a result, some disappear. For example, the Tennessee mesonet has been dismantled, and the Wisconsin mesonet is down to only a few remaining sites. Similarly, USGS stream gauges to monitor hydrologic flow are significantly decreasing in number even though the need in our opinion is becoming more acute. Thus it seems that one need to be voiced from this assessment is better funding support for surface monitoring and measurement network efforts.

4.4. Funding for moderate-to-long-term field campaigns

A related funding issue identified by the sub-committee is the lack of adequate pathways for funding moderate-term and long-term measurement efforts. This unmet need was pointed out with regards to NSF funding mechanisms in the document "Strategic Guidance for the National Science Foundation's Support of the Atmospheric Sciences," a report of the National Research Council. While there have been some long-term funding for studies of the upper atmosphere and the Sun, there have been no like longer term funding mechanisms for lower-atmosphere programs with field deployments longer than a few months. Yet as the report points out, many problems related to weather and climate require sustained measurement strategies for a complete annual cycle or even a few years. Similar funding mechanism gaps are present in many if not all US atmospheric science funding agencies.

5. Gaps

5.1. Gaps in the current database categories

During our May meeting, the ISSSAE Sub-Committee noted that there are a few instruments/platforms that seem not to be covered by any of the sub-committees. Specifically, we do not see where any sub-committee has responsibility for sondes or upper air sites and instruments. Another somewhat related gap we identified is in the area of airborne platforms other than typical large powered aircraft, such as balloon-borne platforms.

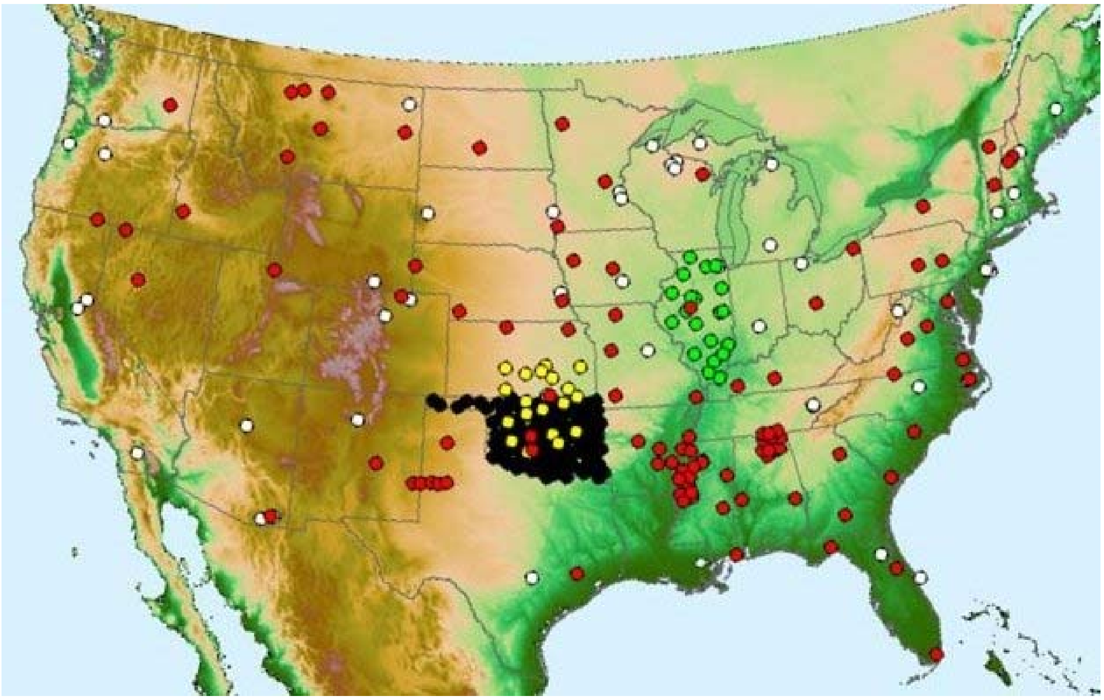
5.2. Current US Measurement Capabilities

5.2.1 Preliminary Assessment

The subcommittee reached the conclusion that the full examination of the gaps in the in-situ surface area could not yet be determined due to the lack of initial response to the survey. However, some general conclusions related to gaps in current capabilities were reached.

5.2.2 Scientific Gaps

The gaps are defined largely by the scientific application under discussion. However, there are some clear gaps related to geographic location (e.g. “holes” within networks, as illustrated in Figure 2), climatic regime (e.g. under representation of certain regimes) or soil types (e.g. soil measurements often occurring within certain soil types). For example, the current density of soil moisture observations in the US is not adequate for high resolution NWP models.



Soil-moisture networks in the U.S. The black dots represent the Oklahoma Mesonet, the green dots, the Illinois state water survey; Yellow is ARM/CART; white dots: AmeriFlux sites; red dots: USDA/NRCS Soil Climate Analysis Network.

5.2.3 Data Quality

The Loehrer survey also reveals gaps involving such issues as calibration, siting and metadata standards, although some of the "network of networks" efforts are addressing these questions. The methods and frequency of calibration vary substantially across the in-situ instrumentation, particularly across the networks. Calibrations vary from the stringent and frequent calibrations performed at the DOE ARM facilities all the way to limited or unknown calibrations performed by some of the networks. This can have substantial impact on the quality of the data collected within the networks.

Much like the issue of calibration standards, the siting standards vary across the networks. Some of the siting issues include exposure (distance from obstructions), distance from artificial heating or cooling sources, land surface type, and heights of instrumentation above the ground. A large part of the siting standards for a network are based on the purpose of the instrumentation. A primary example here is the Road Weather Information Network (RWIS) operated by many state Departments of Transportation. These instruments are focused on determining the state of the roads in particular areas (often areas that are known to have particular issues with icing or fog). So they are typically sited along roads or on overpasses which sometimes makes them less than ideal for use in research. Some networks do not have any hard siting standards required for inclusion in the network.

Finally, the issue of standardized metadata and its centralized availability has been an issue for decades. While substantial progress has been made in the unification of mesonet data through the efforts of groups at MesoWest and MADIS there has not been nearly that level of advancement on the unification of the detailed metadata. Ideally, information is needed on sensor height, station siting, calibration methodology and frequency, and sensors used. The metadata currently unified is primarily limited to station location information. There are some promising trends in this area, for example the centralization of the metadata associated with the large NOAA weather networks (ASOS, AWOS, COOP, etc) into a single database, the NOAA Multi-network Metadata System (MMS) which is starting to centralize access to information such as instrumentation used at each station, data products that include data from the station, etc.

6. Summary of Recommendataions

6.1 Hiring of Staff

The ISSSAE Subcommittee notes that the present method of sending out broadcast questionnaires has not worked well. This reflects a national trend. To improve response, it is recommended that:

- In addition to the current technical staff, the ISSSAE Sub-committee strongly recommends that entry-level (e.g., student) staff be hired to populate the database using websites supplied by survey response and from relevant databases, including those in the Appendix. Furthermore, staff will be needed to respond to “help” queries from those using the database. This is necessary for both building and sustaining the database.

6.2 Design of the database

While considerable progress has been made in database design, the ISSSAE Subcommittee has the following recommendations:

- Use uniform and clearly-defined terminology
    - Agree on common terms for general categories
    - Include definitions in the instructions
    - Provide access to definition of acronyms and specialized terms
- Balance durability with detail. Information that becomes out of date quickly will not be practical, yet the database should be useful.
- Provide flexibility, including the ability to fill out questionnaire partially
- Streamline filing out database
    - Have all those filling out questionnaire start at same place, then go to options (which don’t necessarily have to fit with sub-committee structure)
    - Prevent necessity to fill out same information multiple times
    - Cross-link entries
    - Provide partial information (plus a web site) for commercially-available resources
- Implement search capability
- Install simple button to report problems
- Reorganize home page (present categories, which reflect subcommittee structure, are confusing)

6.3. Trends

Based primarily on the Loehrer entries and supplemental information, the ISSSAE Sub-Committee has a preliminary list of trends:

- Unification of some mesonetworks
- Other efforts to improve measurement capability (e.g., CUAHSI)
- Deterioration of some mesonets because of lack of funding
- Remaining inability to conduct field campaigns using specialized networks on intermediate-to-long time scales

6.4. Gaps Scientific gaps are a function of the application. However, it was noted that

- There is a need for standards for siting, instrumentation, calibration, and metadata

6.4. Final Assessment

- Since the likelihood of fully and comprehensively populating the database is unlikely before the September meeting, it is strongly recommended that supplemental materials and web sites be used in the facilities assessment exercise.

References:

Loehrer, Scot, 2007: Agriculture/ET and Meso Networks in the United States. Presentation to the National Research Council Committee on Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs. Boulder, Colorado, April 4-6, 2007. Available at ftp://ingest.eol.ucar.edu/pub/download/loehrer/nrc/NRC_Loehrer_Networks.ppt.

Loescher and Coauthors: Enhancing water cycle measurements for future hydrologic research. *Bull. Amer. Meteor. Soc.*, **88**, 669-676.

NRC, 2007: *Strategic Guidance for the National Science Foundation's Support for the Atmospheric Sciences.*

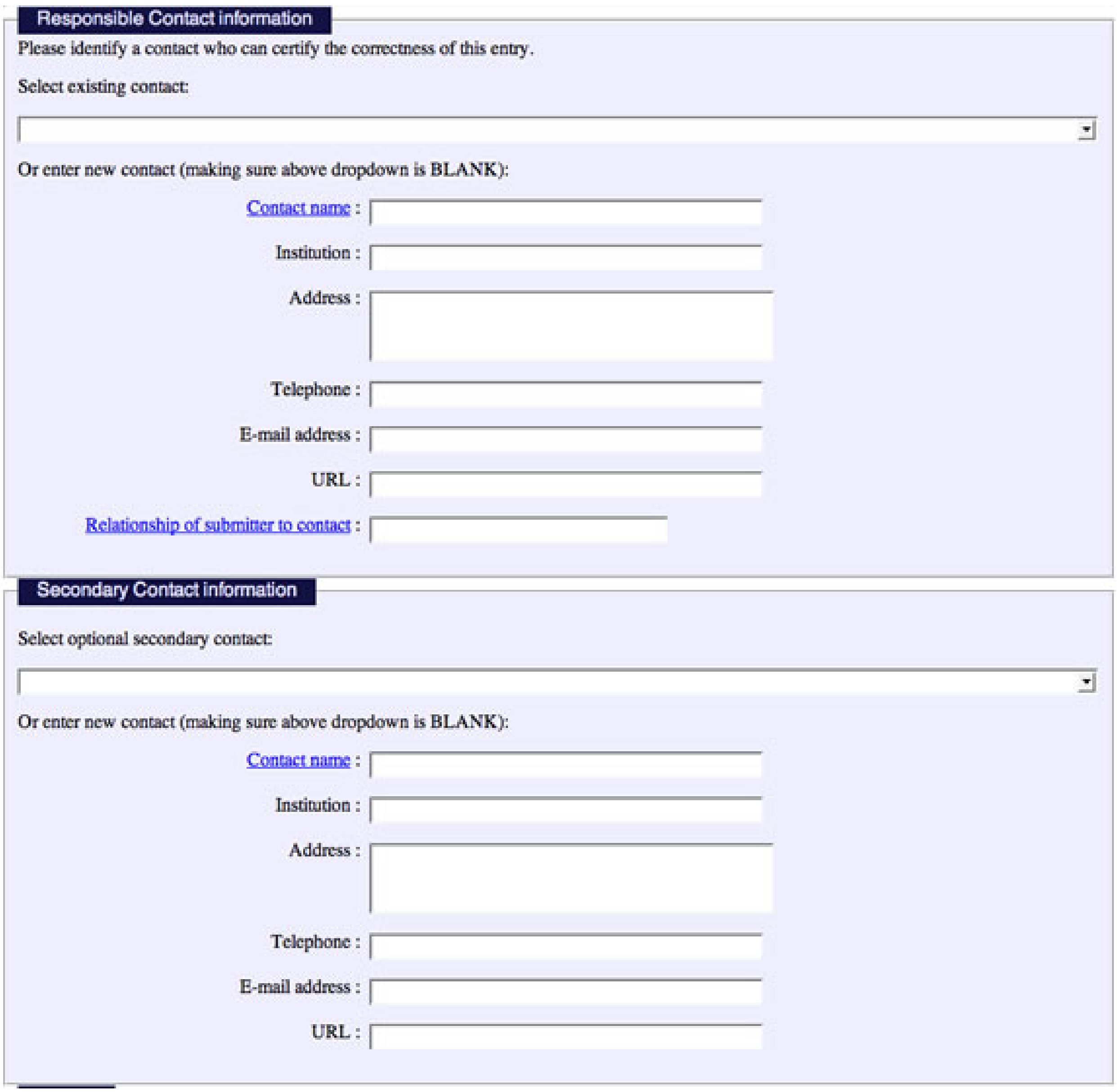
Sheehan, 2001: Email Survey response rates: A Review. JCMC 6, (2). http://jcmc.indiana.edu/vol6/issue2/sheehan.html *Marketing Research*,36-39.

Sheehan, K.B., and M.G. Hoy, 1997: E-mail surveys: Response patterns, process and potential. *Proceedings of the 1997 Conference of the American Academy of Advertisers.*

Appendix: Useful Web Sites (useful for data mining as well as assessment)

Web Site	Contents
http://www.arm.gov	Click on "instruments" goes to locations, instrument type, contacts etc
http://www.empa.ch/gaw/gawsis	Instruments and sites associated with Global Atmosphere Watch
http://www.eufar.net	Aircraft research database in development.
http://www.earthobservations.org (GEOSS)	home page for interagency overview of GEOSS earth observations system. Individual agencies maintain pages (e.g., www.noaa.gov/geoss, www.epa.gov/geoss). EPA site list some networks.
http://GEWEX-RFA.larc.nasa.gov	GEWEX radiative flux assessment (RFA) committee – how well we can measure we can measure radiation at top and bottom of atmosphere, what needs are.) – data will be available, discusses instrumentation as part of assessment
http://www.NARSTO.org	Air-quality data archive (primary ozone and aerosols) Metadata Information on field campaigns, related presentations
NASA DAAC http://www.nasadaacs.eos.nasa.gov	Links to all 9 NASA data centers
http://www.eosweb.larc.nasa.gov	Radiation, clouds, aerosols, chemistry data
http://www.nosa.noaa.gov	NOAA Observing Systems Architecture (networks and observing systems inventory – no data)
www.srrb.noaa.gov	Info about surface radiation instruments
http://dss.ucar.edu	A wealth of datasets and some documentation
http://www.eol.ucar.edu	Data and instrumentation in NCAR/NSF Deployment Pool
http://www.eol.ucar.edu/projects/hydrometnet	Summary of 430 networks developed by Scot Loehrer.

Appendix E - Emerging Technology Online Database Entry Form Screenshots



Responsible Contact information

Please identify a contact who can certify the correctness of this entry.

Select existing contact:

Or enter new contact (making sure above dropdown is BLANK):

Contact name :

Institution :

Address :

Telephone :

E-mail address :

URL :

Relationship of submitter to contact :

Secondary Contact information

Select optional secondary contact:

Or enter new contact (making sure above dropdown is BLANK):

Contact name :

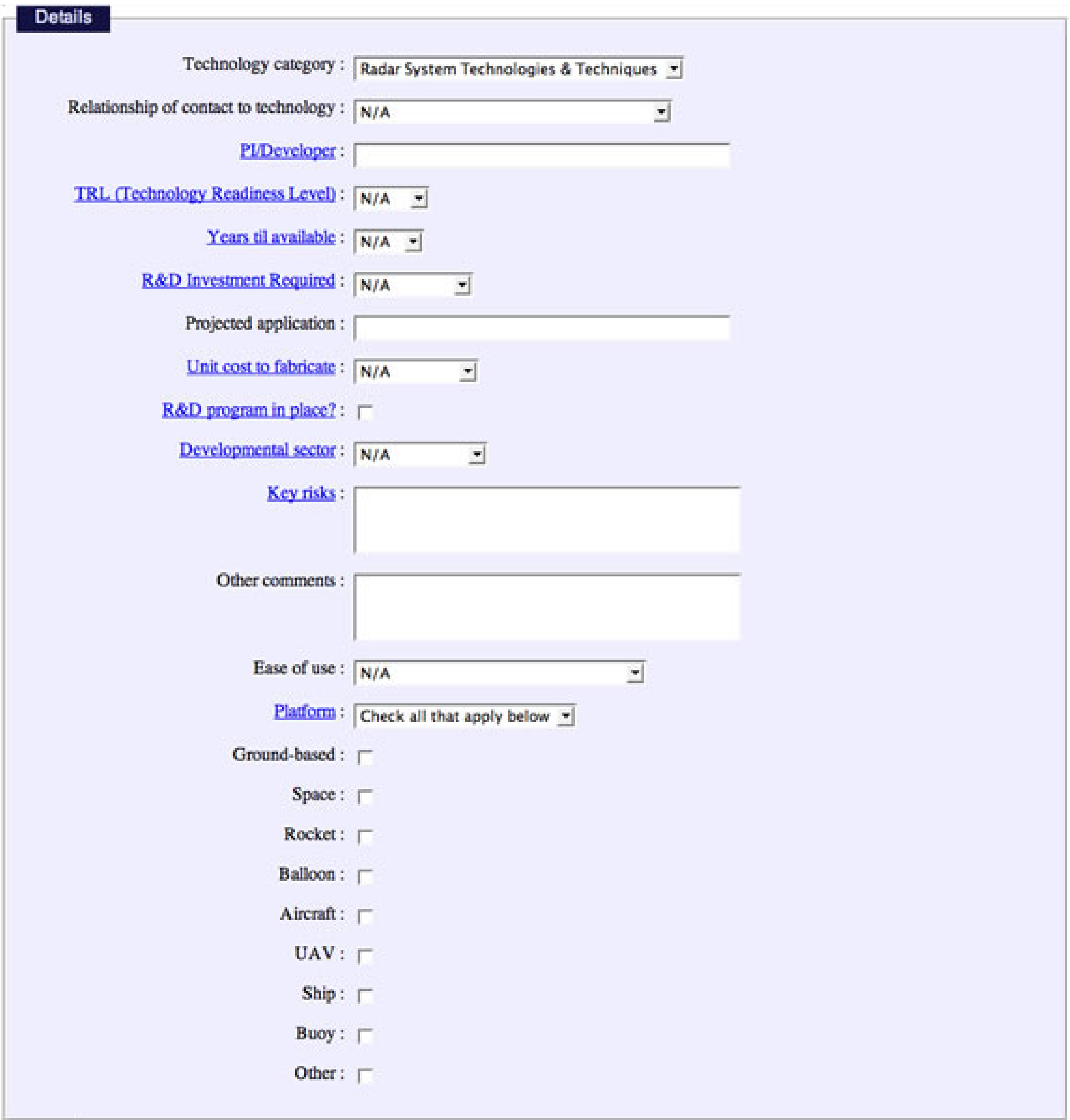
Institution :

Address :

Telephone :

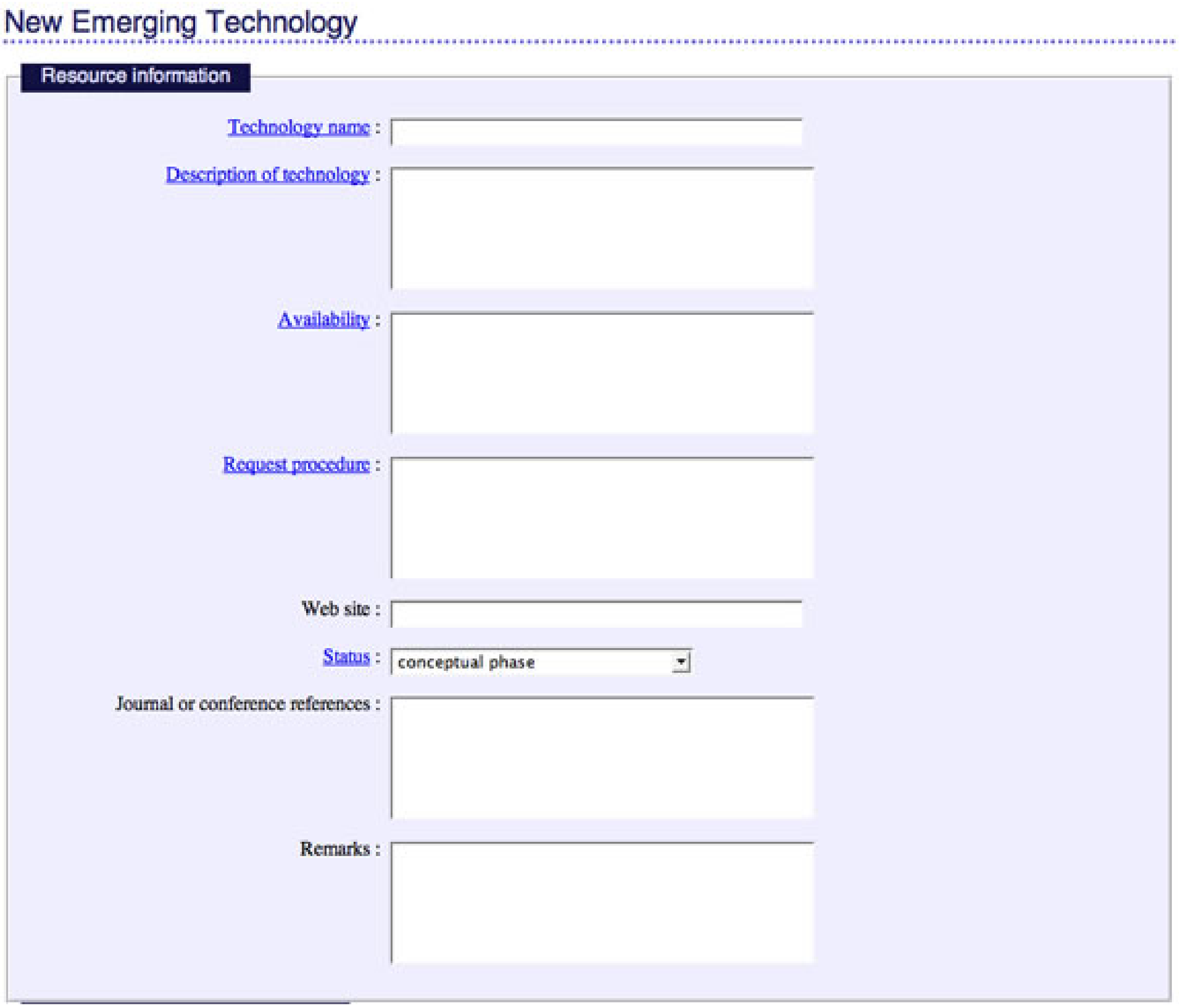
E-mail address :

URL :



Details

Technology category :	Radar System Technologies & Techniques
Relationship of contact to technology :	N/A
PI/Developer :	
TRL (Technology Readiness Level) :	N/A
Years til available :	N/A
R&D Investment Required :	N/A
Projected application :	
Unit cost to fabricate :	N/A
R&D program in place? :	☐
Developmental sector :	N/A
Key risks :	
Other comments :	
Ease of use :	N/A
Platform :	Check all that apply below
Ground-based :	☐
Space :	☐
Rocket :	☐
Balloon :	☐
Aircraft :	☐
UAV :	☐
Ship :	☐
Buoy :	☐
Other :	☐



New Emerging Technology

Resource information

Technology name :

Description of technology :

Availability :

Request procedure :

Web site :

Status : conceptual phase

Journal or conference references :

Remarks :