HIAPER INSTRUMENTATION PRIORITIES

A REPORT TO THE NSF

FROM THE

HIAPER ADVISORY COMMITTEE

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Background

The *High-performance Instrumented Airborne Platform for Environmental Research* (HIAPER) will be an important addition to the national airborne sampling capabilities for the atmospheric, earth, and oceanographic sciences communities. The combination of altitude, range, and payload of the HIAPER platform (Gulfstream V) are unique for a scientifically instrumented jet-powered pressurized aircraft, and will provide tremendous new opportunities for sampling wide regions of the Earth. In preparation for using this platform and developing its instrumentation potential, a community-wide instrumentation workshop was held at NCAR in November 2002. Almost 200 scientists, engineers, and instrument builders representing universities, government laboratories, and private industry attended and participated in discussions about the HIAPER platform, its planned configuration, and ideas regarding measurements of highest priority to be made from HIAPER. This NSF community workshop also provided the opportunity for attendees to exchange views about future environmental research needs and how HIAPER can help to meet them. The workshop objectives were to: 1) identify the science thrusts and types of measurements that will need to be made in the near and mid-term to make significant progress in a number of important areas; 2) ensure that the broad research community has a clear understanding of the HIAPER airframe and its basic infrastructure; and 3) discuss the NSF Announcement of Opportunity (AO) process, schedule, and estimated funding level for proposals to build instrumentation for HIAPER. This instrument fund, from the NSF's *Major Research Equipment and Facilities Construction* (MREFC) account, totaling perhaps $12.5M, represents a unique opportunity to provide the scientific community with a complement of instruments that will take advantage of this new platform. The instrument workshop was organized around a series of focus group discussions concerning the high priority measurements that are required to make significant progress in a number of science disciplines.

At the conclusion of the workshop, NSF asked the HIAPER Advisory Committee (HAC) to synthesize the recommendations of the focus groups, looking for areas of overlap in the measurements, and provide a report on the recommended measurements by priority if possible. This report will assist the NSF in evaluating proposals and deciding funding priorities in response to the Announcement of Opportunity (AO) for the HIAPER MREFC instrument development.

Measurement Categories

The HAC chose to categorize measurements by the ease of which they could be integrated with the HIAPER platform, as a first step in ranking priorities. We've termed the rankings as "*Standard*", "*Routine*", and "*Research*":

1. **STANDARD**: Technologies that are sufficiently mature and straightforward that they can be routinely installed, maintained, operated, and interpreted by NCAR/ATD staff. These measurements are fundamental to most research campaigns and the instruments would typically fly on all missions.
2. **ROUTINE**: Existing or proven technologies that could be adapted to HIAPER (e.g., by miniaturization) by a relatively short R&D effort (e.g., 1-2 years) before the technology could be considered standard. In the interim, their deployment may require additional

support personnel and funds; and possibly require some specialized expertise to analyze and interpret. These instruments may not fly on every HIAPER mission but would be available upon request and could be operated and maintained by NCAR/ATD staff.

3. **RESEARCH**: Technologies that require considerable R&D (i.e., they are primarily "PI-driven" and push the innovation envelope, i.e., requiring extensive PI involvement in development and evaluation) and will likely not be ready to be turned over to NCAR/ATD for routine operations for at least 3 years after the initiation of instrument development. While under development these instruments would likely require a PI for deployment for data analysis and proper interpretation.

Instrument development in each of the three categories involves risks, which may be described as follows: Standard: low; Routine: low-to-moderate; and Research: moderate to high. Because of the limited MREFC funds initially available for the HIAPER instruments, *the HAC is already on record as recommending that MREFC HIAPER funds should emphasize measurement categories 1) and 2), with only a few, potentially high-pay off developments in the 3) category*. We note also that there are other NSF sponsored mechanisms that instrument developers can use to bring technologies in the 3) category to HIAPER. These mechanisms, driven by peer-reviewed proposals, have been used for many years to develop airborne instruments.

Instruments could evolve from one category to another as technology is proven and NCAR/ATD gains experience in their operations and maintenance.

Science Categories and Measurement Priorities

The diverse nature of the potential HIAPER missions makes determining a single set of measurement priorities for all science applications a virtually impossible task. That assignment would require choice between observational requirements between a broad range of NSF science priorities (e.g., clouds and radiation versus Earth sciences), expertise that the HAC does not adequately possess. Accordingly the workshop considered measurement priorities within five sets of science categories, representing a wide range of sciences, and we follow that outline to recommend priorities within each of those categories:

- Aerosols and Microphysics
- Gas Phase Chemistry
- Radiation, Clouds, and Climate
- Large-Scale Dynamics of Weather Systems
- Earth Sciences

Based upon the discussions at the HIAPER Instrumentation Workshop it was clear that all of the presented measurements were scientifically valuable. Accordingly, we limit our priority rankings to three: (1) Essential; (2) Highly Desirable; and (3) Scientifically Important.

State Variable Measurements Common to All Science Categories

All science missions benefit from certain “basic” observations of aircraft location, attitude, altitude, track, as well as in-situ measurements of outside air temperature, humidity, static pressure, etc. We recognize that a certain amount of funding has been set-aside for these "infrastructure" observations in the basic procurement budget, so many of these items are already under consideration by NCAR/ATD and may not strictly fall within the MREFC guidelines. However, the HAC feels the priorities within this category would be useful to assist NCAR/ATD in setting their internal priorities. All priorities within the Standard measurements are equal (i.e., no one observations is rated above the others, and all need to be present for every mission).

1. Standard State Variable Measurements

Priority	Parameter	Comment
1	Aircraft position	Two redundant and independent systems (GPS & INS)
1	Aircraft ground speed	GPS & INS
1	Aircraft attitude	INS. Fast response sensors suitable for use in eddy flux calculations ~50 Hz sampling rate.
1	Aircraft altitude	GPS & radar
1	Static pressure	Fast response sensors suitable for use in 3-D flux calculations, ~50 Hz. Redundant and independent systems.
1	Aircraft air speed	Fast response sensors suitable for use in 3-D flux calculations, ~50 Hz. Redundant and independent systems.
1	Temperature	Fast response sensors suitable for use in 3-D flux calculations, ~50 Hz. Redundant and independent systems. All weather deiced reference sensor.
1	Absolute Humidity	Fast response sensors suitable for use in 3-D flux calculations, ~50 Hz. Redundant and independent systems. All weather deiced reference sensor.
1	3-dimensional wind field	All weather, differential pressure system. Fast response sensors suitable for use in 3-D flux calculations, ~50 Hz.
1	Surface, cloud top, cloud base temperature	Radiometric remote sensing devices (nadir and zenith pointing).
1	Liquid Water	Ice and total liquid water content sensors. Icing rate detector.

Many missions may benefit from a more advanced level of state parameter measurements that fall in the "Routine" category that could be requested from a pool of instruments. Unlike the Standard Measurements, these are ranked by priority.

2. Routine State Parameter Measurements

Priority	Measurement	Comment
1	Static pressure validation of HIAPER sensors or other aircraft calibration	Trailing Cone
2	In-cloud temperature	Near field radiometric techniques
2	In-cloud water vapor	Near field radiometric techniques

3	Temperature Gradient	Scanning microwave radiometer technology
3	Humidity Gradient	Scanning microwave radiometer technology

Because of the relative infancy of making the following measurements from a jet aircraft, the following desirable state parameter measurements should be considered "research".

1. **Research State Parameter Measurements**

Priority	Measurement	Comment
2	Very accurate airspeed	Dopper Lidar or laser technology?
2	Three-dimensional wind field	Scanning or multi-beam Doppler lidar or lasere technology?
3	Electric field	Set of electric field mills on aircraft, mills on dropsondes?

Aerosols and Microphysics

The Earth's atmosphere is composed of a mixture of gases, aerosol particles, and hydrometeors. Natural and anthropogenic emissions of gases and aerosols affect the composition of the Earth's atmosphere. Changes in the chemical and physical makeup of the atmosphere can influence the Earth's radiation budget (incoming solar radiation minus outgoing infrared radiation) as well as affecting the Earth's global climate through large-scale temperature changes. In order to separate natural effects from anthropogenic effects, it is essential that we understand the basic physics and chemistry of interactions in the Earth's gas-aerosol-cloud system and how changes in this system affect the Earth's radiation budget.

1. Standard Aerosol and Microphysics Measurements

Priority	Measurement	Comment
1	Upward and downward short & long wave radiative fluxes	Radiometric techniques
1	Condensation nuclei, Ozone,	In-situ and/or radiative
2	Surface temperature and albedo	Radiometric techniques
2	Vertical temperature profile	Radiative or dropsonde techniques
3	Visual imagery (up, down, forward, aft, day/night)	Video (standard video plus infrared)

3. Routine Aerosol Measurements

Priority	Measurement	Comment
1	Aerosol concentrations and size distribution from nm - mm sizes	In-situ sampling: fast, accurate, high-altitude, water-phase resolved
2	Ambient and in-cloud chemical composition (including organics, carbon, mineralogy)	In-situ sampling: time-integrated, size-integrated, time-resolved (fast), size-resolved, quantitative, externally-mixed
2	Vertical profiles of aerosol amounts	Lidar technology
2	Scattering and absorption coefficients, phase function, extinction (spectrally-resolved)	Lidar technology
3	Hygroscopic growth factors	
3	Particle morphology and density	

2. Routine Microphysics Measurements

Priority	Measurement	Comment
1	Concentrations and size distribution of cloud particles from nm - mm sizes	In-situ sampling: fast, (~5 s^{-1}) accurate, high-altitude, water-phase resolved
2	Vertical profiles of precipitation and cloud amount	Lidar and Radar technology
2	Ambient and in-cloud particle composition	In-situ sampling

3	Droplet and crystal residual number and composition	In-situ sampling
3	Scattering and absorption coefficients, phase function, extinction (spectrally-resolved) in cirrus clouds	In-situ sampling
3	Cloud water and cloud ice content	Radar technology

3. Research Aerosol Measurements

Priority	Measurement	Comment
1	Particle shape	In-situ sampling
2	Sulfur, Oxygen, and Carbon isotopic ratios for individual particles	In-situ sampling
3	The amount and nature of biological aerosol particles	In-situ sampling
3	Surface fluxes of aerosol precursors	
3	Supersaturation spectrum of size-resolved cloud condensation and ice nuclei	
3	Amount and distribution of absorbing aerosols within cloud droplets and ice crystals	

4. Research Microphysics Measurements

Priority	Measurement	Comment
1	Cloud vertical velocity, cloud entrainment processes	Vertical incidence short wavelength radar
2	3-D cloud structure	Doppler radar reflectivity and radial velocity
2	Vector electric field	Field mills
3	Electric charge on particles and cloud elements	Electric field mills on aircraft and on dropsondes.
3	Amount and distribution of absorbing aerosols within cloud droplets and ice crystals	
3	Vertical distribution of particle concentration and size distribution	Video imagery on dropsondes

Gas Phase Chemistry

The capabilities of HIAPER make it a powerful platform for atmospheric chemistry research. The ability of the aircraft to operate for extended periods at altitudes from the boundary layer to the base of the stratosphere (at most latitudes) will advance a wide range of important atmospheric chemistry studies. The endurance and carrying capacity of the HIAPER will allow comprehensive chemical payloads to be deployed to study specific scientific questions in some of the least accessible, yet most important, regions of the atmosphere; such as the tropical Pacific, polar regions, and particularly the middle to high latitude upper troposphere and lower stratosphere (UT/LS). The UT/LS is an especially important and difficult region to study as chemical, radiative, microphysical and transport processes all play significant roles.

One of the major lessons learned from present airborne chemistry research programs, which represent decades of instrument development and observational planning, is that progress in our understanding of the chemical processes in the atmosphere and the role of these processes in the wider system can only be made through coordinated, simultaneous measurements of a wide range of critical components including gaseous constituents, aerosols, radiation and dynamics. Thus, for HIAPER, we require a package of chemical, aerosol and radiation sensors working in concert which can reach the altitudes of maximum effect (upper troposphere) in the tropics, can cover sufficient range to place the processes within the context of larger scale motions and can measure for sufficient duration the time dependence and evolution of the processes.

1. Standard Air Chemistry Measurements

Priority	Measurement	Comment
1	Ozone observations to complement other in situ measurements (T, T_d, p, winds, etc)	Off the shelf technology

2. Routine Air Chemistry Measurements

Priority	Measurement	Comment
1	Ozone, carbon monoxide, and water (1-10,000 ppmv), whole air samples (e.g., NMHC, alkyl nitrates, long lived tracers, etc)	In situ observations for the identification of air mass origins and tracers.

3. Research Air Chemistry Measurements

Priority	Measurement	Comment
1	OH, RO_2, NOx, aldehydes, ketones, and other VOCs and their oxidation products, peroxides, reservoirs of NOx (HNO_3, HNO_4, HONO, PAN and organic nitrates, NO_3, N_2O_5, NOy).	In situ observations for the identification of air mass origins and tracers.
2	Whole air samples (NMHC, alkyl nitrates, long lived tracers like halocarbons), CO_2, N_2O, CO, CH_4	

3	Vertical profiles of ozone, water vapor, and aerosols above and below aircraft	Lidar technology, dropsonde technology

Radiation, Clouds, and Climate

Interactions between clouds and incoming and outgoing radiation represent one of the largest challenges to our understanding of global climate change due to the critical role clouds play in the Earth's radiation budget. For example, low thick stratus clouds primarily reflect solar radiation and shadow and cool the Earth's surface. In contrast, high, thin cirrus clouds can be mostly transparent to incoming solar radiation, while at the same time trap a large percentage of the outgoing infrared radiation emitted by the Earth. These clouds then radiate that energy back downward, thereby warming the surface of the Earth. Whether a given cloud will heat or cool the surface depends on several factors, including the cloud base altitude and thickness, its size, and the composition of the particles that form the cloud. Thus a comprehensive study of the role clouds play in the climate system depends on adequate measurements of cloud properties (including their radiative characteristics) especially the concentration and size distributions of hydrometeors that comprise the cloud. Because cloud processes that shape those particle distributions depend critically on environmental factors such as lapse rates it is important to characterize the clouds in a wide variety of climatic zones, from the poles to the tropics. HIAPER thus becomes a critical tool for those measurements because its long range and altitude capabilities enables it to sample regions of the Earth previously inaccessible.

In addition to characterizing clouds in various climatic regimes, HIAPER will contribute to a large number of high priority research studies that utilize other sensors, especially satellite based observations that will further our understanding of the Earth's climate system and its changes, by validating those remote sensed measurements with HIAPER observations. The research topics include:

- Transport and exchange of air at and near the tropopause.Validation of satellite remote sensing observations of clouds and precipitation.
- Validation of CO_2 budget models and satellite retrievals of budget components.
- Aerosol effects (direct, indirect, and semi-direct) on radiation and climate, studied by multi-platform field experiments.
- Multi-platform validation of new synergistic satellite measurements including water vapor and ozone profiles
- Atmospheric energy budget, including heating/cooling rates.
- Cloud-radiation-aerosol interactions.
- Cloud processes.
- Validation of radiative transfer models.

1. Standard Radiation Measurements.

Priority	Measurement	Comment
1	Ozone flight level observations to complement other in situ measurements (T, T_d, p, winds, etc)	Off the shelf technology

2. Routine Radiation, Clouds, & Climate Measurements

Priority	Measurement	Comment
1	Broadband radiative fluxes	Nadir and Zenith – stabilized platform
2	Spectral shortwave and long wave fluxes	Nadir and Zenith – stabilized platform
3	Spectral Actinic fluxes	Nadir and Zenith – stabilized platform
3	Ozone profiles (up and down)	Remote nadir and zenith sensing lidar? Ozone dropsonde?
3	Ozone profiles and column total	Ozone dropsonde and/or lidar
3	Water vapor profiles	Nadir and zenith imager?
3	Temperature profiles	Nadir and zenith radiometers?
3	3D cloud structure	mm radar backscatter and air velocity.
3	Spectral imaging	

3. Research Radiation, Clouds, & Climate Measurements

Priority	Measurement	Comment
1	Spectral thermal images	
2	Aerosol extinction, optical depth	Pointing
3	Radiances (UV to microwave)	Pointing
3	Liquid water content and ice water content over all surfaces	Zenith and nadir remote sensing
3	Aerosol extinction profiles	Zenith and nadir remote sensing
3	3 dimensional CO_2 fields	Remote sensing?

Large-Scale Dynamics of Weather Systems

Severe weather associated with large-scale cyclones causes substantial damage, disruption of commerce, and loss of life annually. For example, two storms affecting Europe in December 1999 killed over 100 people and blew down over 400 million trees. Improved accuracy in 24 to 28 hour forecasts of surface wind and heavy precipitation would have an enormous societal and economic benefit. Historically, advances in weather predictive skill have come from developments in numerical modeling as well as more complete observations of the atmosphere. Recently, ensemble prediction has quantified the range of probabilities around a given forecast and there is great hope that future satellite observational capability coupled to variational data assimilation techniques will lead to a jump in forecast skill. However, numerical weather forecasts of high impact weather today still suffer significant failures particularly in the extended range (3 days to two weeks). Additionally, predictive skill at the longer ranges is limited because of poor descriptions of tropical influences on extratropical forecasts. To improve the accuracy of high impact weather forecasts a new technique of "targeting" specific observations could be used. Targeting observations is the process of identifying sensitive regions within which observations would maximally improve the skill of a numerical forecast, using dynamically determined information from the forecast model. Preliminary testing of this concept over the last several years using the NOAA G-IV in the northwest Pacific has shown that over 70% of cases showed improved 24-96 hour forecasts with error reduction by 10-25%. The lead-time gain for 2-day forecasts can be as much as 12 hours.

A high-altitude platform such as HIAPER could contribute significantly to long-range numerical weather forecasts of high-impact events by collecting dropsonde observations in model sensitive regions and helping to validate satellite observations within those regions. In spite of several orders of magnitude increase in the number of satellite observations in the next few years, significant problems remain in sampling data-poor regions of the Earth because sensitive regions tend to be within deep cloud layers where satellite observations are lacking. HIAPER can cover a significant part of a sensitive region even at extreme range from its base during a 10-hour flight. Currently the only technology required for targeting is dropsondes, a proven and reliable capability for NCAR/ATD. Future studies of satellite validation would benefit from the three-dimensional characterizing of cloud types within sensitive regions using a HIAPER-borne cloud radar.

4. Weather System Standard Measurements

Priority	Measurement	Comment
1	Temperature, dewpoint, wind vertical profiles	As many as 60 dropsondes per flight (pod?)

5. Weather System Routine Measurements

Priority	Measurement	Comment
1	Cloud characterization (extend, intensity, vertical velocity)	Nadir pointing Doppler & polarization cloud radar (Ku band?)
2	Temperature and moisture profiles through cloud	Radiometer

Earth Sciences

Better predictions of climate change depend upon improved understanding of the mechanisms controlling uptake and release of terrestrial carbon and how carbon sinks evolve with weather pattern variability, human interactions and other environmental forcing. Predicting the linkages between the carbon, water, and nitrogen cycles is crucial to accurate monitoring and forecasting changes in the Earth system, to understand feedbacks to atmospheric concentrations of greenhouse gases, and to estimating primary productivity of the biosphere. Current Global Circulation Models (GCMs) and Biogeochemical (BGC) models use data from many airborne imaging remote sensing instruments to estimate parameters such as vegetation indices which are used to estimate ecosystem properties including evapotranspiration, photosynthesis, primary productivity and carbon cycling.

The current state-of-the-art skill in estimating North American carbon storage is probably no better than 50%, due to poor sampling and analysis. Short-term changes due to biomass destruction (logging, wildfires, and land conversion) significantly contribute to this uncertainty. Improved remote sensing techniques are required that can resolve land cover and biogeochemical properties down to spatial scales of a few meters. HIAPER will provide a platform for a new, more capable generation of remote sensing instruments for obtaining measurements of the Earth's surface at the 1-30 m intermediate scales relevant for model testing and validation.

1. Earth Sciences Routine Measurements

Priority	Measurement	Comment
1	Vegetation types	Laser Vegetation Imaging Sensor
2	Canopy moisture, soil moisture, surface temperature	Radiometry, Imaging Spectrometer
2	Forest fire detection	Radiometry
3	Ocean wave spectra	Active scatterometry
3	Wave heights, ocean surface height	Synthetic Aperture Radar or radar altimetry

2. Earth Sciences Research Measurements

Priority	Measurement	Comment
1	Surface turbulent fluxes	In situ, radiometry
2	Salinity, ocean color, albedo	Radiometry
3	Snow thickness, snow age, sea ice concentration	Imaging Spectrometer?