UNOLS Establishes SCOAR to Promote Research Aircraft Facilities for U. S. Ocean Sciences

BY JOHN M. BANE, ROBERT BLUTH, CHARLES FLAGG, CARL A. FRIEHE, HAFLIDI JONSSON, W. KENDALL MELVILLE, MIKE PRINCE, AND DANIEL RIEMER

The ocean sciences community is currently engaged in the process of defining new facilities that will support oceanographic research, education, and monitoring efforts for the next several decades. New research vessels, drilling ships, coastal and deep-ocean observing systems, satellites, and submersibles will be designed to increase ocean access in terms of geographical coverage, depth, temporal continuity, and resolution of events. Aircraft may be largely overlooked facilities that are capable of providing observations and data in ways that satisfy many research goals, and they should be considered an important component in the future mix of oceanographic facilities.

Aircraft are capable of greater speed, and therefore greater range and spatial coverage during a short time period when compared to surface and subsurface ocean research platforms. Such speed and range attributes lead to better synoptic coverage of oceanic and atmospheric variability. Aircraft-mounted sensors provide data with much of the appeal of the aerial view provided by satellites, but with much greater specificity, spatial and temporal resolution, and scheduling flexibility, and they can provide resolution adaptable to phenomena of interest. Aircraft are ideal for both fast-response investigations and routine, long-term measurements, and they naturally combine atmospheric measurements with oceanographic measurements on similar temporal and spatial scales. Aircraft surveys reach across a wide range of environmental and geographic conditions. For example, an aircraft can survey and collect remote-sensing data over shallow estuaries, the coastline, and offshore with one deployment and can do so in weather that might preclude a surface vessel from covering the same areas. Using smaller, less-expensive aircraft for near-coastal work can result in more coverage for certain types of data at lower cost than using research vessels.

Aircraft have a particular advantage for coastal observing that comes from the combination of speed and range they make available for remote measurements and expendable instrument deployment. The issue of aliasing in space and time is especially significant in the coastal environment where scales of air-sea-land interaction can vary too rapidly to be adequately covered by any affordable combination of ships, moorings, or autonomous underwater vehicles. Satellite remote sensing is valuable, but coverage is sometimes limited by satellite orbit parameters or by cloud cover, especially in coastal marine layers. Using phased-array technology, high-frequency radars can provide excellent coverage of surface currents (except very close to the coast) and surface waves, but they offer very limited subsurface measurements. Airborne remote and expendable measurements of sea surface temperature, subsurface salinity and temperature, surface waves and currents, ocean color, coastal morphology, coastal bathymetry, and important atmospheric and terrestrial variables can significantly enhance data

SUMMARY

The search for the explanation of the narrow currents that deflected *Kon-Tiki* southward started in the summer of 2002 while one author (Legeckis) was sitting at the edge of the ocean in Wildwood, New Jersey, casually reading about Heyerdahl's Pacific adventures. A single sentence relating mysterious currents to changes in water temperature and the corresponding roughness of the sea surface was puzzling. It was assumed that these changes were somehow related to the TIWs. It is of interest to note that finding the connection only became possible due to the steady improvement in the quality of satellite and *in situ* observations. In 2005, Olav Heyerdahl will attempt to duplicate his grandfather's voyage on a new raft. The eyes of many satellites will follow his quest but the currents, winds, and waves will still be controlled by Mother Nature.

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Aircraft are ideal for both fast-response investigations and routine, long-term measurements, and they naturally combine atmospheric measurements with oceanographic measurements on similar temporal and spatial scales.

collected by fixed and mobile oceanographic platforms in coastal regions. The combination of satellite, aircraft, ship, and moored measurements has proven to be especially powerful in both coastal and open-ocean regions.

In this article we give several examples of how aircraft have been used recently for collecting oceanographic and marine atmospheric data, and how the University National Oceanographic Laboratory System (UNOLS) is working through its newly formed Scientific Committee for Oceanographic Aircraft Research (SCOAR) to improve access to research aircraft facilities for the ocean sciences.

RECENT RESULTS FROM AIRBORNE OCEANOGRAPHY

The principal attributes that aircraft provide as oceanic research platforms are speed, range, targetability, and an ability to operate in a wide range of environmental conditions. As an example of the last, Figure 1 shows a view of the high wind and sea-state conditions encountered by the Twin Otter aircraft operated by the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) on a flight over the Sea of Japan (East Sea) during a study of winter storms.

Aircraft speed is often a key factor in obtaining data in rapidly changing conditions. Figure 2 shows results from an aircraft survey of the coastal upwelling system off Oregon during summer 2001. These data were gathered with a small, twin-engine aircraft that was instrumented to measure several oceanic and atmospheric variables with *in situ*, remote, and expendable sensors. The survey, covering 170 km x 80 km, was completed in seven hours and produced a reliable "snapshot" of the coastal environment. Cool ocean surface temperatures delineate the upwelling center off Newport, Oregon, which typically generates a separated upwelling jet over Heceta Bank, the relatively shallow region just north of 44°N. Day-to-day changes in wind forcing and the resultant oceanic upwelling conditions make the aircraft approach ideal for capturing synoptic conditions on these scales.

In another example of how aircraft have been used, the C-130 aircraft operated by the National Science Foundation's (NSF) National Center for Atmospheric Research (NCAR) provided measurements of the surface wave field off Mexico (Figure 3). As in this case, the wind-driven wave field in many coastal regions is characterized by rapid temporal changes and very short spatial scales. The wave field can be observed in a realistic and believable manner with the aircraft approach.

In a dual-aircraft operation, a National Oceanic and Atmospheric Admin-

Figure 1. View from a port-side window of the CIRPAS Twin Otter flying a measurement mission at 100 feet above the Sea of Japan (East Sea) during gale-force winds. This program studied the modification of the upper ocean and lower atmosphere due to high wind stresses and strong ocean-to-atmosphere heat fluxes during winter. The aircraft allowed the ocean and atmosphere to be measured simultaneously and quickly during rapidly evolving weather, gathering data that could not be obtained otherwise. (Research supported by ONR.)

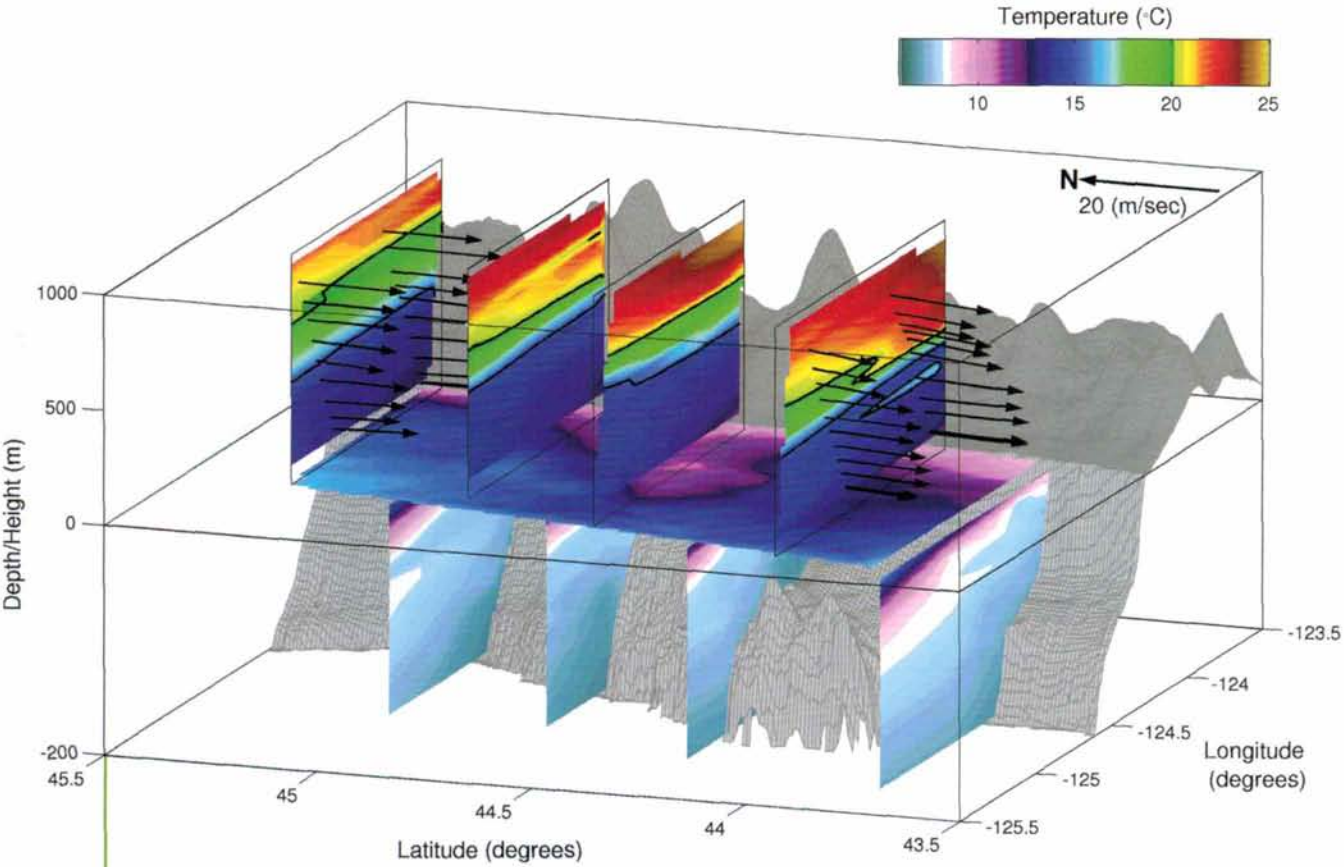

Figure 2. View of the wind-driven coastal upwelling system off central Oregon. Oceanic temperatures, atmospheric equivalent potential temperatures and winds were obtained using an instrumented, light, twin-engine aircraft operated by the University of North Carolina. This survey, covering an area 170 km alongshore by 80 km cross-shore, was completed in 7 hours on July 24, 2001, and it gives a nearly synoptic, three-dimensional snapshot of the ocean and atmosphere. A strong atmospheric temperature inversion typical of this region in summer, can be seen around 500 to 700 m at about the height of the coastal mountains, and the southward winds are somewhat strengthened beneath the inversion. Recently upwelled water near the coast is apparent in the sea surface temperature pattern, with a cool upwelling jet separating from the coast and following the outer edge of the continental shelf adjacent to Heceta Bank, the shallow region immediately north of 44°N. (Research supported by NSF.)

istration (NOAA) P-3 and the NCAR C-130 measured atmospheric and oceanographic structure above and in the equatorial warm pool and along the 95°W transect during the Eastern Pacific Investigation of Climate. Oceanic current, temperature, and salinity profiles using AXCPs (air-deployed expendable current profilers) and AXCTDs (air-

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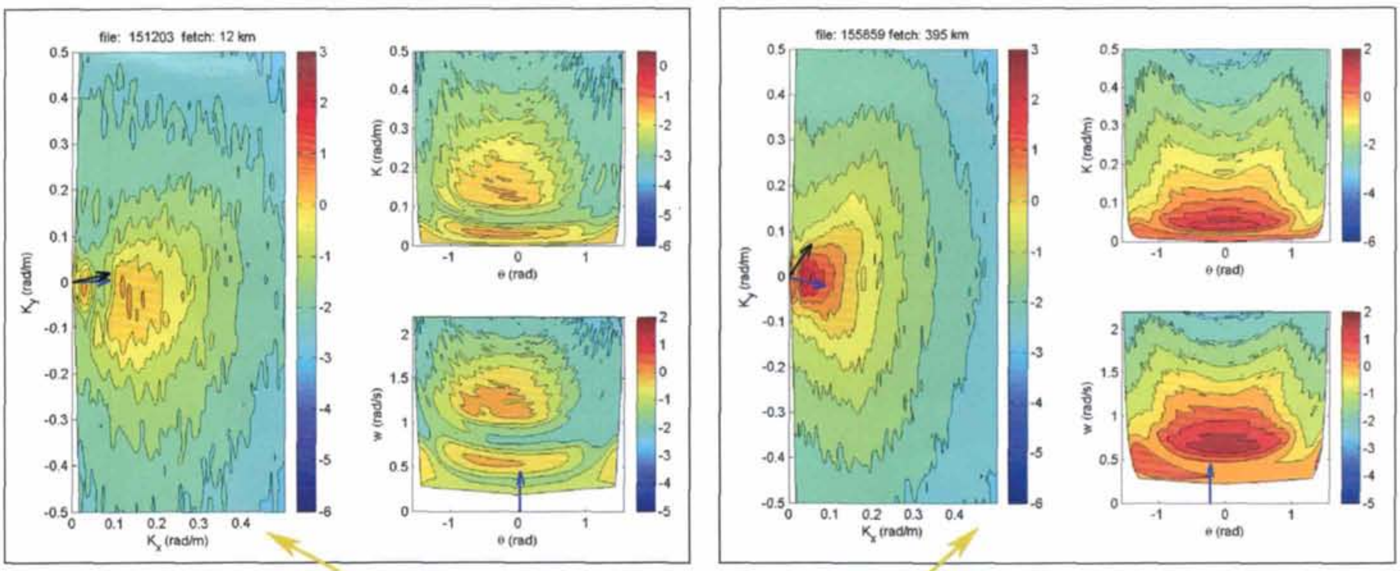
Airborne Measurements of Surface Wave Directional Spectra



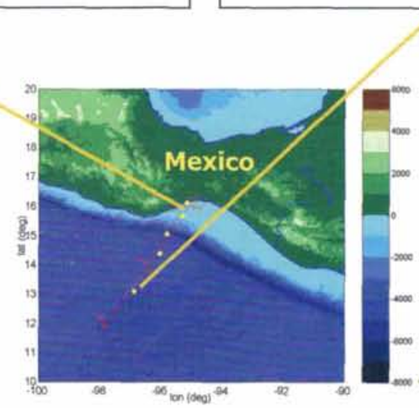


Figure 3. Airborne measurements of the evolution of surface wave directional spectra measured with the NASA Airborne Terrain Mapper (ATM) on board the NSF/NCAR C-130 aircraft in the Gulf of Tehuantepec Experiment, off the coast of Mexico in February 2004. Such coverage provided by airborne measurements of the ocean surface is indispensable in resolving the spatial patterns and temporal evolution of processes that occur on length and time scales shorter than can be measured by other means, whether *in situ* or remote. (Research supported by NSF.)

borne expendable conductivity-temperature-depth profilers) were concurrently mapped with atmospheric structure using GPS sondes to provide three-dimensional, gridded snapshots in and above the warm pool centered at 10°N and 95°W (Figure 4). Sequential snapshots from repeated flights delineated the evolution of the spatial structure in both the atmosphere and the ocean, which was then placed in context with the time series collected by the R/V *Ron Brown* and the TAO (Tropical Atmosphere Ocean) mooring arrays. Such synoptic data have improved understanding of ocean-atmosphere coupling over regional scales for both light and strong wind conditions.

SCIENTIFIC COMMITTEE FOR OCEANOGRAPHIC AIRCRAFT RESEARCH

In recognition of the increasing importance and value of aircraft as observational platforms in oceanographic research, UNOLS established SCOAR in late 2002. SCOAR held its inaugural meeting in February 2003 with seven charter members attending, along with the program managers from NSF, NOAA, the Office of Naval Research (ONR), and the National Aeronautics and Space Administration (NASA) who oversee research aircraft operations within those agencies. SCOAR aims to establish procedures for research aircraft that follow the present UNOLS practices for research-vessel use, with the goal of making it understandable, easy, and thus desirable for ocean scientists to make greater use of research aircraft. To be consistent with the operation of its ships, this will require UNOLS to designate appropriate research-aircraft-operating organizations to be National Oceanographic Aircraft Facilities (NOAFs—sim-

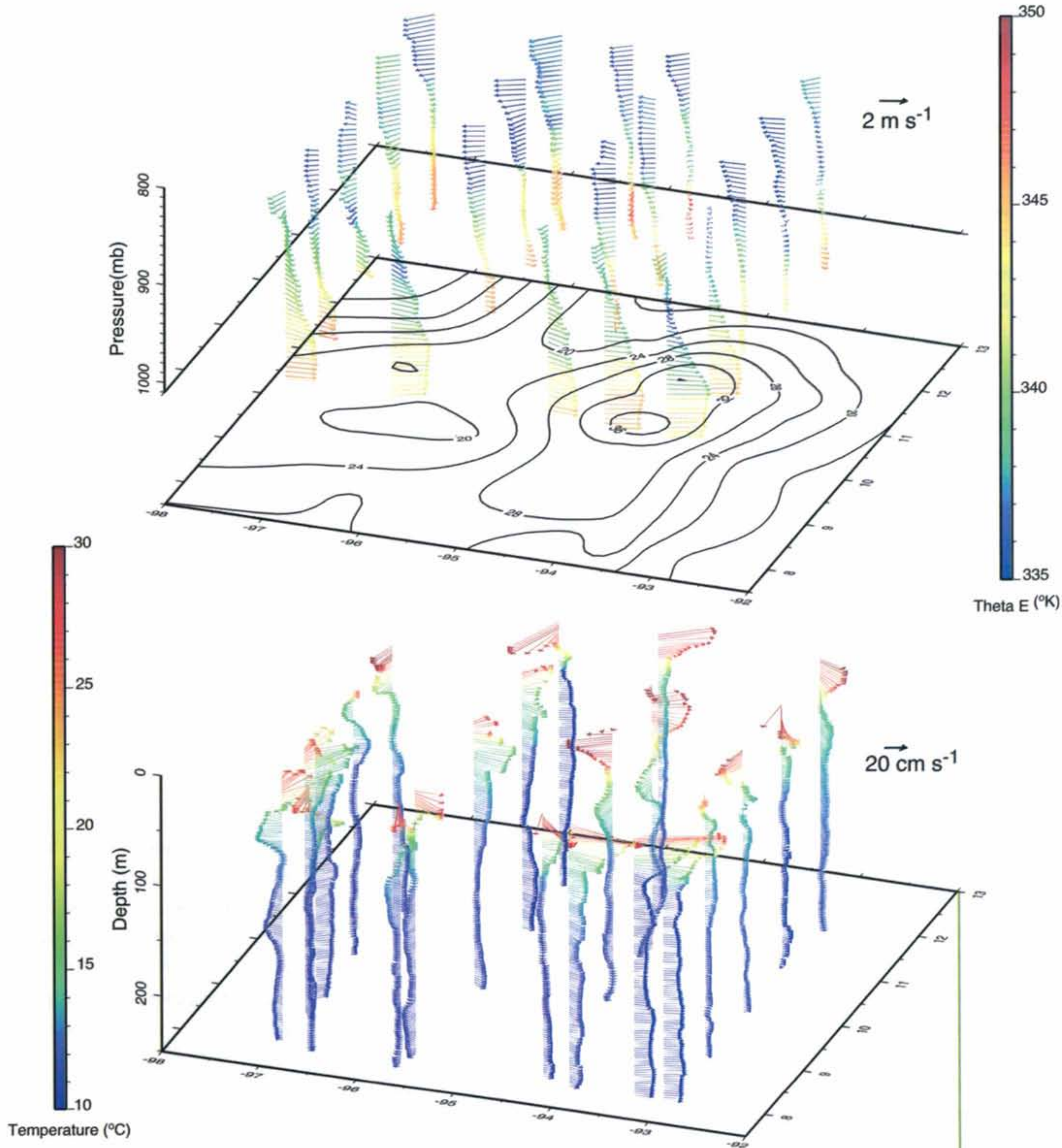


Figure 4. Three-dimensional depiction of atmospheric and oceanographic data acquired during the EPIC field program from a NOAA P-3 research aircraft on September 16, 2001. The upper panel shows atmospheric equivalent potential temperatures in color superposed on vector winds from GPS sondes in the lowest 2000 m of the atmosphere. Oceanic mixed-layer depth, at 2-m intervals, is depicted as the black contours from AXCPs and AXCTDs relative to the lower panel showing temperatures superposed on vector current profiles in the upper 200 m from AXCPs. (Figure courtesy L. Shay, University of Miami.) (Research supported by NSF and NOAA.)

ilar to institutions that operate one or more UNOLS ships). These will typically be university or not-for-profit organizations in the UNOLS style. UNOLS has designated the Center for Interdisciplinary Remotely Piloted Aircraft Studies at the Naval Postgraduate School as the first NOAF. UNOLS also will institute application procedures for NOAF aircraft and will assist in making the application procedures for other nationally available research aircraft more widely known and thereby easier. The SCOAR web site (www.unols.org/committees/scoar) now serves as a first stop for ocean scientists interested in obtaining aircraft facilities for their research. It presently lists and has links to most federally operated research aircraft platforms. On-line application forms for the CIRPAS aircraft and connections to other aircraft-operating agencies are provided there.

The establishment of SCOAR was motivated in part by the recognition that the nation currently supports a sizeable number of research aircraft operated by a range of agencies, universities, and public entities. The federal fleet includes some 40 aircraft operated by or for NSF, ONR, NASA, NOAA, NRL (Naval Research Laboratory), DOE (Department of Energy), FAA (Federal Aviation Administration), and the USCG (U.S. Coast Guard). Most of these aircraft are used for specialized research and development, but several are available for oceanic and atmospheric research. A federal committee, the Interagency Coordinating Committee for Airborne Geosciences Research and Applications (ICCAGRA), is charged with facilitating interagency cooperation and being a resource to senior-level management on airborne geosciences issues, but prior to SCOAR there had been no coordinating body to assist users with the application procedures for this ensemble of aircraft platforms. The university research aircraft fleet is smaller; however, information about these aircraft and how a potential user might gain access to them has been neither centralized nor uniform across institutions. Thus, SCOAR's involvement in gathering information about aircraft and measurement systems, making this information available to users, and facilitating access to these assets is a significant aspect of its mission. The four principal activities and goals for SCOAR are summarized in Box 1.

SCOAR has established a standard list of instruments that will be desirable on each UNOLS aircraft. Specialized sensor/data packages should be accommodated as well, depending upon the specific mission. Box 2 presents the Standard Instrumentation List, which will evolve as UNOLS and SCOAR gain experience with the needs of the user community.

SCOAR members are scientists familiar with research aircraft use. Present committee members are John Bane (University of North Carolina at Chapel Hill, physical oceanographer, SCOAR Chair), Charles Flagg (State University of New York at Stony Brook, physical oceanographer), Ken Melville (Scripps Institution of Oceanography, physical oceanographer), Dan Riemer (University

BOX 1. FOUR PRINCIPAL ACTIVITIES AND GOALS FOR SCOAR

- SCOAR will provide recommendations and advice to the operators and supporting funding agencies of the UNOLS-designated National Oceanographic Aircraft Facilities regarding operations, sensor development, fleet composition, fleet utilization, and data services as appropriate
- SCOAR will provide the ocean sciences user community with information and advice concerning research aircraft facilities, including experiment design, facility usage, scheduling, and platform and instrumentation capabilities
- SCOAR will promote collaborations and cooperation among facility operators, funding agencies, and the scientific community to improve the availability, capabilities, and quality of aircraft facilities supporting the ocean sciences
- By promoting collaboration among the ocean sciences, atmospheric sciences, and other science communities using aircraft in support of their research, SCOAR will work to improve utilization and capabilities for all participating communities

BOX 2. STANDARD INSTRUMENTATION LIST FOR UNOLS AIRCRAFT

Aircraft Flight Parameters

- Position and time
  - GPS – WAAS and/or differential
  - Inertial navigation system (some aircraft)
- Attitude, pressure altitude, rate of climb, heading, true air speed, ground speed and track
- Distance above surface (radar or laser altimeter)

Flight Level Atmospheric Parameters

- Temperature
- Pressure
- Humidity
- Wind speed and direction (horizontal, vertical)
- Atmospheric turbulence
- Liquid water

Remote Sensing

- Solar radiation
- Sea surface temperature
- Visible imaging, digital video, frame grabbing

Deployable Sensors

- Dropwindsondes
- AXBT, AXCTD, AXCP, AXKT, sonobuoys
- Surface drifters and floats

Instrumentation Integration Facility

- Downward looking port
- Data and power bus, including time and/or position stamp

of Miami-RSMAS, atmospheric chemist), Bob Bluth (Naval Postgraduate School, CIRPAS director and ex-officio SCOAR member), Haflidi Jonsson (Naval Postgraduate School, CIRPAS senior scientist and ex-officio SCOAR member), and John Seinfeld (California Institute of Technology, chemical engineer and ex-officio SCOAR member). Committee members will typically be ocean scientists, but those from allied fields such as marine meteorology and terrestrial environmental studies will be welcomed.

THE CENTER FOR INTERDISCIPLINARY REMOTELY PILOTED AIRCRAFT STUDIES

In 1996, ONR established CIRPAS as a research center at the Naval Postgraduate School, and it became the first UNOLS NOAF in 2003. CIRPAS, based at the Marina Municipal Airport in Marina, California (just north of Monterey), serves the scientific community by providing measurements using an array of airborne and ground-based meteorological, oceanographic, and remote sensors. These measurements are supported by a ground-based calibration facility. Data collected by the CIRPAS airborne platforms are reduced at the Monterey facility and provided to the user as coherent data sets. CIRPAS conducts payload integration, reviews flight safety issues, and provides logistical planning and support as a part of its research and test projects around the world.

CIRPAS provides unique flight operation and scientific measurement services by:

- Providing access to manned aircraft, unpiloted aerial vehicles (UAVs), scientific instruments, and support equipment to spare users the cost of ownership, guaranteeing equal access by all interested parties on a first-come, first-served basis
- Instrumenting and operating aircraft to meet the requirements of a variety of individual research and test programs
- Developing new instrumentation to meet increasing challenges for improvements in meteorological and oceanographic measurements
- Calibrating, maintaining, and operating the facility's airborne instruments

in accordance with individual mission specifications
- Integrating auxiliary payloads, as required, and handling flight safety and logistics tasks, allowing the user to concentrate on specific mission goals

CIRPAS presently operates three piloted and several remotely piloted aircraft for scientific and defense research. The platform that has been most widely used in oceanographic projects is the UV-18A Twin Otter (Figure 5). This piloted, twin-turboprop Short Takeoff and Landing (STOL) aircraft can cruise at very low speeds for long durations over the ocean. Several of the external, nose-mounted sensors on the CIRPAS single-engine Pelican-2 aircraft are shown in Figure 6. CIRPAS also can provide a wide variety of oceanographic and atmospheric airborne sensors to the research community. This includes off-the-shelf instrumentation as well as one-of-a-kind custom-built packages. The CIRPAS basic instrumentation package follows the UNOLS-NOAF standard instrument list given in Box 2. Box 3 lists the optionally available instruments for CIRPAS aircraft. To obtain more information on this facility, visit the CIRPAS web site (web.nps.navy.mil/%7Ecirpas/).

THE FUTURE

Rapid developments in ocean-observing systems and research observatories within the nation's coastal oceans and in international deep-ocean regions have prompted SCOAR to consider the utility of airborne observations within these activities. The committee believes that aircraft will be useful in three principal ways: (1) routine observations in areas that do not have fixed, *in situ* instrumentation (e.g., to obtain data for the initialization or verification of oceanic and atmospheric models), (2) observations surrounding observatory sites or moorings to provide more complete, three-dimensional views of the environment, and (3) intense observations for specific, short-term events such as algal blooms, high-runoff episodes, atmospheric storms, Gulf Stream intrusions, and ocean-eddy events.

Long-range aircraft operated by agencies such as NOAA, NCAR, NASA, and NRL are presently available for deep-ocean observatory needs far from a land base. To best serve the nation's growing coastal observing systems and observatories, SCOAR foresees the need for regional research aircraft centers. These centers would operate shorter-range aircraft, such as the Twin Otter and smaller, slow, good-visibility, single- or twin-engine aircraft over coastal and inshore waters. CIRPAS is already filling this role on the U.S. West Coast. A strong case can be made for centers on the U.S. East Coast, in Alaska, on the Gulf of Mexico coast, and in Hawaii to enhance coastal observing systems that are either operating or

Figure 5. The UV-18A Twin Otter turboprop aircraft operated by the Center for Interdisciplinary Remotely-Piloted Aircraft Studies for oceanographic and meteorological research. Important operational characteristics of this aircraft include: Maximum endurance of 8 hrs (extended further during ferry operations), maximum altitude of 25,000 ft, 70-160 knots operational speed range, 200 amps of payload power (DC and AC combined), wing span of 65 ft, gross takeoff weight of 13,500 lbs, and an approximate 6,000 lbs useful load.

planned in those regions.

To help plan for new research aircraft resources for the longer term, SCOAR and ICCAGRA intend to send an open letter to the geosciences research community requesting input on anticipated needs as well as new platform and instrumentation ideas. A community-wide workshop in these areas is envisioned.

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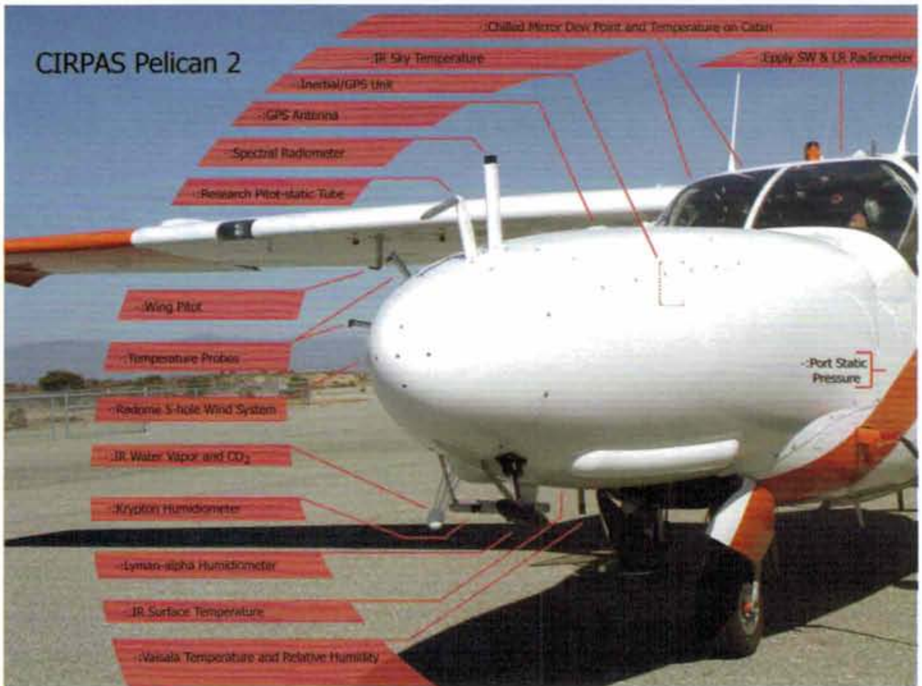

Figure 6. Instruments mounted on the nose of the CIRPAS Pelican-2 single-engine aircraft. These are used in measuring atmospheric variables immediately above the ocean in air-sea interaction studies. The aircraft also supports remote sensing instruments that view the upper ocean and the ocean's surface from side or bottom mounted ports, and it has an expendable instrument capability (launch chutes and data reception system) for AXBTs, AXCTDs, current-following floats, and others.

BOX 3. OPTIONAL INSTRUMENTATION AVAILABLE FOR CIRPAS AIRCRAFT

- Passive cavity aerosol spectrometer probe
- Forward scatter spectrometer probe
- Cloud aerosol precipitation spectrometer
- Aerodynamic particle sizer
- Cloud imaging probe
- Precipitation imaging probe
- Three-wavelength nephelometer
- Three-wavelength soot photometer
- Stereo cloud imaging probe
- 95 GHz cloud radar
- Scanning Doppler wind LIDAR
- Stabilized platform for radiometric measurements
- Cloud condensation nuclei counter
- Aerosol mass spectrometer
- Twin differential mobility analyzer
- Phased Doppler cloud droplet spectrometer
- MOUDI size discriminating aerosol collection system
- Radome flow angle/INS-GPS turbulence system

Eighth International Conference on Paleoceanography

BY FRANCIS E. GROUSSET, PEGGY DELANEY, HARRY ELDERFIELD, KAY-CHRISTIAN EMEIS, GERALD HAUG, LARRY C. PETERSON, THOMAS STOCKER, AND PINXIAN WANG

Every three years since 1983, the paleoceanographic community comes together to share new discoveries and celebrate their discipline at the International Conference on Paleoceanography (ICP). The host country and meeting location are different each time, and the next venue is selected by community vote at the end of each conference. In recognition of the internationally renowned efforts of the French community in both the Integrated Ocean Drilling Program (IODP) and International Marine Global Changes (IMAGES) coring programs, France was selected at the end of ICP-7 in Sapporo (Japan) to be the organizer of the 2004 ICP-8.

ICP-8 took place in Biarritz, France, from September 5 to September 10, 2004, in the conference center of the local landmark casino. The Environnments et Paléoenvironnement Océanique (EPOC) group of University Bordeaux I acted as the local organizing committee. A total of 700 scientists attended from 34 different countries—including 250 students. The overall conference theme was "An Ocean View of Global Change."

Scientific topics addressed during ICP-8 provided attendees with information about the latest discoveries and the current state of knowledge in paleoceanography. Meeting talks and discussions identified emerging new areas of knowledge and raised questions about unresolved scientific problems. The Scientific Committee selected five themes covering two time scales: (1) the Mesozoic (from 248 to 65 million years ago [Ma]) and Cenozoic (from 65 Ma to the present) oceans, but with an emphasis on (2) oceanographic questions concerning the more modern oceans of the Holocene (the last 10,000 years) and the most recent glacial. Two main scientific fields were considered: changes in the chemistry of the ocean (e.g., the carbonate and silica systems of the Pleistocene [1.8 Ma to 10,000 years ago] ocean and biogeochemical cycles) and changes in climate (e.g., high-frequency climate variability and interhemispheric ocean-continent-climate links).

The main highlights and outcomes that emerged from the thirty-five invited talks and the five hundred posters are summarized below. To obtain a copy of the detailed agenda, full abstracts, and a list of invited speakers and their reported results and hypotheses, go to the ICP-8 web site: www.icp8.cnrs.fr.

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