Workshop on Atmospheric Forcing of Ocean Circulation

James R. Scoggins¹ and Christopher N. K. Mooers²

1. Introduction

The workshop on Atmospheric Forcing of Ocean Circulation was conducted on 5–7 January 1988 at Tulane University in New Orleans. Approximately 100 invited scientists from universities, government agencies, and research laboratories in the United Kingdom, France, Germany, Canada, and the United States participated in the workshop.

Planning for the workshop was initiated by the Institute for Naval Oceanography (INO), Stennis Space Center, Mississippi. An Organizing Committee was formed consisting of members who represented the scientific community, including the World Ocean Circulation Experiment (WOCE) and the U.S. component of the Tropical Oceans–Global Atmosphere (US–TOGA) program both of which later became co-sponsors of the workshop with INO. Members of the committee included James R. Scoggins, chairman, Texas A&M University; Kenneth L. Davidson, Naval Postgraduate School; Robert A. Weller, Woods Hole Oceanographic Institution; the late John A. Brown, Jr., and D. B. Rao, National Oceanic and Atmospheric Administration/National Meteorological Center (NOAA/NMC); Christopher N. K. Mooers and Robert C. Willems, INO; J. J. O'Brien and David Legler, Florida State University; Jagadish Shukla, University of Maryland; and William Large and Frank O. Bryan, National Center for Atmospheric Research (NCAR).

As the title of the workshop suggests, the atmosphere and ocean constitute a coupled system, but there are scientific issues as to under what conditions full two-way coupling must be considered as opposed to treating the simpler situation of the atmosphere forcing the ocean circulation in a one-way coupling. It was recognized that before these systems could be coupled in models and an understanding achieved of how they interact, each must be understood with emphasis on the air-sea interface. Specifically, the workshop participants addressed the questions of how to measure and integrate fluxes of heat, moisture, and momentum at the air-sea interface into models, and how to improve the models and model interactions.

2. Objectives

Objectives of the workshop as defined by the Organizing Committee were to (1) review the present status of the prescription of atmospheric forcing of the ocean and the needs for improve-

ment for routine (operational) data, research data sets, and numerical models, (2) define the scientific issues, including the status of algorithms and parameterizations, the roles of boundary-layer models, unconventional data, and coupled atmospheric-oceanic models, and clarify limiting factors; and (3) recommend an overall plan of research on atmospheric forcing of ocean circulation, taking into account the requirements of INO, WOCE, and TOGA.

3. Topics addressed by working groups

The objectives were addressed by defining seven topics, each of which was considered by a working group composed of about 15 scientists. The topics were (1) Bulk Parameterization Schemes for Air-Sea Flux Computations, (2) Computation of Global Air-Sea Flux Climatology, (3) Atmospheric Forecast Model Data Assimilation and Air-Sea Flux Computations, (4) Ocean Model Sensitivity to Atmospheric Forcing, (5) Ocean Surface Boundary Conditions, (6) In Situ Networks, and (7) Satellite Missions.

4. Organization and conduct

The workshop consisted of overview or position presentations, poster papers, and extensive working group sessions. Participation by each individual in several working groups was facilitated by alternating working group sessions, thus permitting participants to "float" if their working group was not in session. The interaction of working groups was encouraged and topics coordinated through plenary sessions held following each series of working group sessions. Charges prepared by the Organizing Committee for the working groups provided guidelines for discussion. In accordance with the workshop objectives, each working group was asked to review the status of its topic, define significant problems, and recommend a plan of research.

5. Recommendations of working groups

Outlined below are the charges to each working group and the group's recommendations.

a. Bulk-Parameterization Schemes for Air-Sea Flux Computations
Henry Charnock, the University of Southampton,
chairman

Charge: Review surface and boundary layer parameterizations

¹ Texas A&M University.

² Institute for Naval Oceanography.

of current forecast models (NMC, FNOC, and ECMWF), and recommend bulk-parameterization schemes for computing the atmospheric forcing of the ocean. Consider and estimate the uncertainty and sensitivity associated with each scheme.

Recommendations:

1. That ocean modelers adopt a particular set of bulk coefficients and continue to use them for some years.
2. That a small group be set up to specify the detailed application of the bulk coefficients adopted.
3. That workers with large climatological data sets delay the use of bulk formulas to as late a stage in their calculations as possible in order to facilitate later adoption of improved parameterization schemes.
4. That a small group be set up to monitor developments in boundary-layer parameterization and to recommend changes when desirable.
5. That particular attention be paid to conditions in light winds and to the effect of non-equilibrium wave fields on the exchange coefficients, especially in strong winds.

b. *Computation of Global Air-Sea Flux Climatology*

R. W. Reynolds, *National Oceanic and Atmospheric Administration/National Weather Service/National Meteorological Center/Climate Analysis Center*, and
S. K. Esbensen, *Oregon State University*, co-chairmen

Charge: Advise whether or not the bulk-parameterization schemes recommended by Working Group A should be used to recompute global air-sea flux climatologies, including consideration of uncertainty and sensitivity estimates, and climatologies of any other fields required for ocean model surface boundary conditions specified by Working Group E. Specify which observational data sets ought to be employed for such a project.

Recommendations:

1. A Comprehensive Ocean-Atmosphere Data Set (COADS) global heat flux and wind-stress climatology should be produced now from COADS monthly summaries with parameterization schemes recommended by Working Group A.
2. Re-analysis of the COADS basic data set Tape Data Family-11 (TDF-11) should be performed only after the proposed COADS climatology has been examined and the data problems discussed below have been understood.
3. "Static" analysis of combined satellite and conventional data should be performed to improve flux climatologies and to provide a point of comparison for flux climatologies produced by dynamical data assimilation schemes.
4. All flux climatologies should have a data density indicator.
5. All flux climatologies should be assigned a measure of uncertainty to provide for observational error and spatial and temporal sampling errors.
6. Funding agencies should insist on uncertainty estimates for any proposed flux climatology.
7. Climatological data bases for different variables and cross products should be developed with spatial scales of one-degree latitude and longitude and temporal scales of one month for the period 1850 to present.

8. The number of observations for each variable and cross product should be saved.
9. Sea surface temperatures (SST) observations made prior to World War II should be corrected based on winds, air temperature, and dew point at the time of each observation.
10. Only nighttime air and sea temperature should be used to compute sensible heat flux.
11. Both daytime and nighttime humidities should be used to compute latent heat fluxes.
12. No major correction of pressure data is needed.
13. Sea level pressure data from island and other coastal stations should be used to augment the surface marine pressure data.
14. For post World War II measurements, correct any Beaufort estimates to ensure consistent scales.
15. Separate the anemometer and Beaufort wind measurements and use the anemometer values with caution.
16. Complete a comparison of the Beaufort winds with geostrophic winds to develop corrections for the pre-World War II Beaufort measurements as a function of time.
17. Global data should be gathered together into clean data sets, covering many years. An update for COADS (for 1980–1986) is needed.
18. Large data sets of different types of data usually should not be merged in the archive. However, it should be easy to merge them together when needed.
19. Catalogs about data should be available and should include appropriate graphics to indicate data coverage.
20. Data products prepared by investigators (monthly or daily climatologies, analyses, etc.) should be gathered into the archives.
21. Important data sets should be located in at least two or three different archives for security.
22. Examine bulk formulas and estimate errors in their formulations.
23. Determine if TDF-11 information can be used to improve the fluxes.
24. Document data sources within archive.
25. Error statistics must be associated with climatology.
26. Re-analysis (dynamical assimilation) is necessary to make use of new data and to ensure consistency in model application.
27. The approach of Ismer and Haase (1987) should be followed for the global COADS heat flux climatology using integral constraints based on existing observations and theoretical expectations.
28. The approach could be used for other calculation of surface heat budget components from Voluntary Observing Ship (VOS) data. Though parameterization schemes are not necessarily perfect, the revised parameterization should give results consistent with meteorological and oceanographic evidence.

c. *Atmospheric Forecast Model Data Assimilation and Air-Sea Flux Computations*

K. Miyakoda, *Geophysical Fluid Dynamics Laboratory*, and E. Sarachik, *Pacific Marine Environmental Laboratory/National Oceanic and Atmospheric Administration*, co-chairmen

Charge: Recommend how to utilize operational atmospheric

forecast models to assimilate observed data, including anticipated satellite data, and how to compute global air-sea fluxes using both models and observed data. Provide a review of computational methods and make recommendations on their use.

Recommendations:

1. In order that the quality at the fluxes be assessed, the surface fluxes of net radiation (R_{net}), evaporative heat (LE), sensible heat (S), and heat into the ocean (Q) should be made standard diagnostics of operational and research forecast models. (Since the fluxes may be "noisy," appropriate averaging in time and space may be necessary to provide a useful diagnostic.)
2. Assimilation of single-level data, especially at the surface, needs to be perfected.
3. Boundary-layer studies need to be performed to determine the formulation that gives the most realistic surface quantities.
4. Efforts should be made now to assure that forecast models will usefully assimilate "scatterometer" winds, which will become available in the early 1990s. The improvement of the measurement of surface winds is expected to make the estimation of surface fluxes.
5. It is important to compare the fluxes from different models to identify and understand the similarities and differences.
6. An effort should be made to compare model generated fluxes with directly measured fluxes on time scales of a day to a few days. This effort need not require new flux measurements since direct flux measurements already exist for JASIN, FASINEX, etc., and a model re-analysis during these time periods may allow the comparison to be made.
7. That the feasibility of re-analysis concept be demonstrated by short period re-analysis. Examples include FGGE (First GARP [Global Atmospheric Research Program] Global Experiment), SEASAT, JASIN, FASINEX, and other special event periods.
8. Every effort should be made to convert hand tabulated data (in the archives of the various meteorological centers) to electronic form, especially data acquired since 1950. The availability of such data could vastly improve our climatic data base and would make a strong case for re-analysis. A re-analysis using this augmented data set would provide a long data set of model derived surface fluxes.
9. Current data that misses the operational cutoff should be collected and archived electronically so that future generations can have access to this valuable data to produce climate data sets in the future.

d. Ocean Model Sensitivity to Atmospheric Forcing

J. J. O'Brien, *Florida State University, chairman*

Charge: Specify the required accuracy of atmospheric surface forcing functions, based on the sensitivity of a complete range of ocean models to the forcing. Comment on the impact of strong and transient forcing events such as hurricanes and mid-latitude "bombs."

Recommendations:

1. That managers and funders recognize sensitivity tests of

oceanic models to atmospheric forcing functions be considered crucial and necessary to more fully understand the impact of the different forcing functions and to evaluate these data fields.

2. Ocean modelers need to improve their understanding of which atmospheric forcing functions have the most effect on various ocean phenomena and how sensitive their models are to these functions.
3. Researchers should strive to achieve the following accuracies for atmospheric forcing fluxes (based on model sensitivity and may not be currently obtainable): latent heat, sensible heat, short-wave radiation, and long-wave radiation should be accurate within 20 percent for periods of 1 hr to 30 days, and with averaging periods of 2 months or longer, $10 \text{ W} \cdot \text{m}^{-2}$ for areas $2^\circ \text{ lat} \times 2^\circ \text{ long}$; and wind stress should be accurate within 10 percent RMS for periods of 1 hr to 1 day and for coastal studies for periods of 1–30 days, and 10 percent for composite means for periods of 1–30 days.

e. Ocean Surface Boundary Conditions

R. L. Haney, *Naval Postgraduate School, chairman*

Charge: Describe the surface boundary conditions being used, and likely to be used, to force ocean models. Specify the temporal and spatial scales of the forcing, and comment on requirements for observational data.

Recommendations:

1. The quantities that are needed to force ocean models should be archived in a form convenient for use by the general oceanographic modeling community. These quantities should be computed and saved as routine diagnostic outputs from the synoptic analyses produced by atmospheric prediction models. The data from regional, as well as global, atmospheric models should be saved. The accuracy and adequacy (in terms of space/time resolution) of the fluxes (or atmospheric quantities) for forcing ocean models is not well known and needs to be studied.
2. Model sensitivity experiments should be performed with available data by using large-scale non-eddy-resolving models, eddy-resolving gyre models, and regional models; by examining model sensitivity to various degradations and averages, in space and time, of the data using both regional and global ocean models; and by using models differing only in their surface-boundary/mixed-layer formulation.
3. Results of ice models should be examined to determine the range and climatology of enhancement (or diminution) of the momentum transfer in ice covered regions.
4. Studies should be undertaken to determine the climatology of freshwater removal and supply due to ice formation and melting.
5. Standardized runoff time series should be developed for each model's major rivers.

f. In Situ Networks

W. D. White, *Scripps Institution of Oceanography, and*
P. K. Taylor, *Institute for Ocean Sciences, co-chairmen*

Charge: Address the design of future, and the utilization of existing, in situ surface data networks that would enhance the

ability to compute surface fluxes and to establish their uncertainties. Address this question separately for high-resolution, limited-area, and basin-scale models.

Recommendations:

1. A continuing need exists to encourage development of accurate instruments capable of unattended measurement of the basic variables when deployed on buoys. Such sensors would also be suitable for use on VOS and Scientific Volunteer Ships (SVS). Each of the following should be regarded as priorities: development of a suitable³ humidity sensor; improvement of air temperature sensors, including better radiation shielding; improvement of wind sensors for use on buoys, and electronic systems for averaging and correcting for platform motion on buoys and ships; production of a suitable near-surface, sea surface temperature sensor; development of suitable radiation sensors; and development of suitable precipitation sensors.
2. All drifting buoy systems to be deployed for World Climate Research Program (WCRP) experiments should be equipped with sea surface temperature sensors and sea level pressure sensors. Since the latter will approximately double the buoy system cost, extra funding will be necessary. If full support for this funding cannot be found, then priority should be given to those buoys deployed in tropical and Southern Hemisphere oceans.
3. A need exists for a small number of research platforms of innovative design, primarily to improve our knowledge of air-sea transfer processes and, hence, the bulk-transfer formulas, but also for satellite sensor calibrations. Examples of such platforms are research spar buoys, and airships or blimps.
4. As improved instrumentation becomes available, it should, in cooperation with the operational meteorological agencies, be installed on chosen VOS, with the eventual aim of at least 100–300 higher-quality VOS. In this latter development, use of the SVS of the WOCE Volunteer Ship Program (WVSP) is recommended, since these volunteer ships are used by scientists who demand accurate measurements. Research to quantify the errors in the VOS data set should be encouraged with the aim of designing improved quality control schemes. Advantage must be taken of the Voluntary Ship Observing Programs—North Atlantic (VSOP-NA) program in this respect.
5. Expendable bathythermograph (XBT) and expendable conductivity, temperature, and depth (XCTD) data from the SVS in the WVSP should be utilized for calibration of the VOS and satellite-derived sea surface temperatures. Consideration should be given to extension of the Pacific Ocean XBT/XCTD networks to the Atlantic and Indian Oceans, allowing global numerical ocean models to be updated and verified.

g. Satellite Missions

Trevor Guymer, Institute of Ocean Sciences, United Kingdom, chairman

Charge: Review present and planned satellite missions that could impact the ability to compute global air-sea fluxes. Comment on the utility of satellite products, and on any in situ data that may enhance this utility. Provide the flow of data from satellites including time delays, so that the ability of atmospheric models (see section 5c) to assimilate the data can be assessed.

Recommendations:

1. An effort should be made to conduct pre-launch calibration and post-launch, long-term validation of the fluxes in order to meet the stringent accuracy requirements for temporal and spatial means. These efforts go beyond the normal activities of the space agencies. In particular, surface humidity and radiation sensors need to be installed in buoys at selected locations and ways of validating precipitation estimates over the ocean need to be found.
2. Satellite data should be made available in both real-time and off-line form, the former for assimilation into atmospheric general circulation models and the latter for their higher quality.
3. The feasibility of producing accurate surface fluxes by assimilating off-line satellite data into repeat runs of atmospheric models, possibly at a research center, should be investigated to enable best use to be made of improvements in satellite data and models while maintaining the internal consistency of a data set.
4. Resources should be allocated to allow reprocessing of satellite data when significant improvements are made to geophysical algorithms.
5. In preparation for generating gridded flux fields, further work should be conducted on the spatial and temporal statistics of the parameters involved, especially precipitation, surface wind, and waves. Methods of combining data from different satellites should be explored.
6. Retrieval algorithms for precipitation should be improved with an emphasis on global applicability and optimal use of multi-spectral information.
7. Methods of obtaining reliable fluxes from polar-orbiting sensors should be explored and particular attention should be paid to the computation of the downward long-wave component.
8. The benefits of a satellite-borne atmospheric lidar system to the estimation of surface fluxes should be investigated.

6. Concluding comments

A comprehensive report on the workshop, which will include the position papers, poster papers, and working group reports from which the above recommendations were extracted, is in preparation and will be available through INO by late summer or early fall of this year. Also included in the report will be the after-dinner speech by Ann Berman, deputy assistant secretary of the Navy.

³ "Suitable" means capable of the required accuracy for a financial cost which, for buoys, enables the system to be considered disposable, and for ships, allows installation of many systems—100 or more.

Acknowledgments. The Institute for Naval Oceanography is sponsored by the Office of Naval Research and managed by the University Corporation for Atmospheric Research. The authors of this summary were co-convenors of the workshop. They express their gratitude to the organizing committee, the working group chairmen, the authors of poster papers, and other participants, and to Tulane University for hosting the workshop.

Reference

- Isemer, H. J., and L. Hasse, 1987. *The Bunker Climate Atlas of the North Atlantic Ocean, Vol. 2: Air-Sea Interaction*. New York: Springer-Verlag. •

announcements (continued from page 1348)

Deadlines Calendar

Fellowships, grants etc.

- 15 November 1988 applications for the National Science Foundation Visiting Professorships for Women (October 1988 *Bulletin*, p. 1163)
- 30 November 1988 requests for participation in Course on Tropical Ocean-Atmosphere Interactions (13 February–10 March 1989), Fortaleza, Brazil (October 1988 *Bulletin*, p. 1067)
- 30 November 1988 applications for NCIM fellowships (summer 1989) (October 1988 *Bulletin*, p. 1067)

- 1 December 1988 abstracts for the International Symposium on Natural Catastrophes and Their Impact, Ankara, Turkey (October 1988 *Bulletin*, p. 1163)
- 15 December 1988 papers for the *Journal of Weather Modification* (this issue, p. 1348)
- 15 February 1989 applications for CIRES Visiting Fellowships (first consideration given to applications received by 1 December 1988) (this issue, p. 1348)
- 1 January 1989 applications for Administrator's awards of the Fulbright Scholar Awards in Germany, the United Kingdom, and Japan, the seminar in German Civilization, the NATO Research Fellowships, and the Spain Research Fellowships (April 1988 *Bulletin*, p. 408)
- 1 January 1989 abstracts for the Third Workshop on Artificial Intelligence Research (2–4 May 1989), Washington DC (October 1988 *Bulletin*, p. 1199)

Handbook of APPLIED METEOROLOGY

Edited by
David D. Houghton

The 46 chapters in the *Handbook of Applied Meteorology* are organized into five main sections: Part 1 deals with fundamental meteorological information; Part 2 addresses the topic of measurements; Part 3 focuses on specific major applications of meteorology; Part 4 provides a general discussion on some major impacts of meteorology on society; and Part 5 summarizes a wide range of resources available for meteorological data and knowledge. Two appendixes give additional information on terminology, units, and climatic data. This handbook presents, for the first time, an authoritative, compre-

hensive reference on meteorological knowledge and technology. Designed for professionals and technicians both within and outside the meteorological profession, this broad-ranging book offers general guidelines for those who need information on the effects of weather.

The *Handbook of Applied Meteorology* was awarded honorable mention in the category for best physical science book of 1985 in the Tenth Annual Professional and Scholarly Book

Awards sponsored by the Association of American Publishers.

To order please send \$94.50 plus \$4.00 postage and handling to:

**AMERICAN METEOROLOGICAL SOCIETY
45 BEACON ST.
BOSTON, MA 02108**