BAMS Article

Relocation of GATE from the Pacific to the Atlantic

Chidong Zhang, John M. Wallace, Robert A. Houze Jr.,
Edward J. Zipser, and Kerry A. Emanuel

ABSTRACT: This article documents historically the planning of the Global Atmospheric Research Program's (GARP) Atlantic Tropical Experiment (GATE), the largest atmospheric field program of all time. In its earliest planning, GATE was called the Tropical Meteorological Experiment (TROMEX) and was designed to be in the tropical western Pacific. For reasons including concerns of the U.S. Department of Defense, the international project was relocated to the tropical Atlantic and renamed GATE.

KEYWORDS: Atmosphere; Tropics; In situ atmospheric observations; Field experiments

https://doi.org/10.1175/BAMS-D-21-0151.1
Corresponding author: Chidong Zhang, chidong.zhang@noaa.gov
Supplemental material: https://doi.org/10.1175/BAMS-D-21-0151.2

In final form 12 March 2022

AFFILIATIONS: Zhang—NOAA/Pacific Marine Environmental Laboratory, Seattle, Washington; **Wallace* and Houze***—University of Washington, Seattle, Washington; **Zipser**—University of Utah, Salt Lake City, Utah; **Emanuel***—Massachusetts Institute of Technology, Cambridge, Massachusetts
* Retired.

The Global Atmospheric Research Program's (GARP) Atlantic Tropical Experiment (GATE) was by far the largest and most ambitious field campaign in the history of the atmospheric sciences. GATE took place over the tropical Atlantic Ocean during June–September 1974 with more than 5,000 scientists, technicians, and supporting staff from 72 countries. Observations were made by 13 aircraft, 39 ships, over 1,000 land surface stations, and six satellites (Kuettner 1974; Greenfield and Fein 1979). The primary objective of GATE was to understand interactions between tropical small-scale weather systems and the large-scale circulation and to advance numerical modeling and prediction of the atmosphere. Analyses of GATE data have been reported in many hundreds of peer-reviewed publications. The scientific achievements of GATE were summarized in several early reviews (e.g., Polavarapu and Austin 1979; Houze and Betts 1981) and officially reported in a collection of papers published by the Joint Scientific Committee of the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) (GARP 1982).[1]

There is, however, a little-known history of events leading up to GATE. Beginning in the late 1960s, a group of planners from several countries and organized by the WMO–ICSU had envisioned a large field project deploying ships and aircraft over the open warm waters of the tropical western Pacific. It was to be called the Tropical Meteorological Experiment (TROMEX). But at one point in the planning, the location of the planned field campaign was abruptly moved to the tropical Atlantic and renamed GATE. Some of the history of GATE and its planning have been documented on websites maintained by the American Meteorological Society[2] and the National Center for Atmospheric Research.[3] However, the TROMEX plan for the Pacific, the reason for relocating the experiment to the Atlantic, and related activities, including experiments conducted by the former USSR, have rarely, if ever, been mentioned in peer-reviewed publications in English-language journals. In this article, we are providing documentation of these lost parts of the story, especially steps and details of the planning of GATE that illuminate the international activities leading up to this great event in the history of science.

Mounting such a massive field campaign as GATE required a tremendous financial commitment. But funding for an unusually ambitious effort in atmospheric science became possible as a side effect of the Cold War, which was raging in the 1960s and 1970s. From the beginning of his administration, President John F. Kennedy was looking for ways that the United States and the USSR could reduce global tensions, and science was seen as a potential area of cooperation between the two superpowers. Kennedy made a speech to the UN General Assembly on 25 September 1961 that has been called "one of the roots of the Global Atmospheric Research Program" (e.g., Perry 1975). During this speech, Kennedy said, "The new horizons of outer space must not be driven by the old bitter concepts of imperialism and sovereign claims. The cold reaches of the universe must not become the new arena of an even colder war. To this end, we shall urge proposals extending the United Nations Charter to the limits of man's

[1] https://library.wmo.int/index.php?lvl=notice_display&id=12509#.YBmJrneQGCg

[2] www.ametsoc.org/sloan/gate/

[3] www.eol.ucar.edu/field_projects/gate

exploration of the universe, reserving outer space for peaceful use, prohibiting weapons of mass destruction in space or on celestial bodies, and opening the mysteries and benefits of space to every nation. We shall propose further cooperative efforts between all nations in weather prediction and eventually in weather control. We shall propose, finally, a global system of communications satellites linking the whole world in telegraph and telephone and radio and television. The day need not be far away when such a system will televise the proceedings of this body to every corner of the world for the benefit of peace" (www.jfklibrary.org).

By the late 1960s, the international cooperation in weather prediction that Kennedy's speech had expressed hoped for was institutionalized in 1967 as the Global Atmospheric Research Program. The purpose and vision of GARP were laid out elegantly in GARP Publication Series No. 1 (GP1), "An Introduction to GARP," published by a Joint Organizing Committee (JOC) of the International Council of Scientific Unions and the World Meteorological Organization (GARP 1969). GP1 opens with the statement that GARP "can be considered to be one of the most ambitious, complex, and promising efforts in the field of international scientific cooperation" and notes that it was the direct outcome of Resolutions 1721 and 1802 adopted by the United Nations in 1961 and 1962, not long after the Kennedy speech.

GP1 discusses how the nonlinearity of atmospheric motion implies that prediction of larger-scales of motion is affected by scales of motion that would not be resolved in global models of the 1960s. Among those smaller scales of motion, convective clouds and associated mesoscale processes stood out to the authors of GP1 as highly problematic because "great quantities of heat and moisture are transported to the upper troposphere and stratosphere by the large cumulus and cumulonimbus towers." And convection over the tropical oceans was of particular concern, as the report states, "Finally, in the great heat and moisture source of the tropical oceans, the situation is even more complex. Here the surface heating cannot be considered as the driving source, and the cumulus towers cluster in mesoscale convergence areas." The report ends up focusing on how numerical prediction of "large-scale motion, at any instant in the computation, is the background for such sub-grid-scale phenomena as are determined by that particular synoptic situation. These small-scale phenomena so determined are producing feed-back into the large scale. These effects, averaged over the large grid-scale, must quantitatively be introduced into the predictive scheme." And, so, the parameterization of convection, especially over the vast tropical oceans, became an organizing focus of GARP at the very beginning of the program. That focus would continue through the planning of TROMEX and its redesignation as GATE.

As GARP became organized, it created several subprograms (appendix II of GP1). The planning of a grand experiment to provide new data on the interaction of tropical convective clouds with the large-scale tropical circulation fell in the purview of GARP's Tropical subprogram. Even before the international GARP Tropical subprogram had been formalized, a group of U.S. scientists met for three weeks in August 1966 in Boulder, Colorado, to envision a large experiment over the tropical ocean. The report of the meeting's Working Group C, chaired by Jule Charney and including 17 other scientists, outlined the scientific basis of the observations envisioned for and required by TROMEX (see supplemental material). This report suggested two potential regions of tropical oceans suitable for the field campaign: the tropical Pacific using the Marshall Islands as a central location (preferred) and the "Caribbean-Atlantic" (not the eastern tropical Atlantic, where GATE ultimately took place).

In November 1966, a meeting held by the WMO Commission for Atmospheric Sciences (known as the WMO Commission for Aerology at that time) in Geneva recommended a specific area in the Pacific region (15°S–25°N, 120°E–180°) for the tropical experiment. Later, a Study Conference on GARP held at Stockholm 28 June–11 July 1967 indicated three possible oceanic areas (the Marshall and Caroline Islands, the South and west Pacific, and the western Atlantic–Caribbean region) and even a continental area (equatorial North Africa). A land area was never pursued in later planning documents for TROMEX. In agreement with the U.S. scientists in Boulder, the Stockholm group considered the Marshall–Caroline Islands region of the tropical western Pacific as best satisfying the criteria established for the selection of the area, namely, "an oceanic area with a region characterized by a high frequency of active disturbances, free, if possible, of complicating monsoonal effects" (GARP 1970a).

The Boulder meeting advocated a series of smaller field programs as predecessors of the much larger TROMEX. These smaller field experiments were subsequently conducted, which helped in the planning of the grand experiment. The Line Islands Experiment (LIE), 1 March–30 April 1967, was conducted by U.S. scientists in the tropical central Pacific (Zipser 1970). LIE provided a template for aircraft observations of mesoscale convective systems of the type that would be seen in GATE. A single research ship, the Environmental Science Services Administration (ESSA) *Surveyor*, participated in LIE. The 1968 Florida State University Barbados Experiment similarly provided valuable experience in probing the boundary layer using an aircraft, a buoy, a tethered balloon on the island itself, and a ship (Garstang et al. 2019). Such boundary layer measurements would be important in the grand experiment because of the necessity of documenting how energy from the warm ocean was being provided to the convection and how the convection in turn affected the energy content of the near surface ocean water. The Barbados Oceanographic and Meteorological Experiment (BOMEX), 1 May–28 July 1969, led by U.S. scientists (Kuettner and Holland 1969), provided an example of how radar and boundary layer measurements could be coordinated in a tropical oceanic environment using aircraft, a buoy, a ship, and a tethered balloon. The USSR was also active in projects laying groundwork for a major tropical experiment. TROPEX-72 (not to be confused with TROMEX) was a USSR shipborne campaign carried out from June through 19 September 1972 over the tropical Atlantic Ocean (Fig. 1).

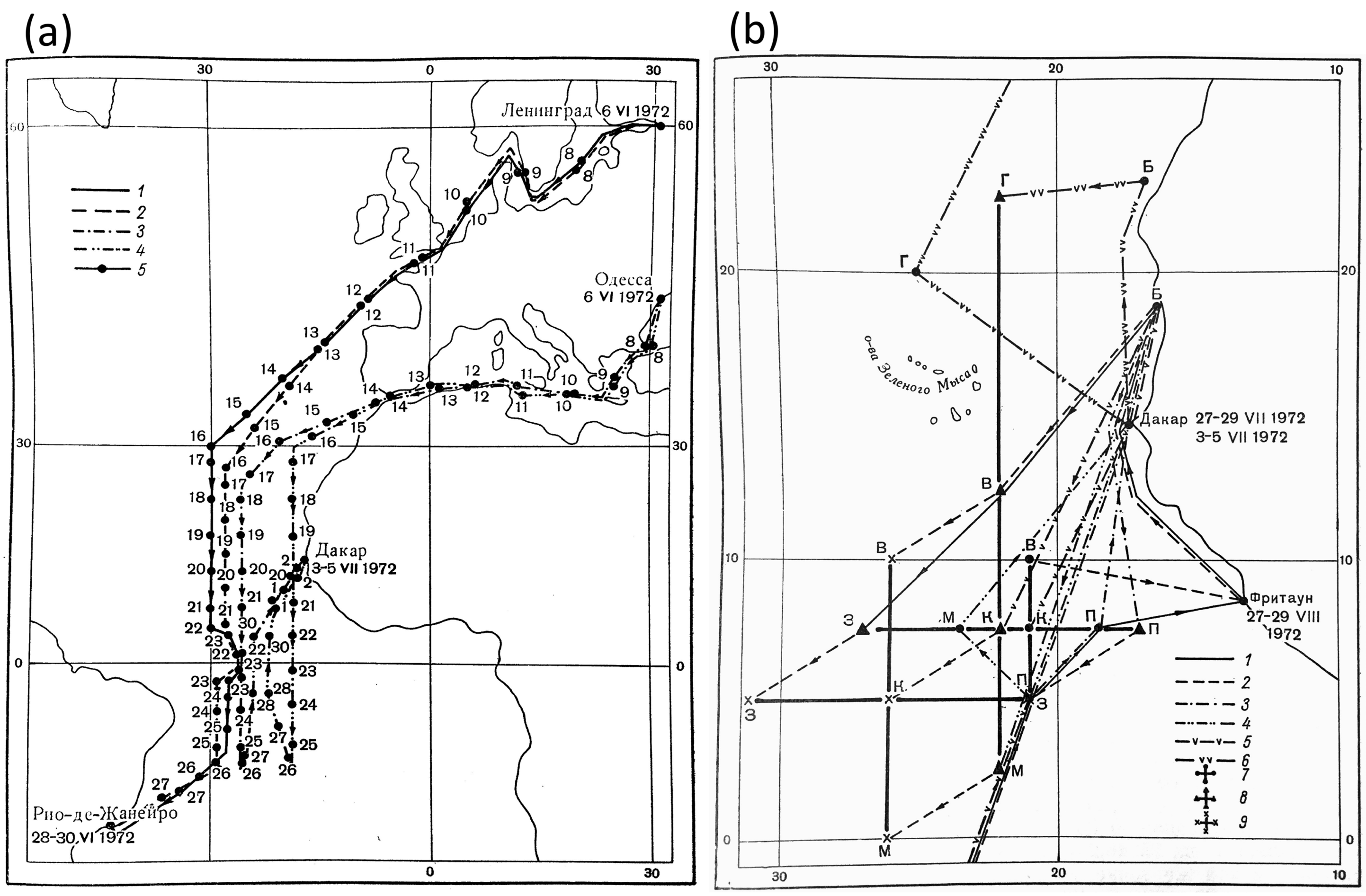

Fig. 1. (a) Ship tracks during the first phase of TROPEX-72. (b) Ship locations in the meso-meteorological array and synoptic array I and II of TROPEX-72 (from Petrosyants 1974).

The two Soviet ships in TROPEX-72 participated in GATE two years later. The Soviet experiment provided a first indication for how shipborne radar could document the mesoscale structure of the precipitation in convective cloud systems over the ocean and served as a prototype for the U.S. and Canadian shipborne radars later used in GATE (Shupiatsky et al. 1975, 1976a,b).

The first detailed plan of an observing network for TROMEX was in GARP Publications Series No. 4 (GP4) and is shown here in Fig. 2. The design called for radiosondes, land surface stations, ships, and aircraft. Possible contributing countries at this stage included India, Japan, the United States, and the USSR. The plans laid out for TROMEX in GP4 defined four characteristic scales of tropical disturbances: A (large wave-scale), B (cloud cluster), C (mesoconvective), and D (convective cells). Different types of observations were to be focused on

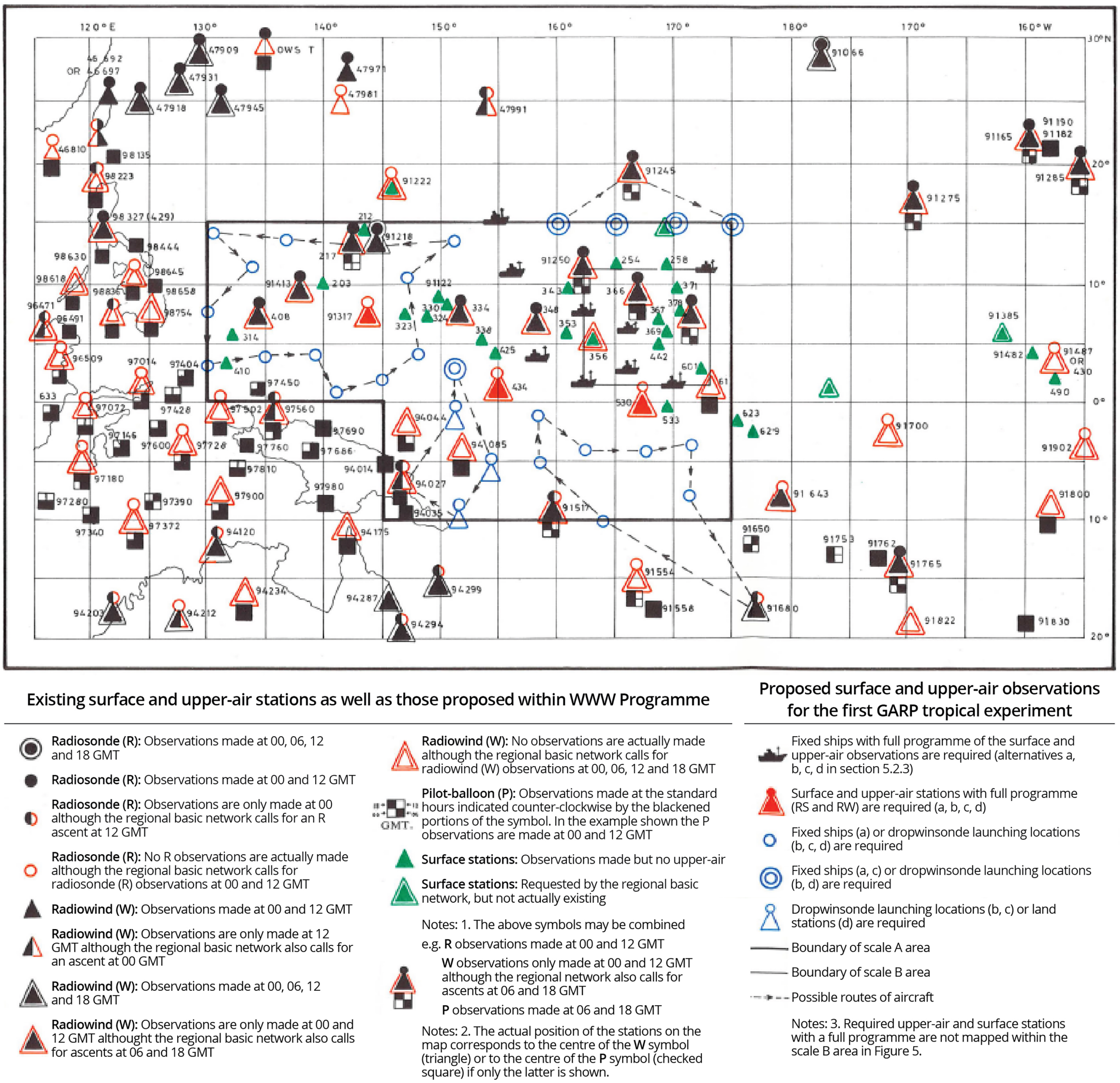

Fig. 2. Observing network designed for TROMEX (after GARP 1970a).

each of these scales and on interactions between the scales. “Type I” experiments were to be studies of interactions between scales A and B, and “Type II” experiments were to examine interactions of B, C, and D.

The TROMEX proposal as described in GP4 was reviewed at a Planning Conference of GARP held in Brussels in March 1970. At the conference, a recommendation was made to move TROMEX from the tropical Pacific to the tropical Atlantic. The reason for the move was notably absent from the report of the conference (GARP 1970b). The report says only:

> “The Conference examined the proposals for experiments of types I and II contained in GP.4. The concepts of these experiments were accepted but it was clear from the discussion in the first plenary session that there would probably not be sufficient international support for an experiment in the Marshall Islands area by 1974. Of the other possible areas, preference was expressed for the Atlantic, and the possibilities of mounting an experiment in this area were therefore examined in some detail. It was concluded that a tropical experiment in the Atlantic would be of great scientific interest and would be technically feasible. The Conference felt that an experiment in the Atlantic can be recommended on the basis of the following considerations.
>
> As originally proposed by JOC,[4] the organization of tropical convection in cloud clusters is the phenomenon of major scientific interest from the point of view of GARP. Although this phenomenon occurs with greatest frequency in the Western Pacific, studies of the tropical Atlantic have indicated that a sufficient number occur also in the western tropical Atlantic, with the highest frequency of occurrence in the period August-November. The clusters there are sometimes associated with easterly waves moving in from the African continent and sometimes with disturbances in the Intertropical Convergence Zone. A large variety of degrees of development occur, from short-lived flare-ups of cumulus development to intense hurricanes.”

[4] Joint Organizing Committee. Footnote added by the authors of this article.

We have searched for published and archived records that could explain why GARP (1970b) asserted that “there would probably not be sufficient international support for an experiment in the Marshall Islands by 1974.” We are now in a position to explain that statement. The reason is in a memorandum from the U.S. Joint Chiefs of Staff to the National Research Council, which resides in the Jule Charney Archives at the Massachusetts Institute of Technology (MIT) (Fig. 3). The memorandum stated that the Marshall Islands could not be used for logistical support of ships or aircraft. This prohibition negated one of the original reasons for the choice of the Marshall Islands: the presumed availability of Kwajalein and Eniwetok as observing sites, but more significantly, as logistical support bases for ships and aircraft in the heart of the planned experiment region. Without ship or aircraft bases close to the experiment area, the costs would have been much larger, perhaps prohibitively, and ferry times for ships and aircraft to the observing sites would have been prohibitive. It is therefore easier to understand that what was essentially a veto by the U.S. military of using Marshall Island bases changed the relative costs and practicability of the experiment so profoundly that most of the participating nations could no longer reasonably consider that location versus what became a more feasible base of operations in Dakar, Senegal.

After the relocation, Japan withdrew from the experiment and proposed the Air Mass Transformation Experiment (AMTEX) in the East China Sea, which took place 17 February 1974–28 February 1975 (GARP 1973). Following the recommendation from the Planning Conference on GARP, an Interim Scientific and Management Group convened in London, 22–24 July 1970, to further discuss the aspects of a tropical experiment in the Atlantic (GARP 1970c). Their experimental design was reported in the GATE Report No. 1 (GATE 1971). GATE was thus born.

Dr. Charney

THE JOINT CHIEFS OF STAFF
WASHINGTON, D.C. 20301

MJCS-444-69
22 September 1969

MEMORANDUM FOR THE ASSISTANT ADMINISTRATOR FOR ENVIRONMENTAL SYSTEMS, ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

Subject: Plan for US Participation in the Global Atmospheric Research Program

1. Reference is made to your letter, dated 28 August 1969, concerning the availability of Kwajalein or Eniwetok as a base for the international Global Atmospheric Research Program (GARP) experiments.

2. The Department of Defense regrets that neither Kwajalein nor Eniwetok can be made available for use for these experiments, nor for any basing activity related to them.

3. The Trust Territory of the Pacific Islands, which includes the Marshall and Caroline Island groups, is a "strategic" area, as specified in Article 82 of the United Nations Charter and the trusteeship agreement between the United States and the Security Council of the United Nations, July 1947. It is probable that some security and/or safety constraints on visits to ports and on operations in these island groups will be in effect in the time frame of the experiment. However, it is too early to provide any definite information on what these constraints might be.

4. There are no locations in the Marshall or Caroline Islands where the Department of Defense now has facilities that could be used by the GARP. It is suggested that the US Committee for the GARP survey possible alternative locations and coordinate directly with responsible agencies or administering nations. It would seem appropriate that in selecting alternative locations the US Committee for the GARP complete its surveys and coordination prior to selection and announcement of the operating bases and experiment area.

For the Joint Chiefs of Staff:

Robert F. Long

ROBERT F. LONG
Brigadier General, USAF
Special Assistant for
Environmental Services

Fig. 3. Memorandum from the U.S. Joint Chiefs of Staff to the National Research Council. Courtesy of MIT Jule Charney Archive.

Although the TROMEX plan was never carried out but rather was moved to the Atlantic and evolved into GATE, the four characteristic scales of tropical disturbances defined in the planning of TROMEX became the organizing concept for the GATE nested observational network (Fig. 4). GATE's A-scale network encompassed the entire Atlantic (and part of Africa). The B-scale network was a hexagonal array of ships off the coast of West Africa. The C-scale was captured by a smaller hexagon of ships within the larger hexagon. Radars on four ships along with instrumented aircraft took care of the D-scale.

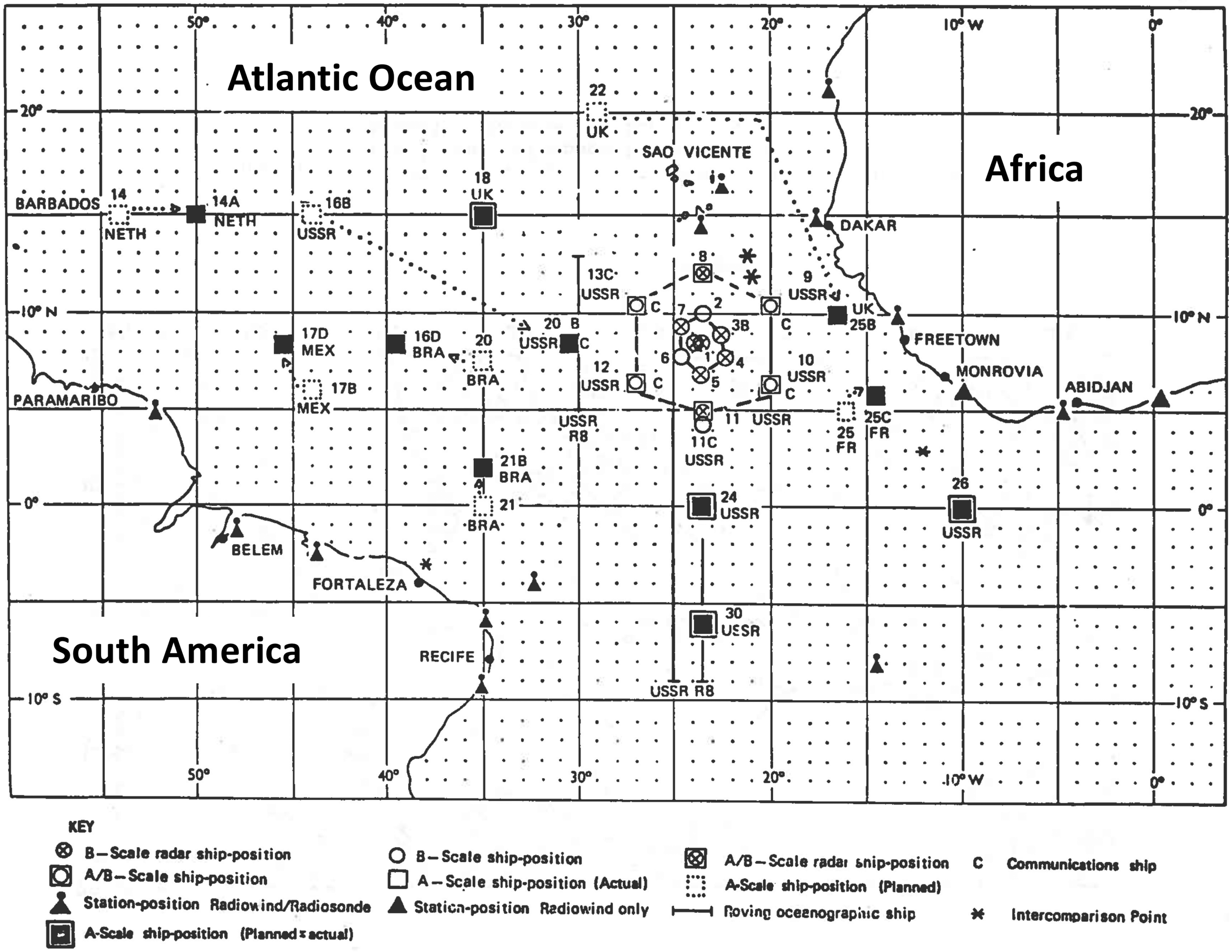

Fig. 4. GATE observing network (after GARP 1982).

Finally, we note that the observational network of GATE (Fig. 4) lay off the coast of West Africa in a zone where the circulation is influenced by the African monsoon. Thus, the GARP planners' requirement to hold the experiment over a portion of tropical ocean unaffected by monsoonal effects was not met. In the end, the monsoonal circulation superimposed on the GATE region did not impede the project, and 18 years after GATE, a campaign resembling TROMEX, the Coupled Ocean–Atmosphere Response Experiment (TOGA COARE), was finally held in the tropical west Pacific, albeit with a smaller number of ships and aircraft than GATE (Webster and Lukas 1992; Godfrey et al. 1998).

Acknowledgments. The authors thank Vasily Titov and Herbert Chang for their translation of information from Russian and Sarah Battle for her help with the preparation of the figures. Comments by Michael McPhaden, Margaret "Peggy" LeMone, Louis Rivoire, and the Editor on early versions of the manuscript have motivated the authors to substantially improve this article. The assistance of the MIT Archive with our historical search is very much appreciated. This is PMEL Contribution 5275.

References

GARP, 1969: An Introduction to GARP. GARP Publications Series 1, World Meteorological Organization and International Council of Scientific Unions, 33 pp.

——, 1970a: The Planning of GARP Tropical Experiments. GARP Publications Series 4, World Meteorological Organization and International Council of Scientific Unions, 90 pp.

——, 1970b: Report of Planning Conference on GARP: Brussels, March 1970. GARP Special Rep. 1, World Meteorological Organization and International Council of Scientific Unions, 42 pp.

——, 1970c: Report of Interim Planning Group on GARP Tropical Experiment in the Atlantic: London July 1970. GARP Special Rep. 2, World Meteorological Organization and International Council of Scientific Unions, 25 pp.

——, 1973: The Air-Mass Transformation Experiment. GARP Publications Series 13, World Meteorological Organization and International Council of Scientific Unions, 54 pp.

——, 1982: The GARP Atlantic Tropical Experiment (GATE) Monograph. GARP Publications Series 25, World Meteorological Organization and International Council of Scientific Unions, 477 pp.

Garstang, M., and Coauthors, 2019: Three early tropical field experiments. *Bull. Amer. Meteor. Soc.*, **100**, 2243–2258, https://doi.org/10.1175/BAMS-D-18-0151.1.

GATE, 1971: Experiment Design Proposal for the GARP Atlantic Tropical Experiment. GATE Rep. 1, World Meteorological Organization and International Council of Scientific Unions, 188 pp.

Godfrey, J. S., R. A. Houze Jr., R. H. Johnson, R. Lukas, J.-L. Redelsperger, A. Sumi, and R. Weller, 1998: Coupled Ocean Atmosphere Response Experiment (COARE): An interim report. *J. Geophys. Res.*, **103**, 14395–14450, https://doi.org/10.1029/97JC03120.

Greenfield, R. S., and J. S. Fein, 1979: The Global Atmospheric Research Program's Atlantic Tropical Experiment. *Rev. Geophys.*, **17**, 1762–1772, https://doi.org/10.1029/RG017i007p01762.

Houze, R. A., Jr., and A. K. Betts, 1981: Convection in GATE. *Rev. Geophys. Space Phys.*, **19**, 541–576, https://doi.org/10.1029/RG019i004p00541.

Kuettner, J. P., 1974: General description and central program of GATE. *Bull. Amer. Meteor. Soc.*, **55**, 712–719, https://doi.org/10.1175/1520-0477(1974)055%3C0711:G%3E2.0.CO;2.

——, and J. Holland, 1969: The BOMEX project. *Bull. Amer. Meteor. Soc.*, **50**, 394–403, https://doi.org/10.1175/1520-0477-50.6.394.

Perry, J. S., 1975: The Global Atmospheric Research Program. *Rev. Geophys.*, **13**, 661–667, https://doi.org/10.1029/RG013i003p00661.

Petrosyants, M. A., 1974: Main tasks and preliminary results of the inter-agency geophysical expedition of the national program of the Atlantic tropical experiment (in Russian). *TROPEX-72: Results of the Inter-Agency Geophysical Expedition of the National Program of the Atlantic Tropical Experiment*, A. M. Petrosyants et al., Eds., Hydorometeoizdat, 6–47.

Polavarapu, R. J., and G. L. Austin, 1979: A review of the GARP Atlantic Tropical Experiment (GATE). *Atmos.–Ocean*, **17**, 1–13, https://doi.org/10.1080/07055900.1979.9649047.

Shupiatsky, A. B., A. I. Korotov, V. D. Menshenin, R. S. Pastushkov, and M. Jovasevic, 1975: Radar investigations of evolution of clouds in the eastern Atlantic. GATE Rep. 14, Vol. II, International Council of Scientific Unions and WMO, 177–187.

——, ——, and R. S. Pastushkov, 1976a: Radar investigations of the evolution of clouds in the East Atlantic (in Russian). *Atmosphere*, Vol. 1, *TROPEX-74*, Gidrometeoizdat, 508–514.

——, G. N. Evseonok, and A. I. Korotov, 1976b: Complex investigations of clouds in the ITCZ with the help of satellite and ship radar equipment (in Russian). *Atmosphere*, Vol. 1, *TROPEX-74*, Gidrometeoizdat, 515–520.

Webster, P. J., and R. Lukas, 1992: TOGA COARE: The Coupled Ocean–Atmosphere Response Experiment. *Bull. Amer. Meteor. Soc.*, **73**, 1377–1416, https://doi.org/10.1175/1520-0477(1992)073%3C1377:TCTCOR%3E2.0.CO;2.

Zipser, E. J., 1970: The Line Islands Experiment, its place in tropical meteorology and the rise of the fourth school of thought. *Bull. Amer. Meteor. Soc.*, **51**, 1136–1147, https://doi.org/10.1175/1520-0477-51.12.1136.