General Description and Central Program of GATE

Joachim P. Kuettner[1]

1. Introduction

The GARP Atlantic Tropical Experiment (GATE)—long planned by the international scientific community—will begin on 15 June 1974 and last about 100 days. The experimental area centered over the tropical Atlantic is shown in Fig. 1. There will be three observing periods of three weeks each (Table 1).

The final plans for GATE follow closely the original "Experiment Design Proposal" (Kuettner, Rider, Sitnikov, 1972) approved by the Joint Organizing Committee for GARP (JOC) and the Tropical Experiment Board (TEB). In this connection, it may be recalled that plans for an international Tropical Experiment (originally to have been located in the Pacific) go back to 1966 when the second meeting of the ICSU/IUGG Committee of Atmospheric Sciences was held at Geneva.

From the very beginning it has been clear that the resources required for this project exceed those available to any single nation. For awhile there has been some doubt whether or not the "critical mass" for a meaningful experiment would be reached. However, the response of the participating nations inside and outside the GATE area (about 70 countries, Table 2) has been such that the necessary platforms and land stations are now assured. Approximately 40 ships and 13 aircraft will be available (Tables 3 and 4). Of the latter, 11 will have the required long range of 4,000 km or more.

The upper-air sounding network over the GATE land area will be nearly tripled during GATE over that available in 1973. This has been accomplished by acceleration and augmentation of the World Weather Watch through an extraordinary effort of the countries concerned, in cooperation with WMO and the nations supporting the Voluntary Assistance Program (VAP). The Global Telecommunication System (GTS) is likewise being upgraded in the GATE area, however not all upper-air soundings can be expected to be available in real-time.

2. The scientific program of GATE

(Central Program and Subprograms)

The design of a complex field experiment such as GATE is essentially the process of condensing its general scientific aims into specific objectives and to translate them into a detailed observing program.

In order to utilize the available scientific resources efficiently it is important to focus the effort on the specific objectives and to keep priorities fixed. The danger in planning this type of experiment is to try to solve too many problems at once. As more and more platforms become available there is a natural tendency to ex-

TABLE 1. GATE operations schedule.

Consecutive days	Dates (1974)		Events
	from	to	
1–9	17 June	25 June	In port, stand-down, en route, intercomparisons
10–30	26 June	16 July	Observation Phase I (21 days)
31–41	17 July	27 July	In port, stand-down, en route, intercomparisons
42–62	28 July	17 August	Observation Phase II (21 days)
63–74	18 August	29 August	In port, stand-down, en route, intercomparisons
75–95	30 August	19 September	Observation Phase III (21 days)
96–99	20 September	23 September	En route, intercomparisons

Note: There will be so-called "intensive periods" during Observation Phases I, II and III in which the rate of data collection is increased.

TABLE 2. States and territories participating in GATE (Members of Tropical Experiment Council).

1. Algeria
2. Barbados
3. Bolivia
4. Brazil*
5. Burundi
6. Cameroon, United Republic of
7. Canada*
8. Central African Republic
9. Chad
10. Colombia
11. Congo
12. Costa Rica
13. Cuba
14. Dahomey
15. Democratic Yemen
16. Dominican Republic
17. Ecuador
18. Egypt, Arab Republic of
19. El Salvador
20. Equatorial Guinea
21. Ethiopia
22. Finland*
23. France*
24. French Polynesia**
25. Gabon
26. Gambia
27. Germany, Democratic Republic*
28. Germany,* Fed. Republic of
29. Ghana
30. Guatemala
31. Guinea
32. Guyana
33. Haiti
34. Honduras
35. Indonesia**
36. Ivory Coast
37. Jamaica
38. Kenya
39. Liberia
40. Libyan Arab Republic
41. Madagascar
42. Malawi
43. Mali
44. Mauritania
45. Mexico*
46. Netherlands*
47. Nicaragua
48. Niger
49. Nigeria
50. Panama
51. Peru
52. Portugal* (incl. Cape Verdes & Port. W. Africa)
53. Rwanda
54. Saudi Arabia
55. Senegal*
56. Sierra Leone
57. Singapore**
58. Somalia
59. Sudan
60. Surinam
61. Tanzania, United Republic of
62. Togo
63. Trinidad and Tobago
64. Uganda
65. United Kingdom*
66. Upper Volta
67. U.S.A.*
68. U.S.S.R.*
69. Venezuela
70. Yemen
71. Zaire, Republic of
72. Zambia

* Members of Tropical Experiment Board.
** Special equatorial observations outside GATE area.

---

[1] Director, International Scientific and Management Group (ISMG), World Meteorological Organization.

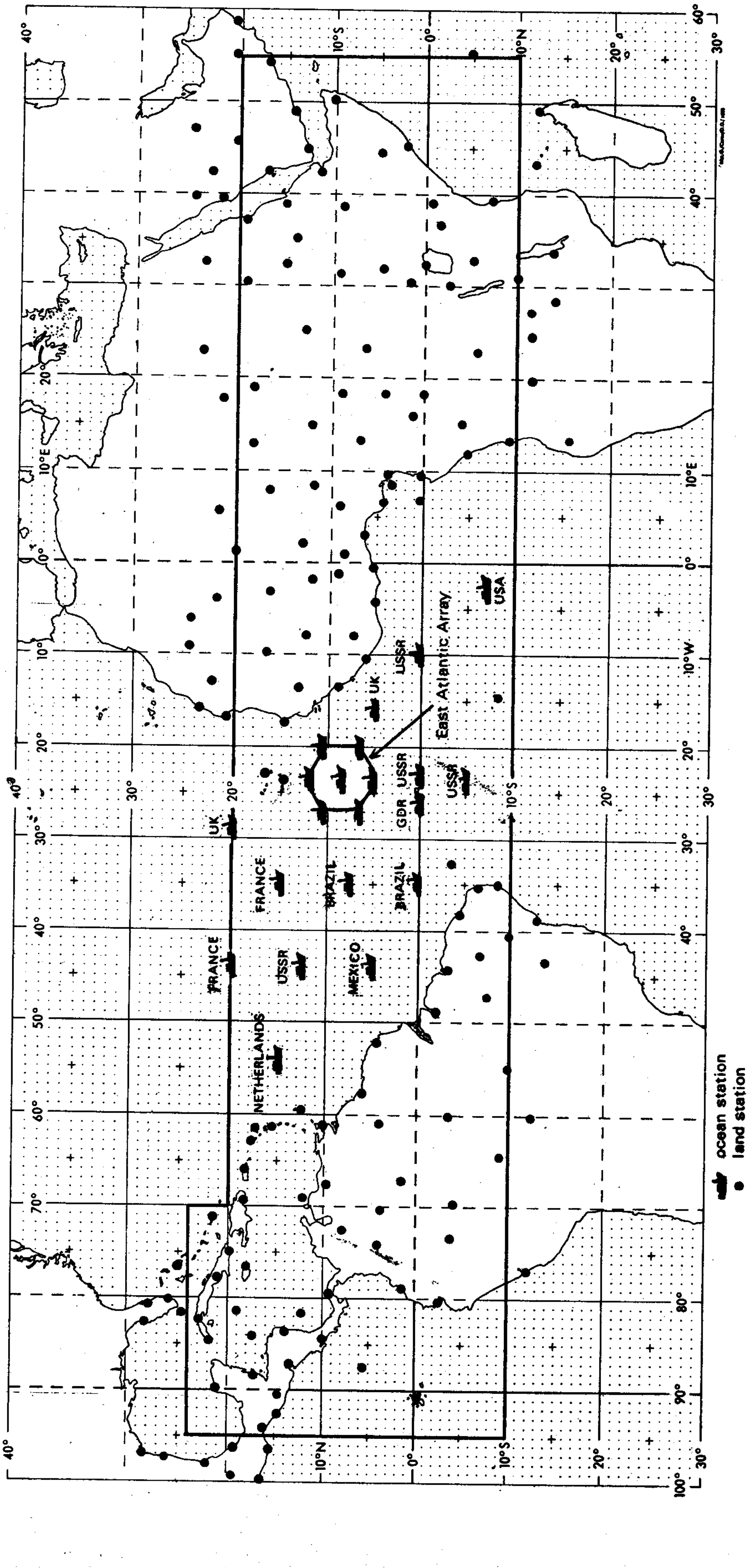


FIG. 1. Ship and land observing network during GATE. Note: the ship distribution changes slightly from phase to phase. For the 17 ships of the East Atlantic array refer to Fig. 6.

TABLE 3.

GATE ship participation.

Country	Name	Full time (F) Part time (P)	Remarks
1. Brazil	*Sirius*	F	
2. Brazil	*Alm. Saldanha*	F	
3. Canada	*Quadra*	F	5.7-cm radar
4. France	*Mar. du Fresne*	P	
5. France	*Bidassoa*	P	
6. France	*Capricorne*	P	
7. France	*Charcot*	P	
8. F.R.G.	*Meteor*	F	3.2-cm radar
9. F.R.G.	*Planet*	P	3.2-cm radar
10. F.R.G.	*Anton Dohrn*	P	
11. G.D.R.	*Alex. Von Humboldt*	P	Oceanography*
12. Mexico	*Mariano Mutamoros*	F	
13. Netherlands	*Onversaagd*	F	
14. U.K.	*Charterer*	F	
15. U.K.	*Endurer*	F	
16. U.K.	*Hecla*	P	
17. U.K.	*Discovery*	P	Oceanography*
18. U.S.A.	*Oceanographer*	F	5.7-cm radar
19. U.S.A.	*Researcher*	F	5.7-cm radar
20. U.S.A.	*Gilliss*	F	5.7-cm radar
21. U.S.A.	*Gyre*	P	
22. U.S.A.	*Dallas*	F	
23. U.S.A.	*Vanguard***	P	
24. U.S.A.	*Col. Iselin*	P	Oceanography*
25. U.S.A.	*Atlantis II*	P	Oceanography*
26. U.S.A.	*Trident*	P	Oceanography*
27. U.S.S.R.	*Prof. Vize*	F	3.2-cm radar
28. U.S.S.R.	*Prof. Zubov*	F	3.2-cm radar
29. U.S.S.R.	*Akad. Korolov*	F	3.2-cm radar
30. U.S.S.R.	*Akad. Kurchatov*	F	
31. U.S.S.R.	*Passat*	F	
32. U.S.S.R.	*Ernst Krenkel*	F	
33. U.S.S.R.	*Okean*	F	
34. U.S.S.R.	*Volna*	F	
35. U.S.S.R.	*Priboy*	F	
36. U.S.S.R.	*Poryv*	F	
37. U.S.S.R.	*Musson*	F	Communication
38. U.S.S.R.	*M. Lomonosov*	F	Oceanography*
39. U.S.S.R.	*Semen Deshnev*	F	Oceanography*
40. U.S.S.R.	*Akad. Vernadsky***	P	Oceanography*

* Primary use for oceanography.
** Ships conditionally available.

TABLE 4. GATE aircraft participation.

Country	Type	Prop	Turbo Prop	Jet	Special Equipment
I. Long-range					
1. Brazil	C-130E		x		Dropsonde
2. France	DC-7	x			Inert. platform
3. U.K.	C-130		x		Gust probe, Inert. platform
4. U.S.A.	CV-990			x	Inert. platform
5. U.S.A.	WC-130B		x		Inert. platform Cloud physics
6. U.S.A.	Electra		x		Gust probe, Inert. platform
7. U.S.A.	RP-3A		x		Inert. platform
8. U.S.A.	DC-6	x			Gust probe, Inert. platform
9. U.S.A.	KC-135A			x	Inert. platform Wind dropsondes
10. U.S.S.R.	IL-18		x		Radiation*
11. U.S.S.R.	IL-18		x		
II. Short-range					
12. U.S.A.	Sabreliner			x	Gust probe, Inert. platform
13. U.S.A.	Queenair	x			Gust probe, Inert. platform

* Primary use for Radiation Subprogram.

pand the scientific scope and to accommodate additional experiments in order to take advantage of the unique research possibilities. In principle this is desirable but not at the expense of the primary objectives.

For this reason a "Central Program" was created which restricts itself to the minimum meaningful experiment. Other research tasks may support the Central Program or they may have different objectives. We have called them "Supporting Programs" and "Other Experiments." They will be implemented only on the basis of non-interference with the Central Program. The three classes of experiments therefore represent also a priority ranking.

The magnitude of the scientific program made it necessary to break it down into subprograms. For practical reasons the entities are selected according to major disciplines involved in the GATE observing program. Their contribution to the Central Program will become clear in the following sections. They are: The Synoptic-Scale Subprogram; The Convection Subprogram; The Boundary-Layer Subprogram; The Radiation Subprogram; The Oceanographic Subprogram. These and the Central Program are available as GATE Reports Nos. 3–8 (1973/4).

Figure 2 illustrates their organization and indicates that each subprogram is not only "horizontally" divided into the three forementioned priority classes (rings) but also "vertically" into four main sections (layers) dealing with the scientific objectives, the experiment design, the data management, and the research participation. The possibility that these subprograms may diverge as a re-

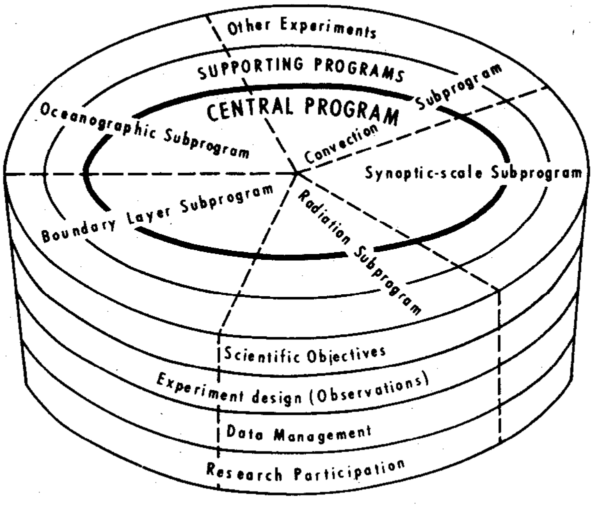


FIG. 2. Scientific organization of the Central Program and the Subprograms.

sult of their own vitality is generally averted by the existence of the Central Program which holds the subprograms together and ensures that the significant interrelationships are not neglected. It is felt that, due to this and the close cooperation among the subprogram scientists in the International Scientific and Management Group (ISMG), the cake depicted in Fig. 2 will be as cohesive and tasty as it looks.

The difficult task of defining the Central Program in detail was undertaken by D. D. Houghton during the year he spent with the ISMG. The brief description in this article follows generally his approach (Houghton, 1974).

3. The Central Program

(Scientific Objectives and Experiment Design)

In the most general terms the aim of GATE is to explore the mechanism by which the solar heat stored in the tropical oceans drives the global circulation of the atmosphere and to incorporate this mechanism into numerical models.

The Central Program states the primary objectives as follows:

1) To estimate the effects of smaller-scale tropical weather systems on the large-scale circulations;
2) To advance the development of numerical modeling and prediction methods.

It can immediately be seen that the first objective comprises studies of "scale interaction" and "parameterization." These have to be based on an adequate description of the tropical phenomena existing on various scales ("scale phenomena") and of the basic state in which they are embedded.

It is also obvious that the second general objective can be achieved by providing a good tropical data set and by an advance in the forementioned parameterization techniques.

Figure 3 illustrates this scheme. The heavy arrows indicate the order in which the scientific work may logically proceed and contribute to the GARP objectives.

a. Scales and related tropical phenomena

Four scales are conveniently used in GATE. They are listed in Table 5.

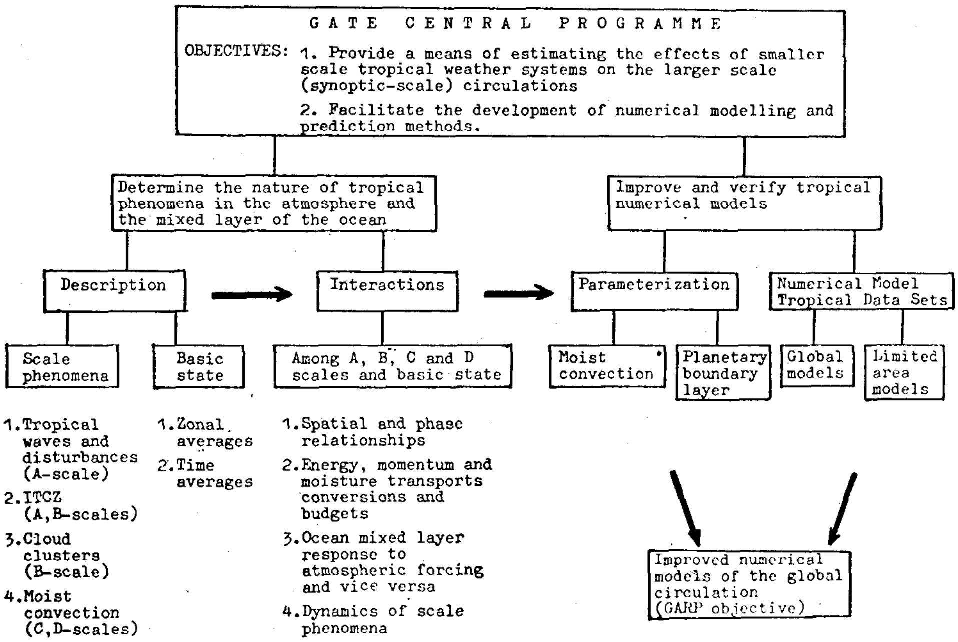
The largest scale, the A-scale (10^3 to 10^4 km), incorporates the synoptic and planetary scales. According to what is known at this time it covers the following tropical features: 1) the westward moving waves of short wavelength (1500–4000 km) in the lower troposphere —called here for simplicity "easterly waves"[2]; 2) the likewise westward but faster moving waves of large wave-

TABLE 5. Scales of tropical disturbances.

Scale	From (km)	To (km)	Name
A	10^3	10^4	Wave scale
B	10^2	10^3	Cloud-cluster scale
C	10	10^2	Mesoscale
D	1	10	Cumulus scale

---

[2] Essentially identical with Riehl's (1954) "Waves in the Easterlies," but not necessarily having all the characteristics described by him.



* Includes certain aspects of radiation parameterization.

FIG. 3. The objectives and components of the GATE Central Program.

length (5000–10,000 km) in the upper troposphere often interpreted as Rossby-gravity waves—called here "Yanai-Maruyama waves" (Yanai and Maruyama, 1966); and 3) the very long eastward-moving waves in the stratosphere discovered by Wallace and Kousky (1968) generally interpreted as Kelvin waves. These waves have long lifetime, sometimes several weeks, as they travel considerable distances around the world. The A-scale is therefore called the "wave scale."

The next smaller scale, the B-scale (10^2 to 10^3) although generally not of great significance at higher latitudes, is the important scale on which tropical "cloud clusters" develop. Discovered by satellite, they form the link between the short-lived smaller scale convective elements and the long-lived tropical waves as well as the Intertropical Convergence Zone (ITCZ). The description of their structure and life cycle and the study of their role in the energetics of the tropical atmosphere are one of the main objectives of GATE which has therefore sometimes been called a "cloud cluster experiment."

The ITCZ, often only 100 to 200 km wide, but thousands of kilometers long, has characteristics of both the A- and the B-scale. As a statistical location of maximum convective activity in the tropics it may be considered a phenomenon of the general circulation.

On the next smaller scale, the C-scale (10–10^2 km), we find those structures of organized convection (bands, rings, etc.) that form the subsystems of the cloud clusters. This scale corresponds to the well known "mesoscale."

The smallest horizontal scale to be studied in GATE, the D-scale (1 to 10 km), contains the individual convective elements themselves, and is therefore called the "cumulus scale."

Figure 4 depicts the scale phenomena described here.

b. "Description" of scale phenomena

The first objective of the Central Program is the description of the forementioned scale phenomena.

The tropical phenomena of the largest scale, the wave (A)-scale, determine the size of the experimental area (150 by 30°) and the spacing of the A-scale land and ocean stations (5 to 10° where possible). The area extends from the westernmost part of the Indian Ocean across tropical Africa, the Atlantic, South and Central America to the easternmost part of the Pacific Ocean and encompasses about 40% of the earth's tropical belt between 20N and 10S (Fig. 1). The upper-air sounding network over the land areas will have a density approaching that now in use over the land areas of the Northern Hemisphere in the temperate latitudes. Over the tropical Atlantic spatial continuity of this network will be preserved by a system of fixed ocean stations of comparable density. These ships are equipped to conduct a minimum of four daily ascents to measure wind, temperature, and humidity to at least 70 mb.

Unfortunately the navigation-aid wind-sounding system (Beukers) installed on the majority of the fixed ships has limitations—caused by the location of the Omega and VLF transmitters—which do not allow the ocean area to be covered south of the equator with as many ocean stations as one would like to see. Some ships equipped with stabilized windfinding radar will, however, be deployed in this region.

Detailed observational requirements on the A-scale are dealt with in the section on the Synoptic-Scale Subprogram below.

As far as the cloud cluster (B)-scale is concerned it would obviously be prohibitive to cover the whole tropical Atlantic with a subsynoptic ship network. Instead, an area in the East Atlantic where convective cloud clusters frequently occur has been selected for a more concentrated ship array (Figs. 5, 6). Most of these ships are highly instrumented, carry meteorological radar and will make more frequent observations when required. The ships in the outer hexagon (A/B-scale ships) serve both the wave scale and the cloud-cluster scale and are spaced about 4° apart while those in the inner hexagon, the B-scale array, are about 1.5° apart. This network should be adequate to provide the needed quantitative information on life cycles, bulk properties, and environment of cloud clusters, but the limited extent of the array may make it necessary to use compositing techniques in addition to case studies.

On the meso (C)-scale the structure of the different types of convective organizations, their life cycles, and the vertical and horizontal fluxes of mass, heat, moisture,

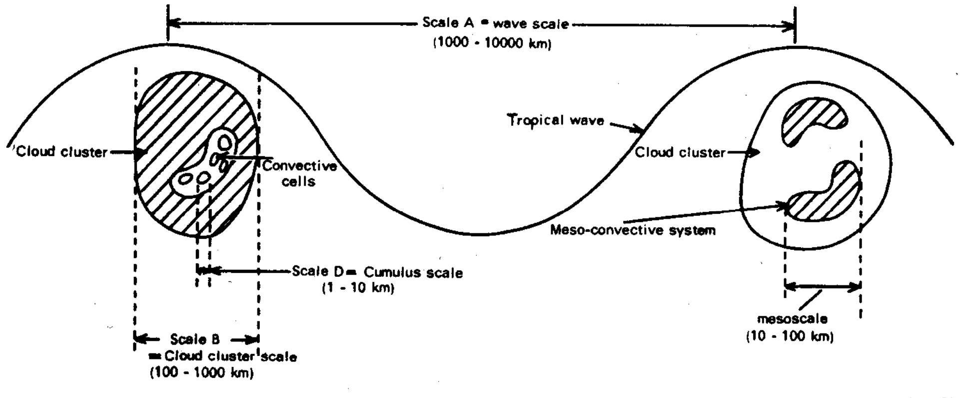


FIG. 4. Scales of atmospheric phenomena in the tropics (after GARP Publications Series No. 4, 1970).

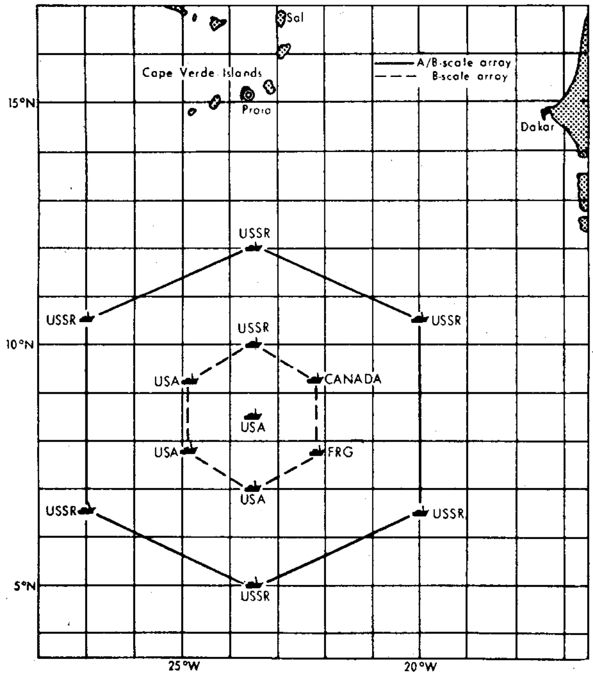


FIG. 5. Special East Atlantic array (observation phase I and II).

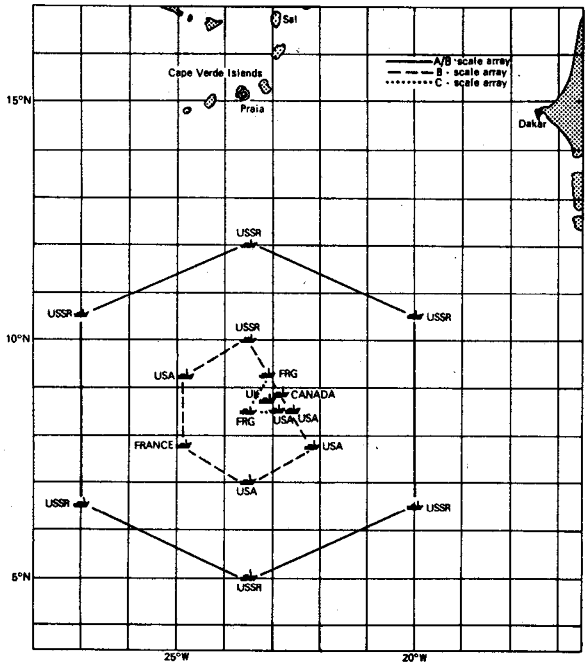


FIG. 6. Special East Atlantic array (observation phase III).

and momentum must be described. The main tool for this program will be the fleet of highly instrumented long-range aircraft (Table 4). These aircraft will operate primarily over the B-scale area. Their flight tracks often flown in a vertical stack are described in the Aircraft Operations Plan (GATE Report No. 11, 1974). An example is given in Fig. 7. In Phase 3 of the project a special "C-scale network" of five ships with spacings of the order of 50 to 100 km will be inserted into the central B-scale area (Fig. 6). A small scale buoy array lies inside the C-scale area.

Regarding the cumulus (D)-scale, some convective towers will be sampled by individual aircraft with regard to vertical motions, liquid water content, and other cloud physics parameters. A cloud census will be conducted supported by satellite images and observations from the French "ESSOR" balloon tethered at 20 km height. The description of the life cycles of individual cumuli is not part of the Central Program.

The system of telescoping scales in the ship network resembles a "nested grid." This system will fulfill the observational requirements only in combination with the forementioned aircraft flights and satellite observations. In this connection it should be pointed out that the geostationary satellite SMS-A will be placed over the equatorial Atlantic and will continuously observe the GATE area in the visible and infrared spectrum with resolutions of 0.5 and 5 n mi, respectively.[3] Imaging and vertical sounding information is also expected from several U.S.A. and U.S.S.R. satellites in polar orbit (NOAA-2 and 3, Meteor, Nimbus-5, possibly DMSP). Some of these data will be used on real-time for operational planning and the necessary ground facilities are being installed at the GATE Operational Control Center (GOCC) in Dakar, Senegal.

c. Scale interaction

Interaction of the different scale phenomena, both among themselves and with the basic state, refers to their spatial and phase relationships and to mass, momentum, moisture, and energy transports, conversions, and budgets. These may give considerable physical insight and reveal the dynamics of a system.

Scale interactions may also be understood in terms of control and feedback. Although, for example, no convincing physical model of the cloud cluster is at present at hand, it is known that cloud clusters are frequently (but not always) associated with tropical waves which in turn are thought to be driven by the release of latent heat of condensation. It is expected that case studies from GATE will shed some light on the possibility that tropical waves and cloud clusters interact by an A → B-scale control with B → A-scale feedback.

A similar situation exists in the ITCZ where convective activity appears to interact with the ocean surface, the atmospheric boundary layer and the tropical waves. Corresponding theories based on ocean-atmosphere coupling, the CISK hypothesis and the so-called "critical latitude" concept may be tested in GATE.

Atmospheric forcing by small- and large-scale circulations may be considered as an atmospheric control of

---

[3] Because of an expected late launch of the SMS-A satellite, these data may not be available in the beginning of the field project. However, ATS-3 data should be available.

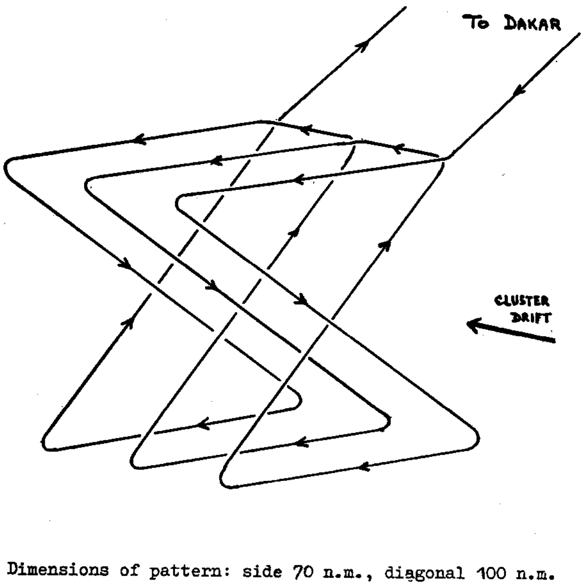
the ocean mixed layer. The resulting surface fields of the ocean then provide the feedback to the atmosphere. This problem will be studied in GATE (see the section on the Oceanographic Subprogram).

In all interaction studies and particularly in the evaluation of heat and moisture budgets of convective systems, the radiative flux divergence, the boundary layer, and the ocean mixed layer processes play an important role involving all subprograms of GATE.

It is especially in the scale interaction studies that accurate wind measurements at height are needed. The wind is the most important parameter to be measured in GATE. The vertical mass flux on all scales except the D-scale must be calculated from vertical integrals of weak divergence fields. The B-scale ship array provides numerous triangles and polygons of various sizes for this purpose. Vertical stacks of aircraft flying so-called butterfly pattern (Fig. 7) will yield detailed divergence fields down to the D-scale. Satellite data on cloud displacements should provide wind and divergence fields over most of the Atlantic for at least two levels. It is expected that this combination of different observing systems will provide satisfactory data. In addition, 90-min ship soundings in the B-scale area are planned during and near aircraft group flights for sufficient statistical sampling.

d. Parameterization

The problem of parameterizing the small-scale convective processes of the tropics in terms of the observable large-scale quantities is, of course, intimately connected with the scale interaction. Unless there is some degree of control of the smaller scales by the large-scale fields, successful parameterization cannot be achieved. While there is indication that such control exists, GATE must provide the supporting data.



Dimensions of pattern: side 70 n.m., diagonal 100 n.m.

Time for one circuit: 1½ hours
Number of circuits: 3

Approximate flying hours for a C-130:-

Transit 500 nm each way at 20,000 ft	3.7 hours
Pattern flying at 5,000 ft	4.5 hours
Total	8.2 hours

FIG. 7. Butterfly pattern following a cluster moving at 15 kt.

It has been known since Riehl and Malkus' (1958) basic work that the heat balance of the tropical atmosphere is maintained by penetrative cumulus towers carrying the released heat almost undiluted into the upper troposphere. This seems to occur on scales and over areas too small to be detected by synoptic-scale observing networks or to be resolved explicitly by even the finest grid mesh used in large-scale models. In other words, the basic elements of the heat engine for the general circulation of the atmosphere slip through the mesh.

Many parameterization schemes have been developed in recent years for moist convection. (See the section on the Convection Subprogram, p. 724). They should now be tested in GATE. Such tests will include the determination of cloud mass flux, diabatic heating rates, vertical profiles of radiative heating, sensible and latent heat fluxes from the ocean surface, the precipitation and a census of cumulus clouds, especially of deep towers (Yanai, 1971). The inferred bulk properties will be validated through direct sampling by research aircraft on the D-scale. Such sampling will include vertical motions and liquid water content. The quantitative determination of precipitation in the inner B-scale area with calibrated radar will be marginal in GATE as only four of the nine radar ships have the specified 5.7-cm radar, but representative estimates may be expected in combination with other observing systems including satellites.

The parameterization of moist convection cannot be separated from that of radiation. The difficult problem of parameterizing the radiative flux divergence under conditions of changing convective cloudiness is one of the central objectives of the Radiation Subprogram (see the section on this subject). It is also shown there that the radiation terms are surprisingly important in the heat budgets of convective systems being of a magnitude comparable to that of the eddy heat fluxes. Radiation equipped aircraft and shipborne radiometersondes are among the main tools for the determination of these terms.

Also closely connected with the parameterization of convection is that of the atmospheric (and oceanic) boundary layer. The turbulent fluxes of momentum and energy and the mass and moisture convergence in the planetary boundary layer are highly related to moist convection. Schemes of parameterization based on the large-scale variables must be tested in GATE not only indirectly through B- and C-scale budget measurements but directly from ship and aircraft working on the turbulent scale in the subcloud layer. The planned tethered balloon systems, structure sondes, and airborne gust probes will provide these data. (See the section on the Boundary-Layer Subprogram, p. 731, and Fig. 15). The oceanic boundary layer will be probed by salinity-temperature-depth (STD) soundings, sea surface temperature surveys, and current-meters. (See the section on the Oceanographic Subprogram, p. 738).

e. Tropical data sets for numerical models

Continuous sets of A-scale data (surface and upper-air) at 12-hr intervals for periods of about 20 days will become available from the entire experiment area. For global models, the data voids around the GATE area and between the observing periods will limit the usefulness of these data sets. Some models, such as those of the Washington NMC and Bracknell, may use the data in real-time. The numerical data sets are developed from the observed data sets by specific operations with a given numerical model. This is necessary to provide compatibility. The data sets will be utilized for initialization and verification of models.

For limited areas and nested models of the tropical atmosphere B-scale area data at frequent intervals and 6-hourly data from certain West African stations (surface and upper air) will serve to develop data sets, for example for a 2° mesh with 20 levels. For these models GATE should provide data of unprecedented quantity and quality.

4. Data management

A follow-up article will describe the GATE Data Management Plan in detail. Here it should only be mentioned that all data will be made available in agreed formats suitable for scientific analysis to all nations and scientists. National Processing Centers (NPCs) in all countries collecting data will be responsible for processing their own data. International processing and validation of these data will be done in five international Subprogram Data Centers (SDCs). These are: a) Synoptic Subprogram Data Center (SSDC), Bracknell, U.K.; b) Convection Subprogram Data Center (CSDC), Washington, U.S.A.; c) Boundary-Layer Subprogram Data Center (BSDC), Hamburg, F.R.G.; d) Radiation Subprogram Data Center (RSDC), Leningrad, U.S.S.R.; e) Oceanographic Subprogram Data Center (OSDC), Brest, France.

These Centers will deposit their validated products in agreed formats at the World Data Centers (WDCs) A and B (Asheville, U.S.A., and Moscow) for archiving and distribution to the users.

The data flow will start immediately after the GATE field phase and is expected to be completed in early 1977. As soon as the first internationally validated data are produced they will be available to users through the WDCs. This is expected to happen six months after the end of Phase III.

Acknowledgments. In developing the GATE Central Program and its subprograms the International Scientific and Management Group had close and harmonious cooperation with JOC, the International Subprogram Advisory Groups, the national project offices and numerous consultants. Without their help the comprehensive program would never have been accomplished. We are grateful to the Secretary-General of WMO, Dr. Davies, and the Chairman of the TEB, Dr. Mason, for their generous support in our work. Special thanks are due to Prof. Döös of the Joint Planning Staff (JPS) and to the JOC GATE Panel, its Chairman Prof. Suomi and its members, Mr. Sawyer, Prof. Yanai, Dr. Miyakoda and Dr. Sitnikov.

References

Aanensen, C. J. M., and E. J. Zipser, 1974: The GATE Aircraft Plan. GATE Report No. 11, Geneva, ICSU/WMO. 158 pp.

de la Mariniere, T. C., 1974: The GATE Data Management Plan. GATE Report No. 13, Geneva, ICSU/WMO.

Hoeber, H., 1973: The Boundary-Layer Subprogramme for GATE. GATE Report No. 5, Geneva, ICSU/WMO. 132 pp.

Houghton, D. D., 1974: The Central Programme for GATE. GATE Report No. 3, Geneva, ICSU/WMO. 37 pp.

——, and D. E. Parker, 1974: The Synoptic-Scale Subprogramme for GATE. GATE Report No. 6, Geneva, ICSU/WMO. 112 pp.

International Scientific and Management Group for GATE, 1974: The GATE International Operations Plan. GATE Report No. 9, Geneva, ICSU/WMO. 141 pp.

Kraus, H., 1973: The Radiation Subprogramme for GATE. GATE Report No. 4, Geneva, ICSU/WMO. 121 pp.

Kuettner, J. P., N. E. Rider, and I. G. Sitnikov, 1972: Experiment Design Proposal for GATE. GATE Report No. 1, Geneva, ICSU/WMO. 195 pp.

Petrossiants, M. A., *et al.*, 1974: Pre-GATE Tests and Studies. GATE Report No. 2, Geneva, ICSU/WMO.

Philander, S. G. H., M. Miyake, Y. Tarbeev, and T. de la Moriniere, 1974: The Oceanographic Subprogramme for GATE. GATE Report No. 8, Geneva, ICSU/WMO.

Riehl, H., 1954: *Tropical Meteorology*. New York, McGraw-Hill. 392 pp.

——, and J. S. Malkus, 1958: On the heat balance in the equatorial trough zone. *Geophys.*, **6**, 503–538.

Rodenhuis, D. R., and A. K. Betts, 1974: The Convective Subprogramme for GATE. GATE Report No. 7, Geneva, ICSU/WMO.

Tarbeev, Y. V., and S. R. Petersen, 1974: The GATE Ship Operations Plan. GATE Report No. 10, Geneva, ICSU/WMO. 231 pp.

Wallace, J. M., and V. E. Kousky, 1968: Observational evidence of Kelvin waves in the tropical stratosphere. *J. Atmos. Sci.*, **25**, 900–907.

Weiss, G., M. Dembitsky, and A. Durkee, 1974: The GATE Telecommunications Plan. GATE Report No. 14, Geneva, ICSU/WMO.

Yanai, M., 1971: A review of recent studies of tropical meteorology relevant to the planning of GATE. Annex I to GATE Report No. 1, Geneva, ICSU/WMO. 43 pp.

——, and T. Maruyama, 1966: Stratospheric wave disturbances propagating over the equatorial Pacific. *J. Meteor. Soc. Japan*, **44**, 291–294.