— SCIENCE AND IMPLEMENTATION PLAN (DRAFT)[1] —

NAURU-99: An International Study of Tropical Climate in the Vicinity of Nauru Island in the Tropical Western Pacific Ocean

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Background

There is a strong relationship between climatic variability in the tropical western Pacific (TWP) and variability in other portions of the globe. These connections are well documented in the meteorological and oceanographic literature (c.f., reports by the United States CLIVAR Implementation Planning Report (CLIVAR, 1996) and the World Climate Research Programme (CLIVAR, 1997)).

The ARM Science Plan (DOE, 1996) lists three primary research objectives for the TWP:

1. Surface radiation budget and cloud forcing.
2. Water and energy budgets of clouds and cloud systems.
3. Ocean-atmosphere interactions.

The Science Plan also gives three critical elements for the TWP observing strategy:

A. A long time series of basic observations at several locations.

B. Intensive field campaigns to augment the long-term measurement sets.

C. Long-term measurements of properties and fluxes at the ocean-atmosphere interface.

The installation of the first Atmospheric and Cloud Radiation Station (ARCS) at Manus Island, Papua New Guinea (Figure 1), begins to address the first observational element (Mather *et al.*, 1997). A second ARCS will be installed on Nauru I. in 1998, and others will be installed at additional tropical sites in the future. The ARCS supplies measurements of the surface radiation budget and radiatively important atmospheric properties at a single point. Manus Island is roughly 75 km in length and 50 km in width. The ARCS site is located on the southeastern extremity of the island on flat, uniform terrain. Nauru is a very small island, approximately circular with a 5 km diameter, and the ARCS site is immediately adjacent to the shore.

The need for the latter two elements of the observing strategy is quite clear. First of all, the ARCS measurements are all being made on small islands. Consequently, the ARM program must make a concerted effort to determine the extent to which those observations represent the oceanic environment around the islands. This requires making similar measurements on the open ocean near the islands. Secondly, the ARCS are located on land surfaces, but the surface of interest is the adjacent ocean. Thus, ARM must support periodic efforts to measure the radiation and heat fluxes at the ocean surface. Thirdly, there are a variety of atmospheric processes, for example, the vertical transport of water and energy by tropical convection, that cannot be addressed within normal operating conditions in the TWP due to logistical and cost constraints.

The ARM program has already begun to work towards testing these observational strategies through participation in joint tropical experiments and ship cruises. Participation in TOGA COARE and MCTEX proved valuable both in terms of the scientific return and the experience gained for instrument deployment and operation in the tropics. Recent ship cruises—CSP cruise (Post *et al.*, 1997) and TOCS-JUSTOS (Reynolds and Smith, 1997)—have provided valuable data sets. Analysis of the CSP cruise data taken in the vicinity of Manus has provided some very interesting insights, although the data are insufficient to provide definitive answers. The indication from the cloud data is that low cloud heights are much the same on the island as over the ocean, but there is greater fractional coverage over the island by low clouds. (Due to the lack of an MPL during the CSP visit, no assessment of high clouds could be made.) A diurnal cycle in the circulation was identified on the island but, interestingly, the same cycle appears over the ocean. The working hypothesis is that the entire oceanic area around Manus experiences a diurnal circulation driven by the influence of the high mountains on the island of New Guinea, as well as the mountains on New Britain and New Ireland. Confirma-

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tion of this awaits further study.

As a first step toward the third element, the NOAA Pacific Marine Environmental Laboratory (PMEL), with support from ARM, has developed new data loggers and shortwave radiometers that will substantially upgrade insolation measurements in the tropical Pacific. Eight TOA buoys along the 165°E meridian (Figure 1) have been instrumented with the new packages. Buoys at 8N, 5N, 2S, and 8S were instrumented with the new packages in June 1997. In January 1998, the line was fully instrumented. These solar measurements will provide a limited but continuous data set to compare to the measurements made on Nauru. Questions regarding the accuracy and utility of these buoy measurements need to be addressed as part of the Nauru99 operation.

Nauru99 was conceived in order to continue implementing observational objectives B) and C) as they relate to island effects. The primary scientific goal of this campaign is to document the local influence of the island and thereby to assess how representative the Nauru ARCS measurements are of the surrounding oceanic environment. A secondary scientific goal is to determine the surface radiative budget of the ocean environment around Nauru, and obtain a data set that can be used to relate TAO buoy measurements to this radiative budget. An additional programmatic objective is to learn how to carry out campaigns in the TWP locale given the logistical difficulties.

The scientific questions that are addressed by ARCS measurements at Nauru (and other sites) basically fall into two categories. The first category is climatological, e.g. What is the monthly-mean downwelling solar irradiance at the site? The second is process oriented, e.g., What is the impact of a cirrus cloud with a given optical depth on the downwelling solar irradiance at the surface? One of our working hypotheses for island sites is that the second category of observations is essentially unaffected by an island. This means that the microphysical properties of clouds over the island site are the same as those of similar cloud types over the ocean. A second working hypothesis is that the first category of observations is weakly influenced by the island, and that we can identify those periods and cloud types that are most likely to be influenced by the island. More specifically, we think that

1. Island effects are minimal during periods of active convection (the active phase of the Madden-Julian oscillation) and at night.
2. Island effects may be detectable during the day during periods of suppressed convection.
3. Island effects are not important for isolated cirrus clouds.
4. Island effects are most likely to be detectable in the measurements of cloud fraction and perhaps liquid water content; however, the impact of these differences on the overall downwelling radiation budget over the island, relative to the open ocean, is likely to be small compared to the overall impact of clouds on the radiation budget.

These hypotheses are the result of our analysis of COARE data collected at island sites and over the ocean (Long, 1996), as well as satellite data analysis (Reynolds, personal communication and Barr *et al.*, 1997). In addition, based on our COARE data analysis, we think that solar irradiance measurements made either on the island or on a buoy and averaged over periods on the order of a month are representative of relatively large spatial areas on the order of hundreds of kilometers. Finally, we think that surface flux measurements made from buoys near the island can be used to characterize the oceanic environment around the island. The Nauru99 field campaign is being designed to address these issues. A full list of project objectives and hypotheses are listed in Figure 2.

Observation Strategy

The ARCS observations on Nauru (Mather et al., 1997) serve as the starting point for our campaign because our primary scientific objective is tied to these measurements. All ARCS instruments will be in operation, especially the solar radiometers, microwave radiometer, lidar, and the millimeter cloud radar. Soundings will be required four times a day in order to characterize the atmospheric state.

Two research ships have committed to participation in Nauru99, the NOAA R/V *RONALD H. BROWN* and the R/V *MIRAI* from the Japanese Marine Science and Technology Center (JAMSTEC). Figure 3 shows these two ships. The ship(s) will carry a complement of instruments that basically matches the instrumentation on the island, including lidar and mm cloud radar. Four-per-day soundings also will need to be acquired from the ship. The final component of the field campaign is the solar radiation observations on the TAO buoys.

A summary of the desired instrumentation for the island and the two ships is shown in figure 4. This list summarizes the instruments and lists institutions which are prime candidates to supply these instruments. Note: this list is subject to change and many elements of it are under negotiation.

Both the *RON H. BROWN* and the *MIRAI* (see below) carry steerable doppler weather radars with approximatey 200 km ranges for echos and 100 km ranges for doppler velocities. The *BROWN* carries a C-band weather surveillance radar system that has been dopplerized to map precipitation velocity and intensity. The *MIRAI* has a new C-band doppler system of equivalent power and range and can be steered over an elevation range of -17–85°±0.3°. The radars will allow mapping of precipitation and clouds over a considerable scale.

The observational strategy is straightforward. Figure 5 shows two observation patterns, the "triangle pattern" and the "spatial pattern." The triangle pattern has a horizontal scale of 200 km which is suitable for comparison to global climate models. During this period we expect to increase the rate of radiosonde soundings to eight soundings per day. The spatial pattern is designed to measure the spatial and temporal correlations of measurements on a scale of 0–100 km. The *MIRAI* will hold a station 100 km from Nauru and the *RON BROWN* will move back and forth between the two.

The current schedule for the intensive period is shown in Figure 6. The *MIRAI* will arrive to the area early and will hold stations at three buoy sites allowing several days of comparison measurements at a Triton buoy, the 5N Atlas buoy, and the 2N Atlas buoy. Then the ship will move to the Equator Atlas buoy where it will hold station for almost five days during the triangle pattern. The *RON BROWN* will occupy a position at the 2S Atlas buoy during the triangle period. After the spatial pattern, the *MIRAI* will leave the area but the *RON BROWN* will occupy a fixed site 25 km from Nauru for a full week thereafter.

Several observing systems would be extremely valuable in the context of the Nauru99 campaign. However, there is no certain funding for these and so we mention them here as "desirable but not necessary."

1. One or two special buoys are suggested. Because the nearest TAO buoy is located at a distance of about 200 km from the Nauru site, we would like to deploy stable buoys (Figure 3) to provide a solid tie point between the island and the TAO moorings. The "multispar" buoys from the University of Miami are extremely stable and have advantages over other types. Namely, they can be tethered from a ship without being anchored in the 4000 m depth water without losing stability, and their cost is nominal. If moored near the island, they would provide additional correlation points among the island, ship, and TAO buoys.
2. Research aircraft. A low-level aircraft based in Nauru could be used to measure turbulent and radiative fluxes in the boundary layer in conjunction with ship and island measurements. These observations would allow us to investigate the 2-D variability of these fluxes in the oceanic environment and thereby supply information about the representative nature of the ship observations themselves. In addition, measurements of the modification of the boundary layer in the vicinity of the island would be useful in understanding the influence of the island on the ARCS measurements. One alternative that we are exploring is the use of a small UAV, the "Aerosonde," from the Bureau of Meteorology in Australia, for this purpose.
3. Supplementary ARCS instruments. A few additions to the instrumentation on the island might be considered. The most costly of these would be the deployment of a research lidar with depolarization capabilities to augment the MPL data. Aerosol optical depth measurements with a sun photometer or light scattering measurements with a nephelometer would also be useful.

We also note that there is some slight possibility of interaction with a TRMM validation campaign planned for Kwajelein atoll during this period. Due to the approximately 800-km separation between Kwajelein and Nauru, this interaction will be limited. However, we are investigating this possibility.

Calendar

A calendar showing major milestones for the next 18 months is shown in Figure 7. All operational periods are shown in red and are elucidated by balloon captions. Specifically, in May–July 1998 a *RON BROWN* cruise in the Atlantic Ocean will afford opportunity to intercompare several crucial instrument packages and to become familiar with the ship.

Also note that the *MIRAI* is scheduled to make a preliminary cruise to the TWP in March 1999, and this will be a dress rehearsal for the intensive oper- ation two months later.

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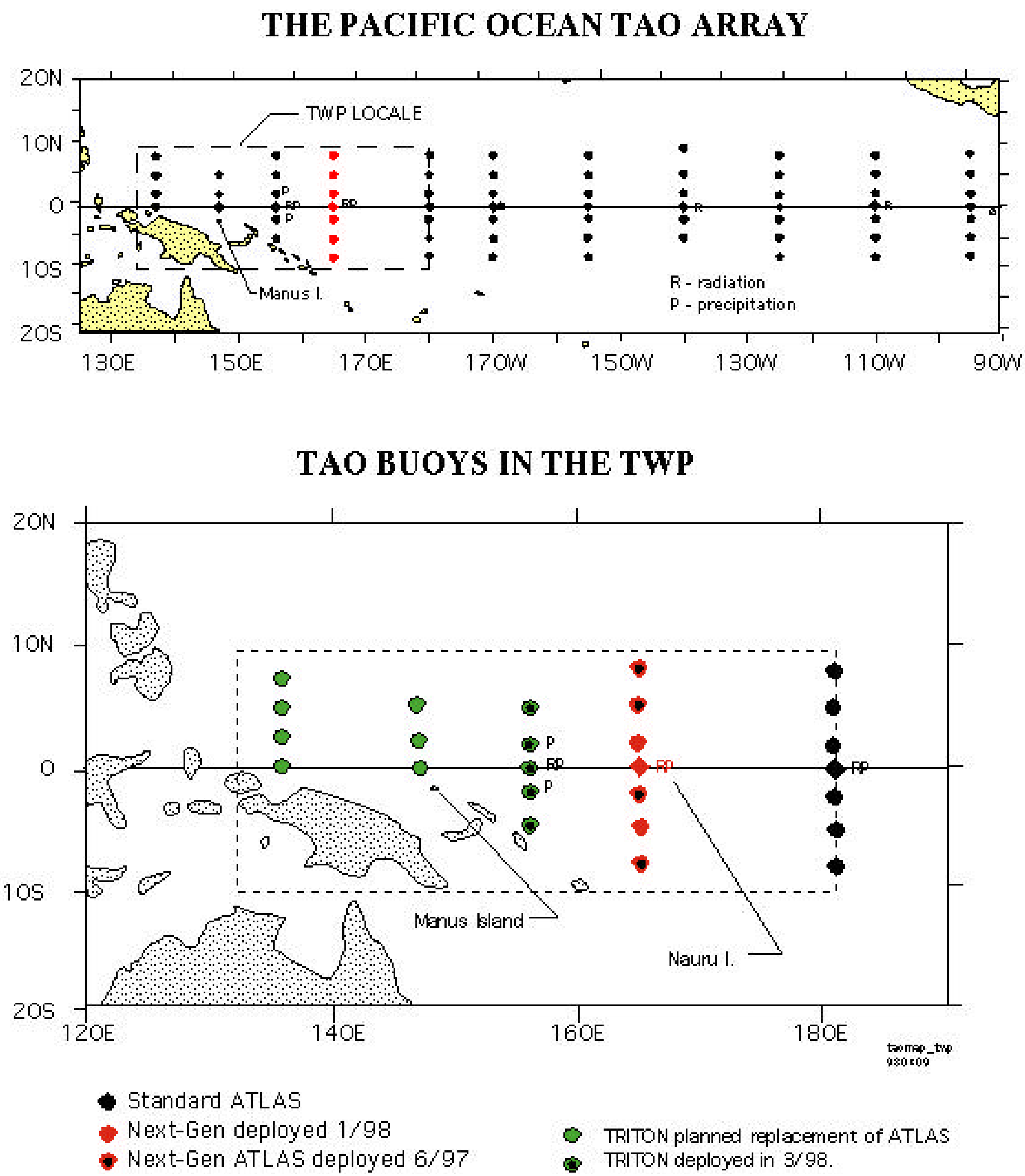

Figure 1: The TAO buoy coverage in the tropical Pacific Ocean. In the near future, JAMSTEC will be responsible for all TAO moorings from 156°E westward. NOAA/PMEL is instrumenting the 165°E line of Atlas buoys with quality radiation sensors. The Japanese Trident buoys will have similar radiation sensors.

NAURU99 INTENSIVE FIELD OPERATION

OBJECTIVES:

1. Evaluate island effects in order to establish the validity of the ARCS measurements.
2. Identify dynamic processes that effect cloud development and spatial-temporal variability. Effects of islands on these processes.
3. Evaluate the quality of TAO buoy radiation measurements by comparing with ship measurements.
4. Carry out a dual doppler radar study of clouds in the TWP.
5. Investigate the spatial variability of air-sea fluxes and spatial correlations of processes in the mesoscale, especially on scales of 10--200 km.
6. Obtain a triangle single-column data set on the scale of 200 km.
7. Compare surface radiation and cloud properties with those obtained from satellite observations from TRMM and EOS AM platform.

HYPOTHESES TESTED:

I. By comparing spatial and temporal correlations between measure ments we can determine anoptimum averaging time for island-based measurements to agree with over-the-water measurements on spatial scales of 10–200 km.

II. After careful regional "tuning" using turbulence flux measurements, bulk transfer algorithms are capable of estimating air-sea fluxes to needed accuracies.

III. Short-wave radiation measurements from the TAO buoys, on some temporal scale, are sufficiently accurate for a long-term climate record.

IV. Satellite observations can provide data of sufficient quality and spa tial resolution to support GCM research in the TWP.

V. A mesoscale network on a spatial scale of 200 km can provide data useful for single-column model forcing and verification.

Figure 2: Objectives and Hypotheses for Nauru99.

Figure 3: Platforms available for the Nauru99 study. The NOAA R/V *RONALD H. BROWN* (LOA 84 m, Tonnage 3250 tons, 35 scientists, 24 crew) will repeat the Combined Sensor Program's 1996 effort. The R/V *MIRAI* (LOA 130 m, Tonnage 8600 tons, 46 scientists and 34 crew) is the new JAMSTEC vessel. The NOAA TAO buoy is a 3 m toroid that is moored to the 4000 m depth with a stretched nylon, taught-line mooring. The U. Miami Multispar buoy is free floating yet highly stable and ideal for an experimental program. It is a good candidate for the ARM special buoy.

NAURU-99 INSTRUMENT LIST

As of 6 Mar 1998

INSTRUMENT	NAURU I.	R/V RON BROWN	R/V MIRAI
Radar - 5 cm		NOAA	JAMSTEC
Radar - S-band	AL	AL	AL
MM clour Radar	ARCS	ETL	?
ASI Fluxes		ETL	JAPAN
Portable Radiation Package	BNL	BNL	BNL
Hemispheric Sky Imager	SRRB-BNL	SRRB-BNL	SRRB-BNL
Balloon system	ARCS	ETL	JAMSTEC
Profiler/RASS	AL	AL	NCAR
IRT (up looking)	ARCS	BNL	BNL
Ceilometer	ARCS	ETL	JAMSTEC
Micropulse Lidar	ARCS	ETL	JAMSTEC
Dual-chan Lidar			NCAR ?
Microwave Radiometer	ARCS	ETL	JAMSTEC
M-AERI		U.MIAMI	U.MIAMI
AEROSONDE	BOM		
ADCP		NOAA	JAMSTEC
Sub-sea optics		U. Dal-housie	U. Dal-housie
Biota assessment		?	?

AL - NOAA Aeronomy Lab
ETL - NOAA Environmental Technology Laboratory
ARCS - Atmospheric Radiation and Cloud Station
JAMSTEC - Japan Marine Science and Technology Center
JAPAN - un-named research group from Japan
BNL - Brookhaven National Laboratory
SRRB - NOAA ARL Solar Radiation Research Branch
NCAR - National Center for Atmospheric Research
BOM - Australian Bureau of Meteorology

Figure 4: The above list is the current array of major instrument packages between the island and two ships.

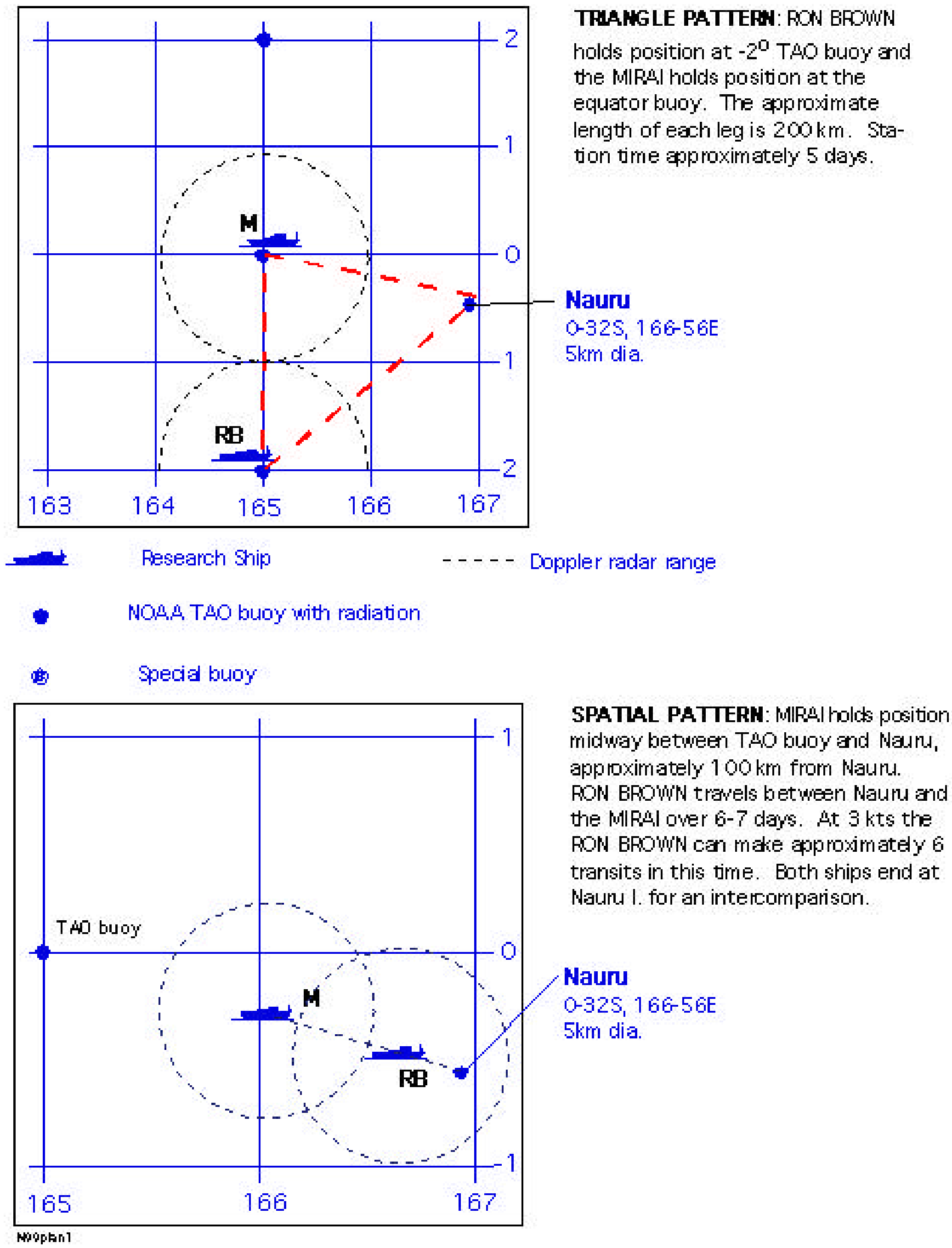

Figure 5: Two phases of the experiment are the “triangle pattern” and the “spatial pattern.”

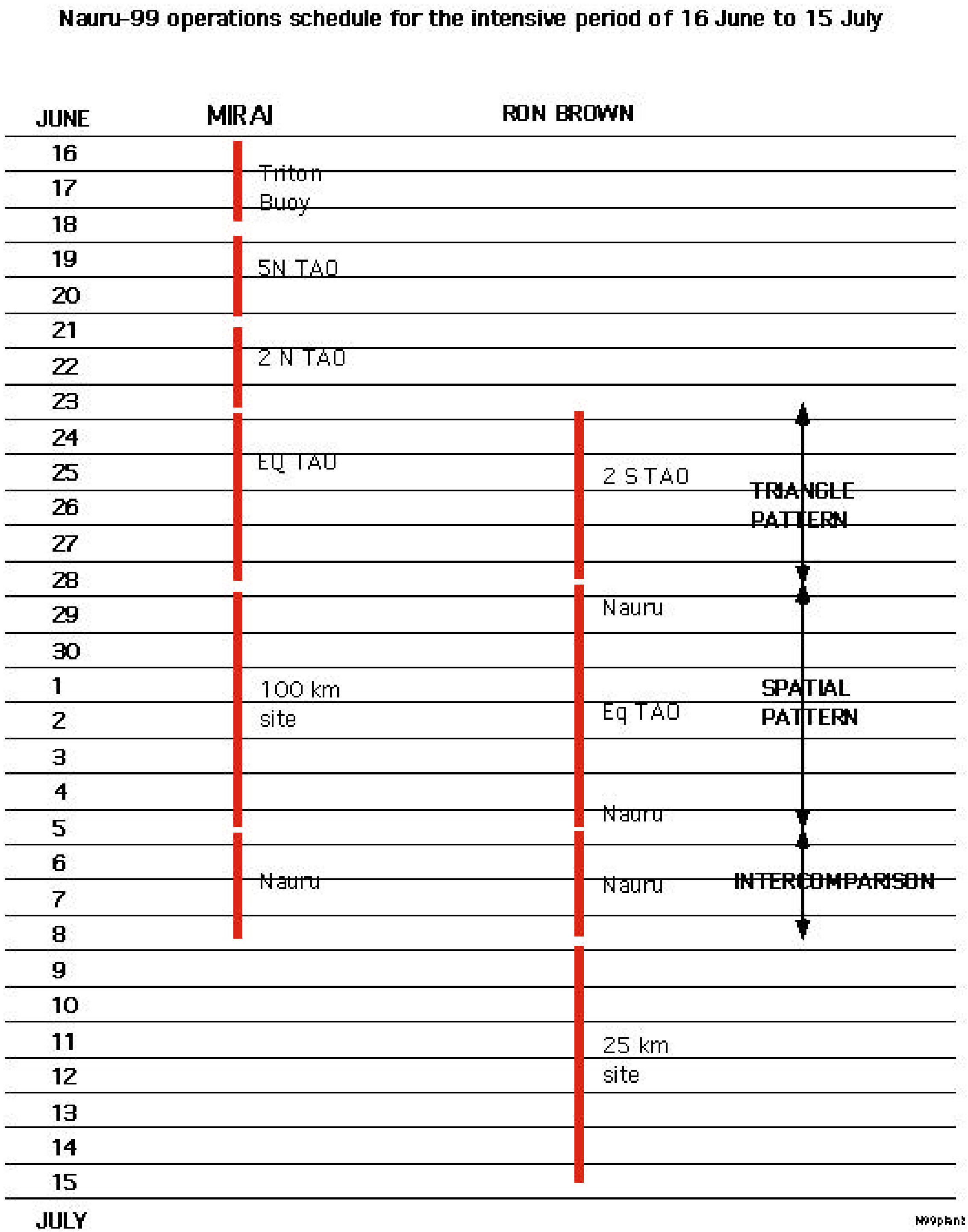

Figure 6: because the ships will arrive and leave from the area at different times, a compromise plan for buoy intercomparison and joint operations is scheduled.

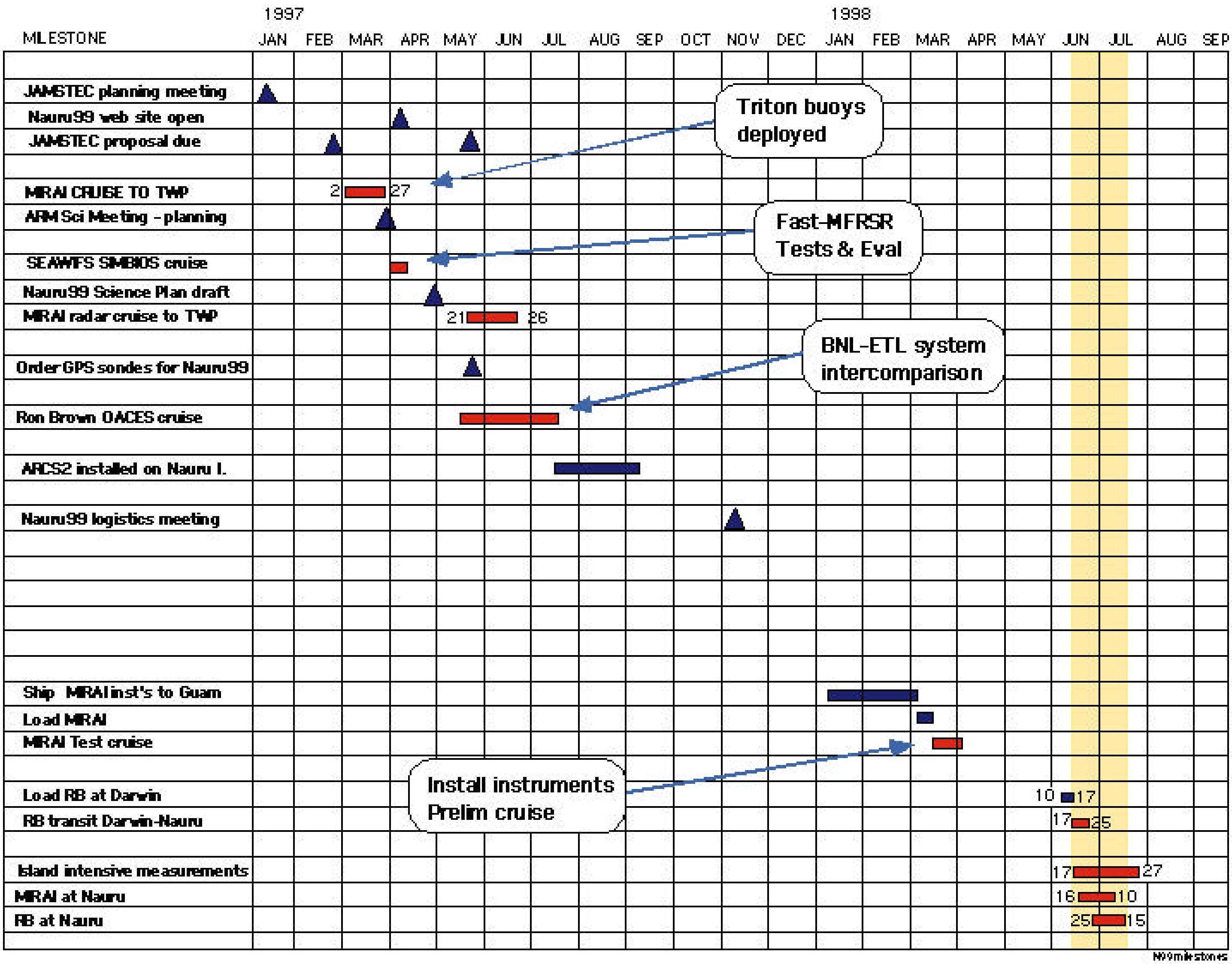

Figure 7: The current major milestone schedule.