

TOGA COARE Aircraft Mission Summary Images: An Electronic Atlas

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Abstract

An electronic atlas of research aircraft missions in TOGA COARE (Tropical Ocean Global Atmosphere Coupled Ocean–Atmosphere Response Experiment) has been prepared and is available on the Internet via World Wide Web browsers such as Mosaic. These maps are in the form of time sequences of color imagery assembled using the NCAR Zebra software. Initial versions of these maps were prepared in the field at the TOGA COARE Honiara Operations Center to aid in the evaluation of each aircraft mission immediately after it was flown. The maps prepared in the field have been updated, corrected, and remapped at standard scales and with common color schemes. They show the meteorological setting of sampling by all seven aircraft participating in TOGA COARE—the two NOAA WP-3D aircraft, the NCAR Electra, the FIAMS C-340, the UK C-130, and the NASA DC-8 and ER-2—by overlaying flight tracks, GMS satellite infrared data, and NOAA WP-3D airborne radar images. The map sequences are combined with text of scientists' notes and other background information on the research flights to form a summary of each aircraft mission. The resulting aircraft mission summaries are intended as a road map to the COARE aircraft dataset. They indicate where and when data were collected and the meteorological context for those data. As an electronic document, the atlas of aircraft mission summaries is available on demand, and it is dynamic: as further information becomes available, the mission summaries will continue to be added to and updated as appropriate, and new releases will be issued periodically.

1. Introduction

The intensive observation period of the Tropical Ocean Global Atmosphere Coupled Ocean–Atmosphere Response Experiment (TOGA COARE) was conducted from 1 November 1992 through 28 Febru-

ary 1993. Its purpose was to document the interactive processes that constitute the joint variation of the tropical atmospheric and upper-oceanic circulations in the region of the large-scale pool of warm water dominating the western tropical Pacific Ocean (Webster and Lukas 1992). The warm pool slowly migrates back and forth across the western Pacific from year to year in connection with the climate variations known as El Niño and La Niña. Cloudiness associated with near-equatorial deep convection is maximum on average over the warm pool. During a typical November–February period, the circulation and cloudiness associated with the warm pool undergoes an intraseasonal oscillation (ISO), typically characterized by two periods of suppressed and active cloudiness (Lau et al. 1989).

The warm-pool convection is a vital link in the chain of atmospheric–oceanic processes in the Tropics. The convective clouds distribute the sensible and latent heat imparted to the atmosphere by the warm ocean vertically into the free atmosphere, and they feed back to the ocean by precipitating cold, fresh water onto the sea surface. They redistribute horizontal momentum via cloud updrafts and downdrafts, produce wind stress on the ocean surface, and strongly affect the vertical transfer of solar and infrared radiation.

Many aircraft measurements were made in TOGA COARE to observe these critical aspects of the warm-pool convective clouds and to document the structure of the atmospheric boundary layer, which overlies the warm ocean and connects the ocean with the clouds above. Researchers working with data collected on these flights need a quick and effective way to locate any portion of any aircraft flight in relation to the positions of other data platforms (ships, buoys, islands, and other aircraft) and to place that flight into the meteorological context prevailing during the mission. An atlas, or road map, through the experiment is needed. To be most effective this atlas should be comprehensive, simple to use, and easy to update. This paper announces the availability of an electronic atlas of the TOGA COARE aircraft program. The atlas contains over 900 images, which have been carefully designed to lead the user of the atlas through each aircraft mission. Text describing the missions is also

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included in the atlas. The networking and color graphics capabilities available on most computer systems allow the atlas to be retrieved on demand and displayed on the screen. This atlas is available on the Internet via World Wide Web browsers such as the National Center for Supercomputing Applications (NCSA) Mosaic software and will be periodically added to and updated as further information on the flights becomes available. Maintaining the atlas electronically makes it accessible to a wide community of users including not only those directly involved with the COARE aircraft data, but anyone interested in the aircraft sampling during this four-month field program centered on the Pacific warm-pool region.

The electronic atlas of aircraft mission summary images began in the field as a graphical tool to debrief and review each mission after it was flown. After the project, these debriefing images were edited, expanded, completed, and combined into the atlas. In the following, we first provide some background on the TOGA COARE aircraft program and describe how the atlas is organized. We also show some examples of the images, and we provide simple instructions on how anyone with an appropriate computer system (e.g., PC, Macintosh, or UNIX workstation) can access and use the atlas.

2. The TOGA COARE aircraft program

a. What the aircraft were trying to accomplish

Convection in the warm-pool region comprises a spectrum (Mapes and Houze 1992, 1993a). Clouds range from small isolated cumulus to giant cloud clusters and groups of clusters called "superclusters" (Nakazawa 1988). The objective of the aircraft program of TOGA COARE was to sample all parts of the spectrum equally. To accomplish this objective, the aircraft sampling was divided into five classes. Class 4 aircraft missions sampled large mesoscale convective systems, which produced infrared cloud-top temperatures <208 K over a contiguous region greater than $60\,000\text{ km}^2$. Class 3, 2, and 1 missions sampled smaller convective clouds whose tops, defined by the 208 K cloud-top temperature contour, were, respectively, $20\,000$ – $60\,000\text{ km}^2$, 6000 – $20\,000\text{ km}^2$, and $<6000\text{ km}^2$. Mapes and Houze (1992) found that each of these cloud-size categories account on average for about one-fourth of the total cold cloudiness over the warm pool in the November–February period. Class 0 missions sampled conditions in which no clouds sampled produced tops with infrared temperatures <208 K. The aircraft program aimed to divide the available flight hours evenly among classes 0–4 in order to sample equitably the cloud spectrum from

relatively undisturbed conditions to large mesoscale convective systems.

The aircraft operations area is shown in Fig. 1. The flights involved from one to seven aircraft. In every case in which more than one aircraft was deployed, the flight tracks were coordinated by airborne mission scientists to obtain the most effective combination of data for the convective weather regime being sampled. The experiment design allows researchers using the aircraft data to investigate the similarities and differences of warm-pool convection in each category of convection, ranging from smallest to largest, and to understand how the convection varies as the ISO progresses through its disturbed and undisturbed phases.

b. How the aircraft were deployed

The seven aircraft participating in TOGA COARE were in two main groups: turboprop aircraft capable of flying at lower levels and at slower speeds, and jet aircraft flying at high altitudes [$>6\text{ km}$ ($20\,000\text{ ft}$)] at higher speeds. The flight tracks and coordination of the aircraft varied according to the class of convection being investigated. [For details see the TOGA COARE Operations Plan (TCIPO 1992).] The idea in class 0–1 missions was to map the boundary layer by either a single aircraft or by a multiple-aircraft "armada" pattern, in which two or more planes flew at low levels

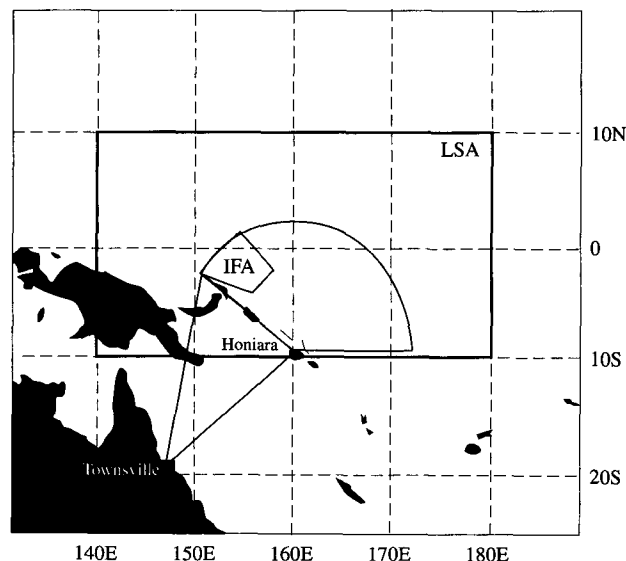


FIG. 1. Map of TOGA COARE region. Locations of Honiara, Guadalcanal, Solomon Islands, and Townsville, Australia, are indicated. The rectangle from 10°S to 10°N and 140° to 180°E is the large-scale array (LSA) where TOGA COARE observations were concentrated. The pie-shaped region anchored at Honiara and the triangular area extending across the Solomon Sea toward Townsville mark the aircraft operations area. The quadrilateral centered near 2°S , 156°E is the intensive flux array (IFA).

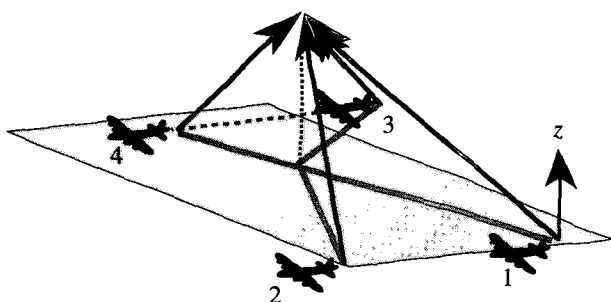


FIG. 2. Schematic of the flight strategy for quadruple Doppler radar observation. Two aircraft fly parallel tracks spaced 20–50 km apart; z is height. Each point in the domain will be seen (depending on attenuation) by as many as four beams—two forward-looking and two aft-looking (from Jorgensen and Matejka 1993).

(below 0.5 km). The turboprop aircraft arrived in close formation at a designated location in the vicinity of research ships and instrumented moorings and then spread out horizontally to map the boundary layer over an $\sim 20\,000\text{ km}^2$ area. While the turboprop aircraft were mapping the boundary layer, airborne Doppler radar measurements were made of any small precipitating convection. In the more convectively active (class 2–4) cases, the turboprop aircraft emphasized airborne Doppler radar documentation of the structure of the deep precipitating cloud and remained in the vicinity of the precipitating clouds rather than spreading out horizontally. In missions during the latter half of the intensive observation period, jet aircraft were flown at upper levels in coordination with the lower-level flying turboprop aircraft to document radiation, temperature, and precipitation structures.

The flight tracks plotted in the atlas images reflect these flight strategies. The user of the atlas will note that the flight tracks of the turboprop aircraft spread out horizontally in class 0–1 missions, while the tracks remain closer together in the class 2–4 missions. To optimize the use of airborne Doppler radars, two new flight strategies were employed in the class 2–4 missions. One new methodology, called quadruple Doppler, was designed to compute more accurate three-dimensional winds (Jorgensen and Matejka 1993). When employing this technique, two Doppler radar aircraft flew parallel tracks to obtain a combination of coverage by two beams from each aircraft (Fig. 2). The user of the atlas will recognize these quadruple Doppler sampling periods as times when two aircraft were flying parallel tracks about 40 km apart. The second new methodology was used to collect profiles of the horizontal divergence over an $\sim 500\text{ km}^2$ area. These profiles are useful to evaluate the vertical profile of heating of the environment by convection (Mapes and Houze 1993b). To obtain these profiles in TOGA

COARE, the concept of flight track “purls” was introduced. By flying a circular loop at intervals along the flight track, like a knitter’s purl in a length of yarn, an accurate and simple-to-calculate divergence profile was obtained in about 4 min (Fig. 3). The user of the atlas will note that the flight tracks in class 2–4 missions contain purls in the form of small loops in the flight tracks regularly interspersed within the quadruple Doppler and other flight patterns.

c. The aircraft participating in the project

The basic aircraft plan of boundary layer armadas and airborne Doppler radar measurements was executed by the two National Oceanic and Atmospheric Administration (NOAA) WP-3D aircraft and the National Center for Atmospheric Research (NCAR) Electra¹ during the entire four months of the field phase of TOGA COARE. These three turboprop aircraft were staged out of Honiara, Guadalcanal, Solomon Islands. During the last two months of the project, these turboprop aircraft were joined by the National Aeronautics and Space Administration (NASA) jet aircraft, the DC-8 and the ER-2, which were staged out of Townsville, Australia. These aircraft flew in close coordination with the turboprops. The NASA DC-8 provided cloud physics and radiation measurements in the upper portions of the convective cloud systems, as well as carrying ARMAR, a downward-scanning Doppler radar that is a prototype for the Tropical Rainfall Measuring Mission (TRMM) satellite radar. This radar provides additional measurements of the structure and intensity of the precipitation observed simultaneously by other radars aboard the turboprop aircraft and on ships. The NASA ER-2 operated primarily above cloud-top level providing high-altitude remote sensing measurements with several radiometers, a lidar, and a multispectral scanner.

The U.K. Meteorological Office C-130 aircraft also participated in the flight plan described above by augmenting boundary layer mapping on several flights during January 1993. Also, single-aircraft boundary layer flights were flown by the Flinders Institute for Atmospheric and Marine Sciences (FIAMS) Cessna (C-340) aircraft based out of Rabaul, Papua New Guinea. The NCAR Electra also flew a large number of single-aircraft missions. The single-aircraft missions of the FIAMS C-340, UK C-130, and the NCAR

¹The ELDORA Doppler radar was not installed on the NCAR Electra until January 1993. During November and December 1992, the Electra flew patterns appropriate to the collection of in situ data. In January, several “shakedown” missions for ELDORA were flown with the Electra flying Doppler patterns. Research-quality Doppler data from ELDORA were continuously obtained during six missions in February (P. Hildebrand 1994, personal communication).

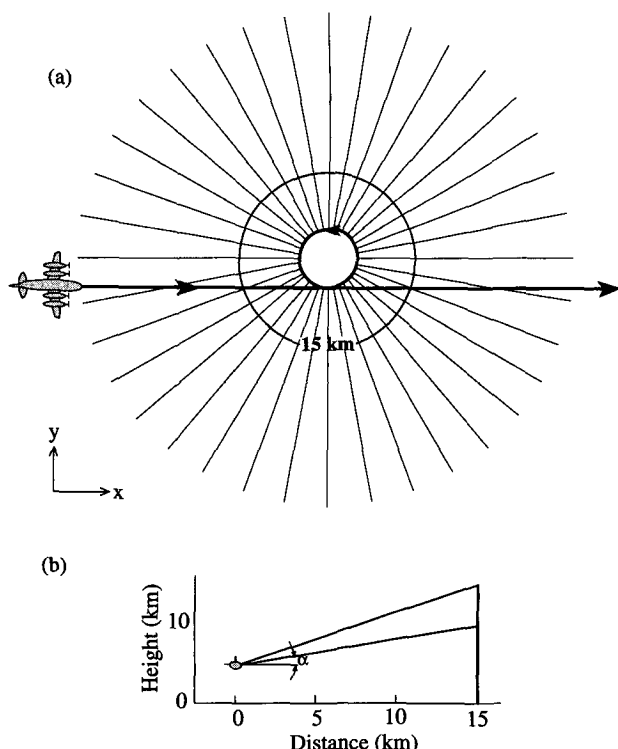


FIG. 3. Purl pattern. (a) Plan view of flight track (heavy line with arrows) with purl (loop). As the aircraft makes a 4-min, 360° turn, Doppler radar beams (thin lines) point outward from flight track. Velocity components along the beams allow the horizontal divergence of the wind to be computed for various levels within a cylindrical volume (e.g., the 15-km-radius circle shown) centered on the purl. (b) Vertical cross section showing that the radar beam scans vertically through a sequence of elevation angles (α) so that the divergence within a cylindrical volume can be determined as a function of height when the aircraft flies in a purl such as (a).

Electra helped fill in information on days between coordinated multiple-aircraft missions. All the missions, involving either single and multiple aircraft, are included in the electronic atlas.

d. When and where the planes actually flew

The satellite climatology of Mapes and Houze (1992) revealed factors that had to be taken into account in planning the aircraft missions.

- The size distribution of the cloud shields was of a truncated lognormal character, meaning that the large systems were rare and the small systems common. The implication was that the small systems (classes 0 and 1) would be common over the highly instrumented intensive flux array (IFA), which was the focal point of the TOGA COARE observational domain (Fig. 1), but that the larger systems (classes 3 and 4) would only occasionally affect that region.

- Over the open ocean (away from island influences) the large systems (classes 3 and 4) exhibited a strong diurnal cycle, characterized by formation around midnight and maximum cold cloud cover around dawn, while the smaller classes exhibited no strong diurnal cycle except near large islands.
- Large (class 3 and 4) systems tended to be involved in “superclusters.” They occurred intermittently with a frequency and structure that is related to the ISO and other large-scale wave organizations of the environmental flow pattern (Lau et al. 1989).

These results implied that the class 0–1 missions could easily be flown over the IFA and at any time of day. The class 2–4 missions, however, had to be flown over a wider area in order to obtain a sufficiently large sample of flights in systems of all sizes, and these missions had to be flown at night, specifically in the early morning hours before and just after dawn. For this reason, the user of the atlas will note that the class 0–1 mission flight tracks were all in daytime when the aircraft could fly lower, while the class 2–4 tracks tended to be at night. The user of the atlas will also note that, because of the tendency for the large systems to arrive in superclustering episodes, the missions in large class 3–4 convection tended to occur in bunches. For many days in a row these large cloud systems would not be available to sample, and then they would occur in an episode, or supercluster event, that would last several days running. Supercluster events were problematic to forecast. When they occurred, their constituent class 3–4 systems were flown several days in a row in order to obtain an adequate sample.

To indicate where the missions were generally flown, all the flight tracks of the two NOAA WP-3D aircraft are combined in Fig. 4. The class 0–1 flights (Fig. 4a) were all conducted over the IFA. In contrast, the class 2–4 missions (Fig. 4b) were spread over a larger area to capture the large convective systems wherever they presented themselves. The reason for this is that the larger cloud systems were much more infrequent and had to be sampled wherever they occurred within range of the aircraft.

The final tally of samples by class is summarized in Fig. 5. The sampling of classes 0–1 was enhanced by additional flights of the FIAMS C-340 and UK C-130. Given the difficulties of forecasting the rare occurrence of the larger systems, the planning of aircraft missions based on imperfect forecasts, the fact that the lead time in planning and launching a mission is of the order of the timescale of the cloud systems, the logistical problems associated with operating in a developing country, and other factors, the sampling is reasonable. Not surprisingly, most cases were obtained in classes 0 and 1. The number of class 3 and

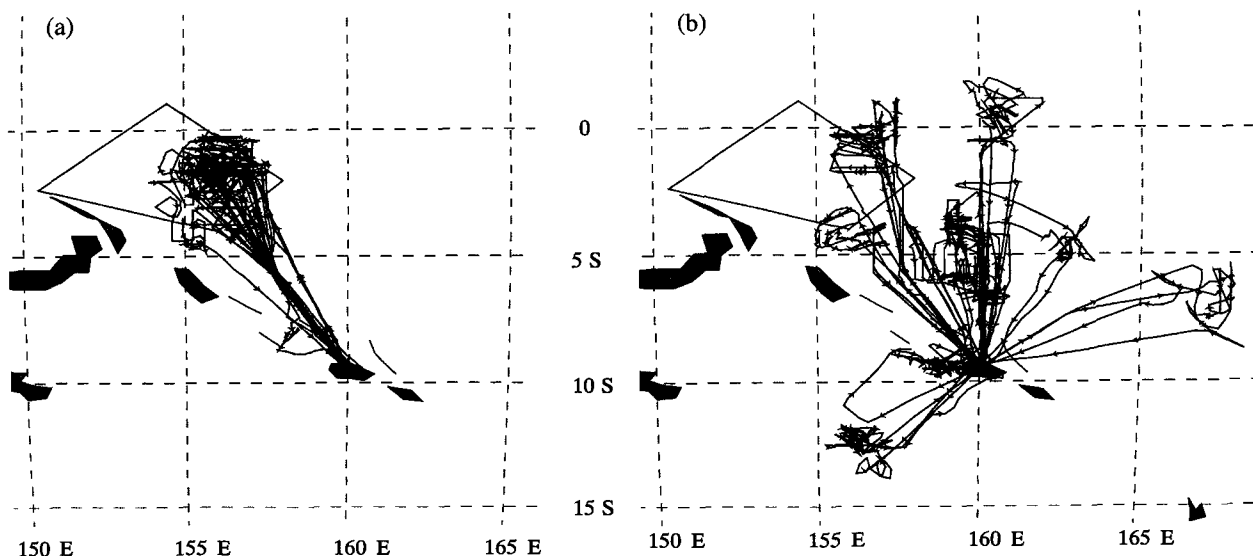


FIG. 4. Combined NOAA WP-3D flight tracks for all missions flown during TOGA COARE. Quadrilateral indicates location of IFA. (a) Tracks for class 0–1 missions; (b) tracks for class 2–4 missions.

4 cases was as large as was possible under the difficult experimental constraints.

e. Monitoring of aircraft missions in the field

Because the objective of the TOGA COARE aircraft program was to sample equally all five classes of convection, a critical activity was to maintain a running evaluation of progress toward this goal. It was therefore important to obtain a quick summary immediately after each mission to determine exactly how the flights had been executed in relation to clouds and precipitation. Therefore, during the field phase of the aircraft program, summaries of the aircraft tracks, radar echo patterns, and satellite imagery of aircraft missions involving NOAA WP-3D and NCAR Electra aircraft were constructed electronically using the NCAR Zebra data display and integration system (Corbet et al. 1994) at the Honiara Operations Center. These images were used by the scientists in the field to review each mission within a few hours after each flight.

To facilitate the viewing of the mission summaries, loops of images at half-hour intervals during the primary data collection period of the mission were assembled and put into a menu for easy access on a workstation screen. Two loops were constructed for each mission—one in which only the flight tracks were superimposed on infrared satellite imagery, and another in which both flight tracks and composites of the radar reflectivity patterns from the lower-fuselage radars of the NOAA WP-3Ds were superimposed on the satellite imagery. These loops of images summarizing the flight tracks in relation to satellite and radar imagery were so useful that it occurred to scientists in the

field that these images would continue to be useful after the field project. Combining the images from all the flights would create a comprehensive electronic summary of the aircraft experiment. Thus, the monitoring of the flights in the field was the genesis of the electronic atlas.

3. The electronic atlas on the World Wide Web

a. Investigators need a road map

The strength of the TOGA COARE aircraft dataset is that it sampled the spectrum of convection over tens of missions and during different stages of the ISO. The logistics of TOGA COARE were more complicated than in previous field projects. The aircraft operations were based out of three widely separated facilities (Honiara, Rabaul, and Townsville) with limited communication between facilities. The four-month length of the field phase of the project meant that most investigators were in the field only part of that time. At the time the project ended, investigators who participated in the field phase had only a partial picture of the total aircraft operations based on where and when they were stationed and with what aircraft they were associated. A complete picture of aircraft operations required an assembly of information from a variety of sources. This information becomes easier to use when it is amalgamated into a form such as a mission summary image where *all* of the flight tracks can be seen at once in the context of the satellite and radar reflectivity data on a common scale.

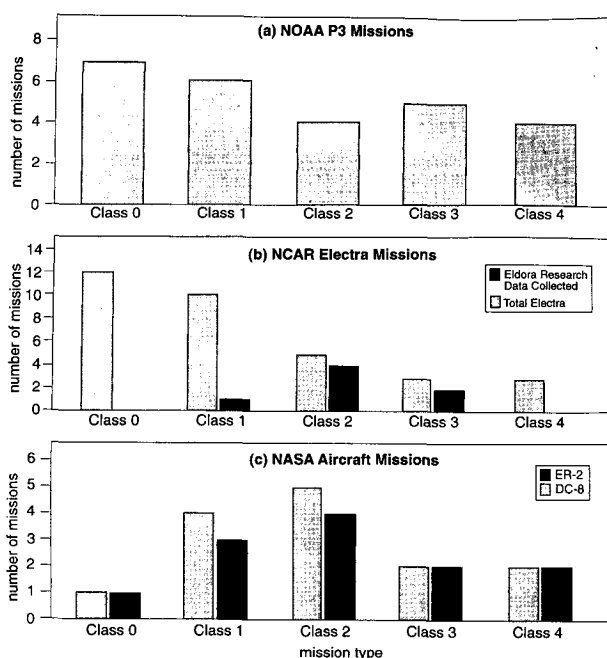


FIG. 5. Tally of aircraft missions flown by class. (a) NOAA WP-3D missions—includes missions flown by N42RF and/or N43RF. (b) NCAR Electra missions. Total Electra missions indicated by lighter bars. Missions when ELDORA radar research data were continuously collected are indicated by darker bars (P. Hildebrand 1994, personal communication). (c) NASA aircraft missions: DC-8 lighter bar, ER-2 darker bar. For each aircraft there was one mission when satellite data were not available to make a classification. These missions are not included in the bar graphs. Some missions investigated convective systems of two different classes and thus were counted twice.

The size and complexity of the aircraft datasets are so great that investigators need a road map in order to navigate the data. With a road map, all investigators, whether they were present in the field or not, will have the benefit of the complete picture of what general types of data were collected, when, and where. Indeed, a good road map through the experiment allows anyone with even a casual interest in TOGA COARE to obtain an impression of what was accomplished by the TOGA COARE aircraft.

b. Why distribute the atlas electronically?

An electronic atlas facilitates use of the COARE aircraft data by not only investigators closely associated with the aircraft program but also by investigators from other areas of COARE, as well as those outside of COARE who may want to browse the dataset to locate potential supplemental data for their own investigations. By making the atlas available via a general purpose, public domain Web browser such as NCSA Mosaic, one can gain a general overview of the dataset without the resources associated with data-specialized software. Making the COARE aircraft

dataset easier to comprehend will aid in its long-term use to its fullest potential.

An electronic atlas has an advantage over a hard copy in that it can be easily kept up to date and it can be more comprehensive. The electronic atlas we have compiled contains over 900 color mission summary images. Such an atlas would be prohibitively expensive to publish conventionally.

c. Organization of the atlas into mission summaries

As noted in section 2e, the idea of an electronic atlas of the TOGA COARE aircraft program began in the field, when investigators first combined the flight tracks, satellite imagery, and radar data into loops of images replaying the mission for purposes of debriefing the flights. After the field phase ended, the loops constructed in the field for the purpose of monitoring the aircraft missions have been carefully reconstructed. Missing data have been filled in and errors corrected. In addition, the loops are now presented on standardized scales and with standard color schemes, and the color scales have been optimized to bring out the information in the overlaid radar and satellite displays. Missions for which loops were not constructed in the field have been included, and the flight tracks of the FIAMS C-340, UK C-130, and NASA DC-8 and ER-2 aircraft have been added.

These edited and revised loops of images containing the aircraft tracks, satellite imagery, and airborne radar reflectivity data have been organized into units called mission summaries. Each mission summary contains airborne scientists' notes regarding the objectives and implementation of the missions and their initial impressions of the flights, plus one or two sequences of color images at 30-min intervals during the primary period of data collection by the aircraft. For all missions, there is a sequence of images of aircraft flight tracks superimposed on Geostationary Meteorological Satellite (GMS) infrared (IR) data on an $\sim 7^\circ \times 7^\circ$ scale. Additionally, for missions that included the NOAA WP-3D aircraft, flight tracks are superimposed on a combination of GMS satellite IR data and radar composites from the NOAA WP-3D lower-fuselage radars on a scale of $\sim 4^\circ \times 4^\circ$. The text files of scientists' notes can be presented on the screen of the computer and referred to while examining the images. Taken together, these mission summaries form an electronic atlas of the aircraft missions of TOGA COARE.

Each mission summary image presents data collected during the interval (nominally one-half hour) leading up to its designated time, which appears prominently in the upper left of the image. Since different platforms (e.g., satellite and aircraft) collected data over different time intervals, the exact

collection time of the data presented for each platform is indicated in every image.

Color coding within the mission summary images is indicated on the right-hand side of the images. Satellite IR data were assigned a gray-scale color according to cloud-top temperature from black (warm) to white (cold). Temperatures <208 K were colored red, orange, pink, and yellow with decreasing temperature. The radar reflectivity data in the NOAA WP-3D lower-fuselage composites are color coded in seven 5-dBZ intervals from 15 to 55 dBZ, which emphasize the precipitation structure. The 15-dBZ threshold aids in removing most of the sea-clutter echo (i.e., echoes produced by radar return from rough seas) from the images. The tracks for each aircraft are the same color as their designation on the right-hand side of the image.²

In addition to the mission summary images, included in the atlas is a “Missions at a Glance” table that identifies the class of each mission based on satellite IR data and the takeoff and landing times of the aircraft involved.

d. Examples of images contained in mission summaries

Examples of the revised and updated mission summary images are shown in Figs. 6–9. Figures 6–7 show a class 4 system observed on 15 December 1992 just south of the IFA. This event was among the largest and most intense precipitating systems observed by aircraft during TOGA COARE, with radar-observed convective echo tops reaching heights up to 20 km. It was associated with a disturbed phase of the ISO. Figure 6 shows a $\sim 7^\circ \times 7^\circ$ image with flight tracks overlaid on satellite data only. The color coding of the satellite image indicates that in this segment of the mission the aircraft were operating in a section of a larger area (roughly $5^\circ \times 2^\circ$) of cloud-top temperature of 208 K and colder. Small white circles are placed on each flight track at 10-min intervals. Figure 7 shows additional detail by overlaying these same tracks

²The aircraft designations in the mission summary image are as follows: n42rf_st—NOAA WP-3D N42RF, n43rf_st—NOAA WP-3D N43RF, n308d_dap—NCAR Electra N308D, dc8_st—NASA DC-8, er2_st—NASA ER-2, c340_st—FIAMS C-340, c130_st—UK C-130.

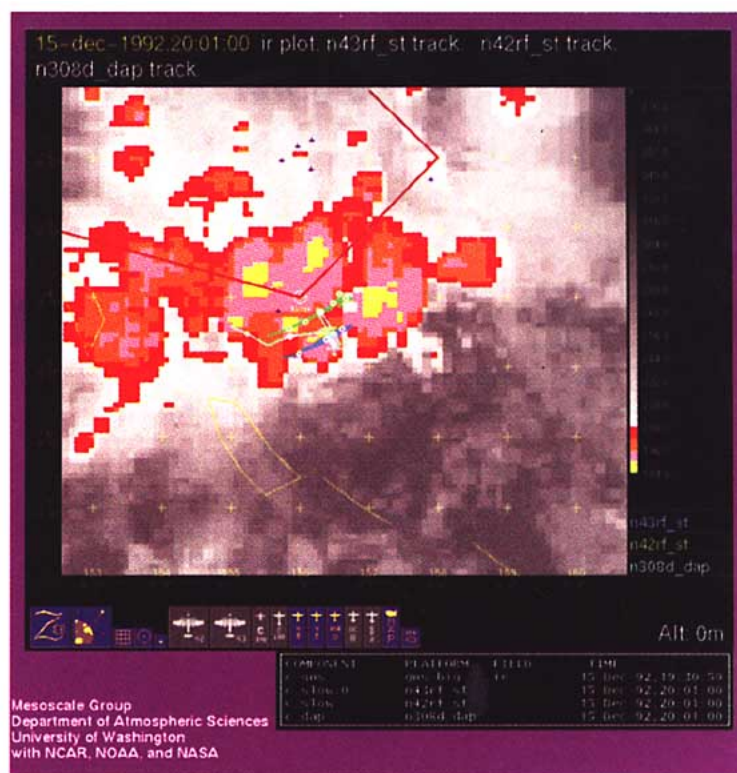


FIG. 6. Mission summary image of IR satellite data and flight tracks on $\sim 7^\circ \times 7^\circ$ scale for 2001 UTC 15 December 1992.

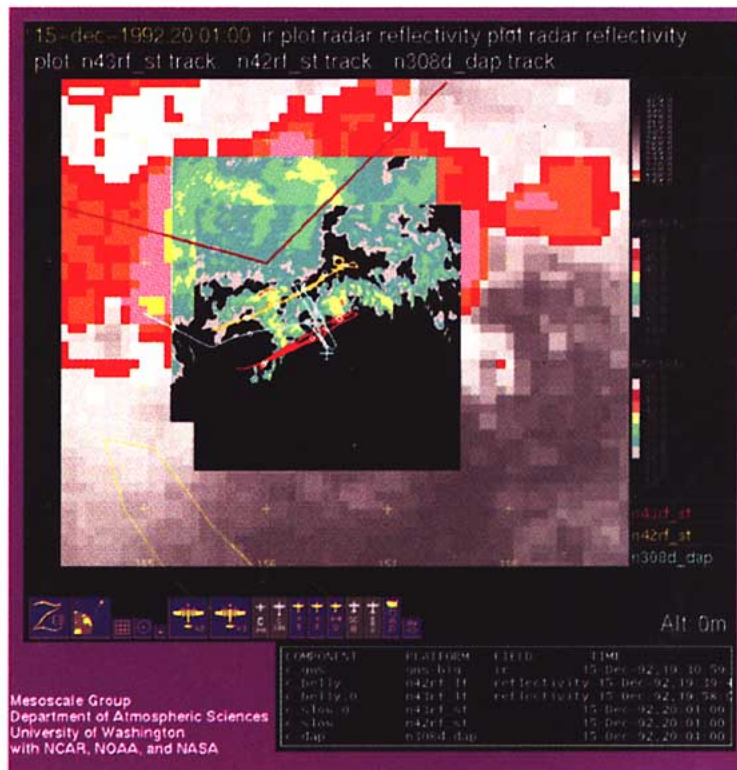


FIG. 7. Mission summary image of IR satellite data: NOAA WP-3D lower-fuselage radar composites and flight tracks on $\sim 4^\circ \times 4^\circ$ scale for 2001 UTC 15 December 1992.

on an $\sim 4^\circ \times 4^\circ$ image that includes composite lower-fuselage radar data, which are in turn overlaid on the satellite image. At this time, the two NOAA WP-3D aircraft were coordinated to fly parallel tracks to collect quadruple Doppler radar data (Fig. 2) on an intense line of convection that lay between them. The small loops in the flight track indicate where purls (Fig. 3) were executed. Meanwhile, the NCAR Electra aircraft flew in a direction orthogonal to the NOAA WP-3D tracks, thus obtaining in situ data in the convectively disturbed region being scanned by both WP-3D Doppler radars. The vast region of radar echo to the northwest of the aircraft consisted mainly of stratiform precipitation.

Figure 8 shows a class 2 system that developed during another disturbed period of the ISO. This system, which only several hours earlier consisted of an elongated east–west band of active convection, was continuously observed as it evolved into the large ~ 200 -km-wide region of stratiform precipitation shown in Fig. 8. This $\sim 4^\circ \times 4^\circ$ image shows the flight tracks of four aircraft in a coordinated pattern that was adjusted to fit the meteorological situation at hand. The two NOAA WP-3D aircraft were again flying parallel to each other in a quadruple Doppler radar data collection mode, but in this instance they were operating at relatively low altitudes to simultaneously provide Doppler radar observations of the deeper atmospheric flow and precipitation patterns, as well as in situ measurements of the atmospheric boundary layer. These data can be used to assess the impact of this cloud system on concurrent air–sea fluxes. In this case, the NASA DC-8 and ER-2 were flying high-altitude tracks to provide complementary measurements down the center of the region observed by the Doppler radar NOAA WP-3D aircraft. The DC-8 provided additional radar data and direct observations of cloud and precipitation particles in the upper portions of the stratiform cloud. The ER-2 obtained measurements of upwelling radiation at several wavelengths.

Figure 9 illustrates a system of the more commonplace class 1 variety, in which precipitating convection was organized along a line but without much accompanying stratiform precipitation. The line of cells was

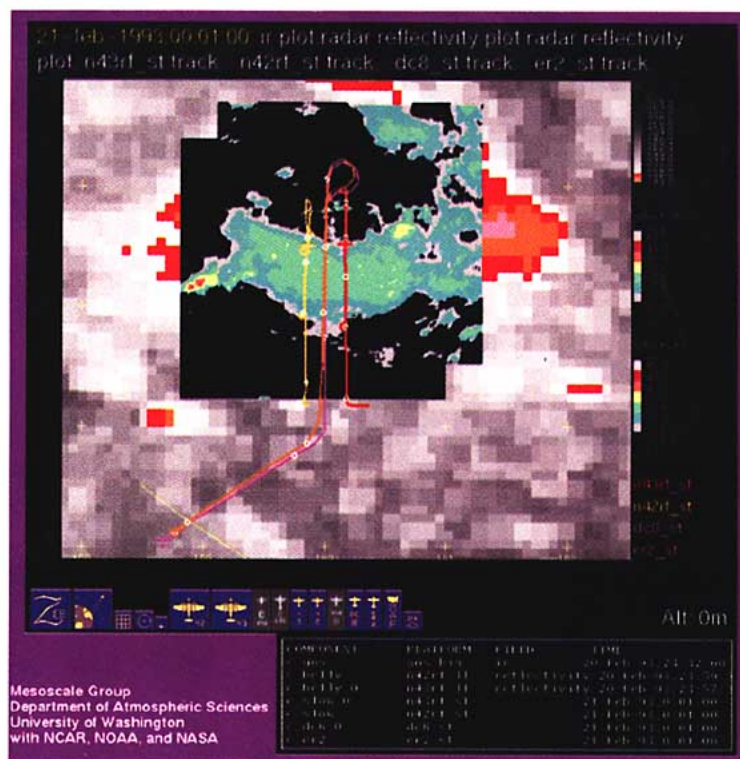


FIG. 8. Mission summary image of IR satellite data: NOAA WP-3D lower-fuselage radar composites and flight tracks on $\sim 4^\circ \times 4^\circ$ scale for 0001 UTC 21 February 1993.

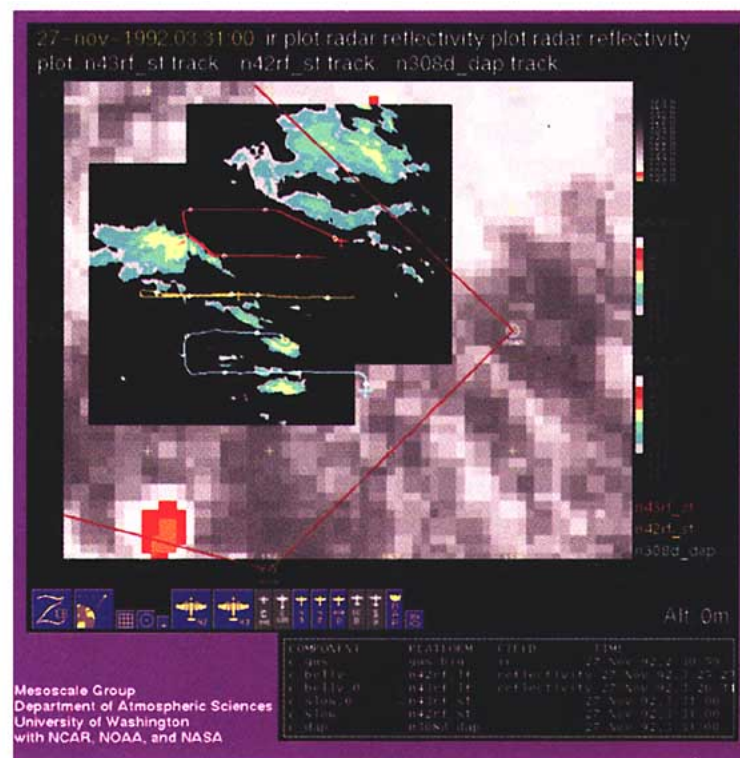


FIG. 9. Mission summary image of IR satellite data: NOAA WP-3D lower-fuselage radar composites and flight tracks on $\sim 4^\circ \times 4^\circ$ scale for 0331 UTC 27 November 1992.

oriented northwest–southeast moving northeastward. In this case, the aircraft were flying an armada pattern whose location and orientation were specified by the location of moored instruments and the direction of the prevailing low-level winds. One NOAA P-3 aircraft remained in the middle of the pattern, executing a “stack” of legs at multiple levels while providing radar surveillance, while the other aircraft proceeded to map boundary layer conditions to the north and south. All of the aircraft operated continuously at altitudes of 25–75 m MSL (except during turns, which were used to obtain truncated sounding profiles) and thus provided extensive documentation of the atmospheric boundary layer in more quiescent conditions.

e. How to look at the images

The more than 900 images of the electronic atlas are readily available to anyone having an appropriately configured computer with access to the Internet. The NCSA Mosaic Web browser is a public domain (free), general purpose, mouse-driven interface to text, images, and data accessible over the Internet. The Mosaic software is straightforward to install³ and will run on a PC with Windows, on the Apple Macintosh, and on a wide variety of workstation platforms running the public domain X Windows system. We chose NCSA Mosaic as the distribution medium for the electronic atlas of aircraft mission summary images since it requires minimal resources to install and its point-and-click interface is simple and easy to operate.

There are two different ways to access the TOGA COARE aircraft summaries on a computer display system with NCSA Mosaic installed. The easiest way is to enter on one line

Mosaic <http://www.atmos.washington.edu/togacoare/summaries.html>

Alternatively, one can perform a two-step process. First, get into Mosaic by entering the word **Mosaic**. Then, using the pull-down File menu in the top left corner of the window, choose **Open URL...** and type on one line

<http://www.atmos.washington.edu/togacoare/summaries.html>

The hypertext main document that will appear by following the instructions above is an annotated out-

line of available information. One can move between the main document and subtopic documents containing additional information and/or images using the mouse.⁴ The arrow slider on the right side of the window is used to scroll up or down to parts of the document not currently displayed in the window. Some words or phrases in the document are highlighted in blue and underlined. Highlighting in this manner indicates a hypertext link. Clicking the mouse on these hypertext links will either bring up additional textual information or perform an action like displaying an image or downloading software. Click on the highlighted text that says **Aircraft summaries** to bring up the title page of the aircraft mission summary document. The **Back** and **Forward** buttons at the bottom of the window are used to move back and forth between levels of text accessed via hypertext links. For additional information, use the **Help** pull-down menu in the top right corner of the Mosaic window.

For users desiring electronic copies of a particular group of images, the atlas provides instructions on how to obtain those images using Mosaic. In addition, for those desiring the ability to view those local copies as a movie, a simple program for this purpose is also provided in the atlas.

4. Conclusion

This atlas of images documenting each aircraft mission in TOGA COARE provides the researcher interested in the data collected on these flights with a road map through the experiment. Since the color images and text associated with each mission are accessible electronically over the Internet via World Wide Web browsers such as Mosaic, the road map is available on demand to a wide community. The electronic distribution will continue to be managed by the Mesoscale Group at the University of Washington. As users of the document provide new information to the Mesoscale Group, that information can be included in future versions of the electronic atlas, which will be assigned a new release number. In this way the electronic document is dynamic and can better serve its users with the most complete and updated information available.

³Mosaic is available from the NCSA Mosaic anonymous FTP distribution site at <ftp.ncsa.uiuc.edu>. The README file in the top-level directory contains the location of the Mosaic program files and installation instructions for the PC, Macintosh, and UNIX systems.

⁴The details of the Mosaic user interface implementation vary somewhat between the versions for X Windows, the Macintosh, and the PC. However, the same generic operations can be performed in all versions. The user-interface discussion in this paragraph refers to the X Windows version of Mosaic. Refer to the documentation accompanying the Mosaic distribution for specific information regarding the user interface on other platforms.

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