The Line Islands Experiment,
Its Place in Tropical Meteorology
and the Rise of the Fourth School of Thought

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Abstract

The Line Islands Experiment has resulted in unique and comprehensive data for studies of the meteorology of the equatorial Pacific. It is one of several recent field programs in tropical meteorology designed to attack the central problem of scale interactions, especially the role of convective and mesoscale systems. Some of the recent evidence is reviewed that indicates the importance of these interactions in understanding the non-steady state aspects of tropical disturbances. A variety of results from the Line Islands Experiment are summarized, with emphasis on their relevance to the planning of GARP tropical experiments.

1. Introduction

The Line Islands Experiment (LIE), conducted on and near Palmyra, Fanning and Christmas Islands (Fig. 1) during February–April 1967, produced a comprehensive sample of satellite, aircraft and surface-based meteorological data. The time seems right to review the progress of LIE-related research and to identify some of the most promising areas for future achievements.

1 The National Center for Atmospheric Research is sponsored by the National Science Foundation.
It would be correct, but not quite sufficient, to trace the origins of the LIE to its formally stated objectives. As one of the first field programs preliminary to GARP tropical experiments, it had a strong pilot program flavor. One of its most important objectives was stimulated by the opportunity provided by the launch of the ATS-1 satellite, geosynchronous at 150°W, to provide "ground truth" for evaluating satellite data and using the combined satellite and conventional data to learn as much as possible about meteorological processes in the vicinity of the equatorial trough zone of the Central Pacific. Much of the emphasis was on sub-synoptic scale processes. Another important objective related to the pilot program aspect was to make use of the restriction to then-available technology in the program, enforced by the short lead time, by evaluating the limits of that technology.

To return to the meteorological objective, the key word is "scale," or more correctly, "scale interaction." In recent years, the need for tropical meteorologists to concern themselves with interactions between different scales of motion has become close to a cliché. But this is a very recent development. In a landmark treatise, Palmer (1951) classified the tropical meteorologists of the day as following one of three "schools of thought." The "climatological school" was characterized by the underlying assumption that the climatological entities of the tropics were adequate representations of conditions at a given time. As applied to the intertropical convergence zone (ITC), for example, this view of the tropics implies that on any given day one could find the ITC somewhere near its mean position for the season. The "frontal school," stimulated by the success of the frontal models in giving insight into higher latitude weather disturbances, attempted to explain departures from climatological mean conditions by applying frontal models in the tropics. The term "intertropical front" was applied to the ITC during this period, and attempts were made to explain some tropical disturbances in terms of waves on this front. In effectively demolishing these two schools of thought, it is important to note that Palmer recognizes the very real contributions of each, but rather quarrels with their unwarranted and usually unstated assumptions.

The third school of thought discussed by Palmer, the perturbation approach, is based in large measure on his own work (e.g., Palmer, 1952) and Riehl's (e.g., 1945). The essence of this approach is to consider most tropical disturbances as being wave-like perturbations of broad basic currents, and historically most attention has been paid to the waves in the (lower) tropospheric easterlies, justifiably, in view of the strong control that they exert upon convection and particularly because of their occasional intensification into tropical cyclones. Although the waves can be and were found often on synoptic charts, the vertical time section has always been the basic analytical tool for their identification and study, and the only tool available in the data sparse regions covering most of the tropics. Those aspects of a given wave that remain in approximate steady state for a few days are obviously the easiest to study in this manner. The existence of convective clouds and mesoscale cloud systems in the waves was never doubted, but the implication was usually that feedback from these could be neglected compared with synoptic scale controls.

Although not explicitly considering synoptic scale disturbances, Riehl and Malkus (1958) planted one of the first seeds of the scale interaction school of thought when they proposed that the deep cumulonimbus clouds of equatorial trough zone disturbances ("hot towers") actually accomplish the vertical transports of mass and energy required by the general circulation scale. In a comprehensive review of sea-air interactions, Malkus (1962) gives many examples of the importance of scale interactions in tropical circulations. Riehl (1958, 1969) was able to show the importance of convection in modifying the thermodynamic stratification of the synoptic scale waves, but mostly within the framework of the steady state wave model.

The advent of daily satellite pictures has been a revelation even to those who had always appreciated the complexities of the tropics. As Palmer (1952) so well put it, "... [when new observations become available] ... it is not only that the griffins and basilisks described by the philosophers are absent; it seems that the country is occupied by creatures of which they have never dreamed." In the case of the new satellite observations, it was less a reincarnation of creatures from dreams than from nightmares. To be sure, the stronger disturbances of the tropics were associated with cloud masses with reasonable time continuity, but most of the more common weaker disturbances did not show one-to-one correspondence with cloud systems, and the cloud systems showed great day-to-day variability. Simpson et al. (1967) were among the first to admit these complexities in print, and to cast doubt on the widespread assumption that all significant disturbed weather over tropical oceans can be tied to moving perturbations of the wind field in a relative steady state, showing several examples of rapid development and decay. Later, Martin and Karst (1969) in a census of about 1000 cloud systems over the tropical Pacific based solely on satellite data, were to find that fully half of them were "oval," meaning that they lacked strong linear or vortical organization (and therefore implying no strong wind disturbance) and that their mean lifetime was two days. The crucial question is whether convection, through its organization on the mesoscale, can have such a controlling influence on the structure of some tropical disturbances that it becomes meaningless to discuss the disturbances out of context of their interactions with smaller scales. Since the evidence is increasing that the influence of the mesoscale can indeed be a controlling one, it appears that for many purposes, we must shift from a "perturbation" to a "scale interaction" school of thought.
At the outset, it must be admitted that the main purpose of the “fourth school” is to discover a fifth school, one we are not yet wise enough to suggest, but one in which the essential scale interactions can be identified and parameterized, which is one of the explicit goals of GARP tropical experiments, lest we become mired in unnecessary complexities. Malkus (1962) recognized this danger explicitly by pointing out the Pandora’s box aspects of completely general scale interaction studies. But if one accepts the deficiencies of the perturbation approach at all, the need to begin observational studies of some of the more important interactions is obvious. The LIE, the 1968 Barbados program (Garstang and LaSeur, 1968; Garstang et al., 1970) and BOMEX, especially the 4th period (Kuettner and Holland, 1969) were among the first field programs expressly designed to examine some of these interactions, particularly the non-steady aspects of tropical disturbances.

2. The LIE data

The LIE was to take place in the early spring, partly because the islands that could be manned would extend from inside the intertropical convergence zone (Palmyra) to the equatorial dry zone (Christmas). Sadler’s (1959) estimate of the flow pattern of surface winds (Fig. 2) for that season proved to be quite accurate, except that the belt of maximum rain was apparently north of Palmyra during April 1967.

The basic LIE data include surface and serial rawinsonde observations on Palmyra, Fanning and Christmas Islands, and the ESSA Research Vessel SURVEYOR about 400 km east of Palmyra, together with measurements by the NCAR aircraft based at Palmyra, with other aircraft providing some large-scale information. The object was to concentrate most heavily on obtaining those observations, hitherto the rarest, of scales up to and including the typical scale of cloud systems (about 500 km) and to associate features on these scales with larger scale motions insofar as possible.

Although there are many unique attributes of the data from the LIE, the most valuable is their comprehensiveness. There have been rawinsonde data in the tropics before, although seldom processed as carefully or with good vertical resolution or as free of orographic effects (Madden et al., 1970). There have been research aircraft flights before, although seldom with good wind data at 150 m altitude. There have been surveys of sea-surface temperature by radiometer, 50 days of continuous weather radar coverage, cloud photography, careful surface observations, reconnaissance aircraft observations, short-wave and infrared radiation measurements, and of course pictures from several satellites, including ATS-1 with as many as 40 pictures per day. But these have not been coordinated in the same area in the same time period, and readily available to the scientific community. When that area is the usually data-void central Pacific, it is a particularly unique data set. Several catalogues are now available, the most complete being by Zipser and Taylor (1968), the most useful for quick look by Yonker (1968). Rawinsonde data are compiled in Madden et al. (1970), and specialized data in reports by Bunker (1969), Chaffee and Bunker (1968), Estoque (1970) and Wyrski (1967). As will be illustrated below, many of the most valuable and intriguing aspects of the data are only beginning to be exploited.

3. Selected results from the LIE

The detailed analysis of the non-steady state aspects of tropical disturbances places rather critical demands on comprehensiveness of the data. The LIE data, while not definitive on all pertinent scales, are sufficiently unique to allow some important inferences to be made on the structure of weather systems of the intertropical convergence zone. The most intensive study to date was able to show that the organization of convection produced downdrafts that in turn organized into squall systems on the mesoscale (Zipser, 1969a). Not only were these squall systems the important agents of energy transfer in the disturbance, but their feedback to the somewhat larger scale of the disturbance (500–1000 km cloud system dimension) was so powerful that the entire active cloud system collapsed in a matter of a few hours (Fig. 3). It is now becoming apparent that some aspects of this work that depended on inferences are being confirmed by flights in the Barbados region (Zipser, 1969b and unpublished data), particularly the ability of the downdraft systems to remain highly unsaturated and to spread over areas of hundreds of km dimensions. It is also clear that these are far from isolated events, and that for a large class of disturbances one of

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Fig. 2. Surface streamlines and isotachs for March–May, Line Islands region, based on data from islands shown by circles. From north to south, they are Palmyra, Fanning, Christmas and Malden (after Sadler, 1959).
FIG. 3a. Schematic streamlines of airflow relative to convective cloud systems in east–west section illustrating the mechanism of downdraft production (see Zipser, 1969a, for details).

FIG. 3b. Same as Fig. 3a, except in north–south section. Both Fig. 3a and 3b represent a disturbance with active cumulonimbus towers, either in individual clusters or organized lines.

FIG. 3c. A north–south section similar to Fig. 3b, but representing the dissipating phase of a disturbance, when maintenance of the downdraft is primarily by rain falling from the extensive cloud shield.

The important ground rules of the “perturbation school of thought” do not apply; mesoscale squall systems modify the structure of these disturbances so profoundly that they cannot be regarded as being in steady state, even for a period of one day. These complexities may be turned to ultimate advantage if they can assist in our understanding the behavior of larger scale systems. For example, there is evidence that the relatively cool and dry squall downdrafts act as a strong constraint on tropical cyclone development. But while squall models are useful tools in grappling with the interaction problem, the last word is a long way off and there are many other potential case studies from the LIE period awaiting the lengthy but rewarding task of analysis and interpretation.

Another approach to the question of the importance of the various scales of motion is through the measure of their statistical properties. From the records of surface wind speed from two anemometers, one yielding high frequency data, the other hourly averages for a 48 day continuous record, Hwang (1970) has constructed a kinetic energy spectrum over a very wide frequency range. It is recognized that even small atolls like Palmyra can have important influences on the surface wind, so the site was selected carefully and compared with other sites, and the weight of evidence is that the exposure is reasonably free of contamination (Hwang, 1970; Zipser and Taylor, 1968). In spite of the short period of record, Hwang’s energy spectrum differs little from typical middle latitude spectra, Hwang’s greatest energy falling into the five to seven day period range (Fig. 4).

FIG. 4. Power spectra of surface wind speed at the causeway site, Palmyra Island. The dashed line is based upon a 30-min period of heavy showers during the passage of an ITC disturbance (after Hwang, 1970).

There is no apparent high frequency peak when only undisturbed weather conditions are sampled, but one seems to exist during a 30-min sample of a heavy shower period when an active ITC disturbance was over Palmyra, in the period range of one to several minutes. Madden (1970) has computed power spectra of the zonal and meridional components of the wind at heights up to 28 km from the LIE rawinsonde data (Fig. 5). Obviously, no climatological significance can be attached in any way to results based on a 47-day sample, but this approach is simply a statistical tool to help interpret what was observed and can serve as a basis for comparison with other periods of special data collections in the Pacific. Some of Madden’s results are similar to those presented by Yanai et al. (1968) who studied the data from the Line Islands during the DOMINIC test program of 1962. In the meridional winds both periods showed evidence of wave motions in the lower stratosphere with downward phase propagation and horizontal wavelength of about 10,000 km. The coherence be-
Fig. 5. Spectra of meridional winds (m/sec) for the period 5 March–20 April 1967. Total variances (m^2/sec^2) in parentheses (after Madden, 1970).

Fig. 6. Height time cross-section of the meridional winds at Christmas in m sec^-1. The time of individual rawinsonde releases is given by the arrows along the top of each section (after Zipser, 1969b).
tween levels is significantly high over a depth of about 5 km. The 4–5 day spectral peak of the meridional wind, characteristic of these waves, was most marked at 17 km in the 1962 data and at 22 km during the LIE, and it is worth noting that the westerlies give way to easterlies 4–5 km above the level of the spectral peak in each case. As Yanai *et al.* point out, there seems to be no difficulty in placing these motions into the theoretical framework of quasi-geostrophic equatorial wave treated by Rosenthal (1965), Matsuno (1966) and Lindzen (1967).

In the lower troposphere, the situation is rather confused. Although daily analysis clearly shows that synoptic scale disturbances affect the ITC region, spectral analysis tends to obscure that fact, as no peak appears at Fanning or Palmyra. On the other hand, a weak spectral peak does show up in the 4–5 day range at Christmas and Canton Islands in the adjacent dry zone. Madden’s (1970) cross-spectral analysis indicates that these “waves” have upward phase propagation and have wavelengths the order of 6–7000 km, or similar to results of Yanai *et al.* As they have pointed out, this is hardly the same disturbance described by Riehl (1945) or Palmer (1952), which moves at about half the speed and has 1/3–1/4 the wavelength. One of the best-marked disturbances of the LIE moved through the data network on 22–23 March 1967 as a wave trough, eventually developing double vortex structure, with cyclones on both sides of the equator. Madden (1970) tracks this disturbance in the satellite cloud pictures using the compositing technique described by Chang (1970), this exercise resulting in an intermediate wavelength of 3500 km. This is a size range found by Wallace and Chang (1969) but their vertical averaging technique would not be appropriate to the sloping waves of the Line Islands. About the only generalization that can be made is that the whole question of wave motions in the tropical troposphere is wide open, and short-term statistics vary widely from place to place and from one period to another. As an example, the LIE data set shows a complete absence of any power spectral density peak in the 4–5 day range in the upper troposphere, which appears to some extent in virtually all other published spectra for the tropics.

One of the rewards usually reserved for the scientist who examines new data from the field is the discovery of the unexpected. By careful processing of the rawsonde data, filtering out only the very short vertical wavelengths (less than about 700 m; see discussion by Madden *et al.*, 1970), the remarkable layering of the winds was clearly revealed and documented (Madden and Zipser, 1970). During the first half of April, there were typically at least 7 distinct layers between the surface and 20 km, or below the region apparently affected by the stratospheric waves during the LIE discussed above. The time and space continuity of even the thinnest layers is so great that it is difficult to question their reality seriously. They are clearly better marked at Christmas (2N, Fig. 6) than at Palmyra (6N, see Madden and Zipser), leading to the suspicion that they may be manifestations of some of the equatorial wave modes already mentioned and summarized by Wallace (1969). In particular, very short vertical wavelengths, the order of 2 km, have been predicted by Lindzen and Matsuno (1968). Wallace also speculates that some of the finer structure visible in the LIE winds might prove to be an observational verification of that prediction.

If a multi-layered structure is a reasonably frequent occurrence in the equatorial regions, it should be most visible on soundings within six degrees of the equator. Unfortunately much routinely collected data from the few stations close enough to the equator may undergo vertical averaging that tends to obscure these layers, and the selection of mandatory levels can complete the process. A quick perusal of equatorial soundings leads the author to the opinion that the medium scale structure can indeed be found, but both intrinsic scientific interest and the obvious significance that widespread layering would hold for GARP tropical experiments almost demand that this question be explored as soon as possible. It should be pointed out quickly that the existence of widespread layering need not place impossible demands on a GARP observing system, because there is every reason to believe that these features have very large horizontal dimensions and thus could be definable by a judicious mix of sensing systems that included some high resolution soundings around the equatorial belt.

Realizing the importance of processes in the equatorial boundary layer, the LIE made a particular effort to concentrate observations there. A great many of the aircraft flights were at 150 m altitude. All soundings were made with raw data collected every six seconds in the boundary layer. A double theodolite pibal program was carried out on Christmas Island, although a careful first look by Estoque (1970) indicates that the eddy components cannot be computed with sufficient reliability for determining stress. Particularly in the Line Islands...

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3 The meteorologists were not the only ones surprised. Wyrski (1967), in his very useful summary of oceanographic data connected with the LIE, describes the direct current measurements made in the equatorial countercurrent, obtained during the second cruise of the SURVEYOR when it anchored on a seamount for 13 days at 6.5N 157.8W in the heart of the current. The measurements were there, but the current was not. This kind of surprise is less unexpected if the strong dependence of some currents on the atmosphere’s highly variable forcing is recognized.

4 Although usually not processed to reveal this structure, most sounding systems can observe it. In the case of the GMD-1, even finer structure is theoretically possible by recording azimuth and by recording elevation angles at six second intervals instead of the usual sixty, although other uncertainties, such as in ascent rate, can be the ultimate limiting factor (Madden *et al.*, 1970). A collection of 6-second or 30-second data from equatorial stations for brief intervals, with original records sent to a central location for processing and analysis, would go a long way toward answering this question and might be done for very little cost indeed.
region, knowledge of sea surface temperature is critical because of the strong horizontal gradients, and this was monitored frequently by radiometers on sub-cloud layer flights by both the NCAR and Woods Hole Oceanographic Institution aircraft.

Estoque (1970) has noted the strong backing of the wind with height at Christmas and attributes this mainly to changes in the geostrophic wind with height which are consistent with observed temperature gradients between islands. Robitaille and Zipser (1970) are investigating the wind variations in the boundary layer, and find that the backing with height is strongest at Christmas, decreasing to nonexistent at Palmyra. This suggests a connection with the cold water along the equator, which is not only verified by direct measurements (see Bunker, 1969) but, as Bjerknes (1969) shows, early 1967 was the period of coldest water at Canton Island in the 17 years of record. Bjerknes singles out early 1967 as representing the maximum development phase of the “Walker Circulation,” which he finds consistent with upwelling and cold water along the equator, strong easterlies along the equator, and maximum development of the equatorial dry zone, all of which were observed during the LIE. Hastenrath (1968), in discussing possible meridional circulations near the equator, proposes the double equatorial cell as appropriate to Line Islands longitudes (Fig. 7). The surface divergence away from the equator is confirmed by Robitaille and Zipser (1970), suggesting a thermally direct circulation, as the cold anomaly near the equator is strongest at the surface, greatly reduced by 800 m altitude. Especially at Christmas, a return current is indicated in the LIE data at only 1500 m, or near the mean inversion height in the dry zone. The suggestion is that at least during well-developed cold water regimes, the “equatorial cells,” although best developed in the sense of sinking motion over the equator, may have a rather complex structure in the vertical. It is logical to look for a mirror image circulation in the Southern Hemisphere and Canton Island does show a weak mirror image in the mean, but as yet no direct relationship with ocean temperatures has been found.

The LIE included measurements of both solar and infrared radiation. Important differences between the dry zone (Christmas) and the intertropical convergence zone (Palmyra), while not surprising, have been quantified and could form the basis for models of radiative heating and cooling in the tropics. Cox (1969) reported his direct measurements of the very high infrared cooling rates at Christmas. Fig. 8 is from very recent results of Cox and Hastenrath (1970) showing the vertical profiles of infrared cooling rates at Christmas and Palmyra, based on some 25 radiometer sondes at each island. At Palmyra, the cooling can probably be largely compensated by convective heat flux; at Christmas the frequency of convective clouds reaching above 850 mb is so small that subsidence must be the main process balancing the cooling. Thus, radiative cooling can be linked to the maintenance of the equatorial dry zone. The role of differential radiative effects in tropical disturbances and in the structure of the low level inversion are other worthy subjects for study with this data set.

Under the general heading of technique development, one of the important motivations of the LIE was to learn how to make optimum use of the geosynchronous satellite pictures. In practice, while the LIE served as a stimulus for much of this effort, it was not essential to

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5 The entire system could then, naturally, be called the “double helix.”

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Fig. 7. One of the mean meridional circulation schemes proposed by Hastenrath (1968) as most appropriate for the Line Islands region. Hastenrath’s “kinematic equator” is given by θ, the same as the geographic equator in the Line Islands. The locations at Palmyra, Fanning and Christmas are marked, and the return current observed during the LIE at 1500 m is added.

Fig. 8. Vertical profiles of infrared radiative cooling rates over Palmyra and Christmas during the LIE, averaged over about 25 radiometer sondes from each island (after Cox and Hastenrath, 1970).
all of the effort. As an example, the techniques for precision display negatives and accurate measurements of reflected radiance developed at the University of Wisconsin (Vonder Haar, 1969) could have taken place without the LIE but the LIE data in many cases will provide the best ground truth for the utility of the techniques. Techniques described by Bradbury and Fujita (1968), Hanson and Vonder Haar (1968), Levanon (1968), Sikdar (1969) and Vonder Haar et al. (1968) all benefit from the existence of LIE data. While the variable quality of tapes of ATS-1 pictures during the LIE has been a handicap in using them to their fullest potential in studying the all-important relationship between satellite derived and observed winds, techniques now in use at the Space Science Center, University of Wisconsin, should permit much greater use of the LIE data in the immediate future.

4. Lessons of the LIE and opportunities

It is premature to philosophize at this time on the ultimate scientific impact of the LIE. Operationally, many of the important lessons emerged in the course of a critique that took place immediately after the field phase (NCAR, 1967). Another lesson, hardly surprising, relates to the extreme difficulty in obtaining reasonable signal/noise ratios in the tropics in the measurement of a number of critical quantities, and some useful information was gained on observational techniques. A significant lesson relates to the immortality of data. Recent history tells us that good data in meteorology have been gainfully employed again and again over years and even decades, possibly due to their rarity. Many will recall incidents of scientists actually competing for “rights” to the data for fear of being “scooped.” The current situation is somewhat different. Several important field programs have taken place in the recent past and more are in the planning process, understandably so, since definitive observations for scale interaction problems are still lacking. Thus far, improvements in data handling and analysis have not kept pace with data collection, which expands the time scale for meaningful integration of the information from any one program. The net effect is to increase the perishability of data, even good data, by diverting the attention of scientists to other programs.6

The other side of this coin, however, is the recognition that there are many opportunities for building on the results that are already available, some of which are being followed up, some not. Some of the greatest opportunity for additional insights from LIE data lies in the matter of defining the role of the mesoscale, now recognized to be crucial. Why does visible evidence of these motions in the form of cloud lines or cellular patterns exist on some days and not on others? What is the relationship between mesoscale cloud organization in disturbed vs. undisturbed conditions? The radar on Palmyra, operated 24 hours daily for 50 days, shows this organization clearly in both conditions, but it is far from clear that the same mechanisms are responsible. The high quality digital ATS-1 pictures7 show this scale, as well as aircraft cloud pictures. Perhaps the most dramatic illustrations of the cloud band scale come from the ESSA-1 satellite (Fig. 9), although it photographs a given area only about every other day. Kuettner (1959) and especially the lengthy work of Malkus and Riehl (1964) describing results of flights in the pre-satellite era, pinpointed the relation of these mesoscale features to the larger scale environment as one of the most obvious and important problems to tackle when good satellite data and sounding data were available simultaneously over the ocean. It would be difficult to imagine a class of problems more ideally suited for attack with the LIE data. Of course, the same problem should also be examined with BOMEX data, since the large scale environments of the two areas are quite different, and comparisons based on these differences should be extremely valuable.

Another class of problems very deserving of attention, although their solution is a long way off, is large scale interactions in the atmosphere, including interhemispheric problems more ideally suited for attack with the LIE data. Of course, the same problem should also be examined with BOMEX data, since the large scale environments of the two areas are quite different, and comparisons based on these differences should be extremely valuable.

6 A specific lesson suggested by the LIE experience is that the bigger and more complex field programs become, the greater the need for “real time” or “fixed time delay” data reduction. Although also necessary for operations and for monitoring, quick access to reduced data may be the most natural and most effective way to ensure efficient transition to the scientific output phase of a program.

7 Not available on all days; note Yonker's (1968) catalogue.

FIG. 9. ESSA-1 satellite photograph of part of the equatorial dry zone, 24 March 1967. Christmas Island is clearly visible near 2N, 157W, northeast of the picture center. Independent data show the island-produced cloud street extending toward about 280°. There are no winds in the moist layer either parallel or perpendicular to the prominent cloud bands near the island.
spheric exchanges. A glance at Fig. 6 will reveal the magnitude and complexity of the mass exchanges between the hemispheres measured from one island. There are important changes in regime during the LIE, the interhemispheric exchanges and extreme layering of the winds being much more in evidence in April than in March (Madden and Zipser, 1970). A significant change in cloud distributions also took place between March and April (Fig. 10), the most prominent being the southeast-northwest band in the Southern Hemisphere sharpening and shifting much nearer the Line Islands. Although speculative, it seems likely that this shift of the cloud band to somewhat northeast of its position in Fig. 11 is directly related to the strong southerly current in the upper troposphere dominating the early April period on the Canton and Line Islands soundings (Fig. 6). The intertropical convergence zones in both hemispheres weaken from March to April. The interrelationships among these events are far from clear, but any progress toward their understanding would surely be an important step.

5. Concluding remarks

The LIE has already resulted in important new knowledge. One of the expressed objectives was to explore the importance of mesoscale processes in synoptic scale disturbances. The isolation of the downdraft-squall mechanism and its rapid feedback to the synoptic scale illustrates the need to consider the non-steady state aspects of many tropical disturbances, to an extent requiring the re-examination of the now classical “perturbation school of thought” of tropical meteorology. Some of the results were even less anticipated beforehand, such as the discovery of the marked multi-layered wind structure of the near-equatorial troposphere. Despite certain obvious limitations as a full scale interaction experiment, the LIE is capable of contributing considerably more to our knowledge of tropical meteorology. The ultimate
limitations on the magnitude of these contributions may be less related to the intrinsic potential of the LIE data than to the availability of interested and enthusiastic scientists to explore the unsolved problems. To this end, NCAR, through the LIE Data Center, and the author, are prepared to serve the scientific community as a data distribution and information center.

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