ATMOSPHERIC VARIABILITY AND AIR-SEA INTERACTION

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ATMOSPHERIC VARIABILITY AND AIR-SEA INTERACTION

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Introduction

Our research proposal, dated 14 November 1978 (starting date 1 January 1979) listed the following research objectives:

(i) Processing of additional northern hemispheric precipitation data, in order to fill in the transition seasons to provide a continuous 40-year data base on the variability of continental precipitation.

(ii) Comparison of seasonally-averaged fields of sea surface temperature (SST) obtained from ship observations in the North Atlantic and North Pacific in 1970 with the corresponding fields inferred from satellite observations. Discussion of any systematic regional differences in terms of possible cloud contamination of satellite data.

(iii) Estimation of seasonal average of total precipitable water at those admittedly few oceanic stations where repeated vertical soundings were made in 1970 and comparison with corresponding values inferred from satellite measurements.

(iv) Comparison of seasonally-averaged evaporation fields determined from ground based observations in 1970 with the field of divergence of the seasonal total horizontal water vapor flux inferred from satellite total water measurements and NMC wind data for the lower troposphere.

(v) Examination of meaning of convection-inversion index $[(\bar{w}-w)/\bar{w}]$ when seasonal averages of reference and actual total precipitable water, $\bar{w}$ and w, are employed. Estimation of effect of clear sky bias on the identification of seasonally-averaged zones of convection. Consideration of interannual variability of zonal mean temperature and relative humidity profiles used to construct $\bar{w}$, and the possible systematic errors introduced in the index when a "climatological" $\bar{w}$ is used in the analysis of data for a particular year.

Funding was granted for the completion of Task (i) alone although NASA expressed interest in results which might be obtained from studies outlined in Task (v). The findings resulting from the research funded under Task (i) were summarized by Corona (1979) and Reiter (1979). In these two publications - copies of which are attached - credit has been given to NASA for its support under Grant NSG-5340.

Using some computer resources remaining after the completion of the funded research, Dr. John Middleton, with the assistance of Mr. Tom Corona, took a preliminary look at some of the tasks related to the inferences from Nimbus 4 IRIS experiments described by Prabhakara et al. (1978) and more briefly by Prabhakara et al. (1979). Task (ii), (iii) and (v) received some attention but Task (iv) was not examined. A description of the results of the exploratory analyses is given in the remainder of this report.

Task (ii) was partially fulfilled by a preliminary comparison of seasonally averaged satellite and ship-based sea surface temperature fields for 1970 in the North Pacific Ocean. Previous contracts held by the Principal Investigator have brought into our possession two ship-based North Pacific sea surface temperature data sets covering the period of April-December 1970. One was obtained from Fleet Numerical Weather Central of the U.S. Navy and the other from the Scripps Institution of Oceanography. Since the differences between these data sets is generally much smaller than the difference between either of them and the satellite-inferred fields, the following discussion is limited to a comparison of the latter with the Scripps data set.

The Scripps data set is composed of monthly averages of sea surface temperature observations within 5°x5° boxes centered on the intersections of a 5° latitude (20N-60N) and 5° longitude (110W-130E) grid. Averages for the periods April-June (Spring), July-September (Summer) and October-December (Fall) 1970 were computed for each grid point. For comparison, the satellite inferences of North Pacific SST presented in Figs. 15-17 of Prabhakara et al. (1978) were used to estimate SST values in 5°x5° boxes centered at intersections of meridians separated by 20° longitude with 20N and 40N. Tables 1-3 present the results of this work.

Table 1. Spring SST (°C)

		140E	160E	180	160W	140W	120W
40N	T_{SHIP}		12.2	12.1	12.3	13.9	
	T_{IRIS}		14.3	15.1	15.1	13.0	
	ΔT		-2.1	-3.0	-2.8	0.9	
20N	T_{SHIP}	28.0	27.4	26.5	24.9	22.4	21.0
	T_{IRIS}	26.8	26.8	24.8	24.3	23.3	21.3
	ΔT	1.2	0.6	1.7	0.6	-0.9	-0.3

Table 2. Summer SST (°C)

		140E	160E	180	160W	140W	120W
	T_{SHIP}		19.6	20.4	19.4	19.4	
40N	T_{IRIS}		14.3	14.8	14.8	13.0	
	ΔT		5.3	5.6	4.6	6.4	
	T_{SHIP}	29.2	27.9	27.8	26.5	23.6	23.9
20N	T_{IRIS}	>26.8	>26.8	26.8	23.3	20.3	19.3
	ΔT	2.4	1.1	1.0	3.2	3.3	4.6

Table 3. Fall SST (°C)

		140E	160E	180	160W	140W	120W
	T_{SHIP}		16.6	16.4	15.4	16.0	
40N	T_{IRIS}		14.3	14.3	14.8	13.0	
	ΔT		2.3	2.1	0.6	3.0	
	T_{SHIP}	27.5	27.2	26.9	25.4	23.6	22.4
20N	T_{IRIS}	25.5	>26.8	>26.8	22.3	21.8	22.3
	ΔT	2.0	0.4	0.1	3.1	1.8	0.1

Although these tables show differences which are at least several times larger than the standard deviations for seasonal averages formed from the Scripps data set, the existence of only one year of data for comparison makes it difficult to assess the practical importance of these differences. Clearly the two estimates will yield distinctly different patterns of SST departure for 1970 from a given climatology of SST be it of satellite or surface origin. However, systematic errors in either data set may be reflected in their respective climatologies so that fields representing departures from respective climatologies may have similar features. No conclusions can be drawn in the absence of a satellite seasonal SST climatology.

The results presented in Tables 1-3 do suggest that the largest differences appear in midlatitudes (40N). Summer differences appear to be larger than those in the other seasons examined. The summer differences are particularly large in midlatitudes and in the eastern subtropical region. It is perhaps significant that climatological data (U.S. Navy, 1956) show relatively high frequencies of low cloudiness in midlatitudes and in the southeastern North Pacific in summer as compared to the subtropical North Pacific from 160W to 140E. It seems possible that IRIS surface temperature estimates might be somewhat depressed by the existence of such clouds but not to the extent that they would fall below the cutoff set for identifying cloud contamination. Tables 1-3 show that the large differences are associated with Nimbus IRIS estimates below those of the Scripps data set except in the Spring along 40N.

Task (iii) was investigated in a preliminary way using radiosonde data from three island stations in the subtropical North Pacific Ocean for which significant levels are reported. Lihue (22N 159W) was chosen on the assumption that the trade wind inversion would appear frequently in its sounding data. Johnston Island (17N 168W) and Wake Island (16N 165E) were utilized because their sounding data were readily available to us. A more diverse sample of oceanic climates could have been assembled had additional resources been available to us.

Total precipitable water was computed for each 0Z and 12Z radiosonde ascent at these stations during the months of April through December in 1970. Specific humidity was determined at each pressure level using the reported temperature and relative humidity values along with the Clausius-Clapeyron equation for the saturation vapor pressure. Total precipitable water for a sounding was then approximated by first summing the products of the pressure difference between adjacent levels and the arithmetic mean of the specific humidities at these levels from the surface to the upper troposphere (~250 mb) and then dividing the result by the surface gravitational acceleration. Comparison of values so computed with those few quoted by Prabhakara et al. (1978, Table 6b) indicates our values to be about 2% higher, hence in good agreement with those in the NASA study.

Seasonal averages for 1970 of total precipitable water were then constructed for 0Z and 12Z for each station. The seasonal periods defined by Prabhakara et al. (1978) are April-June (Spring), July-September (Summer) and October-December (Fall). Seasonal averages for total precipitable water at each station (W_{ISLE}) were estimated by the arithmetic mean of the seasonal averages for the two observing times.

These results are presented in Table 4. This table presents as well the seasonal averages for precipitable water derived from the IRIS (W_{IRIS}) data by Prabhakara et al. (1978). The listed values were obtained by subjective interpolation from Figs. 19-21 of Prabhakara et al. (1978).

Table 4. Precipitable Water (g/cm^2)

	Lihue		Johnston		Wake	
	W_{ISLE}	W_{IRIS}	W_{ISLE}	W_{IRIS}	W_{ISLE}	W_{IRIS}
Spring 1970						
00Z	2.57		2.76		3.22	
12Z	3.07		3.39		3.92	
AV	2.82	~2.8	3.07	~3.2	3.57	~3.6
Summer 1970						
00Z	2.82		3.08		4.14	
12Z	3.34		3.73		4.94	
AV	3.08	~3.5	3.41	~3.8	4.52	~5.0
Fall 1970						
00Z	2.72		3.31		3.39	
12Z	3.19		4.01		4.06	
AV	2.96	~3.0	3.66	~3.7	3.72	~3.5

From Table 4 it is apparent that there is better agreement between Nimbus IRIS and station estimates in Spring and Fall than in Summer. In the former two seasons the differences are all less than ~5% of the station estimates whereas in Summer the differences are in the range 10-15%. This seasonal difference is most apparent at Lihue.

The statistical significance of the difference between seasonal estimates in Summer cannot be properly assessed without further knowledge as to how the IRIS value was composited. However, it may be noted that the differences are of the same order as the standard deviation of the daily radiosonde estimates of precipitable water. The standard deviation of the seasonal averages based on these daily values may be expected to be 4-10 times smaller depending on the autocorrelation between the daily values. If the standard deviation associated with the

IRIS estimates is of the same order then the differences seen in Table 1 in Summer would seem plausibly due to systematic error.

The complexity of the inversion program described by Prabhakara et al. (1978) on which the Nimbus IRIS inferences are based makes it impossible for us to offer specific suggestions as to where the apparent problem may originate. Given the observation described under Task (ii) that the Summer season appears to have relatively large systematic errors in the inferred North Pacific sea surface temperature field, it is reasonable to suggest that cloud contamination and/or departures from assumed water vapor profiles may also affect the inferred precipitable water field. Comparisons with a broader sample of radiosonde data may yield more insight.

Task (v) offered the most interesting scientific challenge met in connection with the Nimbus IRIS analysis but was most time-consuming for scientific personnel. Some of the basic techniques for investigating the physical meaning of the seasonally-averaged convection-inversion index $[(\bar{w}-w)/\bar{w}]$ were developed but little else could be accomplished in the absence of direct financial support.

Of the several goals described in Task (v), that of examining the proportionality between the convection-inversion index and the temperature difference across the trade wind inversion suggested by Prabhakara et al. (1978) occupied most of the allotted research time. The computation of precipitable water needed to evaluate the index led to the work described under Task (iii). The principle remaining task was to develop the methods for computing seasonally-averaged characteristics of the trade wind inversion from radiosonde reports. More specifically, the goal was to develop a computer program which would identify the trade wind inversion in raob data and compile seasonal statistics for inversion height, inversion thickness, relative humidity difference and temperature difference. Examination of individual ascents was necessary since the inversion is averaged out in monthly or seasonal vertical profiles (Roland Madden, personal communication).

Analysis of raob data from Lihue, HA quickly revealed practical difficulties facing the development of an automated analysis of trade wind inversion properties. The fundamental difficulty was the need to quantitatively define the criteria for the presence of the inversion. Several complicating features of actual raob data were

1. multiple temperature inversions
2. temperature inversions not accompanied by large relative humidity drops

3. large relative humidity gradients not accompanied by temperature inversions, and

4. variation in the overlap of the temperature inversion layer and the layer of rapid relative humidity drop when both were present.

Figures 1 and 2 are vertical profiles of relative humidity and temperature from Lihue illustrating these points.

There appears to be little statistical analysis of the trade wind boundary layer in the open literature on which one can draw. Gerrish (1969) has used vertical gradients of radar reflectivity to develop statistics of inversions and other super-reflective layers from sounding data. This approach has an appealing feature in its use of radar reflectivity which incorporates both relative humidity and temperature into a single quantity. Critical values of the gradients can be established from experience with radar echoes.

In preparation for establishing criteria for identifying the trade wind inversion, the distributions of some of the parameters were examined to see if they might suggest natural ranges. The histogram in Fig. 3a presents the number of temperature inversions in Spring 1970 Lihue ascents having heights falling in the indicated 100 m intervals. Clearly a majority of the inversions occur in the interval between 1.5 and 2.5 km and very few occur below it. Figure 4 presents a scatter plot of inversion height (m) versus temperature difference (°C) across the inversion showing that the broadest range of temperature differences are associated with inversions in the vicinity of 2 km.

By contrast, Fig. 3b shows the frequency of temperature inversions having inversion thicknesses in the indicated 10 m intervals to be much

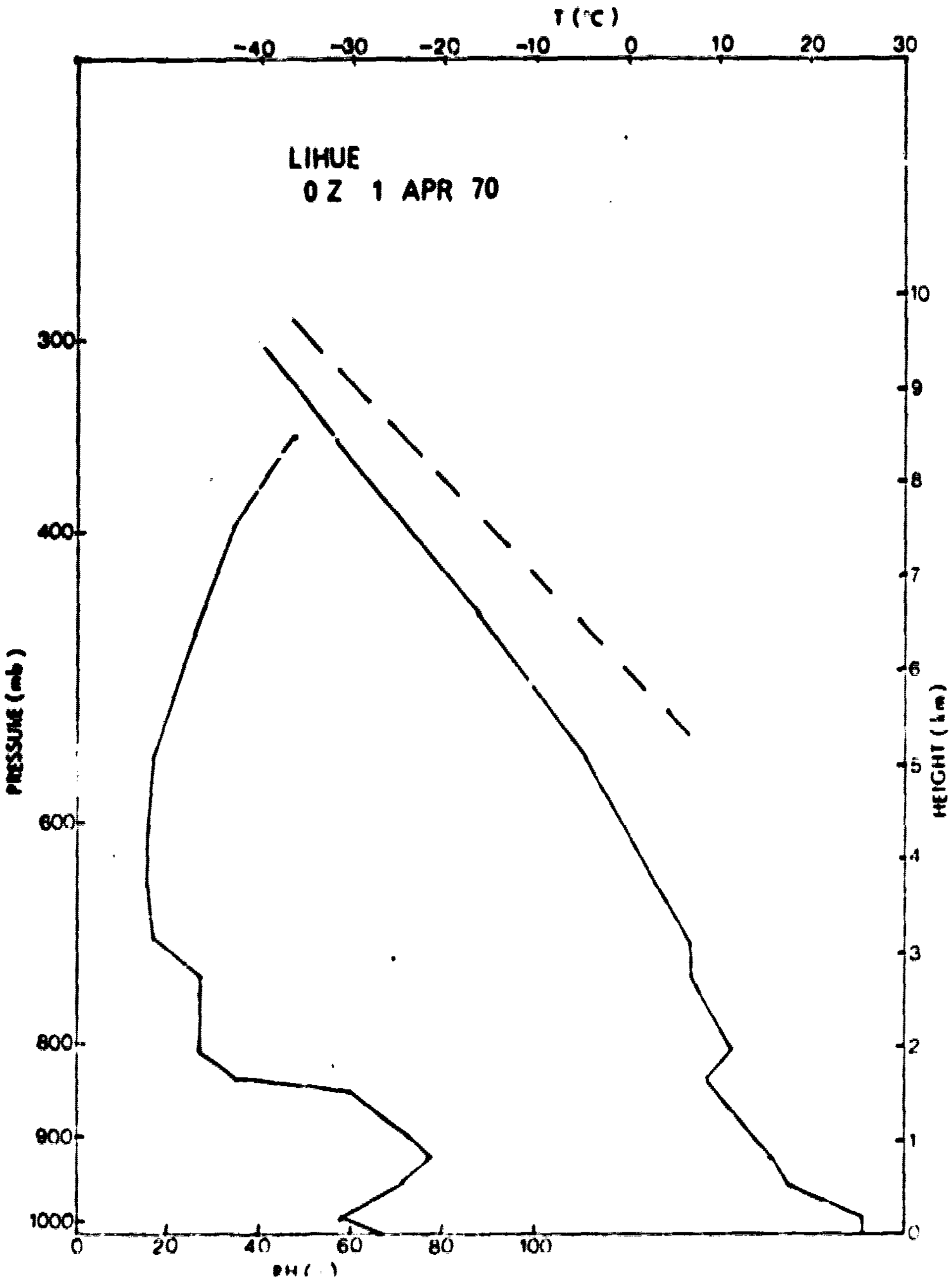

Fig. 1 Plots of relative humidity and temperature from 0Z radiosonde ascent on 1 April 1970 at Lihue, HA. Dashed line has slope of a dry adiabat.

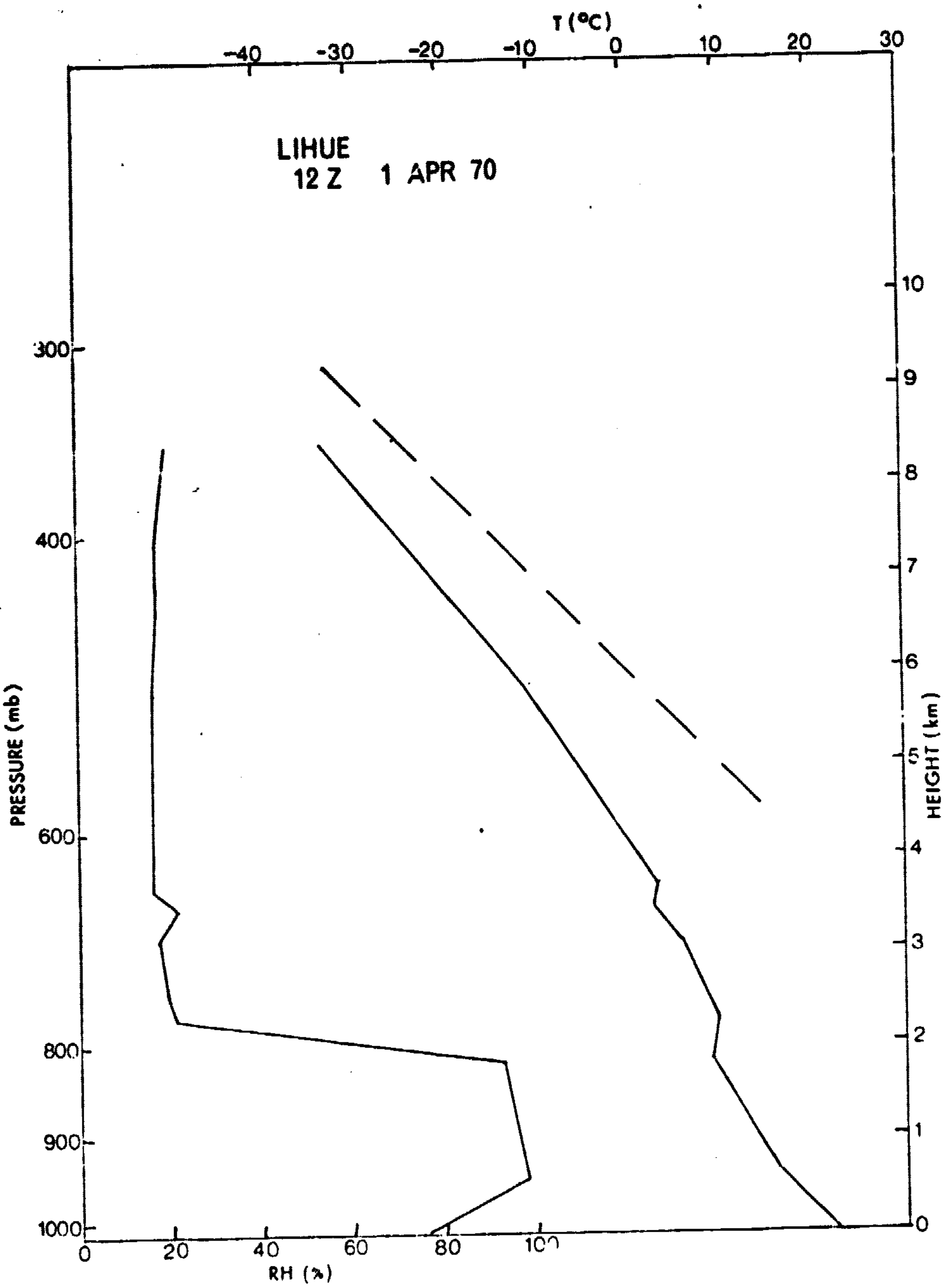

Fig. 2 Same as Fig. 1, but for 12Z ascent.

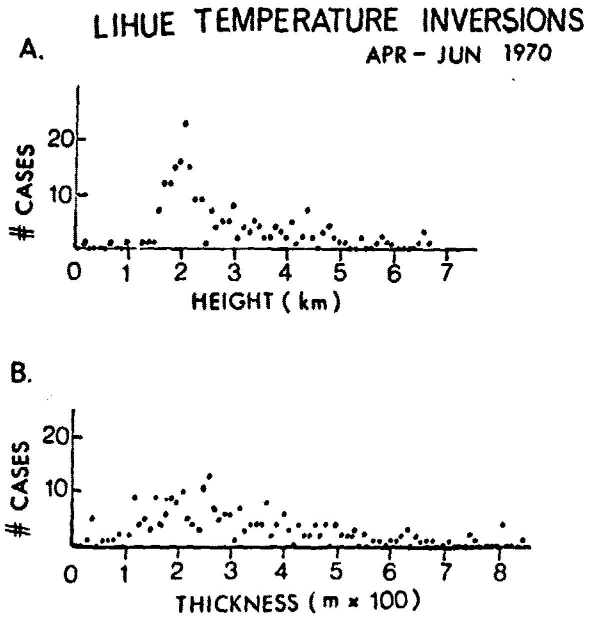

Fig. 3 Histograms of temperature inversion characteristics from Lihue radiosonde ascents in April-June 1970. (a) Number of observations of inversions with heights in 100 m intervals. (b) Number of observations of inversions with thicknesses in 10 m intervals.

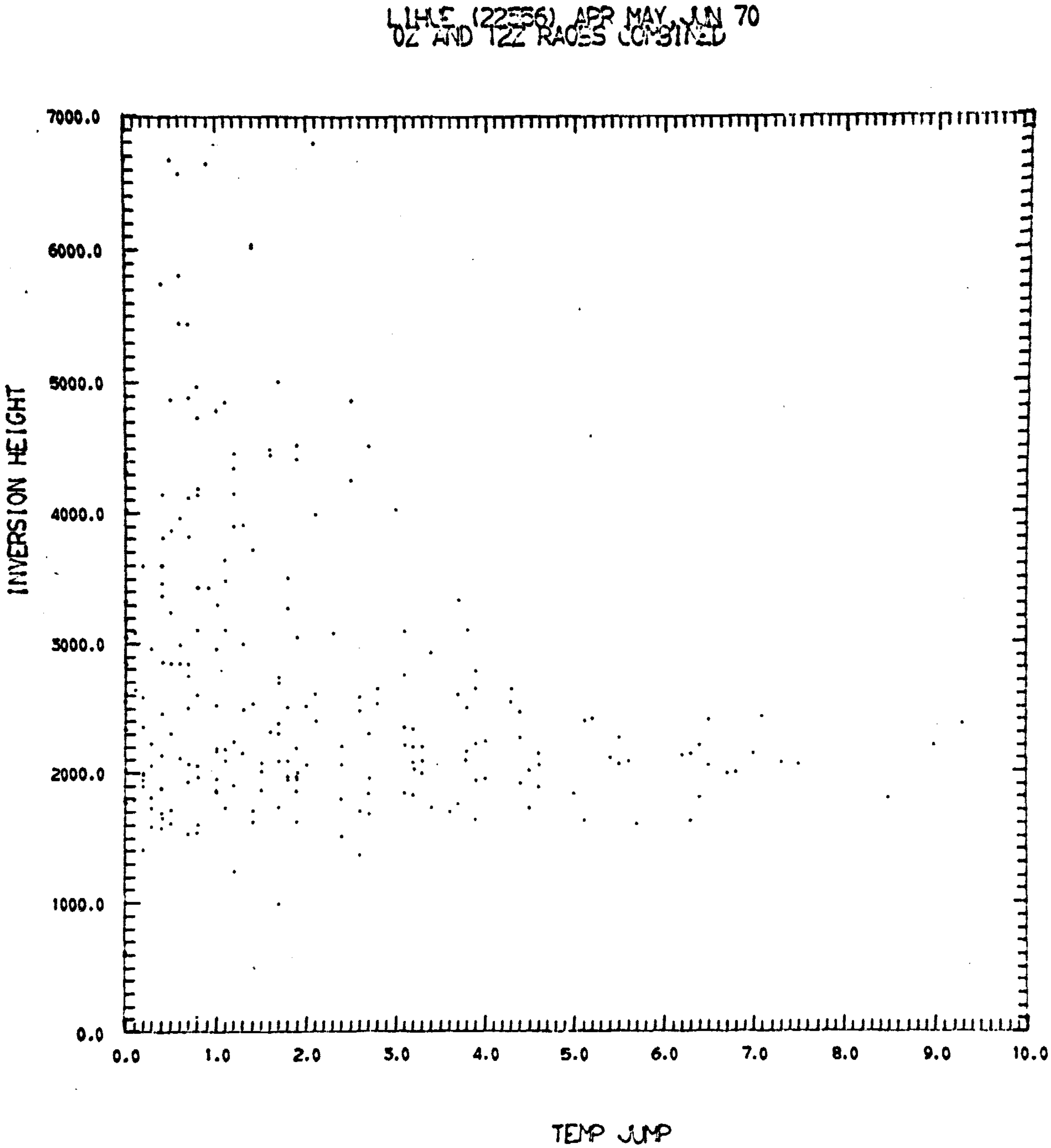

Fig. 4 Scatter diagram of inversion heights (km) and associated temperature differences (°C) for Lihue soundings in April-June 1970.

flatter with a broad maximum between 100 and 300 m. From the scatter plot of inversion thickness versus temperature difference (ΔT) in Fig. 5 it is clear that the strong inversions ($\Delta T > 5°C$) which appear around 2 km in Fig. 4 have thicknesses less than 500 meters. Inversion thickness would not seem a promising parameter for defining classes of inversions in the ascents studied here.

A sharp relative humidity drop associated with the trade wind inversion since the latter exists on the boundary between the moist planetary boundary layer and the much drier air subsiding aloft in the subtropical anticyclones. The large relative humidity gradient associated with the trade wind temperature inversion layer (e.g. Prabhakara et al., 1978, Fig. 7) is, however, somewhat difficult to characterize in individual soundings because it can extend below the inversion layer. The difference between Figs. 1 and 2 illustrates this point. In Fig. 1 the relative humidity decrease through the inversion below 2 km is 8% whereas the decrease from a height 150 m below the temperature inversion layer to its top is 33%. Figure 2 more nearly resembles the standard profile illustrated in Fig. 7 of Prabhakara et al. (1978) in the coincidence exhibited between the inversion layer and the layer of pronounced relative humidity decrease. Variations in the extent of coincidence of these layers is probably responsible for the wide spread of relative humidity changes associated with the strong temperature inversions ($\Delta T > 5°C$) as shown in the scatter plot of Fig. 6. (It should be recalled that these strong inversions all occur at heights in the vicinity of 2 km as can be seen from Fig. 4.)

The observations made above suggest the following strategy for computer identification of the trade wind inversion and estimating the parameters associated with it:

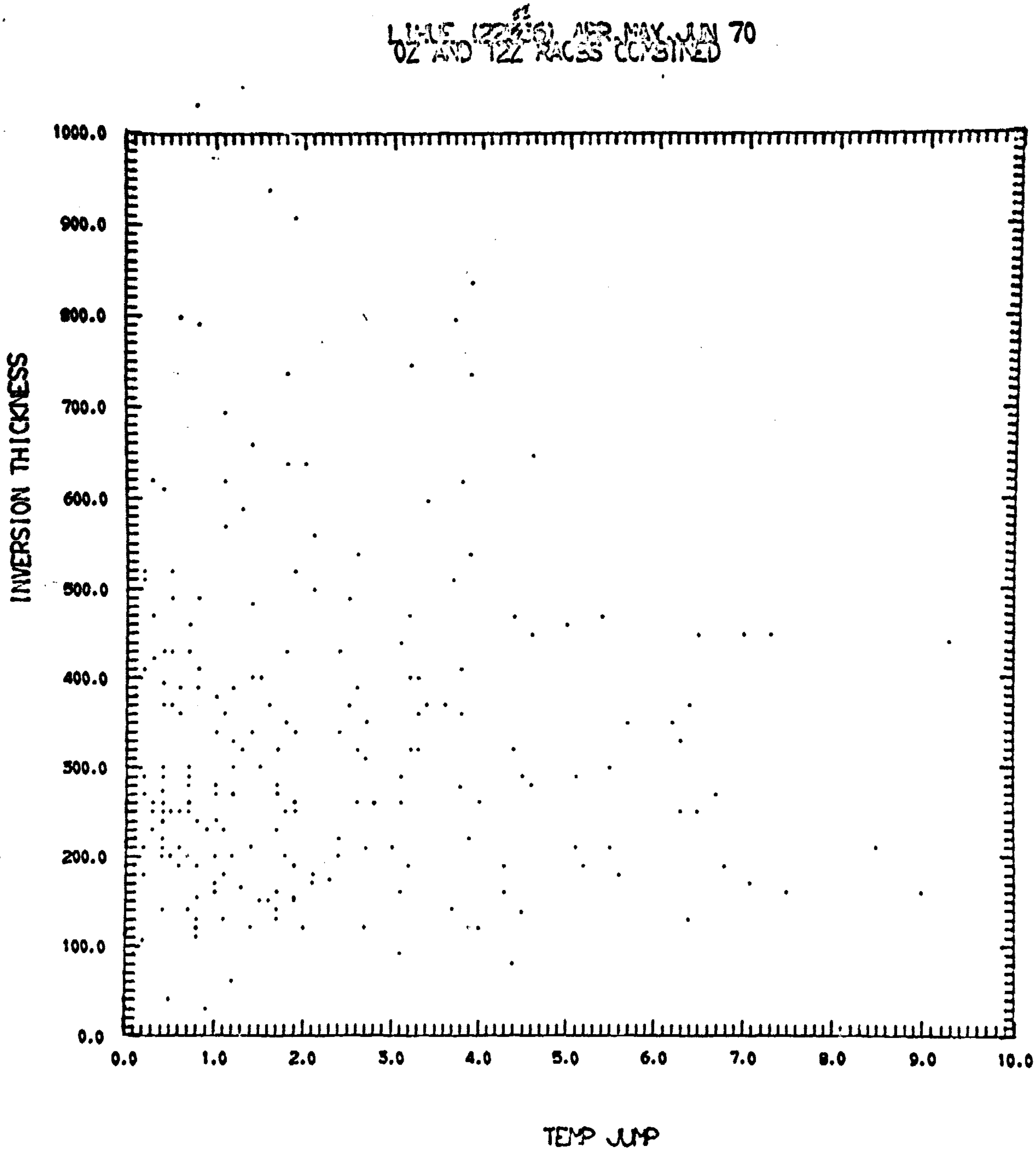

Fig. 5 Same as Fig. 4, but for inversion thickness (m) and associated temperature difference (°C).

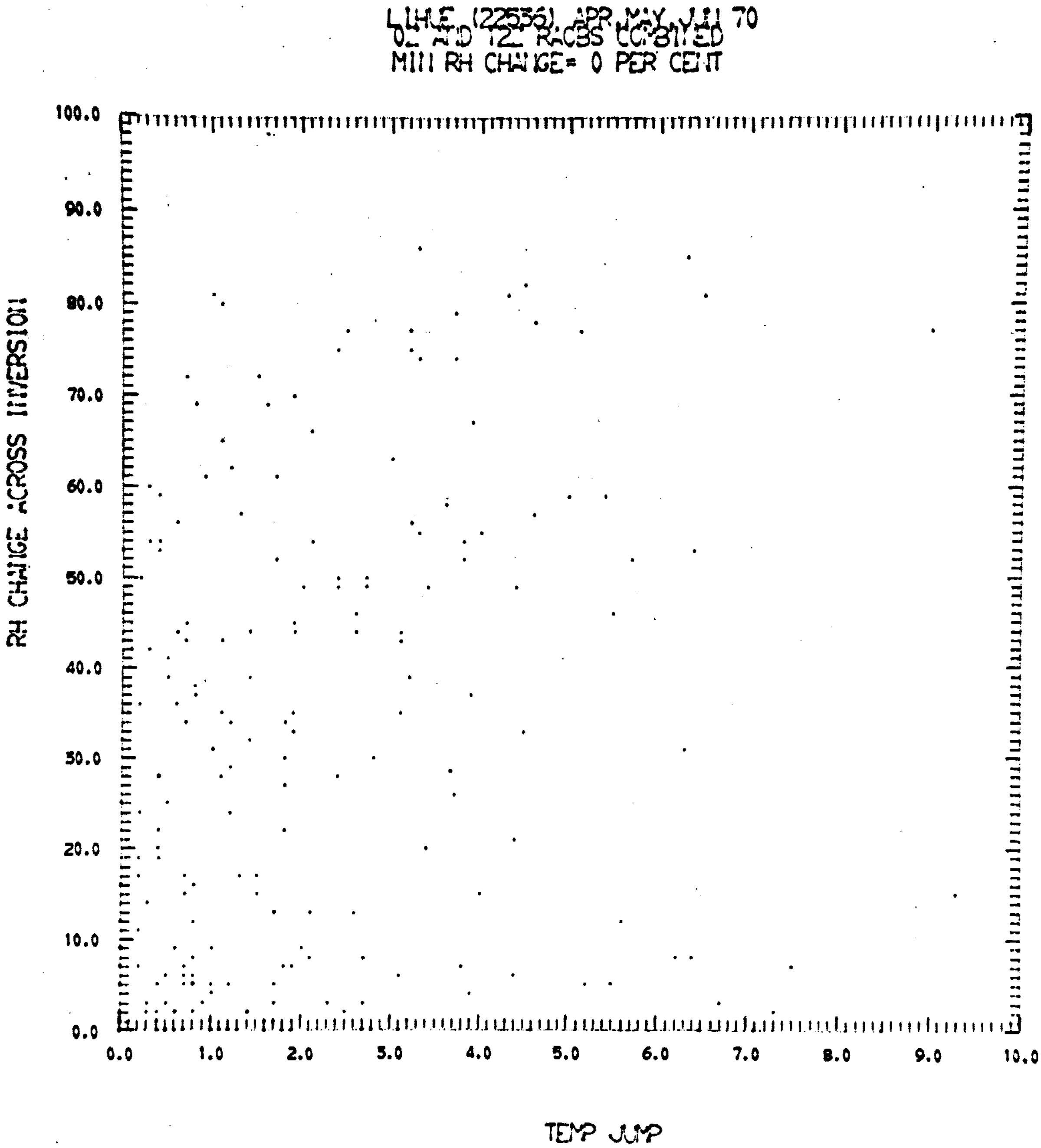

Fig. 6 Same as Fig. 4, but for relative humidity change across the inversion (%) and associated temperature difference (°C).

1. Identify the first inversion layer encountered above the surface which lies below a maximum height which will depend on geographical location and perhaps on season. (For Lihue in Spring, Figs. 3a and 4 would indicate 3 km to be a reasonable choice.)
2. Determine the relative humidity decrease through the layer and/or through the layer and the region several hundred meters below it. If one or the other decrease exceeds a chosen threshold value assume the inversion is the trade wind inversion and store the desired parameters.
3. Compute seasonal statistics for desired parameters from all soundings within the season.

Exploratory analyses such as those presented above for Spring 1970 at Lihue should be used to identify thresholds for inversion height and relative humidity drops. In cases where no obvious threshold values are suggested, the sensitivity of the seasonal statistics to such decisions should be considered.

Due to the lack of resources, the program outlined above was not executed on the Lihue data. It would seem necessary to the understanding of the convection-inversion index $[(\bar{w}-w)/\bar{w}]$ to pursue this line of research. Not only are the questions raised in our original proposal unanswered but the preliminary study we have undertaken raises some additional questions concerning the foundation of the suggested proportionality between the index and temperature difference across the inversion. This suggestion rests on the empirical relationships among inversion height, temperature difference, the relative humidity drop shown in Figs. 8 and 9 of Prabhakara et al. (1978). These relations are not obvious in Figs. 4 and 5 which are the corresponding plots using all inversions found in Lihue raobs for Spring 1970. It is important to see the extent to which a restriction to trade wind inversion events accomplished as outlined above will reveal the required relations.

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