EXPERIENCES WITH ITPP AND 3I OVER THE OCEANS

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1. Introduction

For short-term climate studies, and for intensive field observation programs intended to parameterize regional climate and cloud regimes such as FIRE, remote sensing of the marine atmospheric boundary layer (MABL) and air-sea interactions have gained an increased importance. Satellite remote sensing of the MABL, however, is very difficult due to the relatively coarse vertical resolution of sounding instruments. The MABL is often characterized by a cool, moist layer capped by a sharp inversion with warmer and much drier conditions above. Stratus and stratocumulus clouds frequently are found just beneath the inversion, further complicating remote sensing using infrared observations.

In an effort to assess the quality of temperature and moisture profiles of the MABL, I have implemented and applied both the International TOVS Processing Package (ITPP) and the Improved Initialization Inversion (3I) retrieval packages to several air-sea interaction experiments. These include the Frontal Air-Sea INteraction EXperiment (FASINEX) which took place in February 1986 southwest of Bermuda in the northwest Atlantic Ocean, the Coastal Ocean Dynamics Experiment (CODE) which took place off the coast of northern California during July 1982, and the MIxed Layer Dynamics EXperiment (MILDEX) which took place in October 1983 approximately 500 km southwest of Los Angeles. Each of these experiments occurred in different MABL conditions. The comparisons and conclusions that I will make are necessarily qualitative because of the lack of in situ ground truth over the oceans. The most extensive ground truth is available for the FASINEX program where ship-launched radiosondes were available. Otherwise comparisons and conclusions are based on climatology and internal consistency checks of the satellite data.

The ITPP program has been described previously in the TOVS study conferences by Smith et al. (1983) and Smith et al. (1985). The retrievals described herein used version 3.0 of ITPP and a climatological first guess profile. The 3I package has been described by Chedin et al. (1985) and I used a version supplied in the summer of 1987 (I am not sure if there was a 3I version number). While there continue to be improvements to both packages, I do not believe that the improvements have substantially altered the discussion of the MABL retrievals which this paper discusses. I realize that neither of these packages was specifically optimized for retrieving MABL profiles, but improvements to retrieving MABL profiles should have a positive benefit on retrievals throughout the troposphere. I am grateful to both groups for making their processing packages available to the general remote sensing community.

2. MABL Retrievals During FASINEX Using ITPP and 3I

The FASINEX field experiment was designed to study the ocean-atmosphere interaction in the vicinity of a sharp sea surface temperature front (approximately 2°C change in 10 km). The experimental plan is described by Stage and Weller (1985) and Stage and Weller (1986). An upcoming issue of Journal of Geophysical Research-Oceans is to be devoted to results from FASINEX. Ship-launched radiosondes provided ground truth for retrievals from TOVS using ITPP and 3I. Radiosonde launches were timed to approximately coincide with the polar-orbiter overpasses. A time window of 3 hours and space window of 200 km was used for these matches. Many of the FASINEX soundings contained thin cloud layers or partly cloudy skies. The nearest TOVS retrievals with partly cloudy or clear conditions were used in the matches.

Figure 1 shows a radiosonde profile with a moist MABL up to 750 mb, with the air nearly saturated there, then a drier layer above with another thin cloud near 550 mb. The ITPP retrieval (top panel) used the observed sea surface temperature and a dew point temperature at 80% relative humidity, resulting in a kink in the temperature profile below 1000 mb. The retrieval is saturated up to 750 mb, near the observed cloud top, but the dry layer above this point is not well represented. The 3I retrieval is also saturated in the MABL up to about 800 mb (it appears that 3I relative humidity is constrained not to exceed 95%), but the retrieval shows a significant cold bias. Above 700 mb the temperature profile is quite accurate and the dew point profile shows a much drier layer in general agreement with the radiosonde.

The second example (Figure 2) shows a similar situation with a moist MABL up to nearly 800 mb, a thin, nearly saturated layer, and then drier conditions above. In this ITPP example no surface information was supplied. There is a substantial negative bias in both the ITPP and 3I temperature retrievals in the MABL. Both retrievals do, however, capture the saturated layer about 800 mb. The ITPP temperature retrieval has a negative bias above 700 mb, but the 3I tempearture retrieval shows excellent agreement. The dew point temperature profiles both show a very dry layer above 700 mb. The extreme dryness of the ITPP dew point temperature profile is attributed to the inability of the physical inversion in accounting for non-linear moisture effects (W. Smith, personal communication). Additional physical constraints or some accounting for non-linear moisture effects is required to correct this problem.

The final radiosonde profile (Figure 3) shows a completely saturated MABL up to 700 mb and a very dry layer above. The satellite temperature retrievals for an adjacent clear area are both in excellent agreement with the radiosonde. Both dew point tempearture retrievals are also in reasonable agreement with the radiosonde, showing a moist MABL and a very dry layer above.

3. Retrieved MABL Fields During FASINEX, CODE, and MILDEX

In this section, horizontal fields of MABL parameters retrieved using the 3I method are presented. Although additional spot comparisons using ITPP were produced, horizonatal maps using ITPP were not generated. For each of these three experiments I choose to analyze retrieved values rather than contoured charts. The set of parameters presented includes the HIRS 11 micron window brightness temperatures (channel 8), visible albedo, sea surface temperature, lowest level air temperature, low- and mid-level relative humidity, cloud top pressure, and total precipitable water.

In the FASINEX example, clouds are evident in the albedo (i.e., albedos of greater than 8%) and window channel data (judging by the horizontal inhomogeneties) in the northwest portion and in the eastern quadrent along 28°N. The cloud top pressures appear reasonable given the window channel brightness temperatures. The low-level air temperature field is the most homogeneous field and values are close to the several ship observations (not shown). The sea surface temperature values agree well with those derived from a 5-day composite using AVHRR data (Halliwell and Cornillon, 1987). The AVHRR analysis shows less variability with values of 21°C along 32°N increasing to 25°C along 25°N with the contours zonally oriented. The 3I SST field is somewhat noisy and a few outliers are quite obvious (eg., 31°C near 29°N, 69°W and 20°C near 26°N, 71°W). The SST outliers are accompanied by outliers in the low-level relative humidity field. This is not surprising since the low-level moisture channel is used to correct the window channel to obtain the SST. A constraint on the SST will thus lead to an improved low-level moisture field or, at least, to flagging those data as questionable. The mid-level relative humidity field is more consistent, although I am suspicious of the nearly saturated values of 95% near 25°N, 70°W.

The second example is from the CODE program which took place off the central California coast during the summer of 1982. This pass (Figure 5) is from the morning of July 10. During the summer, this area is characterized by cool water which has upwelled from depth and is often covered by low stratus clouds. Climatological SST's near San Francisco Bay (near 38°N, 122°W) are between 14°-16°C and increase 1°-2°C moving offshore to 130°W (Beardsley et al., 1987). SST's retrieved using 3I are considerably colder than this, suggesting that there may have been a stratus deck that avoided detection. The visible albedo values appear too low (a visible albedo of 5-7% is typical of over ocean clear conditions), so there may have been a problem with the calibration of the visible channel data. Apparently the window channel temperatures were not sufficiently low enough to trigger the cloud threshold for low-level clouds. These conditions are amongst the most difficult to detect for any cloud clearing scheme. Once again, however, reference to some near real-time SST analysis may have allowed for detection of the low clouds. The low-level relative humidity analysis is quite good, indicating saturated conditions over most of the southern half of the over ocean domain. Perhaps there should be a consistency check between the low-level relative humidity analysis and the SST analysis so that if saturated conditions are found the SST values are not used. The mid-level relative humidity analysis also appears reasonable, showing much drier air aloft as is found in the climatological mean.

The final example is from the MILDEX program (Gautier and Frouin, 1985) and this particular pass is from October 12, 1983 (Figure 6). The MABL in this case is typical of conditions often found off the west coast of continents. A cool, moist MABL is capped by a strong inversion and stratus or stratocumulus clouds are often found just beneath the inversion. Sometimes streaks of cirrus clouds from the subtropics move northeastward over the area. This is the case in this example where the cloud top pressure analysis shows at least two layers of clouds; one between 700-800 mb and another betewwn 200-300 mb. Many of the retrieved SST's are between 20°-22°C which is the climatological norm. A few SST's of 25°C are found near 28°N, 128°W. The low-level relative humidities at these locations are slightly higher than surrounding values, suggesting that perhaps the moisture channel brightness temperature is overcorrecting for moisture attenuation of the window channel brightness temperature. SST's near 34°N, 124°W appear biased low relative to climatology. These values seem to be associated with high values of mid-level moisture.

4. Summary of Results

I have examined both the ITPP and 3I packages applied to retrieving SST and low-level profiles of temperature and moisture. Comparisons were made using in situ observations, climatology, and internal consistency checks. Using a climatological first guess profile, ITPP is unable to retrieve the sharp marine inversion, but can retrieve the general pattern of a warm, dry layer over a cool, moist MABL. Adding surface information in the ITPP only improves the surface values. In situ observations suggest that this information should be distributed throughout the depth of the MABL.

The 3I TIGR first guess procedure often does remarkably well in imposing a warm, dry layer above a cool, moist MABL, but the MABL profiles are often biased low relative to in situ observations. The 3I-retrieved SST's are somewhat noisy and values biased from climatology are usually highly correlated with large values of low-level moisture for

SST's biased high and large values of mid-level moisture for SST's biased low.

5. Future Plans

I have recently joined the Climate Research Division of NOAA/ERL and am in the process of implementing both the ITPP and 3I packages to run on our network of SUN computer workstations running the UNIX operating system. I plan to apply both packages, with some improvements to retrievals in the MABL outlined below, to two upcoming air-sea interaction experiments. These include the Atlantic Stratocumulus EXperiment (ASTEX), to be held in the North Atlantic near the Azores in 1992, and the TOGA Coupled Ocean-Atmosphere Response Experiment (COARE), to be held in the tropical western Pacific also in 1992.

The analysis presented above suggests that an ad hoc correction or thermodynamic constraints on ITPP and 3I MABL retrievals would lead to signidficant improvements. An ad hoc correction would include pinning the low-level air temperature to the SST and using a first guess profile with a constant lapse rate between the surface and the top of the inversion. Similarly, the low-level moisture profile would be pinned to a surface relative humidity of 80% of the SST and would use the same first guess lapse rate as the temperature profile. Such a scheme should lead to improved MABL profiles, but does not address the physical processes working in the MABL.

A physically-based approach to improving MABL profiles should couple some sort of mixed layer model to the retrieval scheme. For stratocumulus layers over the oceans, Betts (1983) has shown that atmospheric convective structure and mixing processes could be simplified using air parcel saturation point. This simple model could be used to constrain the ITPP and 3I retrieval schemes with realistic physics. I hope to incorporate a version of Betts model into these retrieval schemes in the near future.

Acknowledgements

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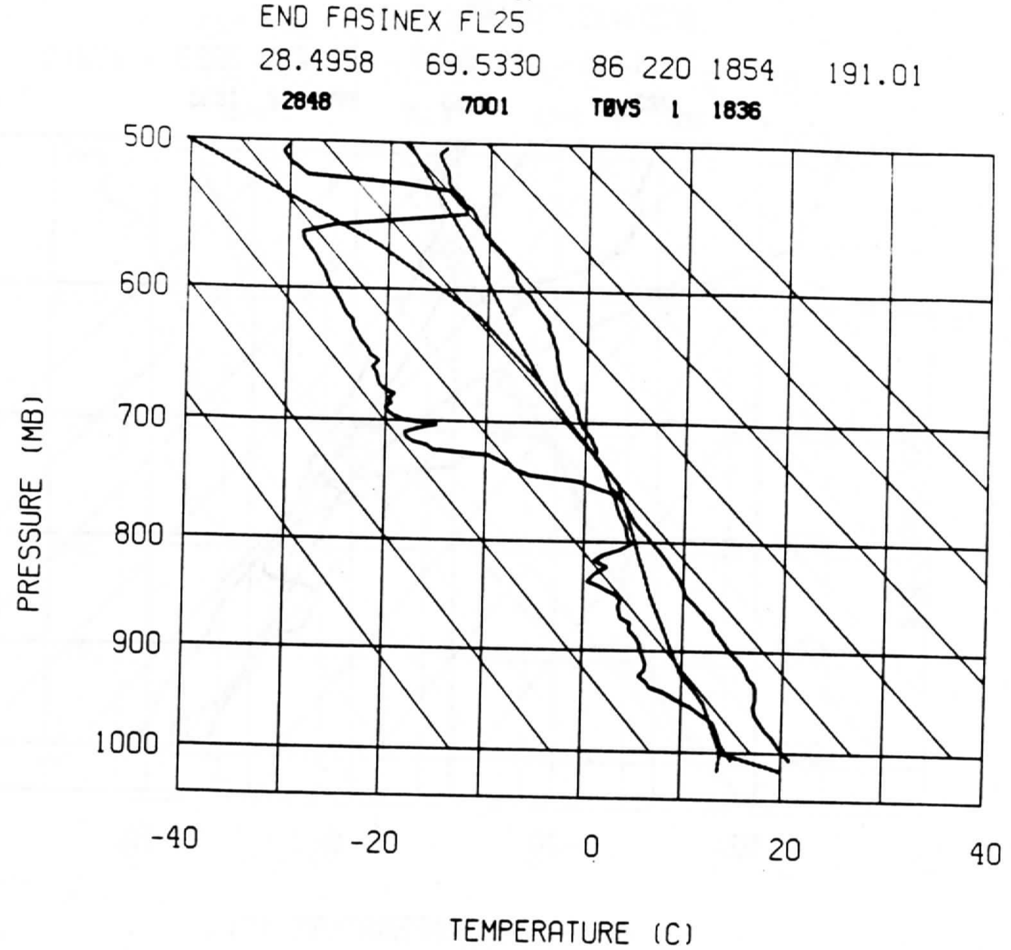


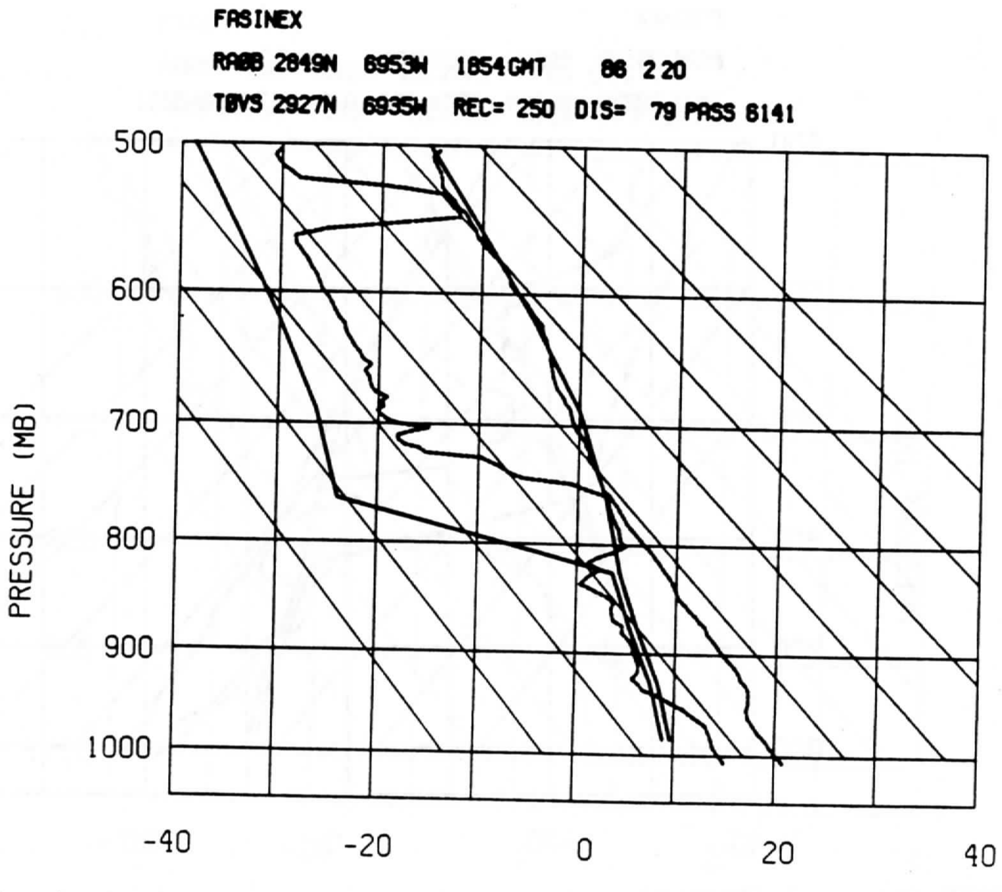
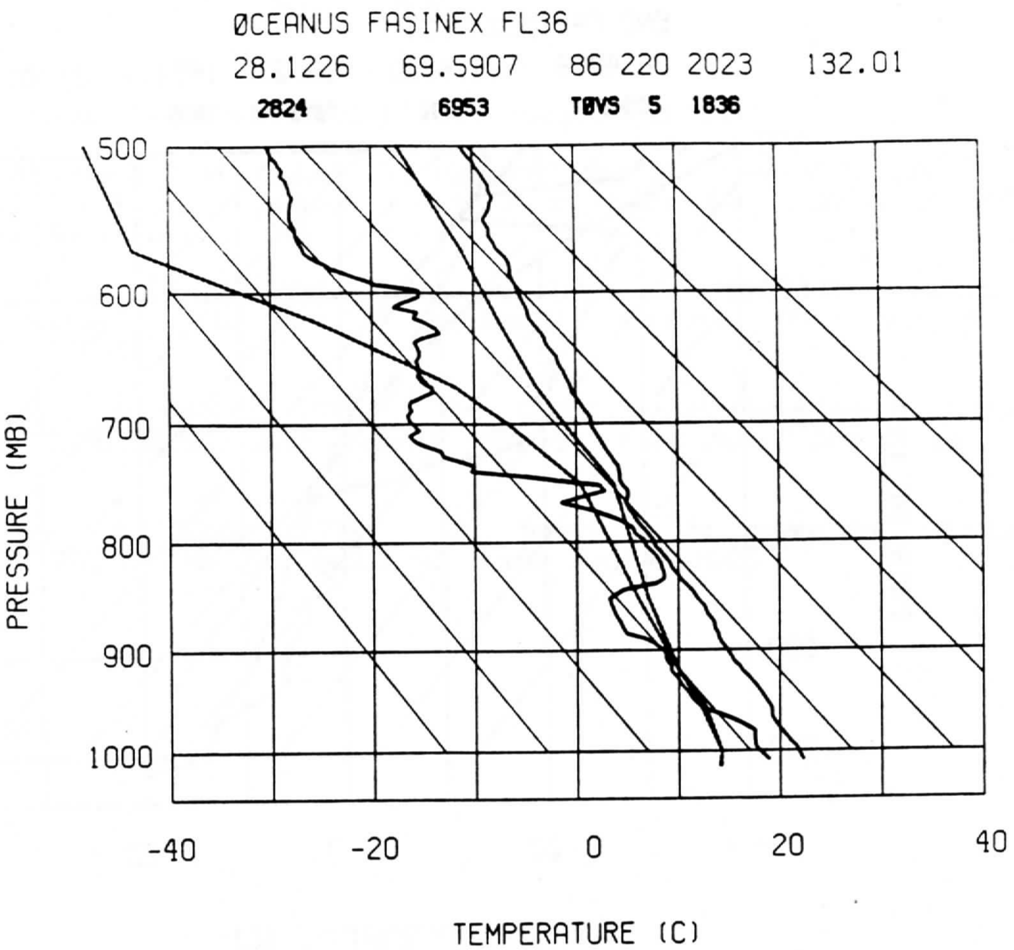
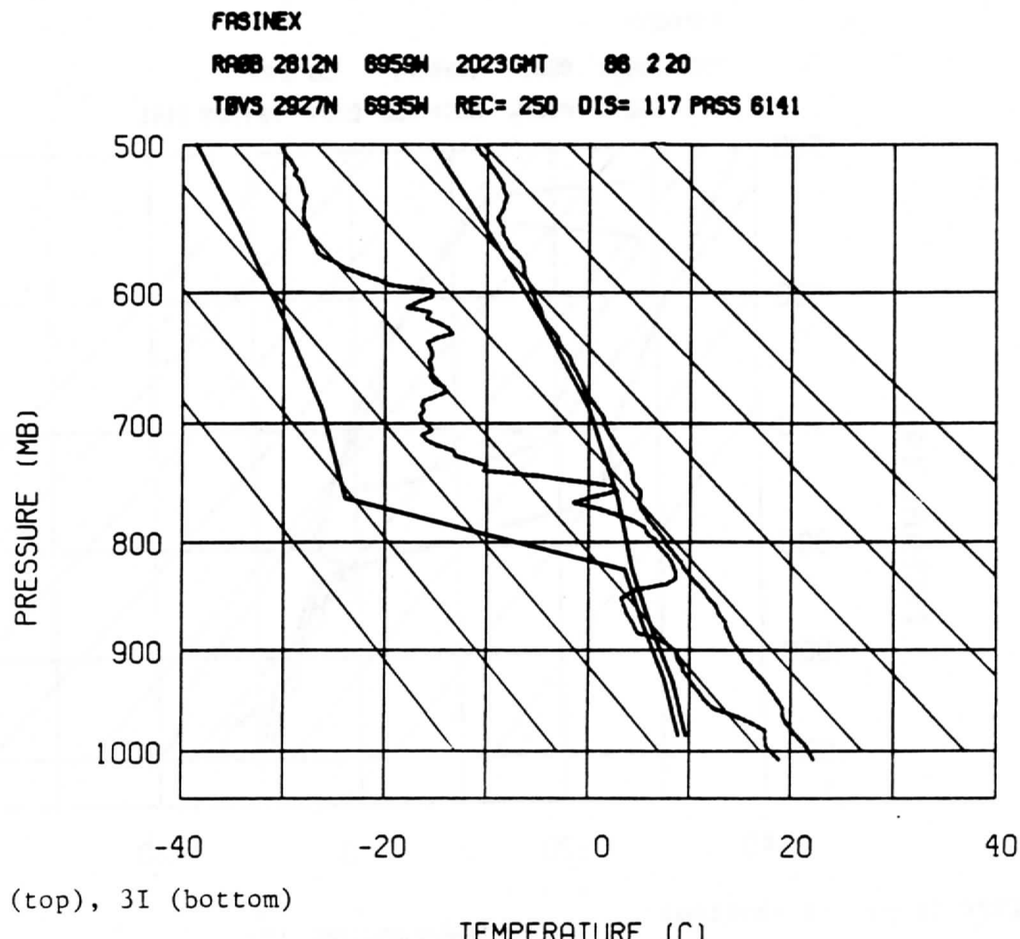


Figure 1. ITPP (top), 3I (bottom)





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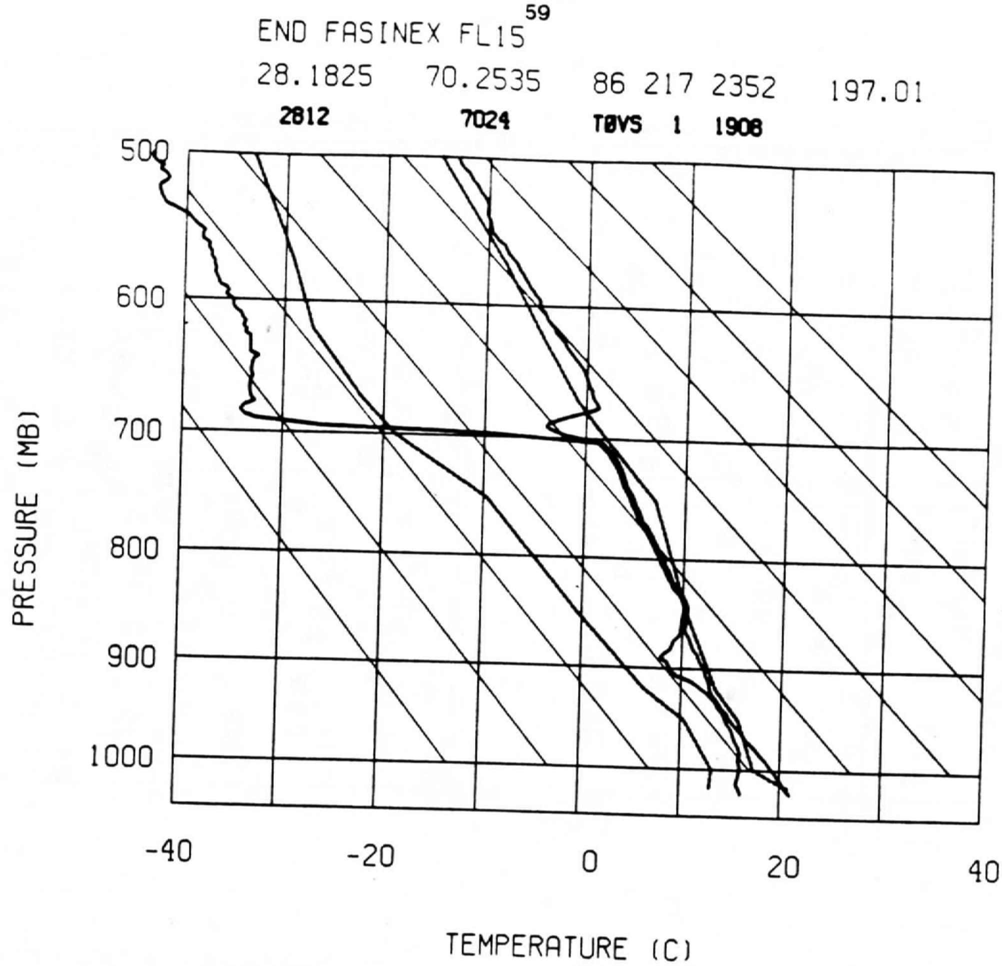

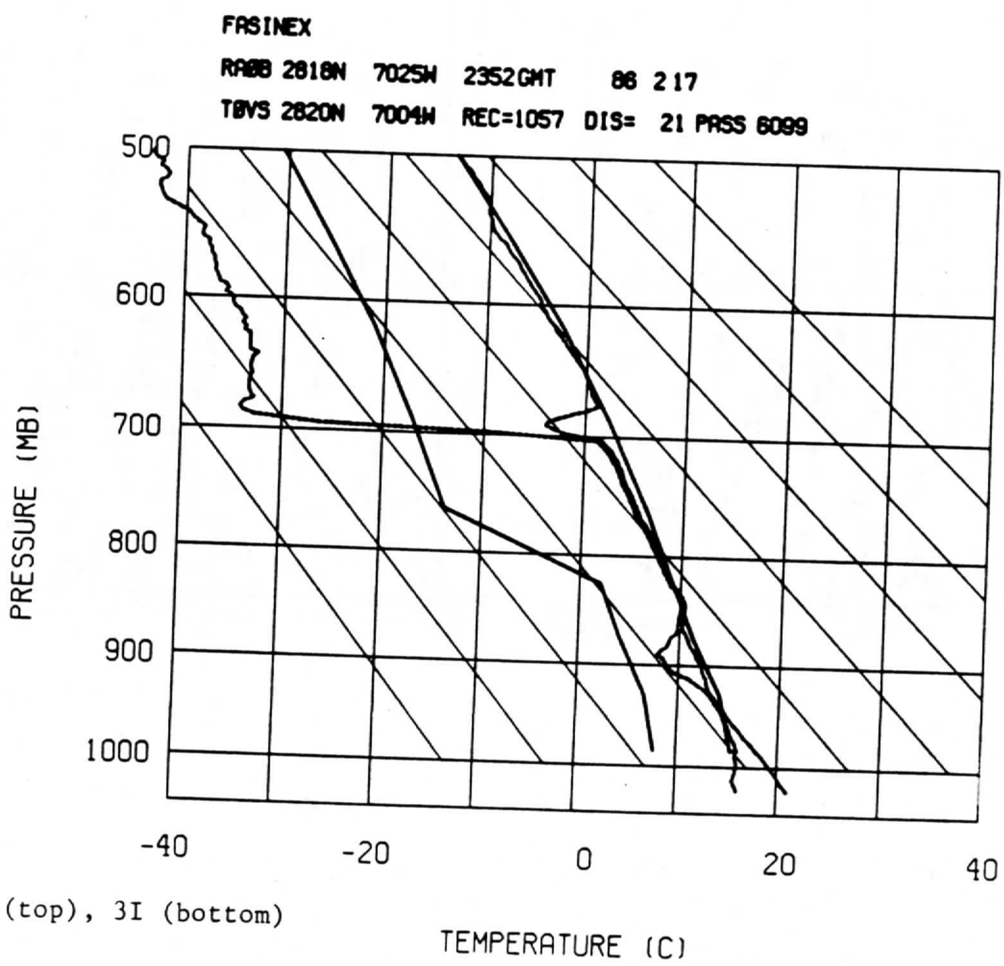

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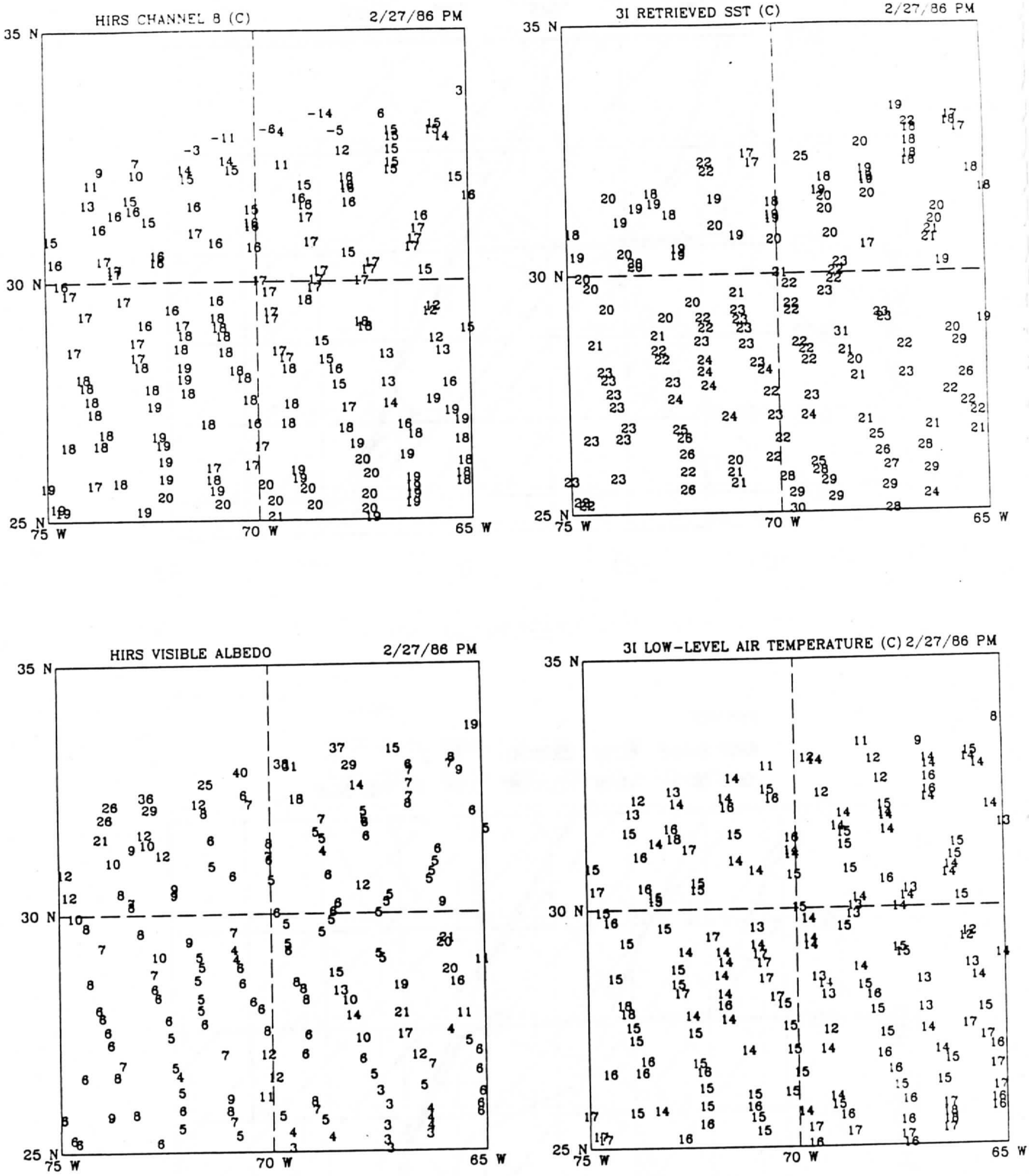
HIRS CHANNEL 8 (C)
2/27/86 PM
3I RETRIEVED SST (C)
2/27/86 PM
HIRS VISIBLE ALBEDO
2/27/86 PM
3I LOW-LEVEL AIR TEMPERATURE (C) 2/27/86 PM
35 N
30 N
25 N
75 W
70 W
65 W

Figure 4.

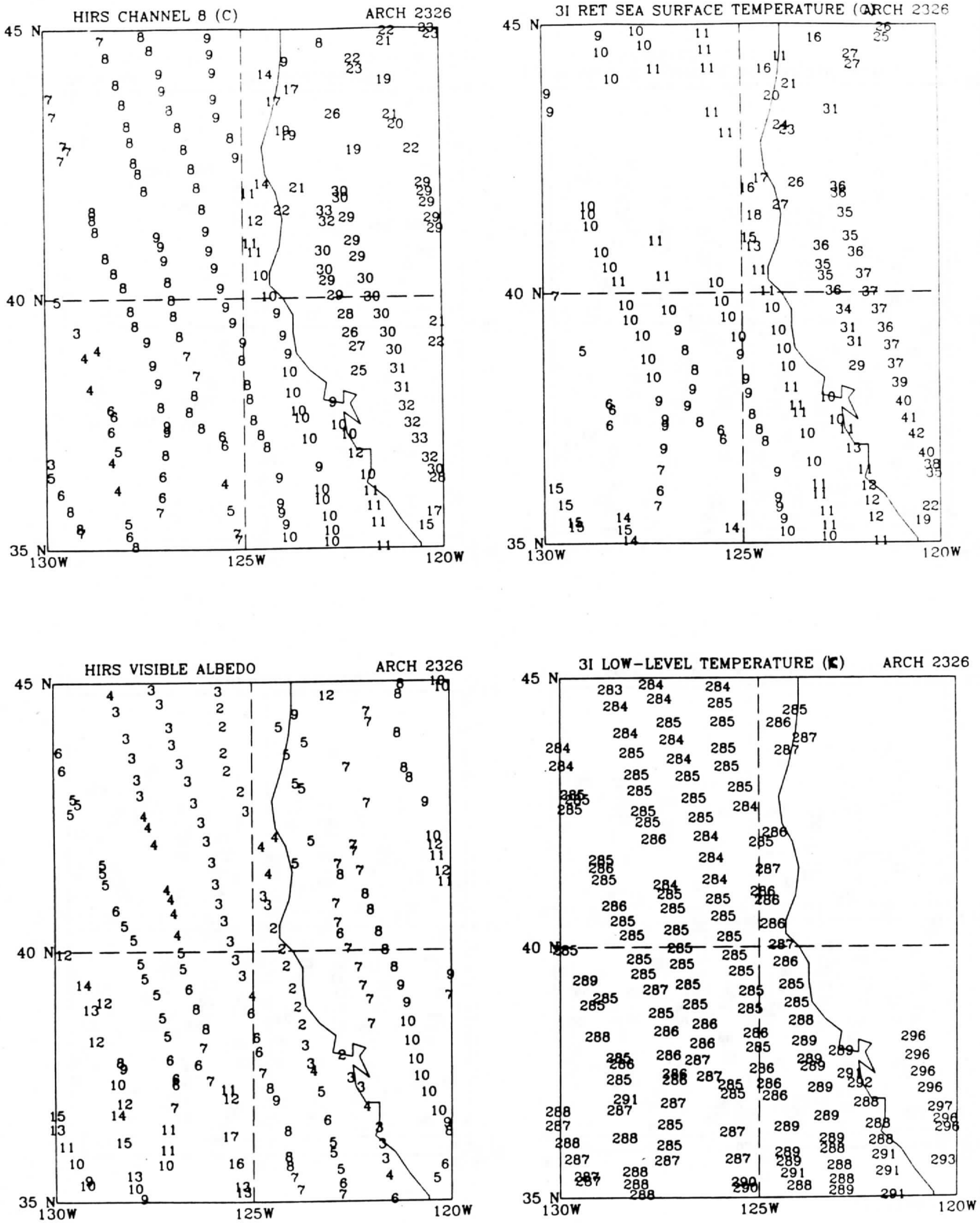
HIRS CHANNEL 8 (C)
ARCH 2326
31 RET SEA SURFACE TEMPERATURE (C)
ARCH 2326
HIRS VISIBLE ALBEDO
ARCH 2326
31 LOW-LEVEL TEMPERATURE (K)
ARCH 2326
45 N
40 N
35 N
130W
125W
120W

Figure 5.

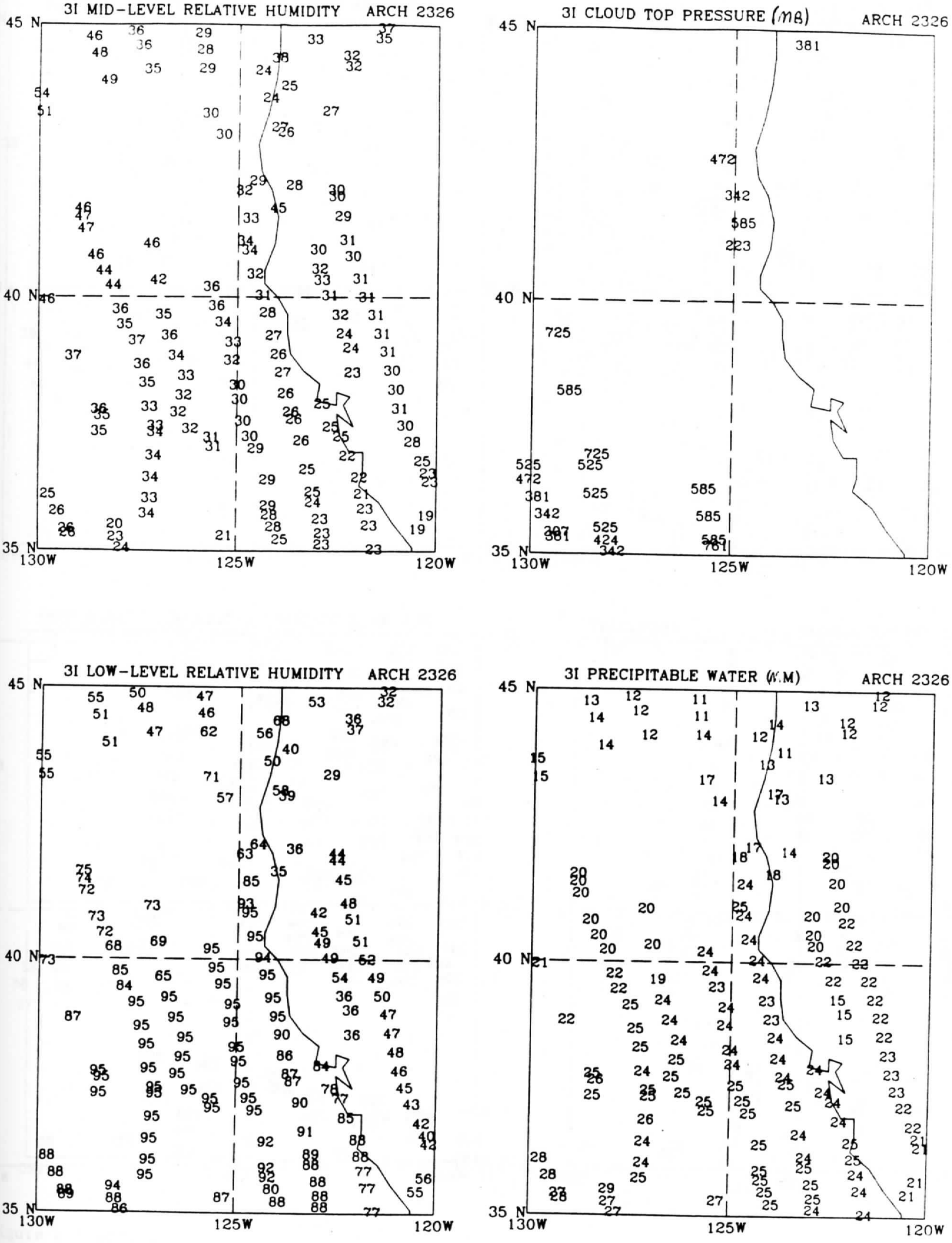

Figure 5 (cont.).

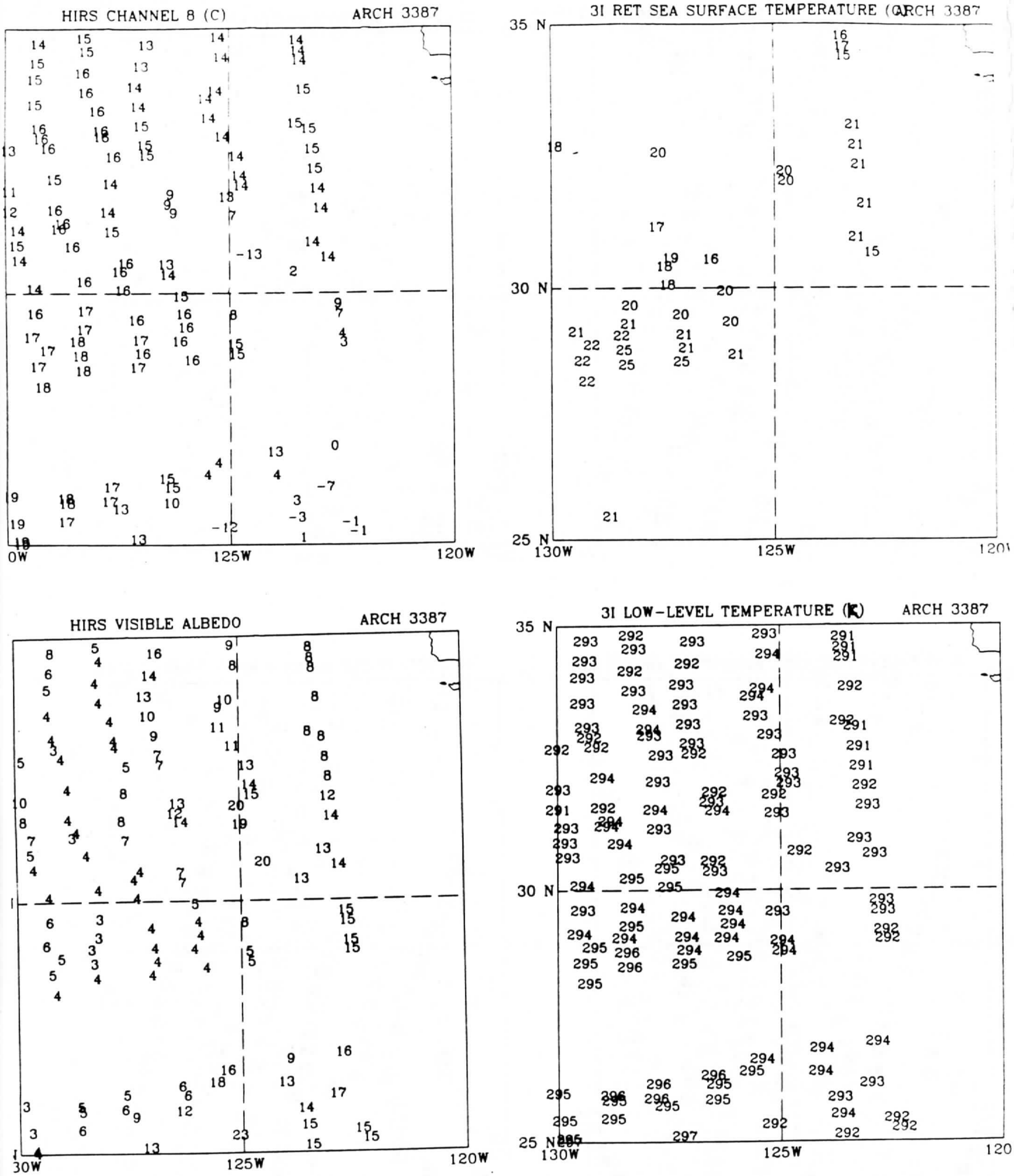
HIRS CHANNEL 8 (C)
ARCH 3387
125W
120W
3I RET SEA SURFACE TEMPERATURE (C)
ARCH 3387
35 N
30 N
25 N
130W
125W
HIRS VISIBLE ALBEDO
ARCH 3387
130W
125W
120W
3I LOW-LEVEL TEMPERATURE (K)
ARCH 3387
35 N
30 N
25 N
130W
125W
120

Figure 6.

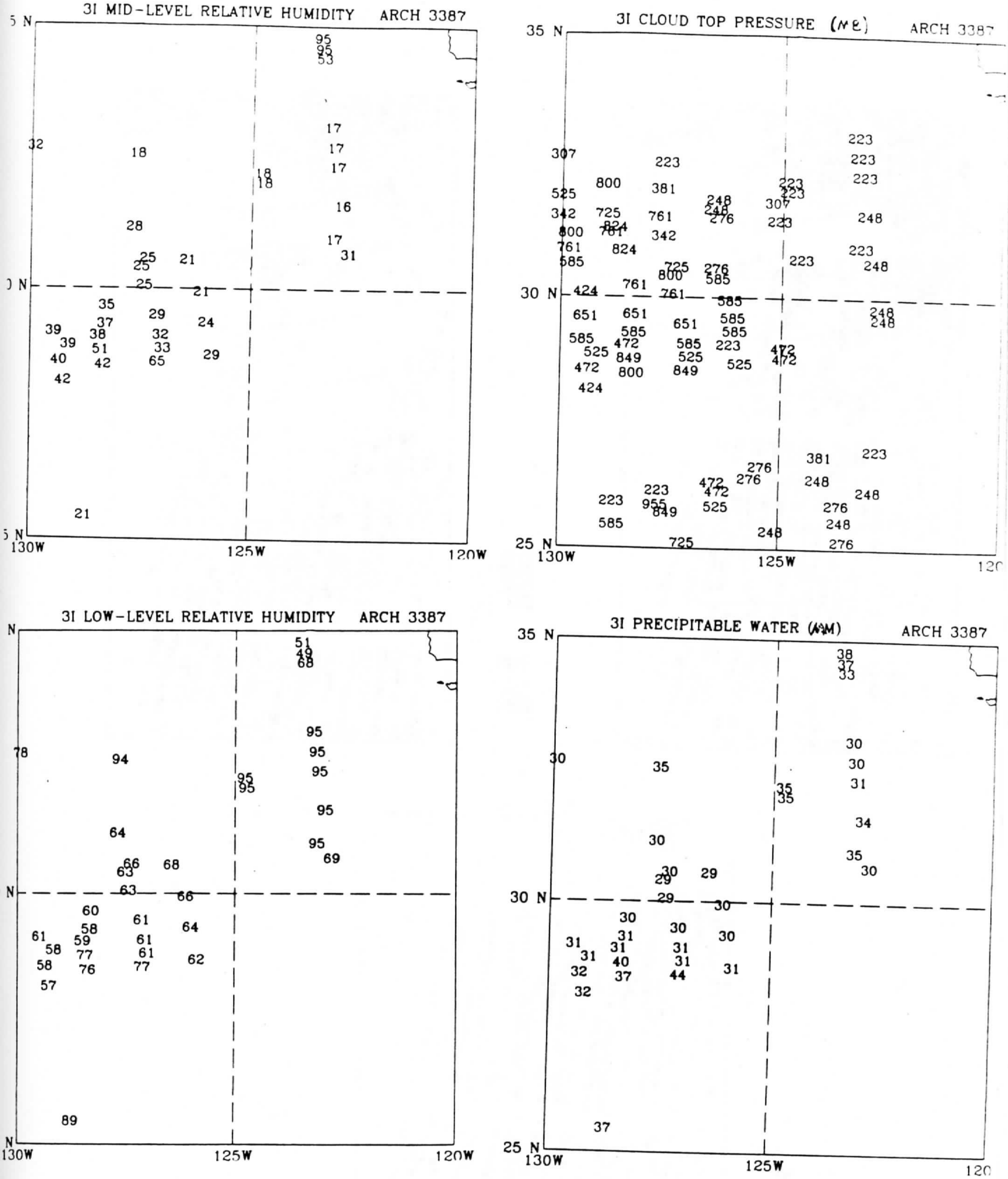

Figure 6 (cont.).

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