INVESTIGATION OF THE RADIATIVE BOUNDARY CONDITIONS DURING THE DEVELOPMENT OF THE SOUTHWEST MONSOON SAUDI ARABIAN HEAT LOW

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Progress Report No. 2

On the Cooperative Research Project
between the Department of Atmospheric Science
at Colorado State University and the Faculty of Meteorology
and Environmental Science at King Abdul-Aziz University
in Accordance with the CID-ARMETED Project
of the University of Arizona

"An Investigation of the Radiative Boundary Conditions during the Development of the Southwest Monsoon Saudi Arabian Heat Low"

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1.0 INTRODUCTION

We have compiled in this report the extended abstract of a formal paper and photographs of a poster paper, both of which were presented at the International Conference on the Scientific Results of the Monsoon Experiment, in Bali, Indonesia, October 26-30, 1981. These results summarize, in a brief format, our initial analysis of the structure of the Arabian Heat Low and its impact on the Southwest Indian Monsoon. The results are based on both the new boundary layer data set available through the CID-KAAU supported research program and some of our earlier MONEX analysis which has been supported by the National Science Foundation.

2.0 DISCUSSION OF THE BALI PAPERS

The first paper presented by Smith, et al. (1981) -- see Appendix I -- outlines some of the key thermodynamic and dynamic features of the Arabian Heat Low and concludes the study with a discussion of the probable role of the Heat Low in the context of the Southwest Monsoon system. The Arabian Peninsula had been designated by the MONEX scientific panel, prior to the MONEX experiment, as one of the important regional heat sink regions which interacted with and is considered to be an integral part of the large scale Southwest Monsoon system. Its assumed heat sink properties would be in contrast to those of a heat source region, such as the precipitation zone along the front range of the Himalayas where a vast amount of latent heat is released during the active monsoon period. Prior to these studies, there had been very little investigation of the Arabian Heat Low.

The results of our analysis have shown that the original speculation concerning the distribution of heat source and heat sink regions may have been in error. In particular we have shown that the Southern Portion of the Arabian Peninsula (i.e. the Empty Quarter) maintains a tropospheric heat surplus in contrast to our classic notion of a desert thermal low which is generally characterized as a radiatively driven heat deficit region (see e.g. Ramage, 1971). These results are discussed in more detail in the extended abstract.

The poster paper, which was presented by Sakkal, et al. (1981) -- see Appendix I -- was used to illustrate our experimental set up in Saudi Arabia and some of the preliminary results. This poster paper was utilized very successfully to attract attention to the new MONEX related measurements which were made available through the CID sponsored research project.

There was very spirited interest in these two papers by a wide variety of scientists during the Bali conference. In addition, there were concrete recommendations made by the Summer MONEX Scientific Panel to continue research on the heat source/heat sink problem with emphasis on the Arabian region. A few scientists expressed interest in sending additional instrumentation to Saudi Arabia to study in more detail the vertical structure of the low and mid troposphere, and to examine more carefully the sources and properties of the extensive dust layer prevalent over the Empty Quarter region.

3.0 CONCLUSIONS

It is our belief that we have paved the way for a more thorough investigation of the role of the Arabian atmosphere in the context of the earth's general circulation. Our scientific group has focused on some very specific aspects of the atmosphere over Arabia with particular emphasis on radiative and boundary layer topics during the Southwest Monsoon season. However there is now much more widespread scientific interest being shown by a number of tropical and monsoon scientists in a variety of other atmospheric science problems concerning the Arabian Peninsula. We believe that the ARMETED project can greatly aid investigations of these problems by continuing to actively support scientific research and by encouraging scientific exchange between KAAU and other universities and government agencies throughout the world who show interest in the many remaining scientific questions.

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APPENDIX I

The Bali Papers

PRELIMINARY RESULTS FROM AN ARABIAN HEAT LOW

BOUNDARY LAYER EXPERIMENT

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INTRODUCTION

We have initiated an investigation of the radiative and thermodynamic structure of the Arabian Peninsula Heat Low that develops prior to the onset of the Southwest Summer Monsoon. In addition we are examining the role of this thermal low feature in the context of the Southwest Monsoon system. We utilize measurements from satellite, the Convair-990 experiment aircraft, and a specialized surface station to analyze the energetics of the heat low. The measurement configuration scheme is schematically illustrated in Figure 1. The surface measurements which are reported here were made possible through the cooperation of the Faculty of Meteorology and Environmental Science, King Abdul-Aziz University, and the Saudi Arabian Ministry of Defense. The results presented in this brief abstract should be considered preliminary.

DESCRIPTION OF THE ARABIAN HEAT LOW

The salient features of the Springtime Arabian Heat Low are illustrated in Figure 2. Part "a" shows the surface temperature field that develops over southern Arabia prior to monsoon onset; these are surface temperature contours derived from a 10-day average of TIROS-N 11-micron window measurements over the monsoon region. Part "b", from van de Boogaard (1977), indicates the response in the pressure field due to the intense surface heating. Part "c", from Ramage and Raman (1972), then shows the dynamical response in the near surface wind field, i.e. a shallow surface cyclonic vortex associated with an upward vertical motion field. Blake, et al. (1981), have described the daytime and nighttime vertical temperature structure and vertical motion/divergence profiles associated with the heat low (during May 1979) based on the CV-990 dropsonde data. Their results indicate a deep well mixed layer over the Arabian Empty Quarter (Rub-al-Khali Desert) extending to nearly 500 mb. The daytime vertical velocity profile indicates shallow upward motion up to 850 mb capped by a deep subsidence layer extending to nearly 100 mb. During the nighttime period the shallow upward vertical velocity layer is supressed or destroyed.

SURFACE ENERGY BUDGET

During the 1981 pre-monsoon/monsoon onset period we were able to deploy a specialized surface boundary layer station in the Saudi Arabian Empty Quarter near the village of Sharouwrah. This system which is equipped with shortwave and longwave flux radiometers, soil probes, and sensors used to monitor the wind and state parameters, is schematically illustrated in Figure 3. From this measurement station we were able to derive the various components of the surface energy budget (radiative exchange, storage, and sensible heat exchange). We have illustrated the daily averaged values of these parameters for the month of June, 1981 in Figure 4. It is pointed out that although the diurnal variation of the soil (sand) storage term is excessive, the mean daily magnitude is very small. Thus the required sensible heat exchange is nearly a reflection of the total net radiation term. A thorough description of the data system and the data sets is given in Smith, et al. (1981).

Superimposed on the energy budget are some rather interesting regional phenomena that we can only describe briefly here. First there is a surprisingly large difference in the visible and mean infrared reflectance of the Empty Quarter sand (22% vs. 55%). This leads to an enhanced solar albedo at the surface. The second phenomena consists of a negative feedback process which is manifested in the surface energy budget. During times when the thermal low intensifies, e.g. a zero solar zenith period, the strong daytime pressure gradient directed toward the thermal low center is sustained long enough to pump in moisture from the south (South Yemen, Indian Ocean). This moistening process in turn interacts with near-infrared radiative exchange and perturbs the nearly uniform energy exchange process, ultimately supressing the sensible heat exchange term. This is seen in Figure 4 at the point marked with an "x".

CONCLUSIONS

If we combine these results with representative vertical radiative heating rates over the heat low region, we can give a simple physical description of the heat low structure. The vertical radiative heating rate profile, shown in Figure 5 from Ackerman and Cox (1981), shows an anomolously thick layer of daily mean total radiative heating due to the presence of the deep layer of dust (aerosol) resulting from the unstable lower boundary layer.

Figure 6 illustrates our physical interpretation of the Arabian thermal low as we now understand it. We divide the atmosphere into three distinct layers: (1) an upper region where radiative cooling balances subsidence warming; (2) a middle region which both radiatively and slightly adiabatically heats, but in which dry convection must maintain the nearly mixed layer properties and the associated dust layer; and (3) a lower layer in which sensible heating from the surface overcomes radiative cooling. The surface sensible heat exchange can be parameterized very reasonably by $-Q^*$ (the net total radiation term). Finally the surface albedo includes an enhanced near-infrared component due to an iron constituent in the Empty Quarter sand grains.

The Arabian Heat Low may play a significant role in the maintenance of the Southwest Monsoon. The energy budget requires an energy transport mechanism to evacuate the net heating over the desert. Our premise is that the excess heat is transported laterally over the Western Arabian Sea where it serves to maintain the boundary layer thermal inversion evident in that region. This inversion plays an important role in trapping moisture near the level of the East African jet which in turn allows the jet to transport moisture into the Indian Sub-continent. This would suggest that the West Arabian Sea thermal inversion involves air mass dynamics rather than just being maintained through subsidence (see also Sen and Das, 1980). These latter points are illustrated in Figure 7.

ACKNOWLEDGEMENTS

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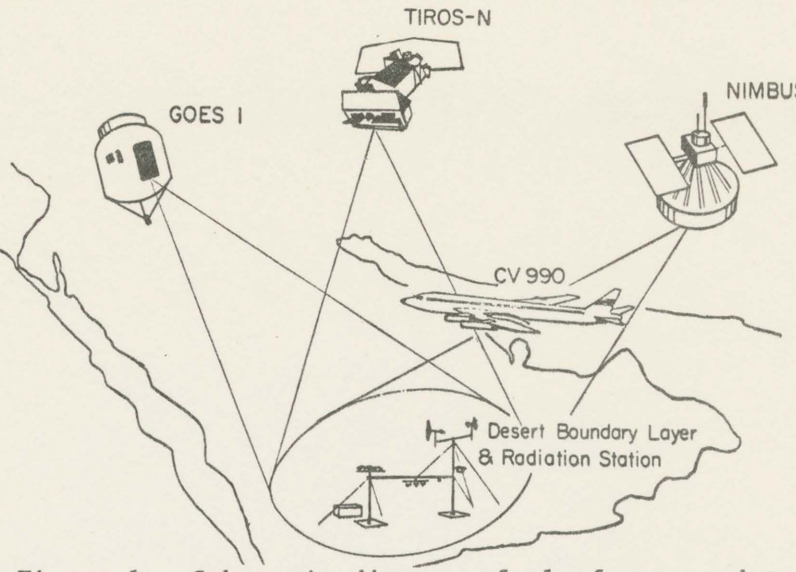

Figure 1: Schematic diagram of platforms used to study the Arabian Heat Low.

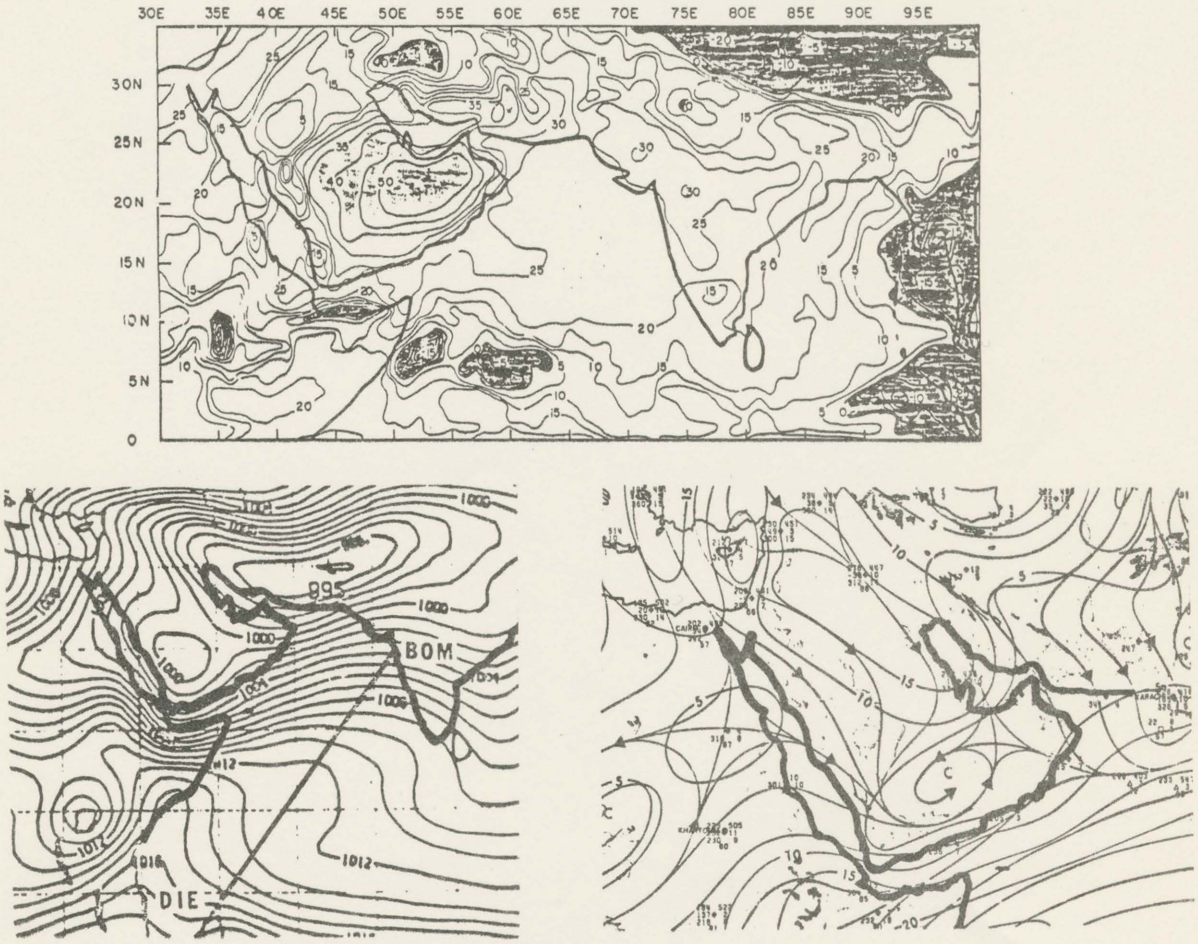

Figure 2: Salient features of the Arabian Heat Low.
(a) Top; satellite derived (TIROS-N) daytime surface temperature field.
(b) Bottom left; July mean surface pressure field.
(c) Bottom right; July 850 mb circulation (Ramage and Ramain, 1972).

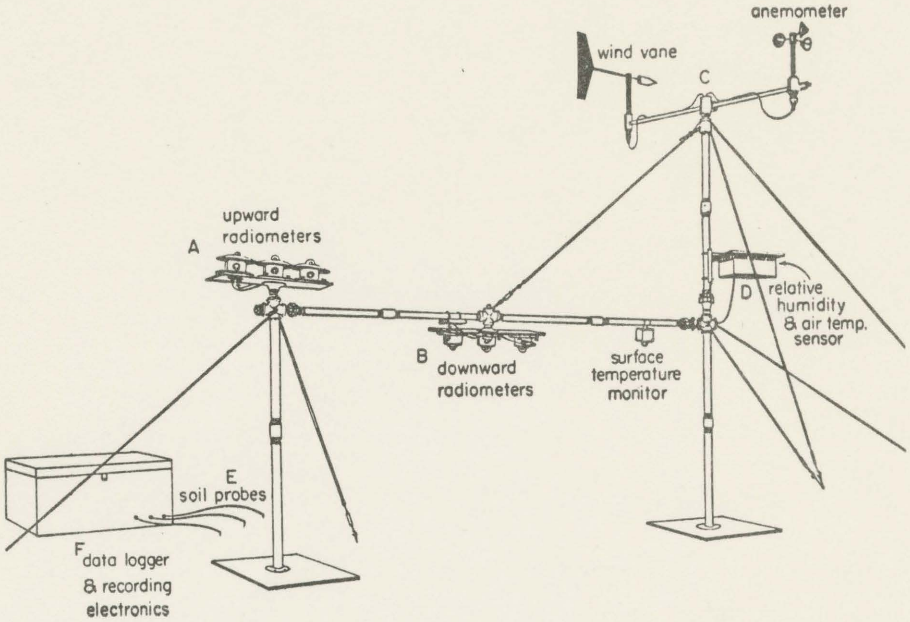

Figure 3: Schematic of Radiative Boundary Layer Station.

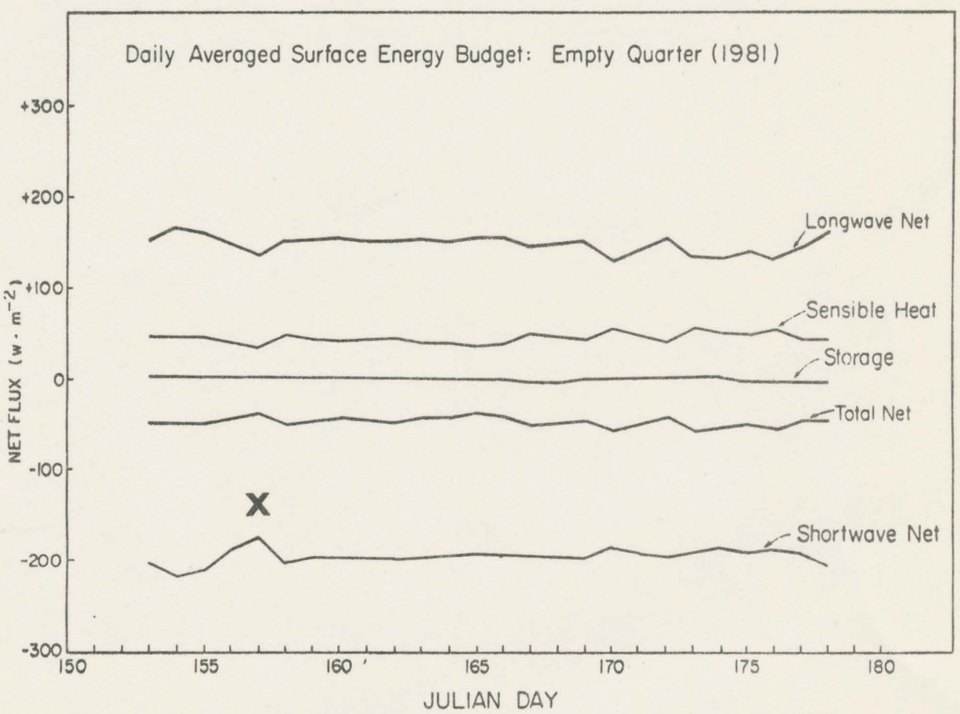

Figure 4: Surface Energy Budget of the Arabian Heat Low (June Daily Averages).

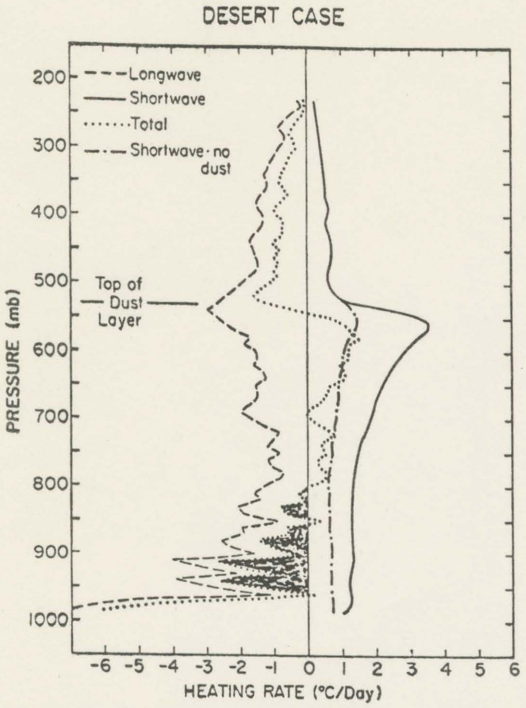

Figure 5: Daily Averaged Radiative Heating Rate of the Arabian Heat Low.

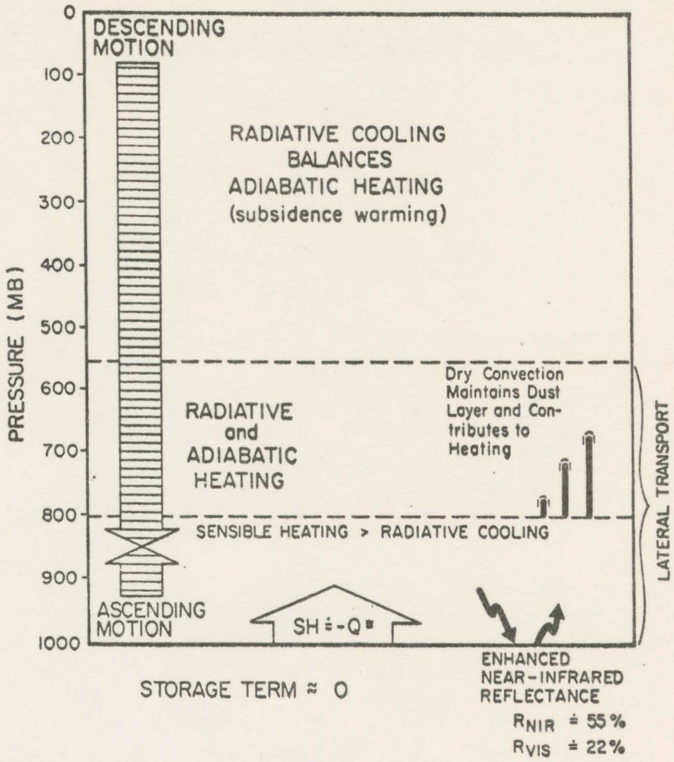

Figure 6: Structure of the Arabian Heat Low.

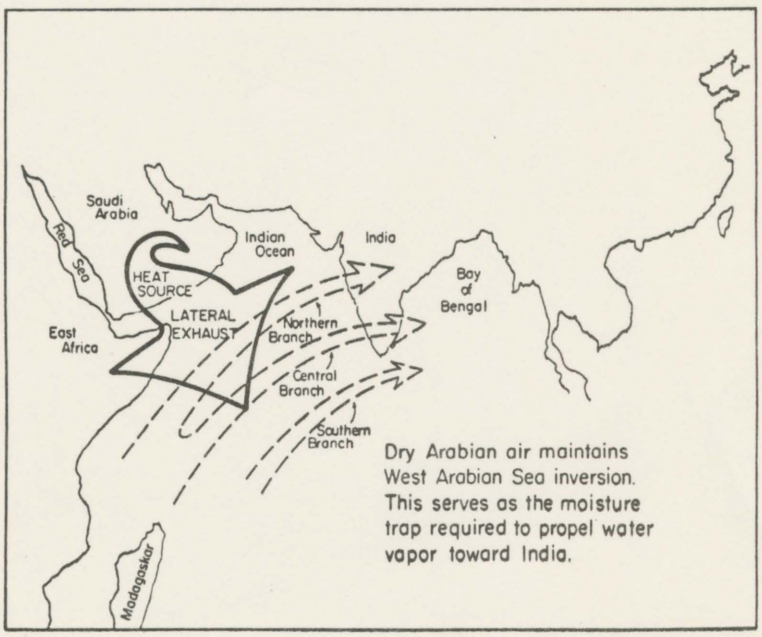

Figure 7: Role of the Arabian Heat Low in the Southwest Monsoon System.

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A Continuing Investigation of the Arabian Peninsula Heat Low

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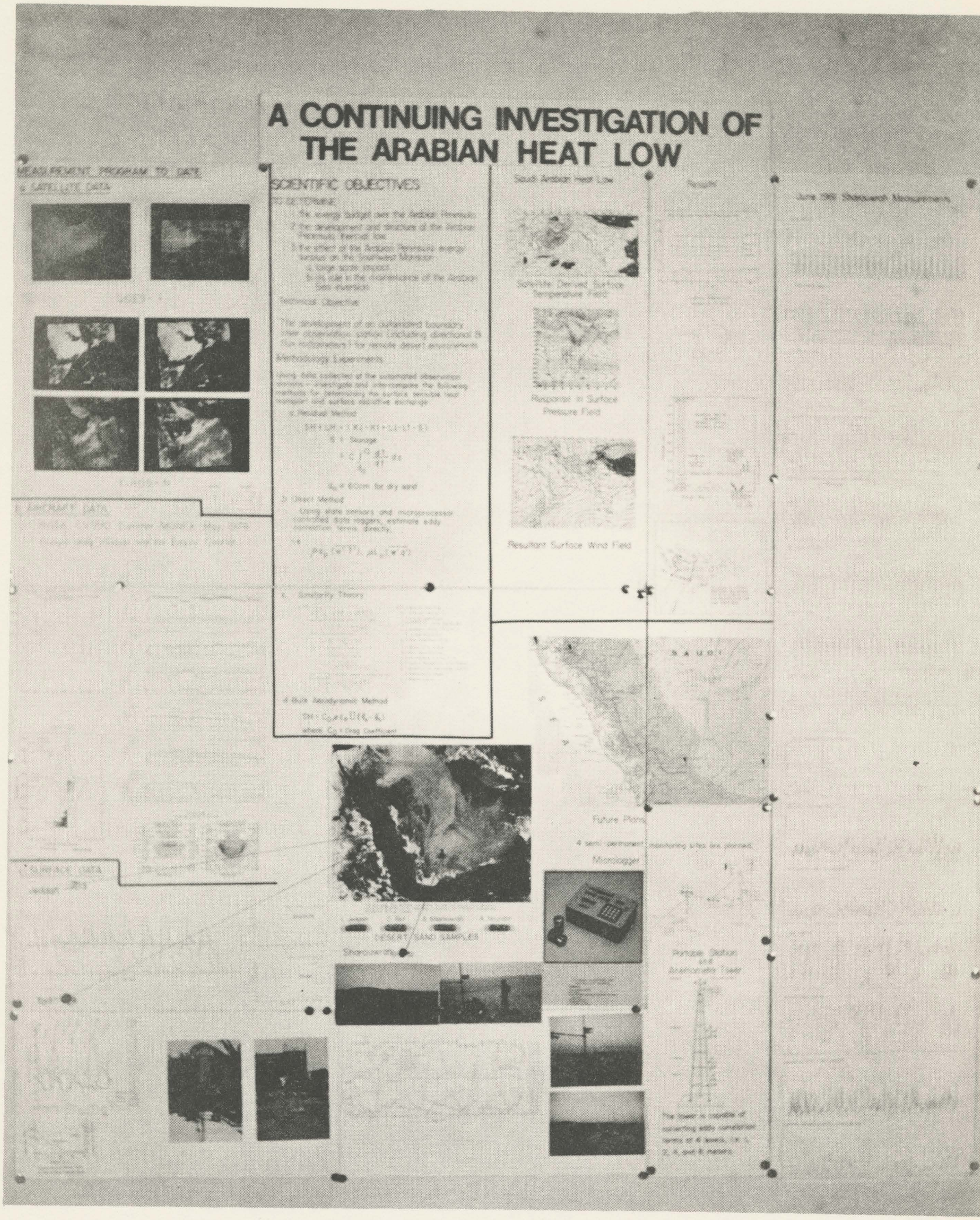

Plate 1: Full view of the poster.

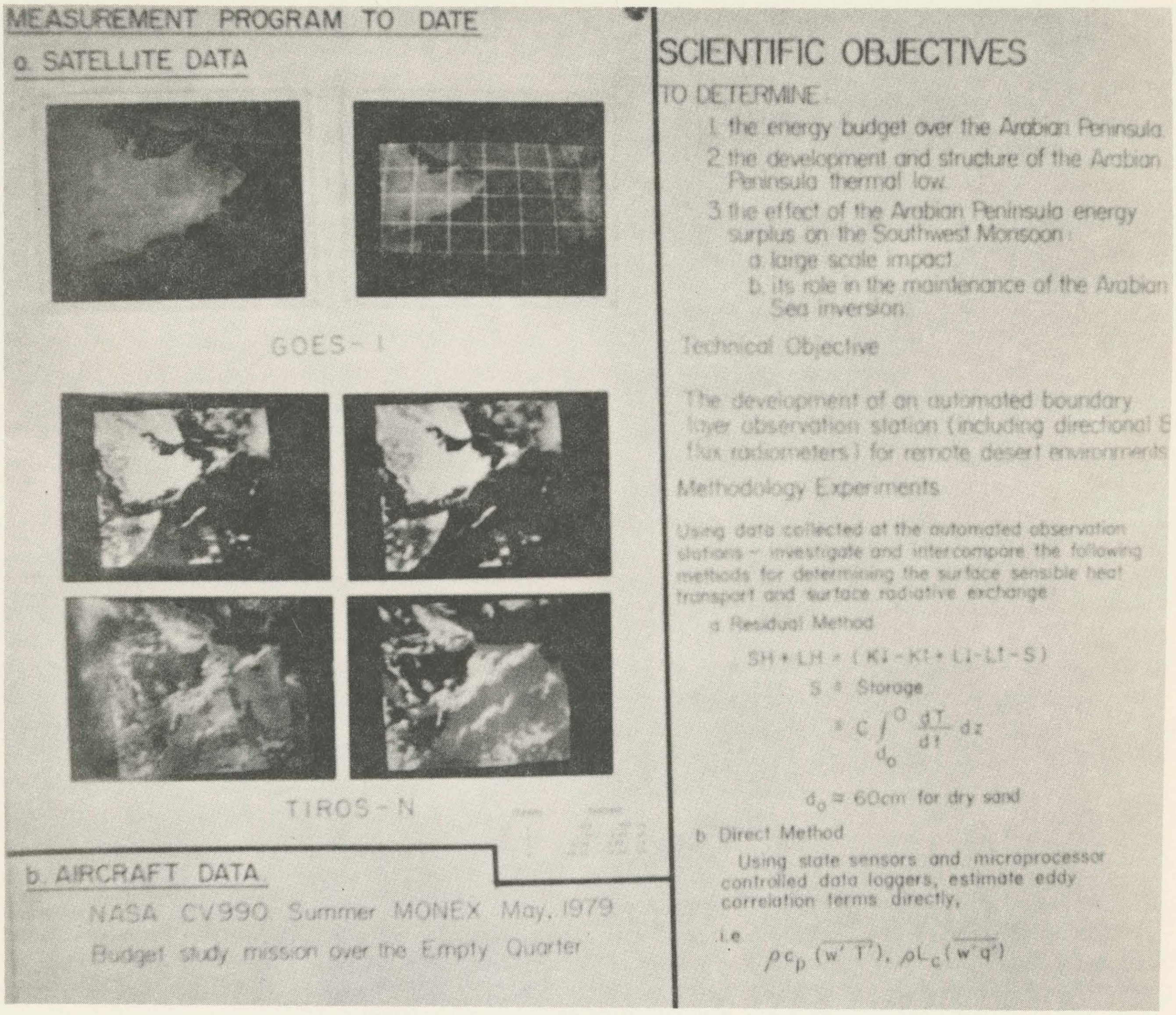

Plate 2: Upper left hand quadrant.

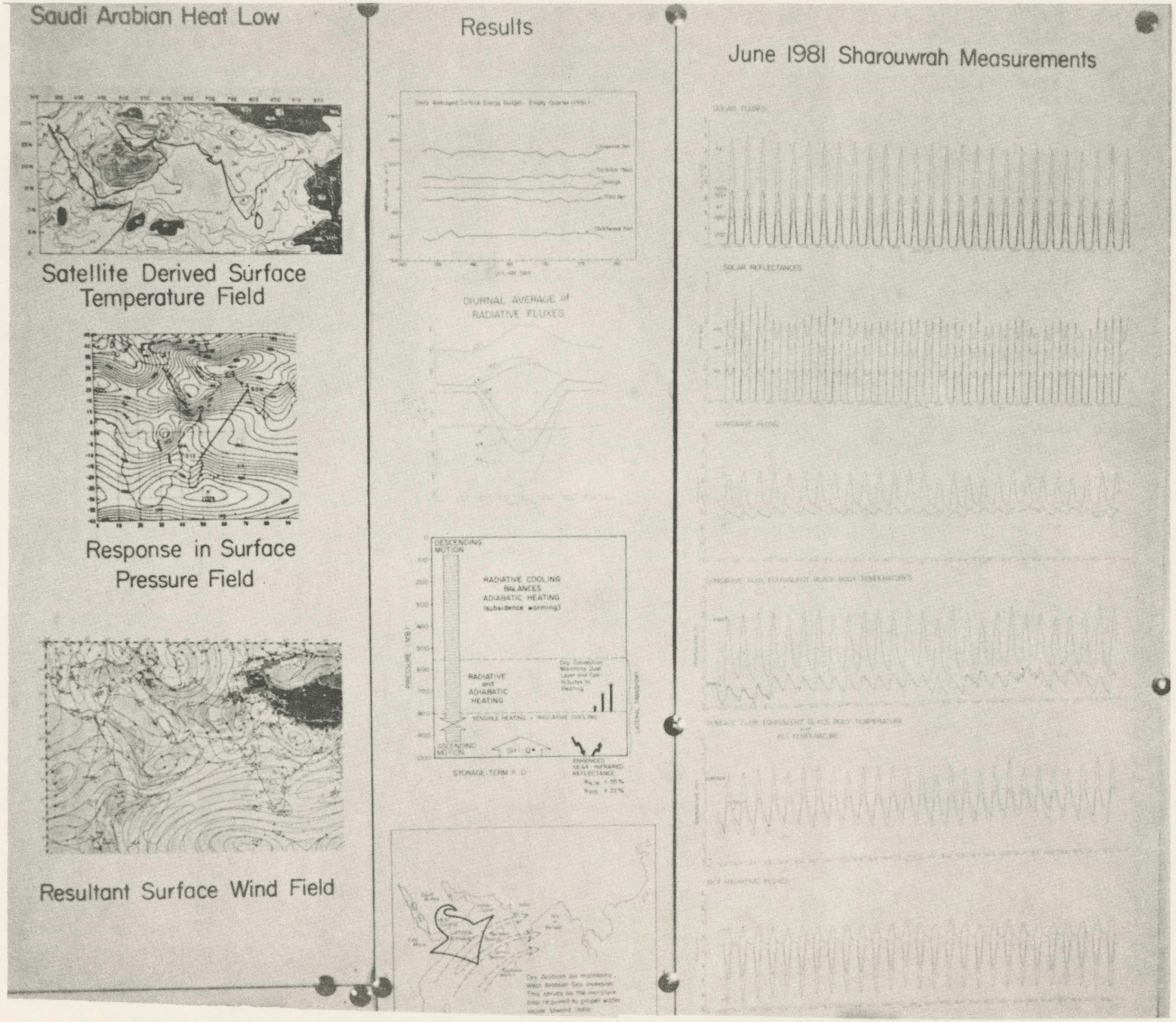

Plate 3: Upper right hand quadrant.

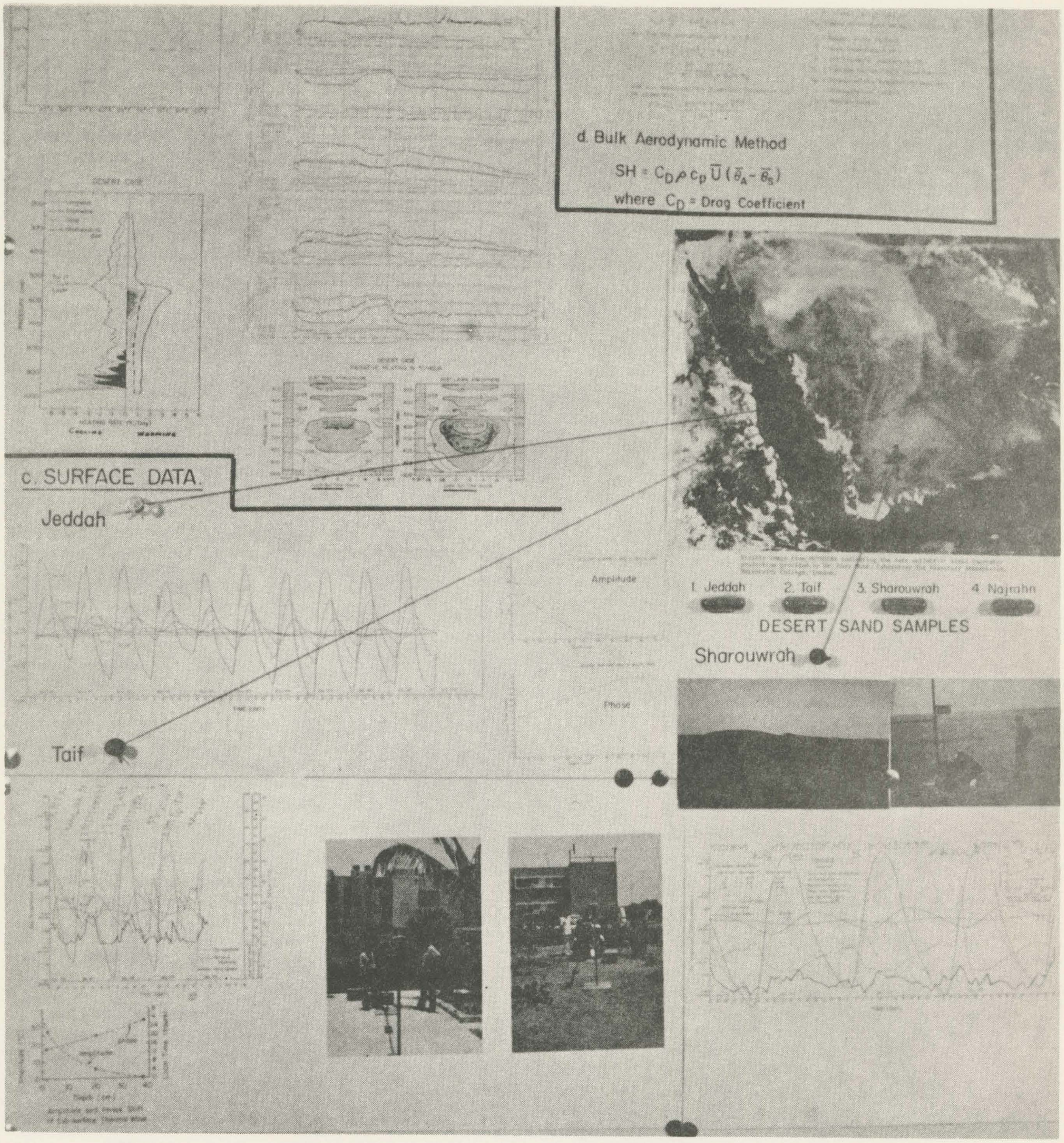

Plate 4: Lower left hand quadrant.

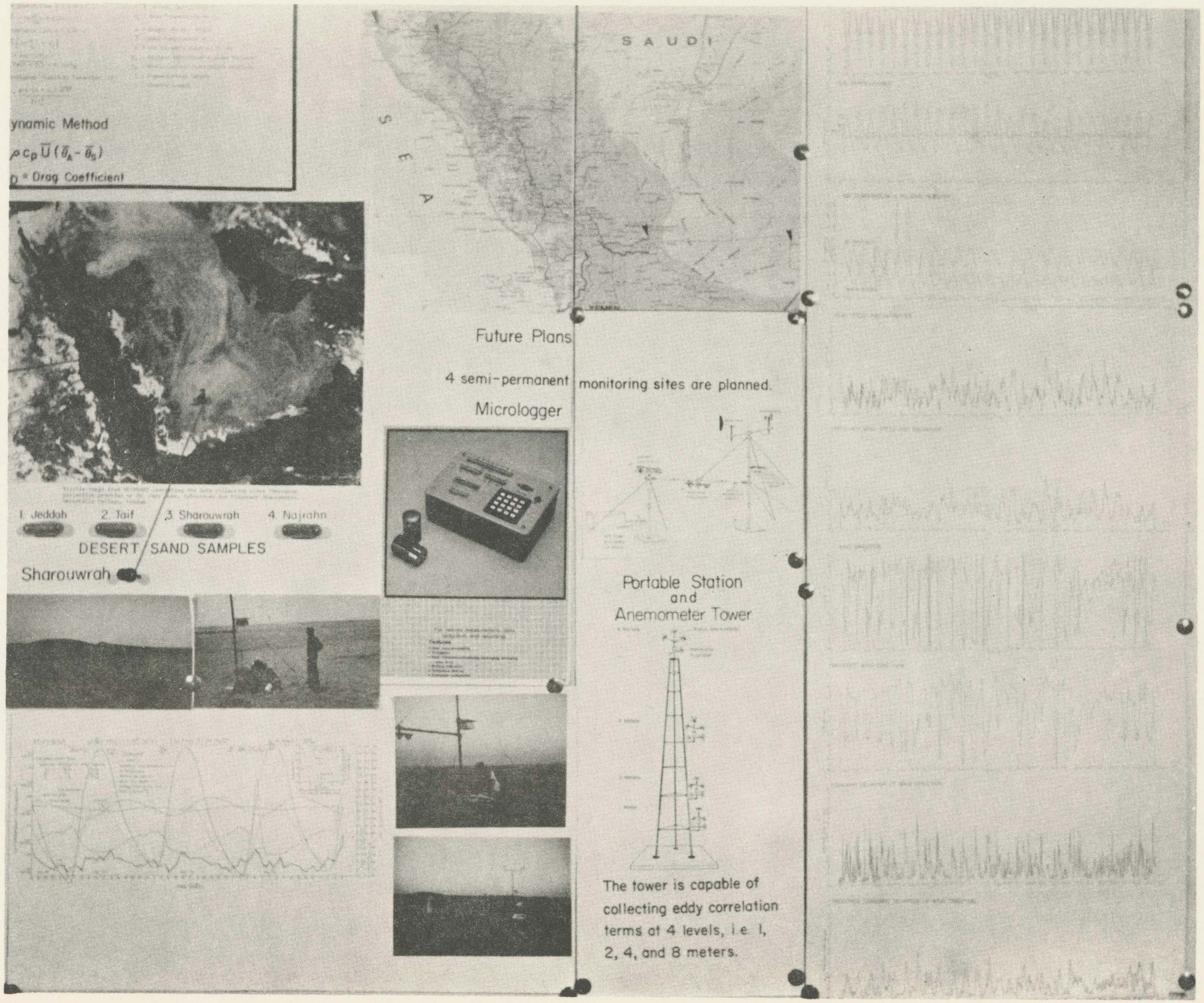

Plate 5: Lower right hand quadrant.