SECOND PROGRESS REPORT ON SATELLITE APPLICATIONS TO SNOW HYDROLOGY

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ABSTRACT

Improvements in the state of the art in meteorological satellite technology, present contractual studies, proposed methods of obtaining hydrological data from satellites and results of recent studies indicate that an up-dating of material presented at the February, 1963 Eastern Snow Confrerence would be useful and informative. Of special interest are Nimbus and TIROS meteorological satellite observations of snow cover over mountains in western North America and arrangements to study methods of mapping snow cover in major midwestern river drainage basins using satellite photography. Compatibility between present requirements to observe snow cover and past, present and future satellite capabilities to fulfill these requirements is examined.

INTRODUCTION

At the February, 1963 meeting of the Eastern Snow Conference, a progress report(1) on snow and ice observations from TIROS meteorological satellites was presented. In that report major emphasis was placed on discussing programs being conducted to develop a satellite ice reconnaissance capability. Part of that report also dealt with the problems of distinguishing clouds against ice and snow backgrounds. The report was illustrated with TIROS photographs of ice in Canada east coast waters, and snow cover on mountainous areas of the western U.S. and mid-western Canada. The principal conclusion to be drawn from that presentation was that satellites undoubtedly could be used to observe snow cover, but that very little effort had been expended to explore this possibility in depth.

Since that report was presented, 6 additional meteorological satellites have been launched, one of these being the polar-orbiting Nimbus R&D satellite. A contract to determine how accurately snow boundaries could be mapped from satellite photographs has been awarded; two independent semi-operational programs to map snow cover from satellite pictures of the western and mid-western U.S. are being conducted; a number of papers dealing with the interpretation of snow features seen from satellite altitudes have been presented, and a comprehensive program to determine how both manned and unmanned space vehicles might be used to complement conventional hydrologic observing methods is currently being undertaken.

(Presented at the Eastern Snow Conference, Hartford, Conn., Feb.10-11,1966)

One of the major reasons for the greater emphasis on studying satellite applications to hydrology has been the closer working relationship developed in recent months between the Weather Bureau's hydrologists and the National Environmental Satellite Center's satellite meteorologists and technologists. This has led to a much better understanding of the problems and technical capabilities and limitations of both agencies. In this present paper, we discuss what some of the hydrologic problems are as they have been made known to us, then illustrate with satellite photographs those areas where evidence has been collected to indicate that satellites can provide at least a partial solution to some of these problems. Also discussed are areas of applied research in satellite snow surveillance techniques, and a brief review of proposed instrumentation or observation techniques which might be applied to these problems.

APPLIED STUDIES AND PROJECTS

In forecasting streamflow, and in determining hydrologic design criteria, it is necessary to know whether a snow cover exists during melting conditions, whether rain is falling on snow or bare ground, and, in remote areas, whether precipitation has occurred as rain or snow. It is rather easy to identify new snow on bare ground in TIROS photographs; more important, perhaps, is the fact that rain on snow-covered surfaces has also been identified, as shown in Fig. 1. This TIROS VII photograph of the northeastern U. S. was taken in March 1963. Moderate rainfall in the hours preceding the time of this photograph has completely depleted what little snow remained in the area just west of Cape Cod and along the Atlantic coast. Further inland, six inches of snow were still reported on the ground, yet the area is very dark, due to the low albedo resulting from rain falling on the snowpack.

In contrast, areas where little or no rain has fallen normally appear considerably brighter, but not as bright as new snow, thick ice, or even certain cloud types. A good example of this is shown in figure 2, where thick ice near the eastern end of Lake Erie appears considerably brighter than the surrounding snow-covered land. Because of this difference in brightness, and the time of the year (April), we inferred that we were viewing an area of "old" snow. An investigation of the weather situation for several days preceding the date of this photograph indicated that relatively clear skies and temperatures in the upper thirties and low forties have prevailed. Under such conditions one would normally expect that the snow would have a lower albedo than fresh snow. However, the importance of this observation is not that we can tell the hydrologist that snow cover in this particular area appears "wet"--this he can deduce from synoptic reports. The importance lies chiefly in the fact that we can tell him when and where wet snow exists in areas where the data network is too sparse to provide adequate synoptic coverage.

In addition to rain on snow and differences in old and new snow, Conover (2) suggests that we can also tell the difference between wet

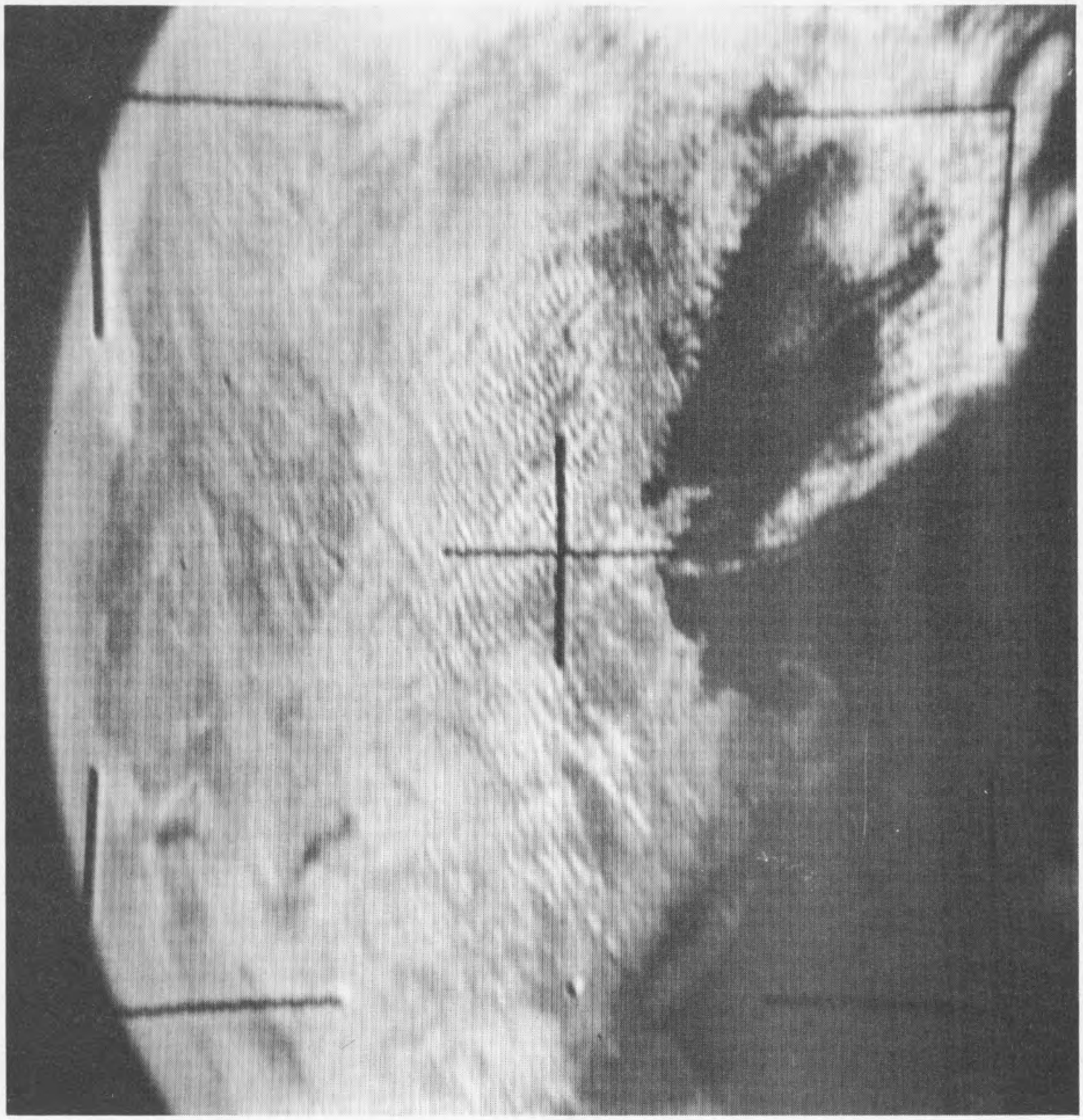

Fig. 1.

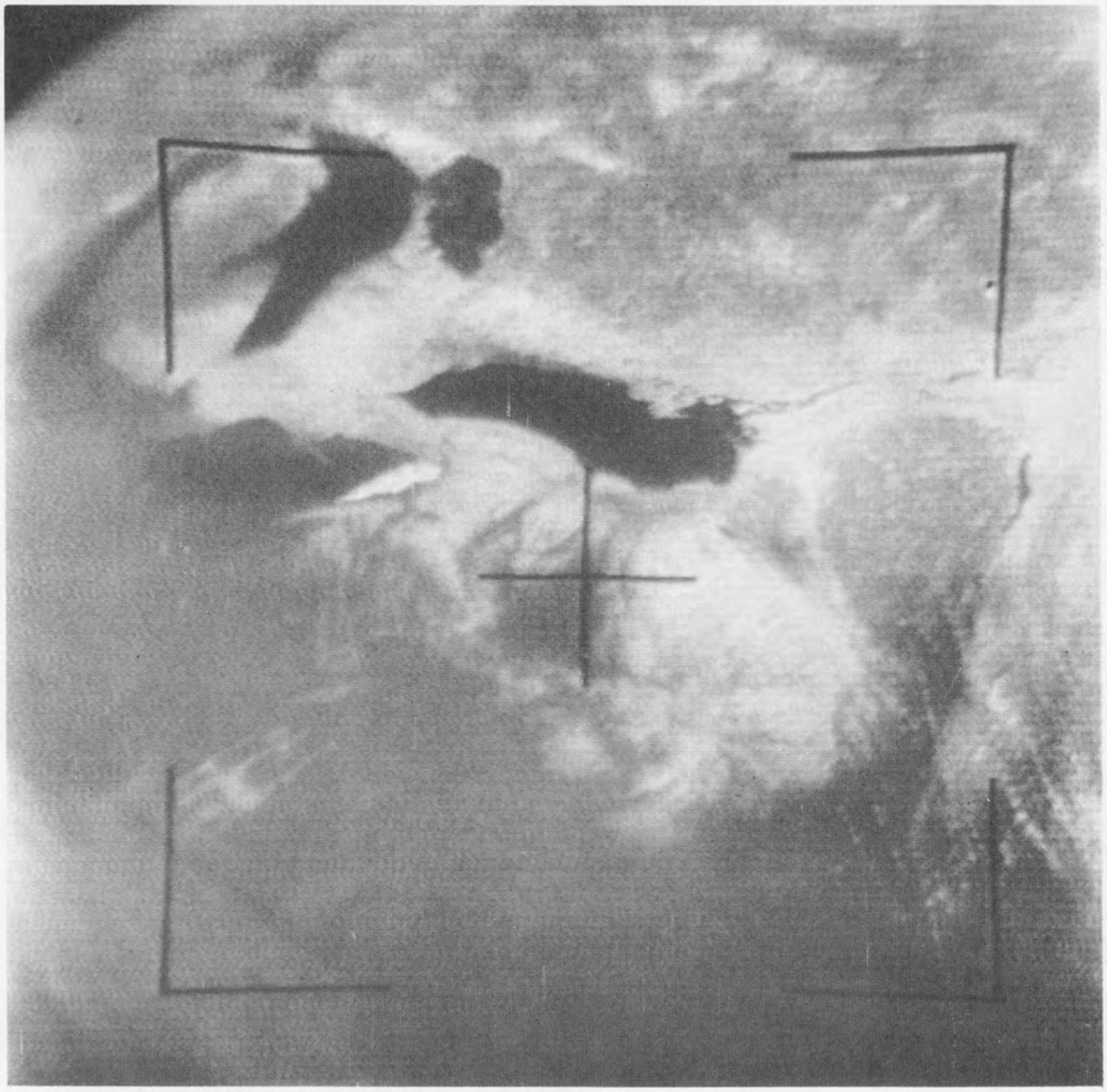

Fig. 2.

and dry snowfalls in satellite photography by observing the effects produced in certain forested areas. The branches of trees in coniferous forests tend to retain wet snow for a period of time, while dry snow, particularly with even a light wind, would tend to be distributed on the forest floor; the area would therefore appear darker than in the case of a wet snowfall.

In order to make practical use of satellite snow cover photography we need first to be able to delineate snow boundaries. A contract was recently awarded to ARACON to study satellite photography of the Missisippi and Missouri River drainage basin areas, to develop satellite snow mapping techniques, and to determine mapping accuracy. From this we also hope to discover features which might be used either directly or indirectly to estimate snow depth or to infer other significant characteristics of the snow pack, and to make recommendations for future spacecraft instrumentation necessary to develop a full-time operational satellite snow surveillance capability. Fig. 3 is a TIROS VIII picture taken in March 1964 showing a rather typical example of the type of photography obtained during periods of extensive snow cover in this region. The dark line just to the left of the center is that portion of the Mississippi which forms the state boundary between Iowa and Illinois.

Forecasts of volume of run-off from seasonally melting snow are made for approximately 400 points in the northeastern and western U. S. where irrigation, municipal and industrial supplies, and hydroelectric operations require knowledge months in advance of the volume of water expected for the coming season. Of the total forecast service provided by Weather Bureau hydrologists, approximately 20% is directed toward water supply forecasting. Since much of next season's water is stored as snow in the higher elevations, observations of snow amount and extent are essential. The present network of regular reporting stations is too sparse to give good areal snow coverage in many regions, even when supplemented by ground surveys and aircraft reconnaissance.

In April 1965, TIROS VII photographs (Fig. 4) of the Colorado-New Mexico region were forwarded on a semi-operational basis to the Weather Bureau Airport Station at Albuquerque, New Mexico, as an aid in determining the extent of snow cover in mountainous regions in these states. The particular geography of these mountains, the relative persistence of daytime cumulus, the short-time period of available photography--three weeks--and picture resolution precluded drawing any valid conclusions from this study. The mountainous areas to the north, in southern Montana, Wyoming and Idaho seems more amenable to studies of this type; individual mountain ranges are more readily identifiable, even under extensive cloud conditions.

However, while no studies of this northern area have been conducted, a program similar to the one carried on with WBAS Albuquerque--one with similar objectives in mind--is currently being conducted with the Weather Bureau River Forecast Centers in Sacramento, California, and Portland,

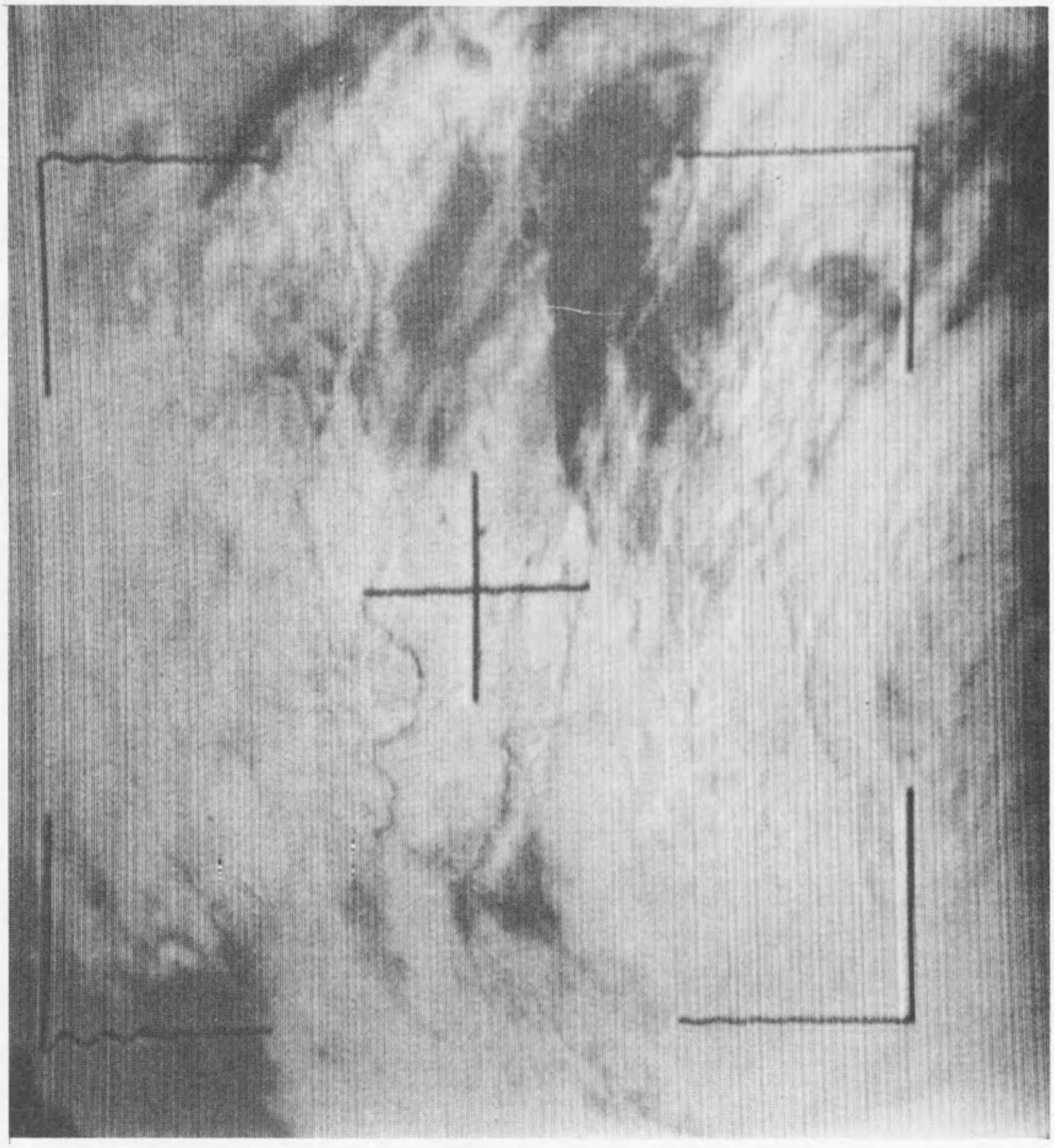

Fig. 3.

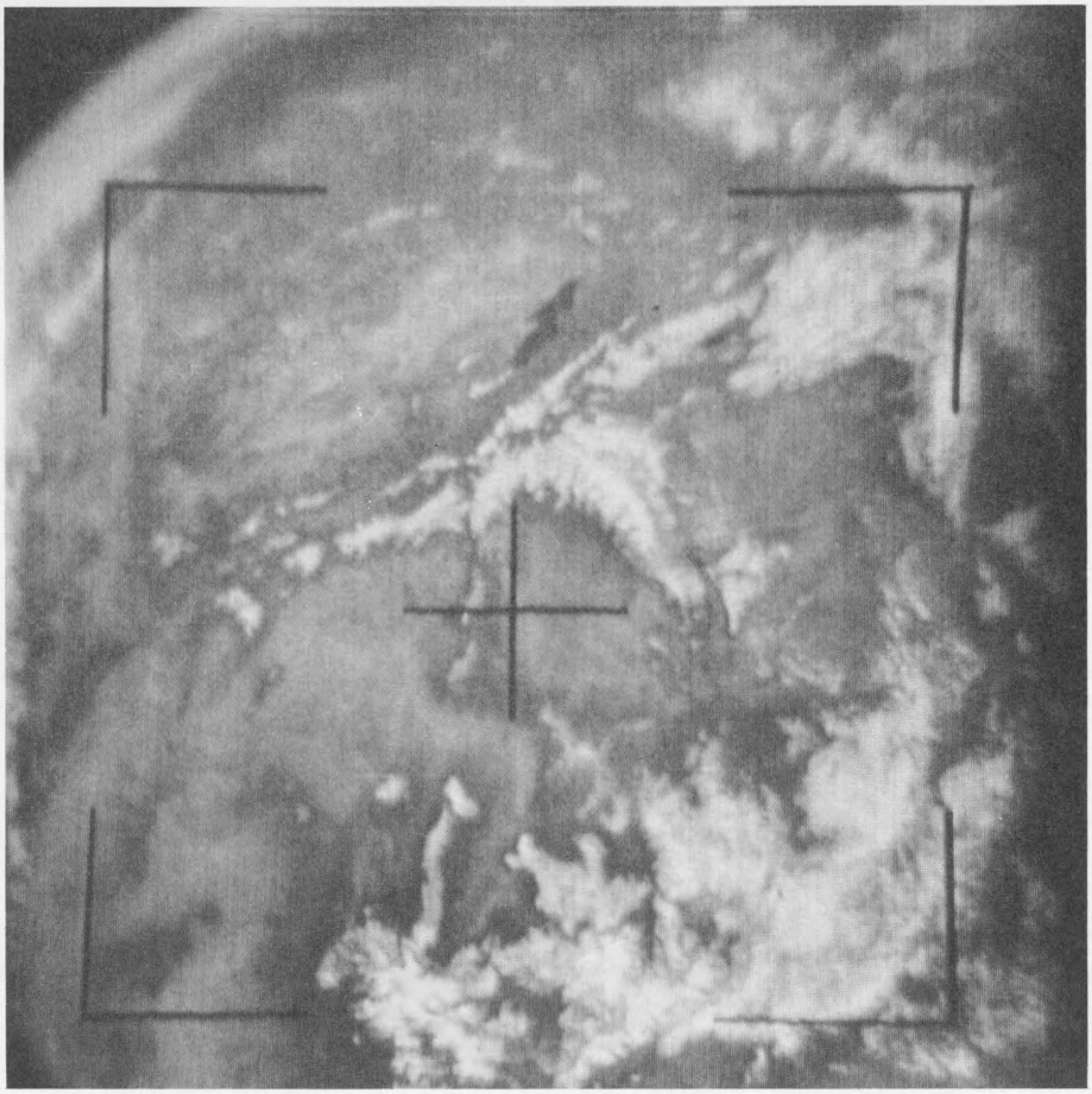

Fig. 4.

Oregon, using TIROS X photography. The recently-launched ESSA I satellite should prove extremely useful for this study. This satellite is in a quasi-polar orbit, at an average altitude of 420 miles, and is producing high-quality, vertical photography (at points directly below the satellite) over most of the earth on a continuous daily basis.

The TIROS IV photograph in Fig. 5, was taken in April 1962, and shows snow cover on the Sierras in California. Four large lakes--Mono, Walker, Tahoe and Pyramid--are readily visible. While such photographs do tell us something about snow distribution in the mountains, a much finer delineation of snow features can be accomplished using the higher quality Nimbus photographs, such as that shown in Fig. 6. The detail in these Nimbus pictures is so good that there is almost no doubt that such imagery, when obtained on a continuous basis, would play a major role in complementing conventional air and ground observations of snow pack boundaries. Unfortunately, Nimbus I ceased transmitting pictures on September 22, 1964 only 25 days after launch, thus precluding the development of an operational satellite snow surveillance program. Three additional Nimbus vehicles are presently scheduled for launch, however, the next one sometime during the middle of this year.

FUTURE POSSIBILITIES

Both the TIROS-type (ESSA) and Nimbus satellites, as well as other space vehicles will carry on-board experiments which may be applicable to satellite hydrologic investigations. One proposed system is an image orthicon camera capable of taking pictures by starlight. This offers one possible solution for avoiding daytime cumulus and the associated cloud-snow discrimination problem. Other camera systems which would also be applicable include a high-resolution image dissector and the metric camera, the latter already scheduled for use as part of NASA's Lunar Mapping Program. High resolution infrared imagery such as that obtained from Nimbus I still appears too coarse to have immediate practical applications to snow hydrology, but there is no doubt that more sophisticated IR instrumentation will be developed. The use of pattern recognition devices, such as the MINOS[3], as well as numerical methods of scanning and interpreting satellite imagery, may prove to be useful--and perhaps essential, considering the amount of data available from satellite systems-- for mapping snow covered areas.

Of more immediate interest perhaps is the possibility of complementing the present network of hydrologic stations with surface-based equipment capable of directly measuring hydrologic parameters and transmitting this information to an earth-synchronous satellite. The information from many of these remote stations would be telemetered upon command to a single ground receiving station for analysis. An experiment to test the feasibility of this method of data collection will be tested later

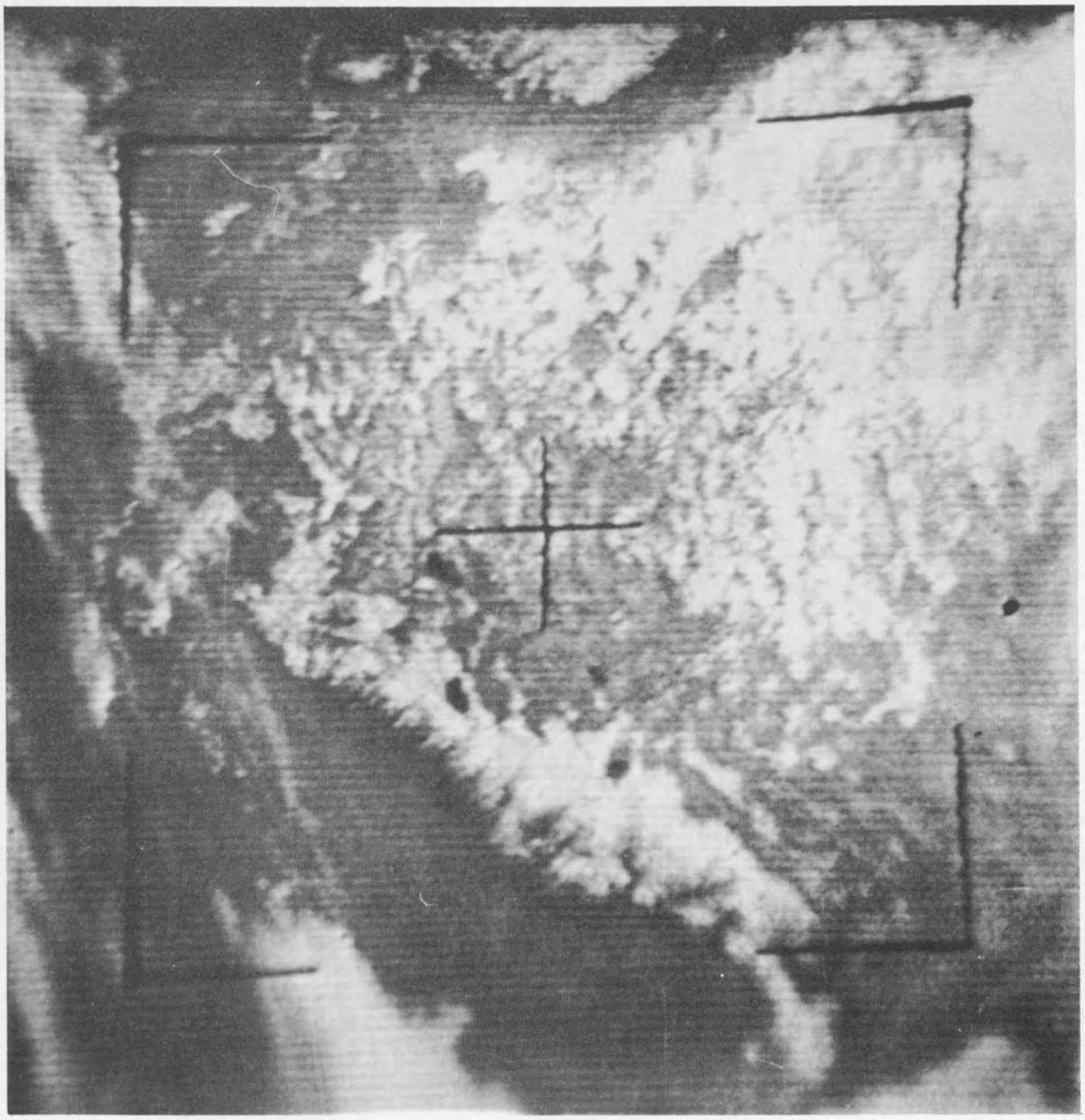

Fig. 5.

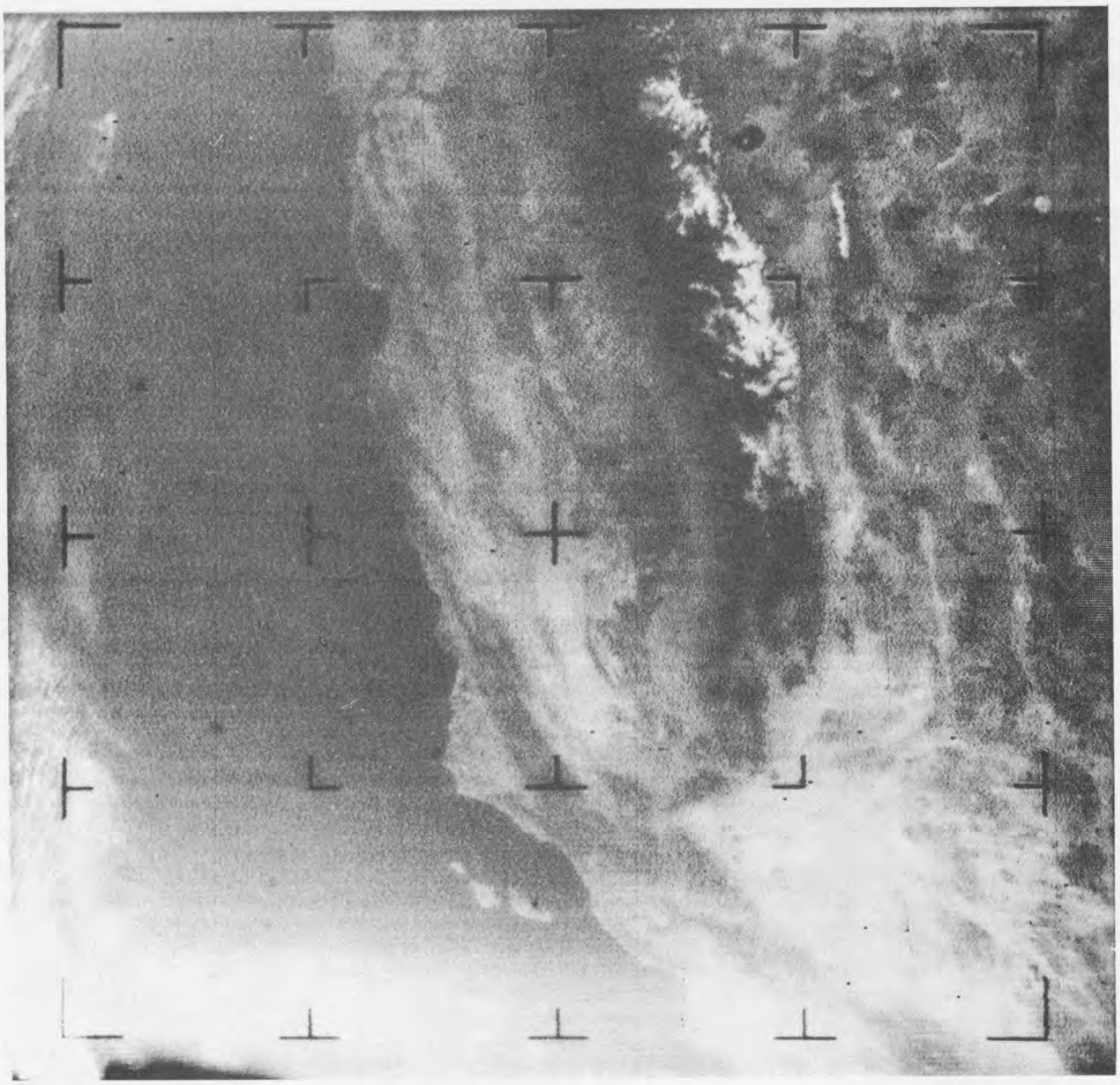

Fig. 6.

this year or early next year using an advanced technological satellite.

With the development of larger boosters, such as the Saturn launch vehicle, heavier payloads and more sophisticated instrumentation can be placed in space for studying the earth and its environment. With the advent of man in space we have the opportunity to be more selective in our choice of the type, quantity, quality and area of our investigations.

The pre-lunar landing phase of the Apollo program includes 27 flights of the Saturn launch vehicle, and at least one of these, sometime in early or mid-1968, will include a 14-day polar orbit mission. In this, as in some of the earlier missions, the astronauts will be able to work in an essentially shirt-sleeve environment, making it easier for them to conduct the many experiments which they will be asked to make.

The mission profile for this mission has not been completely defined at this time, but we hope to have on-board experiments to photographs snow cover over North America for comparison with observations from unmanned vehicles in orbit at that time. This experiment would be part of the Apollo Applications Program, a plan to study the application of potential launch capabilities beyond Saturn requirements for the initial Apollo lunar landings.

SUMMARY

It is hoped that this report has imparted a clear impression that the science of hydrology is not being ignored, but is in fact being given greater emphasis in the design of space programs. This has had the additional benefit that publicity related toward space applications to hydrology has helped make scientists in many other fields, as well as the public in general, much more conscious of water supply forecasting, conservation and management of water resource problems than ever before in the long history of this science. However, it is essential that present research in the use of conventional techniques be continued, and perhaps expanded, if we are going to be able to practically apply the volume of data that will be available from such global observation platforms.

REFERENCES

1. Popham, R.W., "Progress Report on Snow and Ice Observations from TIROS Satellites," Proceedings, Eastern Snow Conference, February, 1963.

2. Conover, J.H., "Note on the Flora and Snow Cover Distributions Affecting the Appearance of Northeastern United States As Photographed by TIROS Satellites," Monthly Weather Review, Vol.93,Number 10,October 1965.

3. ______________, "MINOS II-A Trainable Pattern-Recognizing Machine," Stanford Research Institute Journal, pp. 6-9, 1965.