

METEOROLOGICAL SUPPORT FOR REMOTE SENSING PROGRAMS

James L. Cox

NOAA/NWS
Spaceflight Meteorology Group
Camp Springs, Maryland

ABSTRACT

Many earth-oriented remote sensing spacecraft and aircraft programs are affected by the presence of clouds. Like aerial photography, they require clear or mostly clear skies. To cope with the cloud problem, the National Weather Service through its Spaceflight Meteorology Group (SMG) of the Space Operations Support Division makes cloud cover forecasts, as part of its specialized weather service for various NASA remote sensing and other programs. Forecasting requirements vary in time from a few hours out to several days and in areal extent from a particular locality to nearly global in coverage. Depending on the stage of program development, some remote sensing programs may involve special climatological studies for planning purposes or need ground-truth data for comparison with remotely sensed information.

This paper will discuss briefly the importance of computer and weather satellite products to the SMG meteorologist and describe the nature of SMG's weather support of past, present, and future remote sensing programs. Hopefully, as a result of this paper you will agree that when the weather forecaster is an active participant in specific programs, the chances of success are greatly improved.

1. INTRODUCTION

Remote sensing programs differ greatly as to sensors used; i.e., cameras, microwave radiometers, multispectral scanners, laser profilers, scatterometers, etc.. A program may involve a single sensor or a combination of sensors. The purposes of the many programs are even more varied than the kinds of sensors involved. Yet, regardless of the diversity in sensor types and program objectives, there is a common factor - the weather, which in some way affects all of them. The presence of clouds interferes with many earth-oriented remote sensing programs from spacecraft and aircraft. Usually, clear or mostly clear viewing conditions are required. Aerial photography, of course, is a very old example of an operation which required clear skies and good visibilities.

To cope with the cloud problem, the Spaceflight Meteorology Group (SMG) makes cloud cover forecasts in support of various NASA remote sensing and other programs. Forecasting requirements vary in time and areal extent; in time, from a few hours out to 5 or 6 days and in areal extent, from a specific locality to almost worldwide coverage.

Since 1960 the SMG has provided operational weather support for all NASA's manned space missions - Mercury, Gemini, Apollo, Skylab and the joint United States-Russian Apollo-Soyuz Test Project. Until 1972, when we began daily global cloud cover forecasts for the Earth Resources Technology Satellite (ERTS, now Landsat) Program, our experience with downward-viewing sensing experiments had been with those involving the Manned Space Program and related photography from NASA aircraft. The Landsat Program is an excellent example of how the meteorologist uses remotely sensed information from one program; namely, weather satellite cloud imagery, to support another remote sensing program - NASA's Earth Resources Program. With the launch of Landsat-C in September of this year, both daytime and nighttime global cloud cover forecasts will be required because of the added night sensing capability.

Of a different nature was our involvement in the Geodynamics Experimental Ocean Satellite Program (GEOS-3) and the Tropospheric Research Technology Operating Plan (TRTOP). For GEOS-3, conventionally derived sea state conditions - both those manually prepared and computer generated, were provided for comparison with the data obtained by the GEOS-3 radar altimeter. For TRTOP, satellite derived relative cloud cover climatology was used as an aid in selecting over 100 worldwide ground-truth monitoring sites, of which detailed cloud climatological statistics were prepared from standard weather summaries for some 60 of the initial sites.

Presently, other than the Landsat Program, SMG supports part of NASA's Airborne Instrumentation Research Program, which like Landsat involves experiments in almost every scientific discipline associated with the earth and its environment. Also SMG makes daily forecasts of various weather parameters for the Jet Propulsion Laboratory which is developing a weather model to provide near real-time predictions of weather induced X-band communication degradation at NASA Deep Space Network tracking stations in support of the forthcoming Mariner-Jupiter-Saturn '77 project.

Lastly, there is the upcoming Shuttle Era with six Orbital Flight Test missions to begin in 1979. On two of these missions earth viewing activities are planned and probably will require support similar to Skylab.

The above summation of SMG's participation in past, present, and future remote sensing programs serves to illustrate the diversity of the various programs and yet there is always the weather with which to contend. It is difficult to conceive how weather support for today's various remote sensing programs would be possible without the aid of modern computers and meteorological satellites. Lacking the information provided by these important tools, weather support for remote sensing programs, particularly those having nearly global requirements, would revert to little more than mere climatology for much of the world. Fortunately, developments in these areas have pretty much kept pace with the changing needs of the nation's manned and unmanned space programs during the 1960s and 1970s.

In what follows the importance of computer and meteorological satellite products to today's meteorologist will be discussed briefly and the nature of SMG's weather support for various remote sensing programs will be described.

2. IMPORTANCE OF COMPUTER AND METEOROLOGICAL SATELLITE PRODUCTS IN WEATHER SUPPORT OF REMOTE SENSING PROGRAMS

Before the development of electronic computers in the 1940s, weather forecasting was very much an "art" like the early days of flying when they flew by the "seat" of their pants. Forecasting skill was largely related to one's experience and based primarily on methods of short term extrapolation and recognition of weather patterns including historical knowledge of their most likely sequence of subsequent change. But, the development of the computer in the early 1940s changed all of that.

Electronic computers make it possible to use theoretical models of the actual atmosphere and after myriad mathematical computations, produce analyses and prognoses showing the present and future locations and development of pressure systems (and much other useful information) to aid the forecaster. The present global and hemispheric Primitive Equation models furnish forecast guidance with useful accuracy out to 5 or 6 days. One experimental model under evaluation shows some skill on forecasts out to 15 days.

Whereas, computer programs furnish the forecaster information on the movement and development of pressure systems, it is the meteorological satellite information in the form of cloud photographs that provides the most reliable depiction of the clouds and cloud systems. This fact was immediately apparent from cloud photographs taken by the first meteorological satellite (TIROS 1) launched in 1960.

Satellite cloud photographs are unique in that they provide pictorial representation of the integrated effects of the physical processes at work as evidenced in the clouds and cloud system. Such a perspective permits the meteorologist to deduce many important details regarding weather features of almost every scale as well as something about their interrelationships. In fact, meteorological satellite photographs provide the forecaster an overview and insight not possible by any other means. Many synoptic features, such as, cyclonic storms, fronts, jet streams, ridges, troughs, and vortices are often easily discernable and of great value in weather

analyses and short range forecasting.

Current NOAA polar orbiting satellites provide twice daily global coverage (about 9:00 a.m. and 9:00 p.m. local time). Satellite cloud depictions are particularly helpful in making weather analyses for approximately 70 percent of the earth's surface which has a very limited number of surface and upper air reports. Especially over the vast ocean areas of the Southern Hemisphere, about the only information available is the weather satellite depiction of polar storms and associated frontal systems, and of various tropical weather types. Even where many reports exist, the satellite views of the cloud and cloud systems reveal details which are not otherwise discernible.

Besides cloud imagery, NOAA polar orbiting satellites also obtain, by means of the vertical temperature profile radiometer (VTPR), profiles of temperature and moisture between the spacecraft and the ground. These VTPR soundings along with radiosonde and aircraft data are utilized in the computer models mentioned earlier which provide guidance regarding the movement and development of pressure systems.

In addition to the twice daily global satellite data available from NOAA polar orbiting spacecraft, NOAA GOES geostationary satellites provide 24 hour infrared and daytime visible coverage of North and South America and the adjacent ocean areas. Both GOES visible and infrared imagery are available as still pictures usually at 30 minute intervals and time lapse movie loops. In special situations such as tornado and hurricane conditions, the picture interval is reduced to 15 minutes. Cloud depiction from above gives a much better idea of where the significant weather is occurring. Movie loops enable the meteorologist to examine lower and upper level motions as revealed in the movement of clouds and cloud systems.

As important as computer and meteorological satellite products are in supporting remote sensing programs, you cannot eliminate the weatherman from the program when clouds and weather are a problem. The man-machine combination recognizes the fact that weather forecasting still has a high degree of "art" left in it. Generally, when the meteorologist is an active participant in specific programs, the chances of success are greatly improved. What follows describes the nature of SMG's involvement in past, current, and future remote sensing programs.

3. WEATHER SUPPORT FOR REMOTE SENSING PROGRAMS

The role of the meteorologist with regard to weather support for remote sensing programs varies greatly. It may involve premission planning, the RDTE phase, mission operations or postmission analysis. Mainly our work is operational support. In the Apollo Era of the U.S. Manned Space Program, SMG was involved in some aspect of all the different phases. Our participation in the Space Shuttle Program, as it unfolds, very likely will be similar to our role in Apollo. I would like to describe the nature of SMG's participation in several earth-sensing programs (manned and unmanned) to show how weather information can be used to accomplish specific program objectives.

3.1 U.S. Manned Space Programs

3.1.1 The Apollo Era - Mercury, Gemini, Apollo, Skylab, and Apollo/Soyuz

On July 1, 1960 the antecedent unit of what is now SMG was formed to provide weather support to NASA's Project Mercury. In the early Mercury days there was only partial global weather satellite coverage from TIROS-1, the first U.S. weather satellite launched on April 1, 1960. Computer barotropic atmospheric forecast models reached precariously out to 72 hours. In the Mercury program photography was mostly on a target-of-opportunity basis, although some forecasts were made for specific downward-viewing experiments. These forecasts were based upon climatology and on whatever weather satellite and conventional observations were available in the vicinity of the targets.

On the Gemini flights there was a number of experiments which required the photography of selected earth or cloud features or which required that the astronauts see particular features. The main aim of the Gemini series was the development of manned spaceflight technology. Therefore, there was only limited time for the scientific experiments, and only a limited supply of fuel available for reorienting the spacecraft to get the proper viewing attitude. Sometimes forecasting was important in scheduling the activities of the crew. Throughout most of the Gemini

series the Spaceflight Meteorology Group (SMG) prepared one map each day showing the continental areas where less than three-tenths cloud cover was expected for the daylight passes of the spacecraft.

Color and sometimes infrared photographs of earth features and cloud systems were a significant product of the Gemini scientific program. However, the great majority of the views taken did not require specific forecasts. They were taken as the opportunities arose as part of the general documentation of the flights or in response to prior requests by the experimenters; but some were the result of specific forecasts that the desired features could be seen on particular passes.

In addition to the photographic efforts, there were other experiments which depended on forecasting. For example, on Gemini 5 and again on Gemini 7, there was an investigation of the visual acuity of the crew. One part of this investigation involved the sighting of an array of large white rectangles placed on uniform terrain near Laredo, Texas. The crew had to judge the orientation of the rectangles -- which varied from 152 to 610 feet in length -- to indicate just how small a feature they could see. At one point in the Gemini 7 mission the prediction called for clouds to move over the ground site in about 48 hours and to preclude the conduct of the test at the times at which it had originally been scheduled. Because of that forecast of unfavorable weather, the visual acuity experiment was re-scheduled a day earlier than planned and was conducted successfully. It should be noted that the location of a relatively small target, such as the array of white rectangles in the visual acuity experiment, is difficult to spot in the brief time that it is within the astronauts viewing range. With even a few clouds in the area the difficulty is increased.

In the two manned Apollo earth-orbiting flights, Apollo 7 in October 1968 and Apollo 9 in March 1969, there were quite a few areas scheduled for photography. In the Apollo 9 mission with its greater emphasis on scientific benefits of spaceflights there was a particularly active program of forecasting for a great many potential targets on earth. As in the Gemini program, daily forecast maps were prepared which showed the areas where less than three-tenths of cloudiness was expected.

One of the many aims of the Apollo 9 mission was to get pictures of that year's extensive snowcover in the remote higher elevations of northern Arizona for the Office of Hydrology of the National Weather Service. After many days of cloud cover in that area the forecast for March 12 called for sufficiently clear skies. Accordingly, the crew was prepared and the spacecraft was oriented for photography to the north as it passed near that area. Several excellent pictures of the snowcover were obtained.

The Skylab missions, which required SMG to make sky cover forecasts as part of its overall weather support, involved extensive earth-oriented sensing experimentation. Unlike the Gemini and Apollo missions, where daily forecast maps showing continental areas where less than three-tenths cloud cover was expected for all daylight passes, forecasts for Skylab dealt with up to 4 or 5 candidate passes (each involving a number of experiments) selected five days in advance. Outside the U.S. initial selection was largely on a climatological basis. For the U.S. preliminary selection was made based on 5-day forecasts. Final selection of 1 to 2 passes for recording remote sensed data was made from a 2-day forecast covering all the candidate passes initially chosen three days earlier. The 1 to 2 passes selected to be recorded were the ones having the highest expectancy of favorable weather conditions in relation to the number of experiments along each particular pass. Time-lines of crew activities were developed from 1-day forecasts which took into account changes in weather during the preceding 24 hours affecting the designated tracks. The final go/no-go decision to record along the time-line was made about three hours before the time of overflight and was based upon the latest satellite and other available data.

Granted, such a selection process is rather involved. However, some 90 percent of Skylab's remote sensing program objectives were accomplished during the three Skylab missions. This was a much higher success factor than had been expected on the basis of premission assessment, and in part reflects favorably on the quality of weather support rendered. Skylab experiments were not confined to continental areas but included the ocean areas as well. In addition to forecasting cloud cover (clear, partly cloudy and cloudy) along the tracks, forecasts of frontal positions, storm centers, high pressure areas and wind and sea conditions were also indicated.

One sensor package aboard Skylab was the Honeywell S-192 multispectral scanner. Experimenters and applications mission planners wanted to compare the 13-channel skylab scanner with the four-

channel Landsat system to determine if the more advanced S-192 could achieve results not already obtained by the existing Landsat system or by other, cheaper ground or aircraft sensors. Unfortunately, random noise in Bands 1-5, those in the visible spectrum that were most directly comparable to Landsat bands, precluded such an evaluation. After more than a year's effort some of the noise was removed. This data along with that from the best channels (bands 7, 9 and 11 in the near-and mid-infrared part of the spectrum) provide a broadened collection of useful information for the Skylab experimentors and for future research. Channel 11 is of special interest to agriculture researchers. It has the potential for distinguishing between types of vegetation in imagery, possibly because of the way water is subdivided in plant cells. This band is being considered for use in a thematic mapper on Landsat-D which is another reason for interest in it. Resolution is higher in the S-192 system than in present Landsat imagery.

Skylab instrumentation also included a radar altimeter, which was the forerunner of the instrument flown on the Geodynamics Experimental Ocean Satellite (GEOS-3) Project to be discussed later. The Skylab experiment among other things was to demonstrate the use of radar altimeters to detect and measure oceanographic features such as surface roughness and wave heights. During the Skylab mission, SMG made forecasts of wind and sea conditions along a number of passes over both the Atlantic and Pacific oceans. After the mission careful analyses of surface information for selected portions of some 20 passes were made to provide the best estimate of winds, wind waves, swells and weather conditions for comparison with sea conditions measured by the radar altimeter.

Weather support for the earth-viewing experiments during the joint United States-Russian Apollo-Soyuz Test Project was similar to that for the Skylab missions.

3.1.2 Space Shuttle Era

The role of the SMG meteorologist becomes more operational as the Shuttle Program progresses phase by phase toward the operational Shuttle flights of the 1980s. So far our involvement has been primarily with such matters as meeting overall weather support requirements; special studies involving the effects of certain meteorological conditions on Shuttle landing and rollout; Shuttle approach and landing test simulations; weather aspects in the selection of foreign and domestic contingency landing airfields. SMG also supports the shuttle Astronaut training aircraft operations out to Ellington AFB (Houston, Texas) which began last year.

Recently the "captive inert" (orbiter unmanned) phase of the space shuttle orbiter approach and landing test (ALT) program was completed. This phase, consisting of five flights evaluated the flight envelope of the carrier aircraft/orbiter combination. In late May the "captive active" flights will begin with two astronauts aboard the piggyback shuttle orbiter operating its systems. Up to six flights may be involved. Between July and January 1978, eight free flights are scheduled in which the orbiter will be released from the carrier aircraft as the final phase of the ALT Programs.

With each passing phase of the flight testing programs, the consultant/advisory role of the SMG meteorologist to the NASA Johnson Flight Directorate personnel becomes increasingly more active. In 1979 six orbital flight tests are scheduled and operational shuttle missions will start with the Spacelab-1 mission in mid-1980. With the orbital missions the scope of the meteorologist's responsibility shifts from that of a local area to one involving essentially global operations.

The timetable for reaching specific shuttle development goals noted above makes one realize that shuttle operations are just around the corner. Earth-viewing activities are scheduled for two of the six orbital test flights in 1979. Spacelab-1 in 1980, a joint NASA and European Space Agency (ESA) undertaking, will be a one-week long mission keyed toward atmospheric and solar/terrestrial research, but also will involve significant space processing and life sciences projects. Seventeen NASA Sponsored and 61 ESA research proposals have been selected for the Spacelab-1 mission. NASA's research proposals involve 86 investigators and ESA's 61 proposals involve some 136 scientist. Undoubtedly, a number of the earth-oriented experiments will be affected by clouds thus requiring weather forecasting. Most likely, SMG weather support for earth-sensing Spacelab-1 experiments will be similar to that of the Skylab missions. When the Shuttle program reaches full development in the mid-1980s, up to 40 missions a year are anticipated.

3.2 Earth Observation Programs

3.2.1 Aircraft Programs

Since 1970, SMG meteorologists have provided weather support for earth sensing aircraft experiments conducted by the NASA Johnson Manned Spacecraft Center. In the early 1970s the NASA Earth Observations Aircraft Program (EOAP) was very active, partly as background for experiments scheduled on future space programs. A major effort of EOAP was the 1971 corn blight watch. The purpose of that experiment was to obtain repetitive color photographs in the near-infrared visible spectrum along more than 40 selected flight lines covering the belt of states from Ohio westward to Kansas and Nebraska. The objective was to obtain cloud free photographs of all flight lines every 2 weeks during the period June 15 to October 1. These photographs were analyzed to determine the degree of infection from the Southern Corn Leaf Blight and to monitor the development and spread of the disease. Almost daily forecasts of the cloud cover were required to schedule high-altitude aircraft flights over the target lines. Most flights were made by an Air Force RB-57F flying at an altitude of about 60,000 feet. Due to sun angle requirements for optimum lighting these lines could be photographed only during the hours 0900-1500 CDT.

To support the corn blight survey flights, SMG meteorologists were deployed to support aircraft operations first out of Scott AFB in Illinois and later out of Forbes AFB in Kansas. The meteorologist working with the on-site mission manager and aircraft commander were for the most part able to capitalize on the brief periods of generally clear weather before daytime cloudiness developed and following occasional weak frontal passages. In general there were few of the 2 week periods where any significant segments of the required flight lines were missed due to weather. Direct radio communications with the flight crew were very important to the high degree of success achieved. Such direct contact with the aircraft provided the flexibility to confirm or modify preflight instructions regarding developing weather conditions. The type of remote sensing technology demonstrated in the corn blight and other EOAP experiments is now being used in the Earth Resources Technology Satellite (ERTS - now Landsat) Program.

Again in November 1974, a SMG meteorologist was deployed with the flight crew of a NASA C130 aircraft to Copenhagen, Denmark. The purpose of the mission was to conduct flights out over the North Sea to calibrate radiometer-scatterometer (RADSCAT) and dual-frequency scatterometer (DFS) equipment. The RADSCAT equipment was flown later on the GEOS-3 satellite as part of the NASA Earth and Ocean Physics Applications Program (EOPAP). The North Sea flights were looking for high-wind, rough-sea conditions in various ranges to augment earlier calibration data. Fortunately, the weather cooperated and three missions were flown, one of which was a very good mission encountering the higher wind speeds desired ranging to more than 50 knots with accompanying seas. Improved RADSCAT and DFS equipment will be flown along with other instrumentation on SEASAT-A in May 1978 which is also part of EOPAP. The GEOS-3 and SEASAT-A Projects will be discussed later in regard to SMG's involvement. From the foregoing it is readily seen how interrelated are the aircraft and satellite programs, both manned and unmanned.

As mentioned earlier, the aircraft program was very active during the first part of the 1970s. The NASA Johnson SMG office, as part of its overall center support, provided forecasts for EOAP flights covering the central and western part of the U.S. When the aircraft staged out of Langley Virginia or McGuire AFB in New Jersey, weather support was furnished by SMG meteorologist at Washington, D.C.. A typical mission usually involved 8 to 10 experiment sites scattered over a several state area. Next day scheduling was based on a 24-hour forecast, selecting sites where most favorable weather conditions were expected and the aircraft readied accordingly. On the morning of each flight prior to alerting the flight crew, the final go/no-go decision would be made by the mission manager after being briefed on the latest weather conditions by the SMG meteorologist. The main benefit of this type of weather support arrangement is that having a meteorologist specifically responsible for mission support increases the opportunity to capitalize on favorable weather conditions. Also, it permits more orderly use of flight crew ground time.

Today, the NASA Johnson aircraft program, now known as the Airborne Instrumentation Research Program (AIRP), is not as active as in the early 1970s. AIRP aircraft remote sensors include cameras, microwave radiometers, multi-spectral scanners, precision radiometer thermometer, laser profiler, and scatterometers. Various combinations of these sensors are used to obtain data at locations throughout the U.S. for use by some 100 scientific investigators. Like EOAP,

AIRP is part of NASA's Earth Observation Program developing remote sensors and remote sensing technology.

3.2.2 Landsat - Earth Resources Technology Satellite Program

Remote sensors aboard the Landsat spacecraft put the whole earth under a microscope. Circling the globe every 103 minutes in a near polar 920-km (570-mi.) orbit, the spacecraft's remote sensors view a 185-km (115-mi.) wide strip along a ground track running nearly north-to-south at an angle to the equator of 99 degrees. In this type of orbit, surface coverage of the Earth progresses westward, with a slight overlap, such that complete global coverage is obtained once every 18 days. Landsat-1 (launched July 23, 1972) and Landsat-2 (launched January 19, 1975) are in sunsynchronous orbits with equator crossings at the same time (9:30 a.m. local time) every orbit. Both spacecraft carry the return beam vidicon camera subsystem and the multi-spectral scanner subsystem.

Synoptic, repetitive coverage of the Earth's surface under consistent observation conditions is required for maximum utility of the multispectral imagery collected. Later this year with the launch of Landsat-C nighttime sensing will be possible because of the addition of a fifth channel to the multispectral scanner in the infrared spectral band.

Data from the remote sensors of the Landsat spacecraft are used by more than 100 research teams in Federal, State and Foreign Governments, international organizations, universities and private companies involving the scientific disciplines relating to the Earth, its resources and their use. More than 40 states and more than 40 foreign countries participate in the Landsat follow-on Investigative Program designed to show the practical benefits in resource management utilizing remote sensing from space. Applications of Landsat data are being made in such fields as agriculture, forestry, range resources, marine resources, oceanography, mineral and land resources, mapping and charting, water resources, environment, and land use.

But, what about clouds? Cloud cover interferes with obtaining remote sensed imagery of the Earth's surface. Where clouds exist, reduction in coverage is unavoidable, but it would be wasteful to use up the limited lifetime of the spacecraft recorder on useless imagery. Hence, NASA's operational plans for Landsat included cloud-cover forecasting. To meet this need the SMG Washington Section provides operational global cloud cover forecasts for Landsat support. As a result of SMG's extensive experiences in meeting the worldwide weather requirements of the Manned Space Program, SMG was the logical choice to provide cloud cover support for the Earth Resources Technology Satellite Program.

Each day a forecast of cloud cover is prepared for all the land areas and some adjacent ocean areas beneath the track for each of the next day's 14 passes. For the first pass, the forecast is about a 24-hour prediction; and for the last pass about 48-hours. The cloud forecasts are made in three categories: "clear" (0 to 30 percent sky cover), "partly cloudy" (31 to 69 percent), and "cloudy" (70 to 100 percent).

Daily forecasting of cloud cover for all parts of the world a day or two in advance is certainly not an easy task. The SMG Washington Section making these forecasts is collocated with the National Meteorological Center (NMC) and pertinent parts of the National Environmental Satellite Service (NESS). It has ready access to the global data and products of these two NOAA components. In making the cloud cover forecasts, the forecasters have available all NMC data and guidance products to use in estimating the future location of pressure systems. A special computer program adapts the NMC guidance information to the map base and orbit times to meet the needs of the Landsat Program. The clouds associated with the various weather systems (and clouds not identified with features on analyses) are most reliably depicted in weather satellite photographs. Movie loops made from GOES satellite imagery are also helpful to the forecaster. The basic importance of computer and weather satellite products to the meteorologist in support of today's remote sensing programs has already been discussed. One might almost say, the meteorologist would be lost without them. Certainly the quality of weather support would be adversely affected if they were not available.

How good are the Landsat cloud cover forecasts? A recent verification of 69 days (966 orbits) of Landsat forecasts shows that when clear skies were forecast, they were observed 60 to 70 percent of the time for various parts of the world. Clear or partly cloudy skies were observed about 85 percent of the time when clear conditions were forecast; thus indicating

some useful information is possibly obtained that much of the time.

On a few occasions, special requests for a nighttime forecast are received. One particular case was to satisfy the requirement to take Landsat-2 photographs of "gas flaring" in the vicinity of 32°N 06°E in Algeria for January of last year. Photographs taken captured the gas flaring from petroleum production in that area. The most recent request for a nighttime forecast was along the Santa Barbara channel area northward to San Francisco, California. From the weather standpoint the target area was beautifully clear. Such requests are unusual in that nighttime photographs are being attempted using daytime sensors.

Besides Landsat-C to be launched later this year which will have the added nighttime sensing capability, NASA plans call for the launch of the Landsat-D spacecraft in 1981. It is not certain at this time whether the multispectral (S-Band) scanner flown on the first three Landsat spacecraft will be flown on Landsat-D in addition to the planned high-resolution (X-Band) mapper. NASA was unable to add the multispectral scanner to Landsat-D with its own funds. It remains to be seen if users are willing to fund for inclusion of the scanner. Landsat-D will be designed to be compatible with the Space Shuttle System for retrieval by the Shuttle orbiter.

3.3 Ocean Satellite Programs

3.3.1 Geodynamics Experimental Ocean Satellite (GEOS-3) Project

The GEOS-3 satellite was launched the first part of April 1975. The primary objective of the GEOS-3 Project was to demonstrate the feasibility of utilizing an on-board radar altimeter to measure the time-varying behavior of the ocean's surface and the departure of the sea surface from the geoid, as well as to investigate altimeter instrumentation technology. The altimeter measured variations in the shape of the leading edge of the reflected radar pulse from the ocean's surface. To obtain engineering data on altimeter performance, it was necessary to measure and evaluate parameters such as sea surface roughness and spacecraft libration. To achieve this the altimeter had to be calibrated over an ocean area; the area just off the East Coast of the U.S. was used. Altimeter accuracy was determined by comparing the altitude measured by the altimeter to the spacecraft altitude determined by independent tracking systems located at Wallops Island, Virginia; Cape Kennedy, Florida; Grand Turk; and Bermuda. Precision and resolution were determined by comparing sea surface profiles resulting from altimeter measurements with profiles determined by independent methods.

SMG's primary involvement with GEOS-3 dealt with providing independently determined sea surface profiles for comparison with those determined by the spacecraft altimeter. For the better part of a year, SMG provided the NASA Wallops GEOS-3 Project Manager ground-truth information based upon standard hindcasting procedures using surface weather charts for the two or three passes each day over the calibration area off the East Coast. Separate determinations were made of the wind wave and swell components which together are a measure of the sea surface roughness. Ground truth for some portions of passes outside the calibration area were also estimated. Hindcasting methods represent average conditions along the track and not the instantaneous conditions as measured by the altimeter. Hence, only comparisons of average conditions were possible. Naturally, there were times where significant differences were noted. Generally, there was reasonable agreement when significant changes in sea surface roughness took place even though altimeter recorded profiles usually indicated higher peak values than the hindcast method. The GEOS-3 altimeter is more sensitive to the higher wave heights than the lower ones. It is with the higher end of the wave height spectrum that the observer has difficulty in estimating height values and also where hindcasting methods underestimate the higher values.

For the month of February 1976, a major effort was made to evaluate the performance of the altimeter. Sea surface conditions were recorded for all passes over the North Atlantic during the month. The number of passes varied from seven to nine per day. For each pass, SMG provided ground-truth which consisted of the heights and periods of wind waves (the significant wave height - the height of the highest 1/3 of the wind waves) and swells as well as the direction and speed of the wind at one minute intervals along the ground track. General weather conditions were also indicated along each track. NASA Wallops personnel have made comparisons of the GEOS-3 sea surface profiles with those calculated by SMG. Comparisons with aircraft, data buoy, and ocean weather ship information have also been made. Undoubtedly, the GEOS-3 and aircraft results best represent the instantaneous variations in the roughness of the sea surface. In magnitude, the altimeter results probably best represent a truer picture of the higher wave values. In

spite of shortcomings in the various methods of obtaining comparative data, there was good agreement much of the time. But there were also cases of substantial differences which left in question as to which data source was the better estimate. Nevertheless, GEOS-3 without question demonstrated the feasibility of measuring the sea surface roughness from space.

SMG is presently involved in the NASA SEASAT Ocean Dynamics Program in support of NOAA's SEASAT-A Research and Applications Plan. The SEASAT-A system is unique because its instrument complement is fully dedicated to oceanic requirements. Sensors on SEASAT-A, to be launched in May 1978, will provide near all-weather monitoring of the ocean surface by utilizing the microwave region with each type of microwave sensor represented. The SEASAT-A satellite will carry four microwave sensors consisting of a radar altimeter, scatterometer, synthetic aperture radar and microwave radiometer, plus a fifth sensor, a visible and infrared scanner designed primarily for feature identification. With the exception of the synthetic aperture radar, there is a strong space heritage for each of the instruments. Hence, each instrument has a high probability of meeting its mission objective. The microwave instruments on the spacecraft will provide data on surface wind fields, waves, storm surges, sea surface temperatures, currents, sea and lake ice, geoid, tides and ocean pressure gradients unobscured by cloud or lighting conditions.

For now, SMG is working with other National Weather Service (NWS) personnel continuing to examine the accuracy of GEOS-3 sea state data and looking into ways of possibly incorporating GEOS-3 data in the current NWS computer sea state program experimentally. Such development work using GEOS-3 data, if successful, paves the way for more expeditious use of SEASAT-A data operationally either by incorporation in the computer sea state program or by modification of the computer output products.

3.4 Deep Space Programs

3.4.1 Jet Propulsion Laboratory's Mariner-Jupiter-Saturn '77 Project (MJS '77)

For almost two years SMG has been working with the Jet Propulsion Laboratory (JPL) who has developed a Weather Effects Prediction Model to forecast the degree of weather induced X-band communication link degradation with regard to operation of NASA's Deep Space Network (DSN). The model will predict atmospheric attenuation and noise temperature increase under differing weather conditions affecting the X-band communications link between the DSN stations (Goldstone, California, near Madrid, Spain and near Canberra, Australia) and unmanned space probs, such as, the MJS '77 spacecraft to be launched later this year.

Why is it necessary to predict the weather effects on X-band communications in the operation of the DSN? Clouds and rain adversely affect the quality of the data received. The effect is proportional to the rain rate and cloud liquid water content which is a function of the water particle size and distribution. Under adverse weather conditions in order to maintain consistent high quality picture receipt, it is necessary to slow the data rate, thus reducing the quantity of data received. Under clear sky conditions, including Cirrus (ice crystal) clouds, consistent high quality data receipt can be obtained at high data rates. The data rate may be varied from about 115 kilobits/sec to about 7 kilobits/sec. Hence, advance knowledge of adverse weather effects is desirable in making decisions concerning operation of the DSN.

Up until now, the weather effects model has been tested only for the Goldstone location using actual forecast conditions. This is where SMG fits into the picture. We provide daily forecasts for the 850, 700, and 500 mb. levels, cloud amounts, cloud heights, cloud types, precipitation rate and thickness of the precipitating layer above the ground are also forecast. These forecast values together with judiciously chosen values representing the liquid water content of the forecast cloud types are run by JPL through the computer weather effects model to obtain predicted zenith angle atmospheric attenuation and increased system noise temperatures. The forecast results are compared with measured on-site microwave and weather data to update the weather effects model as necessary.

Weather conditions fall into three general categories: Clear, clouds (partly cloudy to cloudy) without rain, and clouds with rain. For the clear category, weather model forecast values indicate noise temperature increases of less than 1° Kelvin which are in good agreement with measured values. For the partly cloudy to cloudy, no rain situations, increases are small usually 1 to 2° Kelvin at zenith indicating that effects of clouds without rain are small. For the rain category, the two dry winters in southern California have not provided much opportunity to obtain forecast and measured

results to compare. However, hurricane Kathleen which crossed the extreme northern part of Baja California on the 10th of September last year, produced considerable rain in southern California and provided a good opportunity to compare the results of the SMG/JPL forecast values with measurements taken at the Goldstone site.

Hurricane Kathleen formed on the 6th and 7th of September about 600 miles south of the southern tip of Baja California. On the morning of the 9th, Kathleen was moving slowly NNW'ly and was located about 225 miles SW of the tip of Baja. Later on the 9th, Kathleen began to accelerate and tend more N'ly in direction. Acceleration continued on the 10th with Kathleen crossing the Baja California coastline about midday 100 miles south of San Diego. The remains of Kathleen spent herself over southern California and the Southwest.

Now, let us consider the 1, 2, and 5-day SMG forecasts verifying at 2000 G.C.T. for the Goldstone area. Only the 1-day forecast called for rain affecting the antenna site. When the 5-day forecast was made, the cloudiness in the area where Kathleen formed did not indicate any evidence of an organized circulation. GOES satellites provide 24-hour surveillance of the whole area. Disturbances which form south of Baja generally move W or NW'ly and dissipate when reaching the colder waters. Some do recurve striking Baja, but few cross the coast far enough north to affect the southern California area. The SMG 2-day forecast called for clouds only for the Goldstone area. At the time of the forecast, Kathleen was expected to move inland over Lower California further south than she did and produce clouds but no rain at the antenna site. By the time of the 1-day forecast, it was evident that Kathleen would definitely affect the antenna site; accordingly, the SMG forecast called for a thick layer of clouds and a rain rate of 25 mm/hr. (1 in./hr.).

The 1-day forecast (clouds + 25 mm/hr. rain) calculated a noise temperature increase of 58.51°K. The 10 mm/hr. rain rate observed calculated an increase of 30.18°K. The measured values over a four hour period centered on the forecast time, local noon P.S.T., show variations from 15°K to 60°K. For three hours of this period, the measured values fluctuated within 10° either side of the 50°K noise temperature line. Granted there are a number of uncertainties regarding the accuracy of weather forecasts, their verification and the nonhomogeneity of weather conditions surrounding the antenna site. Nevertheless, the differences in the forecast and observed values in this case seem reasonable and suggest that at least model results are in the right ballpark.

Recently, SMG began making weather forecasts for the antenna site near Madrid, Spain. Forecasting for the site near Canberra, Australia will probably begin later this year when background work now in progress is completed.

3.5 Miscellaneous Programs

3.5.1 NASA Langley's Tropospheric Research Technology Operating Plan (TRTOP)

From time to time, SMG has provided meteorological assistance for Langley programs. One such project involved operational forecasting for RB-57 aircraft clear air turbulence investigations over the middle Atlantic coastal states. The most recent project in support of Langley's TRTOP involved the selection of worldwide ground-truth monitoring sites in support of tropospheric pollution monitoring satellite systems to be flown late in the 1970s. Most of their sensors (visible and infrared) will have their observations degraded by the presence of clouds.

Satellite derived relative cloud cover climatology was used to make the initial selection of over 100 worldwide ground-truth monitoring sites. Of this number, annual, monthly and 3-hourly information for 0-1/8, 0-2/8, 3-5/8, and 6-8/8 total sky cover were derived for a network of 60 stations using available standard weather summaries. The cloud cover data was for use in computer simulation studies.

4. SUMMARY

The purpose of this paper was two-fold: First, to be informative regarding meteorological support rendered a number of remote sensing programs, and second, to be persuasive regarding the role of the meteorologist when an active participant in specific programs. Hopefully, this has been accomplished in an interesting manner.