RECENT ADVANCES IN SATELLITE APPLICATIONS IN SUPPORT OF METEOROLOGICAL OPERATIONS

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Summary: Satellite observations and resulting products have been used by meteorologists for more than 20 years. Early applications were limited to qualitative assessments of meteorological phenomena. Today, more quantitative products are being prepared from satellite data. The use of these products ranges from initialization of atmospheric parameters for the models to the issuance of local warnings. Some of the more recent developments and several new products and applications are discussed.

1. INTRODUCTION

Satellite data, observations, and resulting products have been a part of weather forecasting for more than 20 years. Initial data use in operations, was for the most part, limited to imagery products. Various image enhancement techniques and animation capabilities began the transition from qualitative to quantitative data interpretation and utilization techniques. Today, with the advent of high powered computer workstations, meteorologists can quickly ingest, process, enhance, and analyze digital satellite data sets. These workstations also allow forecasters to merge satellite imagery with a wide variety of conventional data observations to facilitate forecast activities, particularly the issuance of watches and warnings.

The performance of numerical models continues to improve. New initialization data sets such as those that describe surface or boundary conditions (e.g. snow fields and vegetation vigor) are being evaluated. Nowcasts, very short (0-3 hour) range forecasts, will be the focus of the modernized National Weather Service in the United States in the next decade. Hourly observations from new ground-based and satellite systems will be needed to fuel the centrally and locally run forecast packages. Some of the new applications of satellite data that are being developed by NOAA at the National Environmental Satellite, Data, and Information Service (NESDIS) in support of current and future forecast requirements are briefly presented in this paper.

2. SURFACE AND BOUNDARY LAYER PRODUCTS

The condition of the earth's surface is receiving increased attention in the initialization of models. Changes in vegetation, snow and ice cover, soil moisture and sea surface temperatures are variables that can be observed in satellite data. Recent volcanic eruptions as well as smoke and airborne dust impact not only the atmosphere, but the accuracy of many of these satellite observations.

2.1 Snow and Ice

High resolution visible and Infrared satellite data have been the basis for the manually derived snow and ice analyses produced by NOAA for more than 30 years. Recently, Special Sensor Microwave/Imager (SSM/I) data from the Defense Meteorological Satellite Program (DMSP) spacecraft have become available for evaluation. This data, although of a coarser resolution ($\approx$25 km), provides an all weather capability that is valuable in the frequently cloud-covered polar latitudes. An experimental SSM/I snow and ice product is shown in Figure 1. Two enhancements have been applied to the data. Sea ice concentration of 25-100% is calculated for the oceanic areas using the Navy Cal/Val (Wentz 1991) sea ice algorithm that uses the 19GHz vertical and 37.GHz vertical and horizontal SSM/I channels. In Figure 1, ice free ocean areas are dark gray, while first year ice and multi-year ice areas are depicted by medium gray and white tones, respectively. Snow cover over land is derived by an algorithm developed by Grody (1991) that uses the 19, 22, and 85GHz vertical channel data. Values of snow scattering indexes range from 10, dark gray to 80, white, over the land areas in Figure 1. This product is currently being evaluated by NESDIS and the National Meteorological Center (NMC).

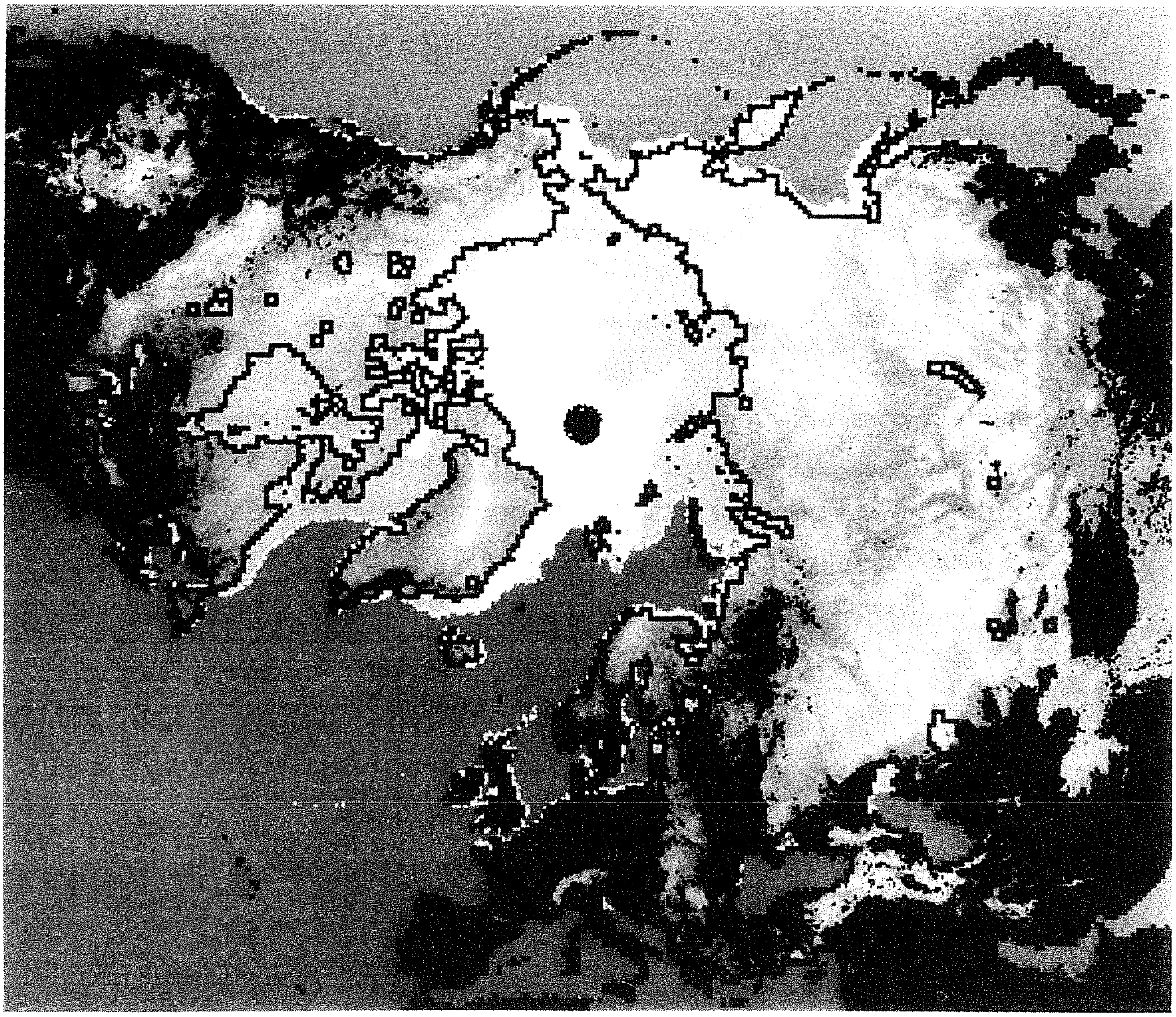

Figure 1. Experimental snow/ice product from the DMSP Special Sensor Microwave Imager (SSM/I), for December 23, 1991.

2.2 Vegetation Index

NOAA polar orbiting data from the visible and near-visible channels (. 63 and 1.0 microns) are differenced and normalized to determine vegetative land cover (Tarpley et. al. 1984). The march of the seasons as well as drought can be easily assessed from this Vegetation Index product. Surface heating and evapotranspiration rates are directly affected by the underlying surface. An averaged weekly Vegetative Condition Index is currently under development. This Index assesses the week to week changes of vegetation that could have potential application to model initialization.

2.3 Aerosol Optical Thickness Index

An aerosol optical thickness parameter is currently produced from visible and near-Infrared (3.7 micron) data from the Advanced Very High Resolution Radiometer (AVHRR) on-board the NOAA polar orbiting satellites (Stowe 1991). Global weekly composites of aerosol optical thickness over oceanic areas have been produced since July 1989. These composites typically have shown the occurrence of haze from industrialized regions, dust from the African and Asian deserts, and smoke from forest fires and agricultural slash burning areas. Most recently it has been a valuable tool to track the distribution of aerosols from the Mount Pinatubo volcano that erupted in June, 1991. Aerosols from the Mount Pinatubo eruption circled the globe in about 21 days (Stowe et. al. 1992). The solar radiation reflected by this aerosol layer was estimated to reduce the globally averaged net radiation by $2.5 Wm^{-2}$ (cooling effect of $\approx$0.5°C), (Stowe et. al. 1992). Further, aerosols impact the computation of satellite derived sea surface temperatures that are used by most numerical models. Algorithms are currently under development to compensate and correct for aerosol impacted areas.

3. SYNOPTIC SCALE PRODUCTS

Satellite imagery has been used by meteorologists to assist in locating synoptic features from the earliest history of the program. Conversion of satellite observations into physical atmospheric parameters that can used by numerical models continues to be a major focus today. Soundings from the polar orbiting spacecraft and cloud wind vectors from geostationary Satellite have been the primary synoptic scale products. Improvements to these products continue to be the primary effort of NESDIS scientists.

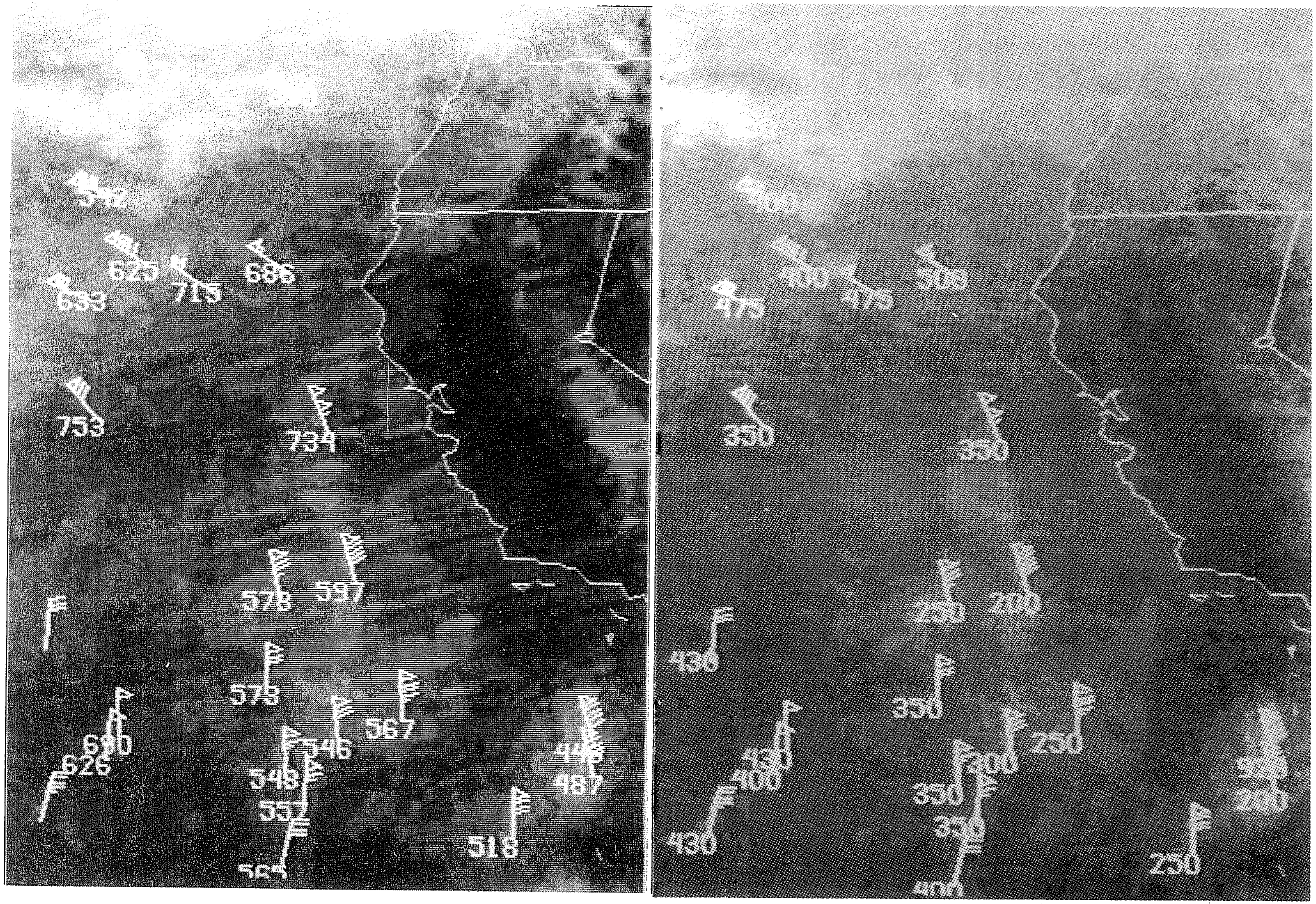

Figure 2. A comparison of satellite cloud motion vectors from GOES 7 derived using Infrared imagery (left) and the CO_2 ratio technique.

3.1 Carbon Dioxide (CO_2) Winds

Satellite cloud motion vectors represent an important meteorological data source over the oceanic areas. However, improvements in numerical weather prediction have surpassed the improvement of satellite wind vectors. The main problems with the derived vectors are slow biases near jet stream cores and improper assignment of heights. Thin clouds, particularly cirrus, are semi-transparent to outgoing radiation, resulting in warmer apparent temperatures. Thus cloud vectors are frequently assigned a height that is too low. A "CO_2 ratio" approach that uses two GOES satellite sounding channels (13.3 and 11.2 micron) has been developed (Merrill, et. al 1991, Eyre and Menzel 1989). Tests show that this algorithm can properly assign cloud top pressure (height) to even thin cloud tracers. Figure 2 shows a comparison of vectors derived from Infrared imagery and the CO_2 ratio technique. Off the California coast, the Infrared histogram technique, cloud pressure (height) for the satellite derived wind vectors range from 753 to 487 mb; the CO_2 ratio more accurately assigns these vectors to the 500 to 200 mb heights. Operational implementation of the CO_2 Winds algorithm is expected in early 1992. At the same time, other improvements will be made including an automated wind program that will search for the best correlation of cloud tracers to the forecast wind field at the CO_2 height. This will also increase the number of winds that will be computed. Shortened loops and image intervals will be used to address problems of cloud dissipation and automated editing and height adjustments are expected to reduce the bias in wind speeds.

3.2 Soundings

Atmospheric temperature soundings are produced operationally from the NOAA polar orbiting sounder (TOVS) and have been generated experimentally from the geostationary GOES sounder (VAS). In the Northern Hemisphere, neither the TOVS nor the VAS can be shown to be demonstratably useful for numerical forecasts (Hayden 1991). That is, they cannot be shown to significantly enhance analyses that have been done without them. This is not the case for satellite derived moisture fields. Experiments to generate dewpoint analyses from VAS data show that good vertical and horizontal detail that support mesoscale features can be achieved. Impact studies to evaluate the effectiveness of moisture retrievals are underway. Operational soundings are planned from the future GOES I spacecraft which will carry separate imaging and sounding instrumentation.

3.3 Clear Air Turbulence

Two products have been developed for the analysis of Clear Air Turbulence (CAT). The first is based on satellite imagery and employs a decision tree process to outlook areas of potential, non-convective, CAT. It is based on characteristic cloud patterns observed in visible, Infrared and water vapor imagery. About seventy-five percent of CAT is associated with a satellite observed cloud signature (Ellrod 1989). These patterns define deformation zones, jet streams, cyclogenesis, etc. The technique involves a step-by-step decision process and has been adopted by several operational forecast centers.

The Turbulence Index (TI) is an analysis and forecast product that is a resultant of horizontal deformation and vertical shear. It can be computed from radiosonde, model, wind profiler, or satellite (sounder) winds for any flight level. Probability of detecting CAT, moderate or greater, is 70%; the false alarm rate is 20% (Ellrod 1990). It is now operational at the National Meteorological Center and the Air Force Global Weather Center.

3.4 Oceanic Cyclogenesis Pressure Estimation Model

Determination of the central pressure of oceanic cyclones is important to marine and coastal forecasts. Outside of a few heavily traveled shipping lanes, and a handful of buoys, little surface data is available over the ocean. Satellite imagery can easily be used to locate and track cyclones. This new pressure estimation model is an attempt to estimate surface pressure and tendency. It is fashioned after a technique developed by Dvorak (1984) for estimating maximum winds and surface pressure in Tropical Storms. A step-by step estimation technique, based on 12 hour interval imagery, was created to determine the central pressure of mid-latitude cyclones in the North Atlantic during the period November to April (Smigielski and Mogil, 1991). Figure 3 shows the developmental cycle and associated cloud patterns for winter cyclones that complete the cyclogenesis process. Baratropic development and storms with limited latitudinal developments, etc. have higher surface pressures. Additional model development and testing of this model will continue through the current winter season.

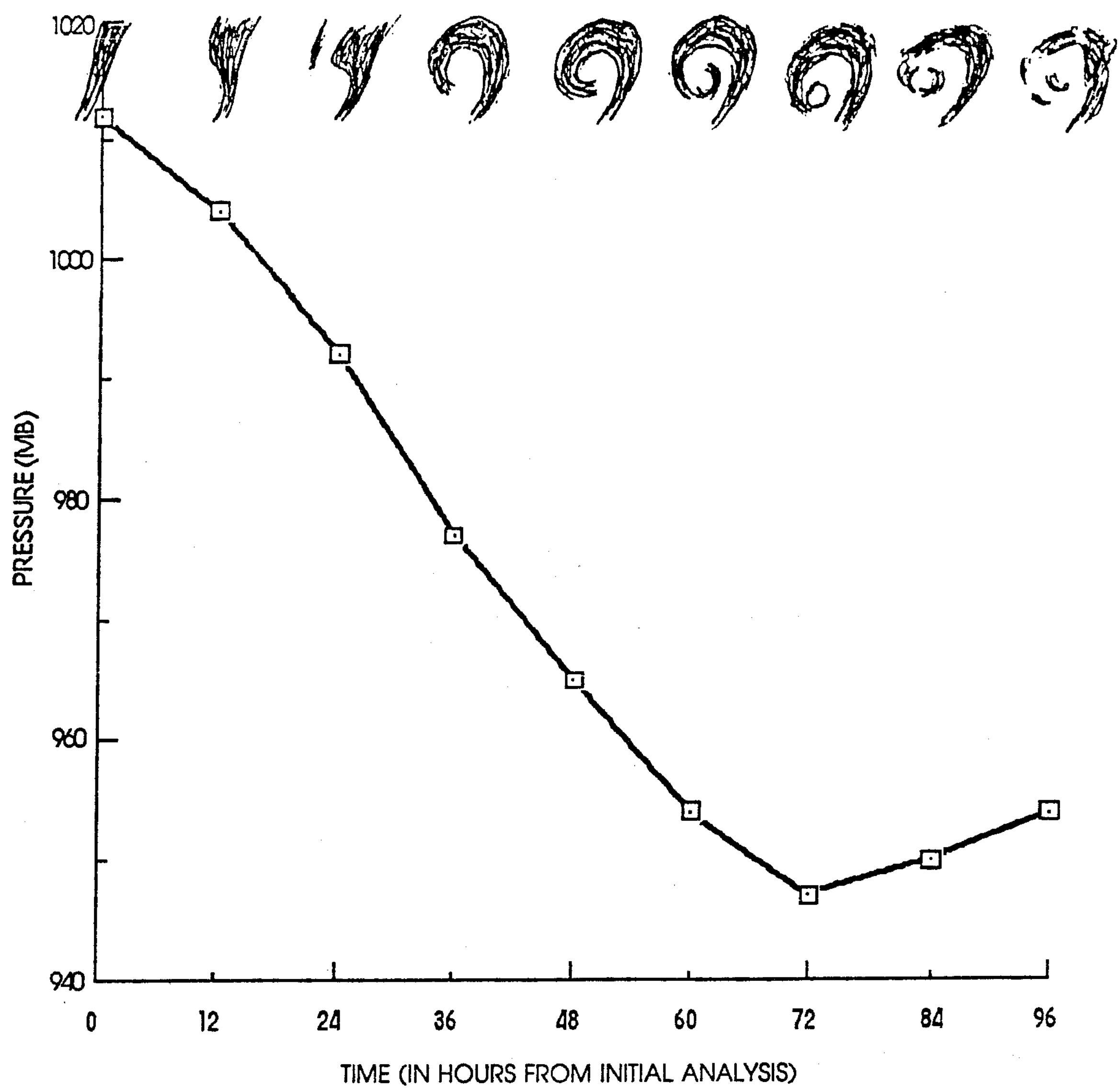

Figure 3. Satellite cloud pattern and surface pressure relationship for mid-Atlantic cyclones during the winter season (from Smigielski and Mogil, 1991).

4. MESOSCALE AND STORM SCALE APPLICATIONS AND PRODUCTS

In the United States, the focus of forecasting in the next decade is on the short-term (0 to 3 hour) forecast or outlook, frequently called the NOWCAST. New observational systems such as doppler radars, wind profilers, automated surface observing systems and the GOES I satellites are being procured and installed to support the requirements of NOWCASTING. Regional numerical forecasts generating hourly updates are planned to support the forecasting of mesoscale weather events and the issuance of severe weather and flash flood watches and warnings. High resolution satellite data and sounding products at frequent intervals will play an important role in the modernized National Weather Service activities. Some of the research and applications being developed are described below.

4.1 Precipitable Water and Lifted Index Products

The separate sounding instrumentation on the future GOES I satellite will allow soundings to be computed over the whole scene or over an area of active weather at frequent intervals. From these sounding various products can be generated. Of great interest are the total precipitable water and the Lifted Index products. These products are being produced experimentally today using data from three VAS channels: 11, 12, and 6.7 microns. These are produced by a physical retrieval algorithm that is augmented by surface observations of temperature and mixing ratio. Both products are processed in 3 minutes and displayed as images on interactive workstations where they can be merged with satellite or conventional data or forecast fields. The ability to process this data in a short time easily meets the needs of severe weather forecasting. Image depiction assists the forecaster in assimilating the data and responding with appropriate forecast decisions.

4.2 Aviation Applications

Three interrelated aviation products are being developed to improve fog and stratus and aircraft icing forecasting. The first is a technique to detect nighttime fog and stratus, particularly over land areas. It is a modification, for the GOES satellite data, of a technique developed by Eyre et. al. (1984) for use with the NOAA AVHRR. The 11 and 3.9 micron channels are differenced to determine the location of low clouds. Although the resolution is limited to 8 km, the satellite observations provide important information where observations are not available through the nighttime hours. Preliminary work is underway to estimate the thickness of the low cloud layer and forecast dissipation time that is directly related to thickness or depth of the cloud layer (Ellrod 1991). Finally, the differenced product is used to identify supercooled water clouds. This data is then colorized to show cloud tops having temperatures ranging from -5°C to -15°C where most icing events would be expected. Preliminary results are encouraging and these or similar products could be available with the new GOES I satellite which will have a 3.9 micron image channel.

4.3 Heavy Precipitation Estimates

Half hourly precipitation estimates have been an operational product for more than a decade. A decision tree technique that employs visible and Infrared imagery is used to determine rainfall amount (Scofield 1978). Variables such as the changes in cloud top temperatures and areal coverage plus environmental conditions (e.g. precipitable water) are used to determine precipitation amounts. Mesoscale Convective Systems (MCSs) and Extratropical Cyclone Systems (ECSs) are responsible for the heaviest rain and snow events. Water vapor imagery has been identified as an important tool in locating the focus of potential heavy precipitation events. Long water vapor plumes such as the one stretching from the eastern subtropical Atlantic across Africa and into western Europe (Figure 4), frequently set the stage for heavy precipitation. Propagating synoptic scale systems, such as fronts, add the catalyst to initiate the heavy precipitation (Scofield 1990). These plumes from tropical and subtropical latitudes are found in all geographic areas. For the most part, the position of the plumes, once established is slow to change, allowing meteorologists to anticipate and forecast heavy precipitation on the longer range and fine tune the local forecasts with ancillary satellite, radar, and local observations.

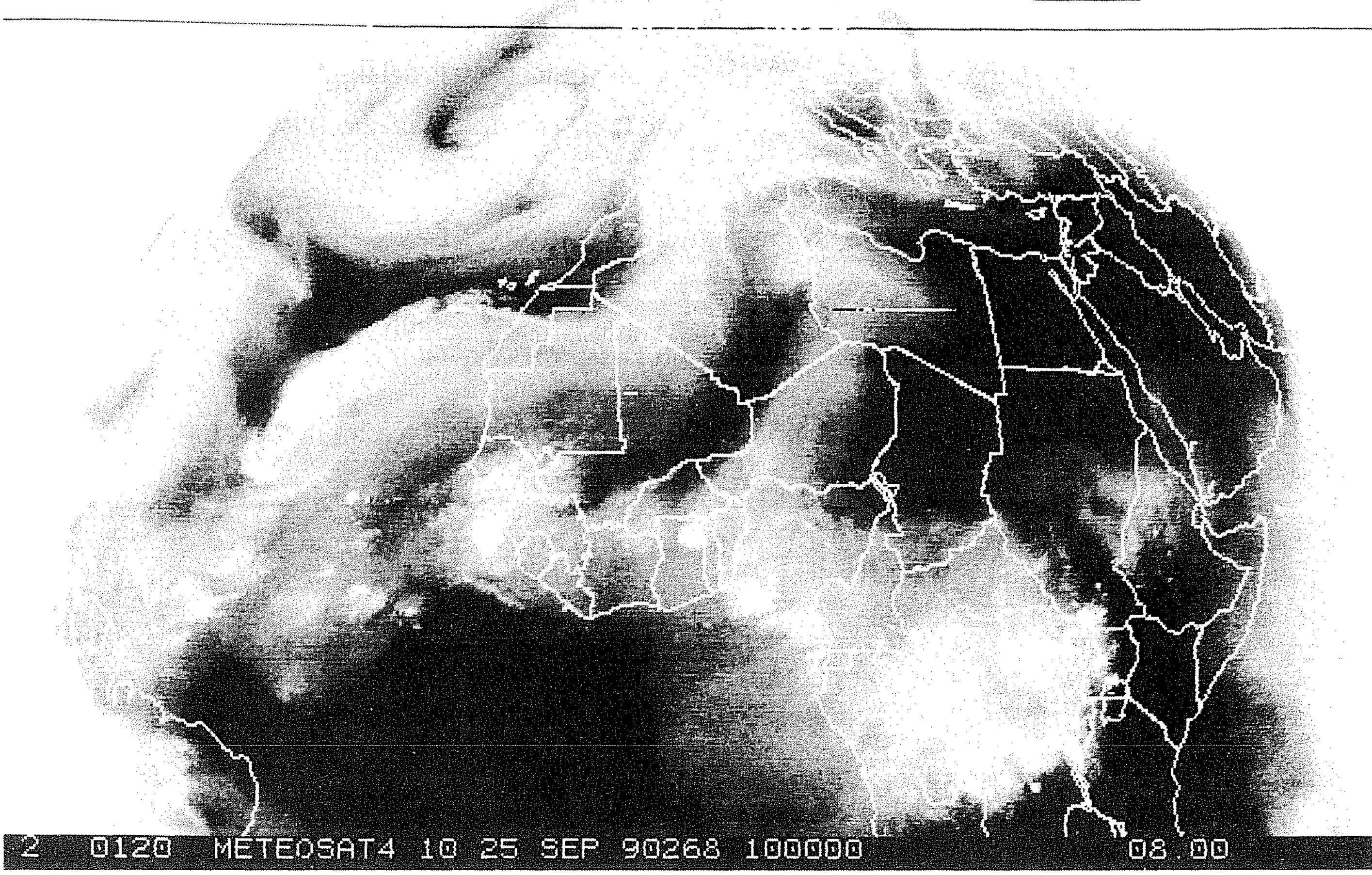

Figure 4. METEOSAT water vapor imagery for September 25, 1990.

5. CONCLUSIONS

Satellite observations from both polar and geostationary orbits continue to provide vital observations and products in support of meteorological operations. The data sets are employed by analysts at all levels in the forecasting process. New sensors together with interactive workstations bring together information that enhances and facilitates the development and applications of products. The ease that today's computers can process both conventional observations and satellite data are allowing scientists to make important inroads toward the development of quantified products for use by numerical models as well as the front line forecaster.

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