United States
Environmental Protection
Agency

Environmental Sciences
Research Laboratory
Research Triangle Park NC 27711

Research and Development

EPA-600/S3-84-044 Apr. 1984

EPA

Project Summary

Determination of Cloud Parameters for NEROS II from Digital Satellite Data

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The U.S. Environmental Protection Agency (EPA) requires statistical descriptions of total cloud amount, cumulus cloud amount and cumulus cloud top height for certain regions and dates as input for their regional-scale photochemical oxidant model of air pollution. These statistics are used to parameterize the presence of sunlight for photochemical reactions, and to diagnose vertical transport of pollutants. The EPA Northeast Regional Oxidant Study (NEROS II) supplied the case studies for the digital satellite data needed to derive these statistics.

The report provides users of the results with dates, times, and regions analyzed, output formats used, and discusses special conditions within the output data. The work reported here demonstrates the viability of deriving total cloud amount, cumulus cloud amount, and cumulus cloud top height characteristics from digital satellite data.

This Project Summary was developed by EPA's Environmental Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The U.S. Environmental Protection Agency (EPA) requires statistical descriptions of total cloud amount, cumulus cloud amount and cumulus cloud top height for certain regions and dates as input for their regional-scale photochemical oxidant model of air pollution. These statistics are used to parameterize the presence of sunlight for photochemical reactions, and to diagnose vertical transport of pollutants.

The EPA Northeast Regional Oxidant Study (NEROS II) supplied the case studies for the digital satellite data needed to derive these statistics. Digital satellite data transmitted from the Geostationary Operational Environmental Satellite (GOES) were analyzed with the help of Colorado State University's (CSU) Interactive Research Imaging System (IRIS) to generate the required diagnoses of total cloud amount, cumulus cloud amount, and cumulus cloud top height. Synoptic rawinsonde data also were used to translate cloud top temperatures to cloud top heights. The IRIS also produced the quantitative cloud field statistics necessary to manipulate the digital data.

Digital satellite data were essential to the success of the study because they provide uniform spatial coverage (unlike surface station data). Furthermore, they are readily processed by human-computer interactive techniques, which are faster than manual analyses of hard copy satellite images. The digital satellite data also produce more precise cloud top height determinations, due to the availability of a wide range of infrared digital counts, rather than the narrow range of gray-shades seen on hard copy images.

Procedure

The cloud field statistics produced for EPA were derived by a two step process. The first step involved displaying the digital satellite data with the IRIS and

generating values for total cloud amount, cumulus cloud amount, and cumulus cloud top temperature. The second step was to convert the cumulus cloud top temperature values to cloud top height values by referring to rawinsonde-derived profiles of atmospheric temperature versus height.

GOES digital satellite data in the visible channel and infrared window (transparent to the earth's surface where cloud free) channel were obtained by CSU from the National Oceanic and Atmospheric Administration's Environmental Data Information Service (NOAA/EDIS). The GOES data archive is maintained for NOAA/EDIS by the Space Science and Engineering Center at the University of Wisconsin. The visible and infrared data were preprocessed within the IRIS to decode the format and then displayed in image form on a video monitor. The horizontal resolution of the visible data was 1 km at the subsatellite point (75°W, 0°N), whereas the resolution of the infrared data was 4 km by 8 km. These resolution values were slightly larger at the latitudes and longitudes of interest for this study.

The satellite-derived cloud statistics were output in gridded form so that they could be easily read into EPA's pollution model. The values of total cloud amount and cumulus cloud amount apply to individual grid cells, whereas the cloud top heights are mean values for each cell. In general, each output grid cell had dimensions of 1/6 degree latitude by 1/4 degree longitude. Each grid was made rectangular with respect to lines of latitude and longitude to facilitate participation of the computer in generating statistics.

Navigation of the satellite data was a routine, but important, part of the analysis. Navigation is the creation of a mapping between points in the coordinate system of the satellite image and geographic points on the earth Precise navigation of the data ensured that the geographic location of each grid cell was known. The accuracy of the navigation of each image was checked by overlaying graphics plots of coastlines, lakes, and reservoirs based upon the navigation calculations. Any discrepancies between these plots and visibly identified landmarks indicated a need to revise the navigation. Finally, care was taken to make sure that cloud features within the visible and infrared images were aligned.

Results and Discussion

The satellite-derived cloud statistics included (1) percentage total cloud cover, (2) percentage cumulus cloud cover, and (3) a frequency distribution of cumulus cloud top heights. Several limitations were encountered in screening the data.

The identification of regions with cloud cover and regions with no cloud depended on the ability of the scientist involved to select a brightness threshold for the visible channel that delineated those areas. The first constraint on this process was related to the size of the geographic area seen within a single field of view of the satellite's visible sensor. In general, the smallest cloud feature resolved by the visible sensor was approximately 2 km^2 in area at the latitudes and longitudes studied.

A second constraint on the cloud amount analysis was the difficulty associated with identifying optically thin cirrus clouds. Cirrus clouds sometimes are so thin that they do not reflect an amount of visible radiation distinguishable from that reflected by the surface

The ability of CSU to identify cumulus clouds and distinguish them from other types of clouds was most affected by the presence of multilayer clouds. Cirriform cloudiness generated from cumulonimbus anvils often conceals new cumulus growth beneath it. The only readily available source of information on the presence of such concealed cumuli is surface station data. However, no attempt was made to incorporate surface station cloud reports into this study.

A second limitation that sporadically affected cloud type identification was the requirement to calculate cloud statistics a few times after the sun had set at the location of interest This fact rendered the visible data useless for all times after 2000 EDT. After 2000 EDT all of the statistics were derived from infrared data alone.

The determination of cloud top heights was impacted by several constraints. The first constraint was related to thermal emission by atmospheric water vapor. Water vapor does have a small emittance in the 11 μm infrared channel used in this study, and the absorption and subsequent radiation by water vapor between the target (cloud or ground) and the radiometer can cause the target to appear colder than it really is. The impact of this process on a satellite-derived surface temperature has a magnitude of approximately 4°C

A second influence on the calculated cloud top temperatures was the response time of the infrared sensor Normally, that sensor does not respond immediately to a rapid change in temperature as it scans across a scene Therefore, the temperature near the edge of a tall, cold cumulus cloud was likely to be overestimated The magnitude of this error ranges from 1 to 5°C, depending on the actual cloud top and background temperatures and the configuration of clouds.

Another limitation that created difficulties in calculating cumulus cloud top temperatures was related to the occasional presence of multilayer clouds. Due to their large size, infrared pixels can contain cumulus clouds and clouds of another type. Such pixels yield cloud top temperatures that are not entirely representative of cumulus clouds. In order to minimize this problem, a cloud top temperature was not calculated from any infrared pixel for which the total cloud cover was composed of less than 70 percent cumulus cloud.

The final sources of error in deriving the cloud top height were related to the rawinsonde data used to translate cloud top temperatures. The few times rawinsonde data were not available from the Bureau of Reclamation, the conversion of temperatures to heights was accomplished using rawinsonde data from the single nearest time rather than from the observation times surrounding the analysis time. Secondly, rawinsonde data has a much lower horizontal resolution than the resolution of the required temperature-height analyses. The horizontal resolution of the synoptic rawinsonde network ranged from 225 to 450 km, whereas the resolution of the temperature-height analyses was approximately 20 km.

A constraint that affected all of the cloud statistics produced for EPA was the misrepresentation of cloud locations due to the viewing angle between the satellite and the clouds. A cloud top that is significantly above the earth's surface appears displaced away from the satellite along the line of sight. The effect is greater for deep clouds than for shallow ones. The impact on the cloud statistics was limited to erroneous placement of clouds near the edge of one grid cell into a neighboring grid cell. When the effects of all the limitations are quantified and summed, the error involving cloud top heights can be assessed This error was assessed by CSU to be 462 meters.

Conclusions and Recommendations

The work reported here has demonstrated the viability of deriving total cloud amount, cumulus cloud amount, and cumulus cloud top height statistics from digital GOES data. The interactive technique developed at CSU allowed the rapid processing of large quantities of satellite and rawinsonde data in order to accomplish that goal The successful

execution of the contracted tasks is significant in that it should allow the EPA model, into which the current results are to be entered, to perform a more accurate and comprehensive simulation of air pollution than has been accomplished previously. The true worth of the work reported here must be determined by the improvement that the cloud field analyses causes in the EPA model.

Several additional tasks should be executed to enhance the usefulness of satellite data for modelling air pollution. The first of these tasks is to compare the satellite-derived statistics with statistics derived from other data platforms. In the near future, CSU and EPA scientists will compare cumulus cloud top heights derived from aircraft-borne LIDAR data and from GOES data, and the results will be published. That study should partially satisfy the need for intercomparison

A second desirable accomplishment would be to further investigate the impact of cirrus clouds on the calculated cloud statistics. In particular, the effect of the transmittance and emittance of cirrus on satellite-derived cumulus cloud top temperatures requires further research. Although Reynolds and Vonder Haar and others have addressed this problem, it still is far from solved.

Other applications of satellite data are possible. For instance, the vertical velocities of convective clouds may be inferred from satellite data to provide details of pollutant transport. Also, the motions of small cumuli may be observed by satellite to quantitatively diagnose horizontal transport processes. Similarly, features within the atmospheric moisture field may be followed using multispectral satellite data. The pursuit of these applications could prove beneficial to EPA or to others concerned about air pollution

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The complete report, entitled "Determination of Cloud Parameters for NEROS II from Digital Satellite Data," (Order No. PB 84-162 601; Cost: $8.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

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☆ U S GOVERNMENT PRINTING OFFICE, 1984 — 759-015/7662

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