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THE LAKE MICHIGAN OZONE STUDY

PROJECT STATUS REPORT - 1993

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INTRODUCTION

The Lake Michigan Ozone Study (LMOS) was initiated by the States of Illinois, Indiana, Michigan, and Wisconsin, and the United States Environmental Protection Agency (USEPA) to develop a regional solution to the ozone ambient air quality problem in the Lake Michigan area. The primary objectives of the LMOS are to collect information on emissions, meteorology, and air quality; develop and evaluate emissions, meteorological, and photochemical models; and deliver to the States a technically credible modeling system to use in supporting revised ozone control plans. A Memorandum of Agreement was established to provide the framework for this cooperative technical effort.

The LMOS data collection efforts consisted of a major field program during the summer of 1991, which provided the essential air quality and meteorological data, and the development of a four-State regional emissions inventory. Internal quality control and external quality assurance procedures were followed during the collection of these data. Subsequently, a multi-level validation of the data was conducted to ensure the accuracy and integrity of the reported data values.

The validated data from four 1991 ozone episodes are currently being used to evaluate the performance of the LMOS modeling system. The photochemical grid model (UAM-V), as well as the models used to generate inputs to UAM-V, are each being evaluated separately. Upon completion of the performance evaluation, the modeling system and associated data base will be delivered to the Lake Michigan States so it can be used as a planning tool.

A second Memorandum of Agreement was established to ensure the regulatory continuation of the LMOS. This next phase of the project (referred to as the Lake Michigan Ozone Control Program or LMOP) deals with the application of the LMOS modeling system, the assessment of alternative control measures, and the development of a regional attainment strategy. The status of LMOS and the plans for LMOP are addressed in the following sections.

DATA BASE DEVELOPMENT

Air Quality and Meteorological Data

A comprehensive field program was conducted during the summer of 1991. The main purpose of this program was to collect air quality and meteorological data either to provide input for photochemical and meteorological models, or to evaluate the performance of these models. The success of the data collection effort depended on the adequacy of the planning, the performance of the data collection teams, and the occurrence of ozone-conducive weather conditions. Fortunately, all three of these conditions were met during the 1991 field program.

The 1991 field program, which cost slightly more than $6.0M, consisted of the following parts:

1. land-based surface air quality and meteorological data throughout the LMOS domain and along the boundary,

2. surface and aloft air quality and meteorological data from ships over the Lake,

3. upper air measurements of meteorological data, and

4. aloft air quality and meteorological data from aircraft over the Lake, near the shoreline of the Lake, and along the boundary of the domain.[1]

Routine surface air quality and meteorological measurements were made continuously during a 3-month period from June through August. Special intensive measurements were collected on seven days during an 8-week period from June 17 through August 9. The intensive sampling days were called by the field management contractor based on forecasts of ozone-conducive weather conditions. Airplanes, ships, volatile organic compound (VOC) and carbonyl measurements, and rawinsondes were deployed on the intensive sampling days.

As seen in Table 1, there were several multi-day periods of elevated ozone levels during the field program.[2] The first event occurred during the period from June 18 to 21. Wind directions were easterly to northeasterly. Ozone exceedances occurred in northeast Illinois and northwest Indiana. This episode was selected for modeling given the unique set of meteorological conditions and the different source-receptor relationships.

The second event occurred during the period from June 25 to June 29. Intensive measurements were taken during this episode. Wind directions were southerly on the first couple of days, and south - southwesterly during the rest of the period. Ozone exceedances occurred in eastern Wisconsin and western Michigan. The peak 1-hour ozone concentration was 175 ppb in Manitowoc, Wisconsin. Because the meteorological conditions during this episode were typical of those associated with historical episodes in the region, this period was selected for modeling.

The third event occurred from July 16 to July 20. Intensive measurements were taken during this episode. Winds were southerly on the first day, and southwesterly during the rest of the period. Ozone exceedances occurred in western Michigan and eastern Wisconsin. The peak 1-hour ozone concentration was 170 ppb at two sites, one near Holland, Michigan and one at Sleeping Bear Dunes National Lakeshore in Michigan. Because the meteorological conditions during this episode were typical of those associated with historical episodes in the region, this period was selected for modeling.

A final event occurred after August 9; from August 24 through August 29. Winds started out from the southeast, and remained primarily from the south throughout this period, with somewhat lighter speeds than the late June and mid July episodes. Ozone exceedances occurred in northeastern Illinois and eastern Wisconsin. The peak 1-hour ozone concentration was 189 ppb near Milwaukee, Wisconsin. Because the meteorological conditions during this episode were typical of those associated with historical episodes in the region, this period was selected for modeling.

In general, the data capture and data quality are sufficient to support model evaluation. Most of the data have successfully passed Level 1 and Level 2 validation. The field contractors were responsible for performing Level 1 validation (i.e., verifying computer files against data sheets, flagging suspect values, eliminating invalid values, and replacing or adjusting values, as necessary). The Information Management and Data Analysis Contractors performed Level 2 validation (i.e., applying consistency checks based on known physical relationships between variables in the data base). A third level of validation will occur as part of the data analysis and modeling. The LMOS data analysis effort is intended to provide a better understanding of the processes that influence the formation and transport of ozone in the Lake Michigan region, and to recommend specifications for the LMOS modeling system which will adequately describe those processes.[3]

Emissions

The UAM-V photochemical modeling requires a regional inventory of gridded, hourly estimates of carbon monoxide (CO), nitrogen oxides (NO_x), and speciated volatile organic compound (VOC) emissions. These data will be processed with an emissions model (i.e., the Geocoded Emissions Modeling and Projections System [GEMAP]) to prepare model-ready emission input files.[4] Two sets of emission files have been prepared: one covering the area in the vicinity of Lake Michigan (i.e., Grid B) and one covering the outer portions of the UAM-V modeling domain (i.e., Grid A) - see Figure 1.

Grid B encompasses the areas of greatest ozone precursor emissions (e.g., urban areas of Chicago, Milwaukee, and Gary) and maximum ozone concentrations (e.g., downwind receptor regions in eastern Wisconsin and western Michigan). As such, it is important that these emissions be of the highest spatial and temporal resolution and of the highest quality possible. Emission estimates for Grid B are based primarily on the point and anthropogenic area source data supplied by the States, and the biogenic and mobile source data derived by Radian for the 74 counties in the vicinity of Lake Michigan (see Figure 1). Emissions from the National Acid Precipitation Assessment Program (NAPAP) data base are used to fill-in those small portions of Grid B that are outside of the 74 counties.

Typical summer day emissions for point and anthropogenic area sources were supplied by the States. Point source data were obtained from the existing state emission inventory systems, which are updated annually through survey questionnaires sent to facilities and site inspection reports. To improve the temporal accuracy of the inventory, day-specific data were reported by over 200 major facilities in the region. Area source data were calculated in accordance with USEPA-recommended methodologies, using specified emission factors and appropriate surrogate factors, such as population and employment.

Emissions rates for on-highway vehicles are calculated by the Motor Vehicle Emissions Model (MoVEM) in GEMAP by multiplying the emission factor (expressed in terms of "g/mi") times the activity level (expressed as vehicle miles traveled [VMT]). USEPA's MOBILE4.1 model was run to provide emission factors. (Note, MoVEM is being updated to reflect USEPA's MOBILE5 model.) Transportation activity data consist of: (a) link-based VMT estimates from urban-scale travel demand models in northeast Illinois, southeast Wisconsin, Grand Rapids, and Benton Harbor; (b) link-based VMT estimates for major roadways from statewide models in Wisconsin and Michigan; and (c) traffic count data for the remainder of the region.

VOC emission rates for biogenic emissions are calculated by the Biogenic Model for Emissions Estimation (BIOME) in GEMAP based on vegetative species-specific biomass and emission factors for saturation conditions. Two significant efforts were undertaken as part of LMOS to improve these emission estimates. First, updated land use/land cover information was derived from recent LANDSAT imagery by another contractor. The resulting database provides information on the land use/land cover for 18 different categories.[5] Second, because of the uncertainty (and magnitude) of the current emission factor for corn and the resulting large amount of estimated VOC emissions for this prevalent midwest crop, two separate research efforts were supported to determine an appropriate emission factor and species distribution for corn.[6]

Given the generally lower magnitude and more distant location of the emissions in Grid A, they are expected to have less impact on high ozone concentrations in Grid B (than local Grid B emissions). For this reason, Grid A emissions need not be of the same detail and quality as Grid B emissions. Consequently, it was decided that a single, representative typical summer day emissions inventory would be sufficient for Grid A. Emission estimates for Grid A were based primarily on updated NAPAP data provided by USEPA. Statewide data, which were available only for Wisconsin, were used preferentially over the NAPAP data. Daily average emission estimates for on-highway vehicles were based on projected VMT and MOBILE4.1 emission factors assuming 1991 Reid Vapor Pressure values and temperatures for a representative, hot summer day (i.e., July 8, 1988). Hourly average emission estimates for biogenic sources were based on USEPA's Biogenics Emissions Inventory System (BEIS) assuming temperatures for a representative, hot summer day (i.e., July 8, 1988). BEIS relies on the land use data from the Oak Ridge National Laboratory's GEOECOLOGY data base, aggregated to correspond to the available emission factors.

Quality Control/Quality Assurance

The project sponsors made quality assurance of the ambient and emissions data a high priority. To guide this effort, a Quality Assurance Project Plan and an Emissions Inventory Quality Assurance Plan were developed and approved by USEPA. These plans outline the quality control (QC) procedures to be followed by the field contractors and States in collecting and processing ambient data, and preparing emission estimates. External systems and performance audits were conducted by independent quality assurance (QA) contractors. Approximately, 10% of the field measurement program budget and 20% of the emissions budget were spent on external QA activities. It is worth noting that the successful development and implementation of a comprehensive emissions QC/QA program played a vital in ensuring the development of a credible regional inventory.

MODELING

The LMOS modeling system consists of the following models:

Urban Airshed Model, Version V (UAM-V) - which will provide concentration estimates for ozone and ozone precursor species

Geocoded Emissions Modeling and Projections System (GEMAP) - which will provide emission inputs for UAM-V

Chicago/Lake Michigan Regional Atmospheric Modeling System (CALRAMS) - which will provide meteorological inputs for UAM-V and ROM

Regional Oxidant Model (ROM) - which will provide initial concentrations and boundary conditions for UAM-V

(Note, it has been found that the ROM predictions for ozone are significantly less than those measured along the upwind LMOS boundaries, especially aloft. Given that the incoming ozone concentrations are on the order of, at least, 80 - 100 ppb during many episodes in the region, it is important that boundary conditions be estimated as accurately as possible. Consequently, two alternative boundary condition approaches will be taken for now: use the observed data alone, and adjust the ROM predictions accordingly. Other approaches being pursued include redoing the ROM runs with an improved regional emissions inventory, and applying the UAM-V model in a regional model over the ROM domain.)

The modeling domain for UAM-V is presented in Figure 2. The nested grid structure consists of Grid C (an innermost grid with 4 km resolution), Grid B (a grid with 8 km resolution covering roughly the 74 counties in the vicinity of the Lake where ambient measurements and emissions data base development have been focused), and Grid A (an outer grid with 16 km resolution). Eight vertical layers will be modeled throughout the domain.

Emission estimates and meteorological parameters are provided with a horizontal resolution of 4 km throughout Grid B, and 16 km outside of Grid B (within Grid A). There are two UAM-V emission input files: one for surface emission sources (i.e., low-level point sources, area sources, motor vehicles, and biogenic sources), and one for elevated point sources. Vertical resolution in the meteorological model consists of 32 layers in Grid B, and 22 layers elsewhere. Interface programs were developed to derive the appropriate UAM-V input files from the full CALRAMS and ROM model output data.

A protocol document has been prepared identifying the procedures for evaluating model performance.[7] Model evaluation will be based on data from the 1991 field program. The four episodes selected for modeling, as noted above, are:

June 26-28   July 17-19   August 25, 26   June 20, 21

The objectives of the evaluation are to subject the models to a series of tests (operational and scientific) designed to assess overall model performance, and to stress the models to reveal flaws in the models or model input; and to render judgments concerning the appropriateness and uncertainties of model use for the application at hand (i.e., emission control strategy testing).

The initial modeling results for Episode 1 (June 26-28) show that UAM-V is doing reasonably well in reproducing the observed spatial and temporal ozone concentration patterns. The magnitude of the predicted concentrations also match the observed values over most of the domain, but are significantly less in eastern Wisconsin, where the peak concentrations occurred. To further investigate the possible reasons for this underprediction, a a series of sensitivity tests are being conducted. These tests focus on three model inputs which significantly affect the modeled concentrations and which possess some degree of uncertainty (i.e., emissions, boundary conditions, and vertical diffusivity). It is hoped that a "best estimate" base case can be determined from the most appropriate values for these parameters.

The modeling is expected to be finished by mid-1993. At that point, the States will have an appropriate planning tool (i.e., the modeling system and associated base case data set) to use to develop revised implementation plans.

FUTURE DIRECTION

In late 1991/early 1992, the Governors from the four Lake Michigan States signed a MOA to establish a cooperative interstate and federal effort for the purpose of identifying and evaluating various control strategies, and demonstrating attainment and maintenance. The MOA defines the organization, schedule, funding, and terms of agreement for this effort.

The evaluation and selection of regional control measures will be guided by a protocol document. A final version of this document was issued in September 1992 following public review and comment. Draft lists of potential stationary and mobile source control measures have been prepared and are being evaluated. Efforts are currently underway to package these measures together to build candidate regional control strategies.

According to the MOA, the States are to agree on the preliminary strategies to model by March 1993. Revised implementation plans must be submitted to USEPA by November 1994. Because the States' will need about one year to complete their complex and lengthy rulemaking processes, agreement on the final regional strategy is needed by about November 1993. This means that the bulk of the control strategy modeling must be performed during the period May - November 1993.

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SITE NAME	MAY 13	15	28	29	30	31	JUNE 1	9	18	19	20	21	26	28	29	JULY 6	16	17	18	19	20	22	AUG 1	2	25	26	27	28	29	SEPT 7
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Sheboygan	---	---	156	---	---	---	---	---	---	---	---	---	153	---	---	129	---	---	---	---	139	---	---	---	---	175	---	---	136	---
Waldo	---	---	140	---	---	---	---	---	---	---	---	---	128	---	---	---	---	---	---	---	---	---	---	---	---	159	---	---	---	---
Manitowoc	---	---	---	130	---	---	---	---	---	---	---	---	175	---	---	---	---	---	---	---	136	---	---	---	---	159	---	---	132	---
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Laketon	---	---	---	147	---	---	---	---	---	---	---	---	---	---	---	125	---	---	148	156	---	---	---	---	---	---	---	---	---	---
Muskegon	---	---	---	139	---	---	---	---	---	---	---	---	---	129	---	125	---	---	145	139	---	---	---	---	---	---	---	---	---	---
N.Holland	---	---	---	---	---	---	---	125	---	---	---	---	---	138	---	---	---	---	161	143	---	139	---	---	---	---	---	---	---	---
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Table 1. Ozone Exceedances in the Lake Michigan Region during 1991

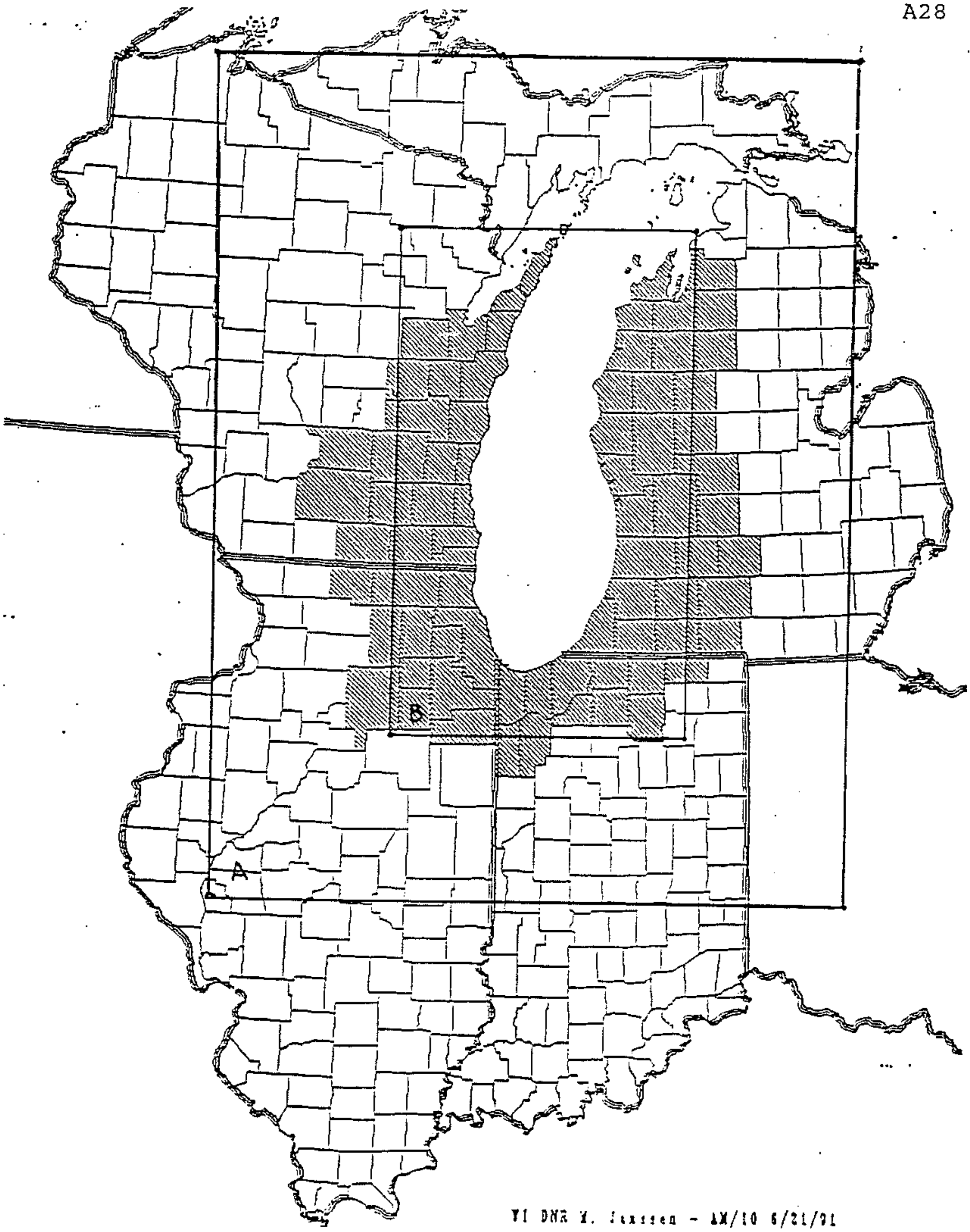

Figure 1. LMOS Emissions Domain and Grid Structure

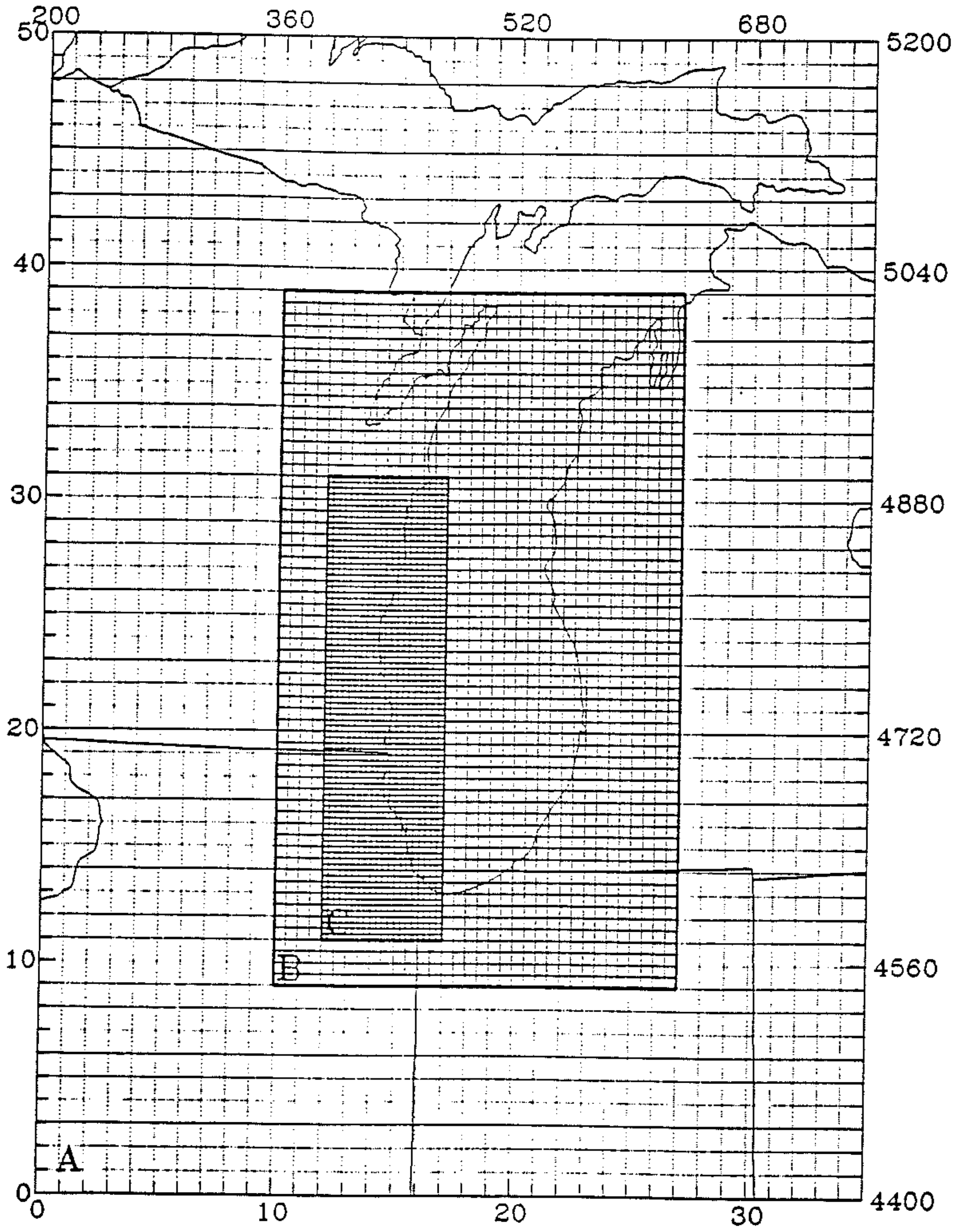

Figure 2. LMOS UAM-V Domain and Grid Structure