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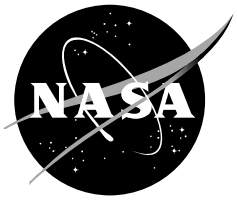

Evaluation of a Potential for Enhancing the Decision Support System of the Interagency Modeling and Atmospheric Assessment Center with NASA Earth Science Research Results

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Executive Summary

The IMAAC (Interagency Modeling and Atmospheric Assessment Center) provides atmospheric hazards predictions in support of Federal agencies responding to incidents of airborne releases with national significance. The IMAAC provides a single point for the coordination and dissemination of Federal dispersion modeling and hazard prediction products that represent the Federal position during actual or potential incidents requiring Federal coordination. IMAAC products are recognized as the single source of Federal hazards prediction and are provided to Federal, state, and local emergency responders and to other government officials as necessary. The IMAAC leverages existing Federal capabilities and is responsible for providing accurate, reliable estimates of predicted hazard areas, with associated concentrations, that serve as the foundation for decisions by the authorized emergency managers.

The NARAC (National Atmospheric Release Advisory Center), located at the University of California's Lawrence Livermore National Laboratory, has been designated as the primary interim provider of IMAAC capabilities and is currently supporting hundreds of Department of Homeland Security stakeholders in addition to its traditional suite of customers and users. The NARAC is a distributed system, providing modeling and geographical information tools for deployment to an end-user's computer system as well as real-time access to global meteorological and geographical databases and advanced three-dimensional model predictions from the national center.

The IMAAC uses a number of software tools to model atmospheric transport and dispersion of hazardous substances in urban environments. These simulations require knowledge of land surface characteristics that may be provided by NASA Earth science research results. The following possibilities for enhancing the IMAAC decision support system using NASA remote sensing data are recommended:

- Aerodynamic surface roughness, for both urban and regional scale domains, provides the best near-term opportunity for incorporation of additional datasets from NASA Earth science measurements into the IMAAC decision support system. Two approaches should be explored, validated, and implemented as appropriate: 1) for urban domains, an approach based on land use classification using Advanced Spaceborne Thermal Emission and Reflection Radiometer imagery, and 2) for regional (non-urban) domains dominated by vegetation land cover types, an approach based on satellite-based vegetation characteristics, such as those derived from the Moderate Resolution Imaging Spectroradiometer.
- IMAAC requires several other land surface parameters; surface albedo and soil moisture are promising areas for collaboration between IMAAC and NASA because of NASA's accumulated research experience in these areas and existence of extensive atmospheric science literature on the sensitivity of meteorological predictions to soil moisture.
- Soil moisture and other land surface state parameters used in the IMAAC atmospheric simulations may be initialized from land surface modeling implemented in the NASA LIS (Land Information System). Combining LIS with an IMAAC atmospheric model could improve accuracy of the hazards predictions.
- Anthropogenic heat flux on an urban scale may be estimated from NASA remote sensing data, but this option requires further evaluation of the feasibility of assimilation into the IMAAC decision support system and of the sensitivity of hazards predictions to anthropogenic heat flux.
- Assimilation of NASA atmospheric measurements of clouds and aerosols into the IMAAC modeling system could be explored.

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1.0 Introduction

NASA's objective for the Applied Sciences Program of the Science Mission Directorate is to expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology. This objective is accomplished by using a systems approach to facilitate the incorporation of Earth observations and predictions into the decision-support tools used by partner organizations to provide essential services to society. The services include management of forest fires, coastal zones, agriculture, weather prediction, hazard mitigation, aviation safety, and homeland security. In this way, NASA's long-term research programs yield near-term, practical benefits to society.

The Applied Sciences Program relies heavily on forging partnerships with other Federal agencies to accomplish its objectives. NASA chooses to partner with agencies that have existing connections with end-users, information infrastructure already in place, and decision support systems that can be enhanced by the Earth science information that NASA is uniquely poised to provide (NASA, 2004).

2.0 IMAAC Overview

2.1 IMAAC Mission

In April 2004, the Department of Homeland Security established the IMAAC (Interagency Modeling and Atmospheric Assessment Center) to consolidate and integrate various Federal efforts into a single emergency response entity to predict behavior of hazardous materials released into the atmosphere. These Federal agencies are currently collaborating on the IMAAC:

- Department of Homeland Security (DHS)
- National Oceanic and Atmospheric Administration (NOAA), Department of Commerce
- Department of Defense (DoD)
- Department of Energy (DOE)
- Environmental Protection Agency (EPA)
- National Aeronautics and Space Administration (NASA)
- Nuclear Regulatory Commission (NRC)
- Department of Health and Human Services (since September 2006)

The IMAAC is responsible for production, coordination, and dissemination of consequence predictions for airborne releases that include nuclear, radiological, chemical, biological, and natural emissions. The IMAAC leverages existing Federal capabilities to provide accurate, reliable estimates of predicted hazard areas, with associated concentrations, that serve as the foundation for decisions made by authorized emergency managers in incidents requiring Federal coordination. IMAAC products are recognized as the single source of Federal hazards prediction and are provided to Federal, state, and local emergency responders and to other Government officials during such major events (DHS, 2004). The IMAAC provides a single point for the coordination and dissemination of Federal dispersion modeling and hazard prediction products that represent the Federal position during actual or potential incidents requiring Federal coordination (DHS, 2006). A further goal of the IMAAC is to improve Federal modeling and assessment capabilities for predicting ATD (atmospheric transport and dispersion).

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The NARAC (National Atmospheric Release Advisory Center), located at the University of California's LLNL (Lawrence Livermore National Laboratory), has been designated as the primary interim provider of IMAAC capabilities and is currently supporting hundreds of new DHS stakeholders in addition to its traditional suite of customers and users. NARAC is a national support and resource center for planning, real-time assessment, emergency response, and detailed studies of incidents involving a wide variety of hazards. NARAC provides tools and services that map the probable spread of hazardous materials that are accidentally or intentionally released into the atmosphere. NARAC provides atmospheric plume predictions in time for an emergency manager to decide whether protective action is necessary to defend the health and safety of people in affected areas (Sugiyama et al., 2004).

2.2 Historical Background

NARAC had its beginnings in the ARAC (Atmospheric Release Advisory Capability) program. ARAC's original mission was to provide reliable and timely assessment advisories to emergency managers at DOE's nuclear facilities and at U.S. nuclear power plants in the event of accidental emissions into the atmosphere. ARAC products and analyses were to be used to reduce exposure to downwind populations and to assist in the planning of any needed countermeasures.

The ARAC began with a feasibility study in 1973 to determine whether the wind prediction models, atmospheric transport and diffusion models, current weather databases, and databases regarding dose response of humans to multiple nuclide exposures could be merged into an integrated system for the DOE. The ARAC was first used for a real emergency during the nuclear accident at the Three Mile Island nuclear power plant in 1979. ARAC demonstrated its usefulness by combining computer technology with meteorology to predict possible levels and areas of radioactive fallout (NARAC, 2002).

Since then, NARAC has responded to such incidents as the Chernobyl nuclear power plant accident in 1986, atmospheric nuclear tests in China in 1978 and 1980, the 1991 Operation Desert Storm contingency for Scud missiles with chemical weapons, the Kuwaiti oil well fires during the Gulf War, and the eruption of Mount Pinatubo in 1991, in addition to many other incidents and exercises. NARAC currently supports about 20+ alerts and emergencies, 100+ interactive exercises (2 to 4 major on the national level), and 7,000 automated responses every year. NARAC collaborates with 300+ local, state, and Federal agencies and emergency operations centers with over 1700 users.

2.3 IMAAC/NARAC Operations

The IMAAC/NARAC supports customers through several channels. The NARAC transport and dispersion decision support services can be accessed through direct telephone calls to expert operations staff, through an Internet interface (*NARAC Web*) to a high-performance computing center, or via Internet-based remote access software installed on a customer's local computer (*NARAC iClient*). Users request, view, and distribute NARAC predictions though the NARAC iClient and the NARAC Web software (Nasstrom et al., 2006a). NARAC software provides an easy-to-use GIS (geographical information system) for display of plume predictions with affected population counts and detailed maps, and the ability to export plume predictions to other standard GIS capabilities.

The basic NARAC Web is intended for wider use by the regular emergency response personnel while the more powerful NARAC iClient is more suitable for expert users. Under the DHS LINC (Local Integration of NARAC with Cities) program, pilot projects are underway in Seattle, New York City, Albuquerque, Fort Worth, and Cincinnati to integrate NARAC capabilities with local emergency management agencies and responders. As part of this program in 2003, NARAC supported a major national exercise (TOPOFF 2; City of Seattle, 2003) and the real-world Staten Island barge fire in New York City. NARAC directly supports the DOE/DHS regional and national Nuclear Incident Response Teams and the Federal

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Radiological Monitoring and Assessment Center. As part of this effort, NARAC is integrated with operational capabilities provided by other DOE laboratories, including Sandia National Laboratories, the Remote Sensing Laboratory, and Los Alamos National Laboratory. Through other programs, NARAC supports and collaborates with

- DOE national and regional operations centers and response teams;
- interagency radiological response centers and teams;
- DHS national and regional operations centers and response teams;
- DOE and DoD fixed nuclear sites;
- NRC national and regional operations centers and teams;
- DoD national operations centers and teams;
- EPA operations centers and regional response teams;
- NOAA national centers and teams;
- national laboratories;
- LLNL centers of chemical, biological, and nuclear expertise;
- NASA;
- local and state operations centers and response teams;
- State Emergency Operations Centers and response organizations; and
- DHS LINC demonstration cities.

NARAC is a distributed system, providing modeling and geographical information tools for deployment to an end user's computer system as well as real-time access to global meteorological and geographical databases and advanced three-dimensional model predictions from the national center. Initial predictions using NARAC-supported tools on the end user's computer are available in less than a minute. Fully automated NARAC central system initial predictions are delivered in 5 to 15 minutes. NARAC can then provide technical and scientific support—including quality assurance of model input data and predictions—until all airborne releases are terminated, the determination of hazardous areas is refined by combining field measurements with model predictions, and the long-term impacts are assessed.

2.4 IMAAC/NARAC Modeling Capabilities

Note: Models described in this section are defined and referenced in Appendix A.

NARAC uses a range of numerical modeling capabilities to support different types of release events, distance scales (local, regional, continental, and global), and response times, over both urban and regional-scale (non-urban) domains. Simpler, fast-running, deployable models are used to perform screening calculations and fast initial response and can be used in the field when connections to the NARAC facility are not available. More detailed three-dimensional dispersion models, coupled to real-time observational data and numerical weather prediction model output, are used by scientific specialists for both near-real-time response and detailed assessments. The NARAC's deployable Gaussian plume models for rapid response and hazard assessment include Hotspot and EPIcode®, while the core operational regional-scale models are ADAPT (land surface and atmospheric data assimilation), LODI

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(particle dispersion simulations), and a customized version of COAMPS® (mesoscale numerical weather prediction). The system also supports specialized models (e.g., nuclear blast and fallout, in collaboration with Sandia National Laboratory, as well as chemical and biological source and effects models) and a computational fluid dynamics model for building-to-urban scale simulations. Canopy parameterizations, empirical models, and building infiltration models provide enhanced understanding of urban effects. Computational fluid dynamics models that explicitly resolve urban structures are used for high-fidelity applications, including vulnerability analyses and planning studies. NARAC modeling capabilities are supported by a real-time meteorological data acquisition system and extensive global databases of geographical, land-use/land-cover, source terms, dose response, and population information (Nasstrom et al., 2006b). For describing nuclear power plant source terms, NARAC applies the NRC RASCAL model. For cases involving toxic industrial chemicals, NARAC can employ the NOAA/EPA ALOHA®/CAMEO® suite of models.

NARAC continuously receives up-to-date surface and upper-air meteorological observations from the worldwide meteorological network via redundant communication links to the U.S. AFWA (Air Force Weather Agency) and the NOAA NCEP (National Centers for Environmental Prediction). Additional meteorological observations are supplied by NARAC-supported sites and by several regional mesoscale networks (*mesonets*) in and near the United States (including the U.S. MesoWest and NOAA Wind Profiler networks). Global and regional numerical weather prediction forecasts from the U.S. Navy FNMOC (Fleet Numerical Meteorology and Oceanography Center) and the NCEP are obtained several times daily. Specifically, NARAC regularly receives data from the NCEP GFS model (1.0° horizontal resolution, 3-hourly data out to 180 hrs from model initializations at 0:00 and 12:00 UTC), the U.S. Navy NOGAPS model (1.0° horizontal resolution, 3-hourly data out to 72 hrs from 0:00 and 12:00 UTC initializations), the NCEP NAM (WRF-NMM) model (40-km horizontal resolution, 3-hourly data out to 84 hrs from 0:00 and 12:00 UTC initializations; 3-hourly out to 48 hrs from 6:00 and 18:00 UTC initializations; 12-km resolution), and the NCEP RUC model (20-km horizontal resolution, 1-hourly to 3 hrs from hourly initializations, continuing with 3-hourly data from 4 to 12 hrs for initializations at 0:00, 3:00, 6:00, 9:00, 12:00, 15:00, 18:00, 21:00 UTC). For special applications, data can be obtained from regional simulations by the FNMOC using the COAMPS model or by the AFWA using the MM5 model. The primary internal NARAC source of prognostic mesoscale weather data is the COAMPS model (Hodur, 1997), which can produce forecasts for any location in the world.

The ADAPT model assimilates data from observations (e.g., from surface stations, rawinsondes, profilers) and/or weather forecast models, as well as land-surface data, for use in the NARAC dispersion model, LODI. ADAPT constructs meteorological fields (mean winds, pressure, precipitation, temperature, turbulence quantities, etc.) based on a variety of interpolation methods and atmospheric parameterizations (Sugiyama and Chan, 1998). ADAPT produces non-divergent wind fields using an adjustment procedure based on the variational principle and a finite-element discretization. A finite-element representation is used for spatial discretization because of its effectiveness in treating complex terrain and its flexibility in dealing with variable resolution grids. The solution is obtained via a choice of conjugate gradient solvers using a stabilization matrix to improve computational efficiency. In emergency response mode, when sufficient representative meteorological data are available and the time scale of the event is relatively short (less than one hour), ADAPT is typically run by ingesting real-time observational data. Terrain and atmospheric stability effects are introduced through the variational mass-conservation adjustment process. Land-surface characteristics and surface heat and momentum fluxes can be used to diagnose horizontally averaged properties of the mean wind and turbulence using similarity-theory relationships (Nasstrom et al., 2000).

NARAC maintains extensive geographical databases of terrain elevation and land-use classifications to specify the lower boundary forcing conditions for its three-dimensional atmospheric flow and dispersion models. Global-coverage terrain elevation is provided by databases obtained from NOAA's National

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Geophysical Data Center (10-km horizontal resolution), the USGS (U.S. Geological Survey; 1-km resolution), and the National Geospatial-Intelligence Agency's Digital Terrain Elevation Data (1-km, 100-m, and 30-m resolution with approximately 60 percent coverage of the world). United States terrain elevation is provided by the USGS Digital Elevation Model (30-m) database. Currently, urban and rural land-use characteristics data are provided by the Global Land Cover Characteristics, primarily derived from 1992-1993 1-km Advanced Very High Resolution Radiometer images and Oak Ridge National Laboratory's LandScan database (1-km horizontal resolution, 24 land-use categories). United States coverage is provided by the USGS's LULC (Land Use Land Cover) database (200-m resolution, 37 categories, generated from 1970s and 1980s aerial photography) and the USGS NLCD (National Land Cover Dataset; 30-m resolution, 21 categories, generated primarily from 1992 Landsat Thematic Mapper imagery).

2.5 Urban ATD Modeling

Because of the high level of interest in urban environments, NARAC maintains and is developing several urban modeling capabilities, including computational fluid dynamics for building-resolving simulations, puff models for rapid modeling of transport and dispersion in urban environments, and coupled models for predictions of indoor and subway concentrations (with Lawrence Berkeley National Laboratory and Argonne National Laboratory, respectively), among others.

For urban-scale scenarios, NARAC's in-house version of the COAMPS model may be used to simulate the mesoscale atmospheric dynamics for an area surrounding the location of the atmospheric release (Chin et al., 2005). Initial and lateral boundary conditions of the simulations are based on large-scale, lower-resolution numerical weather prediction data from NCEP or AFWA. Wind field predictions along with atmospheric stability indicators from the COAMPS simulations are then processed in ADAPT to be used in the Lagrangian particle dispersion model LODI to compute concentration distribution of the released substance.

To consider the urban infrastructure effects in the mesoscale model, a parameterization is required to account for impact of buildings on momentum and heat transfer, turbulence kinetic energy production, and surface energy budget. NARAC has developed an urban canopy parameterization for COAMPS that has been shown to improve the representation of urban flow fields (Chin et al., 2005). Limited data prescribing the characteristics of the urban infrastructure and urban surface at different geographic locations present a major challenge for using an urban canopy parameterization in the mesoscale model. NARAC's current approach is to use the LULC data products (obtained from USGS, often based on NASA remote sensing measurements) to derive the required input parameters for the urban canopy scheme. The urban surface and infrastructure properties derived based on the land-use data consist of

- area fraction covered by urban canopy;
- area fraction covered by buildings (roofs), a part of the urban canopy fraction;
- height of the urban canopy;
- anthropogenic heat flux within the urban canopy;
- surface albedo;
- surface wetness; and
- surface roughness.

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The urban surface properties (albedo, wetness, and roughness) are assumed to have invariable values for a given land-use category at a given time regardless of a location, but seasonal variation is programmed into the model based on the sine function with the winter/summer maximum and minimum values. The values of the surface parameters for each land-use category are based on existing measurements reported in scientific and engineering literature.

Unlike the urban surface properties, the urban infrastructure properties (e.g., building height and anthropogenic heating) for a given land-use category may greatly vary from city to city. In the current NARAC approach, satellite and aerial imagery are used to estimate the urban and roof fraction information for a specific location. The urban canopy height and anthropogenic heating are estimated from actual building height and population data. While the urban infrastructure properties need proper adjustment to fit the actual application for other geographic locations, those properties are assumed to be time-invariant parameters, although they can be customized by a user.

The COAMPS simulations are conducted on multiple, nested grids, with the lowest-resolution grid cell size similar to that of the external meteorological data and the highest-resolution grid cell size close to 1 km. The current land-use classification datasets are available on grids with resolution of 200 m (LULC) or 30 m (NLCD). As a result, the derived urban surface and infrastructure properties of all input land-use categories are taken into account to determine the urban parameters of each COAMPS grid point through the weighted average of land-use category occurrence frequency in each grid cell. This averaging produces better results when more urban land-use categories are provided in the classification scheme; e.g., seven urban classes of LULC (residential, commercial service, industrial, communication, industrial-commercial, mixed urban, other urban) instead of just three (low-density residential, high-density residential, commercial-industrial), as is the case with NLCD.

3.0 Potential NASA Inputs

During the past several years, NASA has worked with universities and other Federal agencies to produce a large number of atmospheric and terrestrial data products through satellite observations and data assimilation models (Parkinson et al., 2006). Specific products include time series of various states (e.g., surface temperature), fluxes (e.g., evaporation, radiation), stores (e.g., soil moisture, atmospheric humidity), and parameters (e.g., leaf area index, albedo) associated with land surface and atmosphere. Of the numerous parameters available, the principal data product identified by IMAAC for improved ATD modeling is the aerodynamic surface roughness for momentum. Surface roughness characterizes the wind profile over a particular location. More specifically, it defines the thickness of the layer above the surface in which the air flow is influenced by the surface. This parameter is an input to several numerical models used in ATD modeling, particularly the ADAPT and COAMPS models.

Generally, when surface roughness is large, as in cities or forests, the surface influences a greater depth of the atmosphere, and wind speeds in a deep layer remain low. The transport of materials in the atmosphere is slow, and the effects of an atmospheric release may be contained in a small, localized area. Conversely, when roughness is small, as in rural areas with low crops or over the ocean, the surface's influence on the atmosphere is constrained to a shallower layer, and winds accelerate more rapidly with height. In that case, the transport of materials in the atmosphere would be more rapid and dispersed over a larger area. The accurate estimation of surface roughness is important to the accurate prediction of the consequences of atmospheric releases of hazardous materials. A change of a factor of 20 in roughness length (equivalent to reducing the height of surface cover from a forested canopy of deciduous trees to agricultural crops) has been shown to change low-level wind speeds by a factor of 2 in an atmospheric general circulation model. More dramatic changes would be expected in models with higher vertical resolution, such as those used at IMAAC/NARAC.

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3.1 Surface Roughness

The current approach for assigning roughness in NARAC models employs a look-up table that associates a specific roughness length with each land-use category. This approach is unable to account for within-class vegetation variability resulting from plant age and density and from seasonal growth and senescence. It also requires up-to-date land-use classifications in dynamically expanding urban areas. Consequently, two approaches to computing NARAC surface roughness using NASA Earth observation data are possible: one for urban and one for vegetated domains.

For urban domains, the current NARAC method based on land-use classifications and roughness length look-up tables can be updated to include more recent datasets and improved classification schemes (Lemonsu et al., 2006). Such an approach based on land cover classification of multispectral images acquired by the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instrument onboard the Terra satellite has been used to improve predictions of building damage caused by hurricane winds (Spruce et al., 2004). The classification preserves the 15-m resolution of the ASTER visible/near-infrared bands while combining them with shortwave infrared bands and band-ratio derivatives. The 15-m resolution is even more adequate for an urban environment than the 30-m and 200-m resolution data currently in use at NARAC, and the ASTER images provide more recent information about the urban land use than these datasets. The ASTER-based classification may be further improved by including an additional data layer consisting of urban canopy height estimates based on digital elevation model data derived from the Shuttle Radar Topography Mission measurements.

For regional scale domains dominated by vegetation land classes, aerodynamic roughness for momentum can be computed using a physical model of surface shear in conjunction with vegetation data products derived from visible/near-infrared imagery (Jasinski et al., 2005). This more theoretical approach that employs satellite-based estimates of canopy density presents an attractive alternative to current look-up table approaches based on land cover type that do not account for within-class variability and are oftentimes simplistic with respect to temporal variability. The approach has been used to create surface roughness grids with 1-km cell size based on the land cover type and LAI (leaf area index) data products created from multispectral images acquired by the MODIS (Moderate Resolution Imaging Spectroradiometer) instruments onboard the Terra and Aqua satellites (Borak et al., 2005). A 4-year time series of surface roughness estimates was generated for the southern United States using the MODIS data, which allows for capturing seasonal variability of the roughness parameter.

Although spatial resolution of the MODIS-derived surface roughness map is lower than in the ASTER-based approach, it matches well with the grid size used in the IMAAC mesoscale atmospheric simulations. In the ASTER-based approach, as well as in the current NARAC approach, surface roughness length is produced for each 1-km grid cell by applying spatial aggregation to the higher-resolution data. In the MODIS-based approach, the aggregation is instead performed during the measurements by the MODIS instrument. Proper processing of the MODIS measurements generates surface roughness estimates at the 1-km scale. The MODIS-based approach is indispensable in extending surface roughness maps to larger, regional areas beyond coverage of ASTER images, especially outside the United States where other alternatives, such as updated NLCD data, are not available.

For highly urbanized areas where MODIS data products provide only the most basic information, surface roughness maps can be augmented with the estimates based on the ASTER LULC classification and the look-up tables. In urban areas dominated by buildings and other manmade structures, surface roughness is expected to have much less temporal variability than in the areas covered with vegetation, and the sparse temporal coverage of ASTER images will still be sufficient for compositing with the time series of MODIS imagery. The MODIS data will give better accuracy in the vegetated areas where surface

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roughness is more spatially uniform but changes with time, while the ASTER data will give better estimates in the urban areas with more spatial variability and less temporal dependence.

Although the MODIS research instrument is deployed on two NASA satellites designed with a limited lifespan, measurements similar to those obtained by MODIS will be acquired in the future by follow-on operational sensors such as VIIRS (Visible/Infrared Imager/Radiometer Suite). VIIRS instruments are to be deployed on the NPOESS (National Polar-orbiting Operational Environmental Satellite System) and NPP (NPOESS Preparatory Project) satellites. LAI Environmental Data Records generated from measurements acquired with the VIIRS instruments could be used to create updated, operational surface roughness data products. Similarly, a future LDCM (Landsat Data Continuity Mission) satellite will acquire multispectral imagery that could be used to create land use classification datasets replacing those based on ASTER data. LDCM data products could also enable extending the LAI-based method to generate aerodynamic roughness estimates with finer spatial resolution.

3.2 Other Parameters

The other two parameters of urban surfaces, albedo and wetness, can also be provided by NASA Earth observations. MODIS generates a surface albedo data product with 1-km resolution on a global scale. MODIS surface albedo measurements in multiple spectral bands can be combined to match a specific broadband albedo definition as required by the IMAAC atmospheric models (Liang, 2001; Liang et al., 2005). Temporal variability of the surface albedo parameter can be assessed based on MODIS data and incorporated into modeling. Surface wetness (soil moisture) can be derived from MODIS data in multiple ways: in vegetation and moisture indices based solely on visible and near/shortwave infrared bands or in combination with thermal infrared bands. Temporal wetness changes can also be captured in these data products.

A potentially more accurate option for providing soil moisture data would be to connect IMAAC atmospheric models with the LIS (Land Information System), an off-line, land surface modeling system developed at NASA (Peters-Lidard et al., 2004), forced with both in situ and satellite data. Such an approach has been used to improve mesoscale numerical weather predictions: the WRF atmospheric model was coupled with LIS using the Earth Science Modeling Framework software (Peters-Lidard et al., 2005) and NOAA's mesoscale Eta model (WRF-NMM predecessor) was initialized with surface data generated by LIS (Cosgrove and Alonge, 2006). In addition to soil moisture, LIS may provide other land surface parameters and state variables to initialize the IMAAC ATD simulations. In the LIS-Eta setup, 18 fields were supplied to the mesoscale weather prediction model: surface exchange coefficients for heat and moisture, surface exchange coefficient for momentum, total soil moisture (at 4 levels), liquid soil moisture content (4 levels), soil temperature (4 levels), canopy moisture content, snow water equivalent, snow depth, and surface skin temperature. To use this approach for simulations with 1-km grid cell size requires significant computational resources, which is achievable with the current technology of distributed, multiprocessor computing.

Anthropogenic heat flux within the urban canopy (one of the urban infrastructure parameters) can be estimated for specific cities from the ASTER and MODIS imagery as well, using mainly the thermal infrared bands (Kato and Yamaguchi, 2005). Feasibility of using this or a similar approach in IMAAC needs further evaluation.

The other parameters characterizing urban infrastructure (area fraction covered by urban canopy, area fraction covered by buildings, and canopy height) could be estimated based on high-resolution remote sensing imagery acquired by commercial satellites, such as IKONOS, QuickBird, and OrbView-3, or based on aerial lidar altimetry measurements and interferometric synthetic aperture radar data, but use of these sensors is beyond the current scope of the Applied Sciences Program.

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Other parameters are measured by NASA Earth observations sensors for research purposes but are not currently used in IMAAC modeling. Examples include amount and distribution of aerosols suspended in the atmosphere as well as density of cloud cover over land areas. While NASA scientists have recognized the importance of these parameters in the modeling of atmospheric dynamics, integration of such measurements into weather and climate models still needs to be developed. This gap creates an opportunity for NASA to work with the IMAAC scientists on incorporating the cloud and aerosol measurements in future generations of ATD models.

4.0 Recommendations

Aerodynamic roughness provides the best near-term opportunity for incorporation of additional datasets from NASA Earth science measurements into the IMAAC decision support system. Both the approach based on the ASTER land use classification and the approach based on the MODIS vegetation characteristics should be explored, validated, and implemented as appropriate. Of the other land surface parameters required by IMAAC, surface albedo and soil moisture are also promising because of extensive research experience accumulated at NASA in these areas and the likely sensitivity of ATD predictions to these parameters. Especially worth noting is that soil moisture and other land surface states used in the IMAAC atmospheric simulations may be initialized from land surface modeling implemented in NASA LIS. Combining LIS with an IMAAC atmospheric model, such as COAMPS or WRF, is expected to improve the accuracy of the ATD predictions. Anthropogenic heat flux on an urban scale may also be estimated from NASA remote sensing data, as could other parameters characterizing urban infrastructure, but these options require further evaluation. The possibility of assimilating NASA atmospheric measurements of clouds and aerosols into the IMAAC modeling system could be explored as well.

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Appendix A. Numerical Model Information Sources

Internet links accessed on December 4, 2006.

ADAPT (Atmospheric Data Assimilation and Parameterization Techniques)

http://narac.llnl.gov/modeling.php

ALOHA® (Areal Locations of Hazardous Atmospheres)

http://www.epa.gov/ceppo/cameo/

CAMEO® (Computer-Aided Management of Emergency Operations)

http://www.epa.gov/ceppo/cameo/

COAMPS® (Coupled Ocean/Atmosphere Mesoscale Prediction System)

http://www.nrlmry.navy.mil/coamps-web/web/home/

EPIcode®

http://www.epicode.com/

Eta

http://meted.ucar.edu/nwp/pcu2/

GFS (Global Forecast System)

http://www.emc.ncep.noaa.gov/

Hotspot

http://www.llnl.gov/nai/technologies/hotspot/

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LODI (Lagrangian Operational Dispersion Integrator)

http://narac.llnl.gov/modeling.php

MM5 (Fifth-Generation Penn State/NCAR Mesoscale Modeling System)

http://www.mmm.ucar.edu/mm5/

NAM (North American Mesoscale)

http://www.emc.ncep.noaa.gov/

NOGAPS (Navy Operational Global Atmospheric Prediction System)

http://www.nrlmry.navy.mil/nogaps_his.htm

https://www.fnmoc.navy.mil/PUBLIC/MODEL_REPORTS/MODEL_SPEC/nogaps4.0.html

RASCAL (Radiological Assessment System for Consequence Analysis)

http://www.osti.gov/bridge/servlets/purl/7947-D51xk4/webviewable/7947.PDF

RUC (Rapid Update Cycle)

http://www.emc.ncep.noaa.gov/

http://ruc.fsl.noaa.gov/

WRF-NMM (Weather Research & Forecasting - Nonhydrostatic Mesoscale Model)

http://www.emc.ncep.noaa.gov/

http://www.wrf-model.org/

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