1 INTRODUCTION

The Global Theater Weather Analysis and Prediction System (GTWAPS) is intended to provide war fighters and decision makers with timely, accurate, and tailored meteorological and oceanographic (METOC) information to enhance effective employment of battlefield forces. Of critical importance to providing METOC theater information is the generation of meteorological parameters produced by numerical prediction models and application software at the Air Force Global Weather Central (AFGWC), Offutt Air Force Base, Nebraska. Ultimately, application-derived data will be produced by the regional Joint METOC Forecast Units and by the deployed teams within a theater. The USAF Air Staff contracted with Argonne National Laboratory (ANL) for assistance in defining a hardware and software solution using off-the-shelf technology that would give the USAF the flexibility of testing various meteorological models and the ability to use the system within their daily operational constraints.

2 SYSTEM BACKGROUND

The Decision and Information Sciences Division (DIS) and the Mathematics and Computer Sciences Division (MCS) of Argonne National Laboratory began design of a system architecture capable of supporting effective theater-level meteorological forecasting. The design goal was to provide forecast data at spatial resolutions down to 10 km, with temporal resolutions adequate for the characterization of all relevant short-term weather events.

The Mesoscale Model version 5 (MM5), developed by the Pennsylvania State University (PSU) and the National Center for Atmospheric Research (NCAR), was selected for use as the prototype theater-level meteorological forecast model (TFM). MM5 is a public-domain, mesoscale meteorological forecast model that is used extensively within the scientific research community and has been used in many operational forecast centers. The MM5 is a nonhydrostatic or hydrostatic, sigma-coordinate, finite-difference model that includes a nesting capability and four-dimensional data assimilation as well as user-selectable physics packages (Grell et al., 1995). For a further description of the MM5 system, see http://www.mmm.ucar.edu/mm5/mm5-home.html. To meet the preliminary operational requirements expressed by the Air Force, a massively parallel adaptation of MM5 (MM90) was prepared by the MCS at ANL for distributed-memory, parallel computers such as the IBM Scalable POWERParallel System 2 (SP2). The parallel version is based upon the nonhydrostatic serial version of MM5 supporting nested domains (Michalakes, et al., 1994). For an in-depth description of MM90, see http://www.mcs.anl.gov/Projects/mpmm.

The prototype implementation of GTWAPS used the Relocatable Window Model (RWM), AFGWC’s operational regional forecast model for the initial and boundary conditions for MM90. Also, AFGWC provided the real-time, surface temperature data as well as snow cover data sources for the modeling suite. AFGWC has many environmental models. Examples are AGRMET (Agricultural Meteorological model), and RTNEPH (Real-Time Nephanalysis cloud analysis model), and many real-time databases. It was desirable to have the software system being designed be capable of using the existing AFGWC databases and model output of these various models. This capability allows a user to query/simulate the “state of the atmosphere” as well as to run diagnostic analyses to produce both forecasts and visualizations of parameters used in war-fighting aviation and maneuver.

The original intent of the system was to output forecast products in Uniform Gridded Data Format (UGDF) and submit them across the Air Force Weather Distribution System (AWDS) network. We also investigated the integration of tactical decision aids (TDAs) that would have access to the data/output within the modeling system.

Another goal was to provide algorithms/models that diagnose present weather (cloud type, height, amount, fog, visibility). These models can be incorporated into the software system and their output used in the TDAs as well as within the visualization scenes.

NCAR’s Biosphere-Atmosphere Transfer Scheme (BATS) model, a high-resolution surface exchange model was integrated with the forecast model to meet the hoped-for needs of producing forecasts down to 1 km resolution (Dickinson, et al., 1993). In order to use the full capabilities of the BATS model within MM90, a source of high resolution, real-time surface characterizations need to be incorporated into the system.

MCS produced a sensitivity-enhanced version of MM5 by using the MCS tool, ADIFOR (Automatic Differentiation of Fortran) (Bischof, et al., 1996). The goal of the ADIFOR work was to understand the sensitivity behavior of MM5...
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so as to aid in the placement of sensors, spatial variation of
sensors, density of observations, and optimal mix of sensors
(Bischof, et. al., 1995). These capabilities are important when
the model is applied over data-sparse or data-denied regions.
Projects/autodiff/weather/MM5.html for a further
description of these techniques.

3 SYSTEM OPERATION

The MM90 forecast model is written in Fortran 90 and
and uses the Run-Time System Library (RSL) during its parallel
execution. RSL, which was written by MCS, is a library of
subroutines that manage and encapsulate message passing and
other lower-level details of the parallel implementation of
MM90 (Michalakes, 1995). The RSL is efficient and portable.
It is optimized for performance on finite-difference, grid-based
codes that employ nesting, and it hides from the programmer
machine-details of message passing. The RSL runs on many
parallel computers (IBM SP2, Intel Paragon, Cray T3D,
Fujitsu AP/1000) and is implemented using MPI, the emerging
industry standard for message passing on parallel computers.

DEEM is a software framework intended to facilitate holistic,
multidisciplinary modeling of environmental processes and
their impact on military operations (Christiansen, et. al.,
1996). DEEM has been copyrighted by Argonne
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cago for the Department of Energy.

The Dynamic Environmental Effects Model
(DEEM) prototype, written by the DIS division for the Joint
Chiefs of Staff/J-8, is the basis for the GTWAPS control shell.
DEEM is a software framework intended to facilitate holistic,
multidisciplinary modeling of environmental processes and
their impact on military operations (Christiansen, et. al.,
1996). To study the interactions between the environment and
military operations, a series of legacy models developed at U.S.
Department of Defense laboratories were obtained and
integrated into the DEEM framework for J-8. These models
represent tools used by the military to perform given functions
and, as such, have been generally tested and validated under
various conditions (Hummel, et. al., 1995). The same frame-
work and high-level architecture were used to integrate the
various legacy software models that make up the TFM (see

DEEM runs on a Sun SPARCStation running the
UNIX operating system (Solaris 2.3 or higher). The source
language for the system includes Smalltalk (ParcPlace Visual-
Works 2.5), C++ (Sun SPARCompiler 3.0), and Fortran 77
(Sun SPARCompiler 2.0).

DEEM contains the user interface (UI) windows and
controls the sequence of the modeling suite execution. When
users are finished setting up a scenario through the menu-
based windowing system (relocating the grids, selecting model
options, etc.), they start the simulation by simply clicking a
button. DEEM uses the parallel virtual machine (PVM) mes-

The DEEM 2D GeoViewer, an object-based geo-
graphic information system module, may be used to visualize
the model output. However, the model output is run through

The DEEM UI allows users to interactively position
and define the grid and nest characteristics and to select the
modeling options. The DEEM Simulation Manager controls
the execution of the simulation. The grid definition and the
modeling suite option windows are used to create an internally
consistent data set for the execution of the various models
within the GTWAPS suite. When a simulation is started
through DEEM, the input files for the models are created from
the user input, and messages are sent across the net from the
Sun to the IBM SP2, where the DEEM Model Controller
receives the messages and interprets their meaning. The Model
Controller then starts the models by calling UNIX shell scripts
for the configuration and execution of each model component.
The models have had minimal alteration (with exception of
parallelizing the MM5) so they are as close as possible to the
NCAR version of the modeling suite.

In the forecast production cycle, the Model Control-
ler runs through the various preprocessors, fhe orecast model,
and the postprocessors for the requested forecast period (usu-
ally 36 hours), while a status window within the DEEM inter-
face is updated.

There are four distinct phases of simulation used for
the interim TFM:

- Defining the area of interest (grid domains)
- Selecting modeling suite options
- Forecasting production (model suite execution)
- Visualizing model output
The parallel implementation of MM5 is very scalable. Figure 1 shows the performance scaling from 4 to 64 processors on an IBM SP2. The graph depicts the 3-domain case listed in Table 1. The horizontal lines indicate the Air Force’s desired performance rates for 2-hour and 1-hour time-to-solution for a 36-hour forecast. The forecast model scales from 126 Mflop/sec on 4 processors to 1568 Mflop/sec on 64 processors (78 percent efficiency). A 36-hour simulation for the 3-domains will require approximately 6 hours on 4 processors and approximately 36 minutes on 64 processors. These performance data were collected November, 1995, on the IBM SP2 at NASA Numerical Aerodynamic Simulation facility using MPMM, the then-current Fortran-77 implementation of the parallel model. Tuning and performance analysis of MM90, the Fortran-90 version is in progress.

4 PERFORMANCE CHARACTERISTICS

The IBM SP2 was selected as the hardware platform principally because it is a cost-effective and scalable alternative to conventional vector/shared-memory supercomputing technology. The Air Force required the system to be work station-based for cost-effective performance and to have no inherent limits that might prevent if from achieving the desired throughput (i.e., the approach should be scalable).

The stated performance goal of the TFM is to produce a 36-hour forecast in 1 hour wall clock time at 10 km resolution over a 1000 x 1000 km theater of interest. The problem, as specified, would require a machine capable of sustaining about 17 billion floating point operations per second. To reduce this to a manageable requirement for the initial workstation configuration, mesh refinement (nesting) is employed. When running either the serial or parallel version of MM5 with two-way nest feedback, the nesting ratio must be 3:1. The actual time it takes the model to process a 36-hour forecast depends on the grid size, number of nests, physics packages chosen, and number of SP2 nodes dedicated to the simulation. Table 1 summarizes the performance data for three different domain configurations. The single domain (no nest) runs were conducted at 100 km resolution, non-hydrostatic, full-physics (radiation, Grell cumulus, explicit moisture, mixed-phase ice physics, Blackadar PBL). Grid size is 61 by 61 by 23 levels. Each time step entails 716 million floating point operations (determined using source model run on Cray). Mflop ratings are determined by dividing this number by the time, in seconds, for an average step. I/O time is not included. The two domain (singly nested) and three domain (doubly nested) runs were conducted at 100km/33km and 100km/33km/10km resolutions, respectively, using the same physics options. All grids are sized 61 by 61 by 23. At a 3:1 nesting ratio, two nests were needed to reach the 10 km resolution. 

The actual GTWAPS TFM performance is summarized in Table 1. These numbers are for the forecast model only and include tuning the model for the SP2 (while still keeping it portable), optimizing the RSL library communications, and implementing load balancing. The 3-domain case executes in 2 hours, 18 minutes wall clock time. Compare this with Figure 1 to see that the number of SP2 nodes would need to be increased to over 32 in order to reach the 1-hour time goal.

Table 1: Run-Time Performance of 36-hour Forecast on GTWAPS SP2 with 14 nodes.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>1 Domain (100 KM)</th>
<th>2 Domains (100, 33 KM)</th>
<th>3 Domains (100, 33, 11 KM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 Hour Cost</td>
<td>12.2 min.</td>
<td>44.3 min.</td>
<td>4 hours, 18 min.</td>
</tr>
<tr>
<td># of Computations</td>
<td>$3.09 \times 10^9$</td>
<td>$1.135 \times 10^9$</td>
<td>$3.447 \times 10^9$</td>
</tr>
<tr>
<td>Fp Rate</td>
<td>423 Mflop/sec</td>
<td>426 Mflop/sec</td>
<td>416 Mflop/sec</td>
</tr>
<tr>
<td>I/O Cost</td>
<td>10 %</td>
<td>4.5 %</td>
<td>2 %</td>
</tr>
<tr>
<td>Forcing Cost</td>
<td>14 %</td>
<td>14 %</td>
<td>19 %</td>
</tr>
</tbody>
</table>

Figure 1. Scaled Performance. Domain configuration, 3 grids (as specified in Table 1), 61 x 61 x 23 levels.

5 FUTURE PLANS

As a proof-of-concept program, the interim GTWAPS system is the first step en route to an enhanced mesoscale forecast capability for the Air Force. Forecast products that can be transmitted to the field and advanced visualizations for the war fighter are the primary goals for GTWAPS model output. The mesoscale model output could also be a new source of input for other models within AFGWC. Conversely, incorporating the data and model output from existing AFGWC sources could be used as input to the GTWAPS modeling suite. This synergy of modeling components within AFGWC will help the Air Force meet its future goals for meteorological support in concurrent theaters.

The technology transition tasks that Argonne is currently working on or may be associated with as follow-on work for the GTWAPS project include:

- Inclusion of an analysis model - A state-of-the-art analysis model will be incorporated into the GTWAPS modeling suite. The NOAA Forecast Systems Lab (FSL), in association with the USAF Air Weather Service, has installed the Local Analysis and Prediction System (LAPS) on the AFGWC SP2. ANL is tasked to make the LAPS model as
easily relocatable as the rest of the modeling suite so as to support the USAF operational needs.

- Investigation of using LAPS to initialize nested domains.
- Investigation of Four Dimensional Data Assimilation (FDDA) methods for inclusion in the analysis and forecast models.
- Visualization - Advanced photorealistic and scientific visualization products that meet Air Force operational needs will be investigated for inclusion into the GTWAPS system. Currently, FSL's WFO-Advanced 3D workstation, which is designed for National Weather Service (NWS) weather forecast offices, is being assessed for usability at AFGWC.
- Navy Operational Global Atmospheric Prediction System (NOGAPS) - As part of the integration of the LAPS system, initial and boundary conditions from the NOGAPS model are being used. This model output would be used instead of the RWM model output.

6 ACKNOWLEDGMENT

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7 REFERENCES


