PHAiRS interoperability and high-performance computing testbed:
Project Overview
Oct. 15 2008

GIO sponsored and managed an Interoperability & High-Performance Computing testbed as an extension to the fifth and final year of the NASA-funded Public Health Applications in Remote Sensing (PHAiRS) project.[a] This Testbed, a collaborative effort between GIO, George Mason University, and the Universities of New Mexico and Arizona, has resulted in the following accomplishments:

- Enhanced end-user access, via Web-based standards[b], to two different atmospheric dust models: the Dust Regional Atmospheric Model (DREAM-Eta) and the Nonhydrostatic Mesoscale dust model (NMM-dust), both based on meteorological models developed by NOAA's National Center for Environmental Prediction (NCEP). Operational Web services running at the University of New Mexico are “powered by” George Mason University's high-performance computing resource via a high-speed (Lambda Rail) Internet link.
- Enhanced model access to NASA MODIS-based land-cover data on demand (again, via Web-based standards[c]) from NASA’s Land Processes Data Archive (LP-DAAC) in Sioux Falls, SD. A suite of scripts retrieve the land-cover data, infer surface dust sources from it, and feed them as input to the two models. This will, in the near future, allow modelers to experiment easily with alternative representations of dust sources – e.g. weekly greenness maps in place of a yearly composite product – from LP-DAAC or anywhere that uses WCS. This may lead to much more precise forecasts.
- Enhanced the performance of the NMM-dust model using parallel computing: e.g., using 60 or more CPU cores speeds up model runs tenfold. Significantly faster run-times open up new possibilities for wholesale model validation (e.g., comparing daily forecasts and observations for a whole year) and for experimental and exploratory usage (e.g., trying out various representations of land cover and surface dust sources).
- Enabled cooperation between the two dust models: forecasts from coarse-grain, regional runs of DREAM-Eta are being used as initial conditions for fine-grain runs of NMM-Dust. This was accomplished by homogenizing the format and content of their dust inputs and outputs, based on the GRIB1 standard from the World Meteorological Organization.
- Developed a new fine-grain dust model, known as NMM-Dust, based on NOAA's Nonhydrostatic Mesoscale Model (NMM). (This was not called for in the project plan, but became necessary upon a staff change on the U. Arizona modeling team.)

In the near future, these outcomes will serve follow-on projects in pollen transport and other related atmospheric modeling. Plans are also underway to validate the models, explore further model interoperation, experiment with alternative inputs, and build out useful end-user applications.

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[a] PHAiRS is a collaboration between the University of New Mexico (UNM)’s Earth Data Analysis Center and the University of Arizona (UA)’s Department of Atmospheric Sciences, to develop an application framework to enhance public-health Decision Support Systems such as the Syndrome Reporting Information System (SYRIS).

[b] Standard Web services serve to streamline the development of Web-based visualization and analytical tools for public health decision support. Examples include the Web Map Service (WMS) and formats such as KML (used by Google Earth and other tools), both in widespread use and adopted as standards by the Open Geospatial Consortium (OGC)

[c] The OGC Web Coverage Service (WCS) is the preferred service standard for retrieval of gridded data useful to models.

Leverage Model Interoperability and High Performance Computing to Improve Public Health Application

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To

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Table of Contents

1 Project overview

NASA produces information about the Earth from satellites, computational models, and other sources; and archives them for use by an extensive research community. These data are most useful when they're easily accessible to NASA researchers and scientists, to NASA's partner Federal Agencies, and to society as a whole. A key NASA objective is to apply its research results about Earth and other planetary systems for improved knowledge and more effective decision support. The NASA Geosciences Interoperability Office (GIO) leads the development, promotion and implementation of geoscience information architectures and interoperability standards, to accelerate and expand the impact of NASA's Earth system science research through integrated systems solutions.

The Public Health Applications in Remote Sensing (PHAiRS) project is a collaboration between the University of New Mexico's (UNM) Earth Data Analysis Center and the University of Arizona's (UA) Department of Atmospheric Sciences. The PHAiRS project developed an application framework to enhance the capabilities of a dust forecast model (DREAM) and existing public-health Decision Support Systems such as the Rapid Syndrome Validation Project (RSVP), developed by Sandia National Labs, and its commercial successor, the Syndrome Reporting Information System (SYRIS). These efforts improve airborne dust alerts for public health officials and clinicians by simulating and predicting dust storms and atmospheric concentrations of respirable (PM_{10}) and inhalable ($PM_{2.5}$) particulate matter. However, to support improved decision making enabled by the RSVP and SYRIS system, the resolution of the dust model output needed to be increased to the zip code level, or about 3×3km resolution.

To achieve this higher resolution, we proposed interoperability and high performance computing technologies to enhance dust storm forecasting. The project is also to demonstrate enhanced web-based visualization and analytical tools to public health decision makers. The project also draws on Web-based access to Moderate Resolution Imaging Spectrometer (MODIS) data from NASA's Land Processes Distributed Active Archive Center (LP-DAAC) for ingest into the Dust Regional Atmospheric Model (DREAM-eta), and into the higher-resolution NMM-dust, developed through this project, (NMM is the National Centers for Environmental Prediction's Non-hydrostatic Mesoscale Model) that interoperates with DREAM-eta.

This project sought to test the use of interoperability to leverage high performance computing, geoscience models, and national applications to increase the spatial domain, spatial resolution, and period of forecast when applying the DREAM-eta model. The project aimed to reduce the execution time for both DREAM-eta and NMM-dust and to introduce end users to model products tailored to perceived needs of public health services. These goals support the PHAiRS project, and the GEOSS Objectives were tested in a proof-of-concept basis; further research is needed to bring the interoperable features of the two models into preferred operational mode.

The project was funded by NASA GIO under the direction of Ms. Myra J. Bambacus; and managed by Dr. John Evans. Drs. Chaowei Yang, Karl Benedict, and William A. Sprigg were the Principal Investigators and responsible technical personnel.

Dr. Evans also provided technical guidance and coordination through a weekly teleconference. A project website hosted by UNM served to maintain and archive communications.

This final report summarizes the activities performed in the project, remaining future research needed from a scientific point of view, and publications and presentations supported by the project.

2 Project activities

2.1 Model Preparation

At the project's outset, we planned to use the DREAM-Eta and WRF-NMM-dust models contributed by Univ. of Arizona (UofA). However, the departure of a senior member of the UofA team led them to engage two other modelers (Goran Pejanovic and Slobodan Nickovic) in configuring an updated DREAM-Eta model (with 8 dust-particle-size bins instead of 4), and in developing a new model based on the NCEP NMM model. The new model leverages theoretical knowledge from Dr. Nickovic and was written by Mr. Pejanovic with significant assistance from Jibo Xie of George Mason University. This major shift required redirecting much of GMU's time to this effort. We refer to the new NMM-based dust model as NMM-dust.

About the models:
DREAM-Eta is built on a National Weather Service (NWS) operational forecast model known as Eta. Eta is defined on the semi staggered Arakawa E grid and uses the technique for preventing grid separation in combination with split-explicit time differencing. The step-mountain Eta model has shown considerable skill in forecasting severe storms, but its spatial resolution (1/3 of a degree in latitude and longitude) is too coarse for many potential applications. With current horizontal resolutions, models used for numerical weather prediction (NWP) are approaching the limits of validity of the hydrostatic approximation. Therefore, a few years ago the Eta model was replaced in NWS operations by a Non-hydrostatic Mesoscale Model (NMM), which has higher resolution and greater computational efficiency (Janjic et al., 2001, Janjic 2003). In turn, NOAA's National Centers for Environmental Prediction (NCEP) recently replaced NMM with WRF-NMM (based on the UCAR Weather Research Framework)for operational use.

The NMM-dust model is used to test both interoperability with DREAM-Eta and supercomputing for large area operation. The NMM-dust model is executable in parallel mode in a High-Performance Computing (HPC) environment, because it is based on the NCEP_NMM weather forecasting model. Thus, the NMM-dust model can produce higher resolution dust simulation results up to about 1×1km.

Model testing was performed through the following steps:

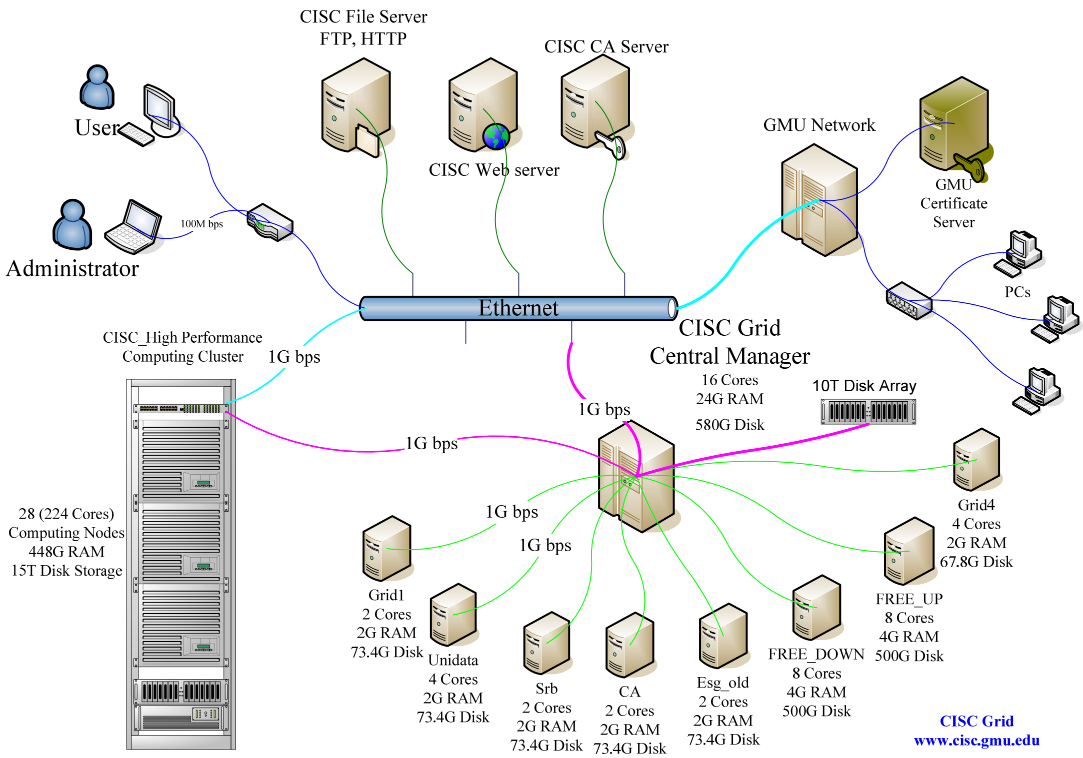
- Initial tests were accomplished by specifying first the elevation and then the surface point source with arbitrary values of injected dust concentration. Only model dynamics were used to test model performance, i.e. horizontal and vertical advection and horizontal and vertical diffusion were used to disperse dust from the point source.

- When expected results were obtained from the previous step, the second phase replaced the point source with the geographically distributed dust sources, specified according MODIS (MOD12) land cover data.

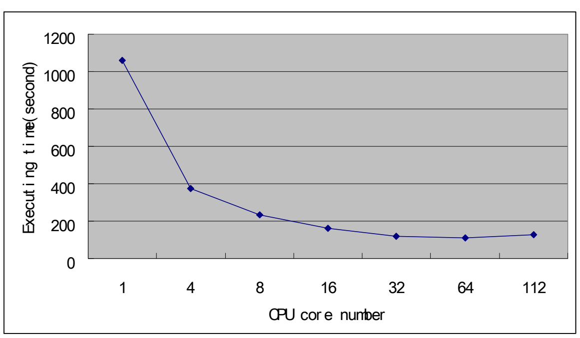
- Final tests included all dust components (dynamics and source/sink components) and NMM-dust results were compared with the DREAM-Eta with the same domain/resolution specification; very comparable features of the dust fields in both models were obtained.

2.2 High Performance Computing (HPC)

The project used a computing cluster hosted by GMU's Center for Intelligent Spatial Computing to provide HPC support. The HPC configuration is illustrated in Figure 1.



The NMM dust model (with 1/9 degree resolution) was tested by using 1, 4, 8, 16, 32, 64 and 112 CPU cores on the GMU HPC server (with 28 computing nodes and 224 CPU cores) for performance comparison. As illustrated in Figure 2 below, the best performance (cost of 111 seconds with a speedup factor of 9.54) was obtained when 64 CPU cores – yielding an efficiency of 9.54/64 = 15% in utilizing the CPU cores.



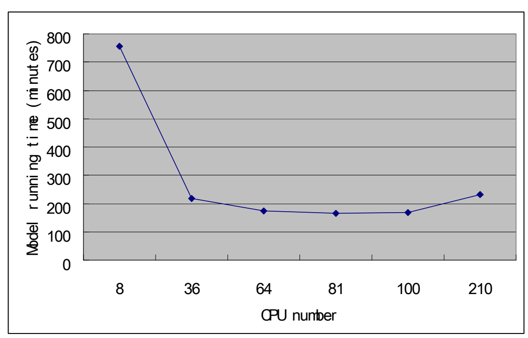


Figure 2. $(1/9)^{\circ}$ resolution NMM performance   Figure3. 3km resolution NMM performance

The NMM-dust model with 3km resolution was tested by using 8, 36, 64, 81, 100, 210 CPU cores on the GMU cluster. Excluding preprocessing and postprocessing time[1], the performance of the model

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[1] Postprocessing is used to quilt the separate tiles into a composite result. It is time consuming, but can only run in serial mode, therefore its performance is independent of the number of CPUs used.

runs was tested and the best performance was obtained when using 81 CPU cores are used as illustrated in Figure 3 above.

2.3 Model Interoperability

Initially, the new DREAM-eta model was run at a coarser resolution and NMM-dust was run with a higher resolution. It would be ideal if we can run NMM-dust for the entire forecasting region, but the NMM-dust is very computing intensive: run times increase as the third or fourth power of spatial resolution. For example, if we triple the resolution (say, from 1/3 to 1/9 of a degree), the computing time will increase by a factor of 27 = 3 (latitude) * 3 (longitude) * 3 (time steps), or even 81 if altitude resolution is increased commensurately. Therefore, it's not feasible to run the high resolution NMM model for the entire continent or the world. Instead, we can use DREAM-eta with coarse resolution when a large geographic area should be covered. The higher resolution model can be executed for specific subregions based on initial dust storm identification of the coarse model. This approach requires the interaction or interoperability between the two models.

The ideal approach of model interoperability is to use the coarse model to identify hotspots of higher predicted dust concentration and run the fine-grain model on the hotspot areas. This requires access to both models, and entails triggering the high resolution NMM model based upon the output of the coarse resolution DREAM-eta model. Therefore, we did a proof-of-concept study to identify dust storms on a static basis and simulate the near real-time dust model interactions.

The use case we identified is to use the coarse model (DREAM-eta 8-bin) to identify hotspots of higher predicted dust concentration and run the fine-grain model (NMM-dust) on the hotspot areas. The dust simulation results from coarse resolution (1/3 degree) DREAM-eta dust model can serve as the initial background dust and can provide more reasonable simulation results. The preprocessing of the NMM-dust model is designed to ingest and transform the output from DREAM-eta dust model. After ingesting the DREAM-eta output the NMM-dust can start simulation. Experiments have been performed to show results of model interoperability. Figure 4 shows the coarse results simulated by DREAM-eta 8p dust model for the southwest U.S. region. Arizona and New Mexico sub domains are selected for high resolution (1/10 degree) NMM-dust model runs as illustrated in Figures 5 and 7 (white dots). The higher resolution results from the NMM-dust model are shown in Figures 6 and 8.

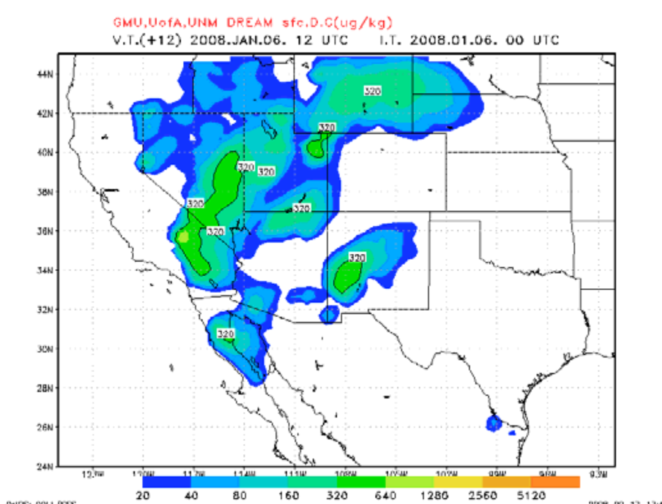
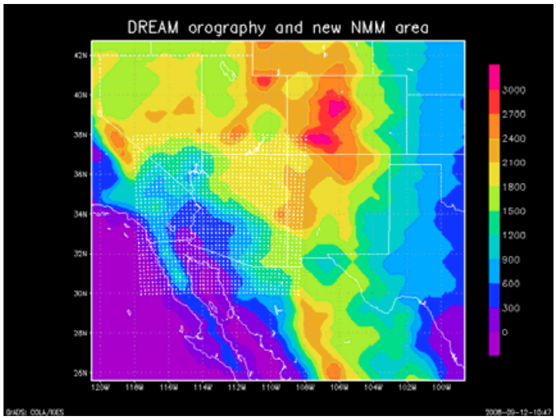


Figure 4. Southwest U.S dust simulation result by DREAM-eta 8p model



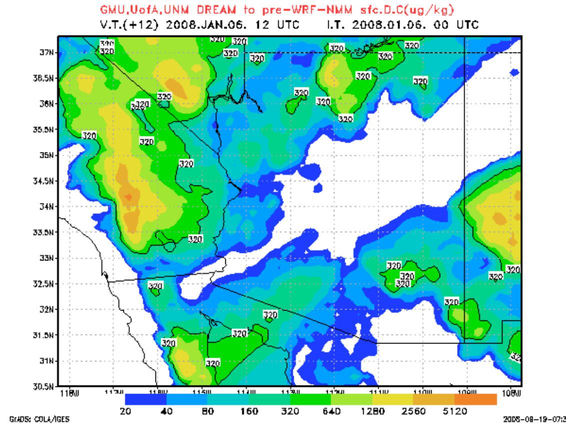
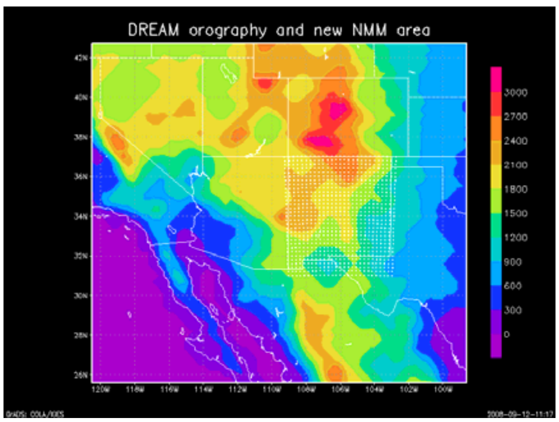


Figure 5. sub domain in AZ (white dotted)

Figure 6 NMM-dust result for the sub domain



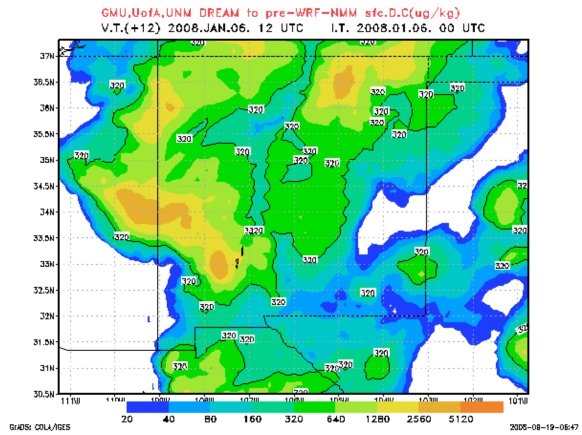


Figure 7. sub domain in NM (white dotted)

Figure 8. NMM-dust result for the sub domain

Model interoperability work for the project has focused on the definition of standard input and output file formats for both the 8p and NMM-dust models so that the outputs of one could be used as inputs into the other. Specifically, it was decided to use the GRIB1 as the file format for the outputs of both models, allowing standard meteorological data processing tools to access and process these products. Specifically, both models are able to read GRIB1 files for model initialization and boundary condition specification, while GRIB1 files may also be read and converted using the *wgrib* utility for use in other systems. Figure 9 illustrates the flow of data through the various system components enhanced or developed as part of this project.

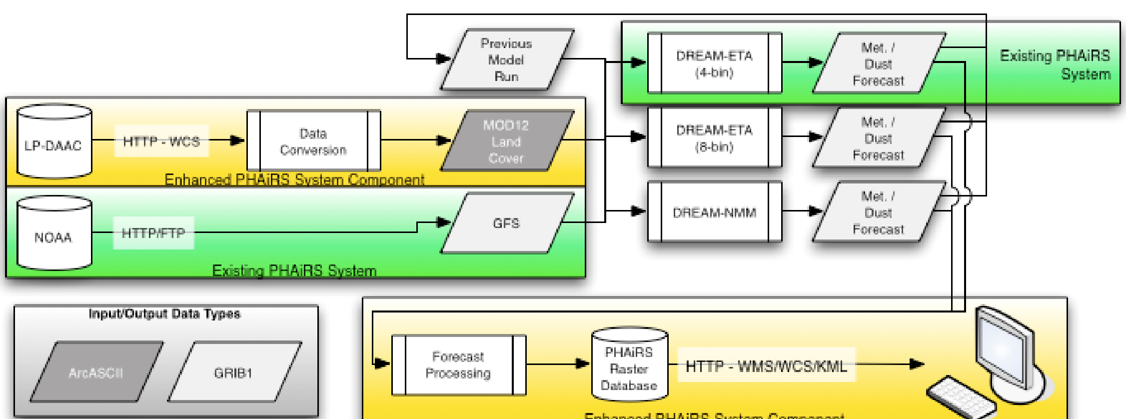


Figure 9, Data Flow and Processing Steps for the PHAiRS and Interoperability Test Components

The figure shows the GRIB1 products (labeled “Met. / Dust Forecast”) generated by both the PHAiRS project’s 4-bin model and the Interoperability Testbed’s 8-bin and NMM models outputs. These products are then linked to the “Previous Model Run” model input GRIB1 component that may be used to initialize any of the three models for a subsequent model run. The use of a common, well supported data format for both model initialization and output significantly streamlines the process of developing multi-model workflows where the output of one model is used to initialize another, either for a model run for a subsequent time step, or for the execution of a higher resolution model for the same time period over which a low-resolution model has already been run.

GRIB (**GRIdded Binary**) is a mathematically concise data format commonly used in meteorology to store historical and forecast weather data. It is standardized by the World Meteorological Organization's Commission for Basic Systems, known under number GRIB FM 92-IX, described in WMO Manual on Codes No.306 (WMO, 1992). Currently there are two versions of GRIB; the first edition (current sub-version is 2) is used operationally world-wide by all meteorological centers, for Numerical Weather Prediction output (NWP). A newer generation, known as GRIB second edition, is used by few centers and in many cases not for operational broadcast. In our project, version 1 is used.

GRIB is an efficient vehicle for transmitting large volumes of gridded data over high-speed telecommunication lines. By packing information into the GRIB code, messages (or records - the terms are synonymous in this context) can be made more compact than character oriented data formats, which permits faster computer-to-computer transmissions. GRIB can equally serve as a data storage format, generating the same efficiencies relative to information storage and retrieval devices.

Each GRIB record intended for either transmission or storage contains a single parameter with values located at an array of grid points, or represented as a set of spectral coefficients, for a single level (or layer), encoded as a continuous bit stream. Logical divisions of the record are designated as "sections", each of which provides control information and/or data. A GRIB record consists of six sections, two of which are optional:

(0) Indicator Section
(1) Product Definition Section (PDS)
(2) Grid Description Section (GDS) - optional
(3) Bit Map Section (BMS) - optional
(4) Binary Data Section (BDS)
(5) '7777' (ASCII Characters)

Although the Grid Description Section is indicated as optional, it is highly desirable that it be included in all messages. That way there will be no question about just what is the "correct" geographical grid for a particular field.

With this project, we created a GRIB-based scheme for encoding dust information. The resulting BRIB dust format is documented in annex A.

2.4 System Interoperability

The system interoperability activities for this project have been related to the development of interoperable interfaces with external data resources used by the PHAiRS system, and in the development of enhanced interoperable services for the delivery of products and data to PHAiRS system users. The interoperability work accomplished for this project relates to the existing PHAiRS architecture (Figure 10) in two specific areas, data ingest (labeled 1 in Figure 10) and map image delivery (labeled 2 in Figure 10).

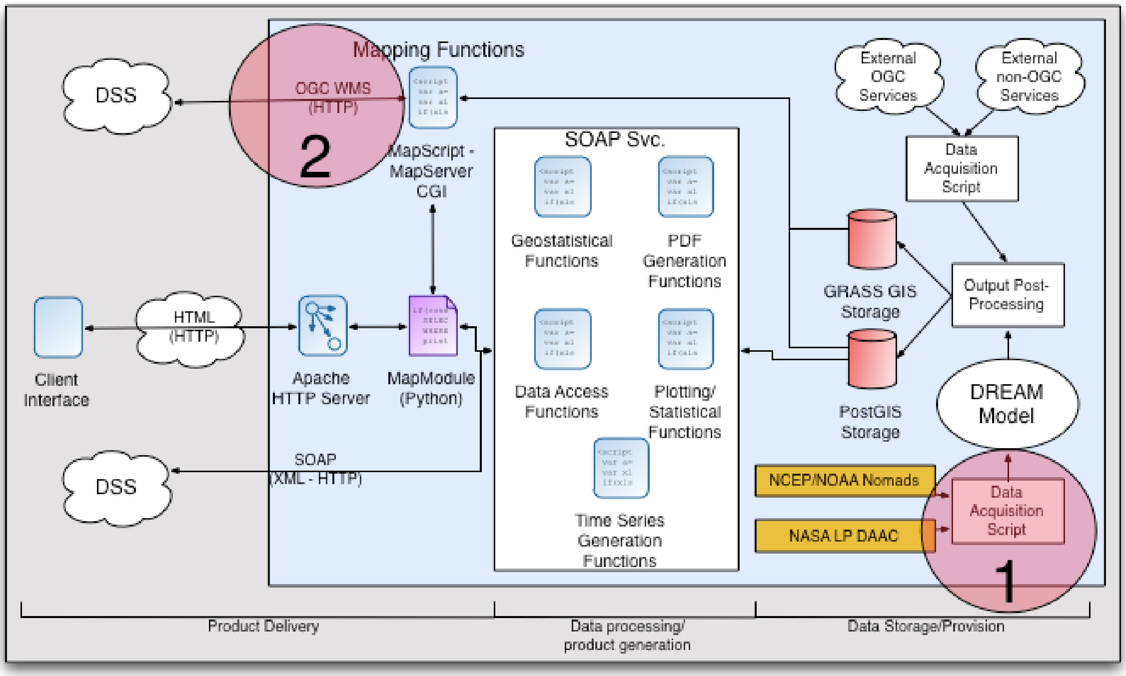


Figure 10, PHAiRS System Architecture highlighting areas of interoperability enhancement emphasized in the project.

The open standards employed in this project closely relate and add to the existing Open Geospatial Consortium (OGC) standards deployed as part of the PHAiRS project. Specifically, system support for OGC's Web Map Service (WMS, de la Beaujardiere, 2006) was expanded to include time-enabled delivery of DREAM model outputs as a complement of the existing time-enabled WMS for EPA AirNOW data. This enhancement greatly streamlined the delivery of model outputs, and led to a re-engineering of some of the existing web-based interfaces developed for the PHAiRS project. These time-enabled WMS for the DREAM-Eta output are also the foundation for the direct integration of DREAM-Eta data into the SYRIS syndromic surveillance system – the public health decision support system that the PHAiRS project is targeting for enhancement. Examples of these time-enabled WMS services may be found online at

- http://phairs-devel.unm.edu/cgi-bin/dreamwms and
- http://129.24.63.59/cgi-bin/mapserv?map=mapmodule_dream8bin_wms.map

The delivery of these time-enabled WMS products was further enhanced through the development of automated KML generation scripts that are executable through a basic web form (Figure 11). These scripts produce a custom KML file that allows for the visualization of a time series of model outputs in any client that supports the WMS and *timespan* components of the OGC KML standard (Wilson, 2008). This capability was tested and demonstrated through the Google Earth virtual globe application (Figure 12).

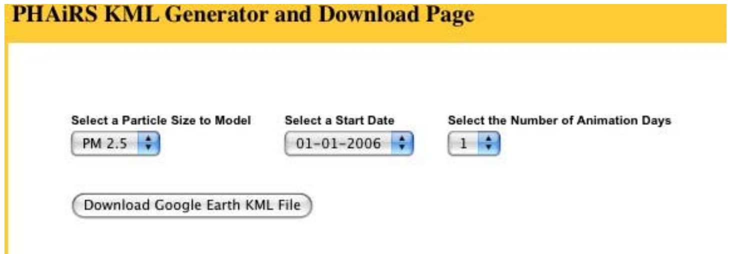


Figure 11, Online form for the automatic generation of a KML file for the visualization of a specified dust forecast product ($PM_{2.5}$ or PM_{10}) for a specified period of time.

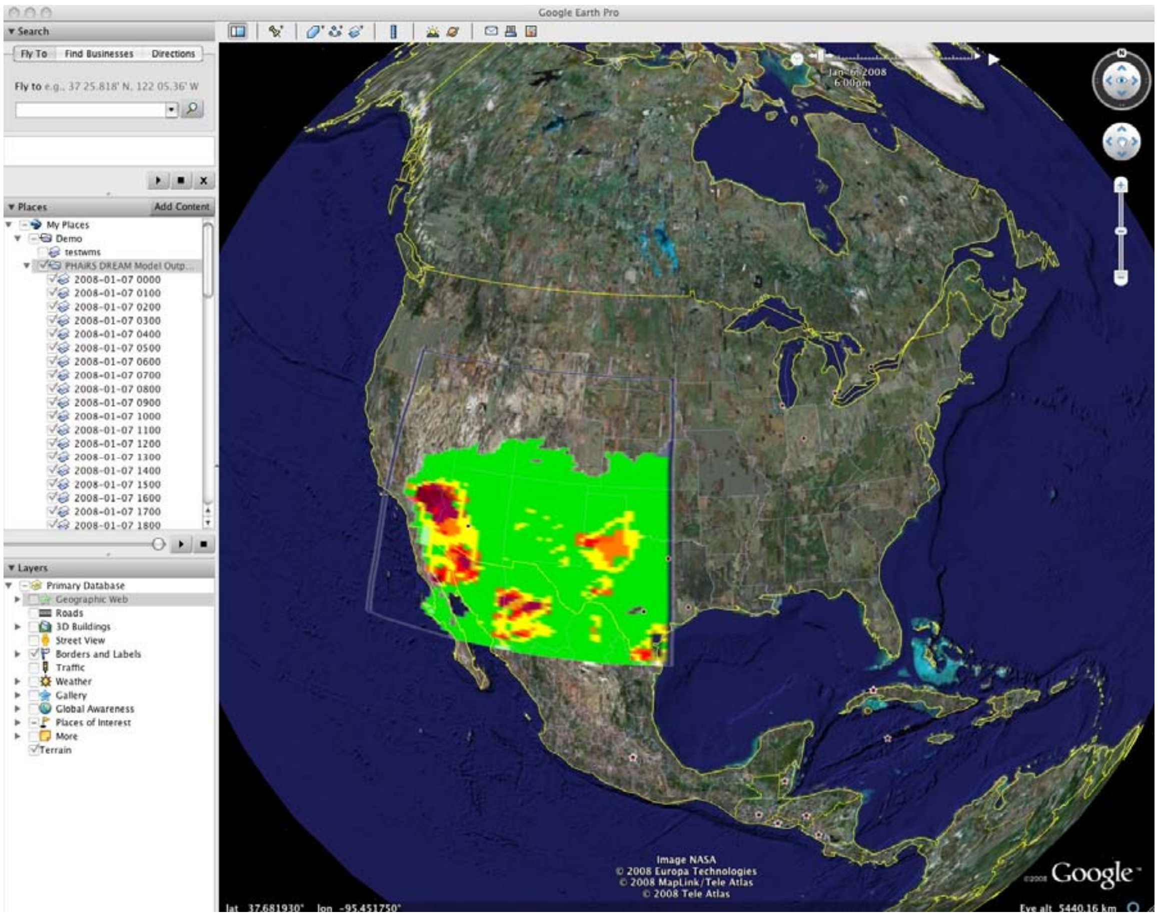


Figure 12, Single frame of a series of WMS requests encoded in KML shown in Google Earth

In addition to the data delivery services described above, the use of interoperable standards-based interfaces was also increased through this project. In particular, automated data access scripts for the OGC Web Coverage Services (WCS, Whiteside & Evans, 2006) published by NASA’s Land Process Distributed Archive Center (http://lpdaac.usgs.gov/main.asp) were developed for the acquisition of MOD12 land cover data products. These data are used in the initialization of all versions of the DREAM model used in the PHAiRS and PHAiRS interoperability projects (Figure 1), with access to recent land cover data via WCS facilitating execution of the DREAM model with current vegetation data.

Additional work in the development of WCS for the outputs of the DREAM-Eta (4-bin) was performed, with initial progress, but limited by the current capabilities of the software solutions currently in use by the PHAiRS project. Specifically, initial services were developed, but ultimate success was limited by the combination of server software (MapServer) and related database application (PostgreSQL/PostGIS) and discovered limitations in the combination of these two technologies to deliver the required time-enabled WCS services.

3 Accomplishments and discussion

3.1 Model

Transition of the 8-bin dust component into NMM-dust was performed by extending the NMM model through the development of an additional dust concentration module. Since the dust component has a similar (mass conserving) structure as, for example, the equation for specific humidity in NMM, dust and specific humidity were handled similarly. They differ in the deposition (source) and emission (sources) as parts specific for dust. These two components were done in a separate routine, following the way of parameterization in the 8-bin code. The two models (8-bin and NMM-dust) are initially tested by comparing to the PHAiRS project's 4-bin code and matched the results in principle. The 8-bin and NMM-dust models are utilized for model interoperability studies and yield good results.

Initial tests within the project have been performed with the DREAM-eta 4 bin system (Nickovic et al. 2001). In this system, DREAM model dust particle distribution is described with 4 sizes, ranging in radius from 0.7 – 40 µm. Since the hydrostatic NCEP/Eta cannot be applied with resolution higher than ~ 5km in horizontal, in the next step we replaced the NCEP/Eta with the Nonhydrostatic NCEP/NMM (Janjic et al., 2001) that may be used in a high resolution mode. At the same time NCEP/NMM can be run in a parallel execution mode, which is not the case with NCEP/Eta.

Theoretical thoughts was made to transfer the DREAM8 component (Nickovic, 2004; Nickovic 2005; Peres et al., 2006) into the NCEP/NMM, DREAM8 being the dust model version that resolves dust particle distribution with 8 particle bins ranging from submicron radius to 10 µm. Smaller particles are used in the project having in mind that such particle size range is more appropriate for possible future use of the modeling system for public health. Incorporating the knowledge gained, we developed the NMM-dust model in the project.

3.2 Interoperability

Through the project, interoperability is built into several activities: a) model interaction is investigated, b) a data service is provided with web map service and web coverage service, c) data ingest is implemented with web coverage service. These aspects made it possible for broader adoption of the research results into other systems. This project made significant contributions to the interoperability capabilities of the underlying PHAiRS project through the development of enhanced OGC services. Specifically, the development and deployment of additional time-enabled WMS for DREAM-eta model outputs has facilitated the deployment of these Earth science products into public health decision support systems (SYRIS) while also demonstrating the value of developing standards-based delivery systems (i.e. KML) into other, more general visualization systems.

While the current project has identified limitations in the current generation of data delivery server software, it has also highlighted areas for further development in these applications, particularly in the areas of server and client support for the OGC standards. These lessons learned are outlined in the next section.

The interoperability concept utilized in this project aims to permit different modelling systems with different domains and resolutions to communicate in a general manner. This is achieved through the use of following approaches:

- a common pre-processor for both DREAM4-eta and NMM-dust; a corresponding decision was therefore made to use NMM with eta-like pre-processing.
- a common post-processor for both DREAM4-Eta and NMM-dust to provide
    - common input formats for initial/boundary conditions for the higher resolution nested model members in the interoperability modelling chain
    - common input for either GRADS or GRASS GIS post-processing and visualization

This required all initial/boundary conditions inputs prepared in the regular lat-lon grids at (10 in our setup) standard pressure levels for conventional and dust concentration data. As a common interface for these input parameters, the GRIB1 format was chosen to be the primary data format between models at all interface levels.

Conventional GRIB encoder/decoder software programs were modified to be able to process dust parameters. The modification relates to the extension of the GRIB metadata information (i.e. extension of parameter tables that originally do not include aerosol data), as documented in Annex A.

3.3 Future Research Topics

While achieving significant results in itself, this project has also identified several areas for future research that are worthy of continuing investment. These areas include technical the application aspects.

3.3.1 Technical

- Migrating the model into WRF-NMM or an Atmospheric General Circulation Model (AGCM) would facilitate wider adoption of the model. It would also allow continuous scanning of North America, for example, for conditions leading to dust storms, and then focusing, or downscaling, to provide timely, “at your zip code,” warnings and forecasts of dust concentrations for public safety and health.
- Testing and evaluating the models to document their skill score and other measures of performance. The models tested here have been validated through comparison with one specific dust storm scenario. Utilizing historical data and EPA *in situ* sensor observations to validate the accuracy of the model would be needed.
- Improve model applications through data assimilation: More data, such as soil wetness and seasonal vegetative cover will be needed to improve the scientific value and credibility of the model.
- Integrating the models within an operation environment to support a GEOSS societal benefit area will further enhance the utility of the modelling system.
- Continue to develop server applications that host OGC WCS services to support time-enabled services. The specific combination of applications used in this project includes MapServer and PostgreSQL/PostGIS, but other server platforms (i.e. ArcSDE/ArcGIS Server) could also benefit from their expansion of support for time-enabled WCS services.
- Develop standards-based service interfaces for common meteorological forecasting models that allow for the integration of initialization parameters obtained from remote data servers.
- Develop queue-based model execution environments in which subsequent model runs may be defined and executed based upon the results of previous model runs.

- Develop high-performance computing capabilities that are capable of executing on-demand model runs that are customized based upon the outputs of other model runs.

3.3.2 Application

Public interest[2] and unsolicited inquiries[3] from a user base broader than the one targeted by the NASA-sponsored PHAiRS[4] project, have been eye opening. PHAiRS has demonstrated that NASA's current observation system is essential if the World Meteorological Organization's International Sand and Dust Storm Warning and Assessment System and any new applications implied by these inquiries are to succeed. The UA and UNM current, NASA-funded, projects expanding upon DREAM and inventing new applications of NASA products include:

- DECISIONS, "Adding NASA Earth Science Results to EPHTN[5] via the NM/EPHT System," a three-year project linking the universities of New Mexico and Arizona, will apply new A-Train and dust forecast products as well as already proven MODIS observations to the New Mexico Environmental Public Health Tracking System, New Mexico's contribution to CDC's Environmental Public Health Tracking Network (EPHTN);
- RPC, "Rapid Prototyping Capability For Environmental Factors Affecting Asthma and Allergies," aka the "Pollen Project," in collaboration with Marshall Space Flight Center and the Universities of New Mexico and Arizona, explores DREAM modifications and additional NASA "vegetation" products to simulate and predict pollen emission and downwind dispersal, a prototype for phenological properties and events.

One of us (Sprigg) leads the international drafting team for plans to implement the WMO Sand and Dust Storm Warning Advisory and Assessment System. The world community would welcome a modeling system empowered by the work accomplished here. This project is **a step-function increase in opportunities and applications** for our regional atmospheric models.

New clients and applications we may now anticipate include:

1) Wildfire control-burn scheduling and management;
2) Forest fire-fighting strategic and tactical support for fire-fighter safety;
3) Assessment of superfund site remediation;

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[2] Newspaper articles in 2008 highlighting our work have appeared in the *Washington Post*, *Arizona Daily Star*, and *Arizona Republic*. Television interviews have been made by the media arm of the American Institute of Physics and by KUAT Public Television. The news magazine *Arizona Highways* has requested an interview; the German news magazine *Der Spiegel* is preparing a feature article for publication in Fall of 2008.

[3] Davis Monthan Air Base needs forecasts of visibility-reducing dust concentrations for flight operations. The California Water Resources Board asked for analysis of potential contamination of water supplies from wind blown mine tailings. The USGS Binational Center calls attention to potential wind-blown transport from toxic waste dumps in the US/Mexico border region. Investigators from an EPA Superfund site ask for assessment of downwind transport of toxic waste. New Mexico health officers have asked about potential DREAM applications to assess concerns over renewed open-pit uranium mining on a Four-Corners' Navajo Reservation.

[4] Public Health Applications in Remote Sensing

[5] Environmental Public Health Tracking Network

4) Assessment of health risks due to toxic waste dumps, relaxation of cross-border truck emission standards with Mexico

5) Assessment of proposed expansion of open-pit mining in Arizona as copper prices continue to rise;

6) Assessment of proposed expansion of open-pit uranium mining on Navaho reservations in the four-corners region of New Mexico, Colorado, Arizona and Utah as nuclear power becomes a more popular energy-producing option;

7) Forecasts and hindcasts of visibility-reducing airborne dust conditions for USAF flight support;

8) Forecasts and warnings of visibility-reducing dust storms for highway safety and emergency response personnel; and

9) Warnings and assessments related to natural, accidental, or intentional release of aerosols and particulates for purposes of homeland security and emergency response.

The team anticipates global use of the new models in the WMO Dust Storm Warning System and, concomitantly, providing a US contribution to the GEO. If carried forward, the models can be an adjunct to Natural Hazards (a service of NASA's Earth Observatory)[6], and contribute to UN-SPIDER[7], enhancing NASA programs, priorities and product applications.

But, we should take our current success a step further to truly capitalize on it. We will demonstrate that the models work together in a few realistic, but not operational, situations. However, the system should be run over a period of time under varying environmental conditions and larger geographical area to see if our interoperability tests are consistent and to estimate error and bias of the modeling system and the satellite data feeding it. We need to quantify joint observation/model reliability and performance as a measure of credibility for our current clients in public health services and to convince potential clients of broader applications for this satellite-based observation and modeling system. Furthermore, the product of the UA and UNM collaboration with Marshall Space Flight Center (the Phenology Regional Atmospheric Model) and the USGS's National Phenology Network, and the WRF-NMM should be added to this project' high-performance interoperable system. The models are similar. Considerable flexibility will be gained with comparatively little effort.

4. Publications and presentations

1) Benedict K., 2008. OGC Time-enabled WMS: an Introduction with Deployment into Google Earth. Invited lecture presented at Denver University, April 28, 2008.

2) Benedict K., 2008. The Development of Standards-Based Services Oriented Architectures at EDAC, Lessons Learned From Three Application Contexts. Paper presented at the AGU General Assembly, Ft. Lauderdale, FL. May 29, 2008.

3) Benedict K., 2008. OGC Time-enabled WMS: an Introduction with Deployment into Google Earth. Paper presented to the NASA DSWG Standards Process Working Group, meeting at the Summer ESIP Federation meeting, Durham, NH, July 15, 2008.

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6 http://naturalhazards.nasa.gov/ http://earthobservatory.nasa.gov/

7 United Nations Platform for Space-based Information for Disaster Management and Emergency Response

4) Benedict K., 2008. The PHAiRS Project - SOA for the delivery of regionalized dust forecast data to public health professionals. Paper presented at the ESIP Federation Summer Meeting, Durham, NH, July 15, 2008.

5) Benedict K., 2008. Public Health Applications in Remote Sensing. Poster presented at the ESIP Federation Summer Meeting, Durham, NH, July 16, 2008.

6) Xie J. and Yang C., 2008. High Performance Computing support for Dust simulation model, manuscript submitted to Journal of *Computers, Environment and Urban Systems*.

7) Xie J., Yang C., 2008. Grid enabling geospatial applications: Methodology & practice, AAG 2008 annual meeting, *AAG annual meeting*, Boston, Massachusetts, April 15-19, 2008. (Oral).

8) Yang C., 2008. GeoCyberinfrastructure, *Cyberinfrastructure Workshop at the GIScience'2008 conference*, Sept. 23, 2008, Park City, Utah.

9) Yang C., 2008. Virtual Globes: Implications and Challenges, *Virtual Globes Panel at the GIScience'2008 conference*, Sept. 26, 2008, Park City, Utah.

10) Xie J., Yang C., Pejanovic G., Zhou B., Huang Q., 2008. Utilize multi CPU cores to improve dust simulation performance, *AGU 2008 Fall Meeting*, San Francisco, December 15-19, 2008, (Poster).

5. References

1) de la Beaujardiere, J. (Ed.). (2006). *OpenGIS Web Map Server Implementation Specification, Version 1.3.0* (Vol. OGC® 06-042): Open Geospatial Consortium.

2) Herring, J. R. (Ed.). (2006). *OpenGIS® Implementation Specification for Geographic information - Simple feature access - Part 2: SQL option, Version 1.2.0* (Vol. OGC 06-104r3): Open Geospatial Consortium.

3) Janjic, Z. I., J. P. Gerrity, Jr. and S. Nickovic, 2001: An Alternative Approach to Nonhydrostatic Modeling. Monthly Weather Review, Vol. 129, 1164-1178

4) Janjic, Z. I., 2003: A Nonhydrostatic Model Based on a New Approach. Meteorology and Atmospheric Physics, 82, 271-285.

5) S. Nickovic, G. Kallos, A. Papadopoulos, O. Kakaliagou, 2001: A model for prediction of desert dust cycle in the atmosphere J. Geophys. Res. 106, 18113-18130.

6) Nickovic, S., 2004: Interactive Radiation-Dust Model: A Step to Further Improve Weather Forecasts (invited presentation). *International Symposium on Sand and Dust Storm, Beijing, China, 12-14 September2004.*

7) Nickovic, S., (2005), Distribution of dust mass over particle sizes: impacts on atmospheric optics, Forth ADEC Workshop - Aeolian Dust Experiment on Climate Impact, 26-28 January, Nagasaki, Japan, 357-360.

8) S. Nickovic, G. Kallos, A. Papadopoulos, O. Kakaliagou, 2001: A model for prediction of desert dust cycle in the atmosphere J. Geophys. Res. 106, 18113-18130.

9) Whiteside, A., & Evans, J. D. (Eds.). (2006). *Web Coverage Service (WCS) Implementation Specification, Version 1.1.0* (Vol. 06-083r8): Open Geospatial Consortium.

10) Wilson, T. (Ed.). (2008). *OGC® KML, Version 2.2.0* (Vol. OGC 07-147r2): Open Geospatial Consortium.

11) WMO Manual on Codes No.306, FM 92-IX Ext. GRIB, WMO 1992 http://www.wmo.int/pages/prog/www/WMOCodes/Guides/GRIB/GRIB1-Contents.html

12) Xie J., Yang C., Huang Q., Cao Y., Kafatos M., 2008. Utilizing grid computing to support near real-time geospatial applications, *IGARSS 2008*, Boston

13) Yang C., Li W., Xie J., Zhou B., 2008. Distributed Geospatial Information Processing" *International Journal of Digital Earth* (in press).

Annex A. Output Dust Encoding Format in NMM-dust

```
/* 200 */ {"DUMSK", "Dust mask [fraction]"},
/* 201 */ {"DUC1", "Dust concentration part.matt. 1 [kg/m3]"},
/* 202 */ {"DUC1", "Dust concentration part.matt.2 [kg/m3]"},
/* 203 */ {"DUC1", "Dust concentration part.matt.3 [kg/m3]"},
/* 204 */ {"DUC1", "Dust concentration part.matt.4 [kg/m3]"},
/* 205 */ {"DUC1", "Dust concentration part.matt.5 [kg/m3]"},
/* 206 */ {"DUC1", "Dust concentration part.matt.6 [kg/m3]"},
/* 207 */ {"DUC1", "Dust concentration part.matt.7 [kg/m3]"},
/* 208 */ {"DUC1", "Dust concentration part.matt.8 [kg/m3]"},
/* 209 */ {"MIXLY", "No. of mixed layers next to surface [integer]"},
/* 210 */ {"var210", "undefined"},
/* 211 */ {"SDUC1", "Surface Dust concentration part.matt.1 [kg/m3]"},
/* 212 */ {"SDUC2", "Surface Dust concentration part.matt.2 [kg/m3]"},
/* 213 */ {"SDUC3", "Surface Dust concentration part.matt.3 [kg/m3]"},
/* 214 */ {"SDUC4", "Surface Dust concentration part.matt.4 [kg/m3]"},
/* 215 */ {"SDUC5", "Surface Dust concentration part.matt.5 [kg/m3]"},
/* 216 */ {"SDUC6", "Surface Dust concentration part.matt.6 [kg/m3]"},
/* 217 */ {"SDUC7", "Surface Dust concentration part.matt.7 [kg/m3]"},
/* 218 */ {"SDUC8", "Surface Dust concentration part.matt.8 [kg/m3]"},
/* 219 */ {"TSD1D", "Std. dev. of IR T over 1x1 deg area [K]"},
/* 220 */ {"NLGSP", "Natural log of surface pressure [ln(kPa)]"},
/* 221 */ {"DUL1", "Dust loading part.matt.1 [kg/m2]"},
/* 222 */ {"DUL2", "Dust loading part.matt.2 [kg/m2]"},
/* 223 */ {"DUL3", "Dust loading part.matt.3 [kg/m2]"},
/* 224 */ {"DUL4", "Dust loading part.matt.4 [kg/m2]"},
/* 225 */ {"DUL5", "Dust loading part.matt.5 [kg/m2]"},
/* 226 */ {"DUL6", "Dust loading part.matt.6 [kg/m2]"},
/* 227 */ {"DUL7", "Dust loading part.matt.7 [kg/m2]"},
/* 228 */ {"DUL8", "Dust loading part.matt.8 [kg/m2]"},
```

```
/* 229 */ {"SNOHF", "Snow phase-change heat flux [W/m^2]"},
/* 230 */ {"var230", "undefined"},
/* 231 */ {"DUD1", "Dry dust deposition part.matt.1 [kg/m2]"},
/* 232 */ {"DUD2", "Dry dust deposition part.matt.2 [kg/m2]"},
/* 233 */ {"DUD3", "Dry dust deposition part.matt.3 [kg/m2]"},
/* 234 */ {"DUD4", "Dry dust deposition part.matt.4 [kg/m2]"},
/* 235 */ {"DUD5", "Dry dust deposition part.matt.5 [kg/m2]"},
/* 236 */ {"DUD6", "Dry dust deposition part.matt.6 [kg/m2]"},
/* 237 */ {"DUD7", "Dry dust deposition part.matt.7 [kg/m2]"},
/* 238 */ {"DUD8", "Dry dust deposition part.matt.8 [kg/m2]"},
/* 239 */ {"SNOT", "Snow temp. [K]"},
/* 240 */ {"var240", "undefined"},
/* 241 */ {"DUD1", "Wet dust deposition part.matt.1 [kg/m2]"},
/* 242 */ {"DUD2", "Wet dust deposition part.matt.2 [kg/m2]"},
/* 243 */ {"DUD3", "Wet dust deposition part.matt.3 [kg/m2]"},
/* 244 */ {"DUD4", "Wet dust deposition part.matt.4 [kg/m2]"},
/* 245 */ {"DUD5", "Wet dust deposition part.matt.5 [kg/m2]"},
/* 246 */ {"DUD6", "Wet dust deposition part.matt.6 [kg/m2]"},
/* 247 */ {"DUD7", "Wet dust deposition part.matt.7 [kg/m2]"},
/* 248 */ {"DUD8", "Wet dust deposition part.matt.8 [kg/m2]"},
```