Environmental Inputs to Electro-Optical Performance Surfaces

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LONG-TERM GOALS

The calculation of electro-optical (EO) parameters depends on atmospheric composition along the path, including water vapor, water clouds and aerosol particles. Today’s operational weather prediction models can forecast these quantities anywhere on the globe several days in advance. However, EO transmission products are available operationally only as global scale NAAPS (Navy Aerosol Analysis and Prediction System) forecasts of extinction. Global cloud fields are not available for use in the extinction calculations nor are any of the mesoscale fields from COAMPS®. Our goal is to provide higher-resolution analyses and forecasts of optical transmission, scintillation, refractivity, and visibility through the use of COAMPS cloud and aerosol particle forecasts. We will provide verification tools, including a baseline 3-D global climatology for aerosol transmission that can be used as a contingency to modeled output. We will further develop and demonstrate a prototype EO performance surface for upward-looking geometries and applications.

OBJECTIVES

The Navy and DoD warfighter require improved near-surface and slant-path visibility and directed energy beam quality analysis and forecasting for use in tactical applications, strategic planning, and operational execution. The proposed approach of developing sophisticated aerosol-influenced mesoscale atmospheric fields as inputs for calculating atmospheric transmission supports ship-borne and surface-based Directed Energy (DE) systems (upward-looking). The same regional fields can also be used in the production of performance surfaces that support space-based and airborne EO systems (downward-looking), including atmospheric correction for ocean characterization (e.g. diver visibility).

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and Intelligence, Surveillance and Reconnaissance (ISR) operations. NWP will benefit from such initiative through improved surface energy budgets, and improvements in cloud analysis.

**APPROACH**

The skill and uncertainty of the COAMPS cloud and aerosol predictions must be evaluated before use in EO guidance and products. We will focus on cloud base and cloud extent as they are most critical to the EO problem and of interest to the warfighter. Due to the limited nature of cloud observations, several datasets will be utilized. Using world-wide surface-based cloud observations, along with existing NRL satellite-derived cloud mask retrievals, we will quantitatively evaluate model cloud predictions. The Air Force World Wide Merged Cloud Analysis (WWMCA) will also be evaluated for its utility in the verification and nowcasting applications. Two existing in-house verification packages will be enhanced for this verification task. The operational ‘VERIFY’ software tool will be modified to ingest aerosol and cloud base forecasts to be verified using observations of visibility and cloud base from airports around the world. The NRL Weather Reentry Interaction Planner (WRIP) cloud analysis and verification package will be modified to utilize either COAMPS or WWMCA cloud amount and cloud distribution patterns.

Near-surface optical turbulence ($C_n^2$) and refractivity parameterizations are generally dependent on air-sea temperature difference and atmospheric stability, wind speed, and humidity. The Navy Atmospheric Vertical Surface Layer Model (NAVSLaM; Frederickson, 2015) is already coupled to COAMPS for electromagnetic (EM) refractivity prediction, and will be modified to characterize the near-surface vertical profiles of optical refractivity and $C_n^2$ for visible through thermal-infrared wavelengths (Frederickson et al. 2000). The inclusion of NAVSLaM is critical to evaluate the impact of the highly turbulent marine surface layer on near-horizon laser propagation in a ship self-defense scenario, for example. To characterize optical turbulence for slant paths through the troposphere, such as for engaging Unmanned Aerial Vehicles (UAVs) and other airborne targets, several methods for estimating upper-air $C_n^2$ from COAMPS forecast fields will be evaluated and modified as necessary, including those from AFRL (Dewan et al., 1993; Jackson, 2004) and NPS (Horne, 2004).

Optical refractivity and $C_n^2$ vertical profile blending algorithms will be developed to merge the near-surface and upper-air characterizations, drawing from similar models already developed for radio-frequencies as appropriate. Similarly, horizontal refractivity and $C_n^2$ structure matching between vertical profiles will be implemented in a manner similar to what is done for EM propagation modeling. The characterization of $C_n^2$ and refractivity produced by this system will be useful for system performance modeling using HELCOMES, HELEEOS and other models. The new EO-capable NAVSLaM and blending algorithm and Refractivity Structure Matching Algorithm RSMA will be submitted to the Oceanographic and Atmospheric Master Library (OAML) and will therefore also be available as necessary components for future EO decision aid development. Recognizing that significant departures exist in shoreline experiments over the globe due to non-ideal boundary layer flows (e.g., Wilson and Fedorovich, 2012), we will look for natural break points for thresholding the performance surface and a binned approach from environmental look-up tables (low, moderate and severe likelihood of deleterious refractive conditions) based on COAMPS output fields will be adopted. Such an approach has peer reviewed precedent with beneficial results (e.g. Cheinet et al., 2011).

A state-of-the-art three-dimensional global climatology for aerosol particle distribution has been derived from nearly six years of space-borne lidar measurements (e.g., Campbell et al. 2012). These
data will serve as a contingency product in the absence of available model-based analyses, and as a baseline to the warfighter for assessing current conditions. Information will be multi-spectral, ranging from the mid-visible to near-infrared. The temporal resolution will be seasonal. The climatology has been independently evaluated for skill using ground-based measurements. Further improvements to the climatology are expected from the addition of a second satellite-based aerosol lidar beginning summer 2014, as well as the integration of a six-year NAAPS/CALIOP reanalysis dataset based on three-dimensional variational model assimilation of CALIOP backscatter fields (Zhang et al., 2011). A distribution method for the climatology will be designed, evaluated and delivered, featuring user-input options for scene creation and multiple-target viewing geometries that calculate first-order transmission parameters as a function of wavelength for the warfighter.

In parallel with the above efforts, we will initiate discussions with potential users, in particular those in the laser weapons arena (DE, GBAD, etc.) to determine the relevant scenarios, geometries, variables of interest, and display characteristics. Likely products include transmission performance surfaces at resolution sufficient to depict trends in tactically relevant conditions updated at 3 hour or less intervals, and with forecasts out to three days. The products may cover conditions from the surface to 30,000 feet with predetermined look angles and have an optional easy-to-use interface for tailored user input. Interaction with the laser weapons community will lead to improvements in performance surface calculation, presentation, and selection of relevant geometries. This development will begin with the climatology and then progress to the forecasted fields as those become available.

We will prototype performance surfaces that will suit their needs and iterate with them during the course of the project, improving the form of the product as well as the quality as the fields become available. The proposed work will also be suitable for atmospheric correction for ocean retrievals and ISR and discussions with those user communities will be initiated. Verification of forecast fields and derived transmission fields will be done using data from Navy programs (RIMPAC, Trident Warrior), field programs of opportunity, and scientific experiments.

Enhancements to COAMPS will be transitioned to The Fleet Numerical Meteorology and Oceanography Center (FNMOC) and other sites as a component of COAMPS-OS®. As COAMPS data is generated, the EO fields that are created will be managed by COAMPS-OS’s Geographic Information Systems (GIS) server, where they will be cataloged and served up using Open Geospatial Consortium (OGC) services. In parallel, the COAMPS data will be delivered to the ISIS database at FNMOC where it will be made available via CAGIPS and to the FNMOC Enterprise GIS Server (Geoserver) for wider distribution. Utilizing these services allows the data to be served to any OGC compliant system via Web Feature Service, Web Map Service, and Web Coverage Service. These OGC services are the same services used within the NITES Next system to provide observations, satellite, and model data to the METOC forecasters. As a proof of concept, the COAMPS-OS Dashboard Viewer (CDV) will be extended to interact with the EO performance surfaces via the OGC services. The forecasters are then able to use this data to develop forecasts and mission impacts for their customers. In addition to the COAMPS-OS proof of concept, we will demonstrate that the COAMPS cloud, aerosol, and optical turbulence products are accessible from the FNMOC Geoserver to the NITES Next suite and other OGC compliant systems.

WORK COMPLETED

FY15 activities focused on improving existing infrastructure and adapting systems applications for EOPS (Electro-Optical Performance Surfaces) activity, preparing pathways for eventual transitions.
Preliminary verification activities included data aggregation and evaluation of current and newly-developed systems efficacies.

**Task 1: Produce combined COAMPS aerosol and cloud transmission fields** - We have completed the second-generation prototype tool (Figure 1) for displaying aerosol extinction and atmospheric transmission. The widget imports aerosol extinction data from the FNMOC Geoserver and displays it within interactive charts and on a world map. A user can click on a location in the world, zoom in to that location, and visually see areas that would allow for good and poor transmission. The technology behind it includes web services and Java for heavy processing, JavaScript and d3js for visualization, and the FNMOC Geoserver for real-time data access. The second generation widget utilizes the NITES Next (NN) Ozone Widget Framework (OWF) and allows interaction with other widgets that may want to utilize features of this tool for specific applications. For example, the NN Plana Terra widget is now used to display the horizontal distribution of visibility. The Plana Terra map is shared amongst other teams developing on the NPS (Naval Postgraduate School) CIE (Continuous Integration Environment) and provides the user with a more customizable experience. As one of the first user groups of the NN OWF widgets, we have reported bugs or suggested enhancements to the NN developers. Our widgets have undergone further revisions to allow display of up to six days of forecast data, data from several watches, and to handle more elevations. A new approach has been taken in regards to how data is retrieved and accessed. Previously, data was downloaded from a Geoserver and stored within a database, point by point. For even relatively small sets of data (say 24 hours’ worth), this approach was extremely time consuming, required an enormous amount of disk space, and was hard to scale. Now, data is still downloaded from Geoserver, but saved into one large grib file (a file of gridded data). This approach is much more direct, requires no database, and can easily handle over five days of forecast data across many elevations. The current Beta implementation of these changes can be found on the CIE.

**Task 2: Produce 3-D cloud products and verify against satellite observations** – We updated the Community Radiative Transfer Model (CRTM) at NRL to work with COAMPS simulations over different regions with the help of Dr. Louie Grasso from the Cooperative Institute for Research in the Atmosphere who visited NRL in June. This capability will allow us to directly compare satellite observations with the synthetic satellite imagery in near real-time for the COAMPS-TC web page. The CRTM capability was successfully demonstrated for three local COAMPS simulations: a tropical cyclone case, a Florida convective case, and an Arctic case.

The cloud/no-cloud satellite based verification was successfully run for the April-June period over the northwest Atlantic COAMPS region. Several cloud liquid water path (LWP) thresholds were tested to determine the best fit to the observed satellite imagery. The tests revealed that satellite-derived LWP values of 10 g/m**2 or above demarcated all regions that were at least partly cloudy, and LWP values of 50 g/m**2 represented regions of full cloudiness. Both of these thresholds were verified against the COAMPS LWP field. The COAMPS cloud base field will also be used to determine if the cloud base product is a better estimator for cloud extent.

We began development of the cloud base verification capability for the standard verify package using the surface-based observations. The METAR and WMO observational data were investigated to determine what variables were available. Cloud base height and cloud amount are regularly reported by many land-based stations. Ceiling observations are not explicitly reported, but cloud cover greater than 60% constitutes a ceiling and this definition can be used to diagnose ceilings. Contingency tables and cloud height bias/RMS statistics are planned. Statistics such as cloud coverage bias and cloud
height bias can be derived using the station data. FNMOC is now collecting the AFWA WWMCA cloud analysis fields. Those will now be investigated for possible usefulness in determining cloud base.

The portion of the cloud base verification software that collects and analyzes the forecast-observation pairs from the database output from the VERIFY was completed and tested successfully. Each set of predicted and observed cloud bases is parsed into separate distributions to compare the ability of the model to reproduce the general shape of the observed cloud base distribution. For those points where clouds exist in both the forecast and the observations, the full set of forecast minus observation differences is collected and sorted. This array will be used for box and whisker diagrams that track the width and shape of the model error at each forecast lead time. The next task is to create python graphics software to display the cloud base distributions as well as the box and whisker diagrams.

Task 3: Apply speciated global aerosol profile climatology to EOPS - A secure online web-server for the lidar-based aerosol climatology has been developed and tested. The transition plan is now being developed and coordinated with FNMOC (John Ertl and the Climatology Group). The plan must consider the technical considerations and customer base for the database and server. The server and GUI will provide access to the global climatological target transmission matrices by both the warfighter and the developer. Based on user inputs for wavelength, time-of-year, time-of-day, geolocation, and land-surface type, the GUI returns the transmission matrices as a function of height above ground and downwind range to target. The application simulates the background conditions that may be anticipated by a ground based DE system. An example is shown in Fig. 2, for the June-July-August seasonal solution over the northern Arabian Gulf from ground to 12,000 ft and 0-20 km downwind. Superimposed on these data is the 50% transmission contour. In this case, where aerosol loading is at local seasonal lows, transmission rates are relatively high everywhere except at very low altitude propagation paths. Below 2,000 ft, transmission efficiencies drop below 10% just past 10 km, for instance.

Task 4: Optical turbulence characterization and HEL modeling tests - The new Navy Atmospheric Surface Layer Model (NAVSLaM) Version 2.0, with the capabilities for computing near-surface over-water vertical refractive index structure parameter (Cn2) and refractivity profiles for optical and infrared wavelengths, has been developed and is undergoing testing and validation with existing datasets. NAVSLaM v2.0 has been incorporated into the NPS Physics Department ANCHOR laser propagation modeling system and simulations are being conducted for different scenarios and environmental conditions to test the applicability and robustness of NAVSLaM and the impact of different conditions likely to be encountered in a variety of relevant locations on laser system performance. Work has begun on the required OAML documentation for NAVSLaM v2.0. Several upper-air Cn2 profile models have been modified and developed based on original work by Doug Miller and Don Walters at NPS (Horne 2004) and other researchers at the Air Force Institute of Technology (Dewan 1993; Jackson 2004), as shown in Figure 3. These models are being evaluated and compared with Large Eddy Simulation (LES) modeling results in collaboration with Ted Rodgers at SSC-Pacific and Shouping Wang of NRL-Monterey. Preliminary work has been accomplished in developing the methodology to smoothly and realistically blend the near-surface Cn2 profiles produced by NAVSLaM v2.0 with the upper-air model Cn2 profiles.

Task 5: Develop, test, and transition a version of COAMPS-OS supporting an enhanced aerosol high-resolution forecasting capabilities - Software has been written to verify COAMPS visibility and aerosol optical depth (AOD) performance. The newly developed software compares the
forecasted COAMPS visibilities against reported surface weather station visibilities. The weather station observations come from compiled WMO, airport, METAR, and ship reports. The algorithm assumes a dust storm is in progress when the observed visibility is less than 3.5 km. With this binary condition four outcomes are possible for the observations and COAMPS: 1) Both predict a dust storm; 2) Both predict no dust storm; 3) COAMPS predicts a false positive; and 4) COAMPS predicts a false negative. Using the results from each of the four conditions, COAMPS model skill statistics can be calculated as dust storm prediction rate, dust storm false alarm rate, dust storm threat score, and dust storm Gilbert score. Using the statistics generated by the software the developer can determine if local or regional dust source areas are over/under producing and if the dust source database needs modifications. The visibility verification software has been used to test, validate, and transition the new high-resolution dust source database for North Africa. The software will be included in the COAMPS-OS MetQC Forecast Quality segment. The second component of the verification software compares observed (AERONET) AODs with COAMPS AODs. For each COAMPS run the software compares the hourly AODs with the hourly COAMPS AODs. The software then calculates statistics, i.e. regression, mean, bias, and RMSE. The time-series comparison of AOD is valuable in determining skill in predicting the onset and cessation of dust events and the magnitude of events. For example, the verification software for North Africa showed the new high-resolution dust source database (DSD) produced AODs nearly equal to the observed AERONET AODs while the operational DSD produced AODs that were two to four times greater the observed AERONET AODs. At this time the AOD component of the verification software is not slated for incorporation into COAMPS-OS since the AERONET data is not available in a timely manner.

RESULTS

FY15 results based on work completed are as follows:

1. The Beta transmission tool displays real-time aerosol extinction and atmospheric transmission and allows the user to evaluate slant path conditions anywhere on the globe for up to 6 days in advance for a set of typical or user-specified geometries.

2. The automated processing of satellite imagery allows real-time evaluation of cloud analysis tools developed from COAMPS fields. Cloud fields serving as verification tools will be used by FNMOC and forecasters for evaluating model skill.

3. Background climatological aerosol transmission context is available for developers and fleet operators, allowing them to evaluate systems efficacies globally for ground-to-target beam propagation under day/night, land/ocean scenarios.

4. The new models provide vertical refractive index structure parameter (Cn2) and refractivity profiles from the surface through the troposphere. The model codes are now available to be incorporated into EO propagation modeling systems.

5. The statistics produced by the dust storm forecast skill software are critical to the warfighter, and the developer, for verifying COAMPS model skill in forecasting dust storms. It provides a quick look on the model performance for each domain and forecast as green, yellow or red confidence levels for dust storms. For the developer, the tools provide performance metrics for the dust source database and the results are used to increase/decrease dust sources upstream.
IMPACT/APPLICATIONS

This project supports FY14 Rapid Transition Process (RTP) Guidance: Cloud & Aerosol Performance Surface for Next-generation EO sensors & weapons. This project also supports CNO N2/N6E Fiscal Year 2015 Guidance for Meteorology and Oceanography (METOC) Research and Development (6.4) Efforts dated 7 Feb 14 in the topic areas of Warfighting First, Operate Forward, and Be Ready.

RELATED PROJECTS

ONR 6.2 “Aerosol Impacts on NWP” supports improvements in aerosol microphysics, model initialization and verification. The implementation of COAMPS at FNMOC is supported by 6.4 funding from PMW-120 for "Small-scale Atmospheric Models" and COAMPS-OS. This funding also supports development and generation of products for use by the fleet.

REFERENCES


Figure 1. A screen dump from the Beta prototype transmission widget showing the impact of an aging Asian dust storm on transmission conditions in the Sea of Japan. Data are from the 12Z October 6 operational watch of NAAPS. The left panel shows the time series of transmission along the user-specified prescribed path. In this case, it is for a target at 5 nm range, located at the surface and at near infrared wavelength. Visibility conditions are good for the first two days, degrade considerably on days 3 and 4, and recover on day 5. The left panel shows the visibility at the surface for the same forecast time indicated by the gray vertical bar.
Figure 2. Spring season (MAM) climatological composite of 532 nm aerosol transmission from a surface-based DE system to a target at varying ranges and altitudes over the open waters of the northern Arabian Gulf. The climatology shows that transmission is high along horizontal paths and steeply sloping paths, but reduced at moderate angles due long path lengths through the low level aerosol layer that is characteristic for this location and season.
Figure 3. Upper-air vertical refractive index structure parameter (Cn2) profiles computed from a sample COAMPS run for the Dahlgren QRC field test using the following models: 1) Naval Postgraduate School Turbulent Kinetic Energy (TKE) mode, 2) Naval Postgraduate School non-TKE model, 3) Modified Air Force Institute of Technology (AFIT) model developed by Dewan (1993), 4) Modified AFIT model developed by Jackson (2004) for the lower troposphere, and 5) Modified AFIT model developed by Jackson (2004) for the entire troposphere. The profiles produced by all the models exhibit similar trends and features, but differ by approximately two orders of magnitude between the lowest and highest models.