Marine EM Climatic Parameters

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LONG-TERM GOALS

Recently there has been increased interest within the U.S. Navy in the use of climatology-based products to support the planning and execution of military operations. Climatological databases of atmospheric features that impact electromagnetic (EM) propagation have been developed to provide guidance on weapons and sensor system performance for expected environmental conditions. However, the marine EM propagation climatology currently in use by the U.S. Navy was developed in the mid-1980s, based on a limited dataset and a now obsolete model, and was focused on open ocean regions. Several factors have made it highly important and opportune at this time to develop an improved and modernized EM climatology database:

1) Since the 1980s, when the current EM climatology was last revised, greatly improved meteorological and oceanographic (METOC) databases have been developed from which EM climatologies can be developed.

2) At the same time, modern methods of climate analysis have been developed which make climatological databases much more useful for practical applications.

3) Evaporation duct models have also been significantly improved.

4) Improved product development tools have been created for translating EM climate information into products that are more useful and relevant for planning and executing warfighter missions.

5) Unlike the 1980s when the current climatology was developed, the U.S. Navy now places a high priority on littoral warfare, and EM climatologies should therefore place more emphasis on coastal regions.

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14. ABSTRACT

Recently there has been increased interest within the U.S. Navy in the use of climatology-based products to support the planning and execution of military operations. Climatological databases of atmospheric features that impact electromagnetic (EM) propagation have been developed to provide guidance on weapons and sensor system performance for expected environmental conditions. However, the marine EM propagation climatology currently in use by the U.S. Navy was developed in the mid-1980s, based on a limited dataset and a now obsolete model, and was focused on open ocean regions.

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In light of the above factors, the long-term goal of this project is to produce a state-of-the-art global climatology for near-surface marine EM propagation conditions from the best available data sets and models and using the latest climate analysis methods. This modernized climatology will greatly benefit the planning and execution of all military operations that depend on low-level microwave propagation over the ocean.

OBJECTIVES

The objective of the Marine EM Climatic Parameters effort is to develop means to improve climatological parameterizations of marine atmospheric refractive effects on low-level microwave propagation. These climatological parameterizations will describe marine surface layer effects for predicting the performance of EM systems in both open ocean and coastal environments, and ultimately for assessing the ranges at which targets can be detected, as well as other measures of system performance, in different geographical regions and seasons, and in various climatic regimes.

APPROACH

The approach being followed in developing an improved and modernized marine EM climatology has four main components, described below:

Use of an improved evaporation duct model

Low–level microwave propagation over the ocean is strongly influenced by the presence and characteristics of the evaporation duct. Therefore, the evaporation duct height (EDH) is a critical component of the EM climatology being developed. Bulk surface layer models must be used to compute the EDH from basic METOC parameters. The existing EM climatology was computed with the Paulus-Jeske (PJ) model (Paulus 1985). Due to its demonstrated superior performance, we use the NPS evaporation duct model (Frederickson 2000) in constructing the new EM climatology.

Use of expanded and improved global data sets

A critical consideration when constructing a climatology database is determining the best data sets to use. The data sets must have adequate global coverage of the ocean areas and include all the parameters required for computing the evaporation duct height. The data set should also have good temporal coverage and must cover a long time period, preferably on the order of at least several decades. The existing climatology was computed with data from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) for the years 1970-84 only. These data are primarily from volunteer merchant ships, rather than research vessels, buoys, or satellite data. The new climatology will be constructed from an expanded data set, which includes data up through at least 2006, and will focus on global reanalysis products, such as the NCEP reanalysis, which have many advantages over ICOADS, as discussed in the following sections.

Use of modern climate analysis methods

Significant advances have been made in climate analysis methods in the last several decades, yet these advances have often not been sufficiently exploited for military and naval applications. Among these advances are data sets, concepts, methods and products collectively known as smart climatology, which is being applied in the development of the new evaporation duct climatology. Smart, climatology is, in brief, the application of state of the art data and methods to produce climate analyses and forecasts that support the planning and execution of military operations [see, for example, Feldmeier (2005), LaJoie (2006), Vorhees (2006), Murphree (2007), and Twigg (2007)]. An important facet of smart climatology is the use of analytical methods that take into account climate variation patterns, such as El Nino-La Nina, the North Atlantic Oscillation and the Indian Ocean Zonal Mode, rather than focusing almost exclusively on long-term means, as traditional climatologies tend to do.

Development of improved and relevant climate products and displays
A critical component of any climatology is presenting and displaying information in ways that are clear, useful and relevant to the user. We will describe the products and displays of this EDH climatology which can be tailored specifically to meet the needs of military planners and warfighters throughout different phases of mission planning and execution. For this project we will outline the methodology to provide improved and more relevant climate displays, such as climatological radar performance surfaces which show map views of EDH values for given regions, months and climate scenarios. The development of performance surfaces for other types of systems and activities, such as EA/IO/ISR effectiveness, will also be explored.

The key performers of this work are Amalia Barrios of SPAWAR Systems Center, San Diego, and Paul Frederickson of the Naval Postgraduate School (NPS). Dr. Tom Murphree at NPS has contributed with climatological advice on an informal basis; his formal participation is proposed for 2008. Lt. Katherine Twigg, RN, has performed important work at NPS in connection with this project for her masters thesis, with Murphree and Frederickson as coadvisors.

WORK COMPLETED

Comparisons have been performed between the existing climatology, based on 1970-84 ICOADS data, and on ICOADS data covering a longer time period (1960-2005). An example of such a comparison, for the Arabian Sea, is shown in Fig. 1, which demonstrates that significantly different results can be expected when using data from the different time intervals. Furthermore, the use of the NPS model in place of the PJ model produces even greater differences. These factors clearly demonstrate the need for updating the existing climatology.

Comparisons have been conducted between the NPS and PJ evaporation duct models based on observations from several recent propagation experiments, including Wallops 2000 (Frederickson 2001 and 2002, Stapleton 2001) and Rough Evaporation Duct (RED) 2001 (Frederickson 2003a and 2003b, Anderson 2003), as shown in Fig. 2. These comparisons involved computing near-surface modified refractivity profiles from both the NPS and PJ models from observed METOC data, and then inputing the resulting refractivity profiles into the Advanced Propagation Model (APM) (Barrios 2006) to compute propagation loss. These predicted propagation loss values are then compared with actual measurements of propagation loss. The comparisons demonstrate that the NPS model is clearly superior to the PJ model, especially in unstable conditions, thereby justifying its use in constructing the new EM climatology. In addition, the PJ model includes an explicit open-ocean assumption, while the NPS model can theoretically be applied in many cases in littoral regions.

Several types and sources of data have been identified and examined as candidates for constructing the EM climatic database, probably the most important of these being atmospheric and oceanic reanalysis products. Among these is the NCEP global atmospheric reanalysis data set (Kalnay et al. 1996; Kistler et al. 2001), which is based in part on ICOADS data, but also includes data from many other in situ and remote sensing sources. The reanalysis data set is a gridded representation of observed values that have been analyzed in a consistent manner for all times using a global numerical prediction model to develop dynamically balanced fields of the different parameters. The NCEP reanalysis set is available at a temporal resolution of six hours and on a Gaussian grid with a horizontal spatial resolution of 1.875 degrees in longitude and a similar but varying resolution in latitude (see Fig. 3).

Comparisons have been conducted between ICOADS data, NCEP reanalysis fields, and long-term National Data Buoy Center (NDBC) data sets (see Figures 3 and 4), primarily from buoys off the U.S. coasts, but also for a buoy in the Arabian Sea. Buoy data are considered the best available comparison benchmark. An example of such a comparison for the Gulf of Mexico is presented in Fig. 4, which shows good agreement between the different data sources. These comparisons are an important factor in determining which data sources are best for constructing the climatology. It should be noted that different databases may be better and more suitable for different geographical regions, depending especially upon the amount and type of data available in different regions.

Smart climatology methods and reanalysis data sets were applied to develop an EDH climatology for the Indian Ocean and adjacent areas in the NPS masters thesis by Lt. Katherine Twigg, RN. Composite analysis methods were applied to improve on traditional climatologies based on long term means and the impacts of climate variation patterns, such as El Nino-La Nina (ENLN) and the Indian Ocean Zonal Mode (IOZM), were determined for EDH and radar propagation performance (see Fig. 5). This new smart EDH climatology shows substantial improvement over the existing climatology in use by the U.S. Navy. Major temporal and spatial variations in EDH were observed, including significant variations associated with the identified climate variation patterns. This work also identified which factors EDH and surface radar propagation are most sensitive to for different regions and seasons. The application of smart climatology methods to other regions and climate variation patterns continues.

An important issue being determined is the optimal geographic partitioning of data for computing and displaying the climatological values. Gridded reanalysis fields provide much higher spatial resolution than the 10 by 10 degree Marsden Squares currently used, as seen in Fig. 3. Marsden squares also may not provide the best coverage in coastal areas, and may include areas with distinctly different climatological regimes in the same square. In addition, the Marsden squares do not optimally distinguish between areas of operational importance to the U.S. Navy. Therefore, we are examining the designation of special areas for producing climate results based on their operational and climatological significance. It may even prove feasible for users to define their own regions for computing climatology results. Where reanalysis data are used, the climatology fields can be provided for each grid point, at a resolution of 2 by 2 degrees or higher, depending on the reanalysis data set used. Another important issue being investigated is how to characterize coastal regions where data may be influenced by nearby land masses.

Improved EM climatology products and displays have already been developed and are being further investigated. Among the most important of the displays developed so far are climatological radar performance surfaces, which show a map view of radar detection ranges for a given radar system and target scenario over a given region. Monthly LTM surfaces have been produced, as well as views showing monthly departures from LTM values due to climate variation patterns (see Figures 5 and 6). It is critical that among the products of the EM climatology package is the ability to produce physically consistent climatological modified refractivity profiles for use as input to propagation models. This is not a straightforward problem and various methods for determining such a refractivity profile are being examined and tested.

The work described above will be presented at the Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) Conference in November 2007 (Frederickson et al. 2007; Twigg et al. 2007).

RESULTS

The results that have already been achieved during this ongoing project can be summarized as follows:

1) Our analyses have conclusively demonstrated that the existing climatology database needs to be updated due to a) its use of the PJ ED model, b) its construction from a very limited data set (1979-84), c) its being based on low-resolution Marsden Squares, and d) its focus only on LTMs and frequency histograms. Furthermore, our work has also shown that the existing climatology can be greatly improved upon using new methods, models and data sets.

2) Comparisons with actual propagation data demonstrate that the NPS ED model is clearly superior to the PJ ED model that was used to compute the existing EDH climatology, especially in unstable conditions. The PJ model often significantly overestimates EDH, and therefore leads to overstated predictions of radar performance, which could have highly adverse impacts on warfighters. The use of the improved NPS ED model by itself leads to a great advance in the EDH climatology and justifies updating the existing climatology.

3) Gridded reanalysis data sets are the best candidates for producing the modernized EM climatology, due to their relatively high spatial and temporal resolution, the spatial and temporal continuity of the data, the fact that the data are dynamically balanced by a numerical reanalysis model and since the data sets include additional measurements not included in ICOADS, such as those obtained from satellites.

4) The application of smart climatology methods to the EM climatology have been shown to yield important information of direct usefulness to warfighters by taking into account well-documented climate variation patterns, such as ENLN and IOZM. These climate variations can have significant impacts on EDH and near-surface radar propagation (Twigg 2007), which should be taken into account to improve mission planning and execution.

5) Climatological radar performance surfaces have been developed (see Fig. 6) based on reanalysis data fields. These performance surfaces are highly valuable tools to warfighters throughout the mission planning and execution cycle. The methods and tools used to construct the climatological radar performance surfaces can also be applied to other weapons/sensor systems.

6) New capabilities already generated include the development of most of the methods and computer codes necessary for the construction of a smart EDH climatology from gridded reanalysis fields. These include codes for reading and manipulating raw NCEP data, for computing EDH, radar detection range and other propagation parameters and a variety of important statistics for gridded fields, and the computation of various climate indices needed to segregate data by different climate variation patterns. These codes also include automated methods that can be applied to any type of gridded data for determining which grid boxes represent land areas, ocean areas, and mixed coastal areas with both land and sea areas across the entire globe.

IMPACT/APPLICATIONS

The development of the modern marine EM climatology will benefit all naval and military operations that are affected by low-level microwave-frequency propagation over the ocean surface, including radar detection, electronic attack (EA), information operations (IO), and intelligence, surveillance and reconnaissance (ISR) activities from a variety of platforms. The EM climatology will be highly useful for long and medium range mission planning and also for short term planning and in the initial phases of mission execution in areas where other sources of METOC data for EM assessment are unavailable, sparse, or of questionable quality. The EM climatology will also serve as a comparison benchmark for other potential EM propagation assessments, such as those derived from numerical weather prediction models. Furthermore, the data sets, methods, tools and products developed for this project will also be directly applicable to climatologies of other properties, such as near-surface EO propagation.

TRANSITIONS

The updated and improved EDH climatology database and related capabilities transition into the Tactical EM/EO Propagation Models Project (PE 0603207N) under PMW 120 which has produced the Advanced Refractive Effects Prediction System (AREPS). This plan will provide a detailed description of the approach to be followed in generating a state-of-the-art climatology to replace the outdated EM climatology now residing in the Oceanographic and Atmospheric Master Library (OAML). We strongly believe that upon the completion of the project outlined above, the methods and tools will have been developed and will be ready for use in producing a greatly improved and much more operationally useful EM propagation climatology.

RELATED PROJECTS

Related projects that will greatly benefit from an improved marine EM climatology and the methods developed in this project, due to their dependence upon near-surface propagation conditions, include the following:

- Performance surface development for non-acoustic (radar) detection of submarine periscopes (SPAWAR PMW-120)

- Electro-Optical Vulnerability Assessment Tool (Naval Undersea Warfare Center, Newport, RI).

- Self-healing Tactical Network in ISR (Tactical Network Topology) (Special Operations Command).

- SeaLancet tactical radio evaluation (Naval Sea Systems Command)

- Joint Tactical Radio System (JTRS)

REFERENCES

Anderson, K. D., P. A. Frederickson, and E. Terril, 2003: “Air-Sea Interaction Effects on Microwave Propagation over the Sea During the Rough Evaporation Duct (RED) Experiment,” Proceedings 12th Conference on Interactions of the Sea and Atmosphere, Long Beach, CA, 9-13 Feb 2003.

Barrios, A.E., Patterson, W.L., Sprague, R.A., "Advanced Propagation Model (APM) Version 2.1.04 Computer Software Configuration Item (CSCI) Documents", SSC SD TD 3214, Feb. 2007.

Feldmeier, J., LCDR, USN, 2005. *Climatic Variations of the California Current System: Application of Smart Climatology to the Coastal Ocean.* Masters of Science Thesis, Naval Postgraduate School, September 2005. Advisors: T. Murphree, R. Tokmakian. Available at: http://wx.met.nps.navy.mil/smart-climo/reports.php

Frederickson, P. A., K. L. Davidson, and A. K. Goroch, 2000: "Operational Bulk Evaporation Duct Model for MORIAH," Draft version 1.2, NPS Technical Report.

Frederickson, P. A. , K. L. Davidson, J. Stapleton, D, Shanklin, R. Wiss, T. Nguyen, E. Burgess III, C. Weeks, W. Thornton, and T. Brown, 2001: "Validation of AREPS Propagation Assessments Using Different Evaporation Duct Models," *Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO 2001) Conference*, Fort Collins, Colorado, 10-12 July 2001. [Army Research Laboratory CD-ROM ARL-SR-01126, October 2001]

Frederickson, P. A., K. L. Davidson, J. Stapleton, D, Shanklin, R. Wiss, T. Nguyen, E. Burgess III, C. Weeks, W. Thornton, and T. Brown, 2002: "Evaluation of Evaporation Duct Model Performance Using AREPS," *National Radio Science Meeting (URSI)*, Boulder, Colorado, 9-12 January 2002.

Frederickson, P. A., K. L. Davidson, K.D. Anderson, S.M. Doss-Hammel, and D. Tsinitikidis, 2003a: "Air-Sea Interaction Processes Observed from Buoy and Propagation Measurements During the RED Experiment," Proceedings 12th Conference on Interactions of the Sea and Atmosphere, Long Beach, CA, 9-13 Feb 2003.

Frederickson, P. A., K. L. Davidson, and A. Newton, 2003b: Evaluating Model Predictions of Low-Level Microwave Propagation Over the Ocean. *Battlespace Atmospheric and Cloud Impacts on Military Operations Conference (BACIMO 2004)*, Monterey, California, 9-11 September 2003.

Frederickson, P., A. Barrios, T. Murphree, and K. Twigg, 2007. Modern Operational Climatologies of Electromagnetic Propagation in the Marine Atmosphere: Part 1. To be presented at the Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) Conference, 6-8 November 2007, Boston, MA.

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteor. Soc*. 77, 437-471.

Kistler, R., and Coauthors, 2001: The NCEP/NCAR 50-year reanalysis: monthly means CD-ROM and documentation. *Bull. Amer. Meteor. Soc*. 82, 247-267.

LaJoie, M., Maj, USAF, 2006. *The Impact of Climate Variations on Military Operations in the Horn of Africa.* Masters of Science Thesis, Naval Postgraduate School, March 2006. Advisor: T. Murphree. Available at: http://wx.met.nps.navy.mil/smart-climo/reports.php

Murphree, T., 2007. Applications of Smart Climatology to Naval Warfare. Brief presented at the Naval War College, 25 January 2007. Available at: http://wx.met.nps.navy.mil/smart-climo/reports.php

Paulus, R. A., 1985: "Practical application of an evaporation duct model," *Radio Sci*., Vol. 20, No. 4, pp. 887-896.

Stapleton, J., D. Shanklin, V. Wiss, T. Nguyen, and E. Burgess, 2001: “Radar Propagation Modeling Assessment Using Measured Refractivity and Directly Sensed Propagation Ground Truth,” NSWCDD/TR-01/132, 49 pp.

Twigg, R., Lt, Royal Navy, 2007. *A Smart Climatology of Evaporation Duct Height and Surface Radar Propagation in the Indian Ocean.* Masters of Science Thesis, Naval Postgraduate School, September 2007. Advisors: T. Murphree and P. Frederickson.

Twigg, K., T. Murphree, and P. Frederickson, 2007. Modern Operational Climatologies of Electromagnetic Propagation in the Marine Atmosphere: Part 2. To be presented at the Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) Conference, 6-8 November 2007, Boston, MA.

Vorhees, D., Capt, USAF, 2006. *The Impacts of Global Scale Climate Variations on Southwest Asia.* Masters of Science Thesis, Naval Postgraduate School, March 2006. Advisor: T. Murphree. Available at: http://wx.met.nps.navy.mil/smart-climo/reports.php

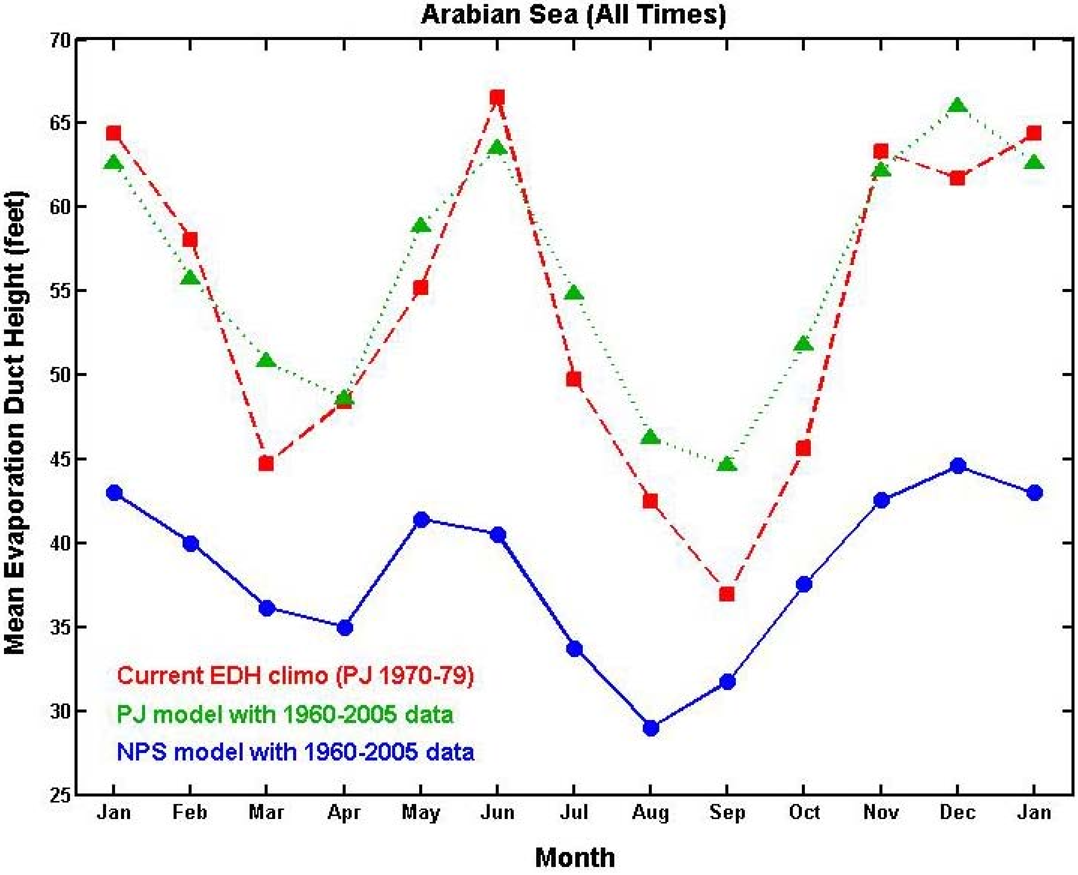

Figure 1. Monthly mean values of the evaporation duct height (EDH) for the Arabian Sea, computed from ICOADS data. The monthly mean EDH values from the current EDH climatology, computed with the Paulus Jeske model from data for 1970-79, are shown in red; monthly mean EDH values computed with the PJ model and data for 1960-2005 are shown in green; monthly mean EDH values computed with the NPS model and data for 1960-2005 are shown in blue. This figure demonstrates two important points, 1) That there are significant differences between monthly mean EDH values computed from a ten year data record and from a 46 year record; and 2) the differences between the EDH climatologies computed with the NPS and PJ models are even more pronounced, with the monthly mean PJ EDH values being greatly overestimated. The over-prediction of EDH heights by the PJ model used in the current climatology could have severely adverse impacts on operations by leading to overly-optimistic estimates of propagation loss (see Fig. 1) and radar detection ranges, for example.

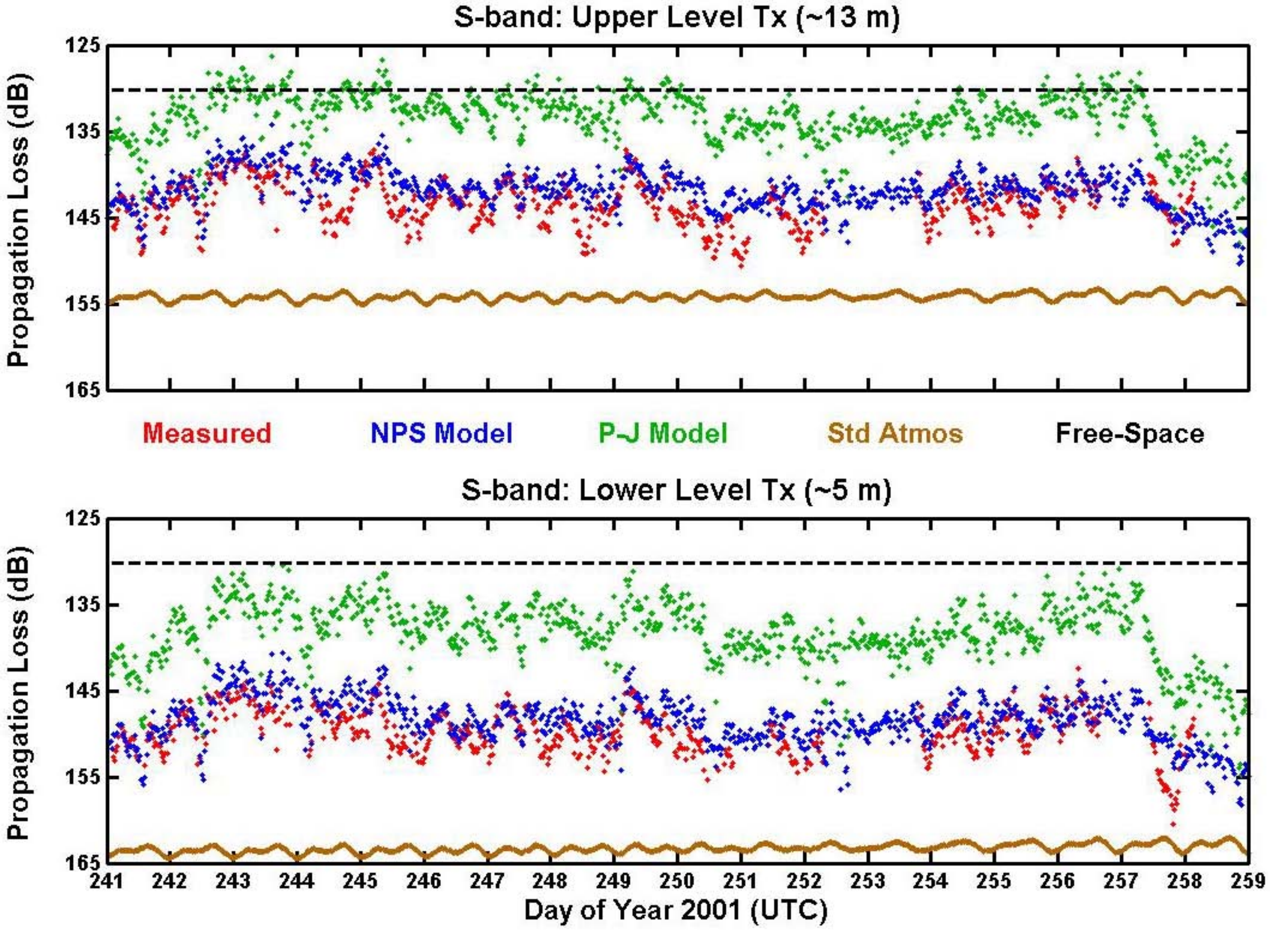

Figure 2. Time series of measured and modeled propagation loss data from the RED 2001 Experiment for transmitters at two different levels: 5 m above mean sea level in the bottom panel and 13 m above mean sea level in the top panel. These and other results clearly show that the NPS model produces superior propagation loss predictions compared to the PJ model, and thus is a much better model to be used in computing the new EDH climatology. It should be noted that these results are almost exclusively for unstable conditions (air cooler than the sea surface).

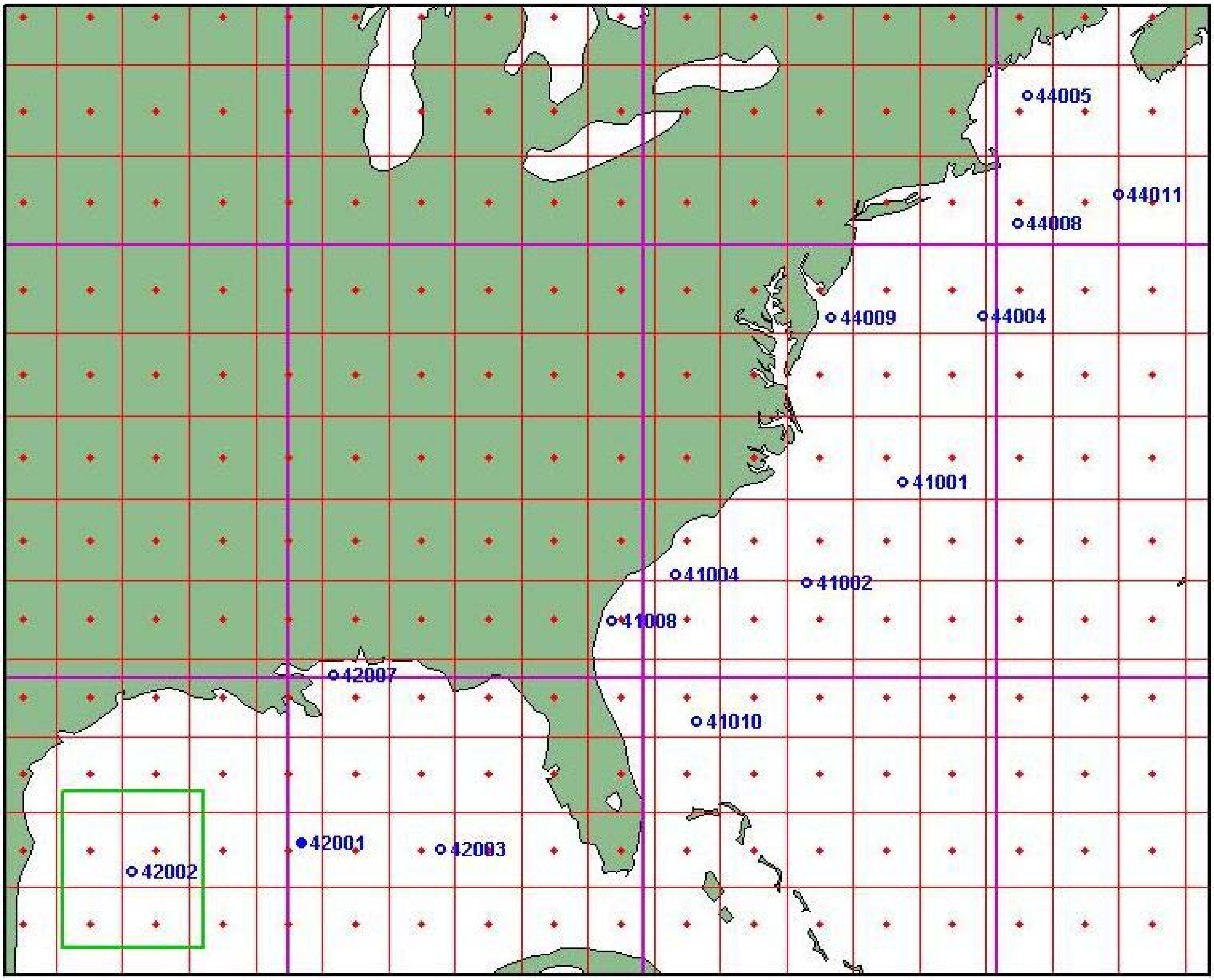

Figure 3. Map of the eastern U.S. and adjacent sea areas of the Atlantic and Gulf of Mexico, showing NCEP Gaussian grid points (red dots) and their associated grid boxes (red lines); Marsden Squares (purple lines); and buoy locations (blue circles). This figure clearly demonstrates the much higher resolution climatology that can be achieved by using gridded NCEP reanalysis fields as opposed to the 10 by 10 degree Marsden Squares. The buoys shown in this figure have been selected as comparison benchmarks for ICOADS and NCEP data and have been selected for their location, long time record of data, and humidity measurements. The buoys close to shore have been selected to examine the use of near-shore NCEP grid points. The green box indicates the area over which ICOADS data were averaged for comparison purposes with the NCEP grid point data and observations from buoy 42002, as shown in Fig. 4. Further comparisons will be made with data from buoys off the U.S. west coast and Hawaii, and other buoys around the world as available.

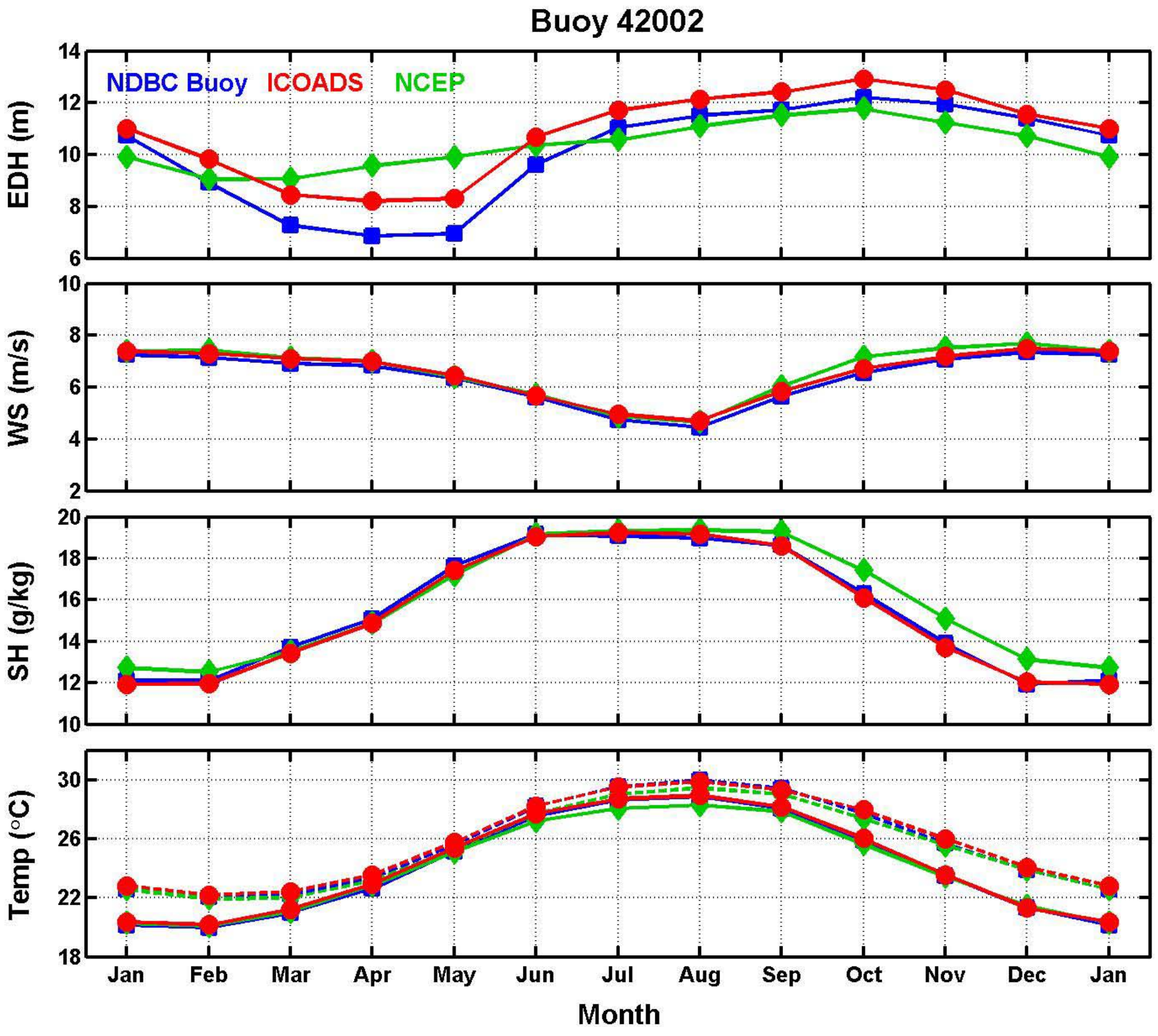

Figure 4. Monthly mean values of air temperature (solid line) and sea temperature (dashed line) shown in the bottom panel; specific humidity in the second panel; wind speed in the third panel; and evaporation duct height (EDH) shown in the top panel. Mean observed data from buoy 42002 are shown in blue; mean ICOADS data averaged over the box shown in Fig. 3 are shown in red and NCEP reanalysis data from the nearest grid point are shown in green. The monthly mean values from the three data sources generally exhibit excellent agreement, although NCEP data has higher humidity in the fall and winter. The monthly mean EDH values also generally agree well, although the reason for the larger disagreement between the NCEP and buoy data in March-May is not yet fully understood.

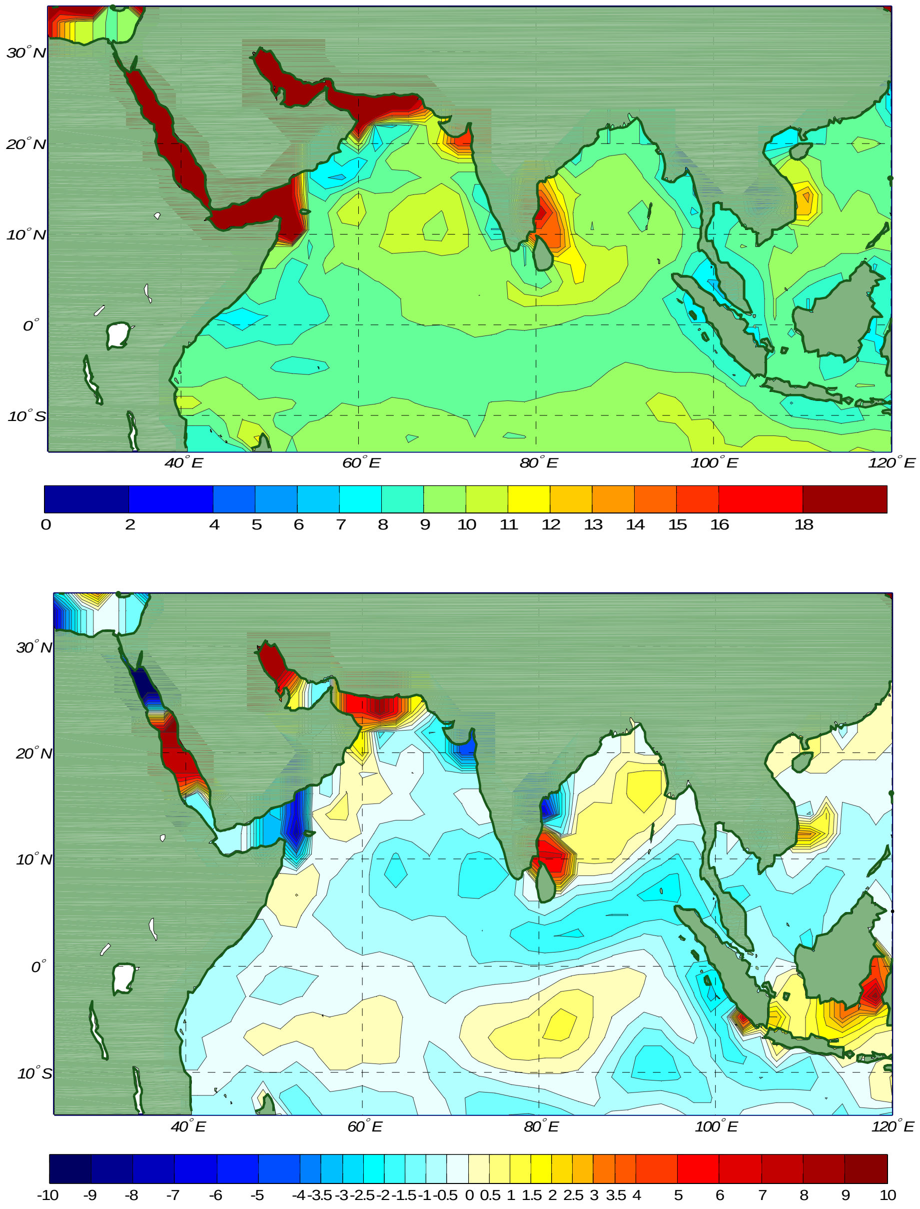

Figure 5. Upper panel: long term mean evaporation duct heights (in meters) for August-October based on NCEP reanalysis fields and the NPS EDH model. We have developed similar displays of LTM EDH for the Indian Ocean for all months of the year. These climatological EDH displays represent the significant improvements over existing EDH climatologies that are possible through the use of smart climatology data and methods. Lower panel: anomalies in EDH for September 1997 (in meters), representing deviations from long term mean EDH values (e.g., panel a). Note the large deviations (e.g., 25-50% or more of the LTM values), especially in coastal regions of importance to naval operations. These deviations were the result of anomalies in the factors that determine EDH (air temperature, sea temperature, relative humidity, and wind speed) that were forced by two strong climate variations at this time, an El Nino event and a positive Indian Ocean Zonal Mode event. The link between EDH deviations and climate variations indicates that the deviations may be predictable at long lead times, since the climate variations that force the deviations can be forecasted with positive skill at lead times of up to several seasons.

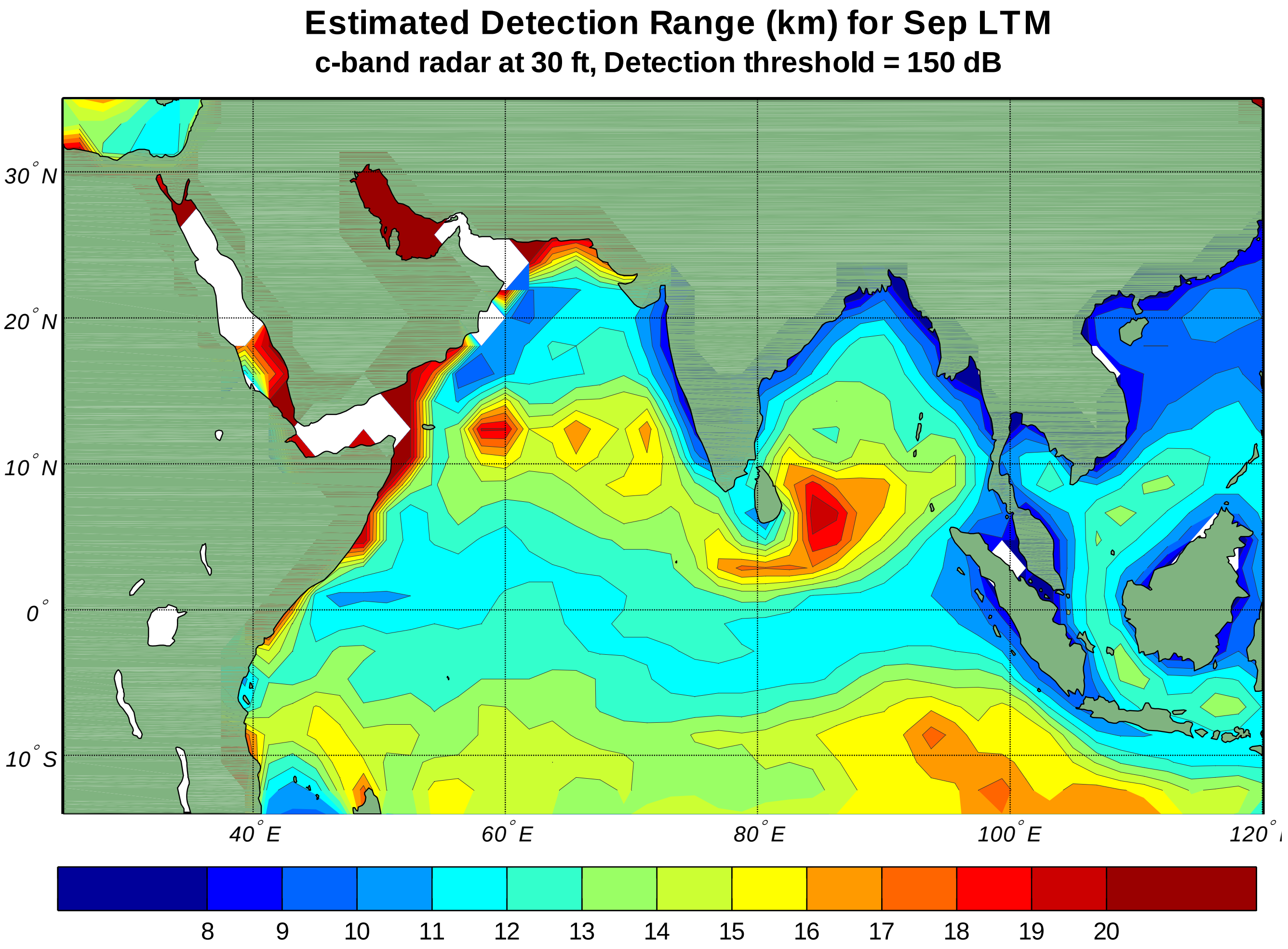

Figure 6. Estimated mean detection range (km) in the Indian Ocean for September 1997 for a C-band radar at 30 feet and a small target at 6 feet with a detection threshold of 150 dB. Detection range was estimated from NCEP reanalysis data using the NPS evaporation duct model and the Advanced Propagation Model (APM). Significant variations in radar detection range are observed across the region, particularly near coastlines in the northwest Indian Ocean and Arabian Sea. This figure is in essence a climatological performance surface for radar detection ranges. Such performance surfaces will greatly benefit the planning and execution of military operations that depend upon low-level microwave propagation above the ocean.