Marine Electromagnetic (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.

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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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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.

In consideration of the factors listed above, the long-term goal of this project is to determine the best methods for producing 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 and data visualization and presentation techniques. This modernized EM 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 the best 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 is determining the best data sets to use. The data sets must have adequate global coverage of the ocean areas, include all the parameters required for computing the evaporation duct height, should 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 and are of uncertain quality. The new climatology will be constructed from global reanalysis products, such as the National Center for Environmental Prediction (NCEP) reanalysis, and will include data up through at least 2006.

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. These advances include improved data sets, concepts, methods and products collectively known as smart climatology, which we are applying 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), Twigg (2007), and Turek (2008)]. 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 the most clear, useful and relevant to the user. The products and displays of this EDH climatology will 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 develop 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 in 2008 were Paul Frederickson and Dr. Tom Murphree of the Naval Postgraduate School (NPS) and Amalia Barrios of SPAWAR Systems Center, Pacific.

WORK COMPLETED

This project has been a two year effort and work completed in 2007 will be only briefly summarized here, as full details were presented in last year's annual report.

Comparison 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 RED 2001 (Frederickson 2003a and 2003b, Anderson 2003) have clearly demonstrated that the NPS model is 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.

During 2007 the NCEP global atmospheric reanalysis data set (Kalnay et al. 1996; Kistler et al. 2001), was selected as a primary candidate for constructing the marine EM climatology. This data set 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. This resolution compares very favorably with the current EM climatology results, which were computed as averages over 10 by 10 degree Marsden Squares.

Figure 1 presents a comparison of the September long-term mean evaporation duct height for the Indian Ocean for the existing Navy climatology computed with the Paulus-Jeske evaporation duct model using ICOADS data and averaging results over 10 by 10 degree Marsden Squares, and the new climatology computed using the NPS evaporation duct model and the NCEP reanalysis data fields. It is important to note that the map view display of evaporation duct height does not exist for the current climatology, and the plot shown was prepared manually specifically for the purpose of comparing it with the new climatology. It is readily apparent that the new climatology has much finer spatial resolution due to the use of the NCEP reanalysis fields, and that the new climatology has significantly lower evaporation duct heights than the old climatology, due to the use of the superior NPS evaporation duct model. A comparison of these two plots clearly demonstrates the vast improvement in the new climatology over the old, not only in terms of improved accuracy of the EDH values, but also in better resolution and improved displays to present the results.

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, Royal Navy. 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. 2). 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.

Improved EM climatology products and displays have already been developed and are being further investigated. Among the most important of the displays developed are climatological radar performance surfaces, which show color contoured map views of radar detection ranges for a given radar system and target scenario over a given region. These types of displays provide the most useful information to operational personnel and decision makers, as they directly show the impact of the expected environment on weapons and sensor systems. Examples of climatological radar performance surfaces are shown in Figure 3.

In 2007, smart climatology EM propagation products were developed for the Indian Ocean area (see the 2007 annual report for this project). In 2008, these same methods were applied to the western North Pacific for different climate variation patterns, including El Nino/La Nina and the relative strength of the Siberian high pressure center. Figure 3 shows monthly means for October of the estimated detection range for an X-band radar at 30 feet looking for a small target at 6 feet for high wind cases at top, and low wind cases at bottom. These plots are essentially climatological radar “performance surfaces” for the detection of a submarine periscope. The high and low wind cases were determined based in part on the relative strength of the Siberian high pressure center, which is computed as a numerical index value. Notice especially the changes in the detection range maxima located between Japan and Taiwan and in the South China Sea. An examination of the differences in estimated detection ranges between the high and low wind cases clearly demonstrates that climate products that take into account climatic variations have much improved value over the traditional climatic statistics based only on long-term means.

The work and accomplishments described above have been presented at both the IEEE AP-S/USNC/URSI and RADAR 2008 conferences during the past year and a refereed paper was published by IEEE in the Proceedings of the 2008 International Conference on Radar (see publications).

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 needs to be updated due to its use of the PJ ED model, its construction from a very limited data set (1979-84), its being based on low-resolution Marsden Squares and 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. Smart climatology products have been developed for the Indian Ocean area (Twigg 2007) and for the Western North Pacific region. These analyses have focused on the important climate variation features impacting these two regions, including the Indian Ocean Zonal Mode (IOZM) and the varying strength of the Siberian high for the Western Pacific area. Due to its global impact, El Nino/La Nina events were examined for both areas. It was shown that very significant variations in radar performance are expected to occur in both regions due to different climate patterns. This demonstrates the great value that smart climatology can bring to mission planning applications through improved knowledge of the battlespace environment.

5) Climatological radar performance surfaces have been developed 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 transition plan is to actually produce the EM climatology based on the methods and tools developed during this project. Upon completion of the project we will deliver to PMW-120 a plan for producing a modern global marine EM propagation climatology. 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)

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.

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.

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. 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.

Turek, A., LCDR, USN, 2008. *Smart Climatology Applications for Undersea Warfare.* Masters of Science Thesis, Naval Postgraduate School, September 2008. Advisor: T. Murphree.

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. 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

PUBLICATIONS

Frederickson, P. A., J. T. Murphree, K. L. Twigg, and A. Barrios, 2008. A Modern Global Evaporation Duct Climatology. Proceedings of the 2008 International Conference on Radar (RADAR 2008), 2-5 September 2008, Adelaide, Australia, pp. 292-296. [published, refereed]

Frederickson, P., T. Murphree, K. Twigg, and A. Barrios, 2008. Developing a Modern Global Evaporation Duct Climatology. IEEE AP-S/USNC/URSI Conference, 8 July 2008, San Diego, CA.

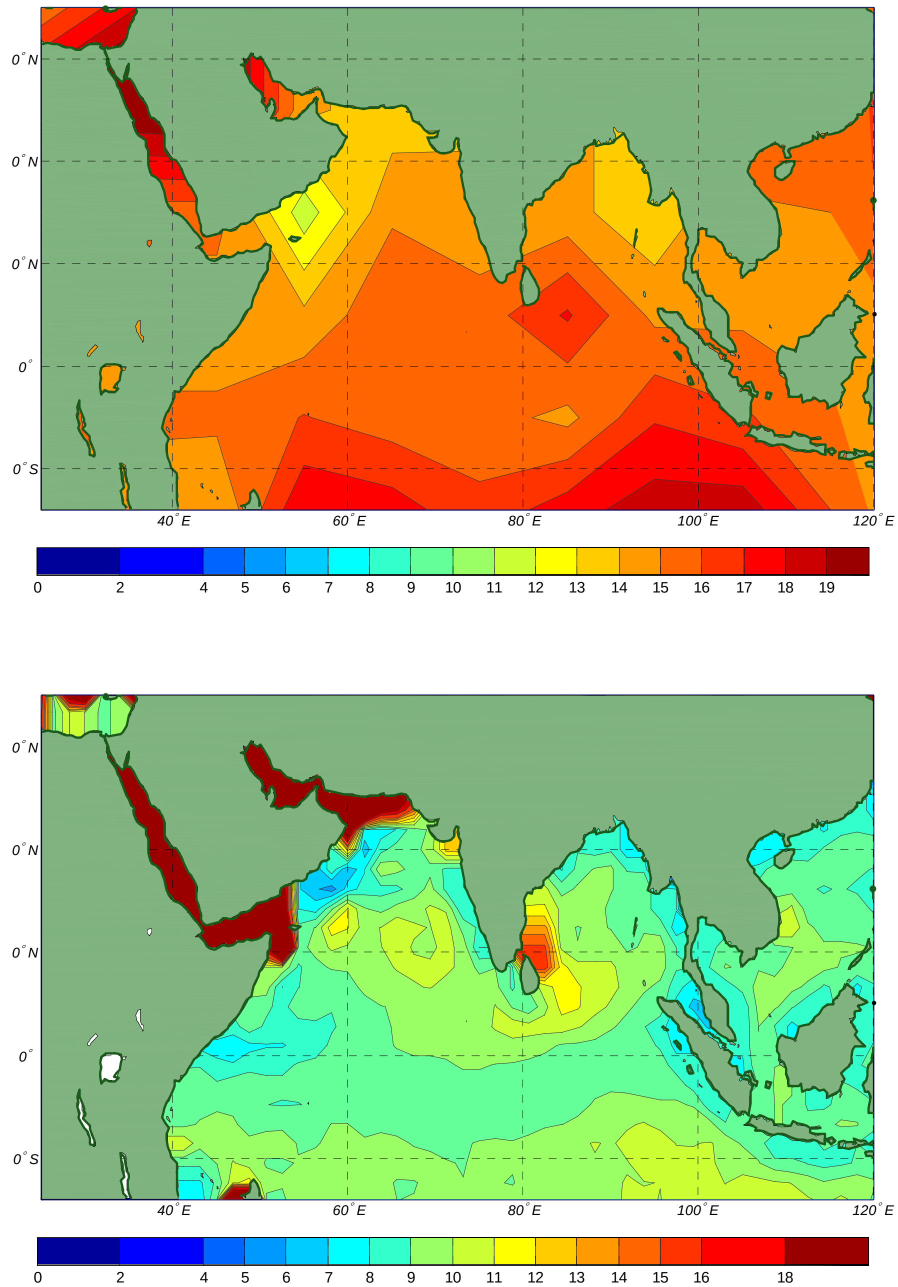


Figure 1. These plots show the September long-term mean (LTM) evaporation duct height for the Indian Ocean area. The upper panel shows the existing Navy climatology, based on averages of ICOADS data over 10 by 10 degree Marsden Squares and computed with the Paulus-Jeske evaporation duct model. This map view display is not included in the current climatology, but was prepared manually for comparison purposes with the new climatology. The lower panel shows the new climatology computed using the NPS evaporation duct model and the NCEP reanalysis data fields. Two striking differences between the old and new climatologies are readily apparent: 1) The new climatology has much finer spatial resolution due to the use of the NCEP Reanalysis fields, and 2) The new climatology has significantly lower evaporation duct heights than the old climatology, due to the use of the superior NPS evaporation duct model. A comparison of these two plots clearly demonstrates the vast improvement in the new climatology over the old.

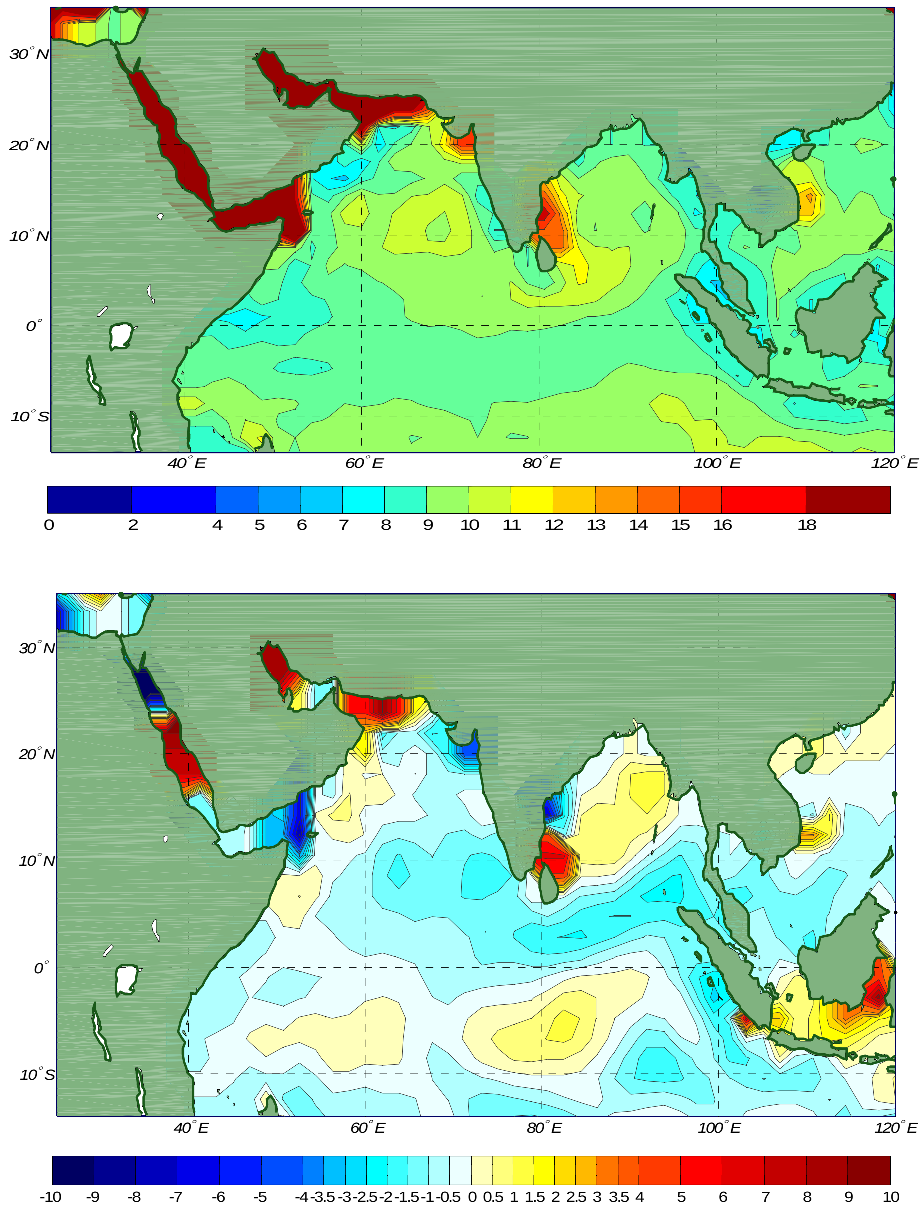
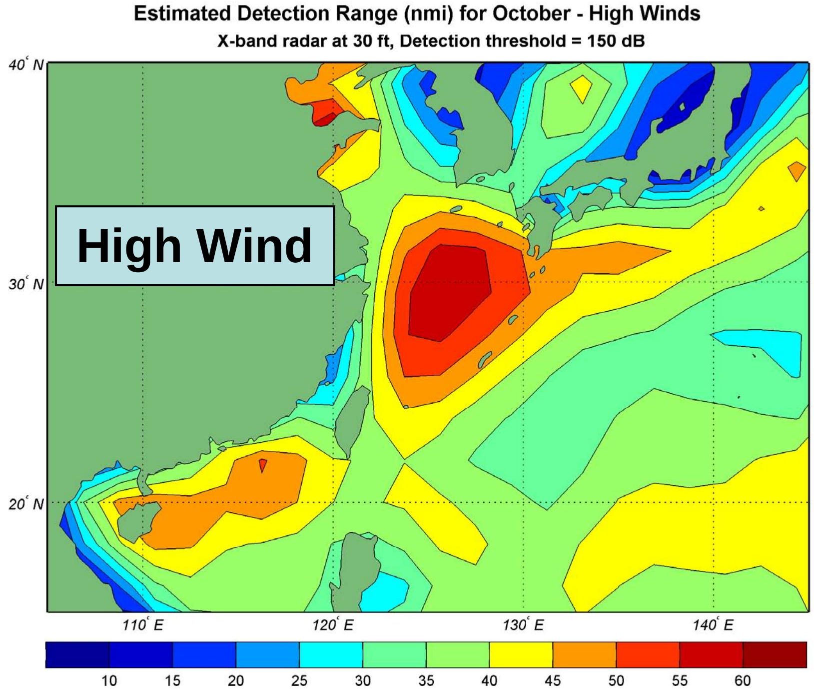


Figure 2. Upper panel: long term mean evaporation duct heights (in meters) for August-October based on NCEP reanalysis fields and the NPS EDH model. We have developed similar displays of LTM EDH for the Indian Ocean for all months of the year. These climatological EDH displays represent the significant 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.



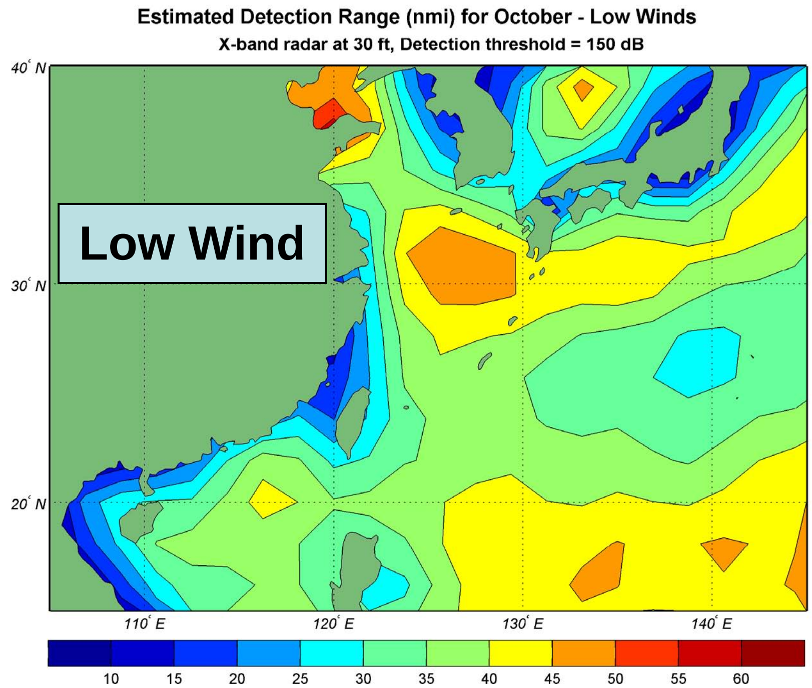


Figure 3. Plots of monthly means for October of the estimated detection range for an X-band radar at 30 feet looking for a small target at 6 feet for high wind cases at top, and low wind cases at bottom. These plots are essentially climatological radar "performance surfaces" for the detection of a submarine periscope. The high and low wind cases were determined based in part on the relative strength of the Siberian high pressure center, which is computed as a numerical index value. The differences in estimated detection ranges between the high and low wind cases clearly demonstrates that climate products that take into account climatic variations have much improved value over the traditional climatic statistics based only on long-term means. Notice especially the variations in the detection range maxima located between Japan and Taiwan and in the South China Sea.