# Advanced Climate Analysis and Long Range Forecasting

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## LONG-TERM GOALS

The major goal of this project is to improve the long range and climate support provided by the U.S. Naval Oceanography Enterprise (NOe) for planning, conducting, and assessing national security operations. The primary planning focus is on operational planning at intraseasonal to interannual lead times (e.g., weeks, months, several seasons, several years). The primary transition focus is on improving the long range and climate support capabilities of the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and the Naval Oceanographic Office (NAVO). FNMOC is the lead organization within the NOe for providing this support. NAVO is a close partner with FNMOC on providing the ocean components of this support.

The improved capabilities are focused on Battlespace on Demand (BonD) tiers 0-2 (environmental data sets, environmental analyses and forecasts, environmental impacts). However, we have more recently been developing an increased focus on BonD tier 3 (decision support). The environmental conditions on which we are focusing are physical atmospheric (mainly tropospheric and lower stratospheric), oceanic conditions (sea surface to sea floor), atmospheric electromagnetic (EM) propagation, and ocean acoustic propagation. The Tier 2 environmental impacts on which we are focusing are impacts of intraseasonal to interannual climate system variations on EM systems operating in the atmosphere (e.g., radar) and acoustic systems operating in the ocean (e.g., sonar).

## OBJECTIVES

Our major objectives are:

1. Transition to FNMOC and NAVO new tools and capabilities in climate and long range forecasting, including: data sets; online data access, visualization, and analysis applications; analysis and forecasting methods; and software tool sets. Transition corresponding education and training materials, documentation, and validation test reports.

2. Conduct research and development on advanced climate data sets, analyses, long range forecast methods and products, performance products, and decision support tools.

3. Coordinate and collaborate with colleagues on the identification of climate and long range support priorities, development and use of data sets, software tool sets, long range forecasting methods, other products, and leveraging of resources. Colleagues will include those at the Department of Defense (DoD), intelligence community (IC), National Oceanic and Atmospheric Administration (NOAA), other government agencies, and civilian universities and research institutions.

**APPROACH**

Our overall approach involves *six major work areas*:

1. Identify high priority needs, and requirements for long range and climate support, in collaboration with FNMOC, NAVO, Naval Oceanography Operations Command (NOOC), fleet oceanographers, research and development (R&D) sponsors, and others.

2. Identify matches between (a) needs and requirements and (b) existing and forthcoming scientific capabilities.

3. Develop prioritized R&D and transitioning strategy with operational partners and with collaborating organizations involved in climate R&D and operational climate support (e.g., civilian universities, NOAA). In this development task:
    a. include both improved analysis and improved forecasting capabilities using statistical, dynamical, and statistical-dynamical methods
    b. include improvements in data access, visualization, and the output of climate support products
    c. account for operational partner resource constraints (e.g., staffing and information technology (IT) constraints)
    d. include corresponding education and training materials for both operational partners and end users
    e. leverage related efforts and resources at the Naval Postgraduate School (NPS) and other Department of Defense (DoD) and civilian organizations (e.g., data sets, forecast products, analysis and forecasting methods, applications software)

4. Develop transition plan with annual updates in collaboration with FNMOC.

5. Develop and transition advanced long range and climate support capabilities for:
    a. national security operations
    b. atmospheric, oceanic, terrestrial, electromagnetic, and acoustic variables and sensor systems (e.g., EM & acoustic systems)

6. Produce and verify experimental climate analyses and long range forecasts (LRFs) in collaboration with FNMOC, NAVO, Joint Typhoon Warning Center (JTWC), fleet oceanographers, and others. Use results from this task to improve planning and outcomes from Tasks 1-3 (e.g., determination of needs and matches, validation testing). Leverage related efforts at NPS and collaborating organizations (e.g., related Navy field experiments and exercises, R&D at NOAA and civilian universities, NPS thesis and dissertation research projects).

## WORK COMPLETED

Our FY14 work was focused on:

1. Identifying and prioritizing warfighter requirements for climate and long range support, especially via collaborations with FNMOC and NAVO. This work led to the selection of several new atmospheric and oceanic data sets, and analysis and forecasting methods and products, for inclusion in future transitions to FNMOC --- in particular, developing, testing, and/or evaluating existing and new climate analyses and long range forecasting (LRF) methods, models, and products. This included:
    a. Developing and validating new multi-decadal atmospheric EM ducting data sets based on radiosonde data sets (in collaboration with Paul Frederickson, NPS; Figure 1)
    b. Developing and validating new multi-decadal ocean acoustic parameter data sets based on ocean reanalysis data sets

2. Developing, testing, and applying climate analysis methods to improve the characterization of intraseasonal to interannual variations in EM ducting (McKeon 2013; Figure 2)

3. Beginning the assessment of products for inclusion in FNMOC's Advanced Climate Analysis and Forecasting (ACAF) online application (FNMOC 2014), especially:
    a. LRF products from the NOAA Climate Forecast System Version 2 (CFS2) and the North American Multi-Model Ensemble (NMME) program (Saha et al. 2014; CFS 2014; Becker et al. 2012; NMME 2014)
    b. Reanalysis products from the Hybrid Coordinate Ocean Model (HYCOM) ocean reanalysis developed by the Naval Research Laboratory (NRL) (HYCOM 2014)

4. Adapting and transitioning to FNMOC climate data sets, analysis and forecasting methods and software, and corresponding documentation, validation, educational, and training materials. This work included collaboration with FNMOC on the operational testing of the data sets, software, and climate support capabilities. The transitioned data sets included ones for clouds, precipitation, upper level winds, EM ducting, and ocean temperature, salinity, sound speed, acoustic ducting, and surface waves (e.g., Figures 3-4). The transitioned software included new versions of the ACAF online application code that provided new visualization, statistical analysis, and output capabilities.

5. Coordinating and collaborating with other organizations engaged in climate and long range research and development, and operational support. This included information and task sharing, resource leveraging, peer reviewing, monthly teleconferences, and participation in workshops and conferences with FNMOC, NAVO, NOOC, JTWC, 14$^{th}$ Weather Squadron, IC organizations, NRL, NOAA Climate Prediction Center, George Mason University, and other organizations involved in the NMME program. This work also included contributing to the development of an ONR Small Business Innovation Research (SBIR) announcement focused on improving Navy operational climate and long range support, and reviewing the proposals submitted in response to that announcement.

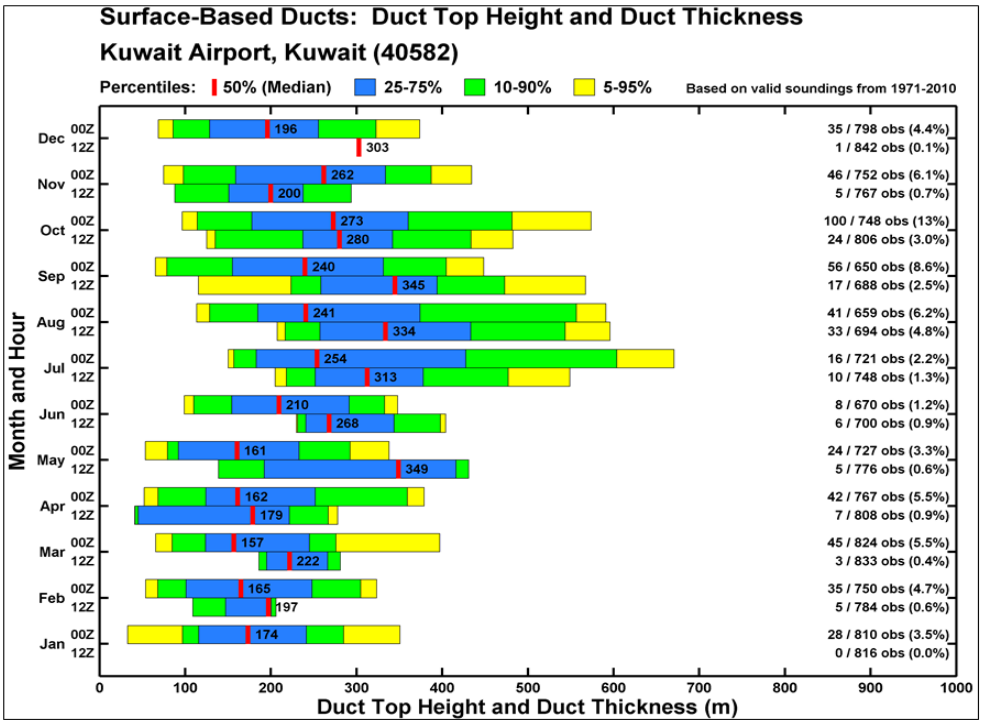


***Figure 1. Long term mean percentiles for duct top height and duct thickness for 00Z and 12Z for each month, January-December, for Kuwait City, Kuwait. These results are examples of the atmospheric electromagnetic ducting climate data set developed and transitioned by this project to FNMOC.***

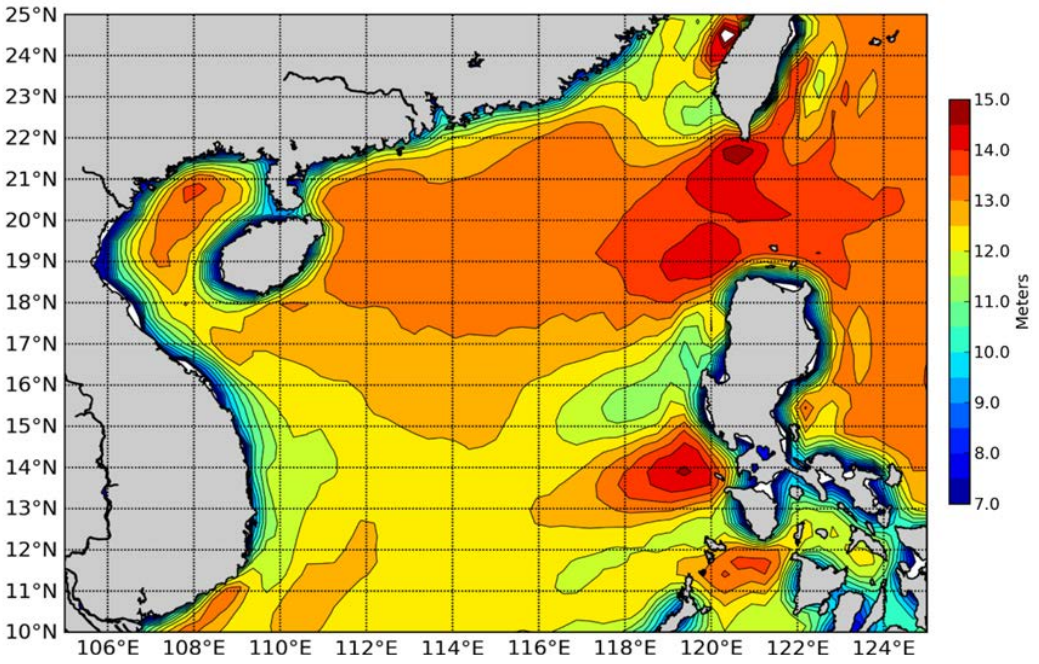


***Figure 2. Long term mean evaporation duct height for 00Z during November over the South China Sea. Results generated using ACAF system transitioned by this project to FNMOC. From climate variation study by McKeon (2013).***

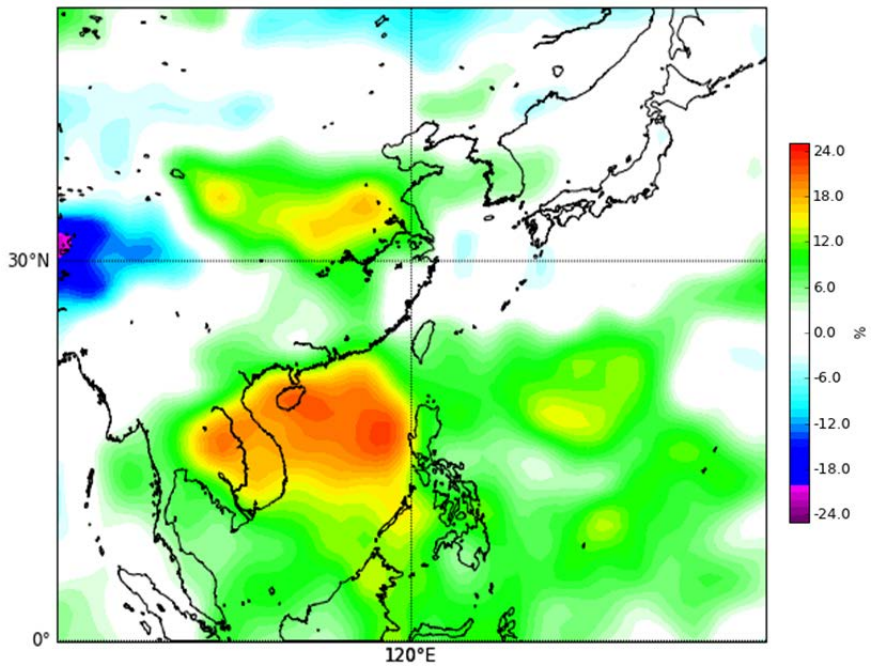


*Figure 3. Anomalous cloud cover (in percent coverage) in October during La Nina over the East Asian – western North Pacific. Note the positive 20-25 percent anomaly in cloud cover during La Nina over most of the South China Sea. Results generated using ACAF system transitioned by this project to FNMOC.*

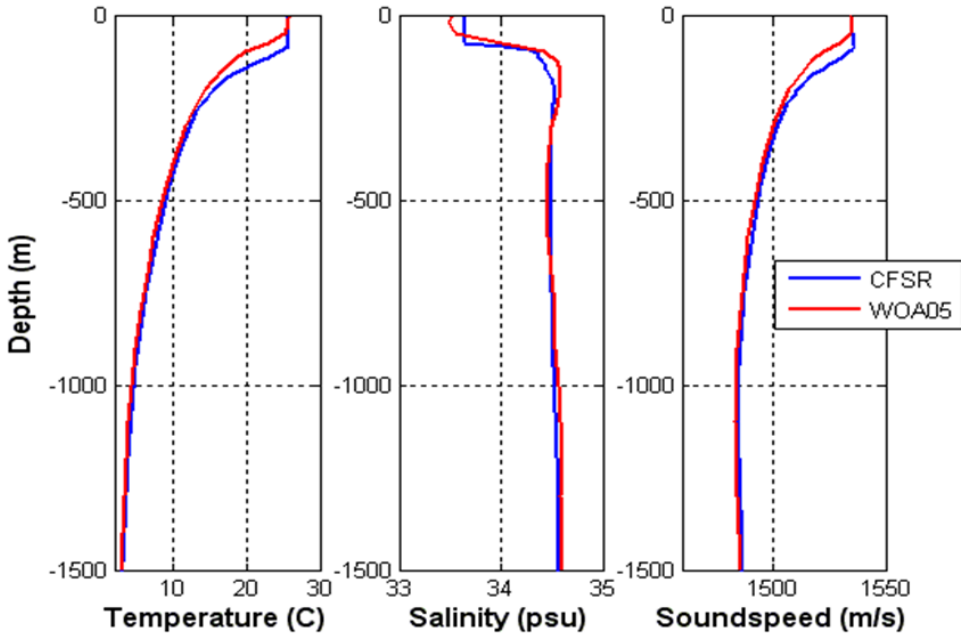


*Figure 4. Upper ocean temperature, salinity, and sound speed profiles for 15 January 2002, from 0-1500 meters depth, for a point in the South China Sea (15N, 115E), based on data from the Climate Forecast System (CFSR; Saha et al. 2010; blue curve) and the World Ocean Atlas 2005 (red curve; WOA 2005). Note the close correspondence between the two curves. Results generated as part of validation testing for the ACAF system transitioned by this project to FNMOC.*

## RESULTS

One of our main objectives is to deliver improved long range / climate support capabilities to FNMOC. These capabilities are delivered to FNMOC mainly via new versions of the ACAF online application (FNMOC 2014). The ACAF application is a tool for accessing data sets (including analysis and forecast output files), visualizing and analyzing data, and developing and outputting analysis and forecast products.

During FY14, we delivered to FNMOC an upgraded version of the ACAF data sets and software, collaborated on the operational testing of that new version, and developed and tested a further upgrade that will be delivered to FNMOC in early FY15. These two new versions provide FNMOC, NAVO, and their customers with additional climate support capabilities for additional atmospheric and oceanic variables, regions and periods, and types of operations (e.g., precipitation, EM ducting parameters, ocean acoustic parameters). The new versions also provide improved analysis, forecasting, display, and output capabilities (e.g., improved statistical tools for use in analysis and forecasting (cf. van den Dool 2007; NRC 201)). With the delivery and transitioning of these new versions, the ACAF online application will have:

1. 30+ climate scale observational, analysis, reanalysis, and forecast data sets: 20 atmospheric and 10 oceanic
2. 300+ atmospheric and oceanic variables
3. Scores of options for generating long range and climate analyses and forecasts

We continued and extended our experimental analysis and forecasting work on several topics. This included an analysis of EM ducting in the South China, including the seasonal cycle and intraseasonal to interannual variations in evaporation ducts (McKeon 2013). This work involved extensive use of the ACAF online application and contributed to the identification of several potential upgrades to the ACAF application for enhancing the ability to generate such analyses and related forecasts (e.g., statistical intraseasonal to interannual forecasts of EDH).

We continued our experimental, real time, intraseasonal to seasonal forecasting of tropical cyclone formations in the western North Pacific based on a hybrid dynamical-statistical forecast system. These are probabilistic forecasts at leads of one to 90 days for formations at specific locations and for valid periods of one to 30 days. We provided our forecasts in real time to the Joint Typhoon Warning Center (JTWC) and the NOAA Climate Prediction Center (CPC) for their operational use. JTWC used our shorter (one to four day lead) lead forecasts to better predict which tropical systems were most and least likely to develop into TCs. CPC used our one and two week outlooks (leads of about 4 and 11 days, respectively) to develop the CPC Global Tropical Hazards and Benefits (GTHB) forecast product (CPC 2014). Our real time preliminary forecast verification, and our post-season forecast verification based on best track data, showed skill at all lead times (e.g., Heidke skill scores of 0.2 to 0.5).

We developed two new collaborations in FY14:

1. Nacy applications of dynamical long range forecasts: This is a collaboration with the CFSV2 and NMME programs to develop priorities and methods for incorporating dynamical LRFs, and products derived from those forecasts, in the climate support provided by FNMOC and NAVO

(e.g., providing NMME forecasts via ACAF). This collaboration will expand in FY15 to include businesses funded via the SBIR effort described above.

2. Coordination of climate support efforts focused on national security: This is a collaboration with other DoD and IC organizations, informally named the Climate Working Group, that provide and/or use climate support to improve the coordination between the organizations, share information, and leverage resources.

## IMPACTS/APPLICATIONS

The results of this project contribute to improved understanding of climate variations and their impacts on national security operations. The data sets and tools delivered by this project facilitate national security related climate analysis and forecasting research (e.g., Gillies 2012; Strong 2012; McKeon 2013; Pasillas 2013). This research results in turn help identify science and operational support gaps that need to be addressed in future R&D. The data sets and tools also allow efficient generation of operational support products for national security applications. ACAF is available in an unclassified version and at two levels of security classification to support a wide range of uses in analysis and forecasting, including reconstruction and forensic uses.

## TRANSITIONS

An upgraded versions of the ACAF system was transitioned to FNMOC FY14 and will become operational in early FY14. An additional upgraded version will be transitioned to FNMOC in early FY15 and will become operational later in FY15.

## RELATED PROJECTS

1. Planning for Climate Change: A study of how climate science is, and potentially could be, used in the development and implementation of Navy policies, plans, and management practices. Focus on sea level rise in the mid-Atlantic coastal region. PI: Tom Murphree.
2. Climate Change Effects on Navy Island Bases: A study of the impacts of actual and potential climate change on Navy island bases. Focus on the impacts on critical Navy infrastructure at fleet concentration island bases. PI: Tom Murphree.
3. Enhanced Electromagnetic Ducting Climatology: A project to develop new global climate scale EM ducting data sets. Focus on upper air ducting. PIs: Paul Frederickson and Tom Murphree.
4. Exploiting Environmental Intelligence in Operational Decision Making: A project to improve decision support tools by better incorporating forecasts of the: (a) operational impacts of environmental conditions; and (b) environmental signatures created by operations. Focus on maritime operations. PI: Tom Murphree.

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**PUBLICATIONS**

- McKeon, B., LCDR, USN, 2013: Climate Analysis of Evaporation Ducts in the South China Sea. NPS Masters of Science thesis. Graduation: December 2013. Advisor: T. Murphree; co-advisor: P. Frederickson.