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LONG-RANGE OPERATIONAL MILITARY FORECASTS FOR IRAQ

by

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The military weather community is mandated by the Department of Defense (DoD) to provide accurate, timely, and reliable meteorological information necessary for commanders to exploit the best windows of opportunity for operations. In order to meet this mandate, the military must apply state-of-the-art long-range forecasting techniques. This study was motivated by the need for long-range forecasts for mission planning in Iraq. To develop these forecasts, we tested and adapted composite analysis and forecasting techniques used by the National Oceanographic and Atmospheric Association (NOAA) for forecasts in the continental U.S. Using these techniques, we conducted seasonal composite analyses for Iraq surface temperature and precipitation rate, with the compositing based on the observed occurrence of the North Atlantic Oscillation (NAO) and El Nino – La Nina (ENLN) climate variations. We then used composite analysis results to produce long range forecasts of Iraq surface temperature and precipitation rate based on the predicted occurrence of the NAO and ENLN. These forecasts outperformed forecasts based on long-term means (LTMs). Forecasts based on LTMs are currently the best available long range forecasts available from DoD. Thus, the composite analysis forecasts developed and tested in this study are a clear improvement over presently available DoD long range guidance products. The outcome of this study is a vector for the DoD weather community to expand out from the almost exclusive use of LTM based climatological products, and to invest in modern state-of-the-art methods for to supporting the global mission of the DoD.

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LONG-RANGE OPERATIONAL MILITARY FORECASTS FOR IRAQ

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ABSTRACT

The military weather community is mandated by the Department of Defense (DoD) to provide accurate, timely, and reliable meteorological information necessary for commanders to exploit the best windows of opportunity for operations. In order to meet this mandate, the military must apply state-of-the-art long-range forecasting techniques. This study was motivated by the need for long-range forecasts for mission planning in Iraq. To develop these forecasts, we tested and adapted composite analysis and forecasting techniques used by the National Oceanographic and Atmospheric Association (NOAA) for forecasts in the continental U.S. Using these techniques, we conducted seasonal composite analyses for Iraq surface temperature and precipitation rate, with the compositing based on the observed occurrence of the North Atlantic Oscillation (NAO) and El Nino – La Nina (ENLN) climate variations. We then used composite analysis results to produce long range forecasts of Iraq surface temperature and precipitation rate based on the predicted occurrence of the NAO and ENLN. These forecasts outperformed forecasts based on long-term means (LTMs). Forecasts based on LTMs are currently the best available long range forecasts available from DoD. Thus, the composite analysis forecasts developed and tested in this study are a clear improvement over presently available DoD long range guidance products. The outcome of this study is a vector for the DoD weather community to expand out from the almost exclusive use of LTM based climatological products, and to invest in modern state-of-the-art methods for to supporting the global mission of the DoD.

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LIST OF ACRONYMS

ACMES	Advanced Climate Modeling and Environmental Simulations
AFCCC	Air Force Combat Climatological Center
AN	above normal
AO	Arctic Oscillation
BN	below normal
CAF	composite analysis forecast
CPC	Climate Prediction Center
DoD	Department of Defense
EN	El Nino
ENLN	El Nino-La Nina Oscillation
ESRL	Earth System Research Laboratory
ETC	extratropical cyclone
FA	forecast accuracy
FAR	false alarm rate
HSS	Heidke skill score
IO	Indian Ocean
IOZM	Indian Ocean Zonal Mode
IRI	International Research Institute for Climate and Society
LN	La Nina
LTM	long-term mean
MEI	Multi-variate El Nino Index
METOC	meteorological and oceanographic
NAO	North Atlantic Oscillation
NAOI	North Atlantic Oscillation Index
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NN	near normal
NOAA	National Oceanographic and Atmospheric Association
NWS	National Weather Service
PFJ	polar front jet
PoD	probability of detection
SST	sea surface temperature
SWA	southwest Asia
TF	tendency forecast

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First and foremost I must thank my wife, Jennifer, whose support provided the foundation for me to stand on during my time here at Naval Postgraduate School. Many thanks go to my advisors, Prof. Tom Murphree and LtCol Karl Pfeiffer. Their guidance was invaluable during this process. Also, thanks to Prof. Patrick Harr for providing guidance which helped keep our research statistically sane. Lastly, I must thank my partner in this endeavor, 1st LT Sarah Moss. Without her partnership, the depth and scope of the research would have never been possible.

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I. INTRODUCTION

A. BACKGROUND

Over the past several decades, there has been rapid progress in understanding of Earth's climate system (e.g., Changon 2004). The challenge the Department of Defense (DoD) now faces is applying this new understanding to operations. In turn, with DoD's current lack of exploitation of the advances made in the civilian community, combatant commanders' operational risk management and decision making abilities are behind the times with respect to awareness of potential intra-/inter-seasonal weather impacts to military operations (e.g., LaJoie 2006, Stepanek 2006, Vorhees 2006). Detailed recommendations for improvements in applied military climatology have been laid out in LaJoie (2006) and Vorhees (2006). Both of these studies propose changes to the current DoD emphasis on climate products based on long-term means (LTMs). In this study, we have examined a new suite of potential military climate products, with a focus on their application to the Iraq region.

Improved long-range outlooks are a critical component of the commander's battlespace awareness. In a an interview on November 19, 2006, with the Associated Press (AP 2006), Brigadier General Douglas Pritt, in charge of U.S. lead efforts to train the Afghan military stated, "[Afghan troops are] much better equipped for winter operations than the Taliban. I'm hoping for a lot of snow this winter." Comparing the Afghan troops to the Taliban fighters, Pritt went on to say that snowfall was already hampering Taliban supply lines (AP, 2006). The General's rationale is that snowfall limits trafficability and maneuvers, making the enemy more vulnerable to an offensive military strike. With limited re-supply and less advanced equipment, the Taliban forces would be less likely to mount an offensive or a strong sustained defense. U.S. and Afghan government military planners could use this knowledge in planning their own winter offensive. However, to do so to best advantage, the planners need to have reliable long-range outlooks that go beyond simply forecasting LTM conditions and identify deviations from the LTMS (e.g., heavy snowfall in the upcoming winter).

Joint Publication 3-59, *Joint Doctrine, Tactics, Techniques, and Procedures for Meteorological and Oceanographic Operations* (Joint Staff 1999), states

> Accurate, timely, and reliable meteorological and oceanographic (METOC) information can provide the commander with knowledge necessary to anticipate and exploit the best window of opportunity to plan, execute, support, and sustain specific operations.

In order to meet this mandate the military must apply state-of-the-art long-range forecasting techniques. This research will examine composite analysis and forecasting techniques developed by the National Oceanographic and Atmospheric Association (NOAA) for use in the continental U.S and their application to support of the DoD global mission.

For this research we have used Iraq as our focus region because of its prominence in national security concerns over the last few decades. Its strategic location and resources make it important to U.S. foreign policy.

B. GEOGRAPHY AND LTM CLIMATE OF IRAQ

For this study, we considered the climate of the southwest Asia (SWA) region in which Iraq is located (Figure 1). Iraq occupies 437,072 square-km of this region (CIA 2007), which is slightly more than twice the size of the U.S. state of Idaho.

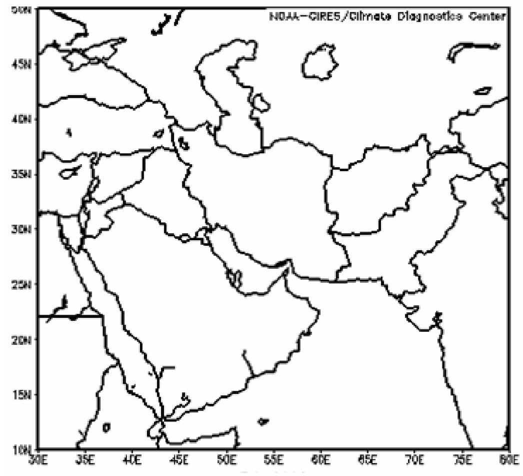


Figure 1. The southwest Asia region examined in our study and located within 10N-50N; 30E-80E

1. Geography

Iraq has an arid to semi-arid inland climate (CIA 2007). The majority of precipitation falls during October to April. Most of this “wet-season” precipitation is associated with transient extratropical cyclones (ETCs).

Most of Iraq’s terrain is relatively flat with little change in elevation. It can be described as a broad plains area with marshes along the Iranian border in the south, where the Tigris and Euphrates rivers empty into to the Persian Gulf. The notable exceptions to the continuous elevation are the Zagros mountain range along Iraq’s eastern border, and the highlands of the Anatolia Plateau and Taurus Mountains along the northern border. (CIA 2007) The distribution of precipitation over Iraq is dependent in part on the orientation of the mountain ranges. Southerly flow into the region can transport significant moisture from the warm tropical waters of the Indian Ocean (IO), Red Sea, and Persian Gulf. The Mediterranean Sea, to the west, can supply eastward tracking ETCs with additional moisture for precipitation in Iraq. (AFCCC 2005)

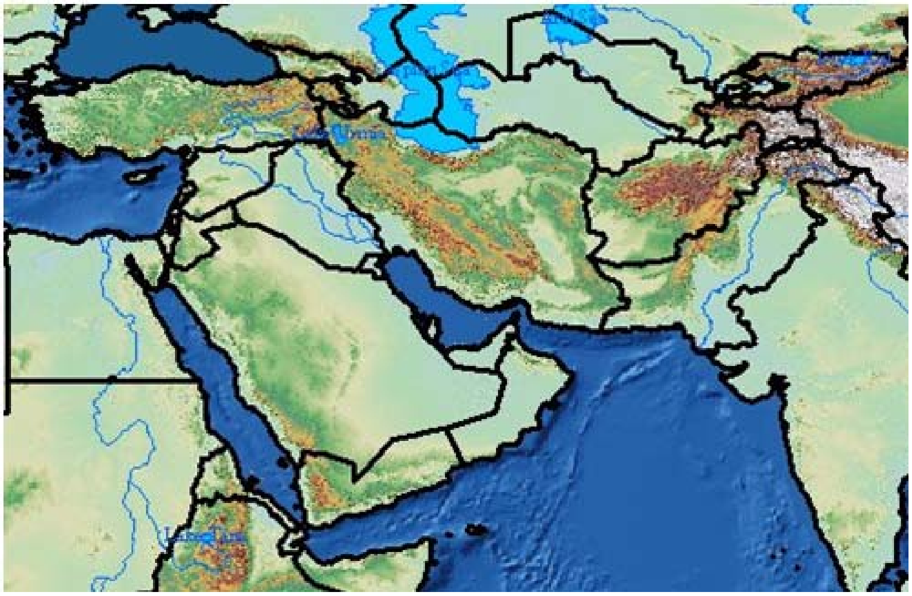


Figure 2. Topography of southwest Asia. Figure courtesy of Air Force Combat Climatology Center (AFCCC) [accessed online at http://www.afccc.af.mil 5 March 2007]

2. LTM Climate of Iraq

In order to understand the effects of climate variations on Iraq, we must understand the LTM climate of the greater SWA region. The LTM climate is summarized in Vorhees (2006), and more detailed studies are provided by Vojtesak et al. (1991), Walters et al. (1991), and Walters and Sjoberg (1988).

a. Winter (Jan-Mar)

The main driver of the winter climate is the lower tropospheric semi-permanent high pressure area known as the Siberian or Asiatic High. The Siberian High is centered over western Mongolia and tends to merge with other lower tropospheric semi-permanent high pressure areas, including the Saudi Arabian (Arabian Peninsula), Saharan High (Sahara Desert), and the Azores High (eastern North Atlantic Ocean). The merging of these high pressure centers tends to create a continuous lower tropospheric ridge in the subtropics and mid-latitudes. During this time, there is a strengthening of northeasterly low level winds from Asia over the northwestern Indian Ocean (IO). During the winter, the polar front jet (PFJ) reaches its southernmost latitudes and its maximum intensity. (AFCCC 2005)

Also during the winter months, eastward shift in deep tropical convection occurs over the Maritime Continent (MC). As a result, there is a corresponding shift in upper level ridging associated with the Rossby-Kelvin wave response to the convection (Vorhees 2006). As winter subsides, the snow caps of the mountains begin to melt, which can lead to extensive flooding in low lying regions. Flooding is especially likely in central and southern Iraq as the snow melts in the mountainous northern region. (CIA 2007)

b. Spring (Apr-Jun)

ETCs still transit the region during spring, although ETC frequency decreases as the season progresses. The decrease is due the northward shift of the PFJ and the strengthening of the Arabian Peninsula High. (AFCCC 2005)

c. Summer (Jul-Sep)

Many of the major features of the summer months are closely related to the Asian summer monsoon. Strong upper level ridging tends to develop over SWA and all of southern Asia in response as deep convection over southern and eastern Asia. At the low levels, a semi-permanent thermal trough stretching from northwestern Africa to southeastern Asia also develops. There is also a northward shift of the intertropical convergence zone (ITCZ). The low level winds south of trough tend to create a broad region of southwesterly flow that converges into the ITCZ. This season is often referred to as the southwest monsoon period.

d. Autumn (Oct-Dec)

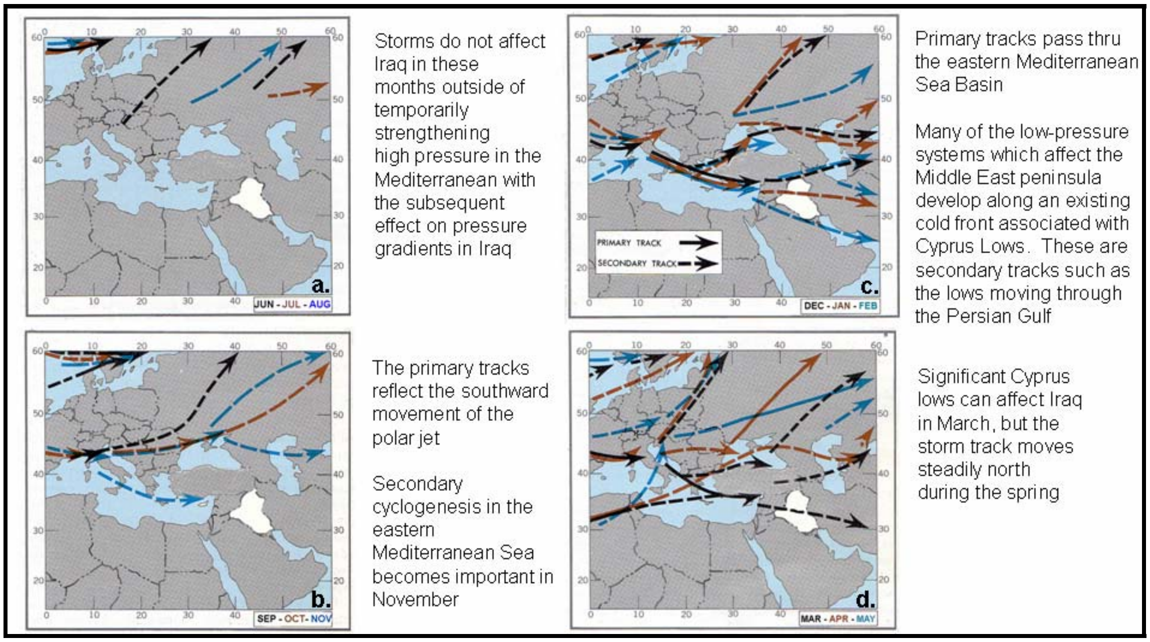
Iraq's autumn season is a transition between the southwest monsoon and the northeast monsoon periods. During this period, a decrease in insolation leads to the eventual collapse of the thermal trough and associated heat lows which setup during the summer season. The Asiatic High begins to build, resulting in a reorientation of the low level flow to northeasterly. The PFJ begins to shift southward in the SWA region as the north hemisphere begins to cool. The shift in the PFJ results in increased ETC frequency in the region. The ETCs bring with them precipitation and can begin as early as October. These ETCs are the primary mechanism for precipitation in Iraq.

C. EXTRA-TROPICAL CLIMATOLOGY

The greater Iraq region of SWA is affected by four main synoptic regimes (AFCCC 2005). The winter regimes include the Asiatic High, Cyprus Low, and Black Sea Low. The summer regimes are the Pakistani Heat Low and the Arabian Peninsula High. These regimes vary the most during the transition seasons of spring and autumn.

As Vorhees (2006) and Barlow et al. (2005) concluded, the amount of precipitation in SWA associated with ETC activity can be strongly affected by moisture advection into SWA from the south. They identified convection variations in the eastern IO and MC region, and the resulting Rossby-Kelvin wave response over the IO and south Asia, as an important mechanism for altering the advection of moisture to ETCs in SWA. But one outstanding question remains from these studies: What climate variation(s) affect the frequency and/or tracks of ETCs in SWA? Through our regional correlation analyses and compositing we hope to shed some light on this question.

In order to understand the climate of Iraq it is important to review the typical storm track of the regimes during the course of a “normal” year. Figure 3a shows the typical storm tracks during the months of June, July, and August. A dominate Sahara High coupled with the Arabian Peninsula High tends to block ETCs that might otherwise enter Iraq.



Storms do not affect Iraq in these months outside of temporarily strengthening high pressure in the Mediterranean with the subsequent effect on pressure gradients in Iraq

Primary tracks pass thru the eastern Mediterranean Sea Basin

Many of the low-pressure systems which affect the Middle East peninsula develop along an existing cold front associated with Cyprus Lows. These are secondary tracks such as the lows moving through the Persian Gulf

The primary tracks reflect the southward movement of the polar jet

Secondary cyclogenesis in the eastern Mediterranean Sea becomes important in November

Significant Cyprus lows can affect Iraq in March, but the storm track moves steadily north during the spring

Figure 3. Primary storm tracks for: (a) June, July, August; (b) September, October, November; (c) December, January, February; and (d) March, April, May. Taken from AFCCC SWA DVD (2005)

September, October, and November storm tracks are shown in Figure 3b. The most notable aspect of Figure 3b is the secondary cyclogenesis in the eastern Mediterranean Sea during November, one of the factors that leads to the onset of Iraq's wet-season. Figure 3c shows the primary storm tracks during December, January, and February. The increased number of storms into the greater Iraq region in this season brings the majority of Iraq's annual precipitation. Figure 3d shows how the wet season begins to subside after March. ETCs become less frequent as the PFJ shifts northward and the Arabian High, begins to strengthen and once again dominate the region. (AFCCC 2005)

D. LARGE-SCALE CLIMATE VARIATIONS

Global scale climate variations, such as the North Atlantic Oscillation (NAO) and El Nino – La Nina (ENLN), have been shown to affect climate in SWA (e.g., Barlow et al. 2005, Vorhees 2006). When researching the world-wide effects of ENLN, Mason and Goddard (2001) suggested, "for many parts of the world this knowledge provides a better estimate of the probable future climate than the assumption that a seasonal condition will be the same as average." As will be demonstrated in our study, this assertion has validity and can be applied to other oscillations other than ENLN.

1. El Nino-La Nina

Of all the climate variations, ENLN has been the most studied. This variation has three phases, El Nino (EN), neutral, and La Nina (LN). The Climate Predication Center (CPC) defines EN as a:

> large-scale ocean-atmosphere climate phenomenon linked to a periodic warming in sea-surface temperatures (SST) across the central and east-central equatorial Pacific (between approximately the date line and 120W). El Nino represents the warm phase of the ENSO cycle, and is sometimes referred to as a Pacific warm episode. (http://www.cpc.ncep.noaa.gov, accessed 5 March 2007).

LN events are defined as:

> Periodic cooling of SST in the central and east-central equatorial Pacific that occurs every 3 to 5 years or so. La Nina represents the cool phase of the ENSO cycle, and sometimes referred to as a Pacific cold episode. (http://www.cpc.ncep.noaa.gov, accessed 5 March 2007).

Further details of the development and cycle of ENLN can be found in Murphree (2006a), Philander (1990), Ropelewski and Halpert (1987, 1989, 1996), and Hildebrand (2001).

As Vorhees (2006) concluded, EN and LN can have significant consequences on the SWA region. That study demonstrated that anomalous eastern IO convection can drive anomalies in SWA's seasonal temperature and precipitation. For example, the anomalous warming of SSTs during LN in the MC region increases convective activity over that region. In turn, deep ascent is enhanced, creating anomalous upper level divergence. The net effect, as shown by Matsuno (1966) and Gill (1980), tends to be an equatorial Rossby-Kelvin wave response (Figure 4a). The reverse set of patterns and processes occurs during EN, leading to a reversal in the sign of the Rossby-Kelvin wave response (figure 4b).

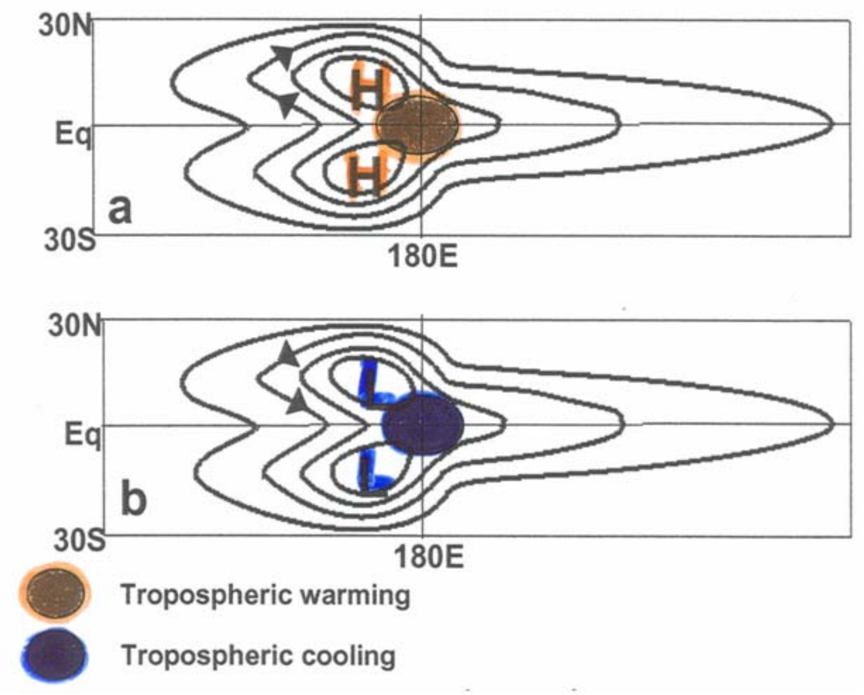
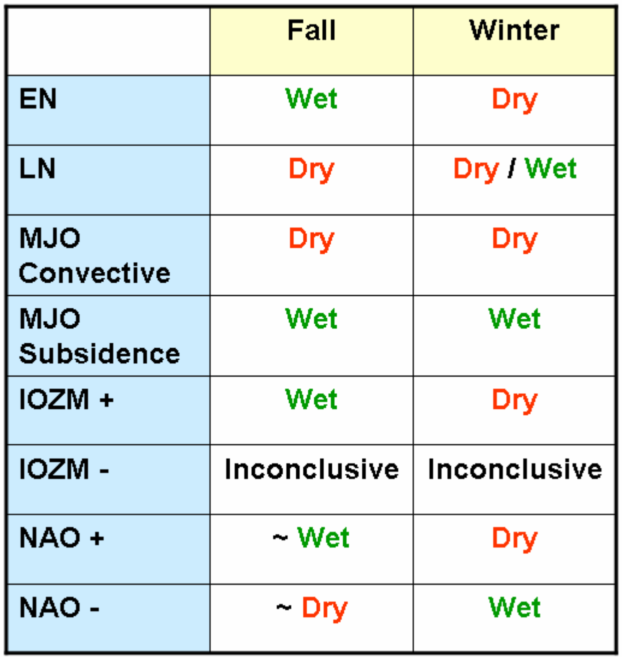


Figure 4. Illustration taken from Ford (2000) shows the upper tropospheric response to anomalous tropospheric warming (a) and cooling (b) centered on the equator. The contours and arrows represent the response in terms of upper tropospheric geopotential heights and winds, respectively. The anticyclonic (cyclonic) circulations to the northwest and southwest of the warming (cooling) region represent the upper tropospheric Rossby wave response. The troughing (ridging) to the west, and the ridging (troughing) to the east, of the warming (cooling) region represent the Kelvin wave response.

Nitta (1987) and others have shown that a Rossby wave response to tropical convection variations can also extend into and generate responses in the extratropics. These responses have been observed far from the area in which they were initiated.

Vorhees (2006) is the starting point for this research. Table 1 shows a summary of his findings.

Table 1. Global climate variations and the associated fall and winter precipitation anomalies in southwest Asia as determined by Vorhees (2006).



	Fall	Winter
EN	Wet	Dry
LN	Dry	Dry / Wet
MJO Convective	Dry	Dry
MJO Subsidence	Wet	Wet
IOZM +	Wet	Dry
IOZM -	Inconclusive	Inconclusive
NAO +	~ Wet	Dry
NAO -	~ Dry	Wet

For our study, the Vorhees (2006) findings for ENLN and the NAO are most relevant. Although, these finding are for all of SWA, we begin with the hypothesis that similar signals will be observed in Iraq, which is located near the SWA region analyzed by Vorhees. It is important to note Vorhees (2006), as with most ENLN studies, did not examine the effects on SWA of the neutral phases of ENLN and the NAO.

2. North Atlantic Oscillation

One of the most prominent and recurring climate variations, the NAO can dictate climate variations over much of the Northern Hemisphere (Hurrell et al. 2003). NAO phases can occur throughout the year, but tend to be strongest during the northern winter. The NAO is fairly predictable at time scales on the order of a week to a month (Hurrell et al. 2003).

There is still debate as to whether the NAO is the North Atlantic branch of the Northern Hemisphere Annular Mode, or Artic Oscillation (AO) (Vorhees 2006). For the purposes of this study, we are more concerned with application of NAO observational data and forecasts, rather than NAO dynamics.

The NAO is divided into three phases: positive, negative, and neutral. As shown in Figure 5a, the positive phase (negative) exists when the Azores High and Icelandic Low are stronger (weaker) than average. The positive and negative phases can produce large anomalies in the mid-latitude westerlies, trades, temperature, moisture advection from North America into western Asia. (Figure 5; Murphree 2006b)

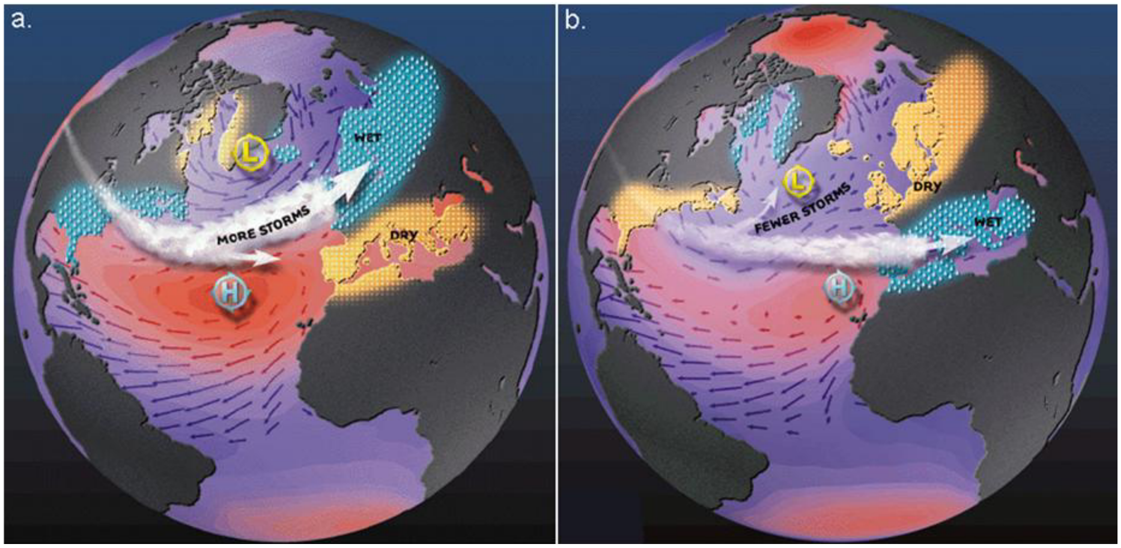


Figure 5. Schematic depiction of the NAO phases: (a) positive and (b) negative. Taken from http://www.ldeo.columbia.edu/NAO/ (Accessed February 2007)

In the positive (negative) phase, ETC storm track across the North Atlantic tends to be located further to the north (south) as it passes over Europe leading to higher precipitation in northern Europe (southern Europe and Mediterranean).

The impacts of both phases on SWA are examined in the Vorhees (2006) study and partially summarized in Table 1, which shows that the positive and negative phases produce opposite effects and that these effects change sign from fall to winter. In particular, Vorhees (2006) found that during positive NAO periods, SWA temperatures and precipitation tends to be cooler and wetter in the fall, and cooler and drier in winter, with the opposite anomalies occurring during negative NAO periods.

E. EXISTING OPERATIONAL CLIMATE MONITORING AND FORECAST PRODUCTS

1. DoD Products

The primary sources of DoD climatological products are AFCCC and Fleet Numerical Meteorology and Oceanography Detachment, both located in Asheville, North Carolina. As shown by the AFCCC website (AFCCC 2007), almost all products produced by AFCCC represent different ways of packaging and presenting LTM data. Although these products have their application, their predictive value is limited.

2. Non-DoD Products

In this section we have highlighted a select few types of products generated by civilian climatological that have a high potential for application in DoD operations.

a. National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) provide numerous oceanic and atmospheric science services to the general public. One of its self-described roles is to be a leader in applied scientific research, to include climate. Specifically, "understand changes in climate, including the EN phenomenon, to ensure that we can plan and respond properly." (http://www.noaa.gov/, accessed 5 March 2007) Much of this charge is met by the work of two NOAA sub-agencies, CPC and Earth System Research Laboratory (ESRL) located at Camp Springs, Maryland and Boulder, Colorado, respectively.

b. Climate Predication Center

CPC's mission is, "serve the public by assessing and forecasting the impacts of short-term climate variability, emphasizing enhanced risks of weather-related extreme events, for use in mitigating losses and maximizing economic gains" (http://www.cpc.ncep.noaa.gov/, accessed 5 March 2007). The CPC website hosts an extensive suite of products, including:

- Statistical 6-10 day, 8-14 day, one month, and three month outlooks of temperature and precipitation

- Assessments of hazards and drought conditions and outlooks
- Climate monitoring and forecasts for ENLN, NAO, MJO, AO, Antarctic Oscillation, and the Pacific/North American Pattern. Most of the forecasts are offered as GFS or ensemble mean based outlooks.

CPC also maintains an archive of the aforementioned indices and forecasts. Although CPC's products are North America centric, many of the methods it uses can be applied all around the globe.

c. Earth System Research Laboratory

NOAA formed ESRL to engage in comprehensive research in Earth system science, including Earth's climate system. This includes applied research leading to operational climate products, including:

- Seasonal Climate Forecast Guidance (Experimental) – A forecasting tool to assess the impact of climate variations on temperature and precipitation forecasts
- Climate Products Interactive Plotting and Analysis Tools – web-based plotting and analysis tool that provides the public with access to a significant number of climate data sets and climate analysis tools.

ESRL's interactive plotting and analysis tools give users access to very useful dataset, the National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) reanalysis dataset. The ESRL tools and the NCEP/NCAR reanalysis dataset were used extensively in this study, as discussed in Chapter II.

d. International Research Institute for Climate and Society

The International Research Institute for Climate and Society (IRI) of Columbia University and located in Palisades, New York offers a suite of products (with verification) including climate analyses and probabilistic seasonal climate forecasts.

DoD climatology products and services would dramatically benefit from developing strong collaborative relationships with, and adapting many of the methods used by, CPC, ESRL, and IRI.

F. MOTIVATION

The motivation of the study is to provide a viable tool for producing climate outlooks for military planners and decision makers. We hope key DoD weather leaders will realize the value and feasibility of our methods and assist in applying them to military weather forecasts.

The data and methods used for our research are discussed in Chapter II. Chapter III contains our main results, and Chapter IV presents our conclusions and suggestions for future research.

II. DATA AND METHODS

A. DATA

1. NCEP/NCAR Reanalysis

One of our main datasets was the the NCEP/NCAR dataset. NCEP and NCAR partnered together to produce a retroactive record, or reanalysis, of atmospheric fields (Kalnay et al 1996) that extends from 2006 to the present. NCEP/NCAR updates the reanalysis every five years to insure the system remains state-of-the-art. After more than a decade of use by the environmental science community, the NCEP/NCAR reanalysis dataset has proven to be a tremendous resource for the field of climatology. (Kistler 2001) For further explanation of the reanalysis we refer the reader to Kistler et al. (2001) and Kalnay et al. (1996).

a. Strengths

One of the main strengths of the reanalysis is its uniform global coverage extending over almost six decades at a horizontal spatial resolution of 2.5 x 2.5 degree and a temporal resolution of six hours. The reanalysis gives researchers an approximation of the state of the atmosphere, using state-of-the-art global analysis methods for many areas which otherwise would be very poorly described.

b. Limitations

The grid resolution of the reanalysis makes examination of mesoscale features challenging. However, alternative datasets have their own problems. For example, station observations in our region of interest, SWA, tend to have major spatial and temporal data gaps over the several decades of record needed for our study. The Advanced Climate Modeling and Environmental Simulations (ACMES) reanalysis dataset, maintained by AFCCC, is available at 44 and 11 km horizontal resolution anf for SWA, but only for ten year periods.

Limitations of the NCEP/NCAR reanalysis data differs according to the variable. The variables are categorized according to four classes — A, B, C, and D) — that indicate the relative influence of the observational data on reanalysis variable. Kalnay et al (1996) describe the four variable categories as follows:

> An A indicates that the analysis variable is strongly influenced by observed data, and hence it is in the most reliable class (e.g., upper-air temperature and wind). The designation B indicates that, although there are observational data that directly affect the value of the variable, the model also has a very strong influence on the analysis value (e.g., humidity and surface temperature). The letter C indicates that there are no observations directly affecting the variable, so that it is derived solely from the model fields forced by the data assimilation to remain close to the atmosphere (e.g., clouds, precipitation, and surface fluxes). Finally, the letter D represents a field that is obtained from climatological values and does not depend on the model (e.g., plant resistance, land-sea mask).

The reliability of the reanalysis variables can also vary with time. Variables representing periods prior to the advent of extensive satellite observation (i.e., from before the 1970s) are based on less observational data and therefore tend to be less reliable.

For this study, the advantages of the NCEP/NCAR reanalysis dataset clearly outweighed its disadvantages. We therefore used it as a main dataset for our study. We worked with data from 1970-2006, a total of 37 years, so that we would have a long enough record to capture a number of ENLN and NAO events, and so that we maximized the numbers of years for which relatively large amounts of satellite observations were available for the reanalysis (i.e., the 1970s onward).

2. Climate Indices

a. El Nino-La Nina

ENLN is one of the most researched climate variations, and there are a large suite of indices that monitor ENLN. CPC alone hosts over 8 different spatial and temporal variations of ENLN indices. One of these, Nino-3.4, is one of the most widely used and forecasted ENLN indices.

(1) NINO3.4 Index. The Nino-3.4 index defines EN and LN according to anomalies with respect to the 1971-2000 mean of the SST in the central tropical Pacific region of 5N-5S, 120-170W. The departure indicates an EN (LN) event when a 3-month average is greater than or equal to the normal 3-month average by +0.5C (-5C) (Higgins et al. 2004) Figure 6 shows the 3-month running mean Nino3.4 values for 1970-2006.

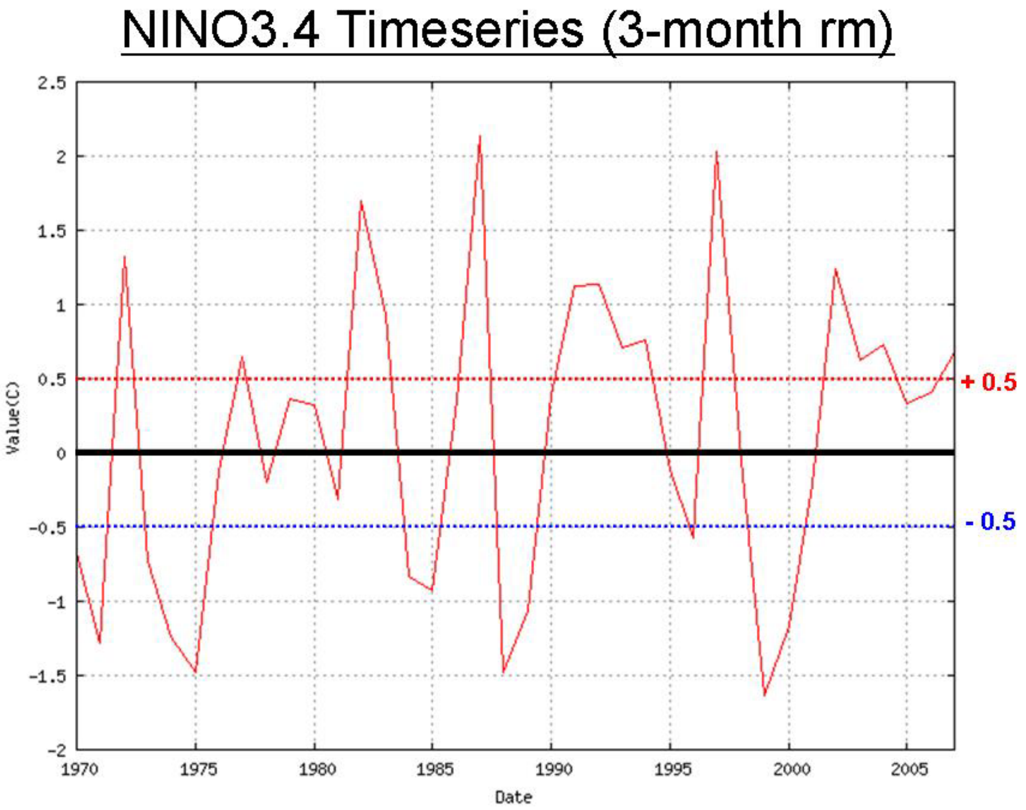


Figure 6. 3-month running mean of Nino3.4 SST anomalies (C) from 1970 to 2006. The +0.5 (-0.5) thresholds for EN (LN) phases used for our study are marked on figure. Generated at ESRL website [accessed online at http://www.cdc.noaa.gov/ March 2007].

CPC produces deterministic and probabilistic Nino3.4 forecasts. One of the main limitations to using Nino3.4, or any index based only on SST, is that it does not directly account for other aspects of ENLN, especially the atmospheric component. Multi-variate indices, such as the Multi-variate El Nino Index (MEI) may give more comprehensive representations of ENLN, especially when ENLN conditions are weak. However, forecasts of multi-variate indices are more difficult to forecast, and less available operationally, than single variable indices, such as Nino3.4.

b. North Atlantic Oscillation

There are a number of NAO indices available. For this study we chose to work with the NAO index produced by CPC, mainly because it is based on data from a large number of points across the North Atlantic basin, unlike most of the other indices which are based on just two points, or two small regions, in the North Atlantic basin.

(1) NAO Index. The CPC NAO index (NAOI) is based on empirical orthogonal function (EOF) analyses of 1000 hPa heights between 20N and 90N (CPC 2007). CPC maintains an up-to-date archive of the NAOI dating back to 1950. Also, CPC issues deterministic NAOI forecasts at lead times up to 14 days based on forecasts from the Global Forecast System (GFS) and ensemble mean outlooks. Like the Nino3.4 forecasts, the NAOI forecasts performance is tracked on CPC website through a model versus observation correlation analysis (Figure 7).

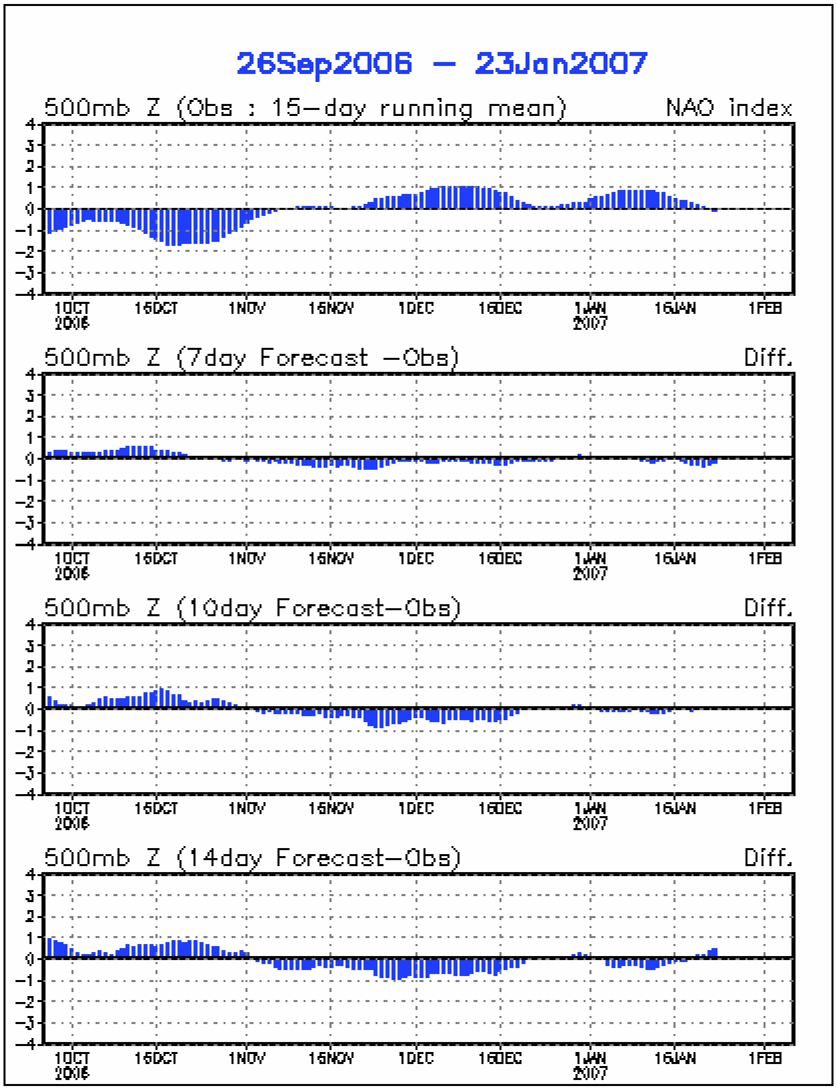


Figure 7. Observed NAOI (upper panel) and differences between observed and GFS forecasted NAOI at lead times of 7, 10, and 14 days (lower three panels). All values are15-day running mean values. Figure from CPC [accessed online from http://www.cpc.ncep.noaa.gov/ March 2007].

For this study, we designated as positive (negative) NAO periods those in which the three-month running mean values of the NAOI were greater (less) than +0.3 (Figure 8). In between values of the NAOI indicated neutral NAO periods.

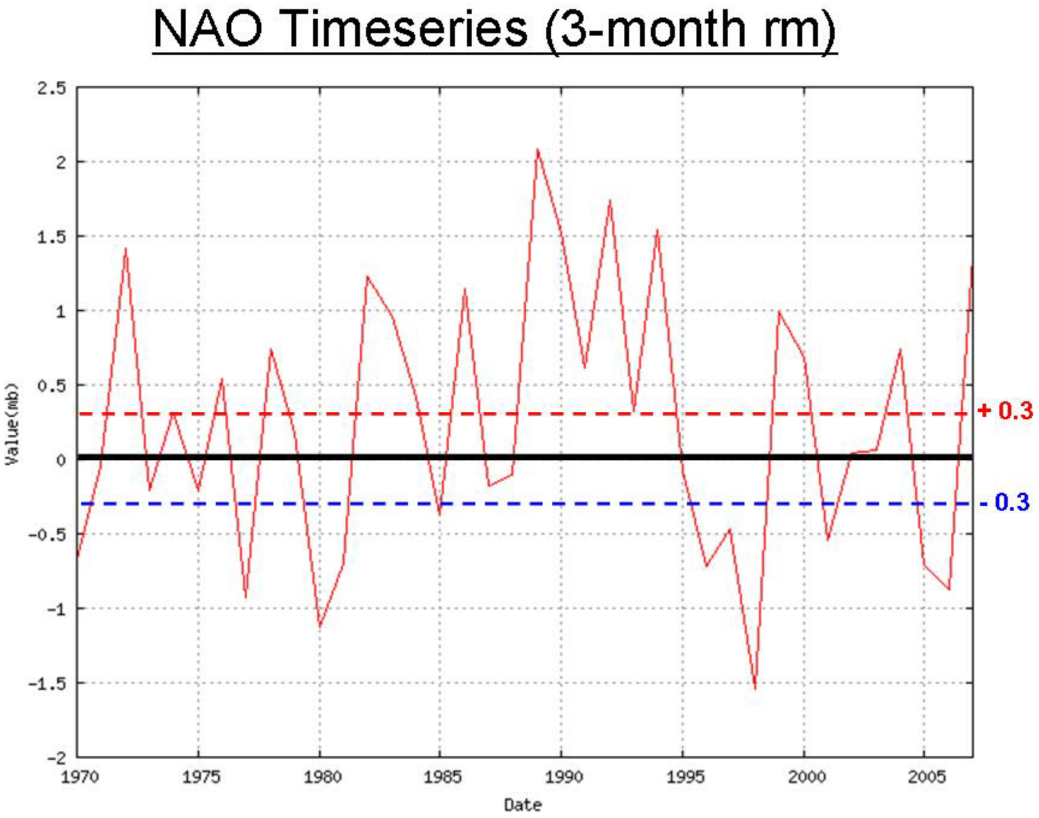


Figure 8. 3-month running mean of NAOI from 1970 to 2006. The +0.3 (-0.3) thresholds for positive (negative) NAO phases used for our study are marked on the figure. Generated at ESRL website [accessed online at http://www.cdc.noaa.gov/ March 2007].

CPC issues NAOI forecasts, but the lead times are relatively short (e.g., 7-14 days) and they are not the probabilistic forecasts needed for the composite analysis forecast method used in this study.

B. METHODS

Our process can be summarized as a three-step process; (1) climate variation based localized composite analysis, (2) application of composite analysis to produce a composite analysis forecast (CAF), and (3) CAF verification.

1. Localized Composite Analysis

This study adapts the composite analysis methods laid out in NOAA's training module, *Creating a Local Climate Product Using Composite Analysis*

(Hauser 2007), which is based on Higgins et al. (2003). The module includes a template and instructions to follow in order to perform a localized composite analysis for a chosen site. This module is used to train National Weather Service (NWS) forecasters in how to produce a CAF. To apply the NOAA composite analysis process, it is very useful to first determine the predictors and predictands that will be used in the process. Based on the prior studies of how global scale climate variations affect SWA (see Chapter I), we selected ENLN and the NAO as our predictors. Based on the sensitivity of many DoD operations to surface temperature and precipitation, we selected these two variables as our predictands. In brief, the composite analysis process uses information about the historical observed occurrence of the predictors and predictands to identify the typical observed relationships between the predictors and predictands. Then a forecast of the predictors is used, along with the historical observed relationships, to create a forecast of the predictands based on the forecast of the predictors.

Sections a-i below list the basic steps in the composite analysis process and described how we performed the steps for our study.

a. Select Area of Application

We defined Iraq as the region within 29N - 37.5N, 38.5E – 48.5E shown in Figure 9.

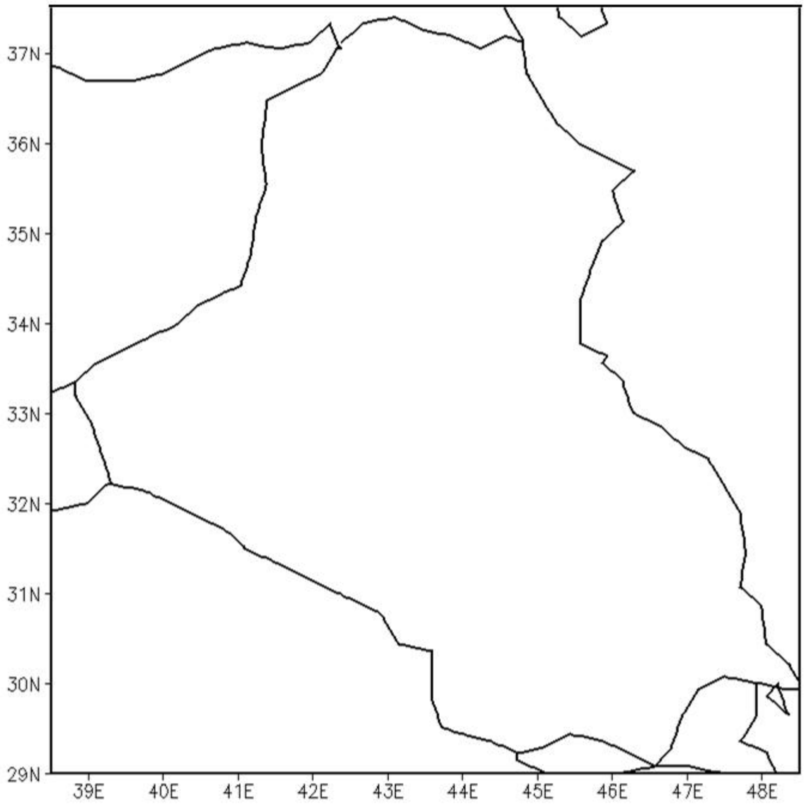


Figure 9. Region used in this study to describe Iraq climate variations: 29N - 37.5N, 38.5E – 48.5E. Map generate at ESRL website [accessed online at http://www.cdc.noaa.gov/ March 2007].

We created spatial averages for this Iraq region of the NCEP/NCAR reanalysis values of our predictands, surface temperature and precipitation rate for each season (Jan-Mar, JFM; Apr-Jun, AMJ; Jul-Sep, JAS; and Oct-Dec, OND) from 1948 to 2006. The resulting timeseries are shown in Figures 10 and 11. Note the large interannual and decadal scale variations. These variations are not represented by LTMs, but the CAF process is designed to both describe and predict such variations. Due to the large variations from one season to the next in these timeseries, and the need to highlight interannual variations in the timeseries, we have used different vertical scales for each season. This makes it more difficult to compare the seasons, but we feel this is acceptable, since the focus of this study is on variations in a given season from one year to the next, rather than on an analysis of the seasonal cycle.

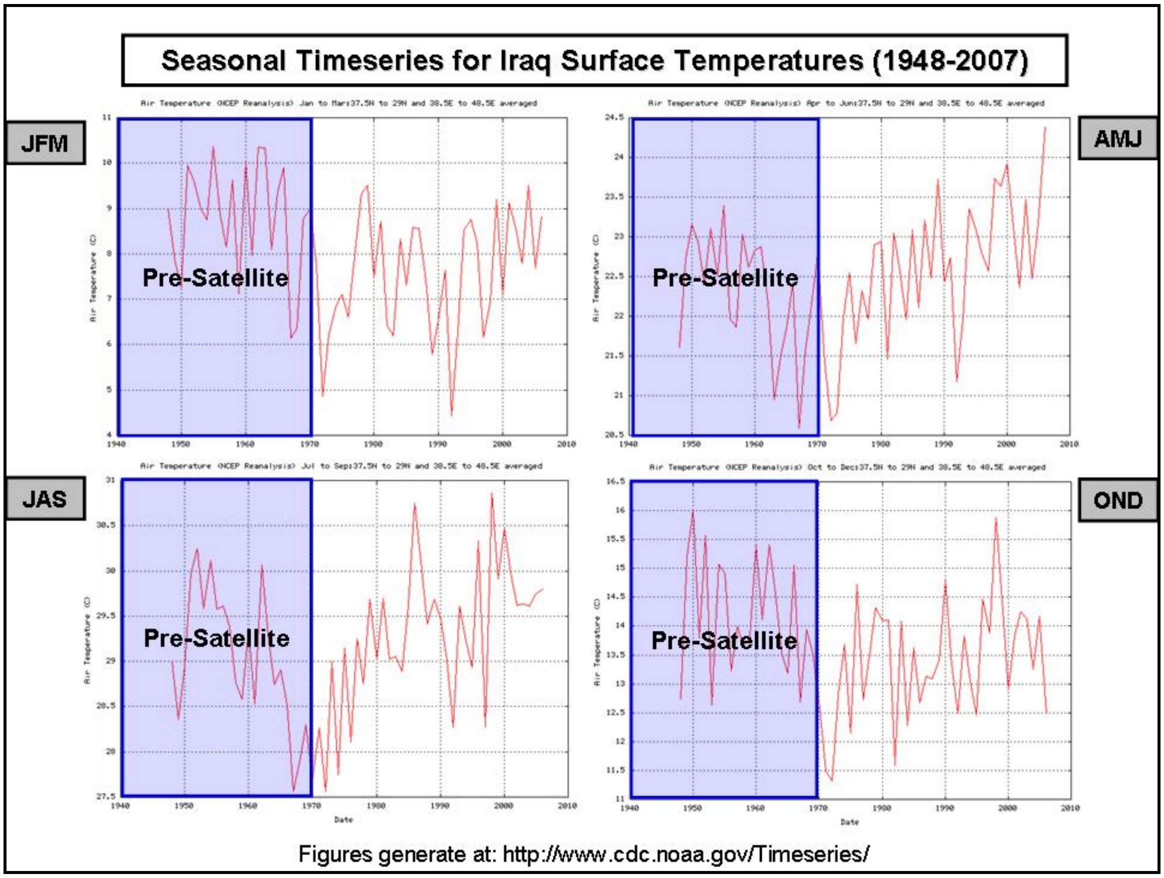


Figure 10. Timeseries of Iraq region spatially averaged seasonal surface temperature (1948-2006). Data from pre-satellite Era (pre-1970, blue shading) were not used in composite analyses done for this study. Figure generated at ESRL website [accessed online http://www.cdc.noaa.gov/Timeseries/ March 2007].

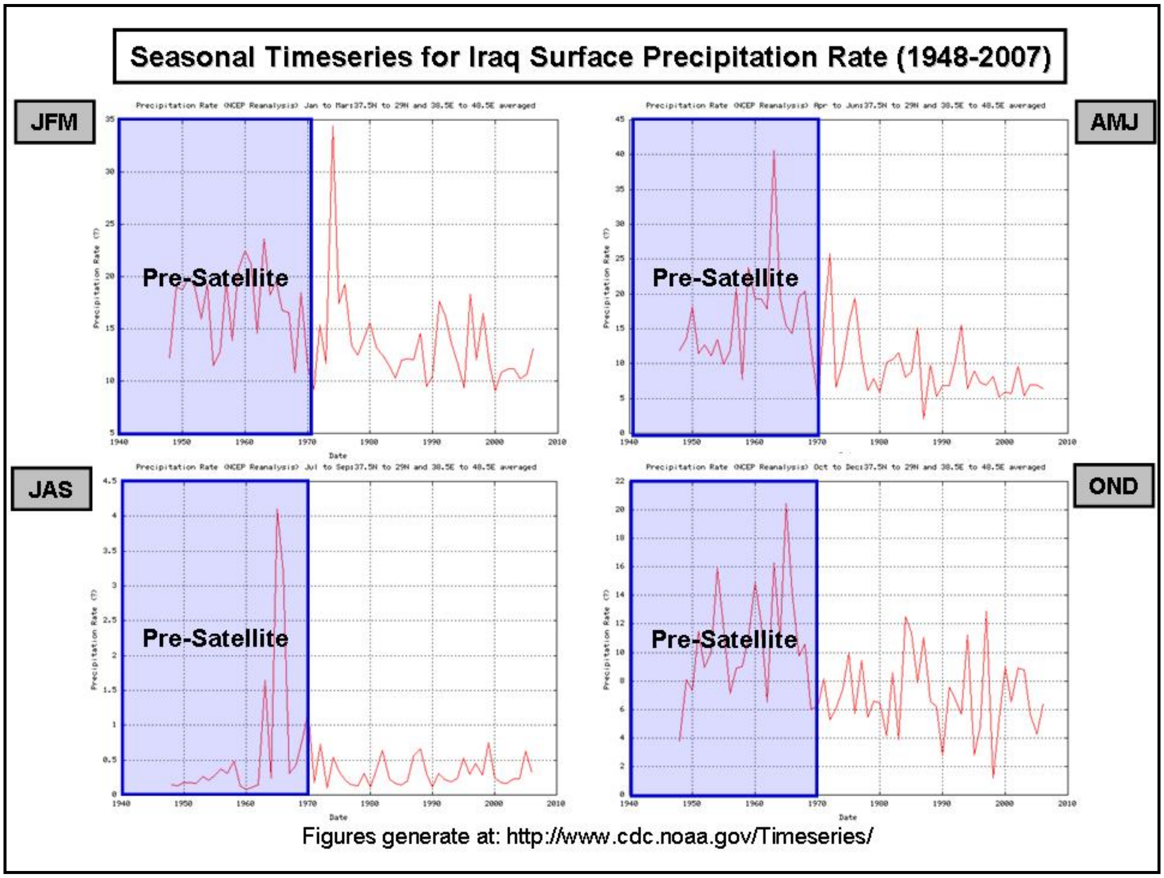


Figure 11. Timeseries of Iraq region spatially averaged seasonal precipitation rate (1948-2006). Data from pre-satellite Era (pre-1970, blue shading) were not used in composite analyses done for this study. Figure generated at ESRL website [accessed online http://www.cdc.noaa.gov/Timeseries/ March 2007].

b. Determine Time-Scales of Composite Analysis

Given the planning lead-time for DoD, our focus in this study was on contributing to the development of forecasts with lead times of 1-3 months. To do this, we chose to perform monthly and seasonal (3-month) composite analyses. The seasons we worked with were JFM, AMJ, JAS, and OND. The time scale selected can affect which climate variations are then used in the composite analyses, since climate variations have a range of time scales (intraseasonal to decadal and longer).

c. Determine Minimum Data Requirements

We needed a dataset large enough to include a relatively large number of ENLN and NAO events — on the order of ten samples of each phase.

This required our data set to be on the order of 30 years long. Due to the lack of a long set of reliable station observations for Iraq, we chose to work with the NCEP/NCAR reanalysis dataset.

d. Select Time Range

For this study we chose 1970-2006, a 37 year period, due to the lack of extensive of satellite data prior to 1970. The NOAA process uses only a 30-year period of record, so in this respect we deviated from this process.

e. Select Predictor Climate Variation Index, Index Threshold, and Corresponding Index Forecast

We selected Nino3.4 as our index and forecast index for ENLN. We chose the NAOI as our index and forecast for the NAO. For Nino3.4 we used the standard index threshold of +/- 0.5 to categorize ENLN phases. For NAOI we used a threshold of +/- 0.3 to categorize the phases of the NAO.

f. Determine Predictand Category Thresholds

We chose a three part, or tercile, categorization for our predictands, with the tercile categories being: above normal (AN), near normal (NN), and below normal (BN). The tercile thresholds were determined separately for each of the four seasons. The thresholds were determined by assigning each of the 37 representations of each season into one of the three terciles, such that there were an approximately even number of individual seasons in each tercile (e.g., 12 in AN, 13 in NN, and 12 in BN).

g. Calculate Frequency of Occurrence During Each Oscillation Phase

For each of the four seasons, the number of the AN, BN, NN seasons that occurred during each of the three phases of each climate variation was determined to get the frequency of occurrence for each phase.

h. Apply Trend Adjustment

Trend adjustment is performed to account for the effects of any long term (e.g., decadal) trends in the predictand timeseries. The trend adjustment is based on the previous 10 years of data, and if the deviation from the trend is statistically significant, then the trend adjustment is applied using a least squares fit method. For this study, we did not apply trend adjustments (see Chapter IV for more discussion of this issue).

i. Conduct Risk Analysis Using a Geometric Distribution.

A geometric distribution is used to describe the probability distribution among all possible outcomes of a category. This analysis is required to determine the statistical significance of the observed frequency distribution. This type of analysis helps assess the certainty that the distribution is not due to chance. We used a 10% significance level (i.e., 90% confidence interval) as a cutoff for an acceptable degree of risk. Further discussion of geometric distributions can be found in Wilkis (2006) and Hauser (2007).

2. Calculation of the Composite Analysis Forecast (CAF)

Steps a-I described in the prior section provide an outline of the composite analysis process. The outcome from that process is a set of observed frequency distributions for the predictands with respect to the predictors, with the statistical significance of each distribution determined. The observed frequency distributions describe how observed AN, NN, and BN values of the predictands were related to the observed phases of the predictors (e.g., surface temperatures were AN in 40% of the JFMs that occurred during EN). The distributions that are statistically significant can then be combined with a probabilistic forecast of the predictor to construct a probabilistic forecast of the predictand. We refer to this forecast as a composite analysis forecast (CAF). An example of the calculation used to create these forecasts is given below for a forecast of AN predictand conditions given a probabilistic ENLN forecast:

> Forecasted probability of AN predictand conditions = (observed probability of being in the AN category given EN) x (forecast probability of EN) + (observed probability of being in the AN category given neutral) x (forecast probability of neutral) + (observed probability of being in the AN category given LN) x (forecast probability of LN)

Here, the observed probabilities are taken directly from the observed frequency distributions. This calculation is repeated for NN and BN predictand conditions to get a full forecast of the probability of all three predictand conditions. Such forecasts (CAFs) are warranted for each season for which there was at least one statistically significant frequency distribution.

The strength of the CAF method is that it exploits the same dataset used to generate LTMs, but does so in a way that yields much more refined and potential useful information for forecasters. In addition, CAFs are relatively easy to produce. Many of the steps involved in generating a CAF can be automated. The method's limitations are: its dependence on the availability and accuracy of the predictor forecast, and the representativeness of the dataset.

a. Developing a Composite Analysis Forecast Without an Official Probability forecast

A composite analysis forecast is not possible without a forecast for the chosen climate variation phases. In the absence of an official version of such a forecast, we can use the observed tendencies of the variation to change phase from one season to the next to develop a probability forecast of the variation. The tendencies are determined by identifying for each seasonal transition (JFM to AMJ, AMJ to JAS, JAS to OND, OND to JFM) the percentage of times that given phase stayed the same, or changed to each of the other two phases (e.g., during the 37 JFM to AMJ transitions, EN stayed the same in 40% of the transitions, changed to neutral in 30% of the transitions, and changed to LN in 30% of the transitions). These percentages can then be used as the forecasts if observations of the climate variation phase at the time the forecast is issued are available. We call the resulting forecast of the variation a climate variation tendency forecast (TF). In our study, we created TFs for the NAO because official probability forecasts of the NAO were not available. We also created TFs for ENLN in order to compare the skill of the TFs to the skill of the official ENLN forecasts from CPC

The obvious strength in the tendency forecast is that it can be performed for all major climate variations. However, the TF method assumes that a given variation will continue to behave as it has in the past. If the sample used to develop the TF probabilities is too small it can cause the forecast to have a bias. Of course, this same weakness also holds for the whole composite analysis and composite analysis forecast process, since it is heavily based on using past observed relationships to predict future relationships.

3. Verification

a. Preliminary Test of CAF Process

We conducted initial tests of the CAF process by using it to forecast JFM precipitation rate related to ENLN in San Diego, California. This season, predictand, predictor, and location were chosen because high quality data is available for this location, and because prior studies have shown a strong relationship in San Diego between winter precipitation and ENLN, with precipitation tending to be higher (lower) than normal during EN (LN) (e.g., Philander 1990). Our application of the CAF process yielded: (1) statistically significant relationships between precipitation rate and ENLN that were consistent with those from prior studies using different methods; and (2) CAFs with positive skill.

b. Verification of CAFs

We conducted hindcasts using the CAF process for periods in which we withheld observational data. We then compared the hindcasts to observations to verify the CAFs. The following skill scores, as defined in Wilks (2006) were used in the verification process:

- Heidke skill score (HSS)
- Probability of detection (PoD) for all events, and for AN, NN, and BN events
- False alarm ratio (FAR) for all events, and for AN, NN, and BN events
- Bias for AN, NN, and BN
- Forecast accuracy (FA)

These skill scores were calculated using a 3 x 3 contingency table to determine the number of hits, misses, false alarms, and correct negatives for each of the predictands (cf. Wilks 2006). Separate contingency tables were developed for each season, predictand, and predictor.

The CAF probabilities for each were used to proportionately distribute the forecast among the three forecast columns of the contingency table. For example, a single forecast that gave of 50% chance AN conditions, a 30% chance of NN conditions, and 20% chance of BN conditions was entered as a 0.5 in the AN forecast column, a 0.3 in the NN forecast column, and a 0.2 in the BN forecast column.

The same skill scores were applied to assess the skill of forecasts based simply on LTMs (the de facto climate forecasts for DoD). All of these LTM forecasts were assigned to the NN forecast column of the contingency table, since NN conditions should be close to LTM conditions. By comparing the skill of the CAFs and the LTM-based forecasts, we assessed the improvement that CAFs offer over the current climate forecasts for DoD.

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III. RESULTS

A. OVERVIEW OF RESULTS

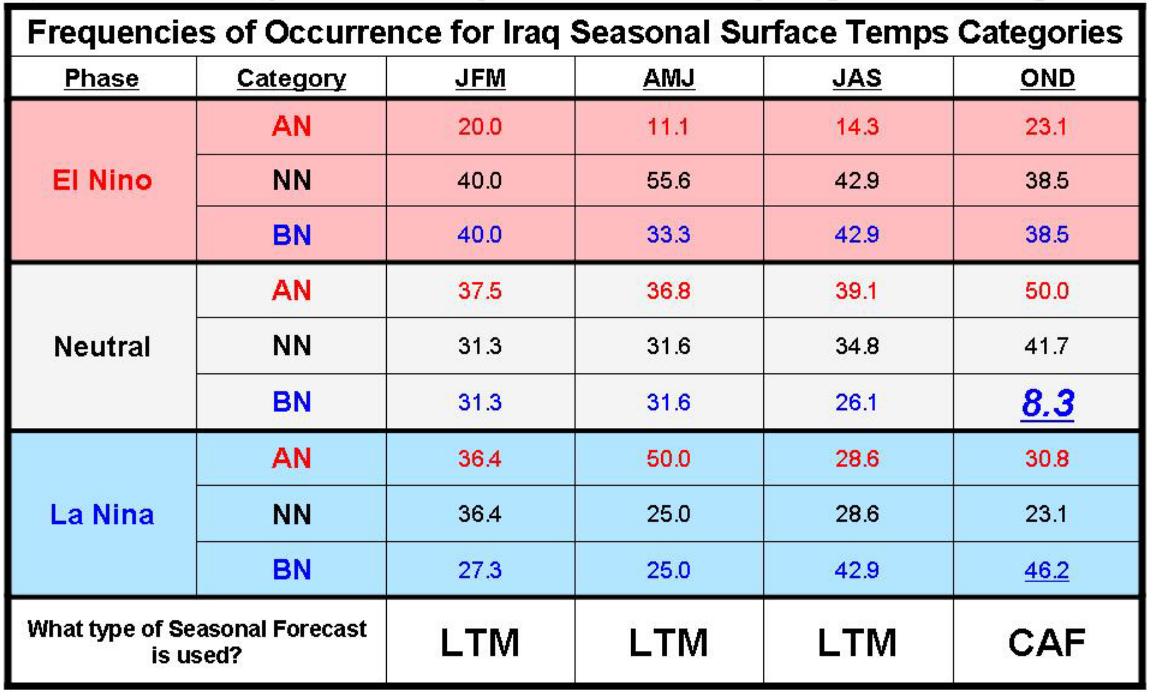
This section presents an overview of our composite analysis results. More detailed results are found in the Appendix, where all composite analyses results are shown in bar chart form.

1. Results for ENLN

a. Surface Temperature

Table 2 shows the frequency distribution results for EN based composite analyses of Iraq surface temperature for all four seasons, with bold, underlined values indicating statistically significant results. The only statistically significant result was for the neutral BN case in OND with a frequency of 8.3%, indicating a low probability of below normal surface temperatures during neutral ENLN periods. Although not indicated in Table 2, some of the results were just below the statistical significance threshold (90%) and may therefore warrant attention in future studies. These include neutral AN case in OND with a frequency of 50%, and EN AN case in AMJ with a frequency of 11.1%. Based on the statistical significance of these results, CAFs would be preferred over LTM based forecasts only in OND.

Table 2. Frequency distributions (%) determined from ENLN based composite analysis of Iraq seasonal surface temperatures. Bold, underlined values are statistically significance (see Chapter II).



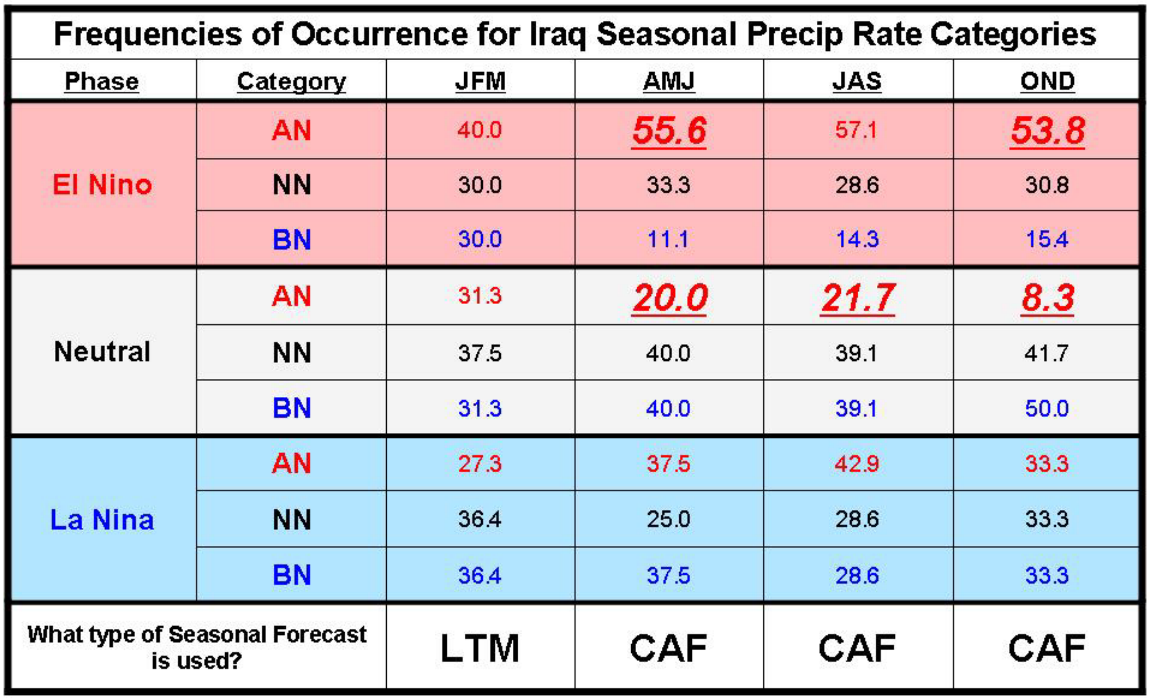
Frequencies of Occurrence for Iraq Seasonal Surface Temps Categories

Phase	Category	JFM	AMJ	JAS	OND
El Nino	AN	20.0	11.1	14.3	23.1
	NN	40.0	55.6	42.9	38.5
	BN	40.0	33.3	42.9	38.5
Neutral	AN	37.5	36.8	39.1	50.0
	NN	31.3	31.6	34.8	41.7
	BN	31.3	31.6	26.1	***8.3***
La Nina	AN	36.4	50.0	28.6	30.8
	NN	36.4	25.0	28.6	23.1
	BN	27.3	25.0	42.9	46.2
What type of Seasonal Forecast is used?		LTM	LTM	LTM	CAF

b. Precipitation Rate

Table 3 shows the frequency distribution results for EN based composite analyses of Iraq precipitation rate for all four seasons, with bold, underlined values indicating statistically significant results. Statistically significant results occurred for all seasons except JFM. All of the five statistically significant results were associated with AN precipitation conditions during EN and neutral phases. No statistically significant signals were observed during LN phases. Note that in all seasons during EN, there is a relatively high probability of high precipitation (cf. Vorhees 2006). The statistical significance results indicate that CAFs would perform better than LTM based forecasts in all seasons except JFM.

Table 3. Frequency distributions (%) determined from ENLN based composite analysis of Iraq seasonal precipitation rates. Bold, underlined values are statistically significance (see Chapter II).



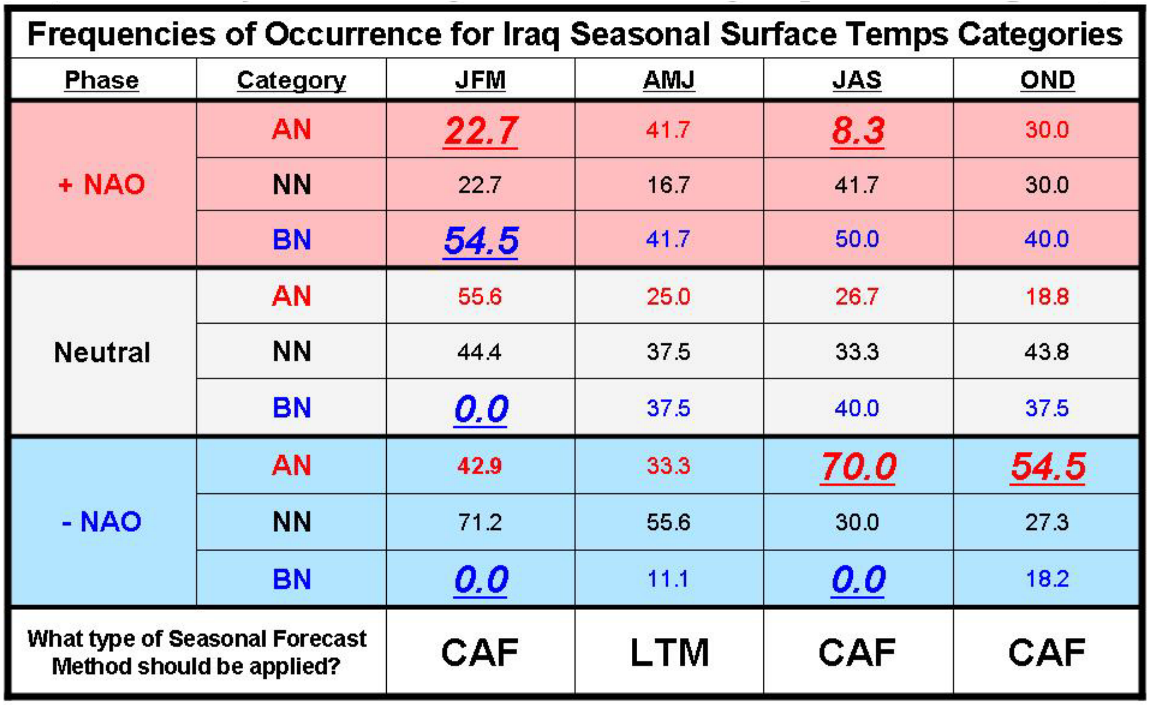
Frequencies of Occurrence for Iraq Seasonal Precip Rate Categories					
Phase	Category	JFM	AMJ	JAS	OND
El Nino	AN	40.0	**55.6**	57.1	**53.8**
	NN	30.0	33.3	28.6	30.8
	BN	30.0	11.1	14.3	15.4
Neutral	AN	31.3	**20.0**	**21.7**	**8.3**
	NN	37.5	40.0	39.1	41.7
	BN	31.3	40.0	39.1	50.0
La Nina	AN	27.3	37.5	42.9	33.3
	NN	36.4	25.0	28.6	33.3
	BN	36.4	37.5	28.6	33.3
What type of Seasonal Forecast is used?		LTM	CAF	CAF	CAF

2. Results for NAO

a. Surface Temperature

Table 4 shows some striking results for NAO based composite analyses of surface temperature. These include a 54.5% frequency of BN temperatures in Iraq in JFM during a positive NAO. The zero values in the JFM column of Table 2 indicates that all JFM BN Iraq seasonal surface temperature conditions in 1970-2006 occurred during a positive NAO phase. So below normal temperatures are very likely during the NAO positive phase and very unlikely during the NAO neutral and negative phases.

Table 4. Frequency distributions (%) determined from NAO based composite analysis of Iraq seasonal surface temperatures. Bold, underlined values are statistically significance (see Chapter II).



Frequencies of Occurrence for Iraq Seasonal Surface Temps Categories

Phase	Category	JFM	AMJ	JAS	OND
+ NAO	**AN**	***22.7***	41.7	***8.3***	30.0
	NN	22.7	16.7	41.7	30.0
	BN	***54.5***	41.7	50.0	40.0
Neutral	**AN**	55.6	25.0	26.7	18.8
	NN	44.4	37.5	33.3	43.8
	BN	***0.0***	37.5	40.0	37.5
- NAO	**AN**	42.9	33.3	***70.0***	***54.5***
	NN	71.2	55.6	30.0	27.3
	BN	***0.0***	11.1	***0.0***	18.2
What type of Seasonal Forecast Method should be applied?		**CAF**	**LTM**	**CAF**	**CAF**

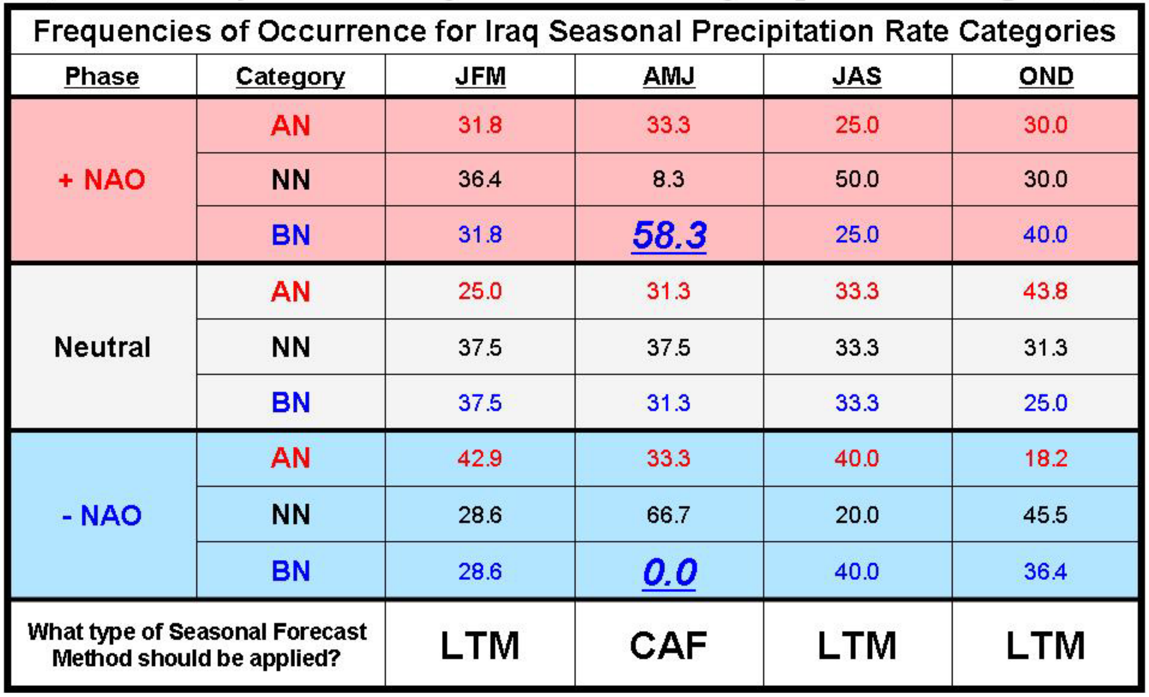
Similar to JFM, positive NAO phases were associated with a statistically significant low frequency (8.3%) of AN events. The negative NAO phase during JAS was associated with statistically significant frequencies of 0% of BN conditions and 70% of AN conditions (the highest of any in this study). The message for forecasters is that during the negative NAO phase, above (below) normal surface temperatures are very likely (unlikely). The same holds true for OND but the relationships in OND are not as strong as in JAS.

These results show strong statistical relationships exist between the NAO and Iraq seasonal surface temperature during the JFM, JAS, and OND seasons. This allowed us to apply the CAF method to those three seasons.

b. Precipitation Rate

The NAO based composite analyses of Iraq precipitation rate yielded only two statistically significant results (Table 5). Both were for BN conditions during AMJ. Positive NAO phases during AMJ, had a statistically significant high frequency (58.3%) of BN conditions, while NAO negative phases during AMJ had a statistically significant low frequency of BN conditions. These results do not support the results from Vorhees (2006) for NA related precipitation rate anomalies in SWA during OND and JFM (se Chapter I).

Table 5. Frequency distributions (%) determined from NAO based composite analysis of Iraq seasonal precipitation rate. Bold, underlined values are statistically significance (see Chapter II).



Frequencies of Occurrence for Iraq Seasonal Precipitation Rate Categories

Phase	Category	JFM	AMJ	JAS	OND
+ NAO	AN	31.8	33.3	25.0	30.0
	NN	36.4	8.3	50.0	30.0
	BN	31.8	***58.3***	25.0	40.0
Neutral	AN	25.0	31.3	33.3	43.8
	NN	37.5	37.5	33.3	31.3
	BN	37.5	31.3	33.3	25.0
- NAO	AN	42.9	33.3	40.0	18.2
	NN	28.6	66.7	20.0	45.5
	BN	28.6	***0.0***	40.0	36.4
What type of Seasonal Forecast Method should be applied?		LTM	CAF	LTM	LTM

3. Forecast Verification Results

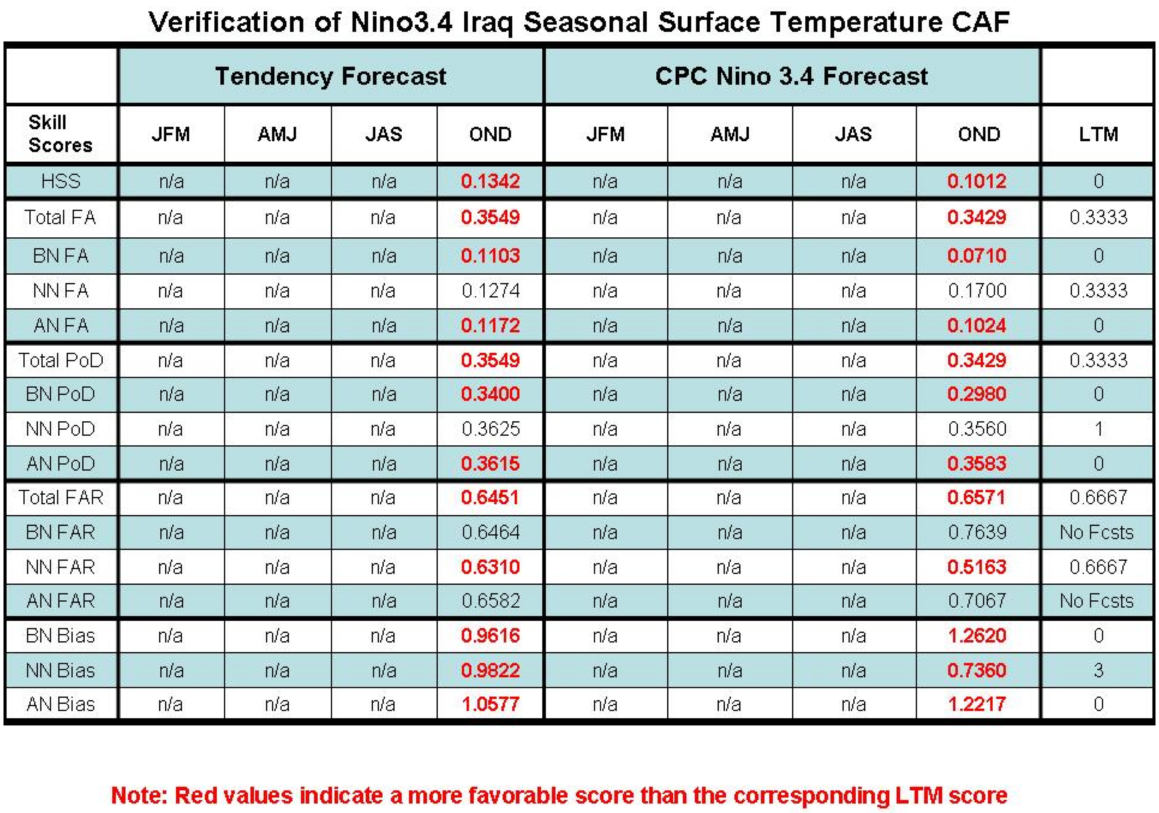
Tables 6-9 show the verification results for the CAF and LTM forecasts. The ENLN results show the skill scores for two types of CAFs, those based on TFs and those based on the official CPC probabilistic Nino3.4 forecast. The skill of the LTM based forecasts is also shown. Verification was not done or some cases (indicated by n/a in Tables 6-9).

The results in Table 6 show that both types of CAFs have higher skill scores than LTM outlooks used for seasonal forecasts. In fact, both types of CAFs demonstrated greater than zero HSS every time they were applied. This means the CAFs performed better than a forecast based on random selection. Neither of the two types of CAFs nor LTM outlook forecasts demonstrated negative skill (HSS less than zero).

Note that the LTM forecasts detected all NN events but no AN or BN events. Thus, the LTM FAR was 66.67% and the total PoD was 33.33%. The HSS is, approximately, a measure of how well a forecast performed compared to a randomly generated forecast (e.g., a randomly selecting AN, NN, BN as forecast) (cf. Wilks 2006). The LTM based forecasts received HSS of zero. This means LTM did no better or no worse than a randomness forecast, implying no skill in using LTM outlooks as seasonal forecasts.

A comparison of the skill of the two types of CAFs shown in Table 7 indicates that the CPC based CAFs had higher HSS in JAS (0.1425) and OND (0.1784), but the TF based CAFs had higher HSS in AMJ (0.0927). The PODs for the CPC based CAFs of AN were quite high for climate forecasts during JAS (46.88%) and OND (40.86) (Table 7). Overall, the CPC based CAFs had somewhat higher HSS and total PoD than the TF based CAFs. Two exceptions were for OND temperature and AMJ precipitation rate.

Table 6. Skill scores of: forecasts of seasonal Iraq surface temperature. Forecasts evaluated in this table are: (1) CAFs based on TFs and CPC Nino3.4 forecasts of ENLN phase; and (2) LTM based forecasts. The skill score types are shown in the leftmost column. See Chapter II and III text for details.

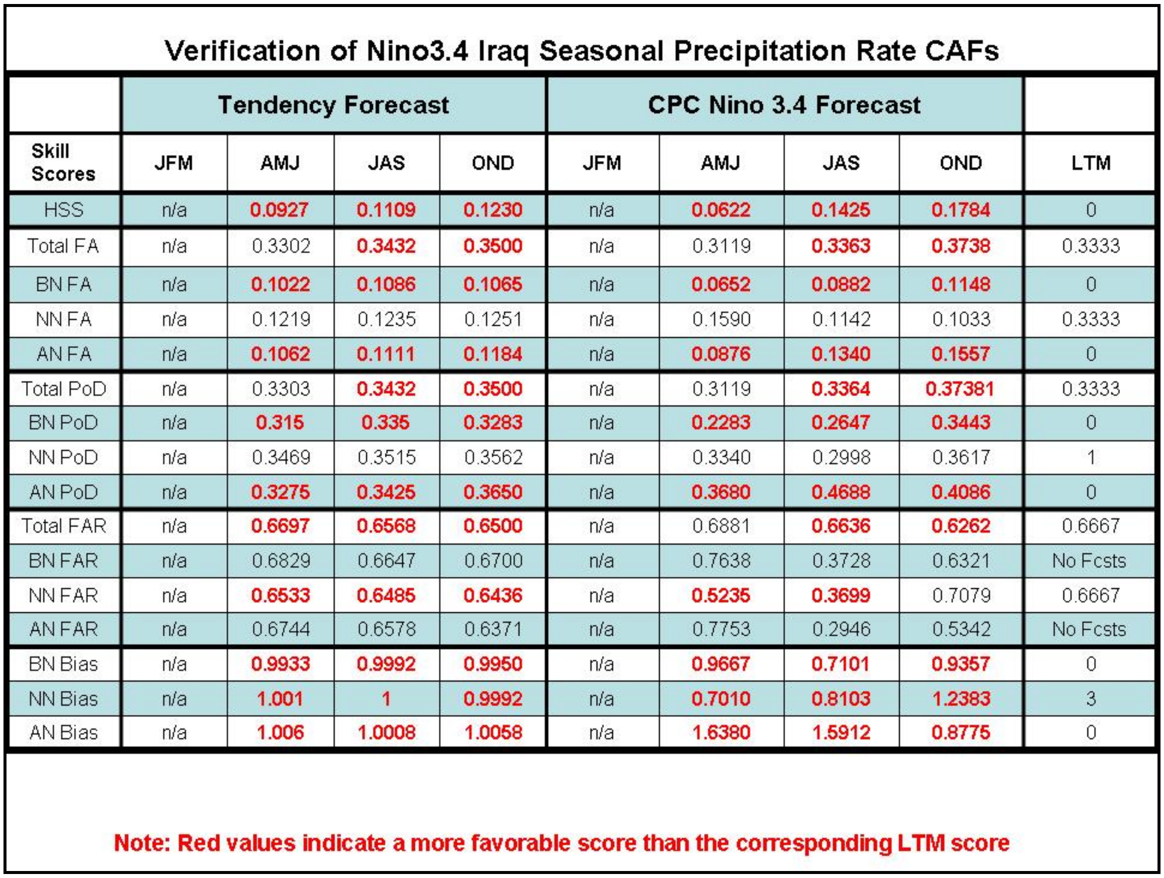


Verification of Nino3.4 Iraq Seasonal Surface Temperature CAF

	Tendency Forecast				CPC Nino 3.4 Forecast				
Skill Scores	**JFM**	**AMJ**	**JAS**	**OND**	**JFM**	**AMJ**	**JAS**	**OND**	**LTM**
HSS	n/a	n/a	n/a	**0.1342**	n/a	n/a	n/a	**0.1012**	0
Total FA	n/a	n/a	n/a	**0.3549**	n/a	n/a	n/a	**0.3429**	0.3333
BN FA	n/a	n/a	n/a	**0.1103**	n/a	n/a	n/a	**0.0710**	0
NN FA	n/a	n/a	n/a	0.1274	n/a	n/a	n/a	0.1700	0.3333
AN FA	n/a	n/a	n/a	**0.1172**	n/a	n/a	n/a	**0.1024**	0
Total PoD	n/a	n/a	n/a	**0.3549**	n/a	n/a	n/a	**0.3429**	0.3333
BN PoD	n/a	n/a	n/a	**0.3400**	n/a	n/a	n/a	**0.2980**	0
NN PoD	n/a	n/a	n/a	0.3625	n/a	n/a	n/a	0.3560	1
AN PoD	n/a	n/a	n/a	**0.3615**	n/a	n/a	n/a	**0.3583**	0
Total FAR	n/a	n/a	n/a	**0.6451**	n/a	n/a	n/a	**0.6571**	0.6667
BN FAR	n/a	n/a	n/a	0.6464	n/a	n/a	n/a	0.7639	No Fcsts
NN FAR	n/a	n/a	n/a	**0.6310**	n/a	n/a	n/a	**0.5163**	0.6667
AN FAR	n/a	n/a	n/a	0.6582	n/a	n/a	n/a	0.7067	No Fcsts
BN Bias	n/a	n/a	n/a	**0.9616**	n/a	n/a	n/a	**1.2620**	0
NN Bias	n/a	n/a	n/a	**0.9822**	n/a	n/a	n/a	**0.7360**	3
AN Bias	n/a	n/a	n/a	**1.0577**	n/a	n/a	n/a	**1.2217**	0

Note: Red values indicate a more favorable score than the corresponding LTM score

Table 7. Skill scores of: forecasts of seasonal Iraq precipitation rate. Forecasts evaluated in this table are: (1) CAFs based on TFs and CPC Nino3.4 forecasts of ENLN phase; and (2) LTM based forecasts. The skill score types are shown in the leftmost column.. See Chapter II and III text for details.



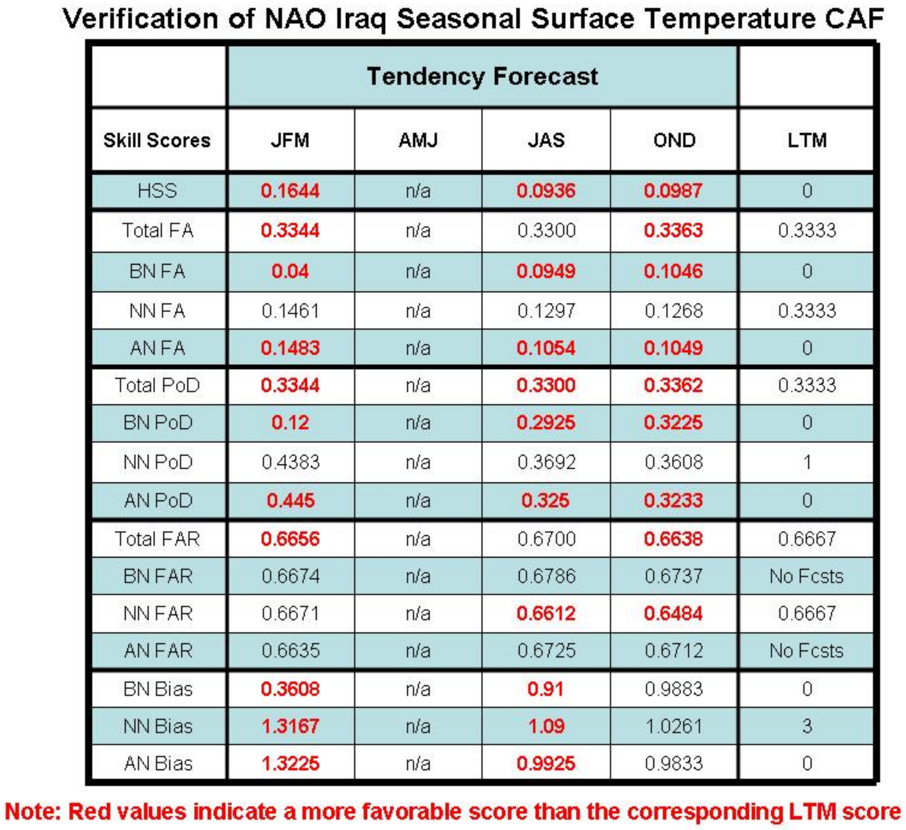
Verification of Nino3.4 Iraq Seasonal Precipitation Rate CAFs

	Tendency Forecast				**CPC Nino 3.4 Forecast**				
Skill Scores	**JFM**	**AMJ**	**JAS**	**OND**	**JFM**	**AMJ**	**JAS**	**OND**	**LTM**
HSS	n/a	**0.0927**	**0.1109**	**0.1230**	n/a	**0.0622**	**0.1425**	**0.1784**	0
Total FA	n/a	0.3302	**0.3432**	**0.3500**	n/a	0.3119	**0.3363**	**0.3738**	0.3333
BN FA	n/a	**0.1022**	**0.1086**	**0.1065**	n/a	**0.0652**	**0.0882**	**0.1148**	0
NN FA	n/a	0.1219	0.1235	0.1251	n/a	0.1590	0.1142	0.1033	0.3333
AN FA	n/a	**0.1062**	**0.1111**	**0.1184**	n/a	**0.0876**	**0.1340**	**0.1557**	0
Total PoD	n/a	0.3303	**0.3432**	**0.3500**	n/a	0.3119	**0.3364**	**0.37381**	0.3333
BN PoD	n/a	**0.315**	**0.335**	**0.3283**	n/a	**0.2283**	**0.2647**	**0.3443**	0
NN PoD	n/a	0.3469	0.3515	0.3562	n/a	0.3340	0.2998	0.3617	1
AN PoD	n/a	**0.3275**	**0.3425**	**0.3650**	n/a	**0.3680**	**0.4688**	**0.4086**	0
Total FAR	n/a	**0.6697**	**0.6568**	**0.6500**	n/a	0.6881	**0.6636**	**0.6262**	0.6667
BN FAR	n/a	0.6829	0.6647	0.6700	n/a	0.7638	0.3728	0.6321	No Fcsts
NN FAR	n/a	**0.6533**	**0.6485**	**0.6436**	n/a	**0.5235**	**0.3699**	0.7079	0.6667
AN FAR	n/a	0.6744	0.6578	0.6371	n/a	0.7753	0.2946	0.5342	No Fcsts
BN Bias	n/a	**0.9933**	**0.9992**	**0.9950**	n/a	**0.9667**	**0.7101**	**0.9357**	0
NN Bias	n/a	**1.001**	**1**	**0.9992**	n/a	**0.7010**	**0.8103**	**1.2383**	3
AN Bias	n/a	**1.006**	**1.0008**	**1.0058**	n/a	**1.6380**	**1.5912**	**0.8775**	0

Note: Red values indicate a more favorable score than the corresponding LTM score

Tables 8 and 9 show the skill scores of the TF based CAFs for Iraq seasonal temperatures and precipitation rate, respectively. Overall, the CAFs performed better than a LTM based forecasts. In particular, all the HSSs showed positive skill, beating randomly generated forecasts and LTM based forecasts.

Table 8. Skill scores of: forecasts of seasonal Iraq surface temperature. Forecasts evaluated in this table are: (1) CAFs based on TFs and CPC Nino3.4 forecasts of NAO phase; and (2) LTM based forecasts. The skill score types are shown in the leftmost column. See Chapter II and III text for details.

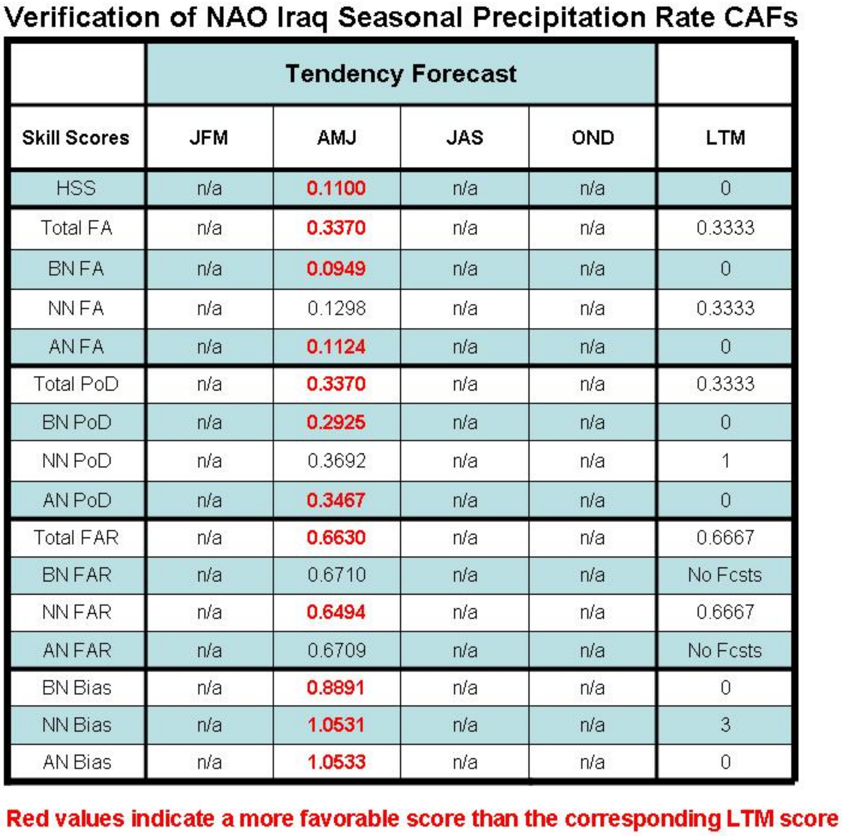


Verification of NAO Iraq Seasonal Surface Temperature CAF

	Tendency Forecast				
Skill Scores	**JFM**	**AMJ**	**JAS**	**OND**	**LTM**
HSS	**0.1644**	n/a	**0.0936**	**0.0987**	0
Total FA	**0.3344**	n/a	0.3300	**0.3363**	0.3333
BN FA	**0.04**	n/a	**0.0949**	**0.1046**	0
NN FA	0.1461	n/a	0.1297	0.1268	0.3333
AN FA	**0.1483**	n/a	**0.1054**	**0.1049**	0
Total PoD	**0.3344**	n/a	**0.3300**	**0.3362**	0.3333
BN PoD	**0.12**	n/a	**0.2925**	**0.3225**	0
NN PoD	0.4383	n/a	0.3692	0.3608	1
AN PoD	**0.445**	n/a	**0.325**	**0.3233**	0
Total FAR	**0.6656**	n/a	0.6700	**0.6638**	0.6667
BN FAR	0.6674	n/a	0.6786	0.6737	No Fcsts
NN FAR	0.6671	n/a	**0.6612**	**0.6484**	0.6667
AN FAR	0.6635	n/a	0.6725	0.6712	No Fcsts
BN Bias	**0.3608**	n/a	**0.91**	0.9883	0
NN Bias	**1.3167**	n/a	**1.09**	1.0261	3
AN Bias	**1.3225**	n/a	**0.9925**	0.9833	0

Note: Red values indicate a more favorable score than the corresponding LTM score

Table 9. Skill scores of: forecasts of seasonal Iraq precipitation rate. Forecasts evaluated in this table are: (1) CAFs based on TFs and CPC Nino3.4 forecasts of NAO phase; and (2) LTM based forecasts. The skill score types are shown in the leftmost column.. See Chapter II and III text for details.



Verification of NAO Iraq Seasonal Precipitation Rate CAFs

	Tendency Forecast				
Skill Scores	**JFM**	**AMJ**	**JAS**	**OND**	**LTM**
HSS	n/a	**0.1100**	n/a	n/a	0
Total FA	n/a	**0.3370**	n/a	n/a	0.3333
BN FA	n/a	**0.0949**	n/a	n/a	0
NN FA	n/a	0.1298	n/a	n/a	0.3333
AN FA	n/a	**0.1124**	n/a	n/a	0
Total PoD	n/a	**0.3370**	n/a	n/a	0.3333
BN PoD	n/a	**0.2925**	n/a	n/a	0
NN PoD	n/a	0.3692	n/a	n/a	1
AN PoD	n/a	**0.3467**	n/a	n/a	0
Total FAR	n/a	**0.6630**	n/a	n/a	0.6667
BN FAR	n/a	0.6710	n/a	n/a	No Fcsts
NN FAR	n/a	**0.6494**	n/a	n/a	0.6667
AN FAR	n/a	0.6709	n/a	n/a	No Fcsts
BN Bias	n/a	**0.8891**	n/a	n/a	0
NN Bias	n/a	**1.0531**	n/a	n/a	3
AN Bias	n/a	**1.0533**	n/a	n/a	0

Note: Red values indicate a more favorable score than the corresponding LTM score

B. SUMMARY OF RESULTS

There were six statistically significant results for NAO based composite analyses of Iraq seasonal surface temperatures during JFM, JAS, and OND. One statistically significant result was obtained for ENLN based analyses of Iraq seasonal surface temperature during OND. There were five statistically significant results for ENLN based analyses of Iraq seasonal precipitation rates during AMJ, JAS, and OND. And there were two statistically significant results for NAO based analyses of Iraq seasonal precipitation rate during AMJ. These statistically significant results allowed application of the CAF method to these seasons, predictors, and predictands. The skill of the CAFs was in most cases small but positive. In addition, the CAFs clearly outperformed forecasts based on LTMs. Since LTMs are the basis for almost all DoD climate outlooks, they are the de facto climate forecasts for DoD. Thus, the forecasts we have tested and applied to Iraq surface temperature and precipitation rate are a clear improvement n the presently available DoD products.

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IV. CONCLUSIONS

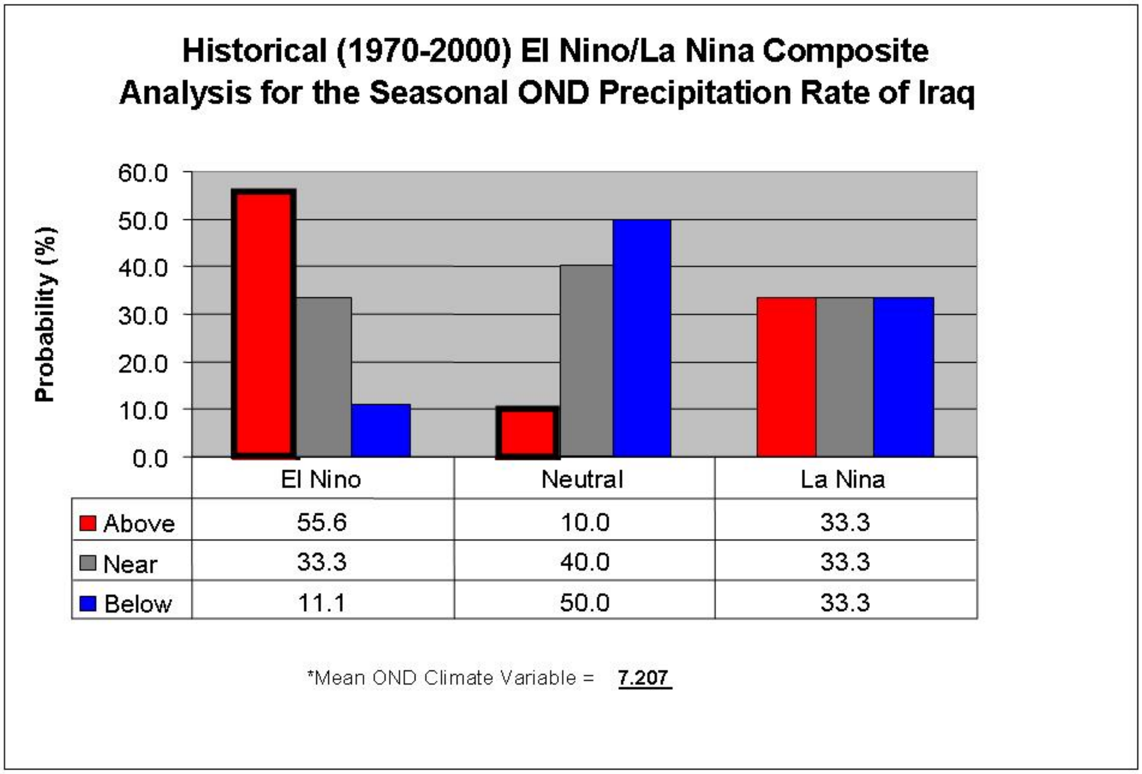
A. SUMMARY

The composite analyses completed for Iraq seasonal surface temperatures and precipitation rates using ENLN and NAO indices implies, there are links between these variables and these oscillations. The forecasts based on these composite analyses (the CAFs) had positive skill and outperformed the use LTM based forecasts. The statistical links between the predictands and predictors (ENLN and NAO) and predictands (temperature and precipitation rate) are significant but do not demonstrate causality. Additional dynamically oriented studies are needed to determine the causes of the links we have identified.

B. JUSTIFICATION FOR MILITARY USE

As stated in Chapter I, AFCCC develops products that are almost exclusively based on LTM. Military forecasters take these products and provide seasonal outlooks to military commanders and planners. This practice does not allow for the consideration of climate variation(s) that affect the area of interest. These effects can lead to considerable deviation from the LTM. It is easy to understand how these deviations have adverse affects on military operations if not accounted for during planning and decision making phases. Although not as accurate or precise as most short-range forecasts, the CAF method has the potential to provide more comprehensive and accurate forecasts than the current practice of using LTM based products for long-range military planning.

In an attempt to provide an example of the benefits of the CAF based product, we used the CAF process to create a hindcast of Iraq seasonal precipitation rate for OND 2002. For this hindcast, we withheld data from later than December 2000 when we did the composite analysis. Figure 10 shows an example of the results from this hindcast experiment; in particular, the ENLN based composite analysis based on data from only 1970-2000.



	El Nino	Neutral	La Nina
🟥 Above	55.6	10.0	33.3
◼ Near	33.3	40.0	33.3
🟦 Below	11.1	50.0	33.3

Figure 12. ENLN based composite analysis of Iraq seasonal OND precipitation rate based on data from 1970-2000. Bars indicate the distribution of AN, NN, and BN conditions during OND for the three ENLN phases. Bars with bold black borders indicate results that are statistically significant (see Chapter II for details).

We then applied the OND TF of Nino3.4 to the composite analysis and generated the hindcast shown in Figure 13.

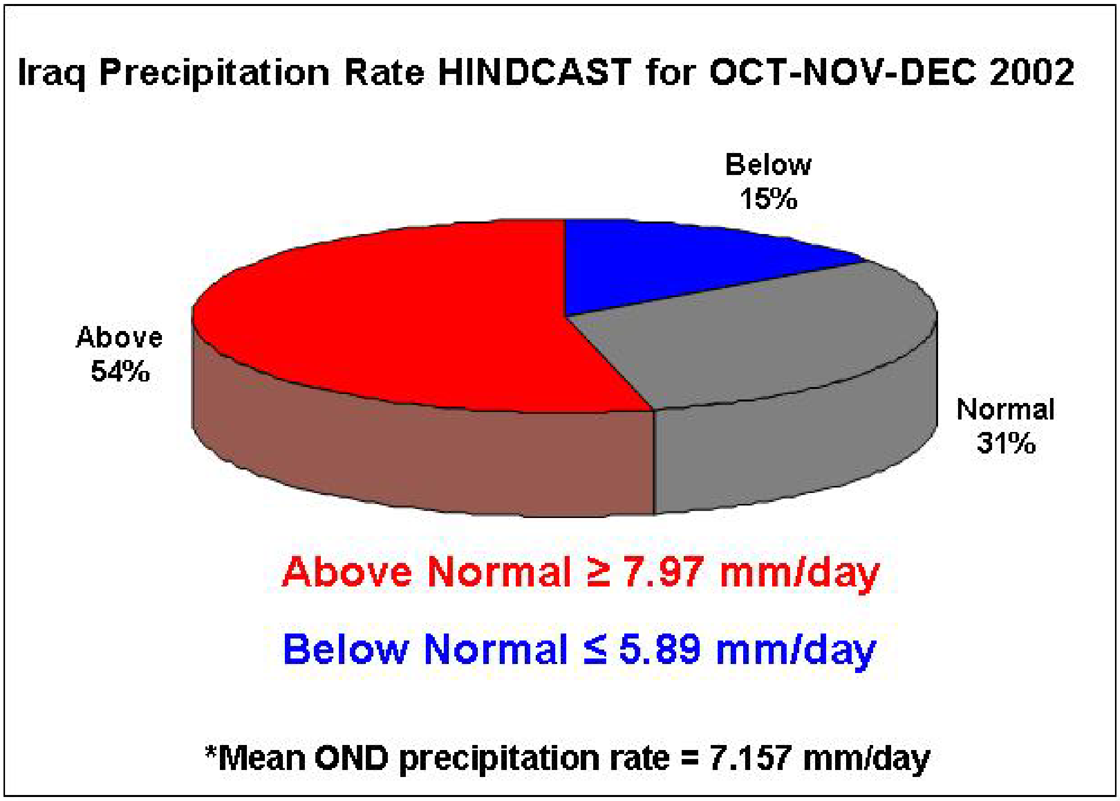


Figure 13. Probabilistic hindcast based on CAF process of Iraq seasonal precipitation rate for OND 2002.

This seasonal forecast for OND 2002 could have been given on October 1 2002 to Central Command planners and commanders in support of the on-going operations of NORTHERN/SOUTHERN WATCH. The forecast would have provided key information to the planning and execution of air portals and intelligence, surveillance, and reconnaissance (ISR) operations over Iraq. Theater commanders and planners would have been made aware of a high potential for increased precipitation, and related high cloud cover, over Iraq. The increased cloud cover could have been expected to result in negative effects to ISR and flight operations. In addition to the effects on the military decision making process, the CAF could have given forecasters better situational awareness of potential conditions for the upcoming seasons. Comparisons of the hindcast shown in Figure 13 indicate that had it been issued as a forecast on October 1, 2002, it would have verified as correct (anomalously high precipitation rates did occur in Iraq during OND 2002, not shown)

C. RECOMMENDATIONS TO DEPARTMENT OF DEFENSE

There are numerous useful applications and variations of a generalized CAF process. In this section we highlight some of the more important ones.

1. Applying CAF with Other Climate Variations, Variables, Datasets, Timescales, and Regions

The CAF method could be used with other variations (e.g., Indian Ocean Zonal Mode, Madden-Julian Oscillation, etc.) which have statistically significant relationships with other regions. These other variations occur on a range of temporal scales (annual, monthly, weekly, etc.). Since the CAF process applies to all time scales, skillful long-range forecasts at intraseasonal to decadal scales could be generated.

2. Potential for Improving the CAF

As stated in Chapter II, one step involved in the CAF process that we did not use was trend adjustment. As seen in Figure 14, the timeseries of the Iraq seasonal surface temperatures reveals a warming trend from 1970 to 2006. This was not accounted for in our study but if applied, would likely have yielded a product with more skill.

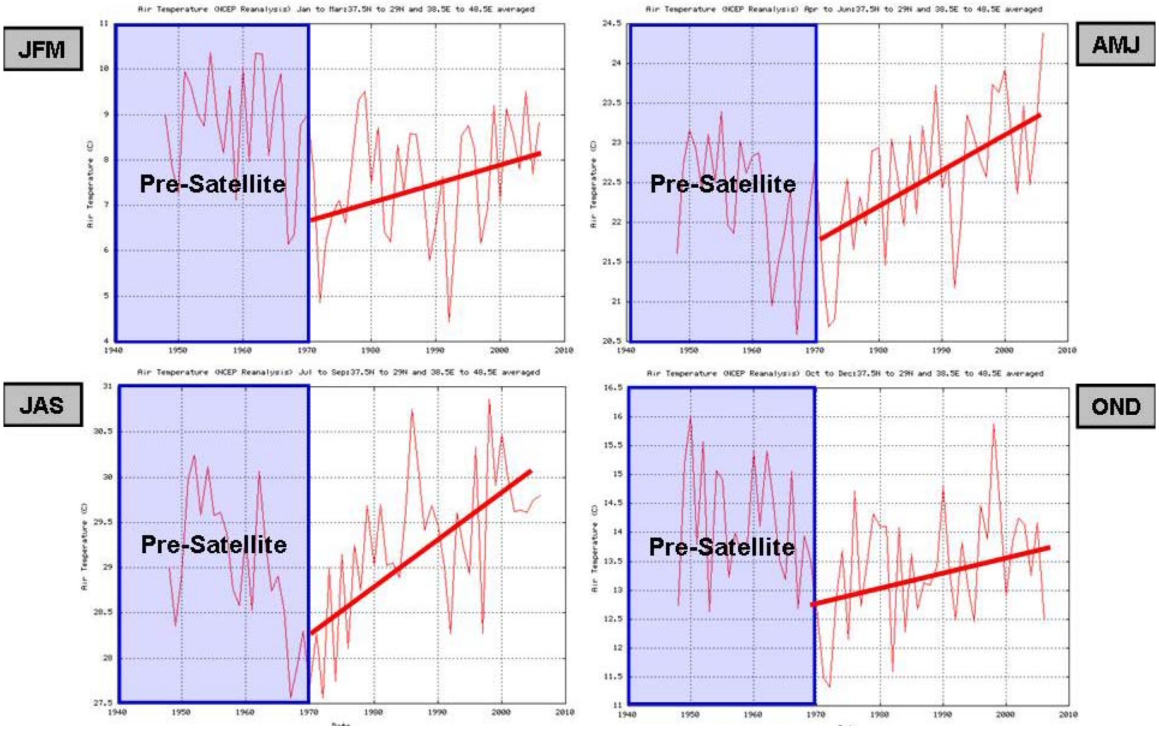


Figure 14. The timeseries of Iraq seasonal surface temperatures for each of the seasons. The bold red lines are approximations of the warming trends seen in each timeseries. Timeseries generated at ESRL website [accessed online at http://www.cdc.noaa.gov/ March 2007].

3. Development of Seasonal Forecasts for MAJCOM Regions

Figure 15 shows an example of seasonal forecast produced by CPC for North America. Using the CAF process, or related processes used by CPC and IRI, similar forecasts could be developed for the DoD unified major commands (MAJCOMs; Figure 16). One potential MAJCOM product is a seasonal probability line-of-sight forecast based on specific ISR platform thresholds. This could provide vital long-range planning for the positioning of key ISR assets (e.g., satellites, Global Hawk, etc.).

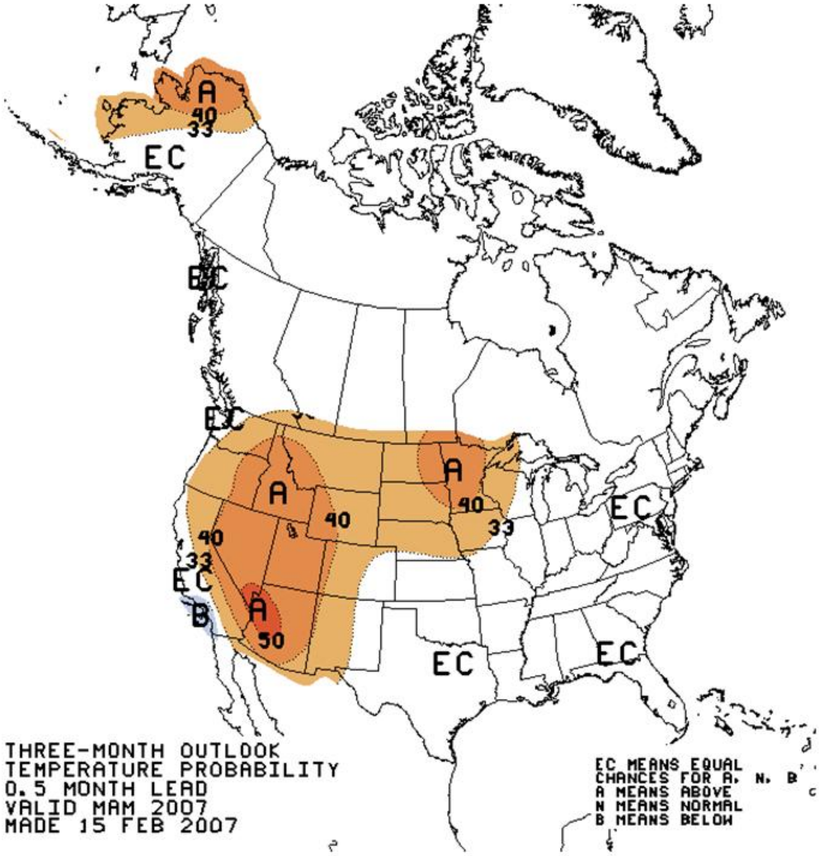


Figure 15. Example of a CPC 3-month outlook of U.S. temperature probabilities. Figure from http://www.cpc.ncep.noaa.gov/ [Accessed 6 March 2007]

Figure 16. Areas of responsibility for the DoD Unified Major Commands. Figure from https://www.army.mil/ [Accessed 6 March 2007]

4. Application Cost Analysis for DoD Operations

Although we can imagine the potential benefits in providing DoD commanders and planners a seasonal climate CAF, we cannot confirm any specifics in the way of cost analysis. We recommend a cost analysis study demonstrating the estimated loss (savings) of DoD time and resources from a incorrect (correct) seasonal forecast of a previous event. A cost analysis study may provide a more definitive value of this type of forecast.

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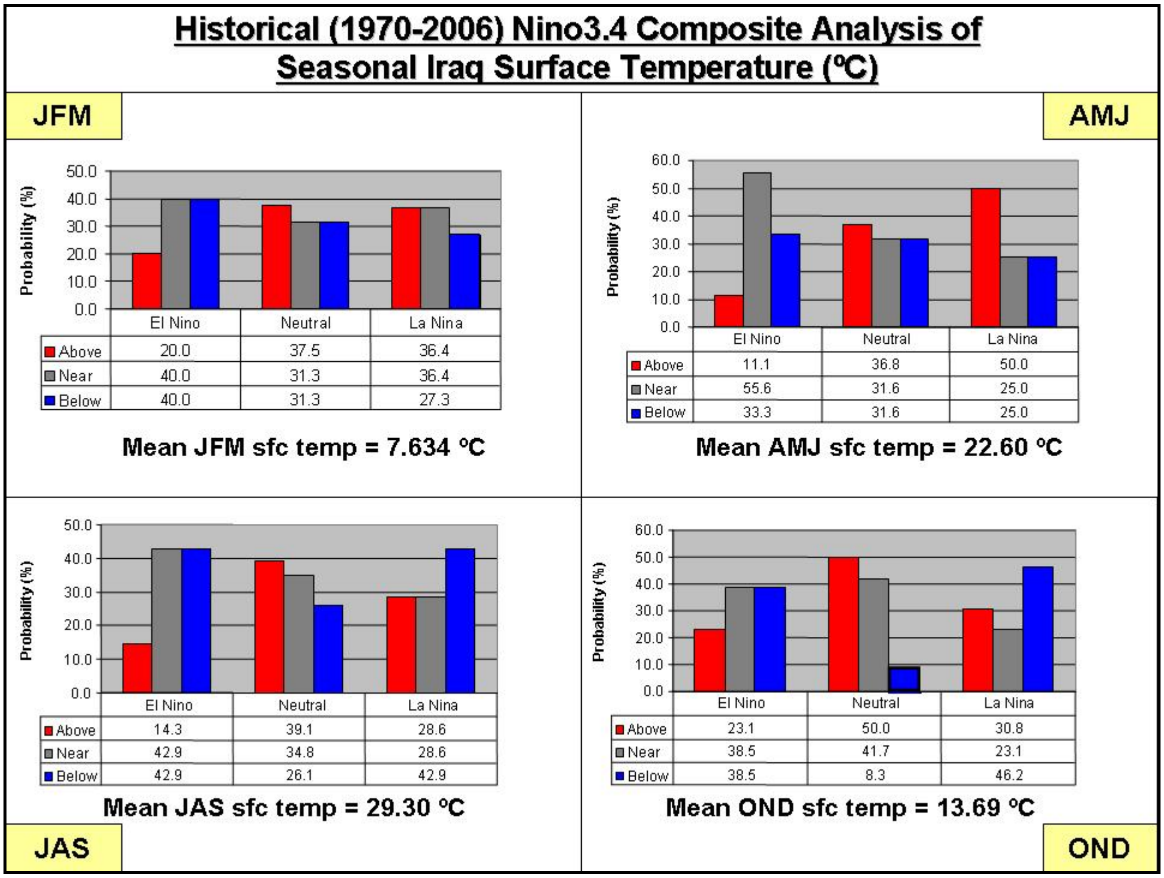
APPENDIX: COMPOSITE ANALYSIS FIGURES



JFM

	El Nino	Neutral	La Nina
🟥 Above	20.0	37.5	36.4
▨ Near	40.0	31.3	36.4
🟦 Below	40.0	31.3	27.3

Mean JFM sfc temp = 7.634 ºC

AMJ

	El Nino	Neutral	La Nina
🟥 Above	11.1	36.8	50.0
▨ Near	55.6	31.6	25.0
🟦 Below	33.3	31.6	25.0

Mean AMJ sfc temp = 22.60 ºC

JAS

	El Nino	Neutral	La Nina
🟥 Above	14.3	39.1	28.6
▨ Near	42.9	34.8	28.6
🟦 Below	42.9	26.1	42.9

Mean JAS sfc temp = 29.30 ºC

OND

	El Nino	Neutral	La Nina
🟥 Above	23.1	50.0	30.8
▨ Near	38.5	41.7	23.1
🟦 Below	38.5	8.3	46.2

Mean OND sfc temp = 13.69 ºC

Figure 17. ENLN based composite analysis of seasonal Iraq surface temperature (1970-2006). Bars with bold black borders indicate statistically significant results.

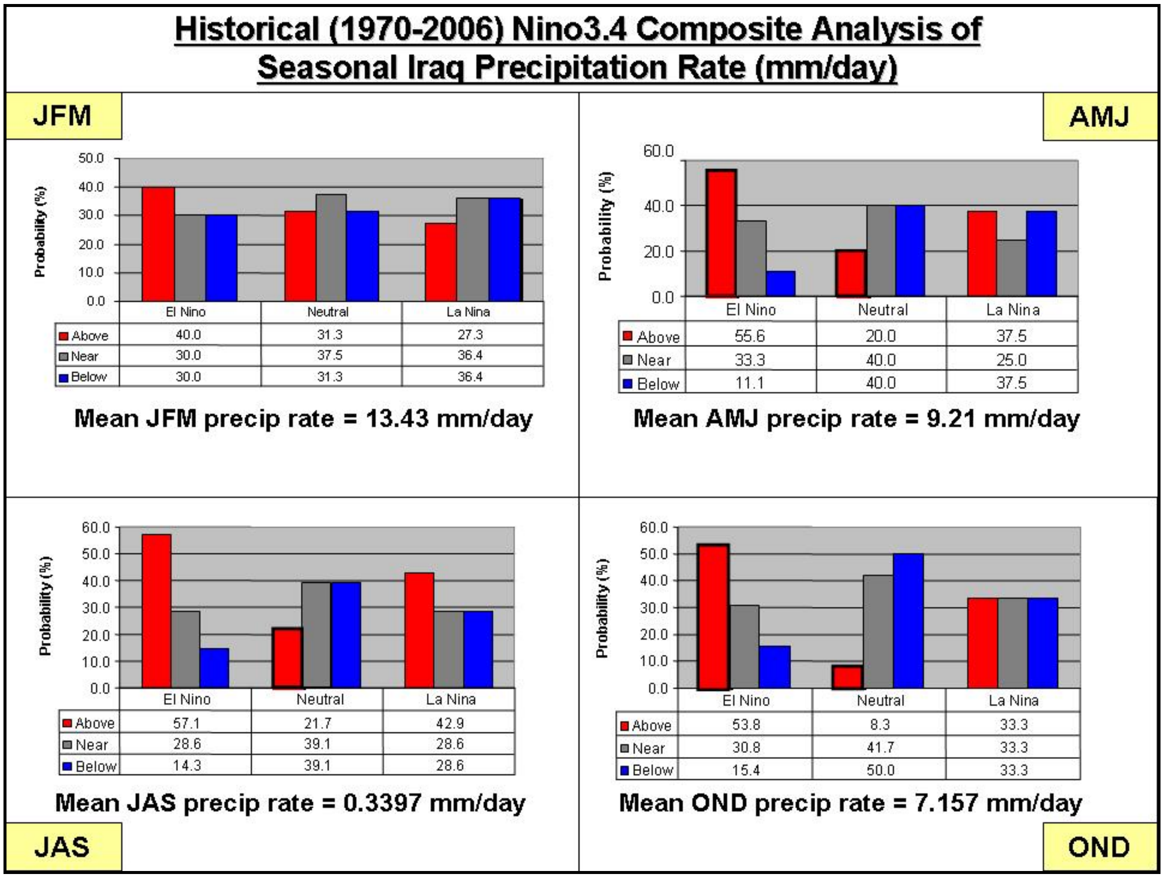
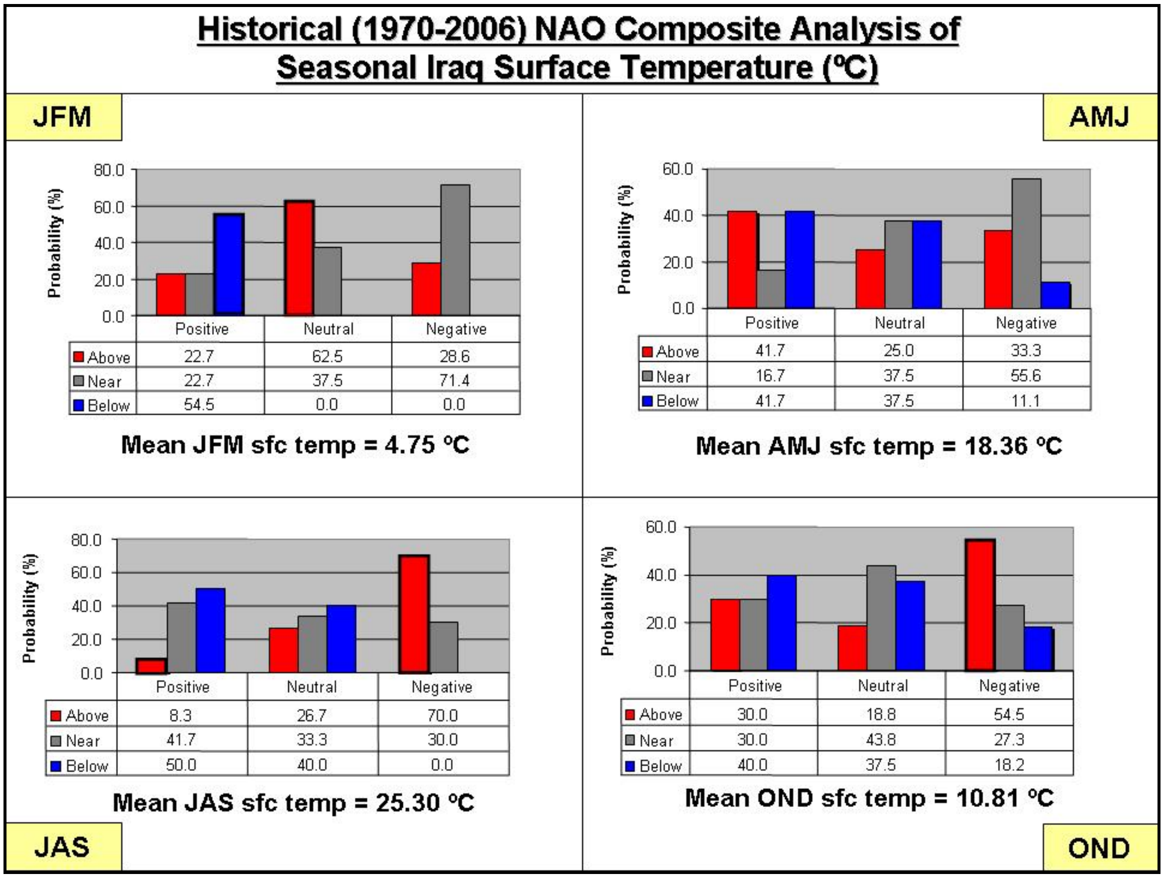


Figure 18. ENLN based composite analysis of seasonal Iraq precipitation rates (1970-2006). Bars with bold black borders indicate statistically significant results.



JFM

	Positive	Neutral	Negative
🟥 Above	22.7	62.5	28.6
▨ Near	22.7	37.5	71.4
🟦 Below	54.5	0.0	0.0

AMJ

	Positive	Neutral	Negative
🟥 Above	41.7	25.0	33.3
▨ Near	16.7	37.5	55.6
🟦 Below	41.7	37.5	11.1

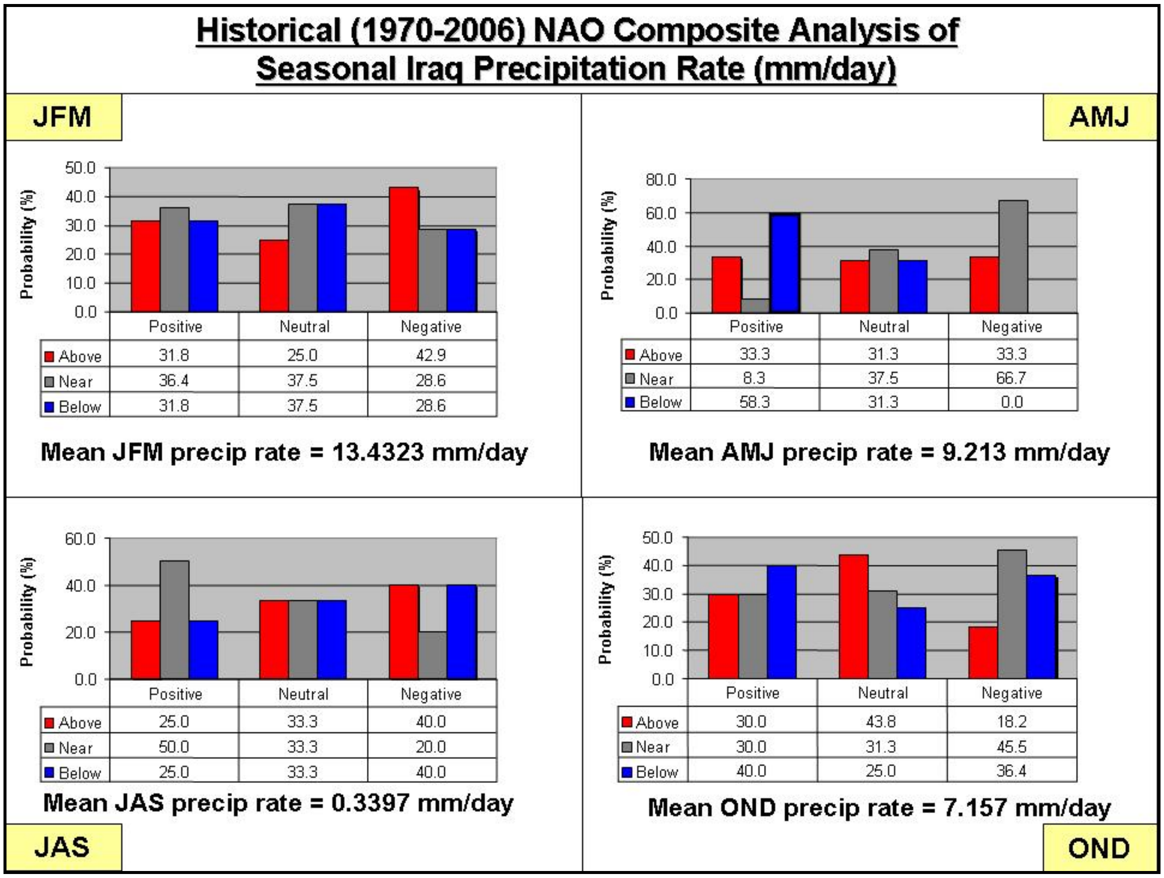
JAS

	Positive	Neutral	Negative
🟥 Above	8.3	26.7	70.0
▨ Near	41.7	33.3	30.0
🟦 Below	50.0	40.0	0.0

OND

	Positive	Neutral	Negative
🟥 Above	30.0	18.8	54.5
▨ Near	30.0	43.8	27.3
🟦 Below	40.0	37.5	18.2

Figure 19. NAO based composite analysis of seasonal Iraq surface temperature (1970-2006). Bars with bold black borders indicate statistically significant results.



Historical (1970-2006) NAO Composite Analysis of Seasonal Iraq Precipitation Rate (mm/day)

JFM

	Positive	Neutral	Negative
🟥 Above	31.8	25.0	42.9
▨ Near	36.4	37.5	28.6
🟦 Below	31.8	37.5	28.6

Mean JFM precip rate = 13.4323 mm/day

AMJ

	Positive	Neutral	Negative
🟥 Above	33.3	31.3	33.3
▨ Near	8.3	37.5	66.7
🟦 Below	58.3	31.3	0.0

Mean AMJ precip rate = 9.213 mm/day

JAS

	Positive	Neutral	Negative
🟥 Above	25.0	33.3	40.0
▨ Near	50.0	33.3	20.0
🟦 Below	25.0	33.3	40.0

Mean JAS precip rate = 0.3397 mm/day

OND

	Positive	Neutral	Negative
🟥 Above	30.0	43.8	18.2
▨ Near	30.0	31.3	45.5
🟦 Below	40.0	25.0	36.4

Mean OND precip rate = 7.157 mm/day

Figure 20. NAO based composite analysis of seasonal Iraq precipitation rates (1970-2006). Bars with bold black borders indicate statistically significant results.

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