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WORKING PAPER

Uncharted Waters:
The U.S. Navy and Navigating Climate Change

Contributors: Sharon Burke, Jay Gulledge, Michael Horowitz, Christine Parthemore, Nirav Patel

Center for a New American Security

Acknowledgements

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PREFACE

Earlier this year, I had an opportunity to travel with the Chief of Naval Operations, Admiral Gary Roughead. Our conversation on that trip ranged from the emerging strategic picture in Asia to the future of the fleet, but it was on the subject of climate change that Admiral Roughead and I had our most interesting interactions.

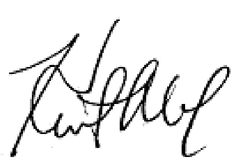
I personally believe strongly that global climate change will become a driving security challenge for the next generation of strategic thinkers – in the United States and around the world. So it was encouraging to hear one of today's great strategic thinkers asking all the right questions about what climate change might mean for the U.S. Navy and maritime forces.

As a result of that conversation, Admiral Roughead asked the Center for a New American Security to do an initial survey for the U.S. Navy of the ways in which climate change may affect the Navy's operations, including the strategic environment of the future.

I hope that all Navy personnel who read this report come away with a sense of looming danger, but also of tremendous possibility. There is much the U.S. Naval Services can do to anticipate, prepare for, respond to, and in some cases even prevent some of the changes and consequences that may occur in the next 30 years (the scope of this study). And let me be clear: there is little doubt today that human activity is spurring changes in the global climate. There are now decades of actual observations – from satellites and other advanced sensors – documenting temperature rises that are putting the world on a path toward a climate not seen in the history of human civilization.

More to the point, Navy personnel have an important source to confirm this; many of their brethren in the maritime services are already bearing witness to the changes in the world's oceans and littorals. Captain Ray Chartier, Commander of the Naval Ice Center, for example, made it clear in a workshop we held that the changes he is seeing in the cryosphere – right now, in real time – are deeply troubling. CNAS has appreciated, in particular, the leadership of Rear Admiral Bill Burke and Commander E.J. McClure in the Navy's Quadrennial Defense Review Integration Group, who have been studying these issues in great depth, as part of the Navy's contribution to the Quadrennial Defense Review.

There are those who will be slow to accept global climate change as an emergent threat or "threat multiplier," but there are many leaders in the U.S. Navy who know better. I hope this study makes a contribution in some small way to their efforts to shape the Navy's response to one of the great challenges of our age.



Dr. Kurt M. Campbell
Co-Founder and CEO
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EXECUTIVE SUMMARY

The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) clarified the nearly unanimous, global scientific opinion that climate change is real, it is already occurring, humans are responsible for most of the change that has occurred since 1950, and that these changes will continue for decades into the future.[1] The 2007 Cooperative Strategy for 21st Century Seapower acknowledges this reality and analyzes how climate change will affect the future strategic environment, but is less clear about the implications for the U.S. Navy's core capabilities.

For the next 30 years, a certain amount of climate change is locked in; a failure to cut global greenhouse gas emissions will mean even more dramatic change by the end of the century. The U.S. Navy must start considering how it will deal with global climate change over the next 30 years, with a tremendous range of impacts and uncertainty. This paper looks at anticipated changes in the operating and strategic environments, with consideration for implications for the Navy's strategy, planning, and requirements. The principal audience of this study is the U.S. Navy. Many of the forecasted impacts to the Navy as outlined in this paper are likely to affect both the U.S. Marine Corps and the U.S. Coast Guard in a similar or related fashion. Therefore, for the sake of simplicity, the term "Navy" or "Naval Services" refers to any or all of the services, as appropriate.

First, the Navy's operating environment is changing. This includes the background environment of politics and national policy, where there are likely to be new requirements for the Navy to curtail fuel use and emissions of greenhouse gases. Legislation, Executive Orders and Presidential Directives for increased energy efficiency and the use of alternative energy sources could affect designs of new vessels, require retrofitting of the existing fleet, and push changes in the design, operations, and management of installations. By anticipating such changes, the Navy can capture the benefits and minimize the costs, help shape the nature of new mandates and directives, and assert national leadership on key security concerns over use of energy supplies and climate change.

There will be changes in the more literal operating environment, as well—the undersea and surface environment. Changing conditions of the oceans—in sea level, temperature, thermocline depth, stratification, currents, acidity, and salinity—may affect undersea and surface navigation and require more frequent mapping and sampling of the ocean. These changes may also affect the maintenance of ships, engines and other equipment.

Other likely effects of climate change, such as sea-level rise combined with increased severity of mid-latitude and tropical storms (including hurricanes), will increase the threat to naval bases, ship-building facilities and other coastal installations. Although sea-level increases for the next 30 to 40 years are likely to be modest (significantly less than one meter), when combined with increased weather intensity, some currently safe facilities may become marginal, and some currently marginal facilities may become unsafe. Because facilities are protected to a given sea height, modest increases in average storm surge height can produce a disproportionate increase in how frequently defenses are overwhelmed. Although vulnerability assessments are clearly being conducted for some installations, a comprehensive assessment is needed, based on the best available regional climate change projections, and such vulnerabilities should be incorporated into all planning for future facilities.

Second, as the 2007 Cooperative Strategy for 21st Century Seapower acknowledges, there are likely to be changes in the strategic environment in which the Navy operates. Climate change is very likely to exacerbate humanitarian suffering. In Africa alone the 2007 IPCC report notes that "by 2020, between 75 and 250 million more people are projected to be exposed to increased water stress due to climate change." And "in some countries, yields from rain-fed agriculture could be reduced by up to 50%." Heat waves and droughts will be more common, and coastal flooding is projected to affect millions more people per year. Africa and parts of Asia with massive coastal populations are very likely to be at a significantly increased risk. As climate change progresses over the next several decades, the Navy is likely to be called upon increasingly to conduct and support humanitarian and disaster relief operations, related to these changes. In this and other ways, these secondary effects could impact the underlying security environment and U.S. security strategy in general, as well as maritime strategy specifically and the demands for naval missions.

There is also a possibility of increased great power conflict. Although it may not be highly likely to see great power conflict over stressed natural resources within a 30-year period, the melting of the Arctic ice may be a harbinger of future tension and conflict. The opening of new sea routes and resources in the Arctic has the potential to herald a new era of great power naval competition and resource competition, and at the very least is likely to open new shipping lanes. There is tremendous uncertainty, however, in the timeline. Because winter temperatures rise more rapidly than summer temperatures, especially at higher latitudes, wintertime warming in the Arctic over the 21st century is projected to be three to four times greater than the global wintertime average. Combined with increased summertime melting of sea ice, increasing winter temperatures ensure that less and less sea ice will reform as warming continues in future decades. In 2005, the Northeast Passage along the Eurasian coastline opened up for the first time in human memory. In 2007, the Northwest Passage through the Canadian Archipelago opened up for the first time. In 2008, both passages were open for a short while. The timing and extent of the Arctic's opening to routine shipping is uncertain, but whenever it occurs it will create new opportunities and risks for the United States, as well as new missions for the U.S. Coast Guard and Navy.

The effects of climate change underscore the importance of many themes in the Maritime Strategy, beyond the most obvious implications for humanitarian assistance and disaster relief (HADR) missions. Climate change will create new challenges for the Navy, particularly as it seeks to grow naval cooperation with allies and prevent conflict escalation in hot spots. And with the expanded stresses on the global commons caused by climate change, the United States may have to rely more on its allies to share some of the naval load.

The specific effects of climate change are uncertain and will be highly variable both across regions and over time. To successfully manage these challenges, the Navy must begin thinking about climate change in a new light, specifically to ensure a strategic approach by considering near-term (the next five years), mid-term (next 20-30 years), and long-term (beyond 20-30 years in the future) elements together in planning and acquisitions processes.

In the near-term, the Navy should anticipate legislation and presidential directives and regulations aimed at cutting energy use and reducing emissions of carbon dioxide and other greenhouse gases. Over the mid-term, the Navy should begin to prepare now for the effects of climate changes over the next 30 years on operations, installations, missions, and strategy.

Over a long-term (more than 20 years) time horizon – appropriate for considering the location of future installations and the characteristics of the next generation of naval capabilities – the continuation and exacerbation of all of the above-noted challenges is likely. Moreover, there is the possibility of catastrophic climatic effects.

Congress mandated in Public Law No. 110-181 that the Defense Department consider climate change in its planning, and use "the mid-range projections[2] of the fourth assessment report of the Intergovernmental Panel on Climate Change," or "subsequent mid-range consensus climate projections if more recent information is available." Because of the enormous uncertainty associated with climate change effects, however, the Navy should also consider the possibility of climate change that is more severe and/or occurs earlier than currently projected. The fact that many climate processes, including sea level rise, contraction of Arctic sea ice, and increases in extreme weather events are already well out-pacing model projections is a strong indication that the IPCC may project more significant changes in its next assessment, due in 2014. The Navy should take current mid-range estimates as a starting point, but be prepared to adjust as new estimates are provided. Improved monitoring and incorporating the possibility of wildcards and abrupt change into strategy and plans will be important tools. Moreover, with a planning horizon of many decades, the Navy must be sure to hedge against the possibility of much more extreme change.

PART I: INTRODUCTION

2008 was a volatile year in climatological terms. Hurricane Nargis ravaged Burma, killing more than 100,000 people and displacing millions more. Many of those affected may still lack reliable access to clean water, food, and basic services six months later, due in some measure to an uncooperative government. Record snowstorms in China stranded millions and caused billions of dollars in damage, stoking popular anger at the government's inability to respond in central, eastern, and southern China. Closer to home, floods in the American Midwest affected thousands and hurricanes in the Gulf of Mexico heavily damaged oil and gas production facilities and almost destroyed Galveston, Texas. Indeed, two months after Hurricane Ike, hundreds of people are still missing and energy production facilities are still recovering. Throughout 2008, parts of the southeastern, southwestern, and western United States have struggled with persistent drought conditions, with wildfires destroying more than five million acres, according to the National Interagency Fire Center.

These weather events may or may not be connected to global climate change, but the Intergovernmental Panel on Climate Change projects that these are the types of events that are increasing in frequency and severity as a result of global climate change. In particular, the volatility of weather patterns and the uncertainty of which effects will occur when and where is likely to be commonplace in the decades ahead. If global emissions of carbon dioxide and other greenhouse gases continue unabated or increase, these effects could become far more dramatic and even catastrophic by the end of the century or sooner.

Climate change is likely to affect the United States naval services in a range of ways, from changing the ocean environment in which the Navy operates to changing the Navy's missions. To investigate how climate change might influence the Navy, the Center for a New American Security (CNAS) convened workshops bringing together naval officers, climate scientists, and experts on climate change and international security from inside and outside the government. The workshops (participants listed in Appendix A) featured presentations on our ongoing research with responses from experts, creating a laboratory of ideas for discussing and debating key concepts. CNAS also conducted interviews with experts familiar with climate change issues, as well as uniformed and civilian members of the Navy whose responsibilities intersect with those areas most affected by climate change.

Building from an assessment of current evidence on climate change, this report considers an array of potential challenges for the U.S. Navy created by climate change, incorporating the strategic priorities as delineated in the 2007 Cooperative Strategy for 21st Century Seapower (referred to subsequently as the "Maritime Strategy").

PART II: THE CURRENT STATE OF KNOWLEDGE

Scientific Evidence of Climate Change

Recent decades have seen record-high average global surface temperatures. Thermometer readings sufficient to provide reliable global averages are available back to 1850.[3] According to data from the University of East Anglia's Climatic Research Unit—the surface temperature data most often used by climate scientists—the 27 warmest years on record all occurred in the 30 years from 1978 through 2007.[4] Over the past century, global surface temperature increased by about 1.4°F (Fig. 1). Over the last three decades, satellite measurements show that the lower atmosphere warmed by 0.22 to 0.34°F per decade, equivalent to 2-3°F per century.[5] The amount of heat energy stored in the oceans has also increased over the past half-century (Fig. 1).[6]

Other evidence that the Earth's surface has warmed rapidly in recent decades includes accelerating global sea level rise (Fig. 2),[7] the synchronous retreat of mountain glaciers at different latitudes around the world,[8] rapid shrinkage of the Arctic sea ice,[9] and net loss of land-based ice on Greenland and Antarctica.[10]

Together, these independent observations led the Intergovernmental Panel on Climate Change (IPCC) to conclude in 2007 that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."[11]

Only a few environmental factors (forcings) could possibly drive a persistent warming of the global climate, some of which are natural, such as changes in solar radiation or volcanic activity. Other possible climate forcings arise from human activities, particularly the release of heat-trapping gases (greenhouse gases) from the burning of fossil fuels and land-surface changes.[12] Which of these factors, or combination of them, is primarily responsible for the strong warming trend of the past century has been the focus of intensive research over the past two decades. The resulting scientific progress led the IPCC to conclude recently that "Most of the observed increase in global average temperatures since the mid-20th century is very likely [i.e. greater than a 90 percent chance] due to the observed increase in anthropogenic greenhouse gas concentrations."[13] Although several forcings are probably involved in producing the detailed pattern of global warming of the past century, no combination of forcings that excludes manmade greenhouse gases can explain the strong trend of the past several decades (Fig. 3). An accessible explanation of the scientific approach to identifying the causes of contemporary global warming is available from the Pew Center on Global Climate Change.[14]

Rising Global Temperature and Changing Patterns of Precipitation

According to the 2007 IPCC Fourth Assessment Report (AR4) "best estimates" of the increase of global average surface air temperature during the 21st century range from 1.8 to 4.0°C (3.2 to 7.2°F), depending on future man-made greenhouse gas emissions.[15] Temperature over land, particularly in continental interiors, warms about twice as much as the global average, as surface temperatures rise more slowly over the ocean. High northern latitudes also warm about twice as fast as the global average.

Extremes change more than averages, leading to fewer freezes, higher incidence of hot days and nights, and more heatwaves and droughts. Larger warming at high northern latitudes leads to faster thawing of permafrost, with consequent infrastructure damage (e.g., collapsed roads and buildings, coastal erosion) and feedbacks that amplify global warming (e.g., decrease in sunlight reflectivity as snow cover declines).[16] Winter temperatures rise more rapidly than summer temperatures, especially at higher latitudes. Wintertime warming in the Arctic over the 21st century is projected to be three to four times greater than the global wintertime average.

A consistent feature of model simulations is an increase in average global precipitation as a result of increasing greenhouse gas concentrations.[17] However, the geographic distribution of this change is very uneven, and some regions experience decreased precipitation. In general, areas that are currently wet (i.e., the moist tropics and high northern latitudes) become wetter, while currently dry areas (i.e., the arid and semi-arid subtropics and mid-latitude continental interiors) become drier (Fig. 4). Consequently, areas that currently suffer from seasonal flooding and areas that currently suffer from frequent drought will see these problems intensified by climate change.[18]

Increases in the average intensity of mid-latitude and tropical storms are also projected.[19] Over the past several decades there has been a trend toward a larger fraction of total precipitation falling in heavy events, with the strongest trends occurring in the wet tropics and the northern mid-latitudes.[20] Similarly, over the past 30 years the strongest tropical cyclones (i.e. major hurricanes and super cyclones) have become more intense on average.[21] The largest intensity increase is observed in the North Atlantic. In the North Atlantic there has also been a 50 percent increase in the average frequency of all tropical cyclones since 1995 compared to the long-term average.[22] Outside the North Atlantic there has been an increase in the number of very intense tropical cyclones but not an increase in total tropical cyclones. Climate model simulations suggest that in most oceans the total storm frequency may decrease as warming proceeds, but the most intense and damaging storms become more frequent, as has already been observed.[23] More intense storms lead to higher average wave heights, higher storm surges striking land, higher wind speeds, and heavier precipitation. Wind damage increases exponentially with wind speed, so that small increases in wind speed greatly increase the destructiveness of an intense storm.

A given change in regional climate, such as a degree of warming or a 10 percent change in precipitation, does not affect all regions the same way. Some regions experience a stable climate, and natural and human systems have developed around this stability; in such regions, even a small change may generate significant impacts. In regions with historically large climate variability, however, larger changes are required to exceed the bounds of climate variability to which natural and human systems have adapted. Appendix B provides a summary of IPCC projections of regional climate change.

Potential Societal Effects of Climate Change

Potential societal effects for the next 30 years that have potential security implications include:

- Coastal and low-lying island settlements disrupted by more damaging coastal storms and degradation of water supplies by saltwater intrusion
- More flashfloods in the wet tropics and mid- and high-latitude regions
- Millions more people under water stress, especially in Asia, Africa, and Latin America (Fig. 4)
- Increased incidence of waterborne diseases in the wet tropics (e.g. the Indian subcontinent and sub-Saharan Africa)
- Changes in the distribution of malaria in Africa, Asia, and Latin America
- Heat and extreme-weather driven declines in crop yields in low-latitude countries and on agricultural deltas in Asia and Africa
- Loss of grazing lands and more heat-related deaths in livestock in Africa and Asia

- Increased incidence of malnutrition in low-latitude countries
- More heat-related human illnesses and deaths in urban centers in Europe, Asia, and North America.

Climate Change Mitigation and Adaptation

Two completely different concepts inform climate change policy decisions: mitigation and adaptation. Mitigation refers to any actions taken to limit the extent of future climate change by reducing manmade greenhouse gas emissions. Adaptation refers to any measures taken to reduce the effects of climate change on nature or society. Examples of adaptation include building levees or sea walls to protect against increased storm surge heights, enhancement of health and safety education to reduce the impact of heatwaves on urban populations, and policies that limit coastal and wildland development to reduce the number of people and built structures vulnerable to coastal storms or wildfires.

Although the degree of future climate change can be reduced by the implementation of policies to reduce manmade greenhouse gas emissions, there is a delay of two to three decades from when a parcel of greenhouse gas is emitted and when the associated global surface warming occurs.[24] This delay results from the thermal inertia and slow mixing of the ocean. More than 80 percent of the additional heat captured by the enhanced greenhouse effect is mixed into the ocean initially. Subsequent equilibration of the atmosphere with this heat takes 20 to 30 years. Since there has been no mitigation of greenhouse gas emissions over the past three decades, the IPCC estimates that the climate system will continue to warm by about 0.2 to 0.4°F per decade for the next 20 to 30 years regardless of future attempts to reduce emissions.[25]

In other words, climate change for the next 30 years is unavoidable. Despite the uncertainties involved in what that climate change will mean for human societies, the Navy must be prepared to adapt. Furthermore, given the risks of unabated carbon and greenhouse gas emissions, the Navy also will be required to aid in mitigation steps where possible. The first step in developing comprehensive adaptation and mitigation measures is to consider how climatic changes could affect the Navy.

Figure 1: Average global surface temperature based on thermometer measurements (red line, left axis; adapted from Brohan et al. 2006; © Crown 2006, data supplied by the Met Office) and average heat content of the upper 700 m of the global ocean (blue line, right axis; adapted from Dominigues et al. 2008). Temperature rise during the 20th century is much larger than the uncertainty range.

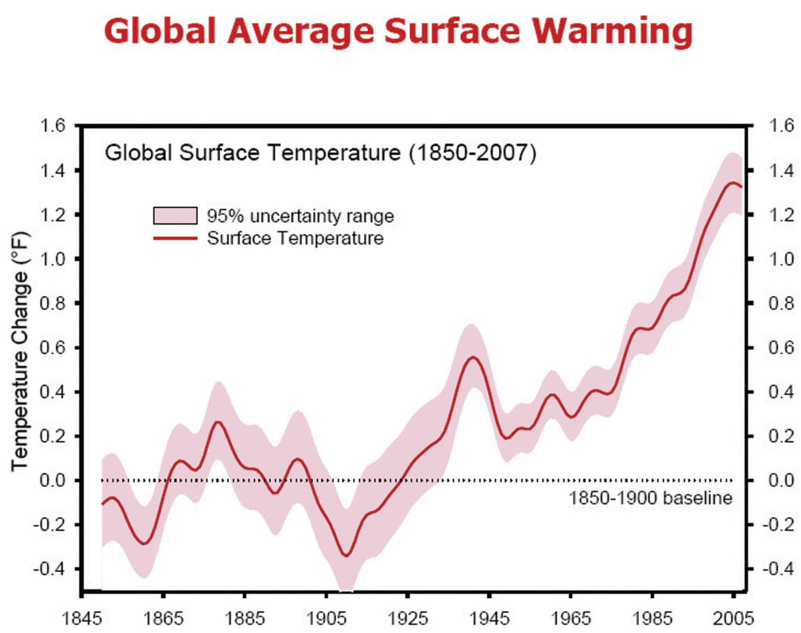


Figure 2: Acceleration of global mean sea level rise. The vertical width of the tide gauge record shows the 95 percent uncertainty range (green shading, adapted from (Church and White 2006). Satellite data (red line) are updated from (Cazenave and Nerem 2004).

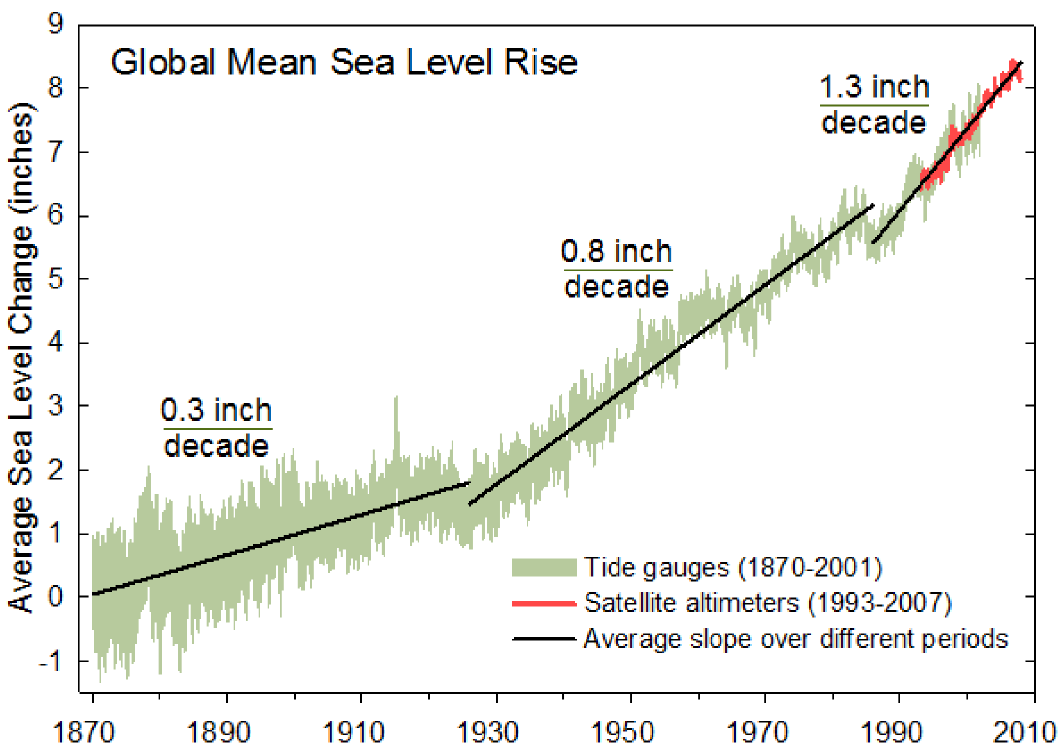


Figure 3: Analysis of the causes of global surface temperature change (Meehl et al. 2004). Results with only natural forcings included (blue line) do not account for warming since 1975. When natural forcings are combined with manmade forcings (red line), the results match the observed climate record (black line). Anthropogenic greenhouse gas emissions strongly dominated the warming after 1975.

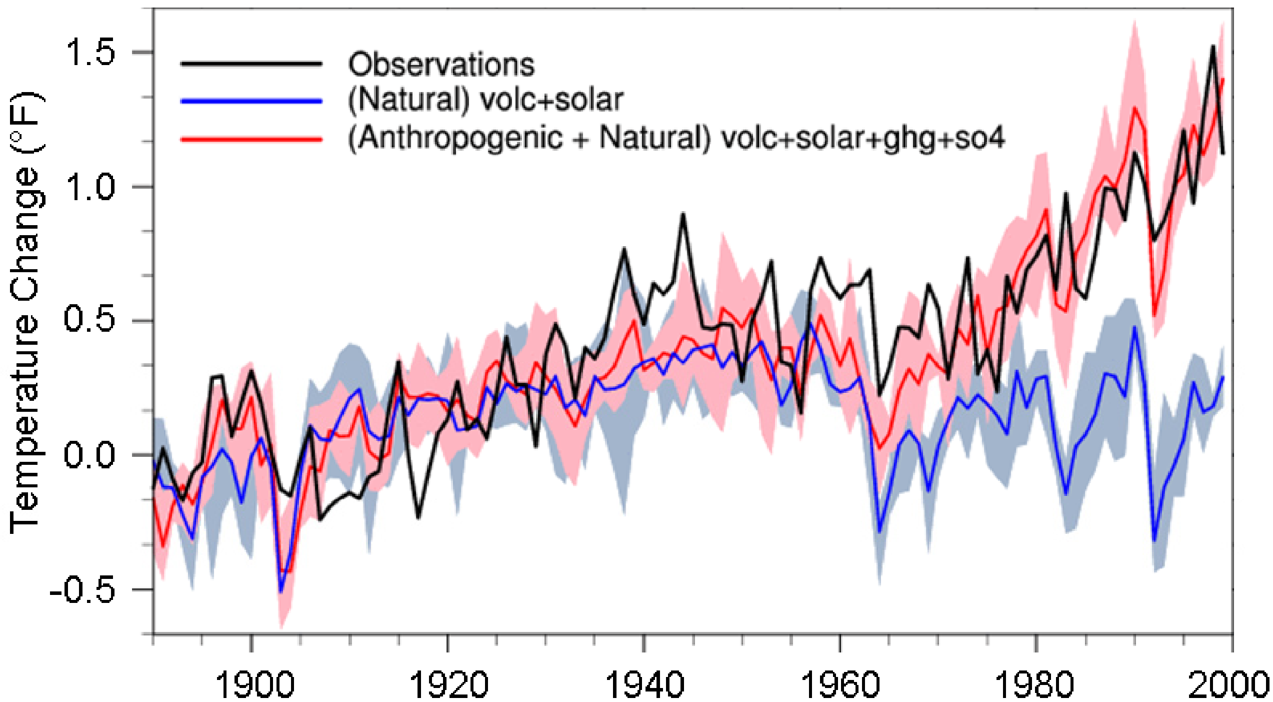
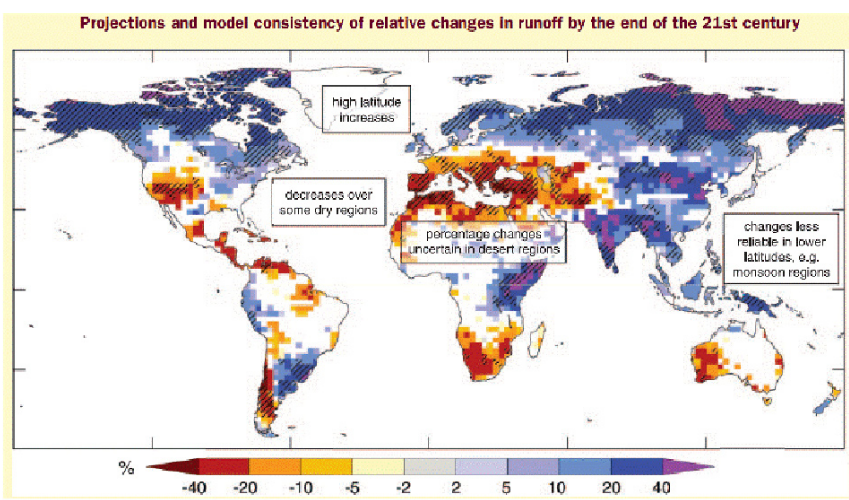


Figure 4: Large-scale changes in annual runoff (surface water availability, in percent) for 2095, relative to 1990. Values represent the median of 12 climate models using a mid-range greenhouse gas emissions scenario. White areas are where less than 66% of models agree on the direction of change and hatched areas are where more than 90 percent of models agree on the direction of change. The global map of annual runoff illustrates a large scale and is not intended to refer to smaller scales. In areas where rainfall and runoff is very low (e.g. desert areas), small changes in runoff can lead to large percentage changes that may have little meaning for impacts. In some areas with projected increases, different seasonal effects are expected, such as increased wet season runoff and decreased dry season runoff. (Source: IPCC AR4 Synthesis Report).



PART III: HOW CLIMATE CHANGE COULD AFFECT THE NAVY

In a globalized world, the oceans are increasingly important. As the avenue for more than 90 percent of global trade and a source of sustenance for billions of people, the global maritime commons are literally the lifeblood of the planet. The new Maritime Strategy also recognizes that this rising importance of the oceans is taking place in an overall context of strategic uncertainty and complexity.

Indeed, the Maritime Strategy lays out an integrated Navy-Marine Corps-Coast Guard strategy specifically to deal with a changing and uncertain world, including global climate change. It defines the goal of the naval services as "apply[ing] seapower in a manner that protects U.S. vital interests even as it promotes greater collective security, stability, and trust." Relative to previous seapower documents, there is a significant shift in emphasis toward preventing wars rather than fighting wars and focusing on cooperative maritime endeavors to promote security and stability on the seas. Indeed, the strategy acknowledges that security and stability are increasingly threatened by common global challenges requiring a global response. The document identifies the Navy's main strategic imperatives: limit regional conflicts; deter major power war; win the Nation's wars; defend the homeland; foster, and sustain cooperative international relationships; prevent or contain local disruptions through forward presence; maintain deterrence; exert sea control; protect maritime security; project power; and conduct humanitarian and disaster relief operations.

Climate change is likely to affect the Navy's ability to execute most if not all of the Maritime Strategy's imperatives through changes in the operational and strategic environment. This paper will look first at how climate change will likely affect the Navy's operating environment, including the political and policy context, surface and undersea conditions, and infrastructure issues. Then the paper will look at the shifting strategic environment, including an increase in local and regional conflicts, possible new homeland defense missions, and the possibility of new sources of major power tension and conflict. Finally, the paper will examine the implications for Navy strategy, planning, requirements, and acquisitions.

A Changing Operating Environment

In this context, we are defining the "operating environment" broadly to mean the political environment in which the Navy as an institution operates, from budgeting decisions to strategy; the undersea and sea surface environment in which Navy ships, aircraft, and submarines operate; and the infrastructural environment that supports Navy operations. In each case, climate change is already changing the environment in which the Navy operates in ways that may have immediate implications, ranging from the laws and directives that guide the Navy's decisionmaking to long-term decisions about new installations and shipbuilding facilities.

CHANGING CONDITIONS IN THE POLITICAL ENVIRONMENT

Volatile fuel prices coupled with concerns about the effects of global climate change have been gradually changing the political context in which the Navy operates. The new president and Congress are virtually certain to continue and deepen this trend, with added pressure from some state and local governments, the private sector, and international partners and allies.

In the political context, energy security (largely referring to oil prices and the security of supply) and climate change traditionally have been treated as separate issues. There is broadening recognition, however, that energy security and climate change are inextricably linked, and that any legislation designed to reduce greenhouse gas emissions will affect the production and cost of fossil fuel energy sources, given that the consumption of fossil fuels is the number one source of manmade greenhouse gases.[26] Indeed, with further budget constraints looming in the current economic crisis, many businesses and interest groups are pushing for policies that address both problems with the same investments.

The last three presidents have achieved such policies through directives and Executive Orders. In particular, past Executive Orders have required federal agencies to trim their energy use and look for ways to reduce carbon emissions, and legislation has directed such measures, as well. The Energy Policy Act of 2005 and Executive Order 13423, for example, required DoD to: reduce energy use by 30 percent by 2015; build buildings that are 30 percent more efficient than ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) standards; supply 7.5 percent of its energy from renewable sources by 2013; reduce fleet vehicle petroleum use by 20 percent by 2015; increase use of non-petroleum fuel by 10 percent annually; and switch to plug-in hybrid vehicles when they become life-cycle cost effective. President-Elect Obama said during the campaign that he would require the federal government as a whole to reduce its energy consumption 15 percent by 2015.

All military installations have been subject to such requirements, although military operations have to date been largely exempt from direct reductions. In the future, at a minimum, the Navy is likely to be subjected to new and more stringent presidential and/or legislative requirements to improve energy efficiency and promote alternative fuels; it is possible that past exemptions for operational energy use will no longer stand. It is also possible that the Navy will be required to reduce greenhouse gas emissions in a measurable way.

More broadly, the domestic debate over how best to address climate change will coincide with U.S. negotiations toward a follow-on international agreement to the 1998 Kyoto Protocol. The U.S. government agreed to a roadmap for a post-Kyoto architecture in Bali in 2007,[27] and will attempt to negotiate the final treaty in Copenhagen in November-December 2009 or sometime before the expiration of the Kyoto Protocol in 2012. According to the roadmap, developed countries will agree to reduce their greenhouse gas emissions dramatically, but without specific, binding targets delineating how quickly or what mechanisms countries must adopt to achieve the reductions.

Whether or not domestic legislation to reduce greenhouse gases passes before international negotiations conclude, a diverse array of interest groups are pushing for cohesive national action of some kind to patch together the current web of state regulations and programs that are making it difficult for businesses—and indeed the military, with bases across the country—to plan effectively. Thirty-four states have standards or goals for renewable energy production;[28] many take part in regional emissions reductions agreements of various kinds, and most have state laws applying energy or emissions rules. This has created a difficult atmosphere for companies and government entities to operate within, and pressure for federal standards is increasing. The most likely legislation to pass through Congress is a so-called "cap and trade" bill, which will cap total carbon emissions and introduce a permitting scheme in which the right to emit carbon dioxide is a tradable commodity. How this may apply to the Navy and other military services, which together are the 10th largest energy user in the country, is unclear.

Implications for the Navy

Higher energy prices have been straining the Navy's budget and may exacerbate tradeoffs in funding for operations, maintenance, reset, procurement and other requirements; new legislation could further affect energy or production prices (i.e. materials such as steel or cement are highly energy intensive to produce).

There could well be further new requirements for the Navy and other military services to cut energy use and/or control emissions. Such requirements may affect the Navy by adding new costs for retrofitting existing installations and systems or adding new Key Performance Parameters to future contracts.

Recommendations

Promote Energy Security Proactively. Rather than waiting for directives, mandates, or legislation to go into effect, the Navy should anticipate and shape how it will meet national energy security and climate change priorities now. The Navy should consider:

- Collaborating with the other services on relevant R&D and strategies for cutting energy use and emissions.
- Finding a way to calculate the Navy's total greenhouse gas emissions in order to establish a baseline against which to measure progress (particularly if required by law to do so).
- Taking proactive measures to cut operational energy use, either through efficiency measures, demand management, or substituting fuels, which would save money and cut emissions, and may well improve operations.
- Accounting for emissions standards and/or higher energy prices in procurement and in considering new technologies.
- Incorporating climate change and energy security reporting and discussions as part of normal interactions with Congress in order to anticipate and shape future legislation.
- Directing the Office of Naval Research to increase R&D on climate change and related technologies. ONR is already conducting relevant R&D, though it is mostly at the discretion of lab directors and investigators. A strategic emphasis on R&D to support an improved energy posture may well yield results with strong possibilities of commercially viable technology development.

CHANGING CONDITIONS IN THE SURFACE AND UNDERSEA ENVIRONMENTS

While navigating the shoals of the political world may be complicated, the Navy has a great deal of experience in navigating a dynamic ocean environment. That experience will be important as climate change is likely to significantly affect the ocean environment.

This section will attempt to identify a range of operational considerations for the Navy from the changing ocean environment. The warming of ocean water and melting of land ice will produce rising sea levels, decrease salinity at high latitudes, increase salinity in the tropics, and could cool ocean water in the northern North Atlantic. The uptake of carbon dioxide in seawater will increase ocean acidity. Climate change is also likely to affect ocean currents. These changes will affect surface and undersea navigation, and possibly affect operation and maintenance of ships, engines, and other equipment. Some changes may require more frequent mapping and sampling of the ocean.

Subsurface Operations

While these changes may affect subsurface naval operations, it is difficult to "strategize against" them because there is tremendous uncertainty about what will happen where, when, and to what extent. This may not require any new equipment or even training, but it may require the Navy to anticipate and plan for more dynamic and unpredictable operational conditions.

The underwater impacts of climate change may have several direct and indirect operational effects on subsurface naval operations. First, ice melt will change water densities, as an infusion of fresh water lowers the density of high-latitude northern waters, while increased evaporation from a warmer atmosphere increases the density of tropical waters. In 1999, the Sturgeon-class nuclear-powered attack submarine, *USS Hawkbill*, noted how changes in water salinity—attributed to polar ice melt—made it harder for the captain to maintain neutral buoyancy. According to one report, "A change in salinity of just one part per thousand causes a buoyancy shift of nearly 8,000 pounds in the Sturgeon-class attack submarine."[29] While such changes are well within the Navy's current capabilities to manage, they may be an important part of the changing environment.

Water density affects not only submarine mobility but also sonar. Submarines have historically played an important role in countering the anti-access challenge—particularly against the Russians—and will likely continue to do so, especially as the Chinese navy grows more sophisticated and potentially more assertive. The use of passive and active sonar to detect approaching Russian submarines and submerged vessels was key to many of the Navy's successes in the Cold War.

Increased seawater acidity may also change underwater acoustical properties. A recent study found that "reasonable projections of future fossil fuel CO_2 emissions" could lead to a decrease in low frequency sound absorption by almost 40 percent by mid-century. The study's authors concluded, "Ambient noise levels in the ocean within the auditory range critical for environmental, military, and economic interests are set to increase significantly due to the combined effects of decreased absorption and increasing sources from mankind's activities."[30] This shift may be well within the Navy's current technical capabilities to meet, but is worth anticipating.

Anti-Submarine Warfare systems depend on long-established predictions systems of underwater acoustic propagation pathways.[31] Widespread changes in the density of ocean water have the potential to complicate sonar-based detection, or at least call for ongoing anticipation and adjustment.

Sonar detection is especially crucial in arctic regions, where it is necessary for detecting underwater ice ridges. Accurate detection will be critical in the coming years, as submarine operators have to contend with the continued break up of major ice sheets, which can drive ice ridges deeper under water. In the 1999, aforementioned expedition by the *USS Hawkbill*, the crew noted risks associated with detecting ice ridges.

Subsurface naval operations may also be influenced by changing thermoclines. In addition, as mentioned in the arctic section, polar melting may also facilitate new azimuths for submarine launched ballistic missiles (SLBMs), creating new opportunities and risks for the United States.

Changes in water salinity, density, and acidity may eventually offer new strategic opportunities and risks for the U.S. Navy. This may include nontraditional threats, such as narcotics traffickers using semi-submersibles but with limited ability to adapt to changing conditions.[32]

The subsurface challenges sketched out in this section are not meant to provide a comprehensive view of how climate change will affect subsurface operations. Instead, it seeks to suggest how climate change might complicate underwater missions. The U.S. Navy may need to conduct further research to better determine the ocean density, salinity, and acidity thresholds at which climate change may impact sub-surface operations.

Surface Operations

Changes in surface conditions may also have implications for the U.S. Navy. Climate change may have effects on ocean currents (e.g., the North Atlantic Current) and induce violent weather events (e.g., hurricanes) that will mean new challenges.

Severe weather events may have consequences on naval mobility, operations, and maintenance.

Today, the Navy deals with extreme weather largely by avoiding it, thanks to an extensive system of sensing technologies, largely managed through the Naval Meteorology and Oceanography Command and civilian agencies.

Despite past and anticipated improvements in forecasting, the possible increase in the frequency of intense tropical storms means that such weather systems may become harder to avoid and more dangerous. Current doctrine is to avoid significant storms by finding safe harbor or calmer seas.

Furthermore, violent tropical storms also put tremendous stress on U.S. ships and vital facilities that are susceptible to damage from high winds and waves. Maintenance and construction schedules could be disrupted, for example, if port facilities are damaged by tropical storms and high storm surges. The late Admiral Donald Pilling, USN (ret.), noted, "We spent a few billion to restore Pascagoula after Hurricane Katrina—and we're not done yet. But at least that's an impact you can see."[33] Restoring operations for these facilities can cost billions of dollars as well as reduce operational availability of ships.[34]

Moreover, severe storms can have direct impacts on operational readiness and training. According to General Paul Kern (USA, ret.) as quoted in the ground-breaking CNA study on climate change and national security, large tropical storms and hurricanes force the military to reposition assets out of harm's way. This involves tremendous amounts of manpower, energy, resources, and time. Kern draws upon an experience when Hurricane Hugo was projected to hit Savannah, Georgia. During this time the Navy was also preparing for a military exercise with NATO counterparts. Unfortunately, the storm diverted resources by forcing American forces to deal with moving equipment to safe harbor, which eventually produced suboptimal results for the military war game. This led Kern to conclude that extreme weather conditions can have deleterious effects on operational readiness.[35]

Additionally, there is growing evidence that power projection can be hindered by extreme weather events. Even though the men and women of America's armed forces are trained and prepared to fight in any condition, inclement weather does take a toll on sailors' physical and mental well-being. For example, in warmer climates, such as the Middle East, surface temperatures on the decks of aircraft carriers can reach temperatures above 120°F, putting great strain on the deck crew's ability to launch planes.[36] Additionally, leading studies have shown that this can have negative repercussions on the crew's ability to sustain high tempo operations.[37] Although naval training already prepares sailors for a variety of inclement conditions, the Navy may need to reassess this training for more persistent high-heat conditions and other new considerations associated with climate change, such as the presence of cyclonic storms in unanticipated locations (e.g. Hurricane Vince in 2005) or more intense storms.

More frequent and intense weather events will also compel ships to deal with greater fluctuation in sea states, which may affect naval mobility. Because of these fluctuations, ships may need to re-chart courses to avoid high-waves or risk being battered and damaged by large waves. Note that the independent deployers are more at risk, given that they rarely have a meteorological capability (METOC detachment) on board. Furthermore, during high-sea states, aircraft carriers may need to curtail flight operations as landing planes becomes extremely difficult. In such circumstances, flight deck personnel and aircraft are at great risk. These operational challenges are difficult to plan against, but training programs can help.

Finally, climate change may result in major changes to ocean currents, though it is possible that such changes may be beyond the 30 year horizon of this report. Scientists believe the most significant climate-induced threat to ocean systems is the potential for a shutdown of the thermohaline circulation system.[38] Increasing amounts of fresh water caused by ice melt in the Arctic will decrease—and potentially stop—the transport of warm waters from the tropical North Atlantic to the northern North Atlantic. These changing currents would have dramatic impacts on the climate of the North Atlantic region and may affect navigation routes. In the near- to mid-term, the United States should consider supporting international efforts aimed at better understanding and monitoring of major ocean currents.

Implications for the Navy

The unpredictability and volatility of climate change mean that in addition to the challenges noted in this section, the Navy may face other emergent operational challenges. The U.S. Navy has unparalleled capability for monitoring and adjusting to a changing ocean environment; in coming years, this capability may be in higher demand by the U.S. Navy, as well as other U.S. military services, civilian agencies, and partner nations.

Recommendations

Move beyond stationarity. Traditionally, planners dealing with the natural environment have assumed "that natural systems fluctuate within an unchanging envelope of variability," a concept known as stationarity.[39] But in a changing climate, the future may be hard to anticipate. New strategies are needed to assess the Navy's future operating environment and for managing risks that fall outside the historical envelope of variability. There is no convenient replacement for the assumption of stationarity and increased uncertainty may be a persistent element of planning for future operating environments. The Navy should train for greater uncertainty and use a "multicasting" strategy of preparing for multiple plausible futures.

Adjust Navy Capacities for Climate Change. The Navy should study which technologies, practices, and skills will be needed more frequently or improved in order to deal with changing undersea and surface conditions. The Navy's scientific and technical support capabilities are robust enough to adjust and adapt to climate change over the course of the next 30 years; however, it will be important that the Office of Naval Research, Meteorological and Weather Command, and other relevant assets work closely with operational fleet forces to focus resources on how climate change is affecting and will affect the Navy's operating environment.

The U.S. Navy should consider, consistent with the cooperative emphasis of the new Maritime Strategy, expanding and deepening cooperation with other services, the maritime forces of other nations, and relevant civilian agencies to track changing conditions.

Build Knowledge Repositories for Climate "Lessons Learned." The U.S. Navy should consider providing a further public good to U.S. civilian agencies and other global navies by coordinating with NOAA and other relevant agencies the development of a set of "lessons learned" for best practices in response to climate change. All navies will have to deal with changes to the undersea and surface environment caused by climate change and handle the implications of rising sea levels for naval operations. Specifically, the Navy could consider:

- Improving the ability to share meteorological, seismic, radar, communications, and other data that can help anticipate and deal with severe events.
- Emphasizing the development of doctrine, training and operational awareness of changing conditions in the oceans. This should extend to national forces and multinational cooperation.

Installations

The IPCC's 2007 report and more recent peer-reviewed scientific research show that sea level rise accelerated during the 20th century.[40] Acceleration of sea level rise is a predictable consequence of climate change because ocean water expands as it warms and because surface warming melts land-based ice, adding more water mass to the oceans. Hence, the rate of sea level rise is expected to increase as global warming continues. However, predicting the rate of acceleration is difficult and there is significant uncertainty regarding how much sea level will rise within a given window of time, such as by the end of the current century.

Based on climate model estimates of thermal expansion of ocean water and ice melt from glaciers and continental ice sheets, the 2001 IPCC Third Assessment Report (TAR) projected that sea level would rise by 0.09-0.88 meters (0.3-2.9 feet) by the end of the 21st century.[41] In 2007, the Fourth Assessment Report (AR4) projected a narrower range of 0.18-0.59 meters (0.6-1.9 feet).[42] The decrease at the upper end of this range relative to the TAR confused many observers, who incorrectly inferred that the IPCC was lowering its overall sea level rise projections. However, the authors of the AR4 omitted a key component of future sea level rise from their calculation—the contribution from future changes in ice flow from land to sea from the Greenland and West Antarctic ice sheets. Because of this omission, the AR4 clearly states: "Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise." Hence, this was not a downward revision of the IPCC projection because the projection was not considered by the authors to be complete.

Since the IPCC's release of the AR4, two peer-reviewed scientific studies have attempted to project sea level rise to the end of the 21st century, taking all contributors into account. The first analysis projected sea level to rise by 0.5 to 1.4 meters (1.6 to 4.5 feet) by the end of the 21st century.[43] Using a different method, another study projected 0.8 to 2.0 meters (3.3 to 6.6 feet) of sea level rise by 2100.[44] We know that sea level rise at this rate is feasible because sea level rise averaged 1.5 meters (4.9 feet) per century during the last warm interglacial about 125,000 years ago, when global average surface temperature was only about 1-2°C warmer than it is today.

The current 10-fold range of uncertainty (0.2 to 2 meters) for 21st century sea level rise is significant; the lower end represents a significant nuisance to most coastal nations—low-lying island nations notwithstanding—whereas the upper end would have severe effects on most major countries.

Implications for the Navy

Taking the range of uncertainty into account, rising sea levels will threaten to some degree naval installations and the other maritime infrastructure necessary for naval operations. Combined with a second maritime implication of climate change—the possibility of increasing hurricanes and other storms with their associated storm surge in water levels—every aspect of maritime operations may face new challenges.

Losing access to key low-lying overseas bases (e.g., Diego Garcia) and reorienting spending to harden domestic naval facilities against storm surges could hamper naval power projection and require greater reliance on long-range strike capabilities. Overseas U.S. naval bases at locations such as Diego Garcia and Guam could be compromised by rising sea levels and higher storm surges.

The Bush administration had committed to upgrading U.S. military facilities in Guam. Guam is slated to host a growing number of submarines and Marine units and to service an increasing share of overall naval and air assets in the Pacific. However, climate change will increase the risk that major storms could cause severe damage on Guam. For example, Super Typhoon Pongsona in 2002 caused over $700 million in damages. As these types of events become more frequent and more intense, they could threaten the viability of many coastal and island installations. America's overseas naval bases, especially its island bases, are critical to U.S. power projection capabilities and ensuring that U.S. ships can navigate global waters with ease. Climate change places these overseas bases at risk due to rising sea levels and growing storms.

A growth in the frequency of intense storms will also threaten U.S. naval installations on the U.S. mainland, requiring costly repairs or even abandonment in the event a storm hits. This is not just a theoretical question – it already became a reality in 1992 when the costs associated with recovering from Hurricane Andrew forced the shuttering of Homestead Air Force base. Additionally, in 2005, Hurricane Ivan-related damage forced the closure of much of the Pensacola Naval Station for a year. There is a large concentration of maritime military installations in the United States that may be susceptible to the effects of sea-level rise, which could include inundation of land, increased storm and flood damage, loss of wetlands, changes in erosion patterns and rates, salt water intrusion in surface and ground waters, rising water tables, and changes in tidal flows and currents.[45] The Department of Defense's Strategic Environmental Research and Development Program is currently studying[46] the susceptibility of:

- Hampton Roads, Virginia Naval Installations
    - Naval Station Norfolk
    - Naval Air Station Oceana
    - Little Creek Amphibious Base
- Marine Corps Base Camp Lejeune, North Carolina
- Naval Station San Diego and Naval Air Station North Island, California
- Naval Station Pearl Harbor, Hawaii

Also, the June 2008 *National Intelligence Assessment on the National Security Implications of Global Climate Change to 2030* included an annex of 31 U.S. military installations judged to be at risk of flood-related damage, based on the U.S. Geological Survey's *Coastal Vulnerability Index*. The *Index* judges vulnerability according to a number of indicators, principally relative sea-level rise, tidal range, and coastal geomorphology. The analysis did not assess level of risk or site-specific vulnerabilities.

One of the most direct threats climate change presents to naval operations comes from the disruption of existing port infrastructures due to climate change. From a commercial port perspective, even minor disruptions in major global ports, such as Hong Kong, can cause hundreds of millions of dollars in damage. A Congressional Budget Office study in 2006 estimated that a one-week shutdown of the ports of Los Angeles and Long Beach, for example, would cost $450 million, or $65 million a day.[47] Major damage to key global ports could cripple global shipping. More frequent intense hurricanes resulting from rapid climate change could induce severe damage to underlying infrastructure at ports around the world.

Disruptions to global shipping and commercial ports resulting from climate change will present challenges to the Navy. First, since open global maritime trade is important for the American economy, the Navy already works to keep sea lines of communication (SLOCs) and other access routes for trade open. As a threat to maritime trade, port disruptions could draw in the U.S. Navy. In particular, as the most powerful maritime actor in the world, maritime rescue and recovery operations could draw on U.S. naval resources, especially if American allies and major trading partners control the at-risk ports. Second, naval deployments are often facilitated by visits to ports in many nations, only some of which host official American naval installations. Disruptions to key commercial ports could force changes in how the Navy plans deployments. Finally, commercial ports serve as coordinating hubs for maritime trade. Focusing trade on key hubs allows for the concentration of safety and security resources around patrolling those sea-lanes between the hubs. Major damage to key commercial hubs could drive a diffusion of maritime trade to many smaller hubs. The growth in piracy off the coast of Somalia in recent years highlights the risks involved in even a relatively coordinated global maritime network.

In addition, climate change could put major commercial and especially military shipbuilding facilities at risk, potentially undermining the defense industrial base. Today, six privately owned major shipyards (Bath Iron Works, ME; Electric Boat, CT/RI; NASSCO, CA; Avondale, LA; Ingalls, MI; Newport News, VA) control all of naval ship construction. Only two yards—Bath Iron Works and Newport News (now renamed under the Northrop Grumman shipbuilding reorganization early in 2008)—can build nuclear-powered vessels. The Navy has already recognized the way extreme weather events can influence the shipbuilding industry and naval procurement. In the aftermath of Hurricane Katrina, shipbuilding was delayed and the Navy awarded special repair and/or replacement contracts to Gulf Coast shipbuilders to help them recover. The Navy feared the impact of losing more shipbuilding facilities.

Dealing with these risks will require extensive cooperation between private industry and the Navy. It is necessary to engage in planning to determine both how to respond in the case of a storm surge and whether the long-term viability of any key shipyards is at risk. Adaptation should begin now to ensure the strength of naval shipbuilding over the long-term.

Recommendations

Conduct Vulnerability Assessments. To deal with the consequences of climate change for naval facilities, both overseas and domestic, the Navy should first and foremost carry out comprehensive vulnerability assessments of naval facilities to storm surges and flooding, as well as evaluate the adequacy of contingency plans.

Vulnerability assessments will help the Navy do the type of cost-benefit analysis that can help the Navy determine if some installations are more at risk than others. This may help determine which, if any, assets should be shifted in anticipation of climate change, as well as cost out and devise response plans.

Assessments might consider at least two mid-term and two long-term scenarios for climate change. The mid-term scenarios should include: (1) the mid-level assessments of the 2007 IPCC report (as required by current legislation), and (2) a scenario with more dramatic change that is more consistent with observations over the last several years (e.g., the A1FI scenario in the IPCC report). The longer-term scenarios, set in the 2100 time frame, can also be taken from the IPCC report, and should span from modest to catastrophic impact.

The Navy also should work with partner nations to conduct combined vulnerability assessments, particularly those that have ports and other installations important to U.S. naval operations and the execution of contingency plans.

Implement Cost-Effective Preventive Measures. Preventive measures to boost the ability of the Navy to rapidly respond to the consequences of extreme weather events on naval installations could also generate long-term cost savings. Given that repairing damaged installations in response to current weather events has already ranged into the hundreds of millions of dollars, events that occur as the result of storm surges would almost certainly magnify those amounts. Accurately predicting rising sea levels could also save hundreds of millions of dollars in long-term costs.

Some naval stations may require significant upfront investments to design them for operations in a world of rising sea levels. Others may become too costly to utilize. Building more robust new facilities or redesigning old facilities will in most cases be cheaper than having to pay to recover from a climatic "event" like a hurricane or a long-term sea level rise, which would involve both paying the damage and cleanup costs and designing new facilities or rebuilding old facilities.

The Navy will want to focus on the highest leverage investments, considering factors including the costs of prevention versus the costs of repairs, potential impact to the Navy's ability to conduct operations and support the full range of engagement and operational plans, the availability of other installations, and (for overseas installations) the potential for partners to contribute to both prevention and response.

Create Local Response Plans. The Navy should also consider crafting response plans to rapidly adjust if naval stations are rendered inoperable due to storms or rising tides. Response plans should incorporate pier readiness—shore cables, hotel services, crane services, and other infrastructure, such as electric power plants—necessary for any repair mission. The Navy should also work with local industry surrounding all of its bases to identify other higher or more inland areas to serve as satellite basing if a naval station is damaged.

Recognize Threat to Power Projection and Prepare for the Worst. The Navy should also prepare for potentially more drastic adjustments in basing locations in response to climate change. The loss of or significant damage to bases at locations such as Diego Garcia and Guam would be important, but if the Navy recognizes the threat and plans in advance, the Navy can reduce the consequences for readiness and power projection. Examples might involve shifting naval forces between nations within broader regions, such as the Mediterranean or Indian and Pacific Ocean. More fundamentally, the Navy should examine potential locations for bases on slightly higher ground that are more likely to survive sea level rise.

Maintain Naval Supremacy. As described above, climate change could present important challenges to the power projection capabilities of the Navy, especially given the risks to overseas bases and the naval industrial base. As the Maritime Strategy describes, the ability of the Navy to project seapower across great distances is critical to U.S. alliance relationships. Ensuring that climate change does not limit the naval power of the United States may be an important step in fulfilling the cooperative maritime vision laid out in the Maritime Strategy.

Changes in the Strategic Environment

Although changes in the operating environment for the Navy—both the more figurative political operating environment and the literal undersea and surface environments—will have broad implications for how the Navy fights and wins the nation's wars, the way climate change will affect the strategic environment will be important, as well.

The high probability of increased humanitarian stress and regional conflict and the possibility of new great power conflict speak directly to the Navy's strategic priorities and may significantly change or reprioritize the Navy's missions. Natural disasters and low-level conflict resulting from migration, resource scarcity, and state failure may be the primary flashpoints for military involvement. Although no country—including the United States—will be immune, low-latitude developing nations with limited adaptive capacity are the most vulnerable to climate change and will see negative impacts even at moderate levels of change.[48] Water stress, declining crop yields, extreme weather events, waterborne diseases, malaria, and exposure to sea level rise will all be more acute in low-latitude developing nations, affecting millions of people. Africa, South and Southeast Asia, Latin American, and the Caribbean are particularly vulnerable.[49] Weak and failing states may be unable to maintain security and protect their citizens from threats such as epidemic diseases that result from changing climate conditions and the migration of exposed populations. Cross-border migration within developing regions may spark ethnic and sectarian conflicts. Attempts to emigrate to developed countries are likely to increase the number of migrants on the seas.

The eventual prioritization of climate change-related missions will have to come from the National Command Authority. In the meantime, the Navy should consider anticipating this shift in its strategy, planning, requirements, and acquisition processes.

THE POTENTIAL FOR INCREASED HUMANITARIAN DISASTER

Among the expected impacts of climate change are growing resource scarcity (including water, agricultural productivity, and forestry products) and a sharp rise in natural disasters, such as floods, wildfires, and tropical storms. The former phenomena tend to be "slow-onset" or chronic disasters and harder to reverse, while the latter are "sudden-onset" events from which nearer-term recovery is possible. Costs for full recovery may become prohibitive in some cases (costs associated with Hurricane Katrina, for example, are estimated to be more than $100 billion, and recovery is ongoing three years later), but rebuilding and returning home is at least feasible. In both cases, advance preparation and resilience can cut costs dramatically, both in lives and resources.

Responding to sudden-onset disasters is a proven capability for the Navy, as has been demonstrated most dramatically in the 2004 Indian Ocean Tsunami. There are a number of lessons in the response to that disaster, Operation UNIFIED ASSISTANCE, for a future in which such relief missions may be more common. First, the Tsunami relief efforts demonstrated the importance of seabasing during disaster relief, both for reasons of cultural sensitivity and due to the destruction of coastal infrastructure. Relief operations also demonstrated the importance of advance information and preparation, joint operations, and the value of partnerships (U.S. forces cooperated with forces from Indonesia, Sri Lanka, Thailand, Australia, Japan, Singapore, Russia, France, and Malaysia). Indeed, Operation UNIFIED ASSISTANCE also demonstrated the importance of joint, combined exercises; U.S. familiarity with the region due to Cobra Gold exercises was crucial to the speed of the response. Moreover, given the forward presence of U.S. assets, within only 10 days of the disaster "UNIFIED ASSISTANCE included over twenty-five U.S. Navy ships, forty-five fixed-wing aircraft, and fifty-eight helicopters. By this point American forces had already delivered more than 610,000 pounds of water, food and other supplies to the region."[50]

These missions may not be in other nations. Recent experience with Hurricanes Katrina, Rita, and Ike has demonstrated that an increase in sudden-onset disasters in the United States is likely to increase the Navy's support to civil authorities in homeland security missions.

Resource Scarcity and Migration

Over the last few decades, social scientists have attempted to unravel the relationship between resource scarcity, migration, and conflict, although the links are complicated and the research limited.[51] Today, around the world, most refugees from political and environmental stress tend to stay within their own regions, and almost all are eventually repatriated to their homes. In such cases, it appears that there is not a noted increase in conflict.[52] Climate change may well introduce new migration patterns, however, if migrants fleeing environmental stress are unable to return home or meet basic survival needs within their regions. There is very little research on how a changing climate may affect migration patterns, particularly if whole regions are experiencing resource scarcity.

Current labor or economic migrants—those who move to find work, rather than to flee a dangerous situation—tend to follow fairly well-established paths, and it is possible that future "climate refugees" (note that the use of such a term is considered controversial, given the multiple causes involved in decisions to migrate) may follow similar paths. If that is, indeed, the case, current patterns of African migration to Europe; Caribbean and Latino immigration to the United States; and Southeast Asian migration into China and Australia may increase.[53]

While there is not total agreement about a causal link between resource scarcity, migration, and conflict,[54] Africa appears especially vulnerable to such conflicts. The Sahel and the Horn of Africa are rife with food insecurity (Fig. 5), and about half of the world's internally displaced people are in Africa.[55] A recent study found that "natural resource-related conflicts are the predominant types of conflict" in the West African Sahel.[56]

Climate change will increase some of the reasons that Africans migrate, elevating the risk of conflict. Pre-colonial African societies developed traditional adaptation strategies to make them resilient to natural climate variability. One of the key strategies was to move when climate conditions became inhospitable.[57] Given population increases and modern settlement patterns, moving may be a problematic option. In recent years, it does appear that competition among migrants in Africa, particularly pastoralists and farmers especially vulnerable to climate changes, may have already contributed to conflicts in the Sahel and in Darfur.[58] As climate change progresses, the number of displaced will grow because of the low adaptive capacity of African societies. As the numbers grow, more people will likely cross borders, increasing the possibility of cross-border conflicts. Water shortages, in particular, are a potential flashpoint across borders as resources dwindle in northern, southern, and Sahelian Africa.

Failed States

A tragic harbinger of the links among resources, conflict, and migration and the ways in which climate change can push a borderline nation further into state failure can be found in Somalia. Engulfed now in a nearly anarchic situation, Somalia is an example of how different types of instability perpetuate one another. It has long been a weak and unstable country, but climate challenges (which may or may not be related to climate change) have exacerbated its already severe economic, social, and political problems in recent years. Nearly two years of harsh drought conditions coupled with inflation and other economic troubles have caused

Figure 5: Estimated food security conditions, 2nd Quarter 2008 (April-June). Source: Famine Early Warning System Network (http://www.fews.net).

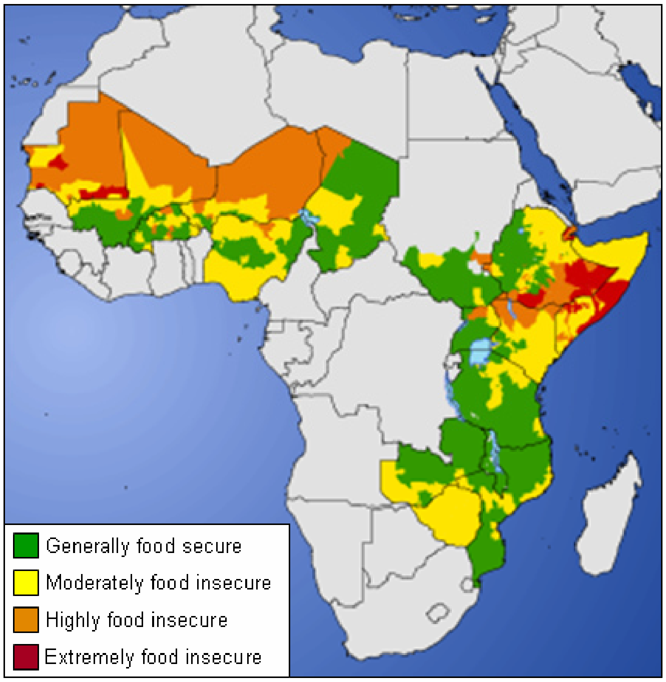


Figure 6: Arctic Sea Passages[85]

widespread famine and strained aid programs.[59] Violence and political turmoil, on top of this, have pushed Somalia's numbers of internally displaced people into the hundreds of thousands. The UN World Food Programme was forced to suspend humanitarian operations late in 2007, and several Somalis were killed in riots over food prices earlier this year.[60] The desperate situation of millions of people starving and on the move has led to widespread lawlessness and affected all neighboring nations. Indeed, one neighbor, Ethiopia, intervened militarily in an as-yet unsuccessful bid to stabilize the situation.

The turmoil in Somalia has translated into military missions for the U.S. Navy in recent years (i.e., subsequent to U.S. action in 1993). First, the instability and violence of the country, including rule by a radical Islamist group, provoked direct U.S. military action in late 2006 and 2007. Second, the lawless climate provides hospitable conditions for terrorists, and the Navy has been involved in striking terrorist locations in Somalia. Indeed, the State Department's Country Report on Terrorism identifies Somalia as the most significant terrorism threat to American interests in Africa, citing the presence of both al-Qaida and local groups. Finally, recent dramatic headlines have focused on the problem of piracy off Somalia's coast—a problem the U.S. Navy has been dealing with for years but which has dramatically increased in recent months. Somali pirates have been taking commercial ships and holding hostages, and since November 2007 international ships delivering food aid to the starving population—those that are not scared away altogether—have required naval escorts.[61]

As climate change exacerbates these ongoing problems in Somalia and other unstable, violent, and underdeveloped failed or failing nations like it, the Navy will likely face more missions to counter opportunistic extremist governments, terrorist organizations (including terrorists of global reach), and piracy that can actually challenge sea control and freedom of navigation in key sea lanes.

According to Raleigh and Jordan,[62] the nations most at near-term risk for chronic vulnerability (i.e., political and economic weakness, low adaptive capacity, and high risk for climate change effects) include: Afghanistan, Bangladesh, Burkina Faso, Madagascar, Malawi, Mozambique, Nepal, Nigeria, Rwanda, Somalia, Sudan, and Tanzania.

Implications for the Navy

The enormous humanitarian spillover consequences from climate change will present an important challenge for the U.S. Navy. Most directly, the Navy is likely to see an uptick in humanitarian assistance and disaster relief (HADR) missions, particularly in Africa and South and Southeast Asia. Hurricanes, floods, droughts, and other climate-induced weather patterns will generate tremendous destruction and insecurity. The first victims of many of these weather events are the poor and people living in the margins of society. Cyclone Nargis in Burma, which caused massive death and destruction in May 2008, is just one example of how major weather events can generate tragic consequences, which weak or perverse governments can magnify. Many of the states most likely to be affected by climate change have such governments, raising the prospect of more international peacekeeping and humanitarian missions. Criminal and terrorist groups that thrive on these conditions also make disaster relief operations critical components of an effective and integrated anti-terror strategy by removing important drivers for terrorist recruitment—mainly, perception of government abandonment and neglect. Of course, the presence of these groups also complicates relief efforts and draws in military assets for the protection of relief convoys.

The migration patterns described above resulting from sudden- and slow-onset disasters will likely redraw the lines for many of the world's most populous regions and threaten U.S. assets abroad. Coastal regions experiencing severe climate change may become increasingly ungovernable, creating economic incentives for piracy, safe havens for terrorists, and a lack of capacity on the part of local governments to deal with the issue themselves. As the leading global guarantor of freedom of navigation, these concerns will necessarily involve the Navy.

Rapid population growth and overfishing compounded by climate change will decrease fish stocks. Disputes over securing rights to fish stocks will increase chances of high-seas skirmishes among fisherman contesting territory. States—such as China and Japan (both highly dependent on fish)—may increasingly intervene to guarantee supply. Involvement by the United States would be diplomatic at first, but if fishery conflicts become intractable they could involve a U.S. naval presence to help ensure the security of fish stocks.

Other areas with implications for the Navy include the consequences of changing coastlines and mass erosion. With respect to rising sea levels, this is likely to be a slow-moving process to which people can adapt, although there is a possibility of abrupt change. However, major storms can dramatically shift the coastal environment in an instant, risking massive short-term refugee flows that can become permanently stateless populations. One result of the changing coastlines and erosion is a major relocation of coastal dwellings toward urban areas. Major population shifts (~1 billion people) toward urban environments may induce overcrowding, competition over scarce resources, riots, and place additional stress on central governments. While this is not directly related to the Navy, naval support is a necessary component of any peacekeeping or humanitarian operations.

Recommendations

Support Assessments of Second-Order Climate Impacts. The level of knowledge of migration patterns, the relationship between climate challenges and state failure, and even more broadly the relationship between humanitarian and disaster relief, migration, and conflict are not well understood. How climate change will affect these conditions, and vice versa, is even less well understood. The Navy could help improve the level of knowledge by funding studies of the nexus between climate, conflict, instability, humanitarian relief, and migration—and the implications for naval forces.

Train and Equip for Humanitarian and Disaster Relief Missions. The Navy should ensure that the SH-60 fleet is ready to respond in difficult environments. Presently, the SH-60 and the CH-53 are the most capable aircraft to support this mission. The Navy might also explore a SH-60 follow-on helicopter variant, V-22 variants, and UAVs optimized for HADR tasks. It might even be possible to partner with other Services or agencies of the government to fund the development of such helicopter variants, since their mission will cross Service and agency lines. The Navy should consider improving existing Search & Rescue (SAR) capabilities and improving doctrine to incorporate missions further inland. Indeed, the future strategic environment may require the Navy to readdress its strategy and long-term programming.

Improve Readiness to Rapidly Respond to Humanitarian Crises. The Navy should leverage the capabilities of Military Sealift Command (MSC) as part of its efforts to bolster its humanitarian response capabilities. Several types of ships under the control of MSC could be helpful for humanitarian missions related to climate change. Combat stores ships (T-AFS), by means of underway replenishment, provide all types of supplies including: fresh, chilled and frozen food, dry provisions, repair parts, and mail. T-AKEs have enhanced dry stores capacity. Fast combat support ships (T-AOE), high speed vessels designed to carry fuel, ammunition and supplies, can quickly and rapidly get to trouble spots. Underway replenishment oilers (T-AO) provide underway replenishment of fuel to Navy combat ships and jet fuel for aircraft aboard carriers at sea. The Navy should work to integrate fuel replenishment ships with the humanitarian mission, not only in their normal role in sustaining forward operations from the sea, but also as platforms for ship-to-shore movement. Also, Maritime Prepositioning force ships, both current (MPF) and future (MPR(F)) ships, properly loaded, can play key roles in HADR from the sea.

Continue Emphasizing Humanitarian Relief as One of the Navy's Missions. The successful deployment of U.S. naval assets in response to the Asian tsunami represents a model for the incorporation of humanitarian relief as a major Navy mission. This is already recognized in the new Maritime Strategy document.

After any disaster, there may be an immediate need to respond with aid. The U.S. Navy/Marine Corps team provides the sea/air/ground skills to deliver these needs. The Navy should plan on enhancing and expanding existing capacity-building exercises to help host governments cope with potential challenges. One example of a possible mechanism for cooperation is the Global Fleet Station concept, which provides platforms for routine cooperation in such regions as the Caribbean and West Africa. The Navy will have to bolster existing naval support to local navies in building capacity in order to ensure the transit of commerce through sea lines of communication, probably with engineering and design assistance. This indicates a need to shape both existing and future naval personnel (including Naval Mobile Construction Battalions) to help assist in training and infrastructure support projects.

Responding to mass refugee movements requires integrated efforts from the land and sea, and seabasing, in particular, proved critical to relief efforts in 2004. Large amphibious ships, LCACs, HSVs, and LCUs are critical assets to execute this mission. In addition to what Marine Expeditionary Units and SEABEEs can provide, the Navy also should consider developing more robust humanitarian-related infrastructure, and be prepared for more frequent forward-deployment construction assets to areas of interest or bases close to potential areas of interest. SEABEE units and other construction assets can restore power grids and water resources to recovering regions. Naval Mobile Construction Battalions (NMCBs) provide responsive military construction support to Navy, Marine Corps and other forces in military operations, and can help construct facilities while being prepared for defensive operations.

Expand Maritime Cooperation Focused on Responding to Climate-Derived Challenges. The priority in the Maritime Strategy on developing partner capacity will be important for dealing with climate change, given the importance of building local capacity, both for response and prevention. The Navy should expand military-to-military operations with friends and allies—and even nations that may not be either, such as China and Russia—focused on humanitarian operations and deployments to deal with environmental crises. Increasing these sorts of exercises can build the capacity of global navies to work with the U.S. Navy and respond to humanitarian and environmental crises as well as traditional conventional military contingencies. While the Navy already participates in a variety of multilateral exercises across the globe, most focus on conventional operations. In part due to cutbacks in naval funding that date back several decades, most other global navies currently lack the experiences in complicated humanitarian and peacekeeping operations gained in recent years by the U.S. Navy. By focusing more on cooperative exercises that emphasize the skill development of potential HADR partners, the Navy can help prepare them to share the burden of response around the globe.

Build Knowledge Repositories for Climate "Lessons Learned." In addition to sharing "lessons learned" for best practices in response to the operational challenges of climate change, the U.S. Navy could extend this to the strategic environment. While not revealing information that would compromise U.S. national security, the Navy could build goodwill with other countries by taking the lead in sharing the best practices it has developed from its humanitarian deployments over the last decade and inviting navies around the world to do the same. The maritime environment is one important area where the costs of cooperation are likely to be relatively low but the benefits potentially very high.

Recognize Link Between Climate Change and Traditional Security Challenges. Climate change could also place pressure on the U.S. Navy in its role of power projection for more traditional military missions. Given the way climate change could increase instability throughout the developing world, especially coastal nations, the Navy should strengthen its "brown/green water Navy" capabilities, increasing its focus on presence in littoral environments. Climate-related disputes could also lead to maritime crisis situations that draw in the U.S. Navy and risk escalation. For example, one potential risk is that a China-Japan fisheries dispute might force U.S. involvement. In that case, the U.S. Navy could end up entrapped in a dispute it was not initially a party to, due to alliance commitments. More broadly, disputes over fisheries and resource development around EEZ borders could lead to conflicts between foreign navies that require American mediation to help prevent escalation and/or conflict.

Support Freedom of Navigation in Affected Areas. The threat to naval facilities from climate change, as described above, requires adapting American basing plans both domestically and overseas. Given that bases are a critical element of sustainable sea control, supporting freedom of navigation over the next generation may eventually require building some new naval bases on terrain that is significantly higher in order to deal with potential sea rise and storm surge. The Navy should also enhance bilateral agreements with various actors and allies in possession of ports capable of supporting U.S. vessels. Finally, to ensure access to bases, the Navy should explore contingency options if key states in affected areas lose the ability to govern. All of these actions are sensible even if climate change predictions turn out to be much less severe than the best available science suggests is likely.

THE POTENTIAL FOR NEW GREAT POWER CONFLICT

Within the next 30 years, it is unlikely that struggles for control of dwindling natural resources or other climate change-related stresses will lead to war between major powers. It is highly likely, however, that these factors will reshape geopolitics and generate new tensions between major powers.[63] Some of this tension, such as disputes over relative contributions to historic greenhouse gas emissions, is unlikely to have a direct effect on the Navy, though it may affect relationships with some partner nations.

There is one geographic area in particular where climate change could generate very traditional security challenges and expanded Navy missions within the next 30 years, however, and that is the Arctic. The Navy has already acknowledged the strategic importance of a thawing Arctic in the new Maritime Strategy, but how the United States and the U.S. Navy handle changing conditions there may be a key element of future great power relations over climate change.

The climate is changing more rapidly in the Arctic than in any other climate zone region. The extent of Arctic sea ice, both its summer minimum and its winter maximum, has been declining steadily for four decades and the rate of decline is accelerating. A succession of new record low summer minima have occurred over the past decade. In 2005, the Northeast Passage along the Eurasian coastline opened up for the first time in human memory. In 2007, the Northwest Passage through the Canadian Archipelago opened up for the first time. In 2008, both passages were open for a short while (Fig. 6). Although one could not say that these passages are generally navigable today, there have been research and military cruises through these passages in recent years. There is a clear and rapid trend toward ice-free conditions during the summer in the Arctic, and the trend is much faster than climate scientists imagined possible a few years ago.[64]

Several nations have claimed iced-over territory in the Arctic for themselves, raising questions of freedom of navigation and resource extraction. Consistent with its more active international profile over the last few years, Russia has been extremely assertive in its claims to sovereignty over Arctic spaces and is already moving to take advantage of the potentially large resource deposits currently encased in or under ice. The timing and extent of the Arctic's opening is uncertain, but whenever it occurs, it will create new missions for the U.S. Coast Guard and Navy. Arctic melting may also create some new azimuths for submarine launched ballistic missiles (SLBMs), creating new opportunities and risks for the United States.

Scott Borgerson, the Visiting Fellow for Ocean Governance at the Council on Foreign Relations, recently estimated that the Arctic could be "ice free" during part of the year by 2013, since it is currently melting much faster than the rate initially projected by the IPCC.[65] There is an important distinction between open water and navigable water. Navigable water can include ice chunks and other potentially significant impediments to transportation, while open water is more easily traversed. Furthermore, even if the Arctic becomes navigable for a larger period of the year, ice shelf breaks will create navigational hazards that are hard to monitor and track via satellite. Therefore, dealing with a melting Arctic will require adaptation on the part of the Navy to prevent Russian dominance, help American companies safely operate, and potentially take advantage of the Northwest Passage as a faster trans-oceanic route.

Implications for the Navy

Rich fossil fuel reserves, the prospect of tourism, and potential fuel savings for the shipping industry give the Arctic allure. The Arctic Ocean could become seasonally navigable within the 30-year span of this report. All of the nations surrounding the Arctic Ocean have relatively advanced economies and clear interests in securing free navigation for their ships and access to the vast mineral resources currently inaccessible due to the Arctic ice cap.[66] Hence, the Navy should plan for greatly increased activity in the Arctic.

Commercial Usage. Melting ice is creating new transit passages through the Arctic, a trend that will accelerate as the amount of "navigable" time in the Arctic increases over time and navigation becomes easier. Commercial shippers and global navies would benefit from these sea routes. There are three main areas of interest; the Northern Sea route (or Northeast Passage) over Eurasia, the Arctic Bridge between the Hudson Bay and Berents Sea, and the famous Northwest Passage, which links the Arctic Bridge to the Bering Straits via North America. The route is already a locus for commercial transport and as key spots along the Arctic Bridge continue to melt, could see growing trade volume. The route is 40 percent shorter for trade between East Asia and Europe than maritime transit through the Suez Canal.[67] The Arctic Bridge offers faster shipping times from the United States and Canada to Europe, and the Northwest Passage offers vastly faster shipping times between East Asia and eastern North America.

In 2008, U.S. satellites confirmed that, for the first time, melting had opened both the Northern Sea Route and Northwest Passage at the same time. Mark Serreze, a senior scientist at the University of Colorado's National Snow and Ice Data Center, stated in 2007 that "We're several decades ahead of schedule right now." Vessels without ice hardening can already pass through the Northern Sea Route for part of the year. By 2025, it is even possible that ice-hardened vessels will be able to travel directly across the North Pole in the summer, circumventing the Northern Sea Route entirely.[68] More conservative estimates suggest such an outcome is possible by 2050.[69]

Unfortunately, conflict over control of Arctic passages could undermine their commercial utility. There are several sovereignty disputes concerning access to the Arctic, including a dispute between the United States and Canada over access to the Northwest Passage. Canada argues that the Northwest Passage is a Canadian territorial sea, meaning they have the right to control passage. The United States believes that the Northwest Passage is open international water, meaning its ships do not need permission from Canada to travel through the passage. While physical limits to transportation through the Northwest Passage limited the scope of this dispute in the past, further melting will eventually force the issue to the forefront.[70] Russia and Denmark both claim sovereignty over the majority of the North Pole, with each arguing that the Arctic seabed is an extension of their territorial shelf, meaning they should have exclusive economic access. Such claims threaten the potential for open shipping in the Arctic. Therefore, one potentially important reason for increasing naval preparedness for Arctic operations is the need to protect American claims and access to Arctic shipping routes.

If the Arctic sea-lanes are opened for trading during the summer, even among a relatively smaller number of vessels due to the need for ice hardening, it could cause a major shift in maritime transportation. The Arctic could become a critical sea line of communication (SLOC) as companies around the world take advantage of the shorter transit time and begin shipping goods through the Northwest Passage. A major growth in Arctic shipping would directly affect the Navy by adding an additional surface theater to patrol to ensure trading lanes stay open.

The resulting shift in global trade could also decrease the relative importance of the Straits of Malacca, for example, and increase the importance of the Bering and Davis Straits. Ports in Norway, Alaska, and Russia could grow in importance at the expense of Southeast Asia locales, such as Singapore, requiring changes in how the Navy plans its patrols and allocates resources across the oceans. Changing trade flows could negatively affect the economies of Singapore, Malaysia, and other states along the traditional Suez, Panama, and Cape Hope trade routes while bolstering regional economies in areas of Canada, Norway, and Denmark. The Navy must be able to anticipate and respond to these challenges, reinforcing naval ties with Northern allies.

Natural Resources. A recent study by the U.S. Geological Survey revealed an enormous quantity of natural resources north of the Arctic Circle: "90 billion barrels of oil, 1,669 trillion cubic feet of natural gas, and 44 billion barrels of natural gas liquids may remain to be found in the Arctic, of which approximately 84 percent is expected to occur in offshore areas."[71] This is estimated to total about 22 percent of technically recoverable, undiscovered global oil and natural gas resources. While many of these resources are concentrated in the Russian Arctic, they also exist in U.S. Arctic waters and international waters. To some extent, interest in natural resources in the Arctic will depend on energy prices, which have recently declined sharply in the face of a global economic slowdown. However, presuming a significant shift to renewable energy sources does not happen in the short- to mid-term, economic considerations will drive interested nations to develop whatever resources are available in the Arctic region.

Decreasing ice coverage combined with shifting fishery stocks in the North Atlantic and Pacific will also drive indigenous and commercial fishing further into the Arctic. While glacial melting might actually generate short-term improvements in the habitat for cold-weather fishery stocks, the Navy and Coast Guard will also likely be required to assist in search and rescue for fishing and other commercial vessels in northern waters.[72]

As referenced above, Russia is already positioning itself to gain access to Arctic resources, but uncertainty over the legal "rights" continues. The United States risks being left out of a scramble for valuable natural resources if the Navy lacks the capability to help American businesses succeed in this environment. More importantly, the United States will have to utilize its bilateral alliances and international institutions to ensure any development of the Arctic occurs in ways consistent with international law.

Naval Competition. At present, the Arctic geopolitical terrain is being shaped by the Russian Navy. Even with faster-than-expected melting, navigating the Northwest Passage and other recently opened passages when they become available in the summer requires heavy ice hardening and icebreaking vessels to clear the paths for commercial transport. Unfortunately, the U.S. Navy lacks icebreaking capabilities, while the U.S. Coast Guard only maintains three icebreakers. Moreover, the Polar Star, one of three ice-breakers, has been out of service since 2006. Despite a recent allocation of over $30 million to undergo much-needed repairs, the Polar Star faces an uncertain future. More generally, even with three active icebreakers, U.S. maritime capacity trails the Russian Navy, which already operates twenty icebreakers and has commissioned a new generation of nuclear-powered icebreaking vessels in preparation for further Arctic melting.[73]

Especially with Russia's more assertive international stance in recent years, Russian control may pose risks to America's ability to secure Arctic waters as vital SLOCs. Russia is aggressively pursuing Arctic control in several areas, including a symbolic mission last year to plant a Russian flag at the North Pole. In the worst case, as climate change continues freeing up the Arctic for naval transit and it becomes an important location for commercial traffic, the Arctic could become a flashpoint for renewed U.S.-Russian naval competition. If the Russians do gain control of a more "open" Arctic, it is possible, certainly in light of recent tensions between the United States and Russia, that Russia could choose to restrict the transit of U.S. Naval vessels, especially submarines, potentially even influencing SLBM launch azimuths.

Naval Operations. Arctic melting means there will be an increasing proportion of the year when military vessels can make it through the Northwest Passage and other Arctic areas without icebreakers. However, transit will remain unrealistic for unhardened commercial vessels and risky for military vessels as well. Building the capacity to increase naval operations in the Arctic on the surface would require designing ships with thicker/hardened hulls and systems that can withstand extremely cold temperatures. For example, ships operating in the Arctic have to be hardened not just against free-floating ice, but also against the extreme cold that could place the safety of sailors at risk. Some electronic systems, to say nothing of helicopters, are not currently designed to survive in the Arctic—even during the summer—and would require adaptation as well. There are two concerns here—the cost of building new ships to operate at higher latitudes and the cost of retrofitting older ships for such operations.

Arctic climate change will also shift the subsurface operating environment. At present, sea ice cover significantly degrades the effectiveness of sonar in the Arctic, making it a prime location for stationing strategic submarines since they are more difficult to detect under ice, and even harder to track if detected. However, submarine operations in shallower waters are very risky due to the ice coverage. Climate change could significantly change the subsurface operating environment. Arctic melting will reduce and in some case eliminate the ice keels that shield submarines from detection and expose the Arctic sea surface to winds, increasing overall ambient noise and allowing for active sonar detection.[74]

Recommendations

Work with the Scientific Community to Investigate Arctic Operations. While some of this undoubtedly occurs already, the Navy should work on integrating its war-gaming of Arctic operations with the scientific community to take advantage of growing expertise in climate change issues. Scientific models of climate change have improved over the last decade. These improved models should allow for more informed planning and gaming of a variety of Arctic naval contingencies. Better war-gaming of Arctic contingencies will also help in developing accurate threat assessments, especially with regards to the growing Russian naval presence.

Invest in Ice Breaking Capacity. Since the U.S. Coast Guard possesses only three icebreakers, one of which is not currently operational, the Navy should encourage and support Coast Guard investment in new icebreakers. The use of icebreakers will still be necessary for the near future even if the Northwest Passage becomes navigable for a greater portion of the year. An operational icebreaker fleet is critical for helping U.S. Naval vessels, as well as maintaining U.S. presence and defending U.S. economic and other interests in the Arctic.

Consider the Cost of Retrofitting Some Existing Vessels for Operations in Higher Latitudes and Building New Vessels. Unfortunately, it will likely be more expensive to retrofit existing vessels for operations in the Arctic than it will be to design new vessels. Hardening against the cold and ice requires strengthening the bow and stern and altering the design of propellers and even fin stabilizers.[75] Ice hardening also requires making sure that air assets and weapons systems can function in the cold and that personnel have cold-hardened quarters. The Navy should also consider building a class of combat vessels specifically designed for Arctic operations. However, the sunk costs in existing vessels and budgetary constraints may make retrofitting a more realistic option in the short to medium term.

Work with the Coast Guard to Meet National Security Responsibilities. As the only service with operational icebreakers, the Coast Guard has a critical role to play in Arctic operations. Coordination between the Navy and Coast Guard is necessary to ensure the safe passage of naval vessels in the Arctic. The Navy and Coast Guard should work together to meet overall U.S. responsibilities for Arctic operations. As commercial fishing and resource extraction in the Arctic increase, there is a greater chance that the Coast Guard (and the Navy) will be called on for search and rescue operations.

Plan for Shifts in Subsurface Environment. If the Arctic becomes a more "normal" subsurface operating environment, it could lead to several operational changes for American submarines. In addition to increasing the utility of sonar, helping American subs track the subs of other countries, it will also make increased submarine operations in the Arctic a more attractive possibility. However, Arctic melting may increase exposure of American submarines to their Russian counterparts as well, meaning the Navy will have to consider the implications for the patrol routes and planned launch points of its strategic submarine force.

IV. CONCLUSION

A Framework for Considering Climate Change

As delineated in this report, climate change is an important issue for the Navy to incorporate into its near-, mid-, and long-term operational, acquisition, training, and infrastructure planning. To add to these challenges, climate scientists have consistently underestimated the rate and scope of climate change impacts over the last few decades. Even the best predictions might be flawed in ways that understate the potential consequences.

Advanced preparedness will therefore prove critical in managing many of these challenges to ensure that the Navy effectively handles these shifts and that the United States maintains its global economic and military leadership role. This is no small task. In an ideal world, the Navy could fully implement all of the recommendations listed in this report. In the real, resource-constrained world, the service's leaders will need a framework for thinking about the climate change issue that aids in setting priorities and allocating resources.

The Navy will have tough choices to make. It will have to decide between expensive maintenance on some of its key bases to preserve their viability or shifting operations to newer locations. Shifts in salinity, key currents, and cyclonic storm intensity might drive changes in optimal navigation patterns. As the nation faces more humanitarian and disaster relief missions at home and around the world, the Navy will likely see a different mix and emphasis in missions and capabilities, which has implications for current procurement.

A robust decision-making framework is needed that is suitable to multiple plausible outcomes, that takes advantage of "no-regrets" policies, and that hedges against severe outcomes that are plausible but for which probabilities are either low or cannot be estimated at this time. The IPCC calls for an "iterative risk management process that includes mitigation [i.e. reduction of greenhouse gas emissions] and adaptation [i.e. changes in systems and practices that reduce vulnerability]."[76] A risk-based planning approach would protect stakeholders against unexpected losses, guided by valuable but incomplete information about future risks. An iterative risk management approach requires flexible policies that can be adapted based on new and improved information over time.

The timeframe under consideration in this report is 30 years. In 30 years, according to the best available climate research at the present time, climate change will have already inexorably influenced the maritime environment as well as the rest of the globe. Though change is unlikely to happen linearly over the next 30 years, and there may in fact be periods of rapid change followed by periods of relative stability, changes in the climate seem inevitable over the next 30 years. Hence, this is not a problem that can be put off for 30 years.

Long term planning is a vital necessity for the Navy for several reasons. First, if climate change requires a shift in maritime strategy, it will also require designing the optimal Navy to implement that strategy. Ship procurement is a long process. From the initial order to commissioning, despite the experience gained from building previous Nimitz-class carriers, it took nine years until the commissioning of the *USS Ronald Reagan* and it will take about eight years for the *USS George H.W. Bush* if it is commissioned on schedule. If a major overhaul is necessary, it could require designing new classes of ships to deal with different maritime environments, meaning the time to adapt for the Navy will be measured in decades. Moreover, because climate scientists have been extremely conservative in their projections over the last two decades, the climate may well continue changing much more quickly and in less predictable ways than researchers originally anticipated.

Given certainty that climate change will occur but uncertainties about its specific consequences, a risk management approach is the best way to frame how the Navy should respond to climate change. The CNAS "Age of Consequences" report usefully lays out three alternative climate futures that the Navy can use to guide its decisions. The first scenario, the "expected" scenario, is drawn from the best current projections of climate researchers, a linear extrapolation of existing trends (drawn from the IPCC's A1FI data series). The expected scenario projects warming of 1.3°C, on average, with an average sea level rise of .23 meters. The "severe" scenario presumes that current projections are systematically biased in a way that underestimates the consequences of climate change. Climate researchers have already been surprised by the extent to which the rate of change outpaces the best models, making this scenario a reasonable second scenario. Warming in the severe scenario averages 2.6°C, with an average sea level rise of .52 meters. Finally, the catastrophic scenario is the worst-case outcome—massive and rapid climate change that is well beyond what current research projects, warming averaging 5.6°C with an average sea level rise of 2 meters.[77]

We recommend that the Navy plan for an "expected-plus" scenario, with the "plus" signifying the fact that climate change is already outpacing the best climate models and may do so in the future. This means the Navy should adopt a hedging strategy for severe to catastrophic risks, including information and intelligence collection (both of real-world climate shifts and how other navies around the globe are responding), gaming and analysis, research and development, and selective investment.

Given budgetary realities, the Navy should still focus its investments on platforms and capabilities that will have utility across a range of different climate scenarios and which will enhance the ability of the Navy conduct more littoral missions, to ensure sea control and power projection. This perspective recognizes that the Navy has a broad range of missions, and faces budget challenges.

Finally, long-term risk-based planning will prove critical to infrastructure and training decisions for an uncertain future.

The Bottom Line

Is the United States Navy prepared for global climate change? The answer is yes—and no.

First, the answer is yes because the Navy has acknowledged that global climate change is a challenge in its Maritime Strategy. Moreover, the Navy largely has the capabilities it will need to adjust current operations to climate change over the next 30 years. Current meteorological forecasting capabilities, for example, should be sufficient to monitor any increase in severity of storms. Current undersea monitoring capabilities should be sufficient to test for and adjust to changing conditions. As for increased humanitarian missions or regional conflict, how much the Navy needs to rebalance its requirements ultimately will depend on a national decision for how to respond to such contingencies.

On the other hand, the answer is no, most immediately, because the Navy has not traditionally considered energy security and climate change as priorities (the Maritime Strategy is an exception, but it is worth noting that while it contains strong analysis of climate change as a strategic challenge, the discussion of "expanded core capabilities" does not illuminate how they will help meet such a challenge). Put simply, Navy personnel will not be anticipating climate change if there is no direction to do so. The Navy will not see changes it does not expect, such as tropical storms at unexpected times and locations (e.g., in 2005, Hurricane Vince was the first tropical system to make landfall on the Iberian Peninsula since 1842). Leadership direction to proactively monitor climate change, look for the unexpected, and plan for how to adapt current systems to projected conditions will be important going forward.

The Navy also has not taken sufficient steps to curtail fuel use and carbon emissions that contribute to climate change. Although the Office of Naval Research is conducting germane work to improve the Navy's use of energy efficient systems and alternative fuels, it is on an ad hoc basis, largely at the discretion of the lab directors or investigators. The Navy should consider providing strategic direction to its R&D organizations and partners (including other services) to incorporate the need to cut fuel consumption and develop alternatives into its research plan. Also, Navy leadership should re-emphasize to the fleet the need to promote energy efficiency and consider how to monitor and reward success in cutting fuel use. The Navy may wish to find a way to measure its greenhouse gas emissions in order to measure its success, particularly as it may be required by law to do so at some point in the future.

Another shortfall is external and has to do with the range of uncertainty involved with global climate change. One facet of that uncertainty is that there is a strong likelihood of unanticipated surprises, including the possibility of catastrophic shocks. The Navy—and indeed, society at large—needs to do more to anticipate the possibilities. Incorporating wildcards into strategic planning, particularly scenario planning and war gaming, is important.

In 2008, Lawrence Livermore National Laboratory (LLNL) produced an analysis of the various responses to global climate change. According to LLNL, if Plan A is business as usual, and Plan B is most of the schemes now in consideration for reducing greenhouse gas emissions—such as efficiency improvements and R&D into alternative fuels—the nation needs a "Plan Z." Plan Z refers to the fact that reality appears to be outstripping our ability to project the future; emissions are rising faster and effects are happening sooner and more dramatically than models projected. Plan Z also refers to the fact that to truly have a chance of heading off catastrophic climate change, the nation will need a way to get to zero emissions of greenhouse gases, and probably within the next two decades, which is very unlikely.

The Plan Z argument points to the fact that in the usual range of defense planning scenarios, from "most likely" to "most dangerous," the "most dangerous" scenario for climate change may soon become the "most likely" scenario. Even though Congress directed the Department of Defense to consider the "most likely" case when incorporating climate change into the National Defense Strategy, National Military Strategy, and Quadrennial Defense Review, the Navy should consider the "most dangerous" case, too, in its planning. The Navy should consider working with civilian agencies (primarily NASA, NOAA, and the National Laboratories) to develop new projections based on current observations, as well as to figure out where current observations are insufficient for understanding longer-term trends.

The Navy should treat the possibility of catastrophic climate change very seriously. This is a worst case scenario that may come to pass—probably not until the end of the century, but there is a chance it could happen sooner. The Navy should incorporate such concerns not only into its strategic thinking, but also develop contingency plans for catastrophic climate change.

Finally, the Navy's ability to adjust to climate change and to prevent catastrophic climate change will depend entirely on national resolve and international partnerships. Simply put, it is not the responsibility of the Navy or of the Department of the Defense to solve the energy and climate change problem on behalf of the nation. It is a national responsibility for all civilian agencies, Congress, and every American – and every citizen of China, India, France, Germany, and any other nation that generates greenhouse gases or is vulnerable to the effects of climate change.

That level of social acceptance and social change is very difficult to achieve, however, and the Navy does have a very important role to play in that process, as well. According to Gallup, the military has been the most trusted institution in America since 1988, by a significant margin. For the nation's military leaders to acknowledge that climate change is a national security issue and a challenge for the armed forces and the nation to meet will be critical to developing national resolve. It will also signal the seriousness and unity of national purpose on these issues. Without question, the Navy will have many opportunities to show leadership on climate change at home and abroad in the coming years.

APPENDIX A: A SUMMARY OF RECOMMENDATIONS FROM THIS PAPER THAT CALL FOR FURTHER STUDY

The Navy should study how to calculate its total greenhouse gas emissions, in part to establish a baseline against which to measure progress in reducing emissions (particularly if required by law to do so) (Part III, p. 18).

The Navy should conduct research to determine the ocean acidity, density and salinity threshold at which climate change may impact subsurface operations (Part III, p. 20).

The Navy should produce a regular "lessons learned" report, in coordination with NOAA and other relevant agencies, on dealing with climate changes in the operational environment. This could also be a report that focuses on best practices, and could be shared with partner nations (Part III, p. 22). In addition to sharing "lessons learned" for best practices in response to the operational challenges of climate change, the U.S. Navy could extend this to the strategic environment. This could, for example, cover humanitarian deployments (such as that produced for Operation UNIFIED ASSISTANCE) and involve sharing reports with partner nations (Part III, p. 34).

The Navy should carry out comprehensive assessments of naval facilities' vulnerability to climate change (particularly storm surges and flooding), as well as evaluate the adequacy of contingency plans. In conducting these assessments, the Navy should consider a mid-level assessment of climate change and a more extreme case. The Navy should also work with partner nations to conduct combined vulnerability assessments. First priority might be given to those that have ports and other installations important to U.S. naval operations and the execution of contingency plans (Part III, pp. 25-26).

Research on localized response plans to rapidly adjust if naval stations are rendered inoperable due to storms or rising tides will be important. Response plans should incorporate pier readiness—shore cables, hotel services, crane services, and other infrastructure, such as electric power plants—necessary for any repair mission. The Navy should also work with local industry surrounding all of its bases to identify other higher or more inland areas to serve as satellite basing if a Naval Station is lost (Part III, p. 27).

The Navy could help improve the availability of data and observations it needs in order to conduct assessments, plan for future contingencies, and improve operations in the near- and mid-term by funding studies of the nexus between climate, conflict, instability, humanitarian relief, and migration – and the implications for naval forces (Part III, p. 33-34).

The Navy should work on integrating its war-gaming of Arctic operations with the scientific community to take advantage of growing expertise in climate change issues. Better war-gaming of Arctic contingencies will also help in developing accurate threat assessments, especially with regards to the growing Russian naval presence (Part III, p. 39-40).

The Navy should incorporate wildcards into strategic planning, particularly scenario planning and war gaming (Part IV, p. 41).

The Navy should consider working with civilian agencies (primarily NASA, NOAA, and the National Laboratories) to develop new climate change projections based on current observations, as well as to figure out where current observations are insufficient for understanding longer-term trends (Part IV, p. 43).

APPENDIX B: WORKSHOP PARTICIPANTS

WILLARD INTERCONTINENTAL HOTEL
WASHINGTON, DC | SEPTEMBER 3, 2008

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APPENDIX C. REGIONAL IMPACTS OF CLIMATE CHANGE

Regional Impacts of Climate Change	
Africa	• By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change. • By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50 percent. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. • Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10 percent of Gross Domestic Product (GDP). • By 2080, an increase of 5 to 8 percent of arid and semi-arid land in Africa is projected under a range of climate scenarios (TS).
Asia	• By the 2050s, freshwater availability in Central, South, East and Southeast Asia, particularly in large river basins, is projected to decrease. • Coastal areas, especially heavily populated megadelta regions in South, East and Southeast Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers. • Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanization, industrialization and economic development. • Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and Southeast Asia due to projected changes in the hydrological cycle.
Australia and New Zealand	• By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the New Zealand Great Barrier Reef and Queensland Wet Tropics. • By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. • By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions. • By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding.
Europe	• Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise). • Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60 percent under high emissions scenarios by 2080). • In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. • Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires.

Regional Impacts of Climate Change	
Latin America	• By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. • There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. • Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (TS; medium confidence). • Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.
North America	• Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources. • In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20 percent, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilized water resources. • Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. • Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.
Polar Regions	• The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators. • For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed. • Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. • In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered.
Small Islands	• Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. • Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources. • By mid-century, climate change is expected to reduce water resources in many small islands, e.g., in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods. • With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands.

This appendix provides examples of some projected regional impacts. It is taken from Table SPM.2. of (IPCC 2007a).

APPENDIX D. AREAS VULNERABLE TO RISING SEA LEVELS

More than 100 coastal cities and low-lying mega-deltas populated by hundreds of millions of people are situated at or near sea level.[78] Examples illustrated here are the San Francisco Bay and Mid-Atlantic regions of the United States, the Australian cities of Sydney and Newcastle, and the Mekong Delta of Vietnam.

United States

The United States has more major cities vulnerable to sea level rise than any other country.[79] Significant portions of the U.S. Atlantic and Gulf Coasts are vulnerable, as well as key sections of the Pacific Coast. The extreme vulnerability of the Mississippi River Delta, oil and gas facilities in Texas and Louisiana, and Florida coastline recently gained notoriety in the aftermath of several major 2005 and 2008 hurricanes. The Sacramento/San Joaquin River Delta is an inland delta connected to the ocean via the San Francisco Bay (Fig. 7a). It is one of the most agriculturally productive regions in the United States and has a population of about 400,000 residents. Most of the land in this delta lies below sea level and relies on more than 1,000 miles of levees to keep 700,000 acres of land dry (Fig. 7b).[80]

The Atlantic Coast from Cape Cod southward is largely susceptible to sea level rise and coastal erosion—especially the coastlines of New Jersey, Delaware, Maryland, Virginia, and North Carolina (Fig. 7c). The coastlines of these states' support strong tourism industries that are dependent on erosion-prone beaches and wetland-dependent sport fishing. Economically and ecologically important estuaries with extensive wetlands would be heavily impacted by 1 meter of sea level rise, including the Delaware Bay, the Chesapeake Bay/Potomac River, and Albemarle and Pamlico Sounds. The Chesapeake Bay fishery is supported by coastal wetlands that would become inundated with only moderate sea level rise (Stedman and Hanson). Major population centers in this region are also vulnerable to inundation and/or increased storm surge, including Baltimore, Washington, D.C., and the Virginia Beach-Norfolk-Newport News metropolitan area (Fig. 7c).

Mekong and Other Large River Deltas

Large river deltas, which support 5-10 percent of the world's human population, are among the most vulnerable land masses to sea level rise and coastal storm surge.[81] Asia hosts the largest number of heavily populated and agriculturally productive mega-deltas (Fig. 8).

The Mekong River Delta in Vietnam, for example, has about 20 million inhabitants and supports a major portion of the region's staple grain (rice) production (Fig. 7e,f). Nearly the entire delta would be inundated by 1 meter of sea level rise; 2 meters would inundate significantly more land area and threaten Ho Chi Minh City. Other major Asian cities situated on large deltas near sea level include Calcutta, Dhaka, Rangoon, Bangkok, Hanoi, and Shanghai. Similar circumstances prevail in mega-deltas on other continents as well, including the Nile, Niger, Amazon, and Mississippi Deltas.

Australia

Australia is largely a coastal nation, with about 50 percent and 30 percent of its population located within 7 and 2 kilometers, respectively, of the shoreline, and about 6 percent (1.25 million) of its residences in coastal zones below 5 meters elevation.[82]

Sydney, Australia's most populous city with 4.3 million residents, is situated partially below 1 meter elevation (Fig. 7d). The nearby city of Newcastle, with about 0.5 million residents, lies mostly below 1 meter elevation. Other Australian cities susceptible to sea level rise include Melbourne, Adelaide, Cairns, and Darwin. Auckland, New Zealand, is also vulnerable.[83]

Figure 7: Examples of coastal areas vulnerable to sea level rise. (a) San Francisco Bay and the Sacramento/San Joaquin River Delta with area inundated by 1 meter of future sea level rise shown in red. (b) Elevation map of the Sacramento/San Joaquin River Delta showing areas below sea level. (c) Middle Atlantic Coast of the United States with area inundated by 1 meter of future sea level rise shown in red. (d) Southeastern coastline of Australia with area inundated by 1 meter of future sea level rise shown in red. (e) Mekong Delta, Vietnam, with area inundated by 1 meter of future sea level rise shown in bright red and additional area inundated by 2 meters of future sea level rise shown in dark red. (f) Mekong Delta, Vietnam, with population density in the low-elevation coastal zone (LECZ; area below 10 meters elevation) shown in shades of red and population density outside the LECZ shown in shades of green. SOURCES: (a),(c),(d),(e): (Weiss and Overpeck 2007); (b): (CDWR 1995); (f): (McGranahan et al. 2007), adapted and used with permission based on Creative Commons 2.5 Attribution. License:http://creativecommons.org/licenses/by/2.5).s

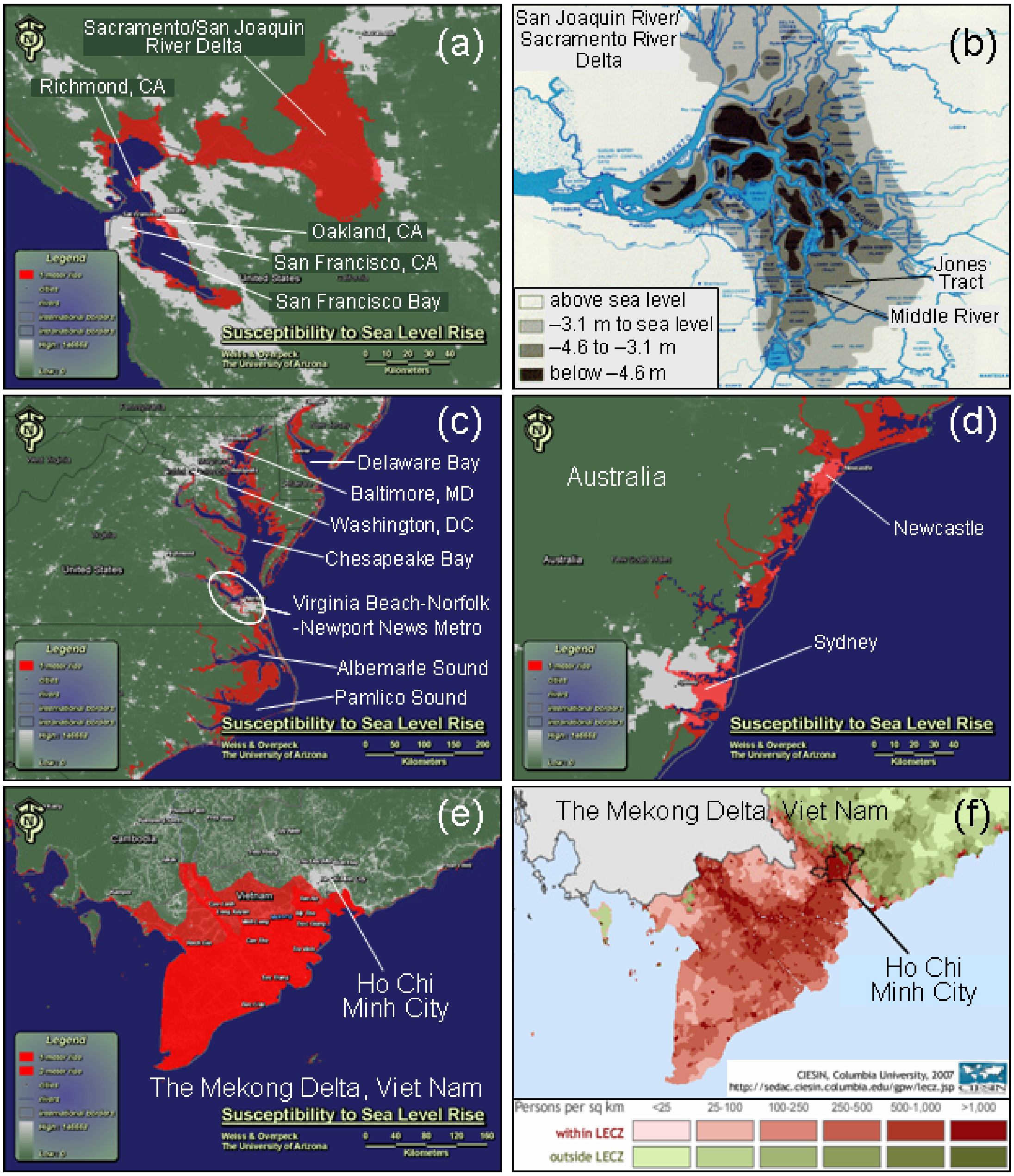

Figure 8: Major populated and agricultural deltas of the world. Color/size of dots indicate relative vulnerability based on population size. However, other criteria could be used to assess relative vulnerability, such as market assets exposed, infrastructure at risk, and impact on food security. Source: IPCC 2007, Working Group 2.

ENDNOTES

1. The phrase global warming refers narrowly to a rise in the global average surface temperature of the Earth, and it is a key diagnostic by which scientists detect changes in the Earth's energy balance. However, average temperature is only one of many elements of climate, and not the most important in terms of the U.S. Navy's interests. Other aspects of climate include daily and seasonal temperature variability, frequency and amount of precipitation, storminess, and the frequency, duration, and intensity of extreme weather events (e.g., droughts, heatwaves, flashfloods, and storm surges). Moreover, global averages are not meaningful to people, towns, or ecosystems, which experience climate through prevailing local weather conditions. The phrase climate change captures the various elements of climate and can be applied to any spatial scale, from an individual town or ecosystem to the globe.

   Climate change is therefore a more useful planning concept than is global warming. The primary cause of climate change is that more heat is accumulating in the climate system as a whole, but the effects of this accumulation play out in different ways in different regions. This heat is altering the prevailing climate conditions in most parts of the globe by changing patterns of temperatures, winds, storms, and precipitation. See IPCC. 2007a. *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and A. Reisinger (eds.)]. Pages 104 pp. IPCC, Geneva, Switzerland.

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CNAS is led by co-founders Dr. Kurt M. Campbell, CEO, and Michèle A. Flournoy, President. The Center is located in Washington, DC, and was established in February 2007. CNAS is a 501c3 tax-exempt nonprofit organization. Its research is nonpartisan; CNAS does not take specific policy positions. Accordingly, all views, positions, and conclusions expressed in this publication should be understood to be solely those of the authors.

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