More than Weather: The Strategic Importance of Remote Environmental Monitoring Capabilities to DOD

Andrew Pfluger and William Wright

Introduction

The Department of Defense (DOD) currently uses several satellite constellations to remotely monitor the environment. One of DOD's primary interests in environmental monitoring is detecting current weather patterns and discerning how they affect the warfighter. While understanding real-time weather is critical to mission success, understanding long-term environmental impacts from population growth and urbanization, land use change, and climate change is also of critical importance to the strategic vision of the US armed forces. Indeed, many high-ranking officers and military officials have acknowledged that understanding effects from these environmental changes is critical to our nation's security. A statement by Leon Panetta, former Secretary of Defense, concerning climate change elaborates this point: "The area of climate change has a dramatic impact on national security…rising sea levels, severe droughts, the melting polar caps, the more frequent and devastating natural disasters all raise demand for humanitarian assistance and disaster relief." In the same speech, Panetta vowed that the Pentagon would take a leading role in combating these changes (Simeone, 2012).

Using currently deployed US-owned satellite systems can provide the data required to detect environmental change and lay the foundation for analysis and predictive modeling. This analysis can lead to an understanding of which regions or countries will be most affected, and in what way. Such predictions allow military decision-makers to make informed decisions and military planners to develop better operational plans or contingency plans. In this manner, data from satellites with environmental monitoring missions is of strategic importance to the US military – now and in the coming decades. The purpose of this paper is to show why environmental monitoring is strategically important, outline some of the most commonly used US environmental monitoring satellites and show how these satellites currently are, and will continue to be, of critical importance in planning US military operations.

Why Understanding Our Changing Environment is Critical to National Security

Many open-source research documents outline how the environment is inextricably tied to national security (Barnett, 2001; Barnett & Adger, 2007; Busby, 2007;

Campbell, et al. 2007; Pumphrey, 2008; Thrum, 2009). Many other documents further outline DODs efforts to study the effects of climate change and how it plans incorporate its findings into long-term operational and contingency planning (Carmen, Parthemore, & Rogers, 2010; Defense Strategic Guidance, 2012; National Security Strategy, 2010; Quadrennial Defense Review (QDR), 2010). One of the most important of these documents is the 2010 Quadrennial Defense Review, which states that environmental changes, such as those induced by climate change, will play a significant role in determining our future security environment (QDR, 2010). Actions that our nation takes today can prepare DOD to appropriately plan and respond to challenges presented by environmental change in the near and distant future. More specifically, the QDR states that climate change will affect DOD in two ways: first, it will shape the operating environment and our missions and, second, it will shape our facilities and capabilities (QDR, 2010).

The QDR cites the 2009 U.S. Global Change Research Program report as a credible source that outlines some of the most important effects of climate change. This report lists climate change induced environmental effects that will affect DOD operations to include retreating glaciers, thawing permafrost, changing crop growing seasons, rising temperatures, rising sea levels, earlier snow melts, and alterations in river flows. It is important to note that climate-related change is already observed in every region of the world and is particularly evident in coastal or littoral regions (QDR, 2010; U.S. Global Climate Change Research Report, 2009). These changes, when coupled with human population growth and increased urbanization in littoral regions, will pose a significant challenge to developing nations (National Military Strategy, 2011; Kilcullen, 2012). Such environmental-related factors are very likely to influence geopolitics worldwide, and create conditions for increased poverty, starvation, water scarcity, disease, environmental degradation, mass migration or displacement, and the weakening of already fragile governments (QDR, 2010). The effects of these changes may accelerate instability, and force civilian, governmental, and/or military institutions worldwide to respond. In many developing nations, the government is too fragile or does not possess adequate resources to respond to such instability. In some instances, the military is the only entity capable of timely response (QDR, 2010). In these cases, the US and our partners will very likely be called to respond – either with direct action or in a capacity building role (QDR, 2010).

In addition to affecting the US military's deployed missions, climate change will also affect home station facilities and capabilities. The National Intelligence Council determined that greater than 30 U.S. military installations are at immediate risk of degradation due to rising sea levels (QDR, 2010). Indeed, the 2010 QDR states that the military must take a comprehensive evaluation of how climate change will affect each installation and training area (QDR, 2010). Efforts to combat DOD's contribution to climate change have already begun to take shape. For example, the United States Army Corps of Engineers (USACE) has on-going efforts to identify how changes in natural habitats will affect the costs of maintaining training and testing areas on military installations. USACE's effort specifically examines how changing weather patterns, projected erosion, drought potential, and an increase in endangered species will affect the Army's ability to train on its approximately 130 CONUS installations (Lozar, Hiett, Westervelt, & Weatherly, 2011). Several critical OCONUS installations, such as Diego Garcia, which has an average elevation of 4 feet, are also at risk (CNA Military Advisory Board, 2007).

As our understanding of the science behind environmental change advances, DOD will continually evaluate risks and develop its plans and policies. DOD relies on space-based environmental monitoring systems to provide immediate and historic data in order to provide data for long-term analysis. With the ever changing world in which we live and the impacts associated with environmental change, DOD's dependence on space-based platforms will continue to increase over time.

Environmental Monitoring Capabilities: Today and Tomorrow

Environmental Monitoring Capabilities Used by DOD

DOD currently gains terrestrial and space weather data from several satellite systems. The National Oceanic and Atmospheric Administration (NOAA) operates, on behalf of the US Air Force, the only DOD environmental monitoring program: the Defense Meteorological Satellite Program (DMSP). DMSP satellites are in low-earth orbit (LEO) and provide high spatial resolution weather-related imagery. DMSP can detect relevant environmental information such as clouds, water, and snow which is in turn used to support military operations (NOAA - DMSP, 2013). DOD also uses the Geostationary Operational Environmental Satellite (GOES) constellation, which consists of four operational satellites located in geostationary orbit (GEO). GOES is also operated by NOAA and provides persistent coverage over an area with lower spatial resolution imagery. GOES can image clouds, the earth's surface temperature, atmospheric water vapor, and can sound the atmosphere for its vertical thermal and vapor structures. This data is useful for tracking the evolution of atmospheric phenomena such as localized storms, cyclones, and hurricanes (NOAA – GOES, 2013).

Aside from DMSP and GOES, the National Polar-orbiting Operational Environmental Satellite System (NPOESS or simply POES) is operated by NOAA and provides DOD with relatively high spatial resolution imagery using the Advanced Very High Resolution Radiometer (AVHRR). The AVHRR is an atmospheric sounder for day, night, and temperature data. POES can provide a range of applications including current weather analysis and forecasting, climate research and prediction, global sea surface temperatures, global vegetation analysis, and atmospheric soundings for temperature and humidity (NOAA- POES, 2013). POES is scheduled to transition to the Joint Polar Satellite System (JPSS), which is a joint venture between NASA and NOAA, in 2016. The JPSS will address NOAA's weather prediction requirements while providing the capabilities for search and rescue, and space weather observations. The upgrade to JPSS will provide continuity for long-term climate observations, which is critical for climate modelers and will advance prediction, mitigation and adaptation strategies for climate change (NOAA, 2010).

Other Environmental Monitoring Space-Based Assets and Programs

The aforementioned satellites are some of the most commonly used by DOD to provide real-time and near-term weather predictions to the warfighter; however several additional space-based environmental monitoring capabilities exist. In total, NASA and NOAA currently have 22 environmental monitoring missions including over 80 individual earth observing instruments (National Research Council, 2012). An explanation of each mission is outside the scope of this paper; however, several of the most critical capabilities are listed in other sections of this document. The National Research Council's 2012 report entitled "Earth Science and Applications from Space: A Midterm Assessment of NASA's Implementation of the Decadal Survey" gives a comprehensive overview of the current status of NASA and NOAA's environmental monitoring satellites. These satellites cover a wide range of environmental monitoring missions to include seal-level measurements, ice loss measurements, fresh water storage in river basin measurements, and stratospheric ozone monitoring, amongst others (National Research Council, 2012).

Additionally, NOAA created the National Environmental Satellite, Data, and Information Service (NEDIS) to operate and manage the US environmental satellite programs, as well as, to manage the data gathered by the National Weather Service and other government agencies and departments. The NEDIS website also provides a broad overview of NASA and NOAA environmental monitoring missions (NOAA – NEDIS, 2013).

A Challenge: the Projected Decline of US Environmental Monitoring Satellites

Due to aging constellations and budget constraints, US environmental monitoring capabilities are likely to be significantly degraded over the next decade. For example, several reports indicate that by 2016, only 7 of NASA's 13 EM satellites are expected to be operational (Parthemore & Rogers, 2011) and that the number of NASA and NOAA earth observing instruments could be as few as 25 percent the current number by 2020 (National Research Council, 2012). A Governmental Accountability Report released in April 2010 states that gaps in satellite coverage lasting anywhere from 1 to 11 years could begin in 2015 (Government Accountability Office (GAO), 2010). Lost information from this gap will adversely affect climate measurements and will decrease our ability to gather data to help our understanding in areas such as climate change and changes in global food production. Recent failures in the acquisition process and technical failures upon launch, such as NASA's Orbiting Carbon Observatory that crashed into the Pacific Ocean in 2009, have served to compound the problem (Parthemore & Rogers, 2011).

With current fiscal restraints and the likelihood of lower budgets on the horizon, other solutions need to be identified. One likely solution to budgetary constraints is bi-lateral or multi-lateral cooperation with other countries that own environmental monitoring satellites, which can reduce US financial burden. A recent example of one such collaboration was the use of Germany's TerraSAR-X satellite constellation, which provides high-resolution radar imagery for detection of changes on the earth's surface, for assistance with Japan's post-earthquake and tsunami recover efforts in March 2011 (Parthemore & Rogers, 2011).

How DOD Incorporates Environmental Monitoring Data into Its Planning Process

Data received from NASA and NOAA's environmental satellites are processed through the Office of Satellite and Product Operations and distributed to users (NOAA - OSPO, 2013). From there, several entities within DOD are charged with analyzing this data and determining the impact on DOD operations and planning. The Strategic Environment Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) are two such entities. SERDP is a partnership between DOD, the Environmental Protection Agency (EPA), the Department of Energy (DOE), and others to pursue solutions to DOD's environmental challenges. ESTCP is charged with transferring knowledge and innovative environmental technology to the field. One of SERDP's featured initiatives, which extensively uses data from environmental monitoring satellites, is the study of climate change and the impacts of the rising sea level (SERDP, 2013). Additionally, the Army's Engineering Research and Development Center (ERDC) has 4 of its 7 labs examining aspects of environmental climate change and how it affects DOD operations (Bridges, 2010).

Information from these DOD research organizations is presented to DOD leaders, and organizations instrumental to implementation, such as the Office of the Deputy Under Secretary of Defense Installations and Environment (DOD I&E, 2013). Decision makers can also direct this information to be incorporated into strategic planning documents such as the QDR, which drives subordinate unit operational and contingency planning.

Applications: Areas that DOD Needs to Monitor

Remote sensing and monitoring of the environment can aid researchers, planners, and decision makers by providing data in many different areas. The below sections detail some of the most relevant to DOD planners; however, there are multiple other areas not covered in this paper that remote environmental monitoring proves crucial, including tracking shrub abundance in the artic (Sturm, Racine, & Tape, 2001), modeling net primary production of vegetation (Field, Randerson, & Malmstrom, 1995), and predicting climate characteristics that facilitate the spread of disease (Lobitz et al., 1999).

Effects of Human Population Growth – Urbanization, Mass Migration

The human population is growing at an exponential rate and is expected to exceed 9.1 billion by the year 2050. Concurrently, expected growth of people living in urban areas is expected to increase from a present day population of 3.4 billion to approximately 6.3 billion people by 2050. This statistic effectively means that urban areas are expected to absorb all human population growth between now and 2050 (Kilcullen, 2012). The preponderance of growth and migration is expected to occur in some of the world's poorest and least developed countries, which will create health, food, energy, water, and governance problems, thereby exacerbating the potential for conflict (Kilcullen, 2012). Possible mass migration of people living in littoral areas due to climate change effects and probable rising sea levels will only further the problem. Being able to remotely track changes in urbanization over time is needed to help predict where conflict will occur.

Imagery taken in the visible spectrum of light or with thermal IR is useful in determining urban sprawl or detecting changes in temperature associated with built-up areas (i.e., urban heat island effect). AVHRR, Landsat, DMSP, as well as the French satellite constellation SPOT (Satellite for Observation of the Earth), are satellites that are mentioned in literature as being able to detect the effects of urbanization (Voogt & Oke, 2002). In addition to the US and Europe, both China and India have conducted remote sensing studies examining the effects of urbanization and population growth on arable land and natural ecosystems (Xu, Wang, & Xiao, 1999; Rahman, Kumar, Fazal, & Bhaskaran, 2010).

Land Use Change – Vegetation, Crops, and Fresh Water

The ability to remotely detect and characterize land use change has several applications to the US military. Remotely sensing changes in terrestrial vegetation, such as forests, can indicate the level of human activity in an area. Deforestation can also indicate the possible growth of agriculture or the increased use of biomass (e.g. trees and shrubs) for energy purposes. As global temperatures change and climates shift, the abundance and location of arable land will invariable shift as well. In regions such as Africa and Southeast Asia, which have very little free land for agricultural expansion, poor crops yields can place additional strain on food supplies.

Many academic researchers such as Defries et al. (2000), Hansen et al. (2003), and Zhang et al. (2003) have used sensors on NASA satellites, such as Moderate Resolution Imaging Spectora-diometer (MODIS), to remotely sense changes in terrestrial vegetation. The MODIS payload, located on NASA's Terra and Aqua satellites, is a moderate spatial resolution (250 meters, best case) land surface monitoring tool that can provide global and regional monitoring and can aid in modeling and assessment (NASA – MODIS, 2013). MODIS provides near weekly coverage and can be coupled with higher resolution data from imagery satellites run by the USGS, such as Landsat 7, which carries the Enhanced Thematic Mappers Plus (ETM+) sensor (USGS – Landsat, 2013). The synergistic use of these two sensors, along with several sensor payloads on Terra and Aqua, can serve to validate and enhance data products (Thome, D'Amico, & Hugon, 2006). Tools such as MODIS and Landsat can identify large scale geographic areas that are undergoing land cover changes. The ability to identify large scale geographic areas with major land coverage changes can help to predict areas with significant population growth that may face food shortages in the future. This information can be transferred to military decision-makers for incorporation into their planning contingencies.

Furthermore, remote sensing can detect changes in the size of surface-level fresh water sources, such as lakes or reservoirs, which can indicate a reduction in another critical area: available drinking water (Borstad et al. 2002; Ritchie, Zimba, & Everitt, 2003). One important example that has national security implications is receding Himalayan glaciers and the resulting reduced river flow to South Asia. Both India and Pakistan, who have existing grievances about the distribution of fresh water, rely on glacier runoff for their drinking water supply (Parthemore &

Rogers, 2011). As populations increase and available drinking water decreases, diplomats and defense planners will need to monitor, how the glacier water is distributed. Failure to do so could exacerbate strained relations and lead to conflict.

Rising Sea Levels, Melting Polar Ice Caps, and Changing Sea Temperatures

Rising sea levels can increase the potential for conflict in developing countries. Some critical thinkers, such as Kilcullen (2012), believe that large littoral developing nations, especially those in the Middle East, Africa, Latin America, and Asia, are where the US military is most likely to fight next. Megatrends such as "urbanization, littoralization, and connectedness", exacerbated by probable economic penalties associated with rising sea levels, will each contribute to instability (Kilcullen, 2012). Beyond developing countries, there is significant impact projected for US military bases in or near littoral areas due to sea level rise. As mentioned, the US Army Corps of Engineers has already begun developing contingency plans to account for this potentially costly problem (Lozar, Hiett, Westervelt, & Weatherly, 2011).

Using MODIS and specialized microwave/imager sensors, such as those found on DMSP, NASA and NOAA have remotely tracked changing sea levels – and polar ice cap melting – for several decades (GAO, 2010; Rosel, 2013). Additionally, NASA's gravity field satellite mission (GRACE) has provided data about changes in the Earth's gravity field and the melting of artic ice sheets since 2002. Analysis of GRACE data indicates that the Earth's ice sheets are melting at a rate of 300 billion tons per year (GRACE, 2013). The increased abundance of open sea in the Arctic has led several countries, such as the US, Russia, Canada, Norway, China, Japan, and South Korea to begin plans for oil and natural gas exploration in the region. Due to the potential economic gain, there is a looming threat of conflict over arctic oil rights, for which DOD must monitor and develop contingencies (GAO, 2010; Reynolds, 2013).

Changes in sea temperature induced by global climate change can also be a catalyst for conflict. For example, changing temperatures in the South China Sea have altered fish migration patterns. Surrounding countries, such as China, South Korea, the Philippines, and Vietnam, which rely on fishing as an integral part of their economy stand to lose access to potentially billions of dollars in revenue. This situation could cause countries that already have tense relationships to result to armed conflict (Parthemore & Rogers, 2011). Environmental monitoring satellites such as POES, and in the future JPSS, are designed to monitor sea temperatures, and can assist military decision-makers.

How Does this Apply to US Army Space Officers (FA40s) and Professionals?

Amongst other concepts, Army space professionals are charged with understanding and applying the five space force enhancement (SFE) areas: Intelligence, Surveillance, and Reconnaissance (ISR); Missile Warning (MW); Positioning, Navigation, and Timing (PNT); Satellite Communications (SATCOM); and Environmental Monitoring (EM). FA40s need to be knowledgeable in each of these areas and able to provide relevant and timely information to their superiors or commanders. Since terrestrial and space weather information is primarily provided by the Air Force and is readily available from sources such as the unit's assigned Staff Weather Officer or the Joint Space Operations Center (JSpOC), it can be argued that many FA40s place less emphasis on EM than other SFE areas. However, understanding EM beyond the tactical fight is also of importance, since many in DOD do not have any idea where most environmental data originates or what space-based capabilities are available (Parthemore & Rogers, 2011). FA40s should be conversant about EM's applications for the tactical fight, and for the strategic planning of tomorrow's battles.

Conclusion

US-owned environmental monitoring satellites are of critical importance to the warfighter because they provide timely weather data. Beyond current weather, however, environmental monitoring satellites can provide data to detect environmental change and lay the foundation for analysis, modeling, and future planning. Environmental monitoring satellites are able to detect changes in a number of important areas, such as climate change, rising sea levels, changing sea temperatures, land use change, and urbanization. Decision-makers in DOD and military planners are currently, and will continue to be, reliant on this data to make informed decisions and develop better operational plans or contingency plans. FA40s should be informed and conversant concerning US environmental monitoring capabilities so they can provide timely and relevant information to their commanders – for both current and long-term planning.

References

Barnett, J. (2001). "Security and Climate Change". Tyndall Centre for Climate Change Research Working Paper 7, October 2001.

Barnett, J. and Adger, W.N. (2007). "Climate change, human security and violent conflict". *Political Geography*, 26 (2007), 639-655.

Borstad, G., Borstad, L., Stacy, R., Stacy, P., Mitchell, C., Holland, G., Wilson, B., Garrett, J., Power, D., Randell, C., Rubinstein, I. (2002). "Trends and Opportunities in Marine in Freshwater Remote Sensing Technology". Report for the Canadian Space Agency, CSA report number CSA-ST-CR-2001-0026.

Bridges, T. (2010). "Science and Technology Implications of Climate Change to USACE". Briefing to Coastal Engineering Research Board, June 2010. Available from: http://chl.erdc.usace.army.mil/dirs/events/319/12%2087th%20CERB%20Bridges.pdf

Busby, J. (2007). "Climate Change and National Security: An Agenda for Action". Council on Foreign Relations, CSR No. 32, November 2007.

Campbell, K., Gulledge, J., McNeill, J., Podesta, P., Fuerth, L., Woolsey, R., Lennon, A., Smith, J., Weitz, R., and Mix, D. (2007). "The Age of Consequences: The Foreign Policy and National Security Implications of Global Climate Change". Center for New American Security, November 2007.

Carmen, H., Parthemore, C., Rogers, W., (2010). "Broadening Horizons: Climate Change and the U.S. Armed Forces". Center for New American Security, April 2010.

CNA Military Advisory Board (2007). "National Security and the Threat of Climate Change". The CNA Corporation, April 2007. Available from: http://www.cna.org/reports/climate

Defense Strategic Guidance (2012). Sustaining U.S. Global Leadership: Priorities for 21st Century Defense, January 2012.

Defries, R., Hansen, M., Townshend, J., Janetos, A. and Loveland, T., (2000). "A new global 1-km dataset of percentage tree cover derived from remote sensing". *Global Change Biology*, 6, p. 247-254.

Department of Defense Under Secretary for Installations & Environment (2013). "I&E Featured News". Available from: http://www.acq.osd.mil/ie/

Field, C., Randerson, J., and Malmstrom, C. (1995). "Global Net Primary Production: Combining Ecology and Remote Sensing". *Remote Sensing Environment*, 51, p. 74-88.

Government Accountability Office (2010). "Environmental Satellites: Strategy Needed to Sustain Critical Climate and Space Weather Instruments". Available from: http://www.gao.gov/new.items/d10456.pdf

Gravity Recovery and Climate Experiment (GRACE) (2013). "GRACE: Mission Overview". Available from: http://www.csr.utexas.edu/grace/overview.html

Hansen, M., DeFries, R., Townshend, J., Carroll, M., Dimiceli, C., Sholberg, R. (2003). "Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm". *Earth Interactions*, Vol. 7, No. 10, p. 1-15.

Kilcullen, D. (2012). "The City as a System: Future Conflict and Urban Resilience". *The Fletcher Forum of World Affairs*, 36 Fletcher F. World Aff. 19, Summer 2012.

Lobitz, B., Beck, L., Huq, A., Wood, B., Fuchs, G., Faruque, A., Colwell, R., (1999). "Climate and infectious disease: Use of remote sensing for detection of *Vibrio cholera* by indirect measurement". *PNAS*, vol. 97, no. 4, p. 1438-1443.

Lozar, R., Hiett, M., Westervelt, J., and Weatherly, J. (2011). "Anticipating Climate Change Impacts on Army Installations". US Army Corps of Engineers' Engineering Research and Development Center (ERDC) publication: ERDC SR-1-1-1, October 2011.

National Astronautics and Space Administration (2013). "MODIS Web". Available from: http://modis.gsfc.nasa.gov/

National Military Strategy, (2011). The National Military Strategy of the United States of America, 2011.

National Oceanic and Atmospheric Administration (NOAA), (2010). "Restructuring the National Polar-Orbiting Operational Environmental Satellite System". NOAA Fact Sheet, February 2010. Available from: http://npoess.noaa.gov/About/NPOESS_Decision_Fact_Sheet_20100201.pdf

National Oceanic and Atmospheric Administration (NOAA), (2013). "Defense Meteorological Satellite Program". Available from: http://www.ospo.noaa.gov/Operations/DMSP/index.html

National Oceanic and Atmospheric Administration (NOAA), (2013). "Geostationary Operational Environmental Satellites". Available from: http://www.ospo.noaa.gov/Operations/GOES/index.html

National Oceanic and Atmospheric Administration (NOAA), (2013). "National Environmental Satellite, Data, and Information Service". Available from: http://www.nesdis.noaa.gov/

National Oceanic and Atmospheric Administration (NOAA), (2013). "Office of Satellite and Product Operations". Available from: http://www.ospo.noaa.gov/Organization/index.html

National Oceanic and Atmospheric Administration (NOAA), (2013). “Polar-orbiting Operational Environmental Satellites”. Available from: http://www.ospo.noaa.gov/Operations/POES/index.html

National Research Council of the National Academy of Sciences, (2012). “Earth Science and Applications from Space: A midterm Assessment of NASA’s Implementation of the Decadal Survey”. The National Academies Press, Washington, D.C.

National Security Strategy, May 2010.

Parthemore, C. and Rogers, W. (2011). “Blinded: The Decline of U.S. Earth Monitoring Capabilities and Its Consequences for National Security”. Center for a New American Study, July 2011.

Pumphrey, C. (2008). “Global Climate Change: National Security Implications”. US Army Strategic Studies Institute, May 2008.

Quadrennial Defense Review (2010). Quadrennial Defense Review Report, February 2010.

Rahman, A., Kumar, Y., Fazal, S., Bhaskaran, S., (2010). “Urbanization and Quality of Urban Environment Using Remote Sensing and GIS Techniques in East Delhi-India”. *Journal of Geographic Information System*, 3, p. 62-84.

Reynolds, I. (2013). “Melting Ice Cap Draws China, Japan to Seek Arctic Riches”. Bloomberg Press, May 13, 2013. Available from: http://www.bloomberg.com/news/2013-05-13/melting-ice-cap-draws-china-japan-to-seek-arctic-riches.html

Ritchie, J., Zimba, P., Everitt, J., (2003). “Remote Sensing Techniques to Assess Water Quality”. *Photogrammetric Engineering & Remote Sensing*, Vol. 69, No. 6, p. 695-704.

Rosol, A. (2013). “Detection of Melt Ponds on Arctic Sea Ice with Optical Satellite Data”. Springer-Verlag, Berling, 2013.

Simeone, N. (2012). “Panetta: Environment Emerges as National Security Concern”. American Forces Press Service, 03 May 2012. Available from: http://www.defense.gov/news/newsarticle.aspx?id=116192

Strategic Environmental Research and Development Program (2013). “Featured Initiatives: Climate Change and Impacts on Sea Level Rise”. Available from: http://www.serdp.org/Featured-Initiatives

Sturm, M., Racine, C., and Tape, K. (2001). "Increasing shrub abundance in the Arctic". *Nature*, Vol. 411, p. 546.

Thome, K., D'Amico, J, and Hugon, C. (2006). "Intercomparison of Terra ASTER, MISR, and MODIS, and Landsat-7 ETM+". IEEE International Conference Proceedings, Geoscience and Remote Sensing Symposium, July – August 2006.

Thrum, F. (2009). "Climate Change: A New Threat to National Security". *Backgrounder*, Truman National Security Project, 10 September 2009.

U.S. Geological Survey (2013). "Landsat". Available from: www.landsat.usgs.gov/

U.S. Global Climate Change Research Report (2009). "Global Climate Change Impacts in the United States", U.S. Global Change Research Program. Available from: www.globalchange.gov/usimpacts

Voogt, J, and Oke. T. (2002). "Thermal remote sensing of urban climates". *Remote Sensing of Environment*, 86, p. 370-384.

Xu, H.,Wang, X., Xiao, G. (2000). "A Remote Sensing and GIS Integrated Study on Urbanization with its Impact on Arable Lands: Fuqing City, Fujian Province, China." *Land Degradation & Development*, 11, p. 301-314.

Zhang, X., Friedl, M., Schaaf, C., Strahler, A., Hodges, J., Gao, F., Reed, B., Huete, A. (2003). "Monitoring vegetation phenology using MODIS". *Remote Sensing of Environment,* 84, p. 471-475.