Climate Change Background
SUPPLEMENT TO
Endangered and Threatened Wildlife and Plants; Proposed Threatened Status for the Rufa Red Knot (*Calidris canutus rufa*)
[Docket No. FWS–R5–ES–2013–0097; RIN 1018–AY17]

BACKGROUND

CLIMATE CHANGE

Our analyses under the Act include consideration of ongoing and projected changes in climate. The terms "climate" and "climate change" are defined by the Intergovernmental Panel on Climate Change (IPCC). "Climate" refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2007a, p. 78). The term "climate change" thus refers to a change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2007a, p. 78).

Scientific measurements spanning several decades demonstrate that changes in climate are occurring, and that the rate of change has increased since the 1950s. Based on extensive analyses of global average surface air temperature, the most widely used measure of change, the IPCC concluded that warming of the global climate system over the past several decades is unequivocal (IPCC 2007a, p. 2). In addition to rising air temperatures, substantial regional increases or decreases in precipitation, shifts in the ranges of plant and animal species, increasing ground instability in permafrost regions, increasing acidification of the oceans, conditions more favorable to the spread of invasive species and of some diseases, and changes in amount and timing of water availability are occurring in association with changes in climate (U.S. Global Change Research Program (USGCRP) 2009, pp. 27, 79–88; IPCC 2007a, pp. 2–4, 9, 30–33; Solomon *et al*. in IPCC 2007b, pp. 35–54, 82–85).

Results of scientific analyses presented by the IPCC show that most of the observed increase in global average temperature since the mid-20th century cannot be explained by natural variability in climate, and is "very likely" (see table 1) due to the observed increase in greenhouse gas (GHG) concentrations in the atmosphere as a result of human activities, particularly carbon dioxide emissions from fossil fuel use (IPCC 2007a, pp. 5–6 and figures SPM.3 and SPM.4; Solomon *et al*. in IPCC 2007b, pp. 21–35). Further confirmation of the role of GHGs comes from analyses by Huber and Knutti (2011, p. 4), who concluded it is "extremely likely" that approximately 75 percent of global warming since 1950 has been caused by human activities.

Table 1. Standard terms used by the IPCC to define levels of confidence and likelihood regarding climate change (Solomon *et al*. in IPCC 2007b, pp. 22–23). When used in this context, these terms are given in quotes in this document.

Confidence Terminology	**Degree of Confidence in Being Correct**
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance
Likelihood Terminology	**Likelihood of the occurrence or outcome**
Virtually certain	greater than 99 percent probability
Extremely likely	greater than 95 percent probability
Very likely	greater than 90 percent probability
Likely	greater than 66 percent probability
More likely than not	greater than 50 percent probability
About as likely as not	33 to 66 percent probability
Unlikely	less than 33 percent probability
Very unlikely	less than 10 percent probability
Extremely unlikely	less than 5 percent probability
Exceptionally unlikely	less than 1 percent probability

Scientists use a variety of climate models, which include consideration of natural processes and variability, as well as various scenarios of potential levels and timing of GHG emissions, to evaluate the causes of changes already observed and to project future changes in temperature and other climate conditions (e.g., Prinn *et al*. 2011, pp. 527, 529; Ganguly *et al*. 2009, pp. 11555, 15558; Meehl *et al*. in IPCC 2007b, pp. 749–782). All combinations of models and emissions scenarios yield very similar projections of average global warming until about 2030. Although projections of the magnitude and rate of warming differ after about 2030, the overall trajectory of all the projections is one of increased global warming through the end of the 21st century, even for projections based on scenarios that assume that GHG emissions will stabilize or decline. Thus, there is strong scientific support for projections that warming will continue through the 21st century, and that the magnitude and rate of change will be influenced substantially by the extent of GHG emissions (Prinn *et al*. 2011, pp. 527, 529; Ganguly *et al*. 2009, pp. 15555–15558; IPCC 2007a, pp. 44–45; Meehl *et al*. in IPCC 2007b, pp. 760–764).

In addition to basing their projections on scientific analyses, the IPCC reports projections using a framework for treatment of uncertainties (table 1). Some of the IPCC's key projections of global climate and its related effects include: (1) It is "virtually certain" that there will be warmer and more frequent hot days and nights over most of the earth's land areas; (2) it is "very likely" that there will be increased frequency of warm spells and heat waves over most land areas; (3) it is "very likely" that the frequency of heavy precipitation events, or the proportion of total rainfall from heavy falls, will increase over most areas; and (4) it is "likely" that the area affected by droughts will increase, that intense tropical cyclone activity will increase, and that there will be increased incidence of extreme high sea level (IPCC 2007b, p. 8, table SPM.2).

(Storms, heavy precipitation, and extreme weather are discussed further below. The effects of accelerating sea level rise on red knot habitats is discussed at length in the proposed rule—Factor A).

Various changes in climate may have direct or indirect effects on species. These effects may be positive, neutral, or negative, and they may change over time, depending on the species and other considerations, such as the interactions of climate with other variables such as habitat fragmentation (for examples, see Chen *et al*. 2011, entire; Forister *et al*. 2010, entire; Galbraith *et al*. 2010, entire; IPCC 2007a, pp. 8–14, 18–19; Franco *et al.* 2006, entire). In addition to considering individual species, scientists are evaluating possible climate change-related impacts to, and responses of, ecological systems, habitat conditions, and groups of species; these studies include acknowledgement of uncertainty (e.g., Fraser *et al.* 2013, entire; Schmidt *et al.* 2012, p. 4421; Beaumont *et al*. 2011, entire; Hale *et al.* 2011, entire; McKelvey *et al*. 2011, entire; Rogers and Schindler 2011, entire; Berg *et al*. 2010, entire; Sinervo *et al*. 2010, entire; Euskirchen *et al.* 2009, entire; McKechnie and Wolf 2009, entire; Deutsch *et al*. 2008, entire; Ims and Fuglei 2005, entire).

Projecting the responses of species and ecosystems to climate change is complicated by the likelihood of thresholds being crossed and feedback mechanisms operating. An ecological threshold is the point at which there is an abrupt change in an ecosystem quality, property, or phenomenon, or at which a small change in one or more external conditions produces a large and persistent response in an ecosystem. Ecological thresholds occur when external factors, positive feedbacks, or nonlinear instabilities in a system cause changes to propagate in a domino-like fashion that are potentially irreversible. Once an ecological threshold is crossed, the ecosystem in question is not likely to return to its previous state. Positive feedbacks are those that tend to increase alteration of the nature of the system, while negative feedbacks tend to minimize these changes. Ecosystems include both positive and negative feedbacks. Globally, there are several ecosystems for which conditions suggest an approaching climate-related threshold; these ecosystems include the arctic tundra, coral reefs, prairie pothole wetlands, and southwestern forests. In the arctic tundra, a series of positive feedback mechanisms may trigger a relatively sudden, domino-like chain of events that result in conversion from low tundra vegetation to shrubland, initiated by a relatively slight increase in temperature (U.S. Climate Change Science Program (CCSP) 2009a, pp. 1–2).

Many analyses involve climate change vulnerability assessments. In relation to climate change, vulnerability refers to the degree to which a species (or system) is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the type, magnitude, and rate of climate change and variation to which a species is exposed, the species' sensitivity, and its adaptive capacity (Glick *et al.* 2011, pp. 19–22; IPCC 2007a, p. 89). There is no single method for conducting such analyses that applies to all situations (Glick *et al.* 2011, p. 3). We use our expert judgment and appropriate analytical approaches to weigh relevant information, including uncertainty, in our consideration of various aspects of climate change.

As is the case with all threats that we assess, even if we conclude that a species is affected or is likely to be affected in a negative way by one or more climate-related impacts, it does not necessarily follow that the species meets the definition of endangered species or threatened species under the Act. If a species is listed as endangered or threatened, knowledge regarding its vulnerability to, and known or anticipated impacts from, climate-associated changes in environmental conditions can be used to help devise appropriate strategies for its recovery.

Global climate projections are informative, and, in some cases, the only or the best scientific information available. However, projected changes in climate and related impacts can vary substantially across and within different regions of the world (IPCC 2007a, pp. 8–12). Therefore, we use "downscaled" projections when they are available and have been developed through appropriate scientific procedures because such projections provide higher resolution information that is more relevant to the spatial scales used for species analyses (see Glick *et al*. 2011, pp. 58–61, for a discussion of downscaling). With regard to our analysis for the red knot, downscaled projections are available primarily for the United States and the Canadian Arctic.

Coastal Storms and Extreme Weather

Several threats to the red knot are related to the possibility of changing storm and weather patterns. While variation in weather is a natural occurrence and is normally not considered a threat to the survival of a species, persistent changes in the frequency, intensity, or timing of storms at key locations where red knots congregate (e.g., key stopover areas) can pose a threat (see proposed rule—Factor E).

The IPCC (2012) recently released a summary report regarding global trends and predictions for extreme events including storms. Predictions about future storm patterns are associated with only "low to medium confidence." There is "low confidence" in any observed long-term (i.e., over the past 40+ years) increases in tropical cyclone (e.g., hurricane) activity (i.e., intensity, frequency, duration), after accounting for past changes in observing capabilities. Average tropical cyclone maximum wind speed is "likely" to increase, although these wind speed increases may not occur in all ocean basins. Heavy rainfalls associated with tropical cyclones are "likely" to increase with continued warming. Globally, it is "likely" that the frequency of tropical cyclones will either decrease or remain essentially unchanged (IPCC 2012, pp. 8, 13), but there may be regional differences in some ocean basins.

The North Atlantic illustrates the difficulty of gaging trends in storm activity. (Regarding tropical storms, "north" is used in the sense of above the equator.) Holland and Webster (2007, p. 2697) and Mann and Emanuel (2006, p. 238) found increasing trends in tropical cyclone activity in the North Atlantic basin extending back to 1900 and 1880, respectively (National Oceanic and Atmospheric Administration (NOAA) 2013a, p. 39). However, assessing trends in storm frequency over the 20th century is confounded by increasing storm detection rates brought on by technological advances, beginning with aircraft in the mid-1940s and increasing further with satellites in the late 1960s (NOAA 2013a, pp. 39–40; Landsea 2007, p. 197). When adjusted for these reporting and monitoring biases, the time series of Atlantic basin tropical cyclone frequency shows only a slight upward trend from 1878 to 2008 (NOAA 2013a, p. 40; Landsea *et al.* 2010, p. 2508). Looking only at the satellite era, 1970 to 2004, Webster *et al.* (2005, pp. 1845–1846) found that the North Atlantic from 5º to 25º north latitude (northern South America to the Florida Keys) showed an increasing trend in hurricane frequency and duration that is significant at the 99 percent confidence level, but concluded that the role of global climate change in these patterns is still unclear. Several studies have found increasing frequencies of high-intensity tropical storms (e.g., Category 4 and 5 hurricanes), as well as increases in the "accumulated cyclone energy index," a metric that incorporates cyclone intensity (wind speed) and duration. These increases in the most powerful storms have taken place since the 1970s, and are attributed to improved monitoring technology, multi-decade climate variability, and human-caused global warming (NOAA 2013a, p. 40; Emanuel 2005, p. 686; Webster *et al.* 2005, pp. 1845–1846). The increase in the number and strength of hurricanes has occurred at times and in areas used by red knots (Committee on the Status of Endangered Wildlife in Canada (COSEWIC) 2007, p. 36). Based on best available data, we cannot draw any conclusions regarding future trends in the total number of tropical storms (e.g., all category 1 through 5 hurricanes) within the range of the red knot; however, we can conclude that the number of high-intensity tropical storms (e.g., category 4 and 5 hurricanes) will probably increase.

The IPCC (2012, pp. 8,13) found it is "likely" that there has been a poleward shift in the main Northern and Southern Hemisphere extra-tropical storm tracks, meaning these storms, on average, are taking place farther from the equator than in the past. (In the Northeast United States, a common type of extra-tropical storm is the nor'easter, which is a winter storm characterized by continuously strong northeasterly winds blowing from the ocean). While there is "low confidence" in the detailed geographical projections of extra-tropical cyclone activity, there is "medium confidence" in a projected poleward shift of extra-tropical storm tracks. There is "medium confidence" that there will be a reduction in the number of extra-tropical cyclones averaged over each hemisphere (IPCC 2012, pp. 8, 13). Due to the poleward shift in extra-tropical storms since the 1970s, nor'easters are now more frequent and intense in the New England region of the United States, but less frequent in the mid-Atlantic United States (Frumhoff *et al.* 2007, pp. 30–31).

The frequency and intensity of extreme precipitation events (from both coastal and noncoastal storms) are increasing. There have been statistically significant trends in the number of heavy precipitation events in some regions of the world. Although there are strong regional variations, it is "likely" that more of these regions have experienced increases than decreases in the number of heavy precipitation events, and there is "medium confidence" that anthropogenic (human caused) influences have contributed to intensification of extreme precipitation at the global scale (IPCC 2012, pp. 8–9). It is "likely" that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe. This is particularly the case in the high latitudes and tropical regions and in winter in the northern mid-latitudes. There is "medium confidence" that, in some regions, increases in heavy precipitation will occur despite projected decreases in total precipitation in those regions. Based on a range of emissions scenarios, a 1-in-20 year annual maximum daily precipitation amount is likely to become a 1-in-5 to 1-in-15 year event by the end of the 21st century in many regions (IPCC 2012, p. 13). In the Northeast United States, for example, increases in precipitation intensity of 8 to 9 percent are projected by mid-century, and 10 to 15 percent by the end of the century. The number of heavy precipitation events is projected to increase 8 percent by mid-century and 12 to 13 percent by the end of the century (Frumhoff *et al.* 2007, p. 8). However, there is "low confidence" in projections of small spatial-scale weather phenomena (IPCC 2012, p. 13).

Over recent decades, temperatures have increased about twice as fast in the Arctic as in the middle latitudes, a phenomenon known as “Arctic amplification” (National Aeronautics and Space Administration (NASA) 2013). New studies are linking Arctic amplification with weather changes in North America, brought about by changes in atmospheric circulation patterns (e.g., changes in the speed and “waviness” of the jet stream). Overland *et al.* (2012, pp. 1, 6) found changes in early summer Arctic wind patterns from 2007 to 2012 relative to previous decades, and implicated these arctic changes in the recent increases in the initiation, persistence, and severity of weather extremes at lower latitudes of North America. Observational analysis by Francis and Vavrus (2012, p. 1) suggested that rapid climate change in the Arctic could lead to increased probabilities of extreme weather events (e.g., droughts, flood, cold spells, heat waves) in the middle latitudes of the Northern Hemisphere. Some researchers have found evidence that Arctic amplification contributed to the unusual conditions surrounding Hurricane Sandy (Greene *et al.* 2013, entire; Eaton 2012). Petoukhov *et al.* (2013, entire) developed equations that describe atmospheric wave motions in the middle latitudes. These authors found that certain types of waves have become trapped and amplified more frequently since 1980 and that this phenomenon is linked to extreme weather events around the world, such as regional heat waves and floods. The increase in these specific atmospheric patterns is associated with rapid warming in the Arctic (Potsdam Institute for Climate Impact Research 2013). The 32-year period studied by Petoukhov *et al.* (2013) provides a good indication of the mechanism involved in increasing extreme weather events, but is too short for definite conclusions (Potsdam Institute for Climate Impact Research 2013).

That the scientific link between Arctic amplification and extreme weather at lower latitudes is not yet widely accepted (Ogburn 2013; Eaton 2012). Barnes (2013, entire) did not find that atmospheric waves were getting wavier, as other research has suggested, and also failed to find strong evidence for a slowdown in the speed of such waves. Modeling by Barnes *et al.* (2013, entire) found that the atmospheric conditions that led to Hurricane Sandy’s turn into the New Jersey coast are actually less likely as the climate changes, not more likely. Screen and Simmonds (2013, entire) found some statistically significant trends in atmospheric wave height in some seasons in some places. These authors found that the possible connections among Arctic amplification, atmospheric waves, and middle latitude weather are complex and sensitive to the assumptions that underpin the modeling, and that more research is needed to understand these connections (Screen and Simmonds 2013, p. 959). Many researchers agree that the science on this issue is unsettled because it is a new field of investigation, available data sets are short, and the climate system is highly complex (Ogburn 2013).