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14. ABSTRACT

With the sea ice cover in the Arctic Ocean declining, the more extensive areas of open water will foster more frequent storms, higher winds, and bigger waves. These conditions can create copious amounts of sea spray. We anticipate that structures placed in shallow water—wind turbines or drilling rigs, for instance—will, therefore, experience more episodes of freezing spray that will create hazards for both personnel on these structures and for the structures themselves. Few observations, however, have been made of sea spray generation in high winds, above, say, 15–20 m/s; and no spray observations have been made in freezing temperatures. Our objective is, thus, to observe the size distribution and rate of creation of spray droplets at air temperatures below freezing and in winds above 15 m/s—and, preferably, above 20 m/s.

Climatologically, Mt. Desert Rock, a small, well exposed island 24 miles into the Atlantic Ocean from Bar Harbor, Maine, provided just such conditions in January. Andreas and collaborator Kathy Jones thus spent most of January 2013 observing sea spray and measuring relevant meteorological and ocean conditions on Mt. Desert Rock. We are continuing our data analysis but did encounter frequent winds near 20 m/s and temperatures below freezing during our deployment.

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ABSTRACT

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LONG-TERM GOALS

The goal of this project is to develop the capability to quantify both the concentration of sea spray over the open ocean and the severity of sea spray icing on fixed offshore structures. We will use existing information on the relationship of the spray concentration distribution to wind speed (Lewis and Schwarz 2004; Andreas et al. 2010; Jones and Andreas 2012) to estimate the sea spray climatology in ice-free northern oceans from reanalysis data and the time-varying extent of the sea ice cover. Our field campaigns will focus on measuring sea spray parameters and relevant meteorological conditions to characterize spray droplet distributions at high wind speeds and low temperatures. Sea spray data at high wind speeds are sparse, and there are no measurements of the spray droplet concentration at air temperatures below freezing. This effort directly addresses two of the focus areas in the core ONR Arctic program:

- Improving understanding of the physical environment and processes in the Arctic Ocean.
- Developing integrated ocean-ice-wave-atmosphere Earth system models for improved predictions on time scales of days to months.

OBJECTIVES

Our objectives are as follows:

- Use reanalysis data to estimate spatially and temporally distributed sea spray concentrations over the northern oceans. Such estimates are currently limited by the sparse information on sea spray at high wind speeds. Adapt the Andreas et al. (2008, 2010, 2014) spray algorithms for high wind speeds and subfreezing temperatures.
- Use these estimates of sea spray concentrations to characterize the icing risk for offshore structures in northern regions by adapting the heat balance calculation for freezing rain in Jones (1996) to saline droplets and by modifying the Finstad et al. (1988) collision efficiency algorithm to take into account the larger mass of saline droplets compared to freshwater droplets.
- Determine the properties of sea spray in high wind speeds by making droplet concentration measurements on fixed offshore structures or at well exposed coastal sites at air temperatures below freezing.
- Measure the density of ice accreted from sea spray on fixed structures and develop a relationship between spray ice density and weather parameters.
- Use our sea spray measurements to revise the Jones and Andreas (2012) spray concentration distribution for high wind speeds; update our initial icing risk analysis.
- Rapidly disseminate all data and metadata.

APPROACH

This project is a collaboration between Andreas and Kathy Jones of the U.S. Army's Cold Regions Research and Engineering Laboratory, who is funded under a separate award (N00014-12-MP-20085).

Our goal is to quantify the concentrations of wind-generated sea spray and the resulting spray icing on offshore structures, such as wind turbines and exploration, drilling, and production platforms. Our approach combines 1) simulating sea spray and icing from reanalysis data and data from moored buoys and coastal stations, 2) a field campaign to measure the quantity and size distribution of sea spray in high winds, 3) developing a spray concentration density function for high wind speeds, 4) estimating the spatial distribution of sea spray in all seasons, and 5) determining icing risk when the air temperature is below freezing in northern oceans.

In the field, we observed the spray size distribution with two techniques. First, we manually exposed coated glass slides briefly to the spray and then used computer software to size droplets in photographs of the slides. Figure 1 shows such spray droplets captured on Vaseline-coated slided.

Our second spray instrument was a cloud imaging probe, which we are borrowing from Chris Fairall of NOAA's Earth System Research Laboratory. This device consists of an optical array; it photographs and then automatically sizes droplets moving through the array. It sizes droplets with diameters from 25 μm up to 1.55 mm in 62 bins that are each 25 μm wide.

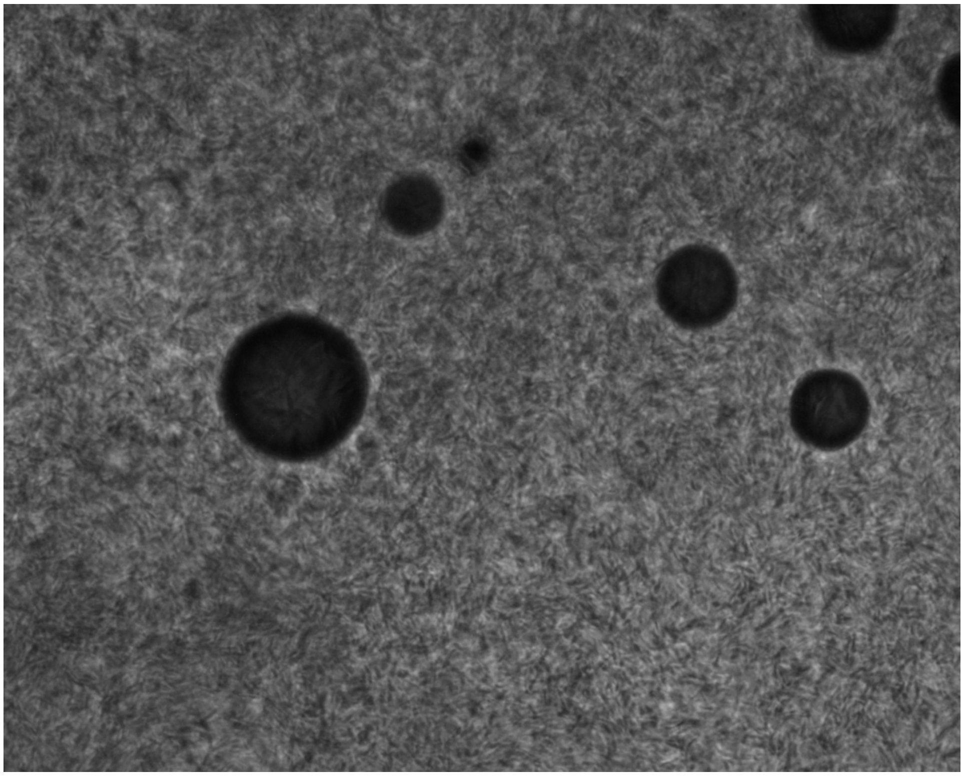

Figure 1. Typical saline droplets captured on Vaseline-coated glass slides. This is an example of the data we collected on Mt. Desert Rock in January 2013.

To characterize the meteorological conditions in which we observed the spray and, thereby, to develop parameterizations for spray concentration, spray production rate, and icing rate, we also deployed a full suite of turbulence instruments. These instruments provide mean wind speed, temperature, humidity, and pressure and the turbulent air-sea surface fluxes of momentum and sensible heat. Figure 2 shows the locations of the cloud imaging probe and its associated sonic anemometer, the turbulence instruments, and where we collected spray on glass slides on Mt. Desert Rock.

WORK COMPLETED

Most of this year's work was analyzing the data collected on Mt. Desert Rock in January 2013. There are several types of data that Andreas has been dealing with. One set is time series of pressure, wind speed and direction, air temperature, and relative humidity to characterize the spray sampling conditions on Mt. Desert Rock. The second set is the spray counts and sizing data from the cloud imaging probe. Both sets of instruments yielded a lot of data, and the analysis is ongoing.

A third set of data is Jones's capturing of the spray droplets on glass slides as in Figure 1. Vaseline-coated slides are hydrophobic; spray droplets therefore have circular shapes when photographed from above (e.g., Johnson and Dettre 1969). Our processing software is able to identify these droplets and to give us the radius of each droplet. The issue, however, is that we need to know the radius of the droplet in air, not just on the glass slide. We did a small lab study this year to deduce how the radius we measure on the glass slide is related to the radius of the droplet in air.

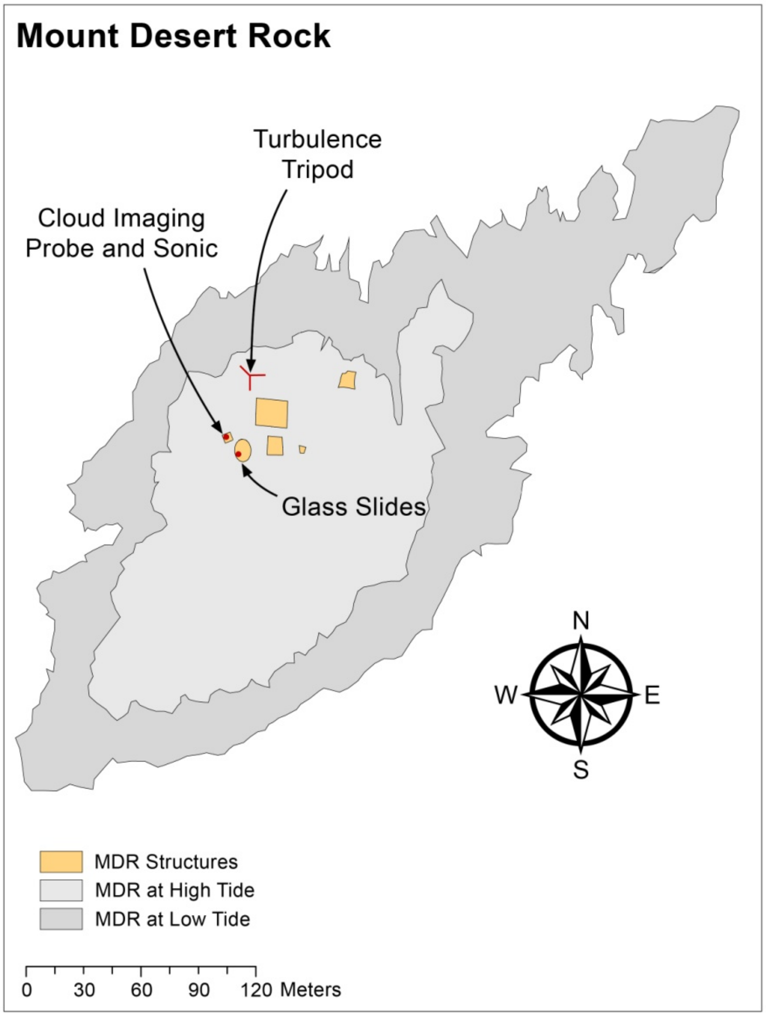

Figure 2. Map of Mt. Desert Rock showing its shoreline at low and high tide, the structures on the island, and locations of our instruments during our January 2013 experiment. The yellow oval is the lighthouse.

Although spray droplets captured on glass slides appear circular when photographed from above, they could, in fact, assume a variety of shapes in profile. Figure 3 shows geometries that a small droplet may asume when resting on a surface. Photos like Figure 1 give us only an apparent radius, r_{ap}, while we desire the radius r_0 of the droplet suspended in air.

In Figure 3, we see that the radius of curvature of the droplet on the slide, r, is the same as r_{ap} for the three cases on the right; but for the second case from the left, $r_{ap} < r$. Figure 3 also defines the height a of the droplet's apex above the slide. By knowing the ratio a/r, we can calculate the volume of the droplet as it rests on the slide, which is also its volume in air, $\left(4\pi/3\right)r_0^3$.

Figure 4 shows the same droplets as in Figure 1, but here we have let the water in these droplets evaporate to leave only the salt particles shown in Figure 4. By sizing these salt particles, associating each with its corresponding parent droplet in Figure 1, and knowing that the original salinity of these droplets was 34 psu, I was able to estimate that a/r = 1.33. That is, on these Vaseline-coated slides, the spray droplets sit pretty high, as in the second example from the right in Figure 3.

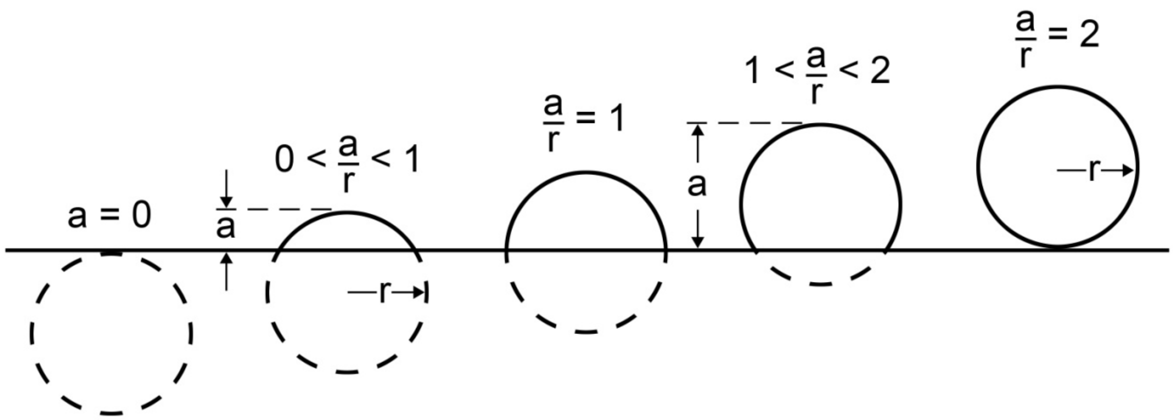

Figure 3. A spray droplet may take a variety of shapes while resting on a hydrophobic surface. The sketch defines the radius of curvature, r, and the height of the droplet's apex above the surface, a.

Our conclusion from this analysis is, for the spray droplets that Jones collected and sized on Mt. Desert Rock, the radius r_0 of spray droplets floating in air is $0.9r_{ap}$—that is, 0.9 times the radius measured on the slides. We will henceforth use this conversion to estimate the actual radii of the airborne spray droplets from the radii that Jones measured.

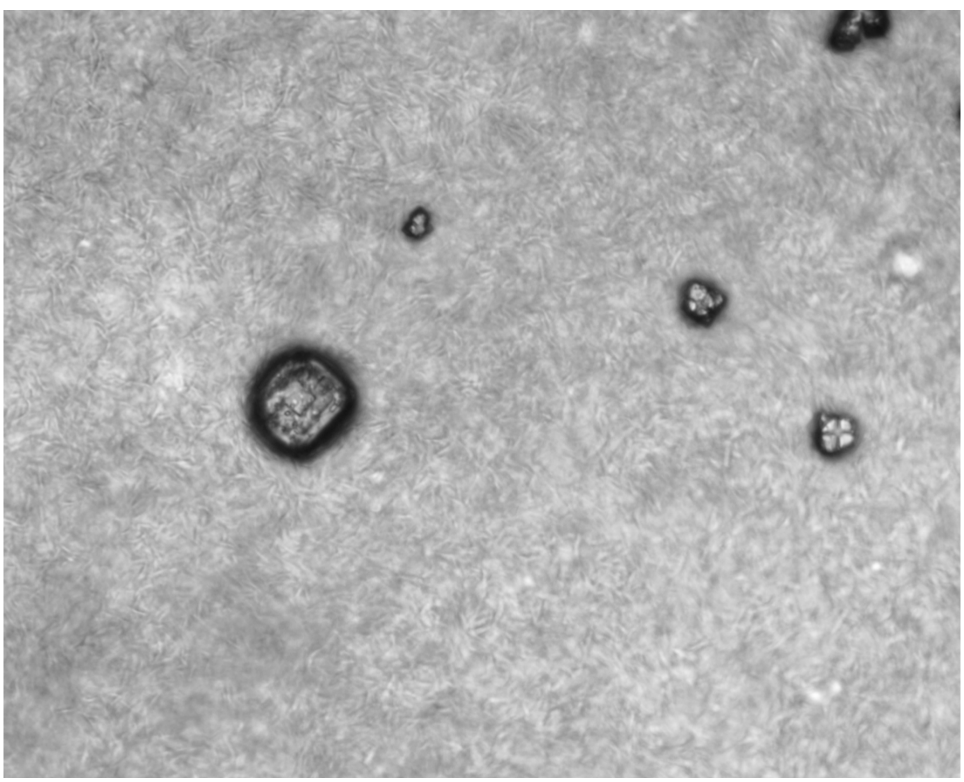

Figure 4. The saline droplets in Figure 1 have been allowed to evaporate. These are the salt particles that the droplets have left behind. We combined the sizing information from this figure and from Figure 1 to estimate the volume of the original droplet and, thus, its original radius, r_0.

DELIVERABLES

This is a basic research project: We are not building things. Rather, our products are scientific knowledge that is generally disseminated in the scientific literature or at scientific conferences. As such, we have made four conference presentations in the last year and have also published associated proceedings papers. These are Andreas (2014), Andreas et al. (2014), and Jones and Andreas (2013a, 2013b).

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