Chapter 13

SEA SPRAY PRODUCTION AND INFLUENCE ON AIR–SEA HEAT AND MOISTURE FLUXES OVER THE OPEN OCEAN

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13.1 Introduction

The question as to whether sea spray affects the air–sea fluxes of heat and moisture has been around a long time, but the answer has remained elusive. Over 50 years ago, Montgomery (1940) concluded that humidity profiles he collected over the ocean in winds less than 10 m/s showed evidence of spray effects. Over 40 years ago, to explain the radial increase in air temperature and specific humidity toward the center of tropical storms, Riehl (1954, p. 287) confidently stated that “A source for the heat and moisture increase is obvious. The ocean is greatly agitated, and large amounts of water are thrown into the air in the form of spray.”

Another wave of scientists rediscovered the spray problem in the 1970s (e.g. Wu 1973, 1974; Bortkovskii 1973; Borisenkov 1974; Bortkovskii, Byutner 1974; Borisenkov, Kuznetsov 1976; Ling, Kao 1976; Ling et al. 1978, 1980). Although they brought new ideas, better instruments, and more powerful analytical tools to the study of sea spray, they were still hampered by scanty data. Near-surface oceanic observations (e.g. Monahan 1968; Chaen 1973; Preobrazhenskii 1973; Fairall et al. 1983; Monahan et al. 1983; Wu et al. 1984), however, finally began to provide some
ground truth for analytical and modeling ideas. Laboratory wave tank and wind–wave tunnels allowed more detailed process studies (Monahan, Zietlow 1969; Lai, Shemdin, 1974; Wang, Street 1978a, 1978b; Wu 1979b, 1982; Cipriano, Blanchard 1981; Monahan et al. 1982; Monahan 1989).

In the early 1980s, the Humidity Exchange over the Sea (HEXOS) program began (Katsaros et al. 1987; S. D. Smith et al. 1990, 1996). A major goal of this ambitious, multiphase, international program was to investigate sea spray’s role in air–sea heat and moisture exchange. To attack the spray question from all possible angles, HEXOS integrated measurements in wave tanks (e.g. Woolf et al. 1987, 1988), in wind–wave tunnels (e.g. Mestayer, Lefauconnier 1988; Mestayer et al. 1989; Edson, Fairall 1994), and over the North Sea (e.g. de Leeuw 1987, 1989, 1990; Edson et al. 1991; S. D. Smith et al. 1992; Katsaros et al. 1994; DeCosmo et al. 1996) with detailed Eulerian and Lagrangian modeling in the lower marine boundary layer (e.g. Mestayer et al. 1989, 1996; Rouault et al. 1991; Edson, Fairall 1994; Edson et al. 1996). In addition to the papers cited earlier in this paragraph, Fairall et al. (1990) and the collections of preprints by Oost et al. (1988) and Mestayer et al. (1990) provide details regarding data collection, analysis, and preliminary results of HEXOS.

Despite this huge HEXOS effort, however, the fundamental question as to whether sea spray affects air–sea heat and moisture fluxes remains unanswered. The evidence is still so ambiguous that, in just the last five years, Ling (1993) could state that “water microdroplets created by breaking waves play a dominant role in the vertical transport of moisture and heat from the ocean to the atmosphere,” even for 10-m wind speeds under 11 m/s; while Makin (1998) could conclude as confidently that “for wind speeds below 18 m/s . . . there is no drastic impact of spray on heat and moisture fluxes.”

In this chapter, we revisit this question of sea spray’s role in air–sea heat and moisture exchange. Figure 13.1 shows our conceptual picture of the processes involved. The ocean is always exchanging sensible \(H_s\) and latent \(H_L\) heat at its interface through turbulence processes. We call these the turbulent or interfacial fluxes. If the wind is strong enough to create waves, whitecaps, and the resulting sea spray, the ocean’s surface area effectively increases. Any constituent normally transferred across the ocean interface can then also be transferred at the surface of the spray droplets. Logically, then, if the total surface area of the droplets becomes a significant fraction of the ocean’s surface area, spray droplets must become significant transfer vehicles. Later, we will estimate total droplet surface area as a function of wind speed.

Continuing with Figure 13.1, we are interested specifically in this chapter in spray’s role in transferring sensible and latent heat. The majority of this transfer occurs within a droplet evaporation layer (DEL) approximately one significant wave height thick (Andreas et al. 1995). If the ocean is warmer than the air, a spray droplet, which starts with the same temperature as the surface ocean, loses sensible heat in the DEL.