Proposal - LDEO Climate Center
David T. Ho
Wind and rain-induced air-water gas exchange: a pilot study at University of Delaware's Air-Sea Interaction Laboratory.

Background

Air-water gas exchange. On global and regional scales, air-sea gas exchange is an important process that strongly influences the budgets of biogeochemical trace gases (e.g., CO₂). Therefore, improving our understanding of the mechanisms underlying air-sea gas exchange, as well as documenting the relationship between environmental forcing (e.g., wind, rain) and gas transfer velocity (\(k\)) are necessary for interpretation of global scale biogeochemical and physical processes and feedbacks, which in turn have important implicate for our understanding of the climate system.

Wind. Considerable effort has been spent on determining empirical relationships between \(k\) and wind speed [e.g., Liss and Merlivat, 1986; Wanninkhof, 1992; Wanninkhof and McGillis, 1999; Nightingale et al., 2000], since wind speed is relatively easy to measure and plays a central role in the generation of turbulence through the transfer of momentum to waves and currents at the ocean surface.

Rain. Laboratory experiments and preliminary field studies in freshwater show that raindrops falling on a freshwater surface significantly enhance \(k\) [Ho et al., 1997; Ho et al., 2000]. The enhancement is mainly due to production of turbulence and secondary motions, while rain-generated bubbles accounted for 0 - 20% of the total gas exchange, depending on rain rate, raindrop size, and gas solubility [Ho et al., 2000]. Furthermore, preliminary laboratory experiments in saltwater indicate that rain induced \(k\) is similar to that predicted from relationship established from freshwater laboratory experiments [Ho et al., 2004]. However, because vertical mixing is mitigated by surface stratification, the overall gas flux is lower than that found during freshwater experiments [Ho et al., 2004].

Interaction Between Rain and wind

The findings on rain induced gas exchange suggest possible mechanisms for increasing the rate of air-water gas exchange in quiescent environments with little wind forcing. For instance, at a rain rate of 150 mm h\(^{-1}\), \(k\) is equivalent to a wind speed of approximately 15 m s\(^{-1}\). However, even though the effects of rain and wind on air-water gas exchange have been studied independently, the combined effect of the two processes has not been examined experimentally. Rain may enhance the wind stress on the water surface [Caldwell and Elliott, 1972], but the combined effect is probably not a simple addition of the two individual processes. Furthermore, the combined effect of rain and wind-induced stress increases surface currents, which ultimately shifts the breaking of small waves to those with shorter wavelength [Schlüsself et al., 1997]. All of these interactions will affect air-water gas exchange, although the magnitude or direction is not yet clear. We propose to conduct a laboratory experiment to examine how wind and rain interact to influence air-water gas exchange.

Research facility

The research will be conducted at University of Delaware's Air-Sea Interaction Laboratory (ASIL) (http://www.udel.edu/ASI-Lab/) in Lewes, DE (see Figure 1), which Wade McGillis and I visited in September 2004. "The Air-Sea Interaction Laboratory's main facility is the Air-Sea-Current flume situated at the marine station on the Lewes campus. The tank overall length is 42 m with a working section 37 m long. It is 1 m wide and 1.2 m high."
"Water depth is generally kept at 0.75 m to allow sufficient air space above the surface. The tank is equipped with a programmable wave maker, and a wind tunnel capable of up to 17 m s\(^{-1}\) wind speed. Air temperature and water temperature are also independently controllable and can be set from 5 to 40 °C. Currents in the tank can be generated using a recirculating pump or by tilting the tank (up to 1.1°). An artificial beach is placed at the end of the tank to dissipate wave energy and eliminate wave reflection." 

A rain simulator, consisting of 8,600 16-gauge needles, is placed in the center of the wind-wave tank to generate rain during the experiment.

**Proposed Experiment**

During the experiments at University of Delaware, 2 rain rates and 3 wind speeds will be used. The SF\(_6\) evasion method will be used to determine the bulk gas transfer velocity, airside profiles of wind, temperature, water vapor and CO\(_2\) will be used to estimate the momentum, heat, and gas fluxes. Flux-profile relationships [McGillis et al., 2001] for marine atmospheric boundary layers have never been explored for rain. By comparing bulk fluxes and atmospheric gradient measurements under wind-rain conditions, we may develop the ability to: understand the atmospheric composition of trace gases a rain atmospheric boundary layer; develop a technique that may be transferred to field studies, and develop turbulent closure models for rain boundary layers for GCMs.

In addition to examining gas fluxes with and without rain in a wind-wave boundary layer, measurements of airside, waterside, and interfacial physical properties will be made. These measurements will include shear, turbulent kinetic energy dissipation, stability, and wave properties. Rain rate, drop size, and fall velocity will be quantified using NASA’s Rain Imaging System.

With the data collected at ASIL, we should be able to examine how rain and wind interact to control the magnitude of air-water momentum, heat, and gas transfer. Again, the implications for scaling-up to field measurements could be addressed from the laboratory data.

**Significance**

- This experiment at University of Delaware will allow us to examine how rain and wind interact to influence air-water gas exchange. The results, along with those from previous experiments, will provide the basis for designing field experiments.
- There are programs, such as SOLAS (Surface Ocean-Lower Atmosphere Study), which are in the implementation phase. Performing this experiment will position us to take a leading role in SOLAS-type work. Building on the results of this work, and previous work conducted at Biosphere 2, we will submit proposals to NSF and NASA to continue both laboratory and field experiment on rain-induced gas exchange.
- The results of the experiment are the necessary steps toward improving our understanding of the factors controlling air-water gas exchange on regional and global scales. Having this knowledge will allow us to better understand the cycling of biogeochemically relevant trace gases, which has important implication for our understanding of the climate system. Currently, estimates of global CO\(_2\) fluxes differ by a factor of 2, depending on which parameterization between wind and \(k\) is used.

**Personnel**

David Ho (LDEO), Wade McGillis (LDEO), Fabrice Veron (Univ of Delaware), Nick Scott (WHOI), Larry Bliven (NASA/WFF), Jon Bent (LDEO), Melissa Stellato (LDEO)
Schedule

The experiment will be conducted between March 16 and 22, 2005.

Budget

<table>
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<tr>
<th>Item</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>Shipping of equipment</td>
<td>$1000</td>
</tr>
<tr>
<td>Rental mini van (and gas)</td>
<td>$800</td>
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<tr>
<td>Housing in Lewes, DE (5 people)</td>
<td>$2000</td>
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<tr>
<td>Meals (5 people, 7 days)</td>
<td>$1000</td>
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<tr>
<td>Laboratory supplies (e.g., tubing, syringes, N₂)</td>
<td>$1200</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$6000</strong></td>
</tr>
</tbody>
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References


