

Observations and modeling of sea splash icing

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Background: Icing from wave-structure interaction

- Mitten 1994: N_RIGICE
 - wave run-up on structure
 - water drops launched from top of wave
 - calibration parameters
- Splash LWC independent of structure
 - Forest et al 2005: RIGICE_04 run-up?
 - Kulyakhtin and Tsarau 2014: MARICE no ice below run-up height of waves



Wave tank experiments for run-up and splash

- De Vos et al 2007
 - Velocity stagnation head theory

$$R_{2\%} = \eta_{\max} + m \frac{u^2}{2g}$$

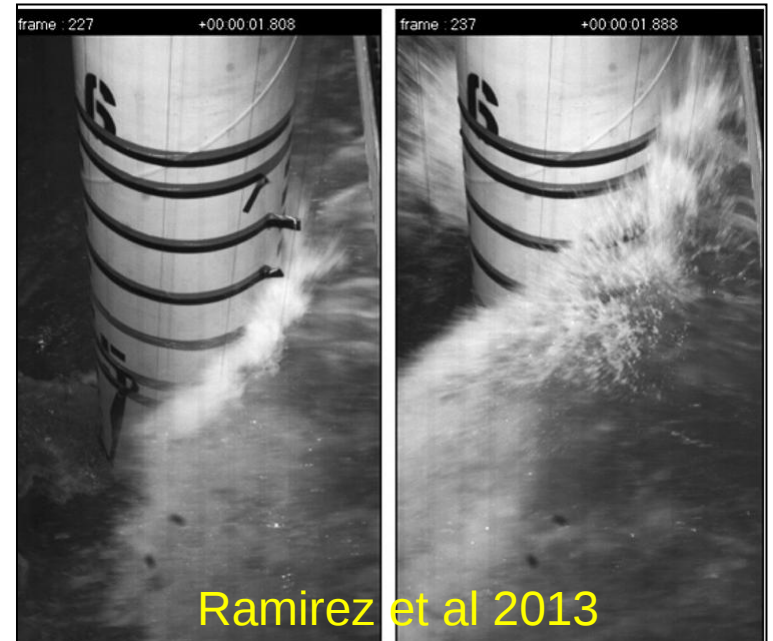
$R_{2\%}$ = run-up height

$\eta_{\max}$ = wave crest height

u = water velocity at top of wave

$$\left. \begin{aligned} \eta_{\max} &= \frac{H}{2} + \frac{\pi H^2}{4\lambda} \\ u &= \frac{HgT}{2\lambda} \end{aligned} \right\} \text{deep water}$$

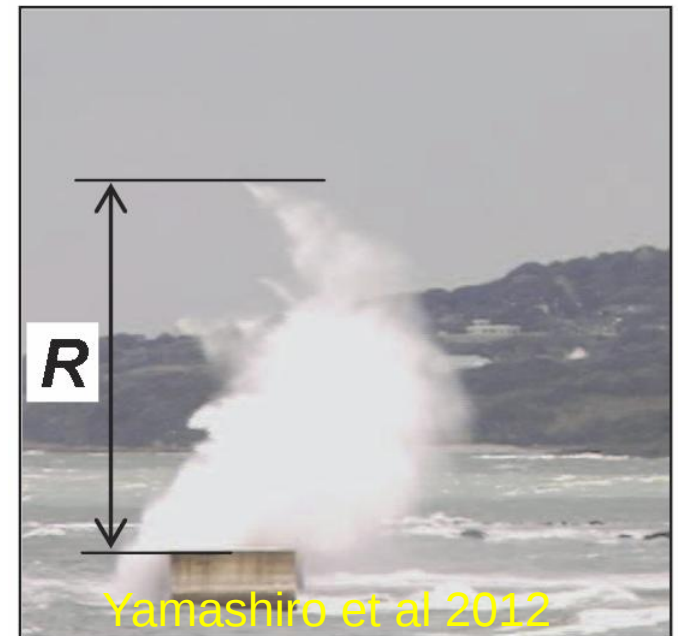
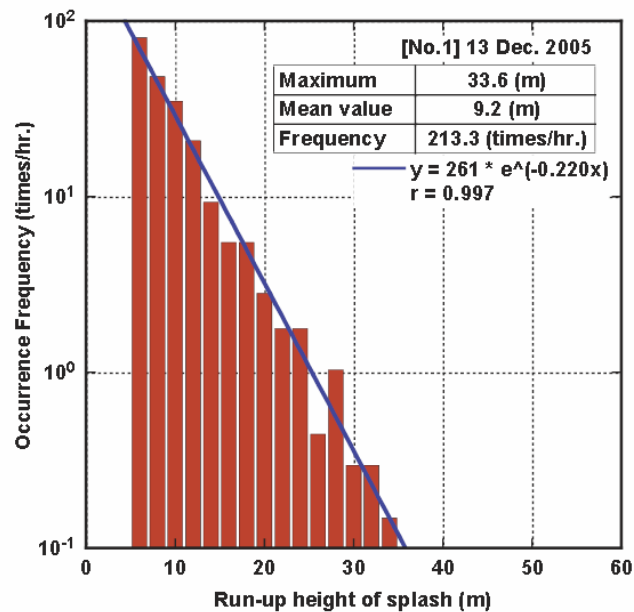
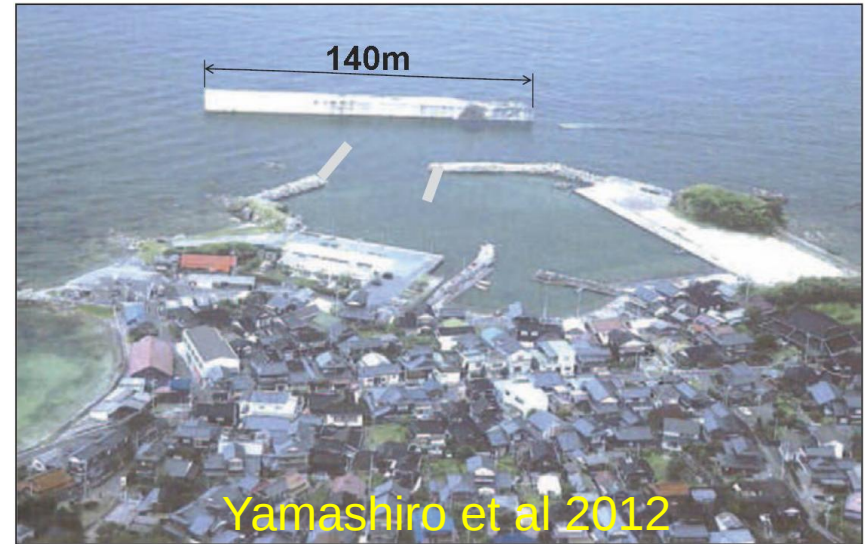
- Lykke Andersen et al 2010
 - scale 1:50
- Ramirez et al 2013
 - scale 1:10
 - high speed video
 - splash heights



Field observations of splash

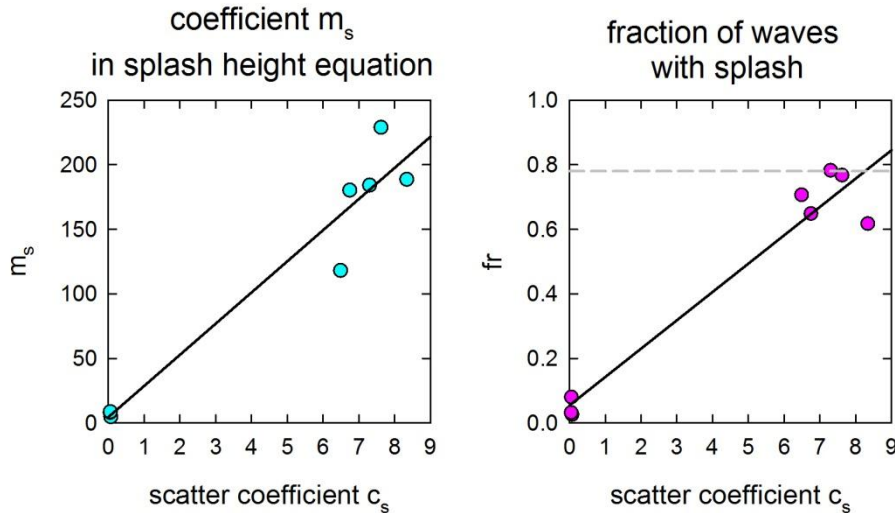
Yamashiro et al 2012

- 140-m-wide breakwater
- vertical sides
- splash drops blown over village
- high-speed video
- splash height and frequency



Splash icing model

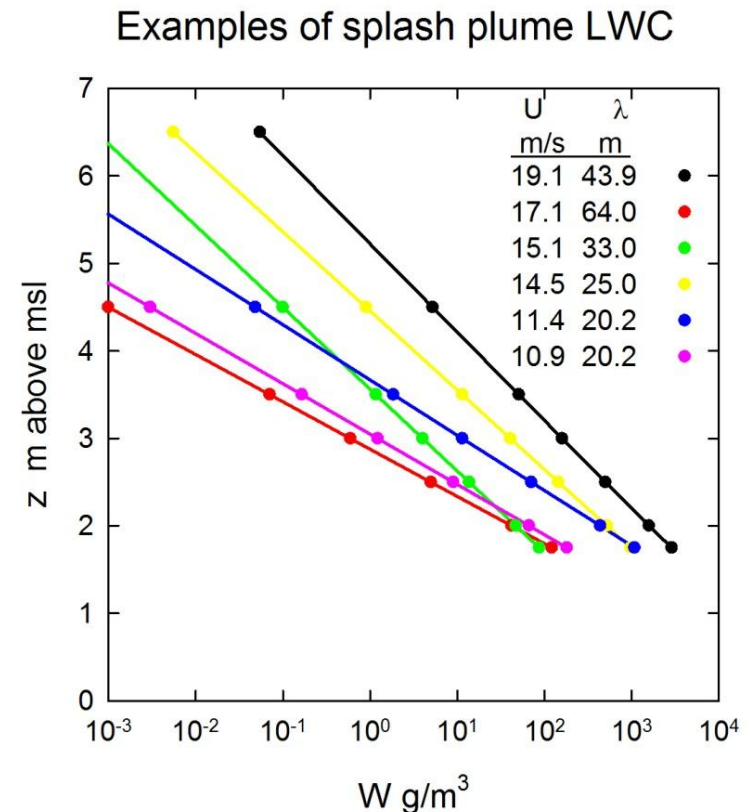
- scatter parameter $c_s = \frac{\pi D}{\lambda}$
- splash height parameter m_s $m_s = 4.7 + 24.1c_s$
- fraction of waves with splash fr $fr = 0.055 + 0.0878c_s \leq 0.78$



Liquid water content profile

- $W = \rho_w = 10^6 \text{ g/m}^3$ at $0.5H_s$
- $W = 10 \text{ g/m}^3$ at top of visible splash
- exponential decrease to splash height S

$$W(z) = W_s \left(\frac{\rho_w}{W_s} \right)^{\frac{S-z}{S-0.5H_s}}$$



Icing heat balance model

- Possible icing for $T_{\text{air}} \leq -1.6^{\circ}\text{C}$
 - convective and evaporative cooling
 - heat generated by cooling splash to -1.6°C
 - heat generated by freezing water
 - no water entrapped in ice
- Splash can remove ice for $T_{\text{air}} > -1.6^{\circ}\text{C}$

23 January 2014

salinity ~ 12 psu (10 to 19)

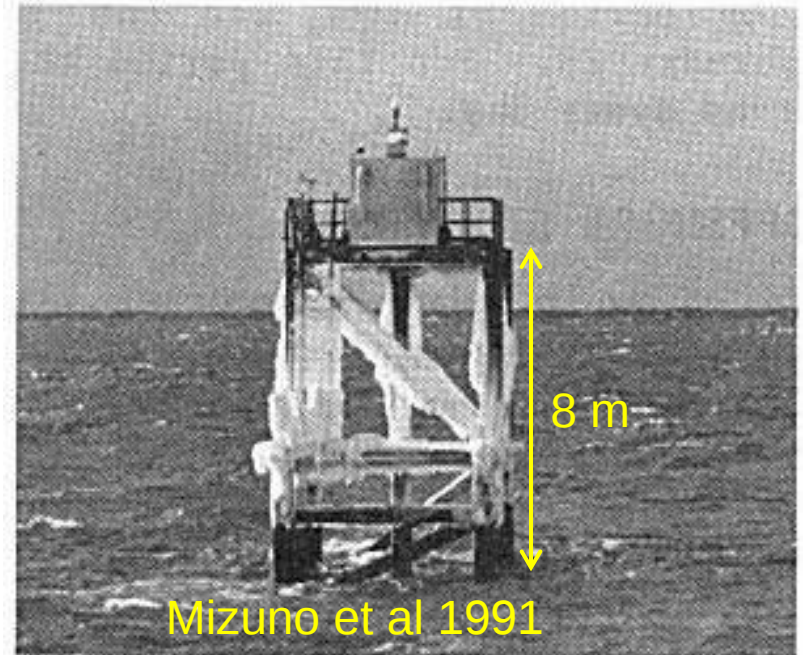


salinity ~ 29 psu (21 to 33)

Splash icing on engineered structures



Water depth ~ 35-40 m
Leg diameter ~ 3 m



January – February, 1988 and 1990

$-15^{\circ}\text{C} < T_{\text{air}}$

$T_{\text{water}} \sim 7^{\circ}\text{C}$

$H_{1/3} < 5 \text{ m}$

$U < 18 \text{ m/s}$

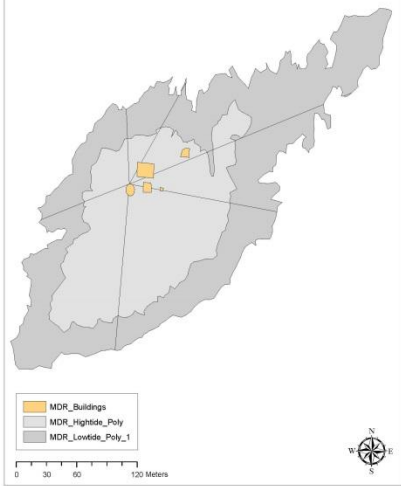
Water depth = 7 m

Diameter = 0.5 m

Ice thickness < 40 cm

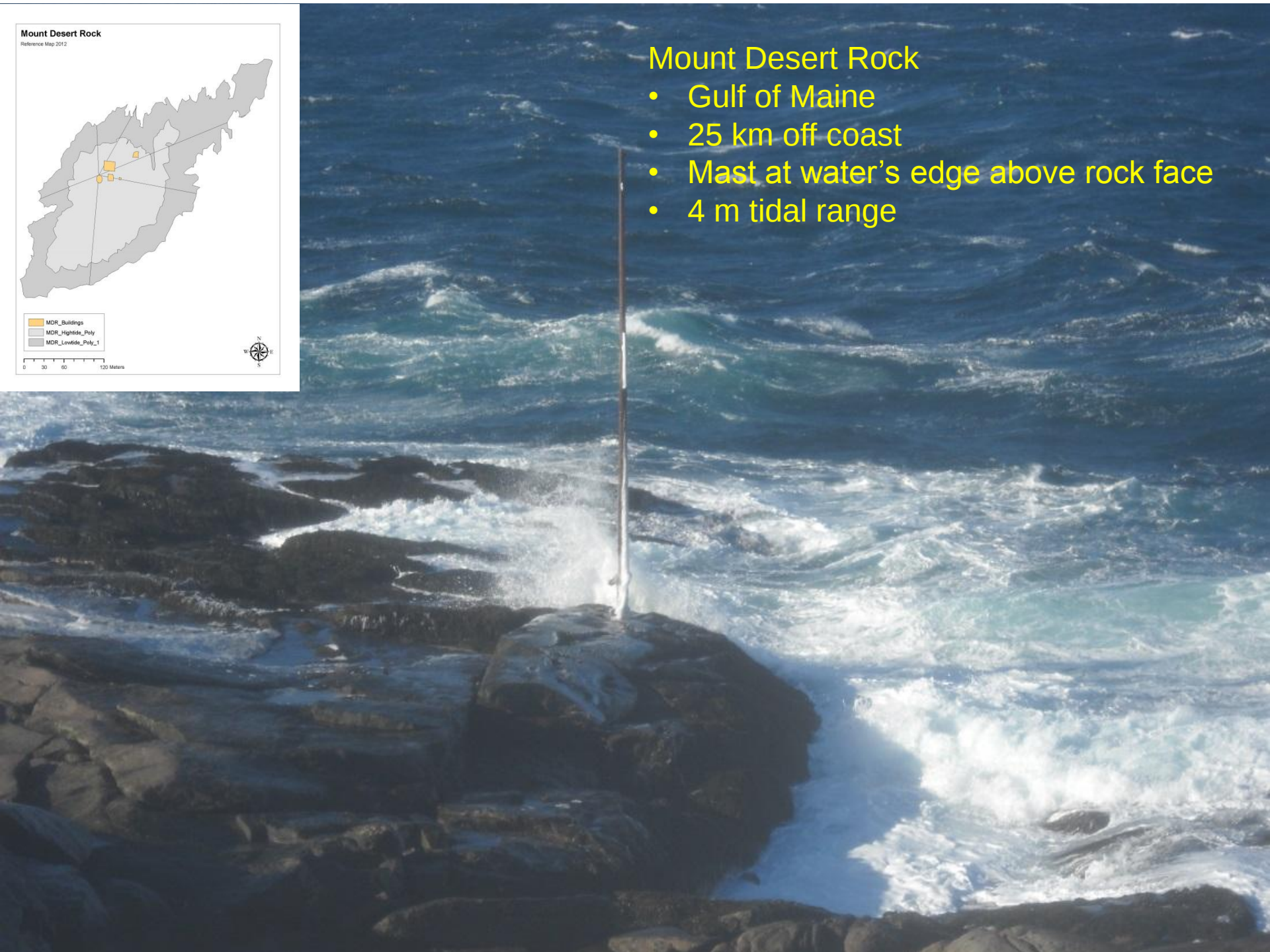
Mount Desert Rock

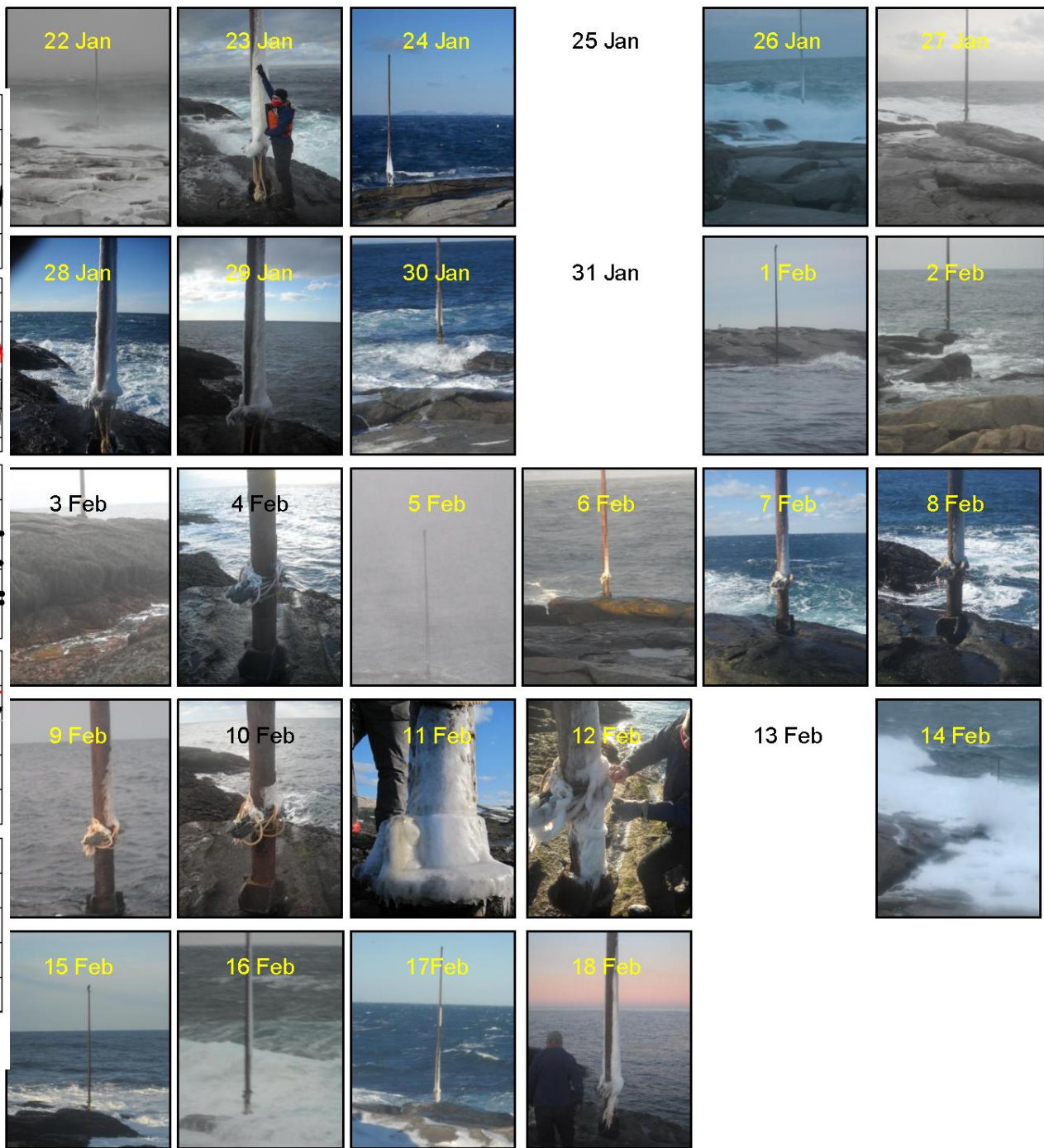
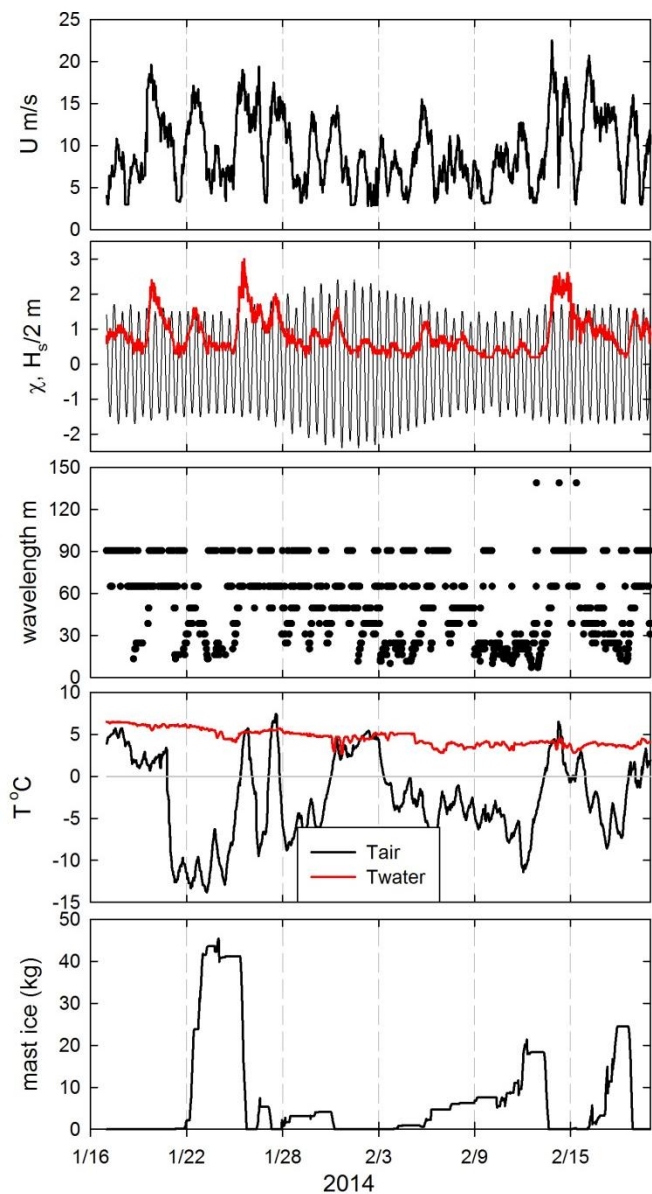
Reference Map 2012



Mount Desert Rock

- Gulf of Maine
- 25 km off coast
- Mast at water's edge above rock face
- 4 m tidal range





Future work

- Field measurements of [splash](#)
- Engineered structures
- Various length scales: 5 to 100 m
- High speed video for splash plumes
- Wind speed, wave period, wave height