Aerosol flux measurements above the ocean surface using unmanned aerial systems

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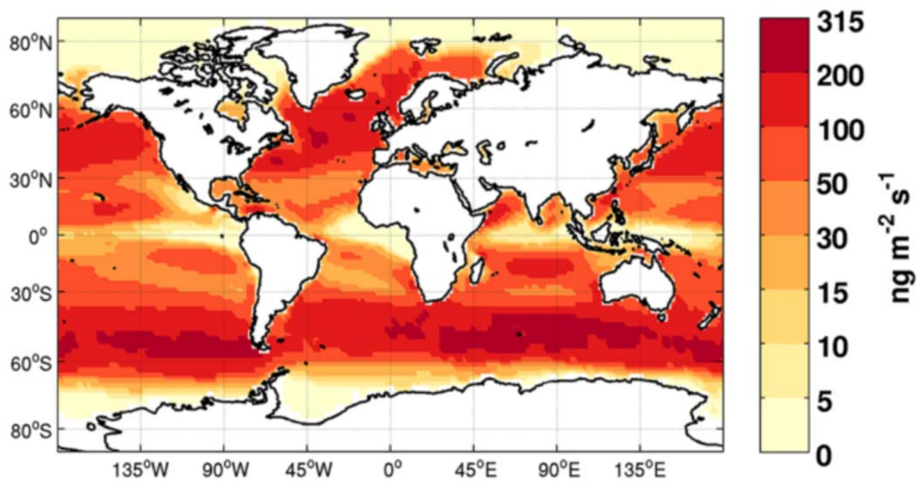
Motivation

- Oceans cover nearly 70% of the Earth's surface,
- yet, contribution of primary marine aerosol to background aerosol remains an important unresolved issue

Annual Sea Salt emissions

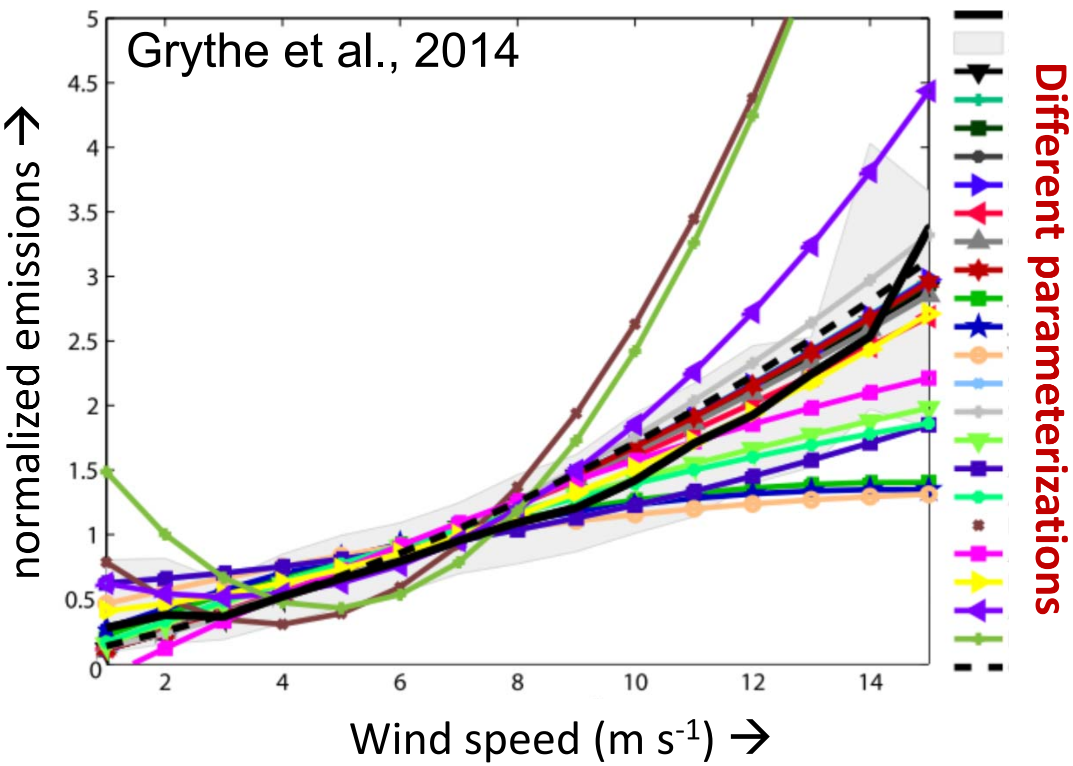


Partanen et al., 2014

- Mass flux of primary marine aerosol (i.e., sea salt) is higher than any other aerosol source
- Large spatial and temporal variability

→ Aerosol and energy surface flux measurements needed to improve weather and climate models

Sea salt emissions in models



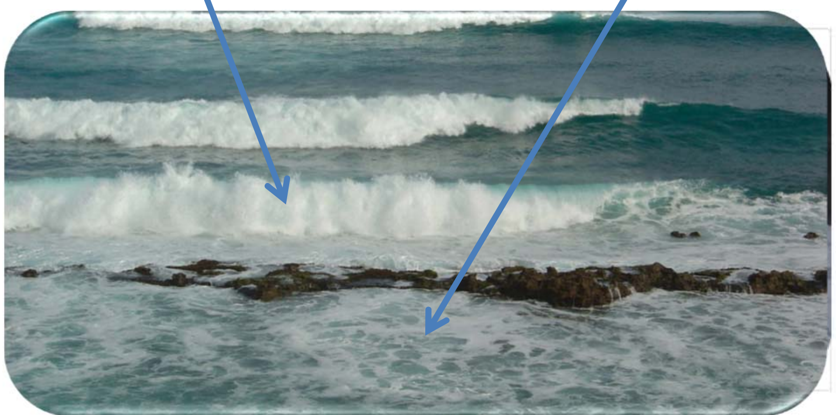
- Most emission parameterizations based on wind speed at 10 m.asl (U_{10})
- Large discrepancy in sea salt aerosol emissions – particularly, at large wind speeds (> 8 m s^{-1})

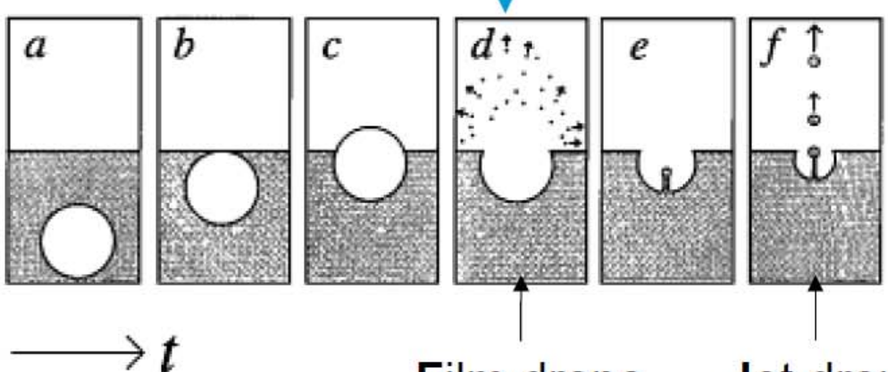
→ different emissions in models create uncertainties in assessing the role of sea salt (as well as anthropogenic aerosol) on Earth's climate

Processes related to sea spray emissions

Wave breaking in open ocean and surf zone

Swash





Louis and Schwarz, 2004

Film drops
R < 1 µm

Jet drops
R > 1 µm

Wave breaking at high surface winds (U > 8 to 10 m s^{-1})

Giant aerosol; R > 10 – 100 um

Different processes related to wind speed and sea surface state → lead to different size (and mass) of primary marine aerosol emissions

Sea salt emission flux

$$\frac{dF}{d\log D} = \sum_{i=1}^{n} \frac{F_i(Re_{H_w})}{\sqrt{2\pi}\ln\sigma_i} \exp\left(-\frac{1}{2}\left(\frac{\ln\left(\frac{D}{\mathrm{CMD}_i}\right)}{\ln\sigma_i}\right)^2\right)$$

Ovadnevaite et al., 2014

Sea salt flux

Wave breaking param.

$$Re_{Hw} = u_* H_s / v_w$$

Wind speed

Wave height

Kinematic viscosity;
f(SST, salinity)

→ Sea salt flux depends on wind speed, sea state and properties of the seawater

A challenge well-adapted for UAS

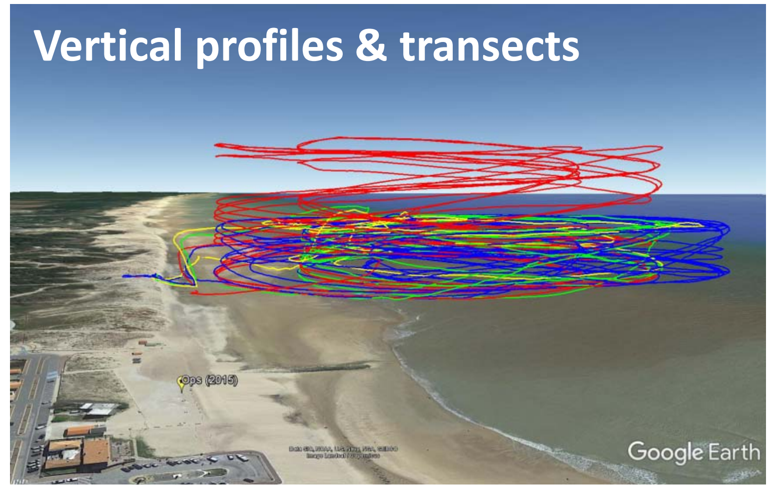
Goal: Conduct aerosol and energy flux measurements near the air-sea interface to top of the marine boundary layer

- Past studies on ships or buoys; single altitude and often perturbed by interactions with the platform itself
- Traditional research aircraft do not fly at such low altitudes (a few 10s m.asl) for obvious safety concerns

→ Unmanned aerial systems (UAS) can conduct research flights relatively safely at low altitude over the sea to characterize the air-sea exchanges

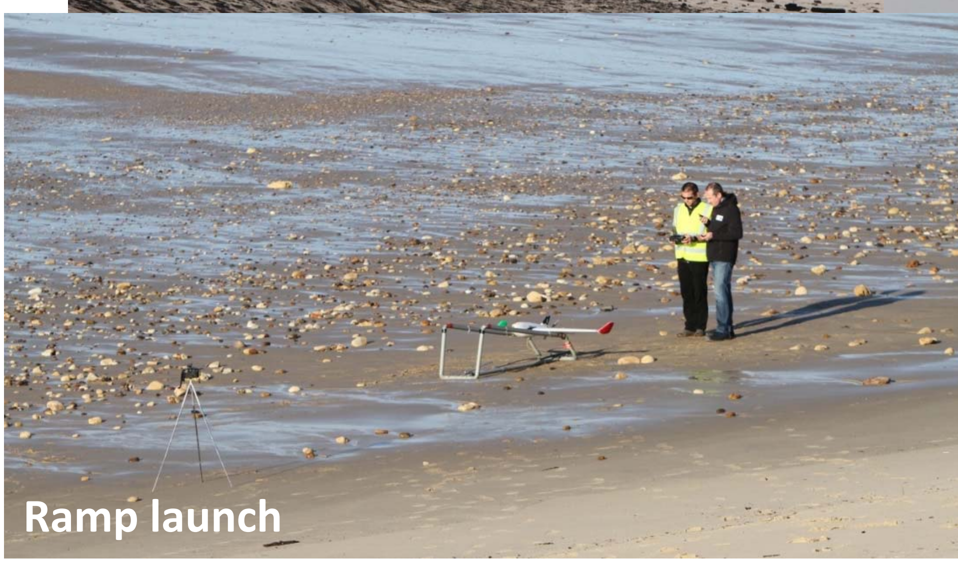
UAS flights above surf zone

- Flights along Atlantic coast in France (2016 - 2018)
- Transects across surf zone & vertical profiles from 7 to 500 m.asl
- Aerosol size distribution (0.3 < Dp < 3 um; RH < 40%), temperature, humidity
- Various meteorological conditions with winds up to 12 m/s

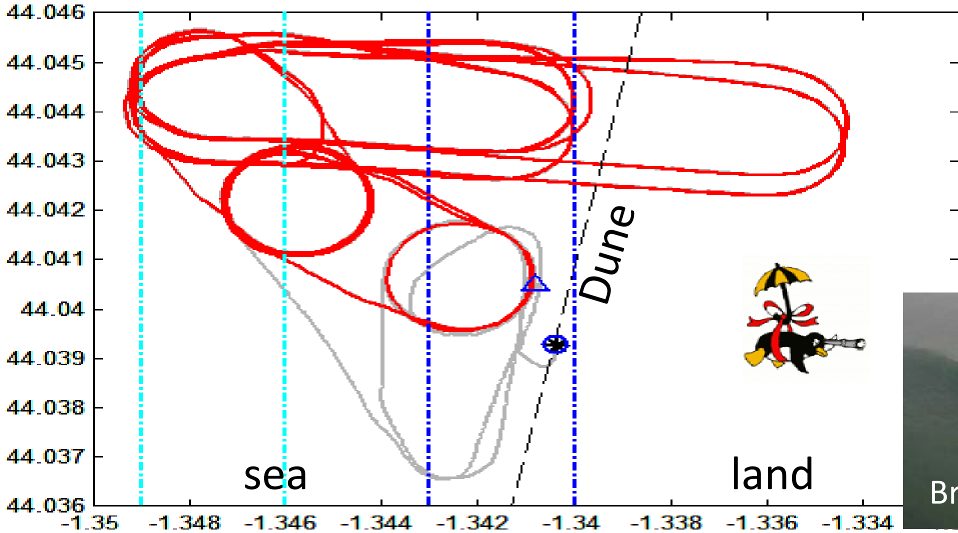


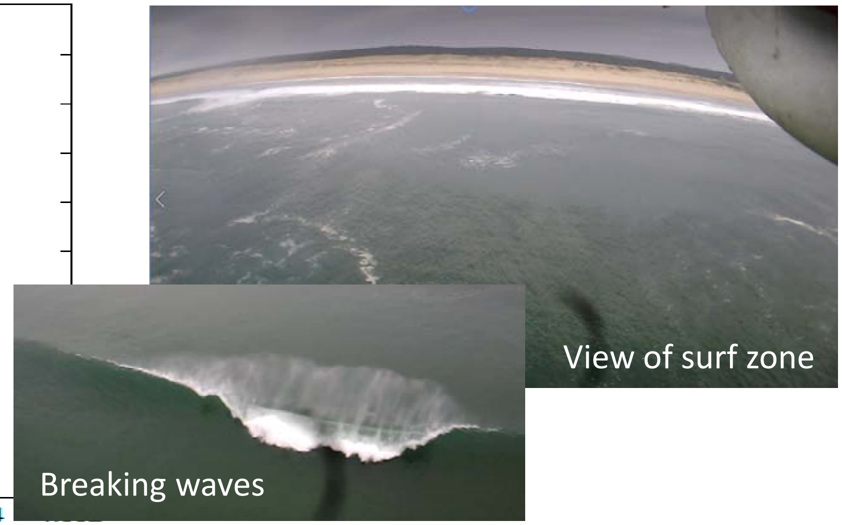
Flight operations and conditions

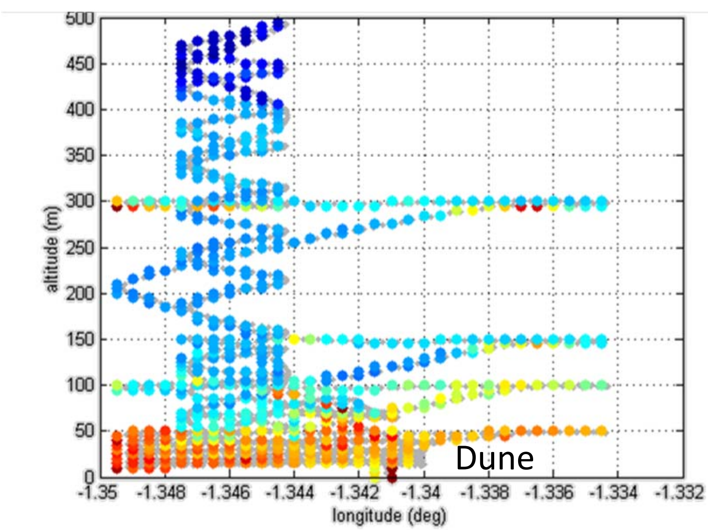
- 500 m.asl ceiling
- Up to 2 km from ground station



Transecting the surf zone



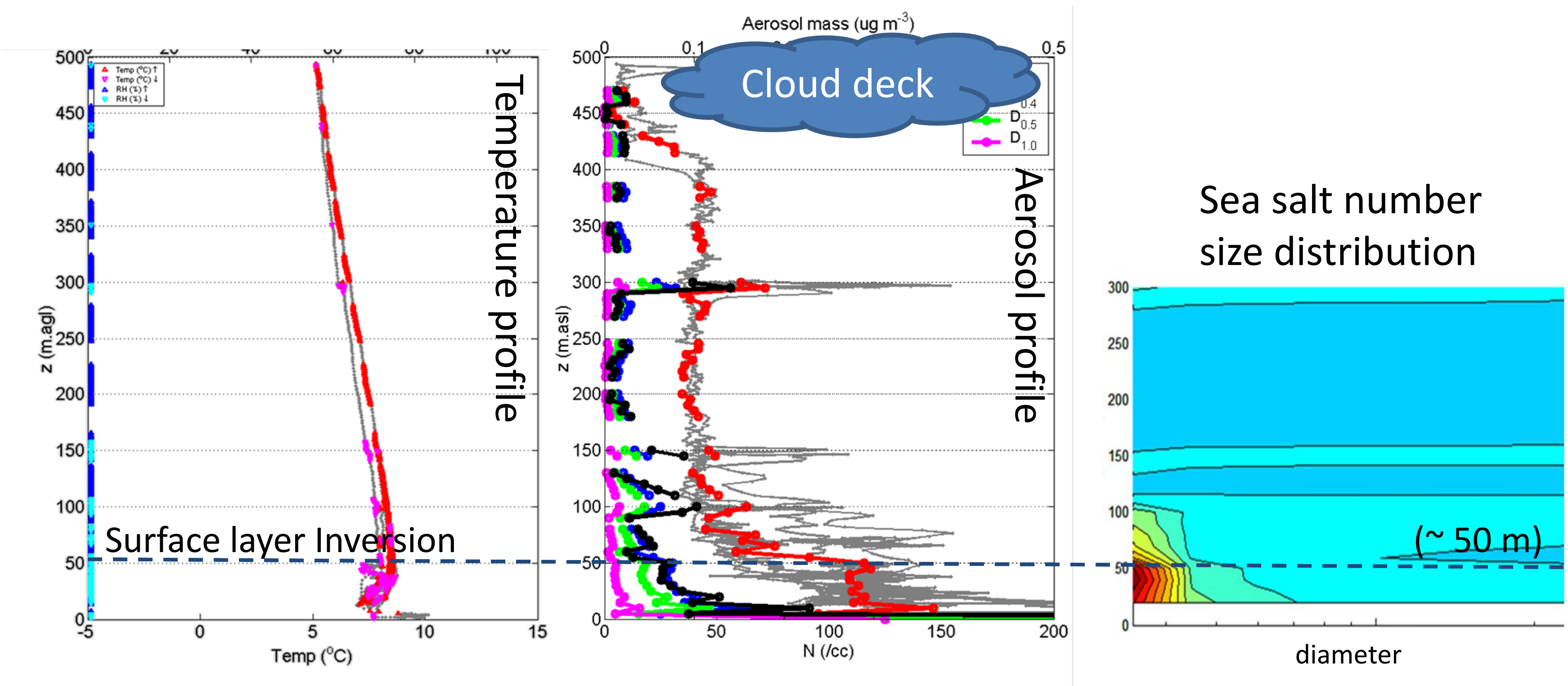




- Meteo : 4 m/s wind (along shore)
- Spiral profile (to 500 m.asl)
- Legs (300, 150, 100, 50, 30, 20, 15 m.asl)
- Spiral profile (to 150 m.asl)
- Flight duration : 37 min

Aerosol

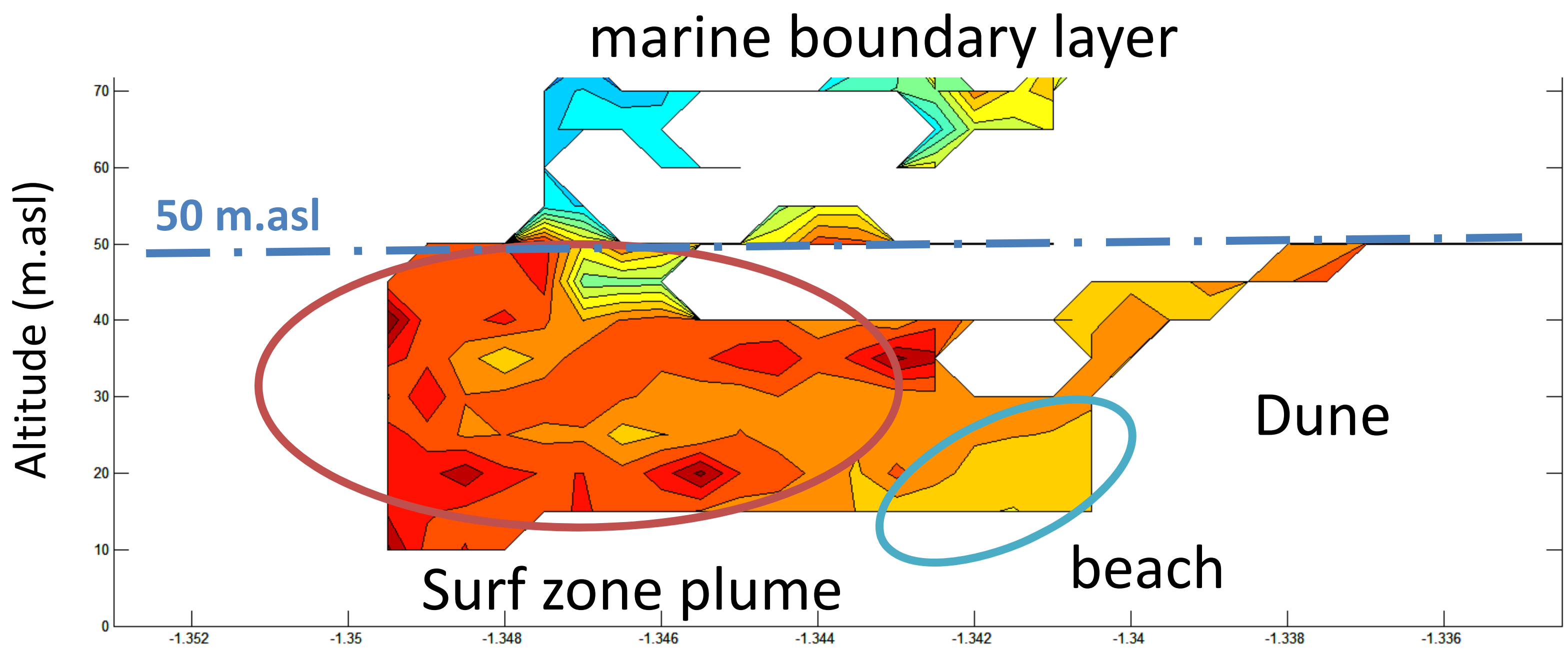
Vertical profiles over surf zone



- Aerosol layer below surface inversion (ca. 50 m)
- Sea salt emissions determined by subtracting background aerosol in marine boundary layer
- Mixing of aerosol within surface layer size dependent

Aerosol

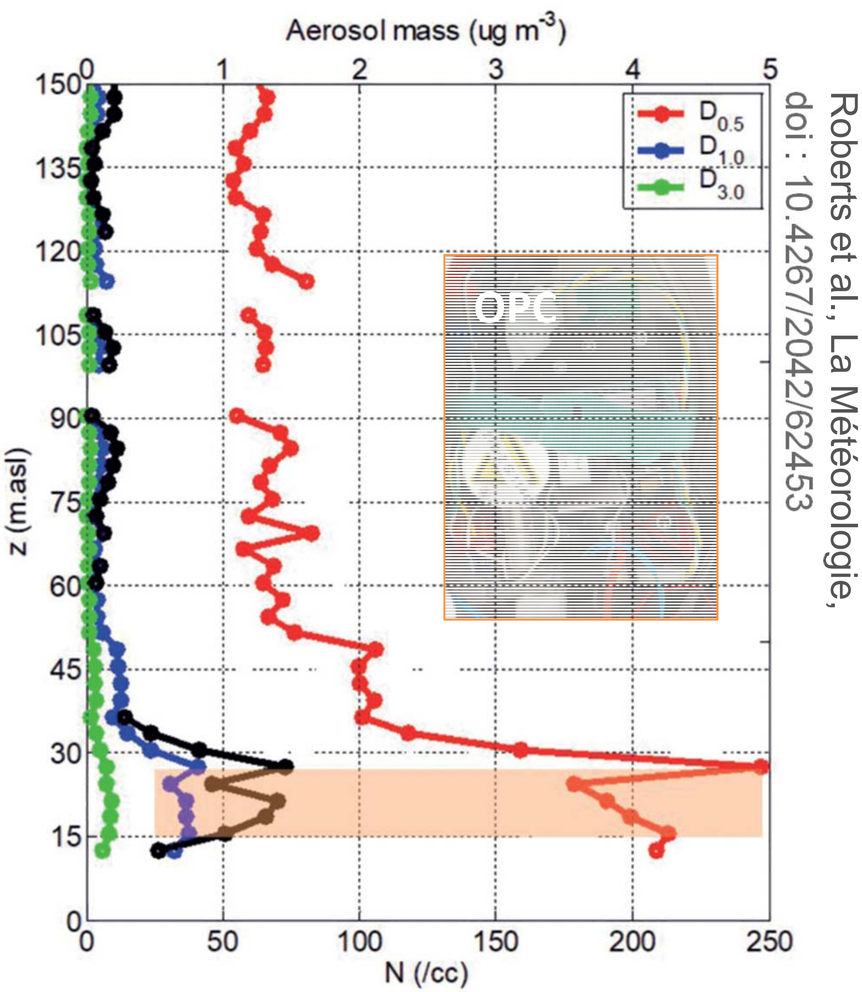
Vertical and horizontal aerosol extent



- Strong vertical and horizontal gradients in aerosol concentrations (Dp > 0.3 um)
- Surf zone aerosol below 50 m (sea salt emissions from breaking waves and swash)

Aerosol

Sea salt emissions (surf zone)



- Steep gradient in aerosol concentration < 30 m.asl
- Number concentrations (Dp > 0.5 um; red): ~ 200 / cc in surface layer; ~ 60 /cc in boundary layer
- Aerosol mass (black): ~ 1.5 ug / m^3 surface layer; < 0.2 ug / m^3 in boundary layer

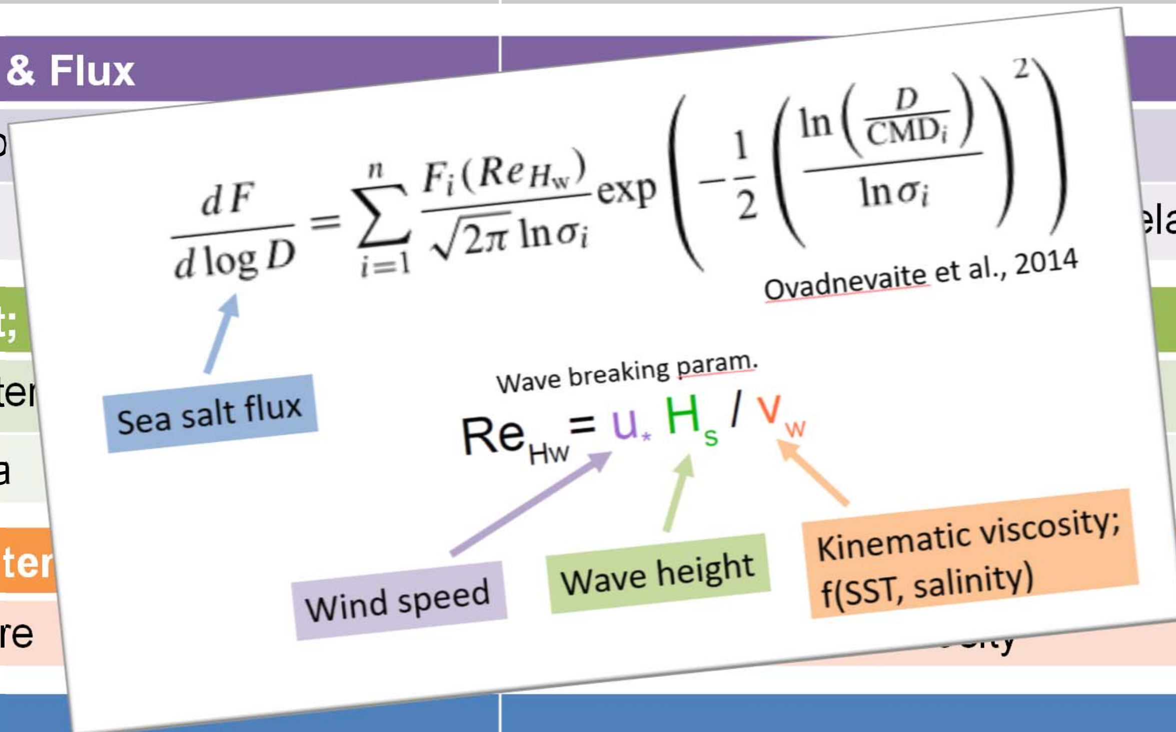
Flux estimate: F = D (dC / dz)
:: ρ ~ 2 g/cm^3; D ~ 10^{-2} m^2 / s

→ F ~ 1 ng / m^2.s (PMA surf zone)

Aerosol

Science payload

Atmospheric state	
Pressure, temperature, humidity	boundary layer stability; lifting condensation level
Wind Speed & Flux	
multi-hole pro	
	elation
Wave Height;	
Radar altimeter	
Video camera	
Sea surface ter	
IR temperature	ity
Aerosol	
Optical Particle Counter	Number & mass concentration (D_p > 0.3 um)
Condensation Particle Counter	Number concentration (D_p > 10 nm)



MIRIAD: système de **M**esures sc**I**entifiques de flux de su**R**face en m**I**lieu m**A**ritime embarqué sur **D**rone

Measurements of aerosol and energy fluxes at the air-sea interface and throughout the marine boundary layer

- Boréal UAS (Toulouse, France)
- 5 kg payload / 20 kg take-off weight
- 10 hour flight duration
- Deploying ultra-light UAS to develop payload instrumentation

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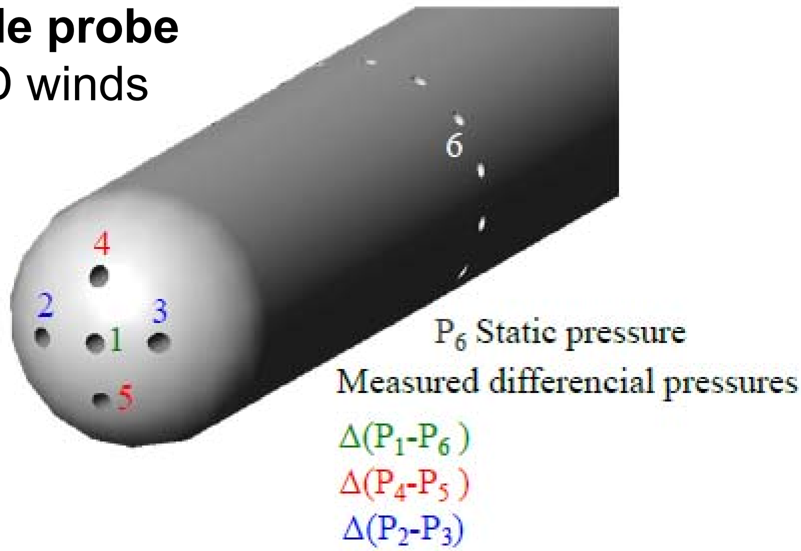
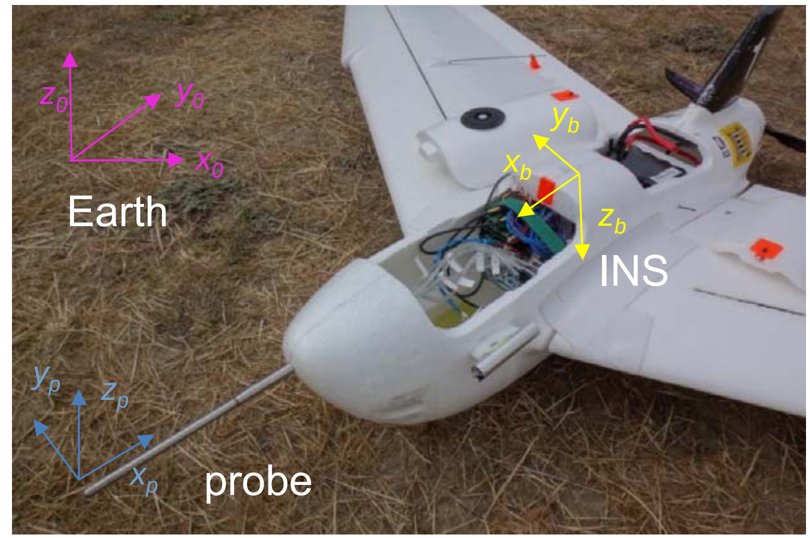
multi-hole probe for 3D winds

5-hole probe

➢ 3D winds



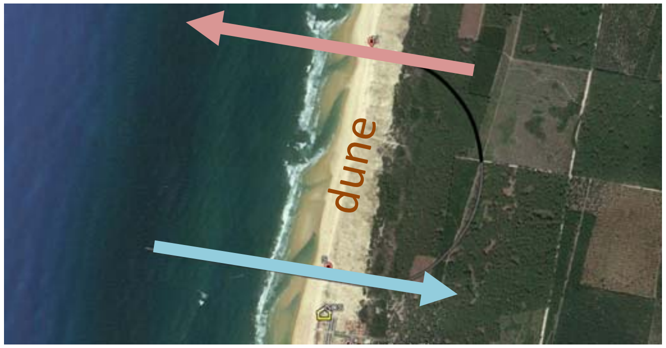


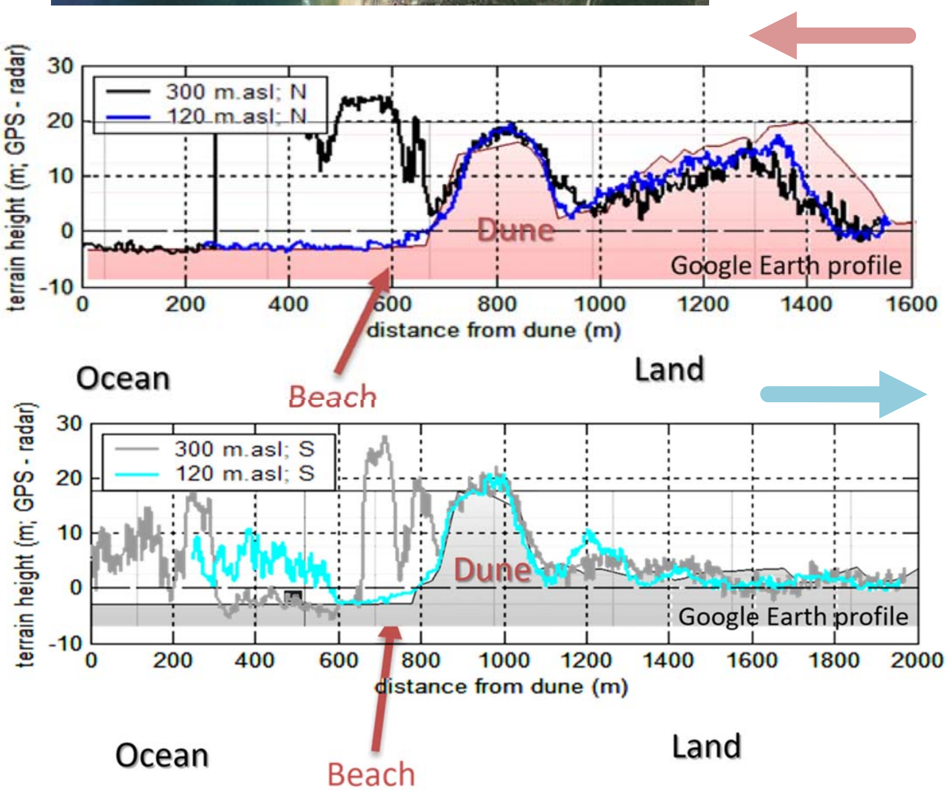
Calmer et al., AMT, 2018

- Horizontal wind vectors throughout the boundary layer
- Vertical fluxes directly measured as the covariance of the vertical wind velocity and the concentration / quantity of measured component (eddy covariance)

Wind Speed & Flux

Radar altimeter



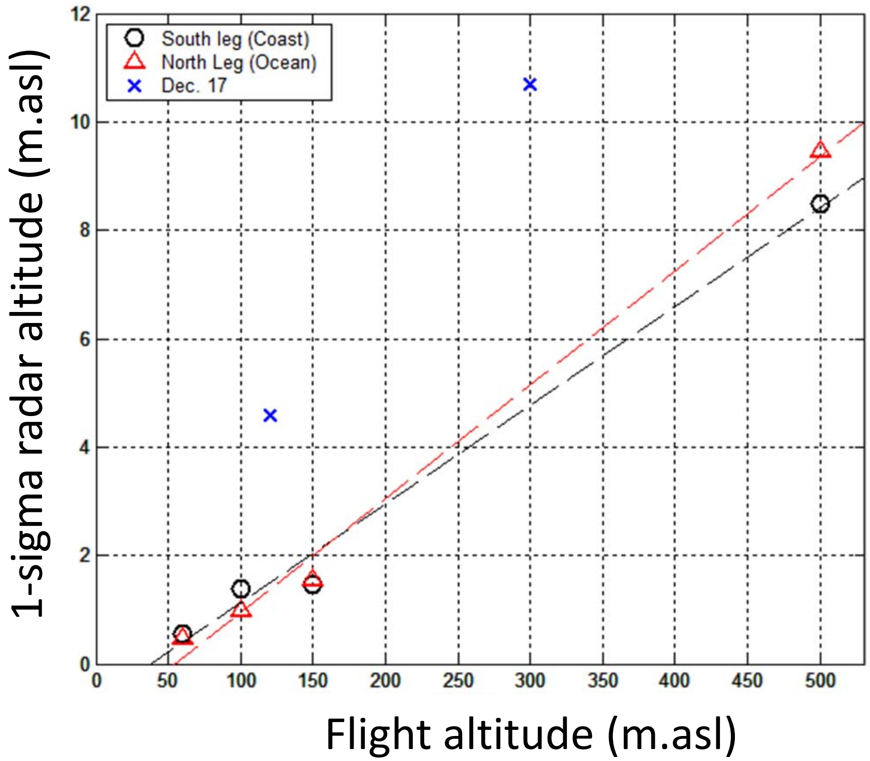


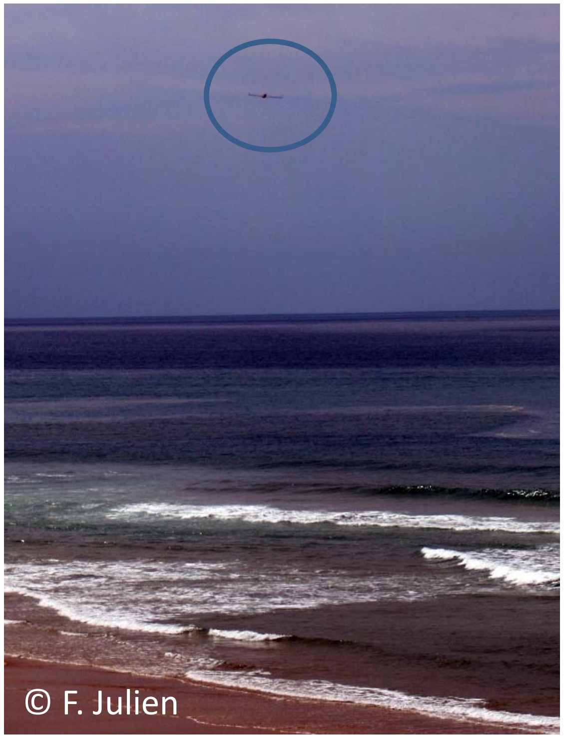
- Terrain height determined by difference between GPS and radar altitude
- Ocean and beach profile less accurate at 300 m.asl
- Higher resolution at 120 m.asl over land

→ Radar measurements over ocean perturbed by breaking waves / surf zone

Wave Height

Performance of radar altimeter



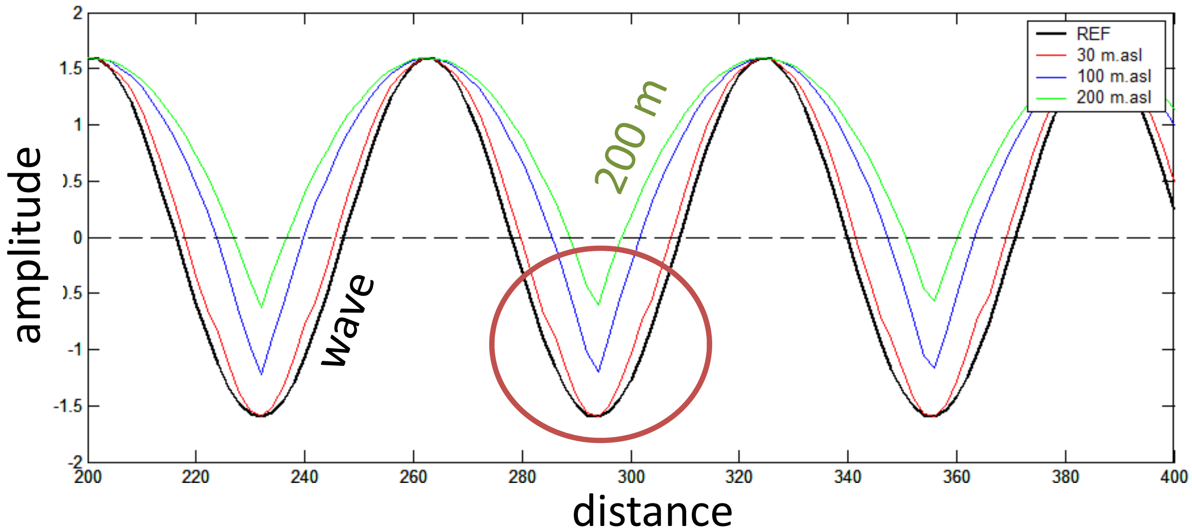


- Variability of radar altitude over the ocean and surf zone
- Decrease in perturbations from waves and white caps at lower altitude

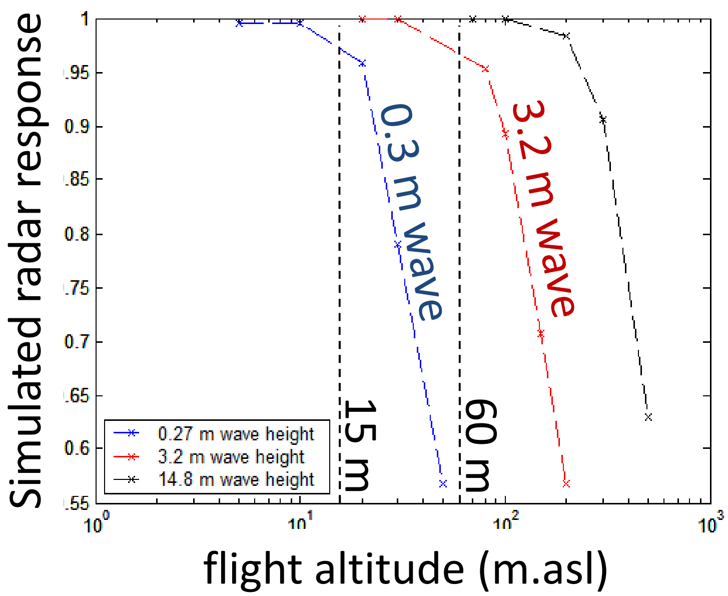
→need to test at higher waves, whitecap conditions, and lower altitude flights

Wave Height

Simulation of radar altimeter response



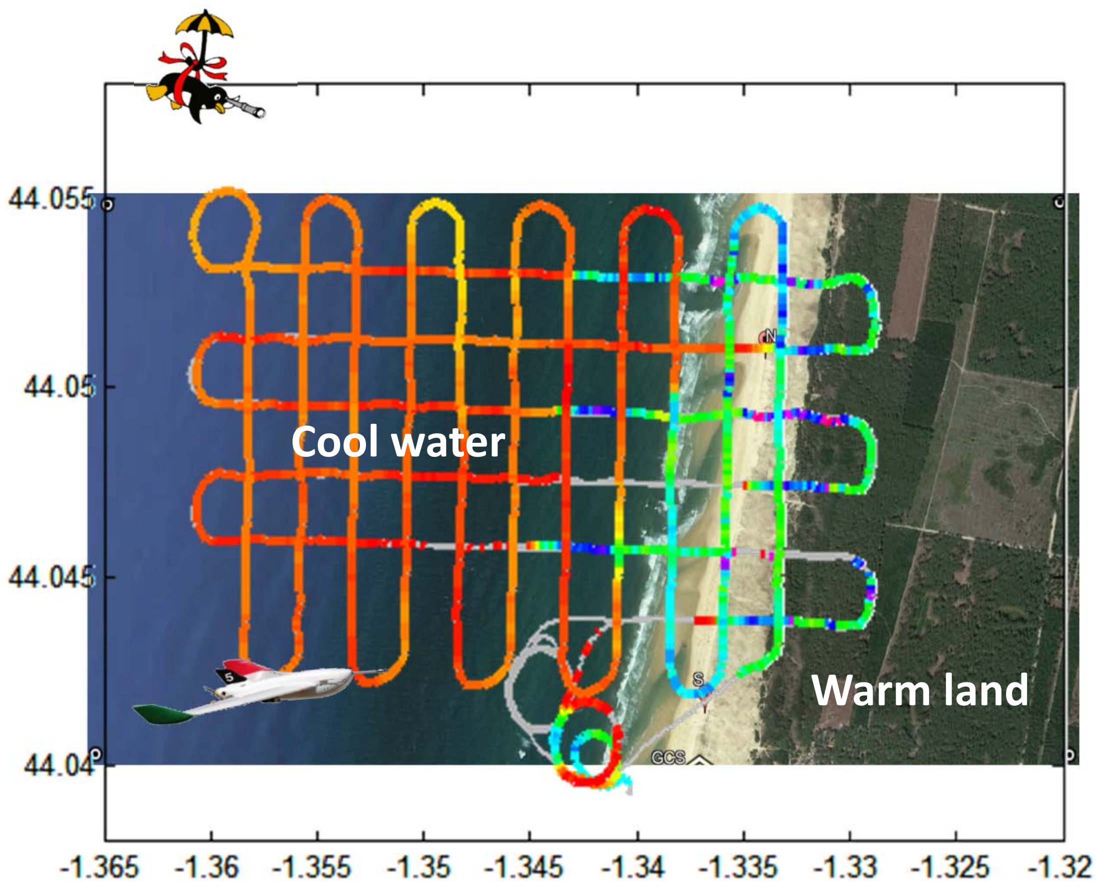
Simulated response of radar at different flight altitudes above sea level for a 3.2 m wave height with a period of 62m.
→ Discrepancy of measurement at trough



- Ratio of simulated measurements of wave height to reference wave height
- 3m waves → flight altitude < ~ 60 m.asl
- 1m waves → flight altitude < ~ 15 m.asl
- Experimental confirmation of radar response at low altitudes still needs to be confirmed

Wave Height

Sea Surface Temperature

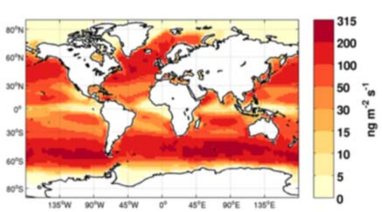


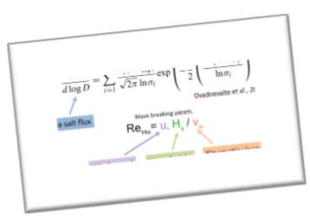
- Measurements at 60 m.asl (X6 Skywalker)
- Preliminary data to show trends (no filter or angle corrections)
- Clear distinction between land and ocean
- Differences in opposing transects related to offset in sampling angle

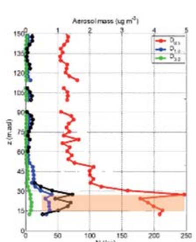
SST → viscosity

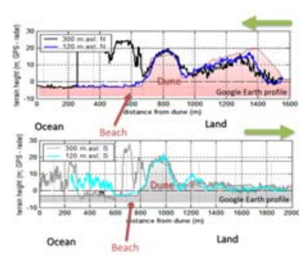
Take aways

- Measurements of aerosol over the ocean are needed to improve emission parameterizations and climate models
- Primary Marine Aerosol (i.e., sea salt) emissions are related to wind speed, sea state, sea surface temperature
- UAS flights conducted above a surf zone between 7 and 500 m.asl
- Strong gradients in aerosol (number & size) near surface → need for *in-situ* observations in lower 10s of meters of boundary layer
- Sea salt flux estimated based on vertical gradients
- Developing payload to directly measure aerosol flux, as well as each component of an emission parameterization for low altitude flights on a long-range UAS









Acknowledgements

Mesures sc*I*entifiques de flux de su**R**face en m**I**lieu m**A**ritime par **D**rone

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