Effect of a sea spray layer on ocean surface signal at GPS frequencies

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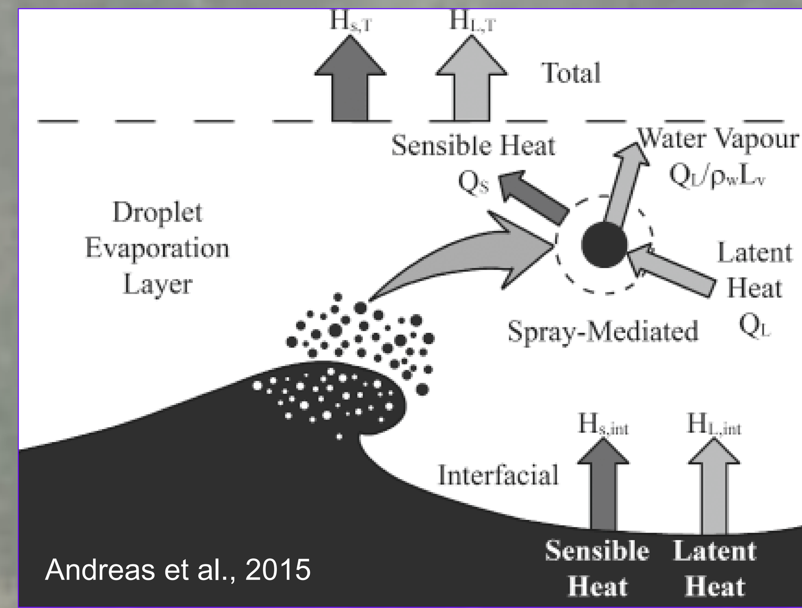
Background

❖ Sea spray intensifies hurricanes by increasing the enthalpy flux

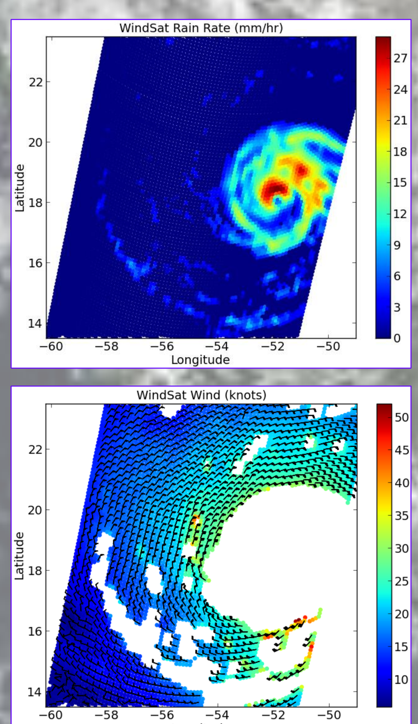
- ➢ Cooling and evaporation of sea spray change the temperature and humidity in the marine boundary layer
- ➢ Spray-mediated latent and sensible heat fluxes increase the enthalpy



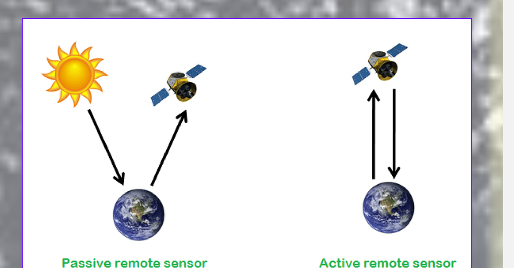
Andreas et al., 2015

❖ Geophysical variables needed for hurricane studies:

- ➢ Wind speed
- ➢ Rain rate
- ➢ Enthalpy (lat + sen heat)
  - ❑ Air temperature
  - ❑ Humidity

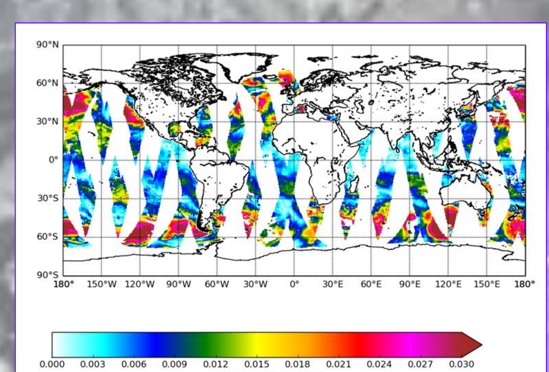


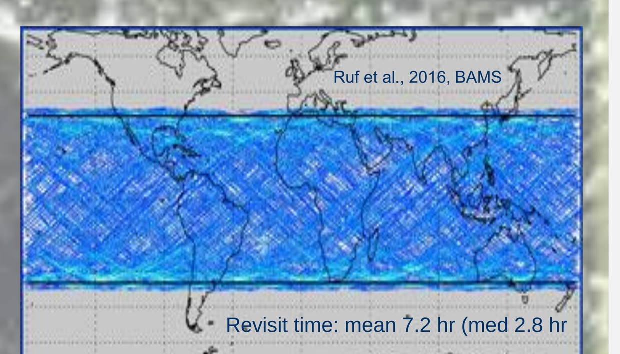
❖ Remote sensing data



❖ Limitation of current hurricane remote sensing:

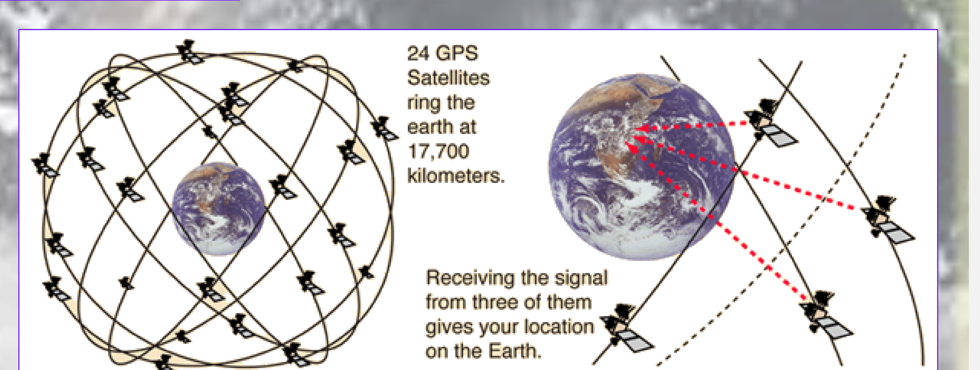
- ➢ Weather conditions
- ➢ Temporal resolution





❖ Use of GPS (L band)

- ➢ High temporal resolution
  - ❑ Multiple GPS transmitters
  - ❑ NASA mission CYGNSS
- ➢ All weather
  - ❑ Low frequency: < 1.6 GHz
  - ❑ Long wavelengths: 19 cm

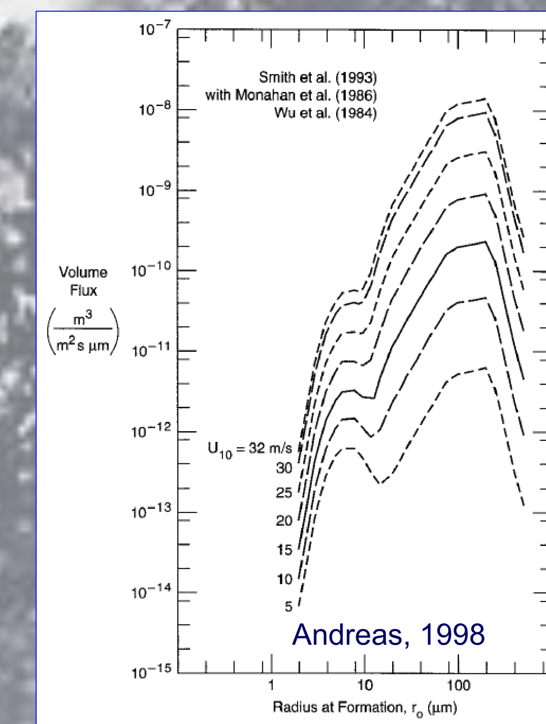


Need radiative transfer model for sea spray

Background image: VIIRS on NOAA Suomi NPP satellite
Three simultaneous hurricanes active on 8 Sep 2017:
Katia (left), Irma (center), and Jose (right)

Approach

Veron, 2015



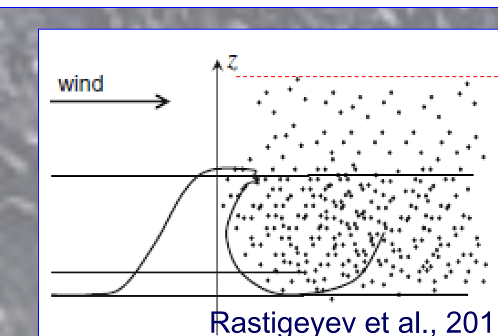
Andreas, 1998

❖ Heat exchange related to the **volume flux** of sea spray

❖ Large **spume** droplets are most relevant

- ➢ Produced at the wave crests
- ➢ Spray above the waves is thus investigated
- ➢ Spray layer scaled with the significant wave height H_s

❖ Vertically inhomogeneous seawater content Q



Rastigeyev et al., 2011

$$Q(z) = z^{-m}, \quad m = \frac{V_g}{k u_*}, \quad k = 0.4$$

Fairall et al., 2009

❖ Dielectric constant of sea spray layer $\varepsilon_s(z)$ (quadratic mixing rule)

$$\varepsilon_s(z) = \left[Q(z)\sqrt{\varepsilon} + \left(1 - Q(z)\right)\right]^2$$

❖ Sea spray layer attenuation

$$\alpha(z) = \frac{2\pi F}{c} \cdot \left|\mathrm{Im}\sqrt{\varepsilon_s(z)}\right|$$

❖ Radiative transfer model for e_s

$$T_B = e_s T = T_{BU} + T_{BD} + T_{Bw}$$

❖ Sea spray reflectivity r_s from e_s

$$r_s = 1 - e_s$$

❖ Input parameters:

- ➢ GPS freqs F = (L1, L2, L5, Aq) = (1.5754, 1.2276, 1. 1765, 1.4) GHz
- ➢ Friction velocity from U_{10N} = 10–60 m s^{-1}
- ➢ With H_s = 5–7 m and z/H_s = 3–5, spray layer from 15 to 35 m
- ➢ Mean $V_g \cong 1$ m s^{-1} for droplets of 100 – 200 µm
- ➢ Seawater temperature T_s = 28 °C
- ➢ Salinity S = 34 psu

References

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Meissner and Wentz, 2004, *TGRS*, **42**, 1836-1849
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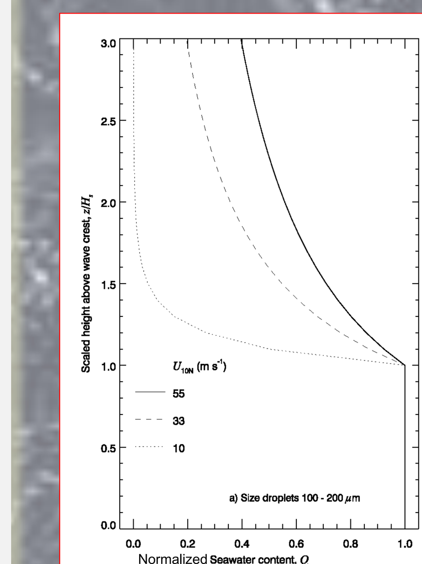
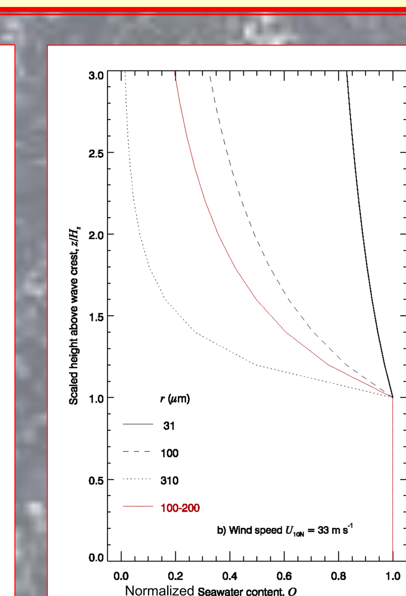
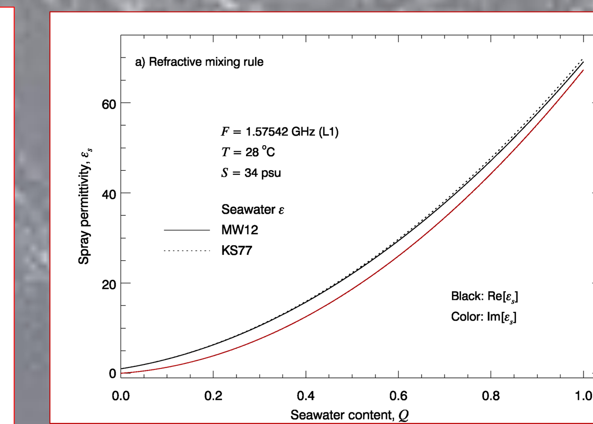
Results

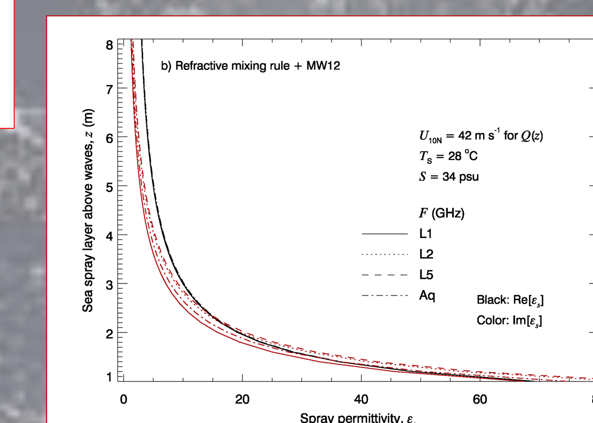
Spray layer vertical properties



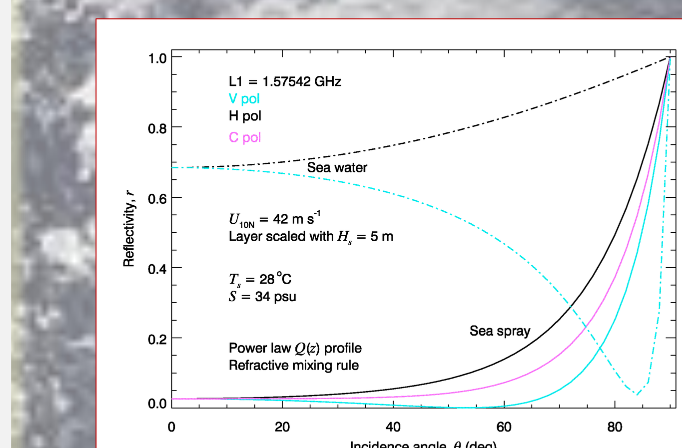


Large droplets and high winds create similar $Q(z)$ profiles

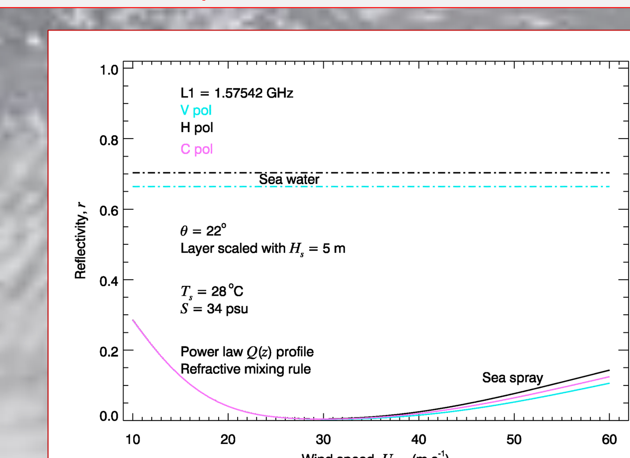




Spray layer reflectivity



The shape of the $r_s(U_{10N})$ curve strongly depends on the droplet size and its terminal velocity



Conclusions

❖ Sea spray layers vary with conditions

- ➢ Partly transparent
- ➢ Weakly to none reflective
- ➢ Attenuating

❖ Gradual change of spray layer permittivity yields

- ➢ Impedance matching with sea surface
- ➢ Facilitates absorption close to the surface
- ➢ May diminish reflection of GPS signal

❖ Skin depth < 5 cm of a spray layer with only Q = 20%

- ➢ Enough to provide a signal at L1
- ➢ Thicker spray layers may form in hurricane conditions