Air-Sea Gas Exchange

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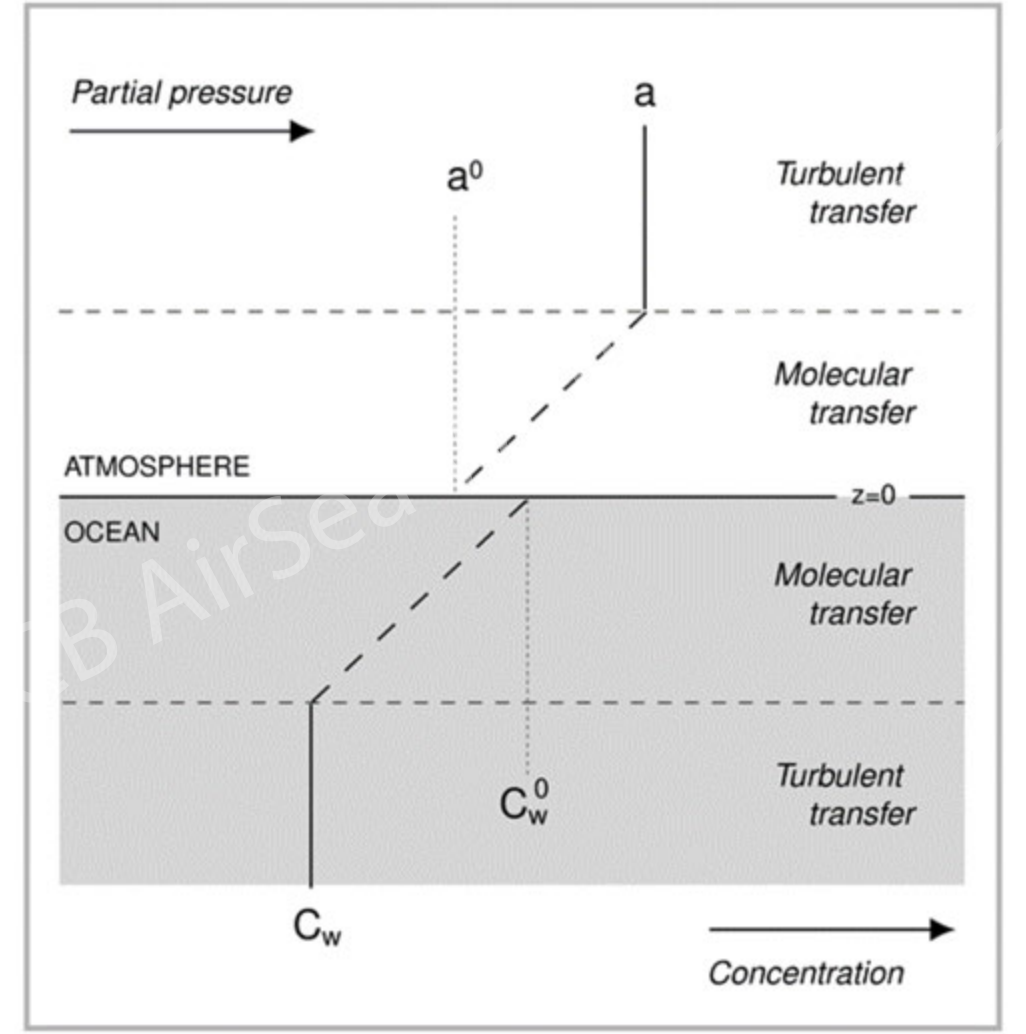
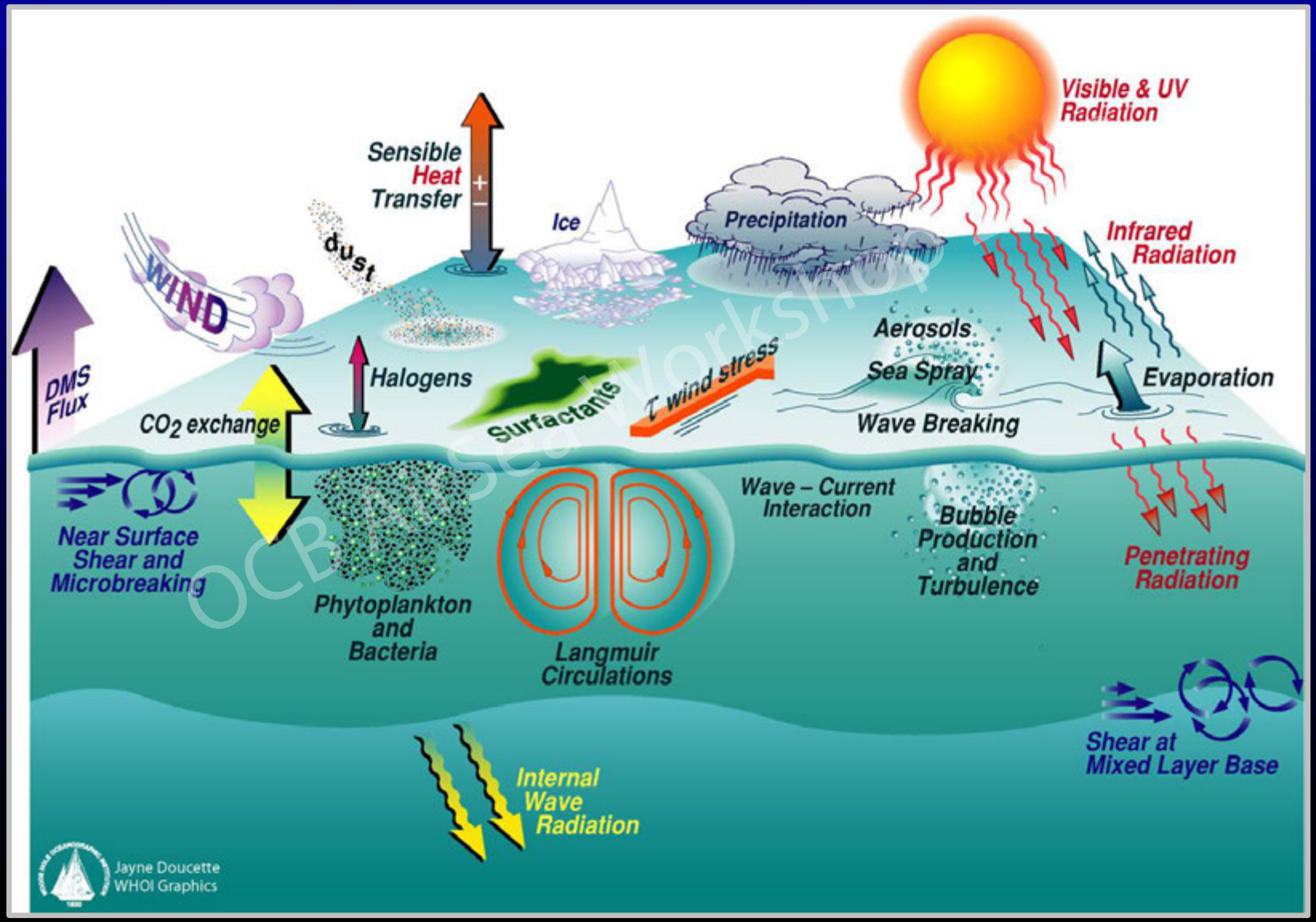
Conceptual Model of the Process

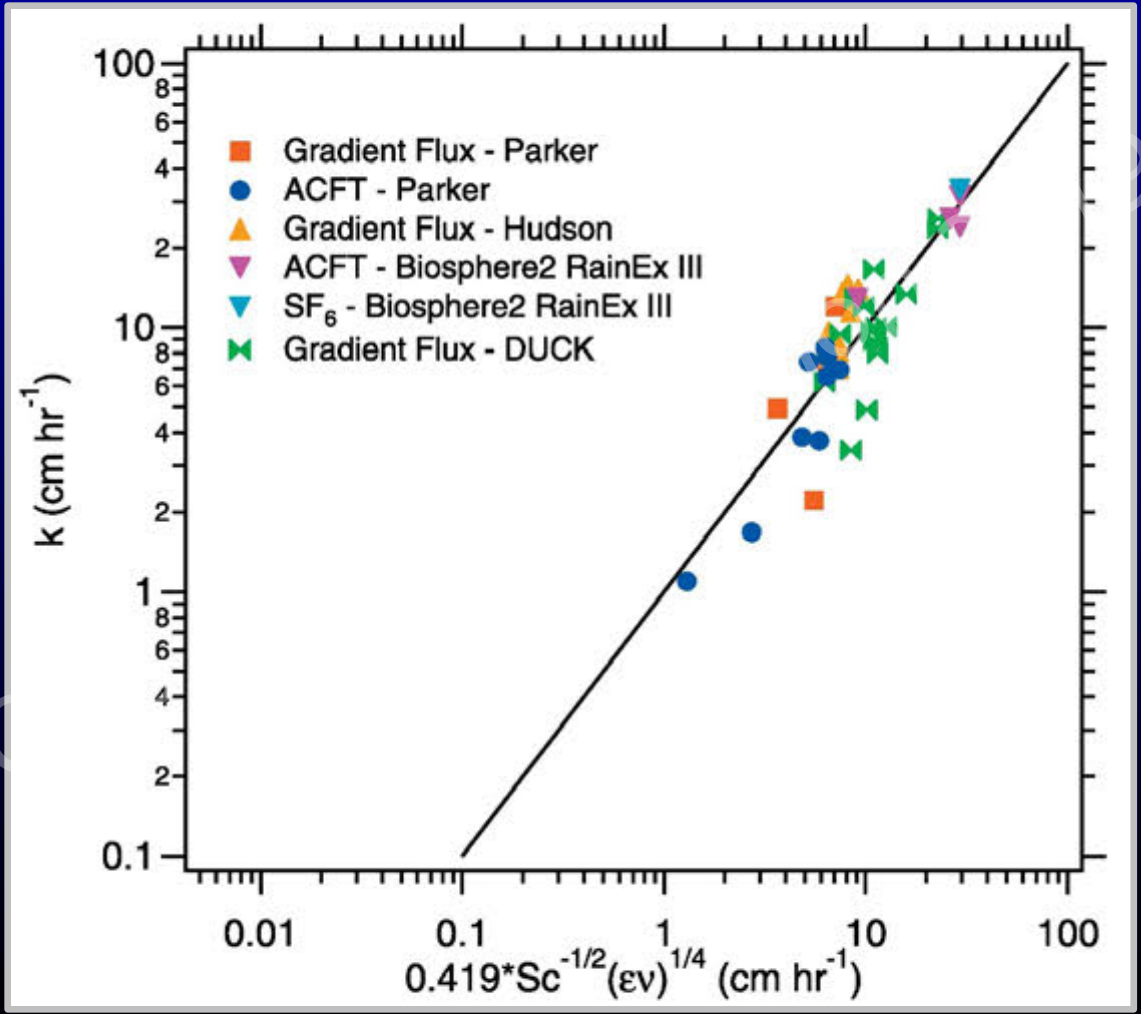


From Sarmiento and Gruber, 2004

Forcing Factors

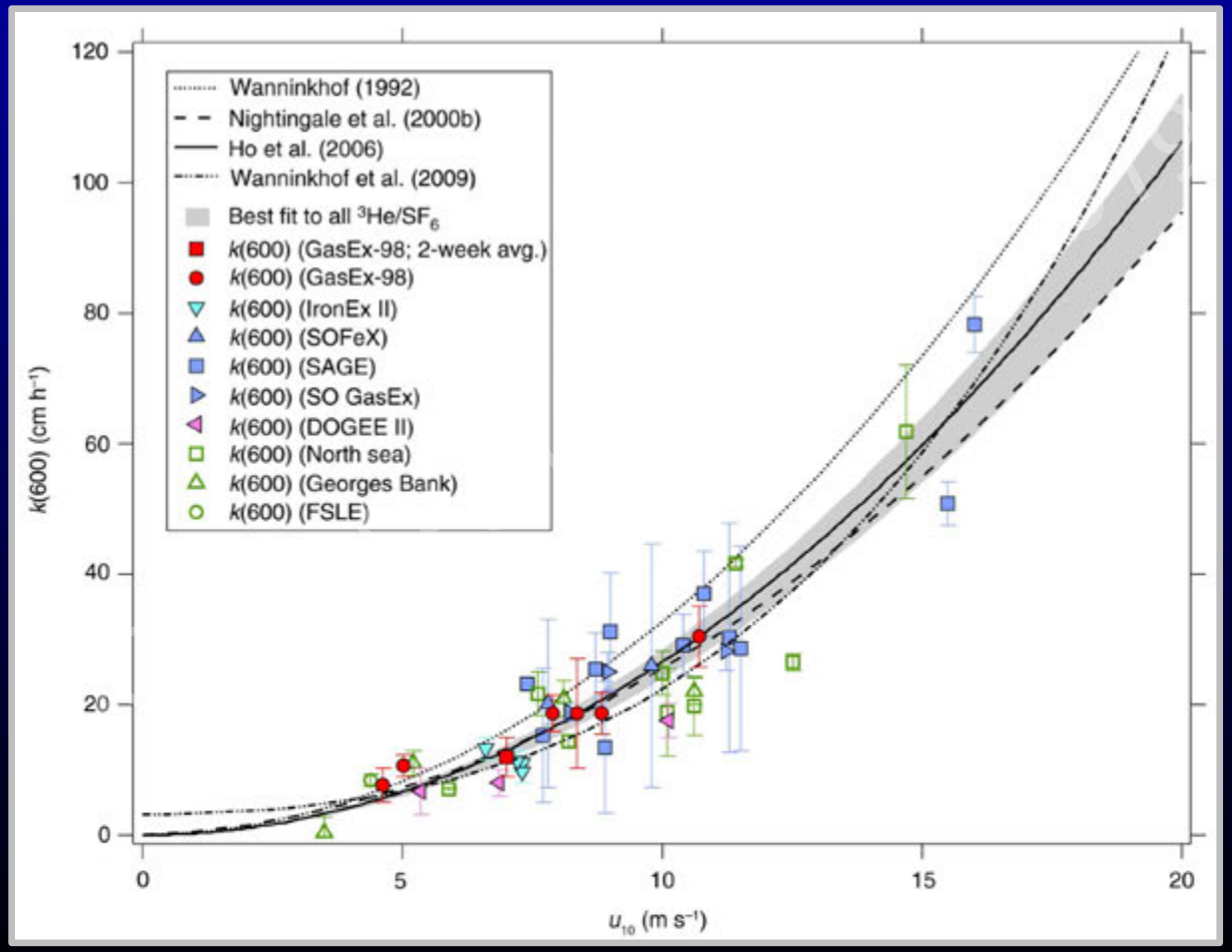


Dependence on Turbulence



Zappa et al., 2007

Central Role of Wind Speed



Ho and Wanninkhof, 2016

Complicated is Way Way Better

$$k_{\mathrm{COAREG}} = \frac{u_{*\mathrm{A}}}{\sqrt{\frac{\rho_{\mathrm{W}}}{\rho_{\mathrm{A}}}}\left[h_{\mathrm{W}}\,\mathrm{Sc}_{\mathrm{W}}^{1/2} + \frac{\ln\left(\frac{z_{\mathrm{W}}}{\delta_{\mathrm{W}}}\right)}{\kappa}\right] + \frac{k_{\mathrm{b}}}{u_{*\mathrm{A}}} + \alpha\left[h_{\mathrm{A}}\,\mathrm{Sc}_{\mathrm{A}}^{1/2} + C_D - 5 + \frac{\ln\left(Sc_{\mathrm{A}}\right)}{2\kappa}\right]}$$

$$h_X = \frac{\Lambda R_{rX}^{1/4}}{\varphi}$$

The COARE-G Parameterization

No Really, COARE-G is Simple

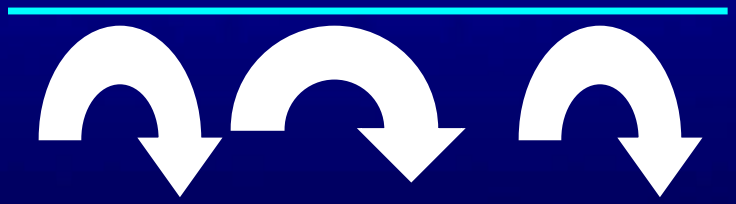
$$k = \frac{u_{*\mathrm{A}}}{r_{\mathrm{W}} + \alpha r_{\mathrm{A}}}$$

$$r_{\mathrm{W}} = \left[r_{\mathrm{Wt}} + \frac{k_{\mathrm{B}}}{u_{*\mathrm{A}}} \right]^{-1}$$

$$k_{\mathrm{B}} = \frac{B V_0 f_{wh}}{\alpha} \left[1 + \left(e \alpha \mathrm{Sc}_{\mathrm{W}}^{-1/2} \right)^{-1/n} \right]^{-n}$$

Do Surfactants Affect Gas Transfer?

Hydrodynamic Control: Affect turbulence near the interface



Clean

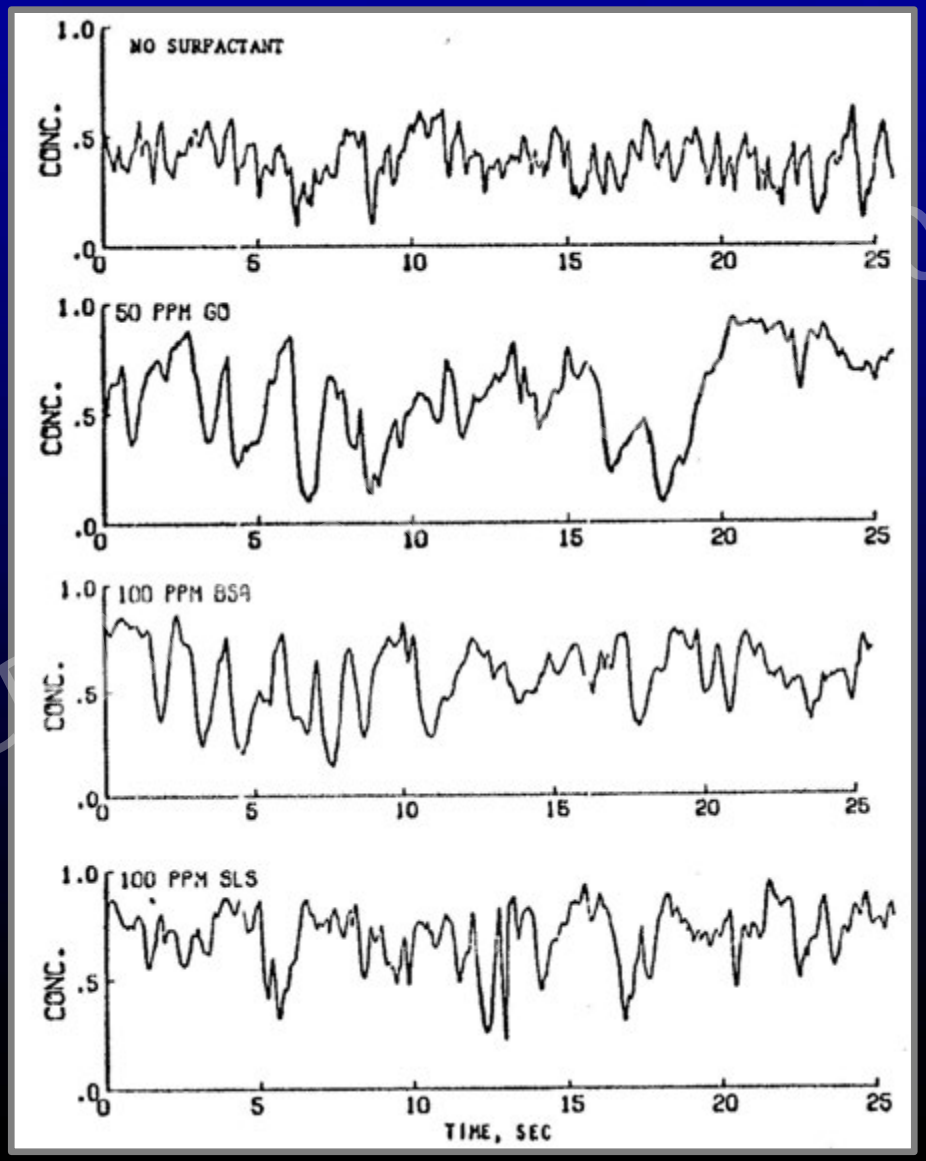
Surfactant-influenced

Soluble and insoluble surfactants
(*e.g.*, 1-octadecanol, SDS, Triton X-100)

Can operate at higher turbulence intensities
(film gets disrupted by turbulence)

Presence of surfactant adds tangential stress
Affects motions very near interface
Damps less energetic eddies

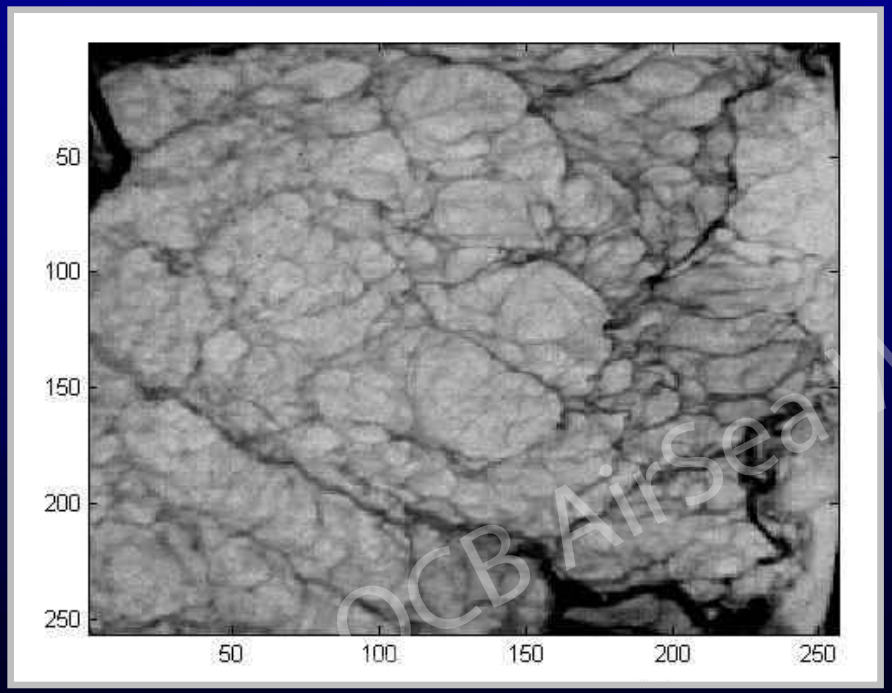
Evidence for Hydrodynamic Effects



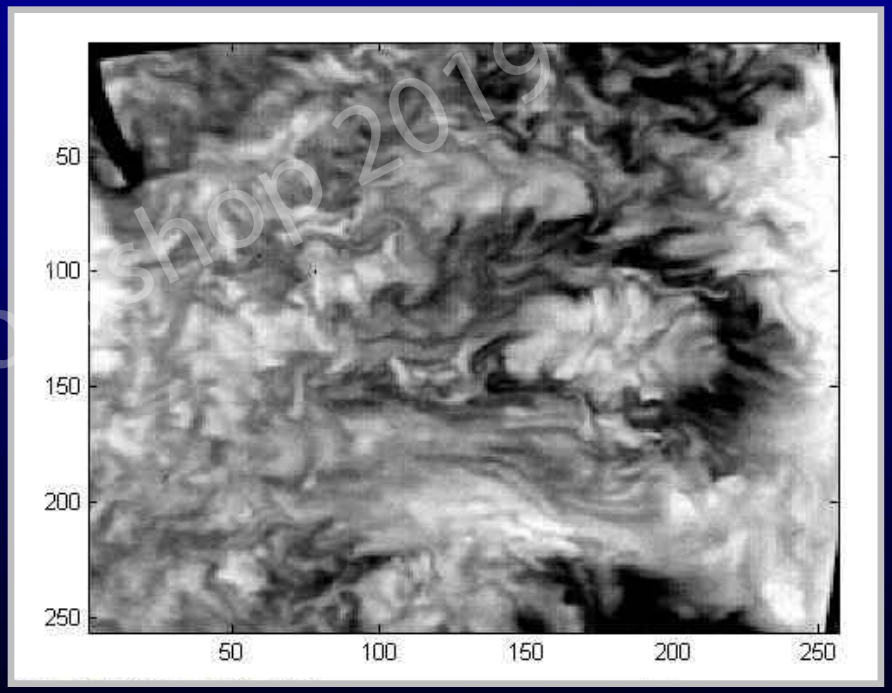
Lee et al., 1978

Evidence for Hydrodynamic Effects

25 cm



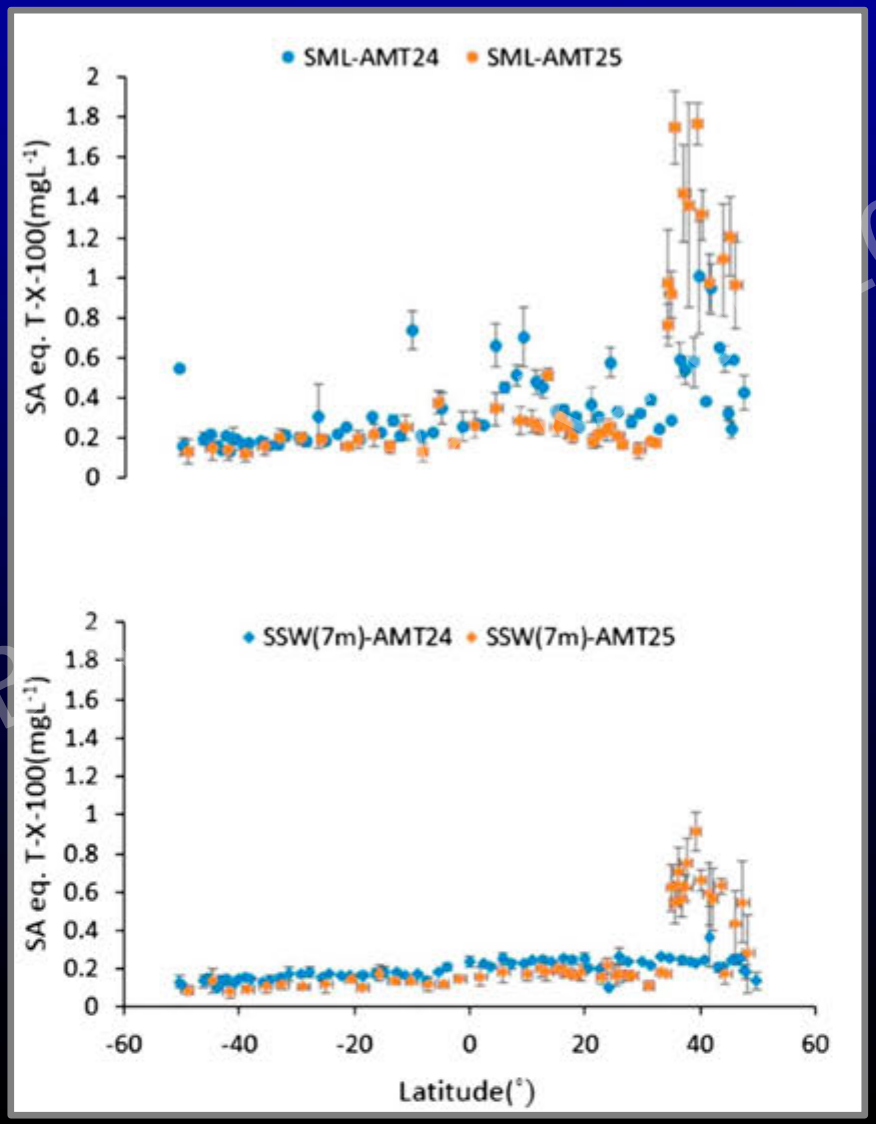
Clean Surface



Surfactant-Influenced Surface

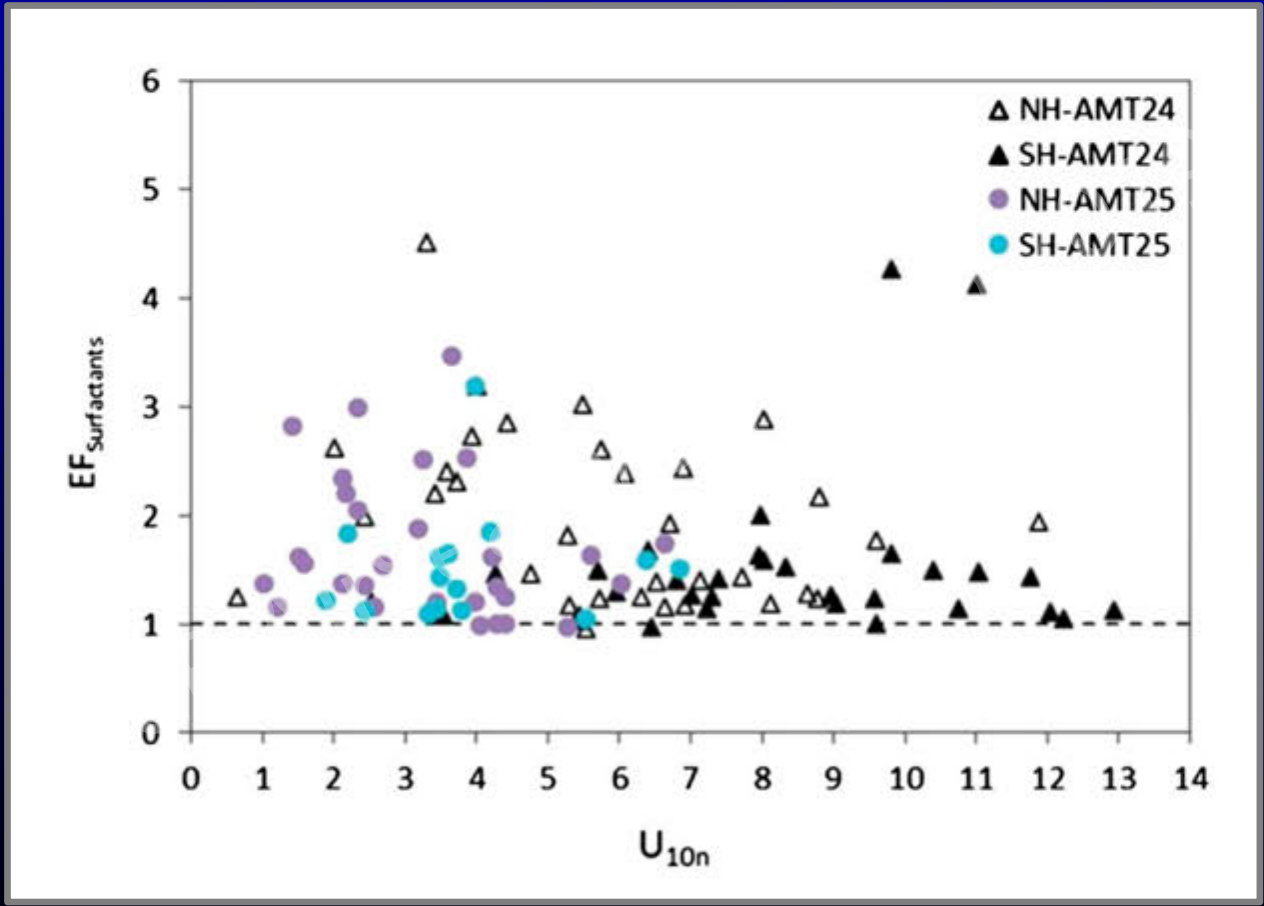
APL-UW, SJAT, 2007

Naturally Occurring Surfactants



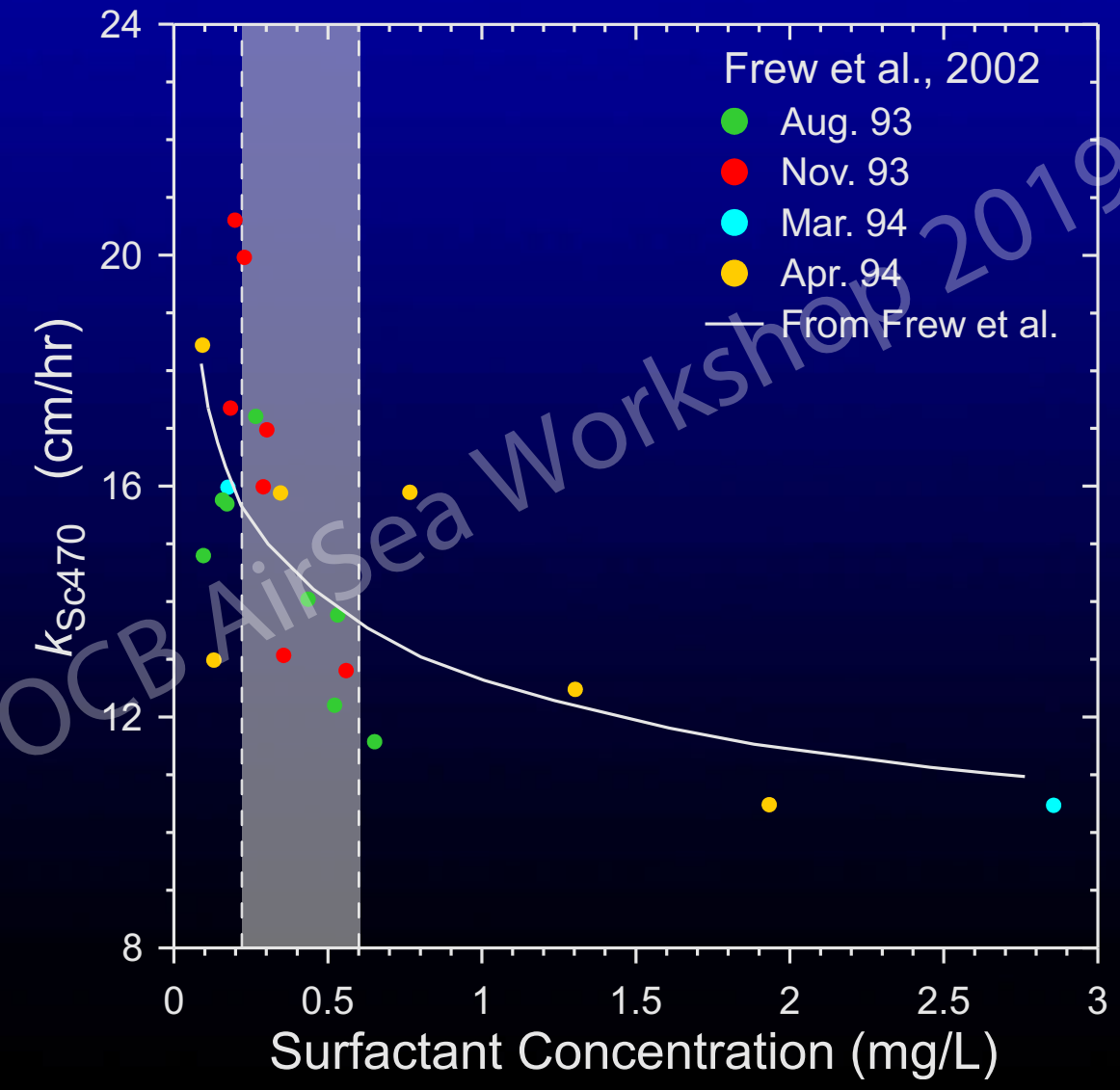
Sabbaghzadeh et al., 2017

Wind Effects on Surface Microlayer

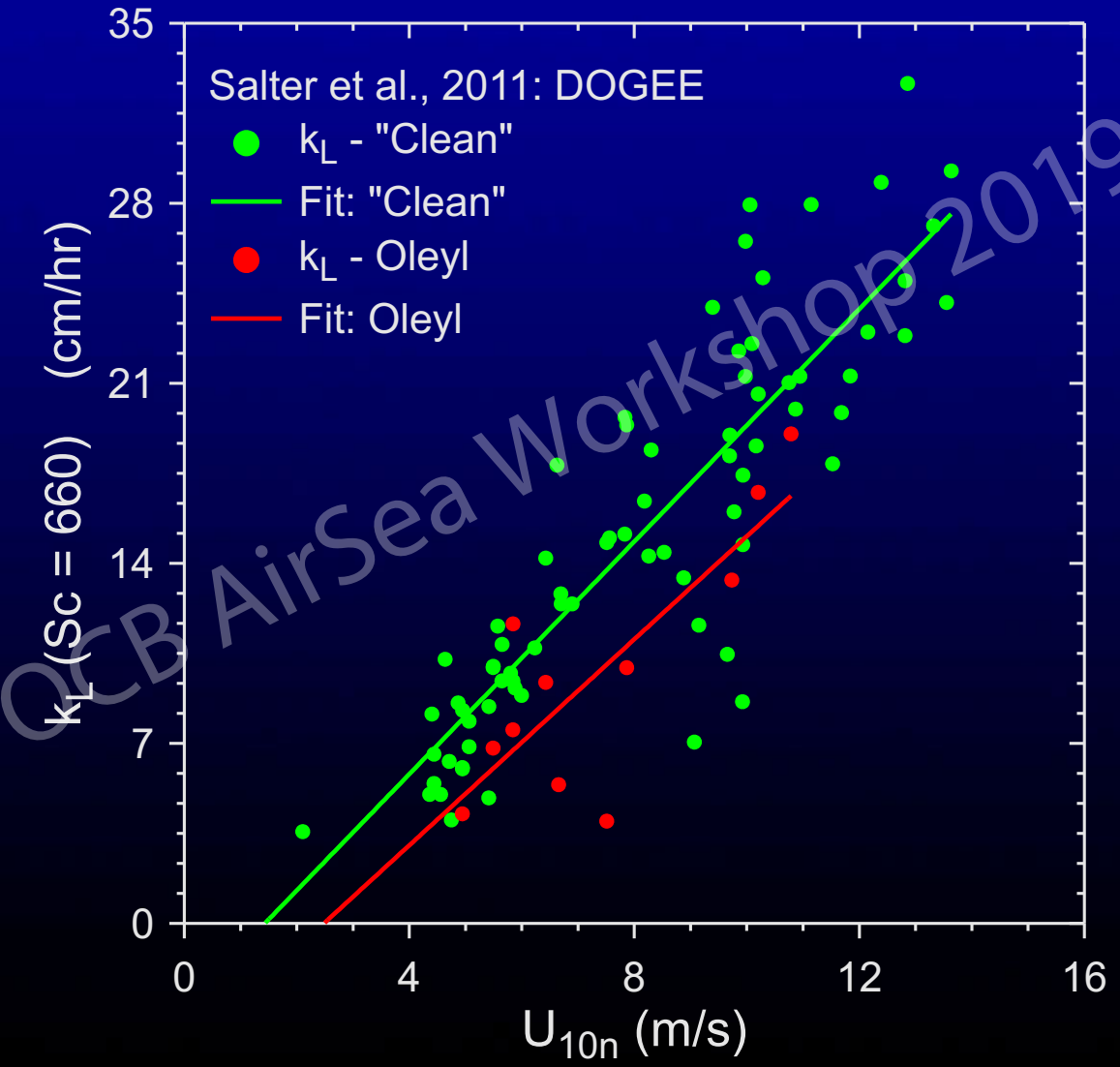


Sabbaghzadeh et al., 2017

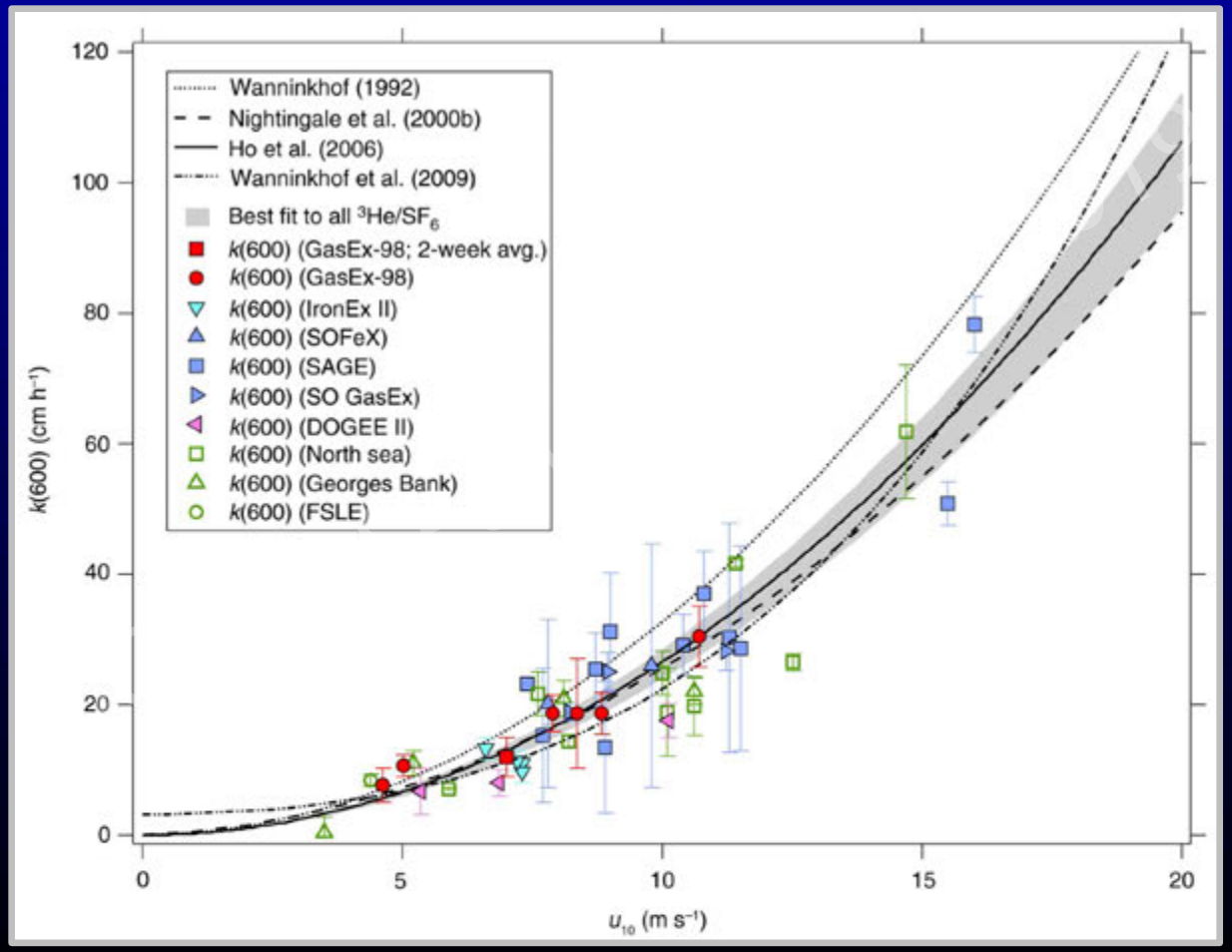
Are these concentrations relevant?



The DOGEE data

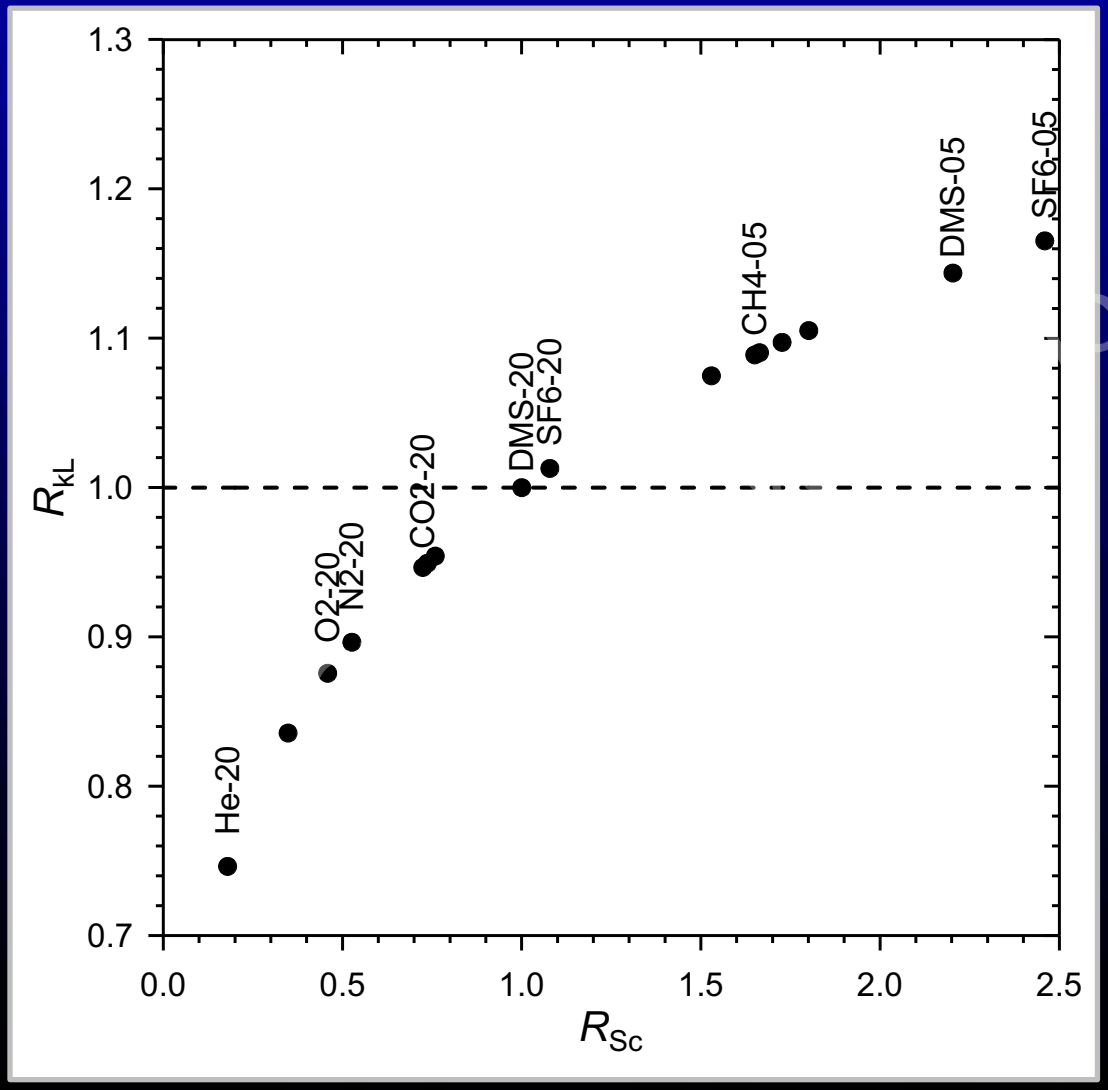


Central Role of Wind Speed



Ho and Wanninkhof, 2016

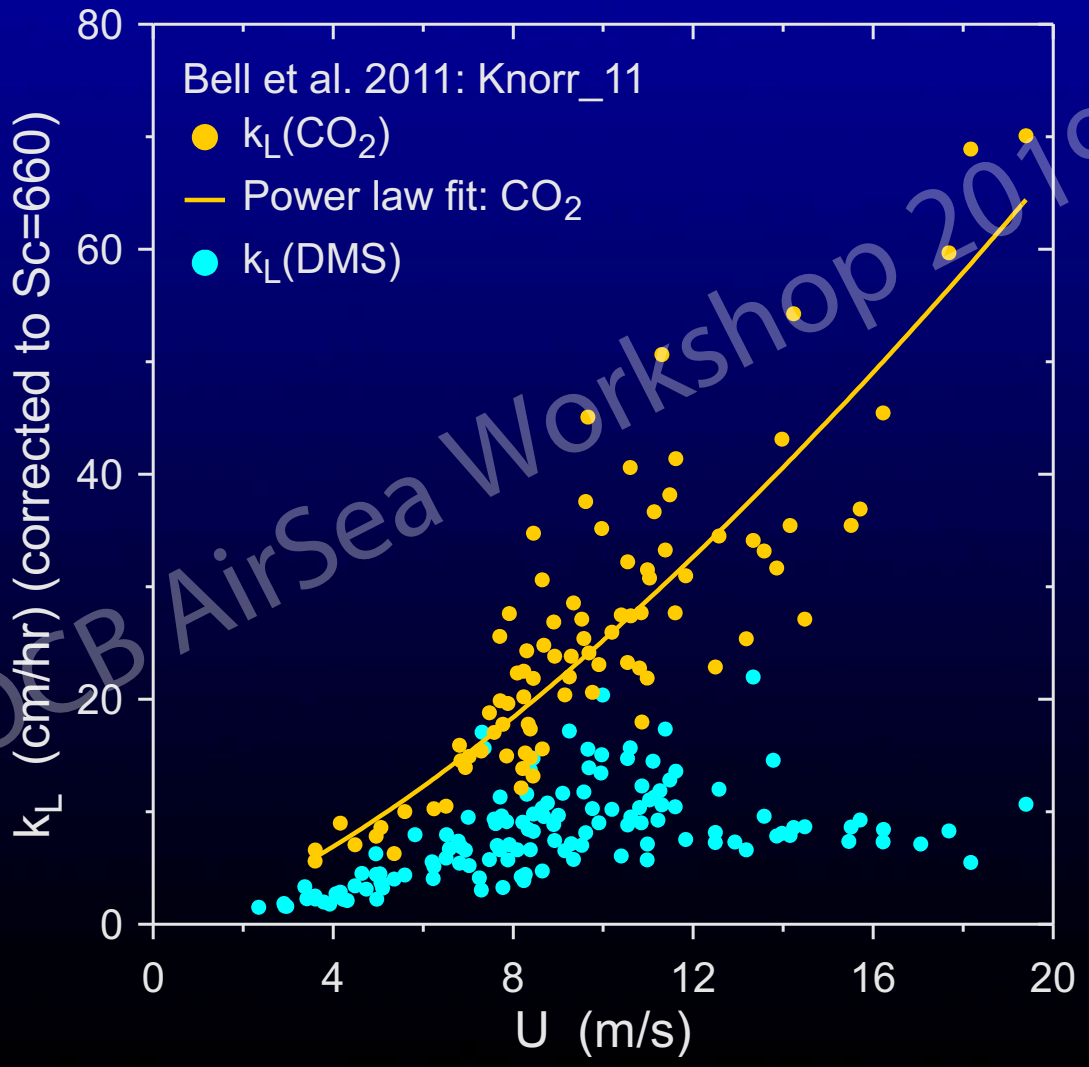
Penalty for Assuming $n = 0.5$ if $n = 0.67$



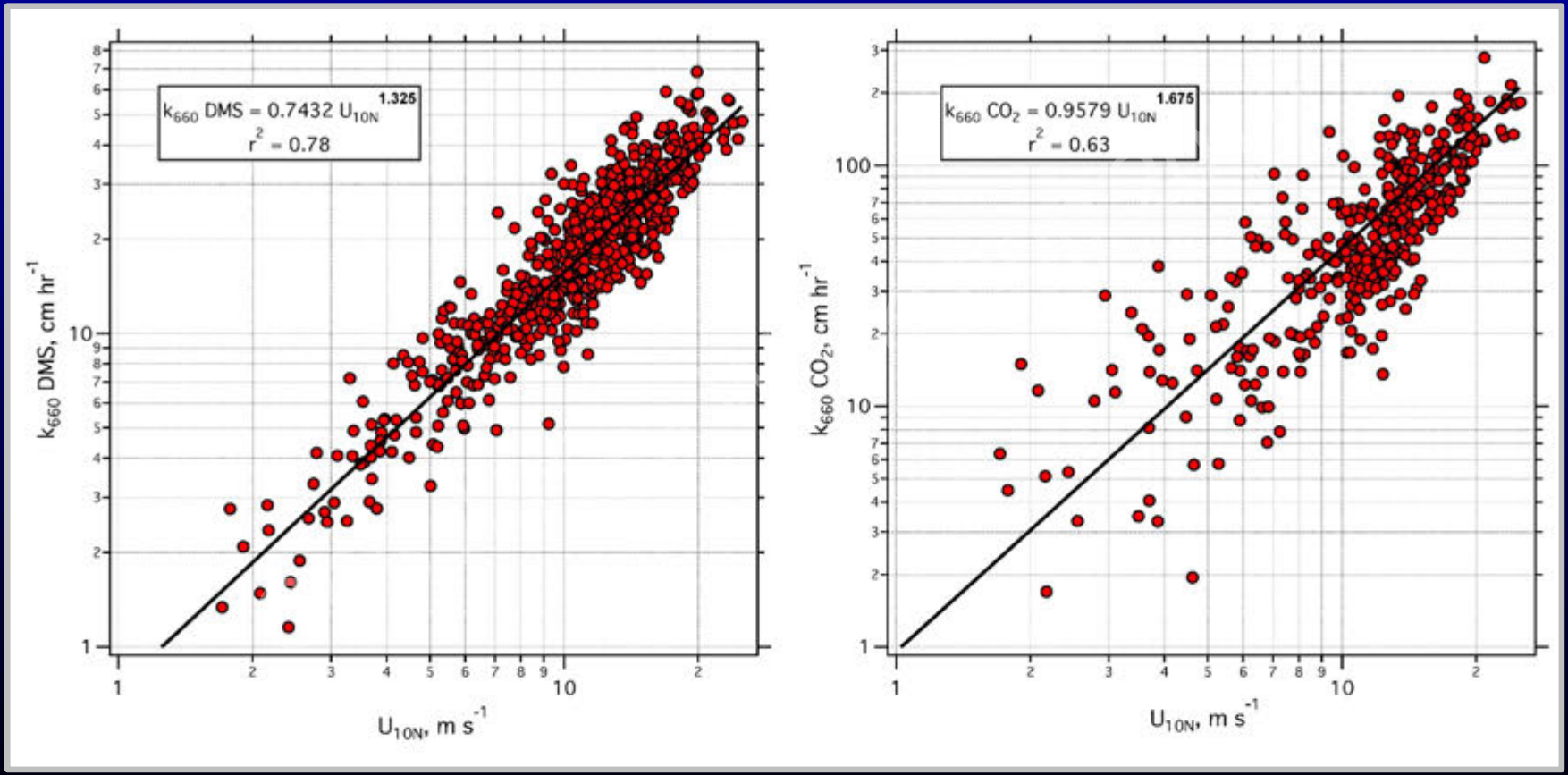
$$k = AU^{x}\,\mathrm{Sc}^{-n}$$

$$R_{kL} = \frac{\left(\frac{Sc_2}{Sc_1}\right)^{1/2}}{\left(\frac{Sc_2}{Sc_1}\right)^{2/3}}$$

High Wind Speeds and Bubbles



Is this a big controversy?



Blomquist et al., 2017

Looking Back

There have been some solid advances over the past 25 years:

1. Have (mostly) quantitative methods for extracting whitecap data
2. Surfactants shown to be ubiquitous at the ocean surface
3. Direct covariance method demonstrated to be useful for gases
4. Parameterizations for k in terms of U or u_* are reaching the point of usability across experiments (for low to intermediate wind speeds)

Going Forward

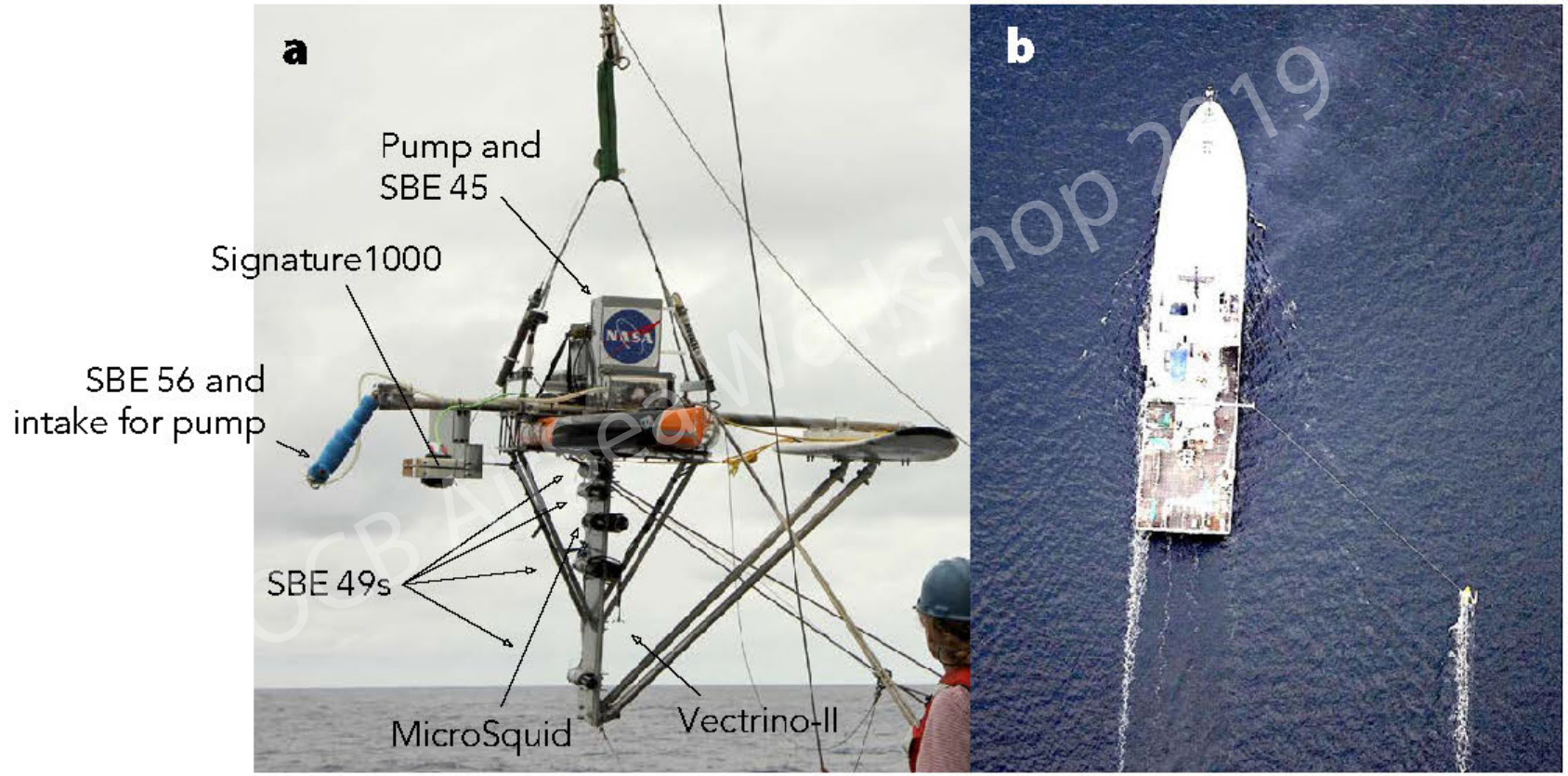
There are some relatively large gaps in parameterizing k:

1. The dependence of k on Sc remains largely unknown in the ocean

2. The effect of bubbles, while understood in principle, is poorly parameterized by existing methods

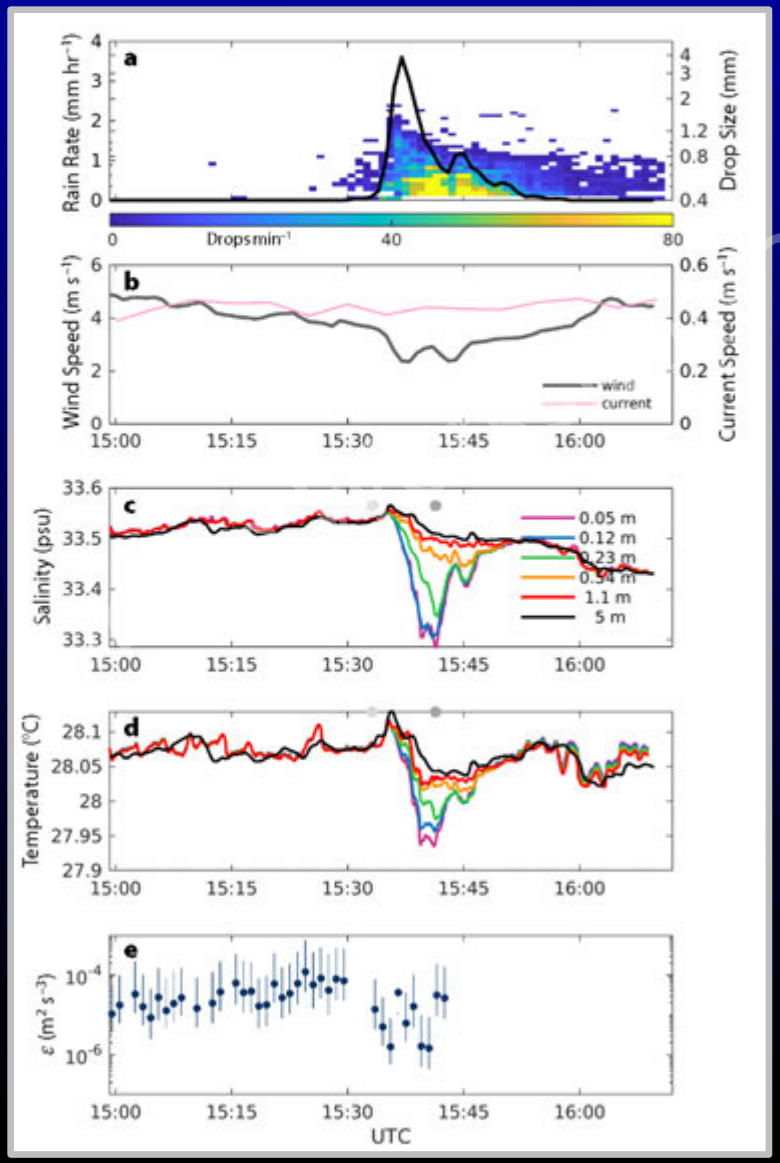
3. It would be useful to have some way to measure turbulence in the upper 50 cm of the ocean

Surface Salinity Profiler



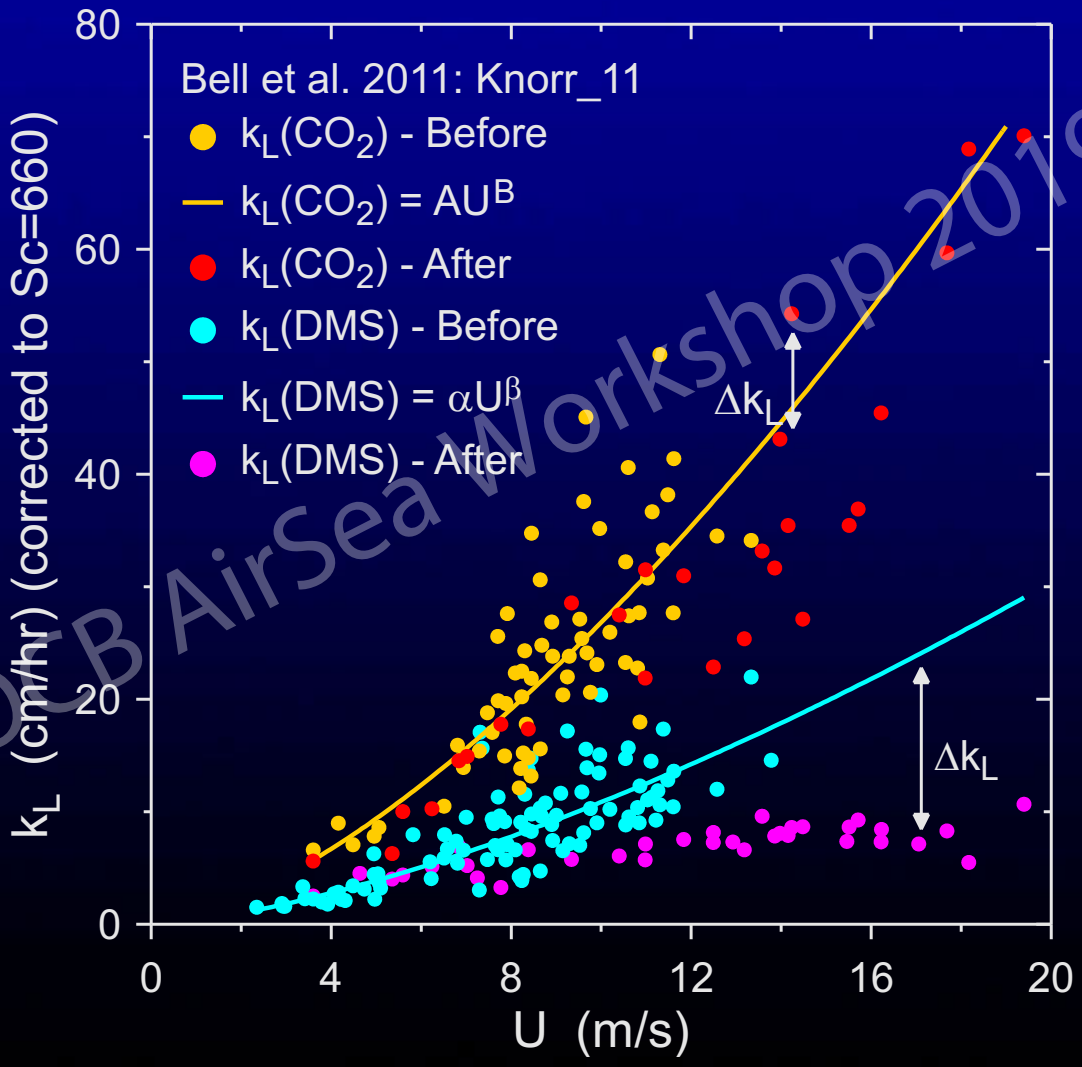
Drushka et al., 2017

SSP Turbulence, Preliminary Data

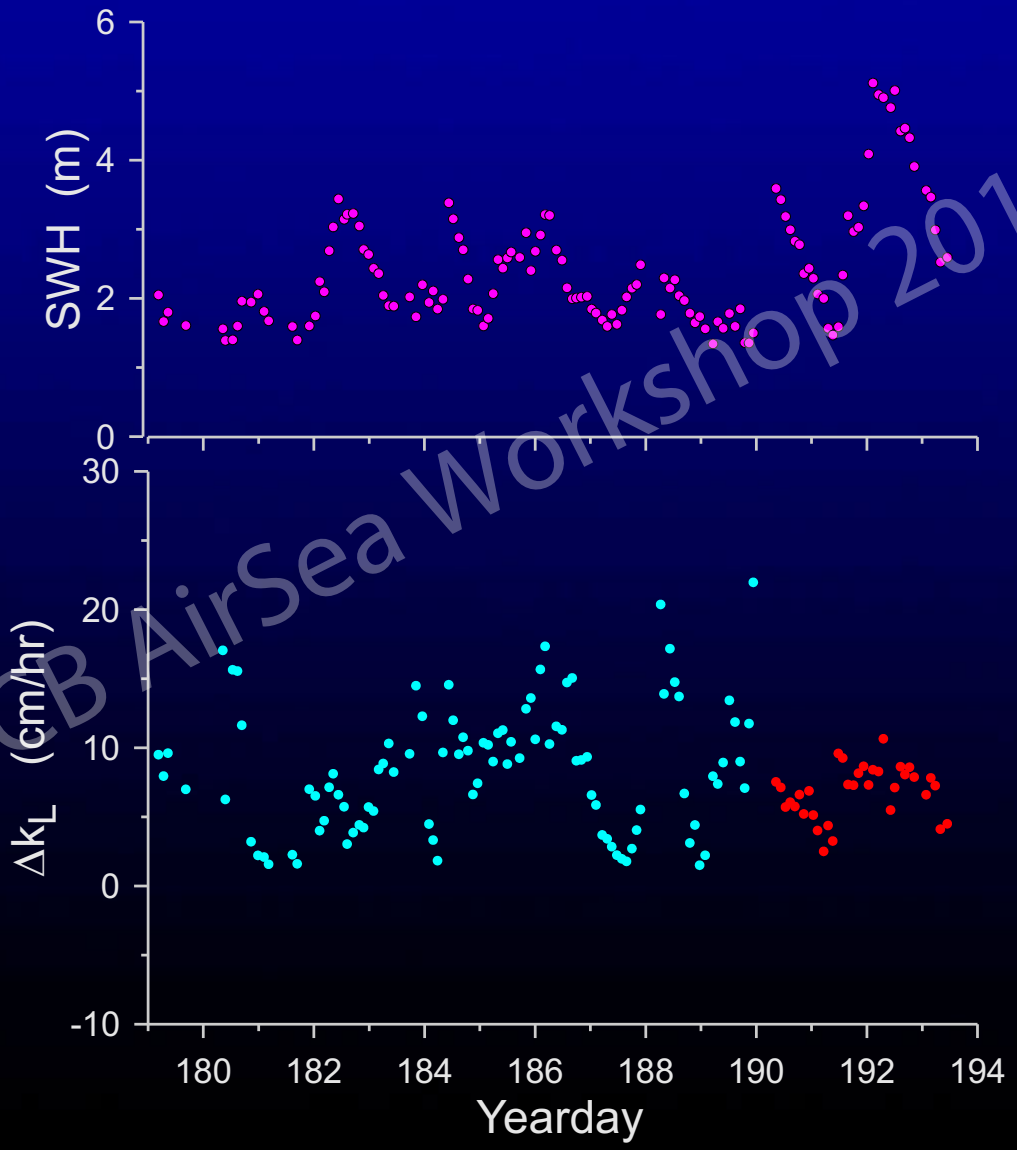


Drushka et al., 2017

Are Conditions Consistent?



Definitely not



Bell et al., 2017