The Physical and Aerodynamic Roughness of Sea Ice

Ed Andreas

NorthWest Research Associates
Lebanon, New Hampshire

Parameterize Turbulent Surface Flux

Momentum Flux:

$$\tau \equiv -\rho \overline{uw} = \rho u_*^2 = \rho C_{Dr} S_r^2$$

Sensible Heat Flux:

$$H_s \equiv \rho c_p \overline{wt} = \rho c_p C_{Hr} S_r \left(T_s - T_r \right)$$

Latent Heat Flux:

$$H_L \equiv \rho L_v \overline{wq} = \rho L_v C_{Er} S_r \left(Q_s - Q_r \right)$$

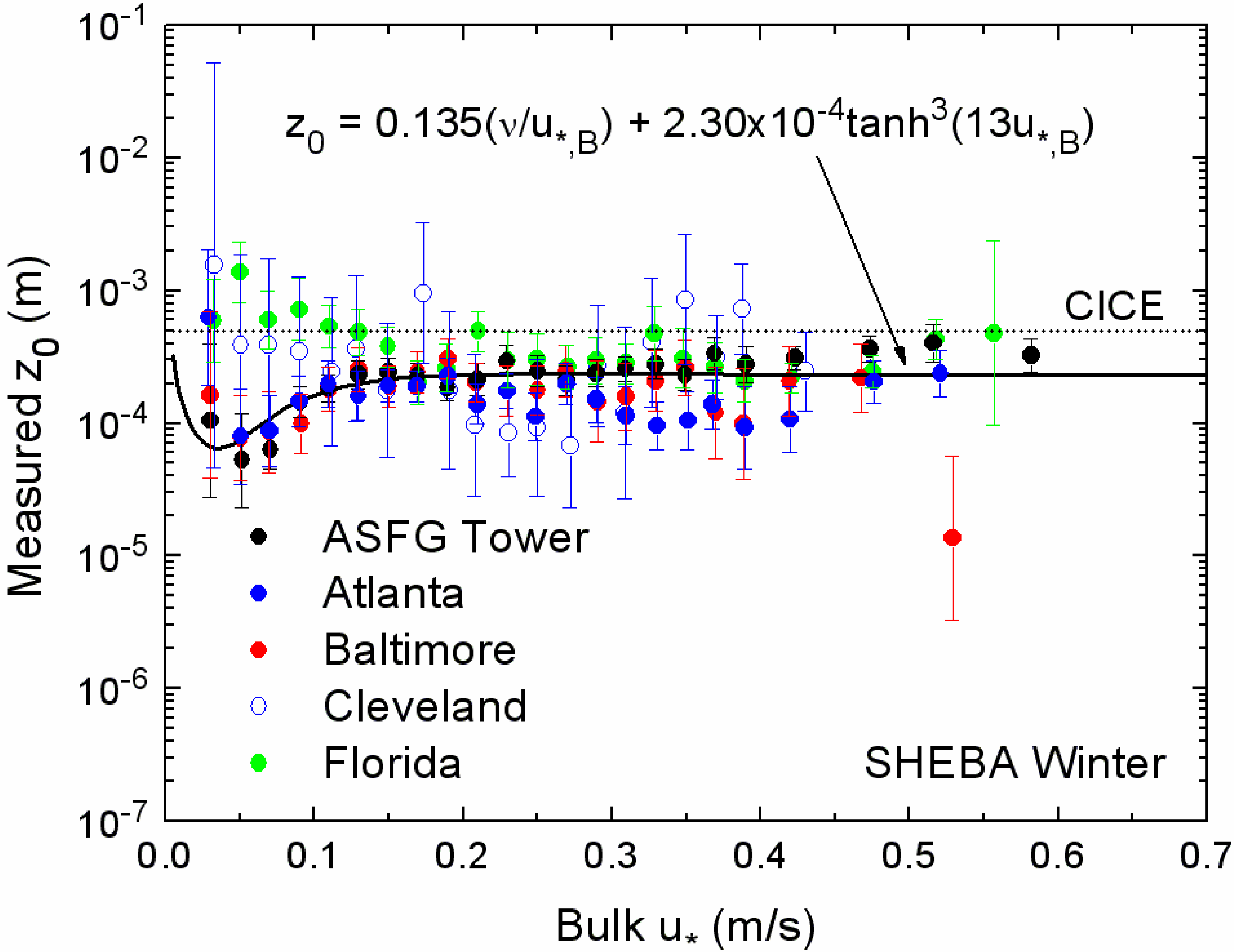
Drag Coefficient

$$C_{Dr} = \frac{k^2}{\left[\ln\left(r/z_0\right) - \psi_m\left(r/L\right)\right]^2}$$

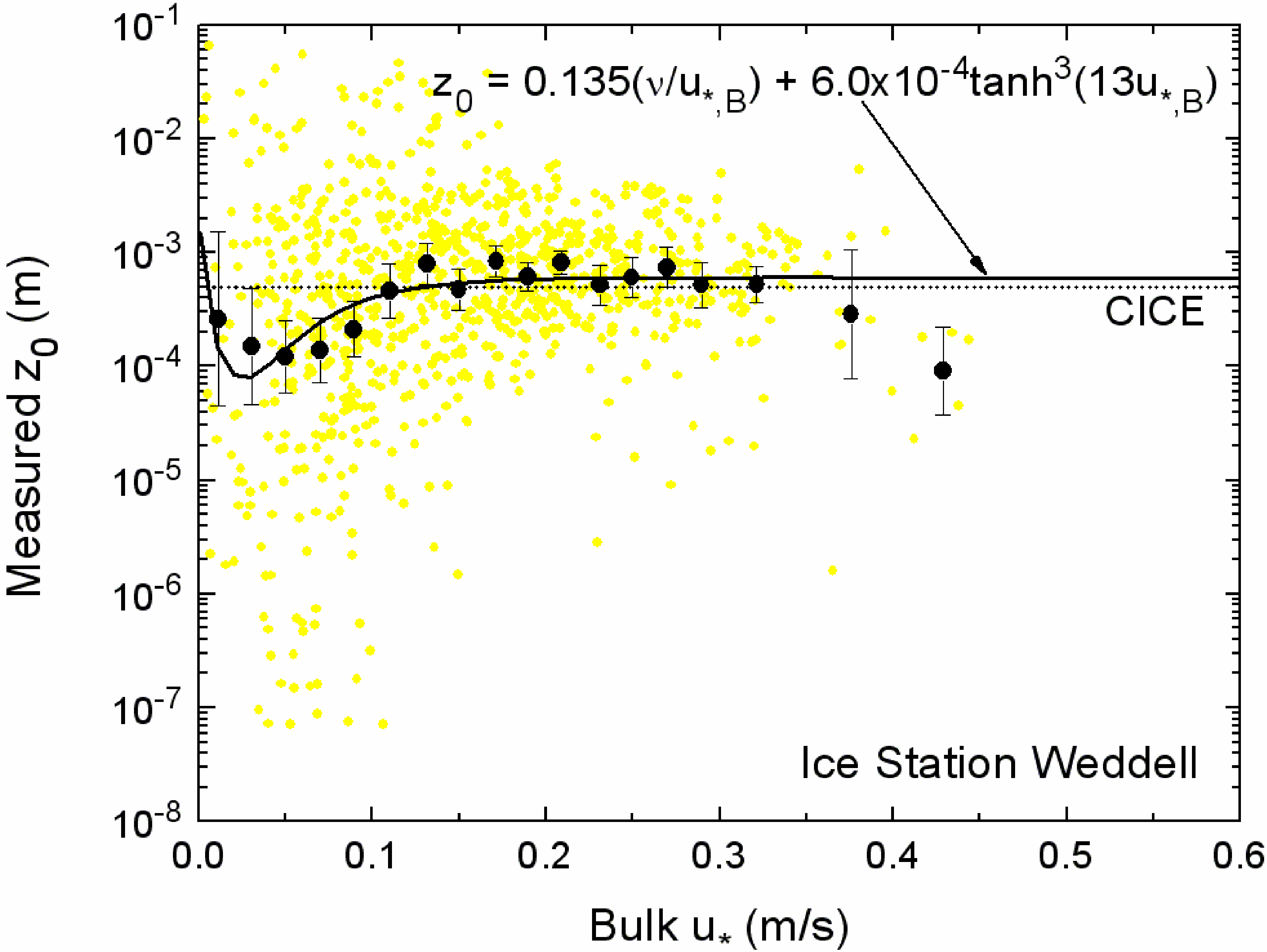
where k is the von Kármán constant, r is an arbitrary reference height, z_0 is the roughness length for momentum, L is the Obukhov length, and ψ_m is a stability correction

Compare Flux Algorithms

Component	SHEBA	CICE
z_0	Depends on u_* and C_i	5.0×10^{-4} m
z_T, z_Q	Andreas (1987)	5.0×10^{-4} m
In low wind	Windless transfer, all fluxes	Windless transfer, only sensible heat, only stable
Stability	Grachev et al. (2007); Paulson (1970)	Holtslag & De Bruin (1988); Paulson (1970)



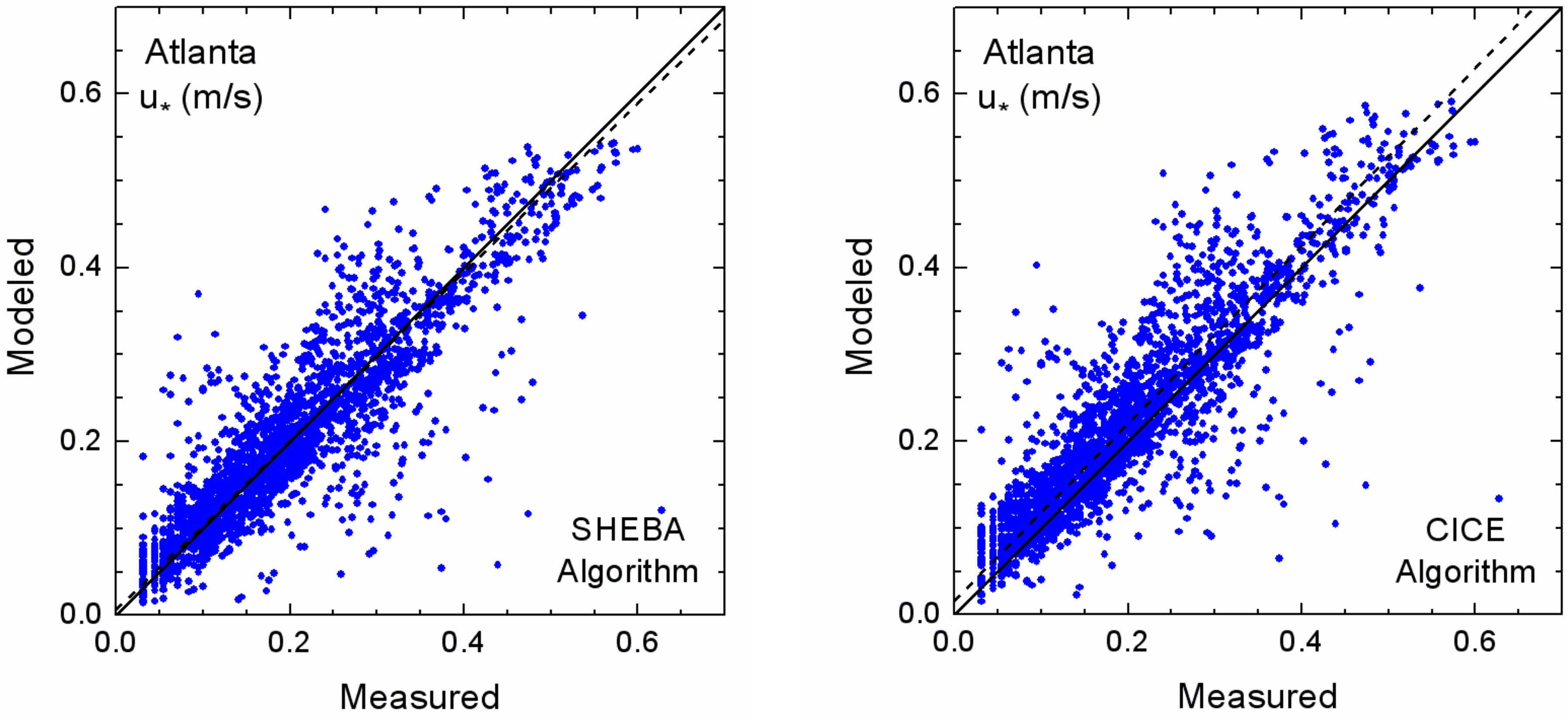
$z_0 = 0.135(\nu/u_{*,B}) + 2.30\times10^{-4}\tanh^3(13u_{*,B})$
CICE
ASFG Tower
Atlanta
Baltimore
Cleveland
Florida
SHEBA Winter
Measured z_0 (m)
Bulk u_* (m/s)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7



$z_0 = 0.135(\nu/u_{*,B}) + 6.0\times10^{-4}\tanh^3(13u_{*,B})$
CICE
Ice Station Weddell
Measured z_0 (m)
Bulk u_* (m/s)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0.0
0.1
0.2
0.3
0.4
0.5
0.6

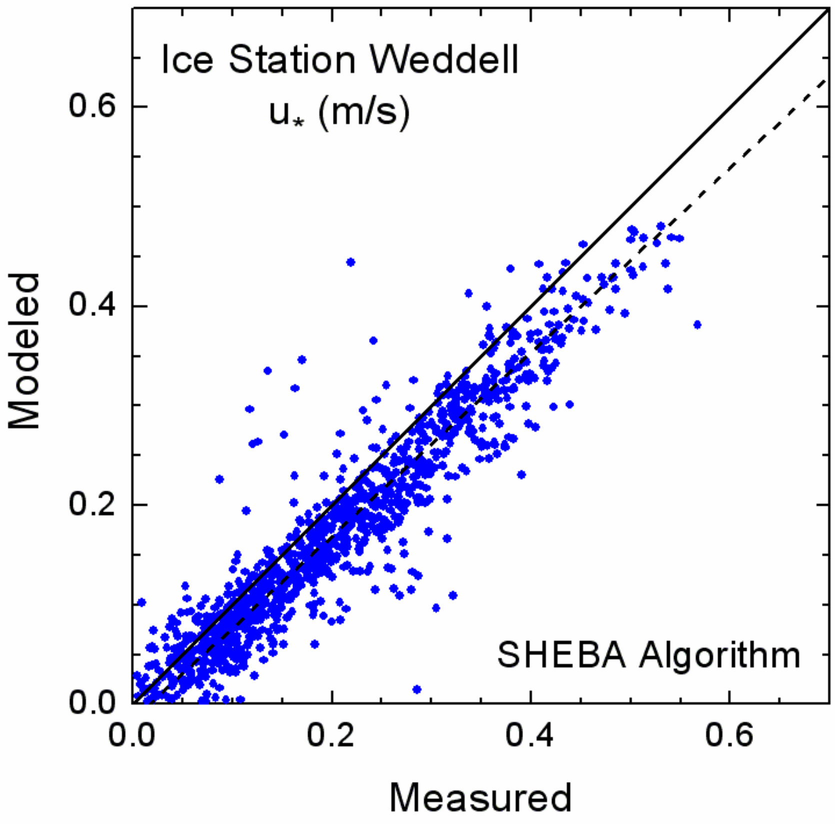
SHEBA Flux-PAM Site Atlanta

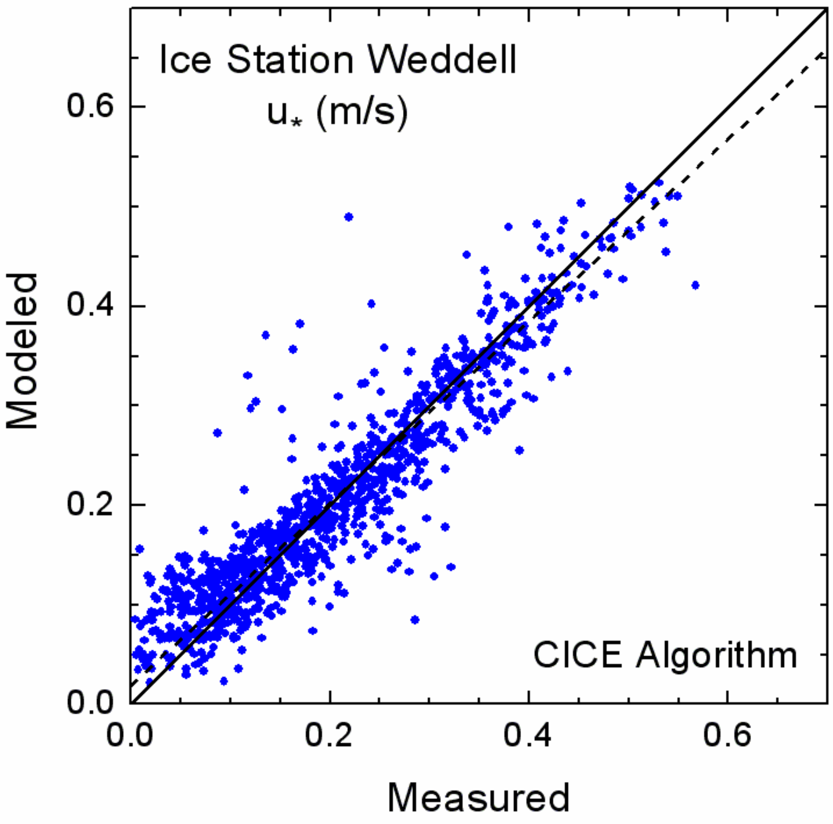
In the Arctic Ocean (Winter Only)

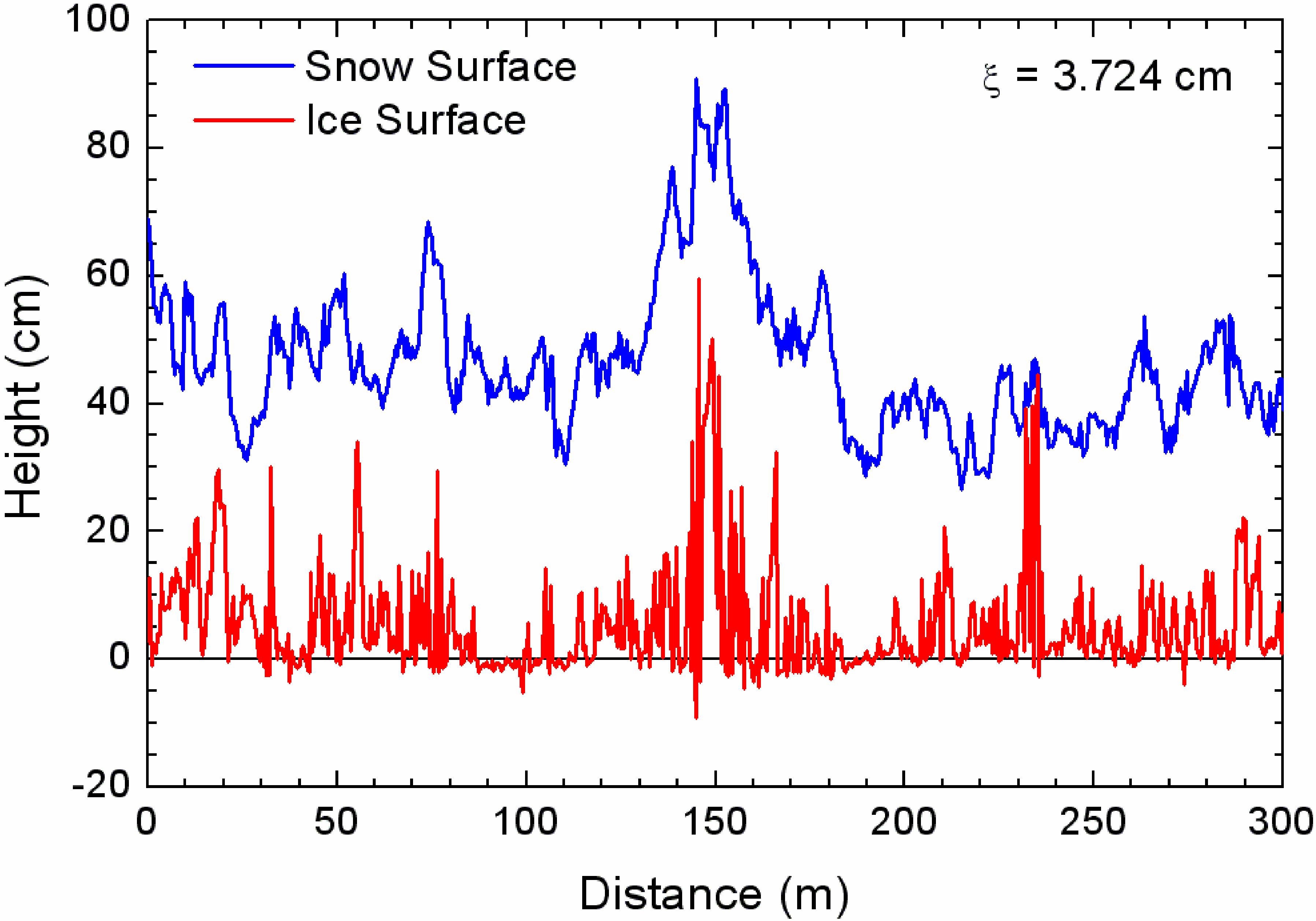



Main Tower on Ice Station Weddell

In the Weddell Sea (Winter)







Snow Surface
Ice Surface
ξ = 3.724 cm
Height (cm)
Distance (m)
100
80
60
40
20
0
-20
0
50
100
150
200
250
300

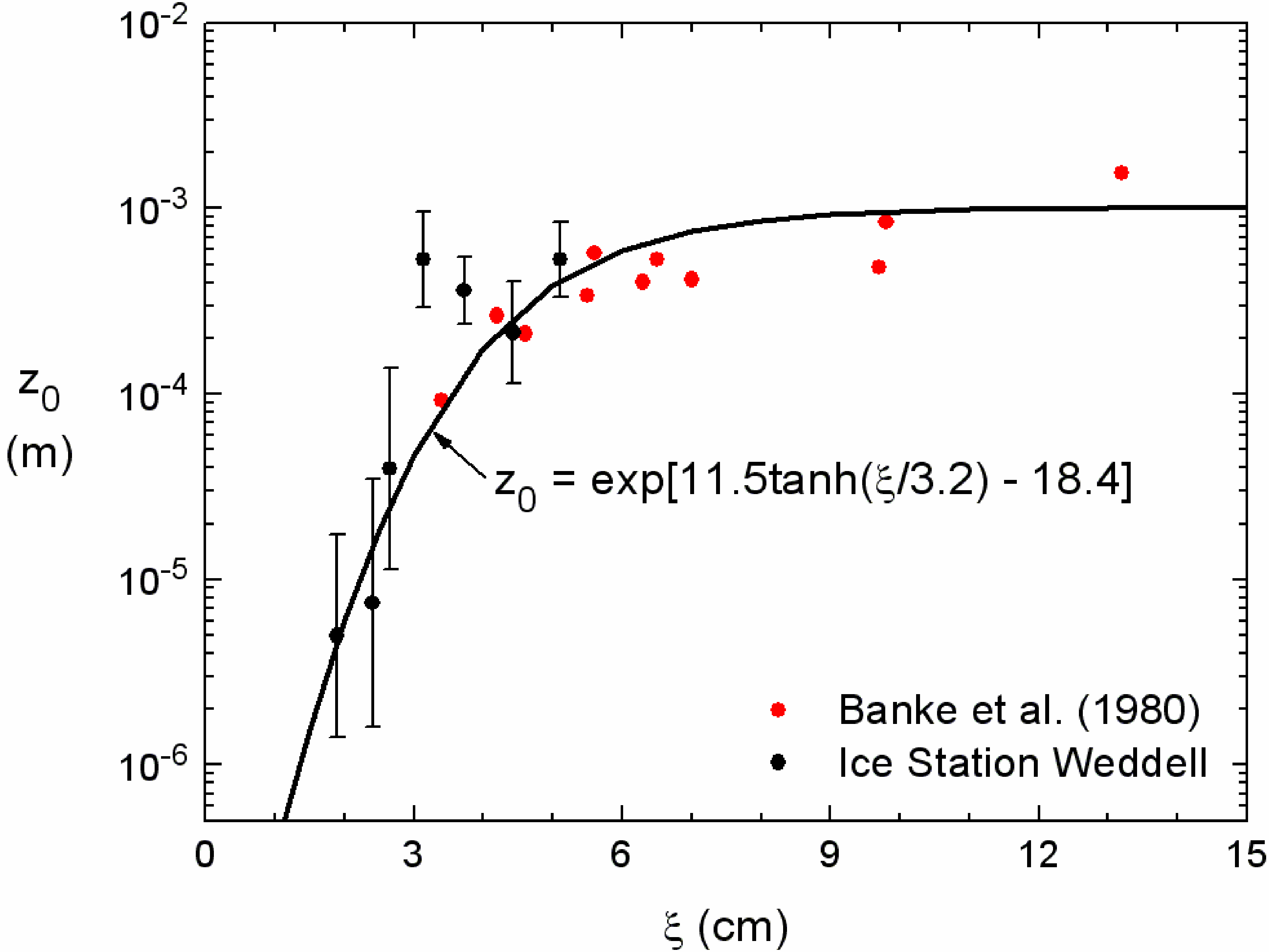
Quantify Physical Roughness

A roughness parameter related to the surface variance (from Banke et al. 1980)

$$\xi^2 = \int_{\kappa_0}^{\infty} \Phi(\kappa) d\kappa$$

where κ is the wavenumber, and $\Phi(\kappa)$ is the wavenumber spectrum of the surface elevation

κ_0 is a cutoff wavenumber of 0.5 rad m^{-1} (equivalent to a maximum wavelength of 12.6 m)



10-2
10-3
10-4
10-5
10-6
z0
(m)
z0 = exp[11.5tanh(ξ/3.2) - 18.4]
Banke et al. (1980)
Ice Station Weddell
0
3
6
9
12
15
ξ (cm)

Summary

- Have presumed that a bulk flux algorithm tuned for multiple SHEBA sites would be good over any sea ice surface
- The SHEBA algorithm's prediction for z_0 is too small, however, to simulate momentum transfer over the Weddell Sea
- Seem to need additional parameters to model a "local" value of z_0 over snow-covered sea ice