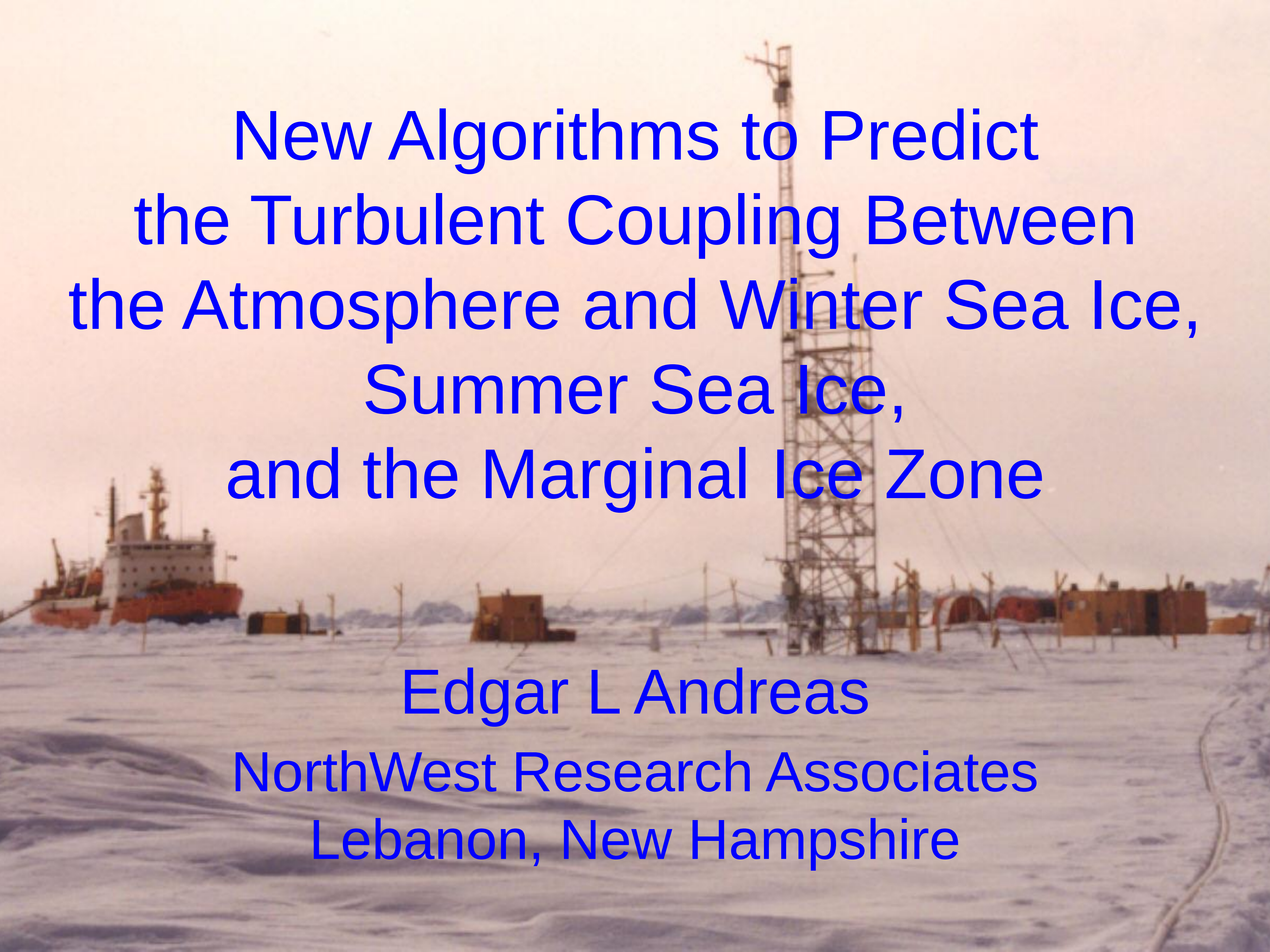

# New Algorithms to Predict the Turbulent Coupling Between the Atmosphere and Winter Sea Ice, Summer Sea Ice, and the Marginal Ice Zone

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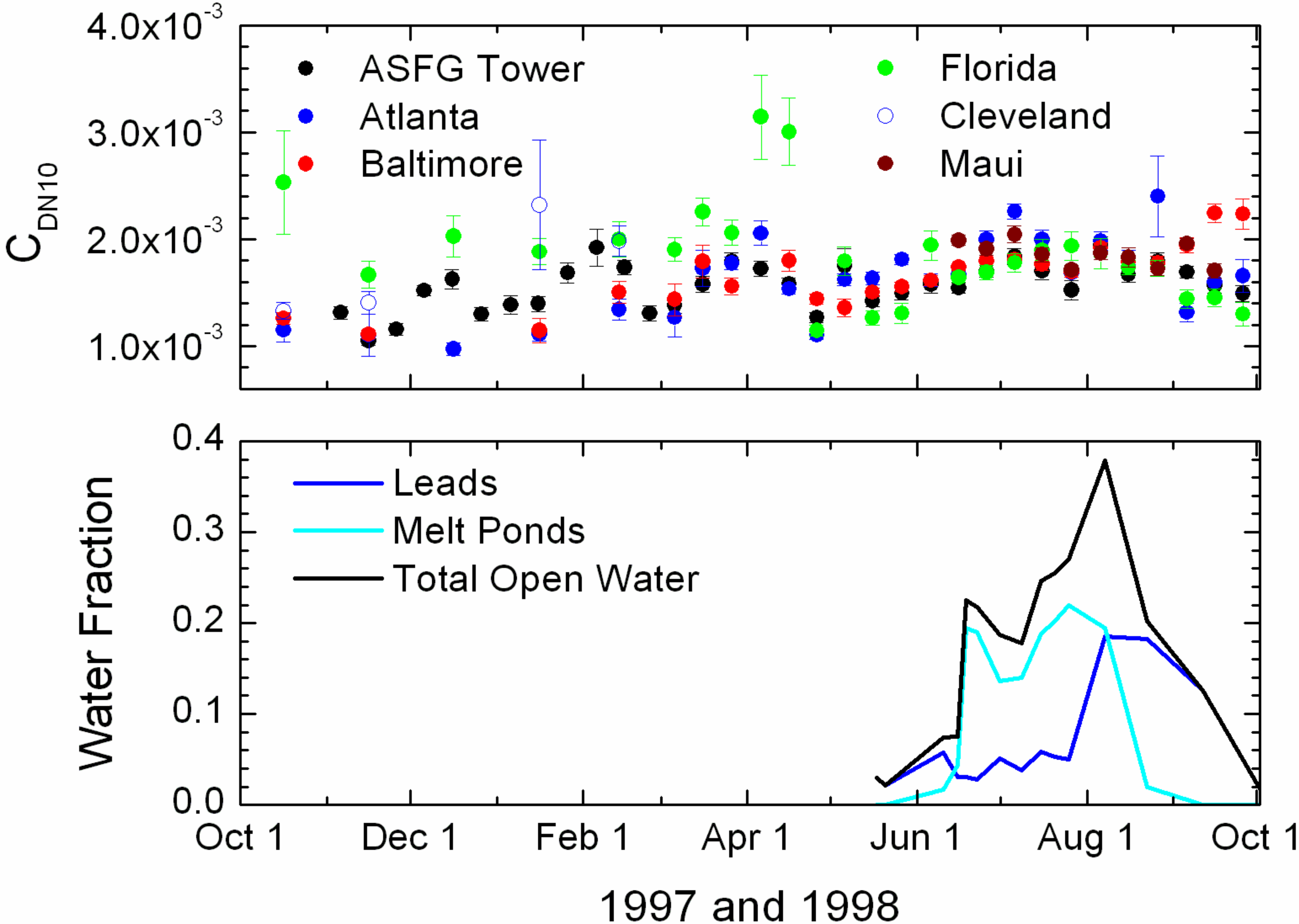


4.0x10-3
3.0x10-3
2.0x10-3
1.0x10-3
C DN10
ASFG Tower
Atlanta
Baltimore
Florida
Cleveland
Maui
0.4
0.3
0.2
0.1
0.0
Water Fraction
Leads
Melt Ponds
Total Open Water
Oct 1
Dec 1
Feb 1
Apr 1
Jun 1
Aug 1
Oct 1
1997 and 1998

# Winter Sea Ice

Summer Arctic Sea Ice, SHEBA Camp

# Summer Arctic Sea Ice,  SHEBA

# Marginal Ice Zone

# Parameterize Turbulent Surface Flux

Momentum Flux:

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

Sensible Heat Flux:

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

Latent Heat Flux:

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

# Drag Coefficient

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

where k (= 0.4) 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 $\psi_m$ is a stability correction

# Drag Coefficient: 10m, Neutral

In neutral stratification, at a standard reference height of 10 m,

$$C_{DN10} = \frac{k^2}{\left[\ln\left(10/z_0\right)\right]^2}$$

Thus,

$$z_0 = 10 \exp\left(-k\, C_{DN10}^{-1/2}\right)$$

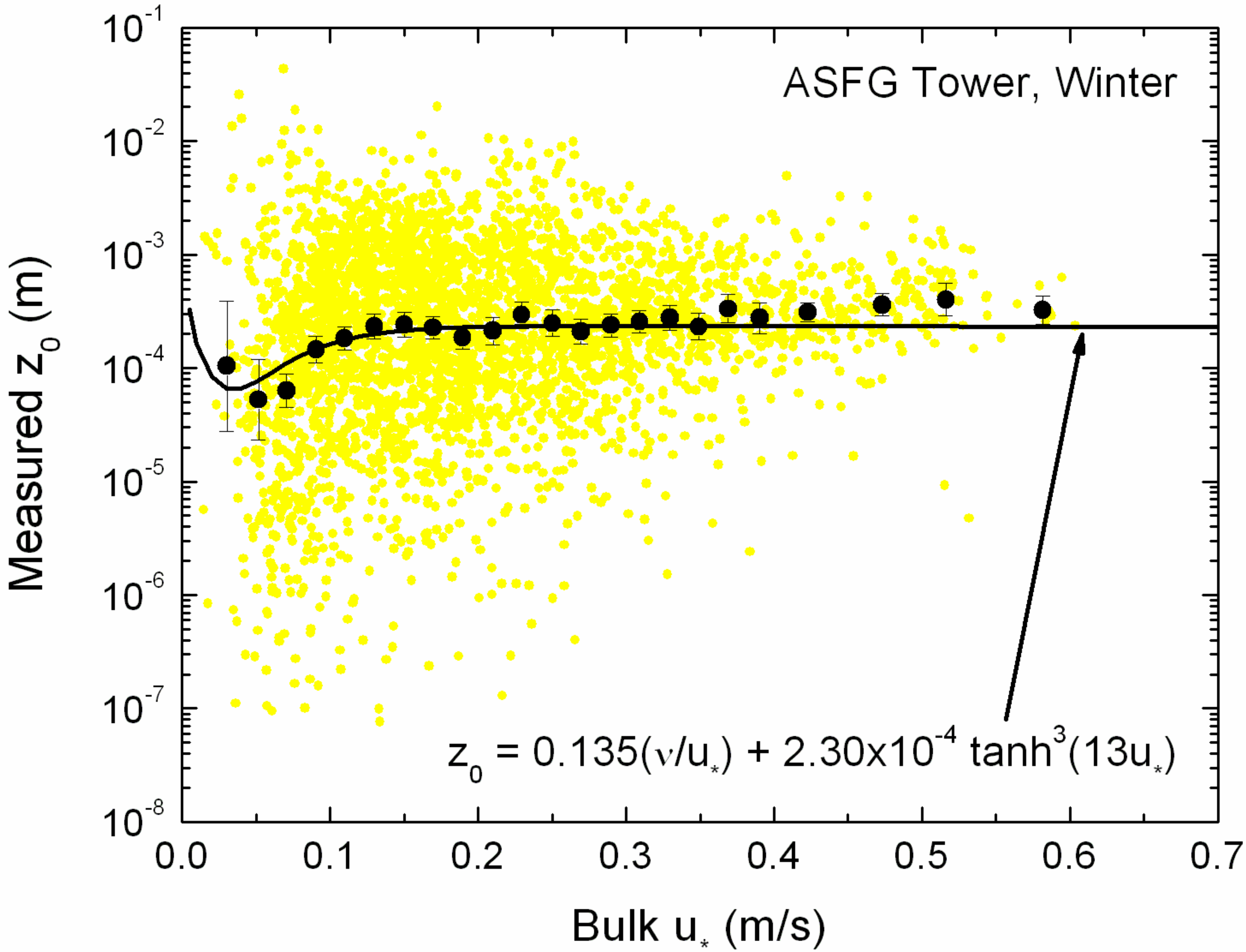
# Scalar Transfer Coefficients

For Sensible Heat:

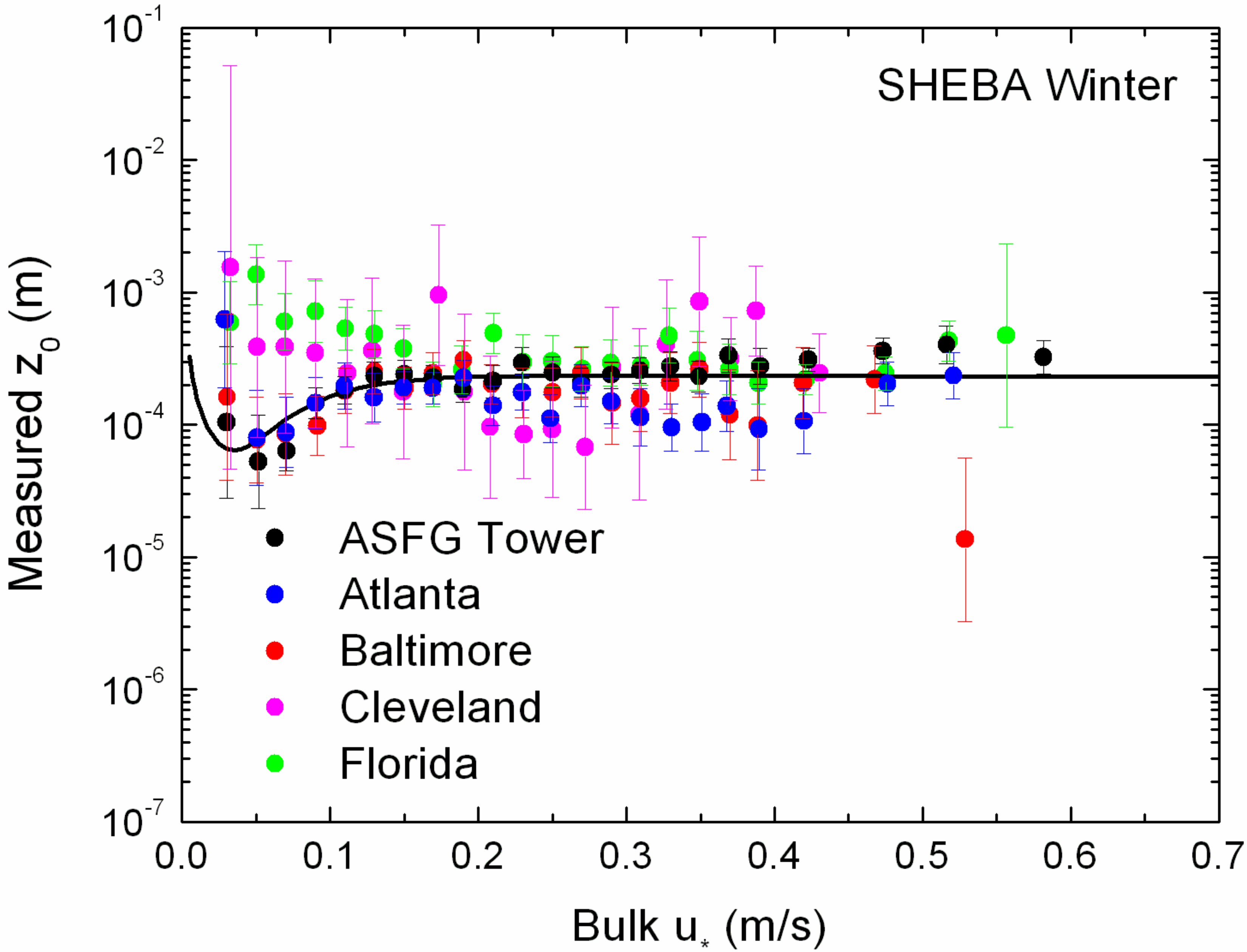
$$C_{Hr} = \frac{k^2}{\left[\ln\left(\frac{r}{z_0}\right) - \psi_m\left(\frac{r}{L}\right)\right]\left[\ln\left(\frac{r}{z_T}\right) - \psi_h\left(\frac{r}{L}\right)\right]}$$

For Latent Heat:

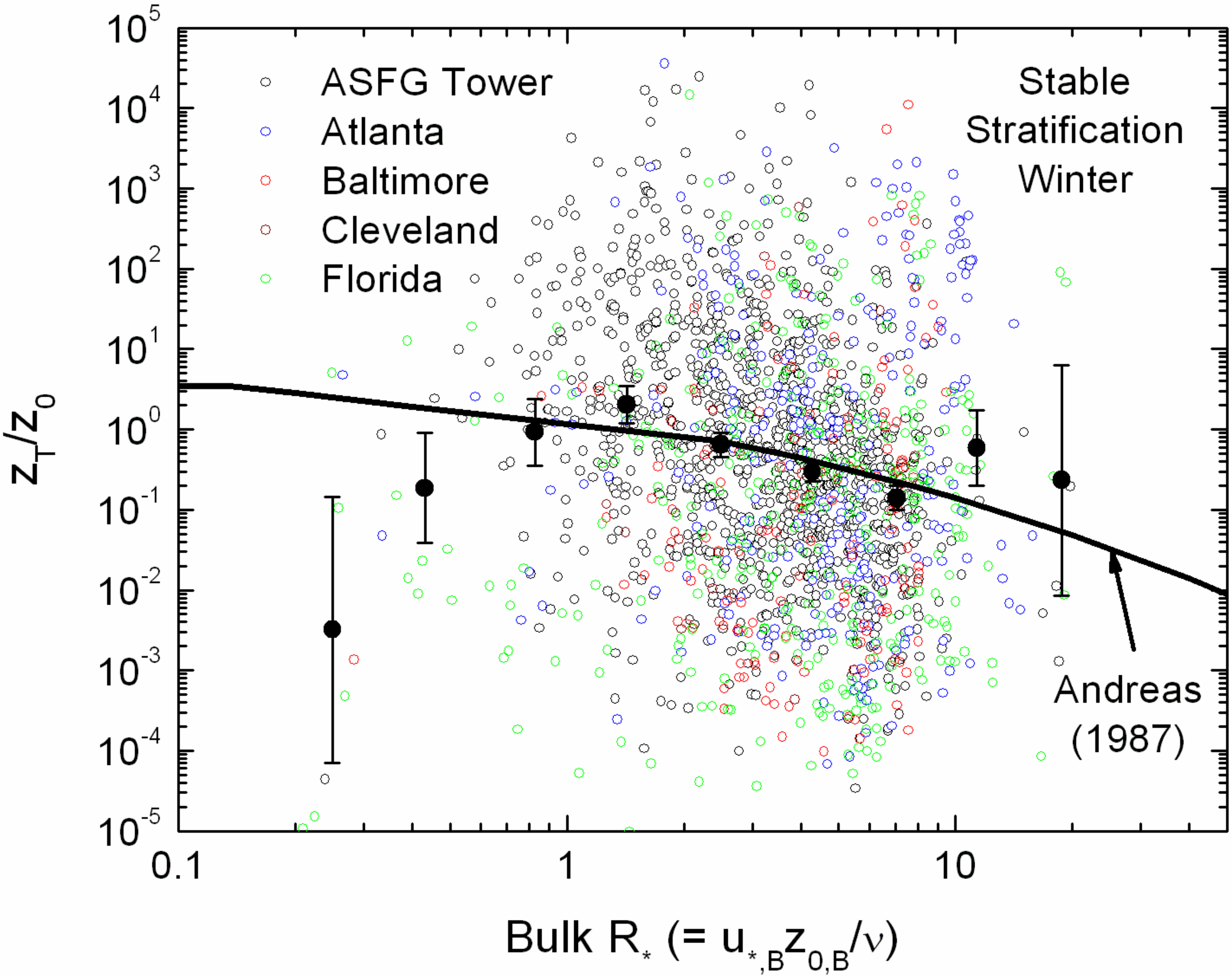
$$C_{Er} = \frac{k^2}{\left[\ln\left(\frac{r}{z_0}\right) - \psi_m\left(\frac{r}{L}\right)\right]\left[\ln\left(\frac{r}{z_Q}\right) - \psi_h\left(\frac{r}{L}\right)\right]}$$



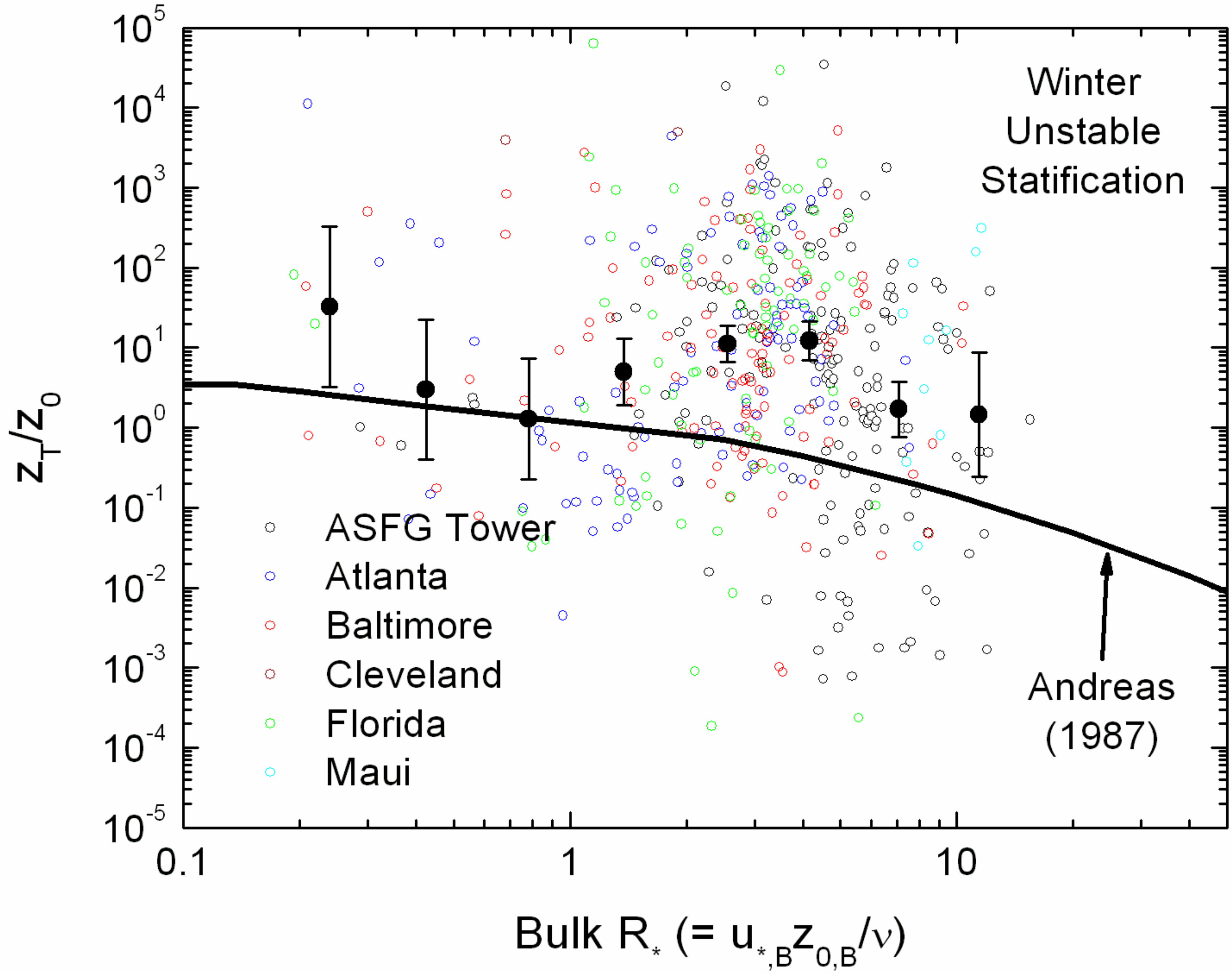
ASFG Tower, Winter
Measured $z_0$ (m)
Bulk $u_*$ (m/s)
$z_0 = 0.135(\nu/u_*) + 2.30\times10^{-4}\tanh^3(13u_*)$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7



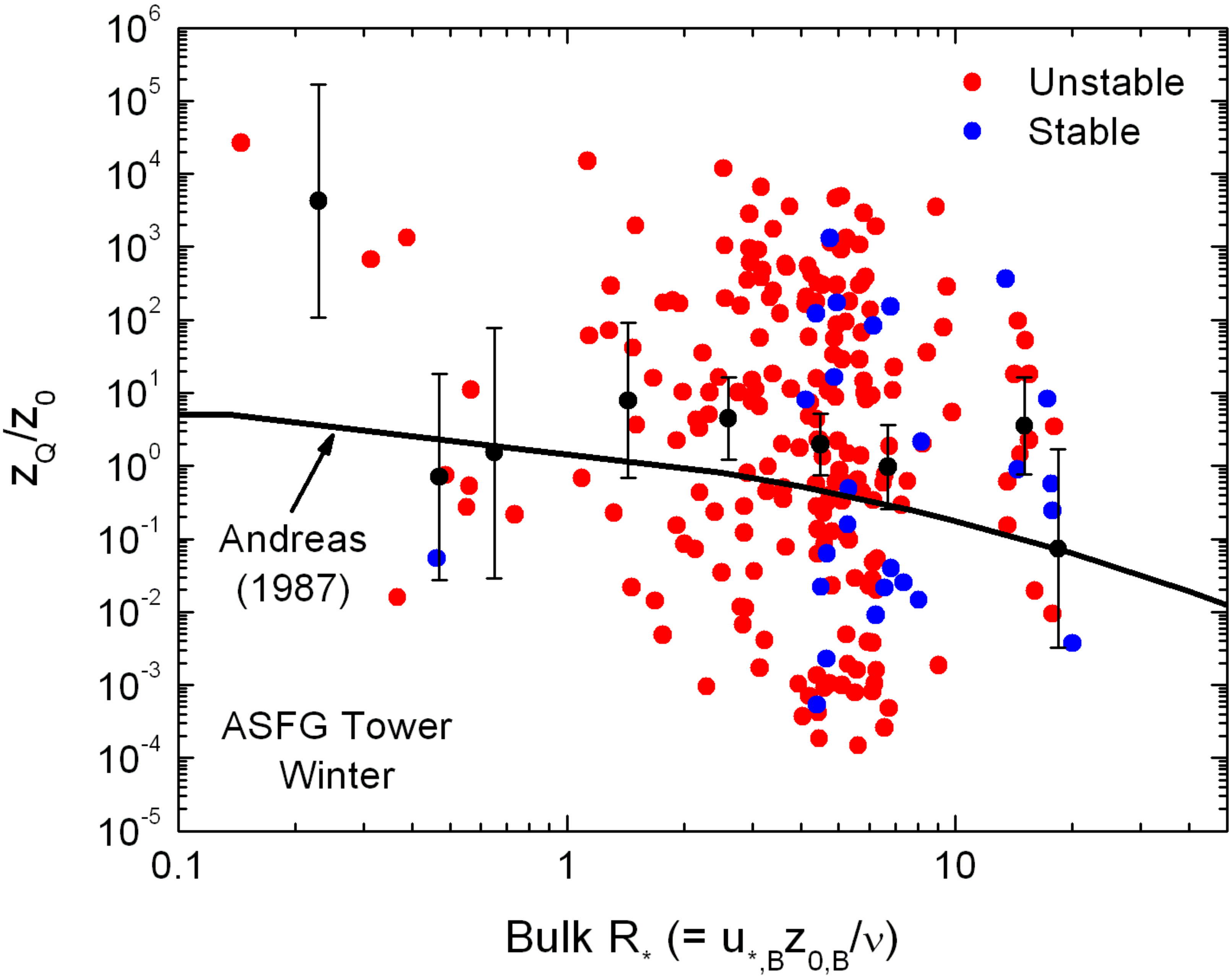
SHEBA Winter
Measured z0 (m)
Bulk u* (m/s)
ASFG Tower
Atlanta
Baltimore
Cleveland
Florida
10-1
10-2
10-3
10-4
10-5
10-6
10-7
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7



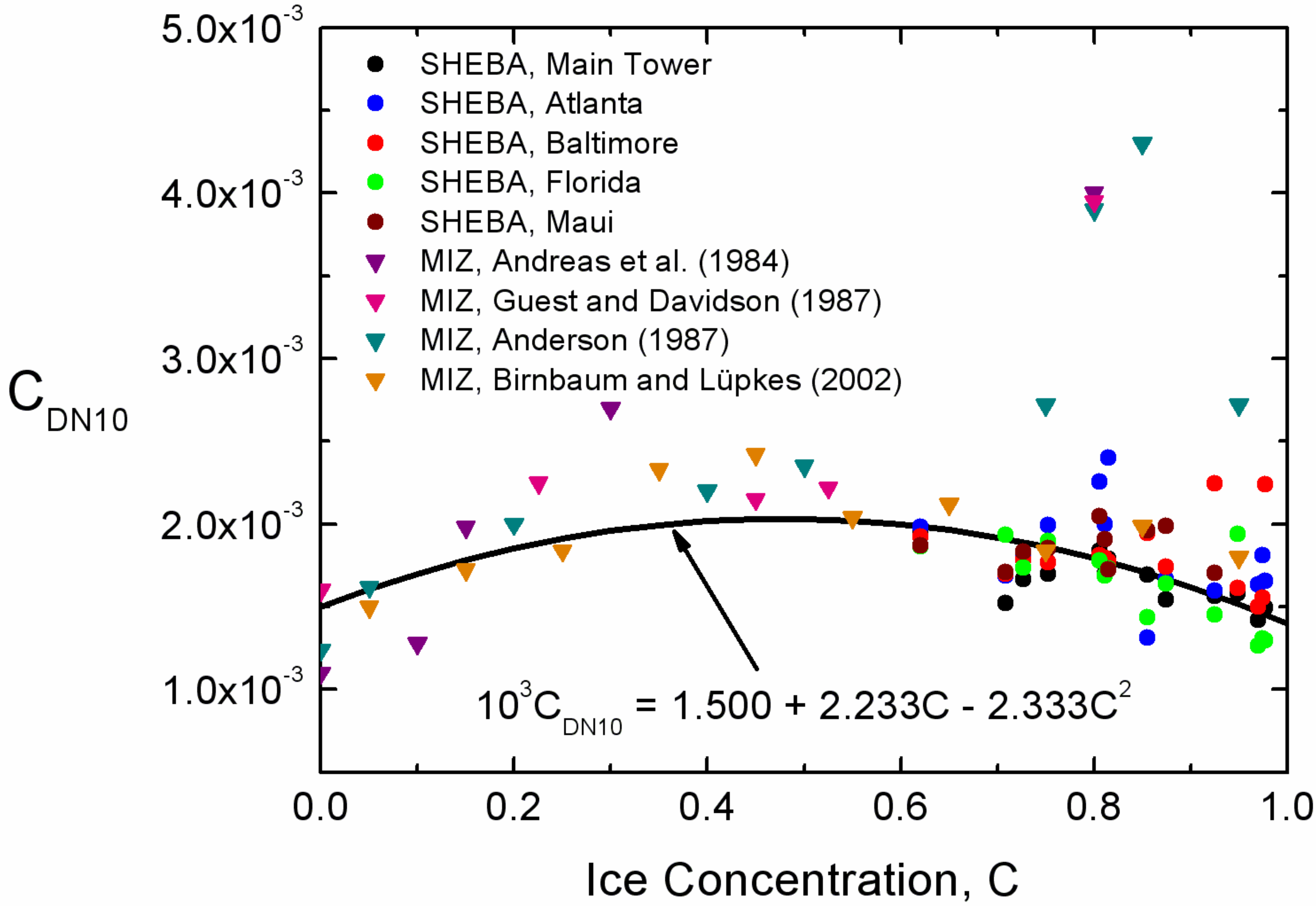
ASFG Tower
Atlanta
Baltimore
Cleveland
Florida
Stable
Stratification
Winter
Andreas
(1987)
$z_T/z_0$
$10^{-5}$
$10^{-4}$
$10^{-3}$
$10^{-2}$
$10^{-1}$
$10^{0}$
$10^{1}$
$10^{2}$
$10^{3}$
$10^{4}$
$10^{5}$
0.1
1
10
Bulk $R_*$ (= $u_{*,B}z_{0,B}/\nu$)



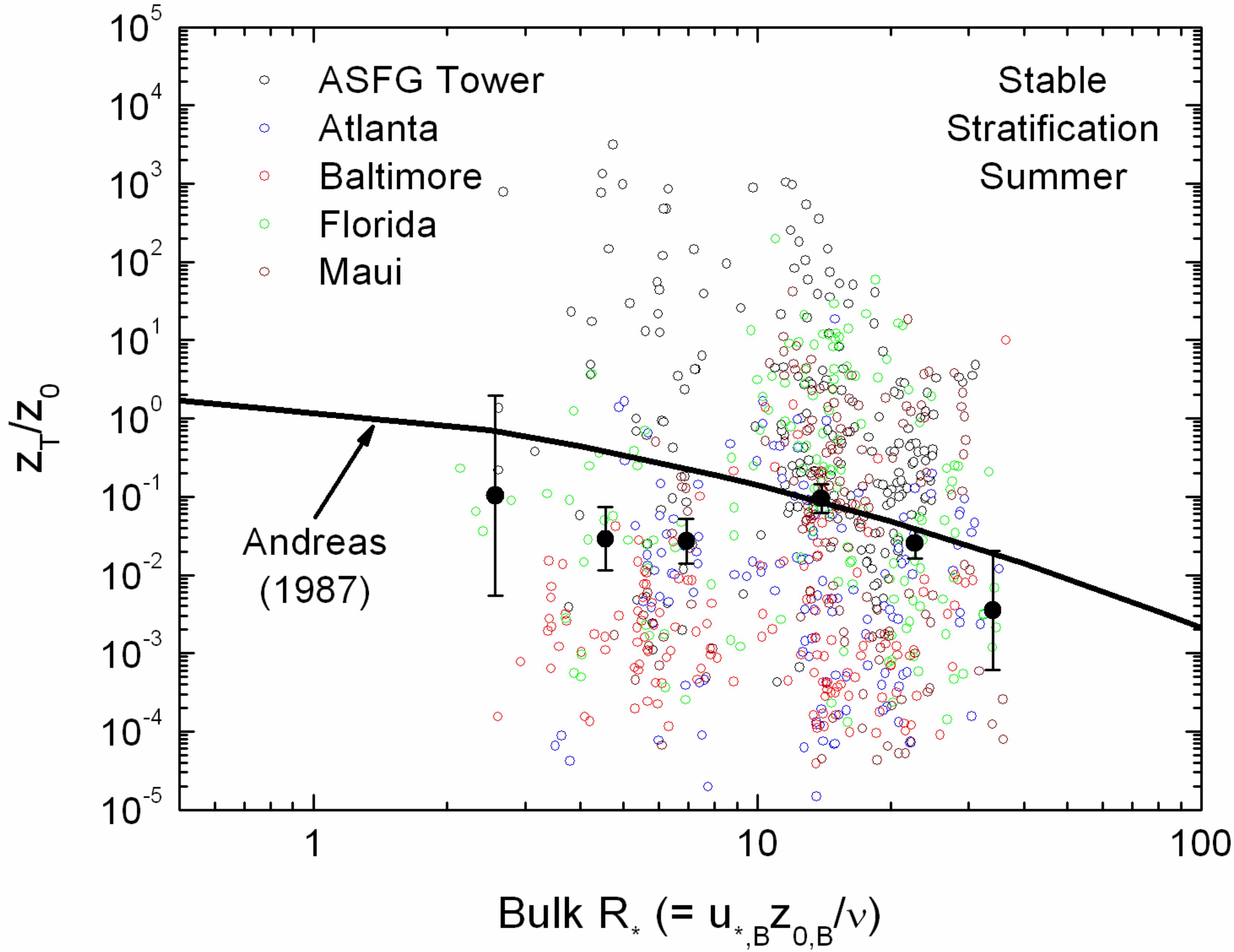
Winter
Unstable
Statification
ASFG Tower
Atlanta
Baltimore
Cleveland
Florida
Maui
Andreas
(1987)
$z_T/z_0$
Bulk $R_*$ (= $u_{*,B}z_{0,B}/\nu$)



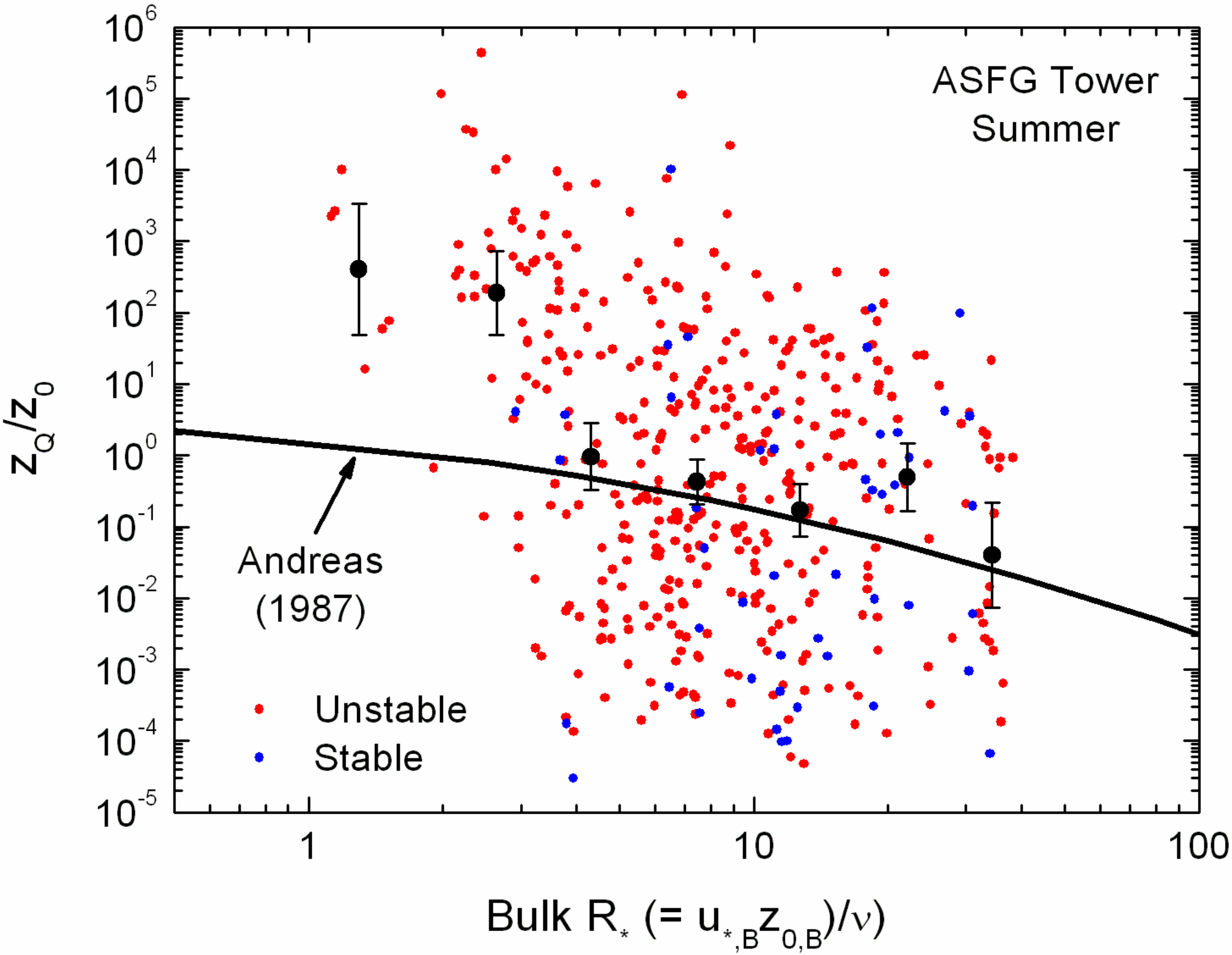
Unstable
Stable
Andreas
(1987)
ASFG Tower
Winter
$z_Q/z_0$
Bulk $R_*$ (= $u_{*,B}z_{0,B}/\nu$)
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
0.1
1
10



5.0x10^-3
4.0x10^-3
3.0x10^-3
2.0x10^-3
1.0x10^-3
C_DN10
SHEBA, Main Tower
SHEBA, Atlanta
SHEBA, Baltimore
SHEBA, Florida
SHEBA, Maui
MIZ, Andreas et al. (1984)
MIZ, Guest and Davidson (1987)
MIZ, Anderson (1987)
MIZ, Birnbaum and Lüpkes (2002)
$10^3 C_{DN10} = 1.500 + 2.233C - 2.333C^2$
0.0
0.2
0.4
0.6
0.8
1.0
Ice Concentration, C



ASFG Tower
Atlanta
Baltimore
Florida
Maui
Stable
Stratification
Summer
Andreas
(1987)
$z_T/z_0$
Bulk $R_*$ (= $u_{*,B}z_{0,B}/\nu$)
$10^{5}$
$10^{4}$
$10^{3}$
$10^{2}$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
1
10
100


ASFG Tower
Summer
$z_Q/z_0$
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
Andreas
(1987)
Unstable
Stable
1
10
100
Bulk $R_*$ (= $u_{*,B}z_{0,B}$)/$\nu$)

# Summary

- In winter, $z_0$ is constant at about $2.3 \times 10^{-4}$ m for $0.20 < u_{*,B} \leq 0.65$ m/s, the upper limit of my data

- Over summer sea ice and in the marginal ice zone, developed a unified prediction for $C_{DN10}$ (or $z_0$) in terms of ice concentration (or water fraction)

- In winter and summer, in stable and unstable stratification, both $z_T/z_0$ and $z_Q/z_0$ follow the Andreas (1987) algorithm