# Southern Ocean Mixing Biases in CESM
# W. Large: CESM OMWG

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- Hypothesis :

Vertical mixing is bias shallow due to neglect of surface wave effects

- Method :

Large Eddy Simulation of strong wind, buoyancy and wave forcing

- First Goal :

Extend M-O similarity theory to the surface layer of these LES

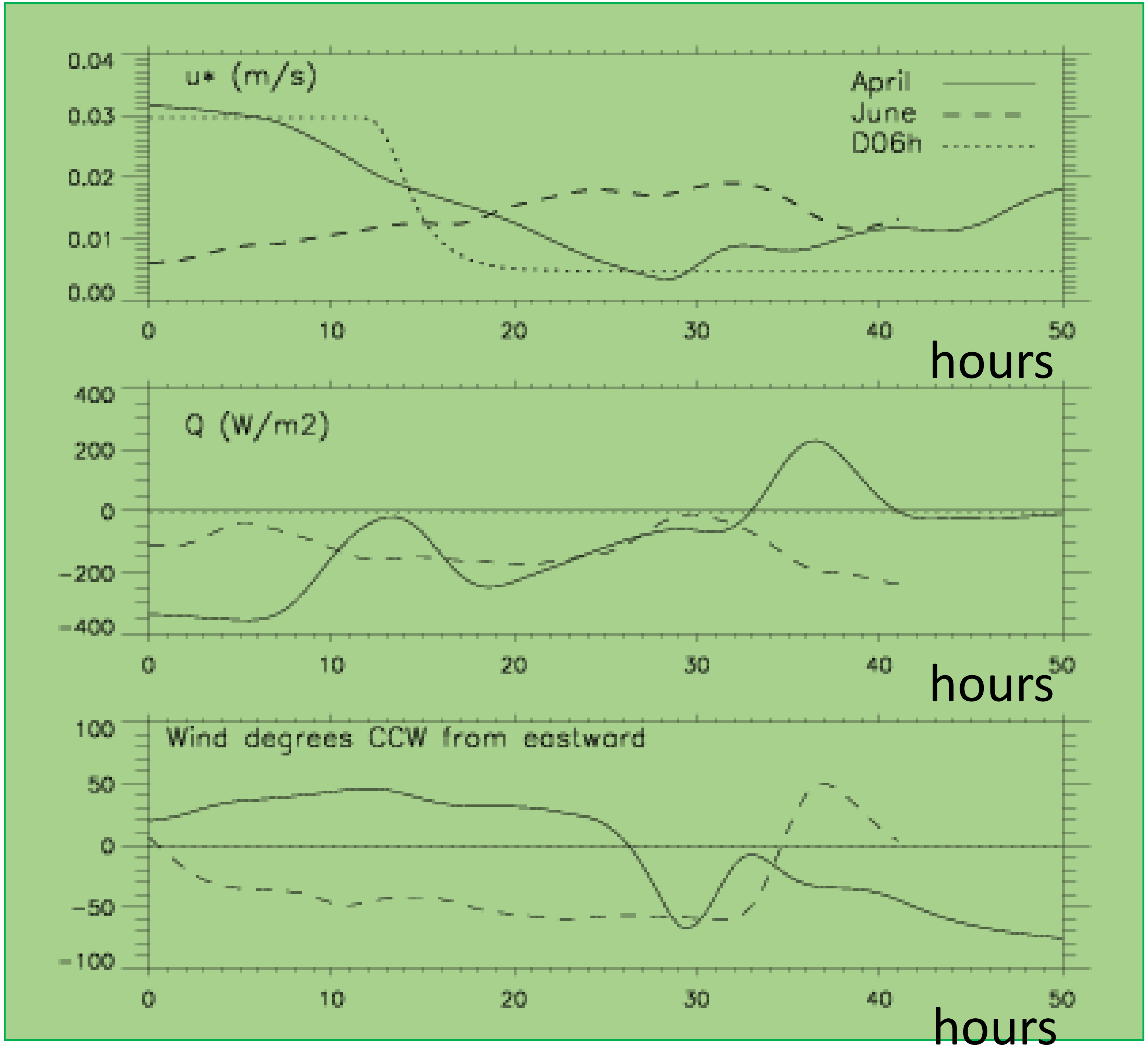
# Southern Ocean Large Eddy Simulations (LES)

- Domain : 1280 x 1280 x 512 ; 1250m x 1250m x 350-500m
- Duration : 50 hours (~ 200,000 time steps; Δt ~ 1 second )

- Met Forcing : SOFS (-47 ˚S; 140˚E) ; April and June 2010
  - -- Wind speed and direction ➔ wind stress vector, **τ**
  - -- Surface heat flux ($Q_0$) ➔ buoyancy forcing ($B_0$)
- Stokes Drift : Swell from Wavewatch III product

  Local waves from Met Forcing of Wavewatch III
- Initial Conditions: Nearby ARGO float with 7 hour profiling

# Met. Forcing:


u* (m/s)
April
June
D06h
0.04
0.03
0.02
0.01
0.00
0
10
20
30
40
50
hours
Q (W/m2)
400
200
0
-200
-400
0
10
20
30
40
50
hours
Wind degrees CCW from eastward
100
50
0
-50
-100
0
10
20
30
40
50
hours

# Monin- Obukhov Similarity Theory (Establishes order in turbulent boundary layers) :

In the surface layer within a fraction ε of the boundary layer depth h;
the structure (gradient) of a general property X (momentum, buoyancy) depends only on the distance and the surface forcing $( u^* x^* )$ ; $u^{*2} = |\tau| / \rho$

Non-dimensional Profiles : $\Phi_x = \kappa\ d\ u^*\ \partial_z X \ / \ (u^* x^*)$

Wind Driven : $\Phi_x = 1$ ; defines von Karman constant, $\kappa = 0.4$

Wind + Buoyancy : $\Phi_x = \phi_x(\zeta_1)$ ; $\Phi_x \ \phi_x^{-1} = 1$

Wind + Buoyancy + Stokes : $\Phi_x = \phi_x(\zeta_1) \ \chi_x(\zeta_2)$ ; $\Phi_x \ \phi_x^{-1} = \chi_x(\zeta_2)$

# Empirical Results:

: From the atmosphere (No Stokes)

--- $\zeta_1 = (d/L) = \sigma\,(h/L)$ ; $\sigma = d/h$

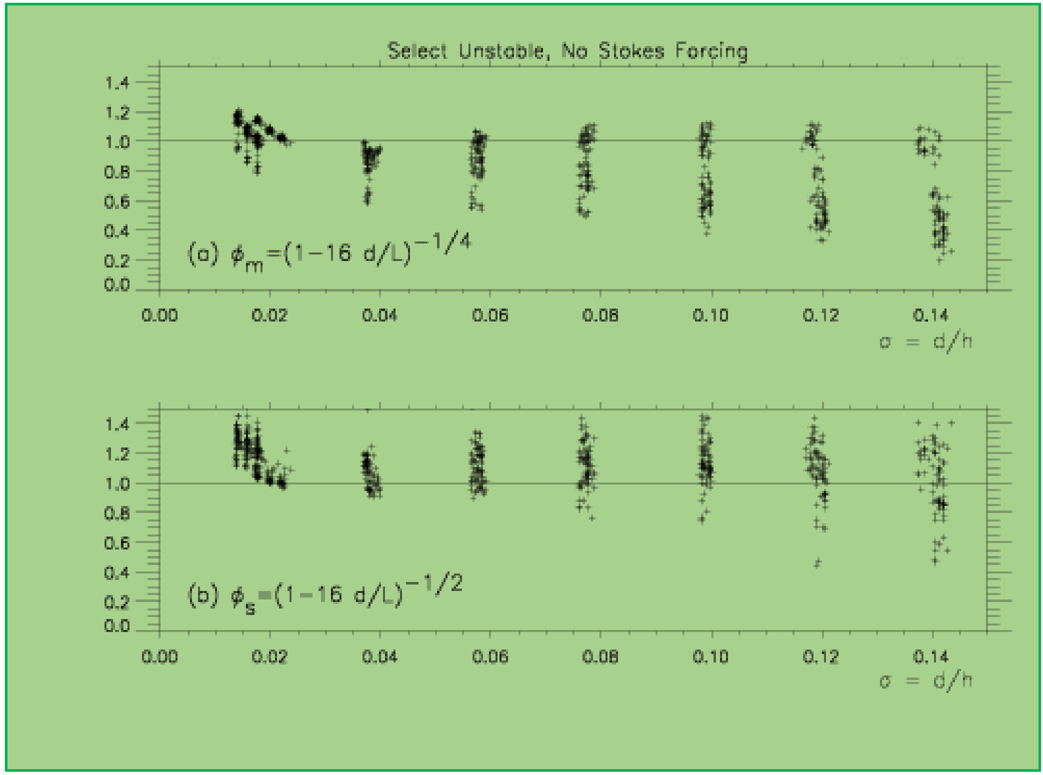
--- Monin-Obukhov depth, $L = u*^3 / (\kappa B_0)$

--- $\Phi_x\ \phi_x^{-1} = 1$ ; $\sigma < \varepsilon = 0.1$

--- $\phi_s < \phi_m < 1$ ; unstable ($B_0 < 0$)

: No Stokes LES (unstable) ?

$\Phi_X\,\phi_X^{-1}$



# Empirical Results :

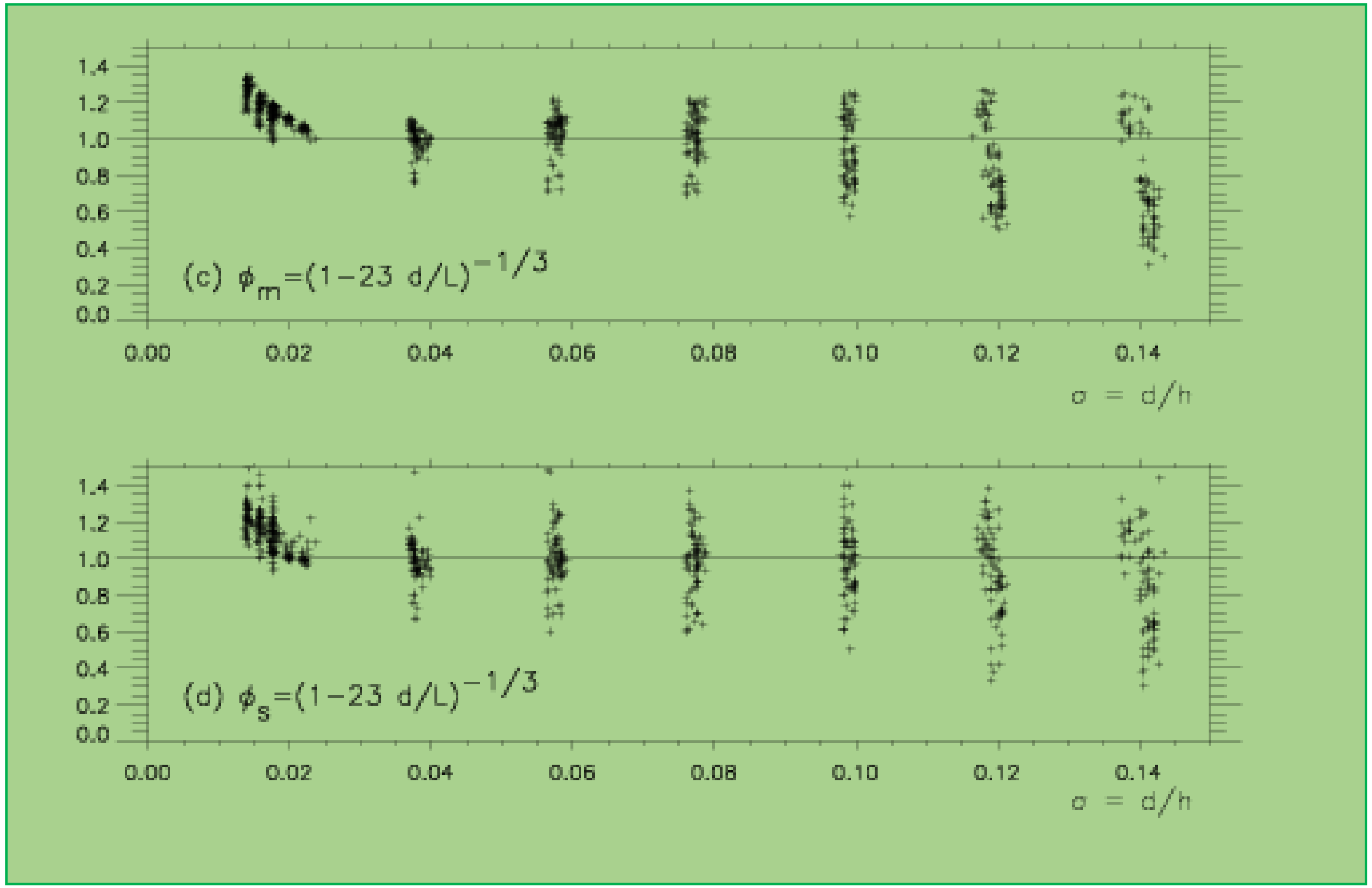
: The LES (No Stokes) ocean surface layer

$$\kappa = 0.40$$

$$\varepsilon = 0.10$$

$$\phi_m = \phi_s = \phi(d/L)$$

$\Phi_x \; \phi_x^{-1}$



# Southern Ocean Large Eddy Simulations (LES)

- Products: Space–time (.5 hour) average profiles (2 billion points) of
  - --- mean currents and buoyancy
  - --- vertical turbulent fluxes of momentum and buoyancy
  - --- mechanical, buoyancy and Stokes production of TKE

- Integration of production terms from 0 to εh, gives velocity scales:
  - --- $\mu_U^3 = P_U \; u^{*3}$
  - --- $\mu_S^3 = P_S \; u^{*3} \; La^{-2}$ ; $La^{-2} = U_S(0) \,/\, u^*$
  - --- $\mu_B^3 = P_B \; w^{*3}$ ; $w^{*3} = -B_0 \; h$
  - --- $\mu^{*3} = (\mu_U^3 + \mu_S^3 + \mu_B^3)$

# Monin- Obukhov Similarity Theory:

Non-dimensional Profiles: $\Phi_x = \kappa\ d\ \ u^*\ \partial_z X\ /\ (u^*\ x^*)$

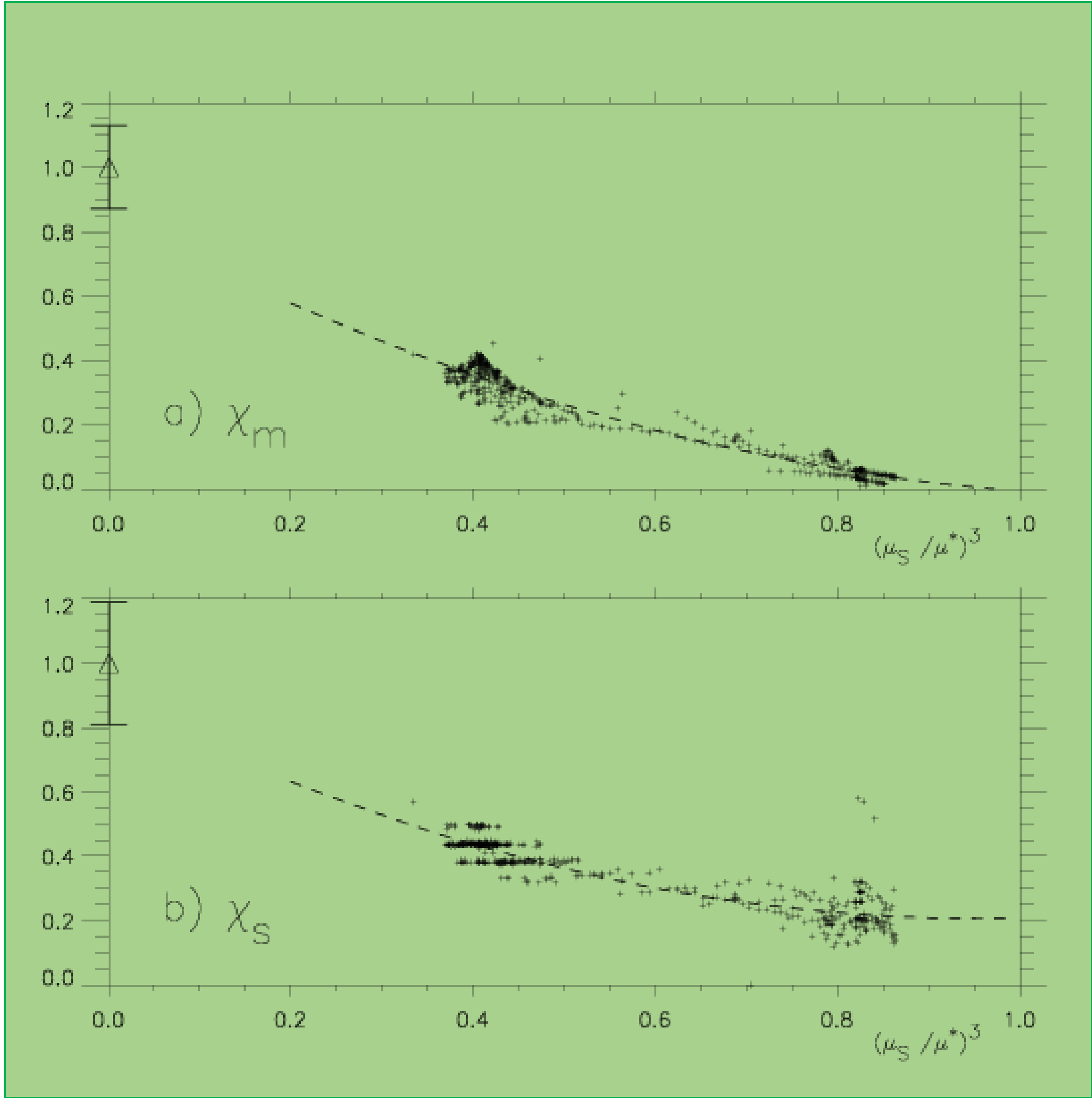
: $\zeta_1 = (d/L) = \kappa\ \sigma\ (h\ B_0)\ u^{*-3} = -\ \kappa\ \sigma\ (w^*/u^*)^3 \rightarrow (\mu_B\ /\ \mu_U)^3$

Suggests : $\zeta_2 = (\mu_S\ /\ \mu^*)^3$

# Empirical Results :

: The LES ocean surface layer

$$\Phi_x \, \phi_x^{-1} = \chi_x(\zeta_2)$$



# Diffusivity/Viscosity Scales:

Non-dimensional Profiles : $\Phi_x = \kappa \; d \; u^* \; \partial_z X \; / \; (u^* x^*)$

Diffusivity: $K_x = (u^* x^*) / \partial_z X = \kappa \; d \; u^* \; \Phi_x^{-1} = w_x (\sigma h)$ ;

Wind Driven : $w_x = \kappa u^*$

Wind + Buoyancy : $w_x = \kappa \; u^* \; \phi_x^{-1}$

Wind + Buoyancy + Stokes : $w_x = \kappa \; u^* \; \phi_x^{-1} \; \chi_x^{-1}$

} Depend on TKE Production terms, $\partial_z$ (TKE)

In contrast many schemes assume: $w_x = (TKE)^{1/2}$ .

# Challenge :

Parameterize $\zeta_2 = (\mu_S / \mu^*)^3$

$= P_s \; La^{-2} / (P_U + P_S \; La^{-2} + P_B \; (w^*/u^*)^3)$

Simplest :

$$P_B = 0.091 \pm 0.006$$

# Challenge :

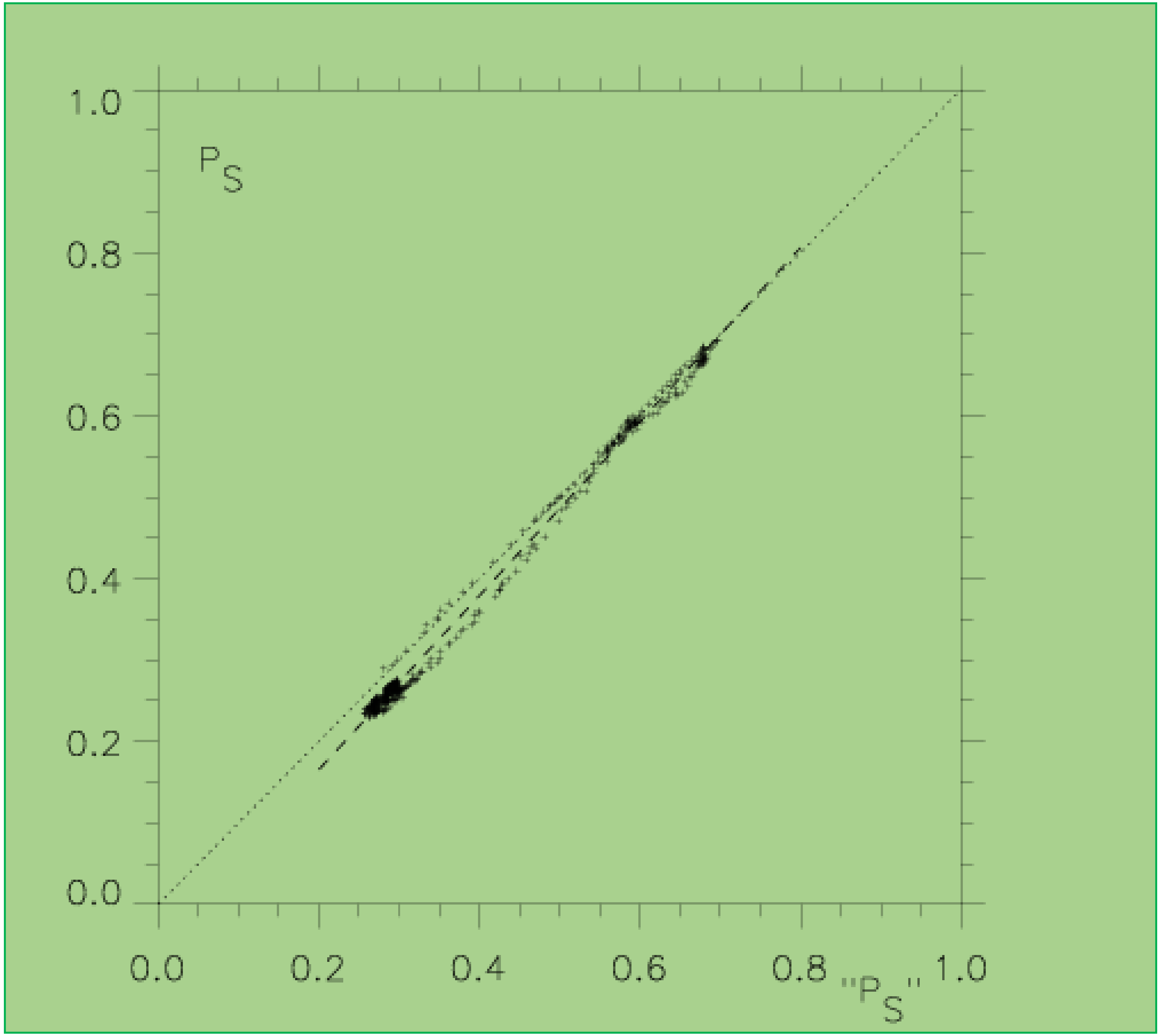
$P_S$

Most Important

Parameterize "$P_S$" assuming:

-- Stokes profile is given forcing

-- the momentum flux falls linearly from the surface stress to zero at a depth h

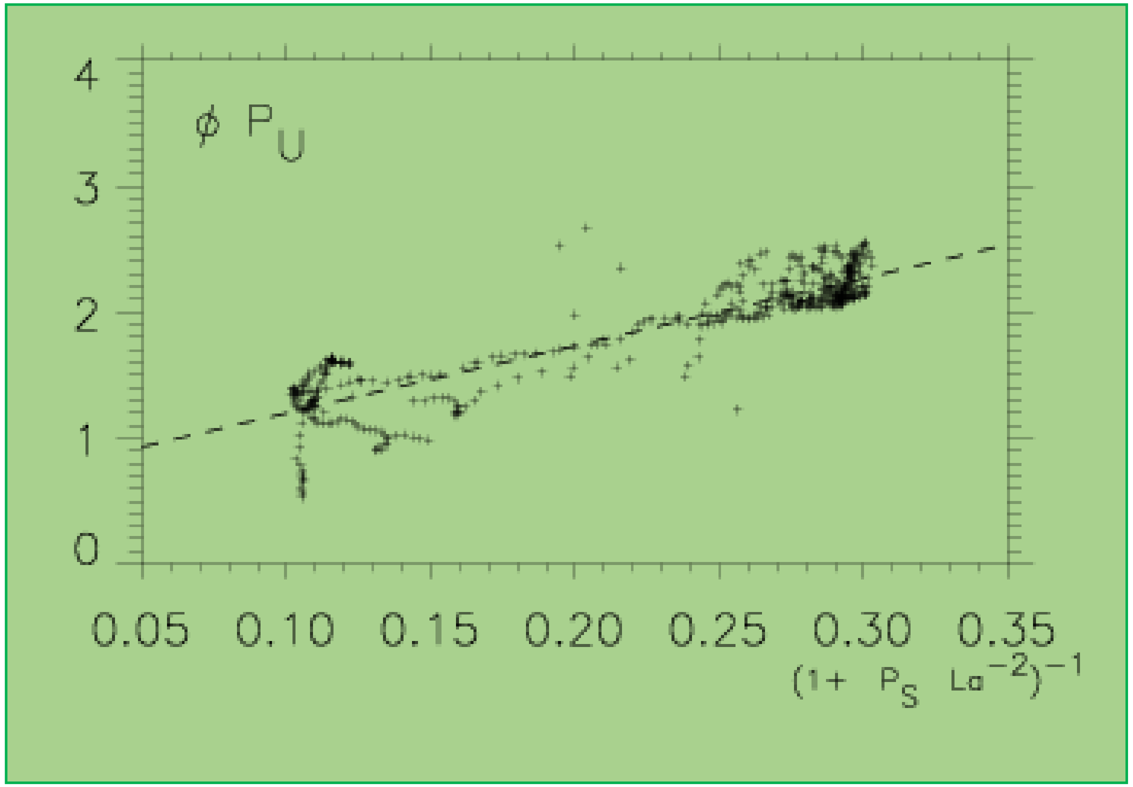


# Challenge :

Most Difficult $P_U$

$$\phi(\varepsilon h)\, P_U = F(\zeta_3)$$

$$\zeta_3 = (1 + \text{“}P_S\text{“}\, La^{-2})^{-1}$$



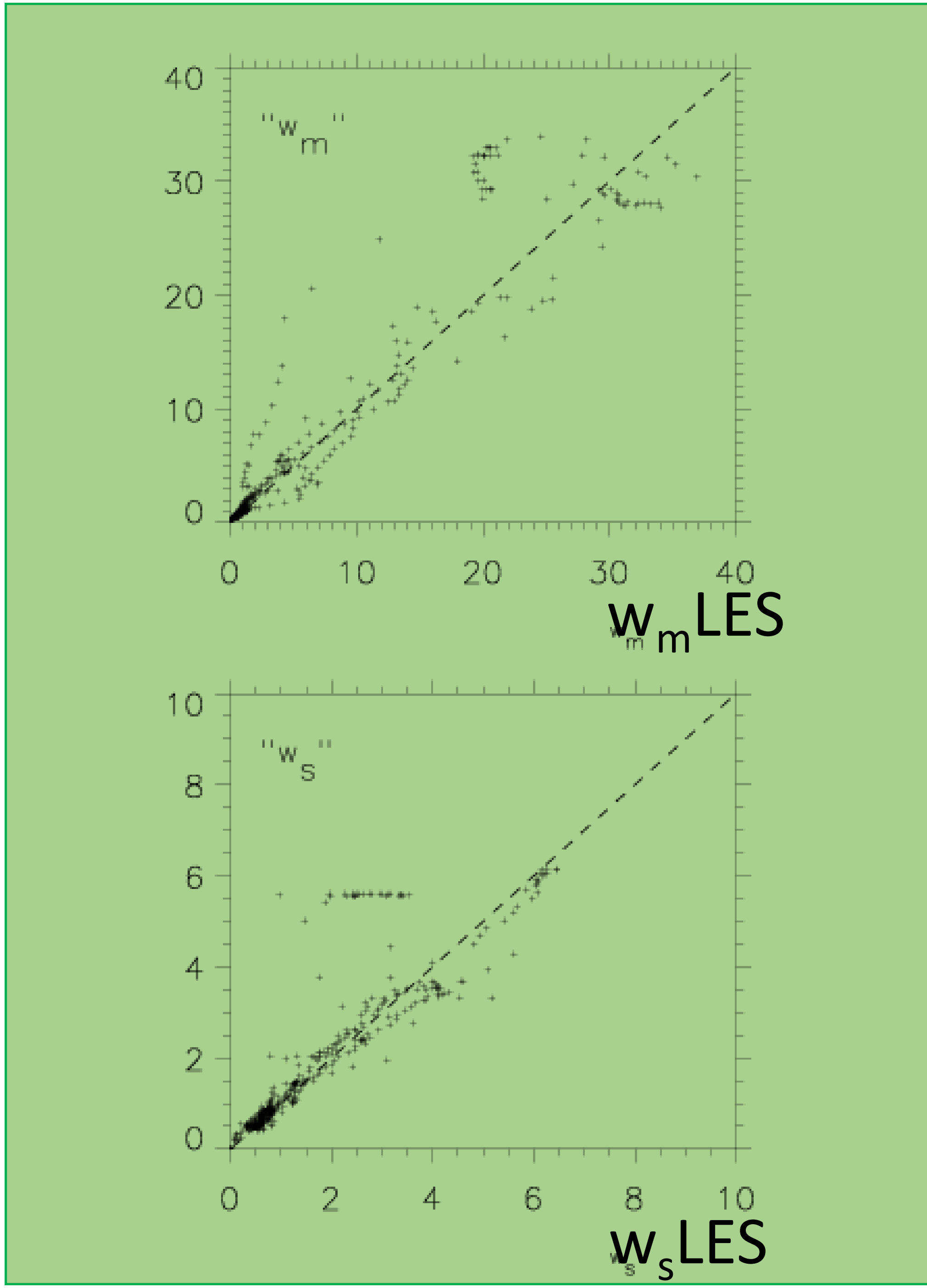
# Velocity Scales: Stokes & No Stokes

$w_x LES = \{ \langle w'x' \rangle (d\, \partial_z X)^{-1} \}_Z$

$\{ \}_Z$ an average from not too close to not too far from the surface

$“w_x“ = \kappa \;\; u^* \;\; \phi_x^{\;-1} \;\; \chi_x^{\;-1}$

$Pr \;=\; (w_m \,/\, w_s) > 1$

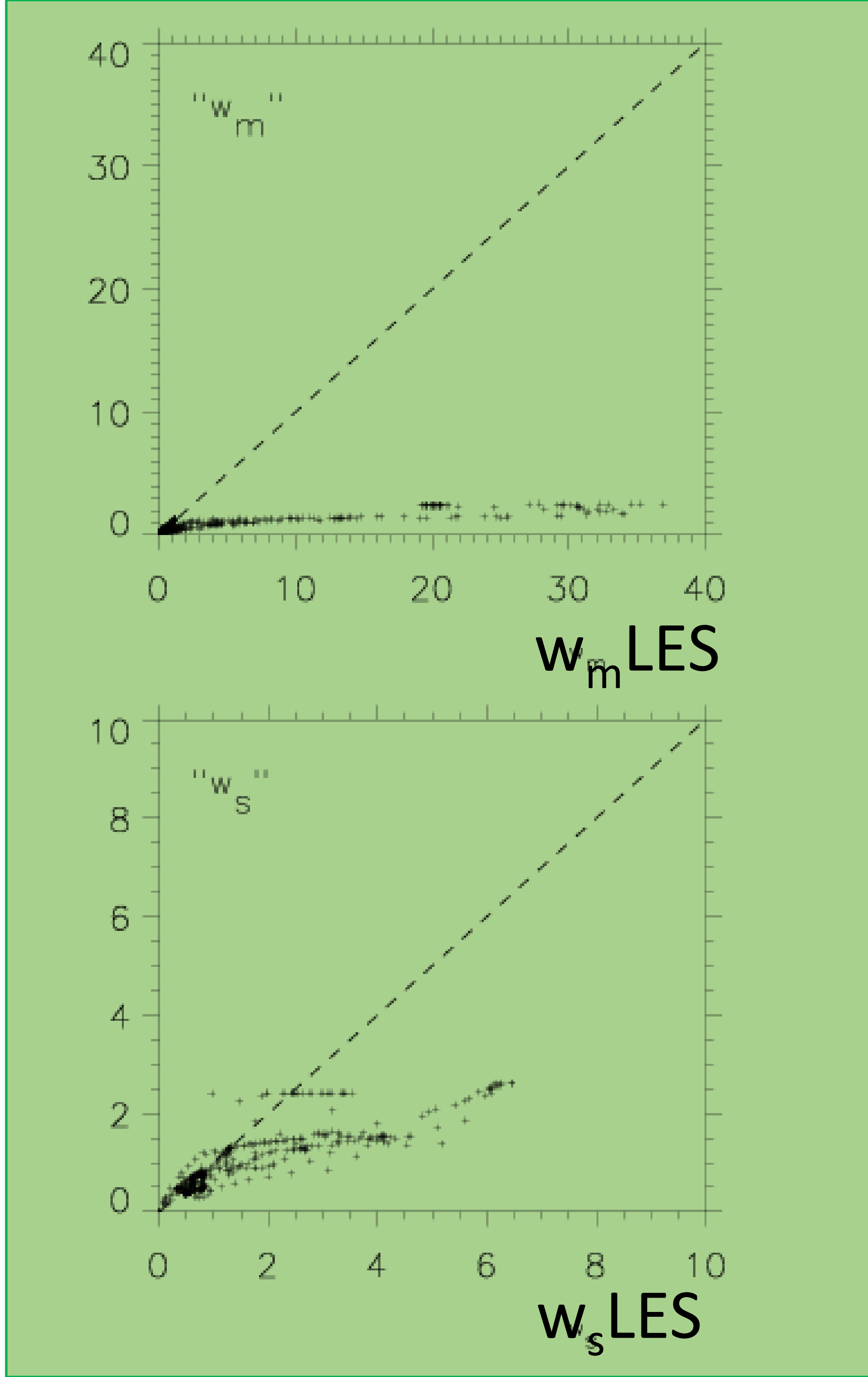


# McWilliams and Sullivan (2000) :

$$"w_x" = \kappa\, u^* \, \phi_x^{-1} \, (1 + A\, La^{-4})^{1/2}$$

$$A = 0.080$$

$$Pr = (w_m / w_s) < 1$$

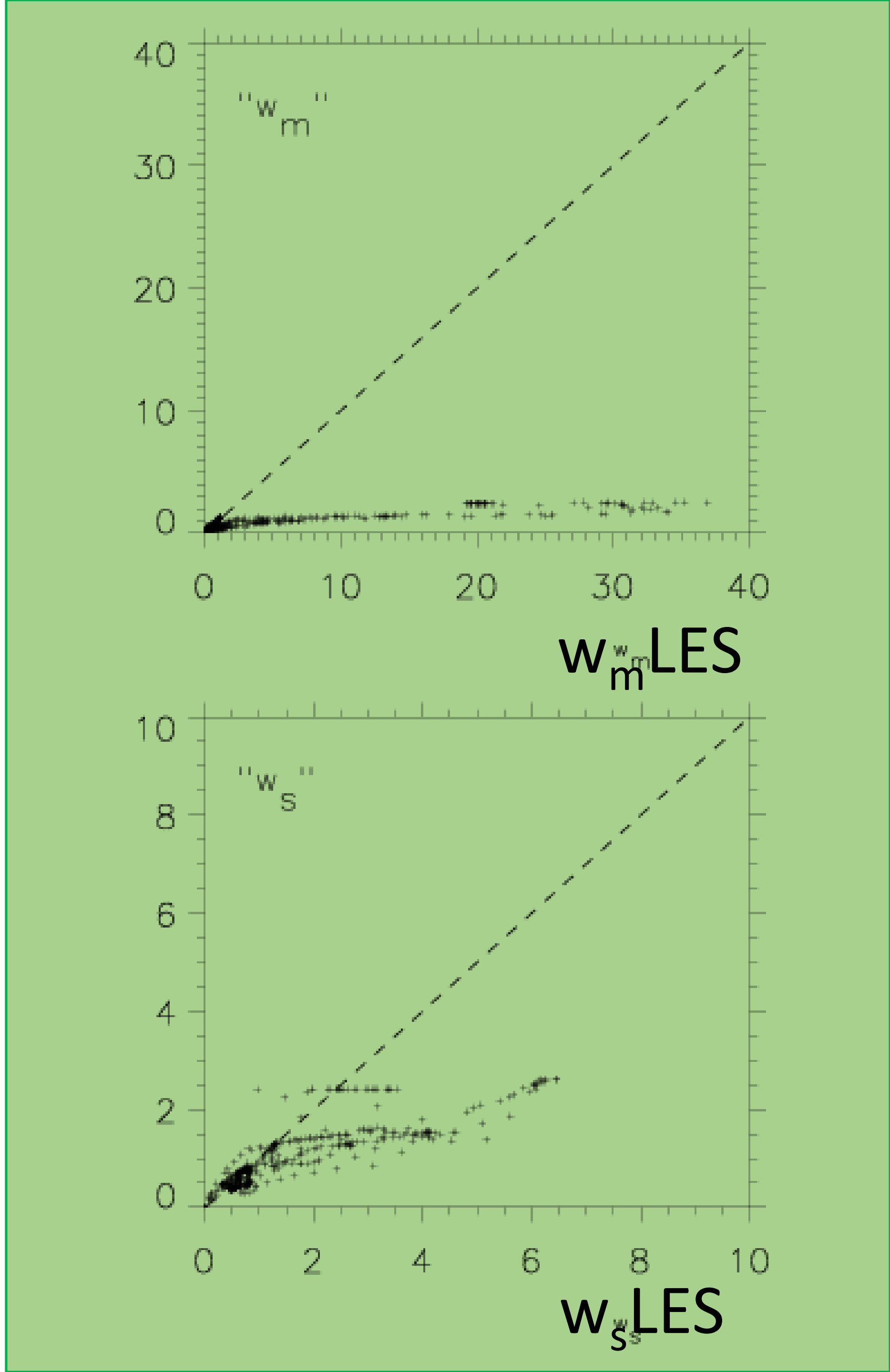


# Smyth et al (2002) :

$$\text{“}w_x\text{“} = \kappa\, u^* \,\phi_x^{-1} \,(1 + A\, La^{-4})^{1/2}$$

$$A = 0.15\,[\,u^{*3}/(u^{*3} + .6\, w^{*3})\,]^2$$

$$Pr = (w_m / w_s) < 1$$



$$\phi(\varepsilon h)\ P_U \;=\; F(\zeta_3)$$

$$\zeta_3 = (\ 1 + \text{“}P_S\text{“}\ La^{-2})^{-1}$$

$$P_U \;=\; F(\zeta_3)$$

$$\zeta_3 = (\ 1 + \ La^{-2})^{-1}$$