The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

Spring Colloquium on
'Regional Weather Predictability and Modeling'
April 11 - 22, 2005

1) Workshop **on Design and Use of Regional Weather
Prediction Models,** *April 11 - 19*

2) Conference on **Current Efforts Toward Advancing the Skill of Regional Weather
Prediction. Challenges and Outlook,** *April 20 - 22*

301/1652-2

ETA Land-Surface, Surface Layer and PBL Parameterization Schemes
Lecture II

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ETA Land-Surface, Surface Layer and PBL Parameterization Schemes

(Lecture Two)

By

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for

ITCP Spring Colloquium on
Weather Predictability and Modeling

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Outline

- Overview of schemes …
  - Land Surface Model (LSM)
  - Surface Layer (SL)
  - Planetary Boundary Layer (PBL)

Lecture 1

- Noah LSM
- Surface Layer
- Planetary Boundary Layer

Lecture 2

Surface Layer & PBL Schemes

Purpose

- Surface layer
    - Exchange of heat, water vapor and momentum between atmosphere and land surface
    - Stability functions from Monin-Obukhov theory

- PBL
    - Vertical turbulent dispersion of heat, water vapor and momentum throughout the PBL.
    - Achieved through turbulent viscosity (K_m) and diffusivities (K_h)

Further Attributes: Surface Layer

- Limits on u_*, z/L, and other parameters to not allow turbulent mixing to diminish to zero in stable stratification (nighttime).
- Surface layer wind speed augmented in unstable conditions to account for downdrafts
- Roughness length for heat lower that that for momentum.

Further Attributes: PBL

- Mellor-Yamada Level 2.5 turbulence closure
- Local diffusion scheme, i.e. flux = -K x (mean vertical gradient)
- Limits on length scale, turbulent kinetic energy to avoid mathematical singularities in Level 2.5 solution space.

Surface Layer

- Sensible Heat Flux Calculation

$$H_s = \rho c_p C_h U_{SL} \left(\theta_s - \theta_a \right)$$

- Momentum Flux

$$\tau = \rho C_d U_{SL}^2$$

- U_{SL}^2 = effective surface layer wind speed = $U_a^2 + U_{conv}^2$

  where U_a is wind speed within first vertical layer

  and U_{conv} is a "convective" velocity (to be defined)

- θ_s = "skin temperature", from land-surface scheme

- θ_a = Air temperature within first eta layer

- C_h, C_d = Exchange coefficients for heat and momentum

Surface Layer Equations

$$\left.\begin{aligned}
C_d &= \frac{k^2}{[\ln(h/z_{0,m}) + \psi_m(h/L) - \psi_m(z_{0,m}/L)]^2} \\
C_h &= \frac{k^2}{\begin{gathered}([\ln(h/z_{0,h}) + \psi_h(h/L) - \psi_h(z_{0,h}/L)] \bullet \\ [\ln(h/z_{0,m}) + \psi_m(h/L) - \psi_m(z_{0,m}/L)])\end{gathered}}
\end{aligned}\right\}$$

FROM
MONIN-
OBUKHOV
THEORY

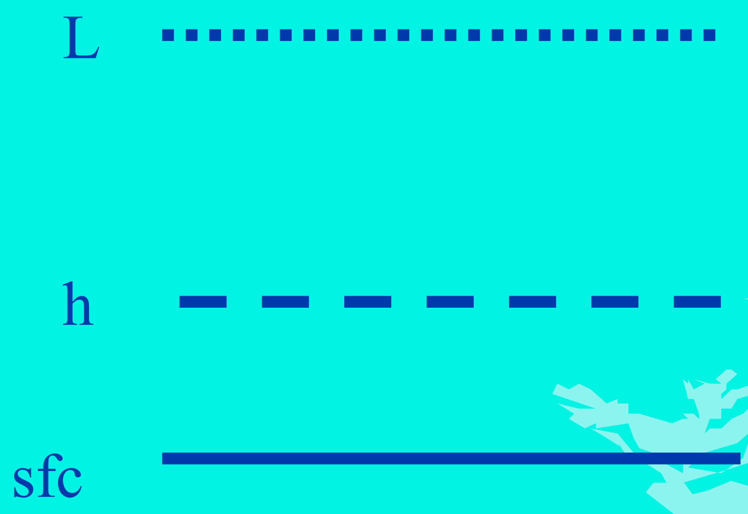
where:

$\Psi_{m,h}$- Stability functions for heat (h) and momentum (m)
L – Monin-Obukhov length
$z_{0,m}$, $z_{0,h}$ – roughness lengths for momentum and heat
k - Von Karman constant = 0.4
h – midpoint of lowest grid layer

Monin-Obukhov Length

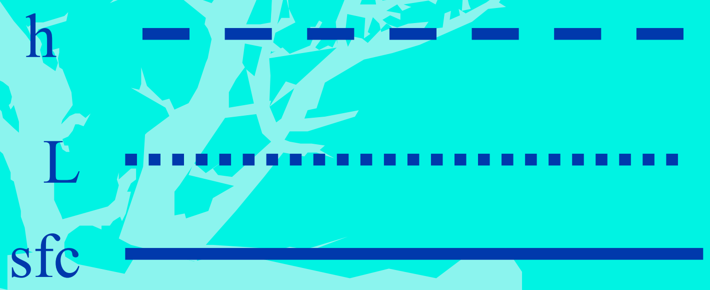
$$L = -\frac{u_*^3}{k(g/\Theta_a)(H_s/\rho c_p)}$$

Weakly stratified



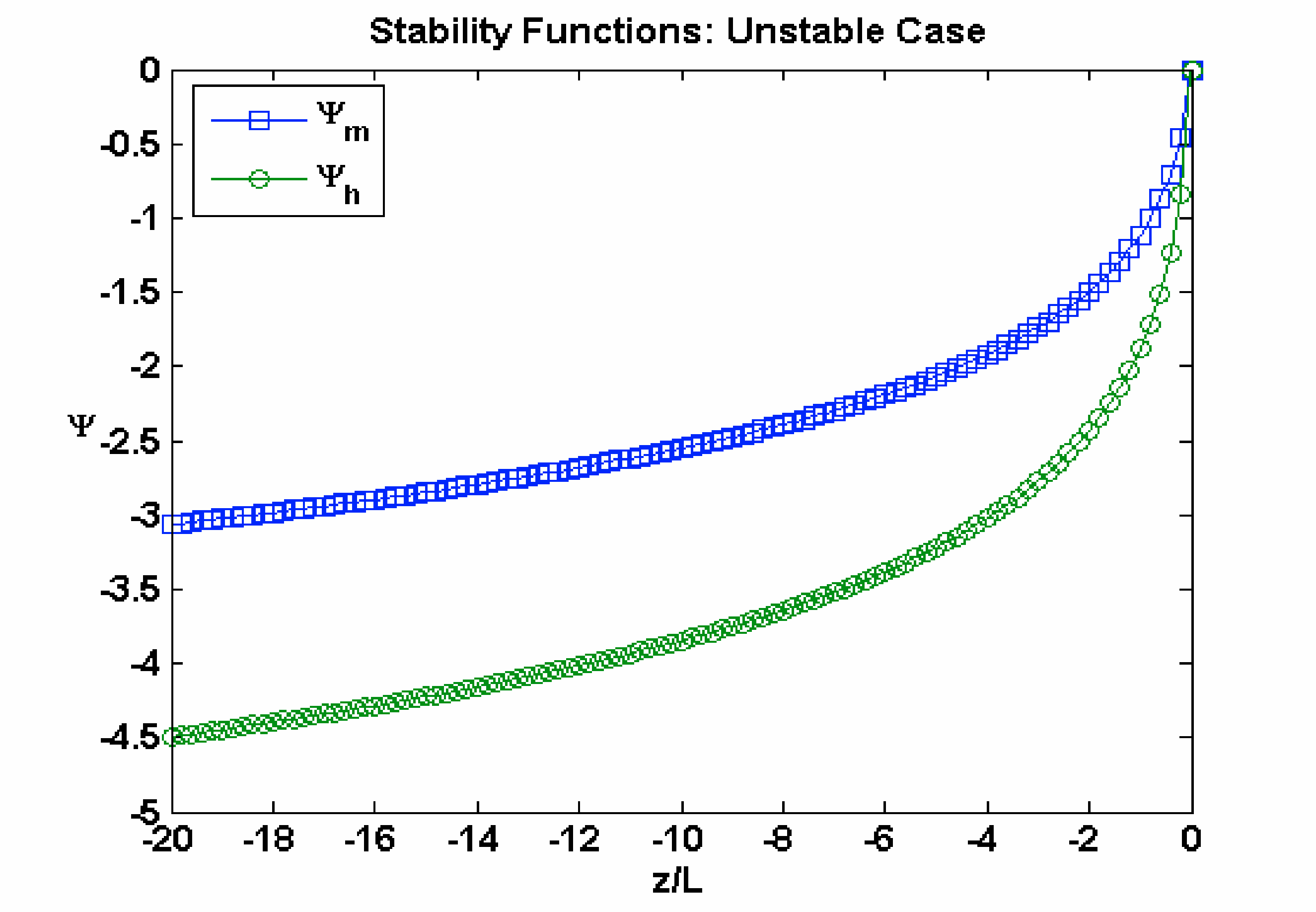
h/|L| << 1 ~ quasi-neutral
Little effect of stratification
on fluxes

Strongly stratified



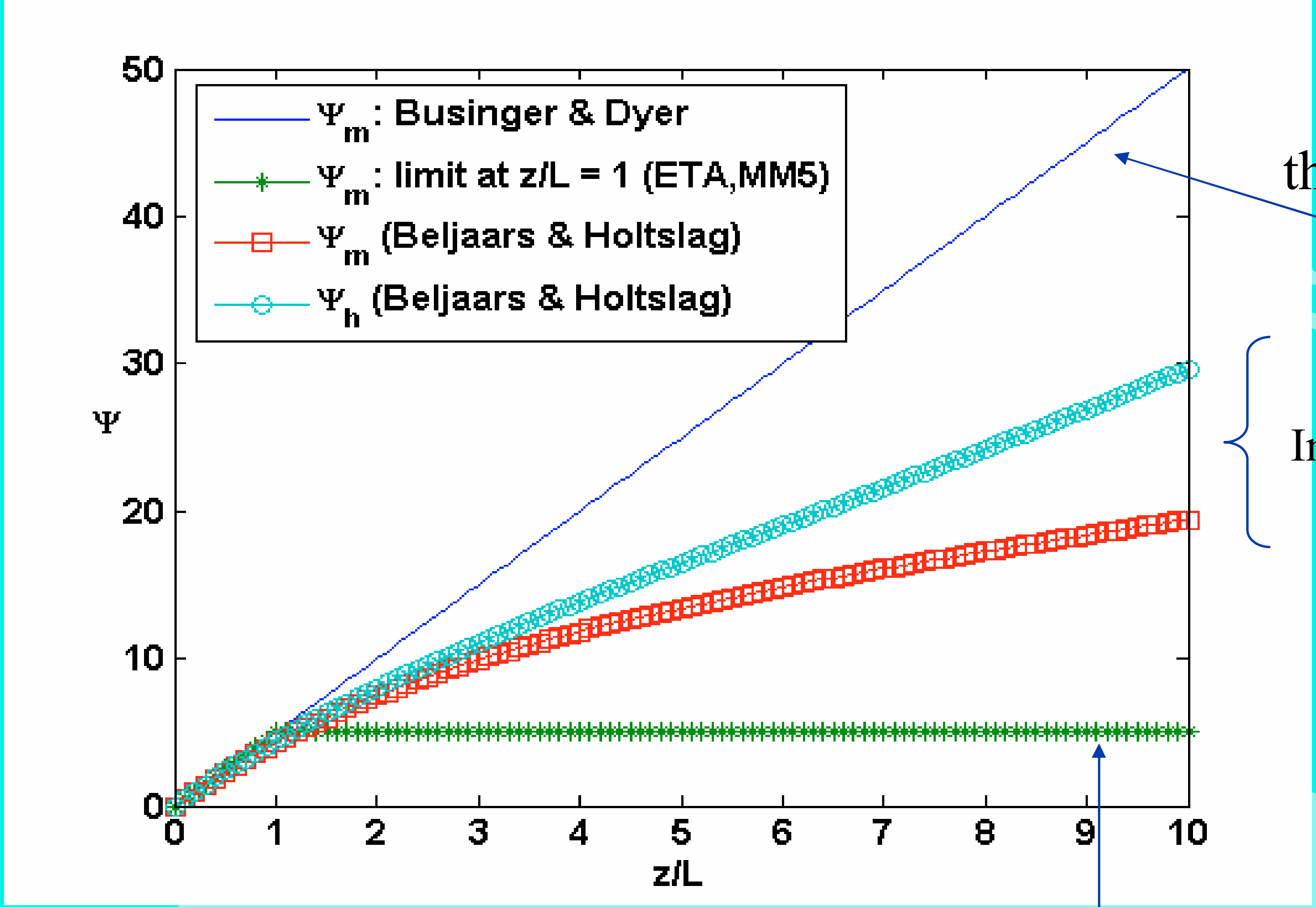
h/|L| > 1
Large effect of stratification
on fluxes

Stability Functions (Unstable Stratification, L < 0)



Equations from Paulson (1970)

Stability Functions (Stable Stratification, L > 0)



theoretical

In WRF/NMM

In current ETA

Elaborations & Limits

1) $z_{0h} < z_{0m}$

from Zilitinkevich (1995) …

$$z_{0h} = z_{0m} \exp\left(- k\, C \sqrt{\mathrm{Re}^*}\right)$$

$$\mathrm{Re}^* = \frac{u_* z_{0m}}{\nu}$$

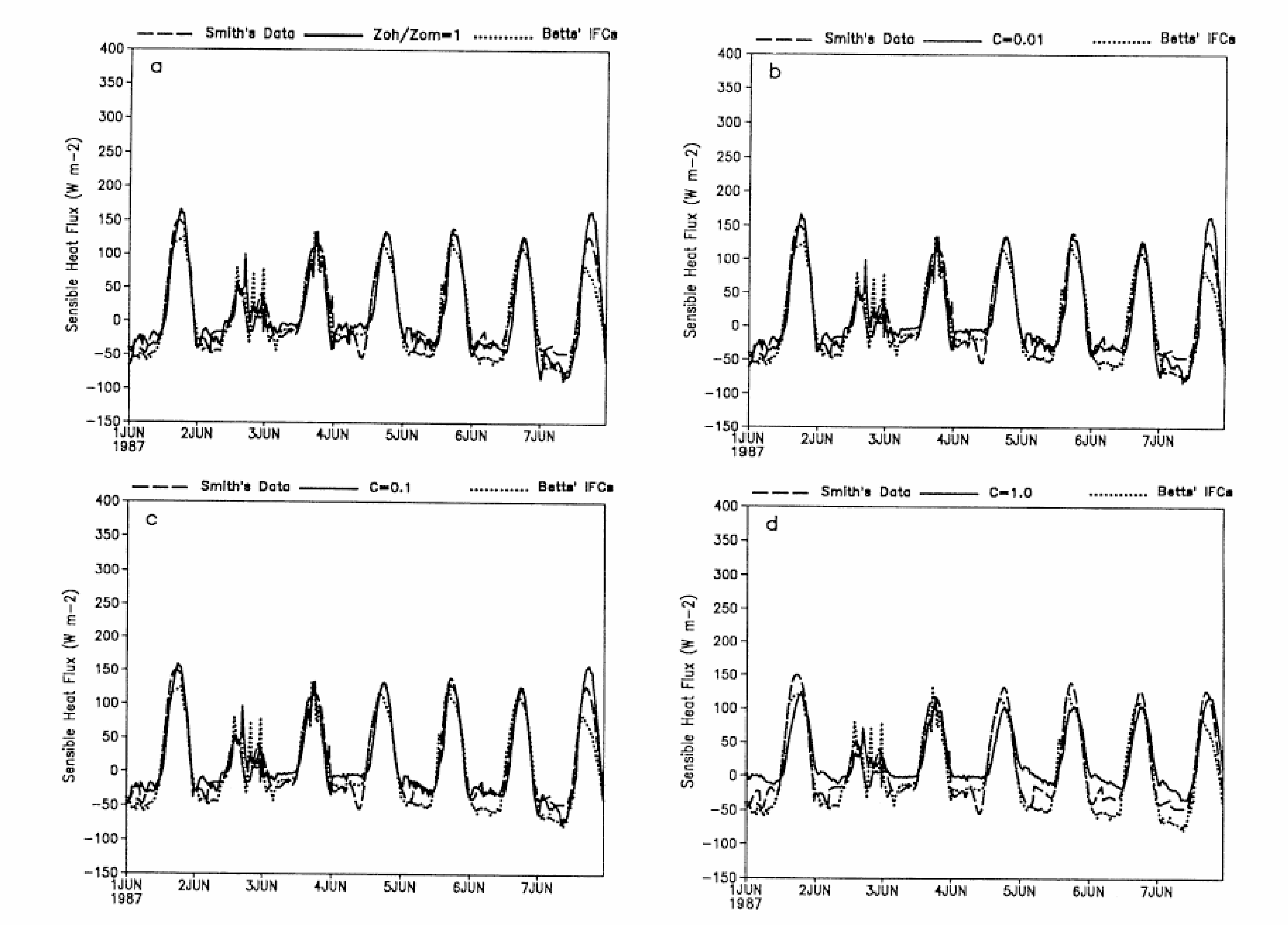
- Heat roughness can be orders of magnitude less than for momentum
- C – constant determined by numerical experimentation
- C = 0.1 chosen for ETA after substantial experimentation
- Affects surface fluxes and skin temperature during daytime conditions
- Positive impact of summer precipitation forecast scores

Details: Chen, Jancic & Mitchell (1997, BLM)

Effect on surface heat flux

Offline testing: Predictions (solid), FIFE observations (others)

Source: Chen, Jancic & Mitchell (1997, BLM)



$z_{0m} = z_{0h}$

C = 0.01

C = 0.1

C = 1

Effect on summer precipitation

ETA2: $z_{0h} = z_{0m}$ ETA3: $z_{0h} = 0.1z_{0m}$

BIAS

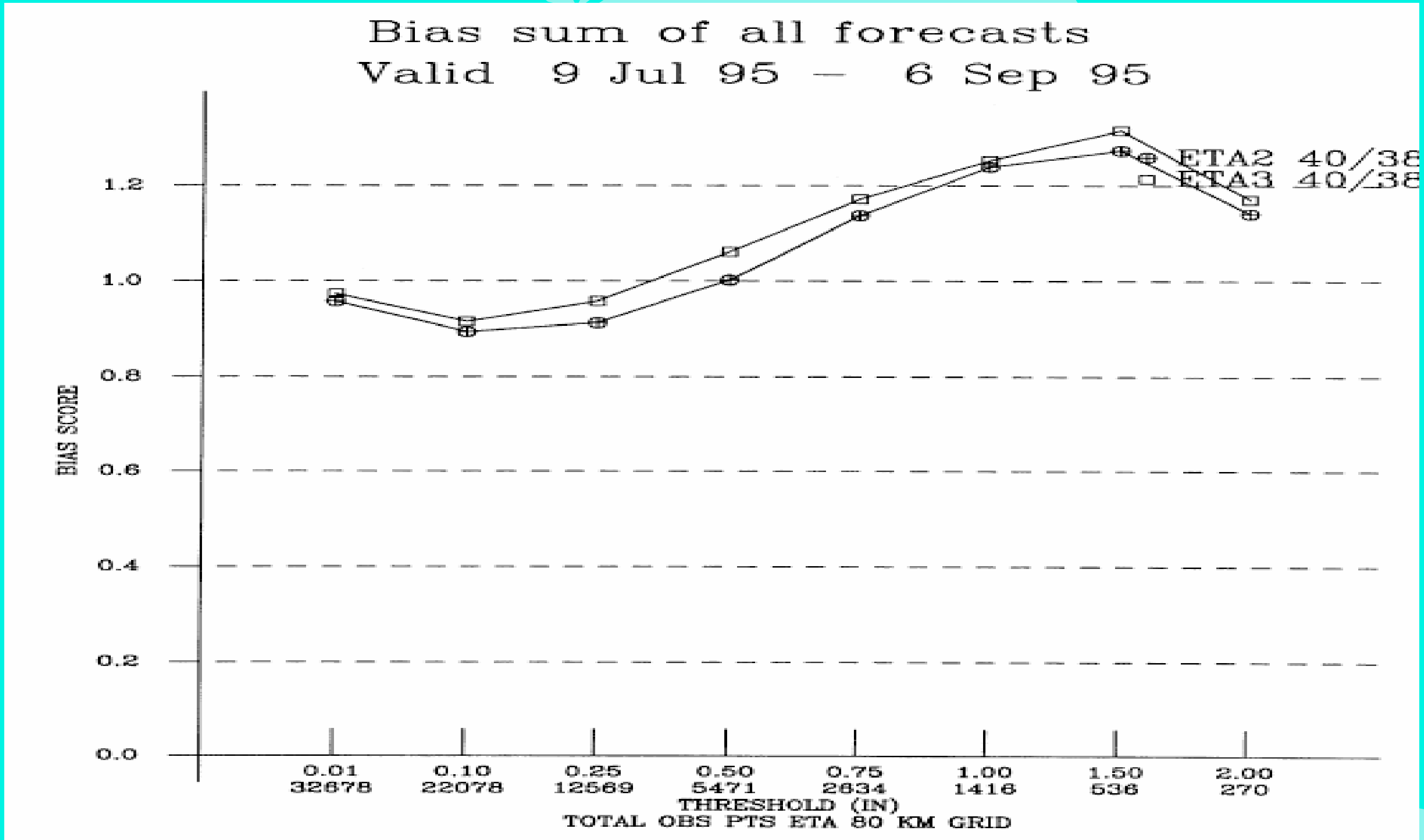


Figure 7b.

THRESHOLD

Source: Chen, Jancic & Mitchell (1997, BLM)

2) Augmented SL wind speed (daytime, $H_s > 0$)

$$U_{SL}^2 = U_h^2 + \underbrace{U_{conv}^2}_{\text{Added term}}$$

where

$$U_{conv} = \alpha w_*$$

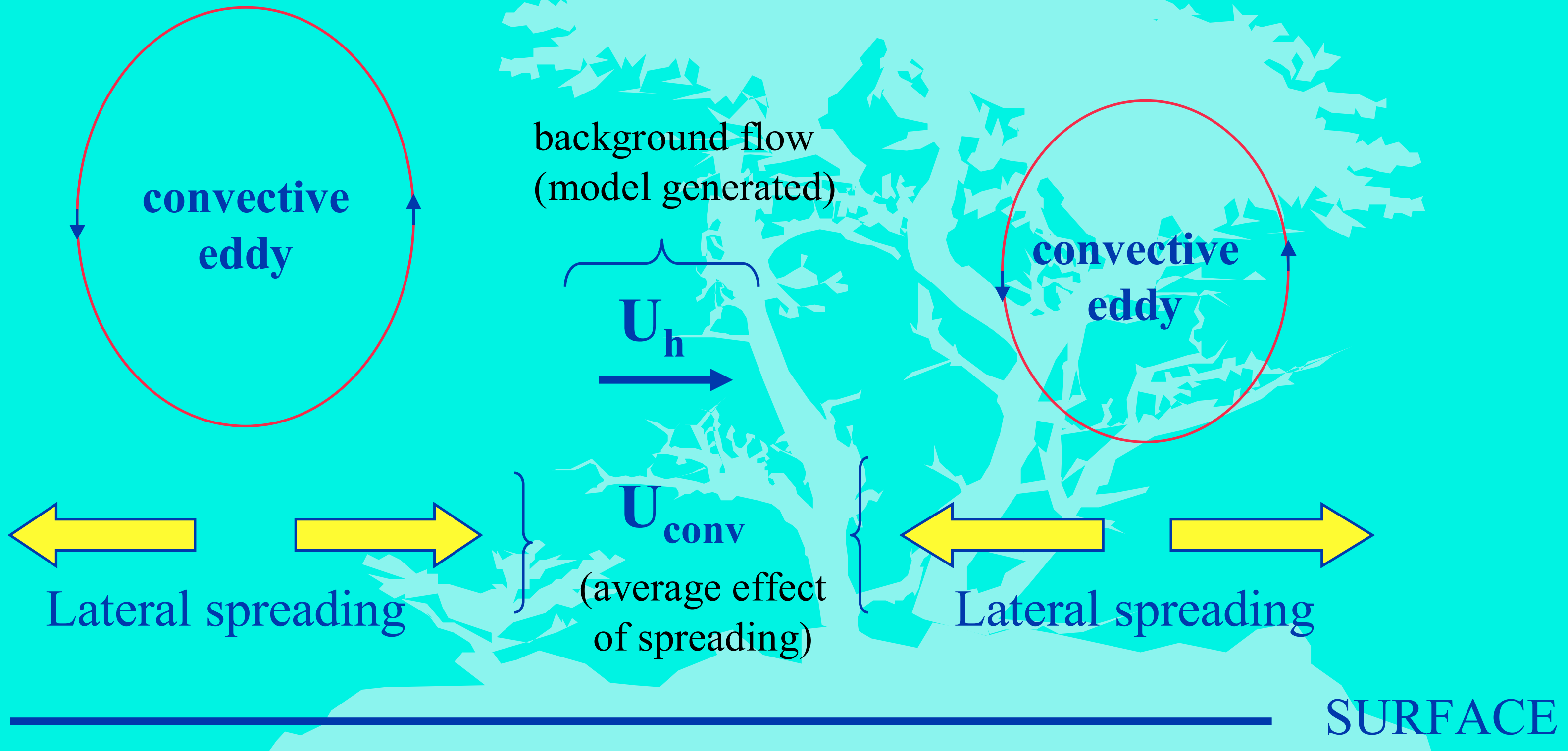
$$w_* = [\underbrace{(g/\Theta_a)(H_s/\rho c_p)}_{\text{Buoyancy flux}}\underbrace{h_{PBL}}_{\text{PBL depth}}]^{1/3}$$

FREE CONVECTIVE VELOCITY SCALE

α ranges from 1-2
(1.2 in ETA)

Description …

(lowest ~ 100 m)



convective eddy

background flow (model generated)

U_h

convective eddy

Lateral spreading

U_{conv}

(average effect of spreading)

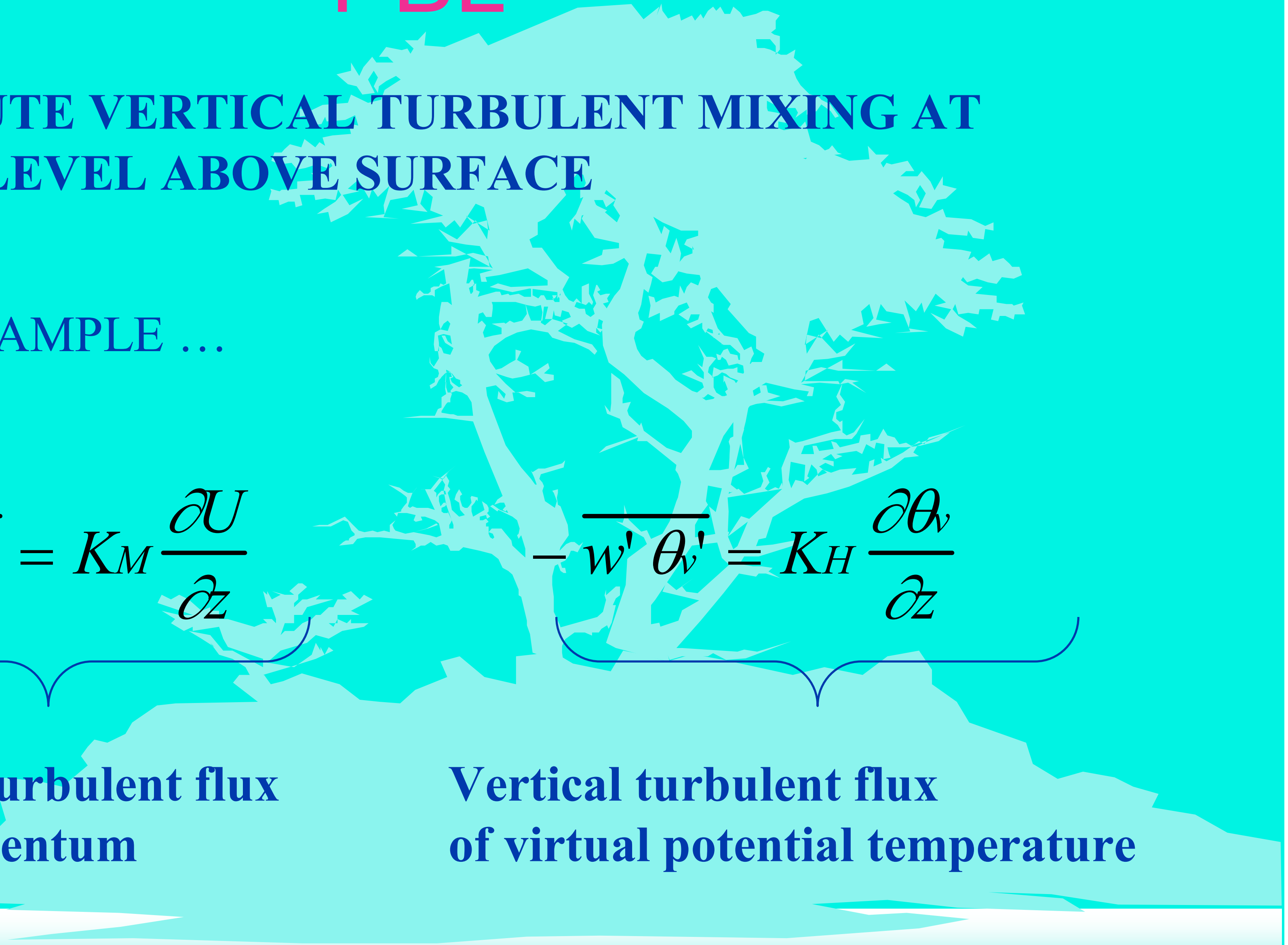
Lateral spreading

SURFACE

3) Limits during stable, nighttime conditions …

- Maximum value of $z/L = 1$
- Minimum value of $u_* = 0.07\ ms^{-1}$
- First imposition limits correction term in C_d, C_h calculation so that these do not become to small.
- Physically: maintenance of a “background level” of turbulent mixing in stable conditions.
- Helps keep near-surface temperatures from becoming too cold at night.
- Active area of research
  - assess origin of such turbulence
  - how to best parameterize from a fundamental basis.

PBL



COMPUTE VERTICAL TURBULENT MIXING AT EACH LEVEL ABOVE SURFACE

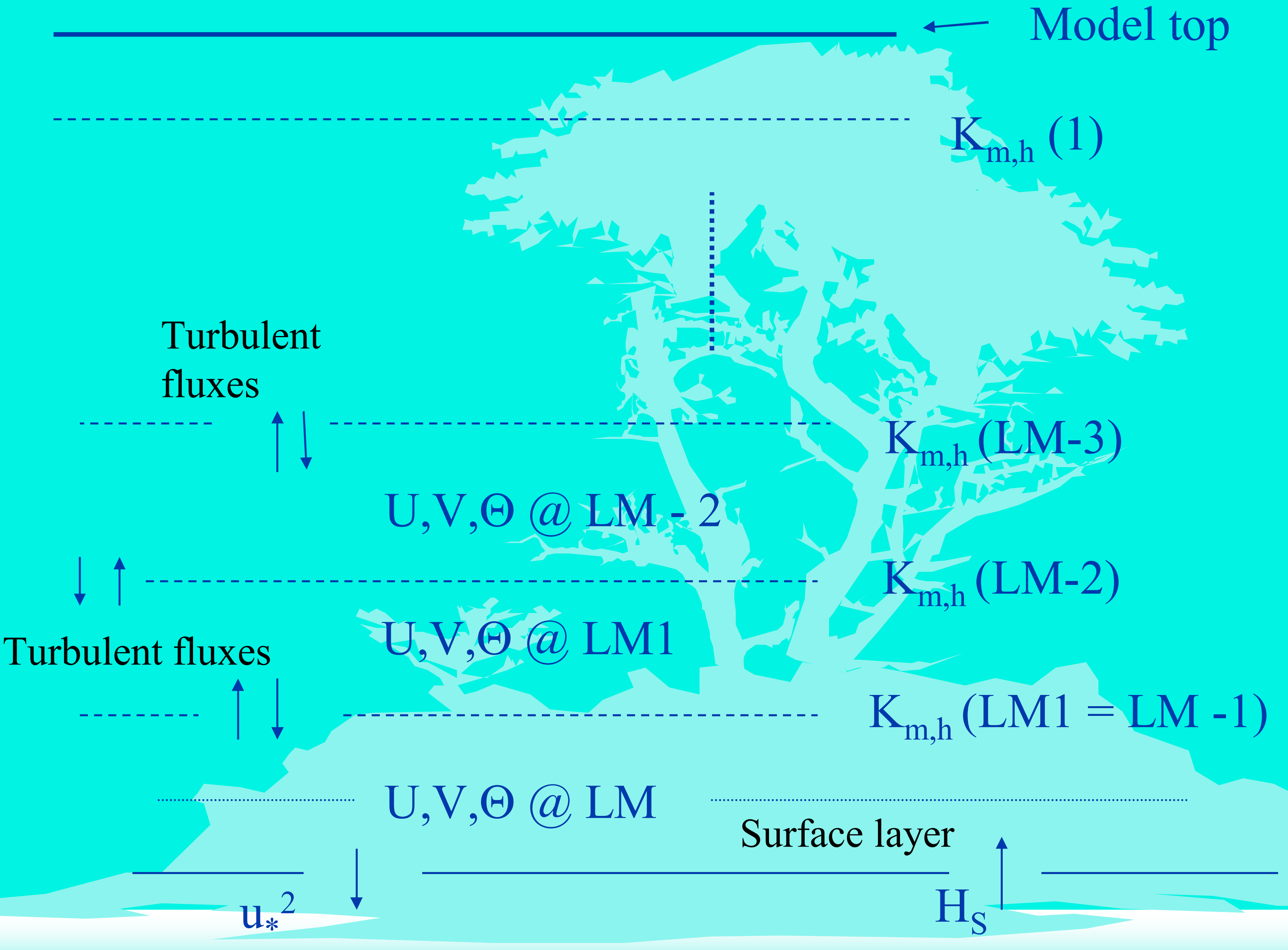
FOR EXAMPLE …

$$\underbrace{-\overline{w'\,u'} = K_M \frac{\partial U}{\partial z}}_{} \qquad \underbrace{-\overline{w'\,\theta_v'} = K_H \frac{\partial \theta_v}{\partial z}}_{}$$

Vertical turbulent flux
of u-momentum

Vertical turbulent flux
of virtual potential temperature

ARCHITECTURE



Model top

$K_{m,h}$ (1)

Turbulent fluxes

$K_{m,h}$ (LM-3)

U,V,Θ @ LM - 2

$K_{m,h}$ (LM-2)

Turbulent fluxes

U,V,Θ @ LM1

$K_{m,h}$ (LM1 = LM -1)

U,V,Θ @ LM

Surface layer

u_*^2

H_S

PBL

- Based on prognostic "turbulent kinetic energy" (TKE):

$$q^2 = 2 \text{ x TKE} = (u')^2 + (v')^2 + (w')^2$$

- Level 2.5 Scheme:

$$K_M = lqS_M\,(G_M) \qquad K_H = lqS_H(G_H)$$

l – mixing length, prescribed function of height and TKE

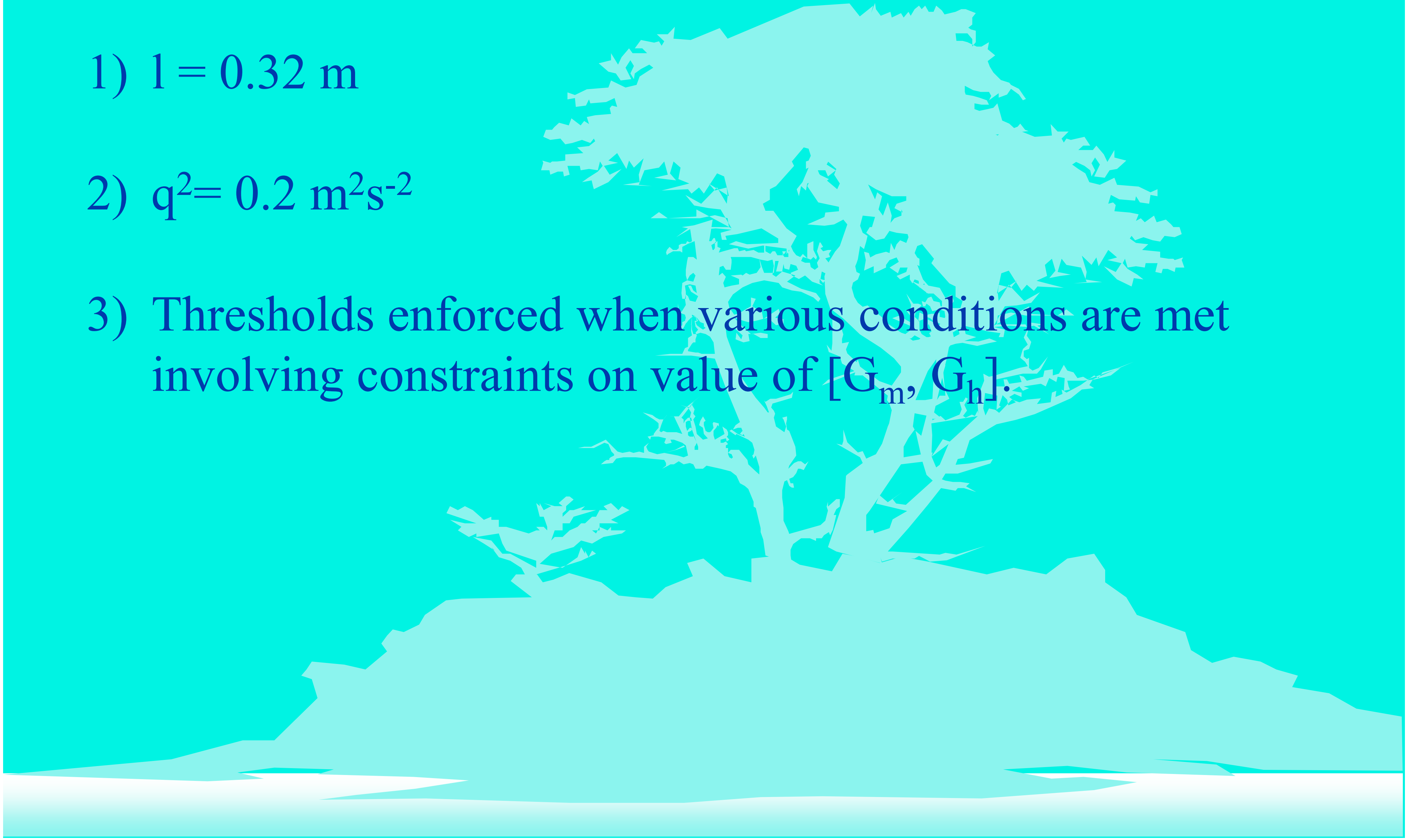
q^2 - solved from prognostic equation

$S_{m,h}$: stability functions of shear (G_m) and stability (G_h)

SUBROUTINES: MIXLEN, PRODQ2, DIFCOF, VDIFQ

Details given by Dr. B. Rajkovic

LOWER LIMITS IN PBL SCHEME …

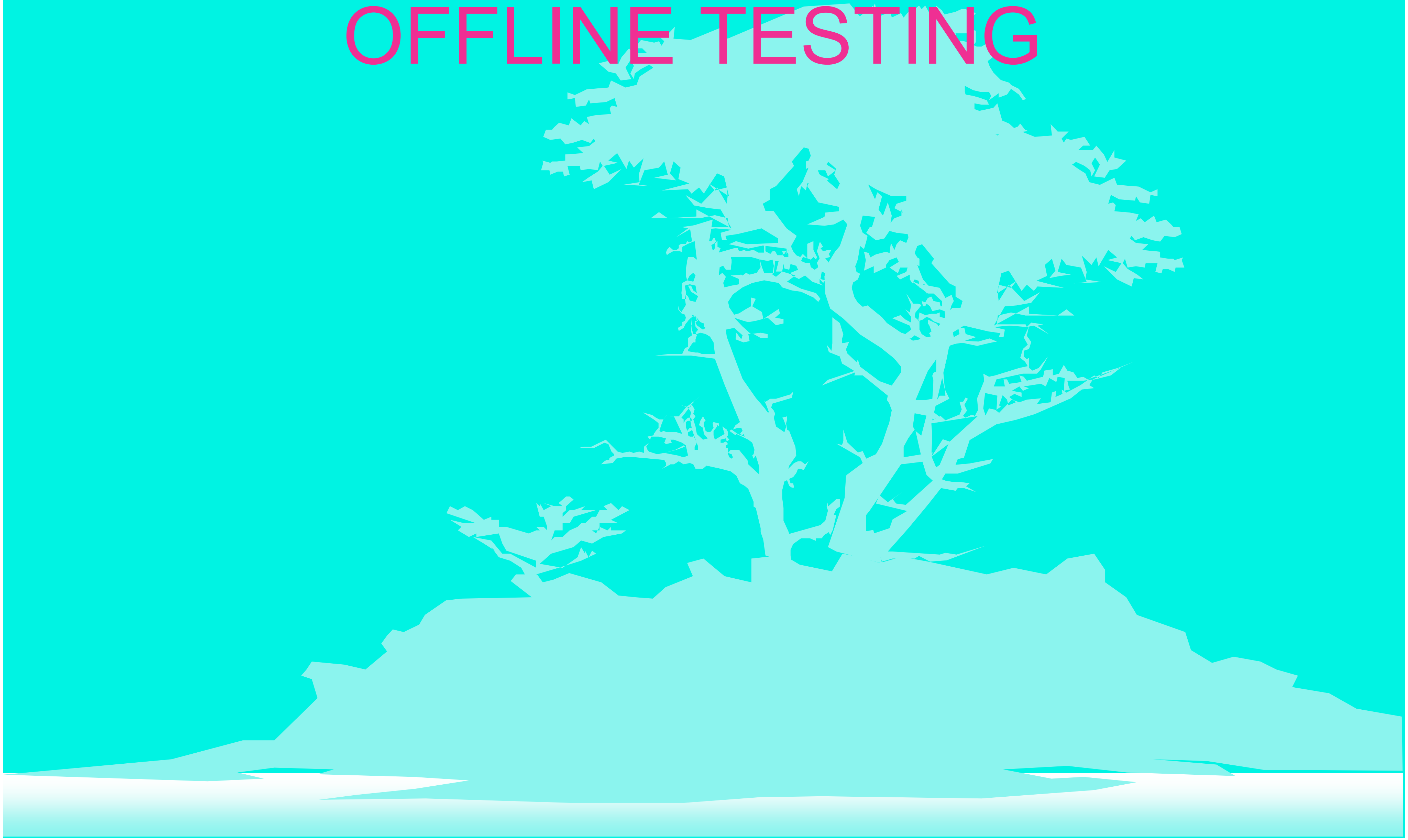


1) $l = 0.32$ m

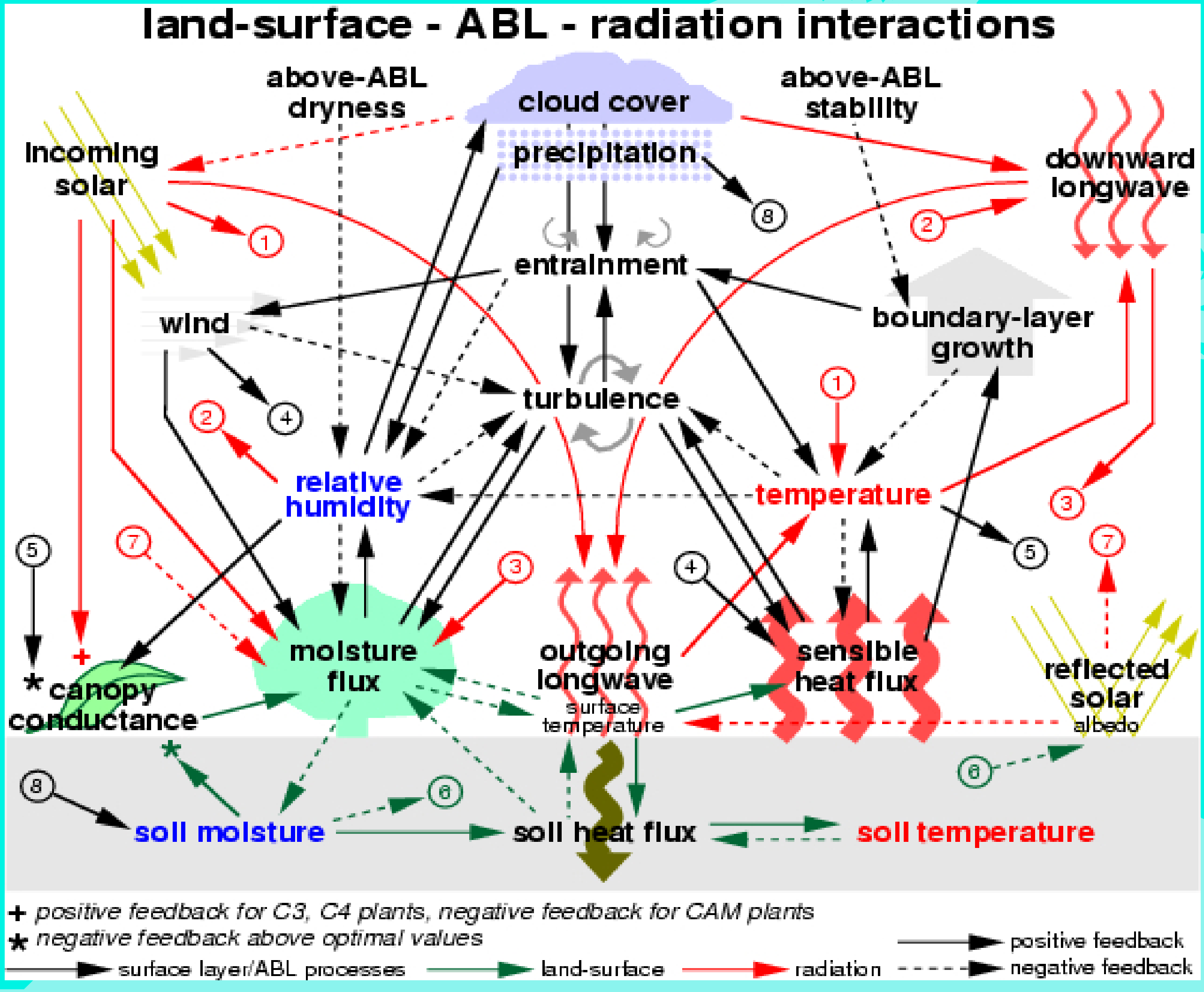
2) $q^2 = 0.2\ m^2s^{-2}$

3) Thresholds enforced when various conditions are met involving constraints on value of $[G_m, G_h]$.

OFFLINE TESTING



PHYSICS "WHEEL OF PAIN"


land-surface - ABL - radiation interactions

\+ *positive feedback for C3, C4 plants, negative feedback for CAM plants*

* *negative feedback above optimal values*

OFFLINE TEST: SURFACE LAYER

- TWO-METER TEMPERATURE, Θ_{2m}
- CAN BE SHOWN (MO THEORY) …

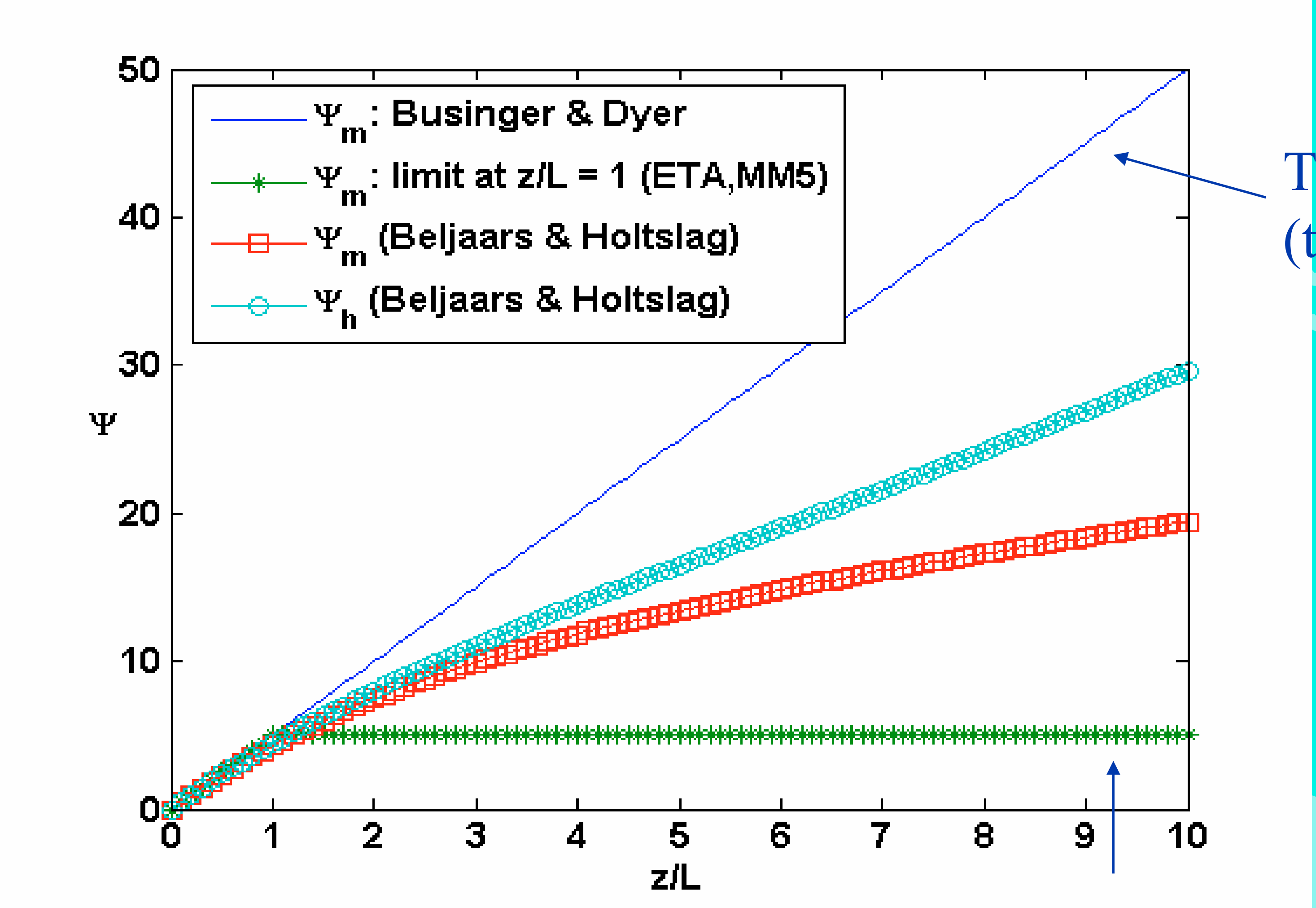
$$\Theta_{2m} = \chi\Theta_h + (1-\chi)\Theta_0$$

WHERE

$$\chi = \frac{\ln(2/z_{0h}) - \psi_h(2/L)}{\ln(h/z_{0h}) - \psi_h(h/L)}$$

- PLUG IN OBSERVED Θ_0, Θ_h and U_h
- COMPARE PREDICTIONS FROM WITH OBS.
- CASES99 DATA (STABLE ABL, KANSAS, 10/2002)
- NIGHTS 18, 19, 21, 22 (10-minute avg. data)
- 288 TOTAL DATA POINTS

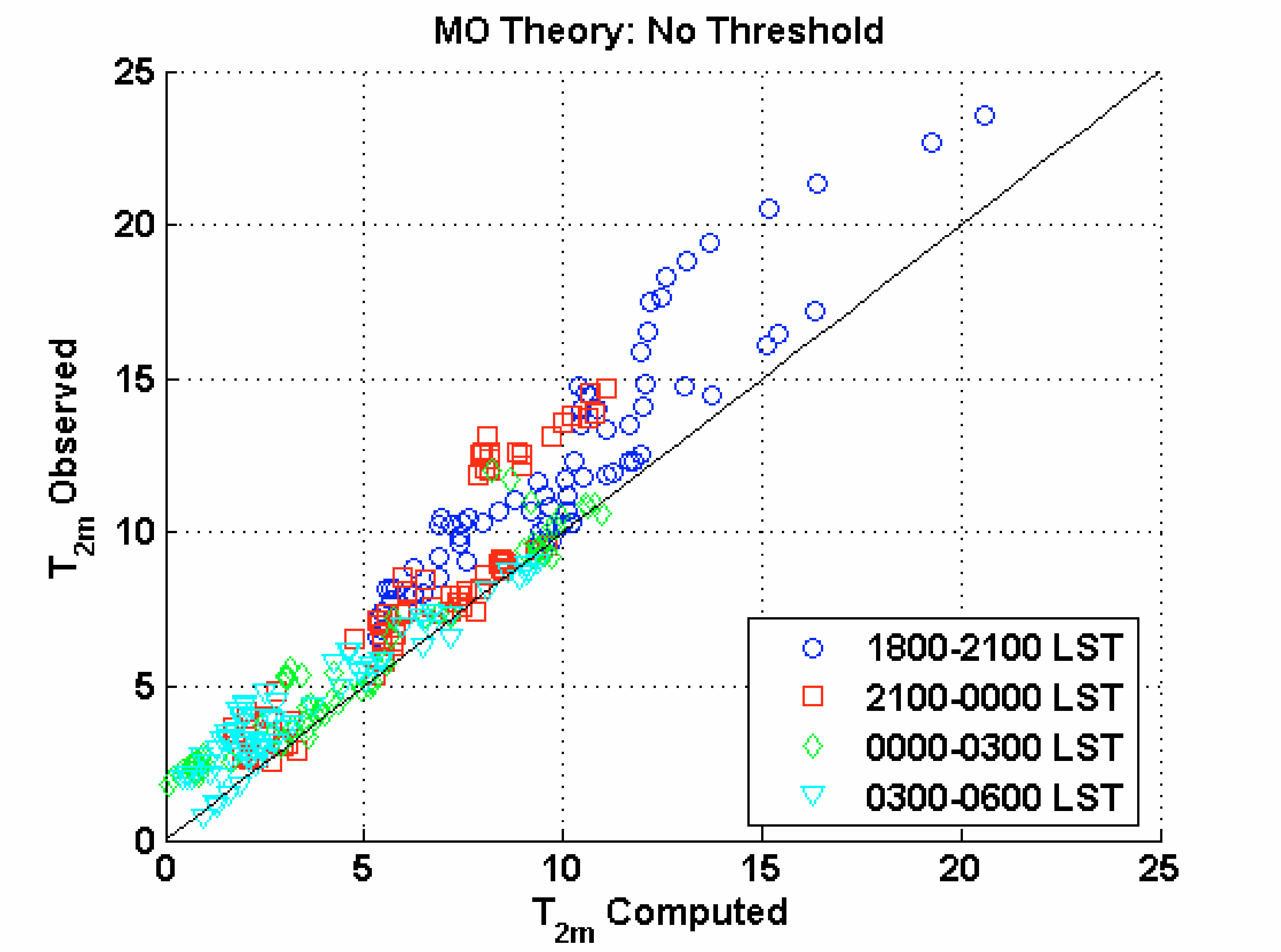
Stability Functions (Stable Stratification, L > 0)



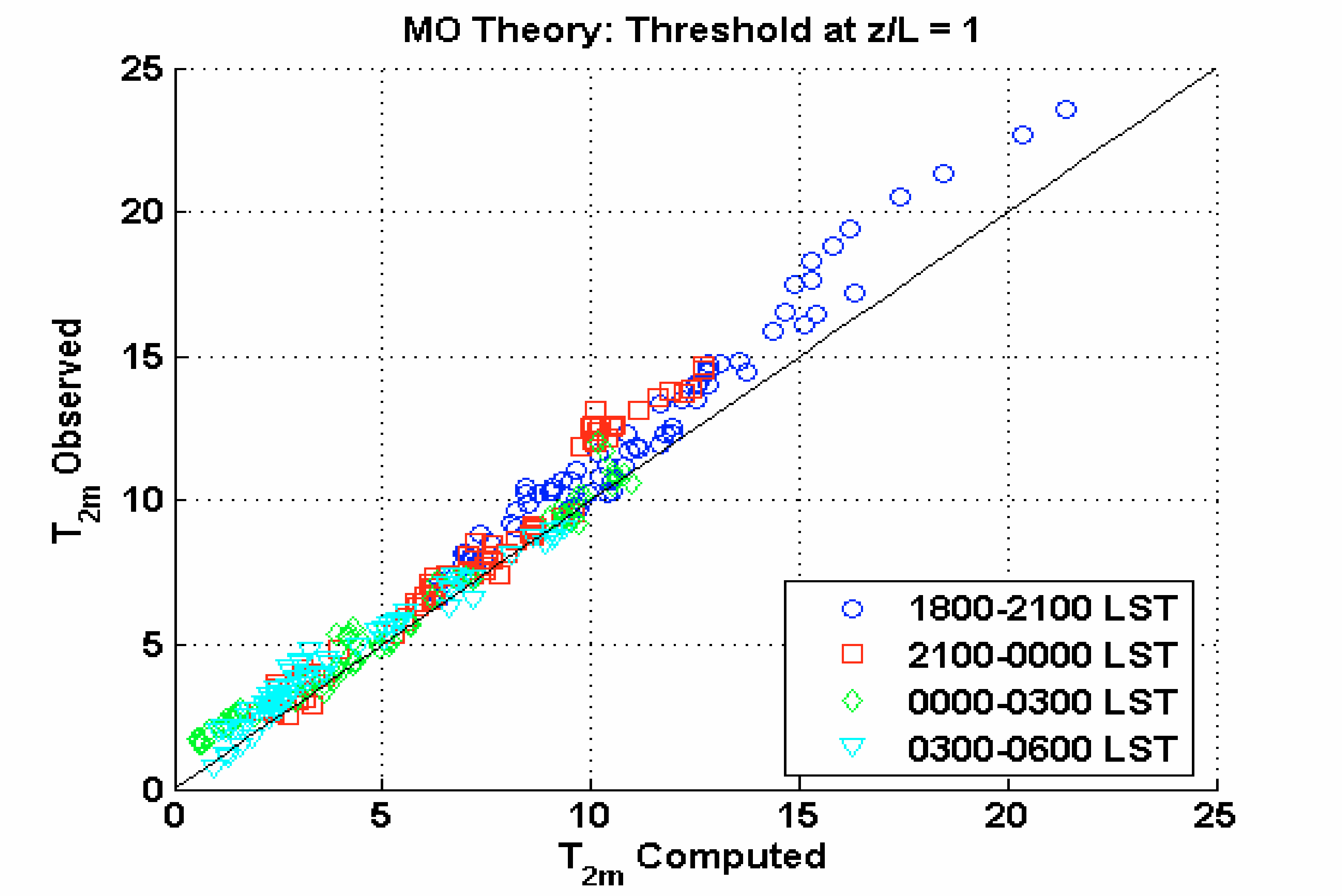
Theoretical
(test this)

Current ETA (test this)

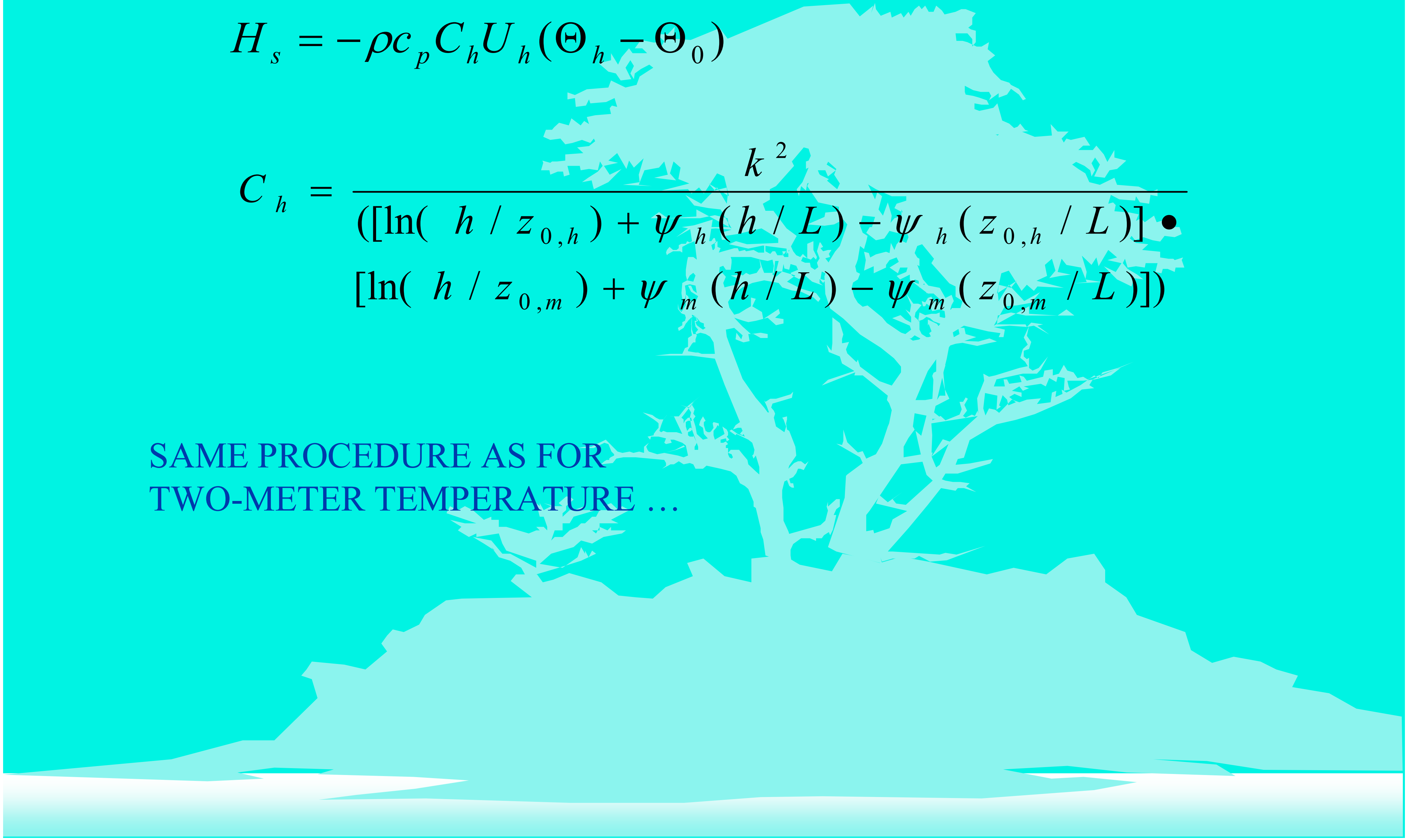
STABILITY FUNCTIONS VIA MO THEORY: NO LOWER THESHOLD ON Z/L (THEORETICAL)



STABILITY FUNCTIONS VIA MO THEORY: LOWER THESHOLD AT Z/L = 1 (CURRENT ETA IMPLEMENTATION)



PERFORM TEST ON SURFACE HEAT FLUX …

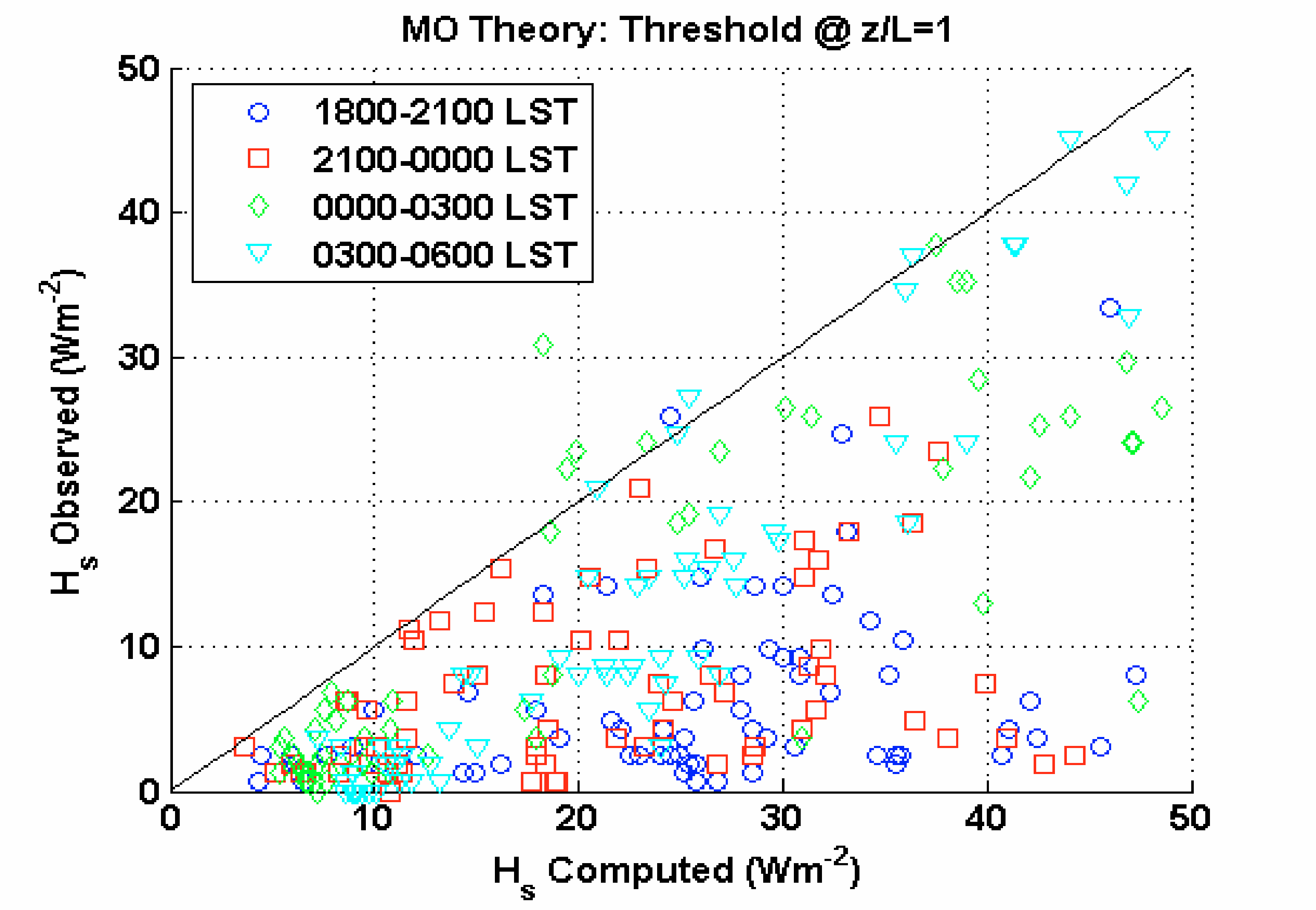


$$H_s = -\rho c_p C_h U_h (\Theta_h - \Theta_0)$$

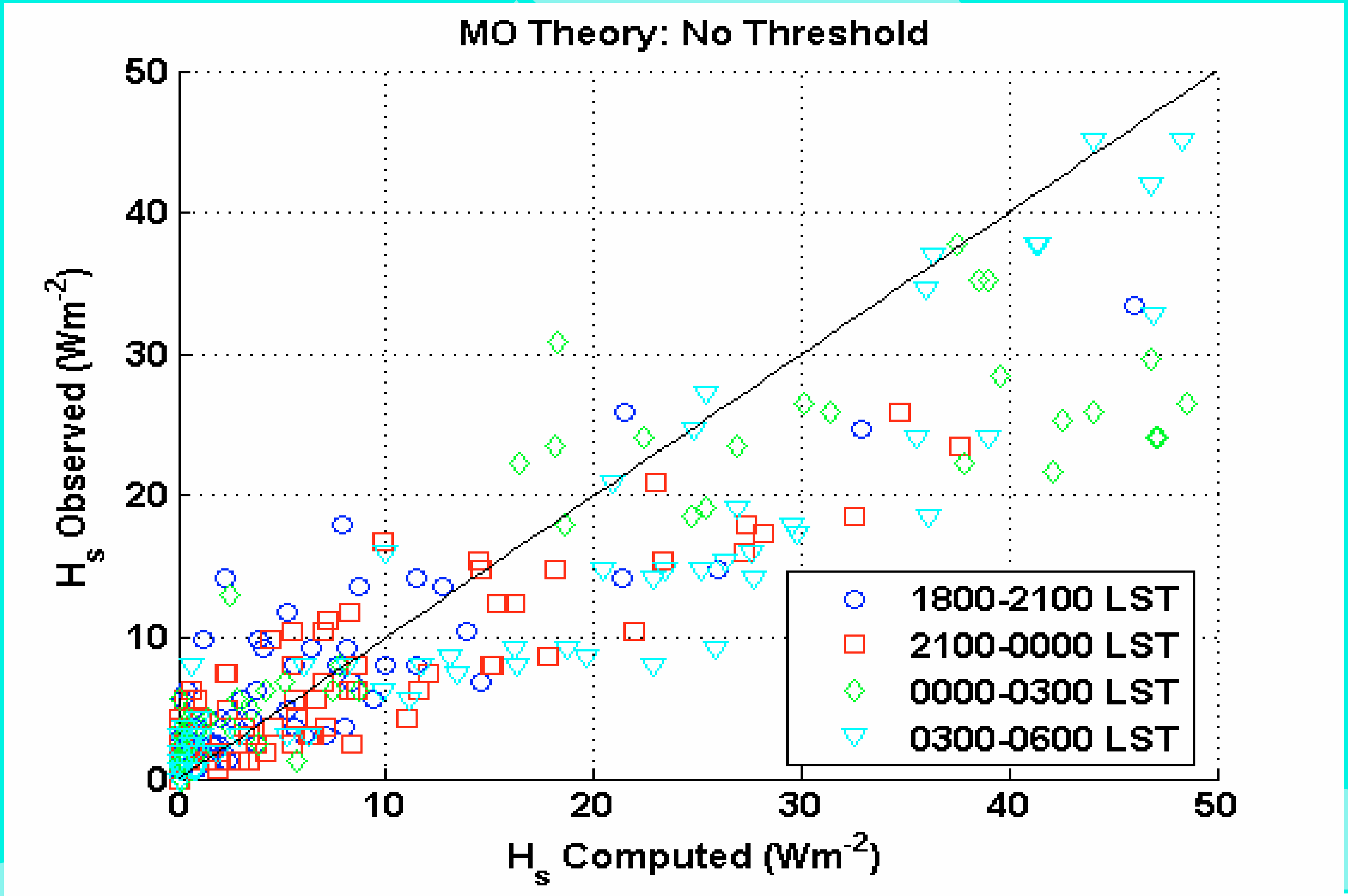
$$C_h = \frac{k^2}{([\ln(h/z_{0,h}) + \psi_h(h/L) - \psi_h(z_{0,h}/L)] \bullet [\ln(h/z_{0,m}) + \psi_m(h/L) - \psi_m(z_{0,m}/L)])}$$

SAME PROCEDURE AS FOR
TWO-METER TEMPERATURE …

STABILITY FUNCTIONS VIA MO THEORY: LOWER THESHOLD AT Z/L = 1 (CURRENT ETA IMPLEMENTATION)



STABILITY FUNCTIONS VIA MO THEORY: NO LOWER THESHOLD ON Z/L (STANDARD THEORY)



SUMMARY OF RESULTS

- LOWER THRESHOLD ON Z/L KEEPS 2-M TEMPERATURES WARMER THAN THEY WOULD BE OTHERWISE

- HELPS ALLEVIATE NIGHTTIME COLD BIAS IN ETA (ALTHOUGH IT STILL EXISTS …)

- TEST SUGGESTS THAT IT DOES SO BY CREATING ARTIFICIAL” DOWNWARD HEAT FLUX

- MUST UNDERSTAND PHYSICS BETTER TO ARRIVE AT MORE FUNDAMENTAL CORRECTION

SUGGESTED EXERCISES I

- C factor in Zilitinkevich thermal roughness equation
  - Subroutine REDPRM (in SFLX.F, change CZIL_DATA in PARAMETER statement from 0.2 to other values between 0 & 1).
  - Subroutine SFCDIF (SFCDIF.F, make identical change to CZIL in PARAMETER statement)
  - Check differences in **daytime** 2-meter temperature, surface fluxes & precipitation patterns

SUGGESTED EXERCISES II

- α factor for surface layer velocity enhancement term
  - Subroutine SFCDIF (make change to WWST in PARAMETER statement from 1.2 to other value in range 1-2)
  - Check differences in **daytime** 2-meter temperature, surface fluxes & precipitation patterns

SUGGESTED EXERCISES III

- Sensitivity to surface layer threshold values (SFCDIF)
  - Change ZTMAX (maximum z/L) in PARAMETER statement from 1 to other values. Large value (~ 100) effectively shuts off threshold since model calculations would not normally exceed this.
  - Change EPSUST (minimum u_*) in PARAMETER statement from 0.07 ms^{-1} to lower value (< 0.01 effectively shuts off threshold)
  - Check **nighttime** two-meter temperature, 10-meter winds, surface fluxes, mean profiles for sensitivity

SUGGESTED EXERCISES IV

- Different stability functions for stable conditions.
- Lines 64 and 66 in SFCDIF
  - Current: PSPMS(YY) = 5*YY & PSPHS(YY) = 5*YY. This is the $\psi_m = \psi_h = 5z/L$, the theoretical relationship plotted in the above figure for stable stability functions (yy = z/L).
  - Change:
    - PSPMS(YY)=0.7*yy+0.75*yy*(6.-0.35*yy)*exp(-0.35*yy)
    - PSPHS(YY)=0.7*yy+0.75*yy*(6.-0.35*yy)*exp(-0.35*yy)
    - Similar to Beljaars & Holtslag functions in stability function plot.
  - Set ZTMAX = 100 (or other large number) to not allow lower threshold to act. See previous slide.
  - Check **nighttime** two-meter temperature, 10-meter winds, surface fluxes, mean profiles for sensitivity