An Overview of Planetary Boundary Layer Physics and Parameterization

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What does a PBL scheme do?

All vertical mixing

Inputs:

- Mean profiles
- Surface fluxes

Outputs:

- Tendencies of T, QV, QC, QI, U, V
- Energy variable (TKE or TE) some schemes
- Diagnostic variables

Where does the PBL fit in the WRF architecture?

PBL

Surface layer

Land surface

Calling sequence:

- Surface layer -> Land surface -> PBL
  - Over water, fluxes from surface layer only

Basic approach

- Gradient transport by eddy diffusion:

$$Flux = -K \frac{\partial \varphi}{\partial z} + \cdots$$

Only two problems:

1. Find K
2. Deal with “issues”

Finding K:
Classes of PBL schemes

By Mellor-Yamada “level”

By “order”

According to what moments are prognostic

- Prognostic equations for basic variables only = M-Y level 1, 1st order
- Prognostic equation for 1 2nd order moment = M-Y level 2.5, 1.5 order
- Prognostics for several 2nd order moments = M-Y level 3, 2nd order

First order schemes

K has a specified profile shape

Shape and magnitude may vary with conditions

Simple, stable, inexpensive

1.5-order schemes

Most use “E-l” formulation:

$K = TKE * length\ scale$

Is this easier to close?

Many choices for length scale:

- Distance from boundaries
- Local or non-local stability
- etc.

TKE is

- produced by shear
- produced or destroyed by buoyancy
- destroyed by dissipation (parameterized)

Issues

- Non-local transport
- Entrainment
- Stable BLs
- Transitions
- Differences between momentum and heat transport
- Non-turbulent motions
- When does column assumption break down?
- Resolution dependence / restrictions
- Coupling to chemistry/particle transport

Non-local transport

Basic assumption is down-gradient transport

$$Flux = -K \frac{\partial \theta}{\partial z}$$

But in neutral and unstable layers, flux and local derivative are decoupled due to transport by eddies the size of the BL depth

Non-local transport

Solutions:

- Ignore (MYJ, MYNN)

  Slightly odd profiles
- Additional term (YSU)

  How universal?
- Explicit non-local treatment (ACM2, TEMF)

  Extra complexity

Entrainment

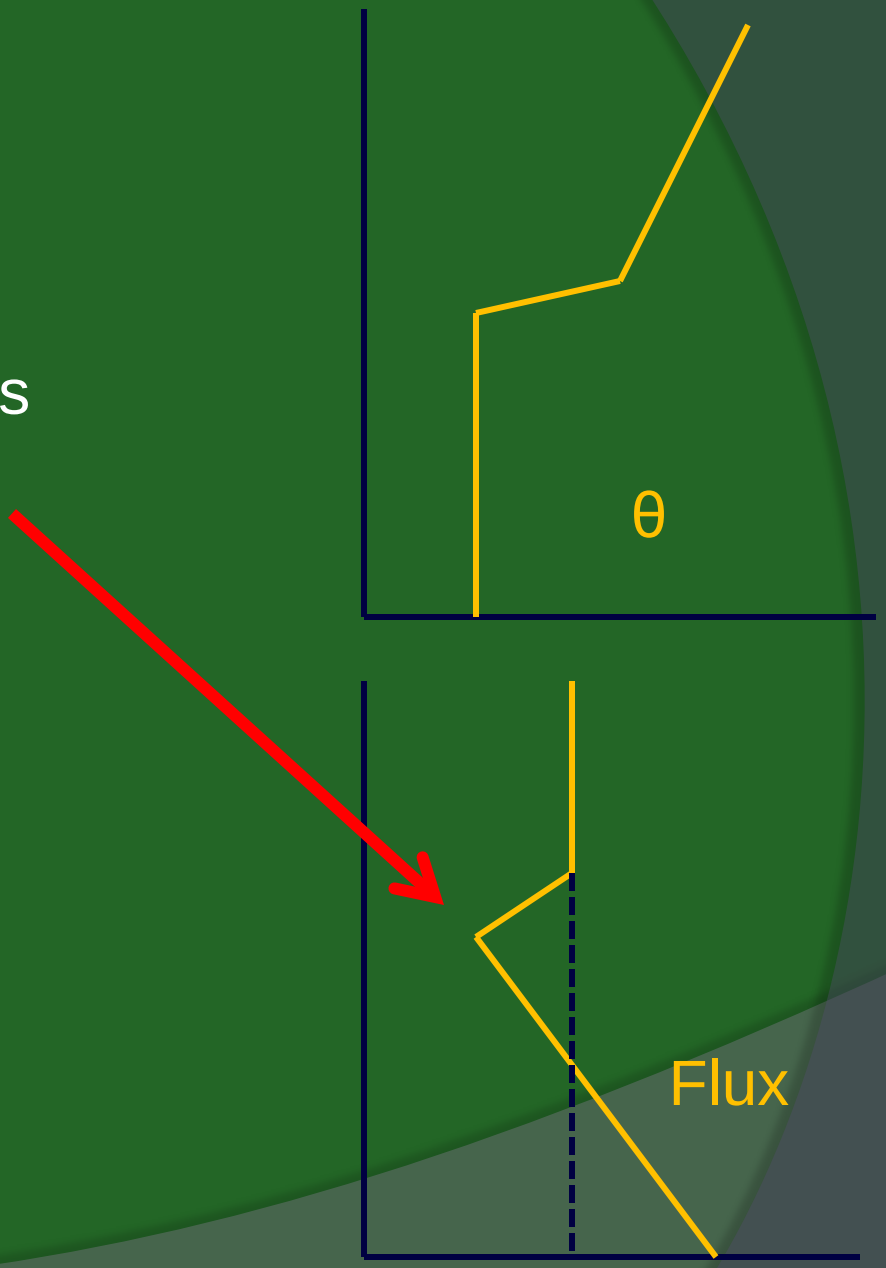
Downward heat flux at CBL top due to impinging thermals *and* shear-driven turbulence

Poorly characterized, highly variable, measurements difficult

Solutions:

Explicit treatment (YSU)

Implicit (others)



Stable BLs

Local (K) approximation not too bad, but…

- Turbulence can be small and/or intermittent
- 3D effects may dominate
- Resolution may be insufficient for shallow SBLs
- Stability functions difficult to define from measurements
- Numerical difficulties

Solutions:

- “Extra” mixing (most operational schemes)
- Novel approaches (QNSE, TEMF)

Transitions

Morning, afternoon, coastal….

- Morning transition dominated by entrainment (see above) so most schemes delay it
- Afternoon/evening weakly forced (can’t ignore otherwise weak processes) and poorly characterized
- Warm air -> cold water dominated by advected turbulence

WRF options

1	YSU
2	MYJ
3	GFS
4	QNSE
5	MYNN2
6	MYNN3
7	ACM2
8	BouLac
9	UW
10	TEMF
99	MRF

1st order, specified K profile, explicit entrainment
Note that recent versions (since v3.0) have significantly different (more diffusive) SBL treatment

WRF options

1	YSU
2	MYJ → Level 2.5 (1.5 order), prognostic TKE
3	GFS
4	QNSE
5	MYNN2
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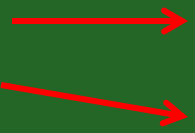

Level 2.5 (1.5 order), prognostic TKE

or

Level 3 (2^{nd} order)

WRF options

1	YSU
2	MYJ
3	GFS
4	QNSE
5	MYNN2
6	MYNN3
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Level 2.5 (1.5 order), prognostic TKE
Novel theory for stable BLs

WRF options

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Level 2.5 (1.5 order), prognostic TKE

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1^{st} order, explicit non-local upward transport

WRF options

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Level 2.5 (1.5 order), prognostic TE (total turbulent energy), Eddy Diffusivity Mass Flux (EDMF) formulation for explicit non-local transport, integrated shallow cloud

Compatibility

Most schemes require a specific surface layer – see User's Guide table

Surface layer schemes (except TEMF) are conceptually similar, but produce different results!

Evaluation and its pitfalls

Differences are and should be small

- Large-scale 3D comparisons are not always helpful

Other processes strongly constrain PBL behavior

- Land surface
- Initialization
- Advection

Offsetting errors lurk!

Evaluation results

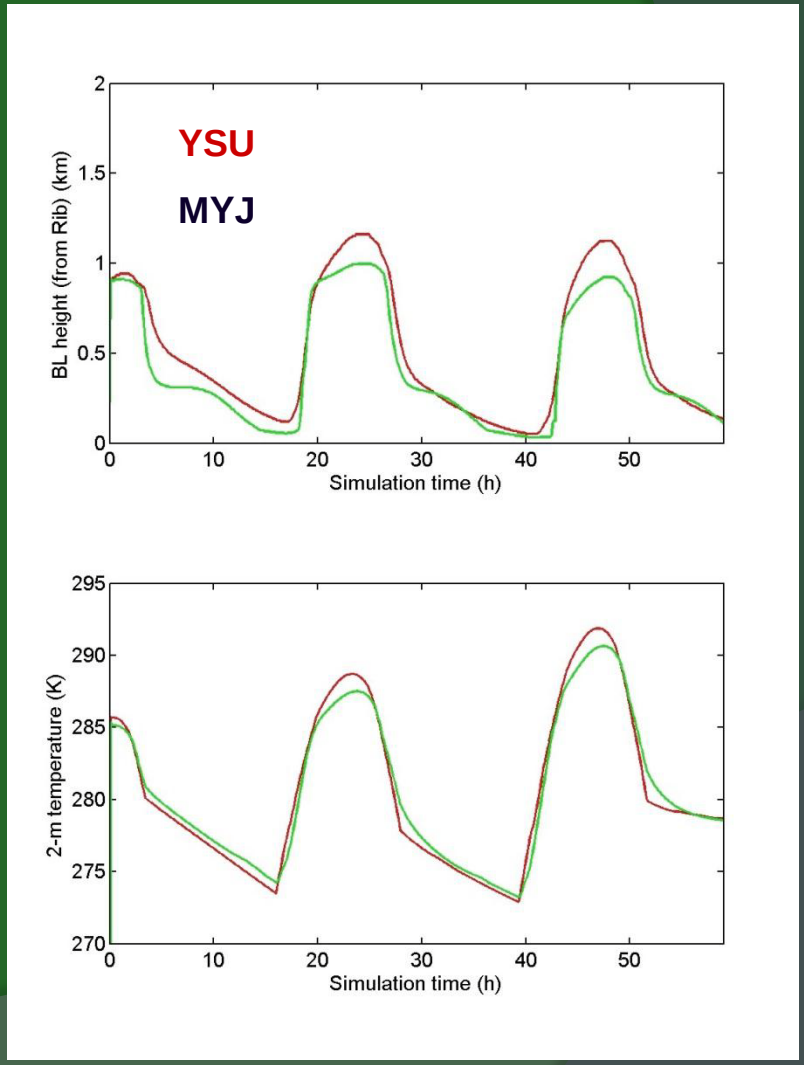
GEWEX Atmospheric Boundary Layer Study (GABLS) cases

One-dimensional runs using WRF SCM

Only a small sample to show some of the issues

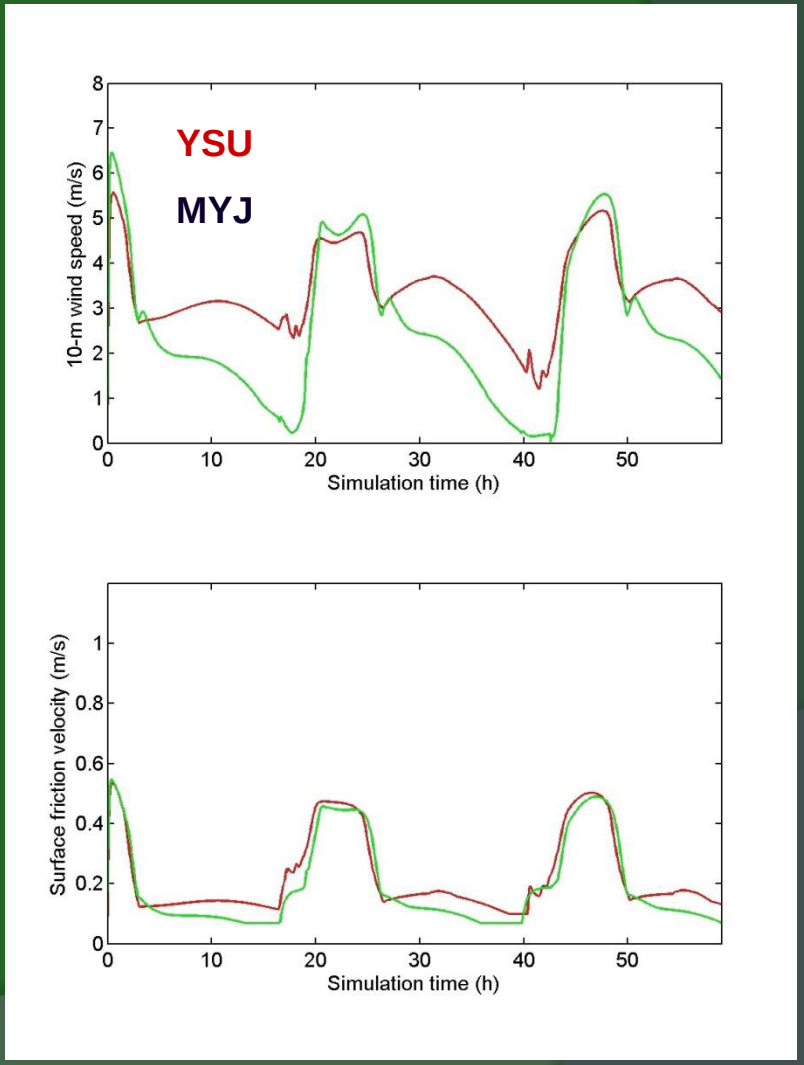
GABLS2
BL height and 2m temperature

- Specified surface temperature, no other physics
- Moderate resolution (40 levels, 1st level = 25 m)
- YSU BL is deeper day and night
- Other models are all over the map at night
- Using Ri_c=0.25 in YSU makes nocturnal BL even deeper



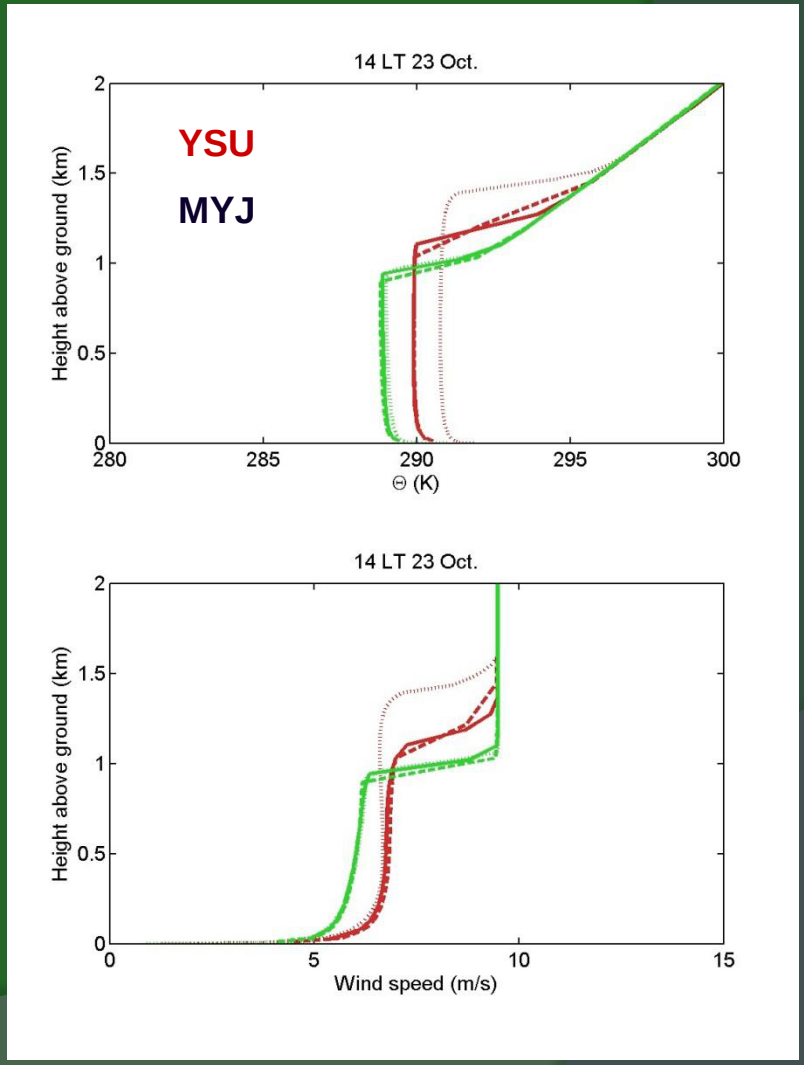
Wind speed and friction velocity (moderate resolution)

- YSU wind speeds are higher at night
- MYJ winds at night are weaker than other models in comparison



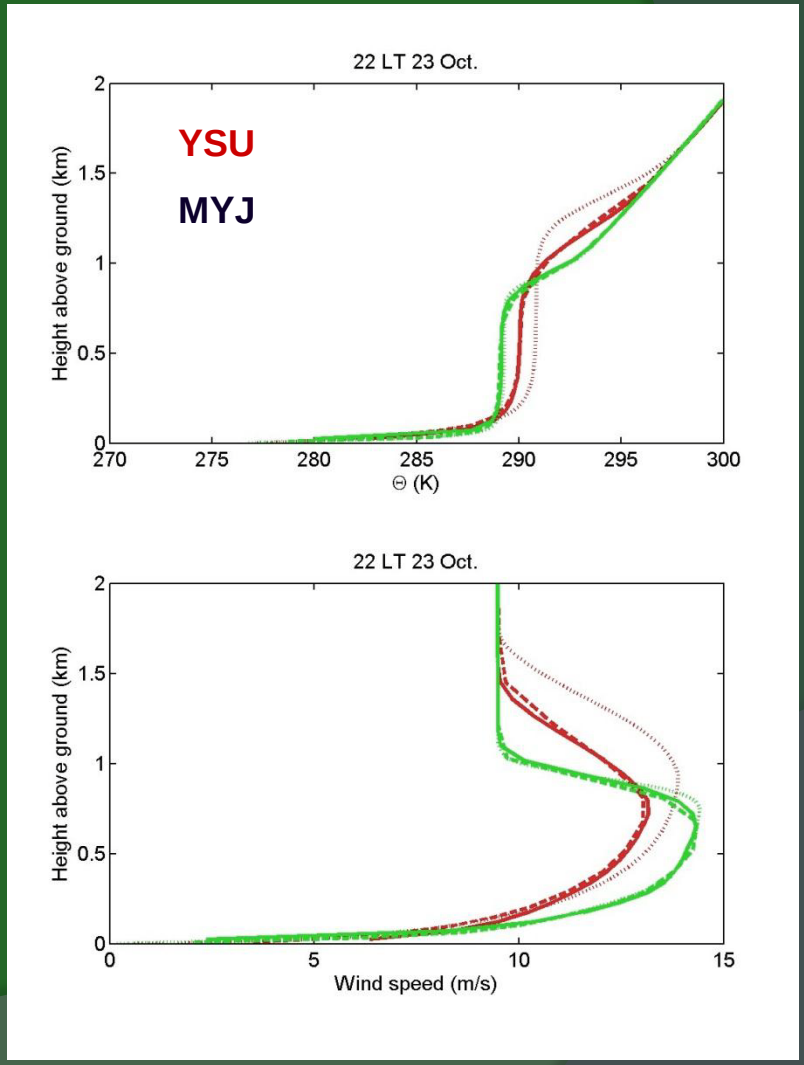
Daytime theta and U profiles

- Note slightly unstable profile of MYJ due to neglect of non-local transport
- YSU BL deeper, depends strongly on resolution
- MYJ not resolution dependent
- MYJ in range of others in comparison



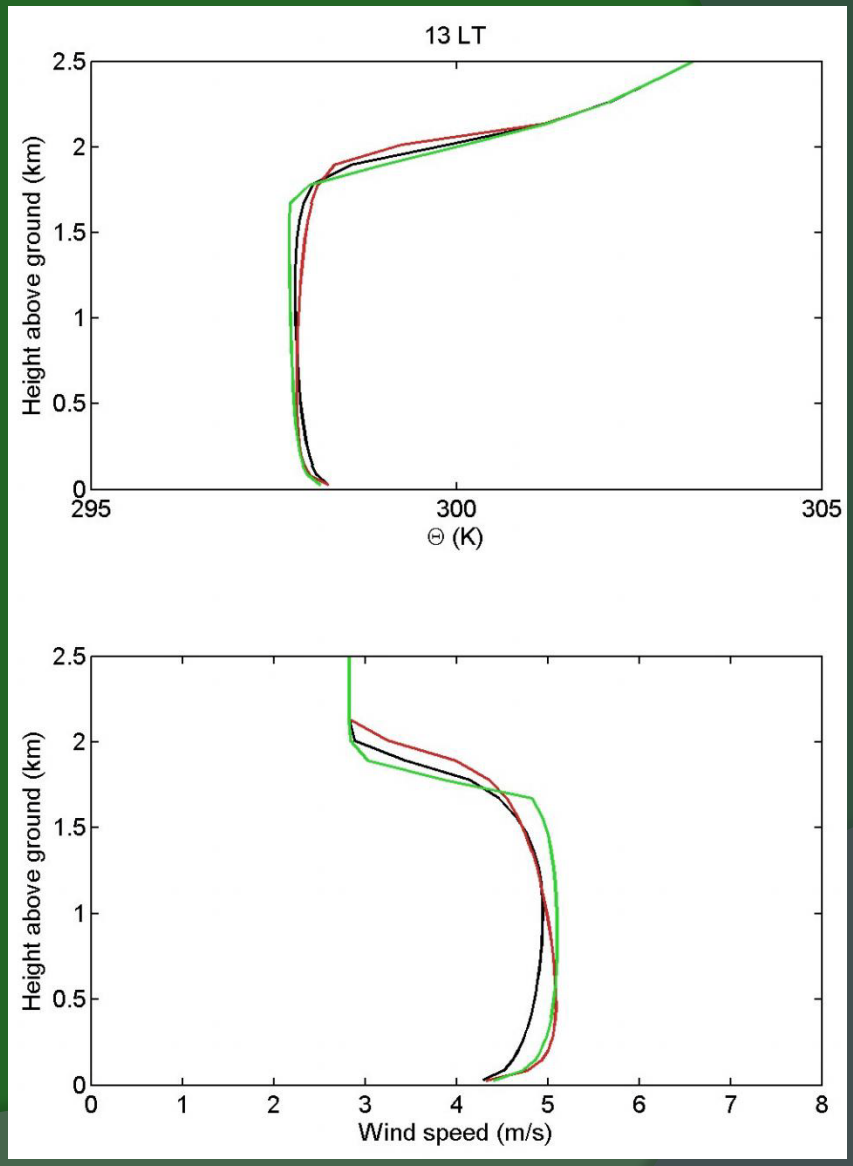
Theta and U profiles at night

- YSU profiles outlying at fine resolution
- Jet stronger in MYJ
- With Ri_c=0.25 in YSU, jet is weaker yet at either fine or moderate resolution



GABLS3

- Early afternoon
- Differences are much smaller than in GABLS2
- GABLS3 uses interactive LSM and radiation



Final opinionated thoughts

We probably have enough PBL schemes

If your simulation is not working the way you want it to, don't immediately blame the PBL

Stick to the old, tested schemes unless you have a problem that one of the newer schemes addresses