• Turbulence and PBL closure:
  • Local & non-local
  • WRF PBL options

Reminders/announcements:
- WRF real-data case assignment, due today
  - Some lessons learned here!
- Project hypothesis assignment, due (presented) Thurs 3/3
- PBL paper discussion for Thursday or Tuesday 2/16
PBL paper assignment

• Read the paper for which you signed

• Present using similar format as before, but need to be very brief (more papers this time)

• For papers presenting PBL schemes, explain:
  • What differentiates the scheme from others?
  • For what purpose was the scheme designed?
  • In what circumstances would you use that scheme over others?
Project assignment (due 3/3)

• A working “control run” or base simulation is required for project hypothesis assignment

• Think and plan *before* firing off model runs
  - Do not perform expensive runs first!
  - Check output early and often
  - Ask: Does basic run perform adequately?
  - Scale: *Avoid* tiles less than ~25x25 grid points

• Do not procrastinate!

• Strive for something meaningful. *Avoid* “namelist meteorology”; you will need to convince your peers
Initial, Boundary Data

- For your cases, *reanalysis* data will be useful for model initial and lateral boundary conditions

- There are many options:
  - NCAR/NCEP reanalysis (back to 1948, 2.5°)
  - North American Regional Reanalysis (NARR, 1979, 32km)
  - MERRA – A recent NASA effort (1979, 0.5°)
  - ERA40, ERA-Interim (1979, 2.5° / 0.7°)
  - JMA reanalysis (1979 – 2004, 2.5°)
  - Climate Forecast System Reanalysis (CFSR, 1979, 0.5°)

- See links on class web page; read references for RA
Upcoming Project Assignment

- **Hypothesis presentations:**
  - Class will evaluate proposals according to:
    - **Scientific merit:** Is the hypothesis well-reasoned from standpoint of processes, physics, previous work? Is it creative and original?
    - **Methods:** Is the project tractable? Are the methods sound? Is this a legitimate test of a hypothesis?
    - **Value:** To what extent would completion of project benefit society, push scientific boundaries, and carry larger implications?
Hypothesis Discussion Questions

What is a hypothesis?
A proposed explanation for an observable phenomenon

Can you name a famous hypothesis or hypothesis test?

What is the difference between an “assertion” and a “hypothesis”?

If you test a hypothesis, and the results are consistent with predictions based on the hypothesis, can we say that we have “proven” the hypothesis? Why or why not?
Hypotheses

Hypotheses are distinct from “assertions”

Assertions state a belief in the truth of a statement

Hypotheses don’t assert anything about the truth; in stating a hypothesis, it is not even hinted that it is true

Hypotheses themselves are not predictions or guesses, but a good hypothesis can lead to predictions
A scientific hypothesis must be falsifiable, a proposition or theory is not scientific if it does not admit the possibility of being shown false (Popper)

Hypothesis development:

In developing a hypothesis, investigator must not currently know outcome of a related test

If researcher already knows outcome, it is a "consequence" — and the researcher should have already considered this while formulating hypothesis
Hypotheses

Karl Popper's formulation of hypothetico-deductive method demands falsifiable hypotheses, framed in such a manner that the scientific community can prove them false.

According to this view, a hypothesis cannot be "confirmed", because there is always the possibility that a future experiment will show that it is false.

Failing to falsify a hypothesis does not prove that hypothesis: it remains provisional. However, a hypothesis that has been rigorously tested and not falsified can form a reasonable basis for action, i.e., we can act as if it were true, until such time as it is falsified.

See http://en.wikipedia.org/wiki/Karl_Popper
Scientific Method

This is not the only way that science advances, but it is a good way.

A method of procedure that has characterized natural science since the 17th century:
- Systematic observation
- Measurement
- Experiment
- Formulation, testing, and modification

Why is this important?
Scientific Method (wikipedia)

1. Use your experience: Consider a problem and try to make sense of it. Look for previous explanations. If this is a new problem to you, then move to step 2.

2. Form a conjecture: When nothing else is yet known, try to state an explanation.

3. Deduce a prediction from that explanation: If you assume 2 is true, what consequences follow?

4. Test: Look for the opposite of each consequence in order to disprove 2. It is a logical error to seek 3 directly as proof of 2. This error is called affirming the consequent.
Some classic hypothesis tests using models

Conditional Instability of the Second Kind (CISK) – Charney and Eliassen (1964) – a theory for hurricane formation

Theory relies upon presence of environmental static instability

Emanuel (1986): New hypothesis, air-sea interaction key mechanism, instability not required

Rotunno and Emanuel (1987) used numerical model to test hypothesis

Hurricane developed in model without environmental instability, CISK rejected as explanation for TCs
The next assignment...

Express your hypothesis as a concise statement of one or two sentences. The hypothesis must be *scientifically based*, and represent an extension beyond what is already known.

The *physical basis* for your hypothesis must be clear. For example, if your hypothesis is that dry air in the environment weakens a hurricane, explain *how* the dry air weakens the storm.

Describe exactly how you will test your hypothesis. Be specific, including a description of a model experiment or experiments, or other data analysis that represents a direct make-or-break test.

Explain what cases or data you will need and use and why these cases or data are needed.

You will need to respond to the comments and concerns raised by your classmates, and the final product will benefit from this exercise.
Micrometeorology and Turbulence Parameterization
Outline

1.) Review of turbulence and properties
   - Characteristics, worksheet
   - Definitions, TKE, introduction to closure problem
   - Tendencies, and flux divergence

2.) Closure strategies
   - Bulk aerodynamic
   - K-theory (mixing length)
   - Local and non-local closures
   - WRF schemes, examples

Conclude with presentation/discussion of journal papers describing schemes
Re-Cap: Turbulence closure problem

Bulk Aerodynamic closure:

- Simplest and least accurate; PBL treated as uniform slab
- Limitations: Omit variations within PBL, much empirical data needed for exchange coefficients, insufficient account of entrainment

\[
\overline{w'q'} = - C_E \left| \vec{V} \right| \left( \overline{q_{10m}} - \overline{q_{sfc}} \right)
\]

Surface layer parameterization

- Surface layer is “constant flux layer”, neutral log wind profile
- Mixing length concept (Prandtl): fluid properties retained over a distance before blending with surroundings
- This distance is proportional to elevation
- Most parameterizations are based on Monin-Obukov similarity theory, which utilizes empirical measurements and dimensionless groups
Re-Cap: Turbulence closure problem

- Two basic PBL closure philosophies: “Local” vs. “non-local” closure

  - **Local**: Parameterize using gradients of known variables *at that point*
    - “small eddy” mindset
    - e.g., Mellor Yamada Janjic (MYJ, MYNN)

  - **Non-local**: Parameterize from known variables at many points, including those not local to point in question
    - View turbulence as superposition of eddies of many scales
    - e.g., Yonsei University (YSU, ACM2)
Re-Cap: Turbulence closure problem

First-order local closure: Flux-Gradient or K theory:

• Utilize analogy with molecular diffusion (on board Thu 2/4)
• Replace molecular viscosity with “eddy viscosity”
• Flux parameterizations related to product of eddy viscosity coefficient and vertical gradient of mean variable:

\[
\theta' w' = -K_h \frac{\partial \bar{\theta}}{\partial z}
\]

• Key is how to determine K values; empirical data crucial
• **Analogy with molecular diffusion breaks down:** Molecular viscosity is property of fluid, eddy viscosity is not
• Simplest: Assume K constant with height, time
• Reality: K values are a function of the flow (stability, TKE, etc.)
Local Closure: 1st Order

- From K theory, derive Ekman spiral (e.g., Holton Ch. 5)

\[ \frac{d \overline{u}}{dt} = - \frac{1}{\rho_0} \frac{\partial \overline{p}}{\partial x} + f \overline{v} + K^m \frac{\partial^2 u}{\partial z^2} \]
Setting K in Practice: Strategies

Constant K is not a good assumption…

K = 0 if there is no turbulence, & immediately at surface
K is function of TKE (K increases as TKE increases)
K is function of static stability
K is non-negative to preserve analogy with viscosity - Need positive K for down-gradient transport

In nature, sometimes observe *counter-gradient* transport
  - Large eddies transport heat down-gradient, despite *local* gradients

**This requires a different approach**: Large eddies in convective boundary layer impart *non-local* effects (later)
Setting K in Practice: Stull (1988) text

<table>
<thead>
<tr>
<th>Neutrally Surface Layer:</th>
<th>Diabatic Surface Layer:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K = \text{constant}$</td>
<td>$K = k z u_*$</td>
</tr>
<tr>
<td>$K = u_*^2 T_0$</td>
<td>from mixing-length theory</td>
</tr>
<tr>
<td>$K = u_*^2 T_0$</td>
<td>$K = k z u_*$</td>
</tr>
<tr>
<td>$K = k z u_*$</td>
<td>where $f = k(z+z_0)/(14 + k(z+z_0)/v)$, $\lambda$=length scale</td>
</tr>
</tbody>
</table>

- $\bar{K} = z^2 \left[ (\bar{\nu} u_0 z) + \left( (g \bar{\theta})_z + (\bar{\theta} \bar{u}_0 z)_z \right) \right]^{1/2}$ for statically unstable conditions
- $\bar{K} = z^2 \left[ (\bar{\nu} u_0 z) - (L/2)^{1/2} \left( (15g \bar{\theta})_z + (\bar{\theta} \bar{u}_0 z)_z \right) \right]^{1/2}$ for statically stable conditions, where $L = 6 u_*/(15 k g v)$

Neutral or Stable Boundary Layer:

- $K = \text{constant}$
- $K = \bar{K}(h) + \left( (h-z_0) \bar{K}(h) \right)$
- $K = \bar{K}(h) + \left( (h-z_0) \bar{K}(h) \right)$
- $K = \bar{K}(h) + \left( (h-z_0) \bar{K}(h) \right)$
- $K = \bar{K}(h) + \left( (h-z_0) \bar{K}(h) \right)$

Unstable (Convective) Boundary Layer:

- $K = 1.1 \left( \frac{f}{R_e} \right) \left( \frac{f^2}{R_e} \right) \left[ \bar{\nu} u_0 z \right]$ for $\frac{\partial \bar{\theta}}{\partial z} > 0$ where $f = k z$ for $z < 200$ m and $f = 70$ m for $z > 200$ m.
- $K = (1.15 \bar{K})^{1/2}$ for $\frac{\partial \bar{\theta}}{\partial z} < 0$

Numerical Model Approximation for Anelastic 3-D Flow:

- $K = \left( 0.25 \Delta x \right)^2 \left[ 0.5 \sum \left( \frac{\partial \bar{u}}{\partial x} \right)^2 \Delta x \right]^{1/2}$ where $\Delta = \text{grid size}$

K in surface layer (mixing length concept) may exhibit different profile.
1.5 order local closure: TKE schemes (MYJ)

- TKE is useful quantity, “pulls weight” as prognostic 2\textsuperscript{nd} order variable

\[
\frac{d e}{d t} = \frac{\partial}{\partial z} K_e \frac{\partial e}{\partial z} + P_{\text{shear}} + P_{\text{buoyancy}} - \text{diss}
\]

\[
e = \left[ u'^2 + v'^2 + w'^2 \right]^{1/2}
\]

“e” is ~ “TKE” in our notation

\[
K_m = S_m \ell \left( 2e \right)^{1/2} \quad K_h = S_h \ell \left( 2e \right)^{1/2} \quad K_e = S_e \ell \left( 2e \right)^{1/2}
\]

\(S_{(m,h,e)}\) are complex functions of shear and stability;
\(\ell\) is mixing length
1.5 order local closure: TKE schemes (MYJ)

- Tendency of variable \( A \) due to turbulent flux given by:

\[
\frac{\partial A}{\partial t} = \frac{\partial}{\partial z} \left( K_A \frac{\partial A}{\partial z} \right)
\]

Determine eddy viscosity coefficient \( K_A \) as function of flow

**b. Algebraic reduction**

In paper A it was shown that the Reynolds stress and turbulent heat flux equations can be simplified further. Thus, after considerable algebraic manipulation, Eqs. (16)–(18) reduced to

\[
(-\bar{uw}, -\bar{vw}) = K_M \left( \frac{\partial U}{\partial z}, \frac{\partial V}{\partial z} \right), \quad (20a,b)
\]

\[
-w\theta_v = K_H' \frac{\partial \Theta_v}{\partial z} - \gamma_c, \quad (21)
\]

where

Mellor and Yamada 1974

\[
K_M = A_1 \left[ (1 - 3c)q^5 + 3q^2 \mathcal{D}_t - 9\beta g A q^2 \left\{ 4A_1 c q^3 + A_2 (q^3 + 3 \mathcal{D}_t) \right\} \frac{\partial \Theta_v}{\partial z} + 9(\beta g)^2 q A_2 q^2 (4A_1 + 3A_2) \theta_v^2 \right]
\]

\[
= \left[ q^4 + 6A_1 q^2 |\partial V/\partial z|^2 + 3A_1 A_2 q^2 \right] \times \left\{ 7q^2 - 18A_1 A_2 q^2 |\partial V/\partial z|^2 \right. \\
+ \left. 36A_1 A_2 q^2 (\beta g) \frac{\partial \Theta_v}{\partial z^2} - \beta g \frac{\partial \Theta_v}{\partial z} \right\}, \quad (22a)
\]
1.5 order local closure: TKE schemes (MYJ)
WRF Turbulence Parameterization Components: MYJ

Visit /WRFV3/phys, explore

- module_pbl_driver.F
- module_sf_myjsfc.F
- module_bl_myjpbl.F
- module_surface_driver.F

- TURBL.F - the PBL mixing code, M-Y-J 2.5 TKE-based scheme
- DIFCOF.F – computes the level 2.5 diffusion coefficients
- MIXLEN.F – computes… you guessed it, the master length scale
- PRODQ2.F – computes production, dissipation of TKE (level 2.5 closure)

Look at the codes… gain a sense of what they do
module_sf_myjsfc.F

! REFERENCES: Janjic (2001), NCEP Office Note 437

MODULE MODULE_SF_MYJSFC

USE MODULE_MODEL_CONSTANTS
USE MODULE_DM, ONLY : WRF_DM_MAXVAL

! REFERENCES: Janjic (2002), NCEP Office Note 437

ABSTRACT:

MYJSFC GENERATES THE SURFACE EXCHANGE COEFFICIENTS FOR VERTICAL TURBULENT EXCHANGE BASED UPON MONIN_OBUKHOV THEORY WITH VARIOUS REFINEMENTS.

INTEGER :: ITRMX=5 ! Iteration count for sfc layer computations

REAL,PARAMETER :: VKARMAN=0.4
REAL,PARAMETER :: CPA=R D/C.P.FL0CP=2.72E6/C.P.RCAP=1./CPA
module_bl_myjpb1.F

```
![gary@login-1 physics]$ more module_bl_myjpb1.F

MODULE MODULE_BL_MYJPBL

USE MODULE_MODEL_CONSTANTS

REFERENCES: Janjic (2001), NCEP Office Note 437

ABSTRACT:
MXJ UPDATES THE TURBULENT KINETIC ENERGY WITH THE PRODUCTION/
DISSIPATION TERM AND THE VERTICAL DIFFUSION TERM
(USING AN IMPLICIT FORMULATION) FROM MEILOR-YAMADA
LEVEL 2.5 AS EXTENDED BY JANJIC EXCHANGE COEFFICIENTS FOR
THE SURFACE AND FOR ALL LAYER INTERFACES ARE COMPUTED FROM
MONIN-OBUKHOV THEORY.
The TURBULENT VERTICAL EXCHANGE IS THEN EXECUTED.

INTEGER :: ITRNX=5 ! Iteration count for mixing length computation

REAL, PARAMETER :: G=9.81, PT=3.1415926, R_D=287.04, R_V=461.6
&
 VKARAN=0.4
REAL, PARAMETER :: PI=3.1415926, VKARAN=0.4
REAL, PARAMETER :: CP=7.*R_D/2.
REAL, PARAMETER :: CAPA=R_D/CP
REAL, PARAMETER :: RLIVW=XLV/XYLV, ELOCP=2.72E6/CP
REAL, PARAMETER :: EPS1=1.E-12, EPS2=0.
REAL, PARAMETER :: EPSL=0.32, EPSR=1.E-7, EPSRS=1.E-7
&
 EPSRTB=1.E-24
REAL, PARAMETER :: EPSA=1.E-5, EPSIT=1.E-4, EPSU1=1.E-4, EPSUST=0.07
&
 FH=1.01
REAL, PARAMETER :: ALPH=0.30, BETA=1./273., ELOMAX=1000., ELOMIN=1.
&
 ELFC=0.23*0.5, GAM1=0.222222222222222222
&
 PR=1.
REAL, PARAMETER :: A1=0.6988514560862645
```

!*** FIND THE MIXING LENGTH
!***

CALL MIXLEN(LMH,UK,VK,TK,THEK,QK,CWMK &
  ,Q2K,ZHK,GM,GH,EL &
  ,PBLH(I,J),LPBL(I,J),LMXL,CT(I,J) &
  ,IDS,IDE,JDS,JDE,KDS,KDE &
  ,IMS,IME,JMS,JME,KMS,KME &
  ,ITS,ITE,JTS,JTE,KTS,KTE)

!*** SOLVE FOR THE PRODUCTION/DISSIPATION OF
!*** THE TURBULENT KINETIC ENERGY
!***

CALL PRODQ2(LMH,DTTURBL,USTAR(I,J),GM,GH,EL,Q2K &
  ,IDS,IDE,JDS,JDE,KDS,KDE &
  ,IMS,IME,JMS,JME,KMS,KME &
  ,ITS,ITE,JTS,JTE,KTS,KTE)

!*** FIND THE EXCHANGE COEFFICIENTS IN THE FREE ATMOSPHERE
!***

CALL DIFC0F(LMH,LMXL,GM,GH,EL,TK,Q2K,ZHK,AKMK,AKHK &
  ,IDS,IDE,JDS,JDE,KDS,KDE &
  ,IMS,IME,JMS,JME,KMS,KME &
  ,GAM,GMH,ELH,TTH,HLS,QR)
module_bl_myjpbl.F

***
*** COMPUTE PRIMARY VARIABLE TENDENCIES
***

DO K=KTS,KTE
   KFLIP=KTE+1-K
   THOLD=TH(I,K,J)
   THNEW=THEK(KFLIP)+CWMK(KFLIP)*ELOCP*APE(I,K,J)
   DTDT=(THNEW-THOLD)*RDTTURBL
   QOLD=QV(I,K,J)/(1.+QV(I,K,J))
   DQDT=(QK(KFLIP)-QOLD)*RDTTURBL
   DCDT=(CWMK(KFLIP)-CUM(I,K,J))*RDTTURBL
   RTHBLTEN(I,K,J)=DTDT
   RQVBLTEN(I,K,J)=DQDT/(1.-QK(KFLIP))**2
   RQCBLTEN(I,K,J)=DCDT
ENDDO

*** Begin debugging
IF(I==IMD .AND. J==JMD) THEN
   PRINT_DIAG=0
ELSE
   PRINT_DIAG=0
ENDIF
IF(I==227 .AND. J==363) PRINT_DIAG=0
*** End debugging

uu:---Fl module_bl_myjpbl.F (Fortran)--L505--34%------------------
More Local Closure Schemes in WRF

• The local Mellor-Yamada scheme has been extended by Nakanishi and Niino, the **MYNN** schemes in WRF

• Extension to higher order (note: “level” = “order” +1)

• More complete account of buoyant effects, and now a stability-depended turbulent length scale

• Built largely on comparisons to LES model output

• Additional modifications by Joe Olson – see .F code comments

• Also **Grenier-Bretherton** schemes: 1.5 order local, with excellent account of entrainment and moist BLs - stratocumulus
Non-Local Closures

Two general classes:

1.) Transilient turbulence theory

   - Consider discrete exchange of air within grid boxes in column
   - Also continuous form for analytical work

2.) Spectral diffusivity theory

   - Apply K-theory ideas, but let $K = f(\text{wavenumber})$
Non-Local Closure

1.) Transilient turbulence theory

For a given variable $\xi$, \( \overline{\xi}_i(t + \Delta t) = \overline{\xi}_i(t) + \sum_{j=1}^{N} c_{ij}(t, \Delta t) \overline{\xi}_j(t) \) + ....

$c_{ij}$ is a matrix of mixing coefficients, the “transilient matrix”

Fig. 6.8
(a) Schematic idealization of the eddies that mix air to and from the center grid box, in a 1-D column of air. (b) Superposition of eddies acting on 3 of the grid boxes. After Stull (1984).
Non-Local Closure

2.) Spectral diffusivity

From before, \( \xi' w' = -K_m \frac{\partial \xi}{\partial z} \)

For case of K not f(z), \( \frac{\partial \xi}{\partial t} = K_m \frac{\partial^2 \xi}{\partial z^2} \)

If we allow K to vary with eddy size, \( \frac{\partial \xi}{\partial t}(\kappa) = K(\kappa) \frac{\partial^2 \xi(\kappa)}{\partial z^2} \)

Integrate over all wavelengths

Fig. 6.15 (Stull): Spectral diffusivity K as a function of wavenumber. Following Berkowicz and Prahm (1979)
Hybrid Local/Non-Local Closures

- Several schemes are based upon both local and non-local strategies
- Asymmetric Convection Model (ACM) and ACM2 (Pleim studies) are hybrid

- Total Energy – Mass Flux (TEMF) scheme uses both

- TEMF best for stable PBL, and cloud-topped boundary layers

- Stable conditions, TEMF is TKE-based local; unstable BL, accounts for some non-local mass transport
Some PBL Applications

Situations/phenomena for which PBL processes play major roles:

- Air-pollution episodes
- CAD erosion
- Warm-frontal movement
- Surface temperature prediction (e.g., mixed layer depth, whether sfc decouples at night)
- Aviation
- Climate and climate change
- Lake-effect precipitation
- Wind energy
- Others…. The list goes on!
Mesonet 1.5m surface temperature and 10m wind

2005-01-11 18:00 CST

wind speed in ms\(^{-1}\)

Compliments of Prof. Fred Carr, OU
Gradual descent of frontal surface

Very stable just prior to passage

Results highly sensitive to PBL scheme choice

Compliments of Prof. Fred Carr, OU
<table>
<thead>
<tr>
<th>bl_pbl</th>
<th>Scheme</th>
<th>Sfc layer</th>
<th>Characteristics</th>
<th>Design</th>
<th>Cloud mixing</th>
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<tbody>
<tr>
<td>1</td>
<td>YSU</td>
<td>1</td>
<td>Explicit entrainment</td>
<td>Local + Nonlocal</td>
<td>QC, Qi</td>
</tr>
<tr>
<td>2</td>
<td>MYJ</td>
<td>2</td>
<td>TKE scheme</td>
<td>Local</td>
<td>QC, Qi</td>
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<tr>
<td>4</td>
<td>QNSE</td>
<td>4</td>
<td>TKE, a spectral scheme (quasi-normal scale elimination)</td>
<td>Local</td>
<td>QC, Qi</td>
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<tr>
<td>5</td>
<td>MYNN2</td>
<td>1,2,5</td>
<td>Improves MY length scale, adds buoyancy effects</td>
<td>Local</td>
<td>QC</td>
</tr>
<tr>
<td>6</td>
<td>MYNN3</td>
<td>1,2,5</td>
<td>Higher order version of MYNN2</td>
<td>Local</td>
<td>QC</td>
</tr>
<tr>
<td>7</td>
<td>ACM2</td>
<td>1,7</td>
<td>Combines non-local, eddy diff., asymmetric mixing</td>
<td>Local + Nonlocal</td>
<td>QC, Qi</td>
</tr>
<tr>
<td>8</td>
<td>BouLac</td>
<td>1,2</td>
<td>TKE similar to MYJ</td>
<td>Tested for orographic turb.</td>
<td>QC</td>
</tr>
<tr>
<td>9</td>
<td>UW</td>
<td>9</td>
<td>TKE scheme, for CAM, explicit entrainment</td>
<td>Designed for GCM</td>
<td>Qc, Qi (?)</td>
</tr>
<tr>
<td>10</td>
<td>TEMF</td>
<td>10 (Ri-based)</td>
<td>Explicit shallow cumulus, considers total turb. Energy</td>
<td>Combines eddy diffusivity, mass flx</td>
<td>Qc, Qi</td>
</tr>
<tr>
<td>11</td>
<td>Shin-Hong</td>
<td>1? +?</td>
<td>Scale-aware non-local PBL scheme for “gray zone” runs</td>
<td>For high-resolution runs with dx ~1 km</td>
<td>Qc, Qi</td>
</tr>
<tr>
<td>12</td>
<td>GBM</td>
<td>9</td>
<td>1.5 order with entrainment, for coarse vert. res (GCM)</td>
<td>Designed for GCM</td>
<td>Qc, Qi</td>
</tr>
<tr>
<td>99</td>
<td>MRF</td>
<td>1</td>
<td>Older version, YSU updates</td>
<td>Local + Nonlocal</td>
<td>QC, Qi</td>
</tr>
</tbody>
</table>
SCM PBL comparisons: Hot August day in NC

Run WRF SCM:
Compare
RTHBLTEN PBLH
SCM PBLH comparisons: Hot August day in NC
SCM PBLH comparisons: Hot August day in NC

TEMF

UW

MYJ

GB
Summary

A wide variety of PBL schemes are available in WRF

Some are designed for specific situations/phenomena

Some are designed to run in conjunction with a separate shallow mixing scheme (to handle entrainment), others are not

Consider outputting and examining PBL tendencies for various fields in order to assess scheme impact on model atmosphere

For very high resolution, consider diffusion scheme carefully, and consider Shin-Hong scale-aware PBL option