A Mass Flux Component for the MYNN PBL Scheme in WRF

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Outline:

Motivation

Two candidate schemes, derived from StEM and TEMF

Single-column tests

Integration challenges

3D tests in the RAP/HRRR framework

Why add mass flux to MYNN?

Better representation of vertical mixing in convective conditions
Boundary-layer clouds included seamlessly and coupled to radiation

Relative to their sources:
EDMF1 (from StEM) has 10 updrafts
Entrainment stochastic in cloud layer only
Updraft area reduced
Many other changes in details

EDMF2 (from TEMF) has 8 updrafts – updrafts differ in lateral entrainment
Updraft initialization changed
Many other changes in details

Both are scale-aware, mass flux reduced for smaller grid sizes

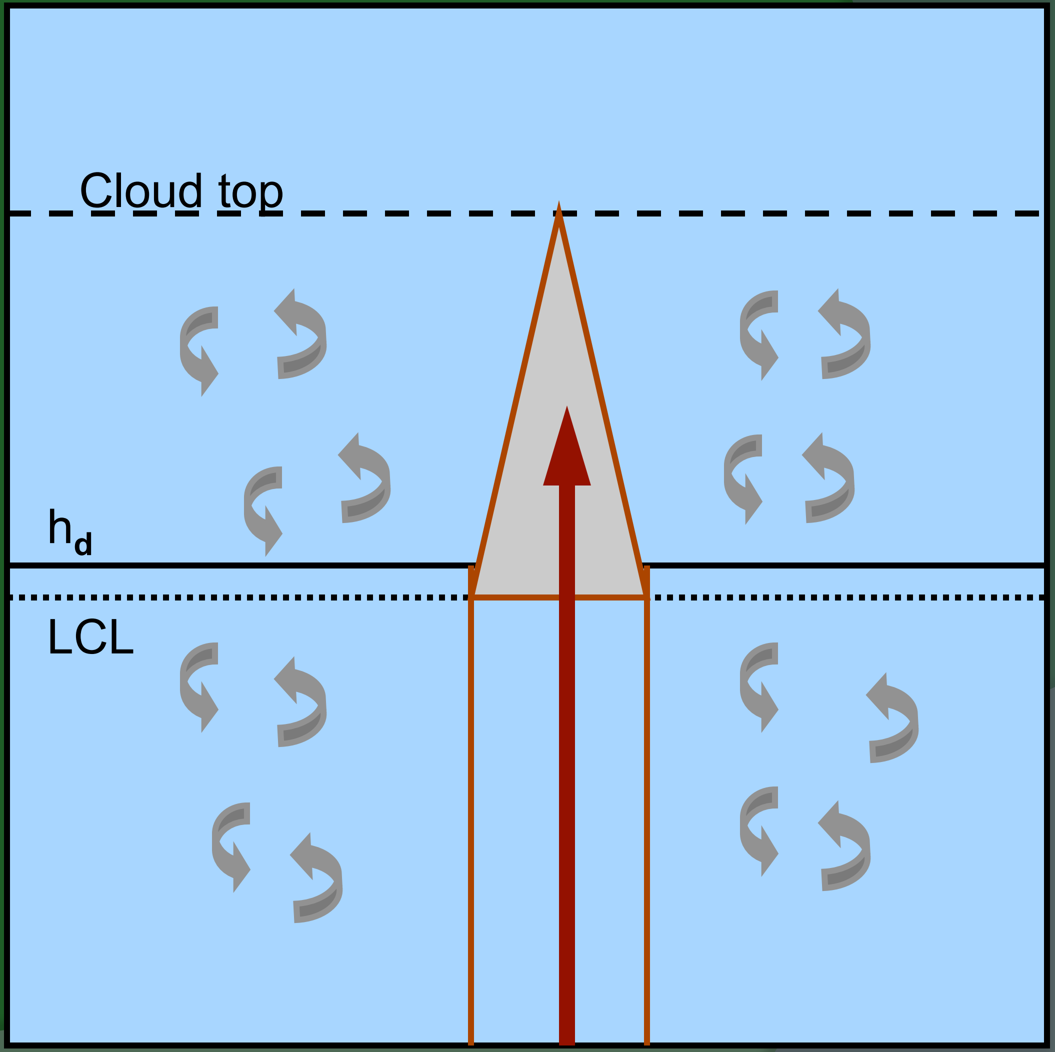
EDMF schemes for PBL and shallow Cu

Originated with Pier Siebesma and Joao Teixeira about year 2000

Eddy Diffusion and Mass Flux in both subcloud and cloud layers

Mass flux provides non-local transport in convective BL (with or without cloud) and natural representation of BL-rooted clouds

Many EDMF schemes are in use for research and operations, mostly in Europe



Entrainment (lateral) is critical

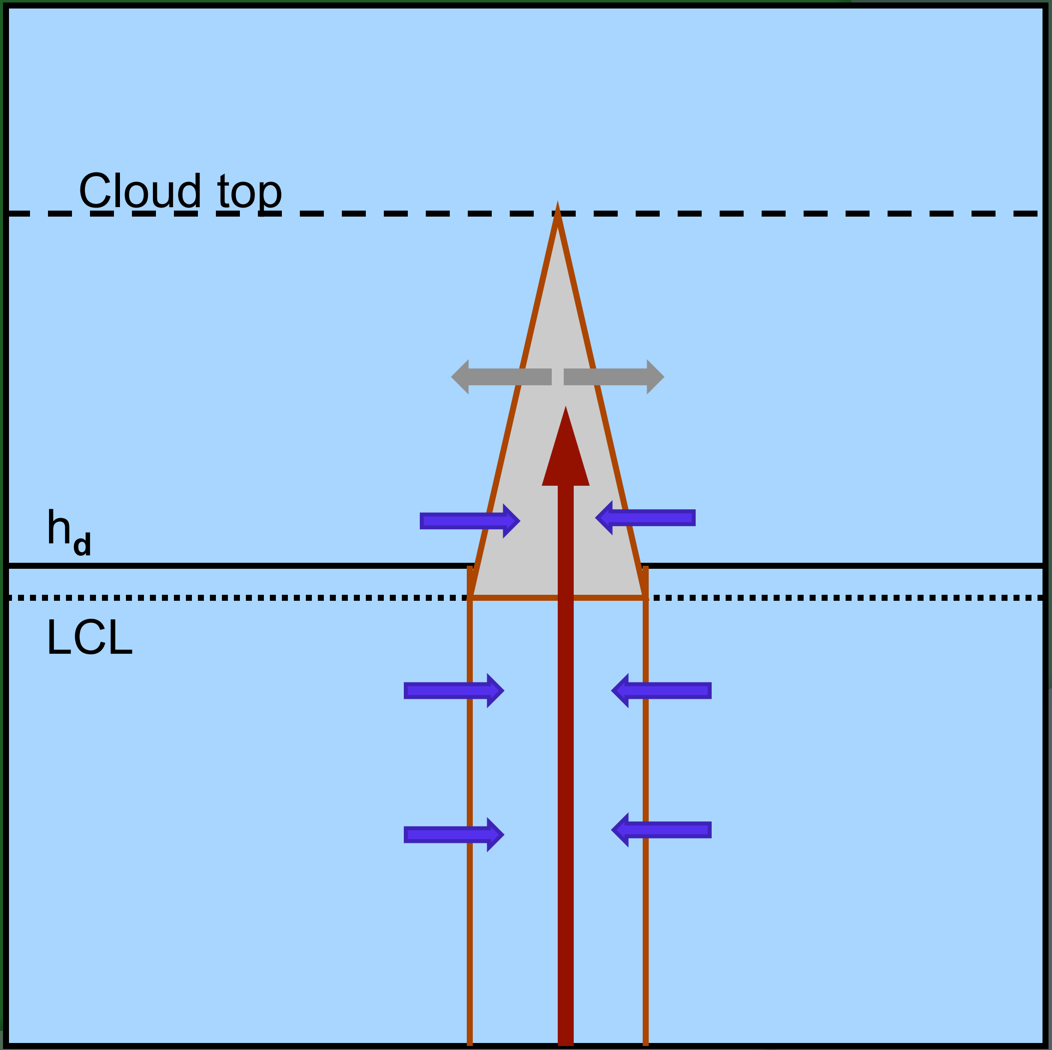
Exchange of air with the environment at the (conceptual) edges of the updraft is the critical control of:

Vertical velocity

Penetration (cloud) depth

Fluxes across the inversion or cloud base

There is a large, current, fascinating and controversial literature on entrainment

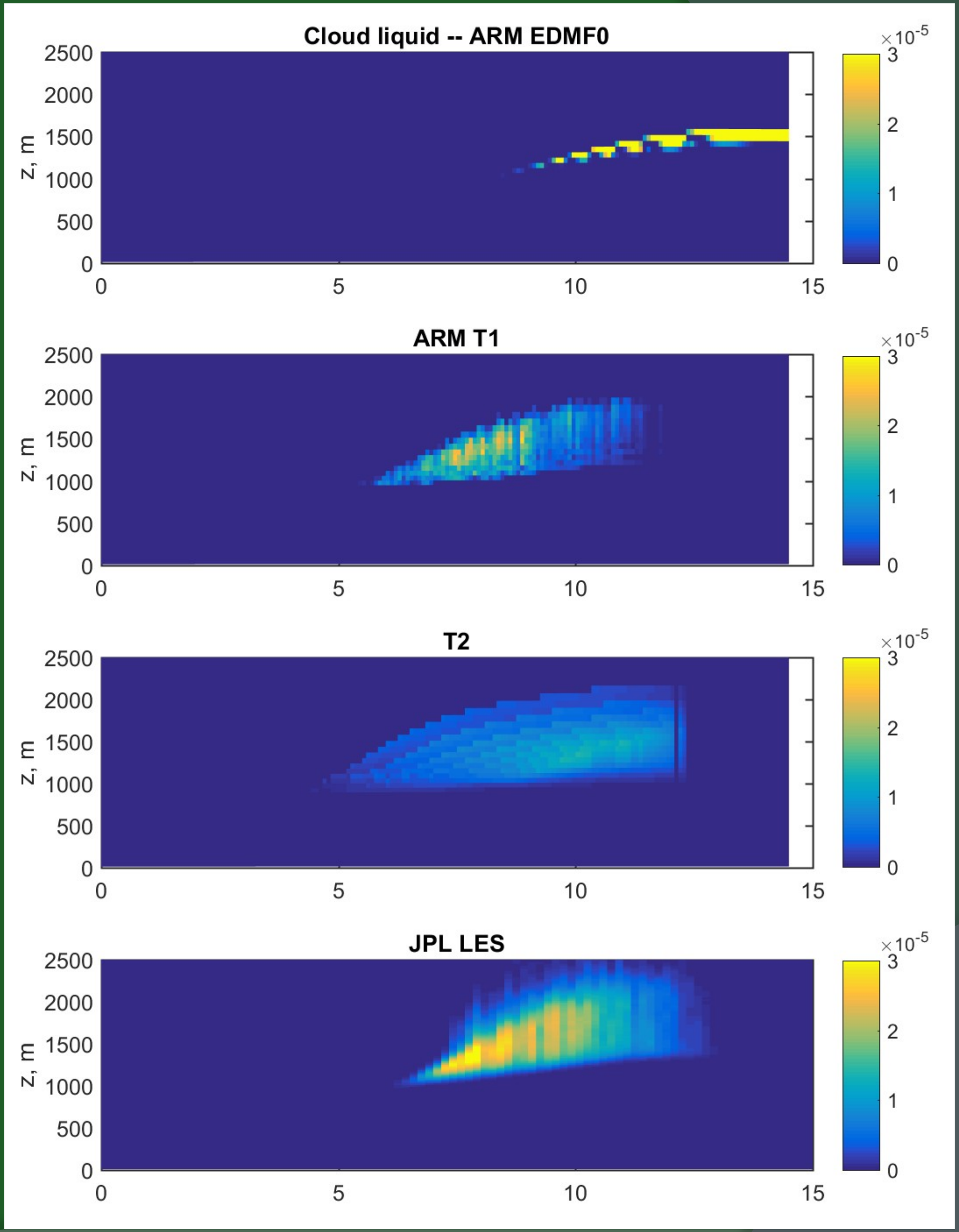


Examples: ARM case

Famous ARM 21 June continental shallow cumulus case

Cloud liquid patterns show improvement with either EDMF scheme

These patterns are particularly sensitive to tuning of entrainment



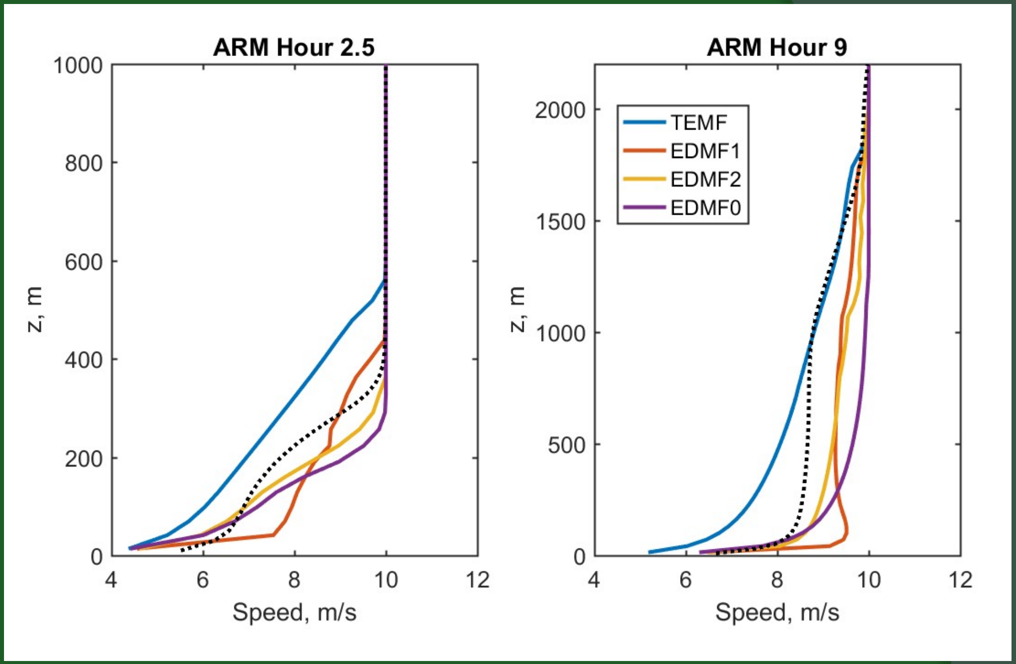
Examples: ARM case

Wind speed profiles:

All are imperfect

No MF and EDMF2 are closest to LES at “hub height” (~100 m)

TEMF best above 1 km late



Examples: ARM case

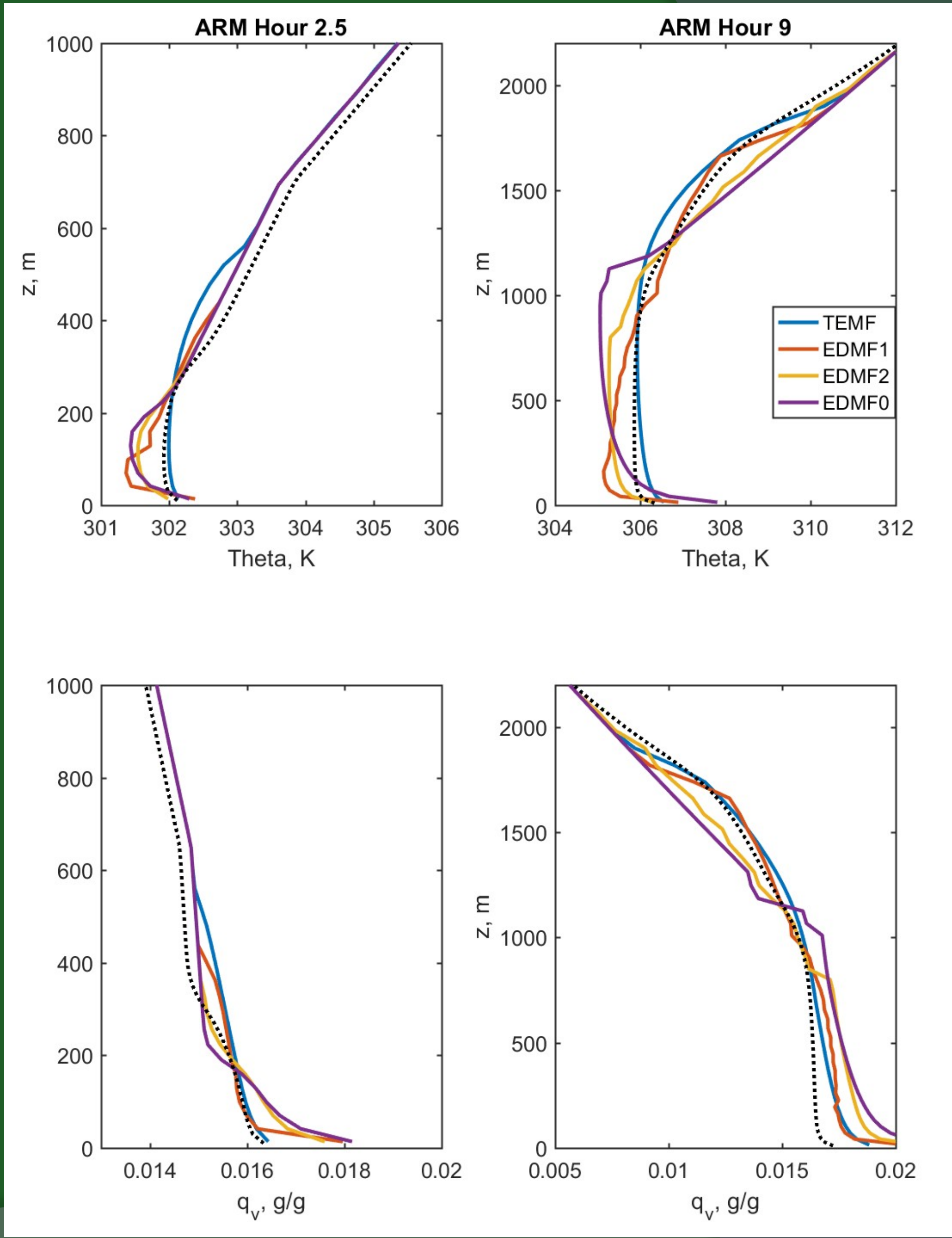
Theta and q profiles:
No MF gives sharp inversion, unstable profile throughout BL

EDMF1 is smooth, stable and cool through BL, superadiabatic layer too strong

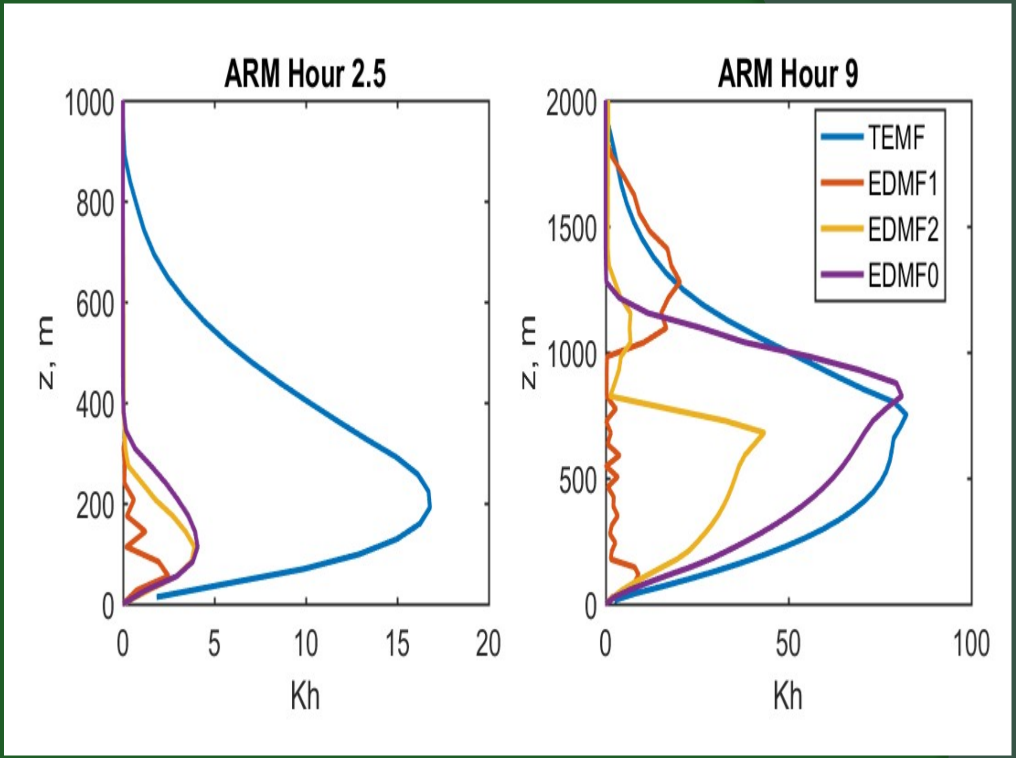
EDMF2 similar but less so

TEMF PBL smooth, best? match to LES (dotted)

Why is TEMF as a package performing better than EDMF2~TEMF MF w/MYNN ED?



Examples: ARM case



TEMF package has much more and smoother K (diffusivity) profile, similar to MYNN with no MF in subcloud layer, but continuing smoothly into cloud layer

TEMF was tuned to work as a package, and specifically tuned to this case

Total energy framework is an advantage in keeping a smooth profile of K and carrying it across cloud base

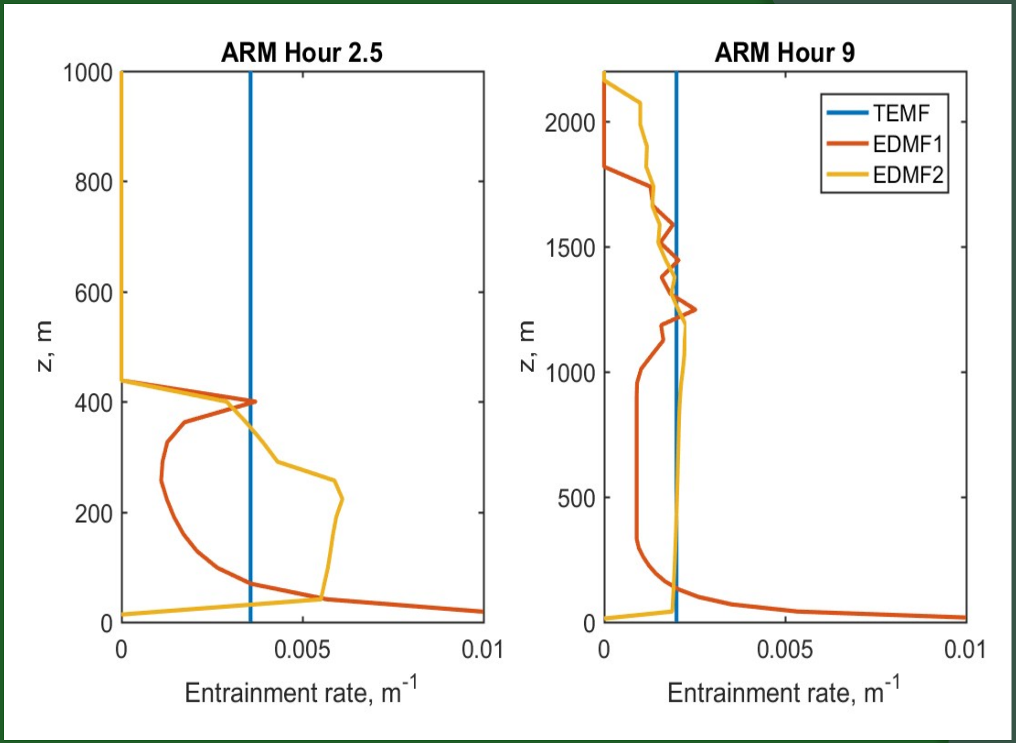
Examples: ARM case

Entrainment rates

TEMF has a single updraft with a vertically constant entrainment rate (proportional to $1/z_i$)

EDMF1 (based on StEM) has stochastic entrainment events, each of which terminates one of its 10 updrafts

EDMF2 (based on TEMF) has 8 updrafts with varying entrainment rates, each vertically constant



Why multiple updrafts?

The real atmosphere has a spectrum of updraft sizes and strengths in a grid-cell-size area

A single updraft cannot represent this very well

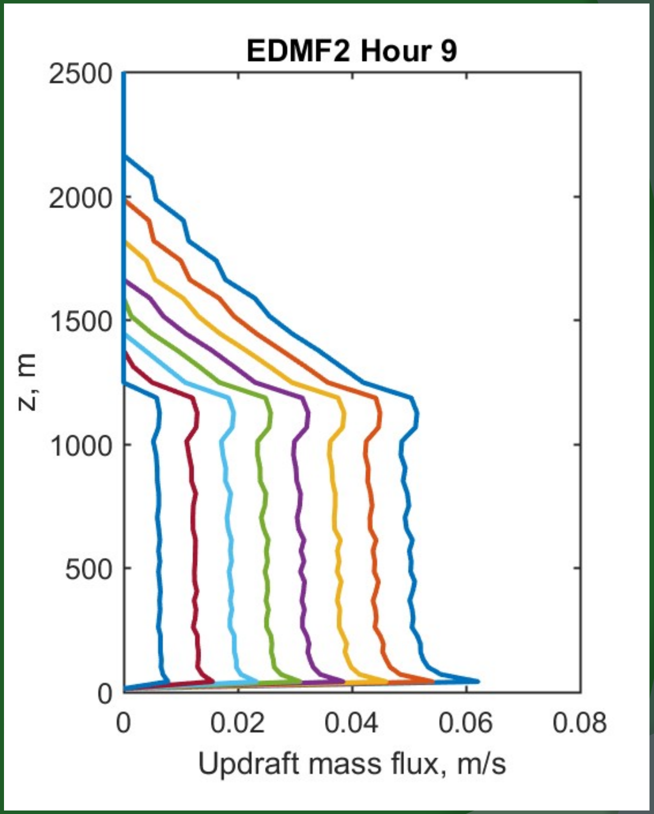
Roel Neggers (2015, JAMES) showed that weaker updrafts improve coupling between subcloud layer and stronger, deeper updrafts, stabilizing the solution

EDMF2 updrafts differ by entrainment rate, simulating a range of sizes

Note how some updrafts terminate at cloud base, others throughout the cloud depth

Is the extra complexity justified?

Cumulative updraft mass flax



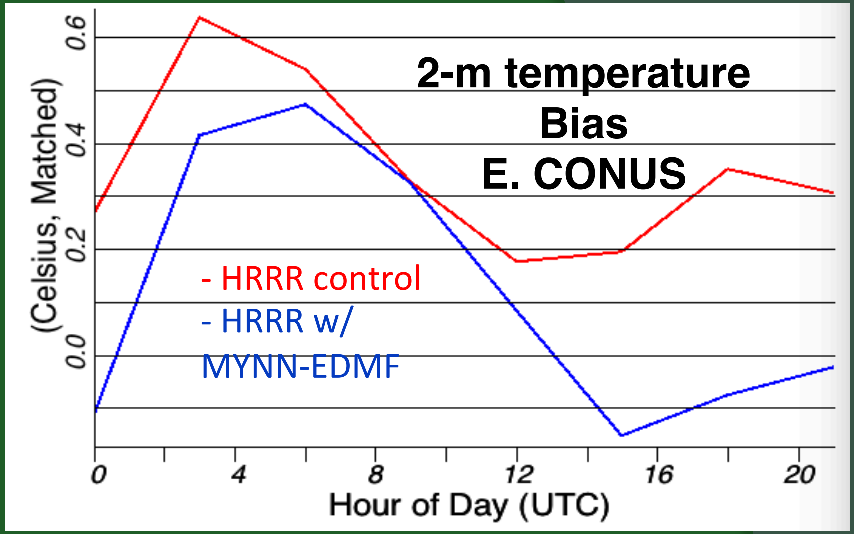
HRRR retrospective tests

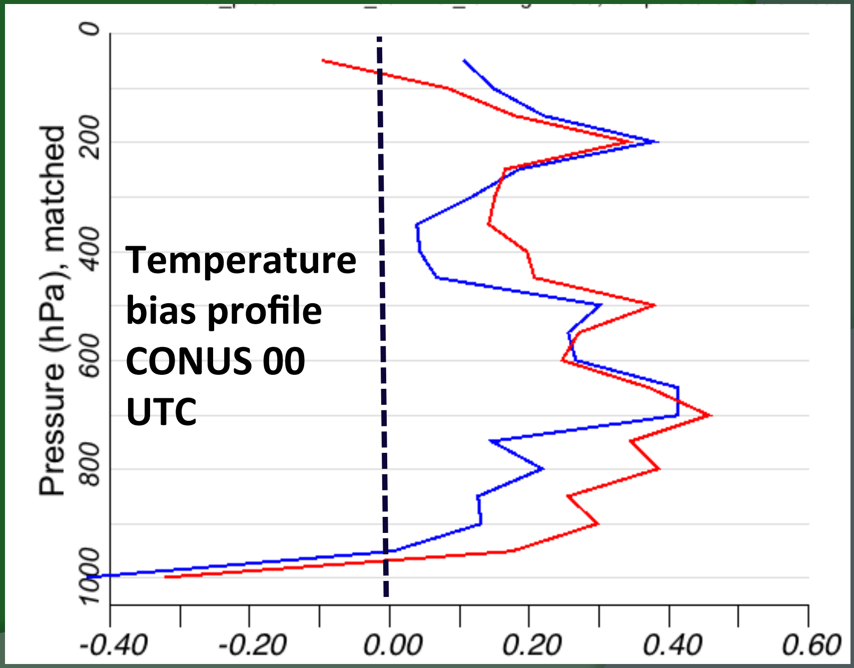
Forecast hour 6 verification for 16-20 July 2014

HRRR with EDMF1 (blue) vs. previous version (red)

Substantial reduction in 2-m temperature bias, especially in daytime

Temperature bias is generally reduced within the troposphere, but slightly larger cool-bias at the surface.



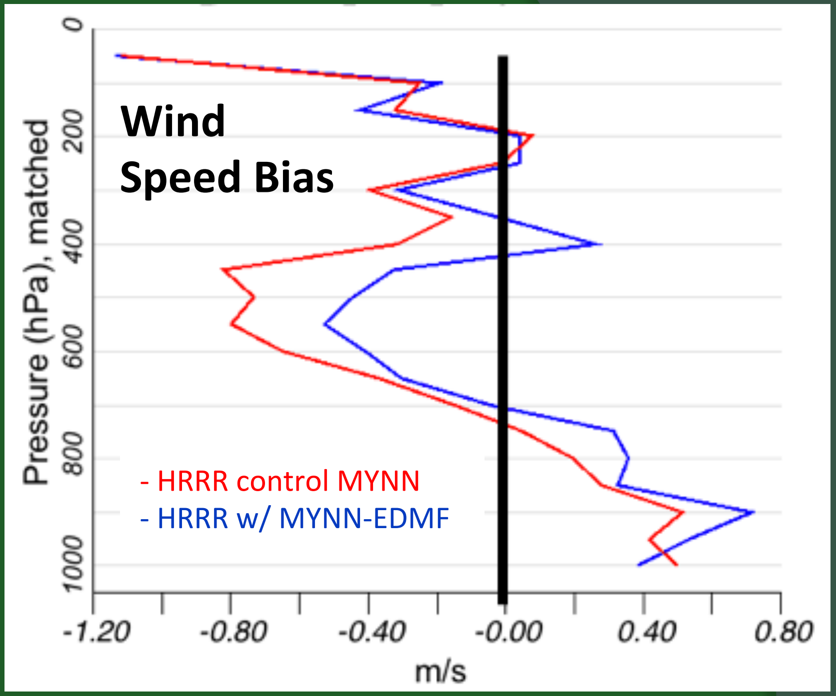


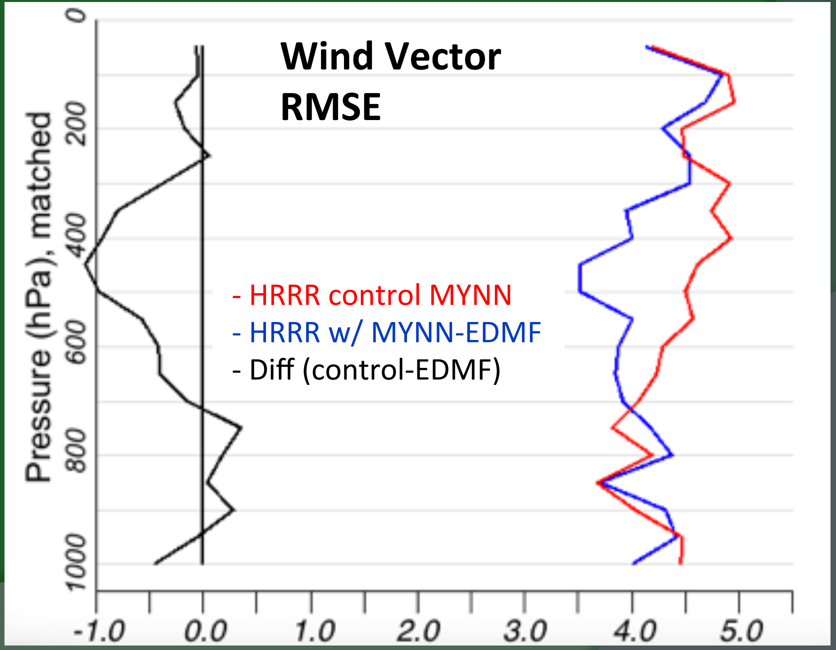
HRRR retrospective tests

Forecast hour 6 verification against radiosondes across continental U.S. for 16-20 July 2014 at 00 UTC

HRRR with EDMF1 (blue) vs. previous version (red)

Biggest improvements in winds are at mid-levels, with a full 1 m/s improvement in RMSE.





Summary

Two mass flux (sub-)schemes added to MYNN
Single-column and 3D tests
Substantial improvements so far

Issues:
Appropriate complexity
Stochasticity tolerable in an operational framework?
Absolute numerical stability
Tuning
- ED vs. MF tradeoffs
- Different convection strengths