Shallow cloud in WRF simulations of the Southeast U.S.

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Thanks to:
Robert Pincus (MODIS data and interpretation)

Why do we care about shallow cumulus?

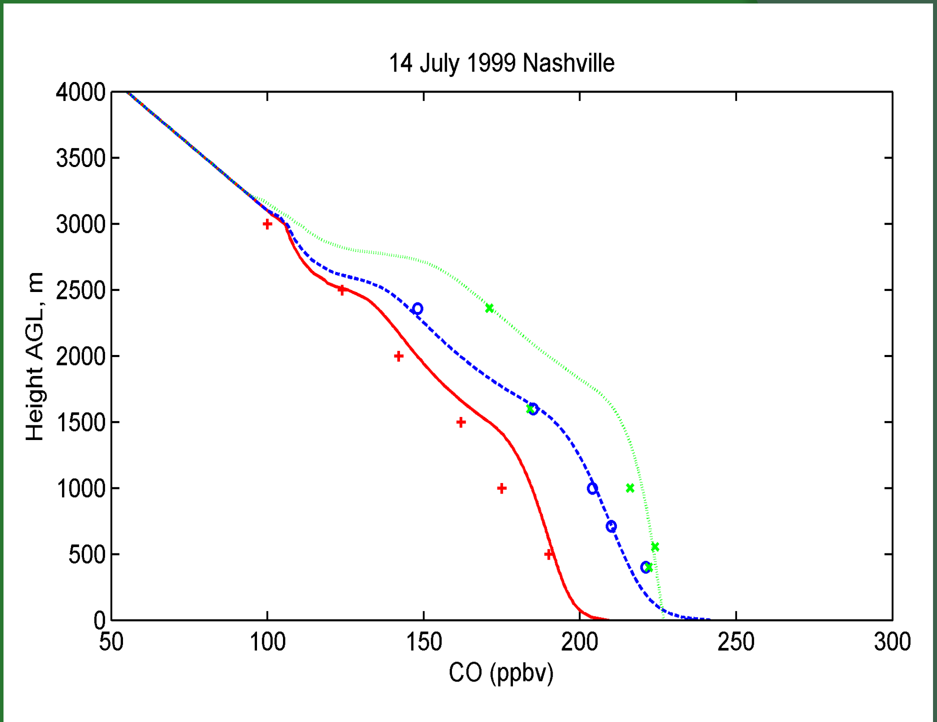
Vertical transport of chemical species
– raises effective PBL height

Radiative impact
– decreases solar input to surface, reducing turbulence intensity and chemical reaction rates

Aqueous processing
– heterogeneous chemistry of gasses and aerosols

Moistening of cloud layer
– preconditioning for deep convection

A severe test of model and data



Profiles of CO upwind of Nashville (red), over downtown (blue), and downwind (green)

Lines are 1D model, markers are aircraft measurements

Not possible to simulate without cloud transport

WRF configurations

Two physics setups
- MYNN2 + Grell-Freitas-Olson shallow Cu
- TEMF PBL

12-km horizontal grid, 60 vertical levels

Domain covers eastern half of North America

(One slide on impact of initialization data)

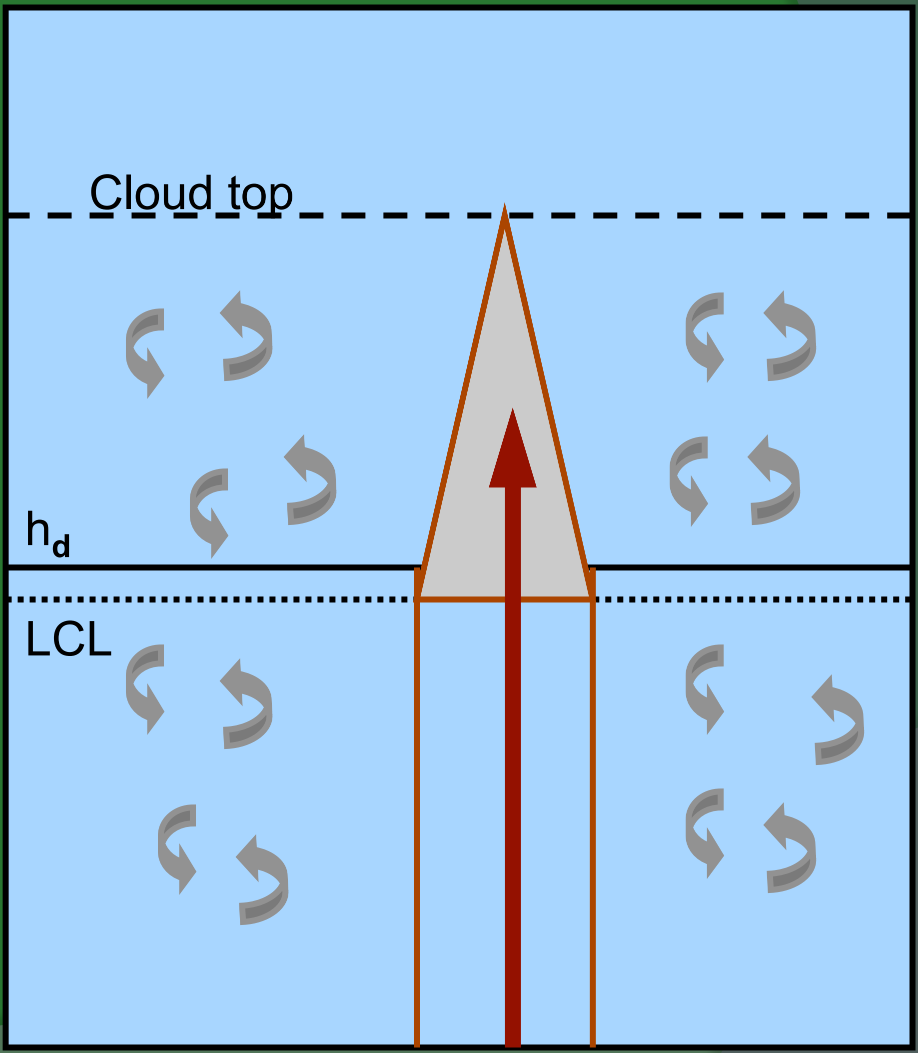
Grell-Freitas-Olson Shallow Cu Scheme

- Scale-aware mass-flux control from Honnert et al. 2011 (JAS)
  - ✧ Similarity based on TKE in entrainment/cloud layer
- Non-precipitating; currently mixing only qv and θ
- Produces sub-grid q_c and q_i for coupling to LW and SW radiation parameterization schemes
  - ✧ Uses Randall & Xu cloud fraction (RH, q_x) over water and a mass-flux-based form over land
- Weighted average of 3 different closures:
  - ✧ Boundary layer quasi-equilibrium, CAPE, and moist static energy
- Implemented for testing in WRF-ARW in shallow-cumulus driver so it can be used independently with any other deep-cumulus/PBL scheme
  - ✧ Will be available in WRF-ARW v3.6.1

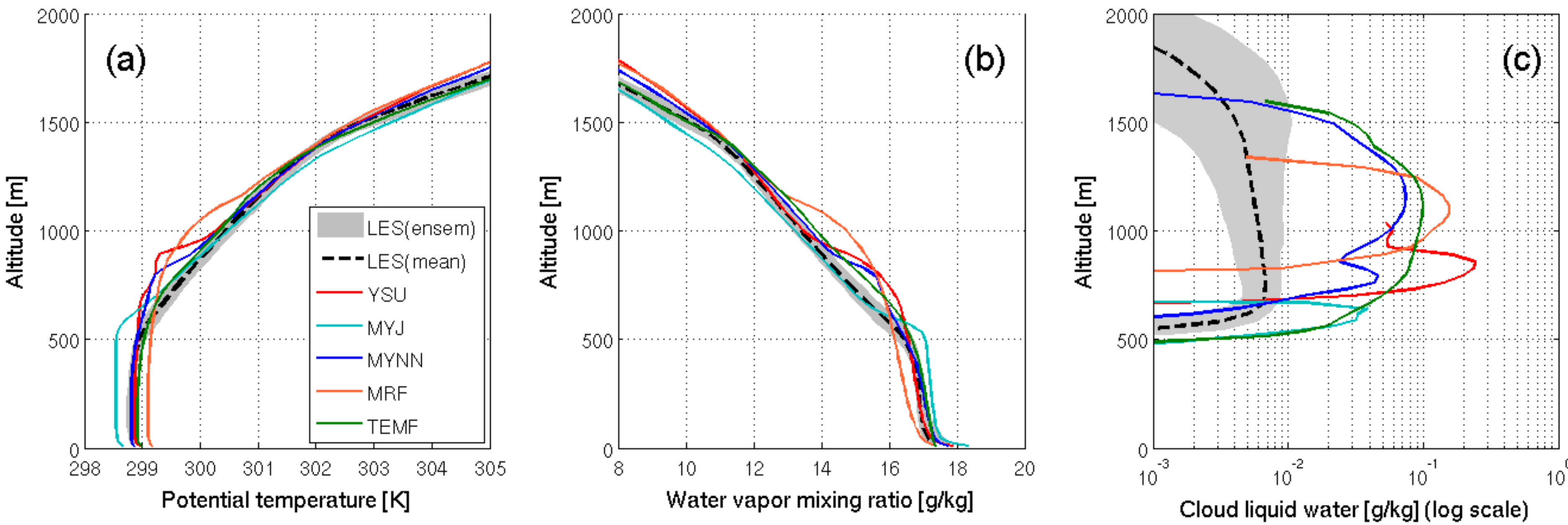
The Total-Energy Mass Flux (TEMF) PBL scheme

- Eddy-Diffusivity Mass Flux (EDMF) scheme
- Mass flux provides non-local transport in convective BL and natural representation of BL-rooted clouds
- 1.5-order (level 2.5)
- Total turbulent energy as prognostic variable
- One transport updraft and one (dry) test updraft
- Multi-component length scale
- Moist conserved variables
- Updraft mass and velocity initialized ~w* at surface
- Cloud base closure is continuity

- Available in WRF since v3.3
- Tested on many ideal cases and in 3D for three field campaigns



BOMEX

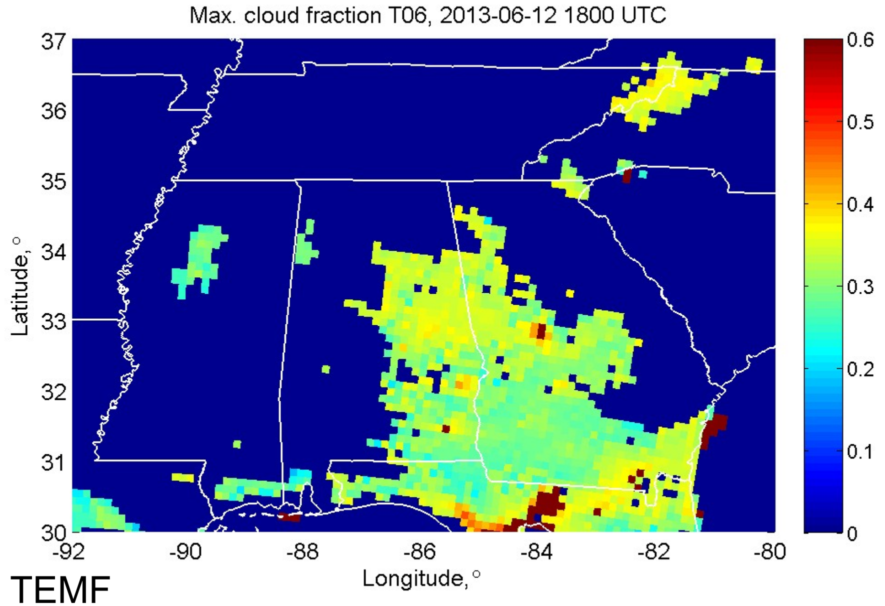


Huang, Hall, and Teixeira,
MWR 2013
Courtesy of H-Y. Huang

Cloud fraction
12 June 2013 SENEX case

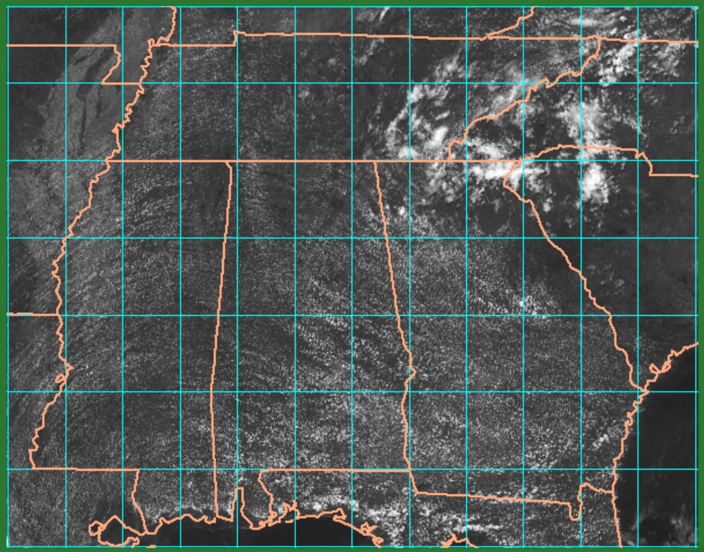
TEMF subgrid cloud fraction diagnosed internally (Cuijpers and Bechtold 1995, de Roode et al. 2000)

MYNN/GF shallow CF also diagnosed internally

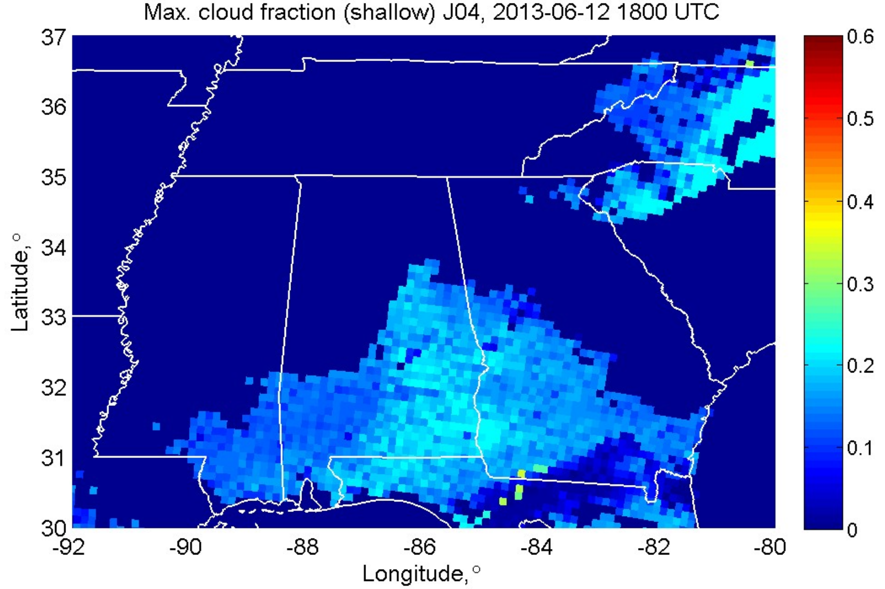


TEMF

Visible satellite



MYNN/GF shallow



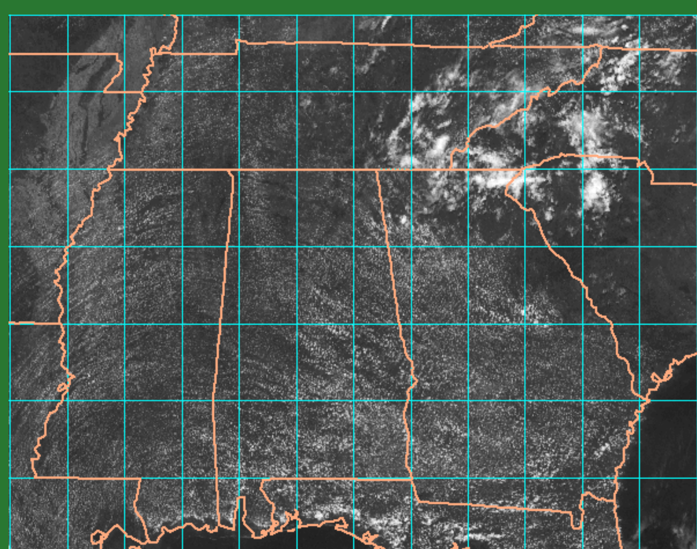
Downwelling shortwave radiation 12 June 2013 SENEX case

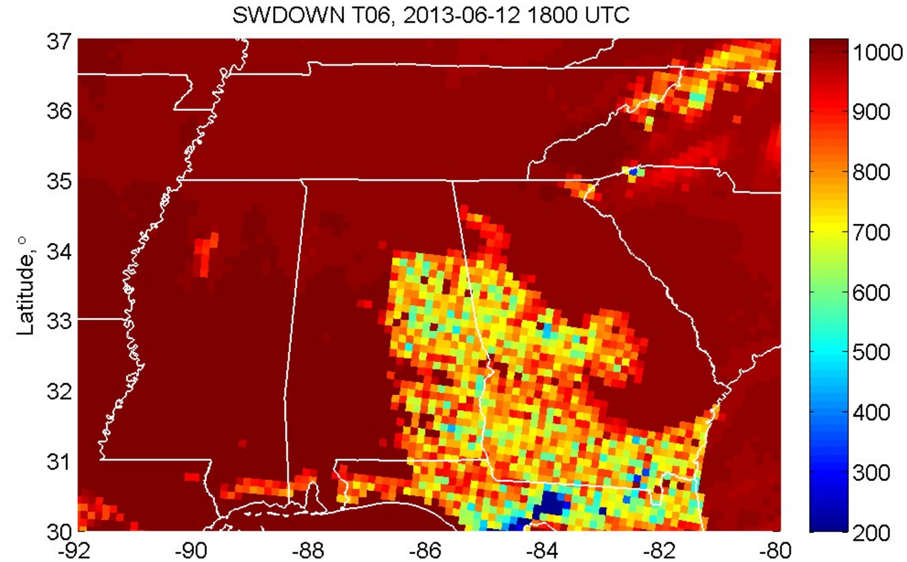
RRTM-G radiation scheme

Reacts to cloud liquid and cloud fraction

TEMF version includes updraft liquid and internally diagnosed cloud fraction

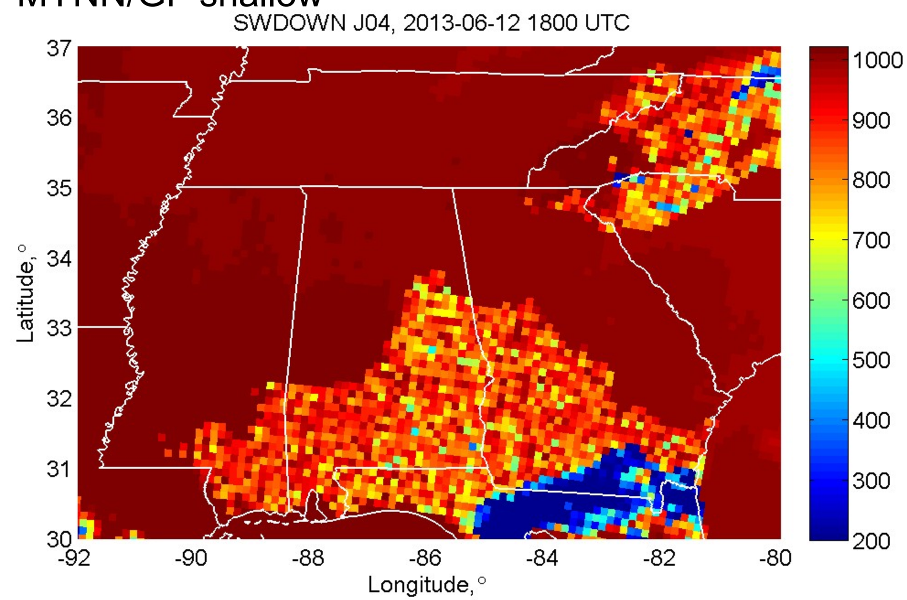
Visible satellite





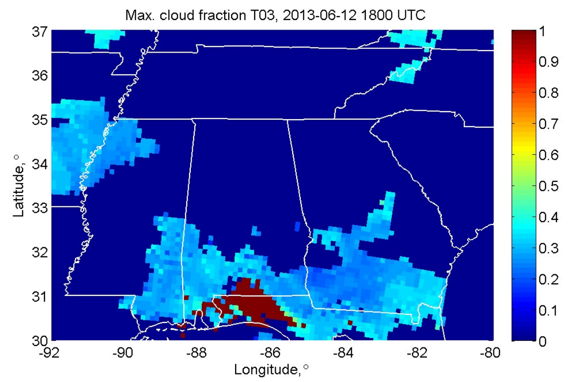
TEMF

MYNN/GF shallow

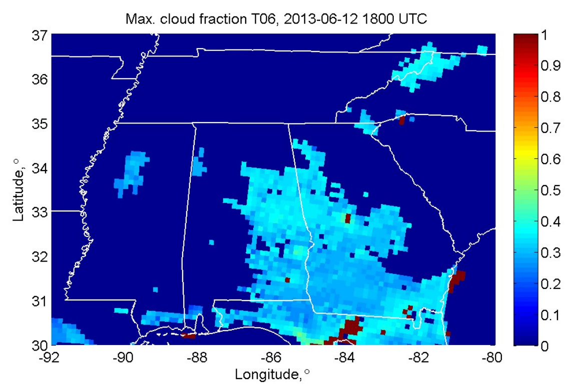


Cloud fraction variation with initialization data

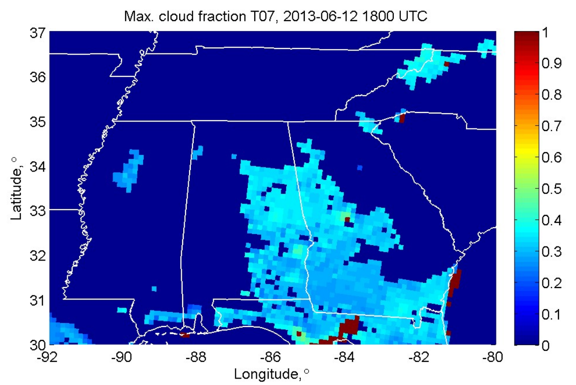
12 June 2013 SENEX case



GFS initialization



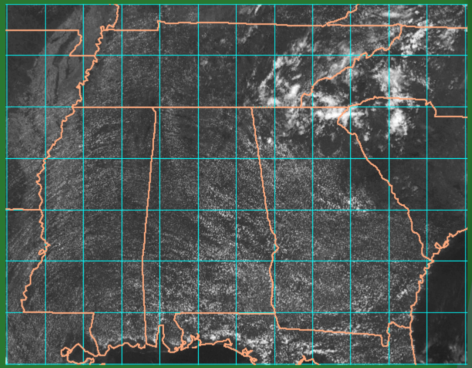
ERA-Interim initialization



ERA init, soil cycled

Initial & boundary conditions matter more than soil treatment

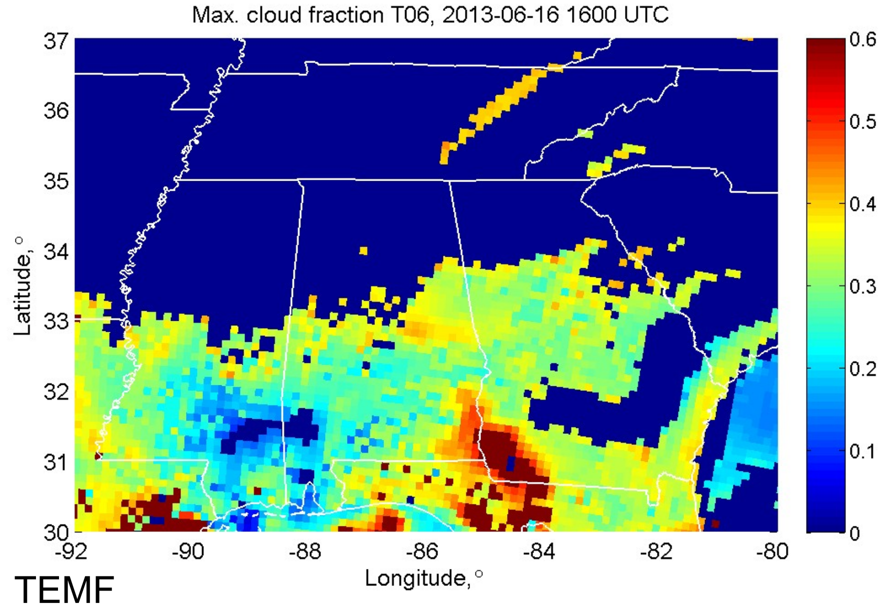
ERA-Interim result clearly better on this day



Cloud fraction
16 June 2013 SENEX case

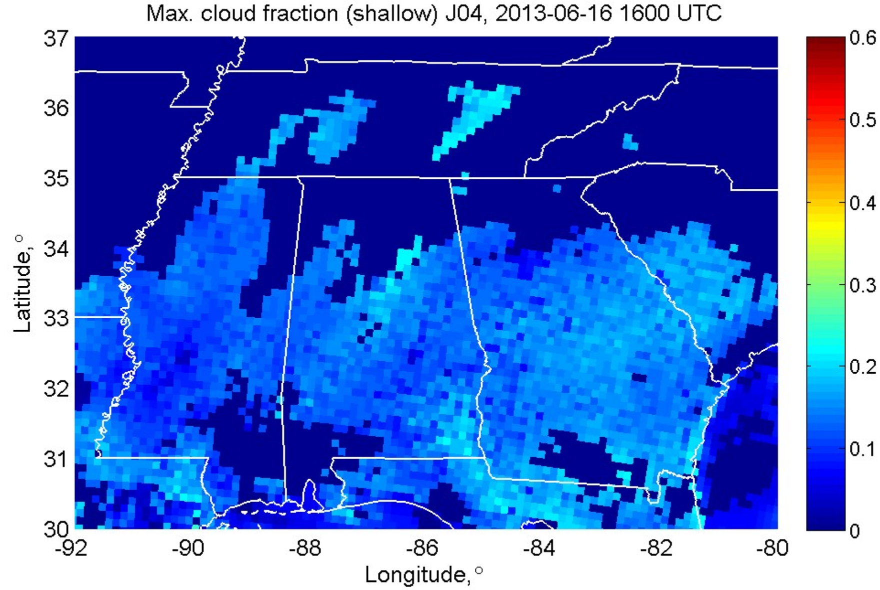
TEMF subgrid cloud fraction diagnosed internally (Cuijpers and Bechtold 1995, de Roode et al. 2000)

MYNN/G3 shallow CF also diagnosed internally

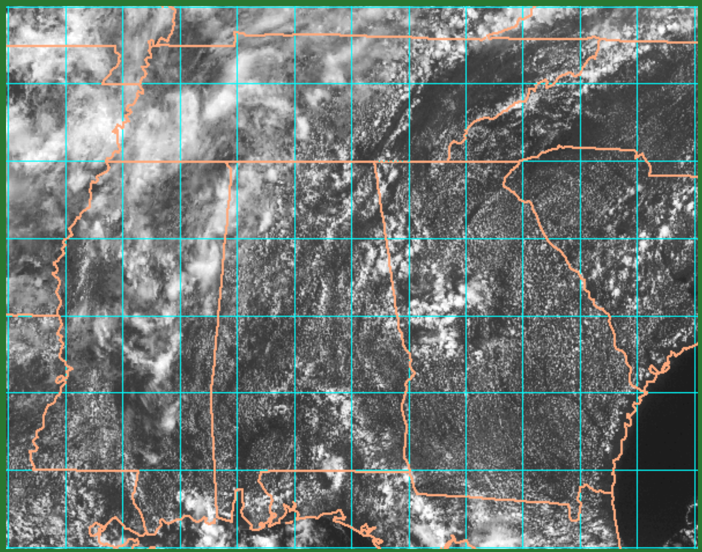


TEMF

MYNN/GF shallow



Visible satellite



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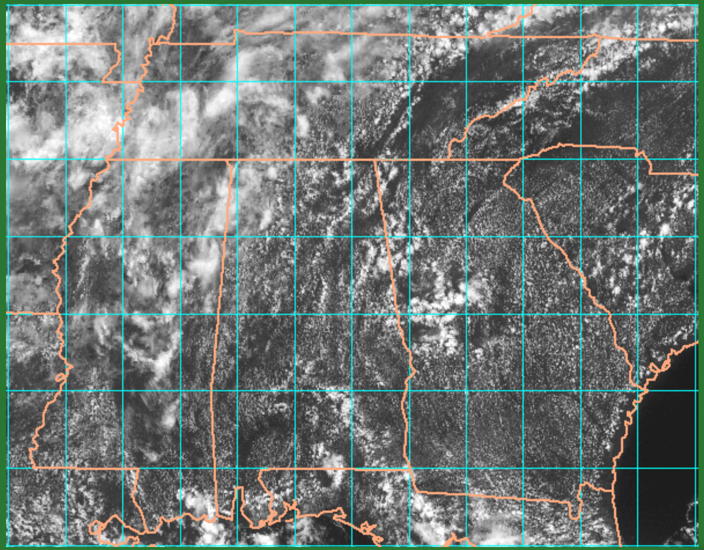

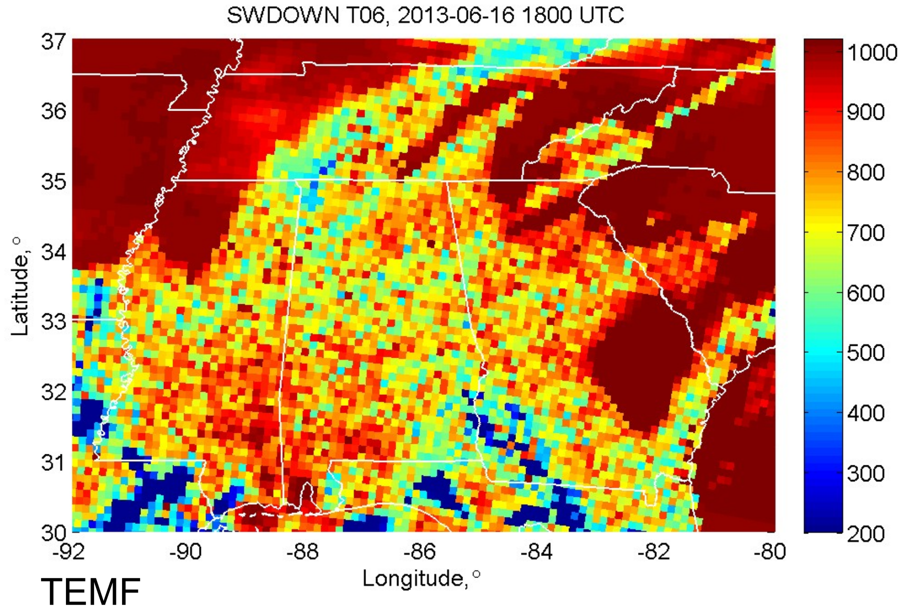

TEMF

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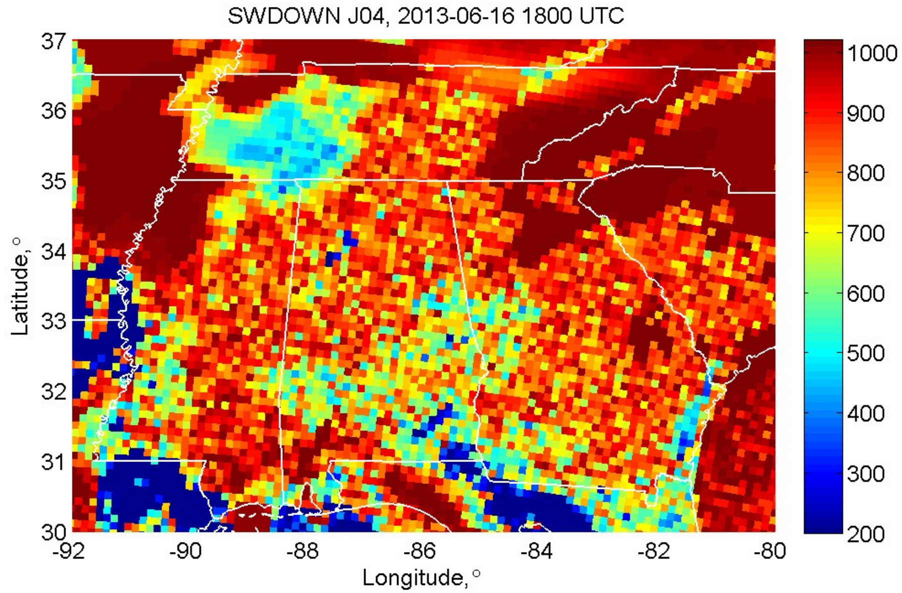
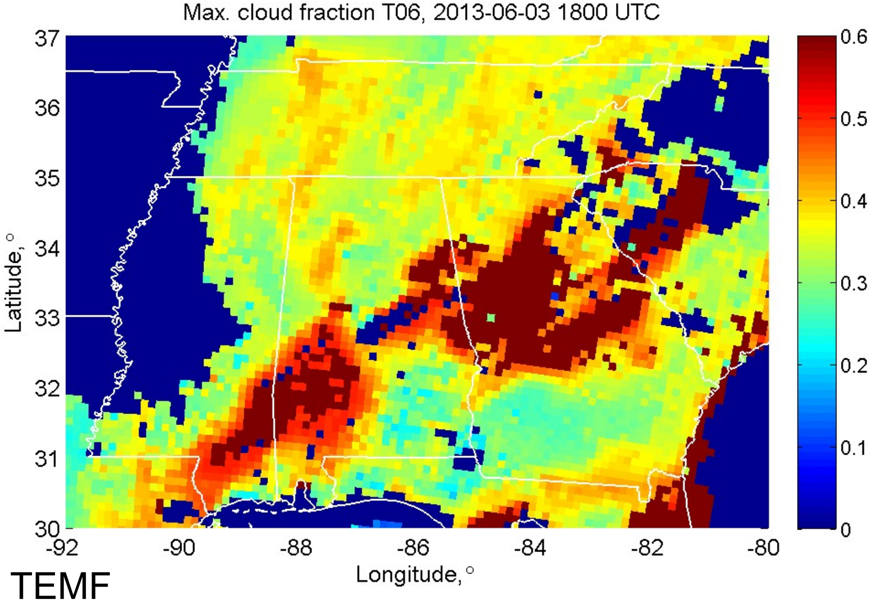


Cloud fraction
3 June 2013 SENEX case

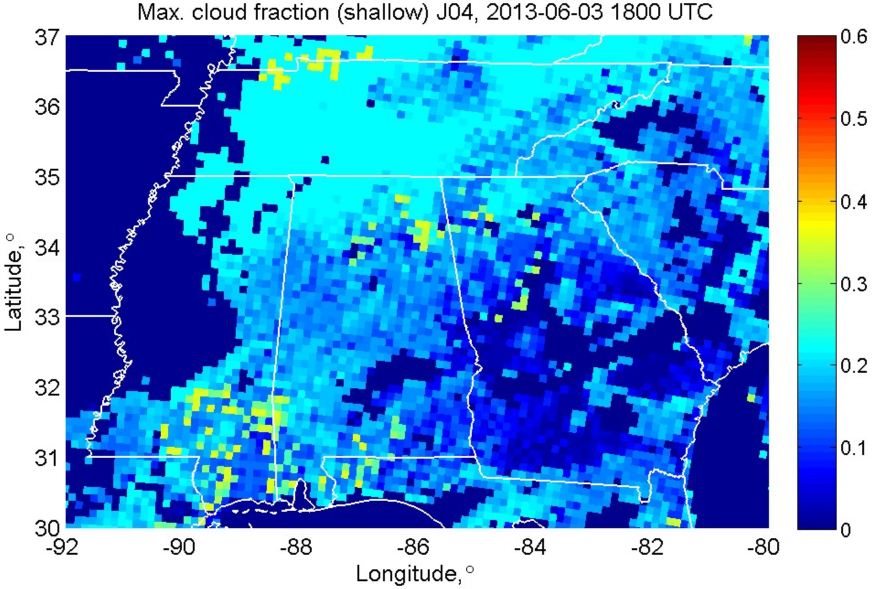
TEMF subgrid cloud fraction diagnosed internally (Cuijpers and Bechtold 1995, de Roode et al. 2000)

MYNN/G3 shallow CF also diagnosed internally

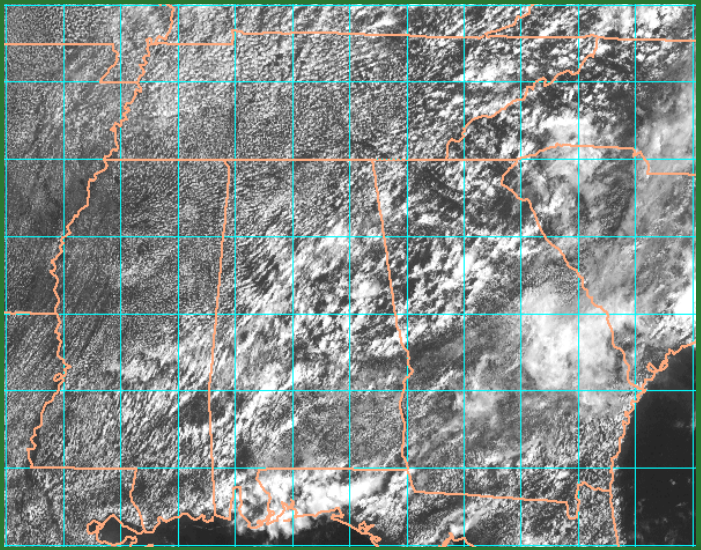


TEMF

MYNN/GF shallow



Visible satellite



Downwelling shortwave radiation 3 June 2013 SENEX case

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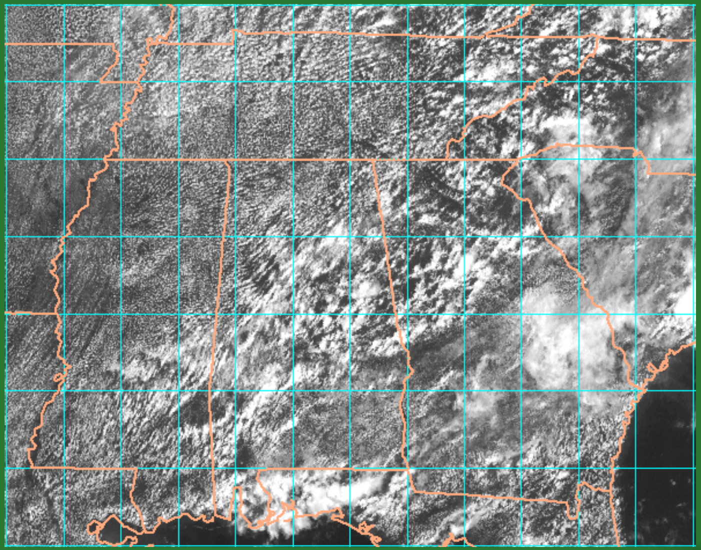

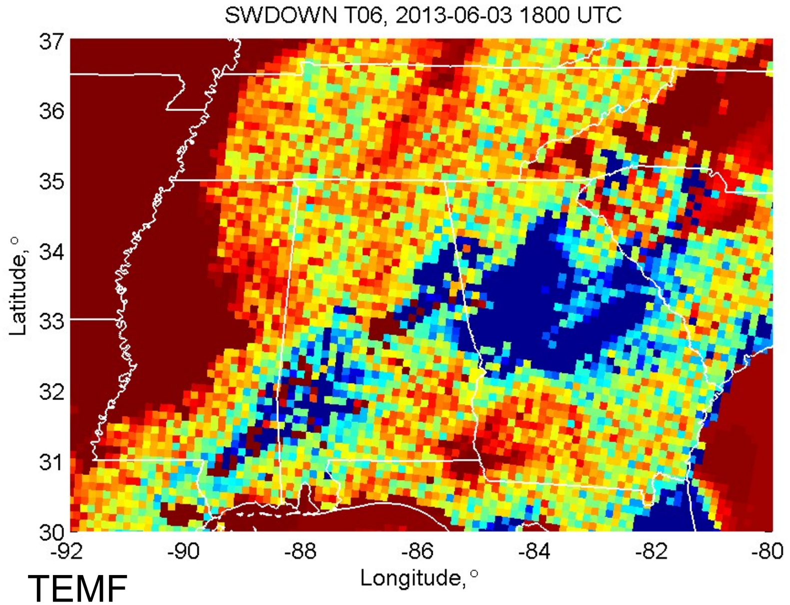

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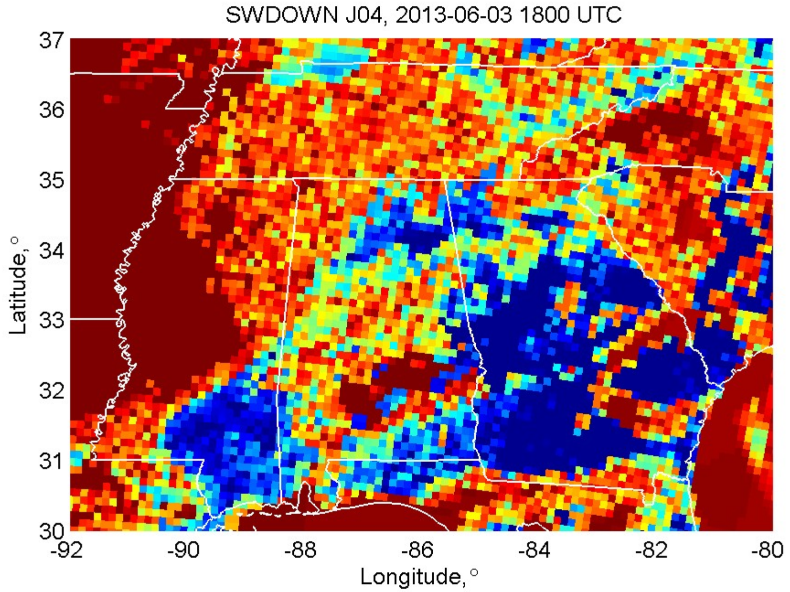
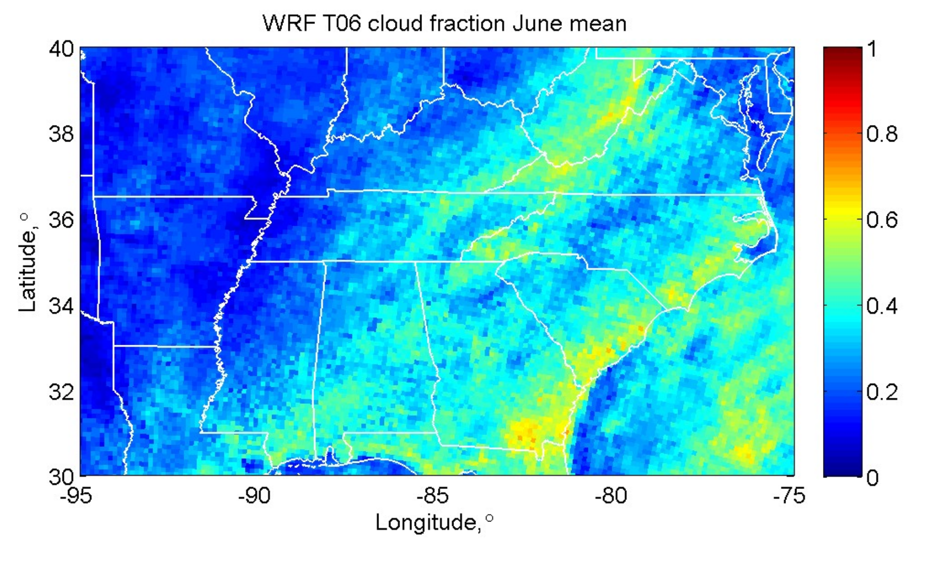


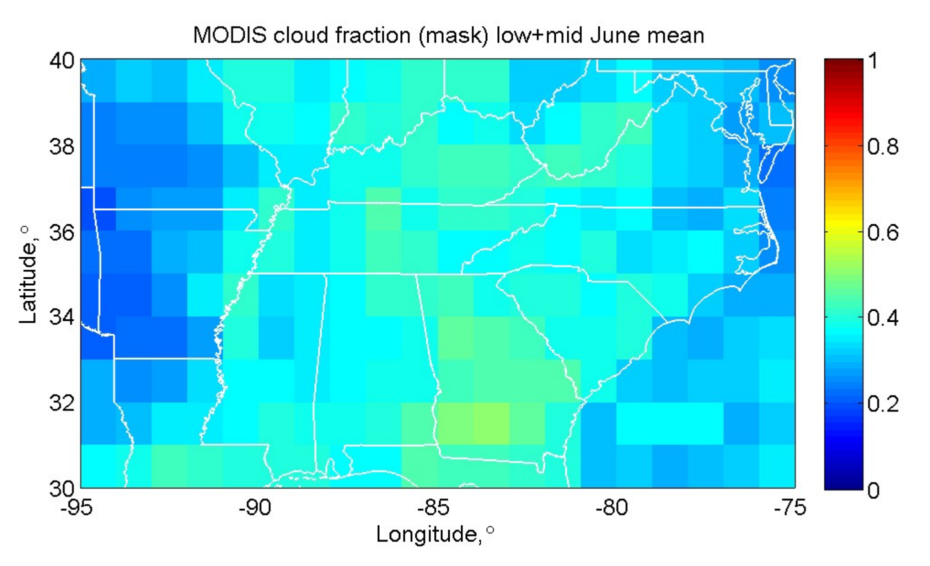
MODIS cloud fraction

June mean "mask" cloud fraction from MODIS (both satellites), 1x1 degree

Low+mid matches best

WRF/TEMF has too much cloud SE coast, too little in Mississippi valley





Conclusions and status

We have (at least) two ways to produce realistic shallow cumulus in WRF

- TEMF PBL with built-in cloud
- MYNN PBL with GFO shallow scheme

Caveats:

- Cloud fractions depend on diagnosis method
- Radiation coupling is critical
- Tuning opportunities abound
- Data for evaluation is difficult to interpret

WRF status:

- TEMF with updated surface velocity scale is in v3.6
  - Radiation coupling to come in a future release, contact me
- GFO shallow scheme will be in v3.6.1

Profiles over water near Catalina Island (CALNEX)

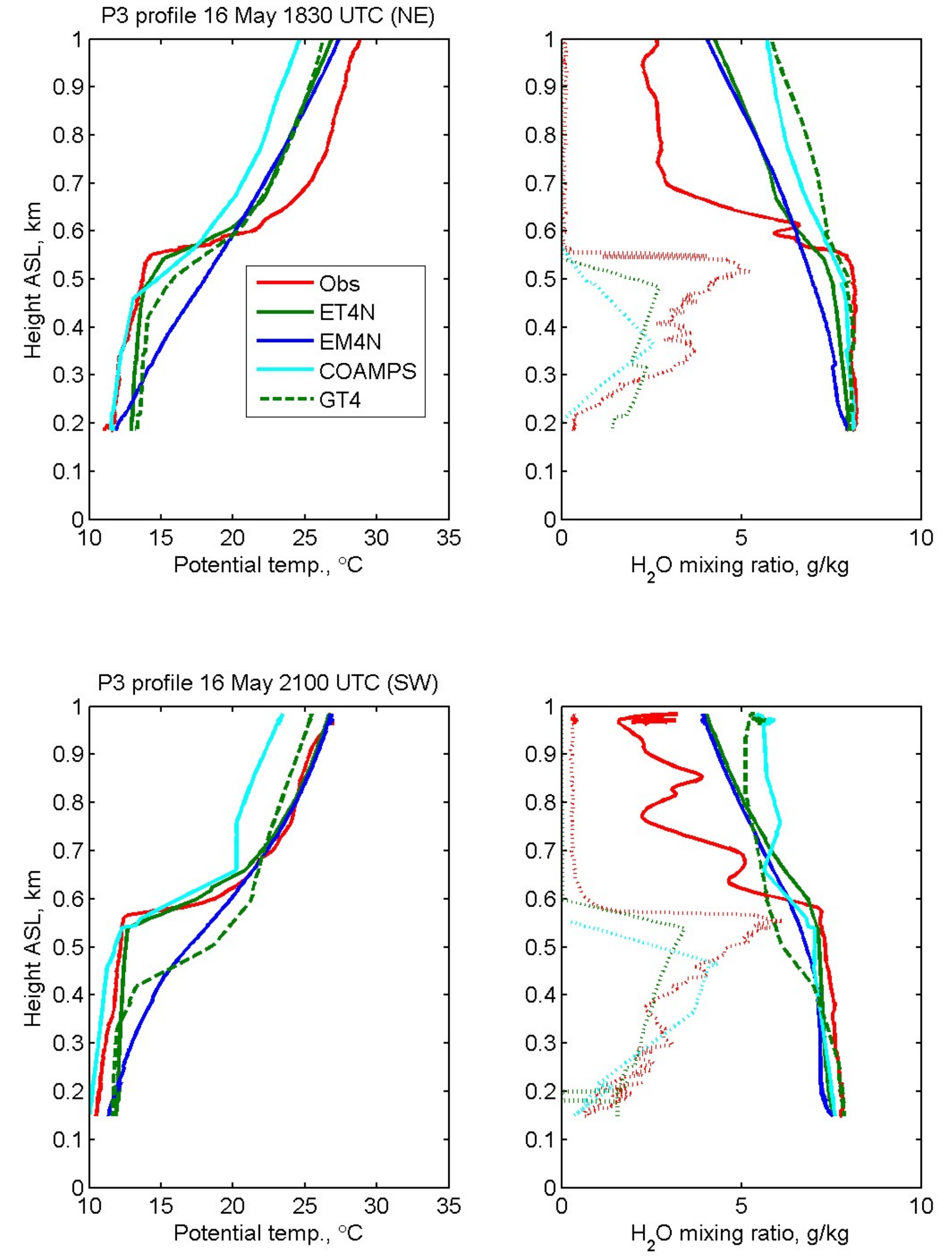
Obs have ~550 m roughly well-mixed cloudy BL with strong, sharp inversion and dry layer above

MYJ has shallow, stable BL
No cloud water because profile is unsaturated

TEMF BL matches obs well
Not saturated at grid scale

COAMPS has shallow BL with good temp and moisture

Red = P3 obs
Blue = WRF MYJ
Green = TEMF
Cyan = COAMPS



Incoming shortwave radiation

Affected by cloud liquid

TEMF has least SWDOWN but maybe still too much (see ship data)