WRF Version 2: Physics Update

Jimy Dudhia

NCAR/MMM

WRF Physics

- Diffusion
- Radiation (longwave and shortwave)
- Surface (surface layer and land-surface)
- Planetary Boundary Layer
- Cumulus Parameterization
- Microphysics

New Options in Version 2

- Grell-Devenyi Ensemble Cumulus Scheme
- WRF Single-Moment Microphysics (3, 5, 6-class options)
- Noah Land Surface Model
- RUC Land Surface Model
- Yonsei University Planetary Boundary Layer Scheme

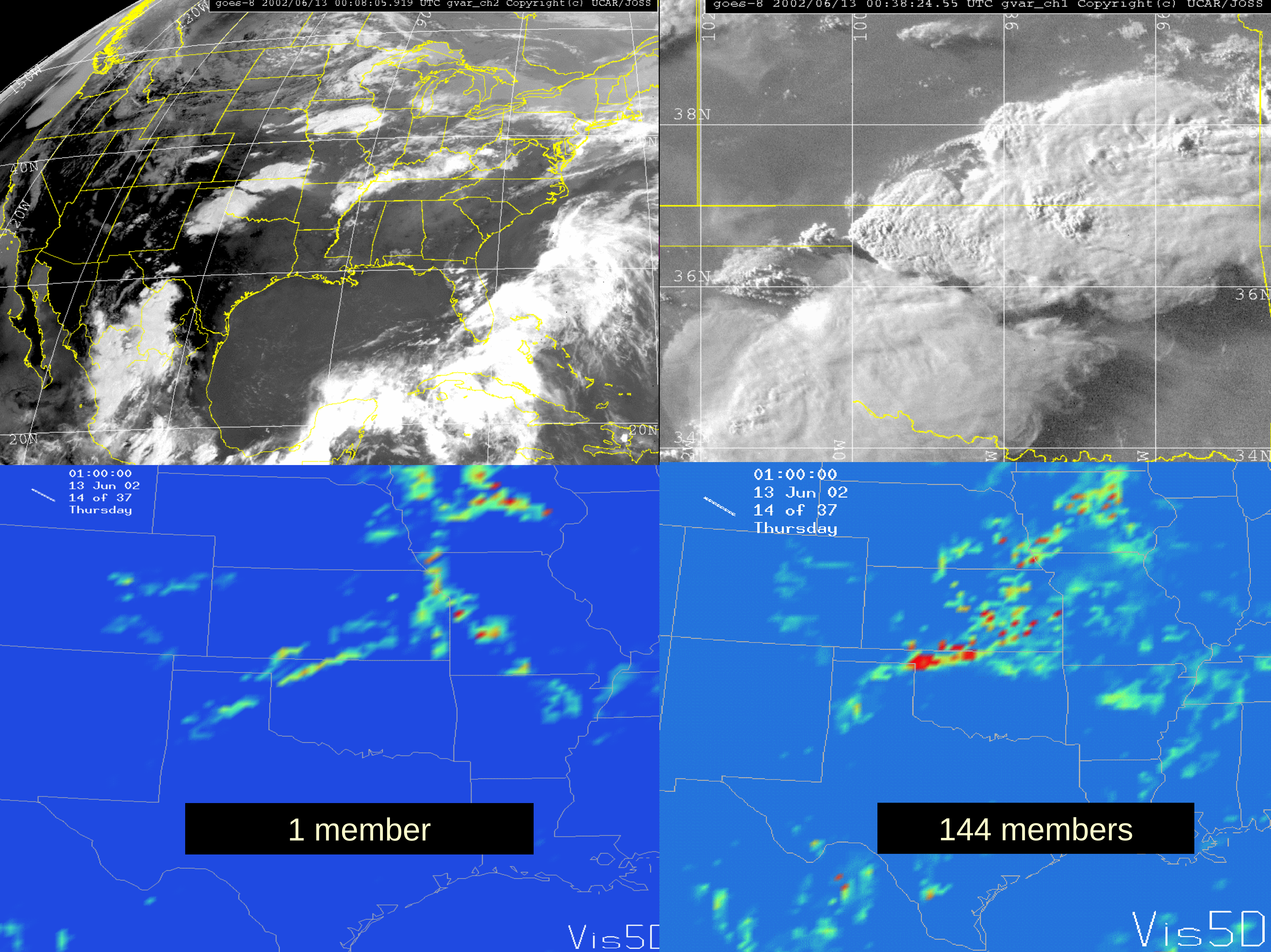
Grell-Devenyi Ensemble Cumulus Parameterization

Developers: Georg Grell, Dezso Devenyi (NOAA/FSL)

- Typically 144 ensemble members calculated per grid column (still efficient)
- Members differ in
  - Closure (CAPE, dCAPE/dt, moisture conv, etc)
  - Trigger (maximum cap stength)
  - Precipitation efficiency
  - Other parameters (updraft assumptions, etc.) may be varied

Grell-Devenyi Ensemble Cumulus Parameterization

- Currently feedback (precip, heating, moistening profiles) is just ensemble average with equal weights
- Statistical methods can be used to train weights regionally and/or diurnally
- Scheme is potentially more optimizable than individual schemes


goes-8 2002/06/13 00:08:05.919 UTC gvar_ch2 Copyright(c) UCAR/JOSS
goes-8 2002/06/13 00:38:24.55 UTC gvar_ch1 Copyright(c) UCAR/JOSS
38N
36N
34N
01:00:00
13 Jun 02
14 of 37
Thursday
1 member
Vis5D
01:00:00
13 Jun 02
14 of 37
Thursday
144 members
Vis5D

WRF Single-Moment Microphysics

Developers: Song-You Hong, Jimy Dudhia, Shuhua Chen, Jeong-Ock Lim

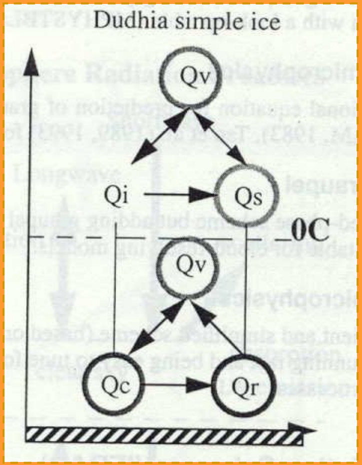
3 schemes

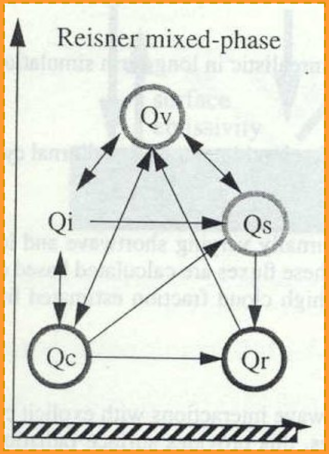
- 3-class (cloud/ice, snow/rain, vapor)
- 5-class (cloud, ice, snow, rain, vapor)
- 6-class (cloud, ice, snow, rain, graupel, vapor)

Bulk parameterization

- Simple ice (Dudhia, 1989), WSM3
  : 3 arrays of moisture

  ➡ q_v, q_{ci}, q_{rs}





- Mixed phase (Reisner et al.,1998), WSM5
  : 5 arrays of moisture

  ➡ q_v, q_c, q_i, q_r, q_s

WRF Single-Moment Microphysics

- WSM3 and WSM5 based on Dudhia (1989) and MM5 Reisner ‘1’ schemes
- WSM6 adds graupel, modified from Lin et al.
- Schemes are distinguished from older schemes mostly by ice crystal size/number assumptions

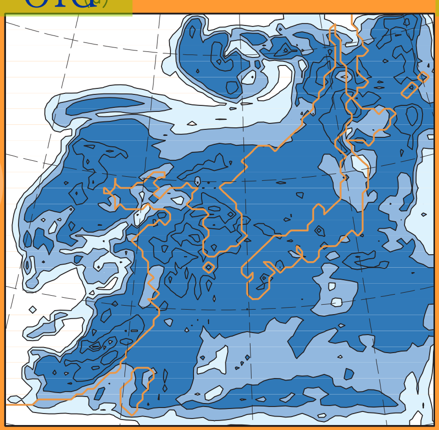
Major modifications suggested by Hong et al. (2004)

	(Rutledge and Hobbs, 1983)	(Hong et al, 2004)
Number concentration of cloud ice	$N_I(m^{-3}) = 10^{-2}\exp[0.6(T_0 - T)]$	$N_I = c(\rho q_I)^d$
Ice nuclei number	$N_I(m^{-3}) = 10^{-2}\exp[0.6(T_0 - T)]$	$N_{I0} = 10^3\exp[0.1(T_0 - T)]$
Intercept parameter for snow	$N_{0S} = 2\times 10^7\ \mathrm{m}^{-4}$	$N_{0S}(m^{-4}) = 2\times 10^6\exp\{0.12(T_0 - T)\}$

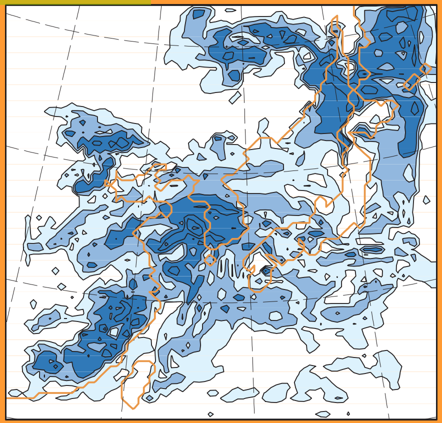
23 –25 June 1997

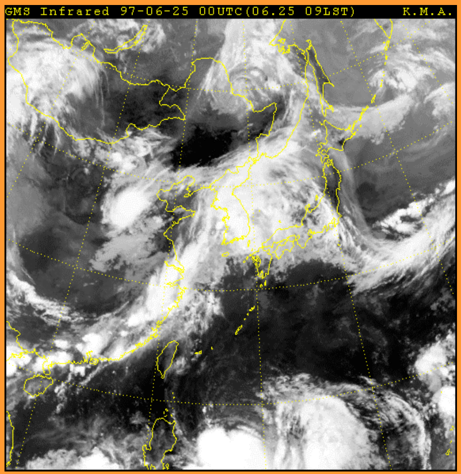
Heavy Rainfall Case

old



new





Ice crystal property

(Mass, Diameter, Mixing ratio, Ice number)

$V_I(ms^{-1}) = 3.29(\rho q_I)^{0.16}$: **Heymsfield and Donner(1990)** **(HD1990)**

$V_I = xD^y, m = \alpha D^\beta$: **Heymsfield and Iaquinta (2000)** **(HI2000)**

$mN_i = \rho q_i$

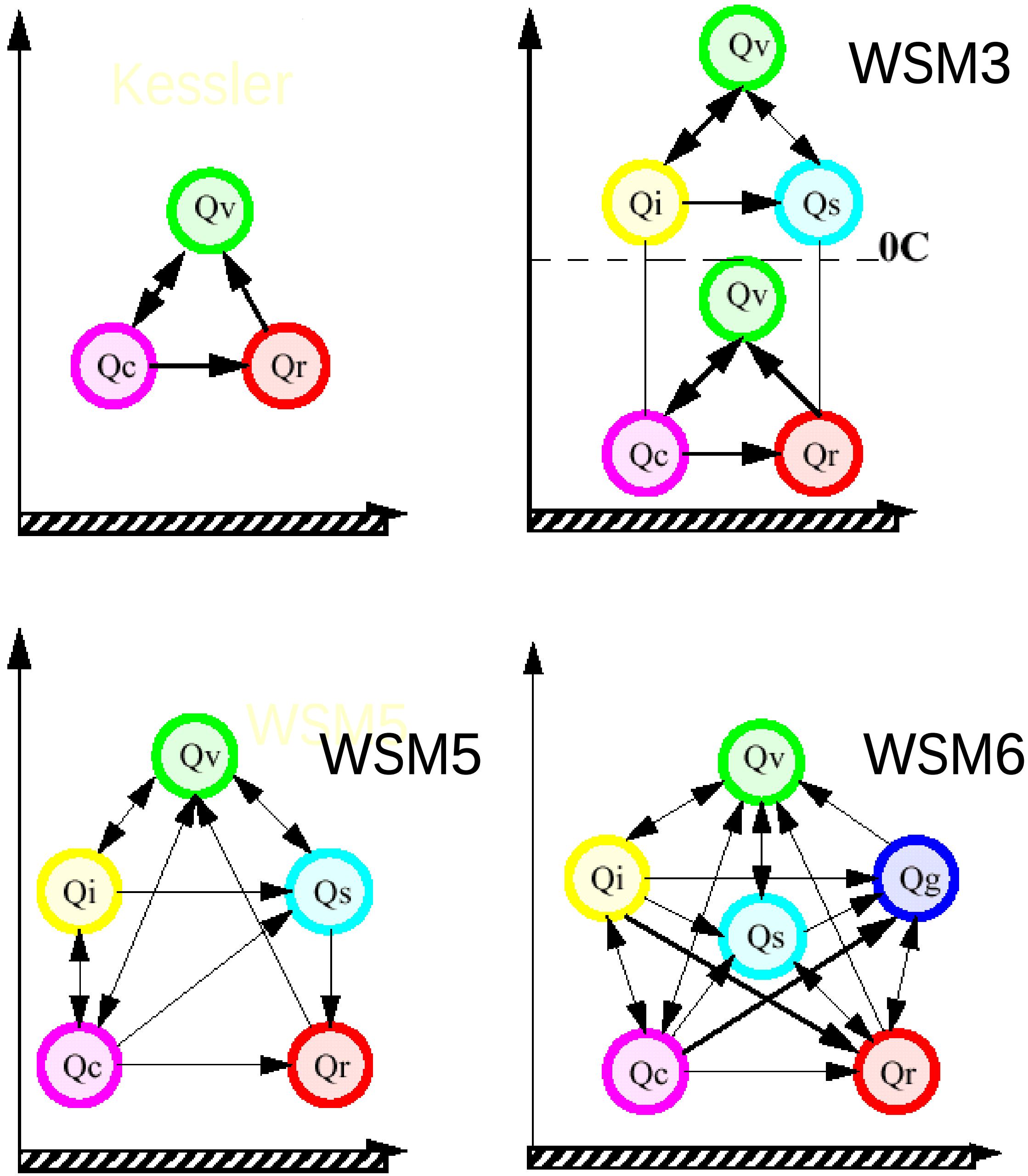
$N_i = c(\rho q_i)^d$

$$V_I(ms^{-1}) = 1.49\times 10^4 D^{1.31},$$
$$D(m) = 11.9 m^{0.5}$$
$$N_I(m^{-3}) = 5.38\times 10^7 (\rho q_i)^{0.75}$$
$$\rho q_I(kgm^{-3}) = 4.92\times 10^{-11} N_I^{1.33}$$

Development of WSM6

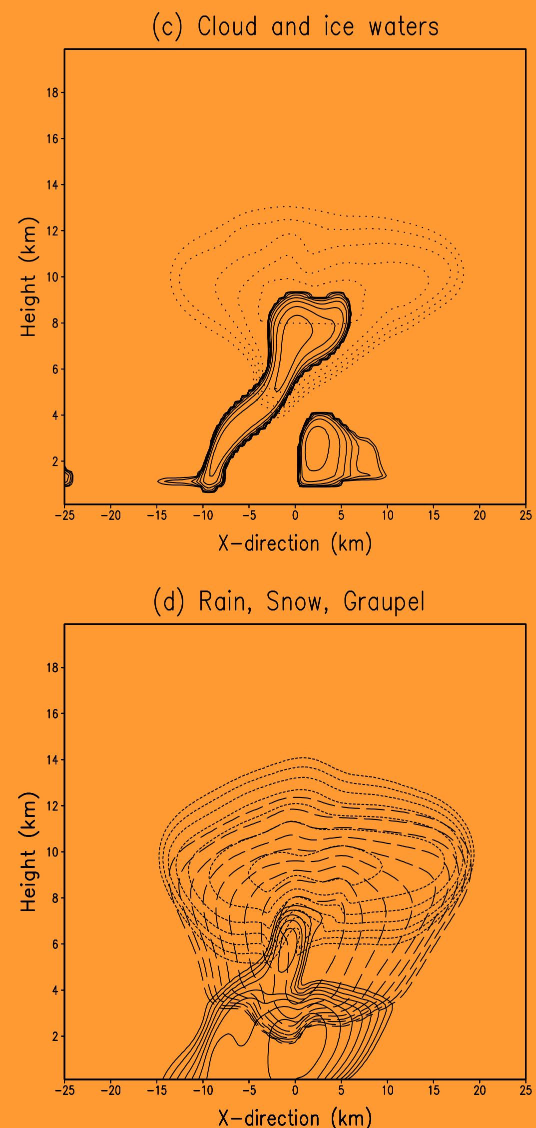
- Riming and graupel processes
- Accounts for relative fall speeds in accretion (idea from M. Gilmore)
- Incorporates melting into fall sub-steps
- Calculation order: sensitivity to timestep length minimized
- Comparison with Lin, Farley and Orville (LFO)

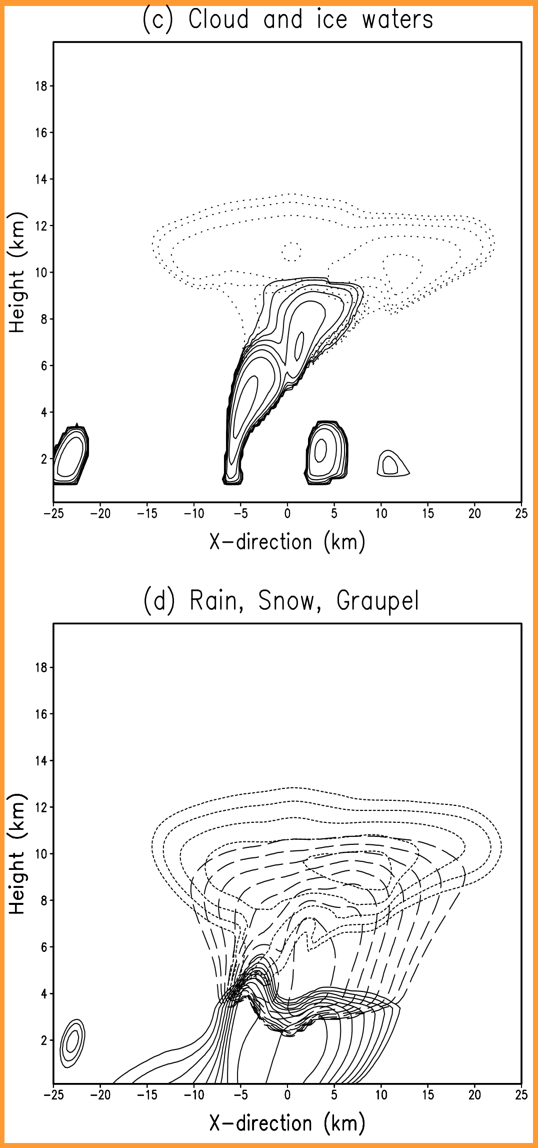
Illustration of Microphysics Processes



Development of WSM6

WSM6





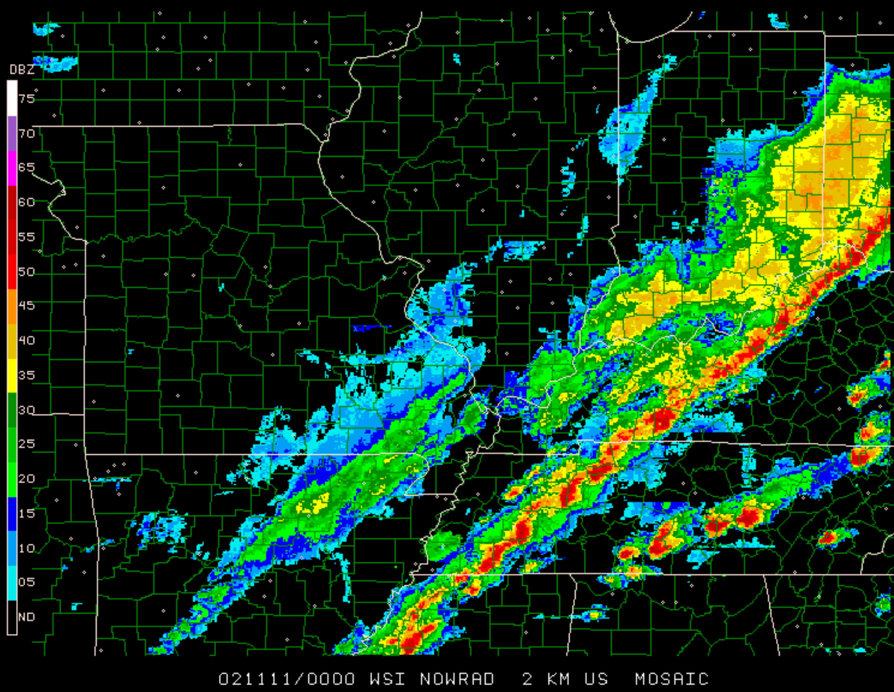
LFO

Real-Data case

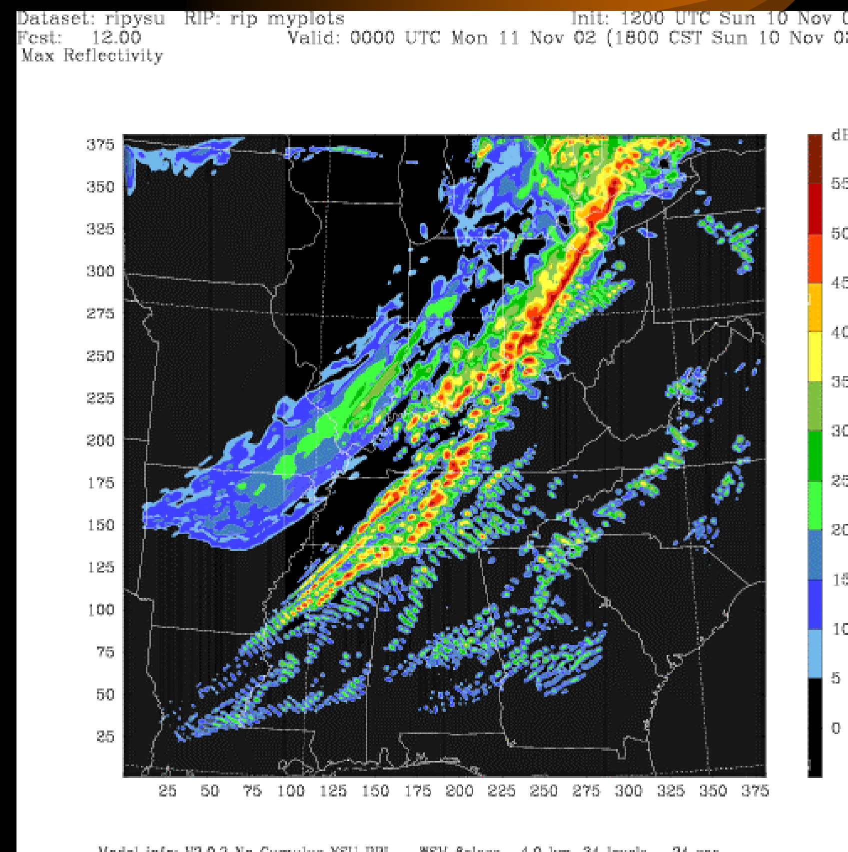
- 10-11 November 2002 tornado outbreak
- East-central US
- 4 km cloud-resolving simulation
- 12 hour forecast
- Simulated reflectivity from
  - WSM6
  - Lin et al (LFO)

00Z 11 Nov 2002 Reflectivity

Radar



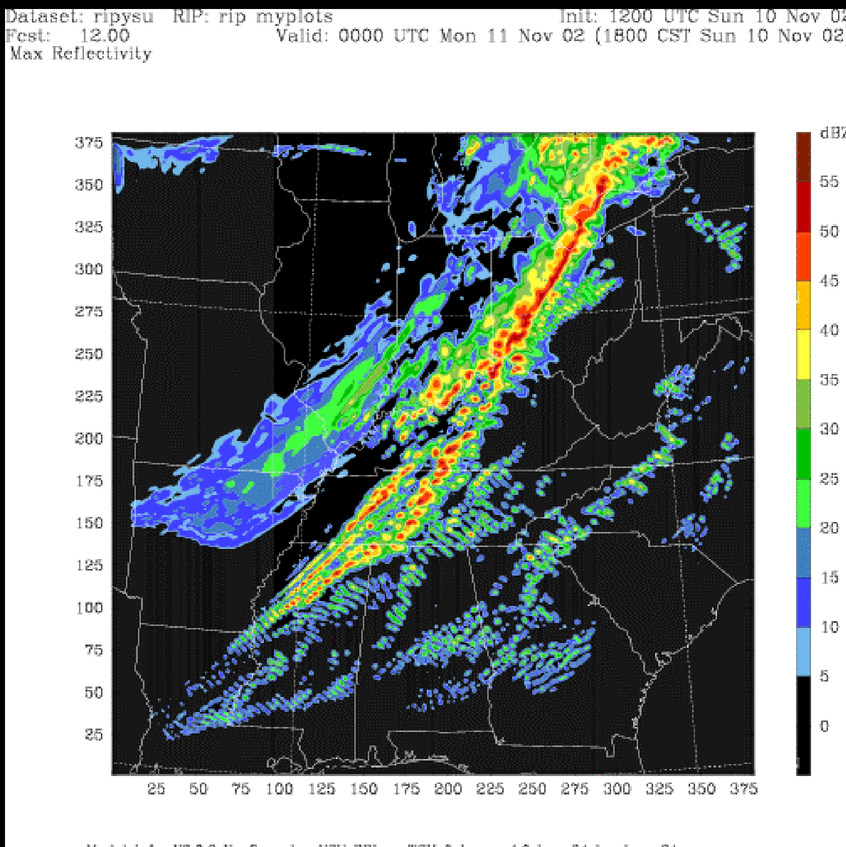
WSM6

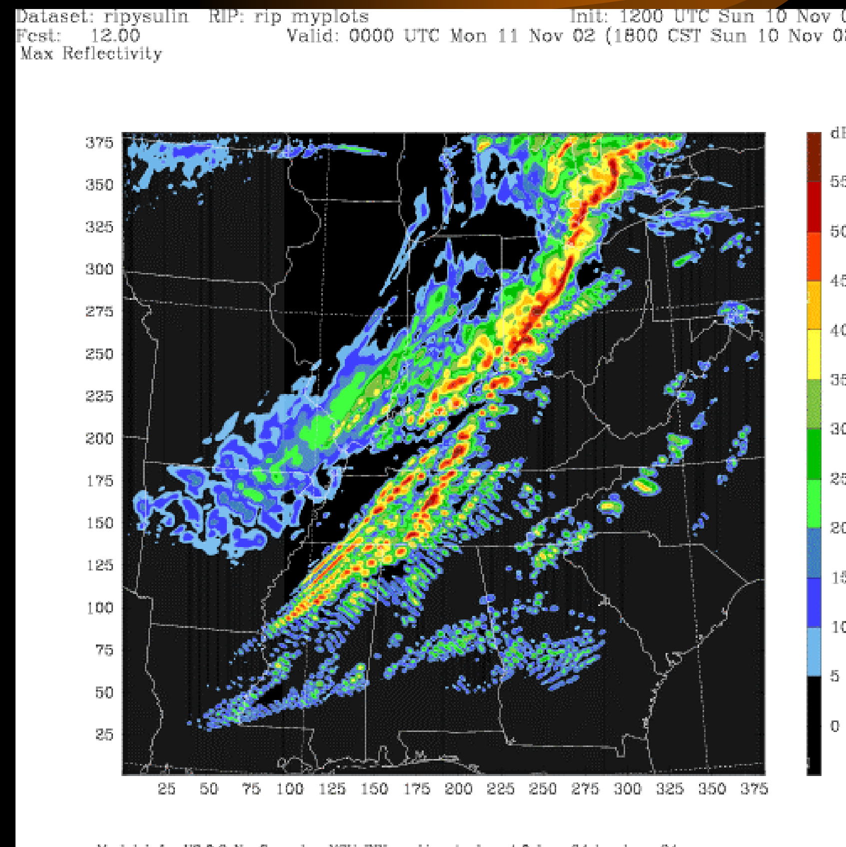


00Z 11 Nov 2002 Reflectivity

WSM6

LFO





Noah Land Surface Model

Developers: Fei Chen (NCAR/RAP), Ken Mitchell (NCEP), Mike Ek (NCEP), Mukul Tewari (RAP), and others

- New unified version of Oregon State University (MM5) scheme and NCEP’s Eta/LDAS scheme
- Snow-cover fraction
- Frozen soil physics
- Other changes, including emissivity and urban effects

RUC Land Surface Model

Developers: Tanya Smirnova (NOAA/FSL)

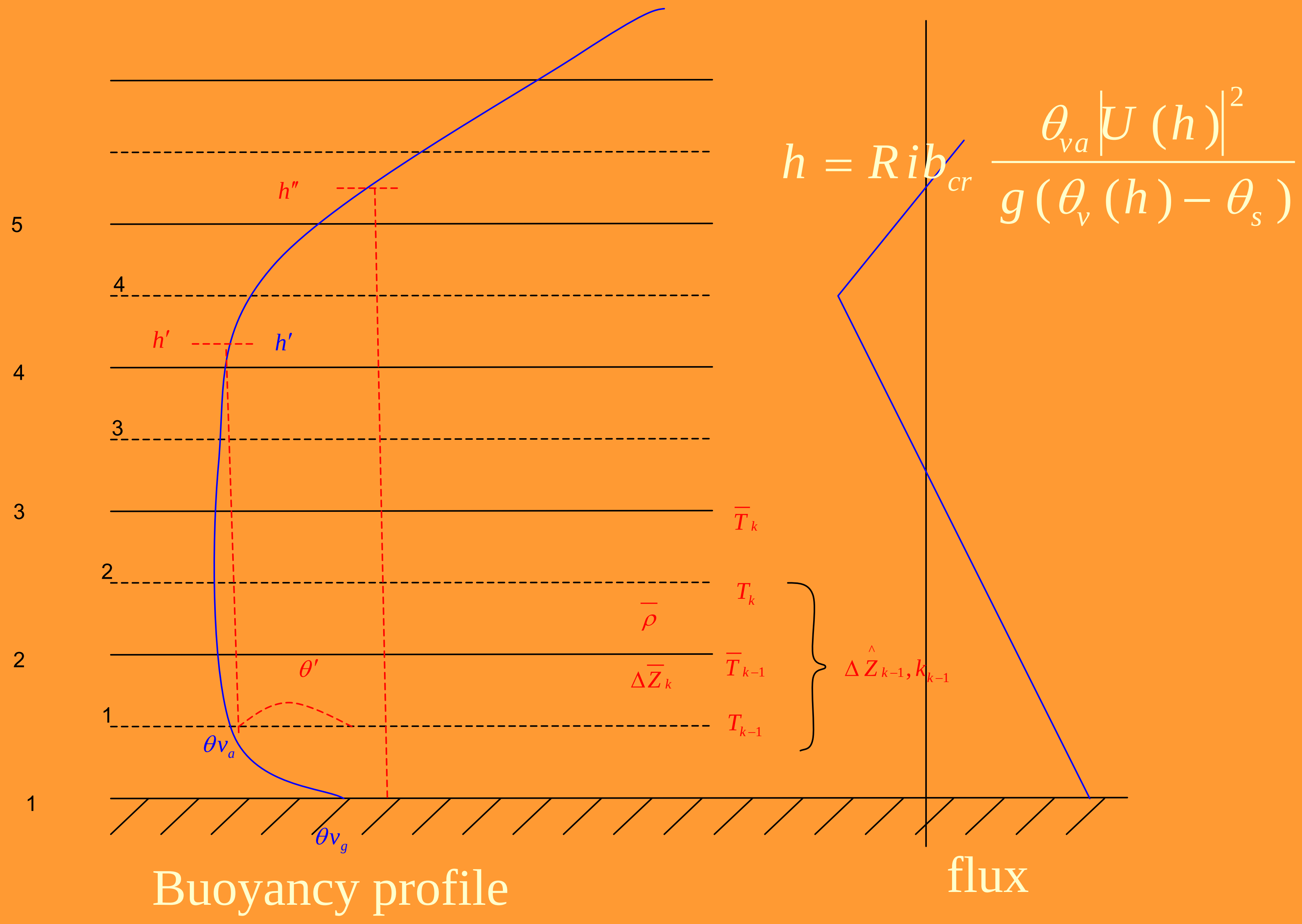
- Operational version from RUC
- 6 sub-soil layers
- Multi-layer snow model

Yonsei University (YSU) Planetary Boundary Layer

Developers: Song-You Hong and Yign Noh (YSU)

- Successor to MRF PBL (Hong and Pan)
- Explicit treatment of entrainment layer
- Based on Large-Eddy Model results
- PBL height is lower because it excludes upper part of entrainment layer

MRFPBL (Troen and Mahrt) represents the entrainment implicitly
YSUPBL (Hong and Noh) represents the entrainment explicitly



TM Model	New Model
• heat flux profile	
i) $z < h$	i) $z < h$
$-\overline{w'\theta'} = K_h\left(\frac{\partial\theta}{\partial z} - \gamma_h\right)$	$-\overline{w'\theta'} = K_h\left(\frac{\partial\theta}{\partial z} - \gamma_h\right) - \overline{w'\theta'}_h\left(\frac{z}{h}\right)^3$
$\gamma_h = b_0 \frac{\overline{w'\theta'}_0}{w_{s0}h}$	$\gamma_h = b\frac{\overline{w'\theta'}_0}{w_s(h/2)h}$
ii) $z > h$	ii) $z > h$
not defined	$-\overline{w'\theta'} = K_h\frac{\partial\theta}{\partial z}$ $K_h = \frac{-\overline{w'\theta'}_h}{(\partial\theta/\partial z)_h}\exp\left[-\frac{(z-h)^2}{\delta^2}\right]$ $\left(\delta = 0.02h + 0.05w_m{}^2/\Delta b\right)$
- h is above the height of the minimum heat flux here	* $\overline{w'\theta'}_h = -Aw_m^3/h, \ \ (w_m^3 = w_*^3 + 5u_*^3)$ - h is the height of minimum heat flux

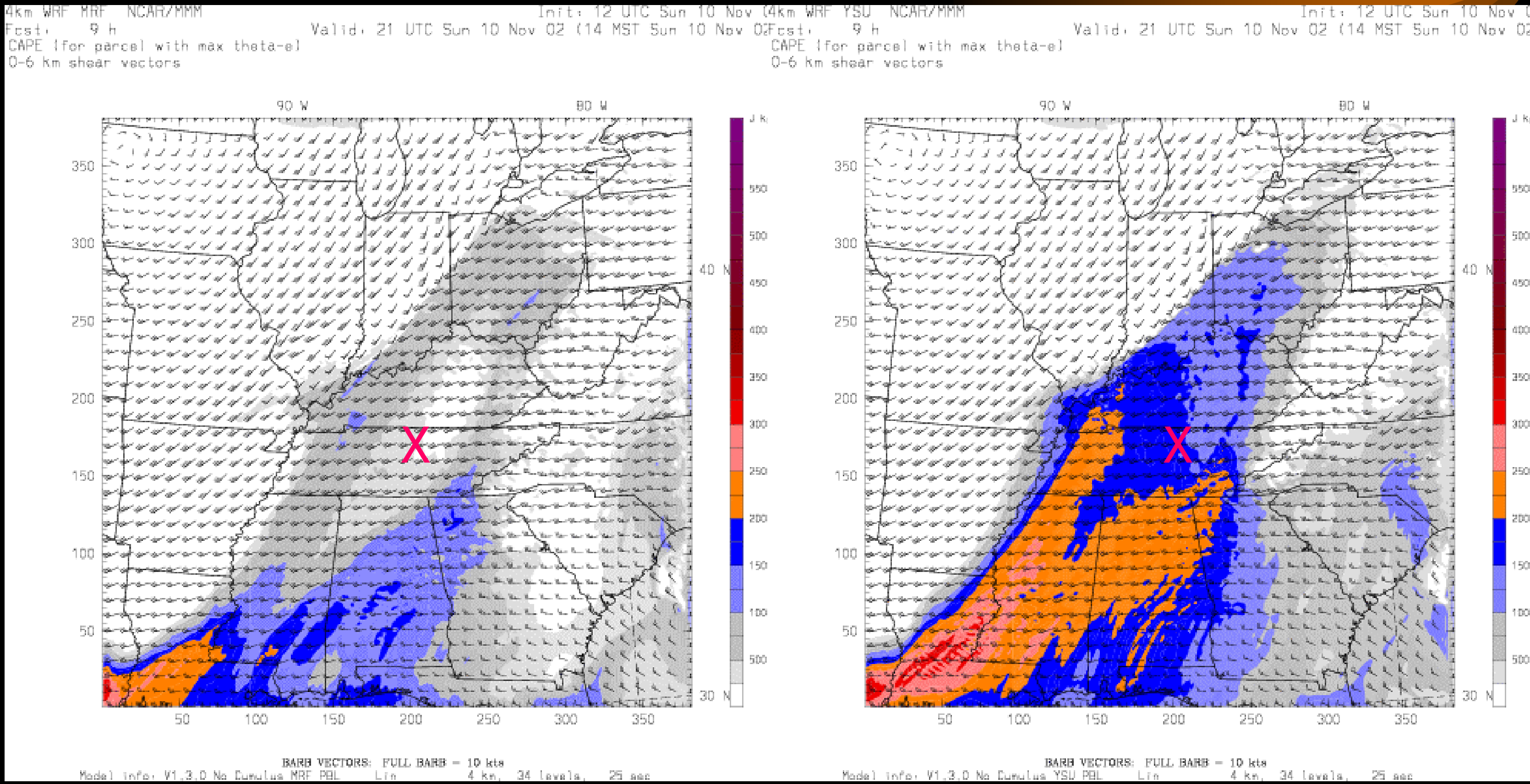
Troen and Mahrt (1986, BLM) Noh et al. (2002,BLM)

Cold front (10-11 Nov 2002)

- 4 km grid (cloud-resolving)
- YSU PBL compared to MRF PBL
- Showing how different pre-frontal soundings affect frontal convection

21Z 10 Nov 2002 CAPE

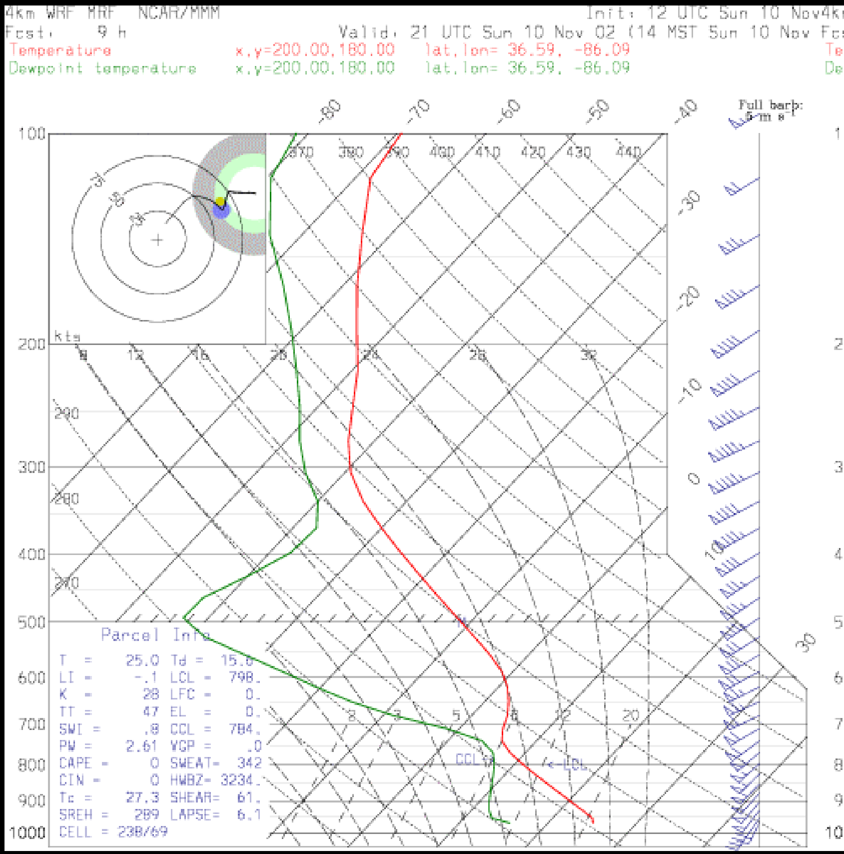
MRF YSU

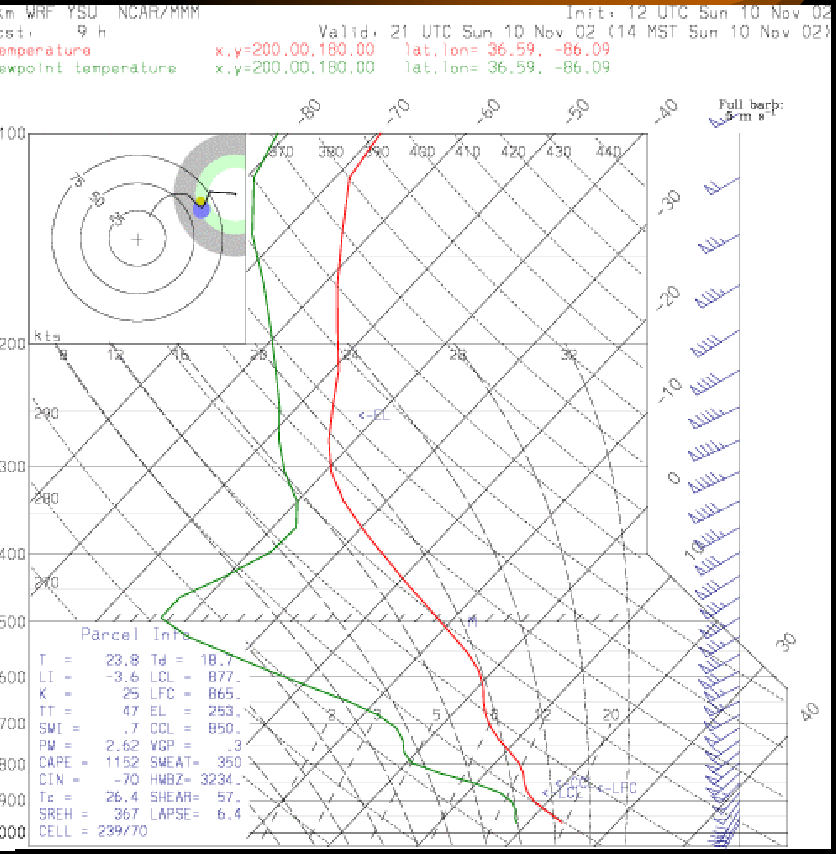


21Z 10 Nov 2002 Sounding

MRF

YSU

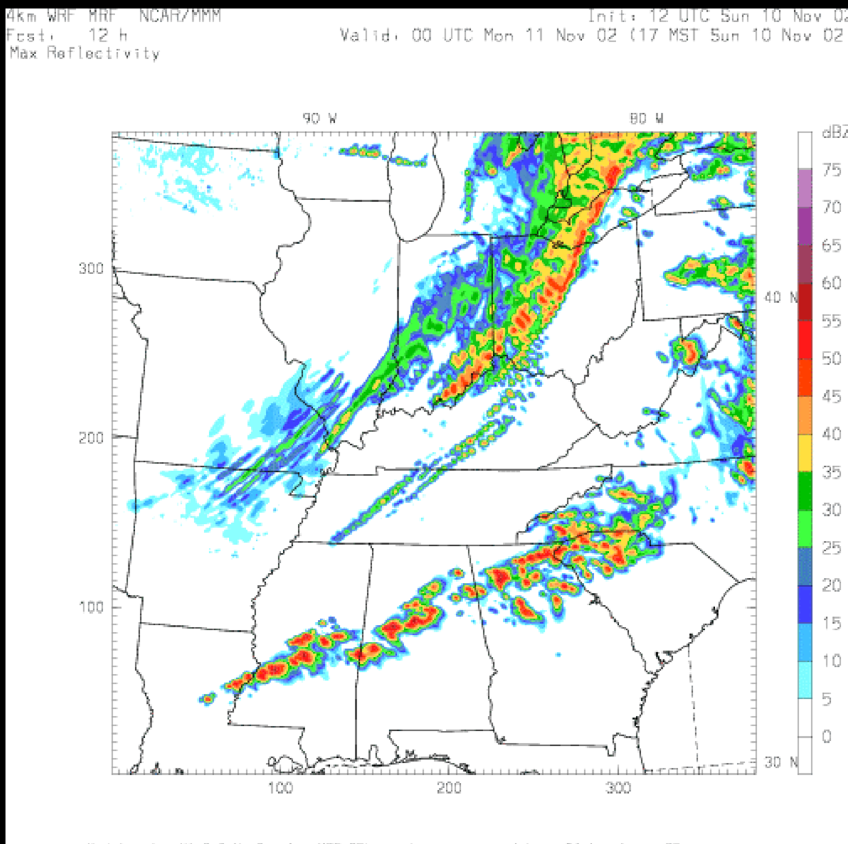


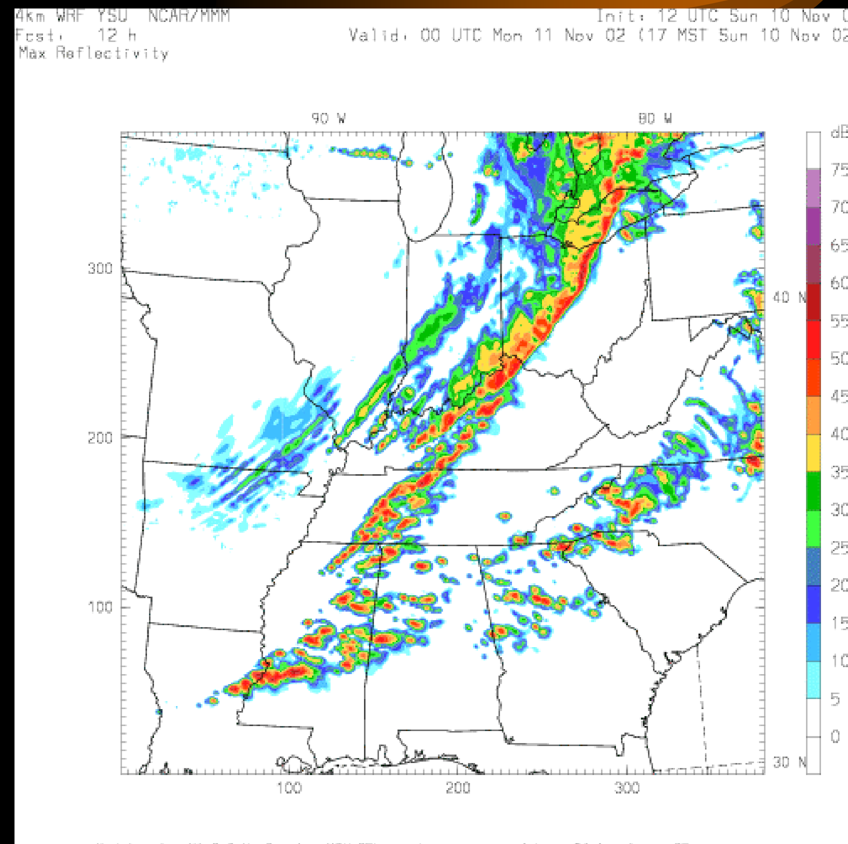


00Z 11 Nov 2002 Reflectivity

MRF

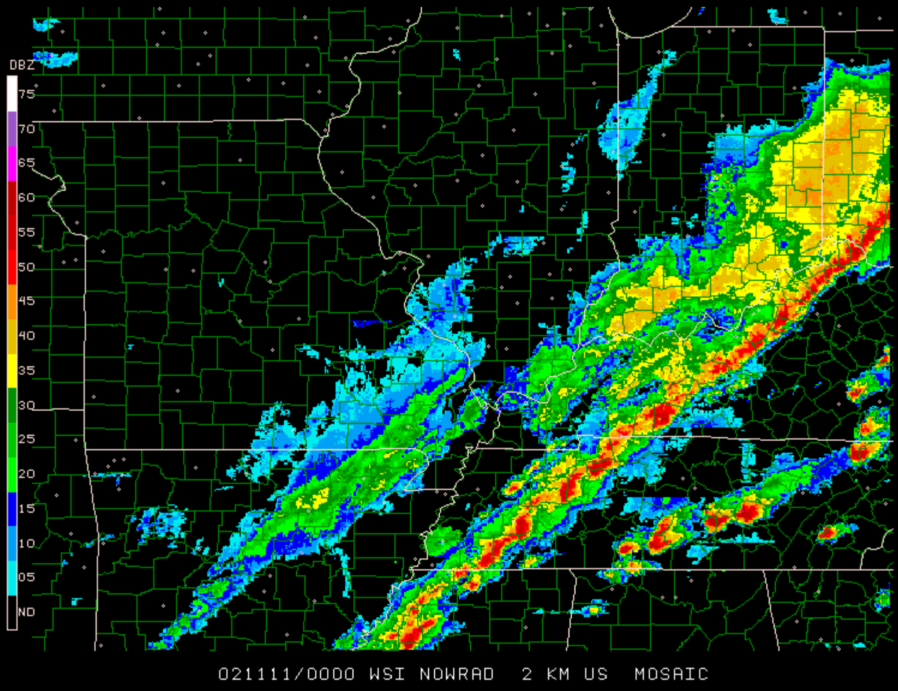
YSU



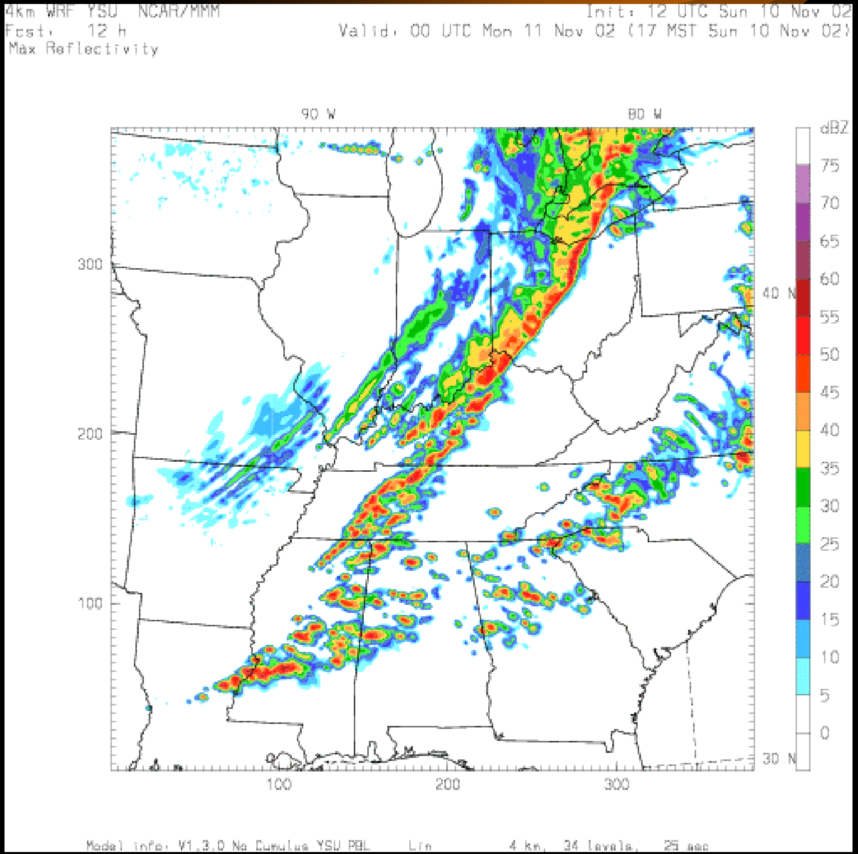


00Z 11 Nov 2002 Reflectivity

Radar



YSU



Summary
New Options in Version 2

- Grell-Devenyi Ensemble Cumulus Scheme
- WRF Single-Moment Microphysics (3, 5, 6-class options)
- Noah Land Surface Model
- RUC Land Surface Model
- Yonsei University Planetary Boundary Layer Scheme