HWRF physics packages

2016 Hurricane WRF Tutorial
Jan 2016 College Park, MD

Presented by Weiguo Wang
EMC/NCEP/NOAA
http://www.dtcenter.org/HurrWRF/users/docs/users_guide/HWRF_v3.7a_UG.pdf

Outline

- Overview of HWRF parameterizations
- Land surface model
- Surface layer physics
- Planetary Boundary Layer (PBL)
- Convection
- Microphysics
- Radiation
- Plan for 2016 operational HWRF upgrades

Overview

1. At the initial operational implementation in 2007, HWRF physics suite was closely following as GFDL hurricane model physics.

2. Roots of HWRF physics packages (3.7a)
    NCEP GFS (PBL, convection, RRTMG)
    NCEP mesoscale, ETA/NMMB (microphysics)
    GFDL (surface physics)
    WRF (LSM, cloud fraction)
    …
    Some modified for the tropical environment.

Thermodynamic equation

Tendency

Dynamics

Physics

$$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} + \frac{P}{R}\omega\sigma + FT + \frac{\check{Q}}{C_P}$$

Time tendency

horizontal advection

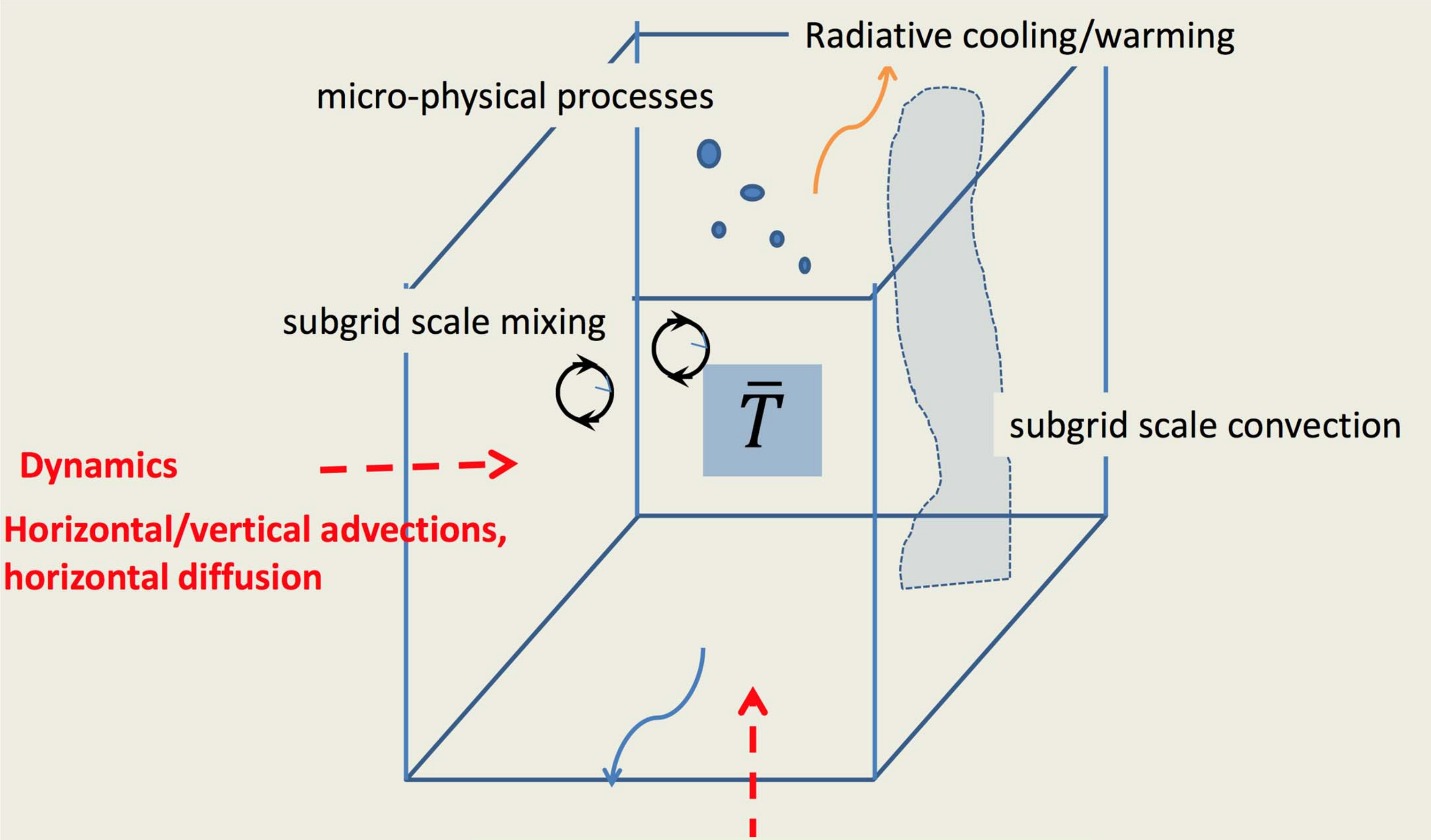
vertical advec. + adiabatic heating

H. diffusion

diabatic heating

where, $\sigma = -\left[\frac{RT}{P\theta}\right]\frac{\partial\theta}{\partial p}$

Diabatic heating: phase change of water – convection, microphysics
Radiative processes – radiation
Subgrid vertical mixing – PBL, convection
Surface fluxes – air-sea interaction, land surface



Radiative cooling/warming

micro-physical processes

subgrid scale mixing

$\bar{T}$

subgrid scale convection

Dynamics

Horizontal/vertical advections, horizontal diffusion

PBL

Surface-layer /Land/Ocean

One column

Phys in 2015 operational HWRF

Scheme	Description
Land model	Community Noah land surface model (LSM)
Surface layer	M-O similarity, GFDL based code, cd, ch match obs.
PBL	GFS PBL + modification of K and Ric #
Convection	Simplified Arakawa-Schubert scheme with modifications #
Microphysics	Ferrier-Aligo scheme for high resolution model#
Radiation	RRTMG, partial cloudiness

#: planned upgrade for 2016

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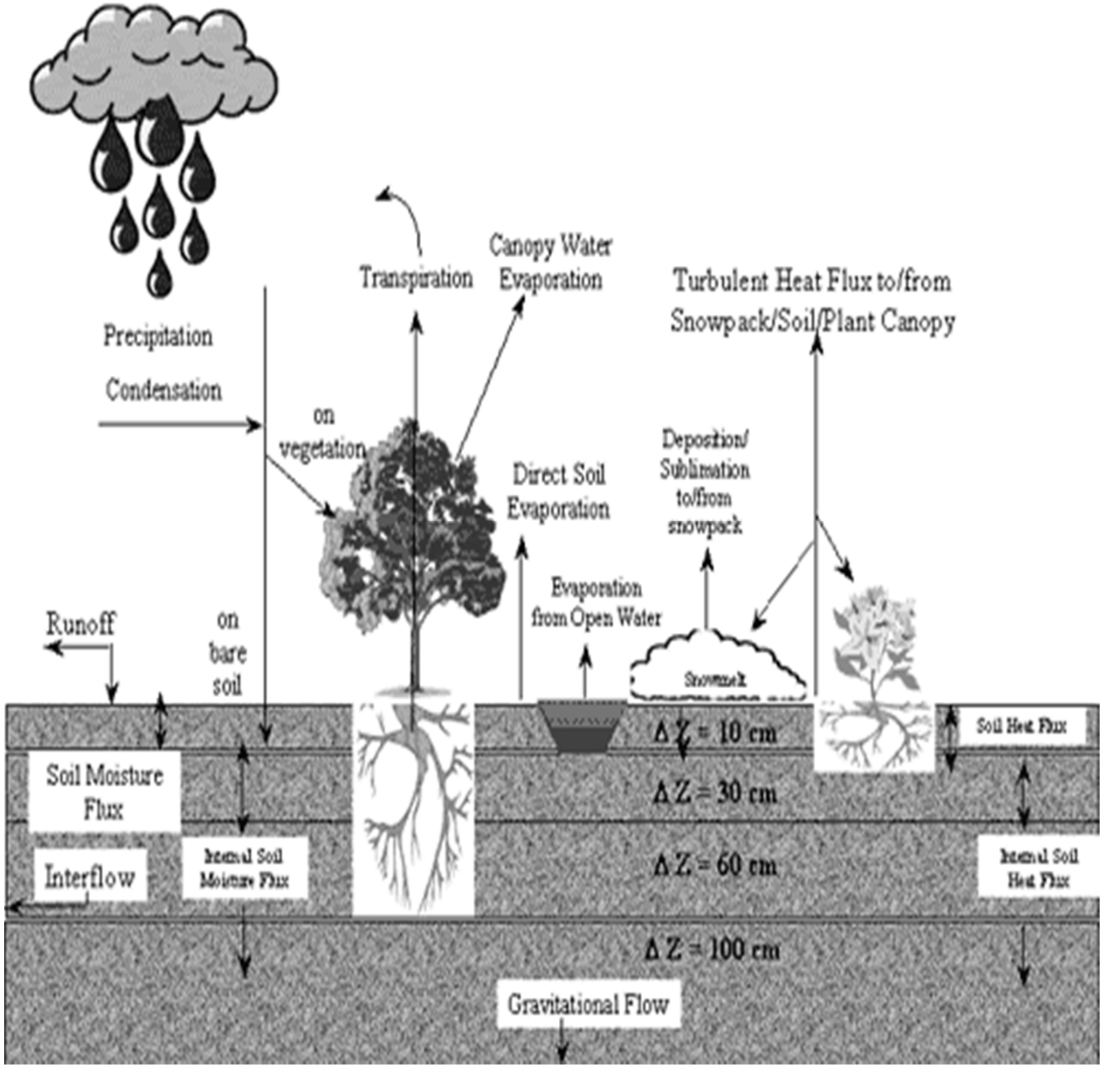
Land surface model (LSM)

- **Why?** To provide heat and moisture fluxes over land points and sea-ice points. These serve as a lower boundary condition for the vertical transport done in the PBL schemes

- **How?** By using atmospheric information from the surface-layer scheme, radiative forcing from the radiation scheme, and precipitation forcing from the microphysics and convective schemes, in combination with layers of the soil and handle vegetation, root, and canopy effects and surface snow-cover prediction.

Noah LSM

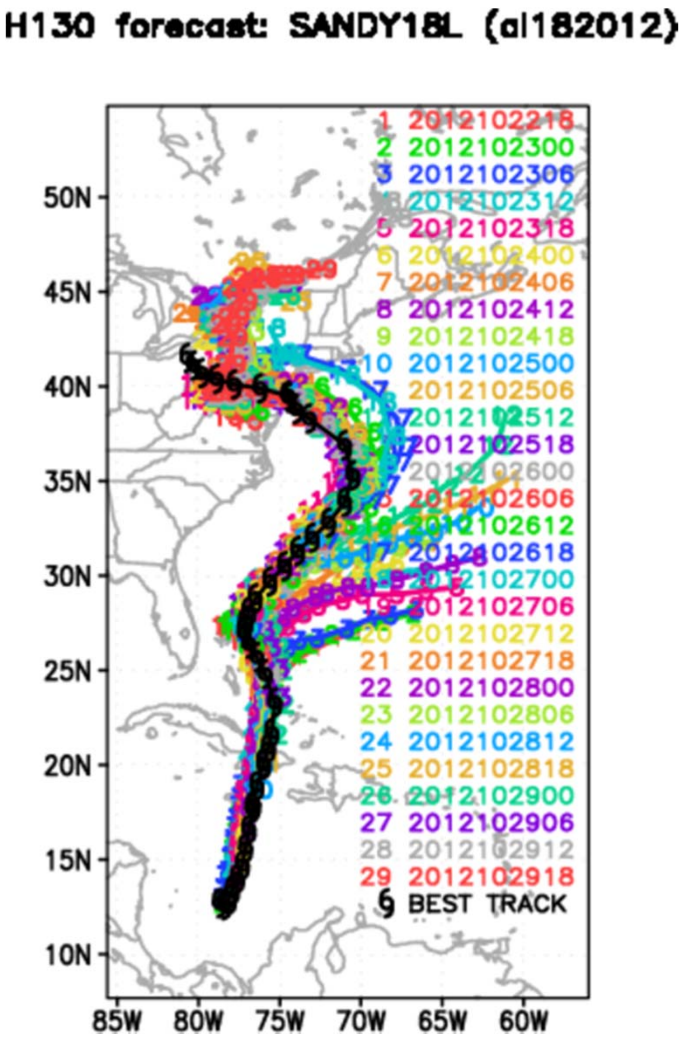


http://www.ral.ucar.edu/research/land/technology/lsm.php

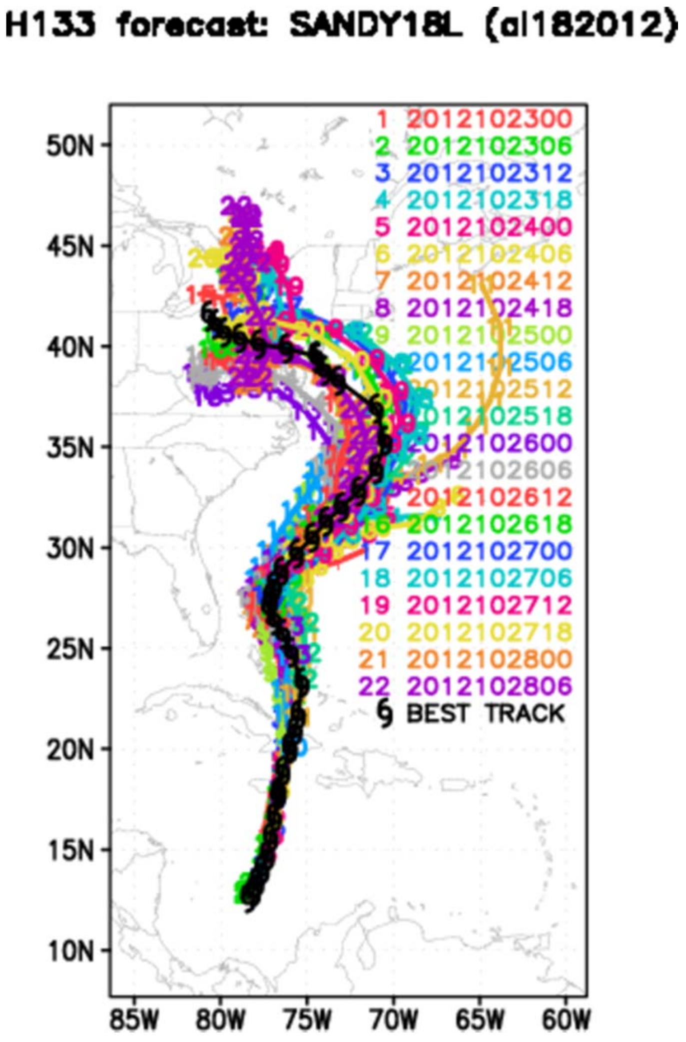
- NCEP/NCAR, Universities
- 1 canopy layer, 4-layer soil
- Prognostic variables:
  - Moisture and temperature in the soil layers
  - Water stored on the canopy
  - Snow stored on the ground.
- It Includes root zone, evapotranspiration, soil drainage, and runoff, taking into account vegetation categories, monthly vegetation fraction, and soil texture.
- Many potential downstream applications with HWRF
- Used by HWRF since 2015

SANDY 18L 2012

HWRF + slab land model



HWRF + NOAH LSM



Slab model: cold bias of TSK; NOAH LSM improved TSK & track simulations

LSM in Namelist

```
&physics
….
  num_soil_layers = 4,
 sf_surface_physics = 2, 2, 2,
….
```

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Surface-layer physics

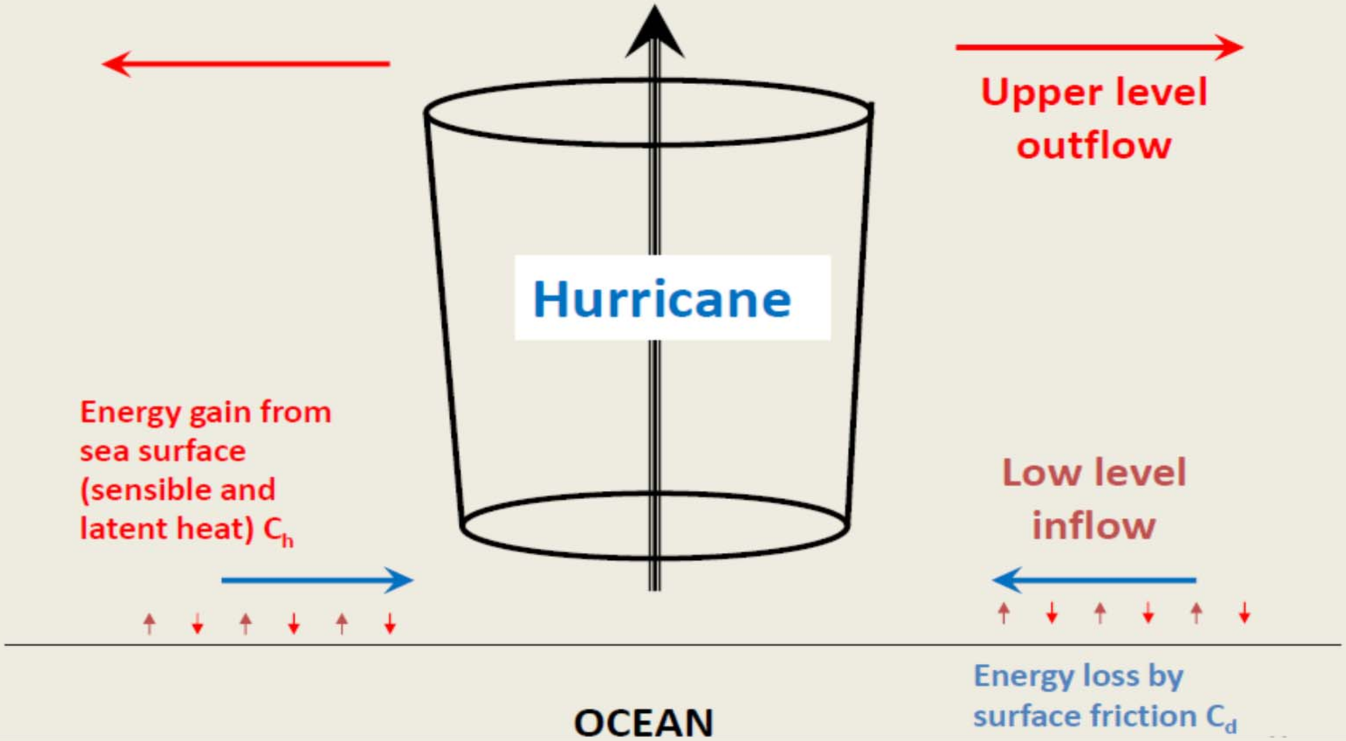
- **Why/what?** calculating stability functions, velocity scales (u_*, w_*…), exchange coefficients, and surface fluxes

- **How?** Monin-Obkuhov similarity theory

Note: provide no tendencies, only the stability-dependent information

Air-sea interactions

Hurricane intensity is proportional to sqrt(Ch/Cd) over ocean – Emanuel(1995)



Upper level outflow

Hurricane

Energy gain from sea surface (sensible and latent heat) C_h

Low level inflow

Energy loss by surface friction C_d

OCEAN

Because main energy sources and sinks of tropical cyclones are sensible/latent heat fluxes over warm ocean and momentum flux (dissipation) over land, the determination of surface fluxes plays a critical role in predicting accurate hurricane intensity.

$$H_o = \rho C_P C_h |V| (\theta_S - \theta_a)$$

$$L_o = \rho L C_h |V| (Q_s - Q_a)$$

$$\vec{\tau_o} = \rho C_d |V| \vec{V}$$

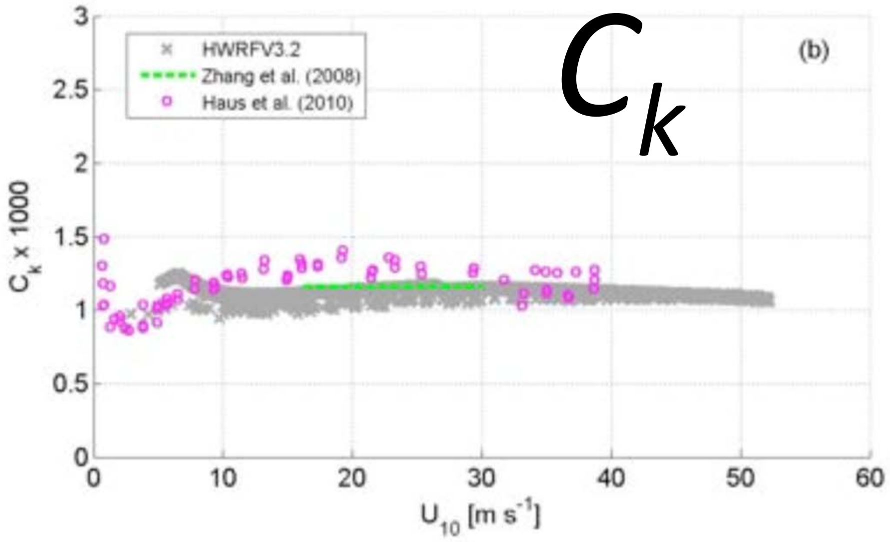
The air-sea flux calculations use a bulk parameterization based on the Monin-Obukhov similarity theory

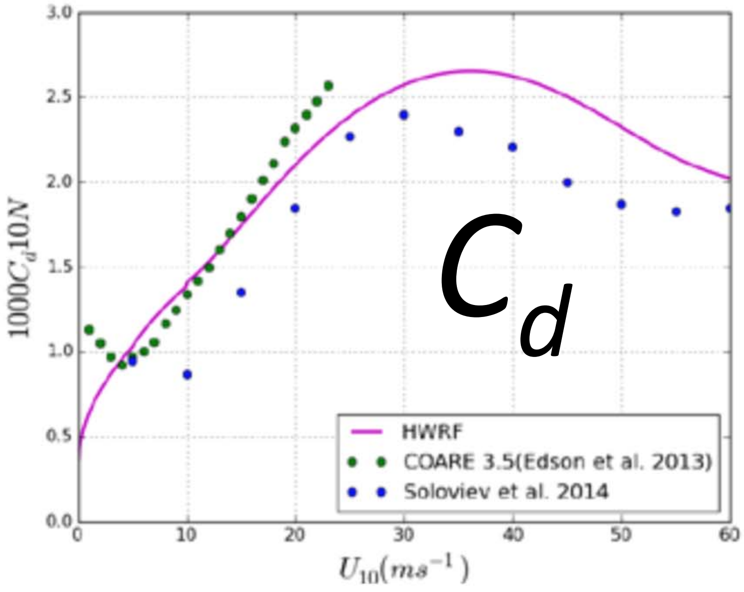
Surface layer parameterization

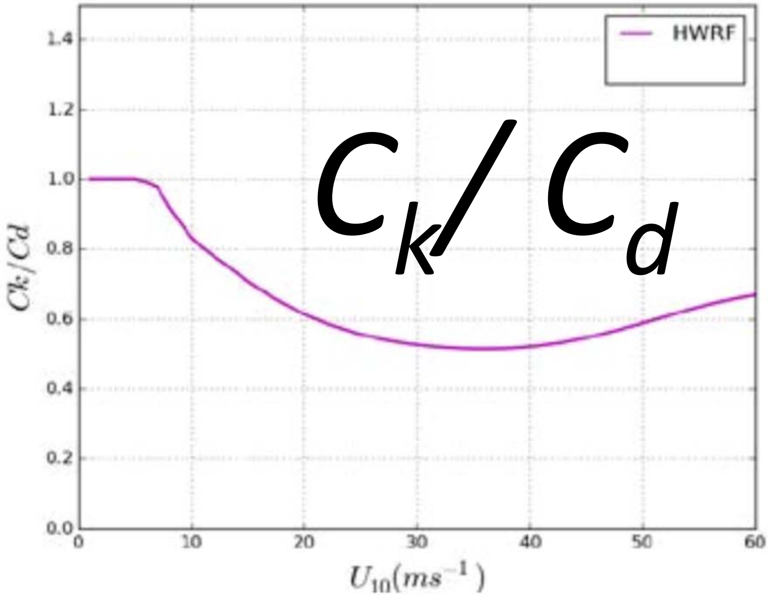
$$C_d = \kappa^2 \left(\ln \frac{z_m}{z_0} \right)^{-2}$$

$$C_k = \kappa^2 \left(\ln \frac{z_m}{z_0} \right)^{-1} \left(\ln \frac{z_T}{z_O} \right)^{-1}$$

HWRF specifies z0 as a function of wind to match obs Cd and Ck







Surface-layer in Namelist

```
&physics
....
sf_sfclay_physics = 88, 88, 88,
icoef_sf = 2, 2, 2,
lcurr_sf = F, F, F,
....
```

GFDL sfc

Choose different Cd, Ck

For ocean, future

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Planetary boundary layer (PBL) parameterization

- **Why?** To represent the mixing effects of eddies too small to be solved by the dynamical core

- **How?** It determines flux profiles and provides atmospheric tendencies (in the entire atmospheric column) of: temperature, moisture (including clouds) Horizontal momentum

$$\frac{\partial \Phi}{\partial t} = -\frac{\partial \overline{w'\phi'}}{\partial z}$$

$$\overline{w'\phi'} = -K\frac{\partial \overline{\phi}}{\partial z} + K\gamma \longleftarrow$$

Counter-gradient term

$$\overline{w'\phi'} = local\ \ flux + non\ \ local\ \ flux$$

Turbulent eddy diffusivity , *K*

$$K = l^2 f(Ri)\left|\frac{\partial \bar{u}}{\partial z}\right|$$

Stable conditions,
or above PBL top

$$K = \kappa\left(\frac{u_*}{\Phi_m}\right)\left[\alpha\left(1-\frac{z}{h}\right)^2\right]$$

Unstable conditions
below PBL top
α: *K adjustment coef*

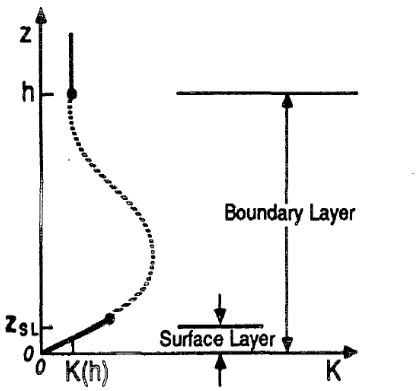


FIG. 1. Typical variation of eddy viscosity *K* with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

nd Pan (1996)

$$h = Ri_C \frac{\theta_{VS} U^2(h)}{g(\theta_V(h)-\theta_S)}$$

PBL height depends on Ri_c, wind, θ_V , and θ_s at ground and PBL top

$$Ri_c = 0.16\left(10^{-7} R_O\right)$$

Critical Richardson number a function of the local Rossby Number

$$R_O = \left(\frac{U_{10}}{f z_O}\right)$$

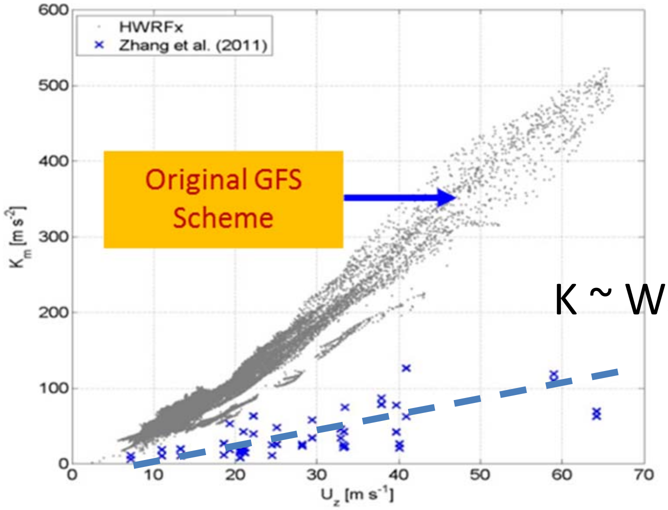
Rossby number depends on 10-m speed and roughness length

K adjustment

<u>Issue:</u> Eddy diffusivity from regular GFS PBL scheme was too large.

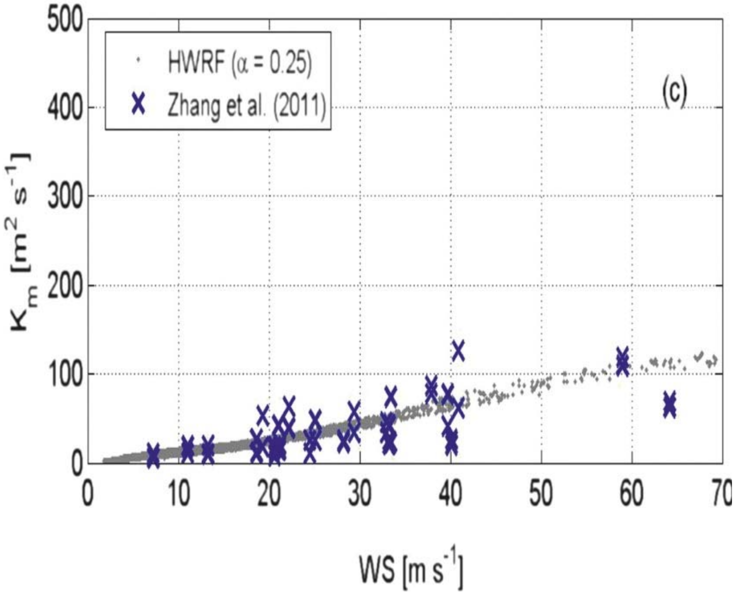
<u>Solutions:</u>

- <u>Upgrade for 2013 operational HWRF:</u> introduce a variable (α) to modulate K (Gapal et al, 2012, 2013)
- <u>Upgrade for 2014 operational HWRF:</u> make critical Richardson number dependent on Rossby number when computing PBL height
- <u>Upgrade for 2015 operational HWRF:</u> set upper boundary for K at ~ 500m to WindSpeed/0.6 (Fovell et al, 2015)



K ~ WS/0.6

Gopal et al. 2012;2013



PBL in Namelist

```
&physics
....
bl_pbl_physics = 3, 3, 3,
var_ric = 1.0,                            1: Use variable Ric# for h; 0:no
coef_ric_l = 0.16,                        Coefficient of Ric# : land point
coef_ric_s = 0.25,                        Coefficient of Ric# : sea point
gfs_alpha = -1.0, -1.0, -1.0,             K adjustment.
                                            alpha=abs(gfs_alpha)
....                                        <0,  Use ws/0.6 method
                                            >0,   Use a constant alpha
```

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Convective parameterization

(also referred to as cumulus parameterization scheme)

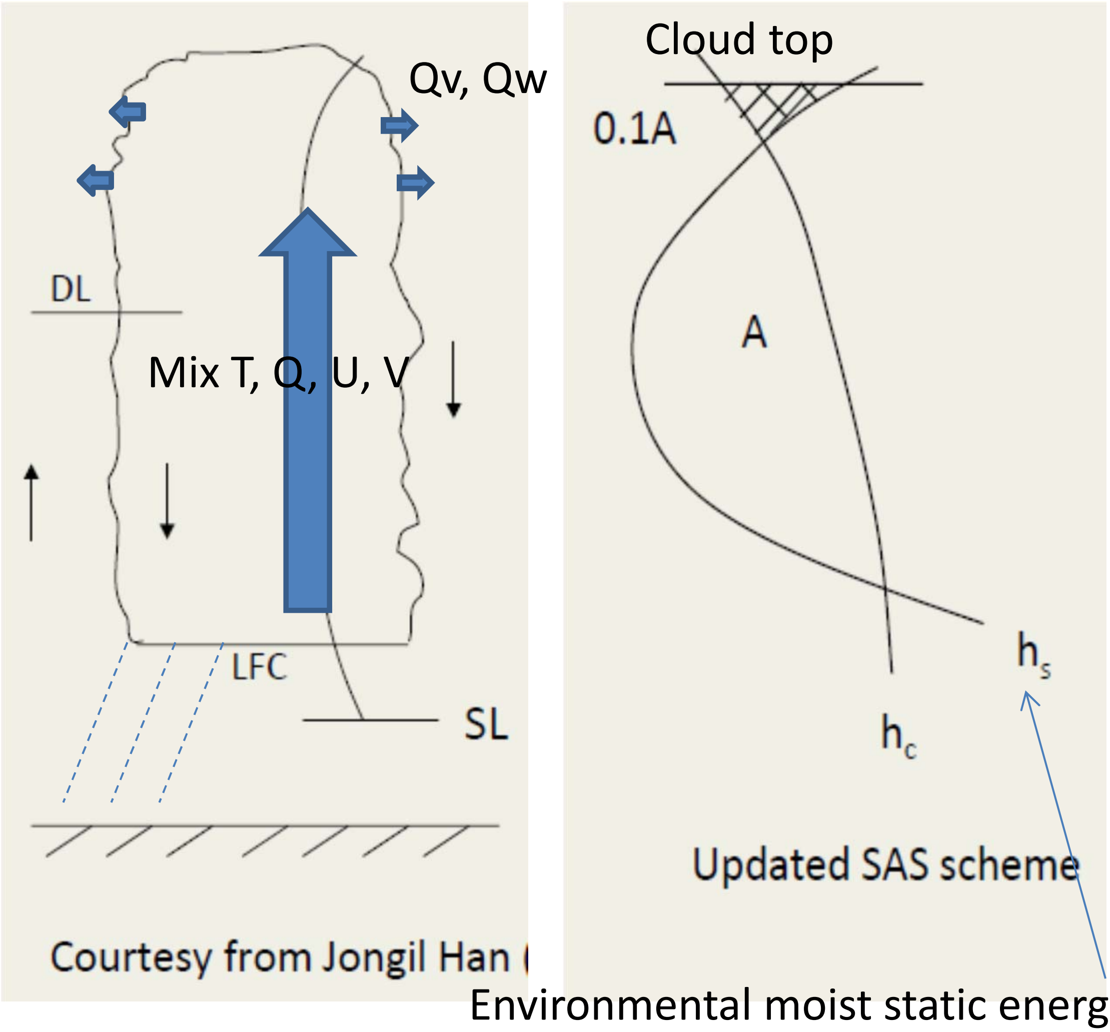
- **Why?** To represent the convection too small to be resolved explicitly given the grid spacing. Convection has the effect of reducing the thermodynamic instability

- **How?** Mass flux scheme

  Vertically transporting:

  - Heat
  - Momentum
  - Moisture

Simplified AS (SAS)



- Arakawa and Schubert (1974) and simplified by Grell (1993)
- Also used in the GFS and GFDL models

Features

- Cloud size << grid size
- One cloud top
- Deep: thickness>150hpa; shallow: < 150
- Triggered when cloud-work function (~CAPE) > threshold
- T, Q adjusted, mass flux method
- Simple microphysics, evaporation, detrain condensation/vapor
- Momentum mixing

CU in Namelist

```
&physics
....
cu_physics = 84, 84, 0,
mommix = 1.0, 1.0, 1.0,
ncnvc = 2, 6, 6,
sas_pgcon = 0.55, 0.2, 0.2,
sas_mass_flux = 0.5, 0.5, 0.5,
....
```

No convection used in D03

Fraction of momentum mixing

Calling frequency, time steps

Convectively forced pressure gradient.

Mass flux limit

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Microphysics

- **Why?** To represent grid-scale microphysical processes such as
  - Aggregation, accretion, growth, precipitation, etc
  - Phase change and latent heat release due to condensation, evaporation, deposition, sublimation, freezing, melting.

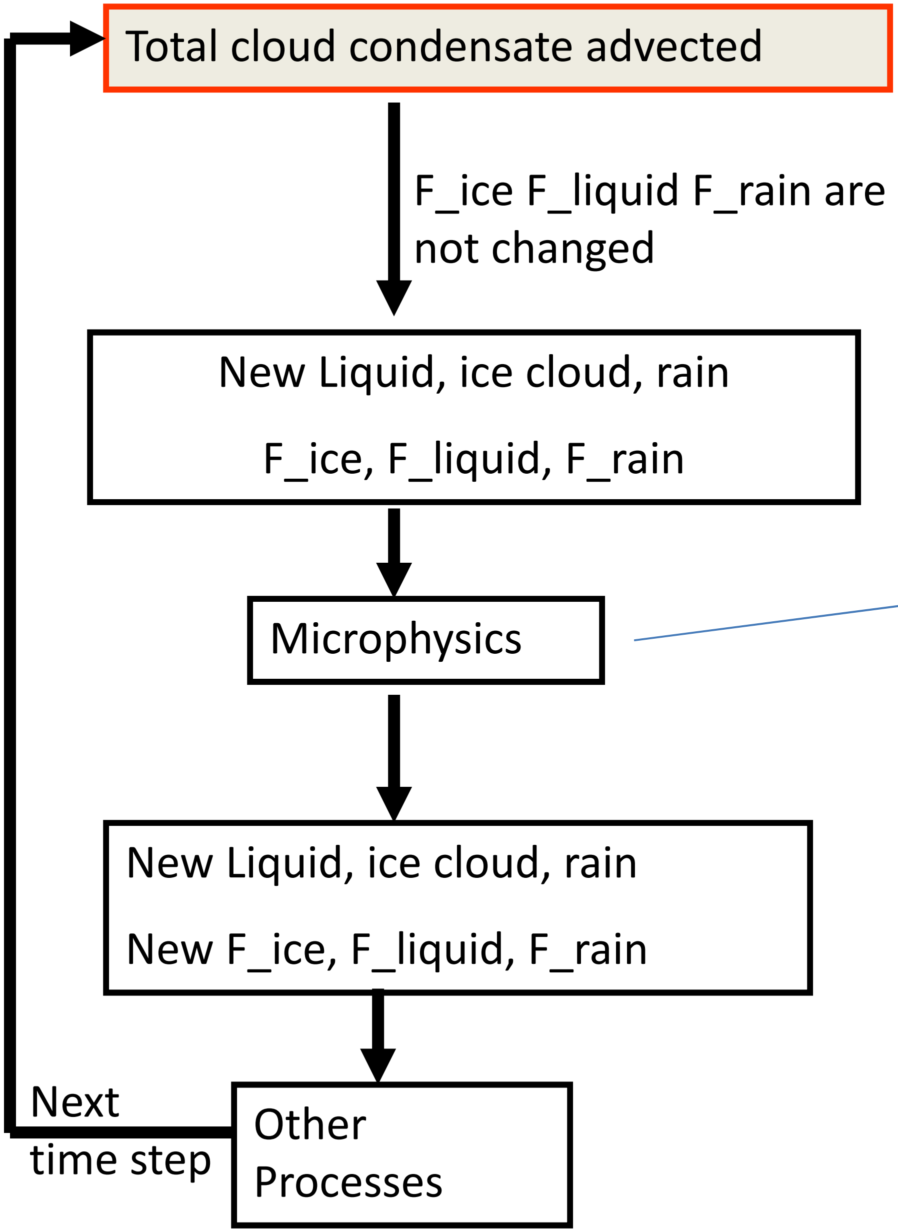
- **How?** Predicting one or more moments of the distribution of various microphyiscs species such as rain, cloud, ice

HWRF uses a single moment scheme
Ferrier-Aligo scheme (NMMB,HWRF) ,
modified from Ferrier/eta scheme

Ferrier-Aligo scheme

- Designed for efficiency
- Predicts mixing ratios; Diagnoses number concentrations
- <u>Advection only of total condensate (CWM)</u> and vapor
- Diagnostic cloud water, rain, & ice (ice/snow/graupel)
- Fractions of cloud water & ice within a column are fixed during advection
- Variable density for precipitation ice
- (snow/graupel/sleet) – “rime factor” (F_rime)
- Maximum number concentration of large ice varies in different cloud regimes. Promote supercooled liquid water.

Flow chart



Total cloud condensate advected

F_ice F_liquid F_rain are not changed

New Liquid, ice cloud, rain

F_ice, F_liquid, F_rain

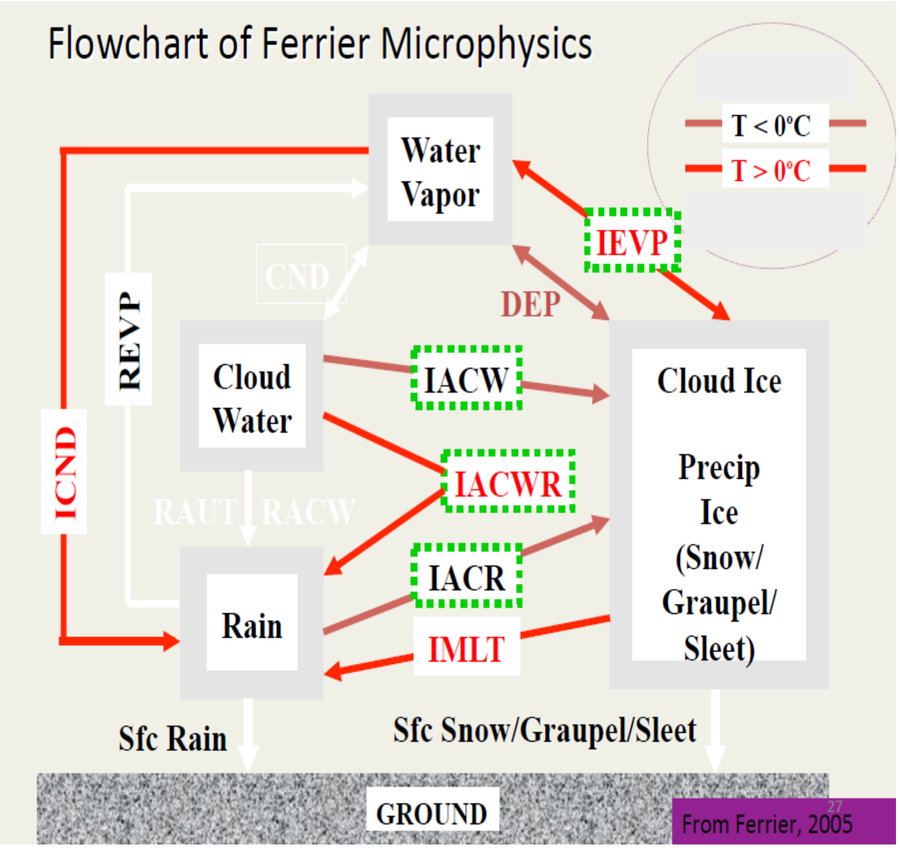
Microphysics

New Liquid, ice cloud, rain

New F_ice, F_liquid, F_rain

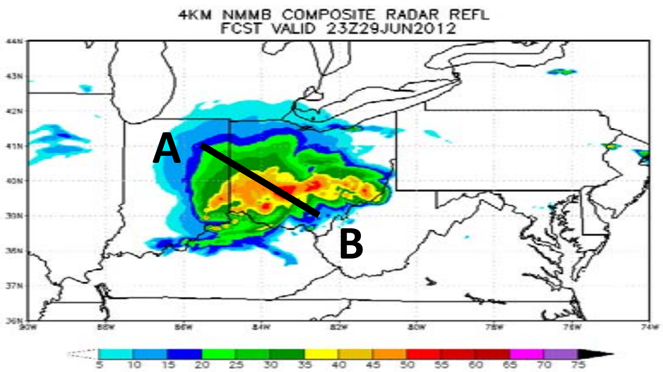
Other Processes

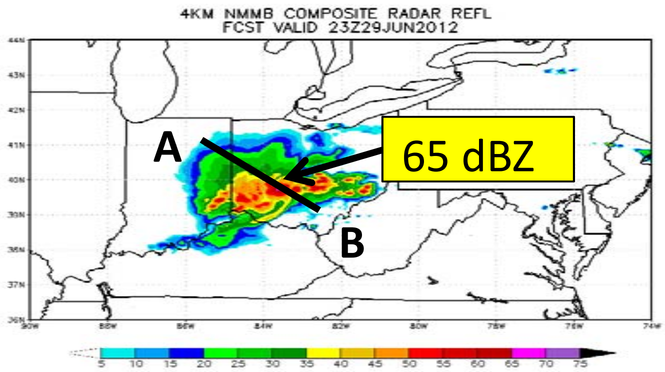
Next time step



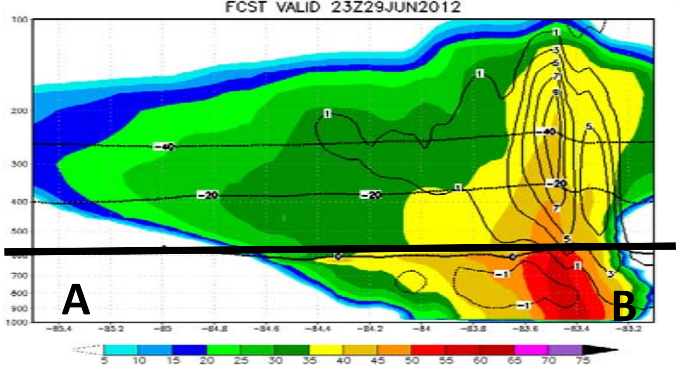
Ferrier/eta Microphysics

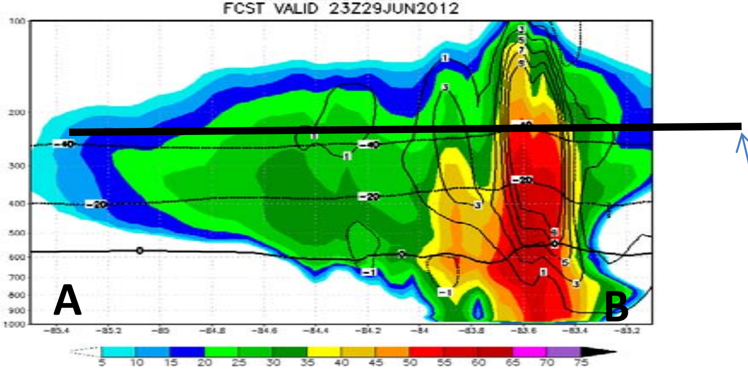
Ferrier-Aligo Microphysics





08h/23Z





50 dBZ reflectivity below 600 mb

50+ dBZ reflectivity up to
250mb

Courtesy Eric Aligo

MP in Namelist

```
&physics
....
mp_physics = 5, 5, 5,
nphs = 2, 6, 6,
....
```

Call frequency in time steps

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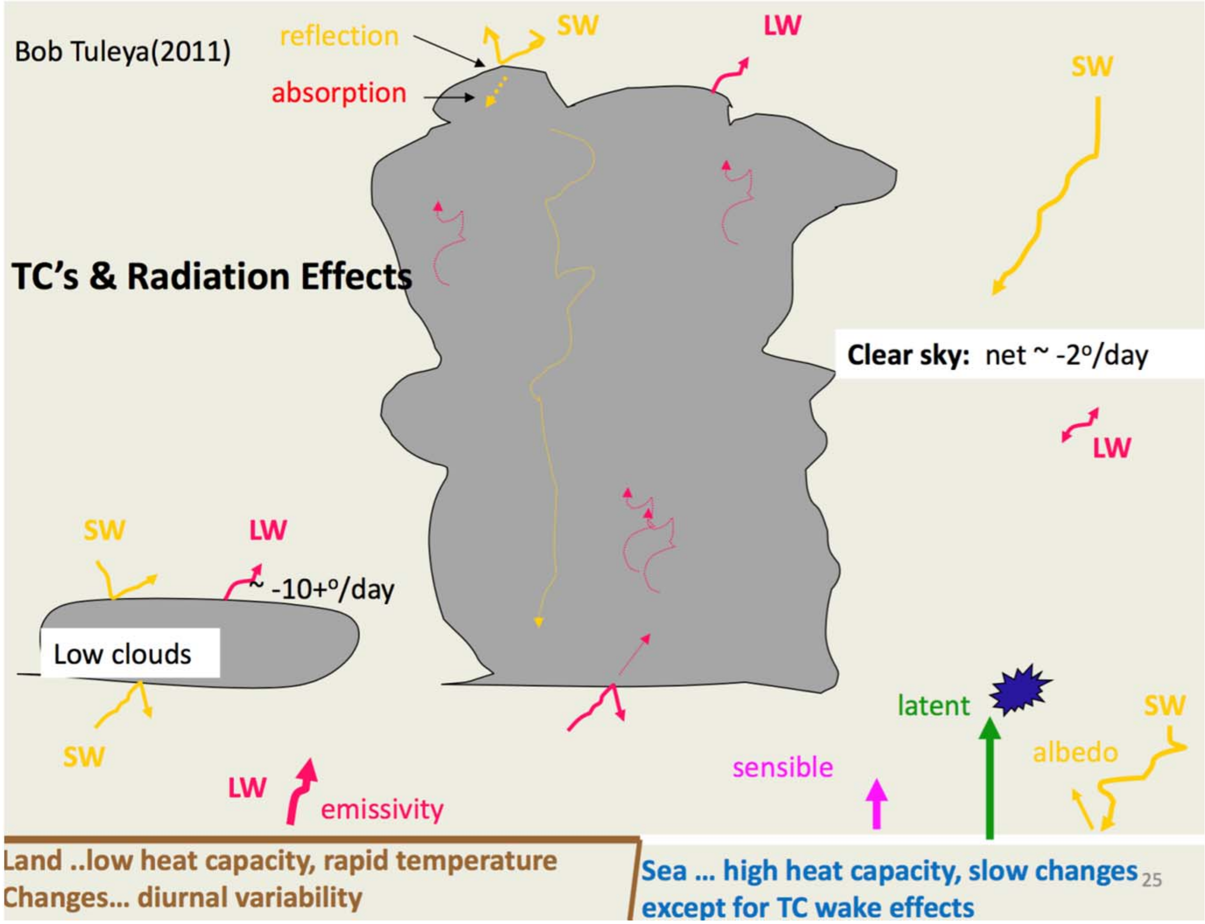
Radiation

- **Why?** To represent the heating and cooling due to short and long wave radiation



Rapid Radiative Transfer Model (RRTMG)

- Modified from RRTM (Iacono et al. 2008)
- Long wave includes absorptions of:
  - water vapor, carbon dioxide, ozone, methane, nitrous, oxide, oxygen, nitrogen, and the halocarbons
- Short wave includes absorptions of:
  - water vapor, carbon dioxide, ozone and methane
- Calculations are made over spectral bands, with:
  - longwave (16 bands)
  - shortwave (14 bands)
- Uses the Monte Carlo Independent Cloud Approximation random Overlap method to overlap clouds
- Uses a cloud fraction scheme developed by Thompson (NCAR) that represents sub-grid scale clouds
- Ice particle size depends on temperature, instead of constant (NMMB tests).

Radiation in Namelist

```
&physics
….
ra_lw_physics = 4, 4, 4,
ra_sw_physics = 4, 4, 4,
icloud = 3,                       Cloud fraction in Radiation
nrads = 30, 90, 270,              Call frequency of SW module
nradl = 30, 90, 270,              Call frequency of LW module
….
```

Full Physics Options in 2015 operational HWRF

Can be configured through “hwrf.conf”

```
&physics
  num_soil_layers = 4,
  mp_physics = 5, 5, 5,
  ra_lw_physics = 4, 4, 4,
  ra_sw_physics = 4, 4, 4,
  sf_sfclay_physics = 88, 88, 88,
  sf_surface_physics = 2, 2, 2,
  bl_pbl_physics = 3, 3, 3,
  cu_physics = 84, 84,  0,
  mommix = 1.0, 1.0, 1.0,
  var_ric = 1.0,
  coef_ric_l = 0.16,
  coef_ric_s = 0.25,
  h_diff = 1.0, 1.0, 1.0,
  gwd_opt = 2, 0, 0,
  sfenth = 0.0, 0.0, 0.0,
nrads = 30, 90, 270,
 nradl = 30, 90, 270,
 nphs = 2, 6, 6,
 ncnvc = 2, 6, 6,
 ntrack = 9, 9, 18,
```

```
gfs_alpha = -1.0, -1.0, -1.0,
 sas_pgcon = 0.55, 0.2, 0.2,
 sas_mass_flux = 0.5, 0.5, 0.5,
 co2tf = 1,
 vortex_tracker = 2, 2, 7,
 nomove_freq = 0, 6, 6,
 tg_option = 1,
 ntornado = 2, 6, 18,
 ens_cdamp = 0.2,
 ens_pblamp = 0.2,
 ens_random_seed = 99,
 ens_sasamp = 50.0,
 icloud = 3,
 icoef_sf = 2, 2, 2,
 lcurr_sf = F, F, F,
 pert_cd = F,
 pert_pbl = F,
 pert_sas = F,
```

Other options

Limited tested:

- Convection schemes: Tiedtke, NSAS, KF, etc, tested by DTC
- Radiation: GFDL
- PBL: MYJ
- LSM: slab
- Surface layer: eta similarity
- Microphysics: Thompson, WSM6, Ferrier

Plan for 2016 upgrades

☐ GFS PBL EDMF scheme

☐ Scale-aware /Aerosol-aware SAS scheme

☐ Advection of Ferrier MP species.

☐ Thompson MP being tested.

GFS PBL EDMF

- Latest version GFS PBL

$$\overline{w'\phi'} = local\ flux + non\ local\ flux$$

HWRF 2015

Counter-gradient method to represent nonlocal flux

$$\overline{w'\phi'} = -K\left(\frac{\partial\overline{\phi}}{\partial z} - \gamma\right)$$

TKE based
dissipation heating

HWRF 2016

$$\overline{w'\phi'} = -K\frac{\partial\overline{\phi}}{\partial z} + M(\phi_u - \overline{\phi})$$

Local Eddy **Mass Flux**

Scale-aware SAS

- For cumulus convection, a scale-aware parameterization will be necessary for the grid sizes of 500m ~ 10 km where the strong updrafts are partially resolved.

$$m_b' = (1-\sigma_u)^2 m_b$$

Scale function

Based on Arakawa & Wu (2013): $\overline{w'\psi'} = (1-\sigma_u)^2 \left(\overline{w'\psi'}\right)_E$

σ_u: updraft area fraction (0~1.0)

m_b : original cloud base mass flux from AS quasi-equilibrium closure

m_b' : updated cloud base mass flux with a finite σ_u

Thanks!