HWRF physics parameterizations

2018 Hurricane WRF Tutorial
Jan 2018 College Park, MD

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EMC/NCEP/NOAA
https://dtcenter.org/HurrWRF/users/docs/scientific_documents/HWRFv3.9a_ScientificDoc.pdf

Outline

- Overview of HWRF parameterizations
- Land surface[#]
- Surface layer
- Planetary Boundary Layer (PBL)
- Convection
- Microphysics
- Radiation

[#]land is included in atmospheric parameterization, while ocean is treated by a separate ocean model.

Overview

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

2. Roots of HWRF physics parameterizations

NCEP GFS (PBL, convection, radiation)
NCEP mesoscale, ETA/NMMB (microphysics)
GFDL (surface physics)
WRF (LSM, cloud fraction)
…
Some were modified for the tropical environment.

Thermodynamic equation

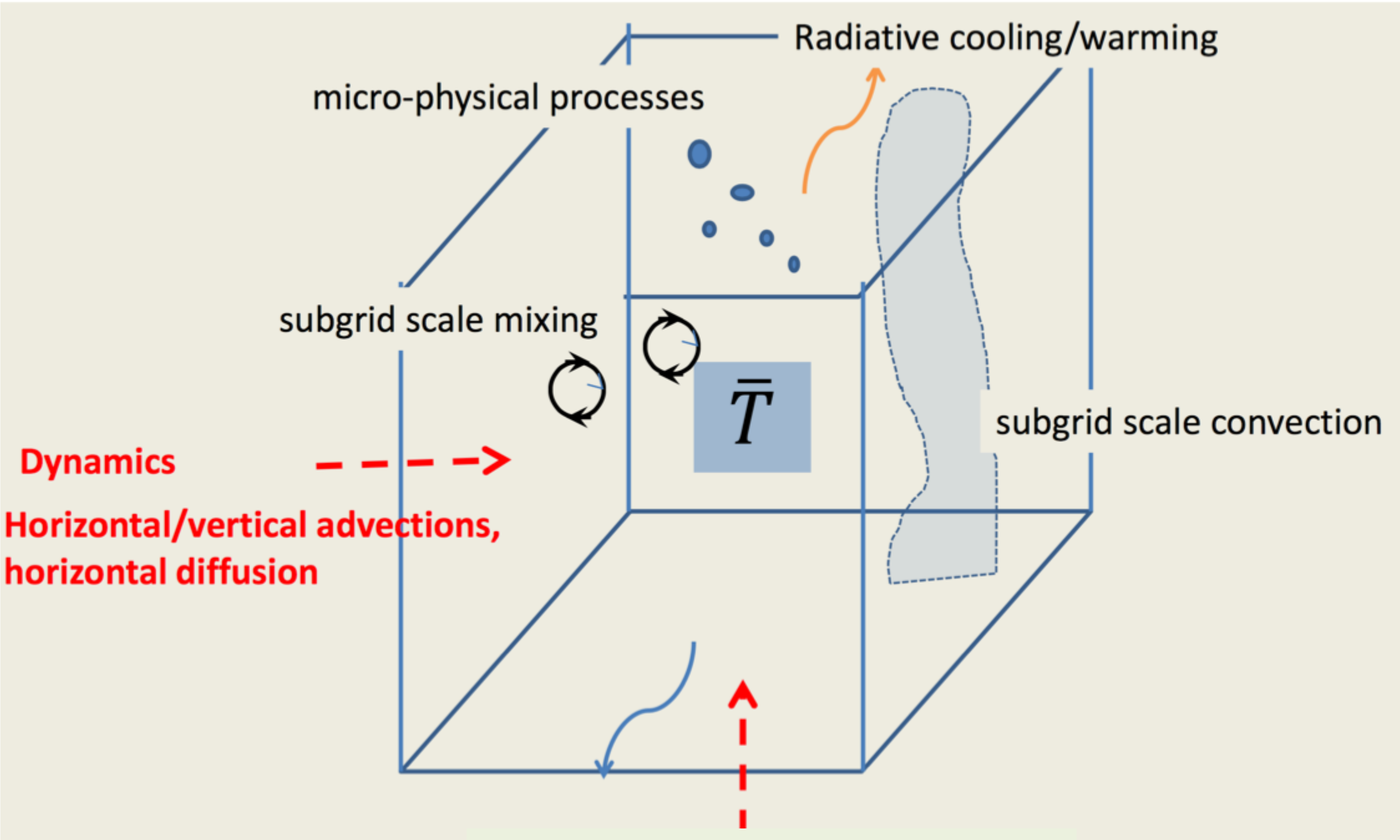
Dynamics | Physics | Tendency

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

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



PBL
Surface-layer /Land/Ocean

One column

Phys in 2017 operational HWRF

Scheme	Description
Land model	Community Noah land surface model (LSM)
Surface layer	Monin-Obukhov similarity, modified from GFDL model, C_d, C_h match obs.
PBL	GFS eddy-diffusivity and mass flux (EDMF)
Convection	Scale-aware Simplified Arakawa-Schubert (SAS)
Microphysics	Ferrier-Aligo
Radiation	RRTMG, partial cloudiness

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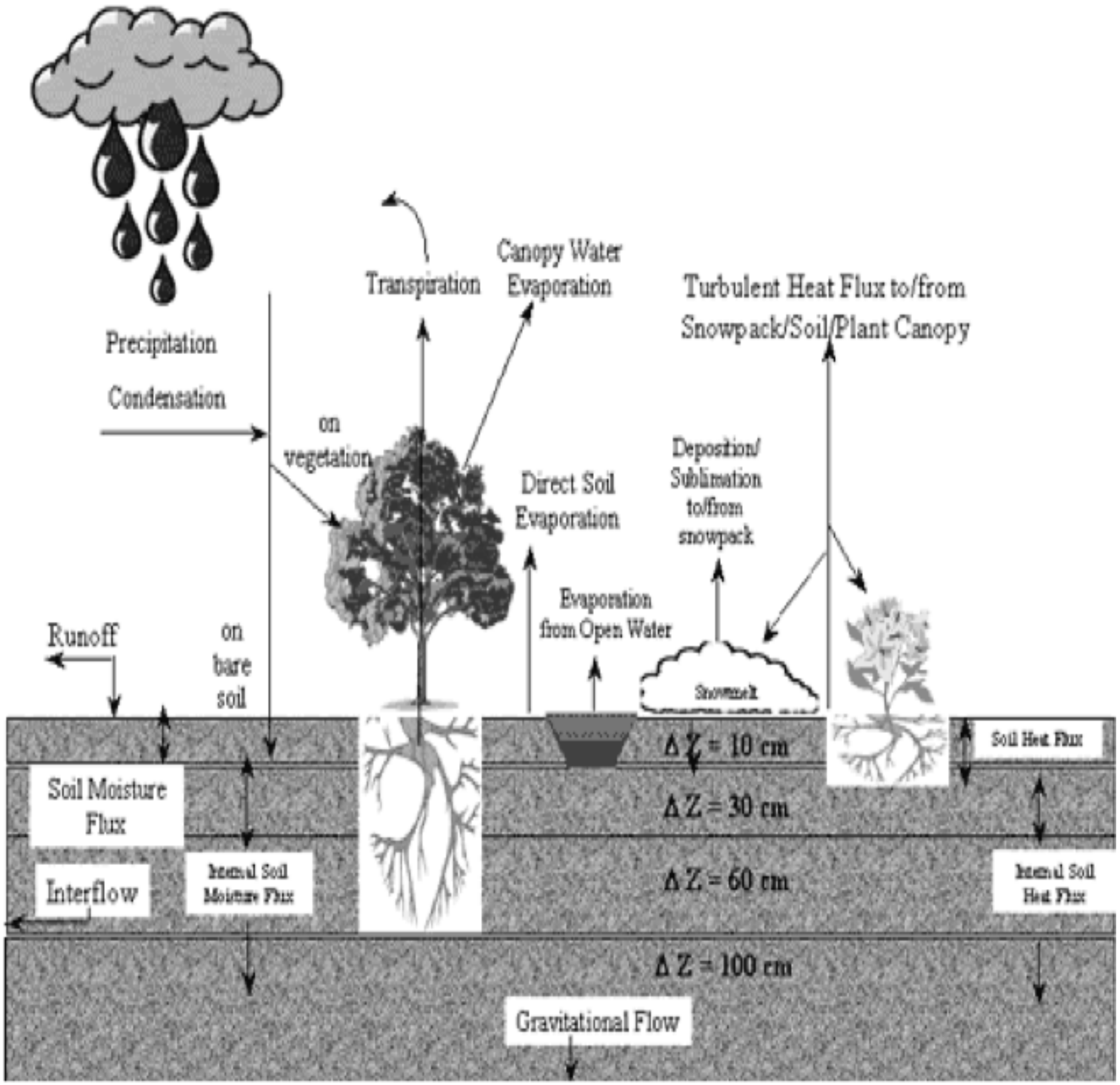
Land surface model (LSM)

- **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?** Atmospheric information from the surface-layer scheme, **radiative forcing** from the radiation scheme, and **precipitation** forcing from the microphysics and convective schemes, are used in combination with land information about the soil, vegetation, canopy effects, and surface snow-cover prediction to compute surface temperature (TSK) and other variables.

Noah LSM

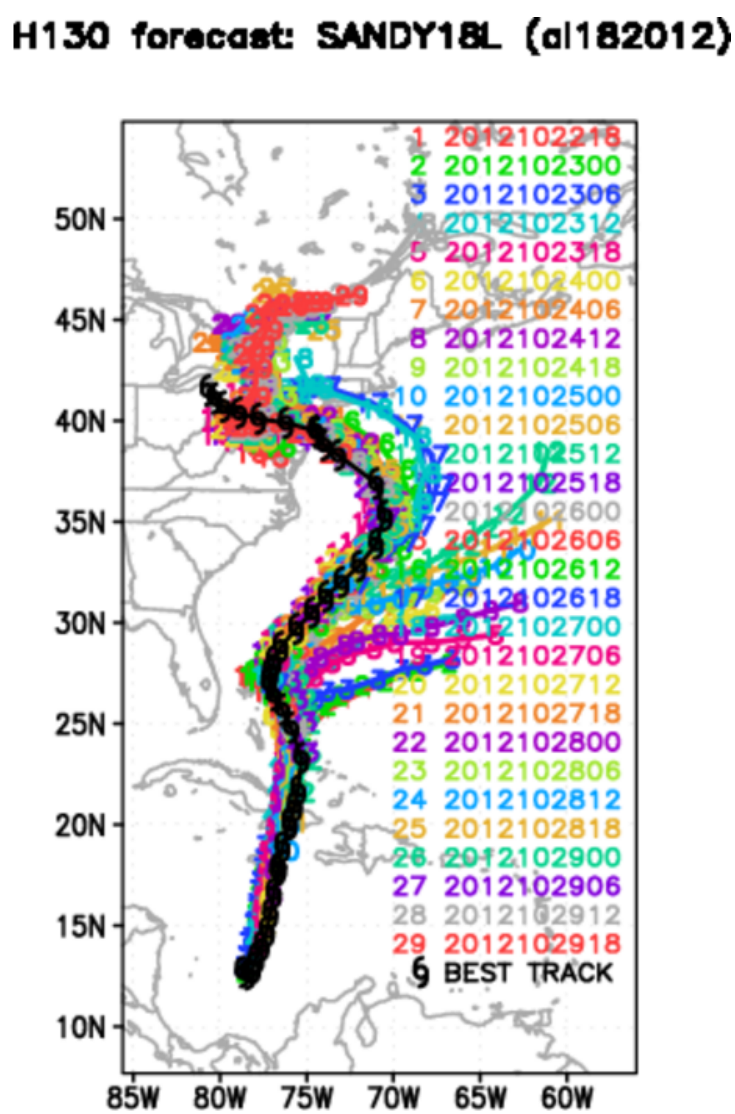


http://www.ral.ucar.edu/research/land/technology/lsm.php

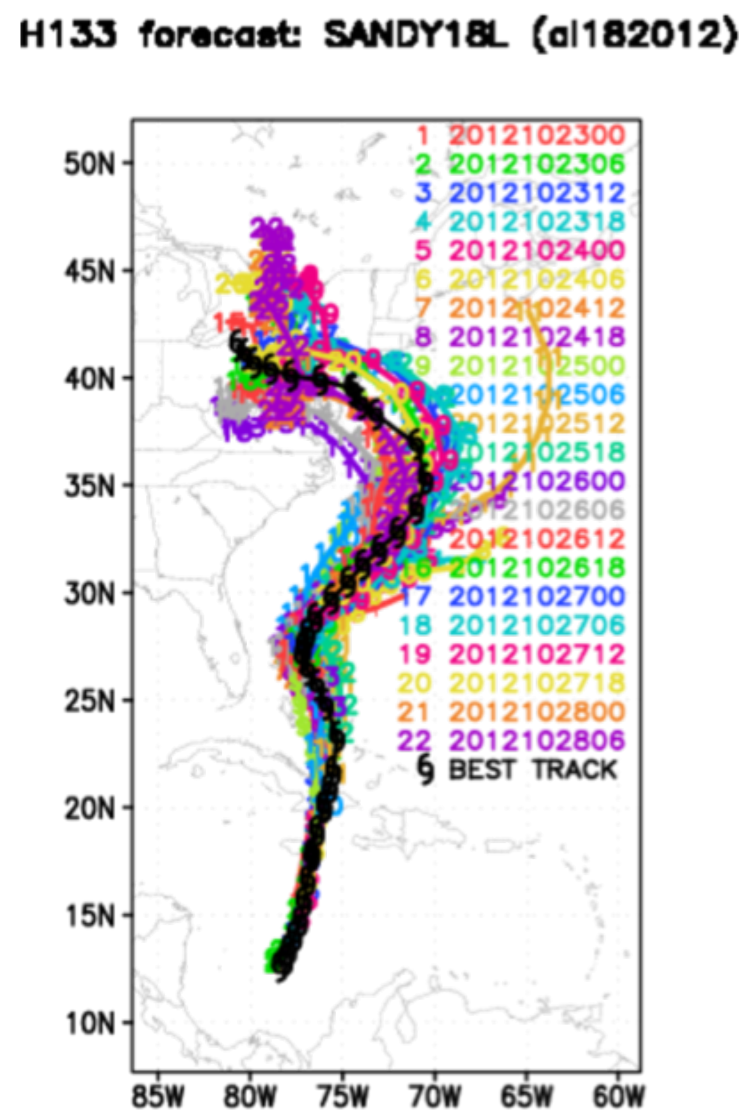
- NCEP/NCAR, Universities
- 1 canopy layer, 4-layer soil
- Prognostic variables:
  - Moisture and temperature in the soil layers
  - Water stored on the canopy
  - Snow stored on the ground.
- It Includes root zone, evapotranspiration, soil drainage, and runoff, taking into account vegetation categories,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

SANDY 18L 2012

HWRF + slab land model



HWRF + noah LSM



noah LSM improved surface temperature & track simulations

LSM in Namelist

&physics

....

num_soil_layers = 4,

sf_surface_physics = 2, 2, 2,

....

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- Plan for 2016 upgrades

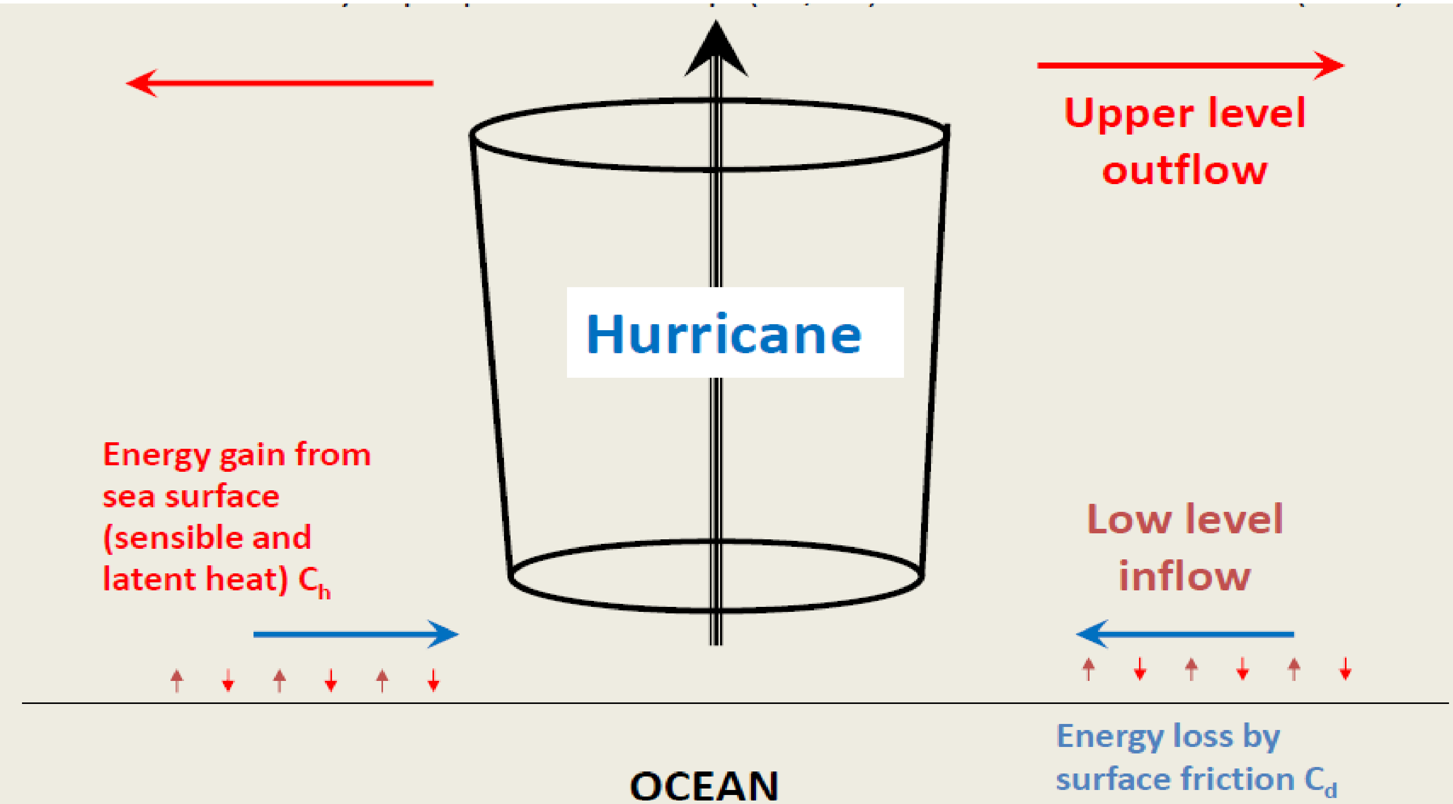
Surface-layer physics

- **Why/what?** To calculate stability functions, velocity scales (u_*, w_*...), exchange coefficients, and surface fluxes needed by LSM and PBL schemes

- **How?** Monin-Obukhov similarity theory

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

Air-sea interactions



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

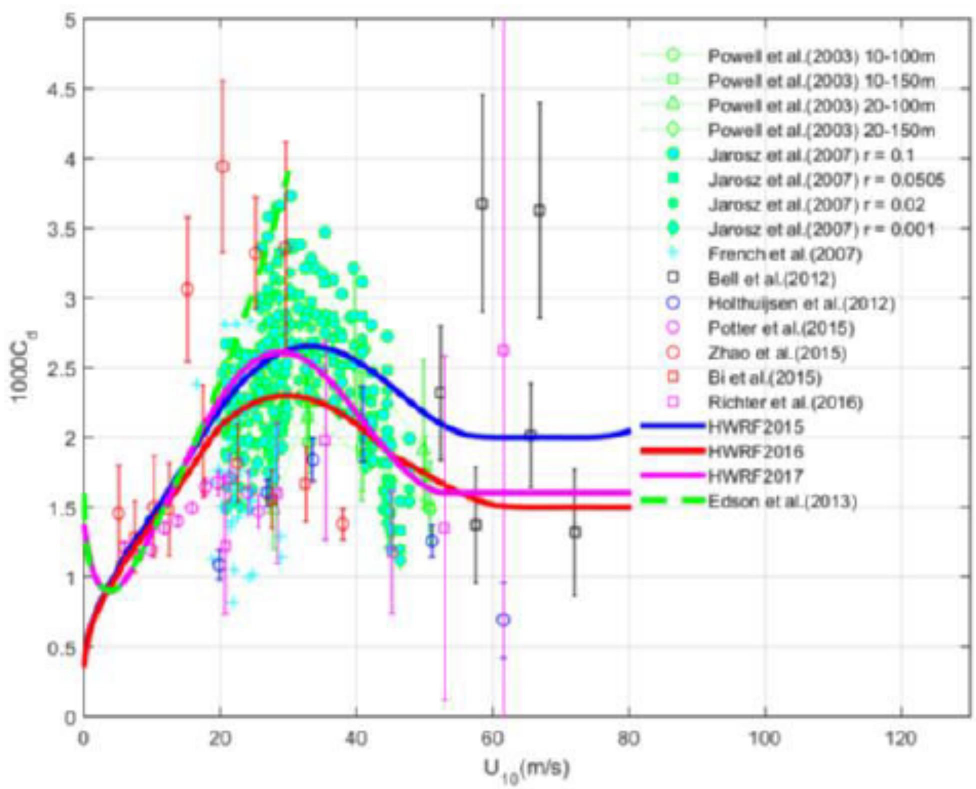
H_0 sensible flux; L_0 latent flux; τ_0 momentum flux

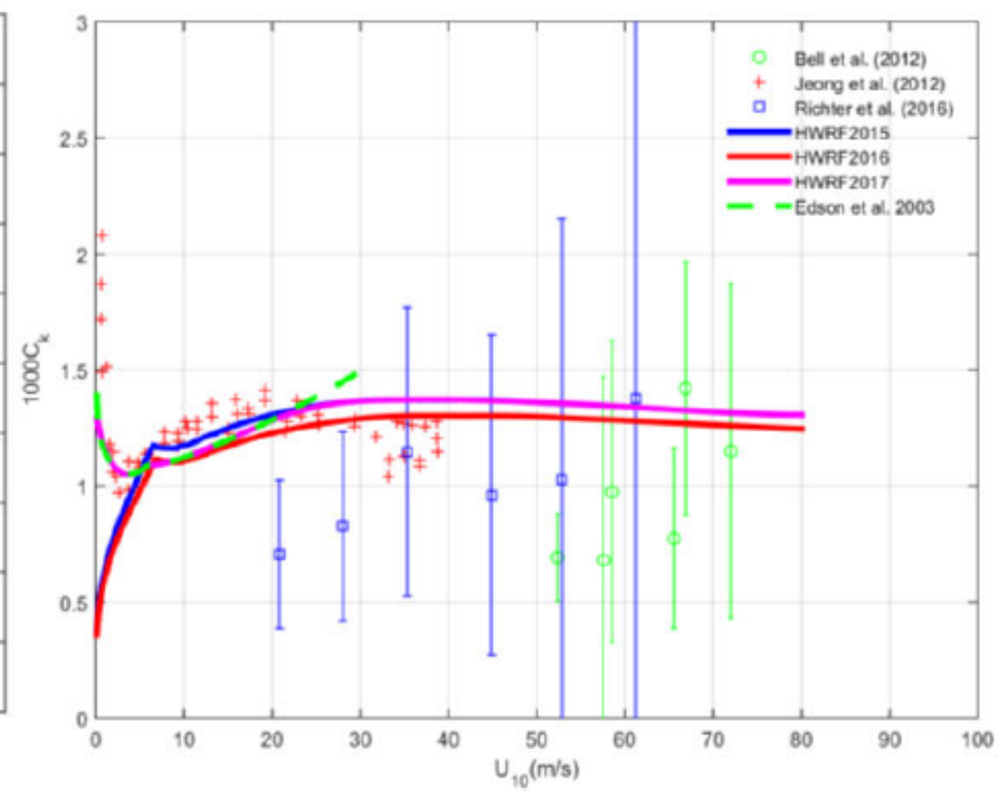
Hurricane intensity is proportional to (C_h/C_d) over ocean (Emanuel, 1995).

Surface layer parameterization

HWRF specifies z_0 as a function of wind to match obs C_d and C_h

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





Surface-layer in Namelist

&physics

....

sf_sfclay_physics = 88, 88, 88, ← GFDL sfc layer scheme

icoef_sf = 6, 6, 6, ← Choose different formula for z_0 to get C_d, C_h

lcurr_sf = F, F, F, ← For ocean, future

....

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Planetary boundary layer (PBL) parameterization

- **Why?** To represent the vertical mixing effects of eddies too small to be solved by the dynamical core using the HWRF grid spacing

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

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

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

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

TKE-based dissipative heating

Computation of turbulent eddy diffusivity , *K*

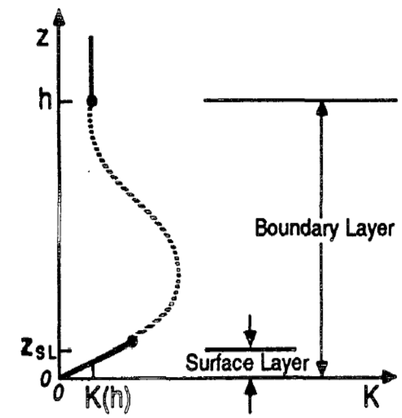


FIG. 1. Typical variation of eddy viscosity *K* with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

Hong and Pan (1996)

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

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*

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

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

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

Critical Richardson number a function of the local Rossby Number

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

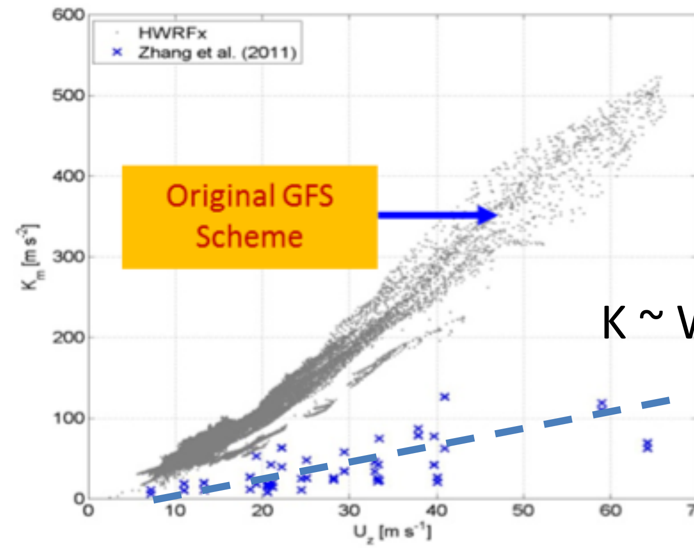
Rossby number depends on 10-m speed and roughness length

K adjustment

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

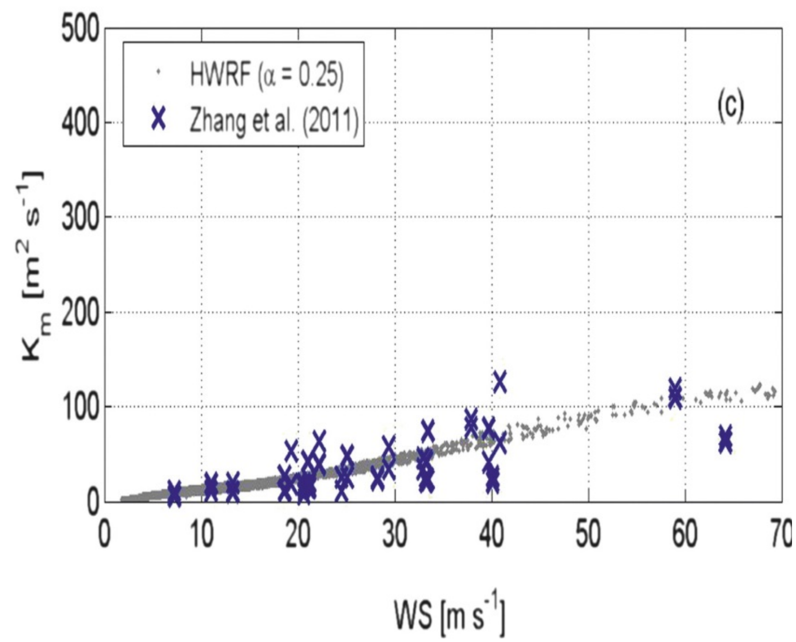
<u>Solutions:</u>

- <u>Upgrade for 2013 operational HWRF:</u> introduce a variable (α) to modulate K (Gopal 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)
- Further modification to have smooth K near surface-layer top in 2016.



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

disheat=.true. — dissipative heating

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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

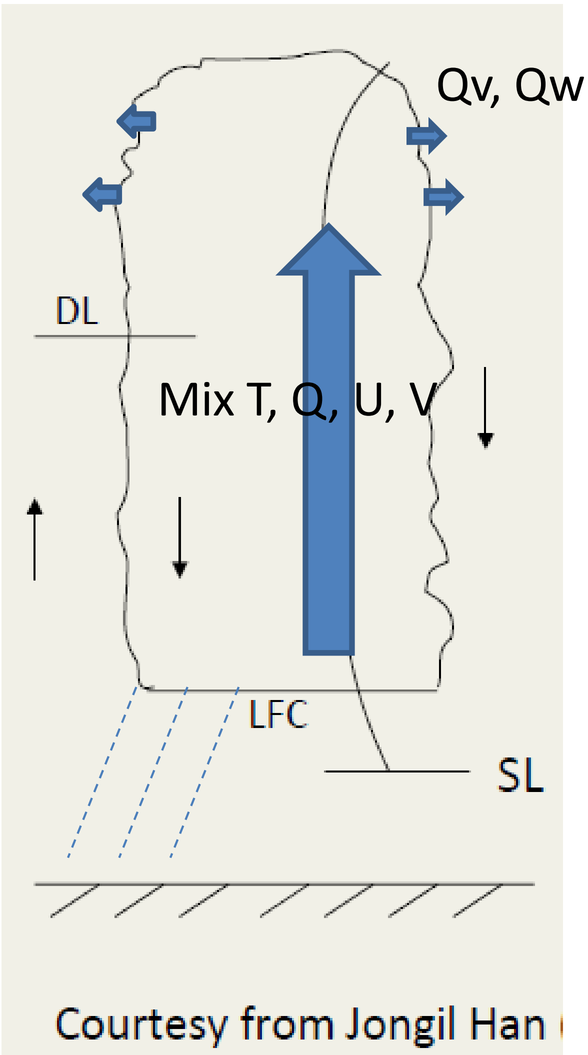
  Vertically transporting:

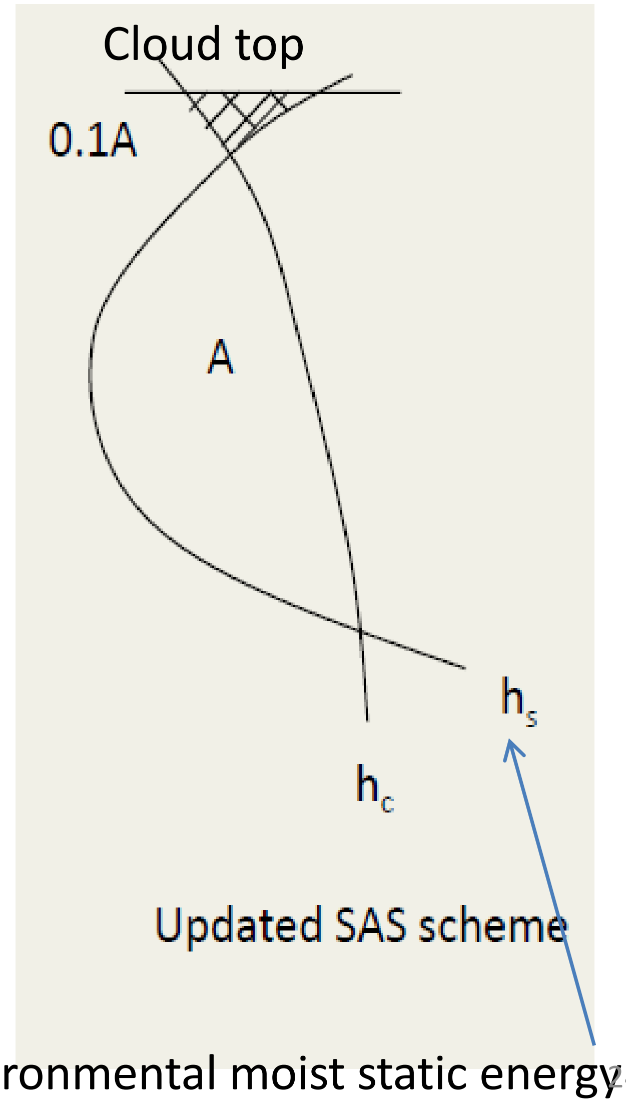
  – Heat

  – 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

Scale-aware SAS

- Old scheme usually assumed updraft area << grid size.
- For the grid sizes of 500m ~ 10 km where the strong updrafts are partially resolved. A scale-aware parameterization is necessary so that SAS effect is reduced for smaller grid spacings for which the condensation processes can be partially resolved by the microphysics scheme

$$m_b' = (1 - \sigma_u)^2 m_b \qquad\qquad \sigma_u = \frac{\pi R_{conv}^2}{A_{grid}}$$

σ_u: updraft area fraction (0~1.0)

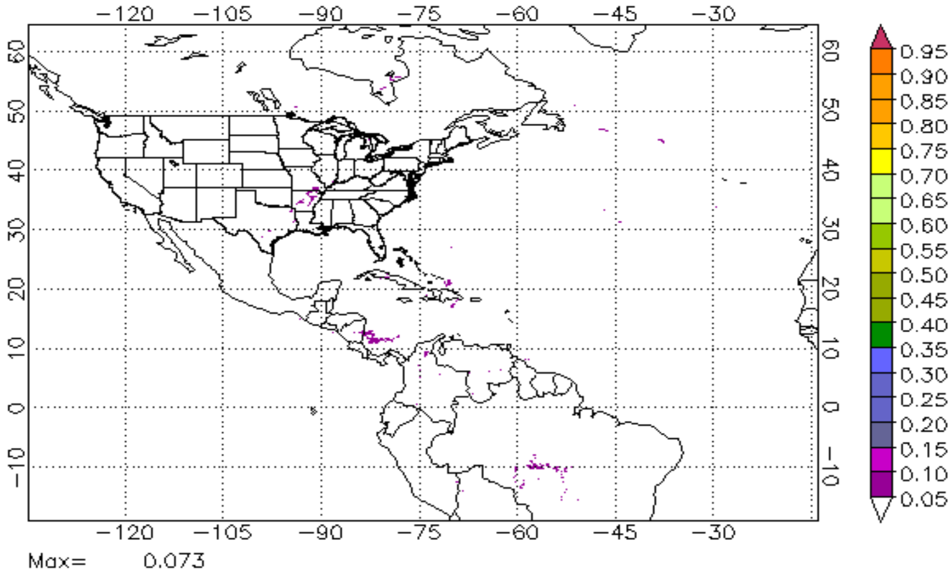
m_b : original cloud base mass flux from AS quasi-equilibrium closure

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

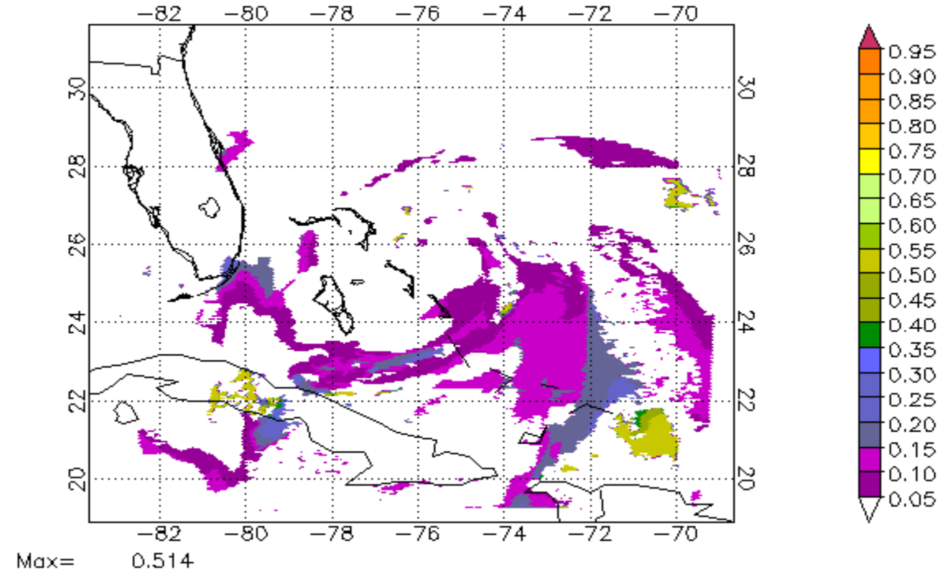
A_{grid} : grid cell area

R_{conv} : updraft radius, 0.2/ε. ε : the updraft entrainment rate.

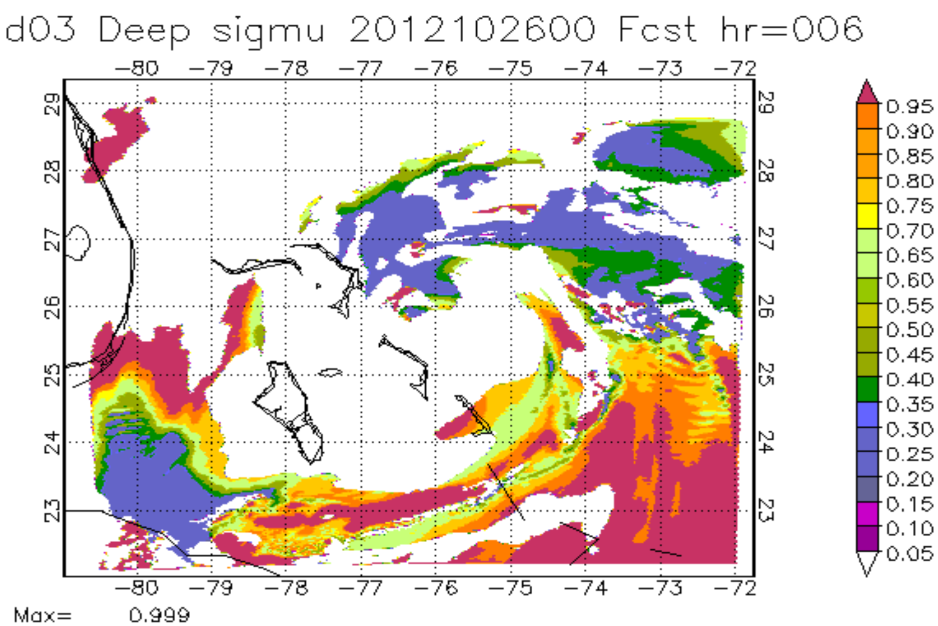
18-km domain



6-km domain



2-km domain



Example of Updraft Fractional Area

- fractional area is larger for smaller grid spacing

CU in Namelist

&physics

....

cu_physics = 4, 4, 4,

ncnvc = 2, 6, 6, Calling frequency, time steps

....

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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 microphysics species such as rain, cloud, ice

HWRF uses a single moment scheme

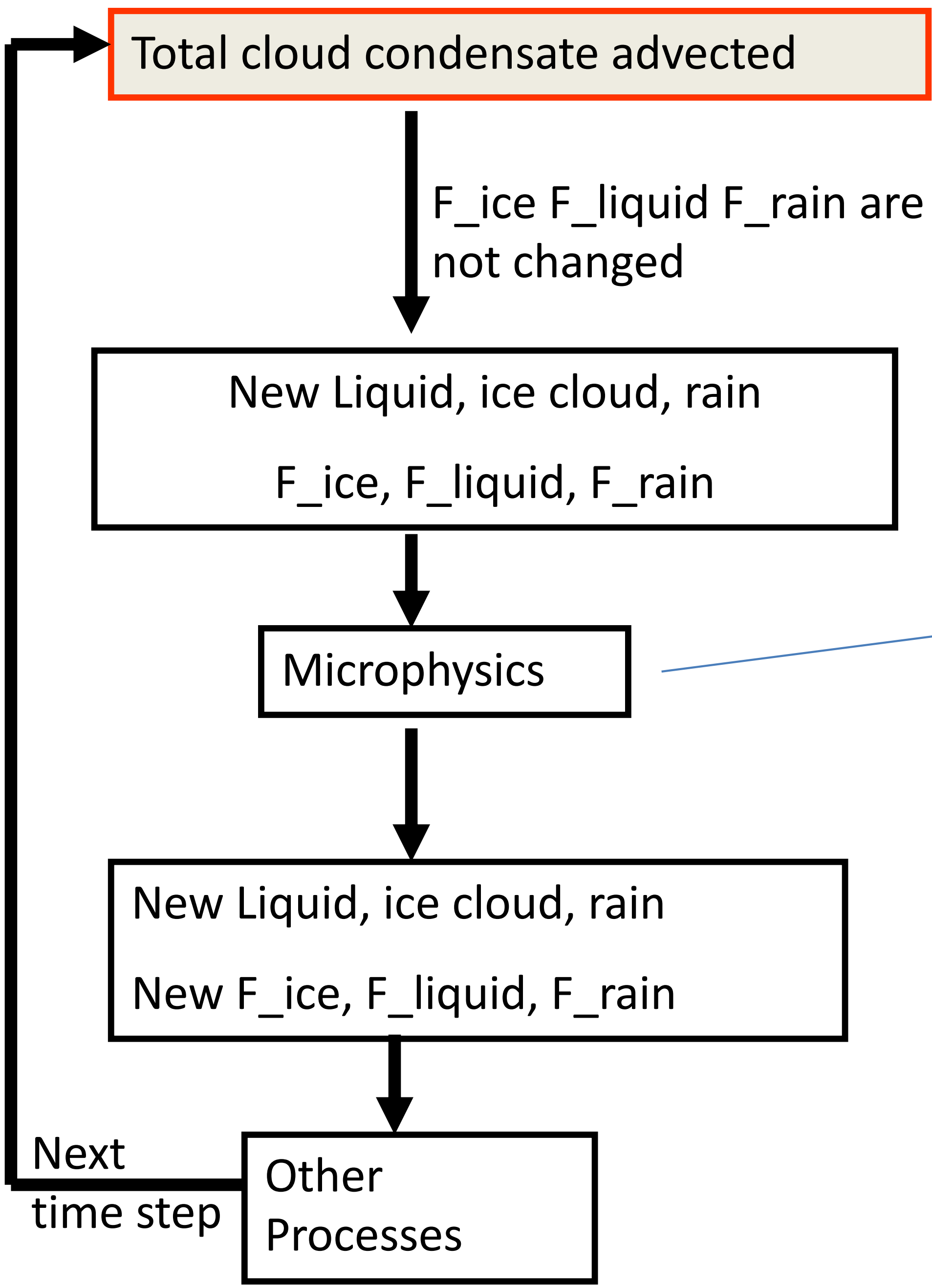
Ferrier-Aligo scheme (NMMB,HWRF) ,

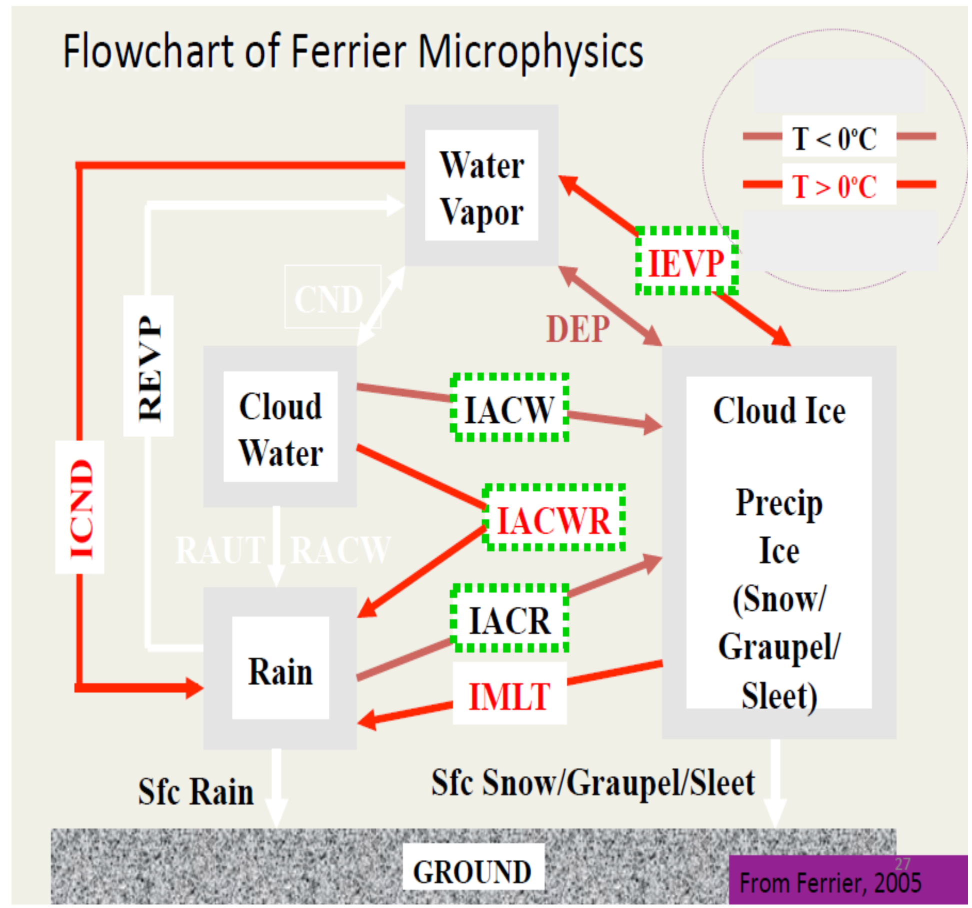
modified from Ferrier/eta scheme

Ferrier-Aligo scheme

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

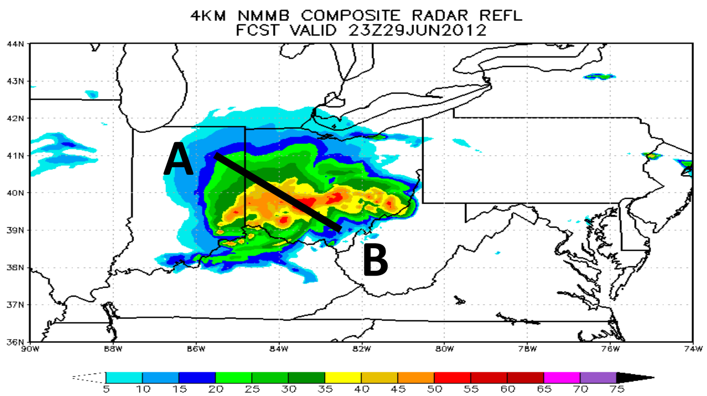
Flow chart

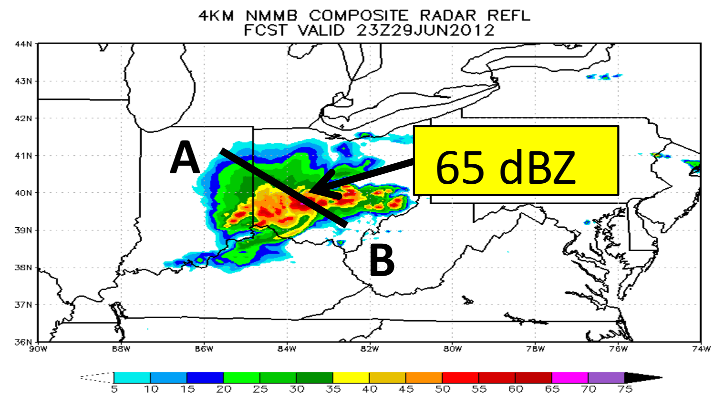

Total cloud condensate advected
F_ice F_liquid F_rain are not changed
New Liquid, ice cloud, rain
F_ice, F_liquid, F_rain
Microphysics
New Liquid, ice cloud, rain
New F_ice, F_liquid, F_rain
Other Processes
Next time step


Flowchart of Ferrier Microphysics
Water Vapor
T < 0°C
T > 0°C
IEVP
DEP
CND
REVP
ICND
Cloud Water
IACW
Cloud Ice
IACWR
Precip Ice (Snow/ Graupel/ Sleet)
RAUT
RACW
IACR
Rain
IMLT
Sfc Rain
Sfc Snow/Graupel/Sleet
GROUND
From Ferrier, 2005

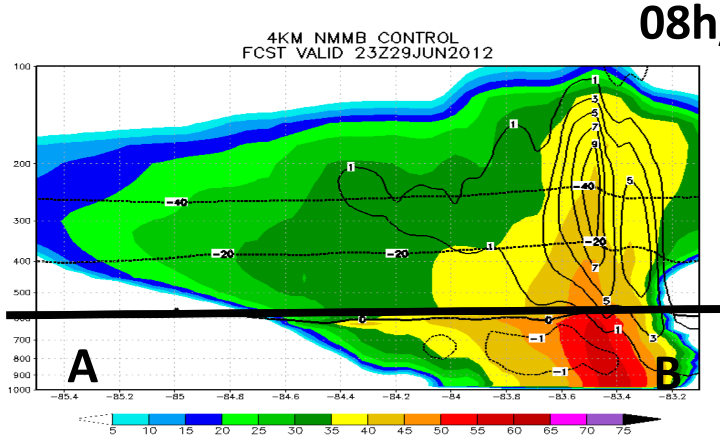
Ferrier/eta Microphysics

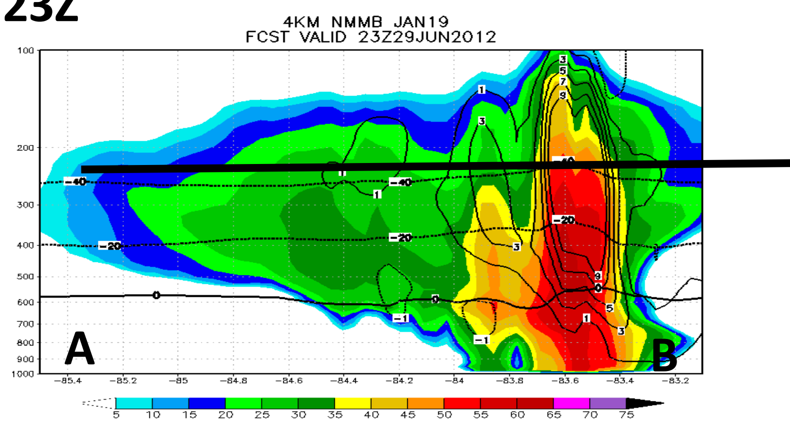
Ferrier-Aligo Microphysics





08h/23Z





50 dBZ reflectivity below 600 mb

F-A improves simulations of deep clouds , which is important in tropical cyclone simulations.

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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- Overview HWRF parameterizations
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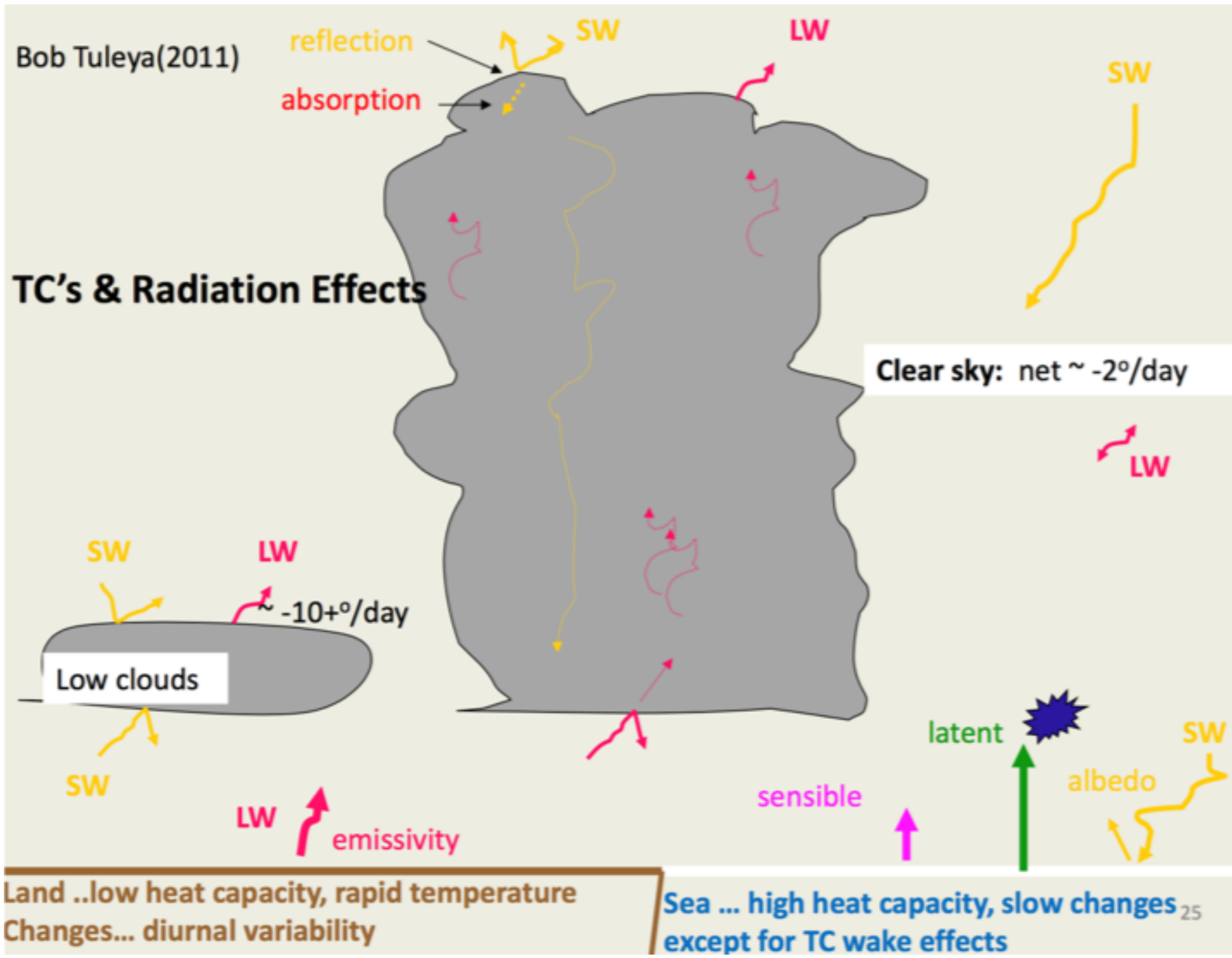
- **Radiation**

Radiation

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



Rapid Radiative Transfer Model (RRTMG)

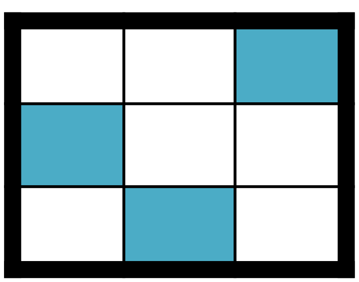
- Modified from RRTM (Iacono et al. 2008)
- Long wave includes absorptions of:
  - water vapor, carbon dioxide, ozone, methane, nitrous, oxide, oxygen, nitrogen, and the halocarbons
- Short wave includes absorptions of:
  - water vapor, carbon dioxide, ozone and methane
- Calculations are made over spectral 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 is a function of temperature, instead of constant (NMMB tests).

Courtesy: L. Bernardet

Partial Cloudiness for RRTMG

WRF v3.6

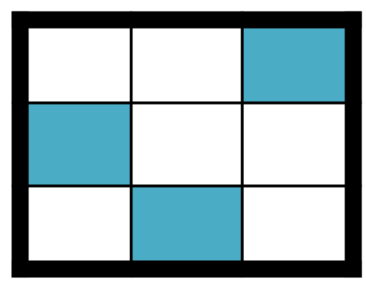
- Older RRTMG scheme
- No partial cloudiness
- Cloud radiative forcing only if resolved cloud present (produced by microphysics scheme)



No CRF from these clouds because box is subsaturated on average

WRF v3.7

- Revised RRTMG
- Sundqvist et al. partial cloud. If *RH* > threshold, fraction of grid box is cloudy
- Radiation attenuation depends on estimated LWC/IWC -> profile of T, q



Includes CRF from partial clouds (1/3)

Radiation in Namelist

&physics

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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

....

Other options

Limited tested:

- Convection schemes: Tiedtke, NSAS, KF, GF etc., tested by DTC
- Radiation: GFDL
- PBL/sfc: MYJ/eta similarity sfc
- LSM: slab
- Microphysics: Thompson, WSM6, Ferrier, advected F-A

Thanks!