CCPP Physics:
Scientific Overview of Supported Physics Suites

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Presentation reflects processes and parameterizations developed by NOAA/EMC, NOAA/GSL, NCAR, NOAA/PSL, NOAA/GFDL, NRL, etc.

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DTC Developmental Testbed Center

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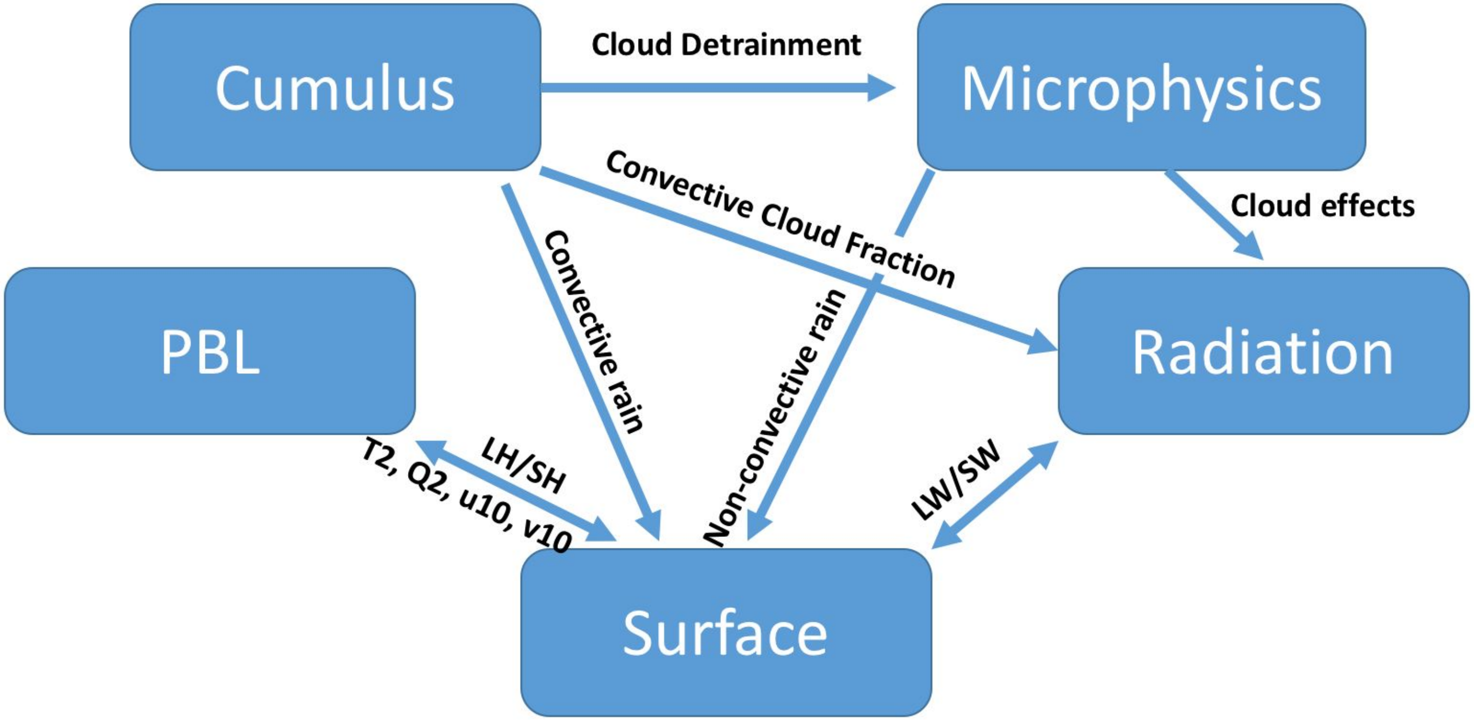
Outline

1. MRW App v1.1-support physics suites and physics-related namelist options
2. Time integration within physical suites
3. Scientific overview of selected physics schemes

1. Current CCPP-support physics suites

“sa” - scale-aware	**Operational**	**Experimental**	**Variants**	
	GFSv15p2	**GFSv16beta**	**GFSv15p2_no_nsst**	**GFSv16beta_no_nsst**
Microphysics	GFDL(sa)	GFDL(sa)	GFDL(sa)	GFDL(sa)
PBL	K-EDMF	Moist TKE-EDMF (sa)	K-EDMF	moist TKE-EDMF (sa)
Surface layer	GFS	GFS	GFS	GFS
Deep Convection	SAS(sa)	SAS(sa)	SAS (sa)	SAS (sa)
Shallow Convection	SAS(sa)	SAS(sa)	SAS (sa)	SAS (sa)
Radiation	RRTMG	RRTMG	RRTMG	RRTMG
Gravity Wave Drag	uGWP	uGWP	uGWP	uGWP
LSM	Noah	Noah	Noah	Noah
Ocean	GFS NSST	GFS NSST	GFS SOS	GFS SOS

Direct connections of parameterizations



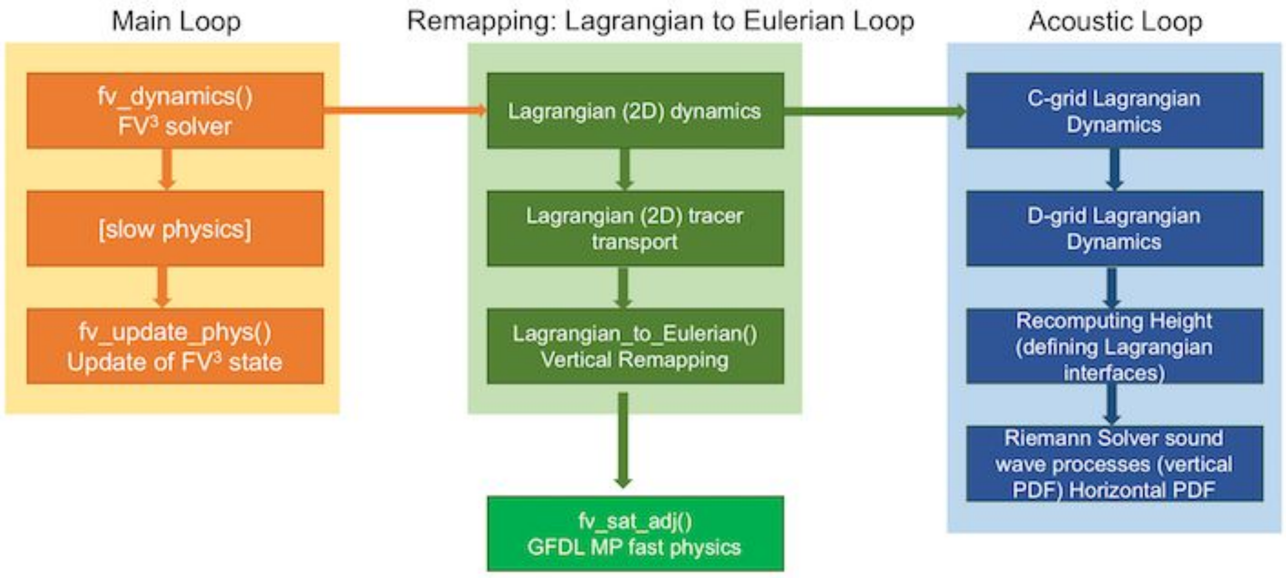
1. Physics-related namelist options (`input.nml`)

- **&gfs_physics_nml** pertains to all the suites used, but some of the variables are only relevant for specific parameterizations (*see GFS_typedefs.F90 and GFS_typedefs.meta*)
- **&gfdl_cloud_microphysics_nml** is relevant for the GFDL microphysics (*see module_gfdl_cloud_microphys.F90 and module_gfdl_cloud_microphys.meta*)
- **&cires_ugwp_nml** specifies the options for the use of Gravity Wave Physics
- **&stochy_nam** specifies the options for the use of stochastic physics including SPPT, SKEB and SHUM.

See more details at [CCPP Scientific Documentation](#) and [Appendix](#) at the end of this presentation

2. Time integration and physics suites (1)

Computed using <u>time splitting</u> shown here, in which the model state is updated between calls to the parameterization (Donahue and Caldwell 2018, Lin and Zhou 2018)

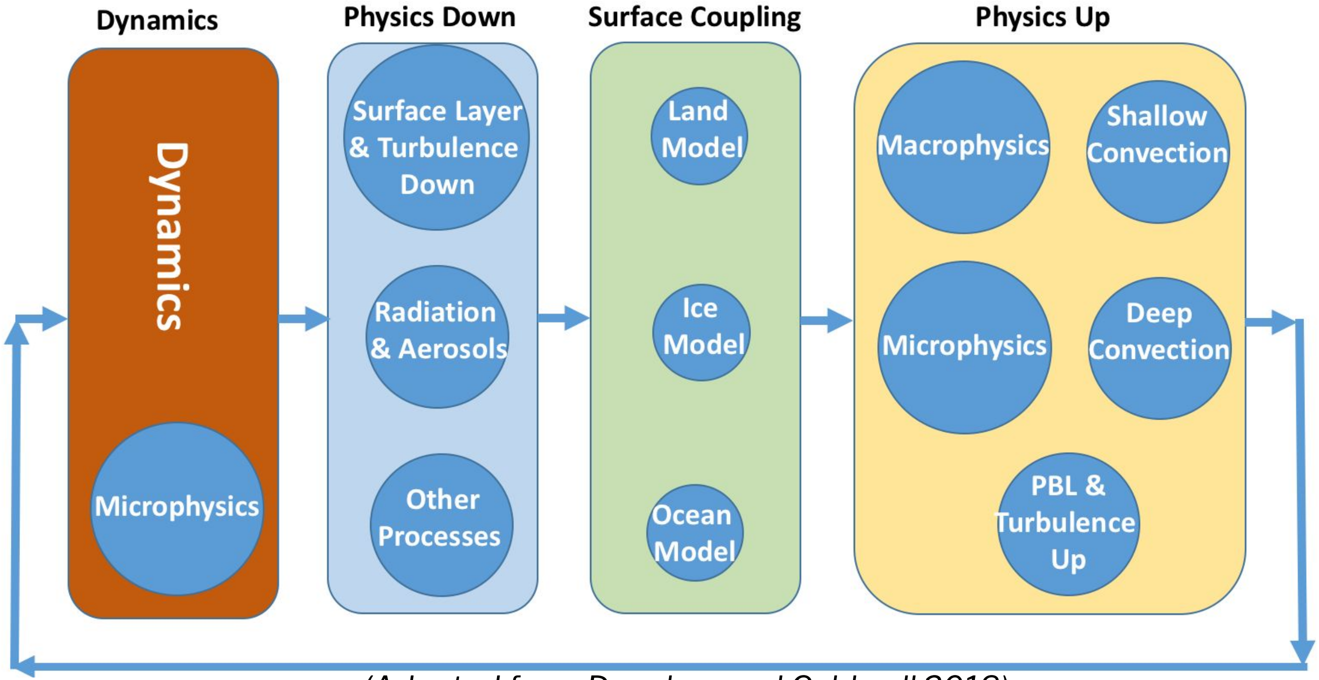


Yellow: once per physics time step (225 for C768)
Green: once per remapping time step (112.5)
Blue: once per acoustic time step (18.75)

2. Time integration and physics suites (2)

Calculation of tendencies

- Tendencies from different physical processes are computed by the parameterizations or derived in separate interstitial routines
- Surface parameterizations (land, ocean and sea ice) are invoked twice in a loop, with the 1st time to create a guess, and the 2nd time to produce the tendencies



(Adapted from Donahue and Caldwell 2018)

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  <group name="fast_physics">
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      <scheme>fv_sat_adj</scheme>
    </subcycle>
  </group>
  <group name="time_vary">
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      <scheme>sfc_nst</scheme>
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      <scheme>lsm_noah</scheme>
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Process-splitting

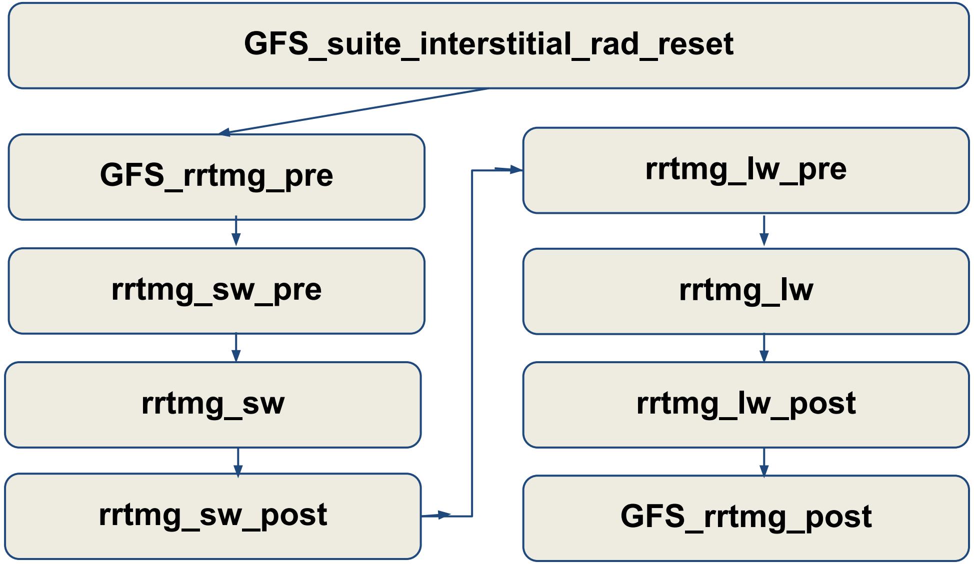
Sequential-splitting

Example: *Suite Definition File (SDF) of GFSv16beta physics suite*

Process splitting: various parameterizations operate on the same model state

Sequential/time splitting: parameterizations are called one after another, and each parameterization operates on an updated model state

2. Time integration and physics suites (3)



Sequence for radiation calculation
(radiation is invoked at longer timesteps)

1st part of the UFS MRW App physics suite

- **Process splitting:** various parameterizations operate on the same model state
- includes radiation, surface layer, surface (land, ocean, and sea ice), boundary layer, orographic gravity wave drag, and Rayleigh damping parameterizations

2. Time integration and physical suites (4)

2nd part of the UFS MRW App physics suite:

- **Sequential/time splitting:** parameterizations are called one after another, and each parameterization operates on an updated model state
- Includes ozone, stratospheric water vapor, deep convection, convective gravity wave drag, shallow convection, and microphysics parameterizations

3. Scientific overview of selected physics schemes

1. **Radiation and Ozone/Water Vapor Physics**
   1.1. GFS RRTMG Shortwave/Longwave Radiation Scheme
   1.2. GFS Ozone Photochemistry (2015) Scheme
   1.3. GFS Stratospheric H2O Scheme
2. **Lower Boundary Condition and Coupling:**
   2.1. Sea Surface, Ocean, Sea Ice, and Land Surface Parameterization
      2.1.1. *GFS Near-Surface Sea Temperature Scheme*
      2.1.2. *GFS Simple Ocean Scheme*
      2.1.3. *GFS Sea Ice Scheme*
      2.1.4. *GFS Surface Layer Scheme*
   2.2. Land Surface Model (LSM)
      2.2.1. GFS Noah LSM
3. **PBL and Turbulence**
   3.1. GFS Hybrid Eddy-Diffusivity Mass-Flux (EDMF) PBL and Free Atmospheric Turbulence Scheme
   3.2. GFS Scale-aware TKE-based Moist EDMF PBL and Free Atmospheric Turbulence Scheme
4. **Gravity Wave Drag and Rayleigh Damping**
   4.1. Gravity Wave Drag and GFS Rayleigh Damping
      4.1.1. *Orographic Gravity Wave Drag (OGW) Scheme in UGWP v0*
      4.1.2. *Orographic Gravity Wave Drag (OGW) Scheme in UGWP v0*

3. Scientific overview of selected physics schemes - cont'd

5. **Cumulus Parameterizations**
    5.1. GFS Scale-Aware Simplified Arakawa-Schubert (sa-SAS) Deep Convection Scheme
    5.2. GFS Scale-Aware Simplified Arakawa-Schubert (sa-SAS) Shallow Convection Scheme
6. **Microphysics and Precipitation Type Diagnosis**
    6.1. GFDL Cloud Microphysics Scheme
    6.2. GFDL MP cloud fraction in FV3 dycore
    6.3. Scale Awareness Example - GFDL Cloud MP
    6.4. GFDL MP cloud fraction in FV3 dycore
7. **Stochastic Physics**

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1.1 Radiation: RRTMG SW/LW Radiation Scheme (1)

- The radiation package provides a fast and accurate method of determining the total radiative flux at any given column
- These calculations provide
  - Components of the radiative flux at the surface to establish the surface energy budget
  - Vertical radiative flux divergence to calculate the radiative heating and cooling rates of a given atmospheric layer
- RRTMG_LW v2.3 and RRTMG_SW v2.3 (Iacono et al., 2008) are used
- The algorithm also includes major and minor absorbing gases (H2O, CO2, O3, CH4, …)
- Interacts with resolved model cloud fields (liquid and ice)
- Interacts with aerosols supplied by climatology
- A Monte-Carlo Independent Column Approximation (**McICA**) method is used to represent statistically unresolved subgrid clouds

1.1 Radiation: RRTMG SW/LW Radiation Scheme (2)

- **Driver module-** prepares astronomy parameters, atmosphere profiles, and surface conditions
- **Astronomy module-** obtains parameters, local solar zenith angles.
- **Aerosol module**- establishes aerosol profiles and optical properties
- **Gas module**- sets up absorbing gas profiles (O3, CO2, rare gases, ...)
- **Cloud module**- prepares cloud profiles
- **Surface module** - sets up surface albedo and emissivity
- **SW radiation module** - computes SW fluxes and heating rates
- **LW radiation module** - computes LW fluxes and heating rates

1.2 NRL Ozone Photochemistry (2015) Scheme *(Ozone Photochemical Production and Loss) (1)*

The addition of stratospheric ozone as a prognostic variable is expected to improve overall forecast and analysis skill of forecast fields

- More accurate assimilation of satellite radiances from channels that are sensitive to ozone (Derber and Wu, 1998)
- Use correlations between ozone and wind to improve wind analyses in the upper troposphere and lower stratosphere (UTLS) (e.g. Riishojgaard, 1996)
- More accurate radiative heating rates, and hence temperature arising from using analyzed ozone rather than climatological ozone in the forecast model radiation scheme (Jackson and Saunders, 2002);
- More accurate analyses and forecasts of surface ultraviolet (UV) radiation

1.2 NRL Ozone Photochemistry (2015) Scheme *(Ozone Photochemical Production and Loss) (2)*

- Net ozone photochemical tendency of ozone mixing ratio (Mccormack et al. 2006)

$$\frac{\partial r}{\partial t} = (P - L)\,[r, T, \Sigma]$$

P−L: diff b/t production and destruction rate
r: ozone mixing ratio
T: temperature
Σ: overhead ozone column amount

- Monthly and zonal mean ozone production (P) and loss (L) rate per unit ozone mixing ratio were provided by NRL CHEM2D model
- GFS uses the four terms of the linearized (*1st-order Taylor series expansion*) photochemical tendency of ozone mixing ratio:

$$\frac{\partial r(\lambda, \phi, p, t)}{\partial t} = (P - L)_0 + \frac{\partial (P - L)}{\partial r}\Big|_0 (r - r_0) + \frac{\partial (P - L)}{\partial T}\Big|_0 (T - T_0) + \frac{\partial (P - L)}{\partial \Sigma}\Big|_0 (\Sigma - \Sigma_0)$$

1.3 NRL Stratospheric H_2O Scheme (1) (*Water Vapor Photochemical Production and Loss*)

- An accurate representation of stratospheric water vapor is important for radiation calculation
- Methane oxidation and photolysis of H_2O in the upper mesosphere due to solar Lyman alpha absorption are an important mechanism for production/loss of water vapor
- The GFS uses a stratospherical H_2O scheme to represent these processes to simulate the H_2O at the stratosphere

1.3 NRL Stratospheric H_2O Scheme (2) (*Water Vapor Photochemical Production and Loss*)

- Mirroring the production and loss terms used in the ozone scheme:
  - Linearized photochemical tendency of specific humidity *q* (McCormack et al. (2008)

$$\frac{dq}{dt} = (P-L)_0 + \frac{\partial(P-L)}{\partial q}\Big|_0 (q - q_0)$$

- Monthly and zonal mean H_2O production (P) and loss (L) rates are provided by NRL CHEM2D zonally averaged photochemical-transport model of the middle atmosphere
- The 2nd term quantifies the linearized sensitivity to local changes in *q*, and yields photochemical relaxation (τ_*) to an equilibrium specific humidity q_0. The equilibrium state and relaxation time is from the perturbation experiments using CHEM2D.

$$-\left[\frac{\partial(P-L)}{\partial q}\right]_0 = \tau_*^{-1}$$

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2. Lower Boundary Condition and Coupling

1.1. Sea Surface, Ocean, Sea Ice, and Land Surface Parameterization
   1.1.1. GFS Near-Surface Sea Temperature Scheme (NSST)
   1.1.2. GFS Simple Ocean Scheme (SOS)
   1.1.3. GFS Sea Ice Scheme
   1.1.4. GFS Surface Layer Scheme
1.2. Land Surface Model (LSM)
   1.2.1. GFS Noah LSM

2.1.1 GFS Near-Surface Sea Temperature (NSST) Scheme (1)

- SST is required in a NWP system as the lower thermal boundary condition of air-sea heat fluxes calculation at
    - analysis time used in radiative transfer model
    - forecast time as bounder condition
- The SST analysis is produced independently and provided to the NWP system as an input
- In the UFS MRW App, the SST can change because it is forced toward the climatology (90 day e-folding)

$$SST^{fcst}(t) = \left[T_f^{an}(t_0) - SST^{clim}(t_0)\right]e^{-(t-t_0)/T_{90d}} + SST^{clim}(t) + T_w'(0,t) - T_c'(0,t)$$

(Courtesy of X. Li at EMC)

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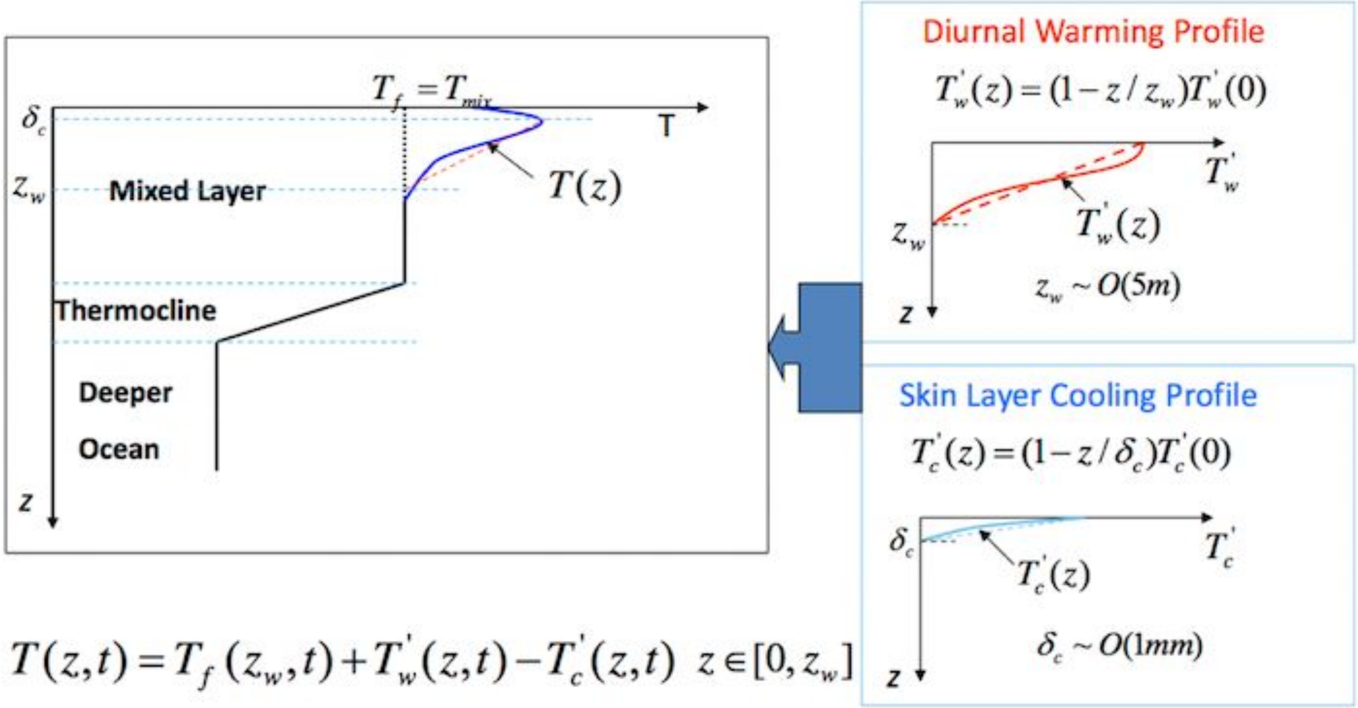
2.1.1 GFS Near-Surface Sea Temperature (NSST) Scheme (2)

In addition, NSST can represent the influence of diurnal thermocline layer warming and thermal skin layer cooling



$$T(z,t) = T_f(z_w,t) + T_w'(z,t) - T_c'(z,t) \quad z \in [0, z_w]$$

(Courtesy of X. Li at EMC)

2.1.2 GFS Simple Ocean Scheme (SOS)

- <u>When the initial conditions do not contain all fields needed to initialize the NSST scheme</u> (such as the GRIB2 files used for the MRW App), a simple ocean scheme (SOS) is recommended for use (*suites such as GFS_v15p2_no_nsst and the GFS_v16beta_no_nsst,* ***the App workflow will automatically choose the suite for them based on the format of ICs***)
- The SOS keeps the SST constant throughout the forecast. The SST can still change if it is updated by other processes, or forced towards the climatology is turned on.

2.1.3 GFS Sea Ice Scheme (1)

- The sea ice strongly interacts with both the atmosphere and the ocean at high latitudes by influencing the latent and sensible heat fluxes.
- A sea ice model may contain subcomponents:

1)* dynamics (ice motion),

2)* ice transport,

3) multiple ice thickness categories (including leads),

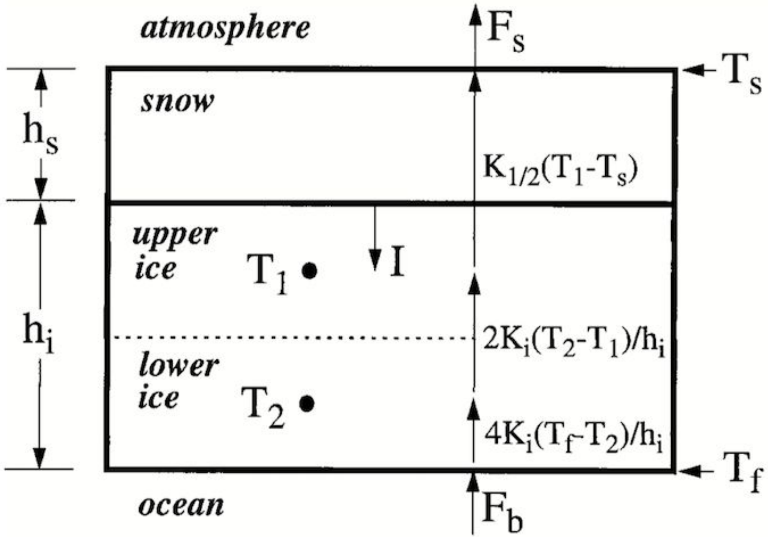
4) surface albedo

5) vertical thermodynamics.

** not included in 1D sea ice model*

2.1.3 GFS Sea Ice Scheme (2)

- GFS is coupled with a 3-layer thermodynamic sea ice model that predicts
  - sea ice/snow thickness
  - surface temperature
  - ice temperature structure
- In each grid box, the heat and moisture fluxes and albedo are treated separately for the ice and the open water.



3-layer thermodynamic sea ice model (Winton 2000)

2.1.4 GFS Surface Layer Scheme

- Function: based on the Monin-Obukhov similarity profile relationship to calculate the surface stress, roughness length, exchange coefficients as an input for other parameterizations including land surface model
- Formulation update:
  - based on *Miyakoda and Sirutis (1986);* modified by *P. Long (1984,1986)* in the very stable and unstable situations; implemented the new vegetation-dependent formulations of thermal roughness formulation (*Zheng et al. 2012*) to deal with the cold land surface skin temperature bias over the arid western CONUS during daytime
  - introduced a stability parameter constraint $(z/L)_{lim}$ in Monin-Obukhov similarity theory to prevent the land-atmosphere system from becoming fully decoupled (*Zheng et al. 2017*):

$$(z/L)_{lim} = \frac{ln(\frac{z}{z_{0M}})}{2\alpha(1-\frac{z_{0M}}{z})}$$

z: height; L: Obukhov length; z_{0M} is the momentum roughness length, α=5

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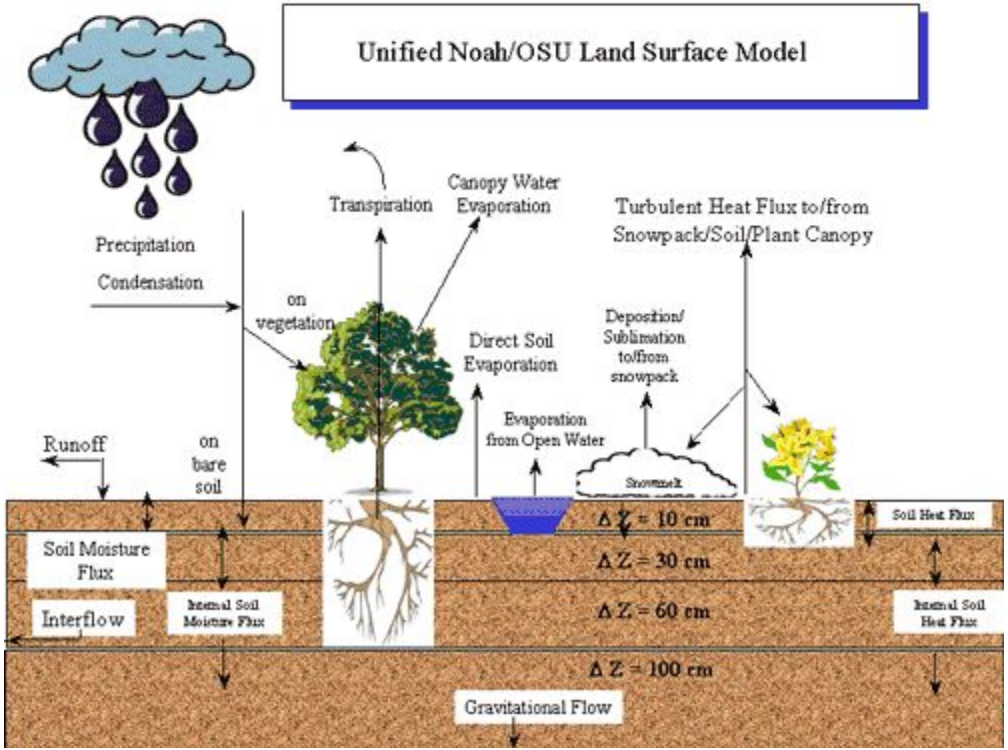
2.2 Land Surface Model

- Land Surface Models (LSMs), driven by the atmospheric model forcing, provide boundary conditions for heat, moisture, and momentum (surface fluxes + upward radiation) to the atmosphere for weather and seasonal prediction systems
- LSMs close surface energy and water budgets
- The MRW App v1.1 supported physics suites use ***Noah LSM***

2.2.1 Noah LSM



https://ral.ucar.edu/solutions/products/unified-noah-lsm

- <u>4 soil layers </u>(10, 30, 60, 100 cm thick)
- Uses soil prognostic equation, surface energy and water budget equations, etc. for creating <u>prognostic land states</u> including surface soil temperature and soil moisture, canopy water content, snowpack water equivalent content, and snowpack depth

(Pan and Mahrt 1987, Chen et al. 1996, Chen and Dudhia 2001, Ek et al., 2003)

3. PBL and Turbulence scheme

- The main task of a PBL scheme is to calculate tendencies of temperature, moisture, and momentum due to vertical diffusion/turbulence throughout the column
- Two options in CCPP-supported suites for App v1.1:
  - GFS Hybrid Eddy-Diffusivity Mass-Flux (EDMF) PBL and Free Atmospheric Turbulence Scheme
  - GFS Scale-aware TKE-based Moist EDMF PBL and Free Atmospheric Turbulence Scheme

$$\underbrace{\overline{w'\phi'}}_{\text{Total turbulent flux}} \simeq \underbrace{-K\frac{\partial\overline{\phi}}{\partial z}}_{\text{ED}} + \underbrace{M(\phi_u - \overline{\phi})}_{\text{MF}}$$

Convective updraft + turbulent eddies (Siebesma et al. 2007)

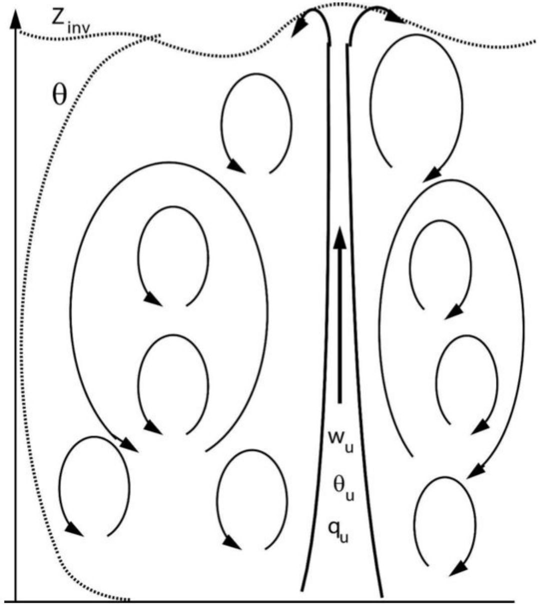


FIG. 1. Sketch of a convective updraft embedded in a turbulent eddy structure.

3.1 GFS Hybrid EDMF PBL and Free Atmospheric Turbulence Scheme

- **Hybrid**
  - Mass-flux (MF) scheme for strongly unstable PBL (i.e., CBL) cases (well-organized updrafts) by considering nonlocal transport by large eddies
  - Eddy-Diffusivity (ED) scheme for weakly unstable PBL (i.e., only called in the tropics where CBL is hardly found) by representing local turbulent mixing (Han et al. 2016)
  - A first-order turbulent transport scheme for stable PBL.
- **General Algorithm**
  - Using PBL height and similarity parameters, diffusion coefficients are updated for levels below the PBL top (Hong and Pan 1996) and levels above the PBL top (Louis 1979) with updated Richardson number-dependent functions.
  - If PBL is diagnosed as stratocumulus-topped, diffusion coefficients are modified (Lock et al. 2000)
  - If the PBL is convective, call MF scheme

3.2 GFS Scale-aware TKE-based EDMF PBL and Free Atmospheric Turbulence Scheme

An extended version of Hybrid EDMF scheme (*Han and Bretherton 2019*):

- ED mixing strength is a function of **prognostic TKE**
- **EDMF applied to all the unstable PBL** (both weakly and strongly unstable PBL) and to the stratocumulus-top-driven downdrafts
- **Enhanced buoyancy** due to moist-adiabatic processes condensation
- **Scale-awareness** for the grid sizes where the large turbulent eddies are partially resolved
- Includes **interaction between TKE and cumulus convection**

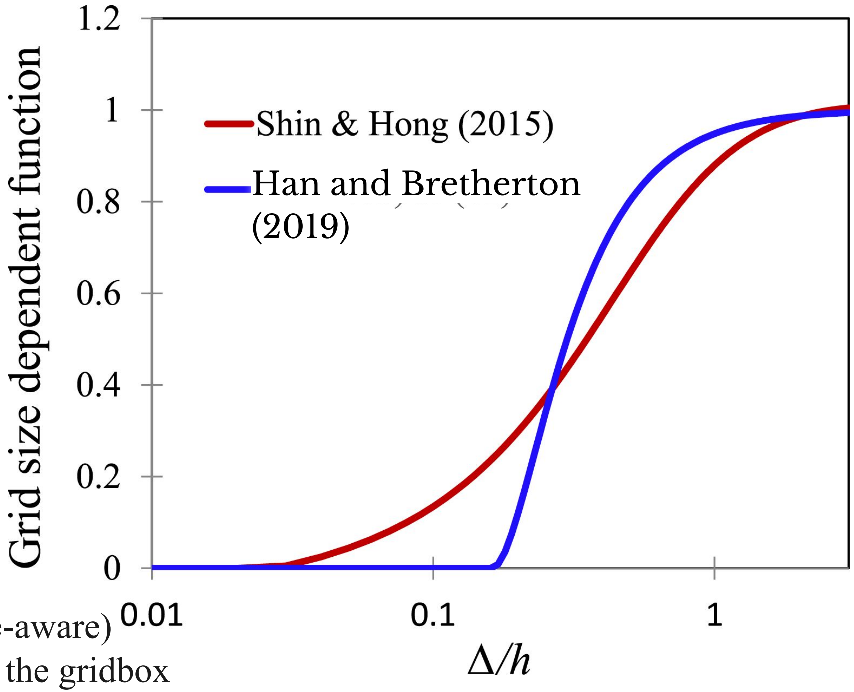
3.2 Scale Awareness Example - TKE-based Moist EDMF PBL

$$M'_u = S(\sigma_u) M_u$$

$$S(\sigma_u) = (1 - \sigma_u)^2$$

$$\sigma_u = \frac{3.14 R_u^2}{A_{\mathrm{grid}}}, \quad R_u = \frac{0.2}{\overline{\varepsilon}_u}$$

$$\varepsilon_u = c_\varepsilon \left[\frac{1}{z + \Delta z} + \frac{1}{(h - z) + \Delta z} \right]$$



where M_u is the mass flux, $S(\sigma_u)$ is a grid-size-dependent (scale-aware) function, and M'_u is a mass flux reduced with a finite σ_u, A_{grid} is the gridbox area, R_u is the radius of the updraft, and the lateral entrainment rate is averaged over the whole updraft, ε_u is the lateral entrainment rate

4.1 Gravity Wave Drag and GFS Rayleigh Damping

- Gravity waves (GWs) are generated by a variety of sources in the atmosphere including orographic and non-orographic forcing
  - **orographic GWs (OGW)**
  - **non-orographic GWs (NGW)**
- **GW effects** include GW drag (also called momentum dissipation), heat dissipation, and mixing by eddy viscosity, conductivity and diffusion
- GWs can impose **a subgrid-scale (SGS) drag force** on the atmospheric stratified flow, which needs to be parameterized to improve predictions esp. for cold season when both atmospheric stratification and winds are strong
- **Rayleigh damping** is introduced to mimic the viscous or frictional dissipation in the atmosphere
  - Top lid model effects - sponge layer to suppress resolved wave reflections and extra-heating
  - Winter-summer zonal wind drag in the strato-mesosphere

4.1.1 Orographic Gravity Wave Drag (OGW) Scheme in UGWP v0

UGWP - identical GW propagation solvers for OGWs and NGWs with different approaches for specification of SGS wave sources (Yudin et al. 2016; Yudin et al. 2018; Alpert et al. 2019).

- The UGWP orographic gravity wave drag (OGW) parameterization calculates the effect of gravity waves produced by flow over irregularities at the Earth's surface such as mountains and valleys.

$$\tau = \frac{\rho\, U^3\, G(F_r)}{\Delta X\, N}$$

where ΔX is a grid increment, N is the Brunt Vaisala frequency, G(Fr) is a monotonically increasing function of Froude number, ρ is air density, τ is gravity wave stress, and U is the speed.

- Two main components of OGW in UGWPv0:

1. Calculate SGS mountain blocking
2. Calculate orographic wave drag

4.1.2 Non-Orographic Gravity Wave Drag (NWG) Scheme in UGWP v0

- The NGW physics scheme parameterizes the effects of non-stationary waves unresolved by dynamical cores. These non-stationary oscillations with periods bounded by Coriolis and Brunt-Väisälä frequencies and typical horizontal scales from tens to several hundreds of kilometers, are forced by the imbalance of convective and frontal/jet dynamics in the troposphere and lower stratosphere (e.g., Fritts 1984)
- A modification of Scinocca (2003) scheme for NGWs with non-hydrostatic and rotational effects for GW propagations and background dissipation is used

5. Cumulus Parameterizations (1)

- Cumulus parameterizations predict the effects of subgrid-scale convection (comprising one or more clouds within a grid box) on the modeled atmosphere in terms of resolved-scale variables
- There are two types of cumulus clouds that parameterizations represent: shallow and deep. Both act to vertically transport/distribute heat, moisture, and momentum; deep cumulus produces rainfall, whereas shallow cumulus typically does not produce precipitation except for drizzle

5. Cumulus Parameterizations (2)

- Convective parameterization continues to be a necessary and important component of many NWP models for predictions across scales. Moist convection comprises <u>subgrid-scale mixtures of updrafts and downdrafts</u> (Stensrud 2007)
- A convective scheme needs to determine:
  - when, where, and if convection occurs using "**trigger functions**"
  - vertical momentum, heat and moisture transport and distribution based on "**a cloud model**"
  - amount or intensity of the convection using "**the closure assumption**"

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5.1 GFS Scale-Aware Mass-Flux Deep Convection Scheme

- An updated version of the Simplified Arakawa-Schubert (SAS) scheme with scale and aerosol awareness. Key points:
    - The cloud mass flux decreases with increasing grid resolution
    - Rain conversion in the convective updraft is modified by aerosol number concentration
    - Closure is scale-aware: cloud-based mass flux based on quasi-equilibrium for dx> 8km but as a function of mean updraft velocity for dx< 8km
- Working concepts from Arakawa and Schubert (1974) but includes modifications/simplifications from Grell (1993), e.g., saturated downdrafts and only one cloud type (the deepest possible)
- The scheme includes the calculation of cloud top with updated cloud model entrainment and detrainment, improved convective transport of horizontal momentum, a more general triggering function, and the inclusion of convective overshooting. (Pan and Wu, 1995; Han and Pan 2011)

5.2 GFS SAS-based Mass-Flux Shallow Convection Scheme

- An updated version of the previous mass-flux shallow convection scheme with <u>scale and aerosol awareness</u> that parameterizes the effects of shallow convection on the environment
- Similar to the deep convection counterpart but with a few key differences:
  - Cloud-base mass flux is parameterized using a mean updraft velocity averaged over the whole cloud depth; no quasi-equilibrium assumption used for any grid size
  - Cloud model <u>without convective downdrafts</u>
  - Shallow convection starts at the level of <u>maximum moist static energy within PBL</u>
  - Cloud top confined to below levels where p=0.7 * psfc.
  - Entrainment rates are larger than in deep convection scheme.

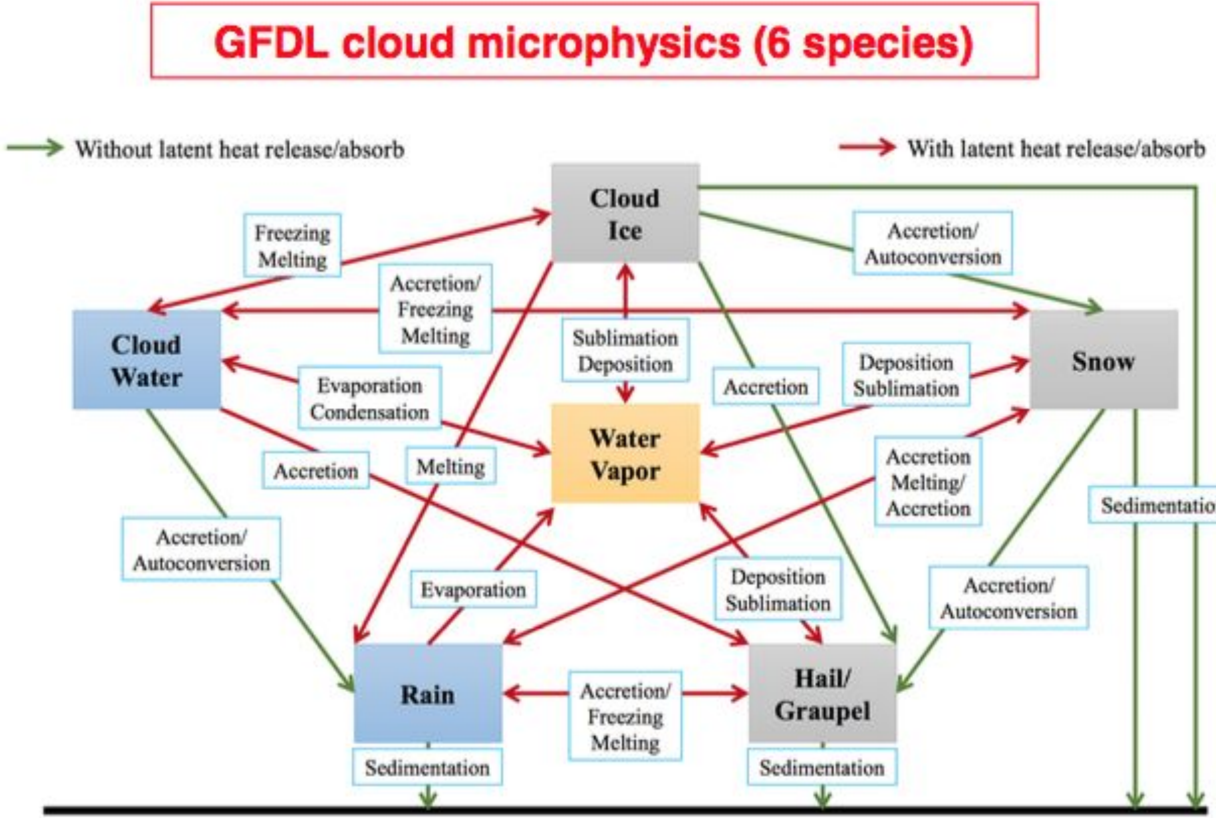
6. Microphysics and Precipitation Type Diagnosis

- GFDL Cloud Microphysics Scheme
- GFS Precipitation Type Diagnosis Scheme

6.1 GFDL Cloud Microphysics Scheme (1)

- Representation of cloud microphysics is a key aspect of simulating clouds. The GFDL cloud microphysics (MP) scheme (Zhou et al. 2019) has the following major features:
  - A single-moment six-category MP scheme
  - Fast-physics: phase changes and latent heating are embedded within the Lagrangian-to-Eulerian remapping in the FV3 dynamical core and can be updated more rapidly than the rest of the physics
  - Total moist energy is precisely conserved within the cloud microphysics

6.1 GFDL Cloud Microphysics Scheme (2)



GFDL Cloud MP at a glance (Zhou et al. 2019)

6.2 GFDL MP cloud fraction in FV3 dycore

- Cloud-radiation interaction may occur even when the atmosphere is subsaturated
- When using the GFDL microphysics, cloud fraction is computed in the FV3 dycore

$$\sigma = \max\left[0.05, \min\left(1, \frac{q_{plus} - q_s}{q_{plus} - q_{minus}}\right)\right]$$

$$q_{plus} = (q_v + q_{liq} + q_{sol}) \times (1 + h_{var})$$

$$q_{minus} = (q_v + q_{liq} + q_{sol}) \times (1 - h_{var})$$

- Cloud fraction (**σ**) depends on the mass of vapor, liquid, and solid water (qv, qliq, qsol), as well as on the saturation specific humidity (qs)
- It also depends on **hvar, the horizontal subgrid variability**, which is a function of measure of grid spacing. (see next slide)
- When the grid spacing is large, it allows fractional cloud to occur at lower mixing ratios. This assumes that even though the grid box is undersaturated, there may be a fraction of the grid covered by clouds.

6.3 Scale Awareness Example - GFDL Cloud MP

- In GFDL cloud MP, scale-awareness is achieved by an assumed horizontal subgrid variability ***(hvar)*** (of cloud fraction, relative humidity calculation, evaporation and condensation processes) that is **directly proportional to grid spacing or cell area:**

- Over land:

$$h_{var} = \min\left\{0.2, \max\left[0.01, D_{land}\left(\frac{A_r}{10^{10}}\right)^{0.25}\right]\right\}$$

- Over Ocean:

$$h_{var} = \min\left\{0.2, \max\left[0.01, D_{ocean}\left(\frac{A_r}{10^{10}}\right)^{0.25}\right]\right\}$$

Where Ar is cell area, D_{land} and D_{ocean} are base values for sub-grid variability over land and ocean

6.4 GFS Precipitation Type Diagnosis Scheme

- A number of algorithms have been devised to determine the precipitation type based on the Tw profile or quantities derived from it (e.g., Ramer 1993; Baldwin et al. 1994 ; Bourgouin 2000; Schuur et al. 2012)
- GFDL MP scheme permits the prognostic surface precipitation to simultaneously consist of ice, snow and graupel at the same location. Hence if the GFDL MP scheme is called, the precipitation type at the surface is directly diagnosed from the explicit surface precipitation (i.e. ice, snow and graupel) predicted by the scheme and convective rainfall predicted by the cumulus scheme if surface temperature is below 0°C
- This is also an input for a LSM

7. Stochastic Physics (1)

- Finite computing resources limit the spatial resolution of numerical weather models, and small-scale processes, such as convection and clouds, are not properly represented.
- Numerical weather predictions relay, sometimes quite strongly, on the resulting bulk-formula representation of unresolved processes
- Stochastic physics schemes within numerical weather models have the potential to simulate the dynamical effects of unresolved scales in ways that conventional bulk-formula representations are incapable of doing. (Palmer and Williams, 2008)

7. Stochastic Physics (2)

- **SKEB: Stochastic Kinetic Energy Backscatter (Berner et al., 2009)**
  - Add wind perturbations to model state. Perturbations are random in space/time, but amplitude is determined by a smoothed dissipation estimate provided by the dynamical core
  - Addresses errors in the dynamics - more active in the mid-latitudes
- **SPPT: Stochastically Perturbed Physics Tendencies (Palmer et al., 2009)**
  - Multiply the physics tendencies by a random number O[0,2] before updating the model state
  - Addresses error in the physics parameterizations – most active in boundary layer and convective regions
- **SHUM: Specific HUMidity perturbations (Tompkins and Berner, 2008)**
  - Multiply the low-level specific humidity by a small random number each time-step
  - Attempts to address missing physical processes - most active in convective regions

Summary - CCPP-support Suites and Schemes

Physics suites	GFS_v15p2	GFS_v16beta	GFS_v15p2_no_nsst	GFS_v16beta_no_nsst
Deep Cu	SAS-based Mass-Flux Deep Convection (sa)	SAS-based Mass-Flux Deep Convection (sa)	SAS-based Mass-Flux Deep Convection (sa)	SAS-based Mass-Flux Deep Convection (sa)
Shallow Cu	SAS-based Mass-Flux Shallow Convection (sa)	SAS-based Mass-Flux Shallow Convection (sa)	SAS-based Mass-Flux Shallow Convection (sa)	SAS-based Mass-Flux Shallow Convection (sa)
Microphysics	GFDL (sa)	GFDL (sa)	GFDL (sa)	GFDL (sa)
PBL/TURB	Hybrid EDMF PBL and Free Atmospheric Turbulence	Scale-aware TKE-based Moist EDMF PBL and Free Atmospheric Turbulence (sa)	Hybrid EDMF PBL and Free Atmospheric Turbulence	Scale-aware TKE-based Moist EDMF PBL and Free Atmospheric Turbulence (sa)
Radiation	RRTMG	RRTMG	RRTMG	RRTMG
Surface Layer	GFS	GFS	GFS	GFS
Land	Noah LSM	Noah LSM	Noah LSM	Noah LSM
GWD	UGWD0	UGWD0	UGWD0	UGWD0
Ocean	NSST	NSST	SOS	SOS
Ozone	Ozone (2015)	Ozone (2015)	Ozone (2015)	Ozone (2015)
Water Vapor	NRL H2O	NRL H2O	NRL H2O	NRL H2O

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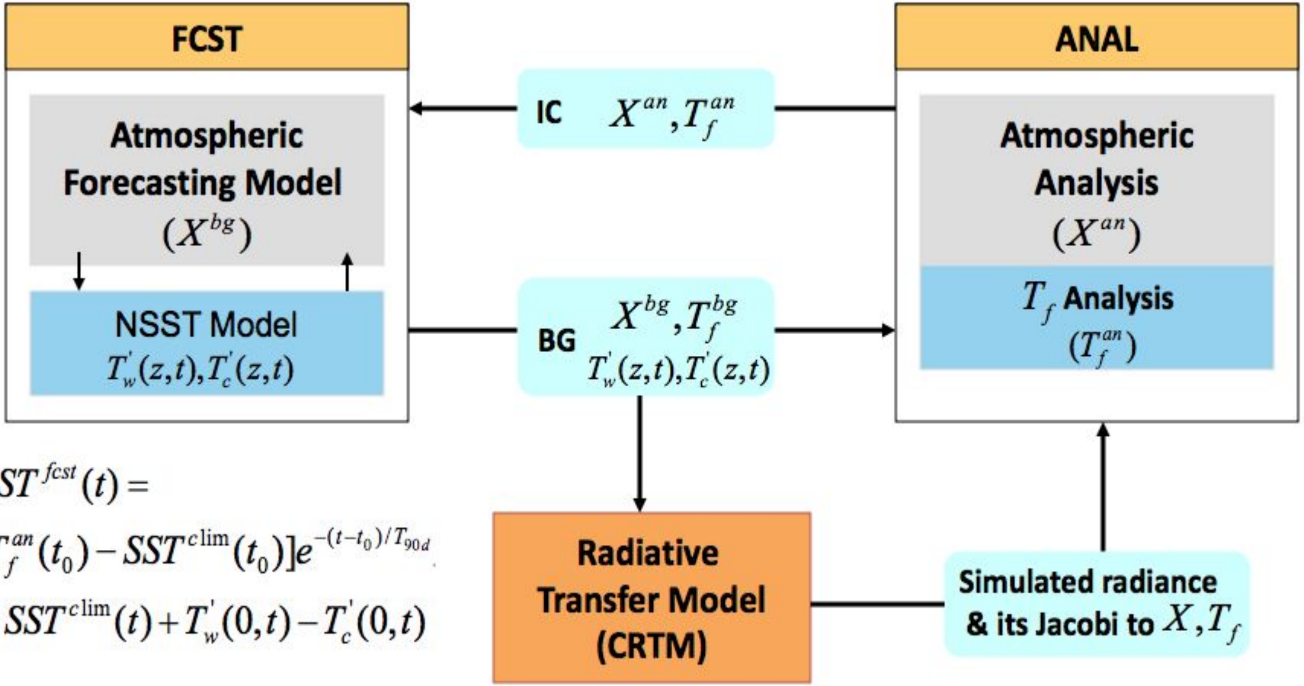
*This is an incomplete list.

Appendix

NSST



$$SST^{fcst}(t) = [T_f^{an}(t_0) - SST^{clim}(t_0)]e^{-(t-t_0)/T_{90d}} + SST^{clim}(t) + T_w'(0,t) - T_c'(0,t)$$

$$T_{crtm}(z_{ch},t) = T^{fcst}(z_{ch},t)$$

$$T^{fcst}(z,t) = T_f^{bg}(z_w,t) + T_w'(z,t) - T_c'(z,t)$$

Cloud-Radiation interaction

- Clouds strongly impact solar and thermal radiation. Clouds cast shadows on the ground which locally reduces convection and feeds back on cloud structure
- The cloud fraction profiles impact the radiation
- Solar and thermal radiation impact cloud formation and evolution indirectly

namelist **&gfs_physics_nml (1)**

Option	Description	Default value
fhzero	time between clearing of diagnostic buckets (hour)	0.0
h20_phys	logical flag for stratosphere h2o scheme	.false.
oz_phys	logical flag for old (2006) ozone physics	.true.
oz_phys_2015	logical flag for new (2015) ozone physics	.false.
ncld	number of hydrometeors	1
imp_physics	options of microphysics scheme: 8: Thompson microphysics scheme 10: Morrison-Gettelman microphysics scheme 11: GFDL microphysics scheme	99
imfshalcnv	options for mass flux shallow convective scheme: -1: no shallow convection used 0: modified Tiedtke's eddy-diffusion shallow convective scheme 1: July 2010 version of mass-flux shallow convective scheme (operational as of 2016) 2: scale- & aerosol-aware mass-flux shallow convective scheme (2017) 3: scale- & aerosol-aware Grell-Freitas scheme (GSD) 4: new Tiedtke scheme (CAPS)	1
imfdeepcnv	options for mass-flux deep convective scheme: -1: Chikira-Sugiyama deep convection (with **cscnv** = .T.) 1: July 2010 version of SAS convective scheme (operational version as of 2016) 2: scale- & aerosol-aware mass-flux deep convective scheme (2017) 3: scale- & aerosol-aware Grell-Freitas scheme (GSD) 4: new Tiedtke scheme (CAPS)	1

namelist **&gfs_physics_nml (2)**

Option	Description	Default value
hybedmf	logical flag for hybrid EDMF PBL scheme	.false.
satmedmf	logical flag for TKE EDMF PBL scheme	.false.
isatmedmf	logical flag for scale-aware TKE-based moist EDMF scheme 0: initial version of satmedmf (Nov.2018) 1: updated version of satmedmf (as of May 2019)	0
do_mynnedmf	logical flag to activate MYNN-EDMF scheme	.false.
shinhong	logical flag for scale-aware Shinhong PBL scheme	.false.
do_ysu	logical flag for YSU PBL scheme	.false.
lsm	logical flag for land surface model to use: 1 Noah, 2 RUC, 3 Noah-MP	1
lsoil	number of soil levels	4
nstf_name(5)	NSST related parameters nstf_name(1): 0=NSST off, 1= NSST on and uncoupled, 2= NSST on and coupled nstf_name(2): 1=NSST spin up on, 0=NSST spin up off nstf_name(3): 1=NSST analysis on, 0=NSST analysis off nstf_name(4): zsea1 in mm nstf_name(5): zsea2 in mm	/0,0,1,0,5/
do_mynnsfclay	logical flag to activate MYNN-SFCLAY scheme	.false.
bl_mynn_edmf	logical flag to activate the mass-flux scheme 0: deactivate mass-flux scheme 1: activate dynamic multiplume mass-flux scheme	0

namelist **&gfs_physics_nml (3)**

Option	Description	Default value
cdmbgwd(4)	multiplication factors for mountain blocking(1), orographic gravity wave drag(2) [1]: GWDPS mountain blocking [2]: GWDPS orographic gravity wave drag [3]: the modulation total momentum flux of NGWs by intensities of the total precipitation [4]: TKE for future tests and applications	2.0,0.25,1.0,1.0
lsoil_lsm	number of soil layers internal to land surface model	-1
……	……	……
do_ugwp	logical flag for CIRES UGWP revised OGW .T.: revised gwdps_v0 .F.: GFS operational orographic gwdps	.false.
do_tofd	logical flag for turbulent orographic form drag	.false.
do_sppt	logical flag for stochastic SPPT option	.false.
do_shum	logical flag for stochastic SHUM option	.false.
do_skeb	logical flag for stochastic SKEB option	.false.
do_sfcperts	logical flag for stochastic surface perturbations option	.false.

namelist **&gfdl_cloud_microphysics_nml**

Option	Description	Default value
fast_sat_adj	logical flag for adjusting cloud water evaporation (cloud water -> water vapor), cloud water freezing (cloud water -> cloud ice), cloud ice deposition (water vapor -> cloud ice) when fast saturation adjustment is activated (**do_sat_adj** = .true. in **fv_core_nml** block)	.true.
ccn_l	base CCN over land. Increasing(decreasing) `ccn_l` can on the one hand boost(decrease) the autoconversion of cloud water to rain, on the other hand make the autoconversion harder(easier). The unit is cm^{-3}	270
ccn_o	base CCN over ocean. Increasing(decreasing) `ccn_o` can on the one hand boost(decrease) the autoconversion of cloud water to rain, on the other hand make the autoconversion harder(easier). The unit is cm^{-3}	90
sat_adj0	adjust factor for condensation of water vapor to cloud water (water vapor->cloud water) and deposition of water vapor to cloud ice	0.9
mp_time	time step of GFDL cloud microphysics (MP). If `mp_time` isn't divisible by physics time step or is larger than physics time step, the actual MP time step becomes `dt/NINT`[dt/MIN(dt,mp_time)]	150
……	….	……

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namelist **&gfdl_cloud_microphysics_nml**

Option	Description	Default value
fast_sat_adj	logical flag for adjusting cloud water evaporation (cloud water -> water vapor), cloud water freezing (cloud water -> cloud ice), cloud ice deposition (water vapor -> cloud ice) when fast saturation adjustment is activated (**do_sat_adj** = .true. in **fv_core_nml** block)	.true.
ccn_l	base CCN over land. Increasing(decreasing) `ccn_l` can on the one hand boost(decrease) the autoconversion of cloud water to rain, on the other hand make the autoconversion harder(easier). The unit is cm^{-3}	270
ccn_o	base CCN over ocean. Increasing(decreasing) `ccn_o` can on the one hand boost(decrease) the autoconversion of cloud water to rain, on the other hand make the autoconversion harder(easier). The unit is cm^{-3}	90
sat_adj0	adjust factor for condensation of water vapor to cloud water (water vapor->cloud water) and deposition of water vapor to cloud ice	0.9
mp_time	time step of GFDL cloud microphysics (MP). If `mp_time` isn't divisible by physics time step or is larger than physics time step, the actual MP time step becomes `dt/NINT`[dt/MIN(dt,mp_time)]	150
……	….	……

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namelist **&cires_ugwp_nml**

Option	Description	Default value
knob_ugwp_version	parameter selects a version of the UGWP implementation in FV3GFS-127L 0: default version delivered to EMC in Jan 2019 for implementation 1: version of UGWP under development that plans to consider the physics-based sources of NGWs (**knob_ugwp_wvspec** [2:4]), options for stochastic and deterministic excitation of waves (**knob_ugwp_stoch**), and switches between different UGWP schemes (**knob_ugwp_solver**)	0
knob_ugwp_doaxyz	parameter controls application of the momentum deposition for NGW-schemes 0: the momentum tendencies due to NGWs are calculated, but tendencies do not change the horizontal winds 1: default value; it changes the horizontal momentum tendencies and horizontal winds	1
knob_ugwp_doheat	parameter controls application of the heat deposition for NGW-schemes 0: the temperature tendencies due to NGWs are calculated but tendencies do not change the temperature state 1: default value; it changes the temperature tendencies and kinetic temperature	1
launch_level	parameter has been introduced by EMC during implementation. It defines the interface model level from the surface at which NGWs are launched. Default value for FV3GFS-64L, launch_level=25 and for FV3GFS-128L, launch_level=52.	55
……	….	……

namelist **&stochy_nam**

Option	Description	Default value
use_zmtnblck	logical flag for mountain blocking. .T. = do not apply perturbations below the dividing streamline that is diagnosed by the gravity wave drag, mountain blocking scheme	.false.
ntrunc	spectral resolution (e.g. T126) of random patterns	-999
lon_s, lat_s	number of longitude and latitude point for the Gaussian grid	-999
fhstoch	forecast hour to write out random pattern in order to restart the pattern for a different forecast (used in DA), file is stoch_out.F<HHH>	-999
stochini	set to true if wanting to read in a previous random pattern (input file need to be named `stoch_ini`)	.false.
sppt	amplitude of random patterns	-999.
sppt_tau	decorrelation timescales in seconds	-999.
sppt_lscale	decorrelation spatial scales in meters	-999.
sppt_logit	logit transform for SPPT to bounded interval [-1,+1]	.false.
iseed_sppt	seeds for setting the random number sequence (ignored if `stochini` is true)	0
sppt_sigtop1, sppt_sigtop2	sigma levels to taper perturbations to zeros	0.1, 0.025
sppt_sfclimit	reduce amplitude of SPPT near surface (lowest 2 levels)	.false.
shum	amplitude of stochastic boundary layer specific humidity perturbations	-999.
……	….	……

namelist **&nam_sfcperts**

Option	Description	Default value
nsfcpert	number of weights for stochastic surface perturbation	0
pertz0	magnitude of perturbation of momentum roughness length	-999.
pertzt	magnitude of perturbation of heat to momentum roughness length ratio	-999.
pertshc	magnitude of perturbation of soil hydraulic conductivity	-999.
pertai	magnitude of perturbation of leaf area index	-999.
pertalb	magnitude of surface albedo perturbation	-999.
pertvegf	magnitude of perturbation of vegetation fraction	-999.
iseed_sfc	random seeds (if 0 use system clock)	0
sfc_tau	time scales	-999.
sfc_lscale	length scales	-999.
sppt_land	sppt over land	.false.