FV3-Physics Coupling

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2020 UFS MRW Application Training

Outline

- Physics Interface
- Mass and Total Energy Definitions vs. GFS Physics
- Moist Thermodynamics
- Application of the GFDL Microphysics
- Integrated Physics

Dynamics: a *Finite-Volume* of moist air:
dry air + water vapor + liquid water + solid water

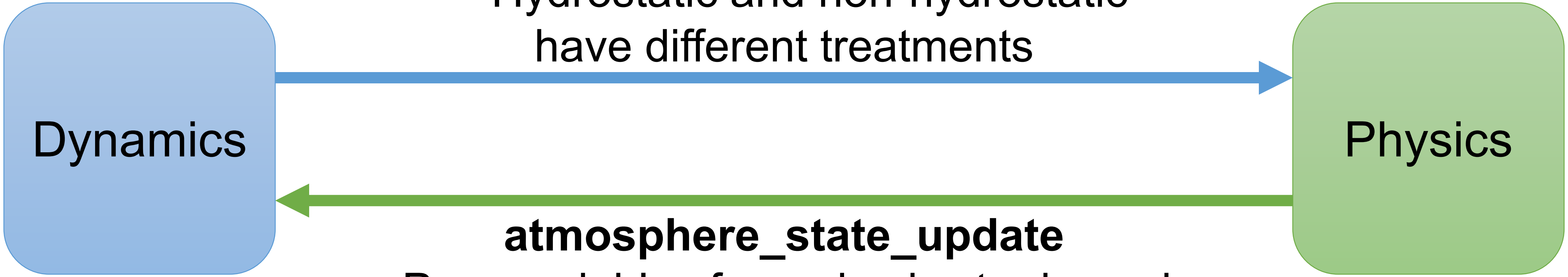
Physics: dry air + water vapor

Heat Capacities ($J \cdot kg^{-1} \cdot K^{-1}$) of
Dry Air = 1004.6/717.56, Water Vapor = 1846/1410, Liquid Water = 4218, Solid Water = 2106

Physics Interface

atmos_phys_driver_statein

- Pass variables from dynamics to physics
- 32-bit to 64-bit conversion (if necessary)
- Hydrostatic and non-hydrostatic have different treatments



atmosphere_state_update

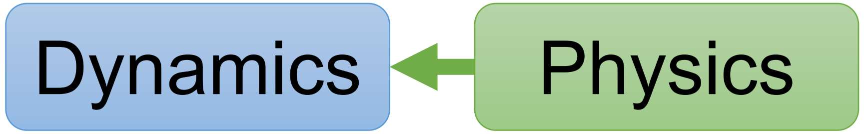
- Pass variables from physics to dynamics
- 64-bit to 32-bit conversion (if necessary)
- Fix negative tracer values by vertical mixing
- Diagnostic of atmospheric variables

atmos_phys_driver_statein

Dynamics → Physics

- Air temperature (T) is passed without change.
- A-grid zonal and meridional wind (u, v) are passed without change.
- Vertical velocity (ω) is passed without change.
- Pressure thickness (δp) is passed after removing liquid and solid water.
- Tracer (q) is converted to mass mixing ratio regarding to dry air and water vapor.
- Edge layer height (z_e) is the sum of height thickness (δz) from the surface.
- Middle layer height (z_m) is the arithmetic mean of edge layer height (z_e).
- Edge layer pressure (p_e) is the sum of pressure thickness (δp) from model top.
- Middle layer pressure (p_m) is computed using the gas law.

atmosphere_state_update



- Air temperature tendency for all physics ($\delta T/\delta t$) is used to update temperature. Heat capacity conversion is applied.
- Zonal and meridional wind tendencies for all physics ($\delta u/\delta t$, $\delta v/\delta t$) are used to update C-, D-grid winds.
- Pressure thickness (δp) is passed after adding liquid and solid water back.
- Tracer (q) is converted back to the mass mixing ratio regarding to total air.

Mass Definition

Dynamics vs. Physics

- Pressure thickness (δp) is defined regarding to the total mass of air:

$$m_a = m_d + m_v + m_l + m_i + m_r + m_s + m_g$$

- Tracers' mass mixing ratio (q) is defined regarding to total mass:

$$q_v = \frac{m_v}{m_a},\ q_l = \frac{m_l}{m_a},\ \ldots$$

- Pressure thickness (δp) is defined regarding to the mass of dry air and water vapor:

$$m_d + m_v$$

- Tracers' mass mixing ratio (q) is defined regarding to the mass of dry air and water vapor:

$$q_v = \frac{m_v}{m_d+m_v},\ q_l = \frac{m_l}{m_d+m_v},\ \ldots$$

Mass Conversion

Dynamics vs. Physics

- Before being passed to the physics, pressure thickness (δp) is converted to that of dry air and water vapor mass:

$$\delta p\left[1-\left(q_l+q_i+q_r+q_s+q_g\right)\right]$$

- Tracers (q) are converted to that of dry air and water vapor mass:

$$\frac{q_v}{1-(q_l+q_i+q_r+q_s+q_g)}, \frac{q_l}{1-(q_l+q_i+q_r+q_s+q_g)}, \dots$$

- Before being passed to the dynamics, pressure thickness (δp) is converted to that of total mass:

$$\delta p\left[1+q_l+q_i+q_r+q_s+q_g\right]$$

- Tracers (q) are converted to that of total mass:

$$\frac{q_v}{1+q_l+q_i+q_r+q_s+q_g}, \frac{q_l}{1+q_l+q_i+q_r+q_s+q_g}, \dots$$

Total Energy Definition

Dynamics vs. Physics

- For the dry dynamics, total energy is defined as (Lin 2004):

$$c_v T + \phi + \frac{1}{2}(u^2 + v^2 + w^2)$$

- If it involves moist processes, internal energy $c_v T$ is redefined as (Emanuel 1994):

$$c_{vm} T + L_v q_v - L_i\left(q_i + q_s + q_g\right)$$

$$c_{vm} = c_{vd} + c_{vv} q_v + c_{vl}(q_l + q_r) + c_{vs}\left(q_i + q_s + q_g\right)$$

$$L_v = L_{v0} - (c_{vv} - c_{vl}) T_0 \quad L_i = L_{i0} - (c_{vl} - c_{vs}) T_0$$

- Total energy is defined as:

$$c_p T + \phi + \frac{1}{2}(u^2 + v^2 + w^2)$$

Total Energy Conversion

Dynamics vs. Physics

- Heating from the physics is converted to proportional heating in the dynamics:

$$\Delta T_{dynamics} = \frac{c_p}{c_{vm}} \Delta T_{physics}$$

Moist Thermodynamics

Dynamics

- According to the definition of total energy for moist processes, define the n-th and (n+1)-th time step internal energy (IE) as:

$$IE^n = c_{vm}^n T^n + L_v q_v^n - L_i\left(q_i^n + q_s^n + q_g^n\right)$$

$$IE^{n+1} = c_{vm}^{n+1} T^{n+1} + L_v q_v^{n+1} - L_i\left(q_i^{n+1} + q_s^{n+1} + q_g^{n+1}\right)$$

- Based on energy conservation ($IE^n = IE^{n+1}$), we can get the relationship:

$$\Delta T = \frac{[L_{v0} + L_{i0} + (c_{vv} - c_{vs})(T^n - T_0)]}{c_{vm}^{n+1}} \Delta q$$

- This thermodynamics relationship applies to moist processes in dynamics, e.g., fast saturation adjustment, the Inline GFDL Microphysics.

Application of the GFDL Microphysics

Dynamics

- The GFDL Microphysics is developed following the definitions of mass and total energy in the FV3 dynamical core.
- Mass and total energy are precisely conserved inside the microphysics scheme.
- To work together with other physics, mass and total energy are converted before and after the microphysics scheme.
- In the past few years, the GFDL Microphysics has been embedded into the FV3. Microphysical processes tie to the dynamics processes and no conversion is needed.

Zhou et al. (2019) BAMS; Harris et al. (2020) JAMES

Integrated Physics

Dynamics & Physics

- Traditionally, dynamics and physics are separated. They are linked through the physics interface.
- Moving forward requires breaking the strict separation of dynamics and physics.
- Sub-grid orographic effects are fast processes; microphysics and pollutant source and sink are intermediate processes; radiation, PBL etc. are relatively slow processes.
- Partially-resolved and fast processes can be integrated directly into FV3 for better dynamical consistency, energy conservation, and efficiency.