WRF Physics Options

Jimy Dudhia

WRF Physics

- Turbulence/Diffusion (diff_opt, km_opt)
- Radiation
  - Longwave (ra_lw_physics)
  - Shortwave (ra_sw_physics)
- Surface
  - Surface layer (sf_sfclay_physics)
  - Land/water surface (sf_surface_physics)
- PBL (bl_physics)
- Cumulus parameterization (cu_physics)
- Microphysics (mp_physics)

Turbulence/Diffusion

Sub-grid eddy mixing effects on all fields, e.g.

$$\frac{\partial}{\partial x} K_h \frac{\partial}{\partial x}\theta + \frac{\partial}{\partial y} K_h \frac{\partial}{\partial y}\theta + \frac{\partial}{\partial z} K_v \frac{\partial}{\partial z}\theta$$

diff_opt=1

- ◆ 2nd order diffusion on model levels
  - Constant vertical coefficient (kvdif) or use with PBL
  - For theta, only perturbation from base state is diffused
- ◆ km_opt selects method to compute K
  - 1: constant (khdif and kvdif used)
  - 4: 2D Smagorinsky (deformation based on horizontal wind for horizontal diffusion only)

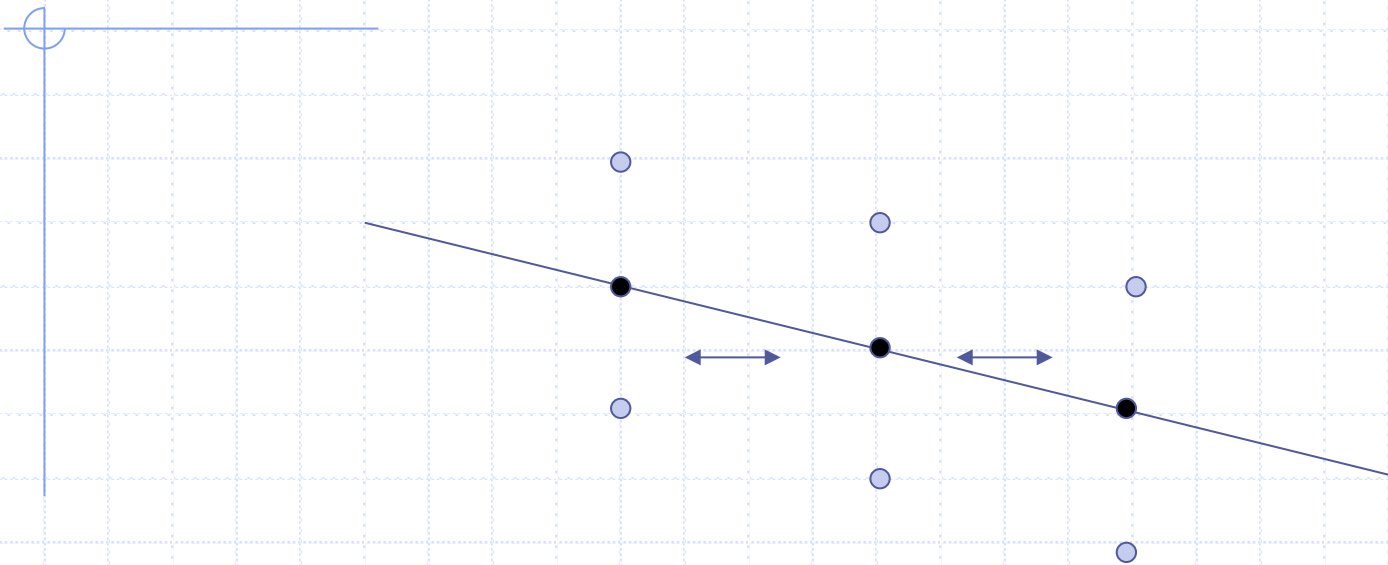# Difference between diff_opt 1 and 2

mixing
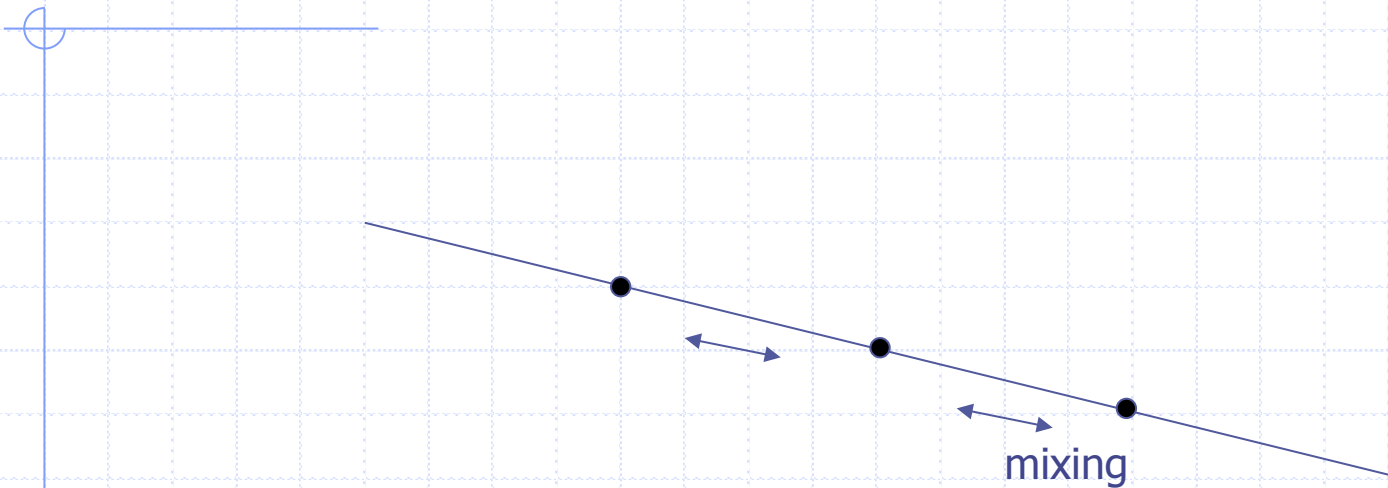
diff_opt=1

Horizontal diffusion acts along model levels

Simpler numerical method with only neighboring
   points on the same model level

Difference between diff_opt 1 and 2

diff_opt=2

Horizontal diffusion acts along model levels

Numerical method includes vertical correction term using more grid points

diff_opt=2

- ◆ 2nd order horizontal diffusion
- ◆ Allows for terrain-following coordinate
- ◆ km_opt selects method to compute K
  - 1: constant (khdif and kvdif used)
  - 2: 1.5-order TKE prediction
  - 3: Smagorinsky (deformation/stability based K)
  - 4: 2D Smagorinsky (deformation based on horizontal wind for horizontal diffusion only)

diff_opt=2 (continued)

◆ mix_full_fields=.true.: vertical diffusion acts on full (not perturbation) fields (recommended, but default = .false.)

◆ mix_isotropic=1: same length scale used for horizontal and vertical diffusion (for dx≈dz)

◆ Idealized constant surface fluxes can be added in diff_opt=2 using namelist (dynamics section). Not available for diff_opt=1.

- tke_drag_coefficient (C_D)
- tke_heat_flux (=$H/\rho c_p$)
- Must use isfflx=0 to use these switches

diff_opt=2 (continued)

- ◆ Explicit large-eddy simulation (LES) PBL in real-data cases (V3) or idealized cases
  - bl_pbl_physics = 0
    - ◆ isfflx = 0 (idealized drag and heat flux from namelist)
    - ◆ isfflx = 1 (drag and heat flux from physics)
      - sf_sfclay_physics=1
      - sf_surface_physics (choose non-zero option)
    - ◆ isfflx = 2 (drag from physics, heat flux from tke_heat_flux)
      - sf_sfclay_physics=1
  - km_opt = 2 or 3
  - mix_isotropic=1 (if dx and dz are of same order)
- ◆ Not available for diff_opt=1.

Diffusion Option Choice

- Real-data case with PBL physics on
  - Best is diff_opt=1, km_opt=4
  - This complements vertical diffusion done by PBL scheme
- High-resolution real-data cases (~100 m grid)
  - No PBL
  - diff_opt=2; km_opt=2,3 (tke or Smagorinsky scheme)
- idealized cloud-resolving modeling (smooth or no topography)
  - diff_opt=2; km_opt=2,3
- Complex topography with no PBL scheme
  - diff_opt=2 is more accurate for sloped coordinate surfaces, and prevents diffusion up/down valley sides
- Note: WRF can run with no diffusion (diff_opt=0)

diff_6th_opt

- 6th order optional added horizontal diffusion on model levels
  - Used as a numerical filter for 2*dx noise
  - Suitable for idealized and real-data cases
  - Affects all advected variables including scalars
- diff_6th_opt
  - 0: none (default)
  - 1: on (can produce negative water)
  - 2: on and prohibit up-gradient diffusion (better for water conservation)
- diff_6th_factor
  - Non-dimensional strength (typical value 0.12, 1.0 corresponds to complete removal of 2*dx wave in a time-step)

damp_opt=1

- Upper level diffusive layer
- Enhanced horizontal diffusion at top
- Also enhanced vertical diffusion at top for diff_opt=2
- Cosine function of height
- Uses additional parameters
  - zdamp: depth of damping layer
  - dampcoef: nondimensional maximum magnitude of damping
- Works for idealized cases and real-data since 2.2 release

ARW only

damp_opt=2

◆ Upper level relaxation towards 1-d profile

◆ Rayleigh (relaxation) layer

◆ Cosine function of height

◆ Uses additional parameters

- zdamp: depth of damping layer
- dampcoef: inverse time scale (s^{-1})

◆ Works for idealized cases only

damp_opt=3

- ◆ "W-Rayleigh" (relaxation) layer
- ◆ Upper level relaxation towards zero vertical motion
- ◆ Cosine function of height
- ◆ Uses additional parameters
  - ▪ zdamp: depth of damping layer
  - ▪ dampcoef: inverse time scale (s^{-1})
- ◆ Works for idealized and real-data cases
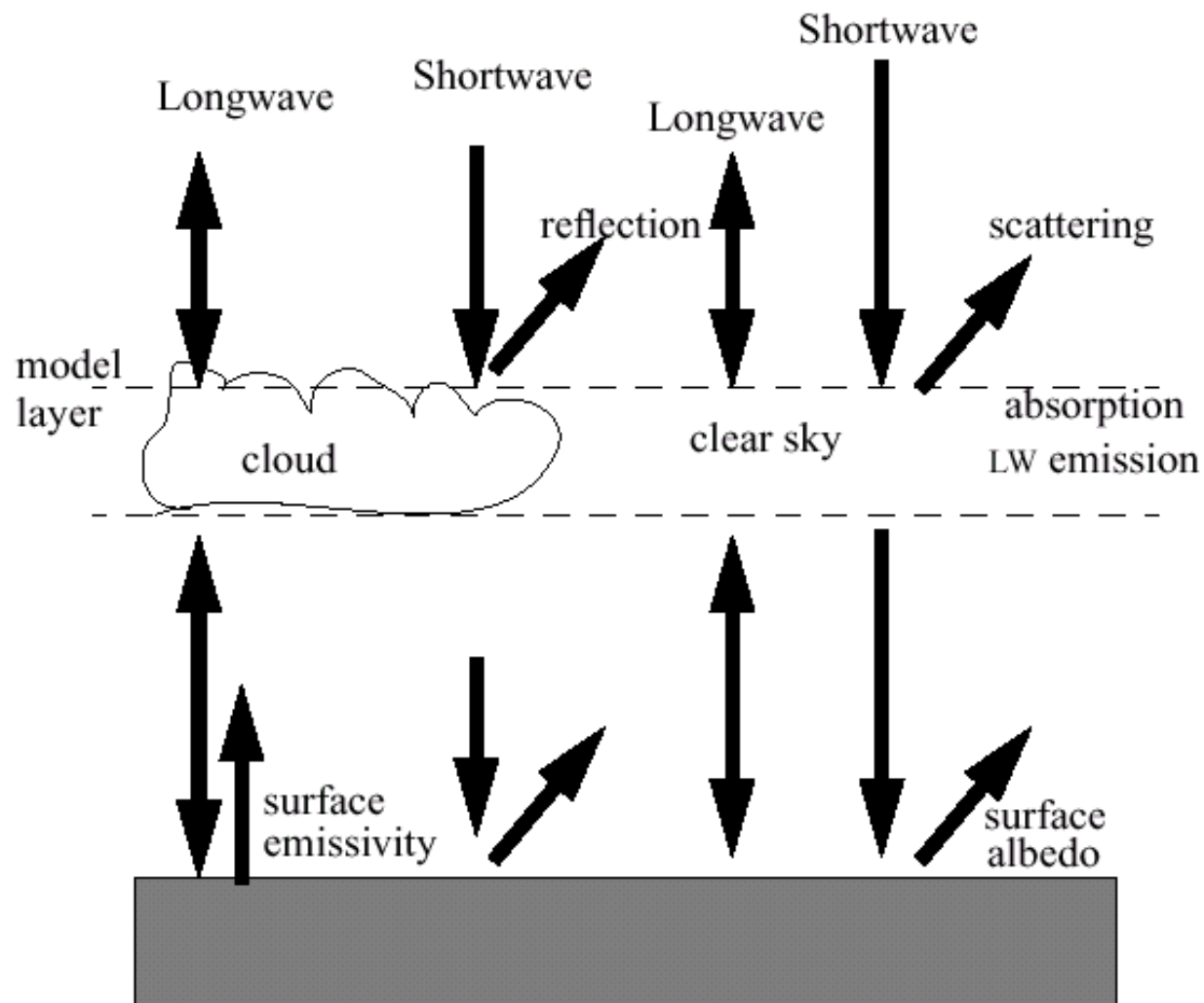- ◆ Applied in small time-steps (dampcoef=0.2 is stable)

Radiation

Atmospheric temperature tendency

Surface radiative fluxes

Illustration of Free Atmosphere Radiation Processes

ra_lw_physics=1

RRTM scheme

- Spectral scheme
- K-distribution
- Look-up table fit to accurate calculations
- Interacts with resolved clouds
- Ozone profile specified
- CO_2 constant (well-mixed)

ra_lw_physics=3

CAM3 scheme

- ◆ Spectral scheme
- ◆ 8 longwave bands
- ◆ Look-up table fit to accurate calculations
- ◆ Interacts with cloud fractions
- ◆ Can interact with trace gases and aerosols
- ◆ Ozone profile function of month, latitude
- ◆ CO_2 changes based on year (since V3.1)

ra_lw_physics=4

RRTMG longwave scheme (Since V3.1)

- Spectral scheme
- 16 longwave bands (K-distribution)
- Look-up table fit to accurate calculations
- Interacts with cloud fractions (MCICA, Monte Carlo Independent Cloud Approximation random overlap method)
- Can interact with trace gases and aerosols
- Ozone profile specified
- CO_2 and trace gases specified

ra_lw_physics=31

Held-Suarez relaxation term

- ◆ For Held-Suarez global idealized test
- ◆ Relaxation towards latitude and pressure-dependent temperature function
- ◆ Simple code - can be used as basis for other simplified radiation schemes, e.g relaxation or constant cooling functions

ra_lw_physics=99

GFDL longwave scheme

- used in Eta/NMM
- Default code is used with Ferrier microphysics
    - Remove #define to compile for use without Ferrier
- Spectral scheme from global model
- Also uses tables
- Interacts with clouds (cloud fraction)
- Ozone profile based on season, latitude
- CO_2 fixed
- ra_lw_physics=98 (nearly identical) for HWRF

ra_sw_physics=1

MM5 shortwave (Dudhia)

- Simple downward calculation
- Clear-sky scattering
  - swrad_scat tuning parameter
    - 1.0 = 10% scattered, 0.5=5%, etc.
  - WRF-Chem aerosol effect (PM2.5)
- Water vapor absorption
- Cloud albedo and absorption
- No ozone effect (model top below 50 hPa OK)

ra_sw_physics=2

Goddard shortwave

- Spectral method
- Interacts with resolved clouds
- Ozone profile (tropical, summer/winter, mid-lat, polar)
- CO2 fixed
- WRF-Chem optical thicknesses

ra_sw_physics=3

CAM3 shortwave

- ◆ Spectral method (19 bands)
- ◆ Interacts with cloud fractions
- ◆ Ozone/CO2 profile as in CAM longwave
- ◆ Can interact with aerosols and trace gases
- ◆ Note: CAM schemes need some extra namelist items (see README.namelist)

ra_sw_physics=4

RRTMG shortwave (Since V3.1)

◆ Spectral method (14 bands)

◆ Interacts with cloud fractions (MCICA method)

◆ Ozone/CO2 profile as in RRTMG longwave

◆ Can interact with aerosols

◆ Trace gases specified

ra_sw_physics=99

GFDL shortwave

- ◆ Used in Eta/NMM model
- ◆ Default code is used with Ferrier microphysics (see GFDL longwave)
- ◆ Ozone/CO2 profile as in GFDL longwave
- ◆ Interacts with clouds (and cloud fraction)
- ◆ ra_lw_physics=98 (nearly identical) for HWRF

Slope effects on shortwave

- In V3.2 available for all shortwave options
- Represents effect of slope on surface solar flux accounting for diffuse/direct effects
- slope_rad=1: activates slope effects - may be useful for complex topography and grid lengths < 2 km.
- topo_shading=1: shading of neighboring grids by mountains - may be useful for grid lengths < 1 km.

radt

Radiation time-step recommendation

- Radiation is too expensive to call every step
- Frequency should resolve cloud-cover changes with time
- radt=1 minute per km grid size is about right (e.g. radt=10 for dx=10 km)
- Each domain can have its own value but recommend using same value on all 2-way nests

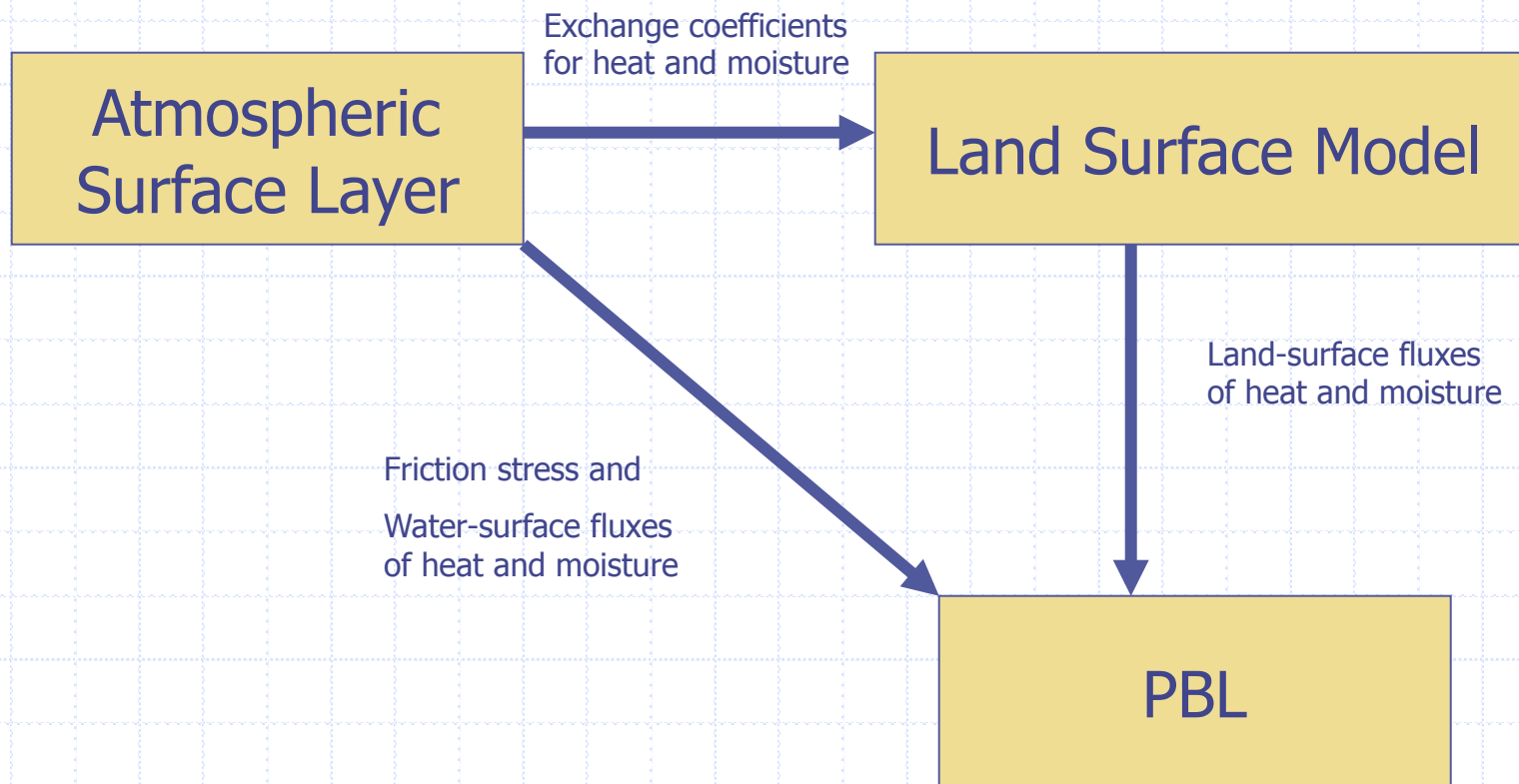# nrads/nradl

Radiation time-step recommendation

- Number of fundamental steps per radiation call
- Operational setting should be 3600/dt
- Higher resolution could be used, e.g. 1800/dt
- Recommend same value for all nested domains

Surface schemes

Surface layer of atmosphere diagnostics (exchange/transfer coeffs)

Land Surface: Soil temperature / moisture /snow prediction /sea-ice temperature

Surface Physics Components

Atmospheric Surface Layer

Land Surface Model

PBL

Exchange coefficients for heat and moisture

Land-surface fluxes of heat and moisture

Friction stress and

Water-surface fluxes of heat and moisture

Surface Fluxes

◆ Heat, moisture and momentum

$$H = \rho c_p u_* \theta_* \qquad E = \rho u_* q_* \qquad \tau = \rho u_* u_*$$

$$u_* = \frac{k V_r}{\ln(z_r / z_0) - \psi_m} \qquad \theta_* = \frac{k \Delta \theta}{\ln(z_r / z_{0h}) - \psi_h} \qquad q_* = \frac{k \Delta q}{\ln(z_r / z_{0q}) - \psi_h}$$

Subscript r is reference level (lowest model level, or 2 m or 10 m)
z_0 are the roughness lengths

Roughness Lengths

- Roughness lengths are a measure of the "initial" length scale of surface eddies, and generally differ for velocity and scalars
- Roughness length depends on land-use type
- Some schemes use smaller roughness length for heat than for momentum
- For water points roughness length is a function of surface wind speed

Exchange Coefficient

◆ C_{hs} is the exchange coefficient for heat, defined such that

$$H = \rho c_p C_{hs} \Delta \theta$$

It is related to the roughness length and u* by

$$C_{hs} = \frac{ku_*}{\ln\left(\dfrac{z}{z_0}\right) - \psi_h}$$

sf_sfclay_physics=1

Monin-Obukhov similarity theory

- Taken from standard relations used in MM5 MRF PBL
- Provides exchange coefficients to surface (land) scheme
- iz0tlnd thermal roughness length options for land points (0: Original Carlson-Boland, 1: Chen-Zhang)
  - Chen and Zhang (2009, JGR) modifies Zilitinkevich method with vegetation height
- Should be used with bl_pbl_physics=1 or 99

sf_sfclay_physics=2

Monin-Obukhov similarity theory

- ◆ Modifications due to Janjic
- ◆ Taken from standard relations used in NMM model, including Zilitinkevich thermal roughness length
- ◆ iz0tlnd thermal roughness length options for land points (0: Original Zilitinkevich, 1: Chen-Zhang)
- ◆ Should be used with bl_pbl_physics=2

sf_sfclay_physics=3

GFS Monin-Obukhov similarity theory

- For use with NMM-LSM
- Should be used with bl_pbl_physics=3
- Option 88 is the HWRF version

sf_sfclay_physics=4

QNSE Monin-Obukhov similarity theory (New in V3.1)

- ◆ For use with QNSE-PBL
- ◆ Should be used with bl_pbl_physics=4
- ◆ Very similar to MYJ SFC
- ◆ New stability functions

sf_sfclay_physics=5

MYNN Monin-Obukhov similarity theory
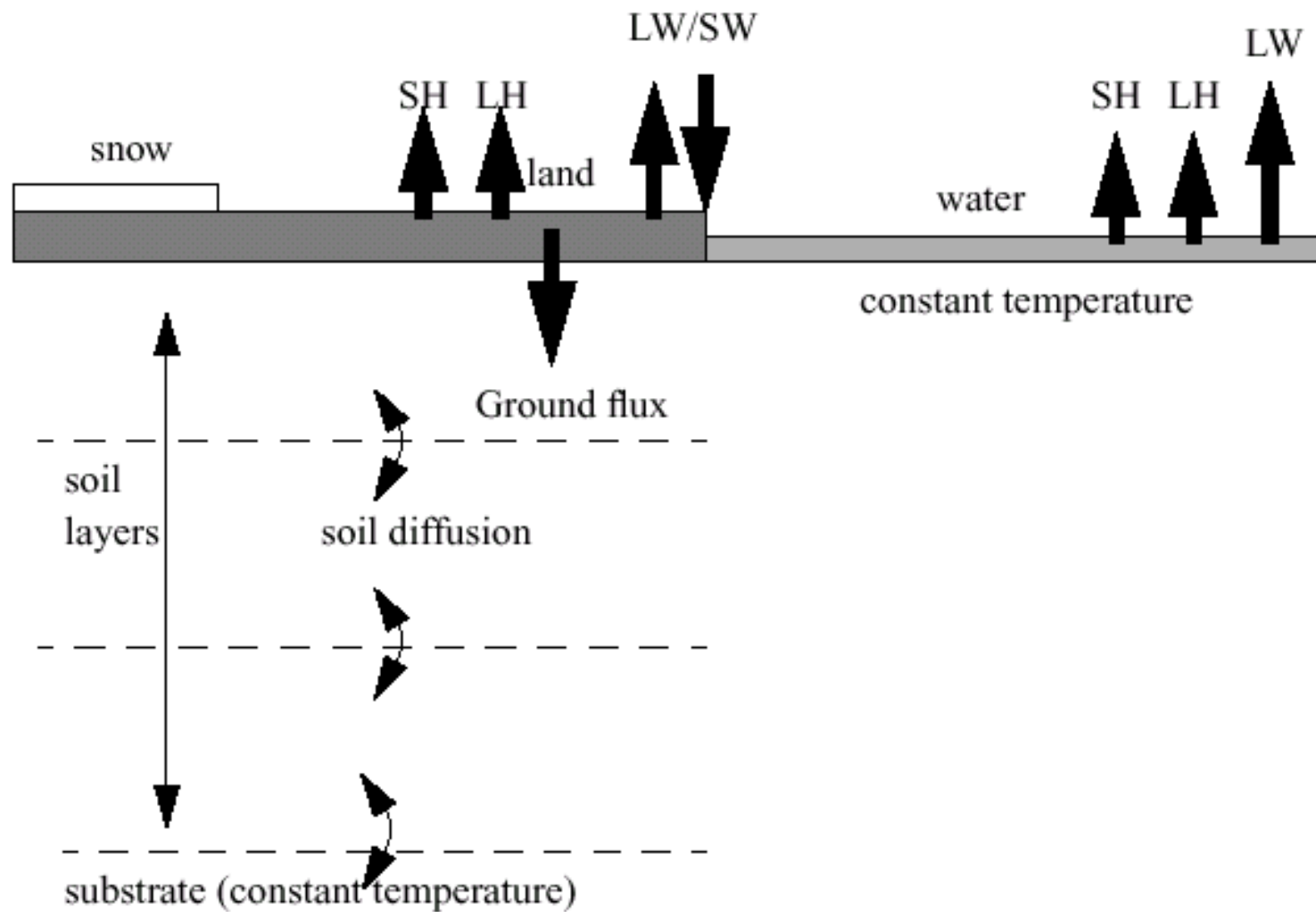 (New in V3.1)

◆ For use with MYNN-PBL

◆ Should be used with bl_pbl_physics=5

sf_sfclay_physics=7

Pleim-Xiu surface layer (EPA)

◆ For use with PX LSM and ACM PBL

- Should be used with sf_surface_physics=7 and bl_pbl_physics=7

◆ New in Version 3

Illustration of Surface Processes

sf_surface_physics=1

5-layer thermal diffusion model from MM5

- Predict ground temp and soil temps
- Thermal properties depend on land use
- No soil moisture or snow-cover prediction
- Moisture availability based on land-use only
- Provides heat and moisture fluxes for PBL

sf_surface_physics=2

Noah Land Surface Model (Unified ARW/NMM version in Version 3)

- Vegetation effects included
- Predicts soil temperature and soil moisture in four layers and diagnoses skin temperature
- Predicts snow cover and canopy moisture
- Handles fractional snow cover and frozen soil
- New time-varying snow albedo (in V3.1)
- Provides heat and moisture fluxes for PBL
- Noah has 2 Urban Canopy Model options (sf_urban_physics, ARW only)

sf_urban_physics=1

Urban Canopy Model (UCM, Kusaka et al.)

- Sub-grid wall, roof, and road effects on radiation and fluxes
- Anthropogenic heat source can be specified
- Can use low, medium and high density urban categories

sf_urban_physics=2

Building Environment Parameterization (BEP, Martilli et al.)

- ◆ Sub-grid wall, roof, and road effects on radiation and fluxes
- ◆ Can be used with MYJ PBL or BouLac PBL to represent buildings higher than lowest model levels (Multi-layer urban model)
- ◆ Needs additional sub-grid building fractional area information

sf_urban_physics=3

Building Energy Model (BEM, Martilli and Salamanca)

- ◆ Includes anthropogenic building effects (heating, air-conditioning) in addition to BEP
- ◆ Can be used with MYJ PBL or BouLac PBL to represent buildings higher than lowest model levels (Multi-layer urban model)
- ◆ Needs additional sub-grid building fractional area information

sf_surface_physics=3

RUC Land Surface Model (Smirnova)

◆ Vegetation effects included

◆ Predicts soil temperature and soil moisture in six layers

◆ Multi-layer snow model

◆ Provides heat and moisture fluxes for PBL

sf_surface_physics=7

Pleim-Xiu Land Surface Model (EPA)

- New in Version 3
- Vegetation effects included
- Predicts soil temperature and soil moisture in two layers
- Simple snow-cover model
- Provides heat and moisture fluxes for PBL

sf_surface_physics=88

GFDL slab model

- Simple land treatment for HWRF physics
- Force-restore 1-layer model with constant substrate

VEGPARM.TBL

Text (ASCII) file that has vegetation properties for Noah and RUC LSMs (separate sections in this table)

- 24 USGS categories or 20 MODIS categories (new) from 30" global dataset
- Each type is assigned min/max value of
  - Albedo
  - Leaf Area Index
  - Emissivity
  - Roughness length
- Other vegetation properties (stomatal resistance etc.)
- From 3.1, monthly vegetation fraction determines seasonal cycle between min and max values in Noah
- There is also a SOILPARM.TBL for soil properties in Noah and RUC

LANDUSE.TBL

Text (ASCII) file that has land-use properties for 5-layer slab model (vegetation, urban, water, etc.)

- From Version 3.1 Noah LSM does not use this table
- 24 USGS categories or 20 MODIS categories (new) from 30" global dataset
- Each type is assigned summer/winter value
  - Albedo
  - Emissivity
  - Roughness length
- Other table properties (thermal inertia, moisture availability, snow albedo effect) are used by 5-layer model
- Also note
  - Other tables (VEGPARM.TBL, etc.) are used by Noah
  - RUC LSM uses same table files after Version 3

Initializing LSMs

- Noah and RUC LSM require additional fields for initialization
  - Soil temperature
  - Soil moisture
  - Snow liquid equivalent
- These are in the Grib files, but are not from observations
- They come from "offline" models driven by observations (rainfall, radiation, surface temperature, humidity wind)

Initializing LSMs

- There are consistent model-derived datasets for Noah and RUC LSMs
  - Eta/GFS/AGRMET/NNRP for Noah (although some have limited soil levels available)
  - RUC for RUC
- But, resolution of mesoscale land-use means there will be inconsistency in elevation, soil type and vegetation
- This leads to spin-up as adjustments occur in soil temperature and moisture
- This spin-up can only be avoided by running offline model on the same grid (e.g. HRLDAS for Noah)
- Cycling land state between forecasts also helps, but may propagate errors (e.g in rainfall effect on soil moisture)

sst_update=1

Reads lower boundary file periodically to update the sea-surface temperature (otherwise it is fixed with time)

◆ For long-period simulations (a week or more)

◆ wrflowinp_d0*n* created by *real*

◆ Sea-ice can be updated since Version 3.0

◆ Vegetation fraction update is included

- Allows seasonal change in albedo, emissivity, roughness length in Noah LSM

◆ usemonalb=.true. to use monthly albedo input

Regional Climate Options

- New in V3.1
- tmn_update=1 - updates deep-soil temperature for multi-year future-climate runs
- sst_skin=1 - adds diurnal cycle to sea-surface temperature
- bucket_mm and bucket_J - a more accurate way to accumulate water and energy for long-run budgets (see later)
- No-leap-year compilation option for CCSM-driven runs

Hurricane Options

- ◆ Ocean Mixed Layer Model (omlcall=1)
    - 1-d slab ocean mixed layer (specified initial depth)
    - Includes wind-driven ocean mixing for SST cooling feedback
- ◆ Alternative surface-layer options for high-wind ocean surface (isftcflx=1,2)
    - Use with sf_sfclay_physics=1
    - Modifies Charnock relation to give less surface friction at high winds (lower Cd)
    - Modifies surface enthalpy (Ck, heat/moisture) either with constant z0q (isftcflx=1), Garratt formulation (option 2)

Fractional Sea Ice

- fractional_seaice=1 - with input sea-ice fraction data can partition land/water fluxes within a grid box
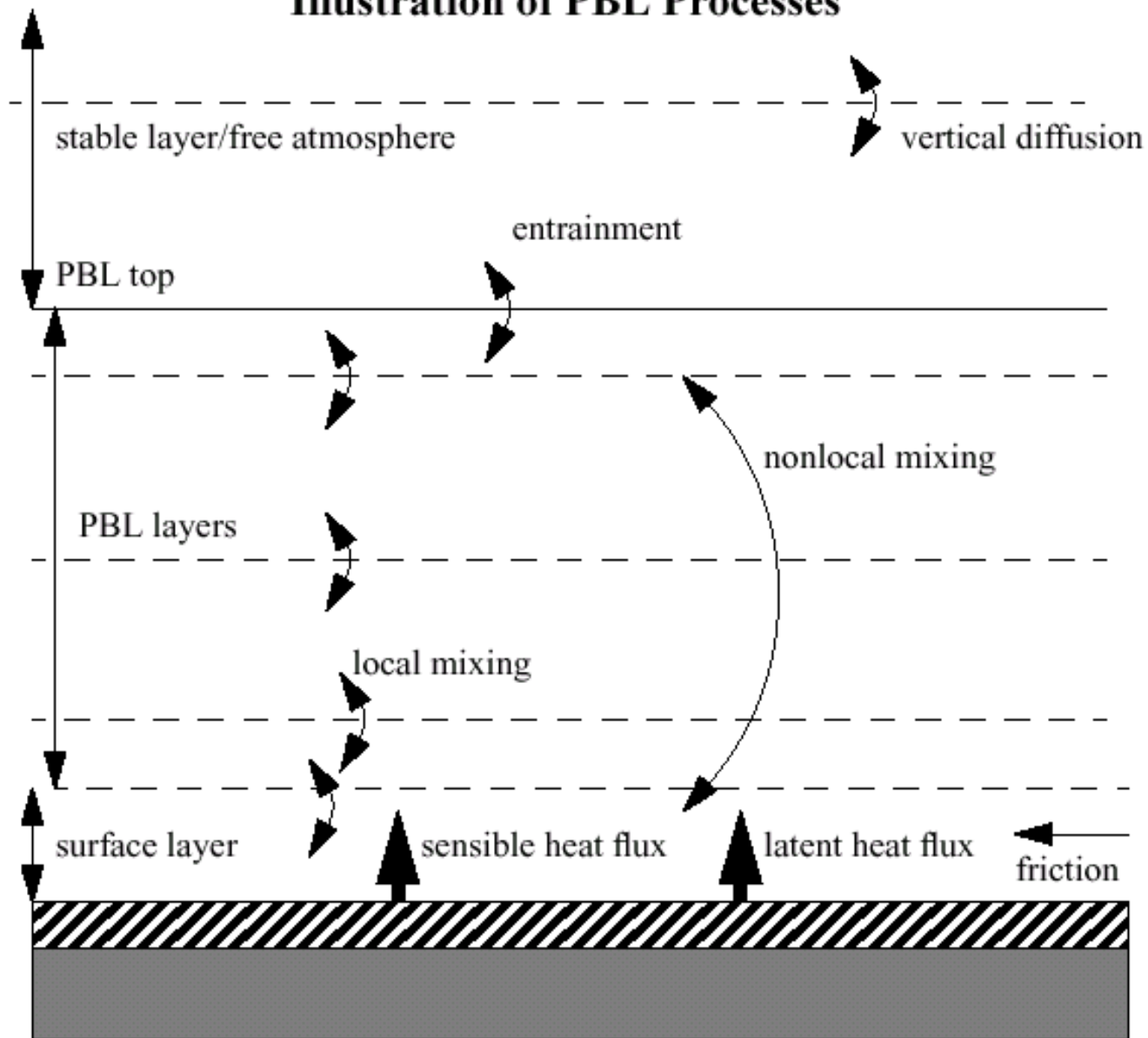- Since Version 3.1

Planetary Boundary Layer

Boundary layer fluxes (heat, moisture, momentum)

Vertical diffusion $\dfrac{\partial}{\partial z} K_v \dfrac{\partial}{\partial z} \theta$

Illustration of PBL Processes

stable layer/free atmosphere   vertical diffusion

entrainment

PBL top

nonlocal mixing

PBL layers

local mixing

surface layer   sensible heat flux   latent heat flux

friction

bl_pbl_physics=1

YSU PBL scheme (Hong, Noh and Dudhia 2006)

- Parabolic K profile mixing in dry convective boundary layer
- Troen-Mahrt countergradient flux (non-local)

$$\frac{\partial}{\partial z}(K_v \frac{\partial}{\partial z}\theta + \Gamma)$$

- Depth of PBL determined from thermal profile
- Explicit treatment of entrainment
- Vertical diffusion depends on Ri in free atmosphere
- New stable surface BL mixing using bulk Ri

bl_pbl_physics=2

Mellor-Yamada-Janjic (Eta/NMM) PBL

- 1.5-order, level 2.5, TKE prediction
- Local TKE-based vertical mixing in boundary layer and free atmosphere
- TKE_MYJ is advected by NMM, not by ARW (yet)

bl_pbl_physics=3

GFS PBL

- ◆ 1st order Troen-Mahrt
- ◆ Closely related to MRF PBL
- ◆ Non-local-K vertical mixing in boundary layer and free atmosphere

bl_pbl_physics=4

QNSE (Quasi-Normal Scale Elimination) PBL from Galperin and Sukoriansky

- 1.5-order, level 2.5, TKE prediction
- Local TKE-based vertical mixing in boundary layer and free atmosphere
- New theory for stably stratified case
- Mixing length follows MYJ, TKE production simplified from MYJ

bl_pbl_physics=5 and 6

MYNN (Nakanishi and Niino) PBL

- (5)1.5-order, level 2.5, TKE prediction, OR
- (6)2nd-order, level 3, TKE, θ'^2,q'^2 and $\theta'q'$ prediction
- Local TKE-based vertical mixing in boundary layer and free atmosphere
- Since V3.1

bl_pbl_physics=7

Asymmetrical Convective Model, Version 2 (ACM2) PBL (Pleim and Chang)

- ◆ Blackadar-type thermal mixing upwards from surface layer
- ◆ Local mixing downwards
- ◆ PBL height from critical bulk Richardson number

bl_pbl_physics=8

BouLac PBL (Bougeault and Lacarrère)

◆ TKE prediction scheme

◆ Designed to work with multi-layer urban model (BEP)

◆ Since V3.1

bl_pbl_physics=99

MRF PBL scheme (Hong and Pan 1996)

- ◆ Non-local-K mixing in dry convective boundary layer

- ◆ Depth of PBL determined from critical Ri number

- ◆ Vertical diffusion depends on Ri in free atmosphere

bldt

- Minutes between boundary layer/LSM calls
- Typical value is 0 (every step)

nphs

- Time steps between PBL/turbulence/ LSM calls
- Typical value is chosen to give a frequency of 1-3 minutes, i.e. 60/dt to 180/dt
- Also used for microphysics

PBL Scheme Options

PBL schemes can be used for most grid sizes when surface fluxes are present

◆ With YSU, ACM2, GFS and MRF PBL schemes, lowest full level should be .99 or .995 (not too close to 1)

◆ TKE schemes can use thinner surface layers

◆ Assumes that PBL eddies are not resolved

◆ At grid size dx << 1 km, this assumption breaks down

- Can use 3d diffusion instead of a PBL scheme in Version 3 (coupled to surface physics)
- Works best when dx and dz are comparable

diff_opt=2 <small>(repeated)</small>

- Explicit large-eddy simulation (LES) PBL in real-data cases (V3) or idealized cases
  - bl_pbl_physics = 0
    - isfflx = 0 (idealized drag and heat flux from namelist)
    - isfflx = 1 (drag and heat flux from physics)
      - sf_sfclay_physics=1
      - sf_surface_physics (choose non-zero option)
    - isfflx = 2 (drag from physics, heat flux from tke_heat_flux)
      - sf_sfclay_physics=1
  - km_opt = 2 or 3
  - mix_isotropic=1 (if dx and dz are of same order)
- Not available for diff_opt=1.

Gravity Wave Drag
(gwd_opt=1 for ARW, 2 for NMM)

- ARW scheme from Hong et al. New in V3.1
- Accounts for orographic gravity wave effect on momentum profile
- Extra sub-grid orographic information comes from geogrid
- Probably needed only if all below apply
  - dx > 10 km
  - Simulations longer than 5 days
  - Domains including mountains

Cumulus Parameterization

Atmospheric heat and moisture/
cloud tendencies

Surface rainfall

Illustration of Cumulus Processes
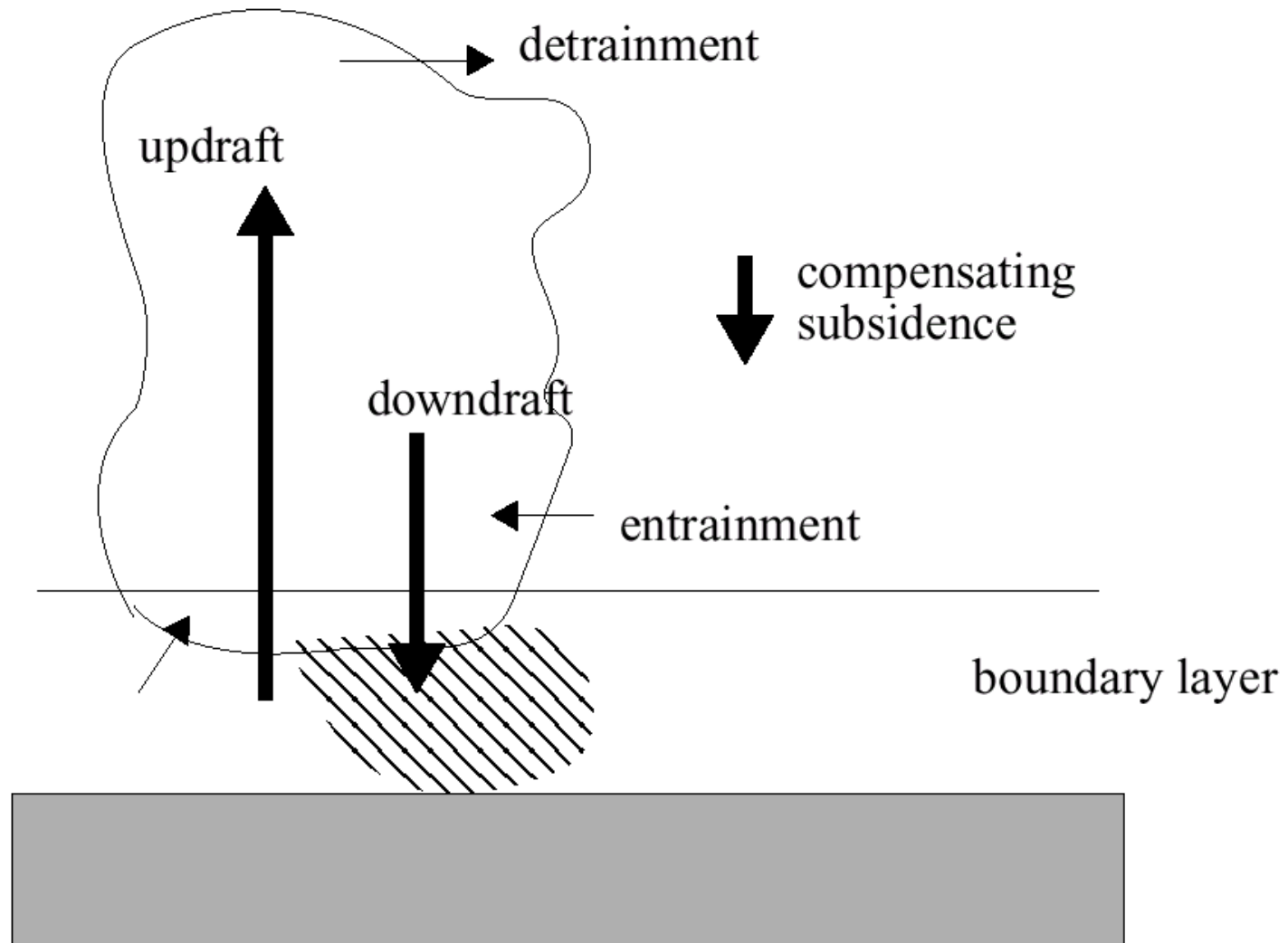
cu_physics=1

New Kain-Fritsch

- ◆ As in MM5 and Eta/NMM test version
- ◆ Includes shallow convection (no downdrafts)
- ◆ Low-level vertical motion in trigger function
- ◆ CAPE removal time scale closure
- ◆ Mass flux type with updrafts and downdrafts, entrainment and detrainment
- ◆ Includes cloud, rain, ice, snow detrainment
- ◆ Clouds persist over convective time scale (recalculated every convective step in NMM)
- ◆ Old KF is option 99

cu_physics=2

Betts-Miller-Janjic

- As in NMM model (Janjic 1994)
- Adjustment type scheme
- Deep and shallow profiles
- BM saturated profile modified by cloud efficiency, so post-convective profile can be unsaturated in BMJ
- No explicit updraft or downdraft
- No cloud detrainment
- Scheme changed significantly since V2.1

cu_physics=3

Grell-Devenyi Ensemble

- ◆ Multiple-closure (CAPE removal, quasi-equilibrium, moisture convergence, cloud-base ascent) - 16 mass flux closures
- ◆ Multi-parameter (maximum cap, precipitation efficiency) - e.g. 3 cap strengths, 3 efficiencies
- ◆ Explicit updrafts/downdrafts
- ◆ Includes cloud and ice detrainment
- ◆ Mean feedback of ensemble is applied
- ◆ Weights can be tuned (spatially, temporally) to optimize scheme (training)

cu_physics=4

Simpified Arakawa-Schubert (SAS) GFS scheme
- ◆ Quasi-equilibrium scheme
- ◆ Related to Grell scheme in MM5
- ◆ Includes cloud and ice detrainment
- ◆ Downdrafts and single, simple cloud

cu_physics=5

Grell-3d

- ◆ As GD, but slightly different ensemble
- ◆ Includes cloud and ice detrainment
- ◆ Subsidence is spread to neighboring columns
  - This makes it more suitable for < 10 km grid size than other options
  - cugd_avgdx=1 (default), 3(spread subsidence)
- ◆ Mean feedback of ensemble is applied
- ◆ Weights can be tuned (spatially, temporally) to optimize scheme (training)

cudt

- Time steps between cumulus scheme calls
- Typical value is 5 minutes

ncnvc

- Time steps between cumulus parameterization calls
- Typically 10 - same as NPHS

Cumulus scheme

Recommendations about use

◆ For dx ≥ 10 km: probably need cumulus scheme

◆ For dx ≤ 3 km: probably do not need scheme

  ▪ However, there are cases where the earlier triggering of convection by cumulus schemes help

◆ For dx=3-10 km, scale separation is a question

  ▪ No schemes are specifically designed with this range of scales in mind

◆ Issues with 2-way nesting when physics differs across nest boundaries (seen in precip field on parent domain)

  ▪ best to use same physics in both domains or 1-way nesting
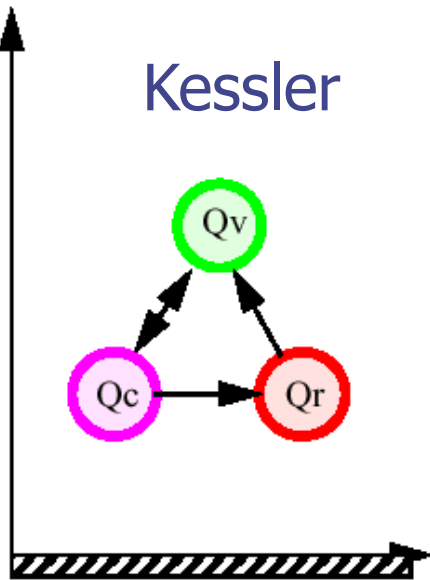
Microphysics

Atmospheric heat and moisture tendencies
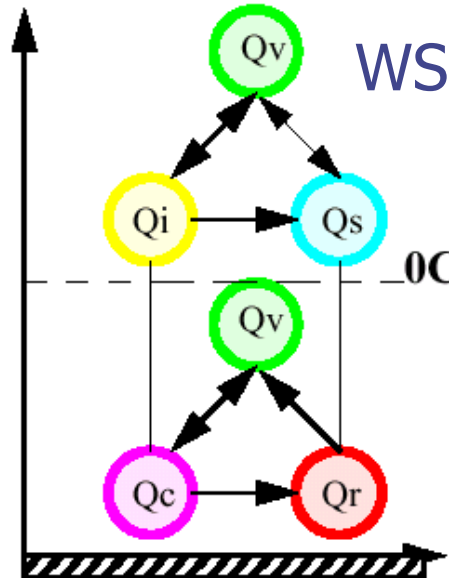
Microphysical rates

Surface rainfall

Illustration of Microphysics Processes
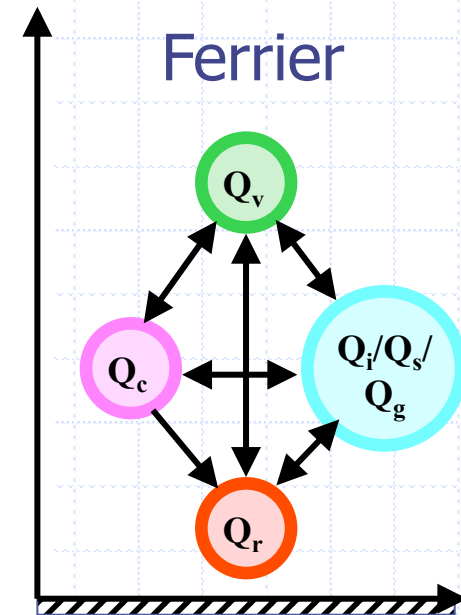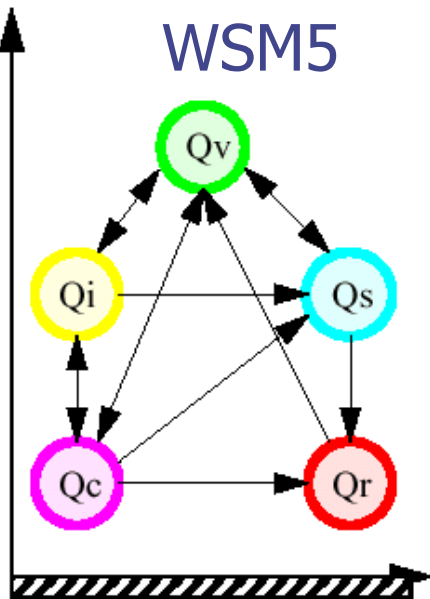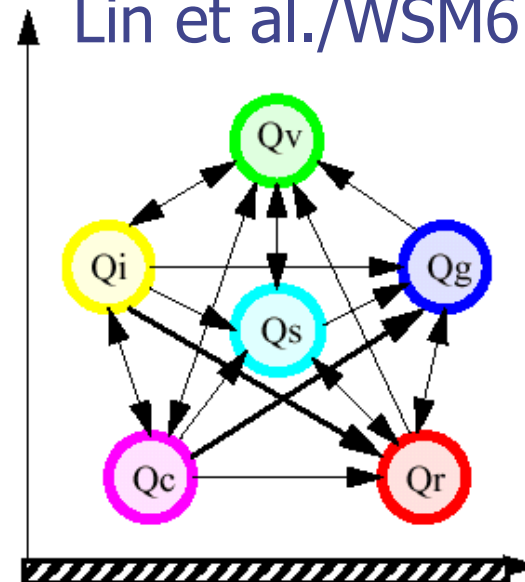
Microphysics: Single and Double Moment Schemes

- Single-moment schemes have one prediction equation for mass (kg/kg) per species (Qr, Qs, etc.) with particle size distribution being diagnostic

- Double-moment schemes add a prediction equation for number concentration (#/kg) per double-moment species (Nr, Ns, etc.)

- Double-moment schemes may only be double-moment for a few species

- Double-moment schemes allow for additional processes such as size-sorting during fall-out

Microphysics: Fall terms

◆ Microphysics schemes handle fall terms for particles (usually everything except cloud water has a fall term)

◆ For long time-steps (such as mesoscale applications dt ~ 60 s, Vt= 5 m/s), drops may fall more than a grid level in a time-step

◆ This requires splitting the time-step or lagrangian numerical methods to keep the scheme numerically stable

mp_physics=1

Kessler scheme

◆ Warm rain – no ice

◆ Idealized microphysics

◆ Time-split rainfall

mp_physics=2

Purdue Lin et al. scheme

- 5-class microphysics including graupel
- Includes ice sedimentation and time-split fall terms

mp_physics=3

WSM 3-class scheme

- From Hong, Dudhia and Chen (2004)
- Replaces NCEP3 scheme
- 3-class microphysics with ice
- Ice processes below 0 deg C
- Ice number is function of ice content
- Ice sedimentation
- Semi-lagrangian fall terms in V3.2

mp_physics=4

WSM 5-class scheme

- Also from Hong, Dudhia and Chen (2004)
- Replaces NCEP5 scheme
- 5-class microphysics with ice
- Supercooled water and snow melt
- Ice sedimentation
- Semi-lagrangian fall terms in V3.2

mp_physics=14

WDM 5-class scheme

◆ Version of WSM5 that is double-moment for warm rain processes

◆ 5-class microphysics with ice

◆ CCN, and number concentrations of cloud and rain also predicted

mp_physics=5

Ferrier (current NAM) scheme
- ◆ Designed for efficiency
  - Advection only of total condensate and vapor
  - Diagnostic cloud water, rain, & ice (cloud ice, snow/graupel) from storage arrays – assumes fractions of water & ice within the column are fixed during advection
- ◆ Supercooled liquid water & ice melt
- ◆ Variable density for precipitation ice (snow/graupel/sleet) – "rime factor"
- ◆ mp_physics=85 (nearly identical) for HWRF

mp_physics=6

WSM 6-class scheme
- From Hong and Lim (2006, JKMS)
- 6-class microphysics with graupel
- Ice number concentration as in WSM3 and WSM5
- New combined snow/graupel fall speed
- Semi-lagrangian fall terms

mp_physics=16

WDM 6-class scheme

◆ Version of WSM6 that is double-moment for warm rain processes

◆ 6-class microphysics with graupel

◆ CCN, and number concentrations of cloud and rain also predicted

mp_physics=7

Goddard 6-class scheme

- From Tao et al.
- 6-class microphysics with graupel
- Based on Lin et al. with modifications for ice/water saturation
- gsfcgce_hail switch for hail/graupel properties
- gsfcgce_2ice switch for removing graupel or snow processes
- Time-split fall terms with melting

mp_physics=8

New Thompson et al. scheme in V3.1

- Replacement of Thompson et al. (2007) scheme that was option 8 in V3.0
- 6-class microphysics with graupel
- Ice and rain number concentrations also predicted (double-moment ice)
- Time-split fall terms

mp_physics=98

Old Thompson et al. 2007 graupel scheme

- From Thompson et al. (2007)
- Was option 8 in Version 3.0
- 6-class microphysics with graupel
- Ice number concentration also predicted (double-moment ice)
- Time-split fall terms

mp_physics=9

Milbrandt-Yau 2-moment scheme

- New in Version 3.2
- 7-class microphysics with separate graupel and hail
- Number concentrations predicted for all six water/ice species (double-moment) - 12 variables
- Time-split fall terms

mp_physics=10

Morrison 2-moment scheme

- ◆ Since Version 3.0
- ◆ 6-class microphysics with graupel
- ◆ Number concentrations also predicted for ice, snow, rain, and graupel (double-moment)
- ◆ Time-split fall terms

no_mp_heating=1

◆ Turn off heating effect of microphysics

- Zeroes out the temperature tendency
- Equivalent to no latent heat
- Other microphysics processes not affected
- Since Version 3.0

mp_zero_out

Microphysics switch (also mp_zero_out_thresh)

- 1: all values less than threshold set to zero (except vapor)

- 2: as 1 but vapor also limited ≥ 0

- Note: this option will not conserve total water

- Not needed when using positive definite advection

- NMM: Recommend mp_zero_out=0

Microphysics Options

Recommendations about choice

- Probably not necessary to use a graupel scheme for dx > 10 km
  - Updrafts producing graupel not resolved
  - Cheaper scheme may give similar results
- When resolving individual updrafts, graupel scheme should be used
- All domains use same option

Rainfall Output

- Cumulus and microphysics can be run at the same time
- ARW outputs rainfall accumulations since simulation start time (0 hr) in mm
- RAINC comes from cumulus scheme
- RAINNC comes from microphysics scheme
- Total is RAINC+RAINNC
  - RAINNCV is time-step value
  - SNOWNC/SNOWNCV are snow sub-set of RAINC/ RAINNCV (also GRAUPELNC, etc.)

Rainfall Output

Options for "buckets"

◆ prec_acc_dt (minutes) - accumulates separate prec_acc_c, prec_acc_nc, snow_acc_nc in each time window (we recommend prec_acc_dt is equal to the wrf output frequency to avoid confusion)

◆ bucket_mm - separates RAIN(N)C into RAIN(N)C and I_RAIN(N)C to allow accuracy with large totals such as in multi-year accumulations

  ▪ Rain = I_RAIN(N)C*bucket_mm + RAIN(N)C
  ▪ bucket_mm = 100 mm is a reasonable bucket value
  ▪ bucket_J also for CAM and RRTMG radiation budget terms (1.e9 J/m^2 recommended)

Rainfall Output

- Cumulus and microphysics can be run at the same time
- NMM outputs rainfall accumulations in mm
- TPREC controls zeroing out frequency
- ACPREC is the total precipitation
- CUPREC is the part that comes from the cumulus scheme
- The microphysics part is ACPREC-CUPREC

Physics Interactions

Direct Interactions of Parameterizations
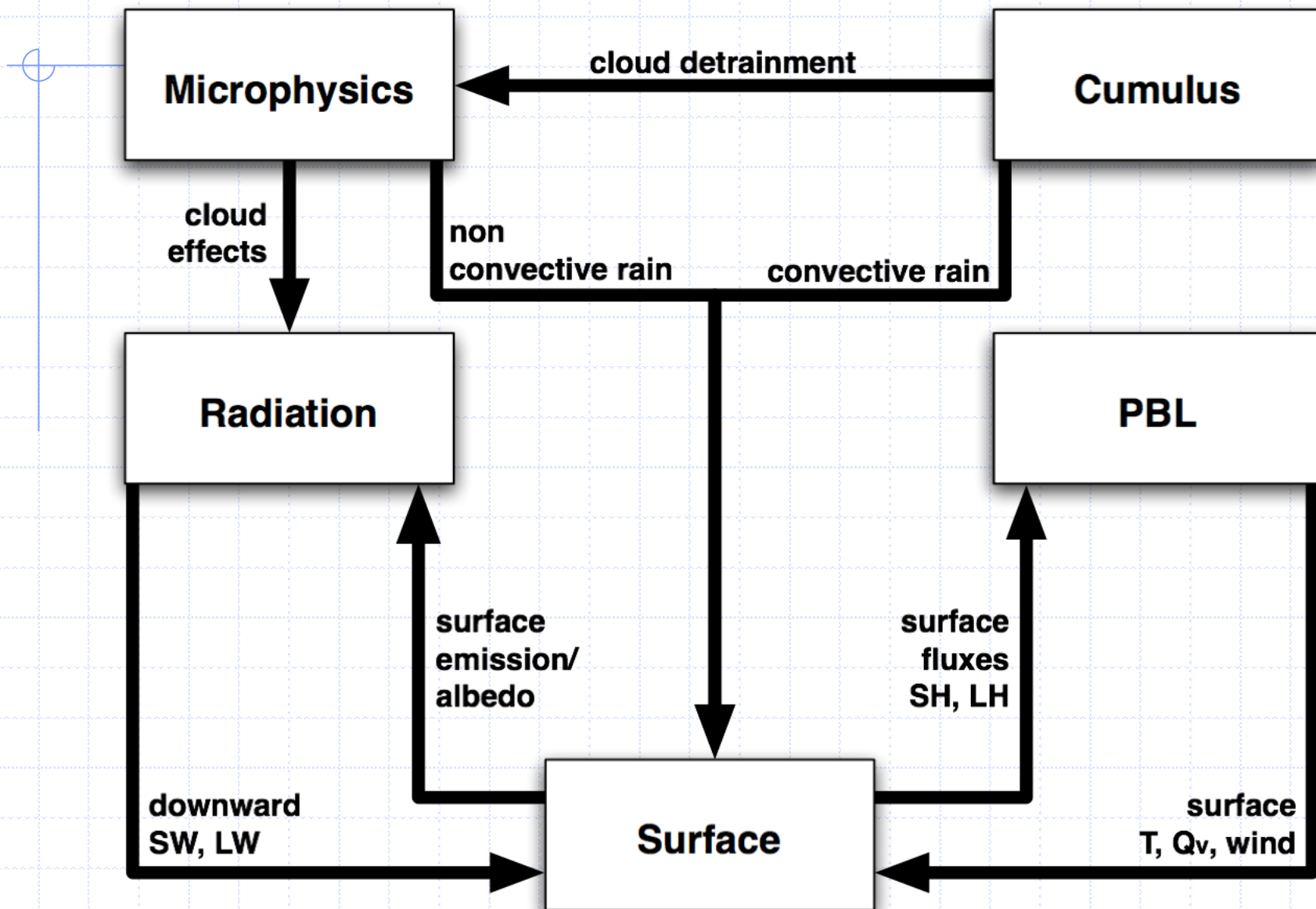
Solver Calling Sequence (ARW example)

Call to solver advances one domain by one model time-step

- ◆ Physics tendencies
  - Radiation, surface, land-state update, PBL, cumulus, grid-fdda, obs-fdda
- ◆ Dynamics tendencies
  - Diffusion, advection, dynamics terms (for 3d momentum, theta, geopotential, surface pressure)
- ◆ Acoustic steps
  - Update 3d momentum, theta, surface pressure, height
- ◆ Scalar dynamics tendencies and update
  - Advection, diffusion of moist (qv,qc, etc.), scalar, tracer, tke, (and chemistry) variables
- ◆ Microphysics update

Solver Sequence ARW

	tendency
	update
	adjust

Time-step →

	ϕ	μ	w	u	v	θ	q	Water ice	Scalar Chem	Soil T Soil Q
Rad						tendency				
Sfc PBL				tendency	tendency	tendency	tendency	tendency		update
Cnv						tendency	tendency	tendency		
Adv Diff	tendency	tendency	tendency	tendency	tendency	tendency				
Dyn	update	update	update	update	update	update				
Adv Diff							update	update	update	
Mic						adjust	adjust	adjust	adjust	

&physics

Seven major physics categories:

`mp_physics`: 0,1,2,3,4,5,6,8,10

`ra_lw_physics`: 0,1,3,99

`ra_sw_physics`: 0,1,2,3,99

`sf_sfclay_physics`: 0,1,2

`sf_surface_physics`: 0,1,2,3,99 (set before running **real** or **ideal**, need to match with **num_soil_layers** variable)

`ucm_call = 0,1`

`bl_pbl_physics`: 0,1,2,99

`cu_physics`: 0,1,2,3,99

PBL schemes in V3.2

bl_pbl_physics	Scheme	Reference	Added
1	YSU	Hong, Noh and Dudhia (2006, MWR)	2004
2	MYJ	Janjic (1994, MWR)	2000
3	GFS	Hong and Pan (1996, MWR)	2005
4	QNSE	Sukoriansky, Galperin and Perov (2005, BLM)	2009
5	MYNN2	Nakanishi and Niino (2006, BLM)	2009
6	MYNN3	Nakanishi and Niino (2006, BLM)	2009
7	ACM2	Pleim (2007, JAMC)	2008
8	BouLac	Bougeault and Lacarrere (1989, MWR)	2009
99	MRF	Hong and Pan (1996, MWR)	2000

PBL schemes in V3.2

bl_pbl_ physics	Scheme	Cores	sf_sfclay_ physics	Prognostic variables	Diagnostic variables	Cloud mixing
1	YSU	ARW NMM	1		exch_h	QC,QI
2	MYJ	ARW NMM	2	TKE_MYJ	EL_MYJ, exch_h	QC,QI
3	GFS(hwrf)	NMM	3			QC,QI
4	QNSE	ARW NMM	4	TKE_MYJ	EL_MYJ, exch_h, exch_m	QC,QI
5	MYNN2	ARW	1,2,5	QKE	Tsq, Qsq, Cov, exch_h, exch_m	QC
6	MYNN3	ARW	1,2,5	QKE, Tsq, Qsq, Cov	exch_h, exch_m	QC
7	ACM2	ARW	1,7			QC,QI
8	BouLac	ARW	1,2	TKE_PBL	EL_PBL, exch_h, exch_m, wu_tur, wv_tur, wt_tur, wq_tur	QC
99	MRF	ARW NMM	1			QC,QI

LES schemes in V3.2

Unified horizontal and vertical mixing (for dx~dz).

Typically needed for dx<~200 m. Also use mix_isotropic=1.

bl_pbl_physics	diff_opt	km_opt	Scheme	Cores	sf_sfclay _physics	isfflx	Prognostic variables
0	2	2	tke	ARW	0,1,2	0,1,2	tke
0	2	3	3d Smagorinsky	ARW	0,1,2	0,1,2	

Namelist isfflx controls surface flux methods

isfflx	sf_sfclay_physics	Heat flux	Drag	Real/Ideal
0	0	From namelist tke_heat_flux	From namelist tke_drag_coefficient	Ideal
1	1,2	From LSM/sfclay physics (HFX, QFX)	From sfclay physics (UST)	Real
2	1,2	From namelist tke_heat_flux	From sfclay physics (UST)	Ideal

Microphysics schemes in V3.2

mp_physics	Scheme	Reference	Added
1	Kessler	Kessler (1969)	2000
2	Lin (Purdue)	Lin, Farley and Orville (1983, JCAM)	2000
3	WSM3	Hong, Dudhia and Chen (2004, MWR)	2004
4	WSM5	Hong, Dudhia and Chen (2004, MWR)	2004
5	Eta (Ferrier)	Rogers, Black, Ferrier, Lin, Parrish and DiMego (2001, web doc)	2000
6	WSM6	Hong and Lim (2006, JKMS)	2004
7	Goddard	Tao, Simpson and McCumber (1989, MWR)	2008
8 (+98)	Thompson (+old)	Thompson, Field, Rasmussen and Hall (2008, MWR)	2009
9	Milbrandt 2-mom	Milbrandt and Yau (2005, JAS)	2010
10	Morrison 2-mom	Hong and Pan (1996, MWR)	2008
14	WDM5	Lim and Hong (2010,…)	2009
16	WDM6	Lim and Hong (2010,…)	2009

Microphysics schemes in V3.2

mp_physics	Scheme	Cores	Mass Variables	Number Variables
1	Kessler	ARW	Qc Qr	
2	Lin (Purdue)	ARW	Qc Qr Qi Qs Qg	
3	WSM3	ARW	Qc Qr	
4	WSM5	ARW NMM	Qc Qr Qi Qs	
5	Eta (Ferrier)	ARW NMM	Qc Qr Qs (Qt*)	
6	WSM6	ARW NMM	Qc Qr Qi Qs Qg	
7	Goddard	ARW	Qc Qr Qi Qs Qg	
8 (/98)	Thompson(/old)	ARW NMM	Qc Qr Qi Qs Qg	Ni Nr (/Ni)
9	Milbrandt 2-mom	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
10	Morrison 2-mom	ARW	Qc Qr Qi Qs Qg	Nr Ni Ns Ng
14	WDM5	ARW	Qc Qr Qi Qs	Nn** Nc Nr
16	WDM6	ARW	Qc Qr Qi Qs Qg	Nn** Nc Nr

* Advects only total condensate   ** Nn= CCN number