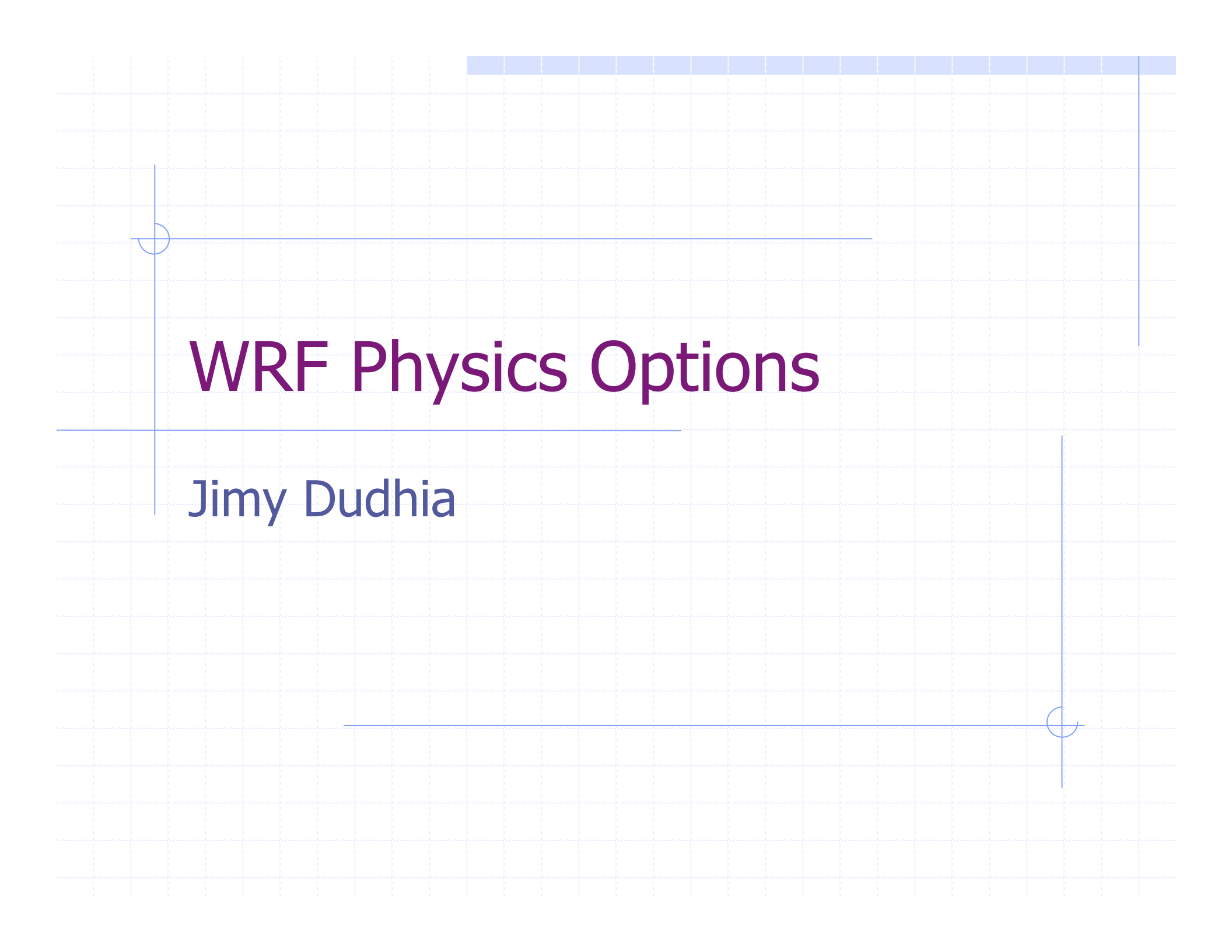


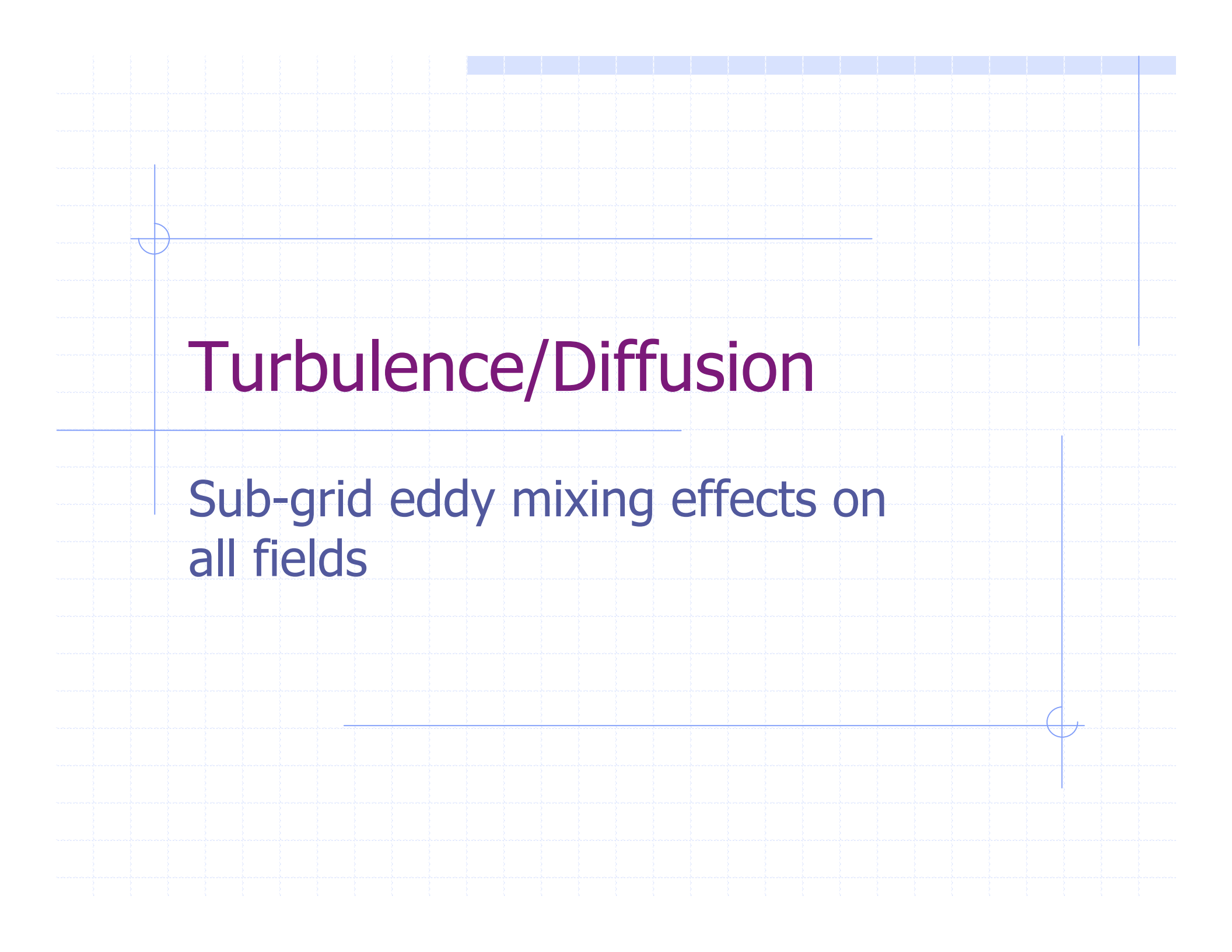


WRF Physics Options

Jimmy 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

diff_opt=1

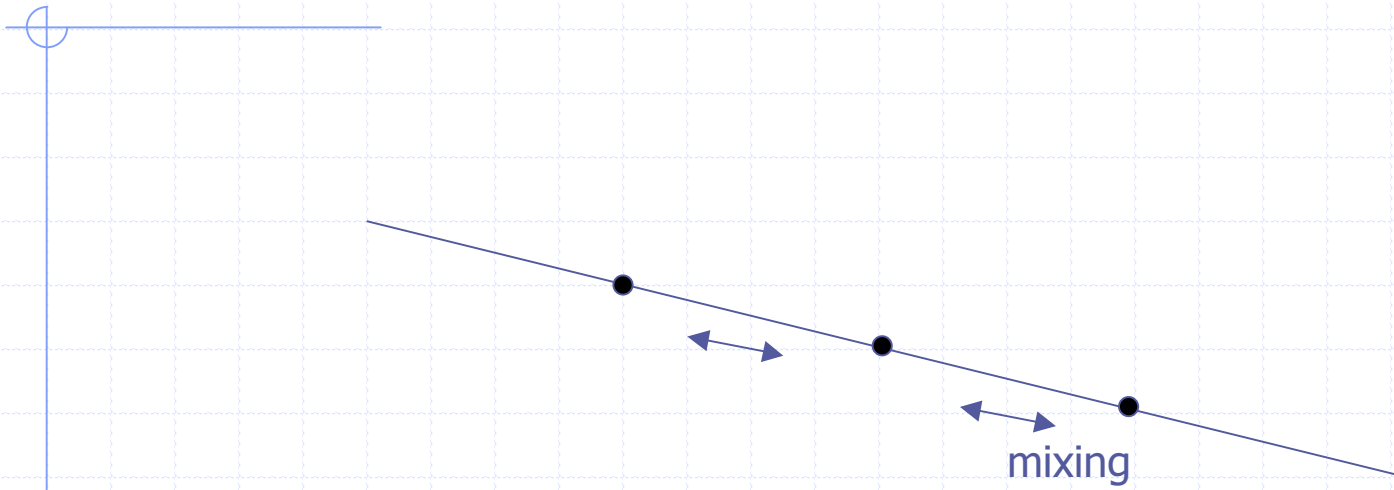
◆ 2nd order diffusion on model levels

- Constant vertical coefficient (kvdif) or use with PBL
- For theta, only perturbation from base state is diffused

◆ km_opt

- 1: constant (khdif and kvdif used)
- 2: 1.5-order TKE prediction (not recommended with diff_opt=1)
- 3: Smagorinsky (deformation/stability based K) (not recommended with diff_opt=1)
- 4: 2D Smagorinsky (deformation based on horizontal wind for horizontal diffusion only)

Difference between diff_opt 1 and 2

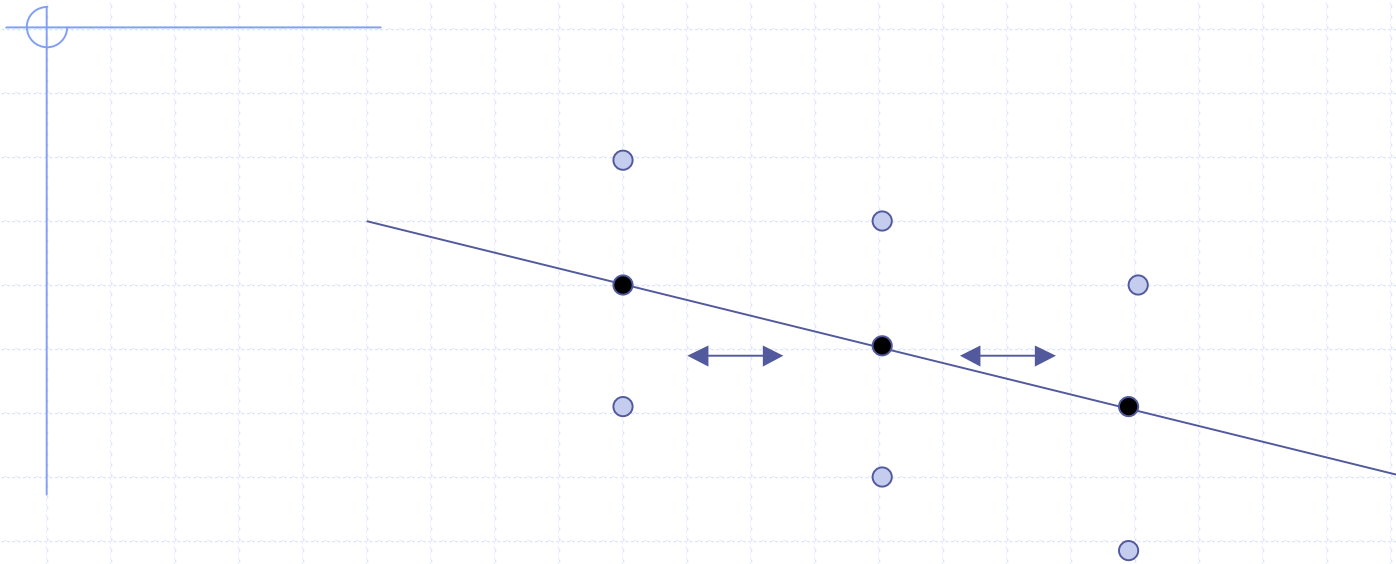


diff_opt=1

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
 - 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.)
- ◆ 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
 - sf_sfclay_physics (only option 1 currently) and sf_surface_physics (choose non-zero option)
 - bl_pbl_physics = 0
 - isfflx = 1 (drag and heat flux from physics) OR
 - isfflx = 2 (drag from physics, heat flux from tke_heat_flux)
 - km_opt = 2 or 3
- ◆ 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 $2 \cdot dx$ 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 $2 \cdot dx$ wave in a time-step)

damp_opt=1

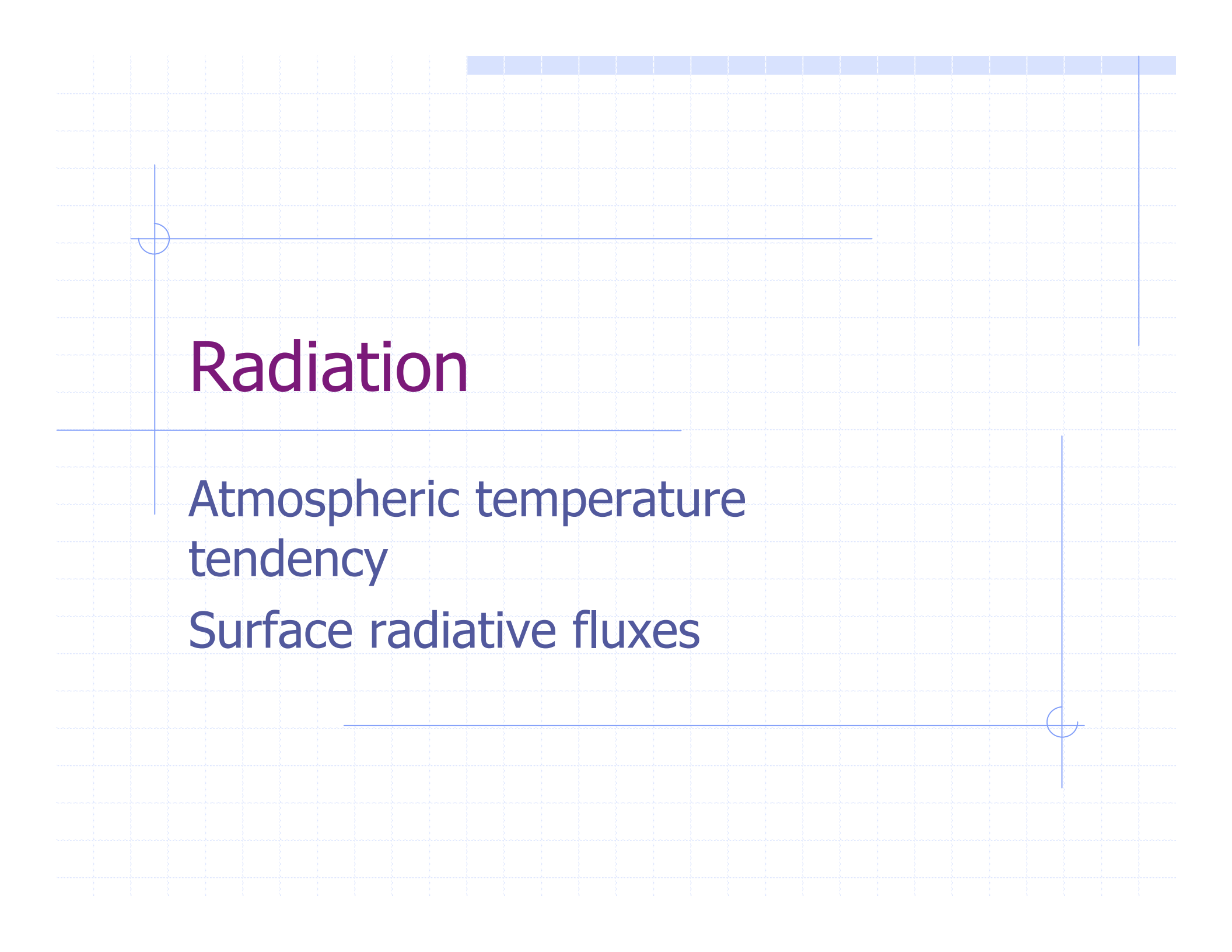
- ◆ Upper level diffusive layer
- ◆ Enhanced horizontal diffusion at top
- ◆ Also enhanced vertical diffusion at top for diff_opt=2
- ◆ Cosine function of height
- ◆ Uses additional parameters
 - zdamp: depth of damping layer
 - dampcoef: nondimensional maximum magnitude of damping
- ◆ Works for idealized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

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)

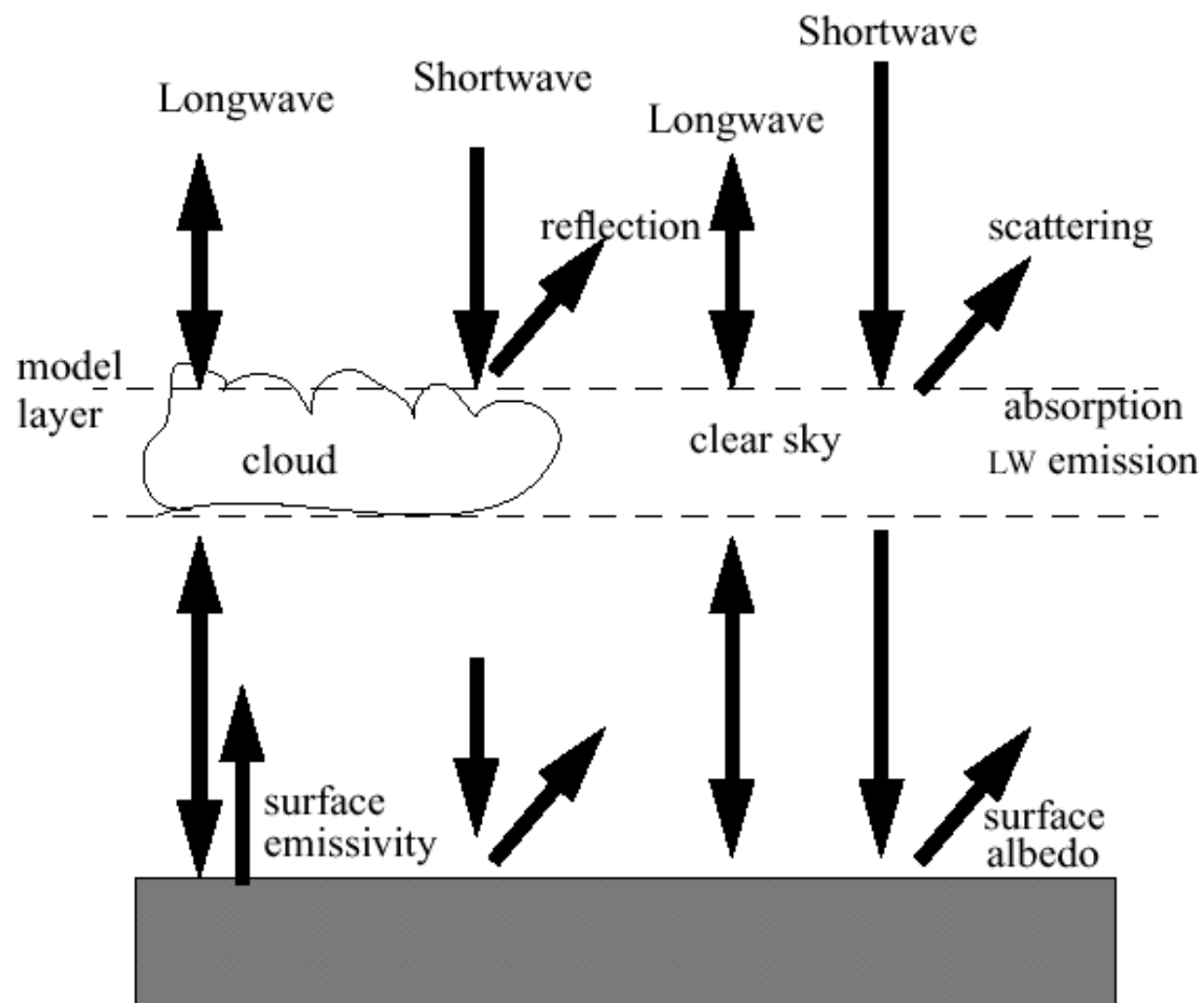


Radiation

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 clouds (1/0 fraction)
- ◆ Ozone profile specified
- ◆ CO2 constant (well-mixed)

ra_lw_physics=3

CAM3 scheme

- ◆ Spectral scheme
- ◆ 8 longwave bands
- ◆ Look-up table fit to accurate calculations
- ◆ Interacts with clouds (RH-based cloud fraction when $RH < 1$)
- ◆ Can interact with trace gases and aerosols
- ◆ Ozone profile function of month, latitude
- ◆ CO2 fixed constant

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
- ◆ Ozone profile based on season, latitude
- ◆ CO2 fixed

ra_sw_physics=1

MM5 shortwave (Dudhia)

- ◆ Simple downward calculation
- ◆ Clear-sky scattering
 - swrad_scatter tuning parameter
 - ◆ 1.0 = 10% scattered, 0.5=5%, etc.
- ◆ Water vapor absorption
- ◆ Cloud albedo and absorption
- ◆ Version 3 has slope_rad and topo_shading switches (0,1) to turn on slope and shading effects in this radiation option only

ra_sw_physics=2

Goddard shortwave

- ◆ Spectral method
- ◆ Interacts with clouds
- ◆ Ozone profile (tropical, summer/winter, mid-lat, polar)
- ◆ CO2 fixed

ra_sw_physics=3

CAM3 shortwave

- ◆ Spectral method (19 bands)
- ◆ Interacts with clouds
- ◆ 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=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

radt

Radiation time-step recommendation

- ◆ Radiation is too expensive to call every step
- ◆ Frequency should resolve cloud-cover changes with time
- ◆ $\text{radt} = 1$ minute per km grid size is about right (e.g. $\text{radt} = 10$ for $\text{dx} = 10$ 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 Fluxes

◆ Heat, moisture and momentum

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

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

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

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

sf_sfclay_physics=1

Monin-Obukhov similarity theory

- ◆ Taken from standard relations used in MM5 MRF PBL
- ◆ Provides exchange coefficients to surface (land) scheme
- ◆ 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
- ◆ Should be used with bl_pbl_physics=2

NMM only

sf_sfclay_physics=3

GFS Monin-Obukhov similarity theory

- ◆ For use with NMM-LSM

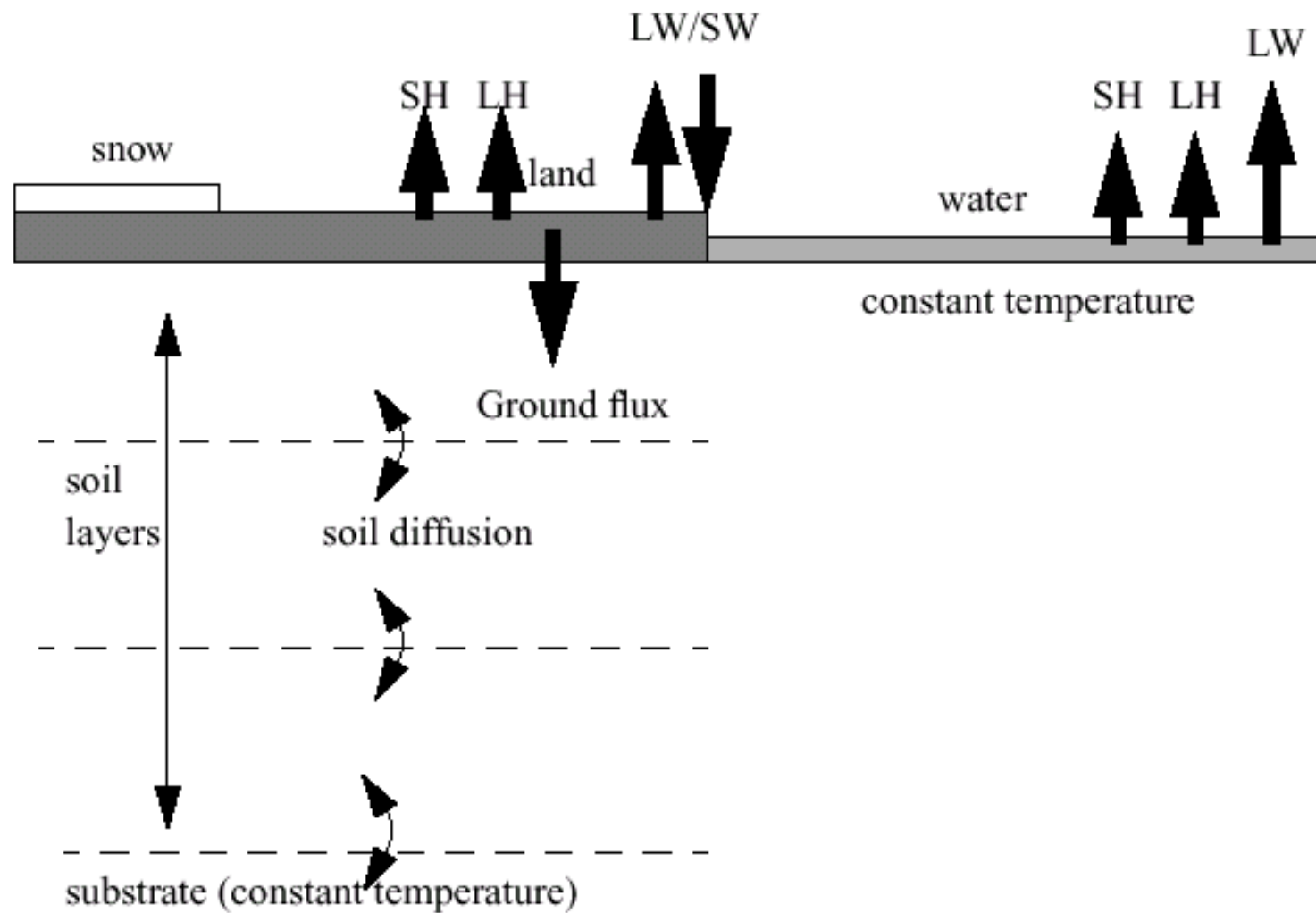
- ◆ Should be used with bl_pbl_physics=3

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 effect for water (Version 3 has ocean mixed-layer model for hurricane applications)
- ◆ No soil moisture or snow-cover prediction
- ◆ Moisture availability based on land-use only
- ◆ Provides heat and moisture fluxes for PBL
- ◆ May be available for NMM in Version 3

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
- ◆ Predicts snow cover and canopy moisture
- ◆ Handles fractional snow cover and frozen soil
- ◆ Diagnoses skin temp and uses emissivity
- ◆ Provides heat and moisture fluxes for PBL
- ◆ 2.2 has Urban Canopy Model option (ucmcall=1, ARW only)

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=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

LANDUSE.TBL

Text (ASCII) file that has land-use properties (vegetation, urban, water, etc.)

- ◆ 24 USGS categories 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)

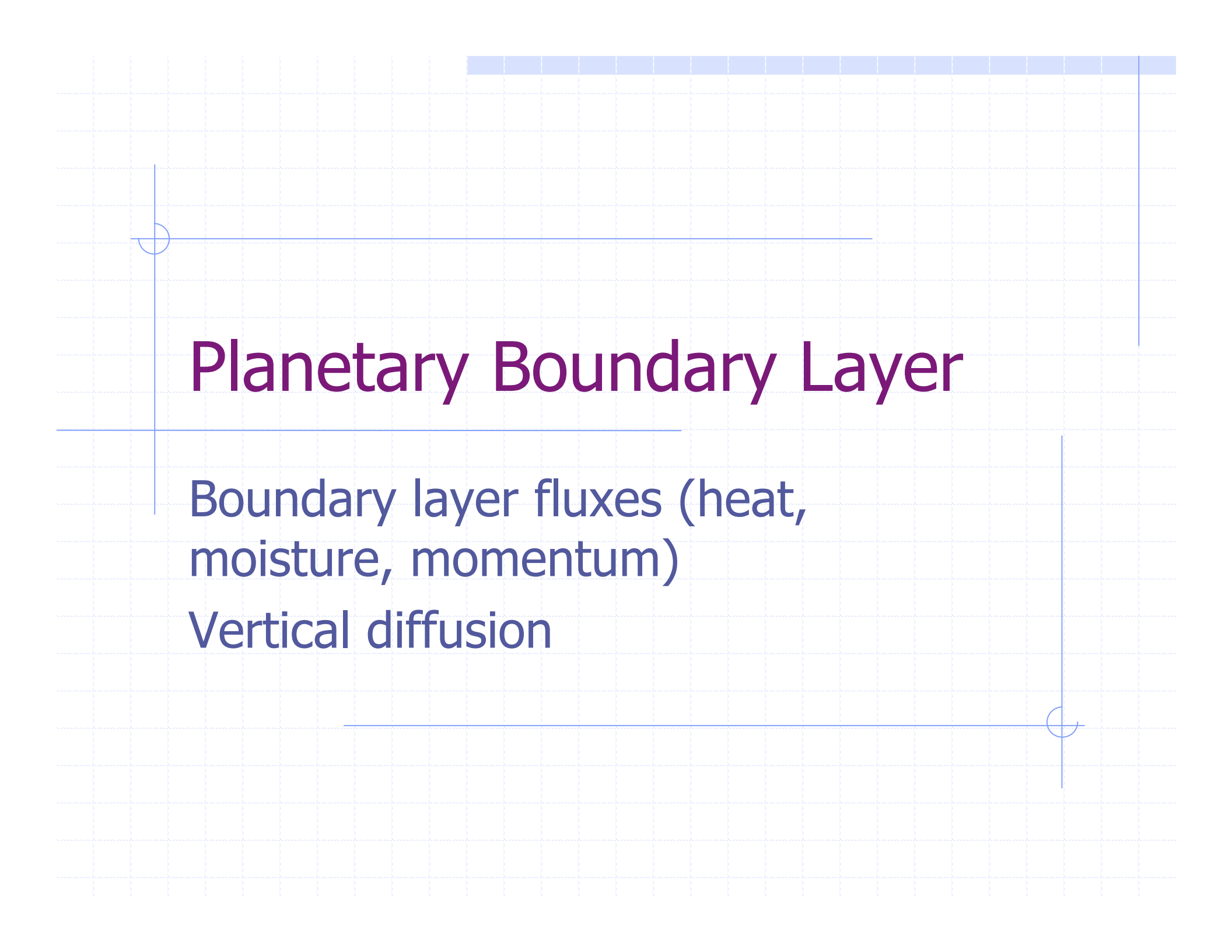
Initializing LSMs

- 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_d0n created by *real*
- ◆ Sea-ice not updated
 - Update available in Version 3
- ◆ Vegetation fraction update is included
 - Background albedo in Version 3

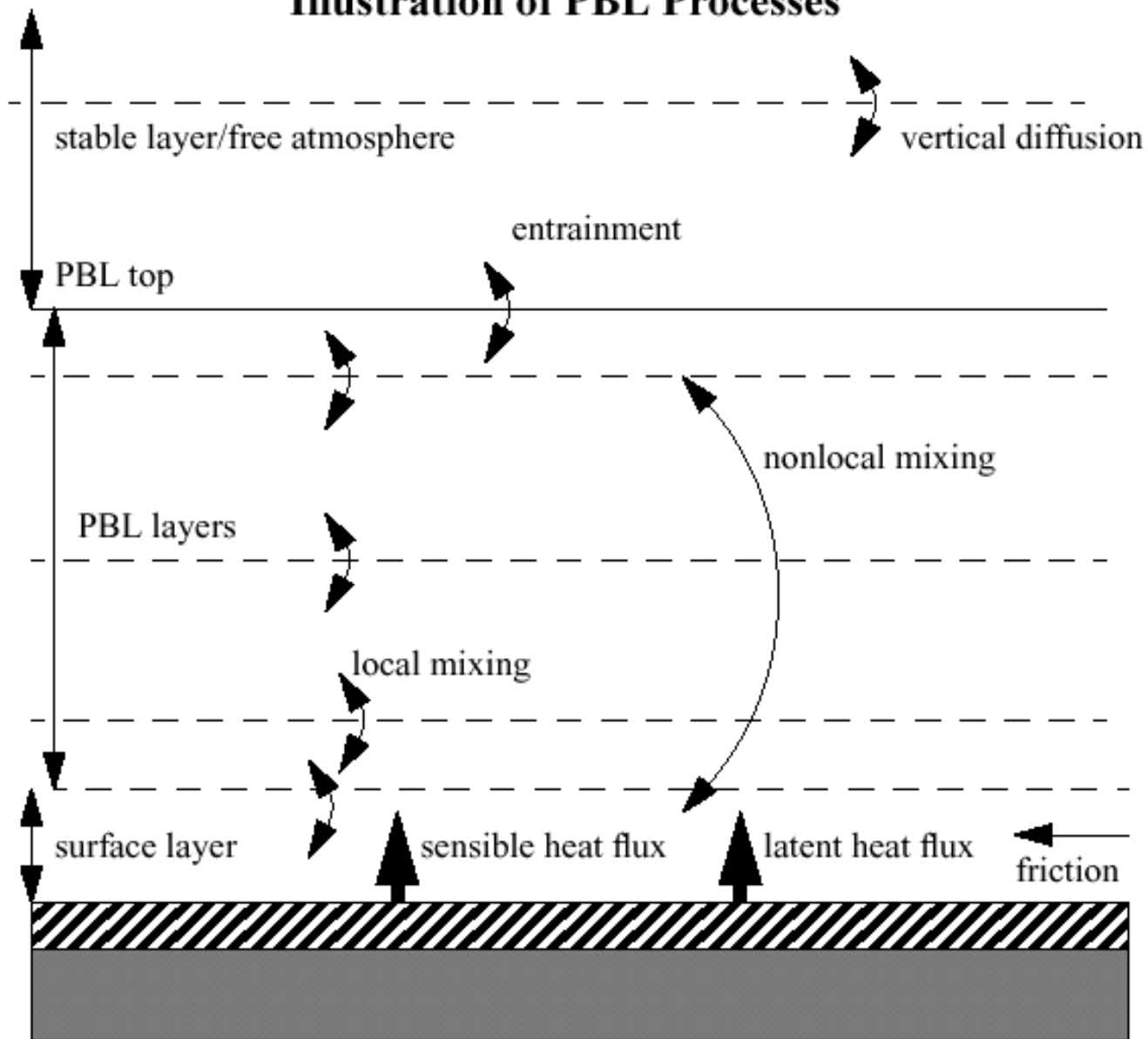


Planetary Boundary Layer

Boundary layer fluxes (heat,
moisture, momentum)

Vertical diffusion

Illustration of PBL Processes



bl_pbl_physics=1

YSU PBL scheme (Hong and Noh)

- ◆ Parabolic non-local-K mixing in dry convective boundary layer
- ◆ Troen-Mahrt countergradient term (non-local flux)
- ◆ Depth of PBL determined from thermal profile
- ◆ Explicit treatment of entrainment
- ◆ Vertical diffusion depends on Ri in free atmosphere
- ◆ May be available for NMM in Version 3

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

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=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=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)

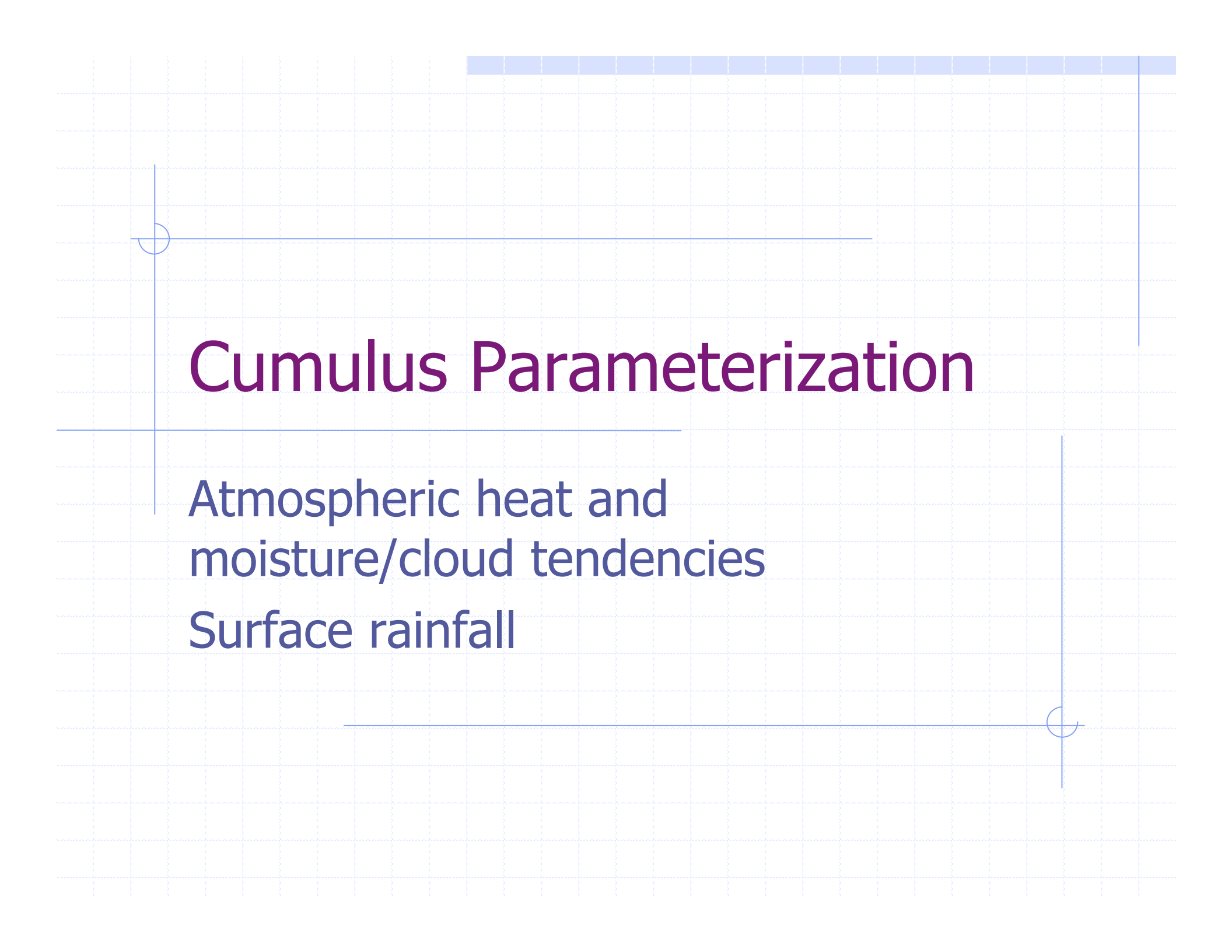
nphs

- ◆ Time steps between PBL/turbulence/LSM calls
- ◆ Typical value is 10 for efficiency
- ◆ Also used for microphysics

PBL Scheme Options

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

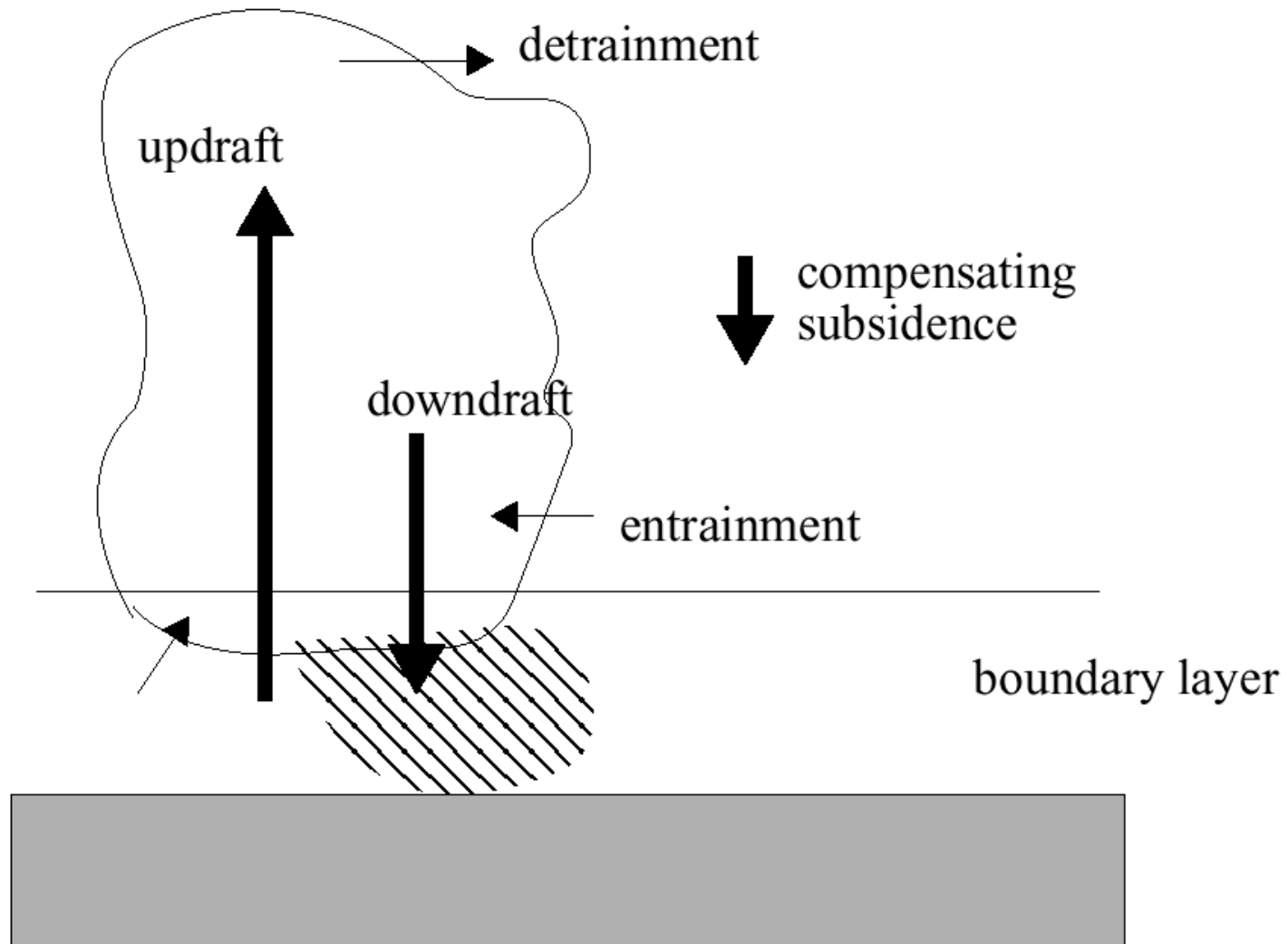
- ◆ With PBL scheme, lowest full level should be .99 or .995 (not too close to 1)
- ◆ Assumes that PBL eddies are not resolved
- ◆ At grid size $dx \ll 1$ km, this assumption breaks down
- ◆ Can use 3d diffusion instead of a PBL scheme in Version 3 (coupled to surface physics)
 - Works best when dx and dz are comparable



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 water and ice detrainment
- ◆ Clouds persist over convective time scale (recalculated every convective step in NMM)

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
- ◆ Scheme changed significantly since V2.1

cu_physics=3

Grell-Devenyi Ensemble

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

cu_physics=4

Simplified Arakawa-Schubert (SAS) GFS scheme

- ◆ Quasi-equilibrium scheme
- ◆ Related to Grell scheme in MM5
- ◆ Downdrafts and single, simple cloud

cu_physics=5

Grell-3d

- ◆ Smaller ensemble than GD
- ◆ Explicit updrafts/downdrafts
- ◆ Subsidence is spread to neighboring columns
 - This makes it more suitable for < 10 km grid size than other options
- ◆ 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

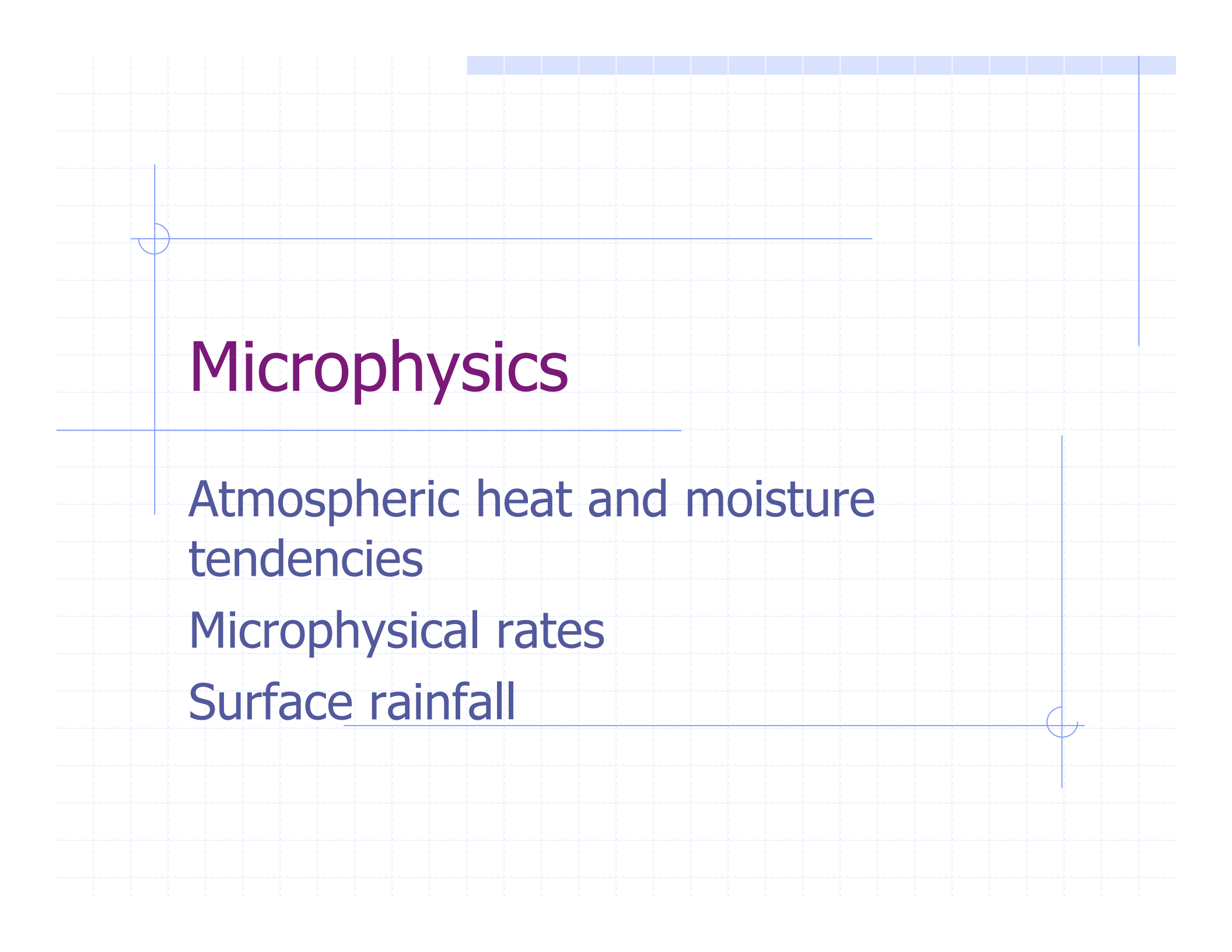
ncnvc

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

Cumulus scheme

Recommendations about use

- ◆ For $dx \geq 10$ km: probably need cumulus scheme
- ◆ For $dx \leq 3$ 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

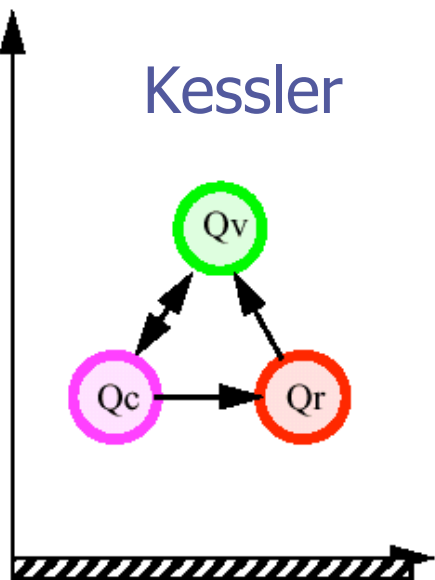
Atmospheric heat and moisture tendencies

Microphysical rates

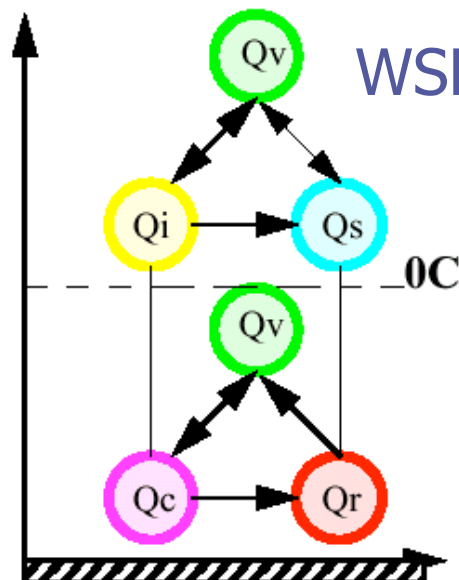
Surface rainfall

Illustration of Microphysics Processes

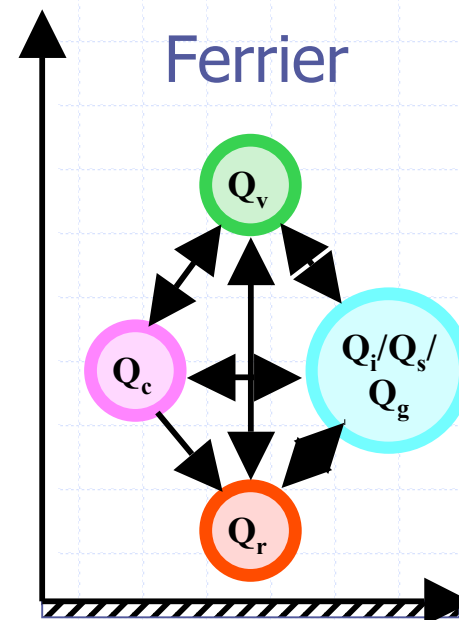
Kessler



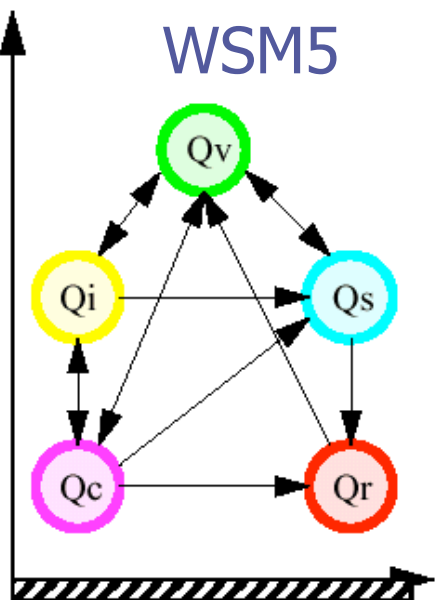
WSM3



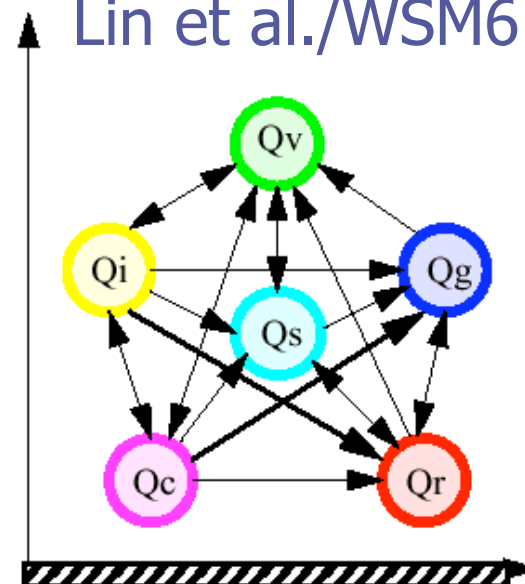
Ferrier



WSM5



Lin et al./WSM6



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 and time-split fall terms

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 and time-split fall terms

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=6

WSM 6-class scheme

- ◆ From Hong and Lim (2006, JKMS)
- ◆ 6-class microphysics with graupel
- ◆ Ice number concentration as in WSM3 and WSM5
- ◆ Modified accretion
- ◆ Time-split fall terms with melting

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

Thompson et al. graupel scheme

- ◆ From Thompson et al. (2006, WRF workshop)
- ◆ Newer version of Thompson et al. (2004) scheme
- ◆ Updated significantly for 2.2
- ◆ 6-class microphysics with graupel
- ◆ Ice number concentration also predicted (double-moment ice)
- ◆ Time-split fall terms

mp_physics=10

Morrison 2-moment scheme

- ◆ New in 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
 - New in Version 3

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

nphs

- ◆ Time steps between microphysics calls
- ◆ Same as parameter for turbulence/PBL/LSM
- ◆ Typical value is 10 for efficiency

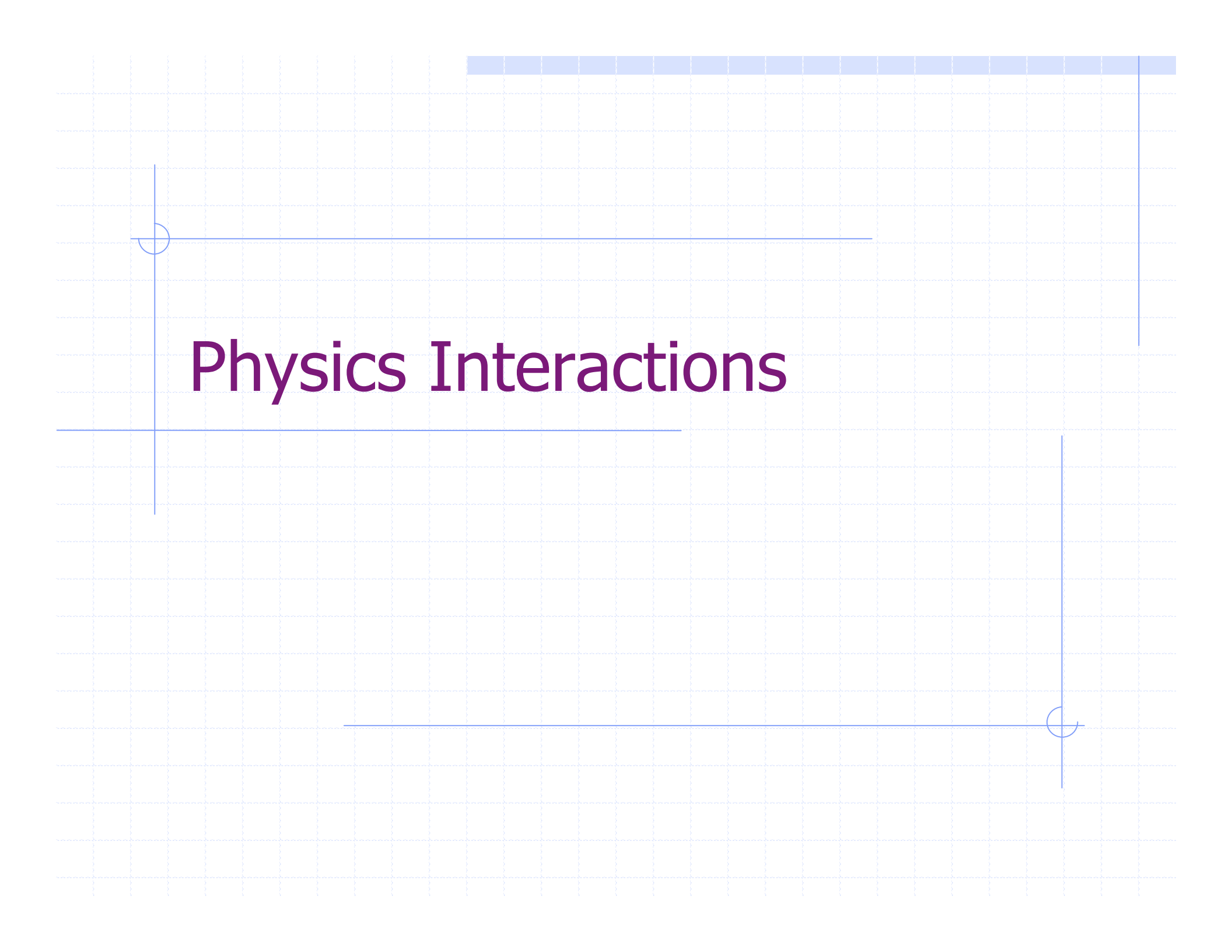
Microphysics Options

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

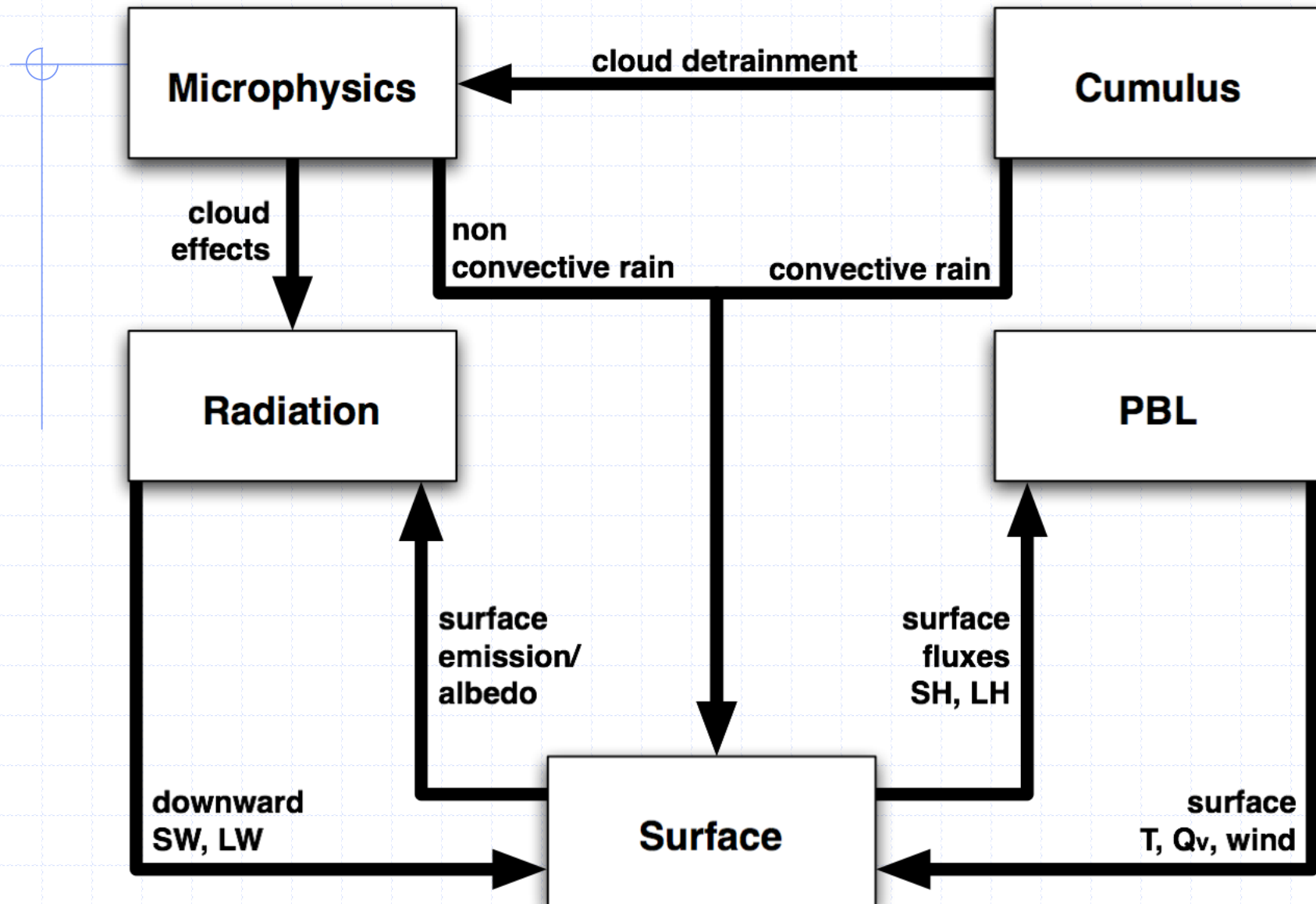
Rainfall Output

- ◆ WRF 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.)



Physics Interactions

Direct Interactions of Parameterizations



&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`

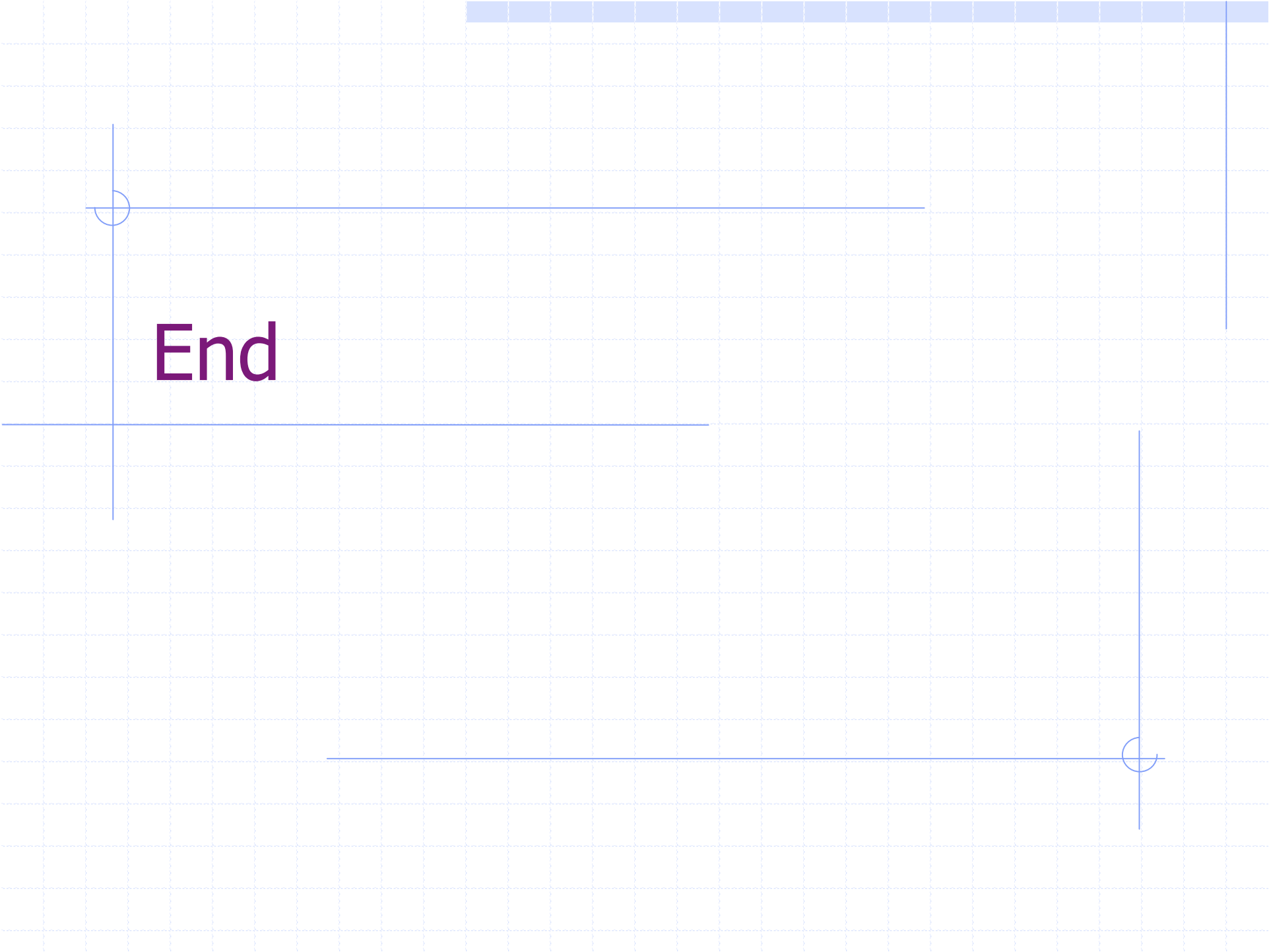
`sf_sfclay_physics: 0,1,2`

`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`



End