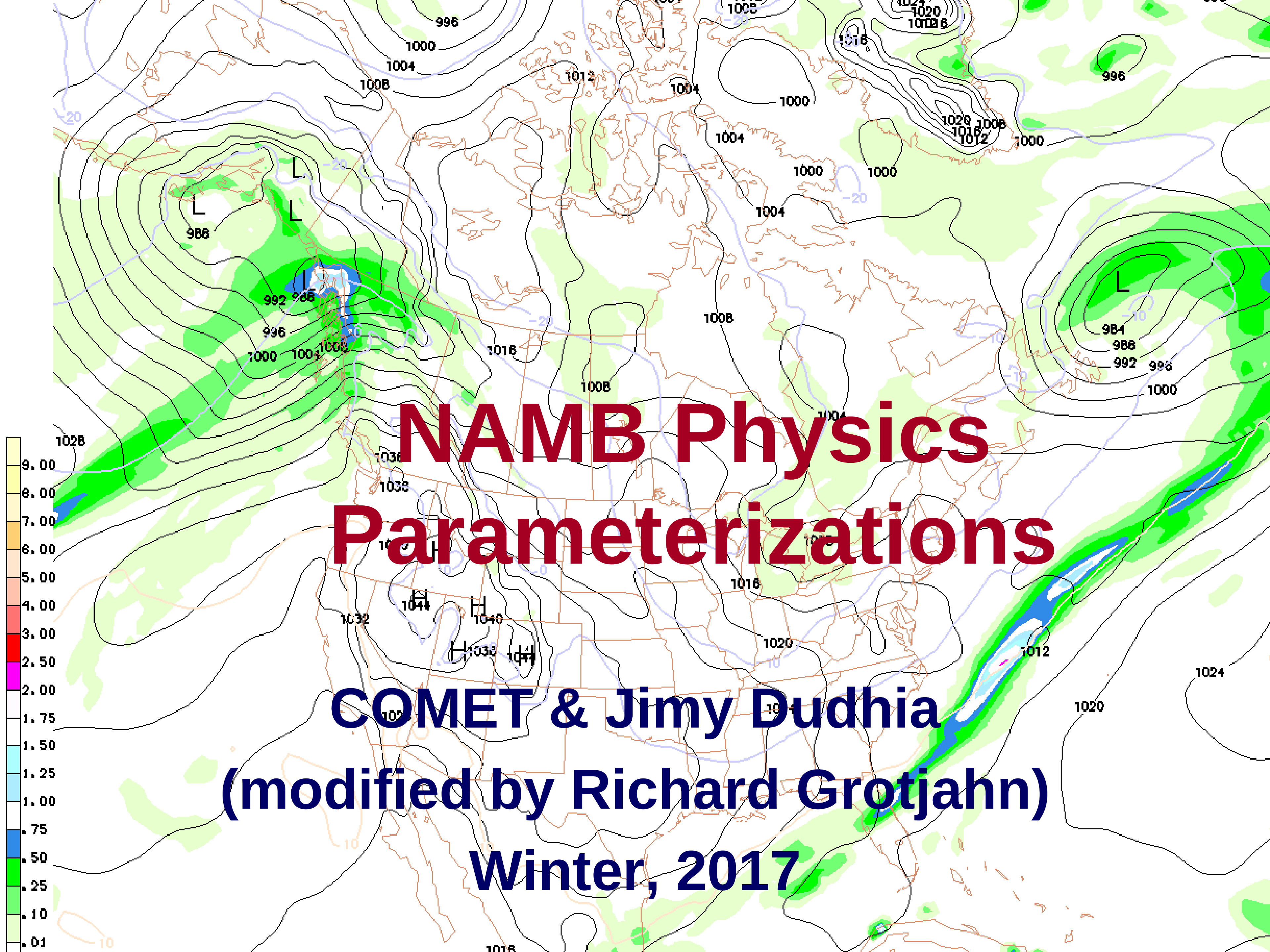


NAMB Physics Parameterizations

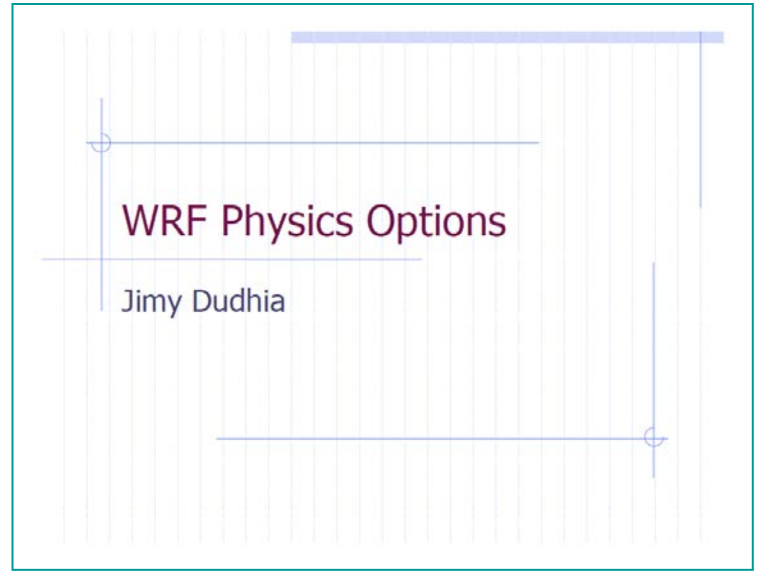
COMET & Jimy Dudhia

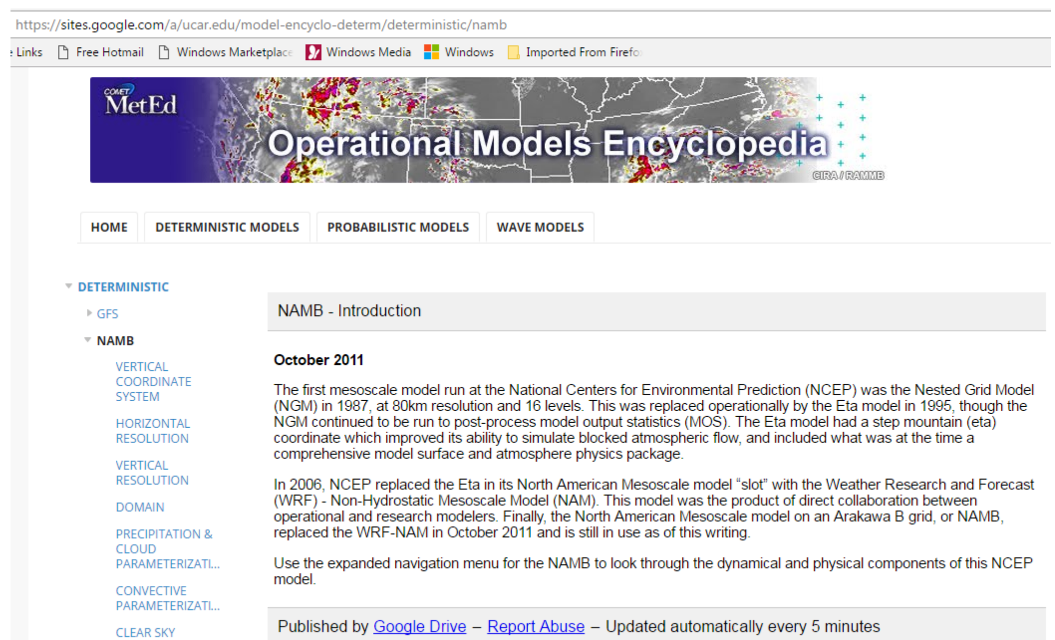
(modified by Richard Grotjahn)

Winter, 2017

Sources:

- Borrowed heavily from this NCEP document and the meted Operational Models Encyclopedia.
- http://www.mmm.ucar.edu/wrf/users/tutorial/200807/WRF_Physics_Dudhia.pdf
- https://sites.google.com/a/ucar.edu/model-encyclo-determ/deterministic/namb





Overview

- A ‘physics parameterization’ is an approximation of a process.
- They are often not of direct interest to a forecaster. (primary exception: precipitation)
- Process parameterized to obtain with ‘sufficient accuracy’ the impact of that process upon a primary variable. (e.g. how radiation affects primary variable T)
- Various approximations (schemes) exist for the same physical process. Different schemes have different advantages/disadvantages: speed, accuracy in certain situations, storage space, etc.
- Generally speaking, the physics parameterizations are more accurate in the regional model than the global model. (partly due to better resolution)
- You do not need to memorize the model details that follow. Just learn the types of processes and issues.

Outline

- Overview
- Microphysics in clouds (heat & moisture tendencies; rates; other surface precipitation)
- Convective parameterization (heat & moisture tendencies; surface precipitation)
- Radiation (longwave & shortwave; clear)
- Radiation (cloud effects)
- Surface schemes (fluxes, land surface models: LSMs, SST)
- Turbulence & diffusion
- Planetary boundary layer (PBL fluxes, vertical diffusion)
- Interactions between physics parameterizations
- Summary

Precipitation & Clouds-1

- The most important features of the scheme are:
  - It allows hydrometeors to grow and shrink in size
  - It uses an ice density to account for different forms of frozen precipitation
  - Fall speeds depend on hydrometeor size and type
    - Sedimentation/sorting occurs as larger and especially denser particles fall faster
    - Collection growth occurs as hydrometeors sweep out others on the way down
    - Precipitation gradually falls to the ground at appropriate speeds and can be advected as part of the total condensate while falling
  - It allows mixed phase precipitation, including
    - Riming
    - Shedding of rain off melting ice
    - Coexistence and interaction of all forms of liquid and frozen cloud and precipitation particles under certain conditions

Precipitation & Clouds -2

- These features allow the model to predict a variety of phenomena:
  - Snow blowing over a ridge crest or downstream from the Great Lakes
  - Density of frozen hydrometeors, which might, after further development and then testing, be able to be used to predict snow:water ratios
  - Good physical realism of precipitation type (caveat: consistent with model's temperature profile, which may differ from the real-life temperature profile!)
  - Feeder-seeder precipitation mechanism
  - Cloud cover at different levels and different types of clouds (water, ice, mixed)
  - More realistic cloud water content than previous scheme
  - Cirrus which precipitates out (fall streaks)
  - Virga and evolution from virga to precipitation on the ground
  - Warm rain processes (no ice) and cold rain processes (start with snow)

Precipitation & Clouds -3

- The scheme assumptions do not allow prediction of some phenomena:
  - Heavier precipitation associated with dendritic growth
  - Hail (riming included but no liquid below -40°C, limited particle size and fall velocity)
  - Growth of snow falling through a temperature inversion (snow will shrink slightly instead)
  - Effects of different aerosol types and concentrations, including marine-continental differences in drop size distribution and precipitation production
  - Convective cloud microphysics, featuring water supersaturation in updraft cores and unsaturated downdrafts side by side, easily fitting within a model grid column
  - Separate advection of different hydrometeor types (mainly affects very high resolution runs)

Precipitation & Clouds -4

- an ensemble of **FIVE** precipitation type algorithms are used and the predominant precipitation type is output to the forecast file. A graphic showing these precipitation types and how they work is shown below.

NAM-WRF: Dominant type among 5 algorithms

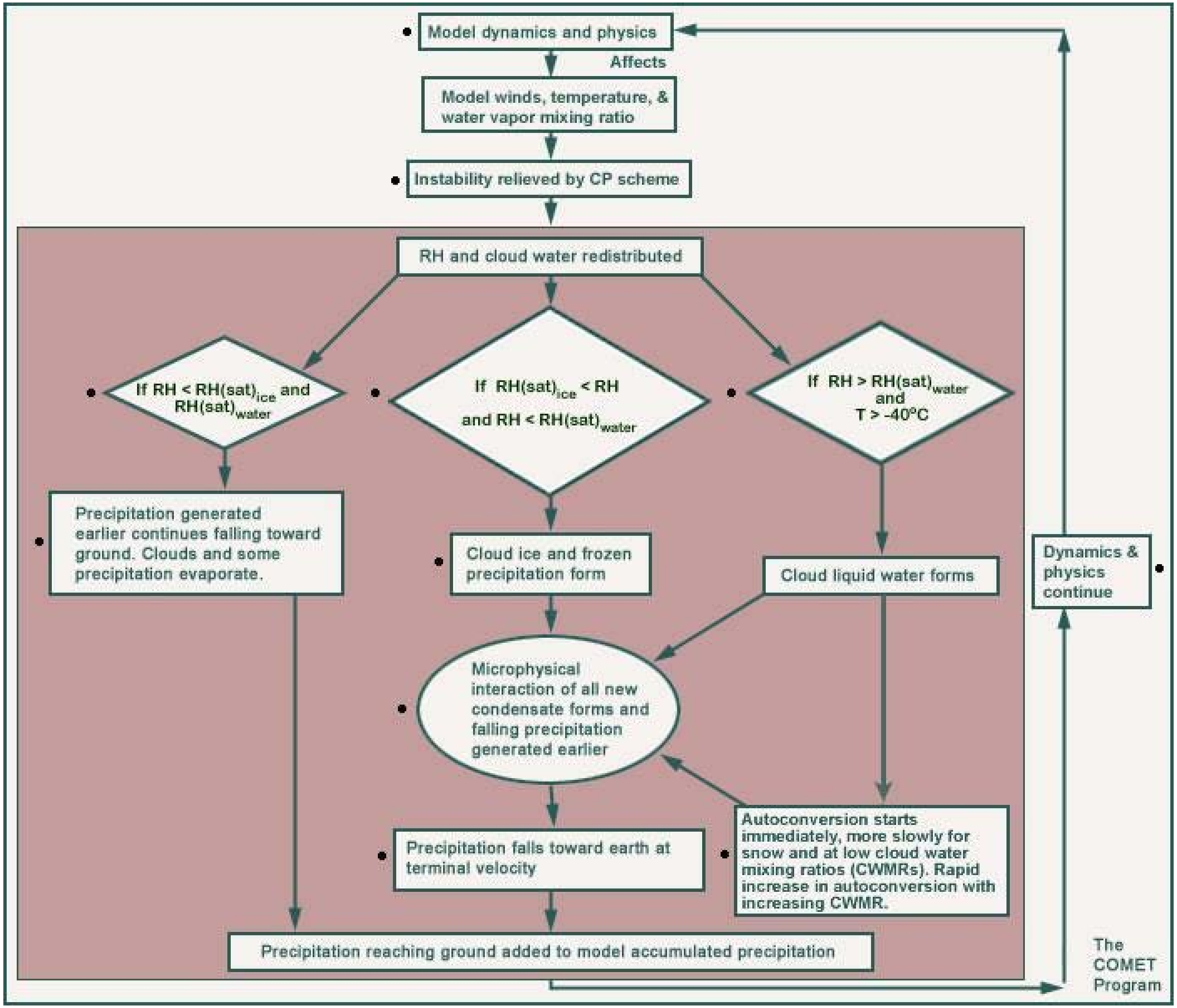
NCEP Baldwin-Schichtel	Revised NCEP	Ramer	Bourgouin	Explicit microphysics
• Small sounding **wet bulb area** > -4 °C → SN • Else, big **wet bulb area** < 0 °C → PL • Overpredicts ZR • Underpredicts SN	• Relax snow criterion so entirely subfreezing sounding → snow	• **Wet bulb** < -6.6 °C all levels → snow • Sfc **wet bulb** > 2 °C → RA • Else, assume top saturated layer = ice or liquid, integrate down using **RH** and 0 °C-T_w → ice fraction, melt history • If mix, *ignored*	• Criteria uses sounding **area of temperature layers** > 0 °C surface, aloft and **area of temperature layers** < 0 °C surface, aloft • If SN/RA mix, random pick SN or RA • If ZR/PL mix, random pick ZR or PL	• **Frozen hydrometeor fraction** < .5: T_{skin}>0 → RA T_{skin}<0→ZR • **Frozen hydrometeor fraction** > .5: low **rime factor** → SN high **rime factor** → PL

Precipitation & Clouds -5

- Process of the 'PCP' (precipitation and cloud parameterization) scheme

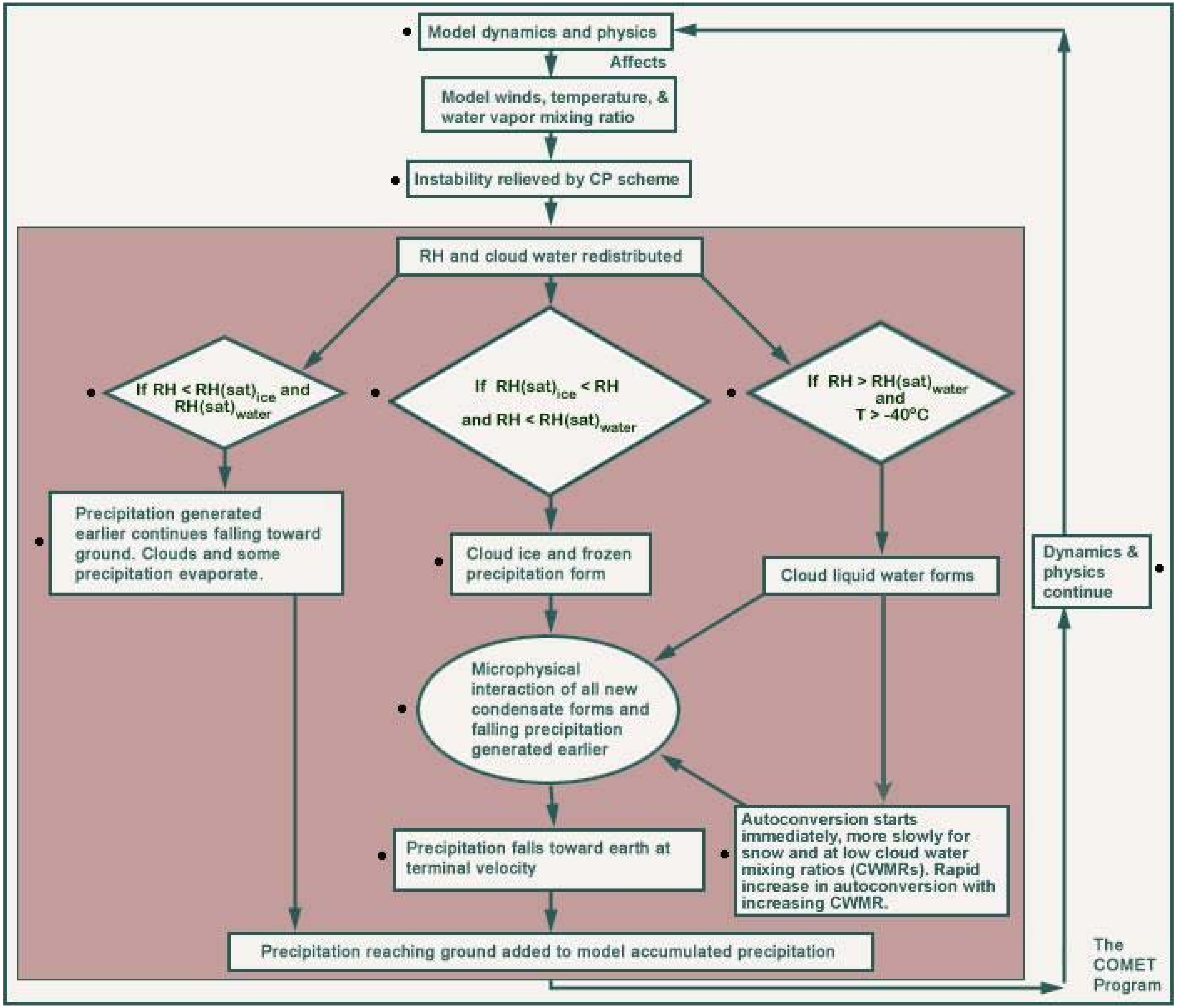
- **Model dynamics and physics**: model's wind, temperature, and water vapor mixing ratio fields. Any existing clouds and falling precip are advected.

- **Instability relieved by CP** (convective parameterization): heat and water vapor redistributed in the grid column, affecting the RH in model layers between LCL and equilibrium level. No condensate is generated; all convective precipitation falls instantly.



Precipitation & Clouds -6

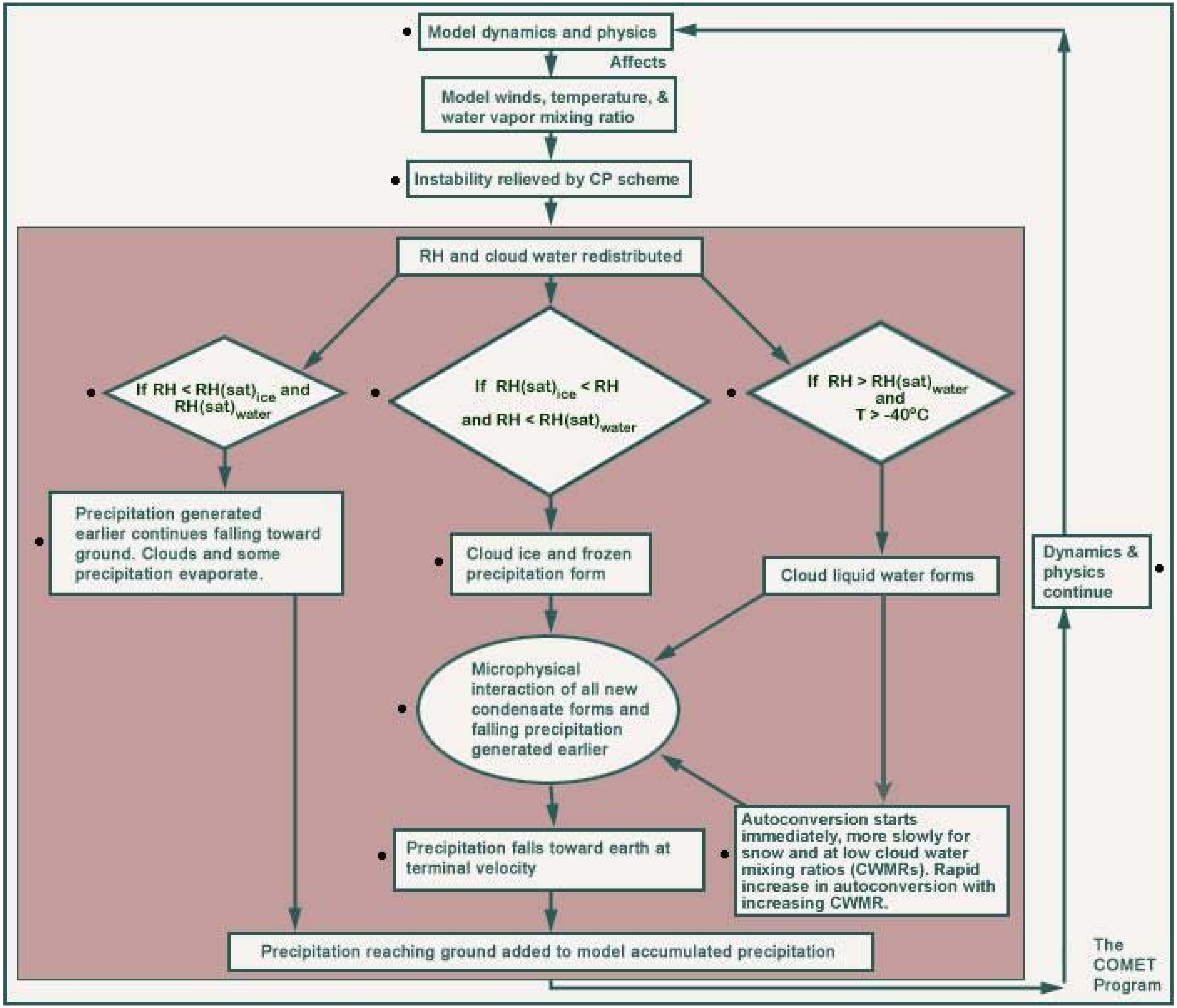
- **If RH(sat)ice < RH < RH(sat)water**: RH greater than 100% with respect to ice but less than 100% with respect to water, cloud ice and precipitation ice are added to any already present.
- **If RH > RH(sat)water and T > −40°C**: If RH exceeds 100% with respect to water within a three-dimensional grid box, cloud liquid water is added to any already present. Some cloud ice will form, with greater amounts closer to −40°C.
- **If RH < threshold RH**: If RH less than RH(sat)ice, no new cloud liquid and/or cloud ice are permitted but falling precipitation generated earlier may be present.



Precipitation & Clouds -7

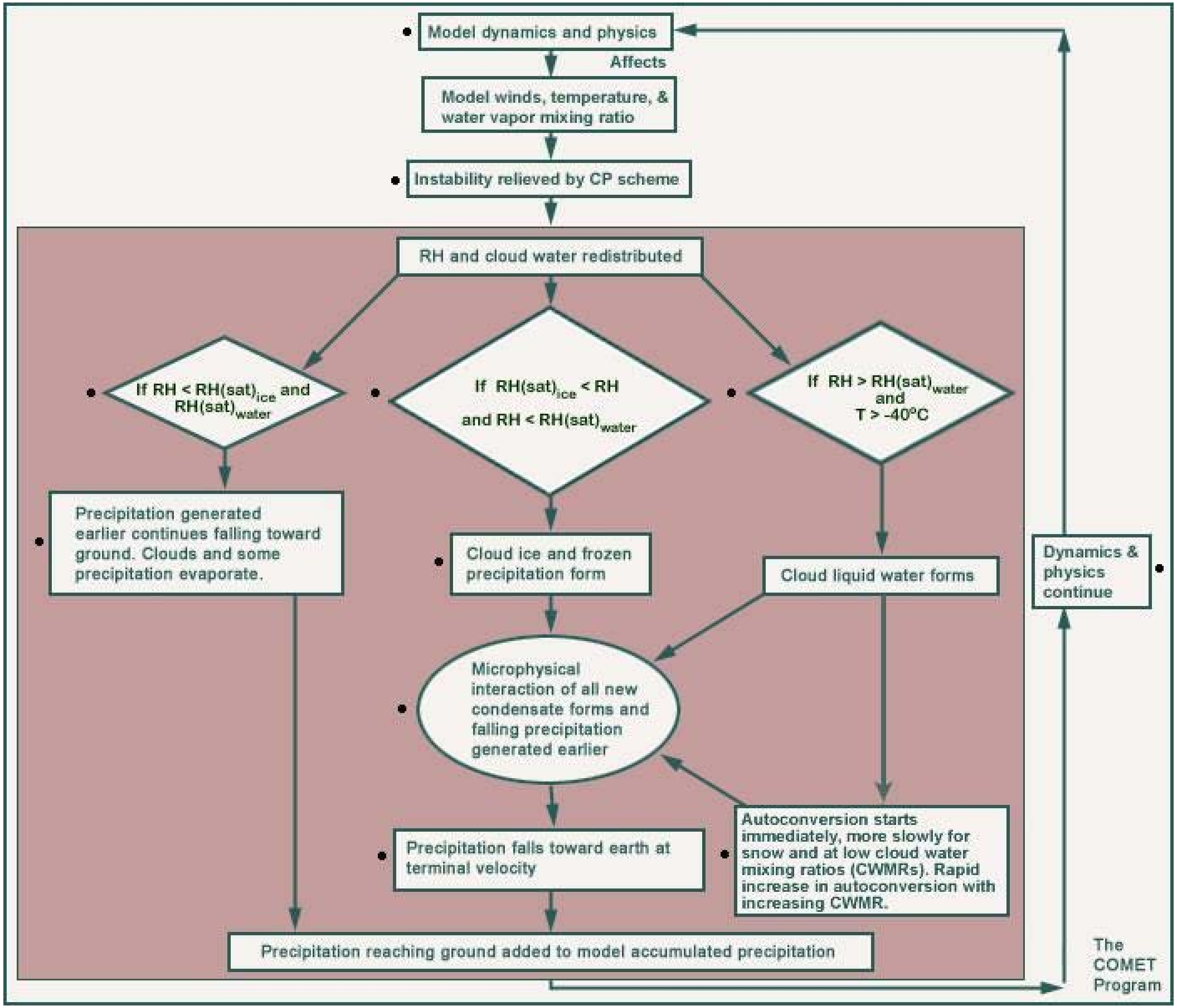
- **Precipitation generated earlier continues falling toward ground**: Precipitation falls at realistic speeds. Light precipitation may take an hour or more to reach ground while heavy rain may reach the ground in a few minutes. Also, some precipitation evaporates.

- **Cloud ice and frozen precipitation form**: Cloud ice and snow form together, ranging from almost equal parts cloud ice and tiny snow crystals for cold cirrus to mainly large snowflakes at warmer temperatures.



Precipitation & Clouds -8

- **Microphysical interaction of all condensate forms**: Precip falling from above, pre-existing cloud ice and cloud water, and newly formed condensate all interact, including forming additional precip by collecting cloud water and cloud ice.
- **Precipitation falls at terminal velocity**: Light precip may take 1+ hour to reach ground while heavy rain may reach ground in a few minutes.
- **Autoconversion starts immediately:** Rates of autoconversion slower for ice at temperatures near 0°C and for low amounts of cloud liquid or ice, with a rapid, nonlinear increase with cloud water increase..
- **Dynamics and physics continue**: Rates of cloud condensation and precip production remain unchanged for 5-9 dynamical time steps (varies from NAMB parent and among inner nests), then get updated again using new RH and hydrometeor fields.



Precipitation & Clouds -9

- Summary.

PCP Characteristic	Implementation in NAM
Time step	Eight minutes (every eighteen dynamical time steps)
Threshold RH	100% for all grid spacings
Cloud water formation and evaporation	Where T < -40°C, ice clouds form (entirely evaporate) when RH with respect to ice > (<) threshold RH Where -40°C < T < 0°C Water clouds form (entirely evaporate) where RH with respect to water > (<) threshold RH but will rapidly convert to ice because Ice clouds form if ice is already present (such as from falling precipitation) where RH with respect to ice > threshold RH Ice clouds entirely evaporate where RH with respect to ice < threshold RH Cloud water and cloud ice both form if ice is already present and RH with respect to water > threshold RH Where T > 0°C, water clouds form (entirely evaporate) when RH with respect to water > (<) threshold RH Formula for conversion of vapor to cloud water and cloud ice is from Asai (1965) and used in many mesoscale models
Advection of cloud	Horizontal and vertical advection
Precipitation production	Snow forms when cloud ice is created Snow grows at the expense of cloud ice crystals as temperature increases (such as when it falls) Rain forms immediately upon cloud water production (i.e. there is no autoconversion threshold) using Liu and Daum (2004) parameterization Much more rain can form from collection of cloud water by falling rain Falling ice also collects cloud liquid water When T > 0°C, the collected water is shed as rain, which may collect more water
Transport of precipitation	Precipitation falls at terminal velocity Snow and light rain may take over an hour to reach the ground Heavily rimed ice and heavy rain may take only a few minutes to reach the ground **Falling precipitation is advected**

Precipitation & Clouds -10

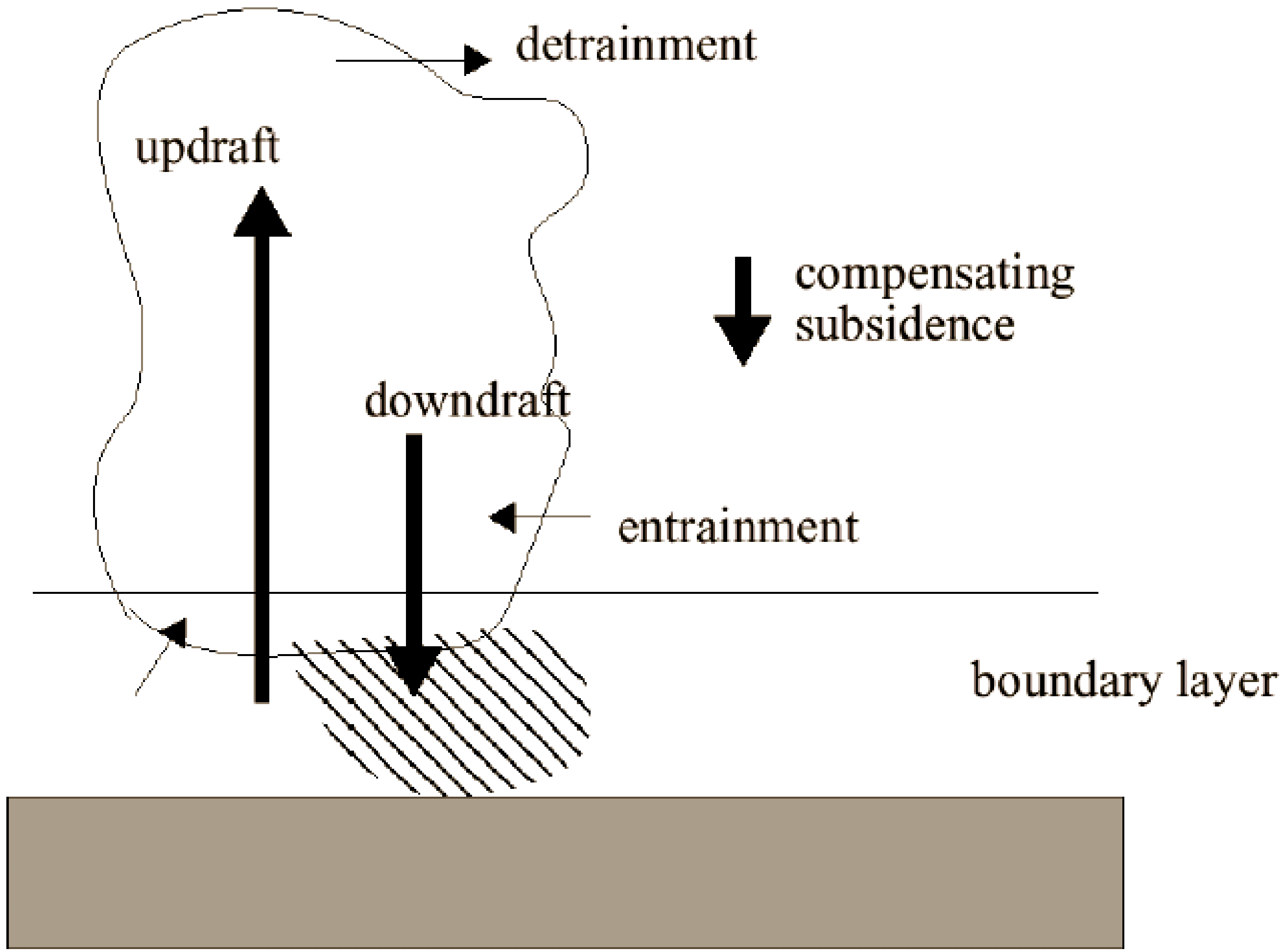
- Summary.

Treatment of falling precipitation	Hydrometeor characteristics Ice density of frozen precipitation affects fall velocity. Ice density may increase by riming and by collisions with supercooled rain drops. Frozen precipitation has a larger average diameter at warmer temperatures, emulating aggregation and cloud crystal collection Rain drops have a larger average diameter when the amount of rainwater is larger, emulating the collection of rain drops by other rain drops Phase change Evaporation (sublimation) of some rain (ice) in layers where RH with respect to water (ice) < threshold RH. Precipitation may fall through dry layers with only a little evaporation; smaller crystals and drops evaporate more readily. Freezing of a small fraction of rain at T < 0°C ("stochastic freezing") Freezing of some rain in presence of ice at T < 0°C (collisions) Partial melting of ice at T > 0°C, typically melting completely by about the 3°C level. Melting level may be affected: If dewpoint > 0°C, water condenses on melting ice, warming air with latent heat release If dewpoint < 0°C, meltwater evaporates, cooling air with latent heat extraction
Precipitation type at the earth's surface	The scheme explicitly predicts rain, supercooled rain (rain at T<0°C), and frozen precipitation reaching each model layer, including the surface. Output of these fields and the scheme's prediction of the percentage of precipitation in frozen form is included in the NCEP grib files but is not distributed to AWIPS over the SBN Postprocessed precipitation-type diagnostic (rain, freezing rain, sleet, and snow) is also available and an ensemble of 5 precipitation type algorithms are used. The predominant (most often occurring) precipitation type is the output sent over the SBN; **this may disagree with precipitation type coming directly from the microphysics scheme.**
Interaction with surface physics	Rain goes into soil and is available for evaporation Frozen precipitation reaching the surface accumulates and is treated as snow, affecting albedo Rain landing on frozen ground adds to the snowpack water content and liberates the latent heat of fusion, slightly warming the ground
Interaction with radiation	Cloud cover used in radiation depends upon total condensate (cloud and precipitation) and RH_{ice} or RH_{liquid} Cloud cover used in radiation is NOT based on the model outputs of low, middle, and high clouds

Convective Parameterization

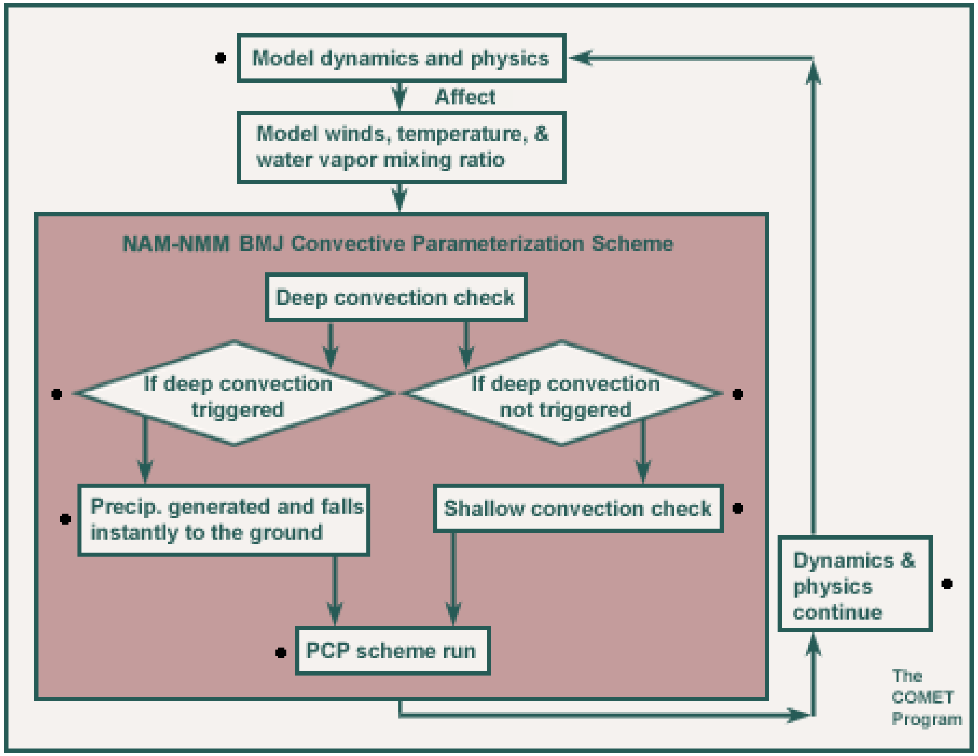
- Superadiabatic profiles of temperature can form from advection, heating below, cooling above, etc.
- Various situations trigger convection
- NAMB uses Betts-Miller-Janjic (‘BMJ’) scheme
  - adjusts the model temperature and moisture profiles toward reference profiles with temperature resembling a moist adiabat and dewpoint depressions of 4 to 6°C

Illustration of Cumulus Processes



Convection

- **Model dynamics and physics:** Change winds, temperature, and the water vapor mixing ratio fields. Any existing clouds are advected.
- **If deep convection is triggered:** Reference temperature and moisture profiles are determined and the model sounding is adjusted slightly toward the reference profiles, such that if the adjustments continued over a convective timescale of **~40 to 50 minutes,** it would reach the reference profiles.
- **Convective precipitation is generated and fall instantly to the ground:** No microphysics are involved, no evaporation of convective precipitation occurs, and no convective cloud water is created. Convective clouds are flagged for using the radiation scheme.
- **PCP scheme is run:** The cloud and precipitation scheme runs using the adjustments to the RH field (if any) created by the convective scheme.
- **If deep convection is not triggered:** Shallow convection may be triggered for mixing through the top of the boundary layer (for instance, like the effects of moderate cumulus).
- **Shallow convection is checked:** If activated, the shallow CP scheme modifies the top of the boundary layer acting as an extension of the model physics boundary-layer mixing process.
- **Dynamics and physics continue:** Convective precipitation and convective sounding changes continue at the same rate for a total of **nine minutes (six dynamic time steps)**, then get updated again using new model soundings.



Convective Tuning parameters

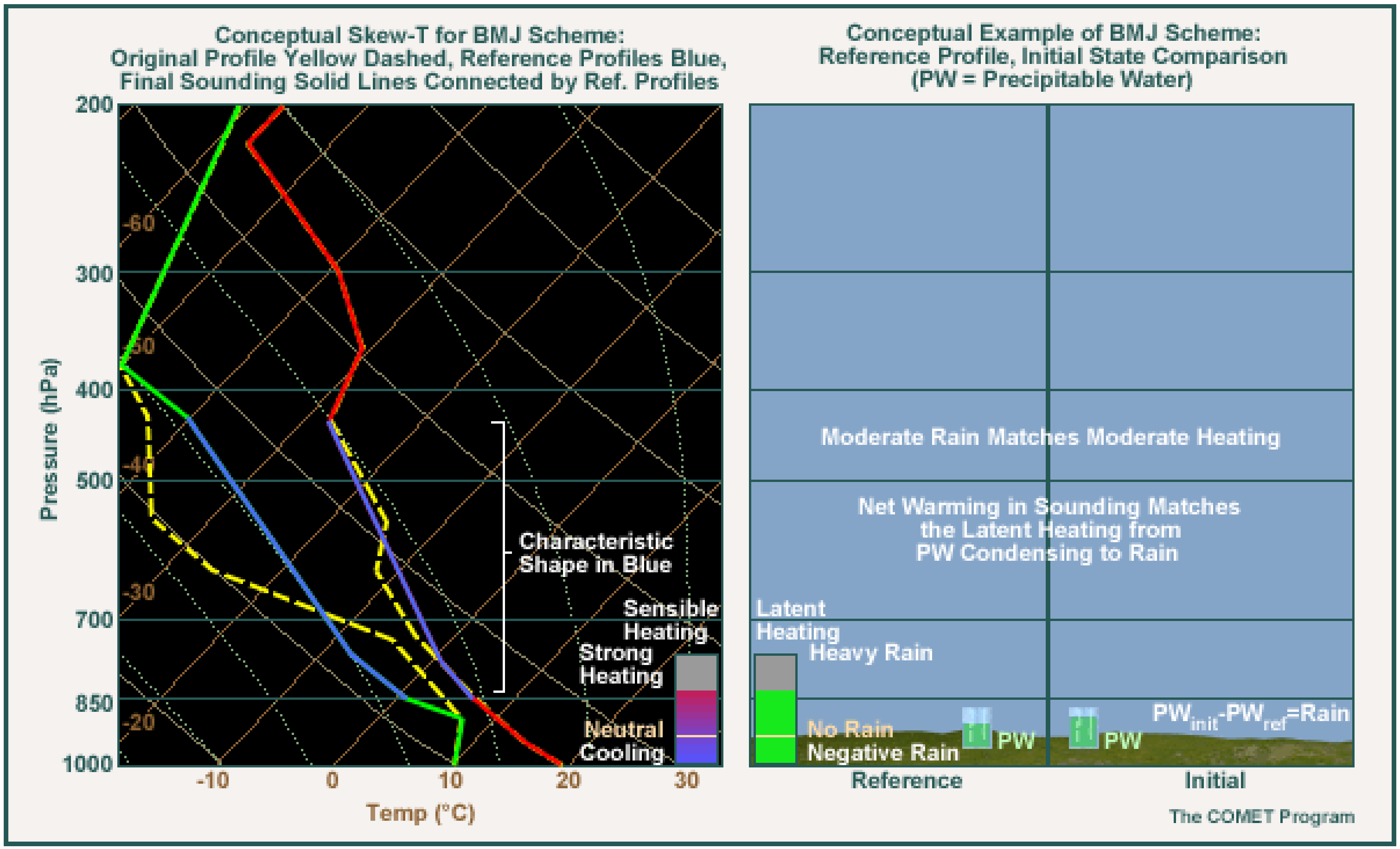
- Values that are set to improve the forecast
- ‘Current’ (2/2017) values shown
- Other parameters are also available for change

Scheme Elements	Definition & Explanation
Parcel source	Generally, the parcel source layer is calculated as the most unstable model layer within ***400 hPa * (P_{sfc}/1000 hPa)*** of the ground (the lowest 40% of mass in a model grid column), where P_{sfc} is the model surface pressure (not reduced to sea level). The parcel source may also be above the most unstable layer if such parcels can become buoyant when lifted to their LCL. For elevated convection to trigger in the model, it must be rooted within this depth of the model topography
Convective cloud base	The convective cloud base is taken as the model level just below the source parcel LCL. If this is too close to the ground (for example, in the lowest above-ground layer or within ***25 hPa*** of the middle of the lowest above-ground layer), cloud base is raised to the lowest model level that's not too close to the ground.
Convective cloud top	The convective cloud top is defined as the first model level where the source parcel would ***exactly*** lose its buoyancy following moist-adiabatic ascent, ***including water loading effects***. Parcel buoyancy empirically accounts for the latent heat of fusion at subfreezing temperatures. (*In nature, a saturated rising parcel receives and extra latent heat boost when ice forms. A standard skew-T moist adiabat does not account for this while a cloud model usually account for it directly. The BMJ scheme attempts to account for this extra latent heat associated with ice processes.*)
Trigger requirements	For the scheme to trigger: There **must** be an unstable parcel For deep convection, the convective cloud depth must exceed ***200 hPa* (P_{sfc}/1013.12 hPa)*** (i.e. 20% of the grid column by mass), otherwise the shallow convection scheme is followed. The adjusted reference profile must produce net warming and drying. The pre-convective sounding must have more precipitable water ***in the cloud layer*** than the adjusted reference profile, otherwise deep convection is not triggered. Scheme sounding changes must increase entropy, which usually means upward transport of heat and moisture

Parameters related to moisture profiles	Value
Cloud base, freezing level, and cloud top DSP ("fast" profiles)	***-38.75, -58.75, -18.75 hPa***
If cloud base is warmer than freezing but beneath the freezing level by less than this amount, only interpolate with DSP for freezing level and cloud top; do not use DSP for cloud base (When this situation occurs, it results in a drier profile in the lower part of the cloud and thus a little more precipitation)	***150 hPa * (P_{sfc}/1000 hPa)***
"Slow profile" multiplies DSP values by this amount	***.85***
"Fast" timescale for forcing sounding to the reference profile	***40 minutes***
The longest timescale for forcing the sounding to the reference profile ("slow") = "fast" timescale / F_1	***F_1 = 0.7 57 minutes***
Dewpoint values at very high altitude (above this level) are not altered from the pre-convective sounding	***200 hPa***

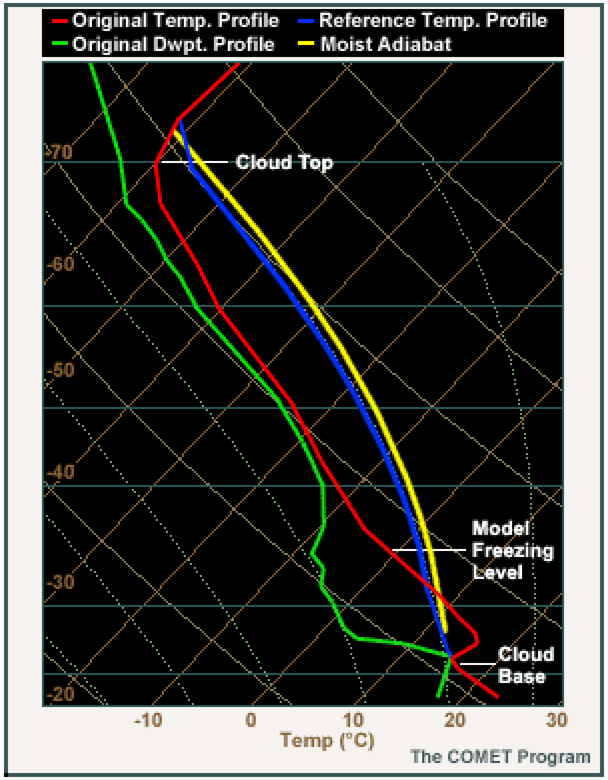
Convective adjustment -1

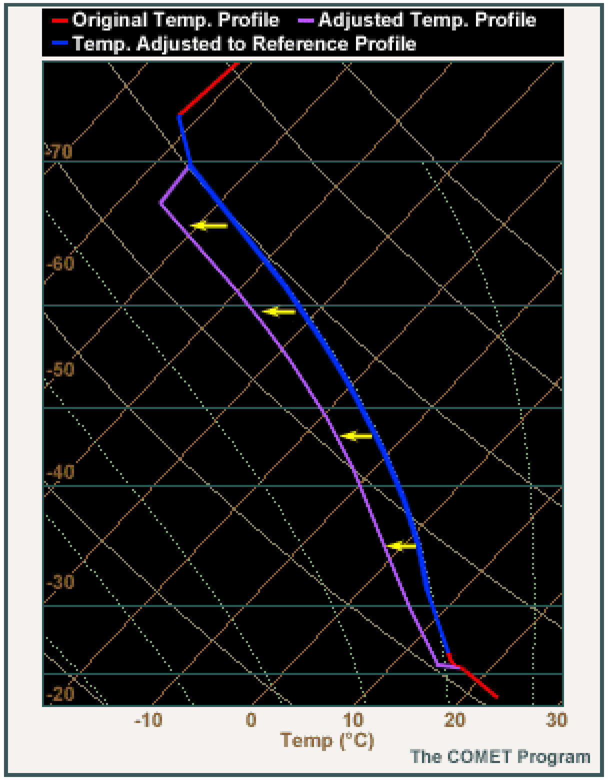
- Part of the model sounding (yellow dashed, ‘Y-shaped’) forced towards reference profiles (blue).
- Rate of adjustment varies with intensity of the precip, location, etc.

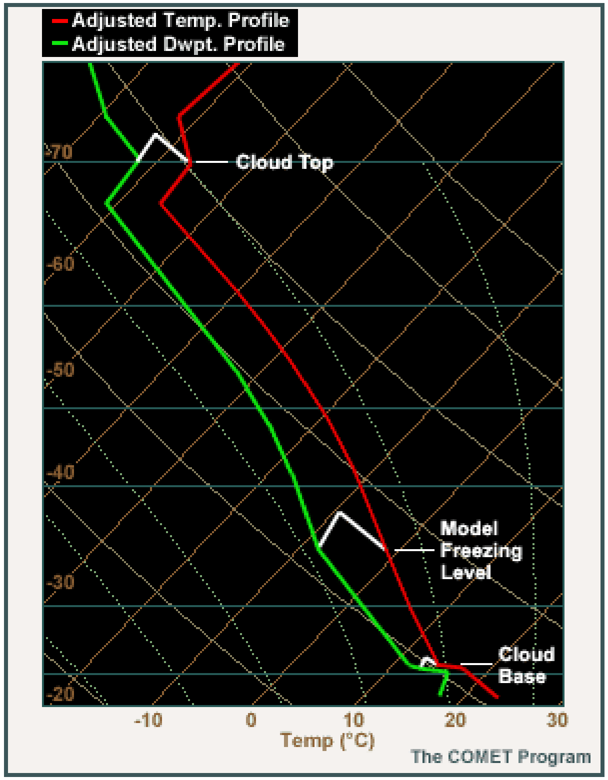


Convective adjustment -2

- Reference profiles constructed from first guess T, T_d that are adjusted
- For T: criteria applied in different T ranges (e.g. T<0C)
- Based on moisture change, T remains warmed as in lifted parcel (middle, blue) or must be cooled (purple) to have ‘same’ amounts of cooling and heating layers
- For T_d: this adjustment determines amount of precip generated (which may have different types, interact, etc.) Deficit saturation pressure (DSP) at 3 levels (right fig) which specify the shift of the profile based on the adjusted T profile







Cumulus scheme

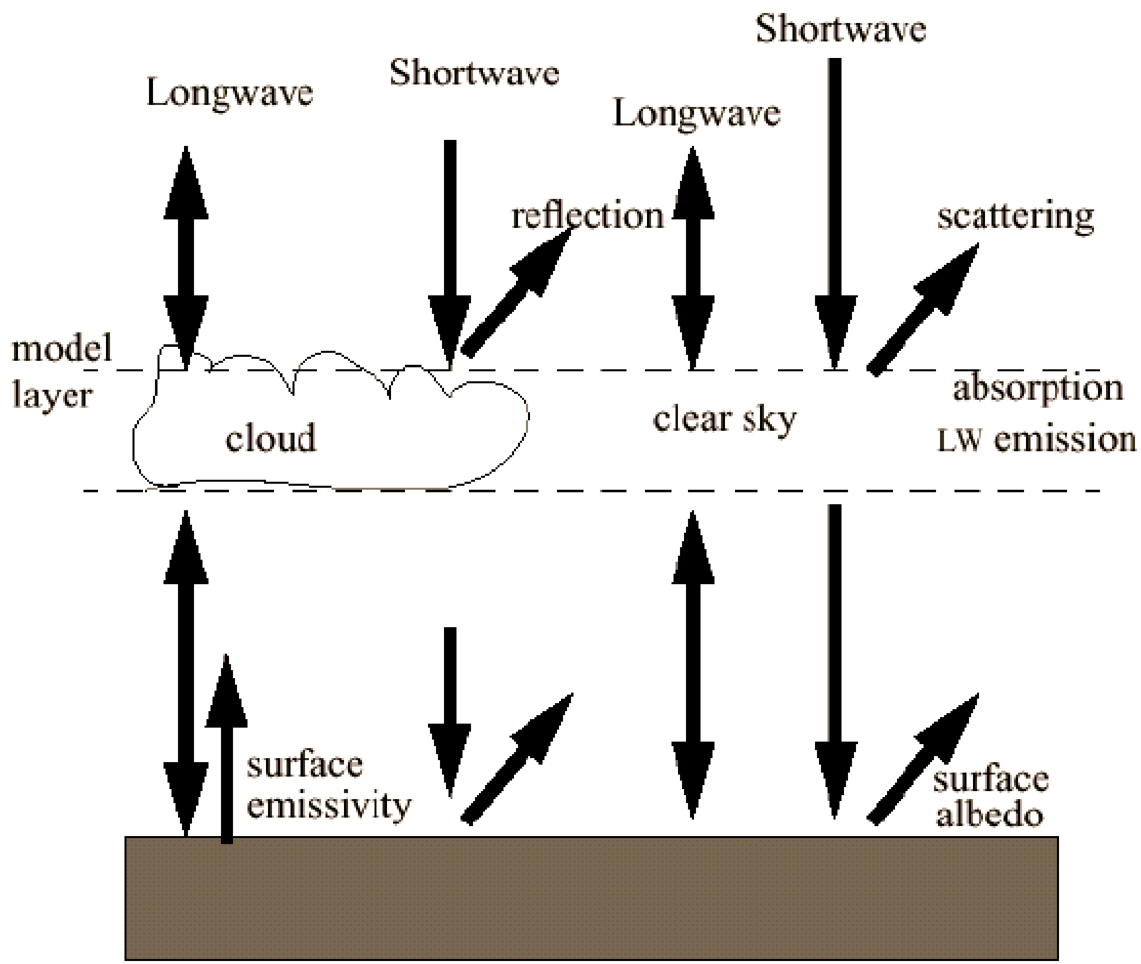
Recommendations about use

- 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

Radiation

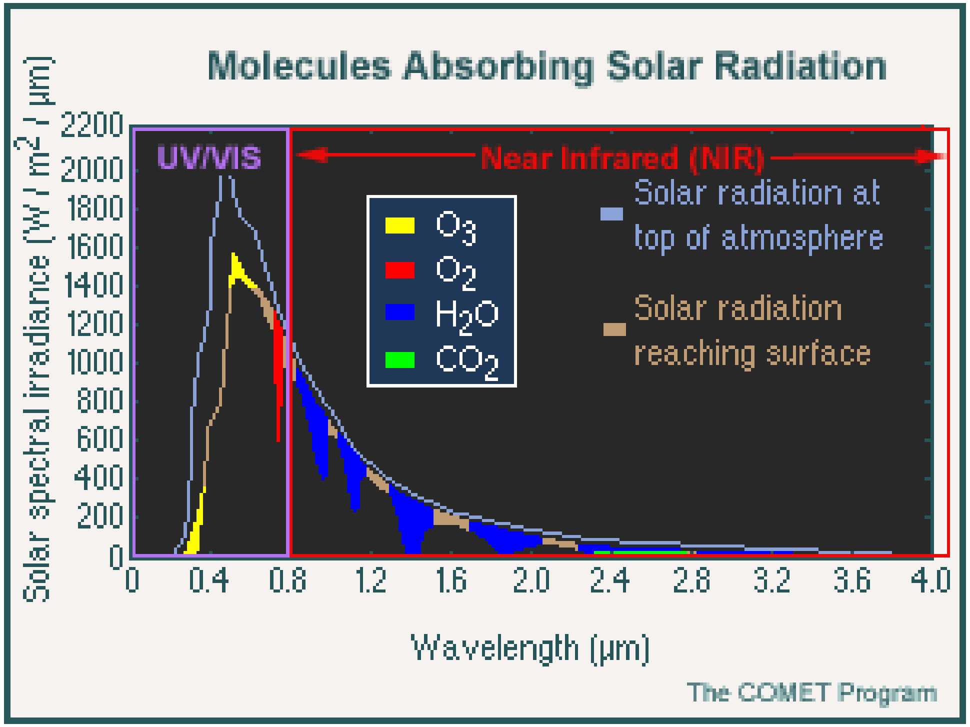
- Clear sky
- Cloudy sky

Illustration of Free Atmosphere Radiation Processes



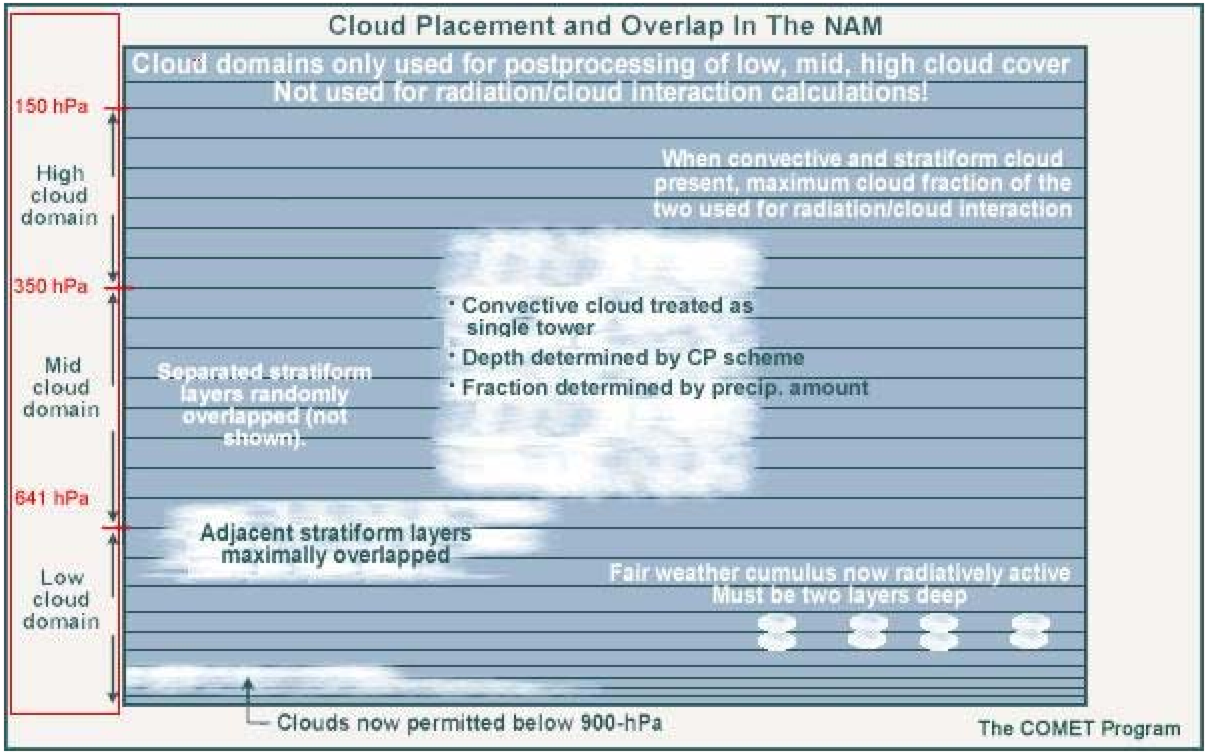
Solar Radiation – clear sky

- Absorbers:
  - Seasonal prescribed ozone
  - Predicted water vapor
  - Prescribed CO_2
  - Oxygen (diatomic)
  - Aerosols
- Shortwave spectrum divided into halves of energy (Lacis and Hansen scheme)
- Amount of absorber estimated in each layer, then absorption accumulates as sunbeam heads down
- Reflection & scattering diminish the beam
- Varies diurnally and seasonally
- Is a heating term in the temperature tendency eqn.
- Impacts the surface energy budget (radiation reaching sfc)



Solar Radiation – cloud

- Assumptions about opacity differ for different cloud types (see fig)
- Reflects, absorbs, transmits sunbeam
- Hydrometeors included
- Again, T tendency in layers and sfc energy budge impacted



Shortwave radiation (NMM)

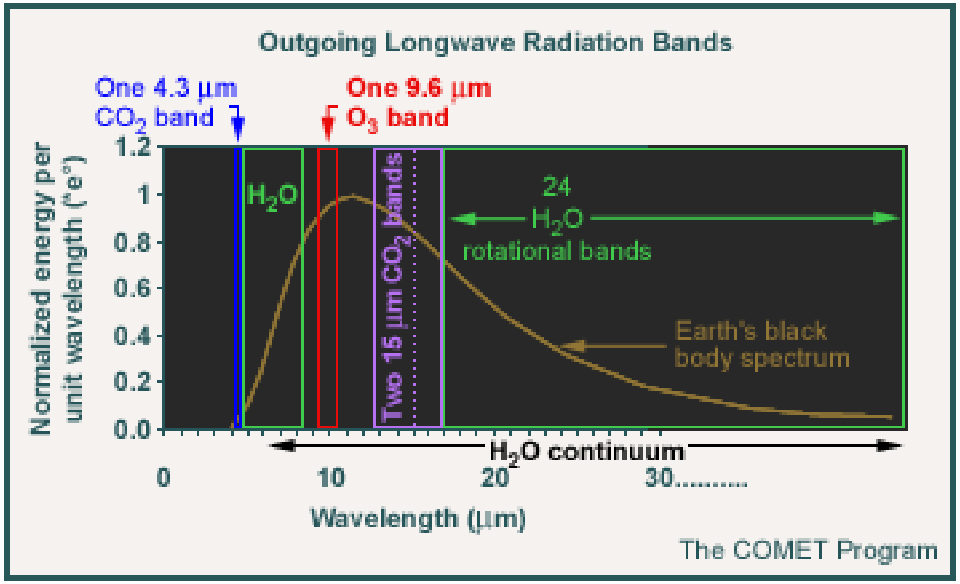
ra_sw_physics=99

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

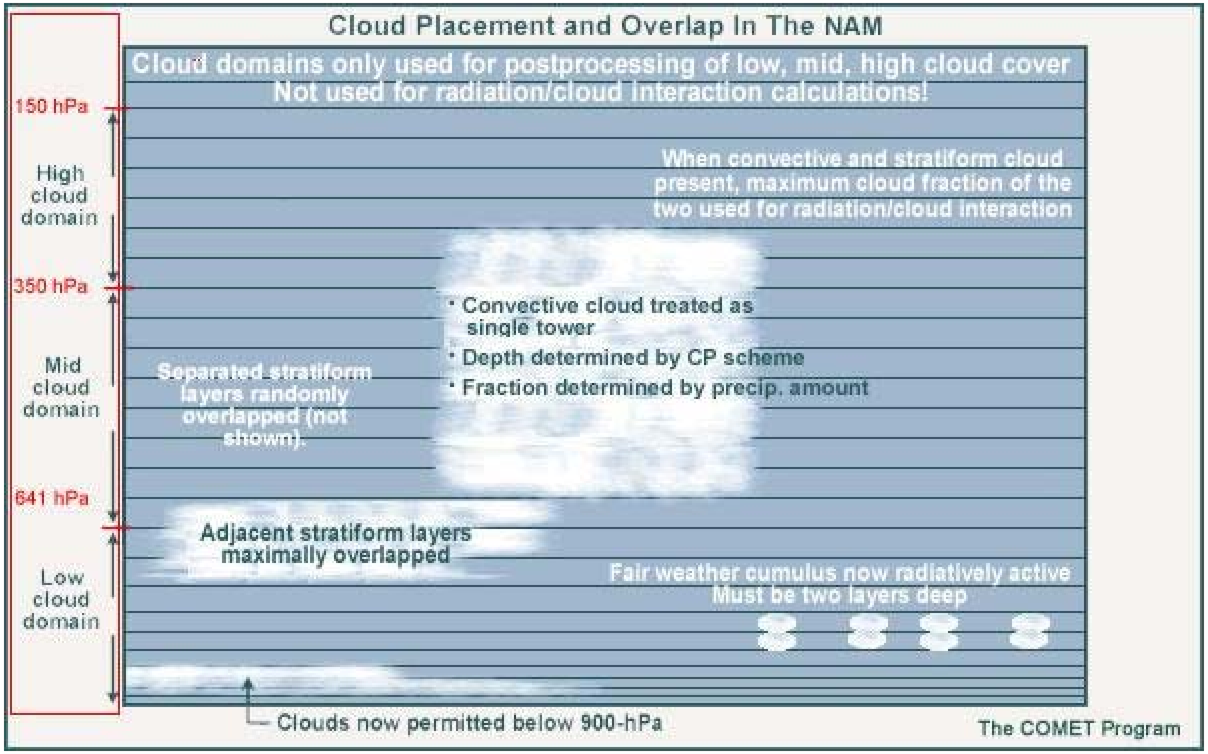
Terrestrial Radiation – clear sky

- Longwave radiation, LWR
- Absorbers:
  - Seasonal prescribed ozone
  - Predicted water vapor
  - Prescribed CO_2
- Model sfc radiates as black body (calc. every time step)
- Absorption in bands (fig) Schwarzkopf and Fels scheme. Bands overlap for different gases.
- Layers absorb & emit both upwards and downwards
- Impacts temperature tendency in layers
- Impacts surface energy budget



Terrestrial Radiation – cloud

- Assumptions about optical depth differ for different cloud types (see fig)
- Absorbs, emits, transmits longwave radiation (up & down)
- Hydrometeors included
- Again, T tendency in layers and sfc energy budge impacted



Longwave radiation (NMM)

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

Interval between radiation calculations

NMM only

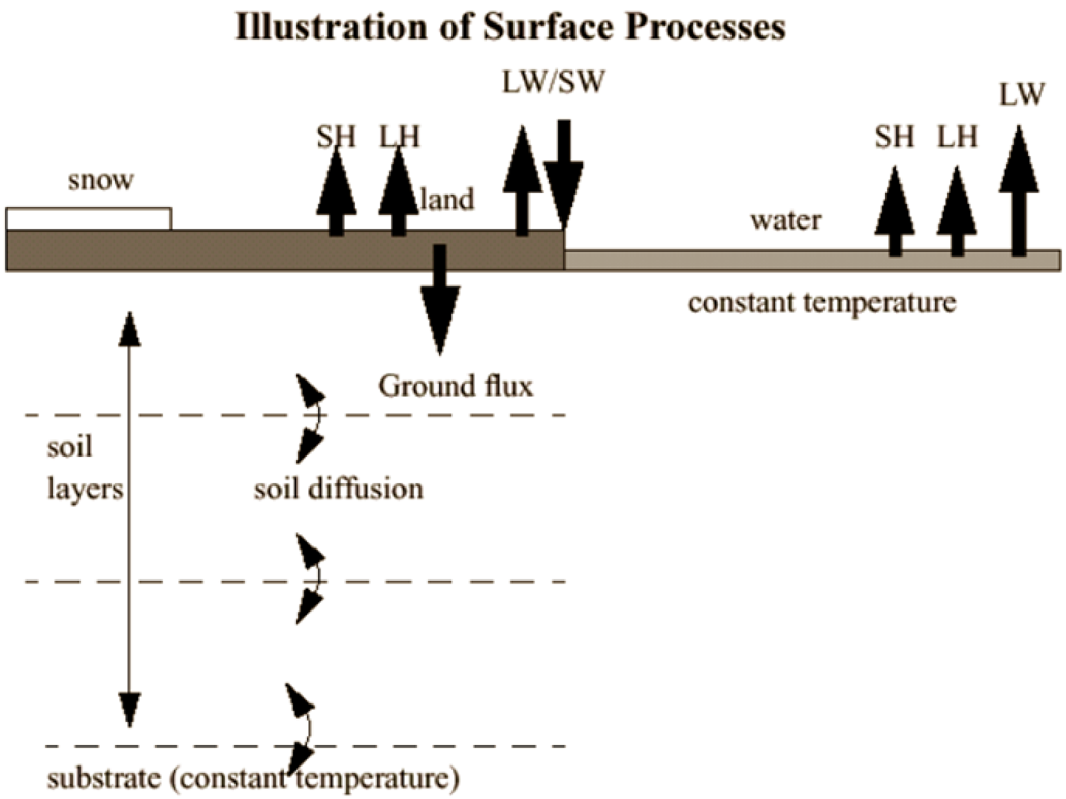
nrads/nradl

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

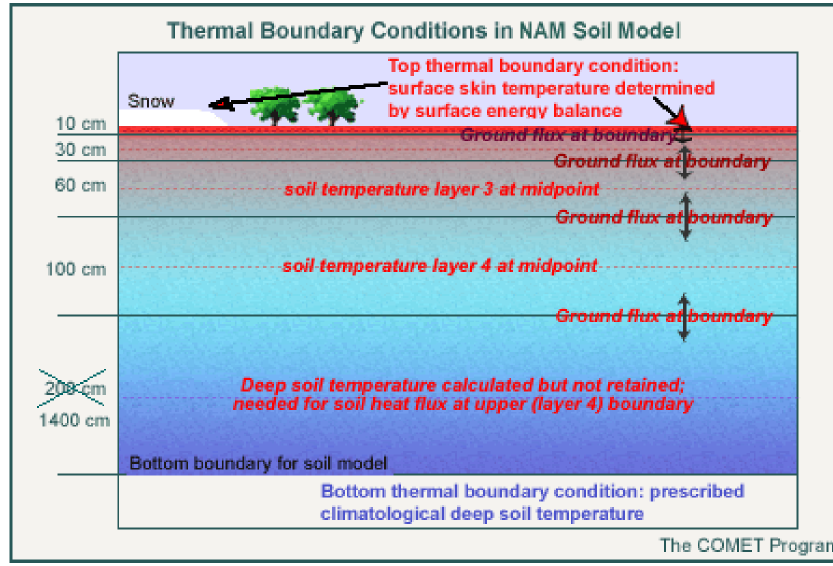
Surface models (land, water, snow)

- Land models
  - Vegetation type
  - Soil moisture
- Water
  - Lakes
  - Ocean
  - Sea ice
- Snow cover

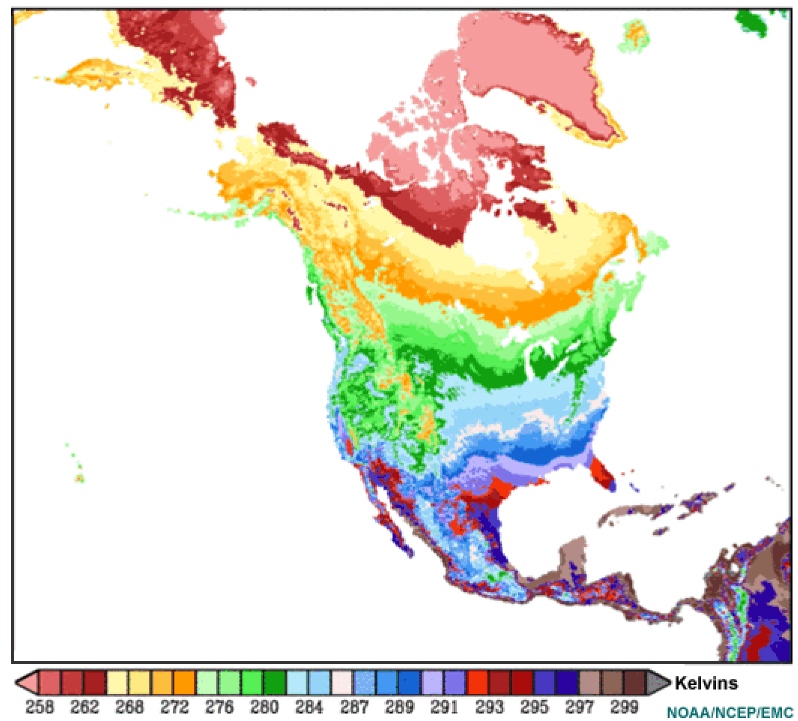


land

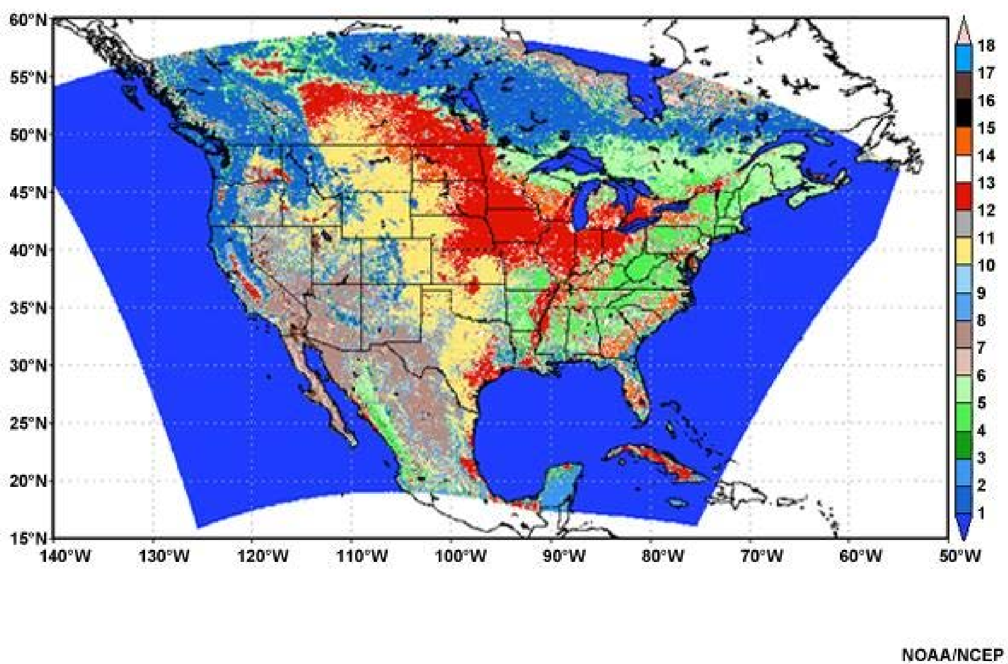
- Soil layers
  - T, moisture, etc.
- Vegetation type
  - Transpiration, albedo, etc.



NAM-Eta Deep Soil Temperature Climatology

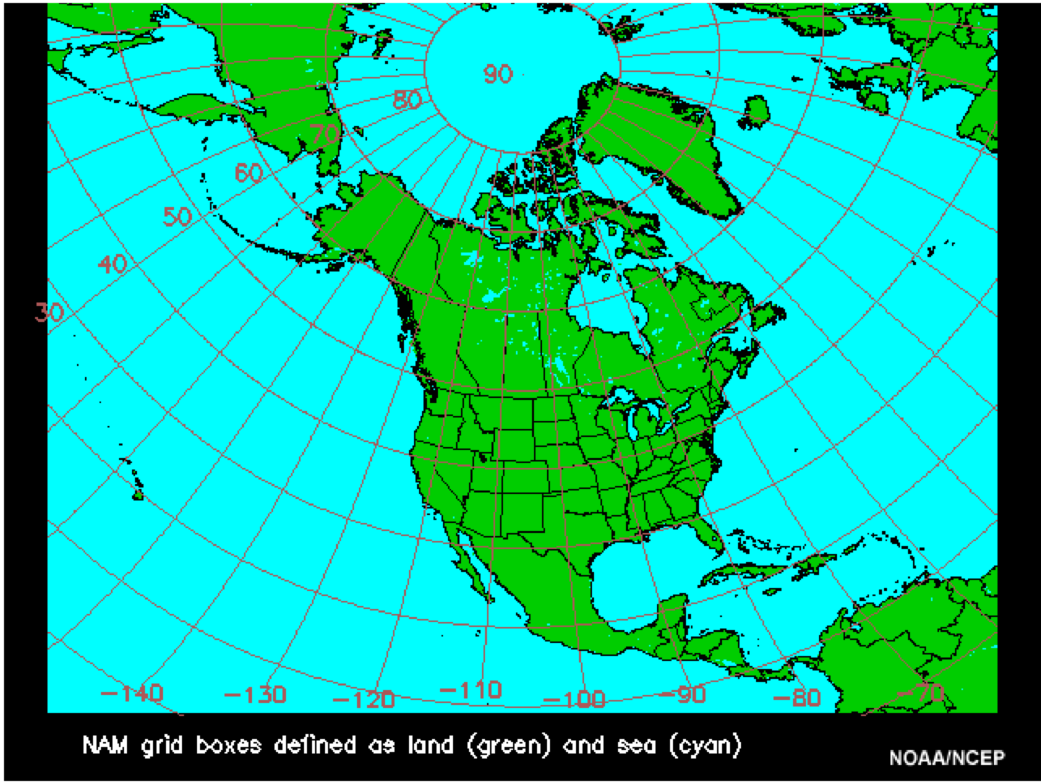


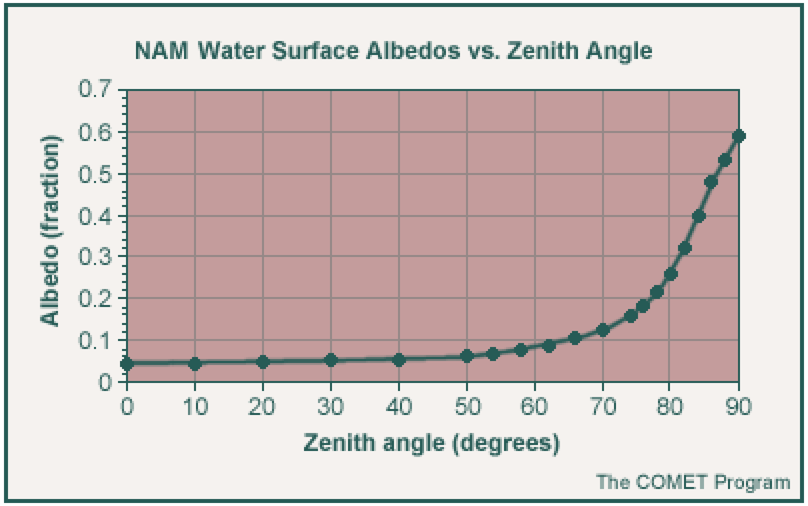
CONUS NMM-B Nest Vegetation Type



water

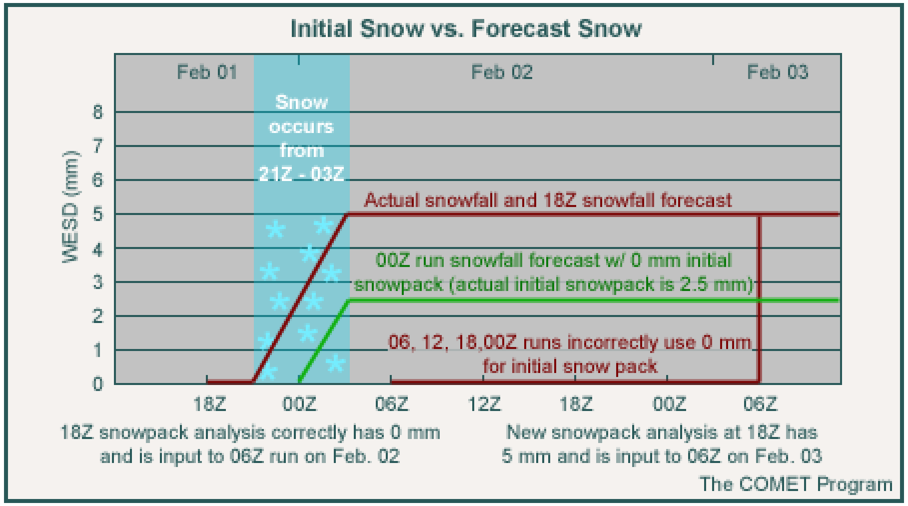
- Water
  - Lakes
  - ocean
- Prescribed water surface T changes slowly
- daily values for large bodies: ocean, great lakes, Salton sea
- Surfaces specified (map)
- Sea and lake ice specified
- Water has low albedo except for low sun angles

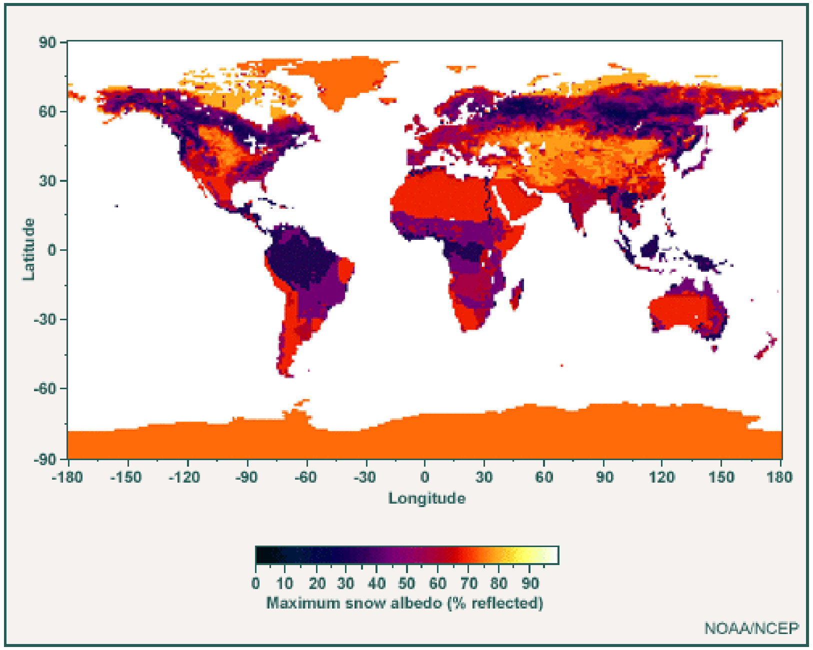


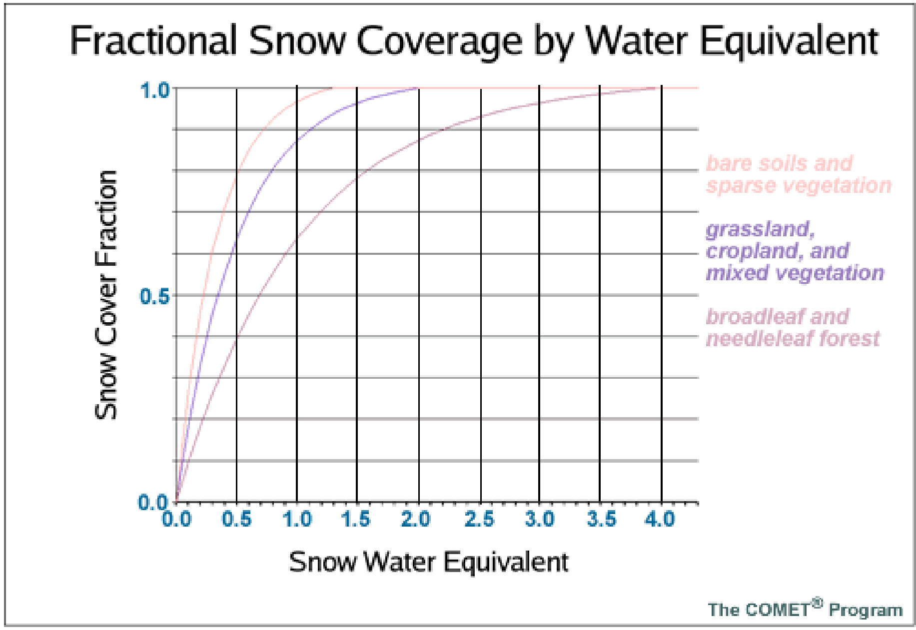


Snow cover, ice cover

- Albedo
- Fractional (patchy) coverage
- Snowpack evolution (density, thermal conductivity, depth) function of time, past conditions, vegetation type, ...
- Sea ice (daily) analysis, but fixed during integration (affects albedo, sfc budget, etc.)







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)

Initializing LSMs

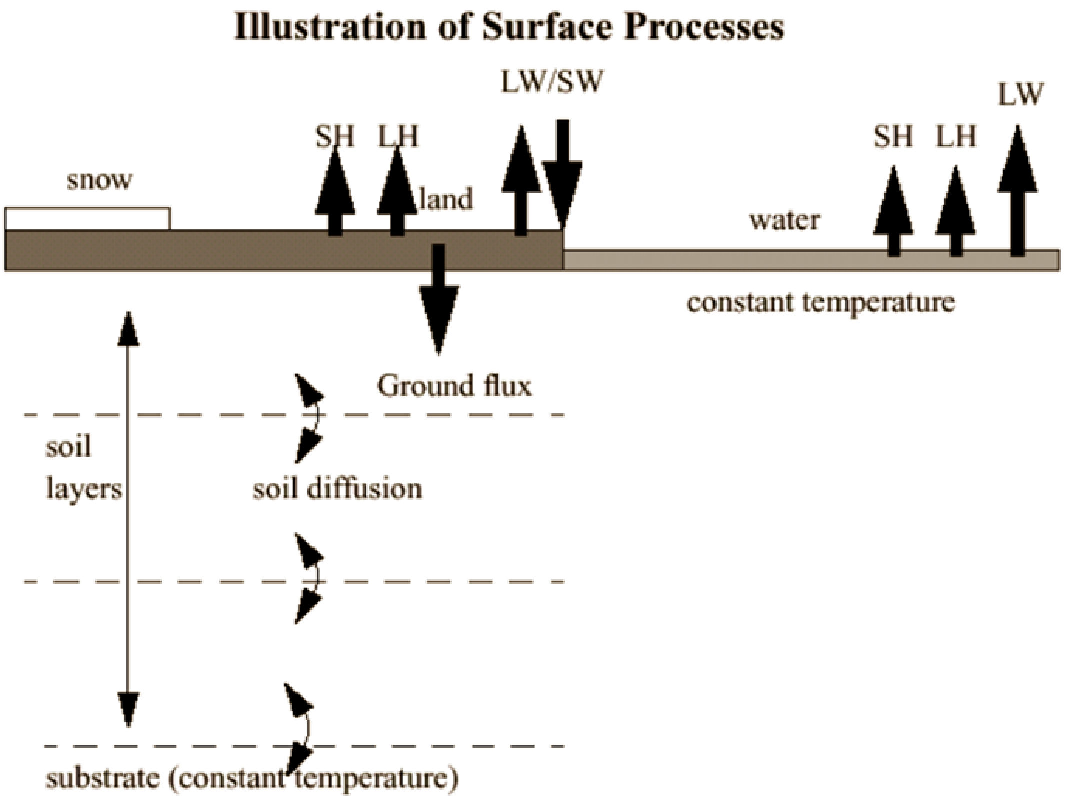
- Noah and RUC LSM require additional fields for initialization
  - Soil temperature
  - Soil moisture
  - Snow liquid equivalent
- These are in the Grib files, but are not from observations
- They come from "offline" models driven by observations (rainfall, radiation, surface temperature, humidity wind)

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)

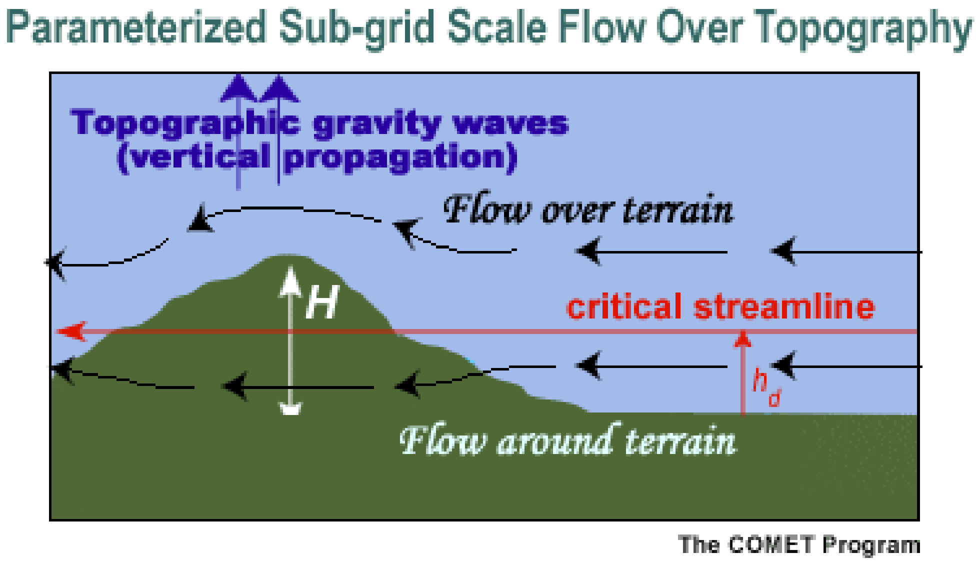
Turbulence & PBL

- Turbulence
- Surface energy budget
- Planetary boundary layer (PBL)



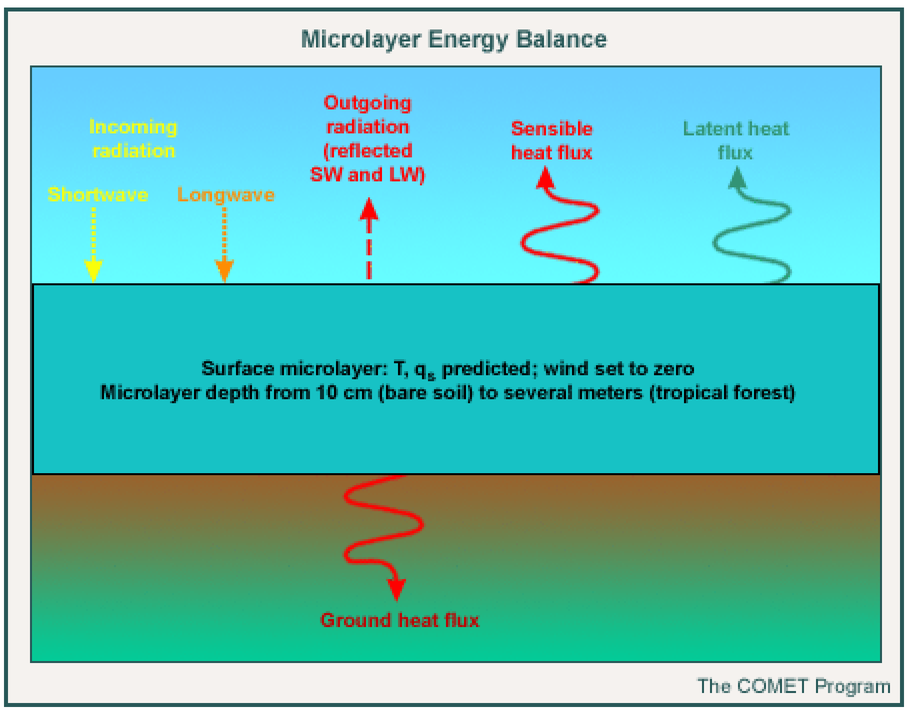
Turbulence & Topography

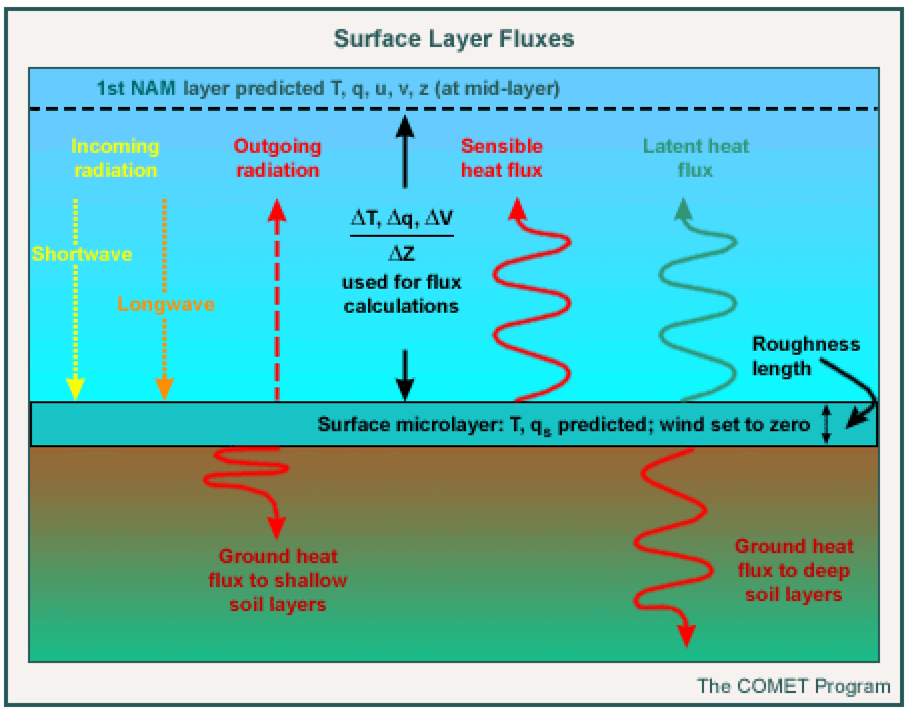
- Turbulent diffusion (moisture, heat, momentum) function of wind shear and static stability
- Topographically generated
  - Gravity wave drag
  - Flow blocking

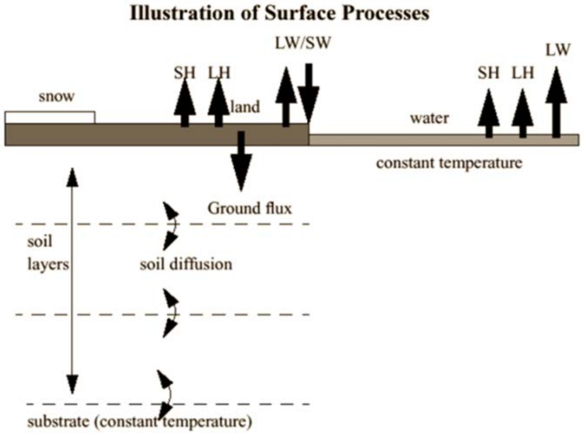


Surface Energy Balance

- Thermal balance in ‘microlayer’ (not skin temperature)
- SWR + LWR down = LWR up + LH + SH + GH
- Figs have some details, e.g. no wind in microlayer.
- Constraints on max LH, emissivity, plant ET, …







Surface Fluxes

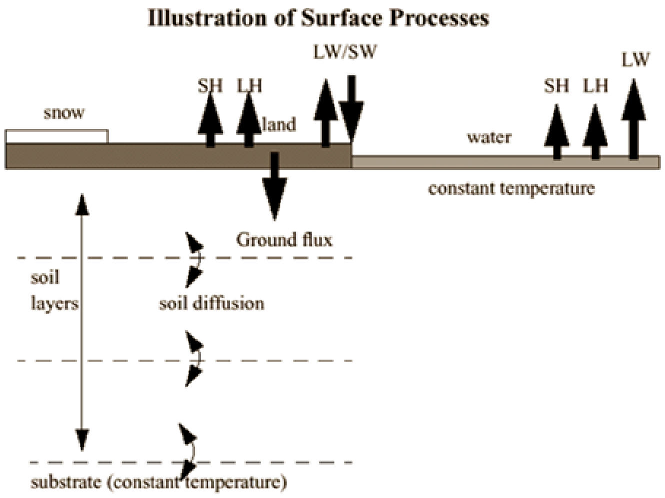
- Heat, moisture and momentum

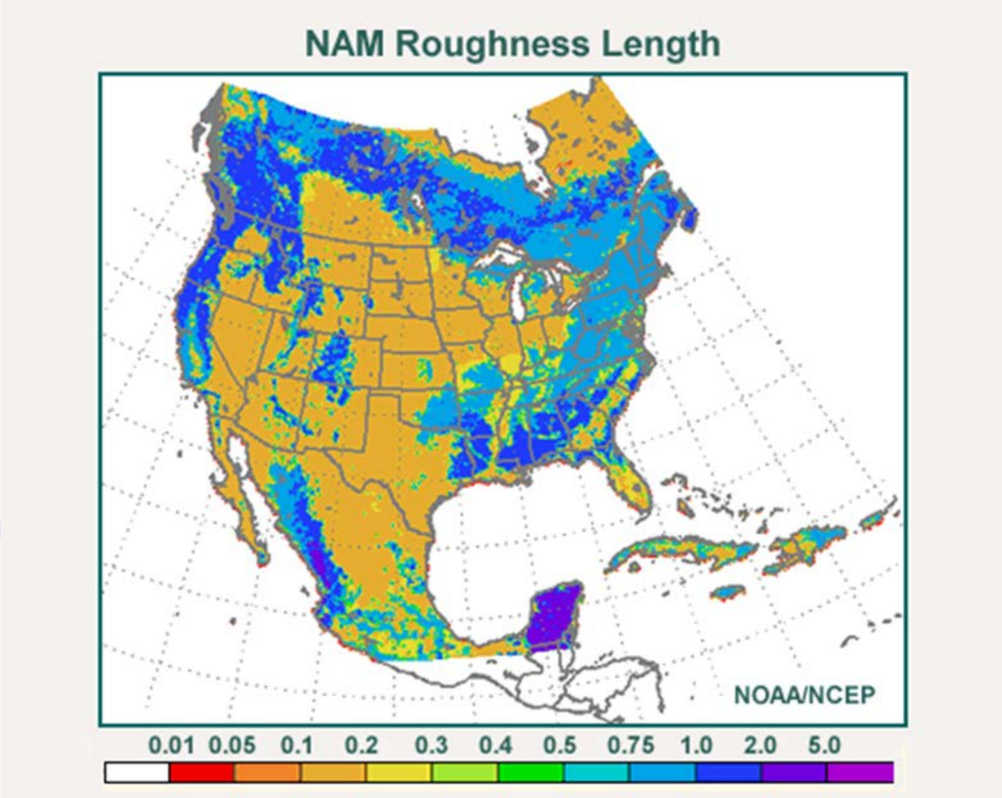
$$H = \rho c_p u_* \theta_* \qquad E = \rho u_* q_* \qquad \tau = \rho u_* u_*$$

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

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

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

z_0 are the roughness lengths

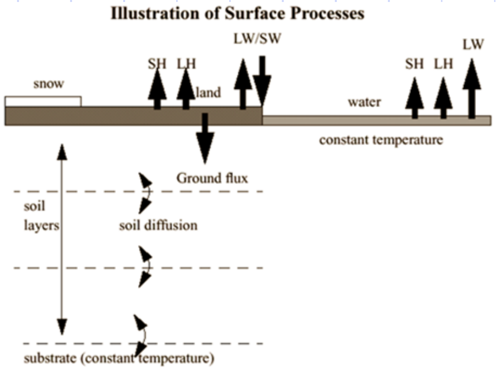
Exchange Coefficient

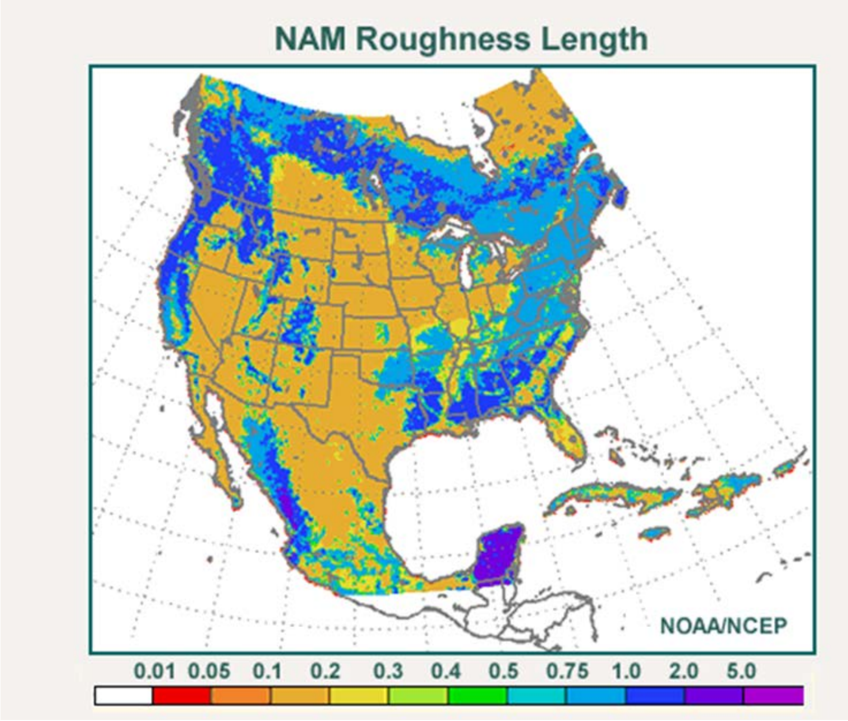
- C_{hs} is the exchange coefficient for heat, defined such that

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

It is related to the roughness length and u* by

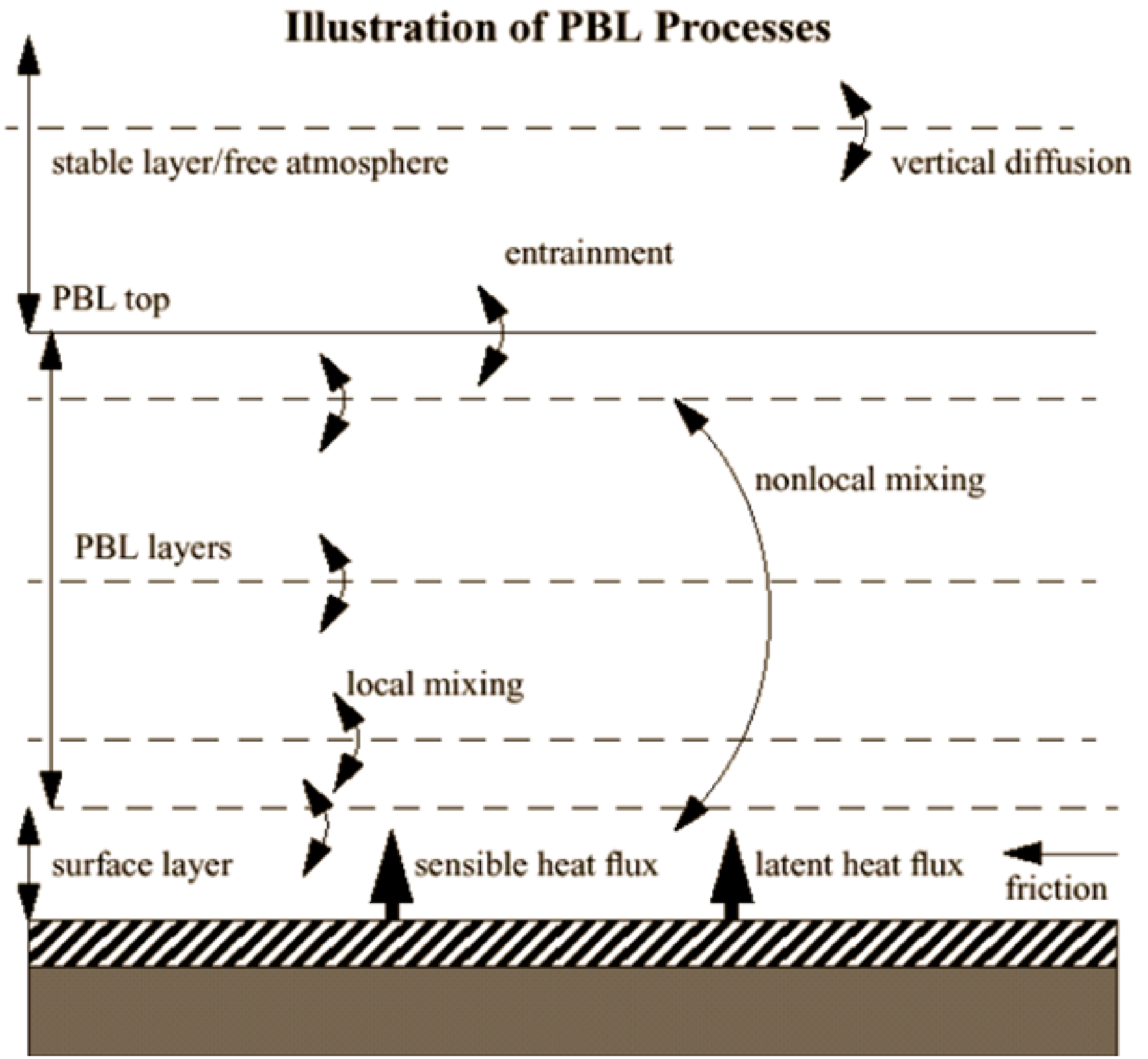
$$C_{hs} = \frac{k u_*}{\ln\left(\frac{z}{z_0}\right) - \psi_h}$$



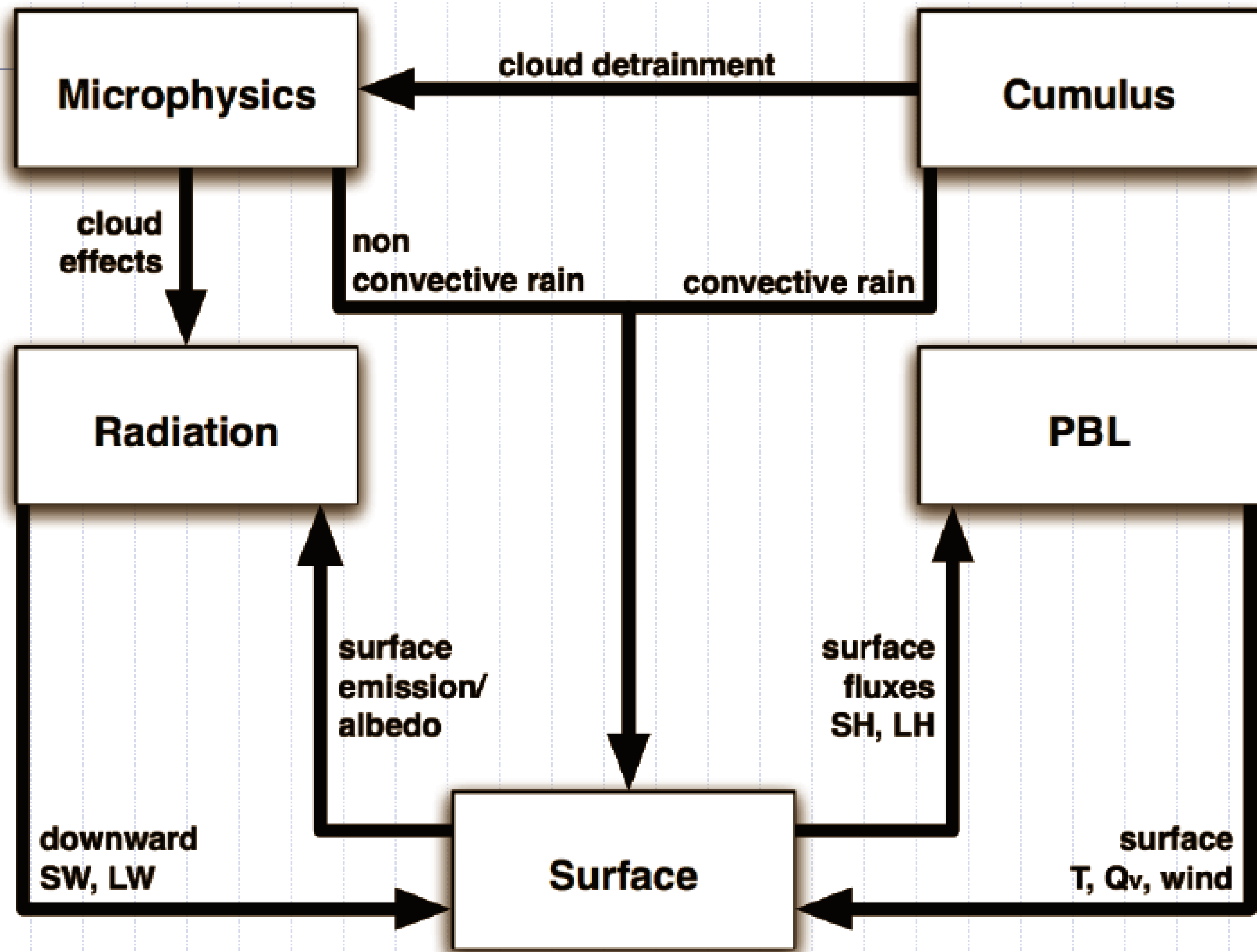


Planetary Boundary Layer

- Diffusion through the PBL uses modified Mellor-Yamada **2.5-order** scheme. The amount of TKE determines the amount of mixing, and in turn the TKE increases from its production and reduces through dissipation.
- TKE production results from
  - Vertical wind shear
  - Buoyancy/instability
- TKE dissipation results from
  - Eddy and molecular viscosity
  - Surface friction
- Production and dissipation parameterized. Model production of TKE is function of diffusion rate (momentum, heat, or moisture) and
  - Differences in zonal and meridional wind speeds across a model layel
  - Differences in potential temperature across a model layer
- The diffusion rates in each layer depend on the layer TKE and other empirically determined stability parameters
- TKE production from vertical gradients of wind and T (mechanical and buoyant production). Dissipation from molecular, eddy, and surface friction are calculated first. Resulting TKE values used to adjust the vertical diffusion rates and changes in TKE resulting from vertical diffusion.



Direct Interactions of Parameterizations



Summary

- A ‘physics parameterization’ is an approximation of a process.
- They are often not of direct interest to a forecaster. (primary exception: precipitation)
- Process parameterized to obtain with ‘sufficient accuracy’ the impact of that process upon a primary variable. (e.g. how radiation affects primary variable T)
- Various approximations (schemes) exist for the same physical process. Different schemes have different advantages/disadvantages: speed, accuracy in certain situations, storage space, etc.
- Generally speaking, the physics parameterizations are more accurate in the regional model than the global model. (partly due to better resolution)

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 << 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

Illustration of Microphysics Processes