Overview of WRF Physics
Radiation Physics

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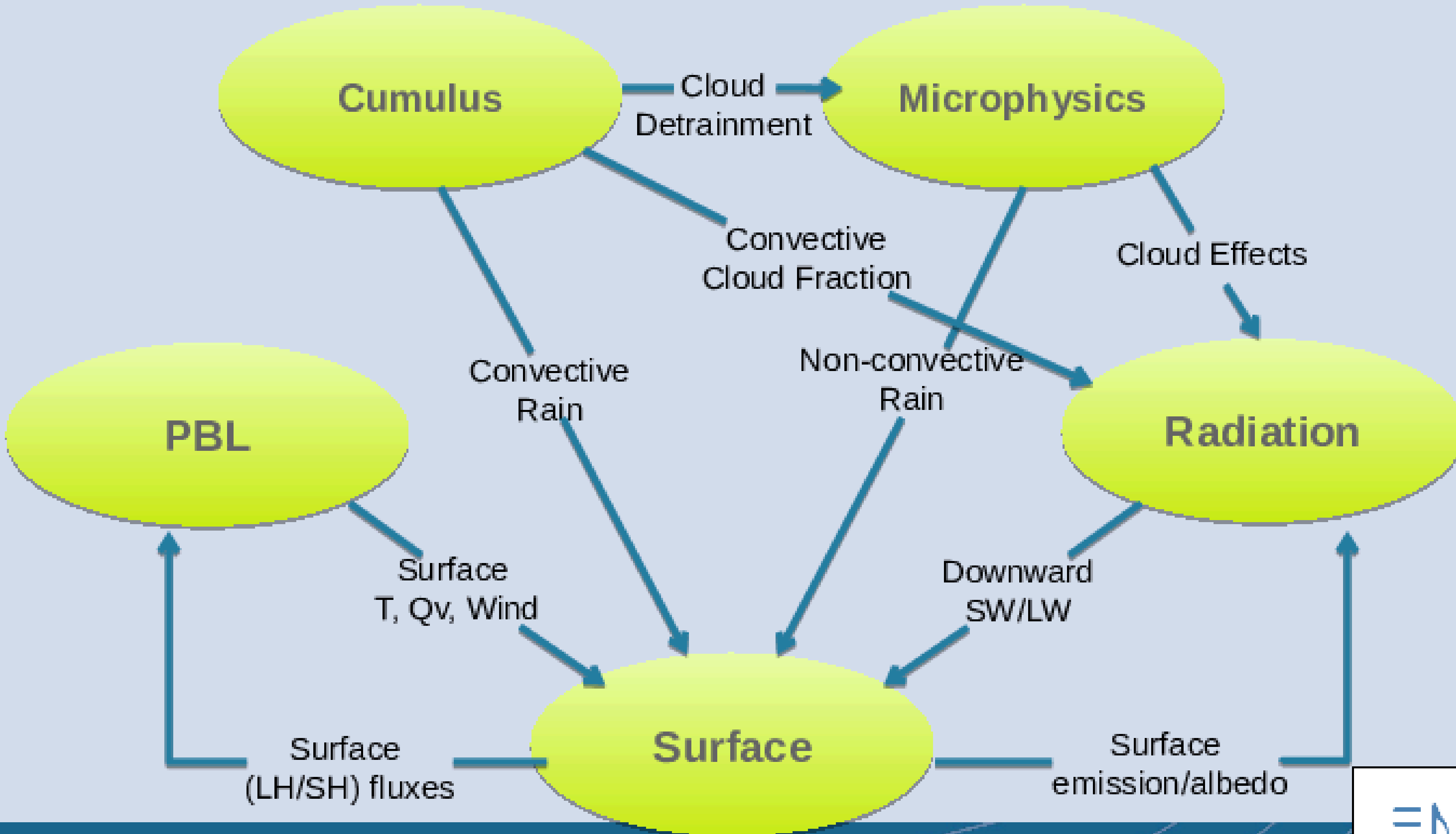
WRF Physics

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

Direct Interactions of Parameterizations



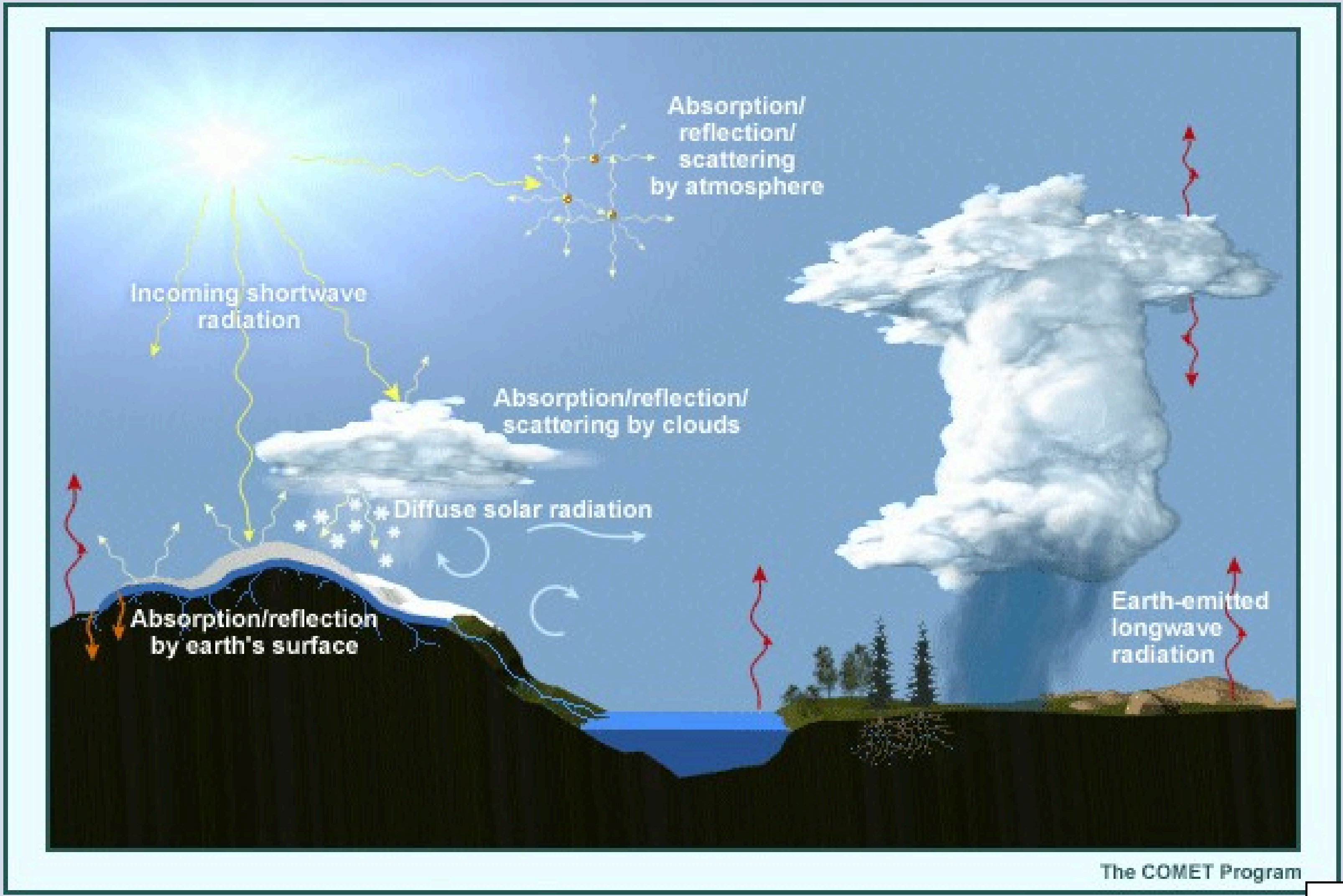
Radiation

Provides

Atmospheric temperature tendency profile

Surface radiative fluxes

Atmosphere Radiation Processes



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WRF Longwave Radiation Schemes (ra_lw_physics)

- Compute clear-sky and cloud upward and downward radiation fluxes
  - Consider IR emission from layers
  - Surface emissivity based on land-type
  - Flux divergence leads to cooling in a layer
  - Downward flux at surface important in land energy budget
  - IR radiation generally leads to cooling in clear air (~2K/day), stronger cooling at cloud tops and warming at cloud base

Longwave Radiation schemes

ra_lw_physics	Scheme	Reference	Added
1	RRTM	Mlawer et al. (1997, JGR)	2000
3	CAM	Collins et al. (2004, NCAR Tech. Note)	2006
4	RRTMG	Iacono et al. (2008, JGR)	2009
5	New Goddard	Chou and Suarez (2001, NASA Tech Memo)	2011
7	FLG (UCLA)	Gu et al. (2011, JGR), Fu and Liou (1992, JAS)	2012
14	RRTMG-K	Baek (2017, JAMES)	2018
31	Held-Suarez		2008
99	GFDL	Fels and Schwarzkopf (1981, JGR)	2004

Longwave Radiation schemes

ra_lw_physics	Scheme	Cores+Chem	Microphysics Interaction	Cloud Fraction	GHG
1	RRTM	ARW NMM	Qc Qr Qi Qs Qg	1/0	constant or yearly GHG
3	CAM	ARW	Qc Qi Qs	Max-rand overlap	yearly CO2 or GHG
4	RRTMG	ARW +Chem(τ)	Qc Qr Qi Qs	Max-rand overlap	constant or yearly GHG
5	New Goddard	ARW	Qc Qr Qi Qs Qg	Max-rand	constant
7	FLG (UCLA)	ARW	Qc Qr Qi Qs Qg	1/0	constant
14	RRTMG-K	ARW	Qc Qr Qi Qs	Max-rand overlap	constant
31	Held-Suarez	ARW	none	none	non
99	GFDL	ARW NMM	Qc Qr Qi Qs	Max-	constan

Clear Sky: IR-active Gases

- H_2O – from model prognostic vapor
- CO_2 – well-mixed, specified constant in whole atmosphere
  - Since V4.2 CO_2 is calculated from year in RRTMG
  - For CAM, RRTM and RRTMG, GHG input file can update CO_2, N_2O and CH_4
- O_3 – schemes have own climatologies
  - CAM and RRTMG have monthly, zonal, pressure-level data
  - Others use single profiles (Goddard has 5 profiles to choose from)

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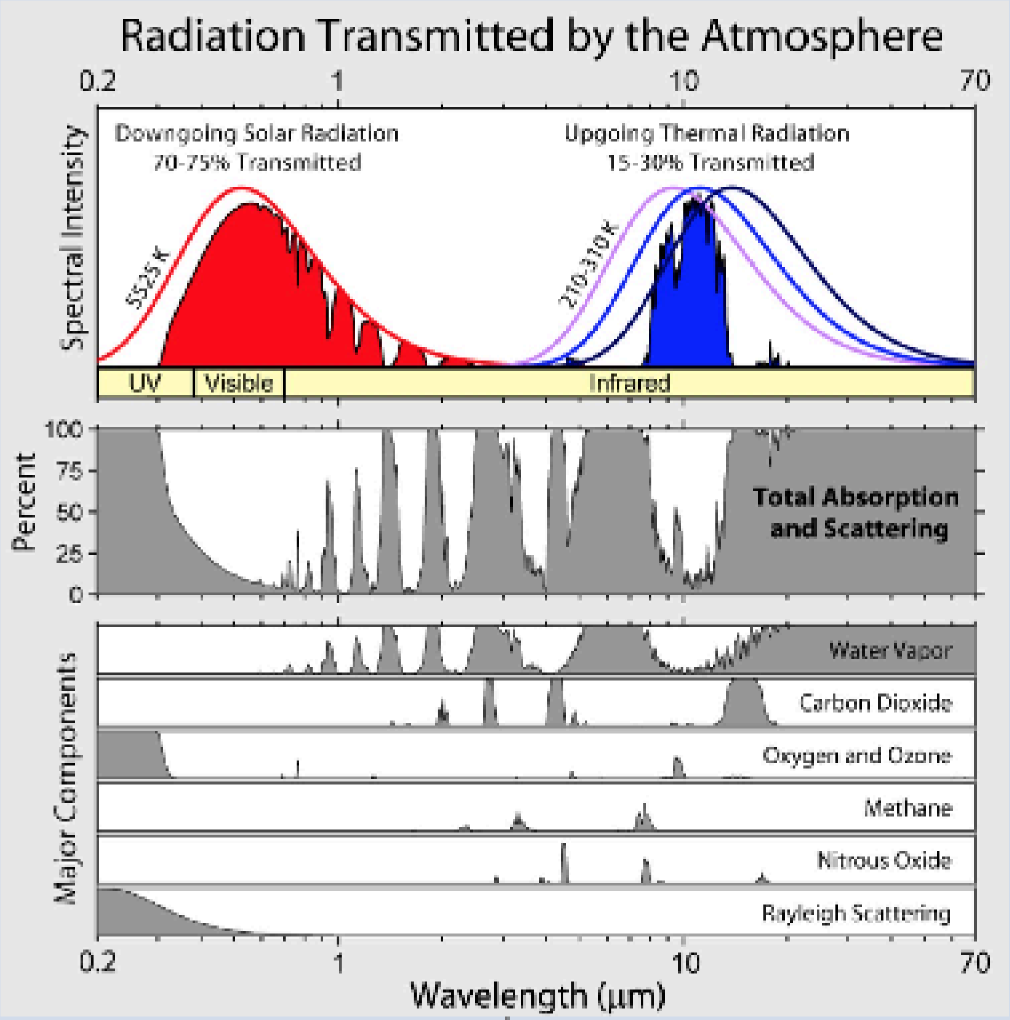
Radiation Effects in Clear Sky



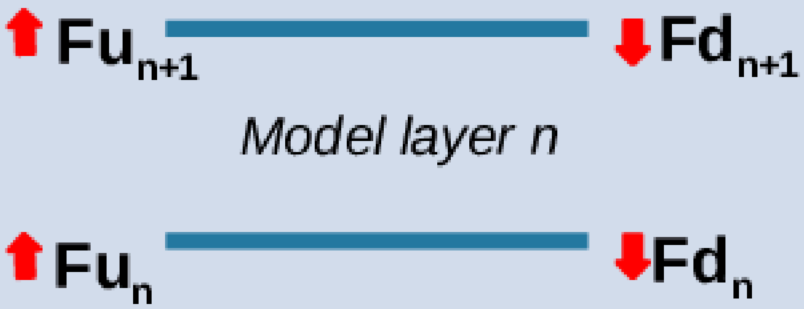
shortwave | **longwave**

Spectral Bands

- Schemes divide IR spectrum into bands dominated by different absorption gases
- For example, RRTMG bands 1-16
- Computations use look-up tables for each band
  - Tables were generated from results of line-by-line calculations (LBLRTM models)

Longwave Radiative Transfer

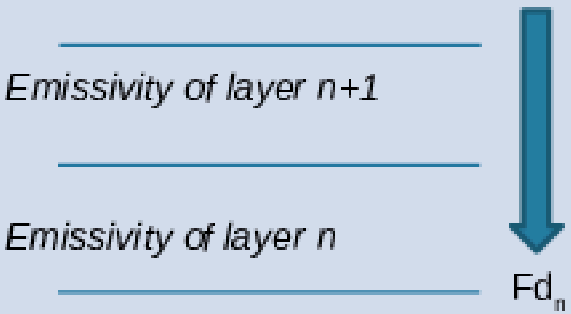
Upward and downward IR fluxes, $\mathbf{F_u}$ and $\mathbf{F_d}$ in W/m^2



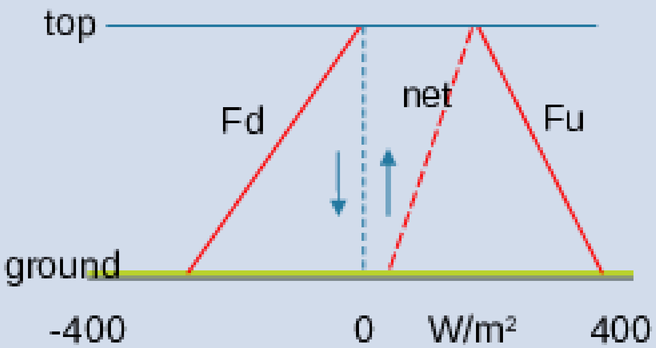
Temperature tendency is given by vertical flux convergence

$$\rho \; c_p \, dT_n/dt = d(F_u + F_d)/dz$$

Longwave Radiative Transfer



Flux Profiles



F =

B(T,ν) is Planck function of frequency
ε is layer emissivity

For Fd_n integrate upwards from each level n

Sum *B(T)*Δε from levels above

Emissivity ε depends on

gases, clouds, aerosols, pressure, T

For Fu integrate downwards from level n

Clouds

- All schemes interact with resolved model cloud fields allowing for ice and water clouds and precipitating species
  - Some microphysics options pass own particle sizes to RRTMG radiation (cloud droplets, ice and snow)
  - Other combinations only use mass info from microphysics and assume effective sizes in radiation scheme
  - Rain and graupel effects are smaller than cloud/snow and not often explicitly considered
- Clouds strongly affect IR at all wavelengths (considered "grey bodies") and are almost opaque to it

Cloud Fractions

- Cloud fraction for microphysics clouds
  - icloud=1: Xu and Randall method
    - Fraction only < 1 for small cloud amounts, 0 for no resolved cloud
  - icloud=2: simple 1/0 method with small resolved cloud threshold
  - Icloud=3: Thompson option since V3.7 (RH dependent)
    - 1 > Fraction > 0 for high RH and no resolved clouds
- Cloud fraction for unresolved convective clouds
  - cu_rad_feedback = .true.
    - Only works for GF, G3, GD and KF options
  - ZM separately provides cloud fraction to radiation

Cloud Fraction

- Overlap assumptions needed with multiple layers of varying fraction
  - Random overlap
  - Maximum overlap (clouds stacked as much as possible)
  - Maximum-random overlap (maximum for neighboring cloudy layers, random for layers separated by clear air)
- Different WRF schemes may use different cloud overlapping assumption. For example, RRTMG, CAM use max-random overlap
- RRTMG radiation has overlap choice switch (*cldovrlp*)
  - adds an exponential and exponential-random overlap optio in recent versions

WRF Shortwave Radiation Options (ra_sw_physics)

- Compute clear-sky and cloudy solar fluxes
- Include annual and diurnal solar cycles
- Most schemes consider downward and upward (reflected) fluxes
  - Dudhia scheme only has downward flux
- Primarily a warming effect in clear sky
- Important component of surface energy balance

Shortwave Radiation schemes

ra_sw_physics	Scheme	Reference	Added
1	Dudhia	Dudhia (1989, JAS)	2000
2	Goddard	Chou and Suarez (1994, NASA Tech Memo)	2000
3	CAM	Collins et a. (2004, NCAR Tech Note)	2006
4	RRTMG	Iacono et al. (2008, JGR)	2009
5	New Goddard	Chou and Suarez (1999, NASA TM)	2011
7	FLG (UCLA)	Gu et al. (2011, JGR), Fu and Liou (1992, JAS)	2012
14	RRTMG-K	Baek et al. (2017, JAMES)	2018
99	GFDL	Fels and Schwarzkopf (1981, JGR)	2004

Shortwave Radiation

ra_lw_physics	Scheme	Cores+Chem	Microphysics Interaction	Cloud Fraction	Ozone
1	Dudhia	ARW NMM + Chem(PM2.5)	Qc Qr Qi Qs Qg	1/0	none
2	GSFC	ARW +Chem(τ)	Qc Qi	1/0	5 profiles
3	CAM	ARW	Qc Qi Qs	Max-rand overlap	Lat/ month
4	RRTMG	ARW +Chem(τ), NMM	Qc Qr Qi Qs	Max-rand overlap	1 profile or lat/month
5	New Goddard	ARW	Qc Qr Qi Qs Qg	Max-rand	5 profiles
7	FLG (UCLA)	ARW	Qc Qr Qi Qs Qg	1/0	5 profiles
14	RRTMG-K	ARW	Qc Qr Qi Qs	Max-rand overlap	1 profile or lat/month
99	GFDL	ARW NMM	Qc Qr Qi Qs	Max-rand overlap	Lat/date

Clear Sky and Aerosols

- Main gas effect in troposphere is water vapor absorption (CO_2 minor effect)
- Aerosols would be needed for additional scattering (WRF-Chem interacts with Goddard and RRTMG shortwave)
  - Dudhia scheme has tunable scattering
  - RRTMG has climatological aerosol input options
    - aer_opt=1 Tegen (EC) global monthly climatology
    - aer_opt=2 user-specified properties and/or AOD map
    - aer_opt=3 Thompson microphysics nuclei (V3.8)

Ozone

- Ozone heating maintains warm stratosphere
- Important for model tops above about 20 km (50 hPa)
- Usually specified from profiles as with longwave options
  - Dudhia scheme has no ozone effect
  - CAM, RRTMG have zonal climatology
- CAM, RRTMG, Goddard can also handle trace gases mainly N2O and CH4 (set constant)

Spectral Bands

- Many schemes use multiple spectral bands
  - As with longwave, bands are ranges of wavelengths usually dominated by different gases (RRTMG bands 16-29)
- Look-up tables
  - Also as with longwave

Radiative Transfer

- In contrast to longwave, shortwave has no emission from the atmosphere but does have reflection from internal layers (aerosols and clouds) and as well as the surface
- This requires a matrix solution rather than integrals
  - Dudhia scheme is the exception that just does downward integral and neglects further interactions of reflected beam

Clouds and Cloud Fraction

- Similar considerations to longwave
- Interacts with model resolved clouds and in some cases cumulus schemes
- Fraction and overlap assumptions
- Cloud albedo reflection
- Surface albedo reflection based on land-surface type and snow cover

Slope effects on shortwave

- Available for all shortwave options
- Represents effect of slope on surface solar flux accounting for
  - direct sunlight fraction and
  - slope aspect relative to solar position
- Two levels of detail (namelist options):
  - slope_rad: activates slope effects - may be useful for complex topography and grid lengths < 2 km.
  - topo_shading: shading of neighboring grids by mountains - may be useful for grid lengths < 1 km.

Radiation Time Step (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

Surface Shortwave Fluxes

- swint_opt=1
  - provides a smooth surface downward flux over time (interpolates between radiation steps using cosine zenith angle and clearness index)
  - This also allows smoother variation of ground variables and fluxes (eliminates steps seen in time series plots)
- Diffuse, direct, and direct normal shortwave components are output (swddir, swddif, swddni) – aerosols mostly affect diffuse/direct ratio not so much the sum

Direct Interactions of Parameterizations