Overview of WRF Radiation

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Direct Interactions of Parameterizations

- **Microphysics**
  - cloud effects
  - cloud detrainment

- **Cumulus**
  - non convective rain
  - convective rain

- **Radiation**
  - surface emission/albedo

- **Surface**
  - downward SW, LW
  - surface fluxes SH, LH
  - T, Qv, wind

- **PBL**
  - surface fluxes SH, LH
Radiation

Provides
Atmospheric temperature tendency profile
Surface radiative fluxes
Radiation parameterizations

- Shortwave (solar) – use astronomical equations to calculate the sun’s position as a function of time of day and day of the year.
Radiation as part of the entire model energy budget

-69 Energy lost to space

SOLAR

-9 Infrared

-95 Infrared

-51 Infrared

Energy gained by atmosphere

+155

+23 Latent heat

+105 Infrared

+20

-9

-7 Convection and conduction

-23 Evaporation

-114

-7 Energy lost at Earth’s surface

+49

+95

+144 Energy gained at Earth’s surface

-155 Energy lost by atmosphere
Illustration of Free Atmosphere Radiation Processes

- Longwave
- Shortwave
- Reflection
- Longwave
- Scattering
- Absorption
- LW Emission
- Surface Emissivity
- Surface Albedo
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 Options

- RRTM
- CAM
- RRTMG
- Goddard
- Held-Suarez (idealized)
- GFDL
## Longwave Radiation schemes

<table>
<thead>
<tr>
<th>ra_lw_physics</th>
<th>Scheme</th>
<th>Reference</th>
<th>Added</th>
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<tbody>
<tr>
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<td>RRTM</td>
<td>Mlawer et al. (1997, JGR)</td>
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<td>Iacono et al. (2008, JGR)</td>
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<td>7</td>
<td>FLG (UCLA)</td>
<td>Gu et al. (2011, JGR), Fu and Liou (1992, JAS)</td>
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<td>Held-Suarez</td>
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<td>99</td>
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<td>Fels and Schwarzkopf (1981, JGR)</td>
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## Longwave Radiation in V3.5

<table>
<thead>
<tr>
<th>ra_lw_physics</th>
<th>Scheme</th>
<th>Cores+Chem</th>
<th>Microphysics Interaction</th>
<th>Cloud Fraction</th>
<th>CO2*</th>
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<tr>
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<td>RRTM</td>
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<td>ARW NMM</td>
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</table>

* 2012 value = 392
Clear Sky: IR-active Gases

• H2O – from model prognostic vapor
• CO2 – well-mixed, specified constant in whole atmosphere (CAM has year-dependent table of values)
• O3 – schemes have own climatologies
  – CAM has monthly, zonal, pressure-level data
  – Others use single profiles (Goddard has 5 profiles to choose from)
Radiation effects in clear sky

![Atmospheric Absorption Bands](image)

- **Shortwave**
- **Longwave**
Spectral Bands

• Schemes divide IR spectrum into bands dominated by different absorption gases
• Typically 8-16 bands are used
• Computations use look-up tables for each band
  – Tables were generated from results of line-by-line calculations (LBLRTM models)
Clouds

• All schemes interact with resolved model cloud fields allowing for ice and water clouds and precipitating species

• Clouds strongly affect IR at all wavelengths (considered “grey bodies”) and are almost opaque to it
Cloud Fractions

- Schemes are capable of handling cloud fractions
- WRF can provide cloud fractions based on RH, but mostly the fraction is 0 or 1 in a grid box
- Cloud fraction methods
  - cldfra2 used by CAM and RRTMG
  - cldf2ra used by others except GFDL (computes its own)
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)
• WRF schemes use max-random overlap
ra_lw_physics=1

RRTM scheme
• Spectral scheme
• K-distribution
• Look-up table fit to accurate calculations
• Interacts with resolved clouds
• 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 cloud fractions
- Can interact with trace gases and aerosols
- Ozone profile function of month, latitude
- CO2 changes based on year (since V3.1)
- Top-of-atmosphere (TOA) and surface diagnostics for climate
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)
• Ozone profile specified
• CO2 and trace gases specified
• WRF-Chem optical depth
• TOA and surface diagnostics for climate

ARW only
ra_lw_physics=5

New Goddard longwave scheme (Since V3.3)
- Spectral scheme
- 10 longwave bands
- Look-up table fit to accurate calculations
- Interacts with cloud fractions
- Can interact with trace gases and aerosols
- Ozone profile specified
- CO2 and trace gases specified
- TOA and surface diagnostics for climate

ARW only
ra_lw_physics=7

Fu-Liou-Gu (UCLA) longwave scheme (Since V3.4)
• Spectral scheme with correlated k-distribution method
• 12 longwave bands
• Look-up table fit to accurate calculations
• Cloud fraction 0/1 based on cloud presence
• Can interact with trace gases and aerosols
• Ozone profile specified similar to Goddard
• CO2 and trace gases specified
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
• CO2 fixed
• ra_lw_physics=98 (nearly identical) for HWRF
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 Options

• Dudhia
• Goddard (original version)
• CAM
• RRTMG
• Goddard (new)
• GFDL
## Shortwave Radiation schemes

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<thead>
<tr>
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<th>Cloud Fraction</th>
<th>Ozone</th>
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<tr>
<td>1</td>
<td>Dudhia</td>
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<td>Qc Qr Qi Qs</td>
<td>Max-rand overlap</td>
<td>Lat/date</td>
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Clear Sky

• Main effect in troposphere is water vapor absorption (CO2 minor effect)

• Aerosols would be needed for additional scattering (WRF-Chem interacts with Goddard and RRTMG shortwave)
  – Dudhia scheme has tunable scattering
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, Goddard can also handle trace gases (set zero or constant)
Spectral Bands

• 11-19 spectral bands used by CAM, RRTMG and Goddard schemes
• Look-up tables
Clouds and Cloud Fraction

- Similar considerations to longwave
- Interacts with model resolved clouds
- Fraction and overlap assumptions
- Cloud albedo reflection
- Surface albedo reflection based on land-surface type and snow cover
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.
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
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 depths
**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
- TOA and surface diagnostics for climate
- 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
• Trace gases specified
• WRF-Chem optical depths
• TOA and surface diagnostics for climate
ra_sw_physics=5

New Goddard shortwave scheme (Since V3.3)

- Spectral scheme
- 11 shortwave bands
- Look-up table fit to accurate calculations
- Interacts with cloud fractions
- Ozone profile specified
- CO2 and trace gases specified
- TOA and surface diagnostics for climate

ARW only
Fu-Liou-Gu (UCLA) shortwave scheme (Since V3.4)

- Spectral scheme with correlated k-distribution method
- 6 shortwave bands
- Look-up table fit to accurate calculations
- Cloud fraction is 1/0 based on cloud presence
- Ozone profile specified similar to Goddard
- CO2 and trace gases specified
- Capability for aerosol effects
ra_sw物理学=99

GFDL短波辐射

- 用于Eta/NMM模型
- 默认代码用于与Ferrier微物理（参见GFDL长波）
- 臭氧/CO2剖面与GFDL长波相同
- 与云（及云分数）相互作用
- ra_lw物理学=98（几乎相同）用于HWRF
New Capabilities In Version 3.5

• Climatological ozone and aerosols for RRTMG radiation
  – Provided by Wei Wang (NCAR)

• Option: o3input=2
  – Using CAM ozone climatology (month, lat, pres)
  – o3input=0: 1d climatology (old method)

• Option: aer_opt=1
  – ECMWF (Tegen) aerosol climatology (month, lat, long, pres)
  – aer_opt=0: no aerorol (old method)
New Capabilities In Version 3.5

• Updating capability for CO2, CH4, N2O, in long climate runs for RRTMG, RRTM and CAM longwave radiation
  – Activated with #ifdef CLWRFGHG (-D CLWRFGHG)
  – Provided by Claire Carouge, Luis Fita (U.NSW, Australia)
  – Reads data files for chosen greenhouse-gas scenario (user can edit these)
    • A2, RCP6, RCP8.5, etc., annual values
  – Default uses constant values of these gases
  – Note also: RRTM constant CO2 value updated to 379 ppm
Plans for Radiation

• Solar radiation additions for solar energy applications
  – Aerosol input (from analyses or MODIS level 3 AOD) (Jose Ruiz-Arias)
  – Produce Direct Normal Irradiance (DNI) in addition to Global Horizontal Irradiance (GHI, swdown)
    • Requires separation of direct and diffuse components
  – Cloud-aerosol interaction (Greg Thompson)
  – Shallow convection and cloud fraction (AJ Deng, Penn State, Georg Grell)
To account for aerosol extinction, we need to parameterize...

... **aerosol optical depth (AOD)**

... **aerosol single-scattering albedo (SSA)**, and

... **aerosol asymmetry parameter (ASY)**

at **each spectral band (11 / 14)** and every grid-cell of the domain, including each model vertical layer (we assume an exponential profile).

The proposed parameterization only requires...

... the **total aerosol optical depth at 550 nm**

... the predominant **type of aerosol**, and

... the **relative humidity**.
Needs for aerosol effect

\[ \omega_o \quad g \quad \alpha \quad T_{0.55} \]

\[ p_w \rightarrow \text{RRTMG-SW} \rightarrow \text{WRF} \]

\[ GHI \quad DNI \quad DIF \]
Implementation with aerosol input

RRTMG-SW

AEROSOL PARAM

RHR

GHI

DNI

DIF

WRF

Aerosol

T

\mathcal{w}_o

g

\tau_0.55

\phi

\tau_\lambda

Jose A. Ruiz-Arias
Plans for Radiation

• Microphysics-Radiation interaction (Greg Thompson)
  – Use effective particle radius (ice, snow, cloud) from microphysics in RRTMG radiation
    • Instead of assumption in radiation scheme
  – Initial implementation with Thompson microphysics ready for V3.5.1 (later)
    • Possibly more microphysics by 3.5.1 release
  – Shows some improved results (Thompson talk)
Plans for Solar Radiation

• Improve local solar time calculation (equation of time adjustment)

• Interpolate surface shortwave between radiation steps
  – Time-step adjustments according to gradual change in solar angle
    • Avoids radiation-call-frequency steps in skin temperature, fluxes (seen in surface time series)