Implementation of the Updated Goddard Longwave and Shortwave Radiation Packages into WRF

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Outline

I. Goddard WRF modifications and applications

II. Goddard longwave and shortwave radiative transfer schemes

III. Differences between current (old) and new WRF Goddard shortwave radiation scheme

IV. Computational performance of Goddard radiation schemes

V. Comparison with different WRF radiation schemes

VI. Summary

Cases: IHOP, Katrina, Regional climate simulations (aerosol impact on Monsoon development), Lake effect snow storm, Winter snowstorm, Summer fire
**WRF Modifications (Goddard Suite) and Applications at Goddard**

- Water/energy cycle against data from field programs
- Semi-Real and Real Time at GPM Super sites and C4, NAMMA
- Hurricane/Typhoon (Impact of microphysics and land surface on intensity - fine resolution simulation - diurnal cycle?)
- Regional Climate
- Cloud-Aerosol Interactions (transport - Asia and NE USA)

**Blue Boxes: Goddard Physical Packages**


Goddard radiation packages

- Goddard radiation package has been developed for two decades at NASA Goddard by Ming-Dah Chou and Max J. Suarez for use in general circulation models (GEOS GCM), regional model (MM5) and cloud-resolving models (Goddard Cumulus Ensemble mode, GCE model).

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>SW (solar)</th>
<th>LW (thermal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flux solution</td>
<td>Two-stream adding method</td>
<td>Schwarzchild equation</td>
</tr>
<tr>
<td># of bands</td>
<td>UV&amp;PAR(8 bands) Solar-IR(3 bands)</td>
<td>10 bands</td>
</tr>
<tr>
<td>Optical approximation</td>
<td>Delta-Eddington approximation (for scattering and transmission)</td>
<td>Henyen-Greenstein function (for scattering), One/two-parameter scaling, modified k-distribution (for absorption)</td>
</tr>
<tr>
<td>Optical parameters</td>
<td>H₂O, O₂, O₃, CO₂, condensates (cloud water, cloud ice, snow, rain, and graupel), aerosols (sulfate and precursors, dust, black carbon, organic carbon, sea salt)</td>
<td>H₂O, O₃, CO₂, trace gases (N₂O, CH₄, CFC11, CFC12, CFC22), condensates (cloud water, cloud ice, snow, rain, and graupel), aerosols (sulfate and precursors, dust, black carbon, organic carbon, sea salt)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Heating rate error within 5% accuracy in comparison with a LBL model.</td>
<td>Cooling rate error within 0.4K/day in comparison with a LBL model.</td>
</tr>
</tbody>
</table>

Allow explicit cloud-radiation interactions (a routine to calculate cloud optical property that can be used for other WRF Microphysics) and aerosol direct effect
Important for high-resolving model simulations

References
New Goddard SW radiation in comparison with old Goddard SW radiation in WRF

1) **Optical depths for condensates (1st-order effect)**
   - NewRad has a strict **threshold of cloud optical depth (0.0001)** for cloud flags in order to account for thin-cloud radiative effects. (OldRad has a loose threshold (0.05), and does not account for thin-cloud radiative forcing.)
   - NewRad accounts for **optical properties of rain, ice+snow, and liquid cloud droplets. Ice cloud effective radius** (25~125micron) depends on ambient temperature. (OldRad accounts for only ice and liquid cloud droplets. Ice cloud effective radius is fixed value (80micron). )

2) **Radiative Transfer (2nd-order effect)**
   - NewRad has a correct two-stream adding approximation in diffuse transmissivity. (OldRad uses **incorrect diffuse transmissitivity. This is a critical bug in the code.**).
   - NewRad uses delta-Eddington approximation for reflection and transmittance of direct and diffuse radiation. (OldRad also uses delta-Eddington approximatatin for direct radiation, but it uses equations in Sagan and Pollock [JGR, 1967] for diffuse radiation.)

3) **Molecular absorption (3rd-order effect)**
   - NewRad weights the molecular absorption coefficients by **cosine of solar zenith angle.** (OldRad uses the same molecular absorption coefficients without considering cosine of solar zenith angle.)
   - NewRad accounts for **water vapor absorption.** (OldRad does not account for water vapor absorption.)
   - NewRad accounts for **O₂ and CO₂ absorption above and below cloud-top level.** Below cloud-top level, the flux reduction rate depends on the ratio of clear-sky and cloudy-sky net radiation. (OldRad accounts for O₂ and CO₂ absorption only above cloud-top level.)
**CPU time in OldRad, NewRad and NewRadFast (Lookup Table)**

**Test**
- Old (OldRad) and new (NewRad) Goddard SW radiation were tested in all-sky conditions of 45x45x30-grid (1 km grid spacing) domains to compare CPU time. This case is a Canadian lake-effect-snowstorm event. (Use 2.16GHz Intel Core processor, g95 -O1)

**Overcast option**
- In both Goddard SW radiation schemes, there is a logical option (overcast)
  
  overcast = .true.
  cloud fraction = 0 or 1

  overcast = .false.
  cloud fraction = 0~1
  requires two-stream solutions in different combination of clear-cloudy-sky cases, which result in much longer computational time.

  *Note that overcast is always .true. if dx < 2-3 km grid spacing.*

<table>
<thead>
<tr>
<th>overcast</th>
<th>OldRad</th>
<th>NewRad</th>
<th>NewRadFast</th>
</tr>
</thead>
<tbody>
<tr>
<td>.true.</td>
<td>1.6sec</td>
<td>3.0sec</td>
<td>2.1sec</td>
</tr>
<tr>
<td>.false.</td>
<td>4.5sec</td>
<td>4.1sec</td>
<td>4.1sec</td>
</tr>
</tbody>
</table>

**Results**

NewRad takes nearly twice in CPU time in comparison with OldRad in overcast=true option. This is because NewRad requires double solutions of the two-stream adding method for clear- and cloudy-sky conditions in order to compute cloudy-clear-sky net radiation ratio ($F_{cloud}/F_{clear}$) for within cloud CO$_2$ and O$_2$ absorption.

**New feature**

Add new logical option (fast_overcast), and “fast_overcast = .true.” uses a pre-computed look-up table for $F_{cloud}/F_{clear}$ as a function of cloud albedo. This version is called NewRadFast
Comparison in SW flux and heating rate between *NewRad*, *OldRad*, and *NewRadFast*

**Results**

*NewRad-OldRad* differences in surface downwelling shortwave radiation are up to ±40 W/m². This is mostly due to upgrade (1). *It has large discrepancy in heating profile up to ±2 K/day.*

*NewRad-NewRadFast* differences in surface downwelling shortwave radiation are up to ±1 W/m². *It has discrepancy in heating profile up to ±0.5 K/day.*

Note that all the case uses overcast=.true.

Y-distance=120km
Similar comparison, but using the same cloud-detection threshold

Results

Difference down to \(~5\text{W/m}^2\) in surface downwelling shortwave radiation. This is mostly due to upgrade (3). It still has large discrepancy in heating profile due to upgrade (2).

Note that all the case uses overcast = .true.

Y-distance = 120km
Options in Goddard LW radiation code and CPU time

Goddard LW logical options

- "high=.true." computes transmission functions in the CO₂, O₃, and the three water vapor bands with strong absorption using look-up table, while "high=.false." uses k-distribution methods (faster).

- "trace = .true." accounts for absorption due to N₂O, CH₄, CFCs, and the two minor CO₂ bands in the LW window region, while "trace = .false." does not account for (faster).

- A combination of "high=.true." & "trace=.true." is most accurate.

- Note that these options can be modified at the top of code in the module_ra_goddard.F.

<table>
<thead>
<tr>
<th>Exp Name</th>
<th>high</th>
<th>trace</th>
<th>CPU time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHT</td>
<td>.true.</td>
<td>.true.</td>
<td>2.80 (170%)</td>
</tr>
<tr>
<td>RH</td>
<td>.true.</td>
<td>.false.</td>
<td>2.13 (129%)</td>
</tr>
<tr>
<td>RT</td>
<td>.false.</td>
<td>.true.</td>
<td>2.19 (133%)</td>
</tr>
<tr>
<td>R</td>
<td>.false.</td>
<td>.false.</td>
<td>1.65 (100%)</td>
</tr>
</tbody>
</table>

Results

Each option (high or trace) costs about 0.6sec, thus the no-options experiment (R) save 1.2sec CPU time in comparison with the full-option experiment (RHT).
Comparison in LW flux and heating rate between \textit{RHT}, \textit{RH}, and \textit{RT}.

\textbf{Results}

- Downwelling longwave radiation between \textit{RHT} and \textit{RT} are similar.

- LW cooling profiles between \textit{RHT} and \textit{RH} are largely different near the cloud top.

- LW cooling profiles between \textit{RHT} and \textit{RT} are slightly different at TOA. If one include the stratosphere in model, the RHT-RT difference would become larger [Chou and Suarez 2001].

\textit{Y-distance}=120km
Physics:
- Cu parameterization: Grell-Devenyi scheme (for the outer grid only)
- Cloud microphysics:
  Goddard microphysics 3ice-Graupel
- Radiation:
  shortwave: Dudhia, old and new Goddard
  longwave: RRTM and Goddard
- PBL parameterization:
  Mellor-Yamada-Janjic TKE scheme
- Surface Layer:
  Monin-Obukhov (Janic)
- Land Surface Model: Noah land-surface

Resolutions: 27, 9 and 3 km
Grid size: 391x313, 427x427, 451x451, and 31 vertical layers
$\Delta t = 90$ seconds
Starting time: 00Z 05/01/2005
Initial and Boundary Conditions:
  NCEP/GFS, no data assimilation
Larger difference in LW (>0.5 K/day) in middle troposphere than SW (<0.3 K/day), and virtually no difference in LW below 900 mb

Larger difference in upper troposphere in both LW and SW due to different cloud optical properties

Next: Separate heating/cooling in the cloudy and cloud free region
Conclusions and Future Works

• Goddard long- and short-wave radiative transfer modules have been implemented into WRF

• Goddard radiative transfer modules can allow explicit interactions with microphysical processes (cloud optical property) - required for high-resolution WRF simulations

• Goddard radiative transfer modules can include aerosol direct effect by coupling the Goddard global aerosol transport model (i.e., GOCART aerosol mass and optical properties)

• Differences between current and new WRF Goddard shortwave transfer module have been identified - difference can be 40 w/m² at surface (cloud properties, molecular absorption and radiative transfer)

• Difference in computational cost between current and new WRF Goddard shortwave transfer module have been identified (depends on requirement - accuracy)

• WRF has linked to satellite (Earth) simulators (microwave, dual frequency precipitation radar, lidar, cloud radar, IR…).
END
Multi-Scale Modeling Systems

fvGCM

Observation

Satellite Data
Field Campaigns
Re-analyses

Data Management
Visualization

GCE Model

Initial Condition

MMF

LIS

Physical Packages

Microphysics
Radiation

MMF: Multi-Scale Modeling Framework
LIS: Land Information System
GCE: Goddard Cumulus Ensemble Model
WRF: Weather Research Forecast
Microphysical Package (4 options)
Long/Shortwave Radiative Transfer
GOCART

MMF

Initial Condition

fvGCM 5 day forecast

TRMM

Hurricane Katrina
High-resolution

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fvGCM

MMF

GCE Model

WRF

Data Management
Visualization

TRMM

MMF

LIS

Physical Packages

Microphysics
Radiation

MMF: Multi-Scale Modeling Framework
LIS: Land Information System
GCE: Goddard Cumulus Ensemble Model
WRF: Weather Research Forecast
Microphysical Package (4 options)
Long/Shortwave Radiative Transfer
GOCART
Goddard WRF supports NASA Global Precipitation Mission (GPM)

- Radar reflectivity and microwave brightness temperature are computed in off-line using the WRF-simulated meteorology and hydrometeors field via satellite-data simulation unit (SDSU).

- Simulated Tb and reflectivity are used to support NASA Global Precipitation Mission (GPM).