Aerosol Climate Impact Assessment

Primary

Precursors

GTP

Emission Control

In-Direct

GCM

Cloud/Precip

Direct Impact

GCM

Aerosol Distributions

δ-4 Stream

Wet/Dry Depositions

Aerosol Processes

Condensation

Nucleation

COAG

[5,7]

Stream

Primary Processes

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Implementing the Delta-Four-Stream Approximation for Solar Radiation Computations in the CCC AGCM III

By

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Outline

1. Introduction
2. Solar Flux Simulations
3. Computational Time
4. Conclusions and Recommendations
Introduction

- Solar-radiation computation: fundamental in climate modeling
- Radiative transfer eq. for a plane-parallel homog. atmos.
  \[
  \mu \frac{dI(\tau, \mu)}{d\tau} = I(\tau, \mu) - \frac{1}{2} \int_{-1}^{1} I(\tau, \mu') P(\mu, \mu') d\mu' - \frac{\bar{\omega}}{4\pi} F_0 P(\mu, -\mu_0) e^{-\tau/\mu_0}
  \]
- Gauss-exp. for intensity & Legendre-exp. for phase func.
  \[
  \frac{dI(\tau, \mu_i)}{d\tau} = I(\tau, \mu_i) - \frac{1}{2} \sum_{l=0}^{N} \bar{\omega}_l P_l(\mu_i) \sum_{j=-n}^{n} a_j P_j(\mu_j) I(\tau, \mu_j) - \frac{\bar{\omega}}{4\pi} F_0 \left[ \sum_{l=0}^{N} (-1)^l \bar{\omega}_l P_l(\mu_i) P_j(\mu_0) \right] e^{-\tau/\mu_0}
  \]
- GCM-coupled models: computational constraints
- Resort to simplest two-stream approximations
CCC GCM III: SW layer reflectance and transmittance

clear-sky: 2-stream (TS), whole-sky: δ-Eddington (DE)

δ-four-stream (DFS): matrix formulation by Liou et al. (1988)

compromise between accuracy & efficiency

Introduction

- Code input: Layer cloud fraction, optical depth, single-scattering albedo (SSA), asymmetry factor; underlying albedo, cosine of solar zenith angle (CSZA)

- Code output:
  - DE-equivalent: Layer reflectance & transmittance, with & without reflection from underlying surface
    Follow from original DFS formulation by solving BVP
  - TS-equivalent: Layer reflectance & transmittance, with multiple/single reflection from underlying surface
    Some manipulation to derive layer reflectance with single reflection
Introduction

- GCM run for 2 years (six months for spin-up)
- Parallel calls to shortwave radiation routine, with original & DFS-modified codes, at every model-hour
- Include optical properties of aerosols simulated by CAM
- Examine changes in modeled SW flux at TOA and surface
Solar Flux Simulations

July-zonal mean of diff. in surf. whole-sky, SW flux (Wm\(^{-2}\))

**DTS**

Relative accuracy (%) of reflectance from DTS & DFS with respect to adding method, at SSA of 0.8 (Liou et al. 1988).

**DFS**

July-zonal mean of column-integrated cloud optical depth for 1st solar band (0.25 – 0.69 μm) vs. maximum CSZA
Solar Flux Simulations

July-zonal mean of diff. in surf. whole-sky, SW flux (Wm\(^{-2}\))

July-zonal mean of column-integrated cloud optical depth for 1\(^{st}\) solar band (0.25 – 0.69 \(\mu\)m) vs. maximum CSZA

Mean
Lower limit
Upper limit

DTS
DFS

Relat. accuracy (%) of transmittance from DTS & DFS with respect to adding method, at SSA of 0.8 (Liou et al. 1988).
Solar Flux Simulations

Jan-zonal mean of diff. in surf. whole-sky, SW flux (Wm⁻²)

Jan-zonal mean of column-integrated cloud optical depth for 1st solar band (0.25 – 0.69 μm) vs. maximum CSZA

Relat. accuracy (%) of transmittance from DTS & DFS with respect to adding method, at SSA of 0.8 (Liou et al. 1988).
Solar Flux Simulations

April-zonal mean of diff. in clear-sky, SW flux (Wm\(^{-2}\))

TOA

Surface

April-zonal mean of column-integrated aerosol optical depth

at 0.55 µm vs. maximum CSZA
Solar Flux Simulations

Mean percentage diff. in TOA whole-sky SW flux

Mean TOA SW cloud radiative forcing (Wm$^{-2}$)

Jan

July

Solar Flux Simulations
Solar Flux Simulations

Mean percentage diff. in surface whole-sky SW flux

Jan

July
Whole-sky computations: weighted by cloud fraction (CF)

Layer Ref = \((1 - CF) \times TS\text{-Ref} + CF \times DE\text{-Ref}\)

Layer Trans = \((1 - CF) \times TS\text{-Trans} + CF \times DE\text{-Trans}\)
Computational Time

- Running-time ratio of modified to original SHORTW8: 2 – 3
- Arrays equivalenced in original scheme, so that TS computation is performed once
- Attempts to equivalence arrays for DFS code resulted in numerical errors, so clear-sky DFS has to be called again in whole-sky
- Potential to reduce running time of DFS-modified SW scheme
Conclusions and Recommendations

- DFS code developed for SW radiation computations in CCC AGCM
- Significant changes in GCM computation of solar fluxes:
  - Whole-sky differences: within 5 Wm\(^{-2}\) TOA & 10 Wm\(^{-2}\) surface can be as large as +20 and –40 Wm\(^{-2}\)
  - Clear-sky differences: within 2 Wm\(^{-2}\) can be as large as +25 and –12 Wm\(^{-2}\)
  - Percentage differences: 4–6% TOA & >20% surface
- Most prominent at Tropics & high latitudes
- Mostly determined by cloud optical depth & solar zenith angle, and by aerosol optical depth in a clear sky
Conclusions and Recommendations

- Chou (1992): accuracy of DFS computations in GCM within 7.5 Wm$^{-2}$
- Reduction of computational time?
- Further research:
  - Improvement of the overall accuracy of GCM flux simulations
    (Closure experiments against observational data)
  - Implications to GCM simulation of climate dynamics