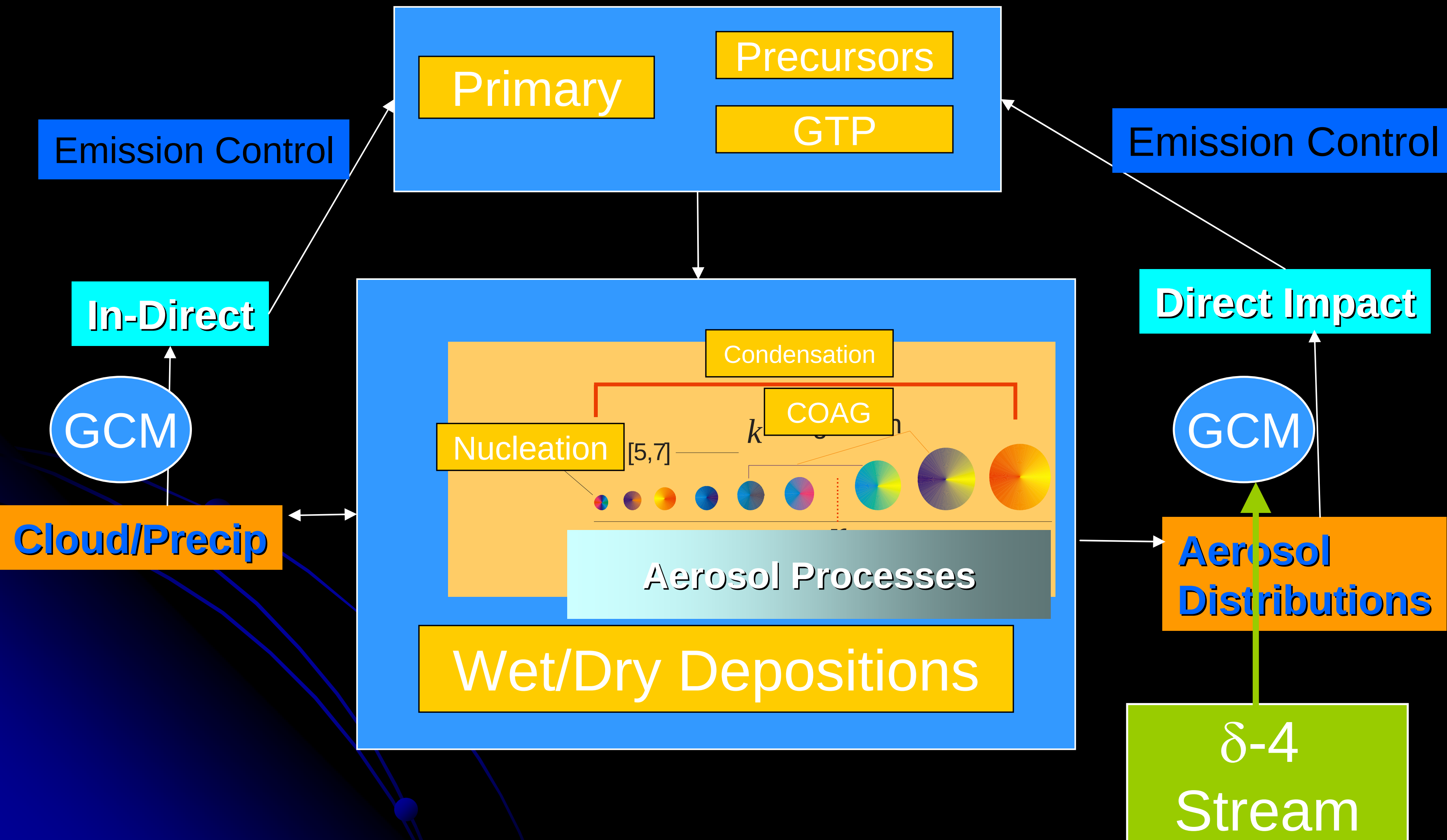
Aerosol Climate Impact Assessment



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.

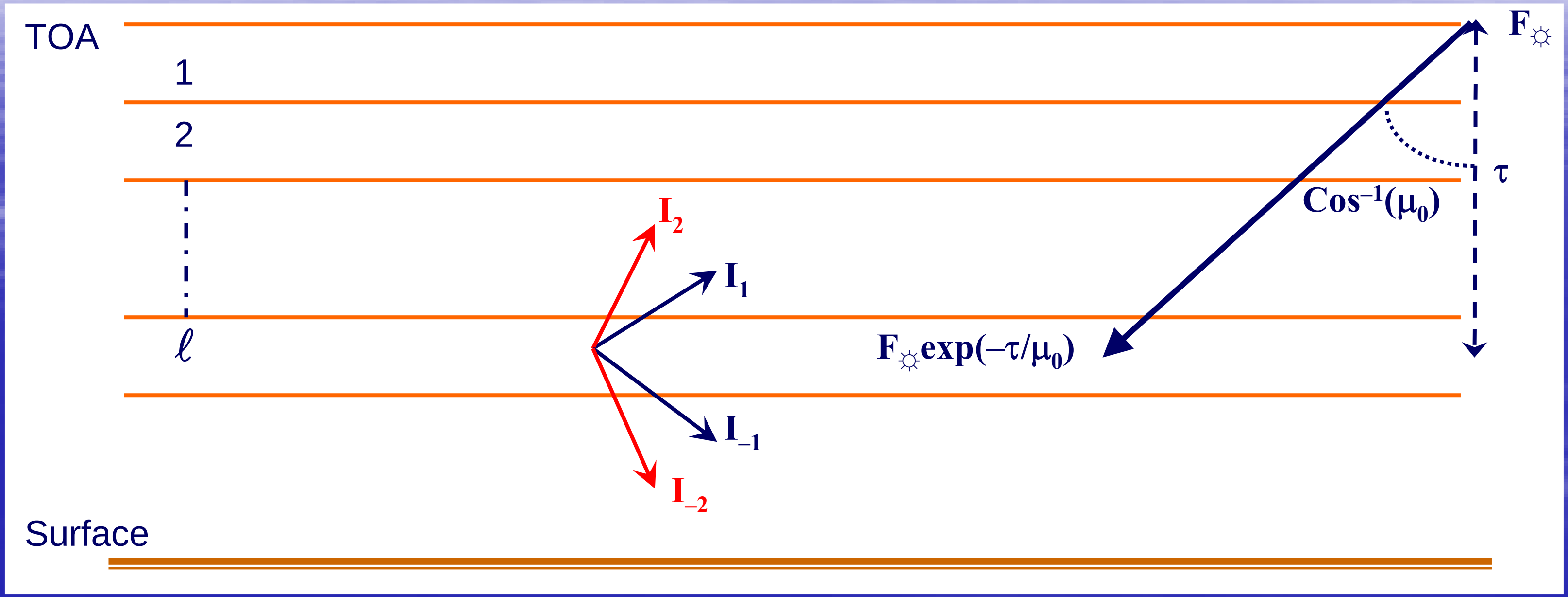
$$\mu \frac{dI(\tau,\mu)}{d\tau} = I(\tau,\mu) - \frac{\tilde{\omega}}{2}\int_{-1}^{1} I(\tau,\mu')\cdot P(\mu,\mu')d\mu' - \frac{\tilde{\omega}}{4\pi}F_{\Theta}P(\mu,-\mu_0)\cdot e^{-\tau/\mu_0}$$

- Gauss-exp. for intensity & Legendre-exp. for phase func.

$$\mu_i \frac{dI(\tau,\mu_i)}{d\tau} = I(\tau,\mu_i) - \frac{\tilde{\omega}}{2}\sum_{l=0}^{N}\tilde{\omega}_l P_l(\mu_i)\sum_{j=-n}^{n} a_j P_l(\mu_j) I(\tau,\mu_j) - \frac{\tilde{\omega}}{4\pi}F_{\Theta}\left[\sum_{l=0}^{N}(-1)^l\,\tilde{\omega}_l P_l(\mu_i) P_l(\mu_0)\right]\cdot e^{-\tau/\mu_0}$$

- GCM-coupled models: computational constraints
- Resort to simplest two-stream approximations

Introduction



- 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

Liou, K. N., Q. Fu, and T. P. Ackerman, 1988: A simple formulation of the delta-four-stream approximation for radiative transfer parameterizations. *J. Atmos. Sci.*, **45**, 1940–1947.

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

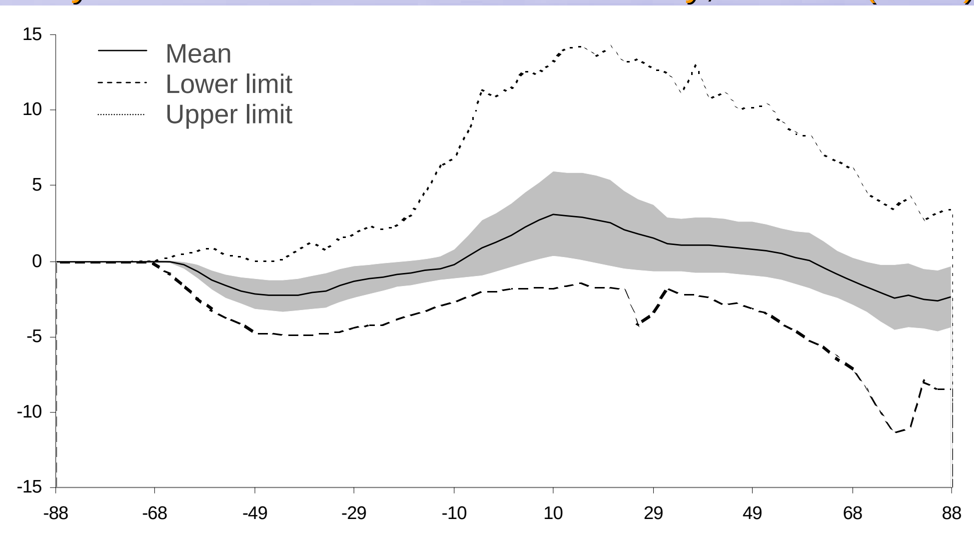
    single reflection

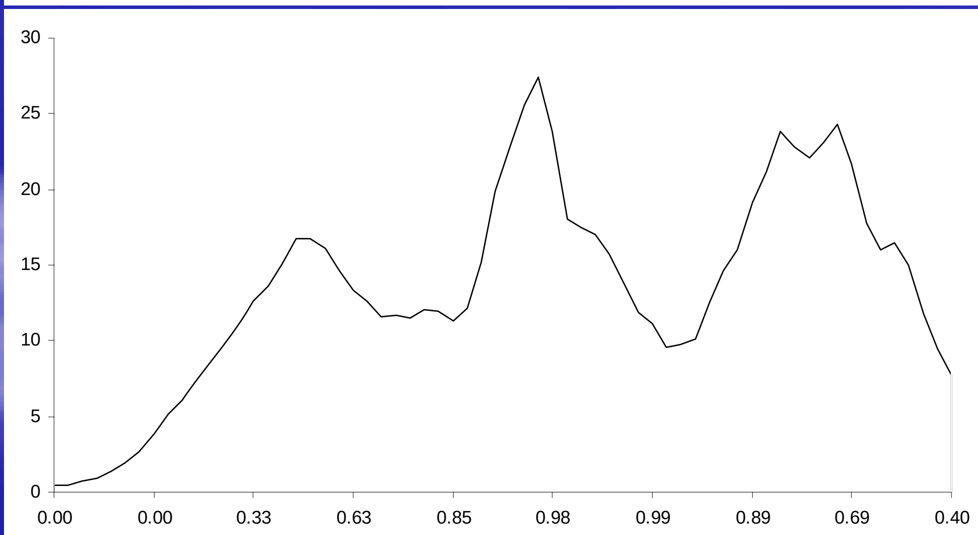
Introduction

- 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

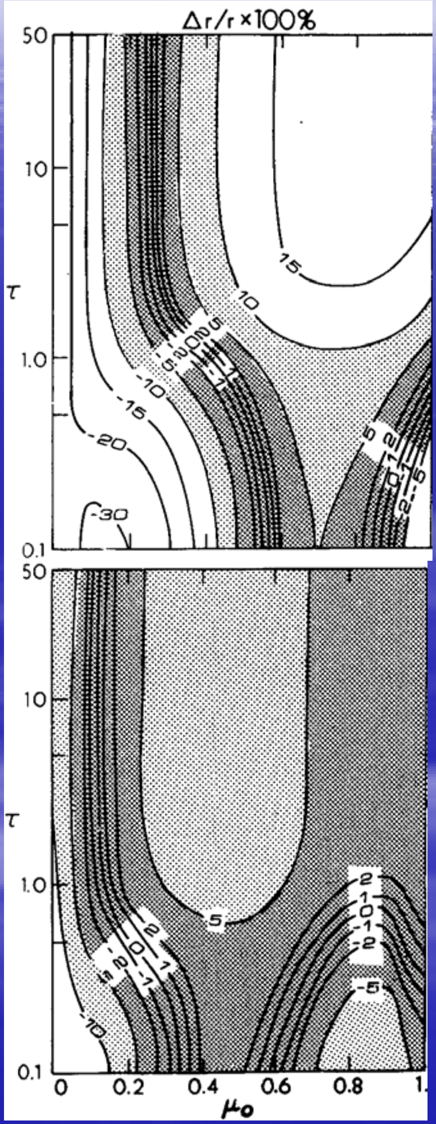
Solar Flux Simulations

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





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



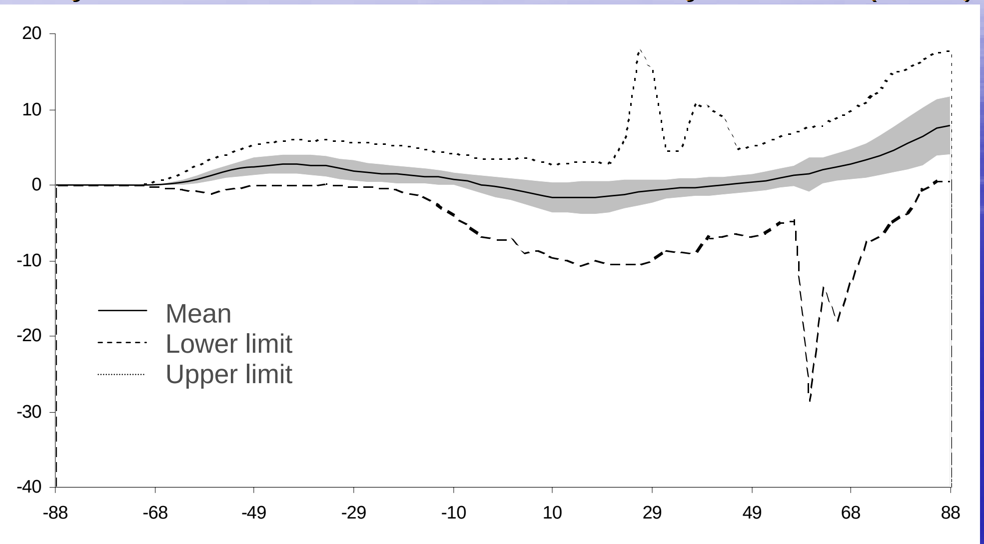
DTS

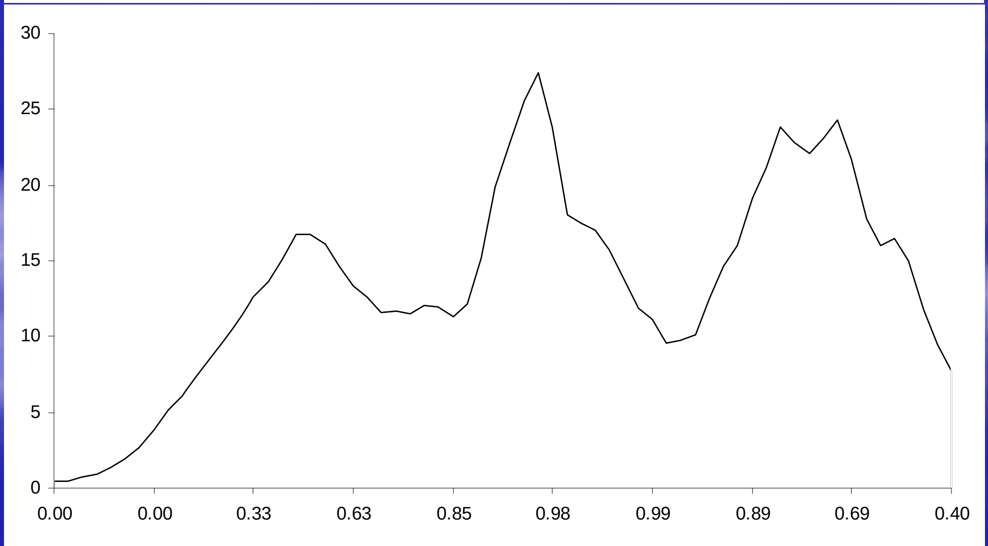
Relative accuracy (%) of reflectance from DTS & DFS with respect to adding method, at SSA of 0.8 (Liou *et al.* 1988).

DFS

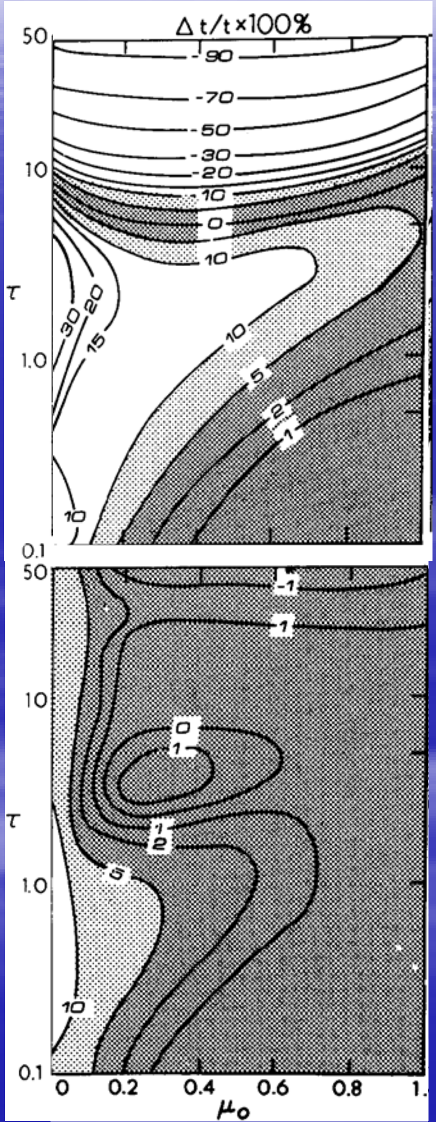
Solar Flux Simulations

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





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



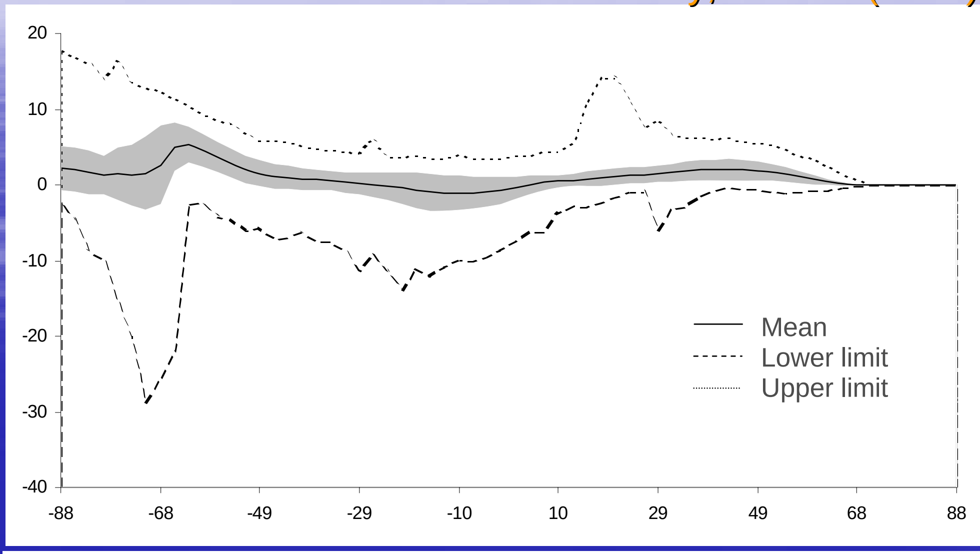
DTS

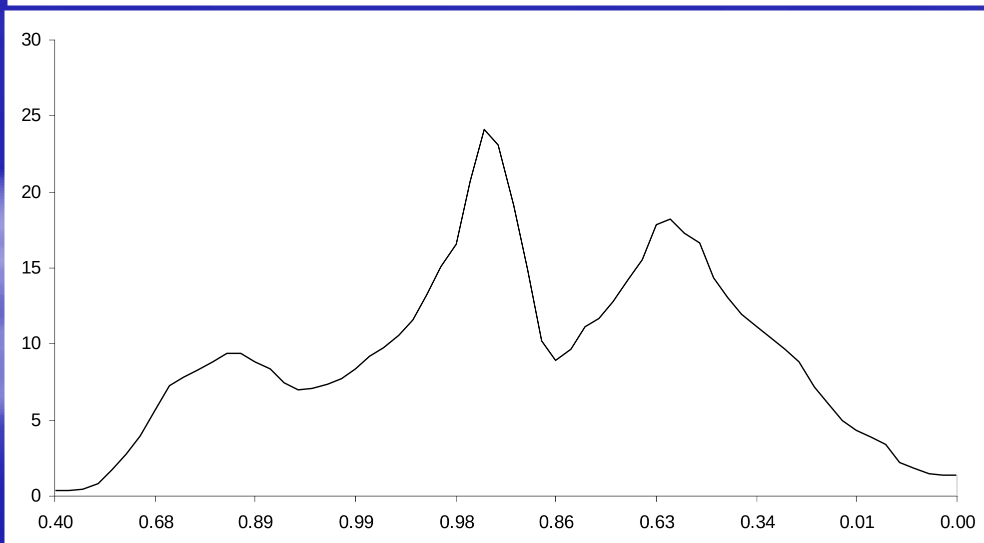
Relat. accuracy (%) of transmittance from DTS & DFS with respect to adding method, at SSA of 0.8 (Liou *et al.* 1988).

DFS

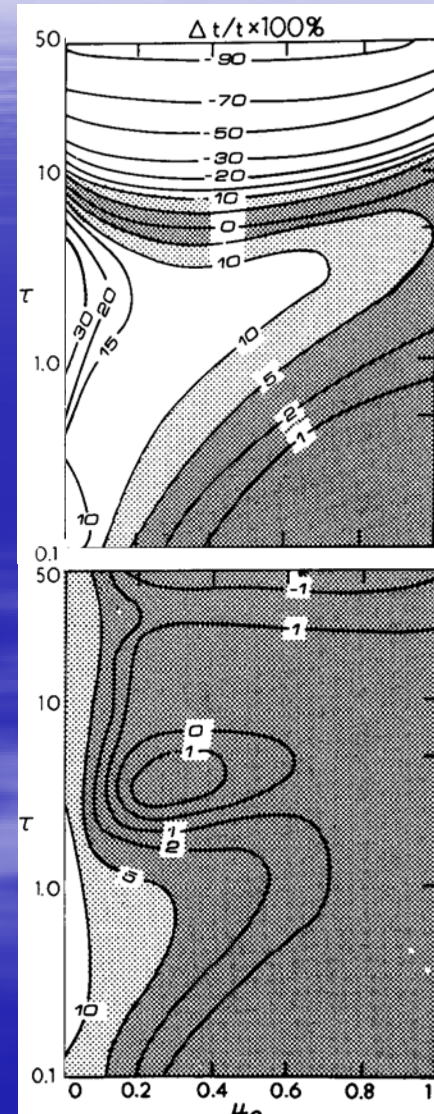
Solar Flux Simulations

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



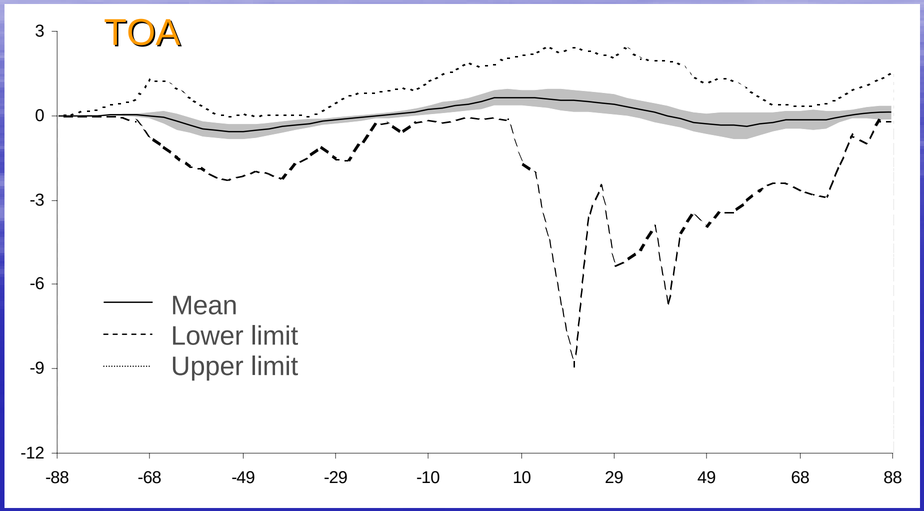
DTS

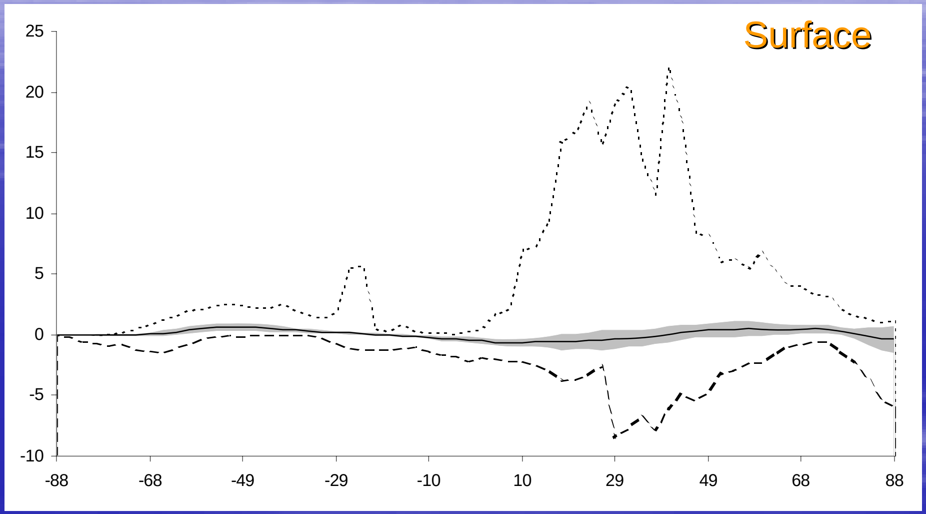
Relat. accuracy (%) of transmittance from DTS & DFS with respect to adding method, at SSA of 0.8 (Liou *et al.* 1988).

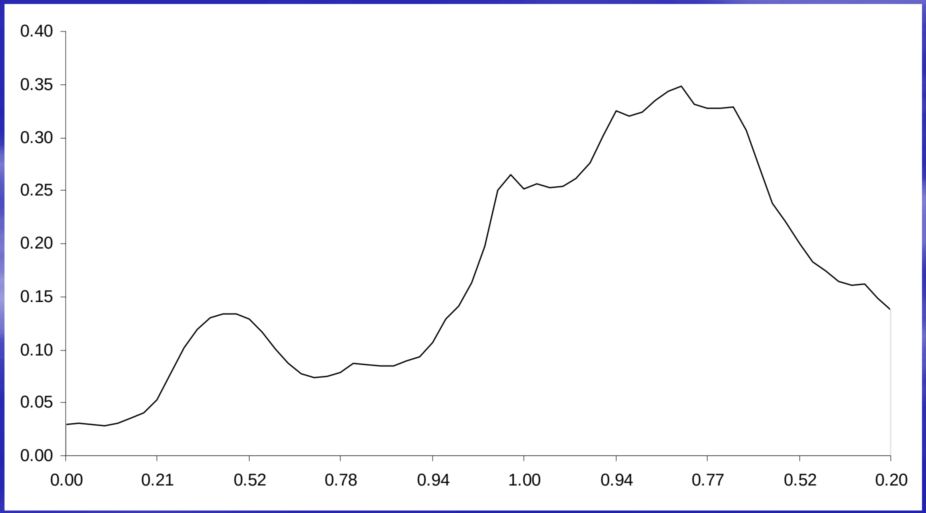
DFS

Solar Flux Simulations

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



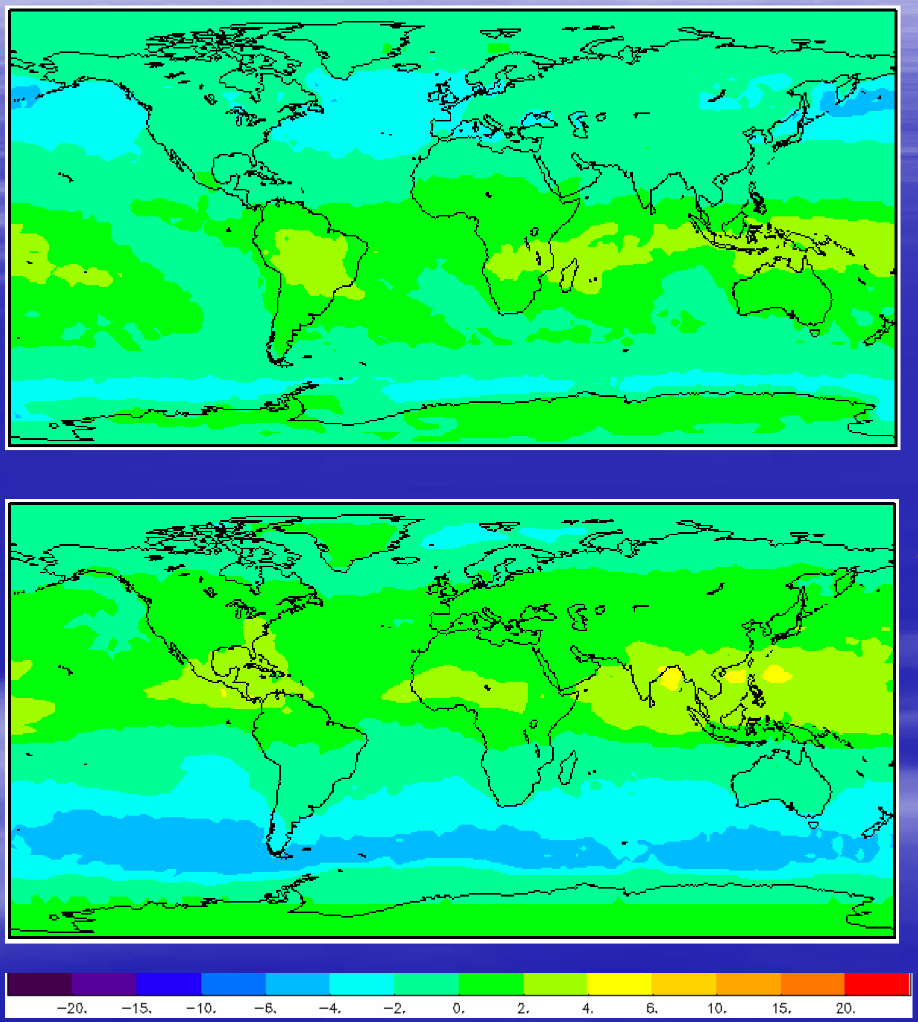




April-zonal mean of column-integrated aerosol optical depth at 0.55 μm vs. maximum CSZA

Solar Flux Simulations

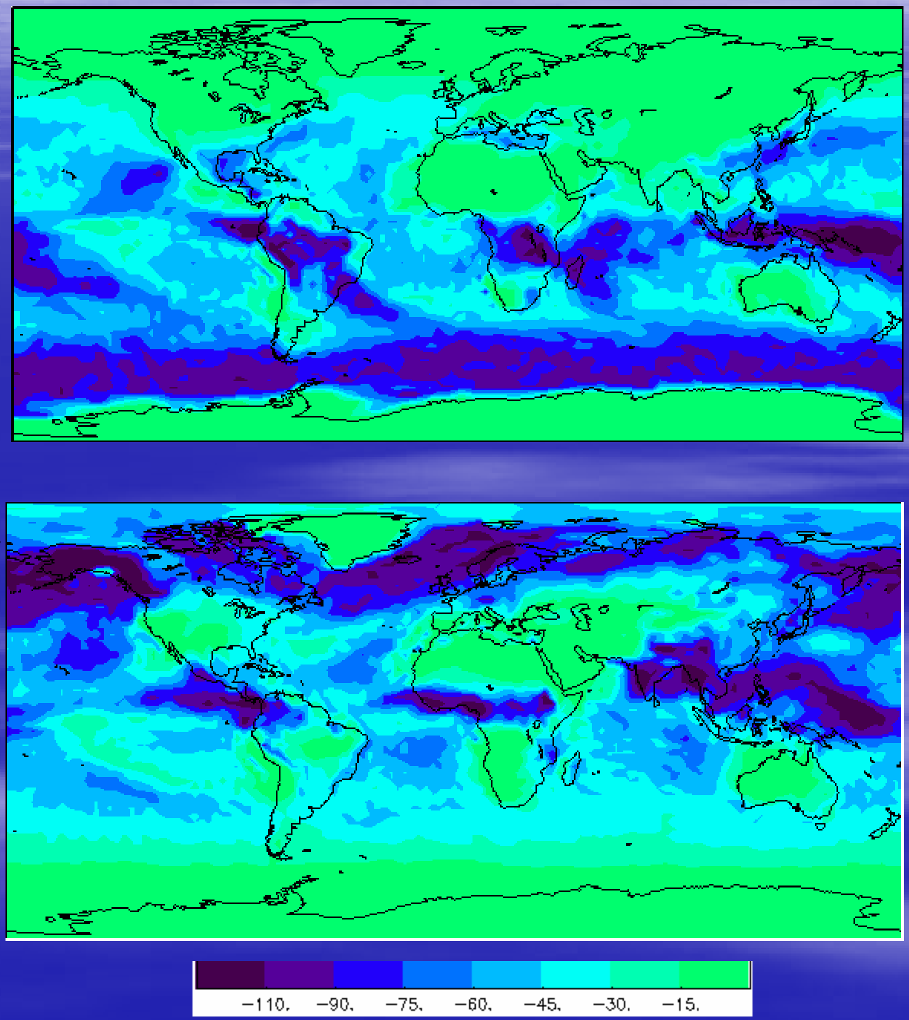
Mean percentage diff. in TOA whole-sky SW flux



Jan

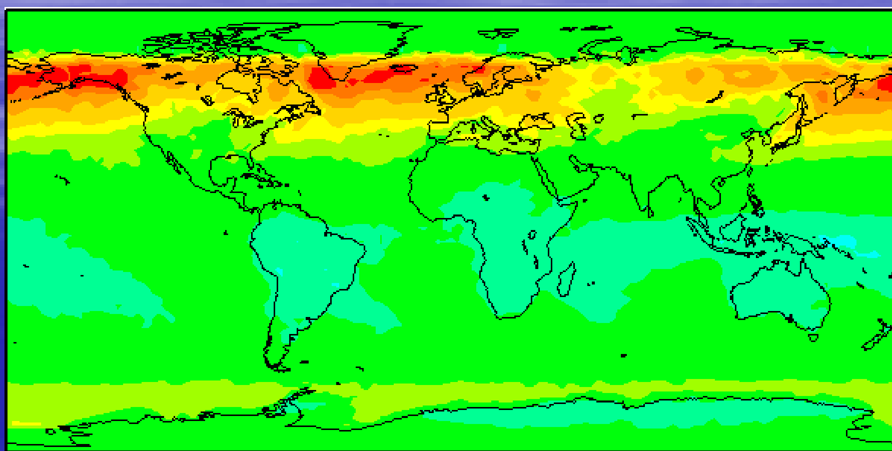
July

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

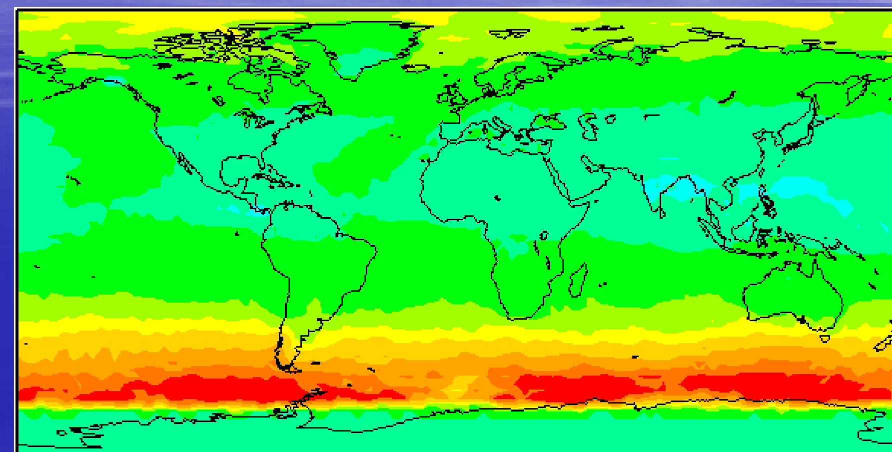


Solar Flux Simulations

Mean percentage diff. in surface whole-sky SW flux



Jan



July

Computational Time

PHYSICdd
Physics subroutine

RADNEW9
Main radiation subroutine

SHORTW8
SW radiation subroutine

SWLINK4
SW column ref & trans

TSTREAM
Clear-sky layer ref & trans

DELTAE
Whole-sky layer ref & trans

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

Layer Ref = (1 – CF)×TS-Ref + CF×DE-Ref

Layer Trans = (1 – CF)×TS-Trans + CF×DE-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

Chou, M.-D., 1992: A solar radiation model for use in climate studies. *J. Atmos. Sci.*, **49**, 762–772.