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Several Issues for Current Radiation Algorithms in Climate Models

Jiangnan Li

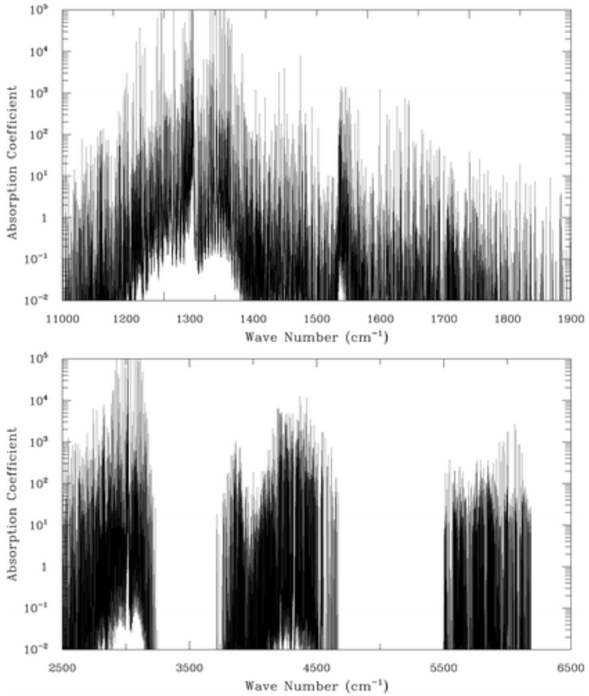
Canadian Centre for Climate Modelling and Analysis, Canada

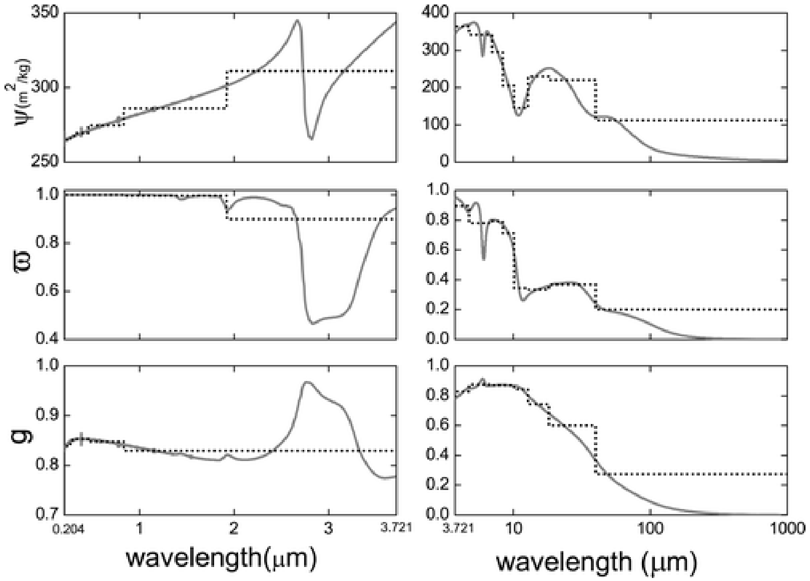
In cooperation with Howard Barker and Jason Cole, and other collaborators

CKD cloud

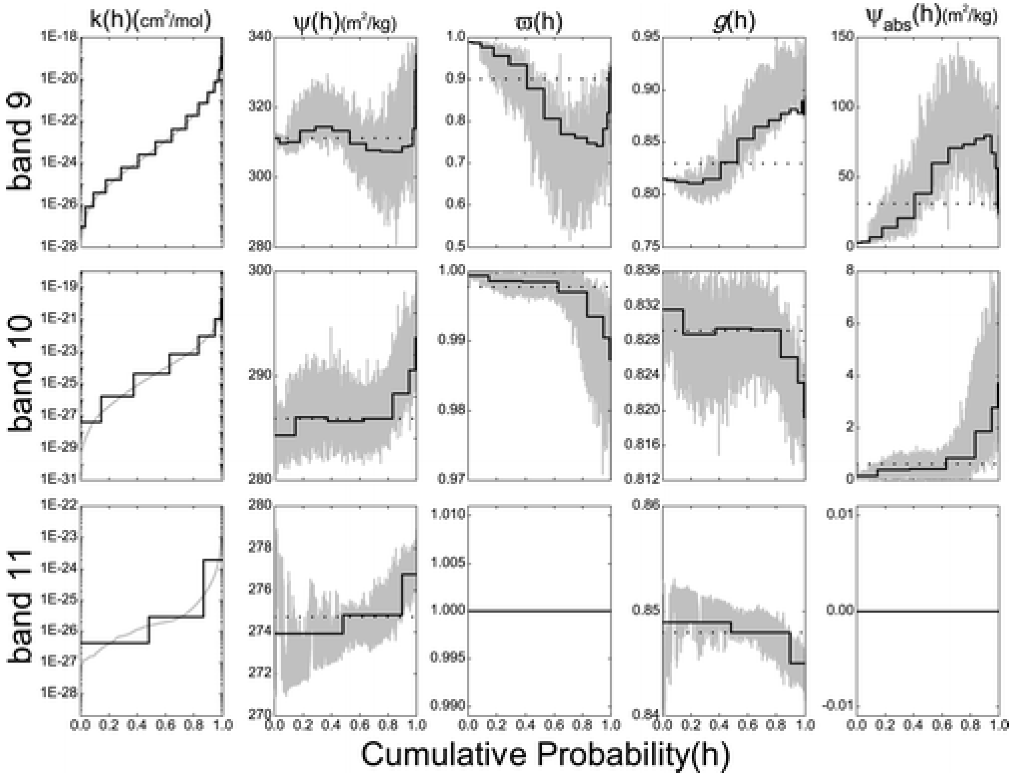
The correlated-k distribution (CKD) method makes gaseous transmission be much more accurate in climate models. However the sorted gaseous absorption coefficient and the band mean cloud optical property is consistent.

Physically, we have to make the correlation in spectral distributions between the gaseous absorption coefficient and cloud optical properties be maintained.

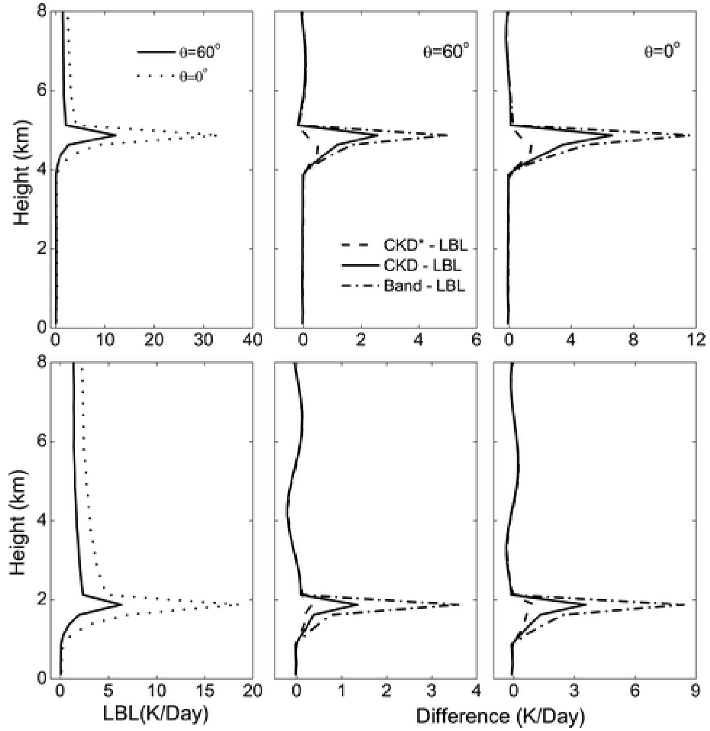




An extension of the CKD method from gas to cloud by dealing with the gas absorption coefficient and cloud optical properties in the same way.



correlation between gaseous absorption and cloud absorptance the error of band-mean cloud optical property in solar heating rate and flux



	MLS (θ_0 = 60°)				MLS (θ_0 = 0°)			
	Broadband	Band 9	Band 10	Band 11	Broadband	Band 9	Band 10	Band 11
$F^{\uparrow}$ at TOA	459.58	9.01	127.85	241.76	880.98	14.85	245.23	466.67
Error (band mean)	−7.79	−4.78	−5.81	2.8	−20.7	−9.43	−16.8	5.46
Error (CKD)	−1.02	−1.79	−1.74	2.51	−5.09	−3.93	−5.97	4.81
Error (CKD*)	1.96	−1.01	0.46	2.51	2.35	−2.37	−0.09	4.81
$F^{\downarrow}$ at surface	64.48	0.02	12.71	38.62	192.68	0.07	38.11	115.53
Error (band mean)	−4.48	−0.02	−4.76	0.3	−13.6	−0.07	−14.1	0.57
Error (CKD)	−1.61	−0.01	2.28	0.68	−5.29	−0.05	−6.91	1.67
Error (CKD*)	−0.37	−0.01	−1.94	0.68	−1.63	−0.04	−3.26	1.67

Why

Σ

$$\sum_{i=1}^{N} F_{0i} e^{-\langle k_i q \rangle D/\mu_0} (1 - e^{-\psi_{\text{abs}\,i} \text{LWC} d^m}) < \left(\sum_{i=1}^{N} F_{0i} e^{-\langle k_i q \rangle D/\mu_0} \right) \left[\frac{1}{N} (1 - e^{-\psi_{\text{abs}\,i} \text{LWC} d^m}) \right] <$$

$$\left(\sum_{i=1}^{N} F_{0i} e^{-\langle k_i q \rangle D/\mu_0} \right) (1 - e^{-\overline{\psi}_{\text{abs}\,i} \text{LWC} d^m}),$$

Chebyshev inequality:
for two groups of variables with sequence conditions of
a1 ≤ a2 ≤, … , ≤ aN and b1 ≥ b2 ≥, … , ≥ bN or
a1 ≥ a2 ≥, … , ≥ aN and b1 ≤ b2 ≤, … , ≤ bN, then

$$N \sum_{i=1}^{N} a_i b_i \le \left(\sum_{i=1}^{N} a_i \right) \left(\sum_{i=1}^{N} b_i \right). \qquad \text{(A1)}$$

and vice versa

arithmetic-geometric inequality

$$\frac{1}{N} \sum_{i=1}^{N} e^{-a_i} \ge e^{-(1/N) \sum_{i=1}^{N} a_i},$$

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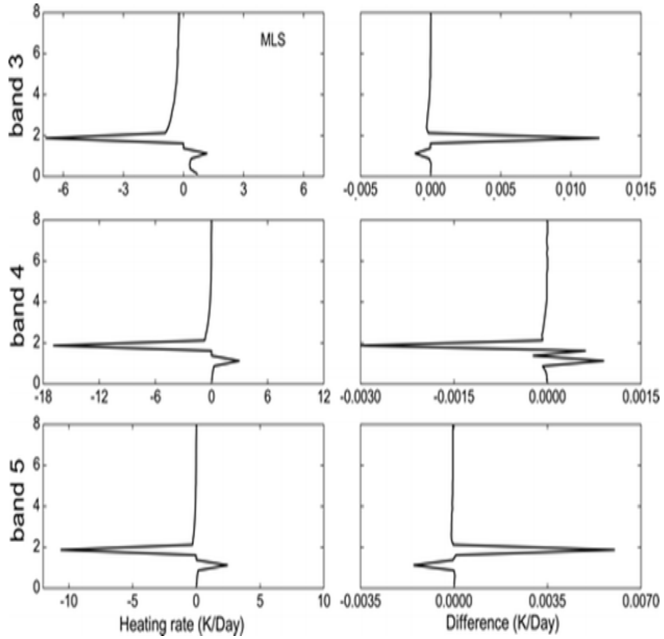
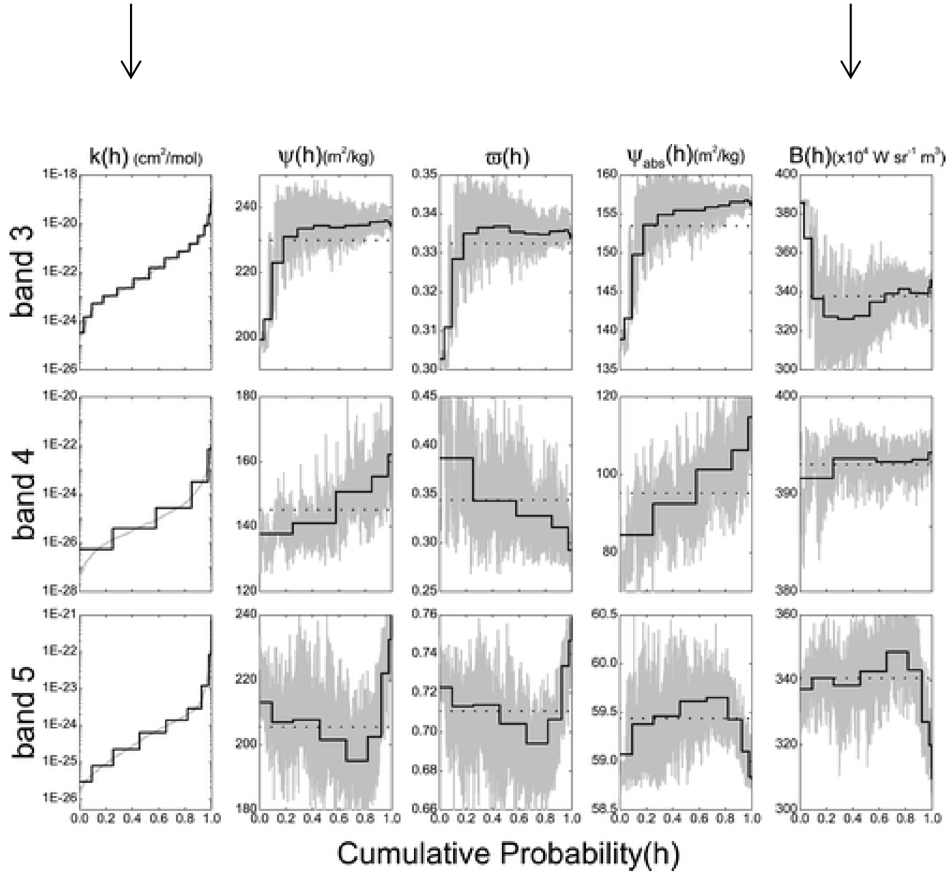
no impact on LW

Planck



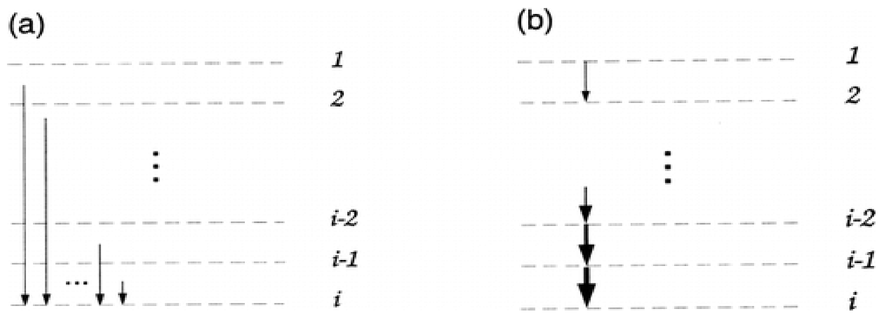


Lu et al 2011 JAS

no obvious correlation
between gaseous absorption
and Planck function

Infrared radiative transfer with cloud scattering

most of radiation algorithms have not include LW scattering (Oreopoulos et al 2012 JGR)



computing time ~ n^2 ~ n !!!

Absorption Approximation (AA)

$$\mu \frac{dI(\tau, \mu)}{d\tau} = (1 - \tilde{\omega}) I(\tau, \mu) - (1 - \tilde{\omega}) B[T(\tau)]. \quad (4)$$

$$B[T(\tau)] = B_i + \alpha_i \tau/\tau_i, \quad (7)$$

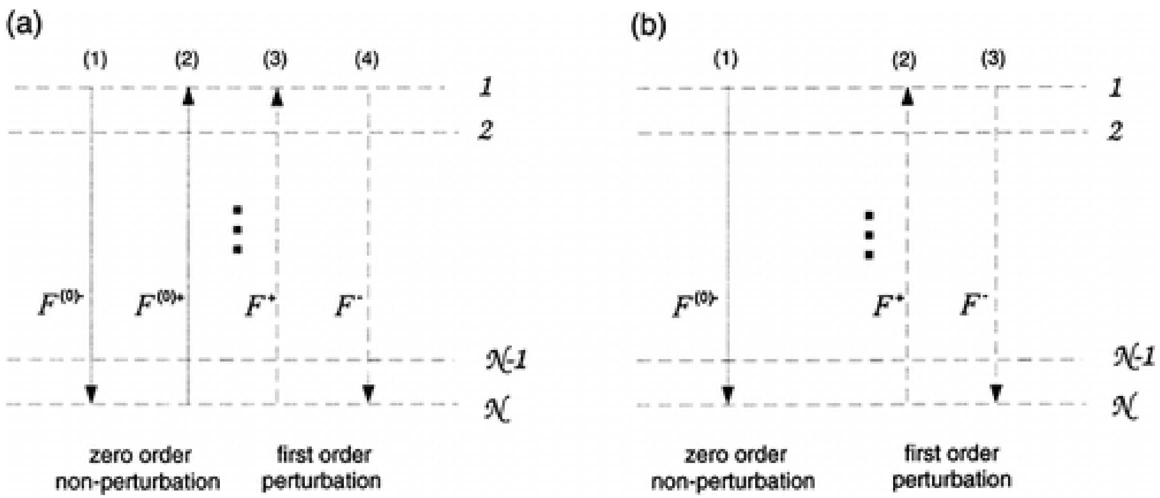
$$I_i(\mu) = I_{i+1}(\mu) e^{-\kappa_i/\mu} + B_i + \alpha_i \frac{\mu}{\kappa_i} - \left(B_{i+1} + \alpha_i \frac{\mu}{\kappa_i}\right) e^{-\kappa_i/\mu}; \quad (8a)$$

advantage: the upward and downward paths are independent, extremely fast in computing, can easily do any number of stream

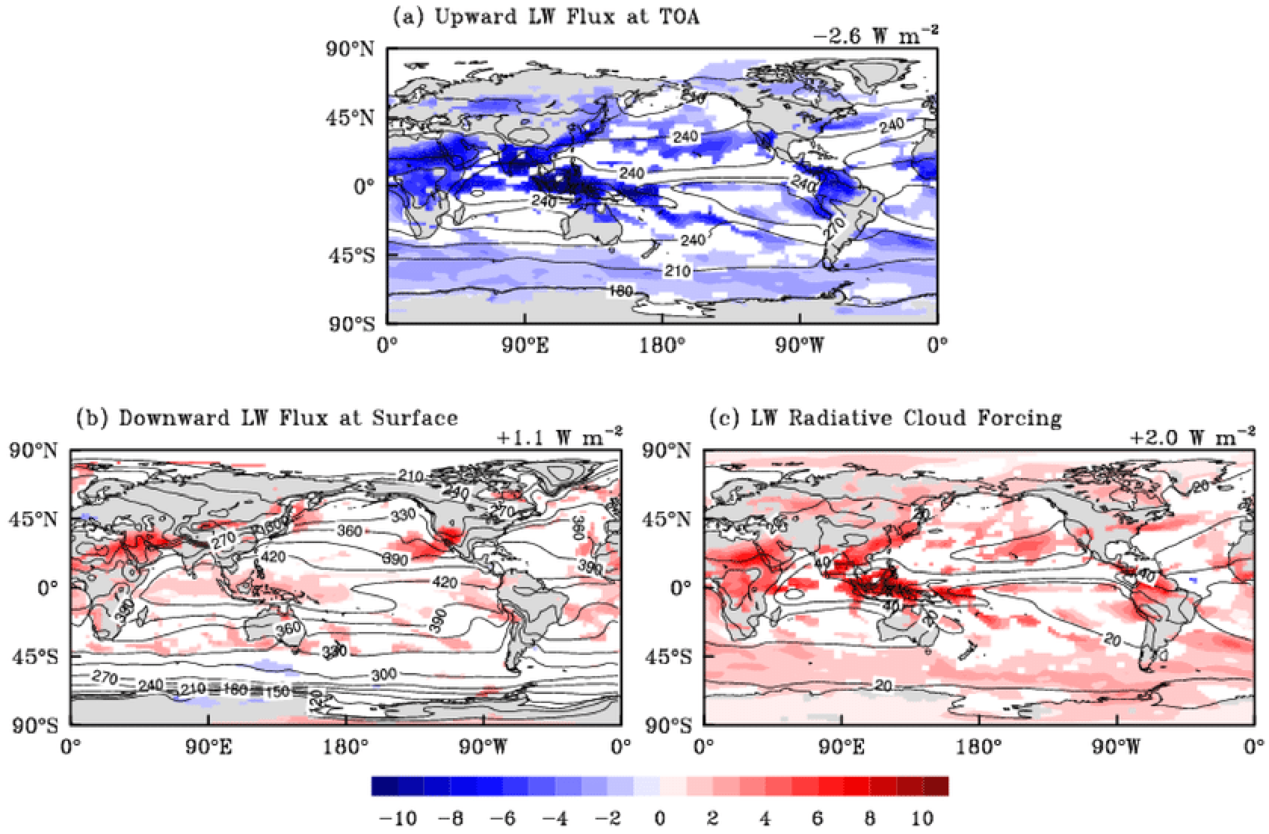
disadvantage: not working for gravity wave LW damping in the upper stratosphere/mesosphere, why?

$$\mu \frac{dI(\tau, \mu)}{d\tau} = I(\tau, \mu) - \frac{\tilde{\omega}}{2} \int_{-1}^{1} I(\tau, \mu')P(\mu, \mu')\, d\mu' - (1 - \tilde{\omega})B[T(\tau)], \quad (1)$$

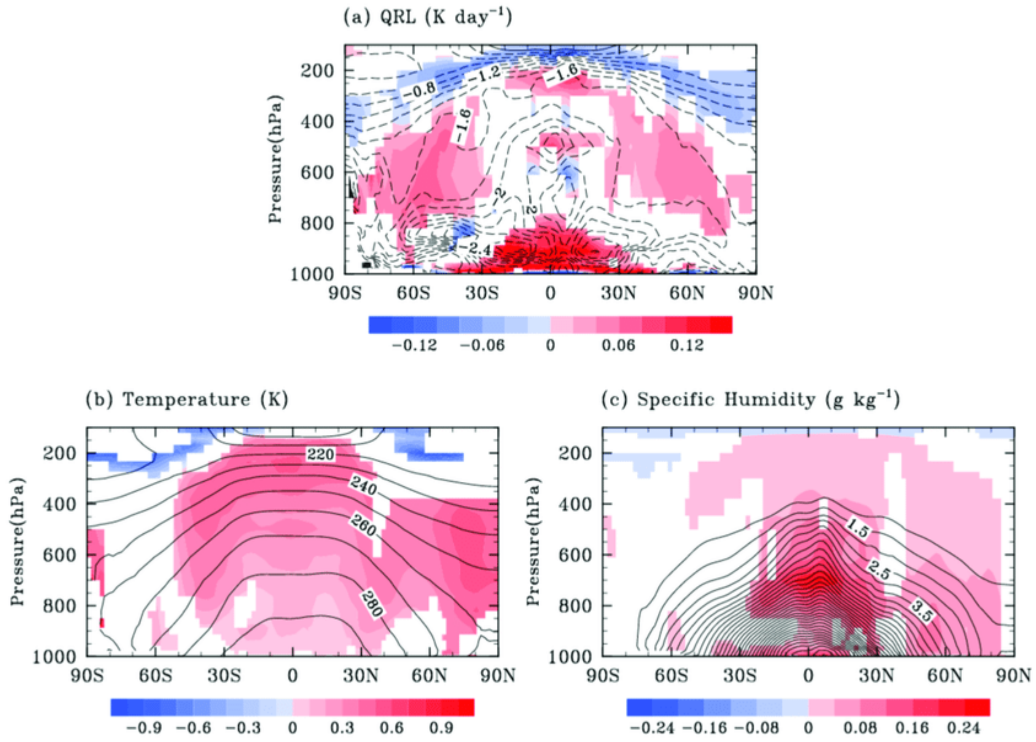
1. Exact solution with doubling method from Chandrasekhar invariance principle (Zhang et al 2016, JAS). Computing time 1600% more than of AA
2. Perturbation method since single scattering albedo < 1 (Li 2002 JAS) . Computing time only 50% more than AA



OLR $-2.6Wm^{-2}$

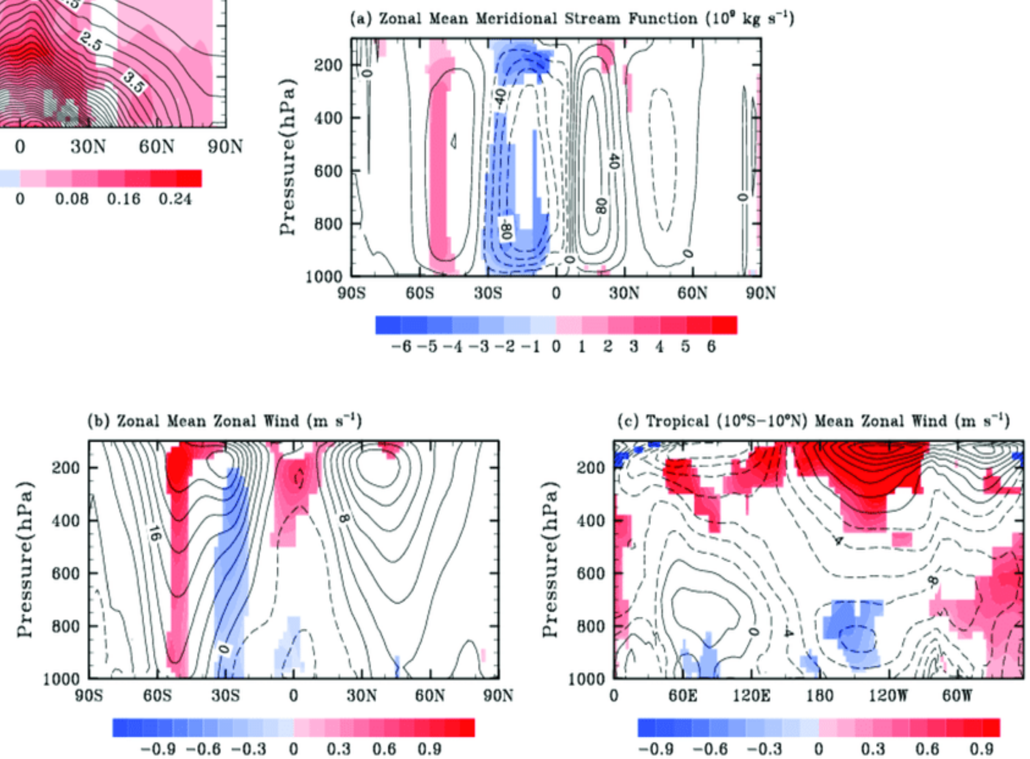


(Zhao et al. 2018 atmosphere, using CAM5)



impact on thermodynamic

on dynamic



Solar and infrared spectral overlap

The solar spectrum extends into the infrared, with about 12 Wm^{-2} in the 4--1000 um range. But only 0.33 Wm^{-2} of LW spectral energy in the solar spectral range of 0.2 – 4 um.

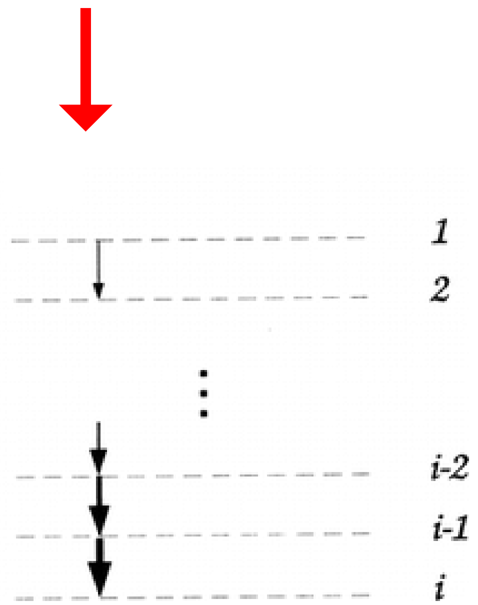
1. The solar spectrum comprises wavelengths up to 4 um but make all incoming solar energy deposited in that range. The spectral energy shifted.

2. RRTM creates a special solar band over all infrared range. In such wide spectral range the cloud/aerosol optical property cannot be parameterized accurately, the interaction between solar and infrared radiation is ignored.

Both methods are physically wrong and can cause large errors.

We don't need to do anything! The incoming solar energy flux can be direct put at the upper boundary for downward flux in each LW bands

12 Wm^{-2}

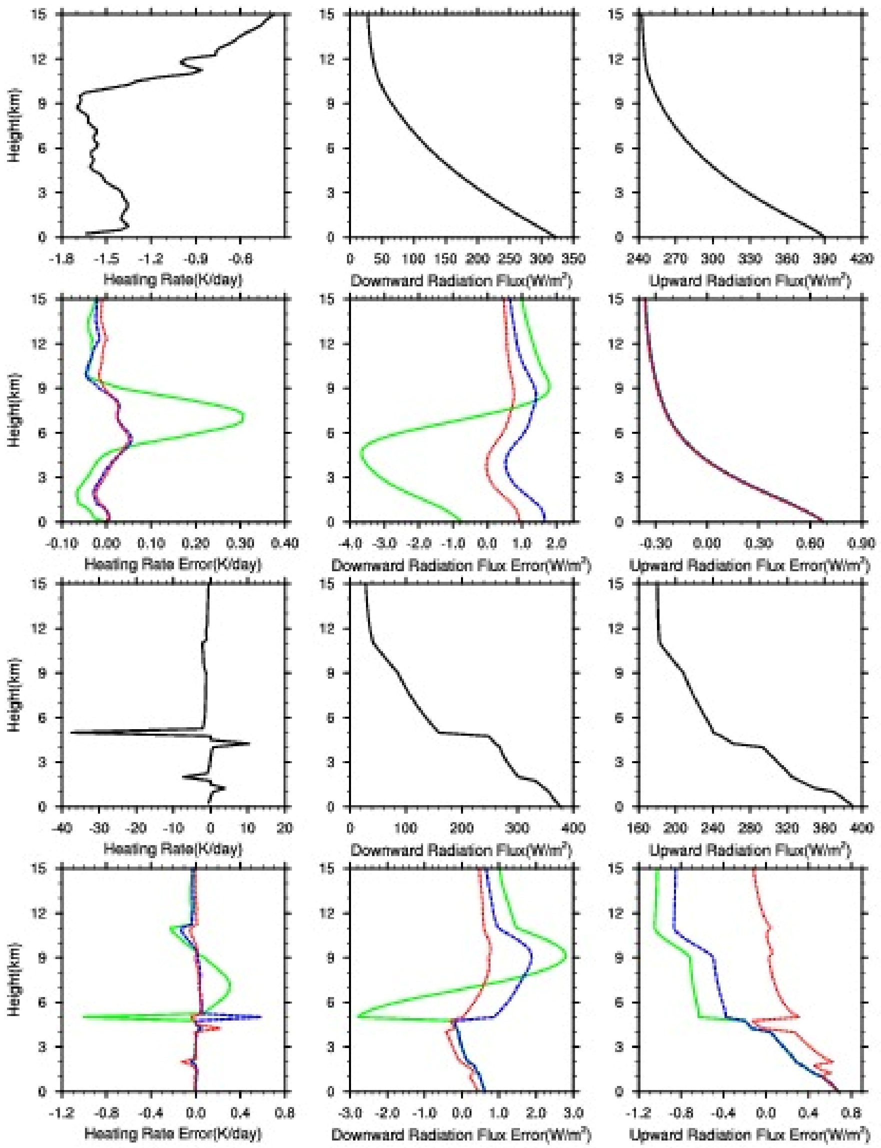


1. In each band, the cloud/aerosol optical properties are there, no more parameterization.
2. The LW scattering, surface reflection etc. are automatically included.

(Li et al 2010 JAS)

Clear sky

Cloudy sky

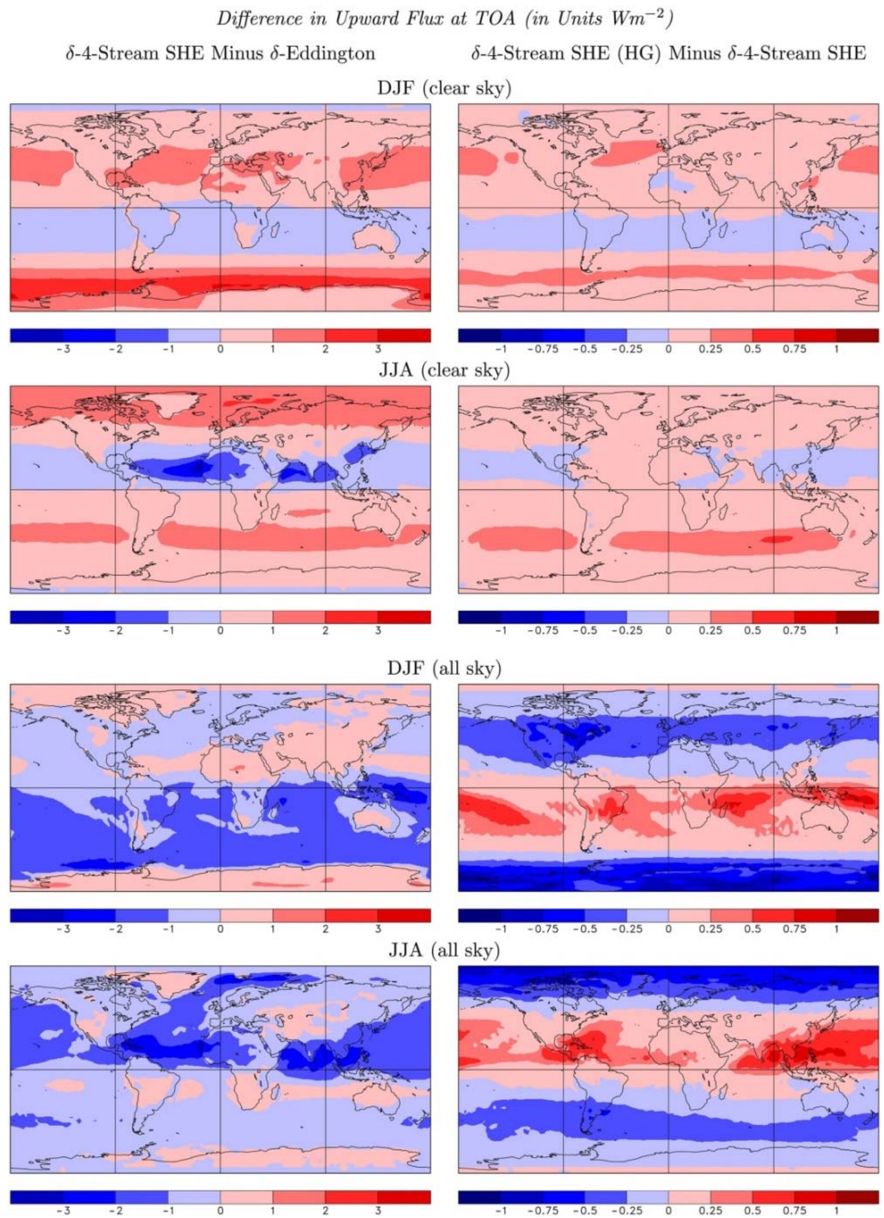


--- extra band method (RRTM)
--- perturbation with top input
--- exact solution with DA

4-stream

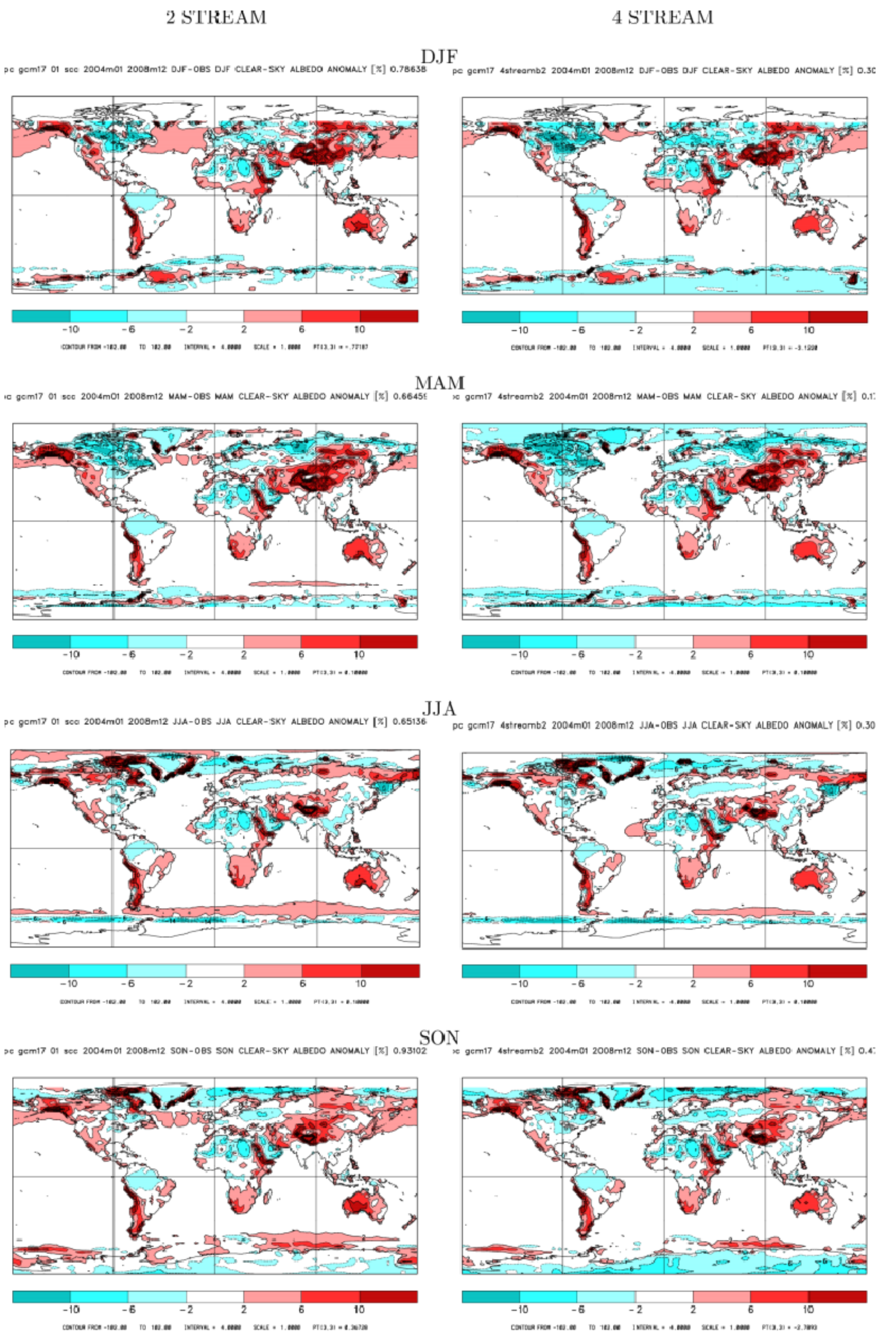
the moments of cloud/aerosol phase function must be obtained from Mie,

the Henry-Greenstein approximation:
g, g2, g3, g4, …
could make the 4-stream poorer than the 2-stream,
especially for larger particles:
sea salt, dust, cloud droplets ,

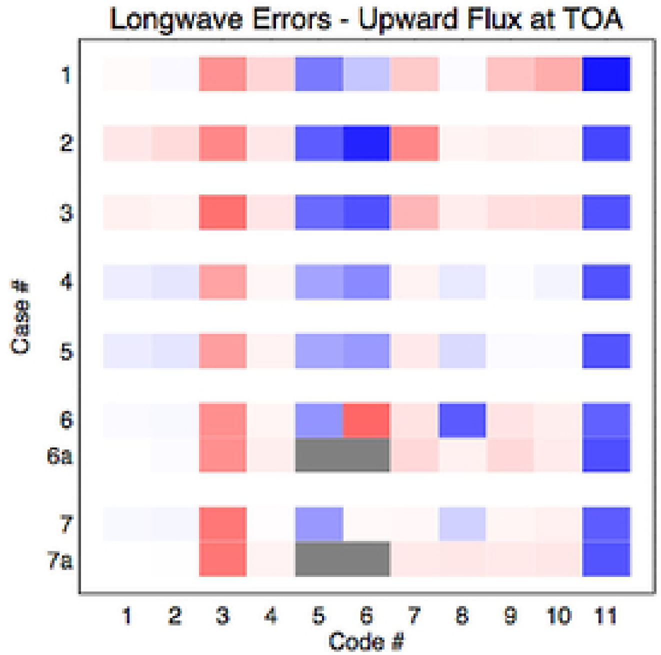


Li et al 2015 JGR

Clear sky results against CERES
4-stream improves CCCma GCM



One more issue is CKD, should we need so many k number as RRTM. Many k points are saturated.



Conclusions

- In the last 20 years, a radiation algorithm was developed in CCCma GCM. Special attention has been paid on above issues. Hope to discuss with the experts here on these issues.

  If the radiation modeling is monopolized by one model, the modeling community will become less interesting.

Thank You