Radiation Processes in the GFDL GCM:

How Accurate is the GFDL GCM Radiation Code?

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GFDL, Princeton, New Jersey

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Grand Challenges in monsoon modeling: Representation of processes in climate models workshop

Summary of GFDL Radiation Codes

The GFDL AM3 GCM uses two ‘in house’ radiation codes

Shortwave:

ESFSW - 18 Bands, Exponential Sum-Fit with two stream Delta-Eddington (*Freidenreich and Ramaswamy;1991,1999*). Liquid clouds: Slingo (1989), Ice Clouds: Fu et al. (1996), Aerosol: Internal mixing and hygroscopic growth

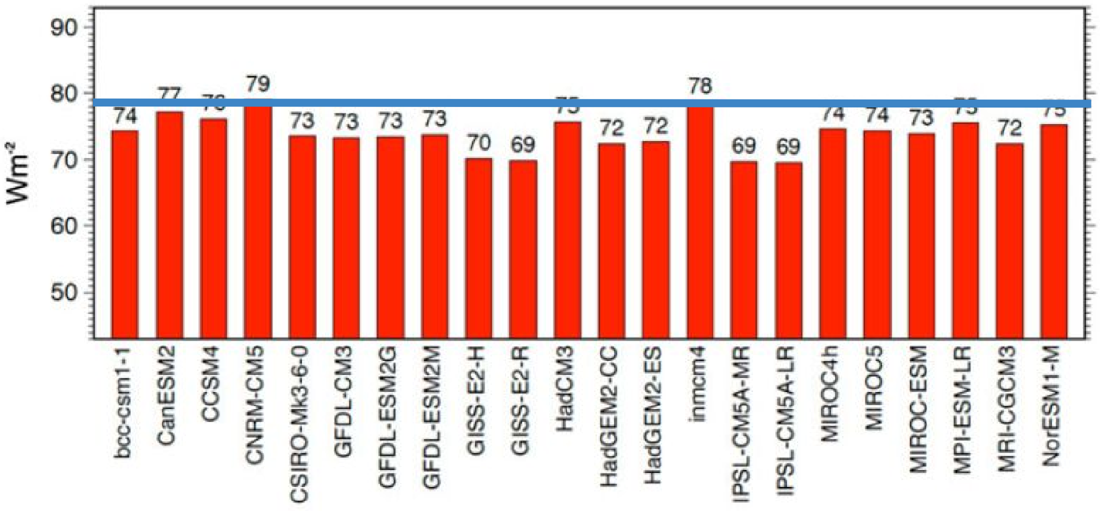
Longwave:

SEALW - 10 Bands, Random (H2O/O3) and LBL-derived (WMGHG) band parameters (Schwarzkopf and *Ramaswamy; 1999,* Schwarzkopf and Fels;1991,1985, Fels and Schwarzkopf; 1981,1975) -Diffuse beam approx (no scattering) ,Liquid clouds: 0.1*cloud liquid, Ice Clouds: Fu et al. (1996). Aerosol: Internal mixing and hygroscopic growth

Summary of Talk

1) A Best Estimate of Shortwave Absorption by the Atmosphere
2) Global Line-by-Line Benchmarking of GFDL Longwave code.
3) Looking ahead to RFMIP
4) Conclusions

GCMs Underestimate Shortwave Absorption by the Atmosphere (SWA) Compared to Observations



CERES EBAF-
78 Wm^{-2}

CMIP5 model estimate of shortwave absorption by atmosphere

From Wild et al. 2012

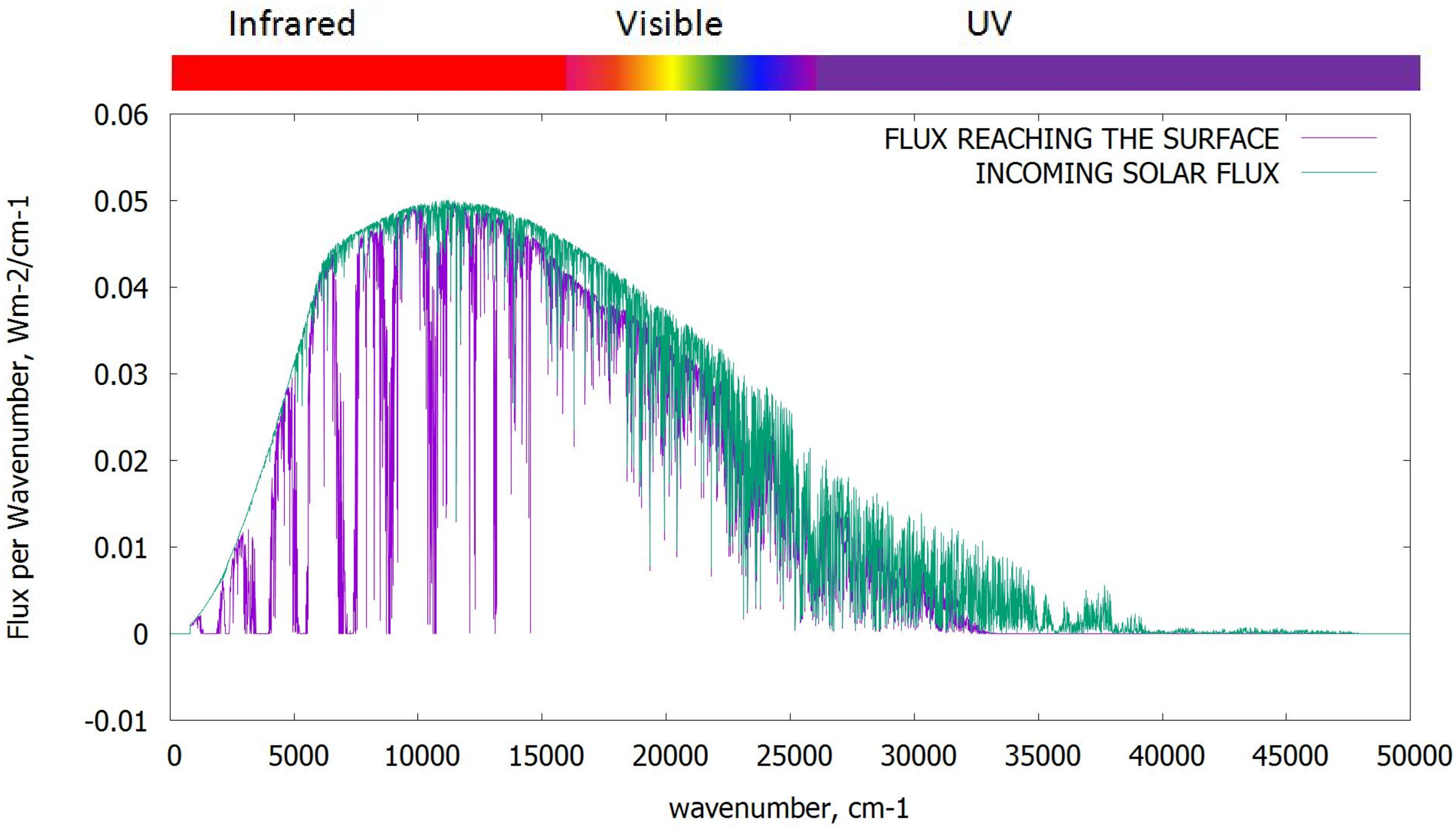
Clim Dyn (2013) 40:3107–3134
DOI 10.1007/s00382-012-1569-8

A Best Model Estimate of Atmospheric Shortwave Absorption

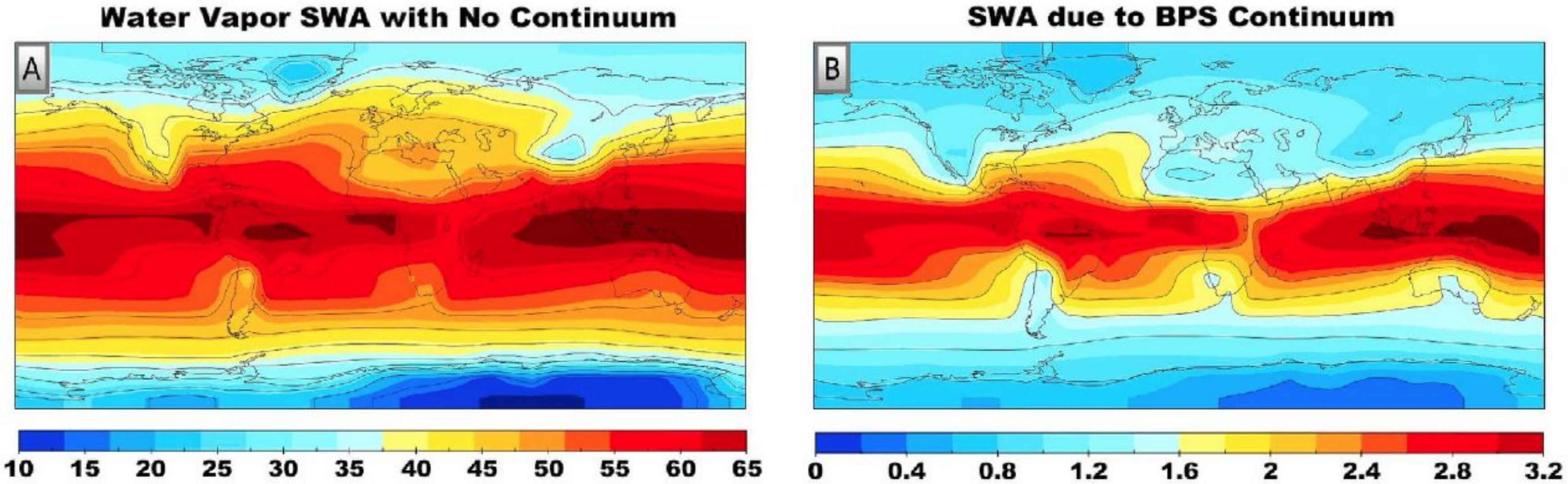
- If we use the latest physics to estimate the properties of absorbers in the atmosphere what value of shortwave absorption (SWA) do we obtain?
- Can we use this information to improve the GFDL model?

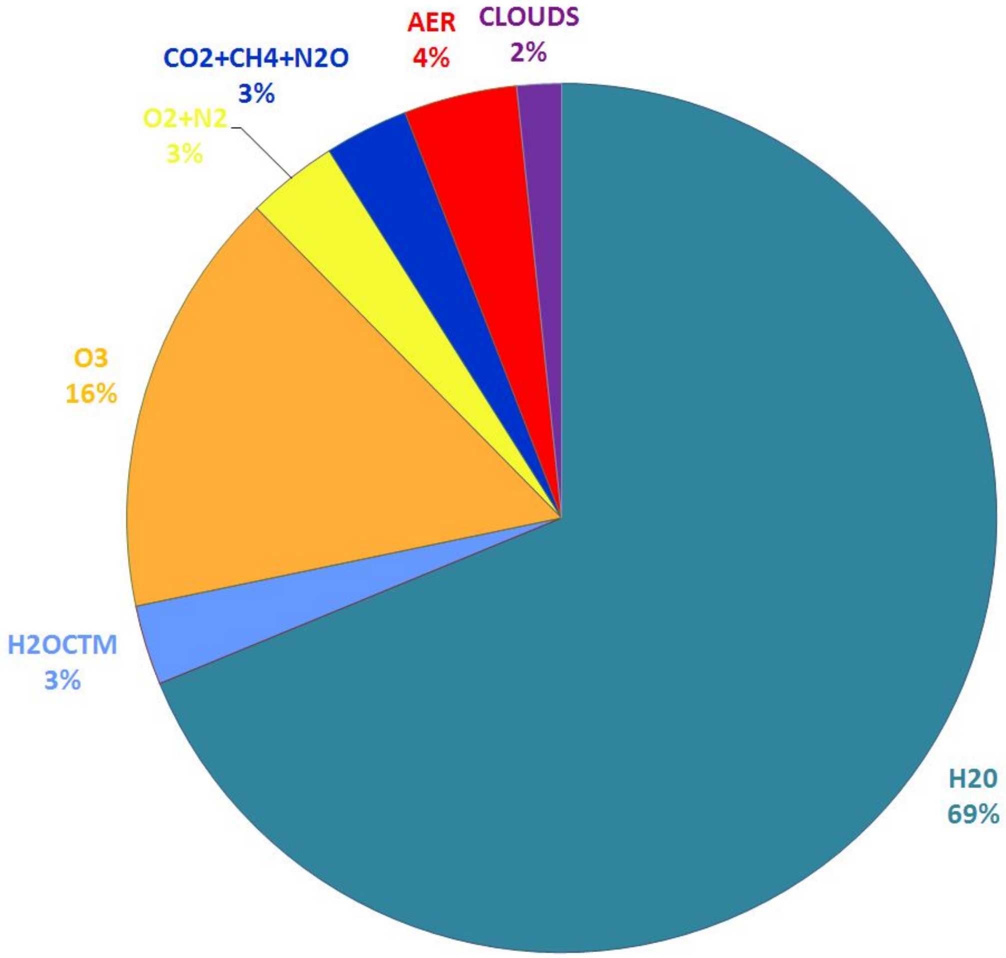
How we Calculate the Estimate:

- Greenhouse Gases (H_2O/H_2O ctm/CO_2/N_2O/CH_4/O_2/O_3) -HITRAN + Global Line-by-Line calculations using ERA Climatology (Paynter and Ramaswamy, 2013)
- Radiation Solver: DISORT, 4 stream Delta-Eddington
- Clouds and Aerosols, GFDL CM3/CM4 GCM



Infrared
Visible
UV
FLUX REACHING THE SURFACE
INCOMING SOLAR FLUX
Flux per Wavenumber, Wm-2/cm-1
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
wavenumber, cm-1


Water Vapor SWA with No Continuum
SWA due to BPS Continuum
A
B
10 15 20 25 30 35 40 45 50 55 60 65
0 0.4 0.8 1.2 1.6 2 2.4 2.8 3.2



Global Annual Mean Shortwave Absorption by Atmosphere

All-Sky

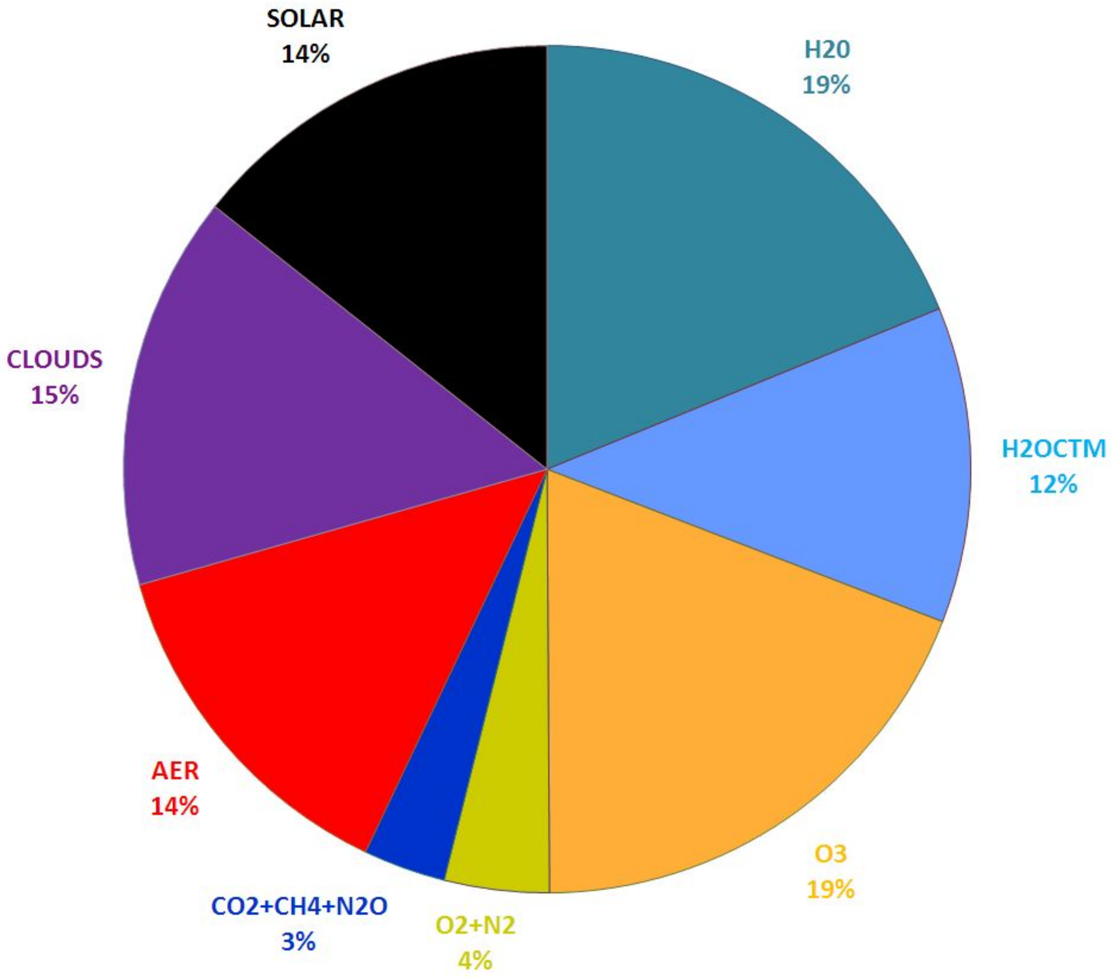
78.4 Wm^{-2}

23.1% of incoming solar radiation

Clear Sky

77.1 Wm^{-2}

22.7% of incoming solar radiation

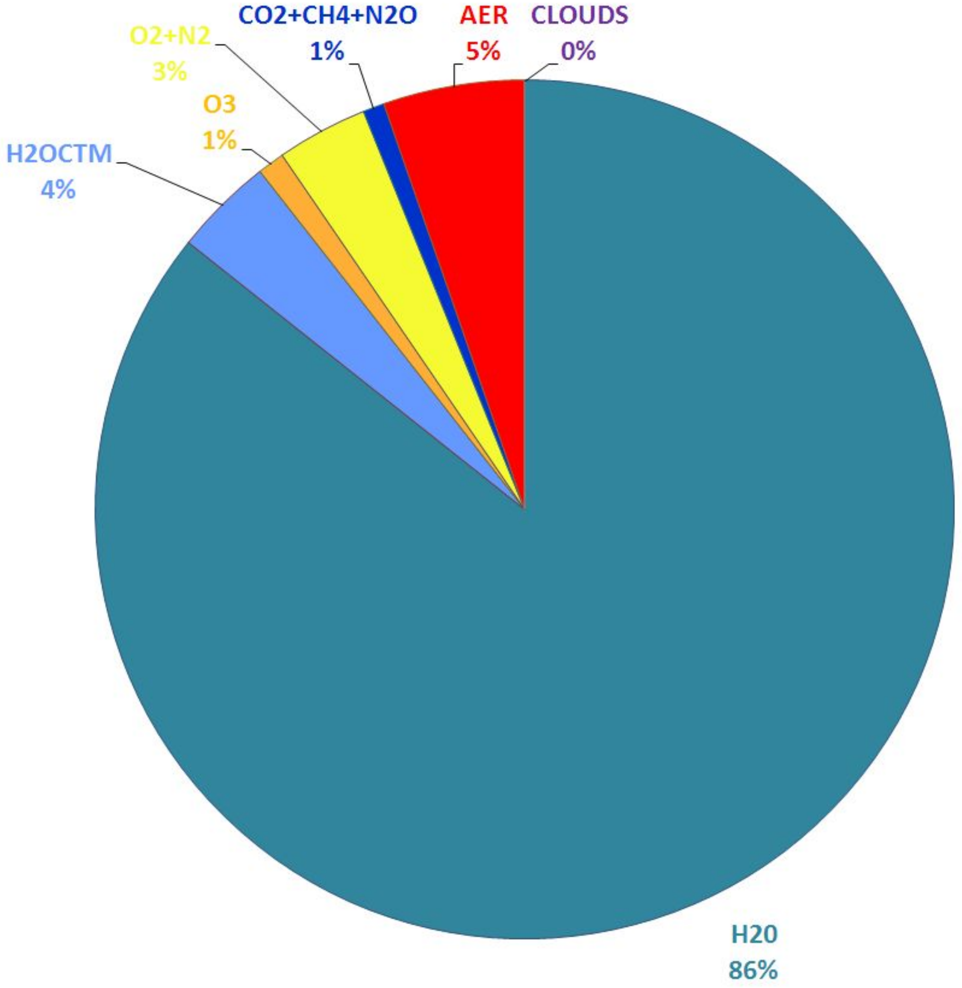


Uncertainty Global Annual Mean Shortwave Absorption by Atmosphere

All sky Uncertainty

±6.6 Wm^{-2}

RMSE = ±2.6 Wm^{-2}



Global Annual Mean Shortwave Absorption by Atmosphere: **TROPOSPHERE**

All-Sky

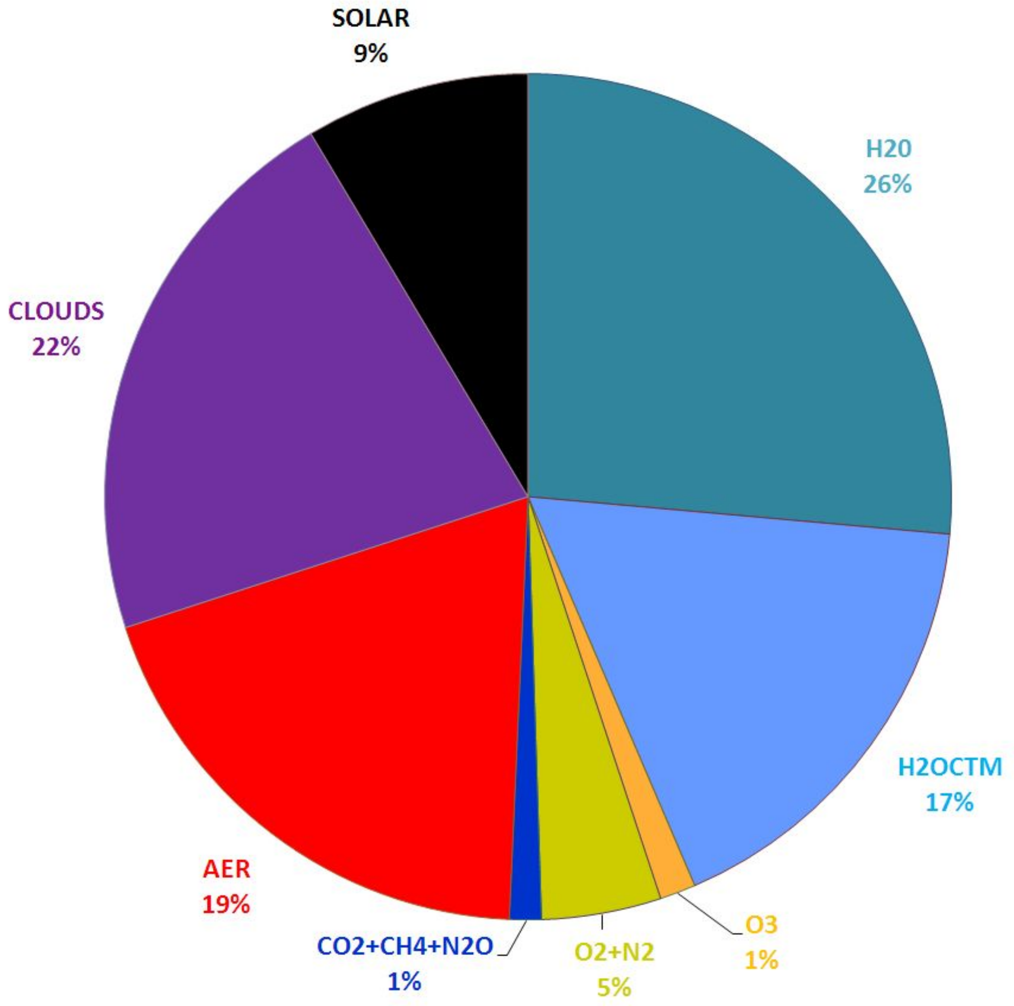
62.0 Wm^{-2}

18.2% of incoming solar radiation

Clear Sky

62.0 Wm^{-2}

18.2% of incoming solar radiation

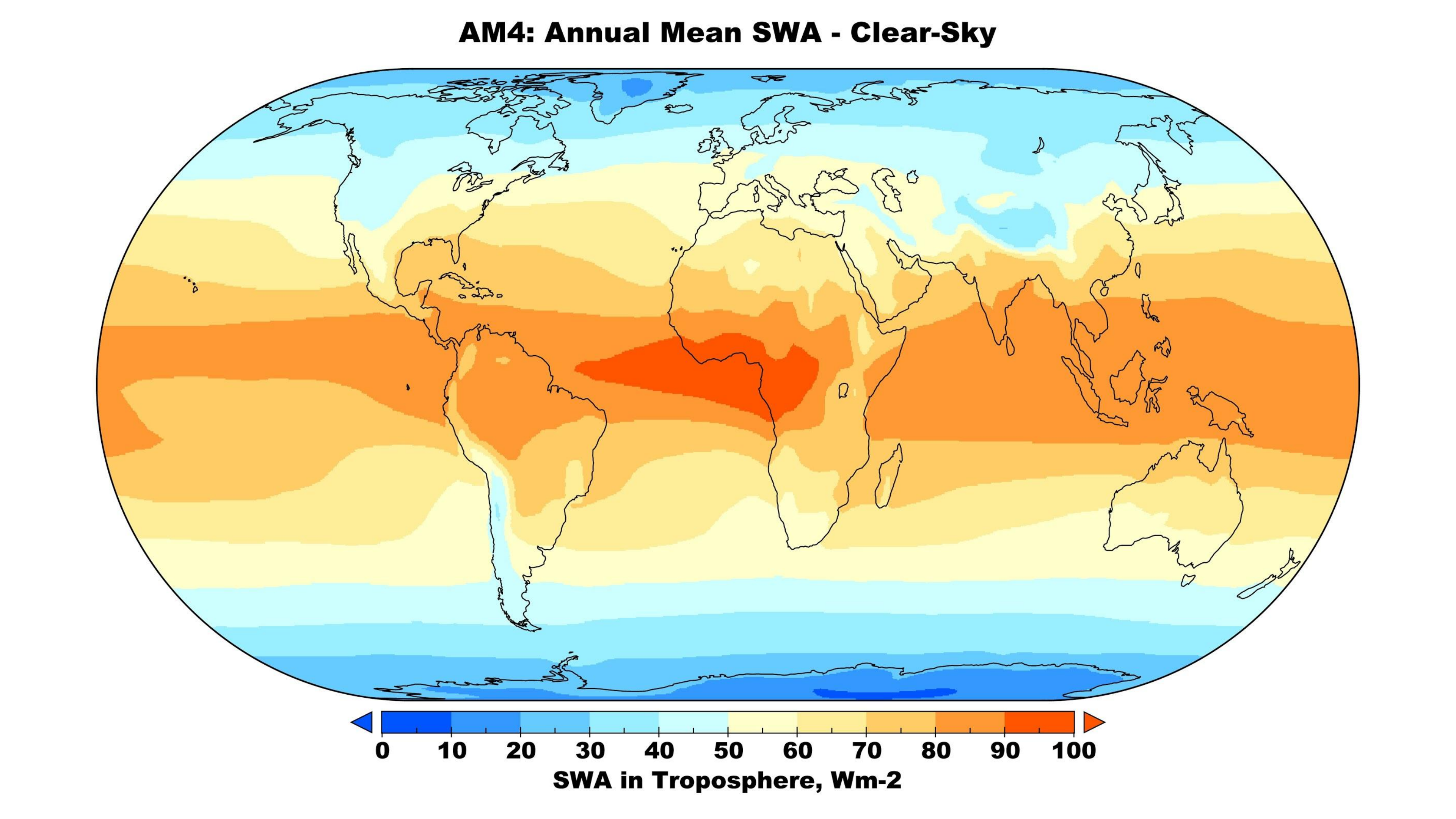


All sky Uncertainty

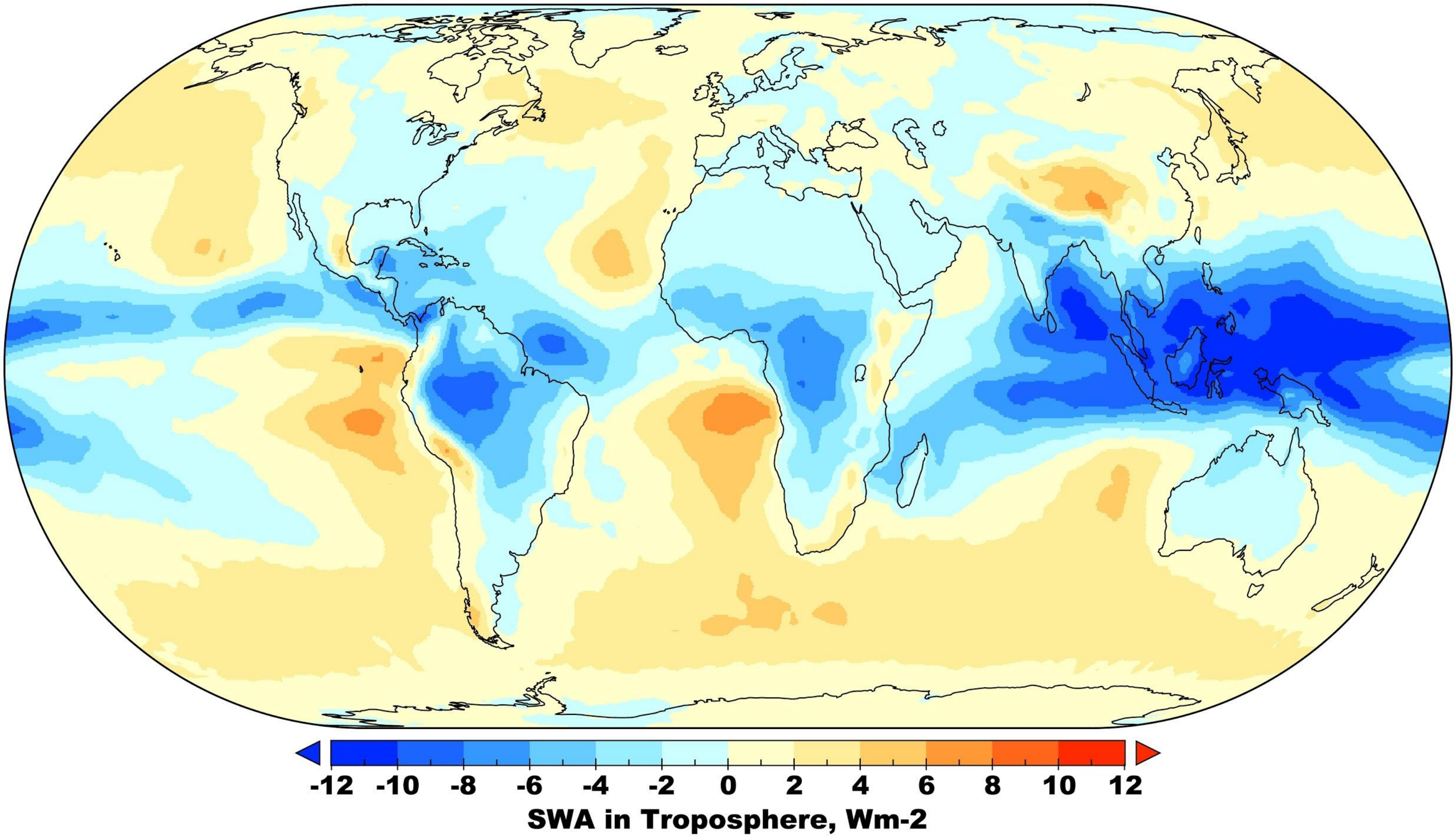
±4.7 Wm^{-2}

RMSE = ±2.0 Wm^{-2}

Uncertainty Global Annual Mean Shortwave Absorption by Atmosphere: **TROPOSPHERE**


AM4: Annual Mean SWA - Clear-Sky
0
10
20
30
40
50
60
70
80
90
100
SWA in Troposphere, Wm-2

AM4: Reduction in SWA due to Clouds

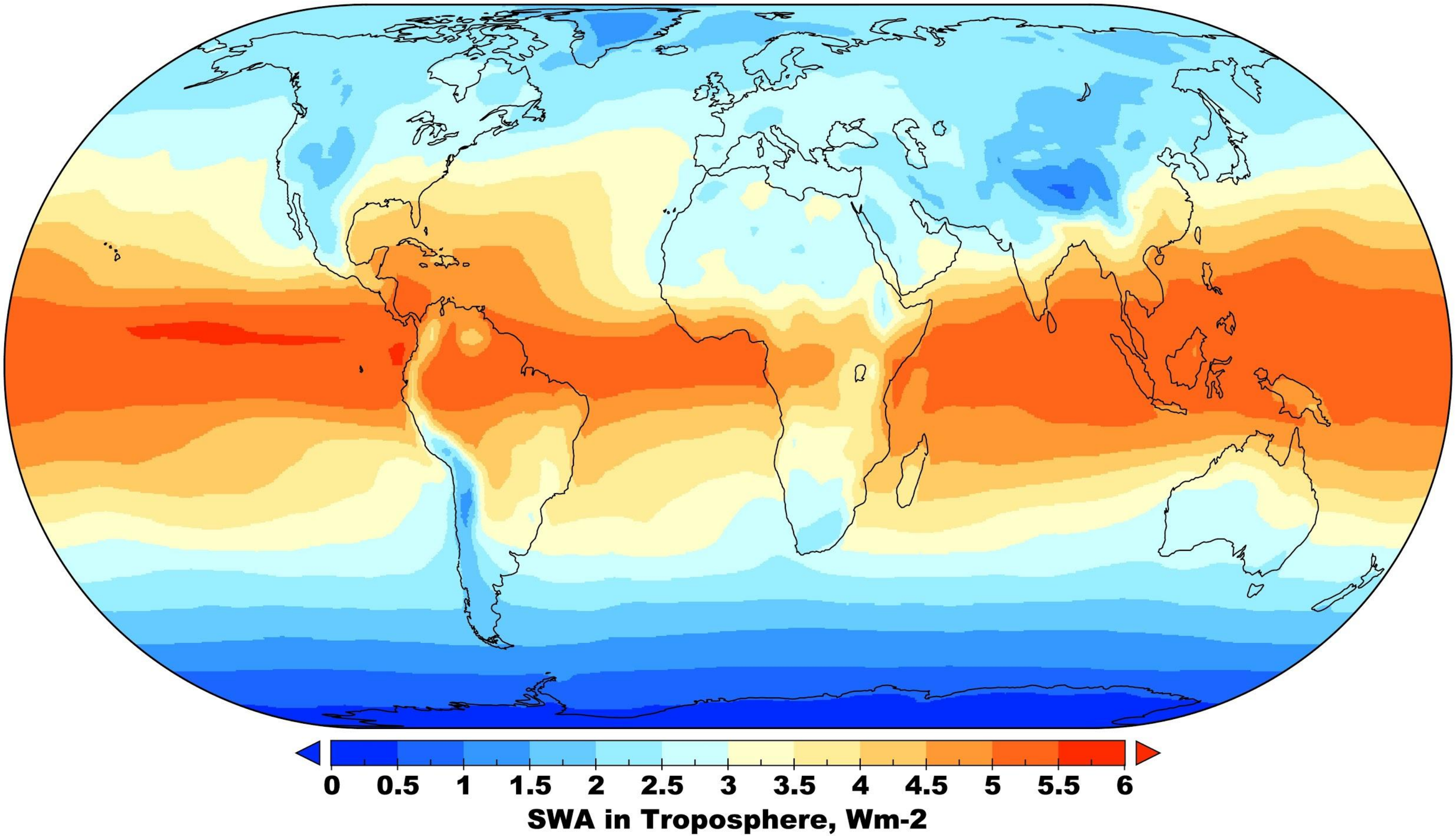


Updating the GFDL Shortwave Radiation Code

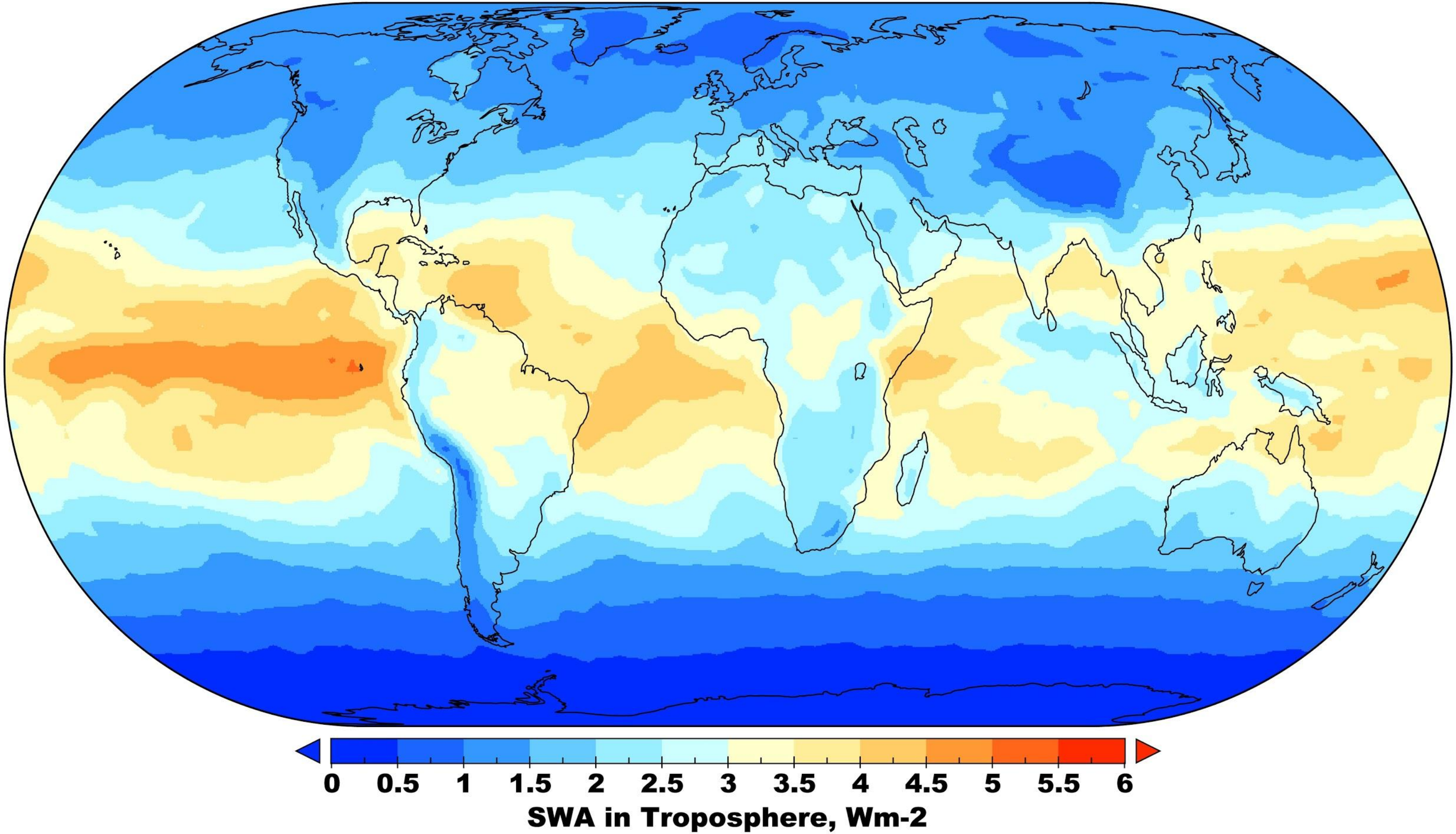
- GFDL CM3 radiation code was missing gas absorption by H2O Continuum, CH4, N2O, N2 and some O2 bands.
- Spectral properties for H2O, CO2 were from HITRAN 2000.
- For AM4 we have added in the above absorbers and updated spectral properties to HITRAN 2012: This Increased global average shortwave absorption:

All-Sky	AM3:	74.6 Wm^{-2}	AM4:	**77.4 Wm^{-2}**
Clear-Sky	AM3:	72.3 Wm^{-2}	AM4:	**76.0 Wm^{-2}**
Troposphere only				
All-Sky	AM3:	58.8 Wm^{-2}	AM4:	**61.1 Wm^{-2}**
Clear-Sky	AM3:	57.9 Wm^{-2}	AM4:	**61.1 Wm^{-2}**

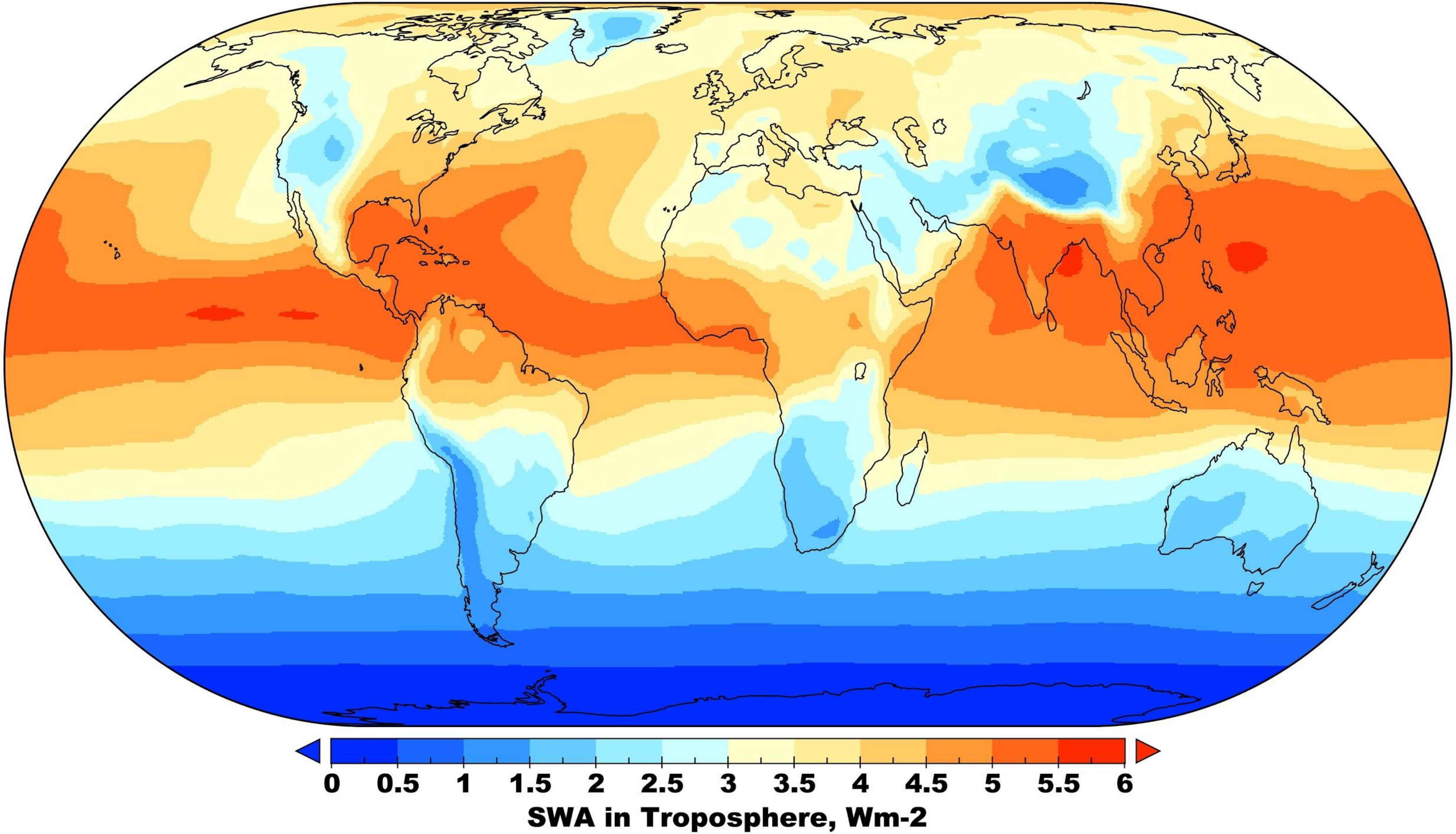
Radiation Code Update: MAM - Clear-Sky



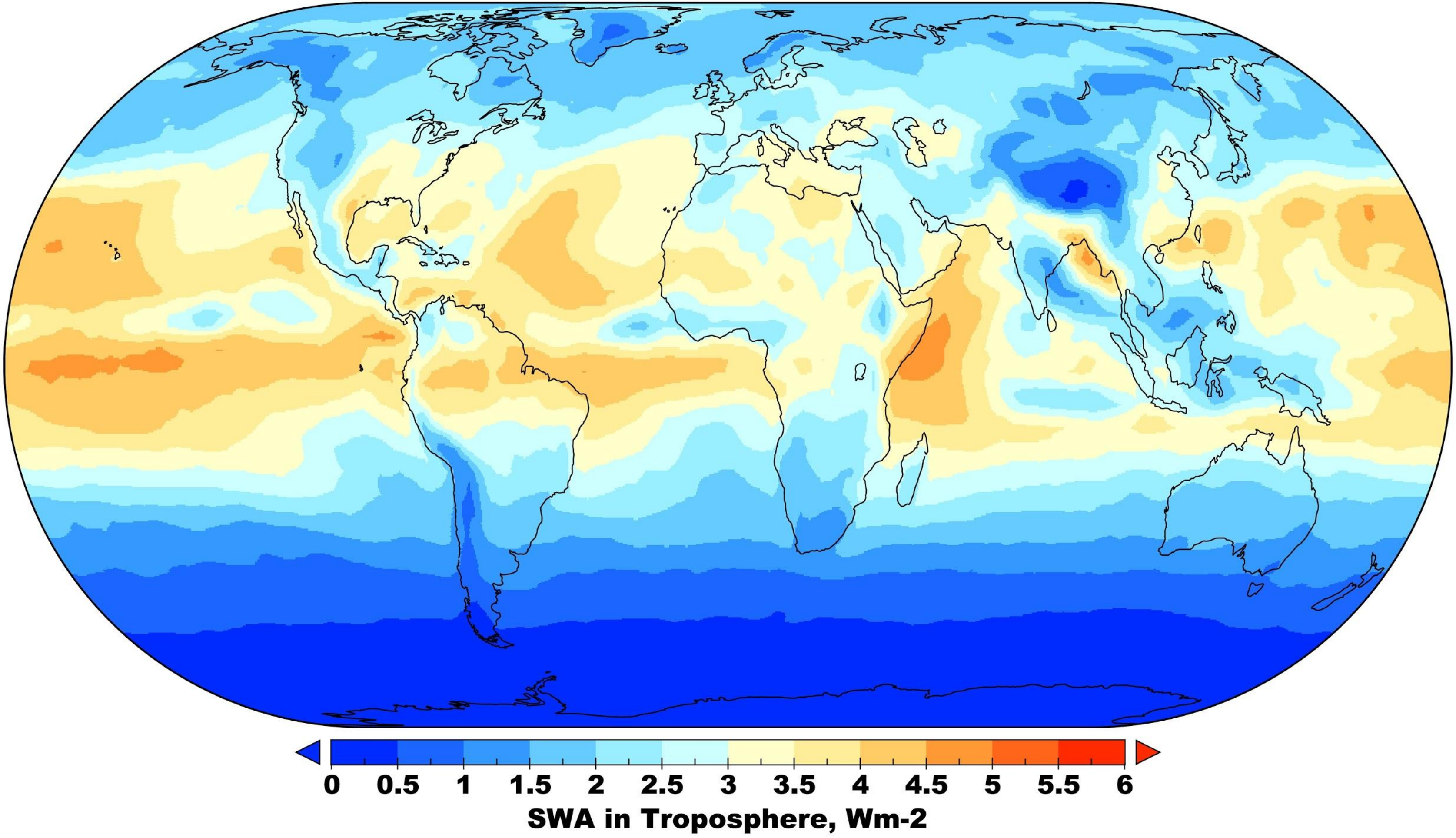
Radiation Code Update: MAM - All-Sky



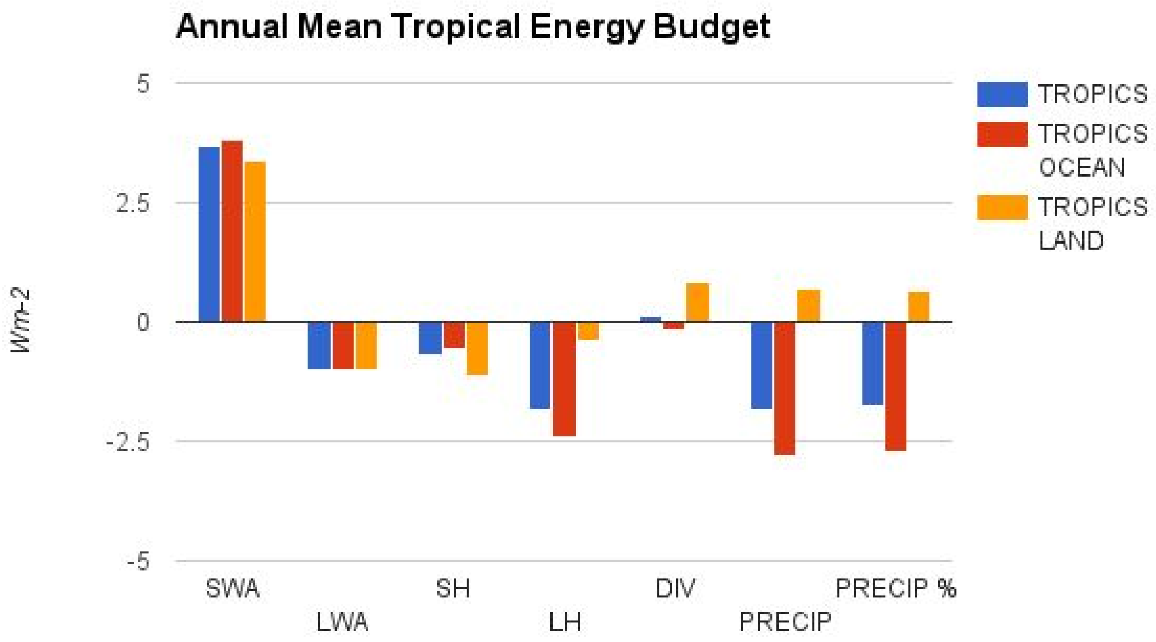
Radiation Code Update: JJA - Clear-Sky



Radiation Code Update: JJA - All-Sky



Impact of Radiation Code Update on GCM Precipitation: Tropical Average



- Around 30% of SWA is balanced by decrease in LWA.
- Over Ocean LH decreases, largely matched by decrease in precipitation.
- Over Land, small LH change and bigger DIV change drives a small increase in precipitation

Key

SWA =Shortwave absorption by atmosphere
LWA = Longwave absorption by atmosphere
LH = Latent Heat Flux
SH = Sensible Heat Flux
DIV =Flux out of region
PRECIP = Precipitation, Wm-2
PRECIP % = Precipitation change as percent of climatology.

Updates to the GFDL Longwave Radiation Code for AM4

- Updated all Band Coefficients to HITRAN 2012
- Updated H_2O Continuum from CKD2.1 to MT_CKD 2.5
- Added in CO_2 lines at greater than 800 cm^{-1}

Impact upon climatology of updates is quite modest, Increase OLR and SDR by 0.7 Wm^{-2}

However radiative forcing due to the 4 times CO_2 is now 10% stronger!

The Future of Benchmarking Radiative Codes

Traditionally Radiation Code Intercomparisons have involved testing radiation codes on idealized single column atmospheres. This method has several drawbacks:

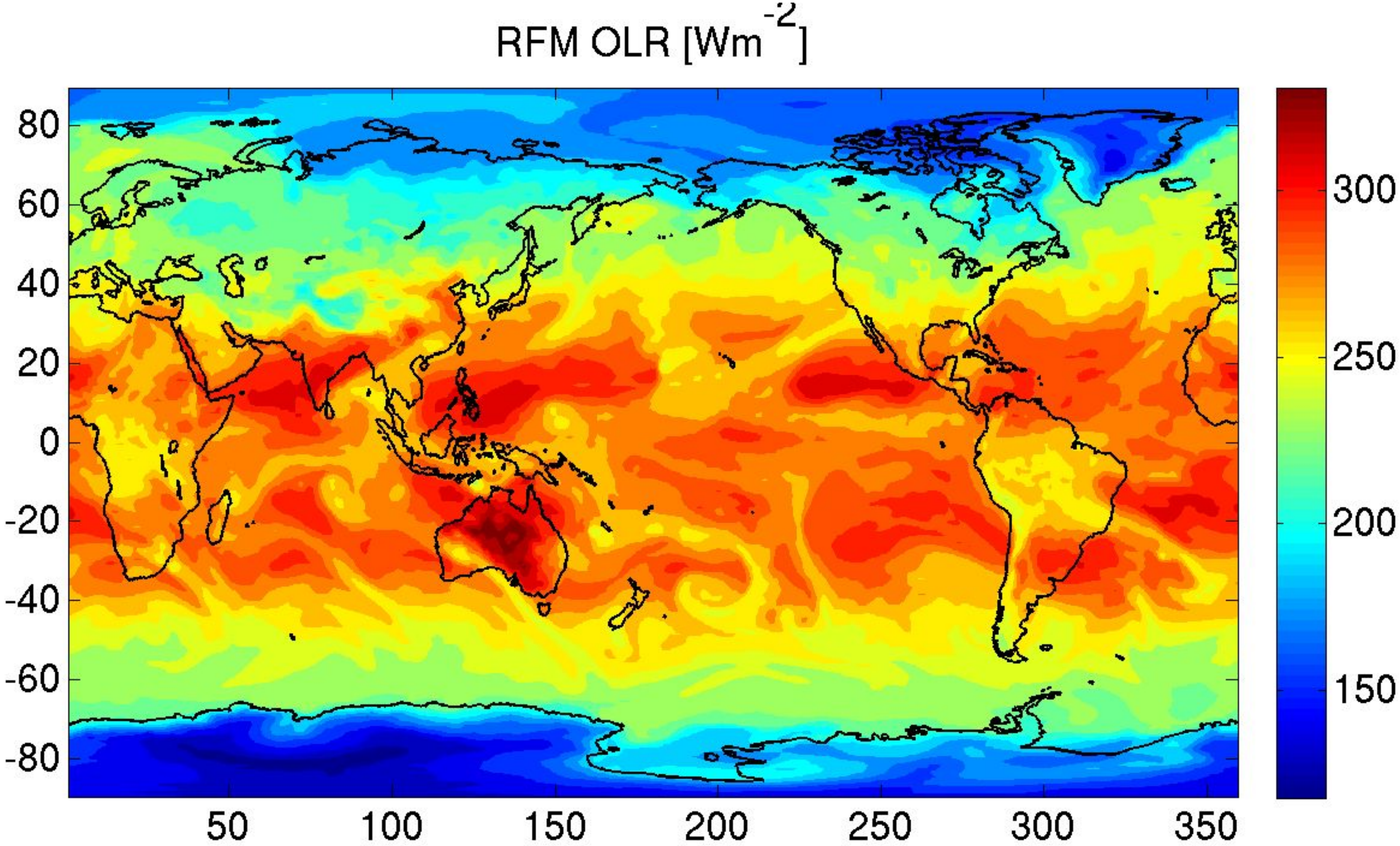
1) It only tests the radiation code over a small subset of atmospheres and misses extreme cases
2) It does not allow for easy understanding of how errors in the radiation code impact both regional and global climate.
3) Creates difficulty in communicating the accuracy of radiation codes to the wider community.

Global LBL Benchmarking

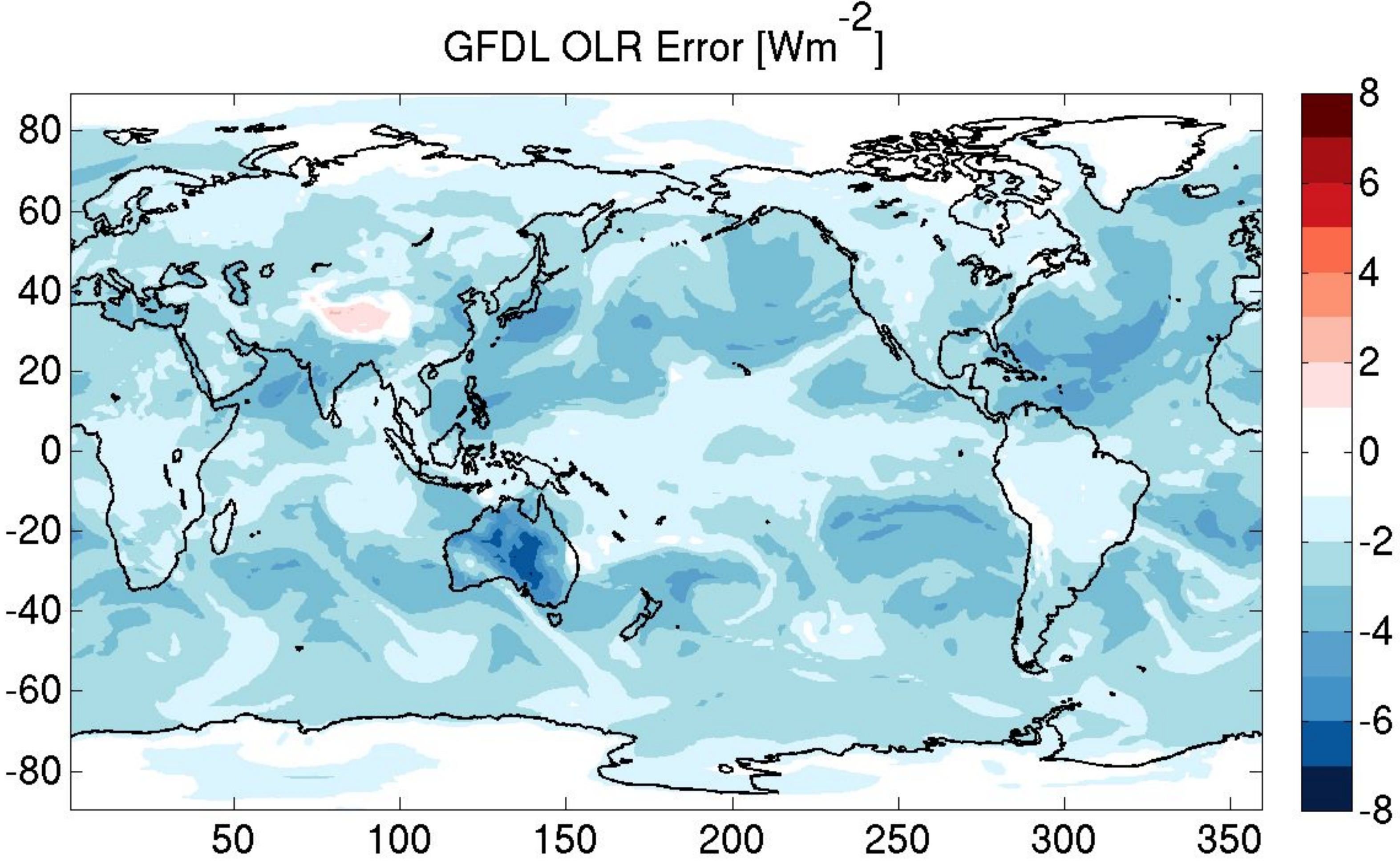
- Previously it was too computationally expensive to run a Line-by-Line (LBL) radiation code on a GCM model grid.
- However, with increased computational power this is no longer an obstacle

How we perform the calculations:

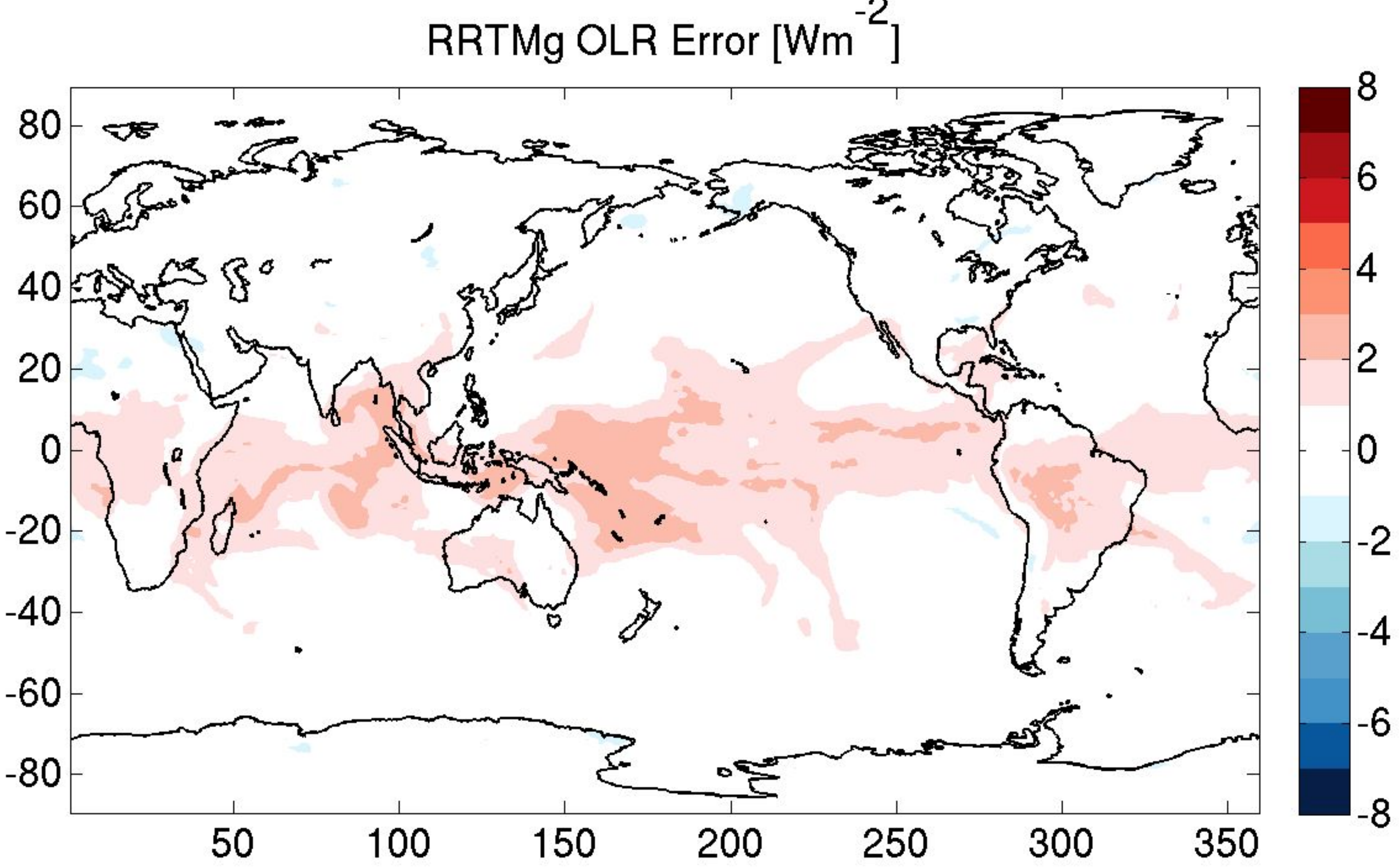
1) Take the GCM meteorology at a single-timestep and run it through the RFM LBL radiation code and RRTMG band model (that is used in many GCM radiation codes).
2) Compare the results to output from the GFDL radiation code at the same timestep



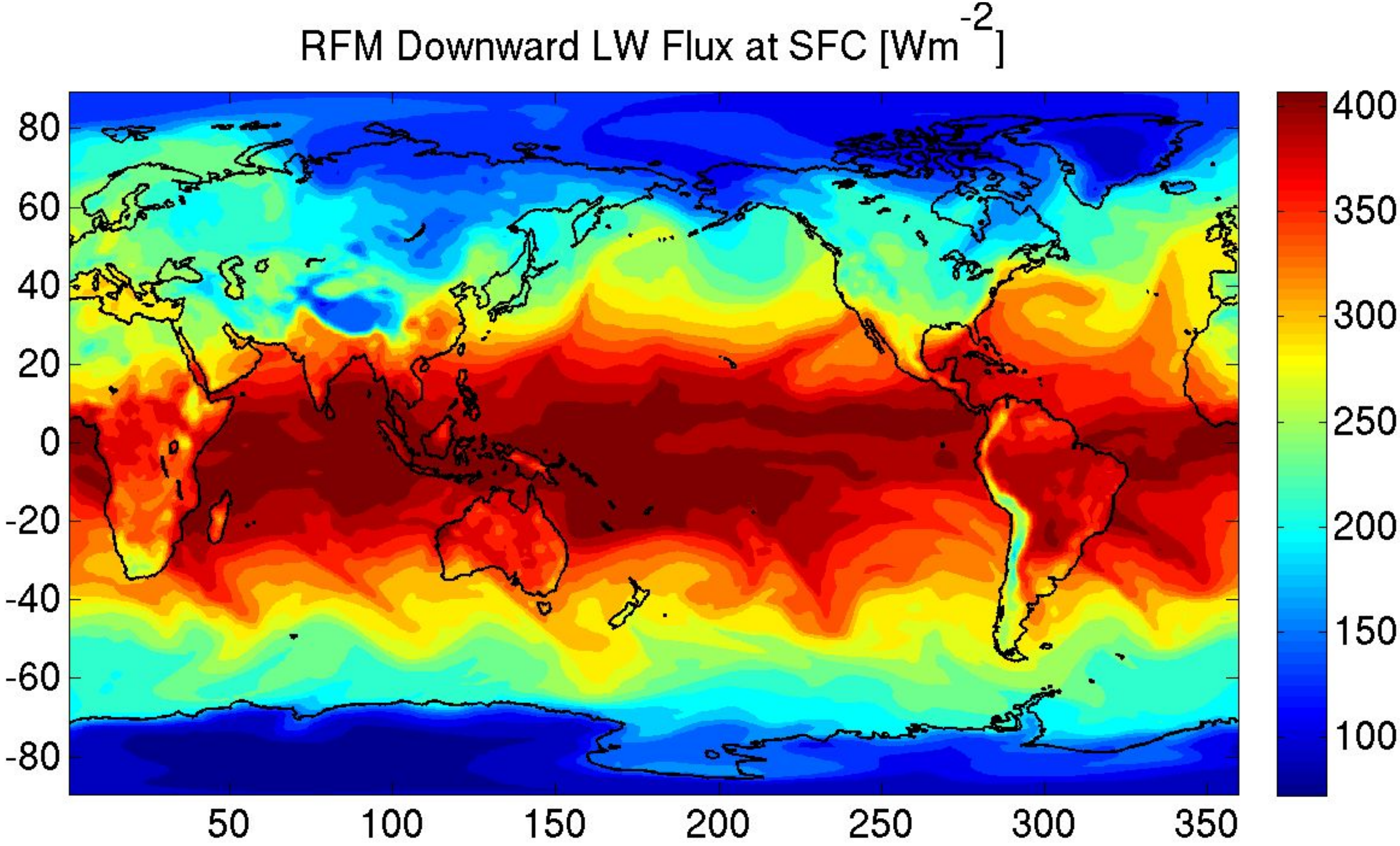
LBL calculation of Clear-Sky OLR for 22nd March at 0:30 GMT **Global Mean: 262.0 Wm^{-2}**



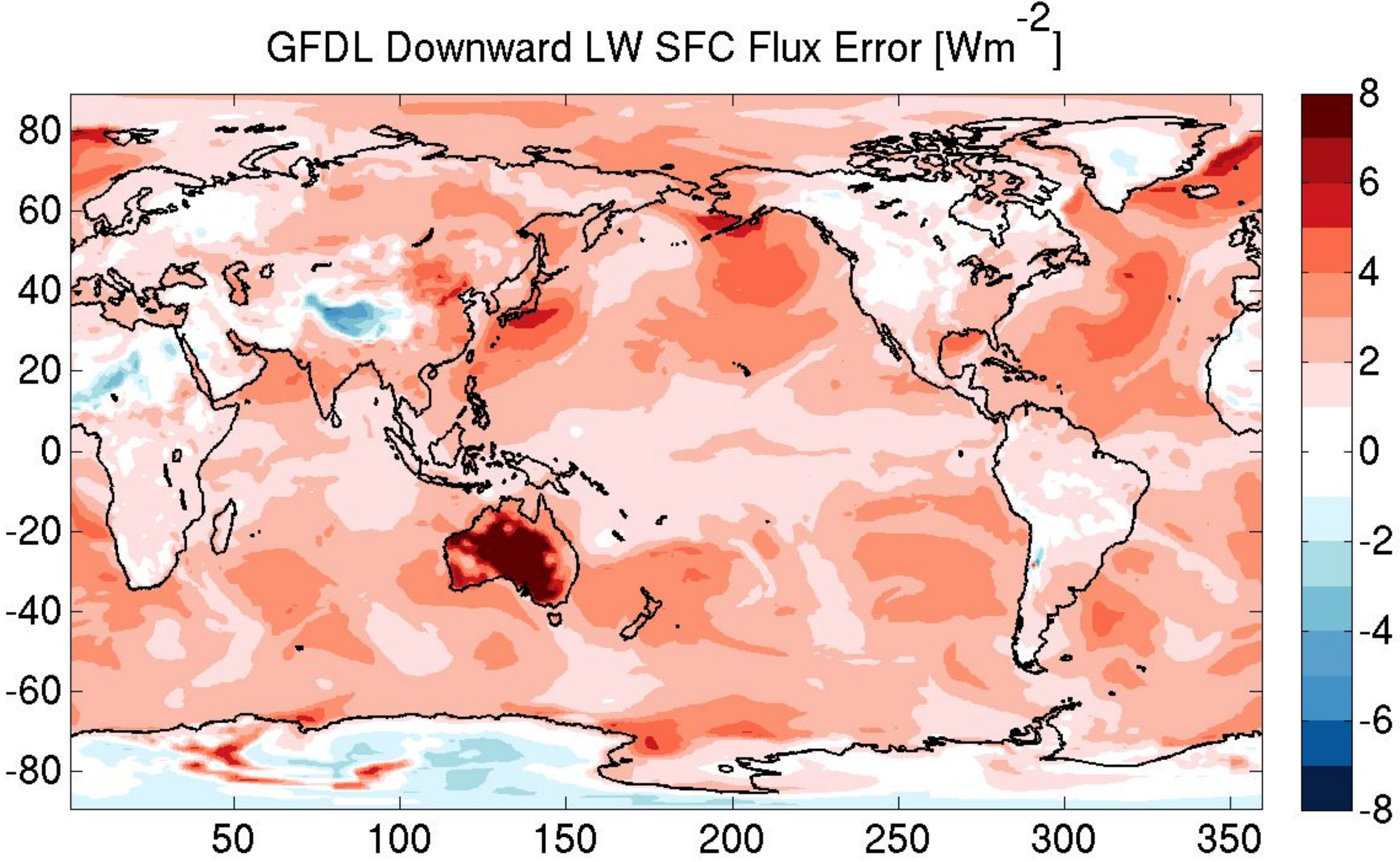
Error in GFDL calculation of Clear-Sky OLR for 22nd March at 0:30 GMT **Global Mean: -2.0 Wm^{-2}**



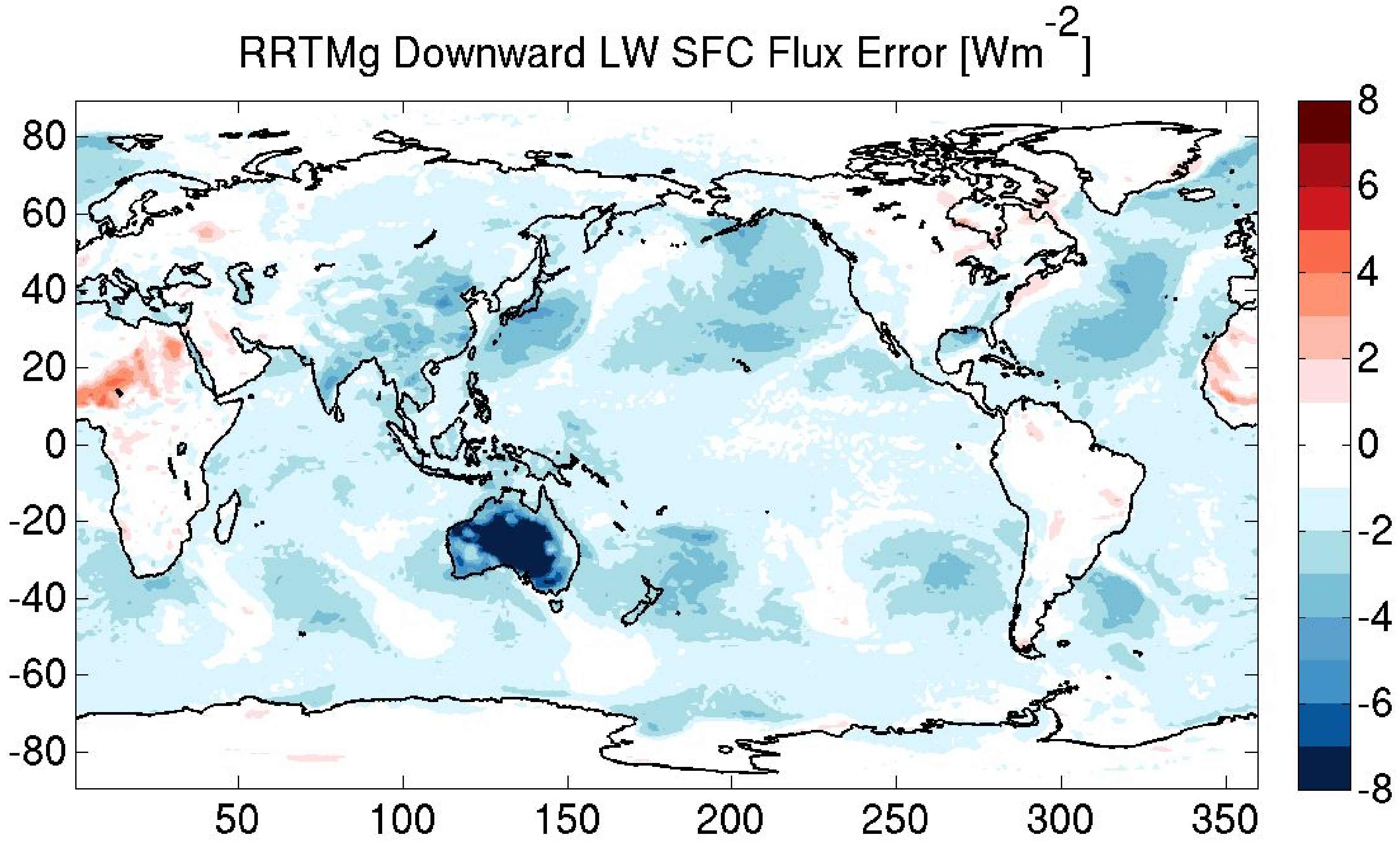
Error in RRTMG calculation of Clear-Sky OLR for 22nd March at 0:30 GMT **Global Mean: 1.0 Wm^{-2}**



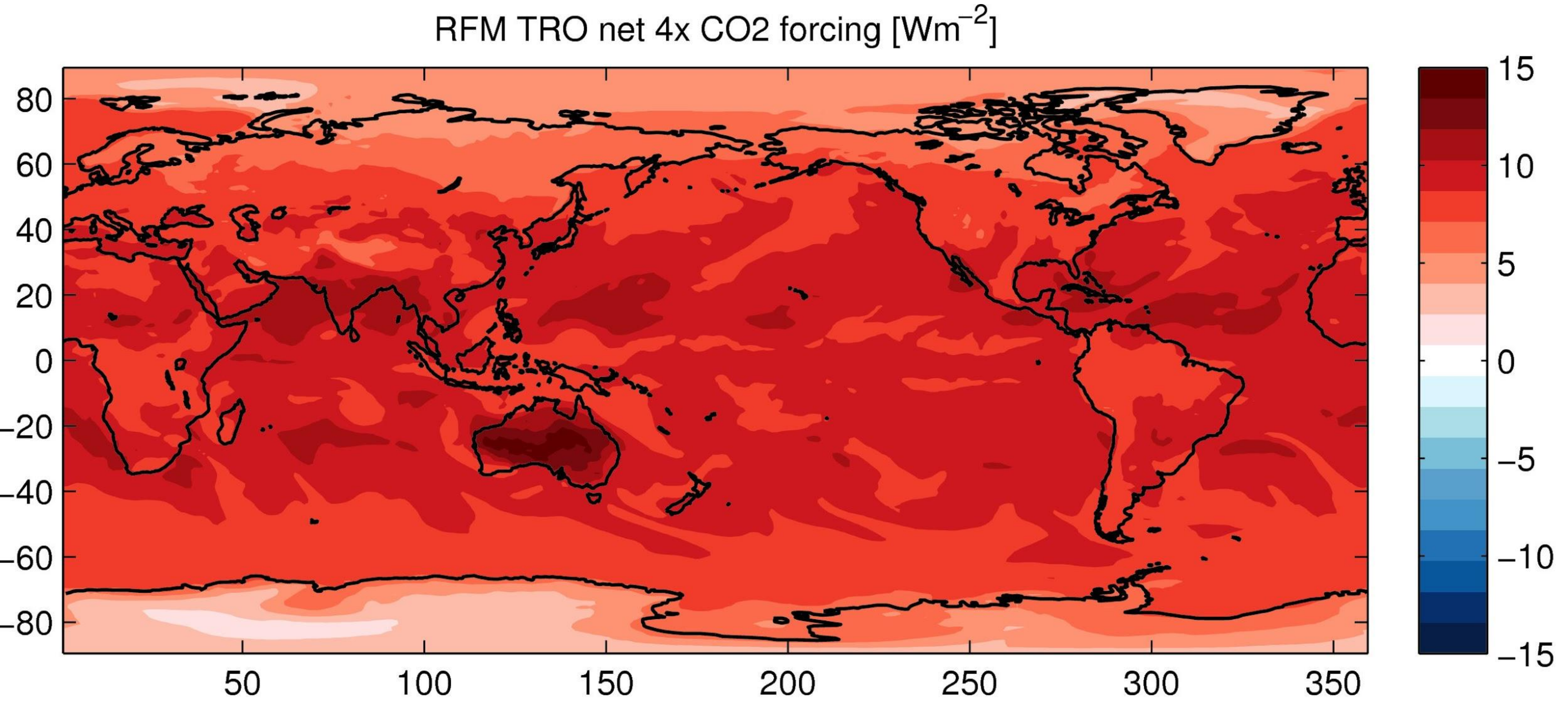
LBL calculation of Clear-Sky LWDN for 22nd March at 0:30 GMT **Global Mean: 309.9 Wm^{-2}**



Error in GFDL calculation of Clear-Sky LWDN for 22nd March at 0:30 GMT **Global Mean: 1.6 Wm^{-2}**

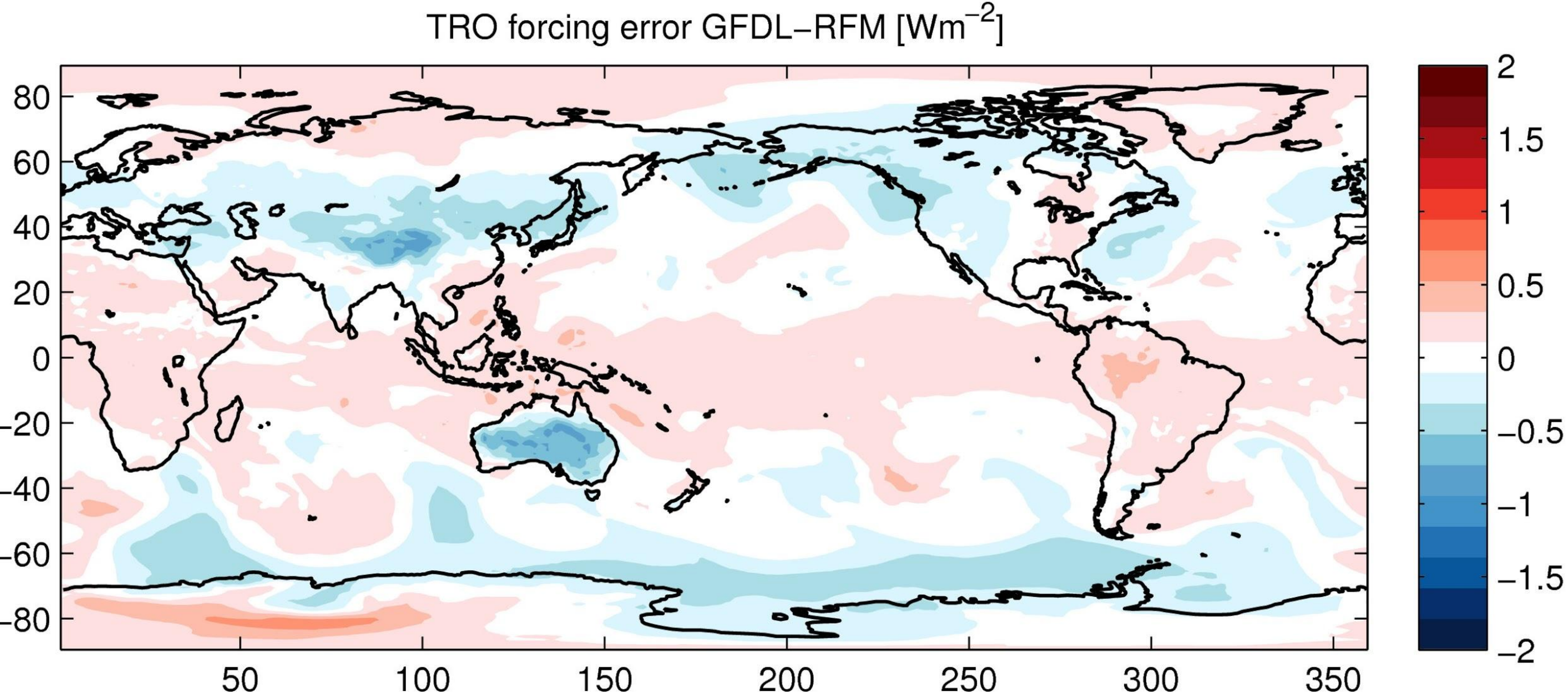


Error in RRTMG calculation of Clear-Sky LWDN for 22nd March at 0:30 GMT **Global Mean: -1.0 Wm^{-2}**



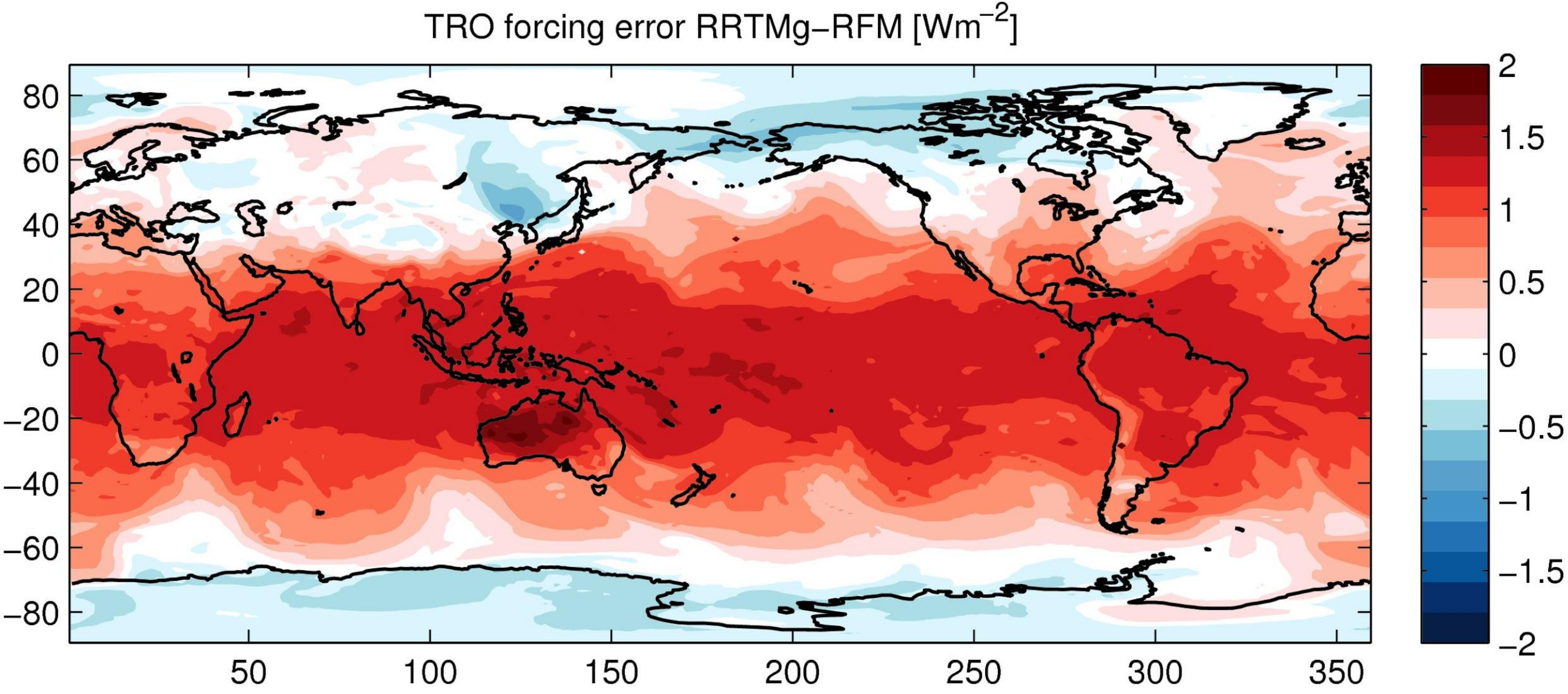
Global Mean: 10.1 Wm^{-2}

LBL calculation of Clear-Sky 4xCO2 Tropopause Forcing for 22nd March at 0:30 GMT



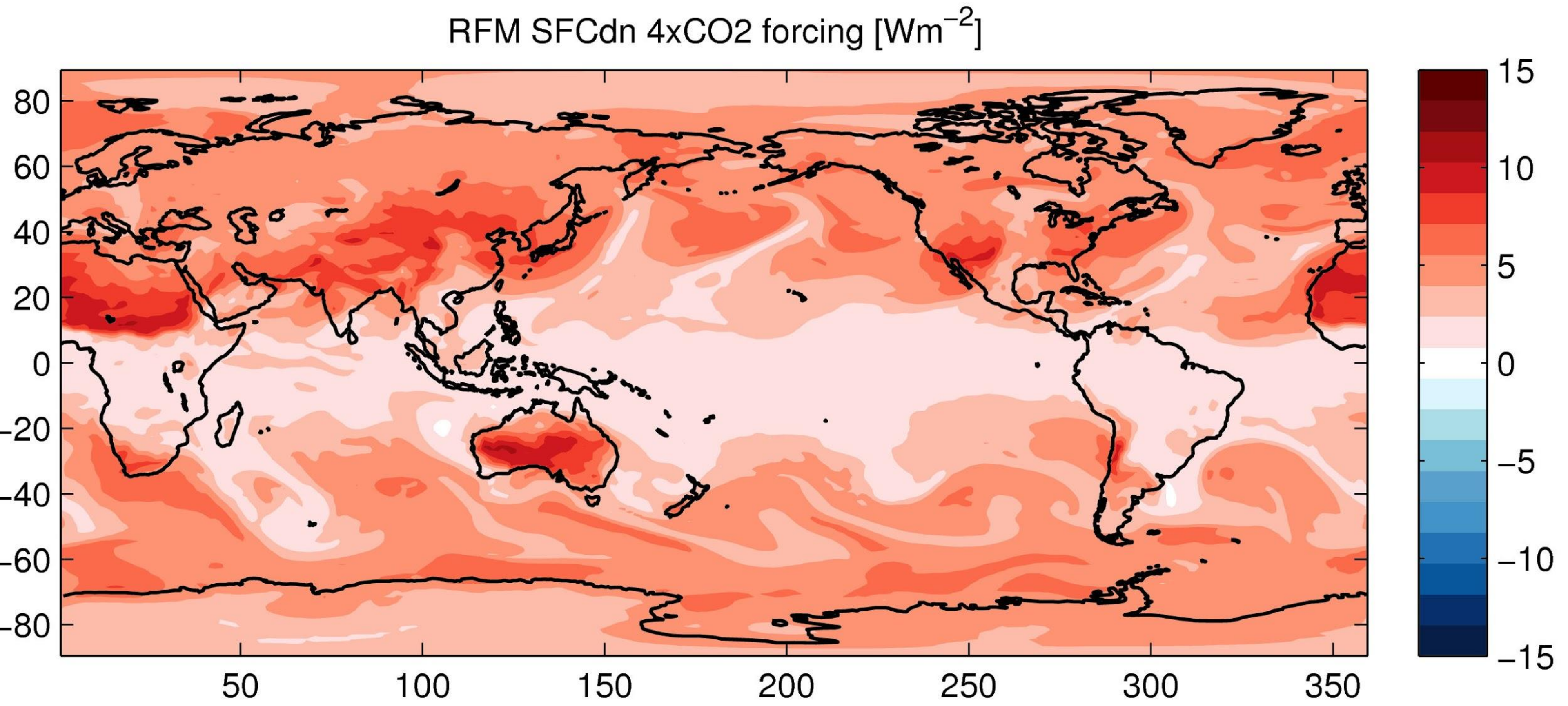
Global Mean: 0.1 Wm^{-2}

Error in GFDL calculation of Clear-Sky 4xCO2 Tropopause Forcing for 22nd March at 0:30 GMT



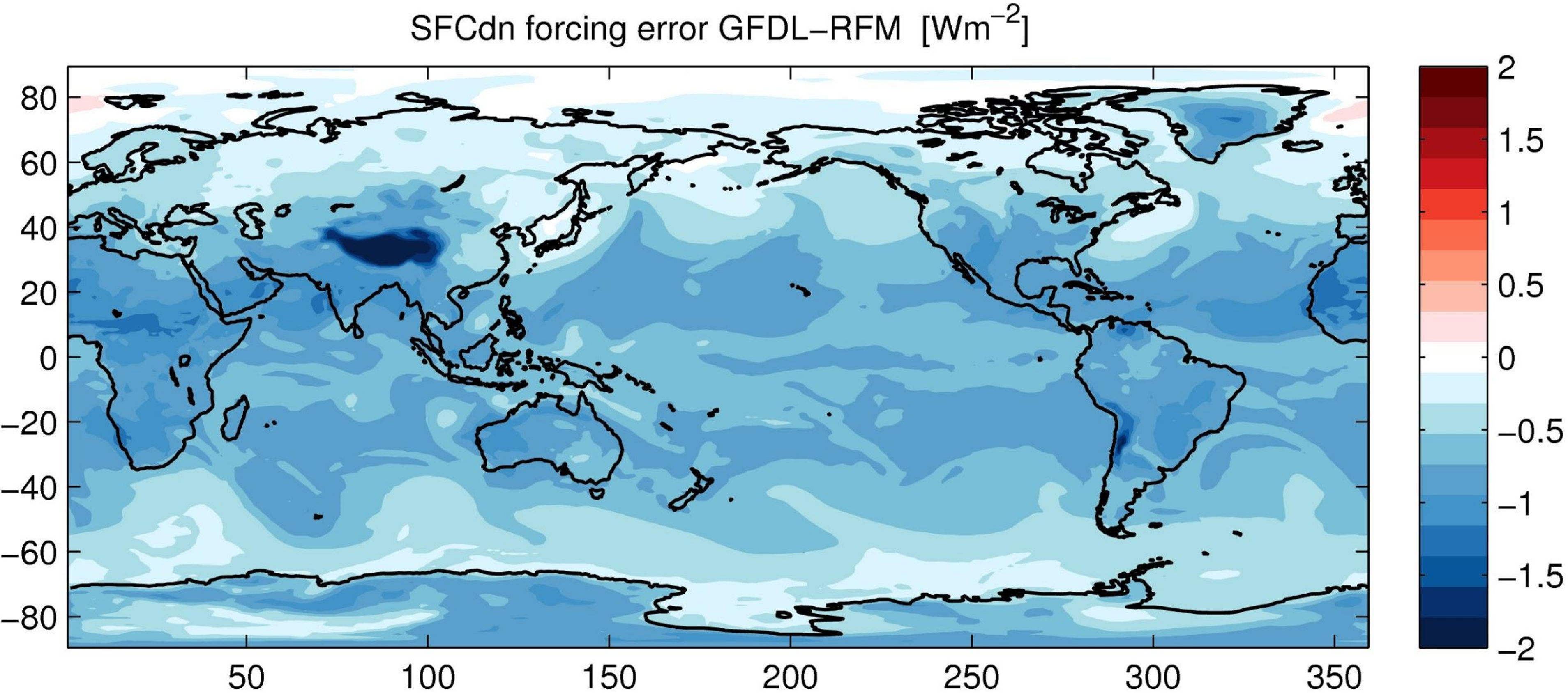
Global Mean: 0.9 Wm^{-2}

Error in RRTMG calculation of Clear-Sky $4xCO_2$ Tropopause Forcing for 22nd March at 0:30 GMT



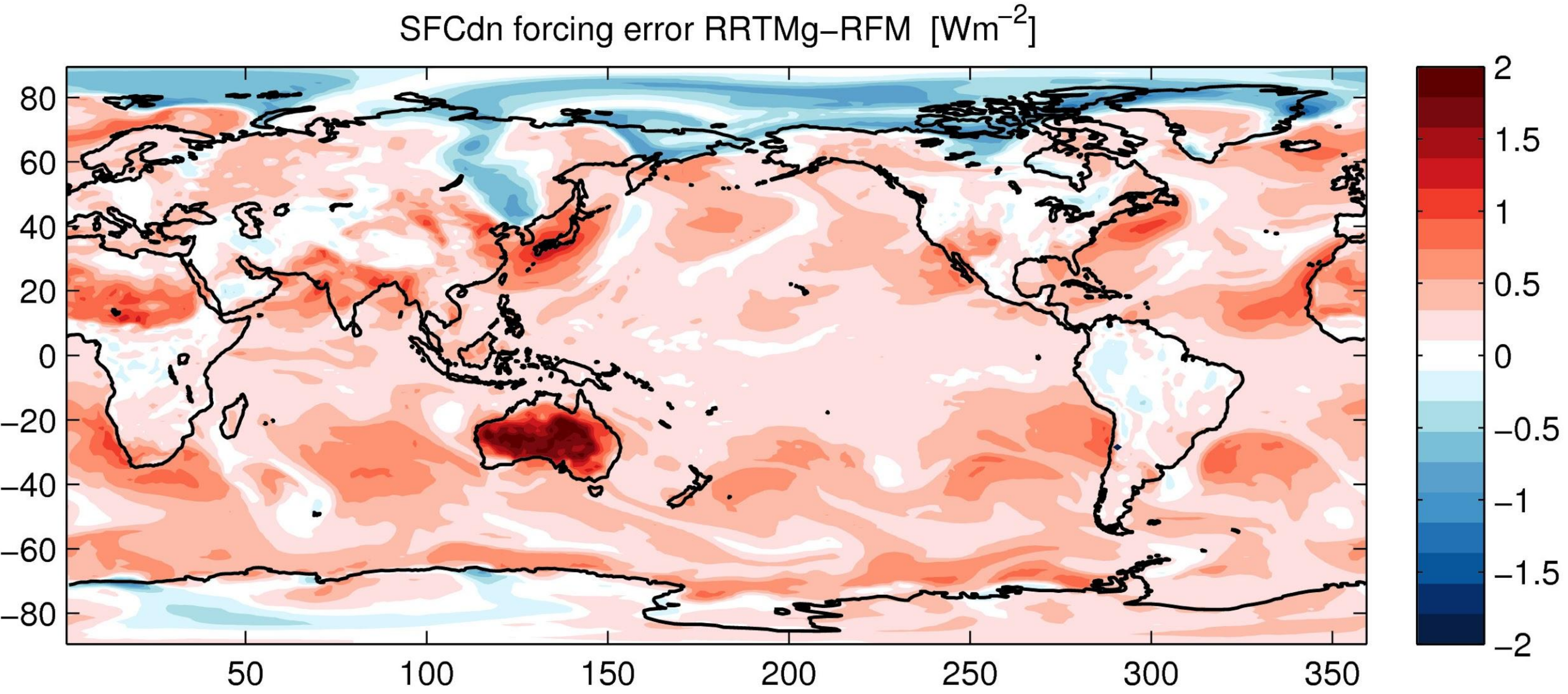
Global Mean: 4.9 Wm^{-2}

LBL calculation of Clear-Sky 4xCO2 Surface Forcing for 22nd March at 0:30 GMT



Global Mean: -0.6 Wm^{-2}

Error in GFDL calculation of Clear-Sky 4xCO_2 Tropopause Forcing for 22nd March at 0:30 GMT

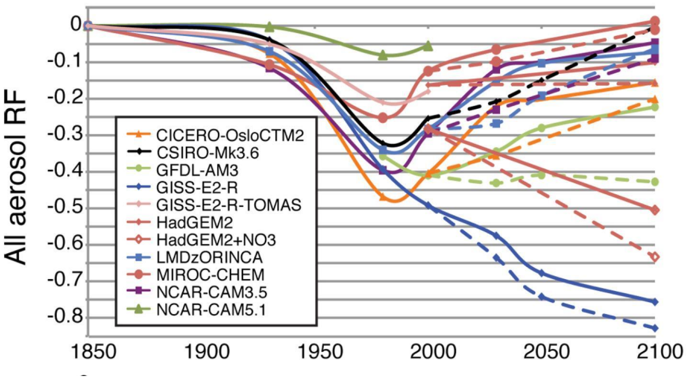


Global Mean: 0.4 Wm^{-2}

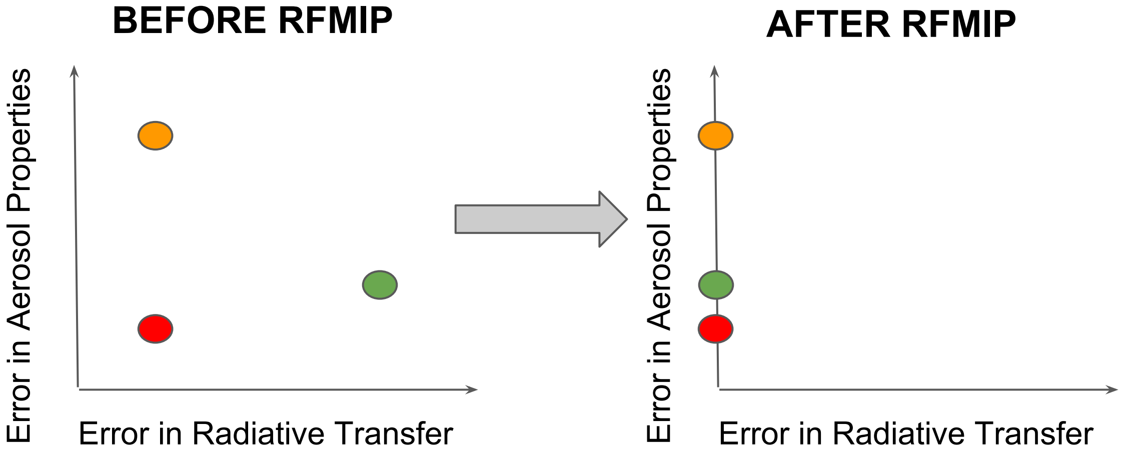
Error in RRTMG calculation of Clear-Sky 4xCO_2 SFC Forcing for 22nd March at 0:30 GMT

RFMIP - Aerosol Component

- Spread in direct aerosol forcing can be split into two causes: Differences in aerosol optical properties or differences in the radiative code solver.
- For RFMIP, we will take the aerosol optical properties of each participating GCM and run them through a LBL radiation code.
- This results in a benchmark aerosol radiative forcing value for each model.



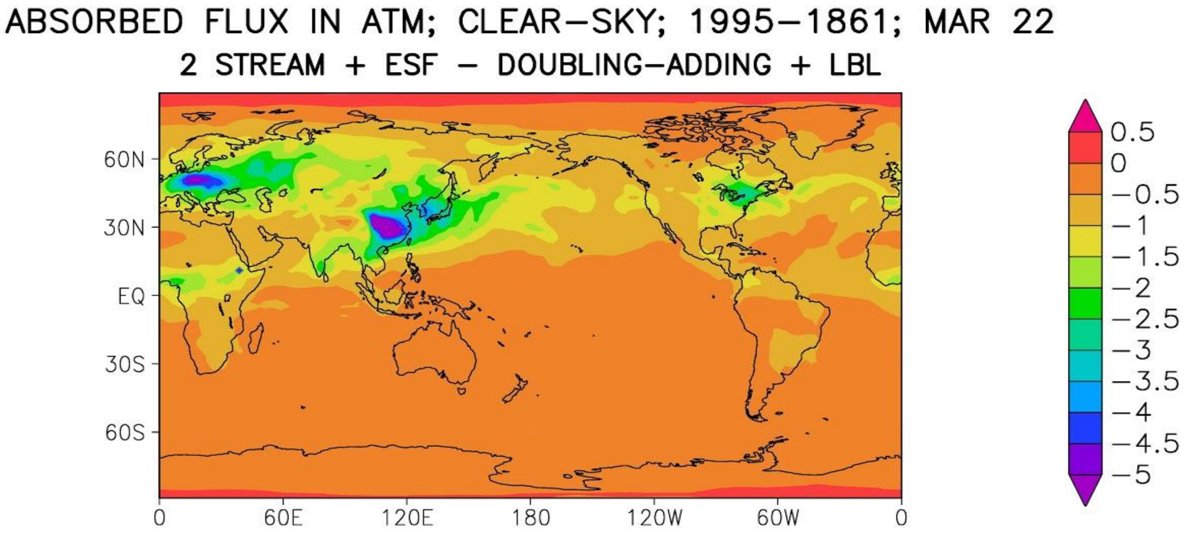
D. T. Shindell et al.: Radiative forcing in the ACCMIP historical and future climate simulations
2013



Initial Results…..

Have tested the protocol using GFDL CM3.

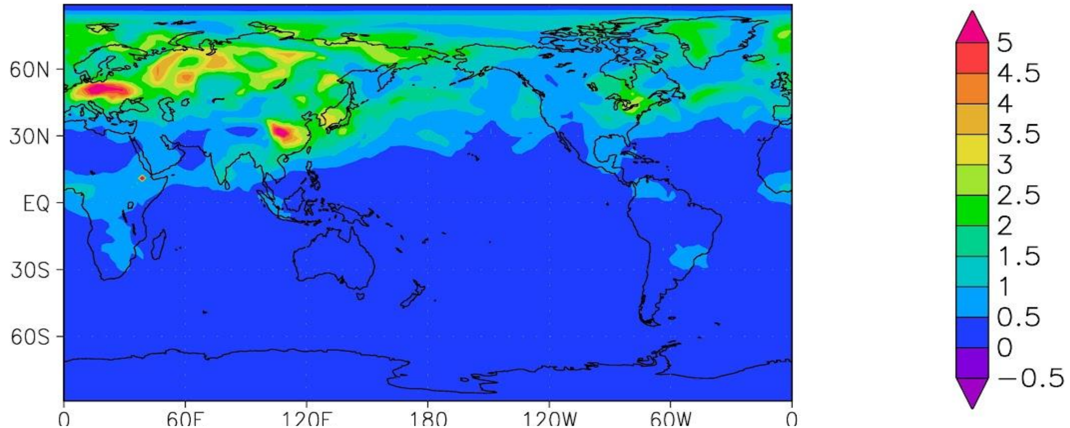
The initial results suggests that the GFDL radiation code underestimates the absorption by aerosol. Implies that too much energy is reaching surface



Global Mean Error in Aerosol Absorption is **-0.8 Wm-2, 25% of the total forced absorption**

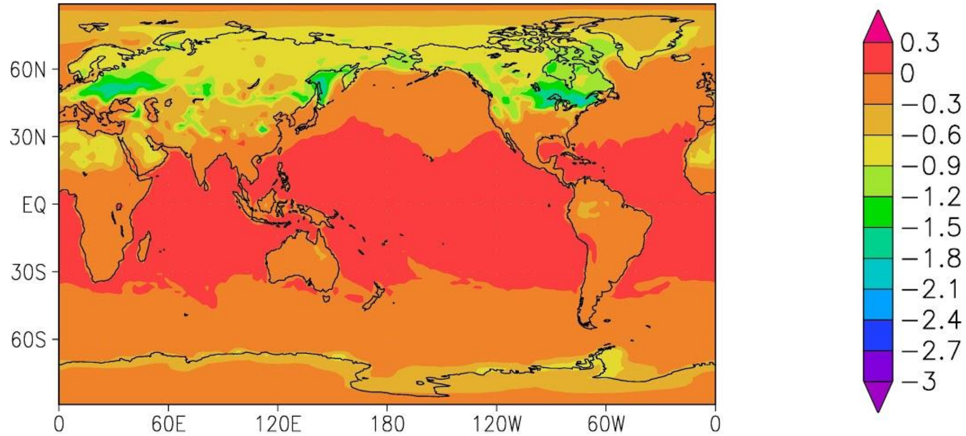
DOWNWARD FLUX AT SFC; CLEAR–SKY; 1995–1861; MAR 22

2 STREAM + ESF – DOUBLING–ADDING + LBL



UPWARD FLUX AT TOA; CLEAR–SKY; NO AEROSOL; MAR22

2 STREAM+ESF – DOUBLING–ADDING+LBL



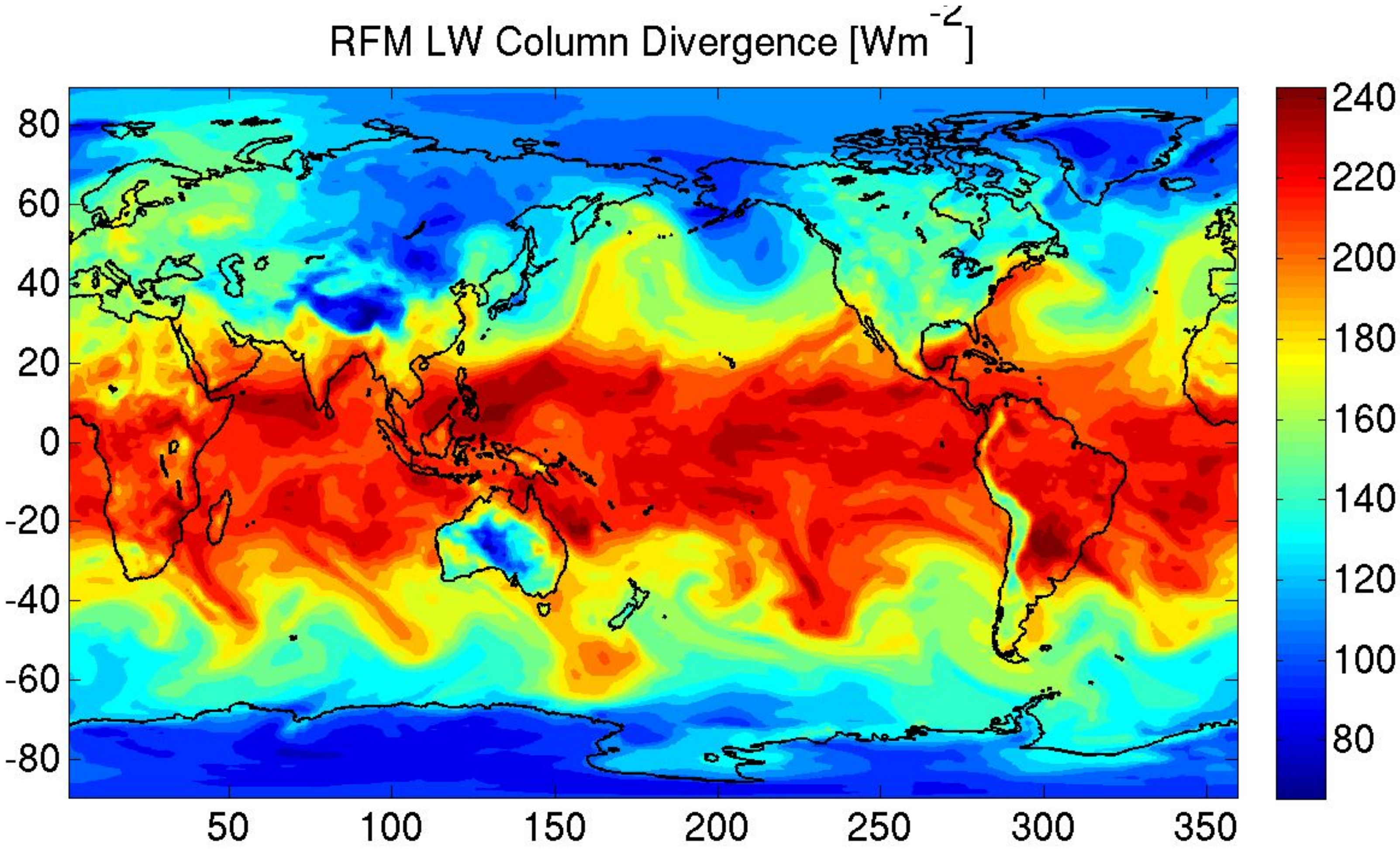
Conclusions

Shortwave:

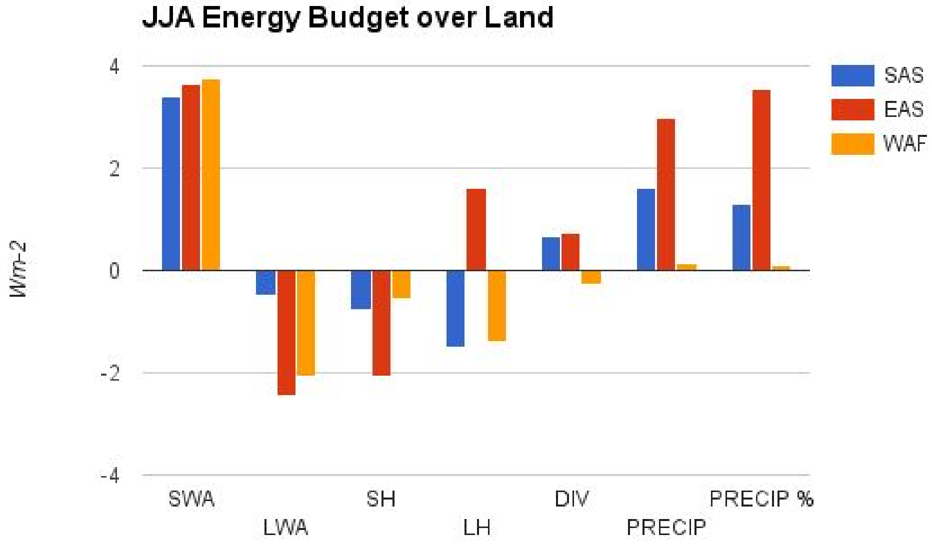
- We estimate Shortwave Absorption by the atmosphere of 78.4 ± 5.2 Wm^{-2}.
- No leading causes of uncertainty, increasing accuracy a matter of improved understanding of each contributor
- Any GCM with a value of less than 75 Wm^{-2} either has no absorbing aerosol or is missing out some minor absorbing species. We increased SWA by ~3 Wm^{-2} though adding the H2O continuum, CH4, N2O and additional O2 bands.

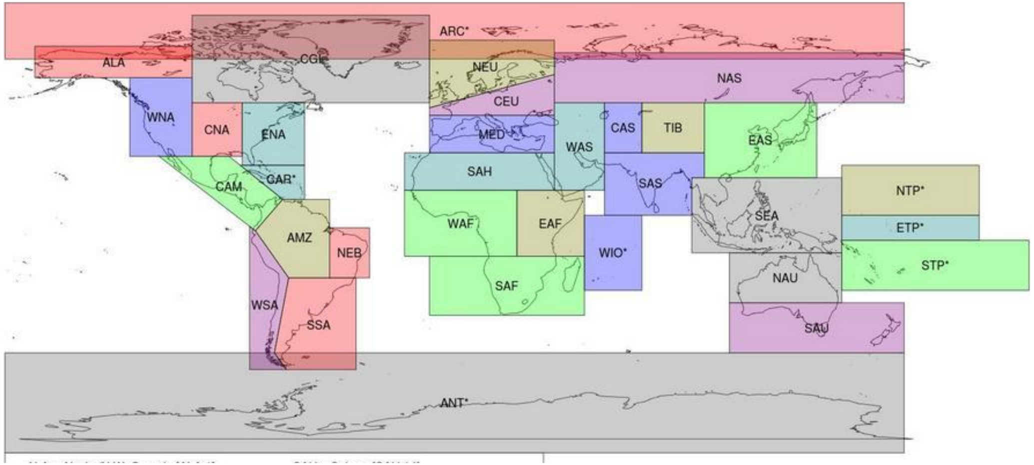
Longwave:

- Global LBL calculations show that both the GFDL and RRTMG band models obtain a reasonable level of accuracy (~2 Wm-2) in most atmospheres.
- However, the GFDL model has clear large-scale biases in OLR and LWDN. Both RRTMG and GFDL struggle where there are big temperature differences between the surface and atmosphere.
- Both models perform badly at predicting the change in LWDN due to CO2 increasing.



LBL calculation of Clear-Sky Longwave Column Divergence for 22nd March at 0:30 GMT





- Looking at select land regions, all show very different changes in JJA precipitation.
- Big differences in how the regional energy budget adjusts to similar SWA.
- EAS shows an increase in LH and rainfall, suggesting local and remote causes.

Key

SWA =Shortwave absorption by atmosphere
LWA = Longwave absorption by atmosphere
LH = Latent Heat Flux
SH = Sensible Heat Flux
DIV =Flux out of region
PRECIP = Precipitation, Wm-2
PRECIP % = Precipitation change as percent of climatology.

Updates to the GFDL Longwave Radiation Code for AM4

- Updated all Band Coefficients to HITRAN 2012
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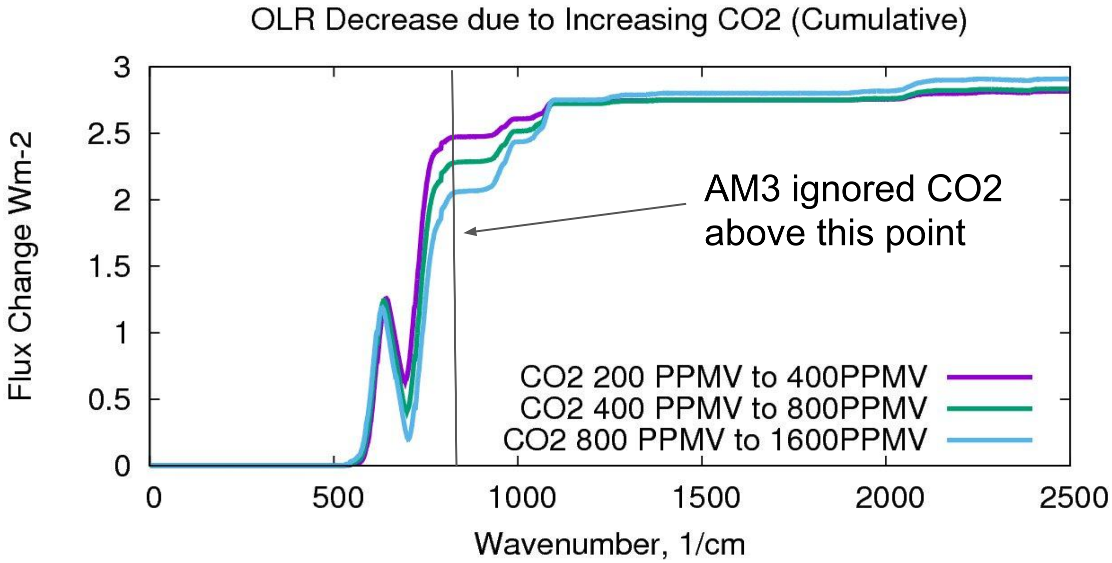
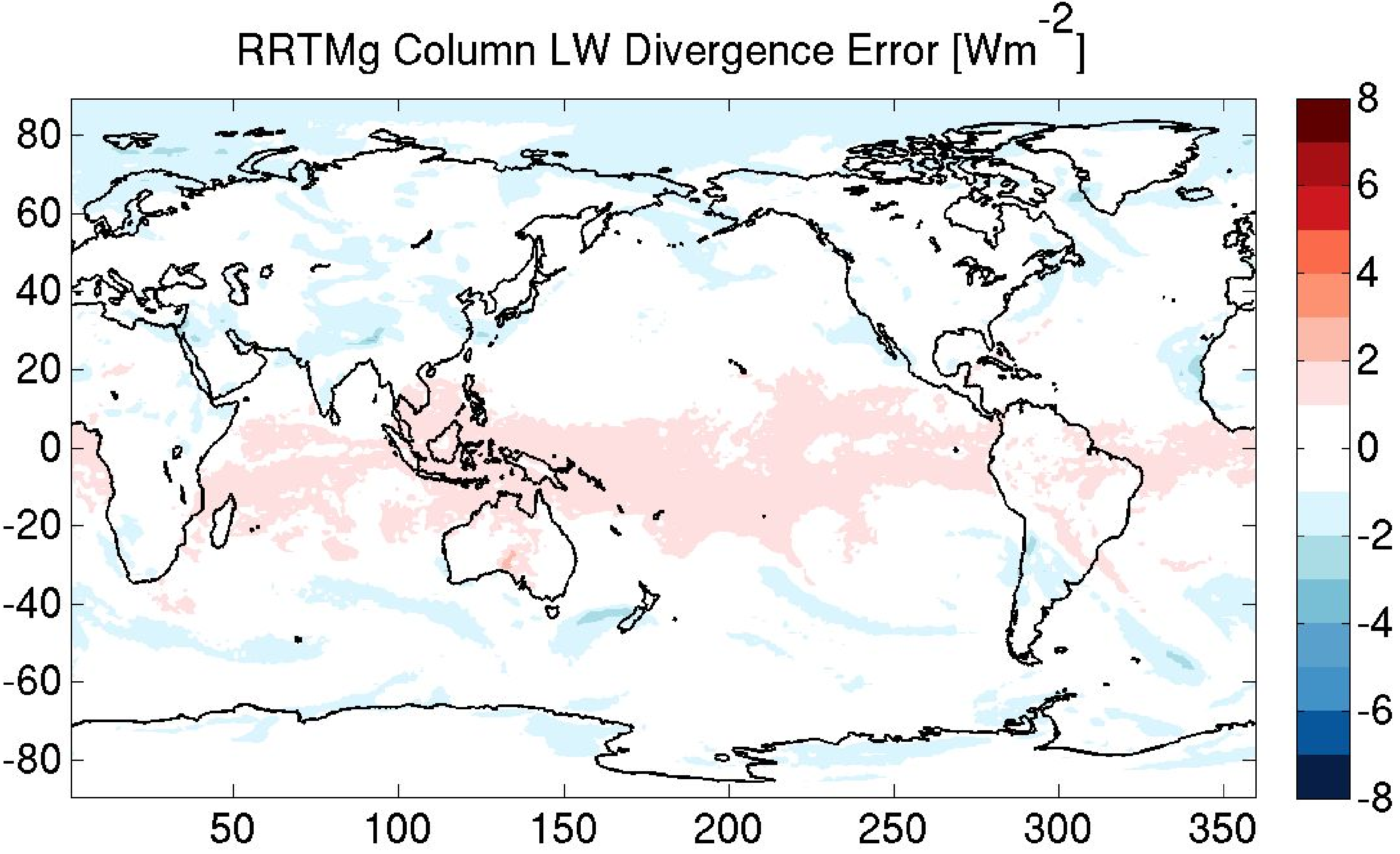
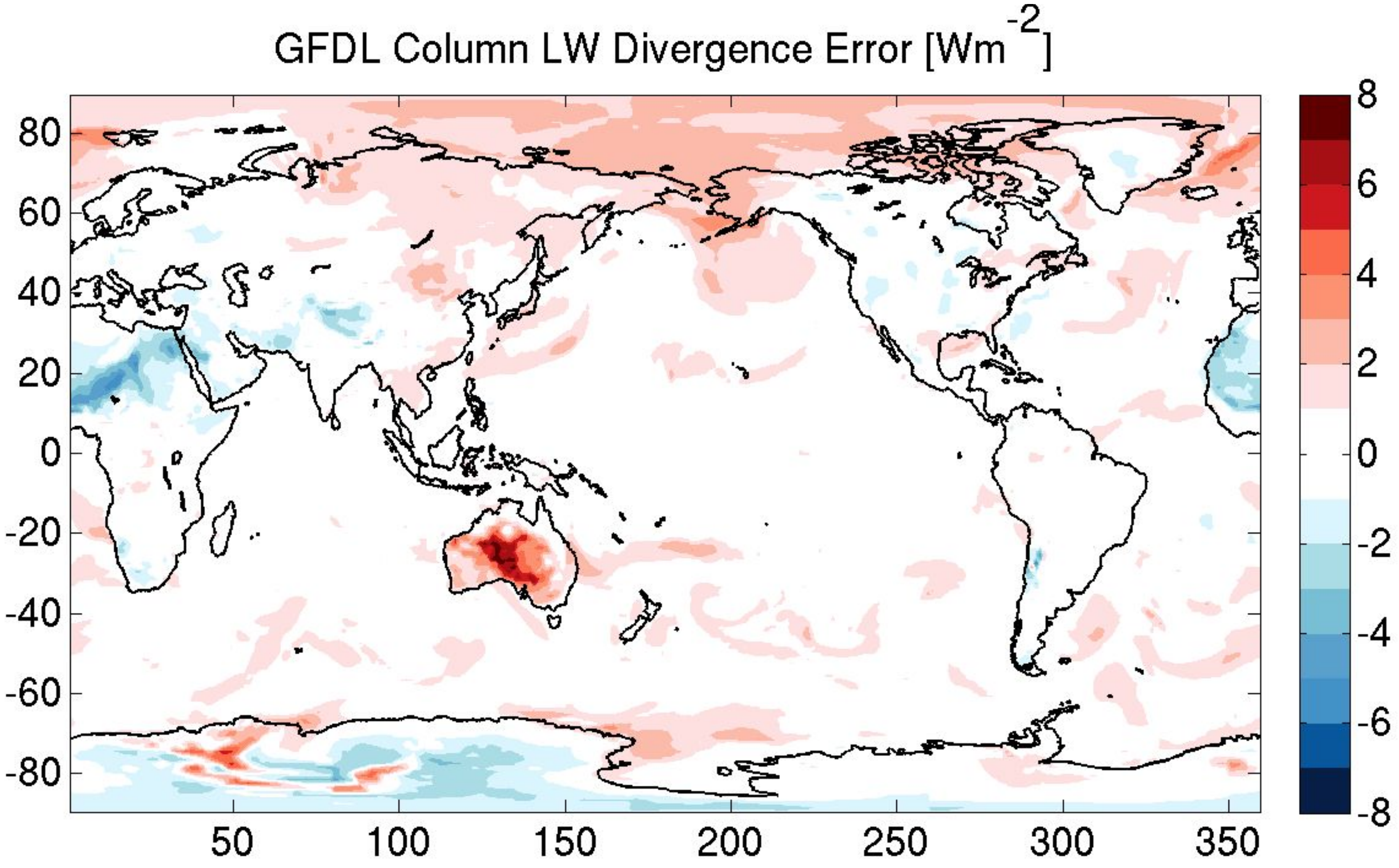
- Added in CO_2 lines at greater than 800 cm^{-1}

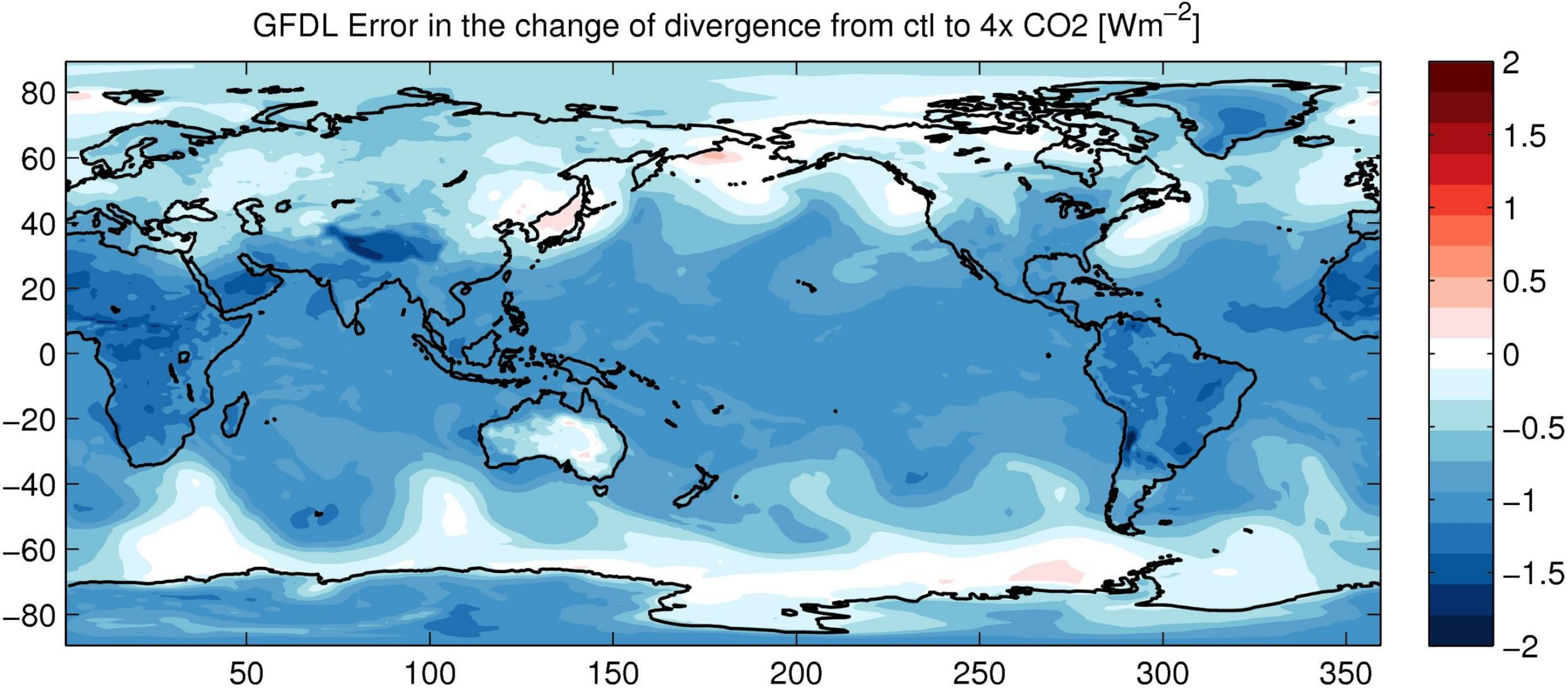


Impact upon climatology of updates is quite modest, Increase OLR and SDR by 0.7 Wm^{-2}

However radiative forcing due to the 4 times CO_2 is now 10% stronger!

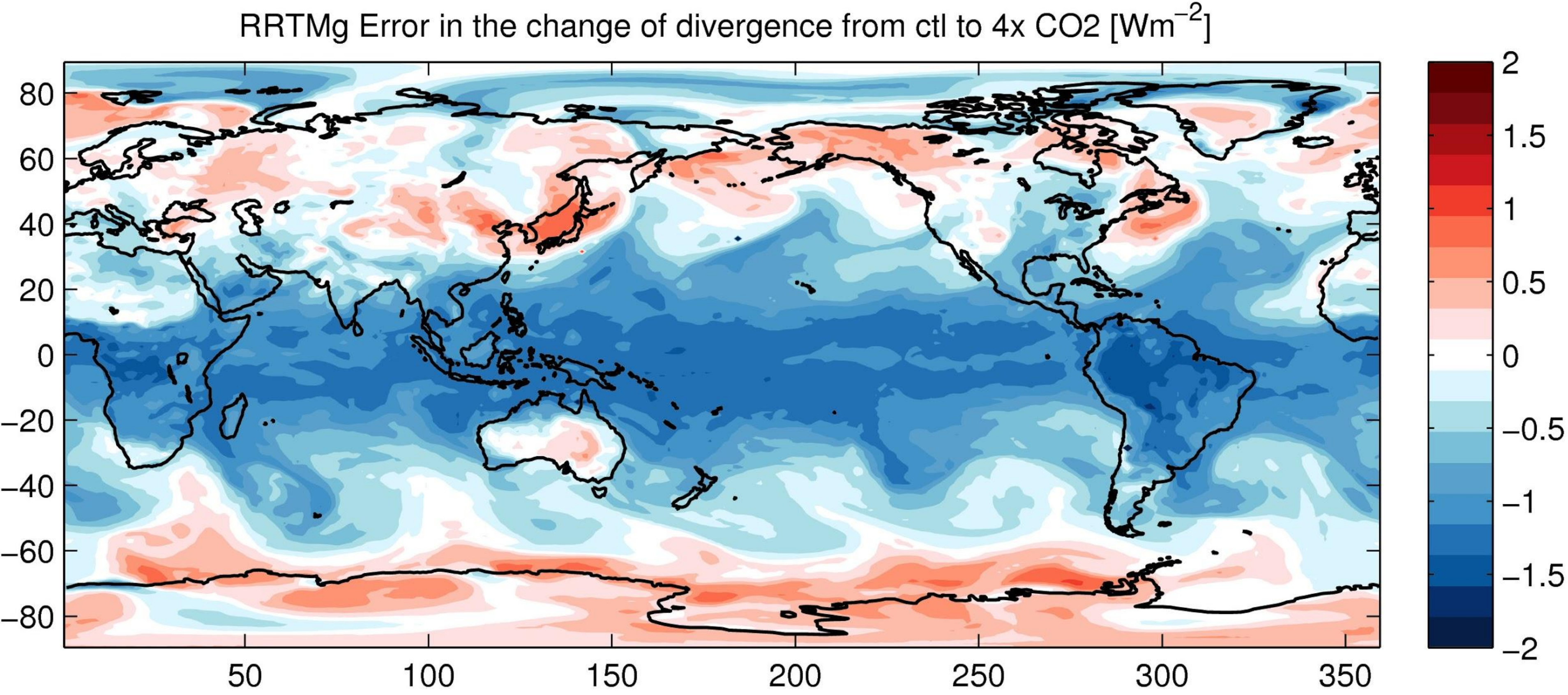

RRTMg Column LW Divergence Error [Wm^{-2}]
80
60
40
20
0
-20
-40
-60
-80
50
100
150
200
250
300
350
8
6
4
2
0
-2
-4
-6
-8


GFDL Column LW Divergence Error [Wm-2]
80
60
40
20
0
-20
-40
-60
-80
50
100
150
200
250
300
350
8
6
4
2
0
-2
-4
-6
-8



Global Mean: -0.7 Wm^{-2}

Error in GFDL calculation of Clear-Sky $4xCO_2$ Tropopause Divergence for 22nd March at 0:30 GMT

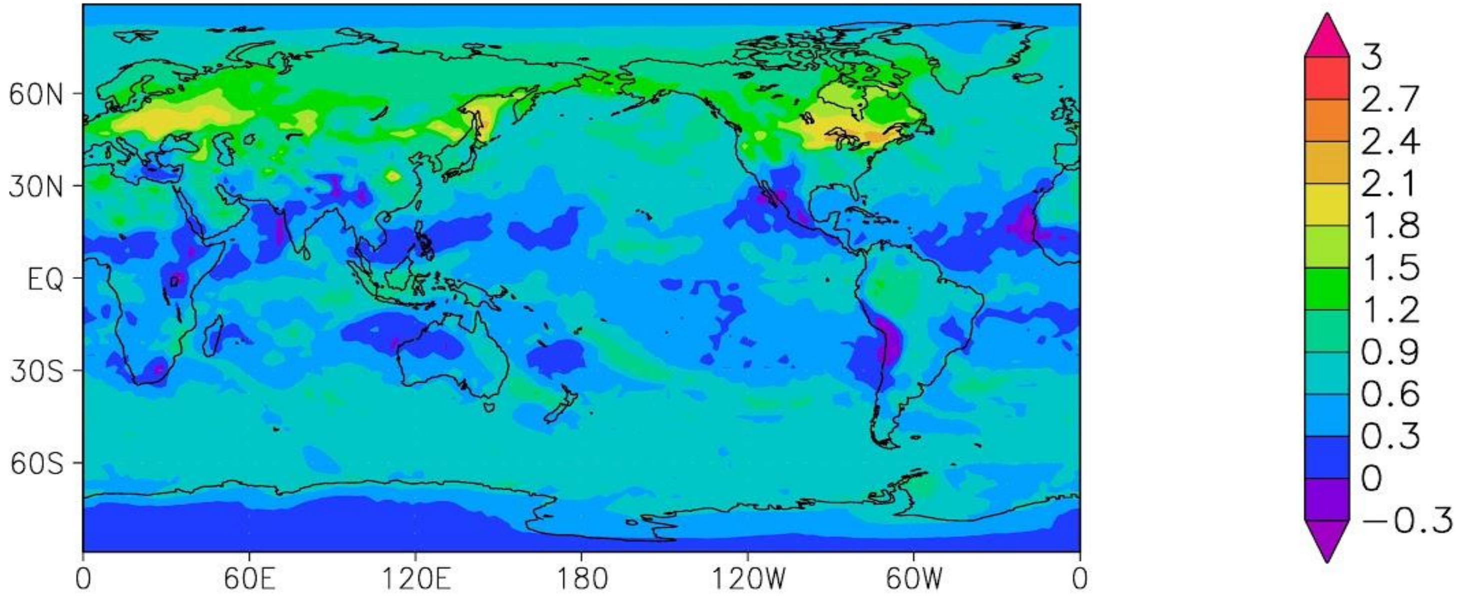


Global Mean: -0.4 Wm^{-2}

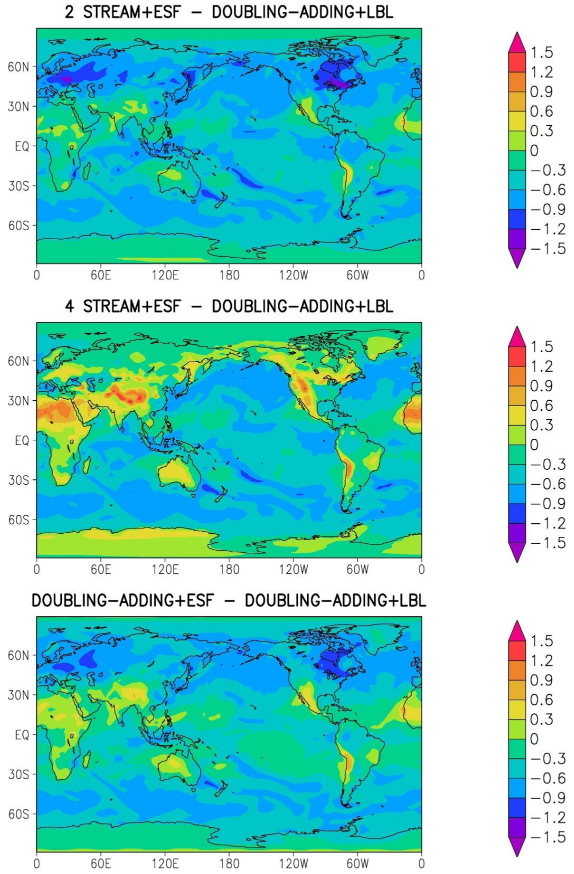
Error in RRTMG calculation of Clear-Sky 4xCO2 Tropopause Divergence for 22nd March at 0:30 GMT

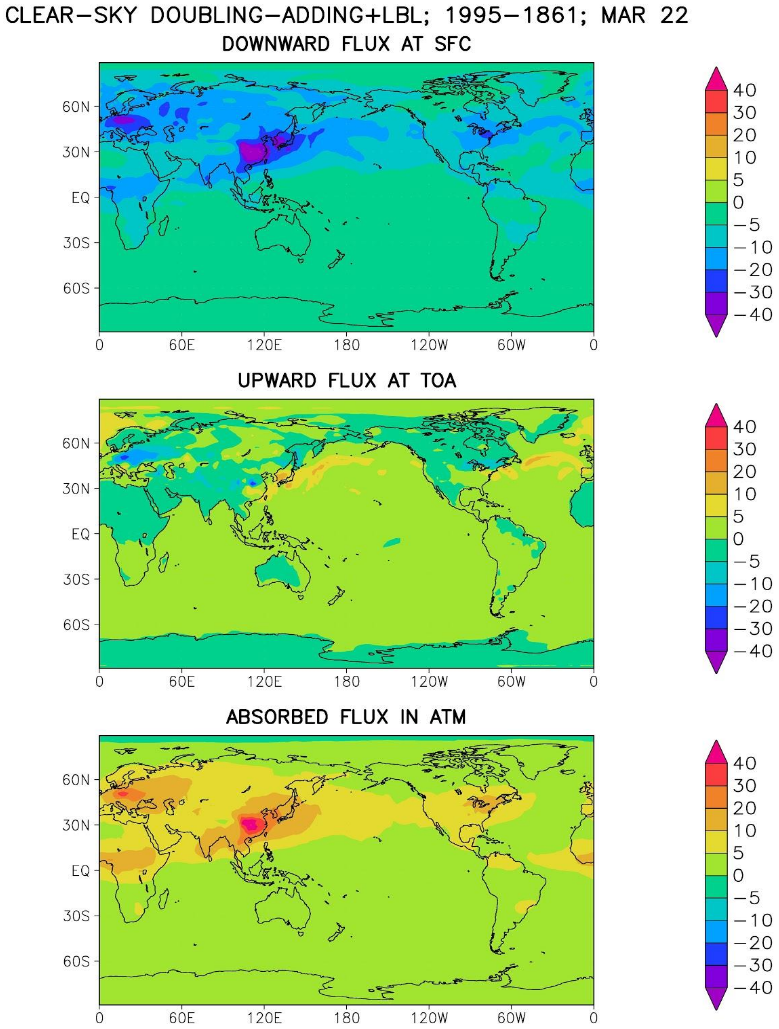
ABSORBED FLUX IN ATM; CLEAR-SKY; NO AEROSOL; MAR22

2 STREAM+ESF – DOUBLING-ADDING+LBL



DOWNWARD FLUX AT SFC; CLEAR-SKY; NO AEROSOL; MAR22




CLEAR-SKY DOUBLING-ADDING+LBL; 1995-1861; MAR 22
DOWNWARD FLUX AT SFC
UPWARD FLUX AT TOA
ABSORBED FLUX IN ATM
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
40
30
20
10
5
0
-5
-10
-20
-30
-40