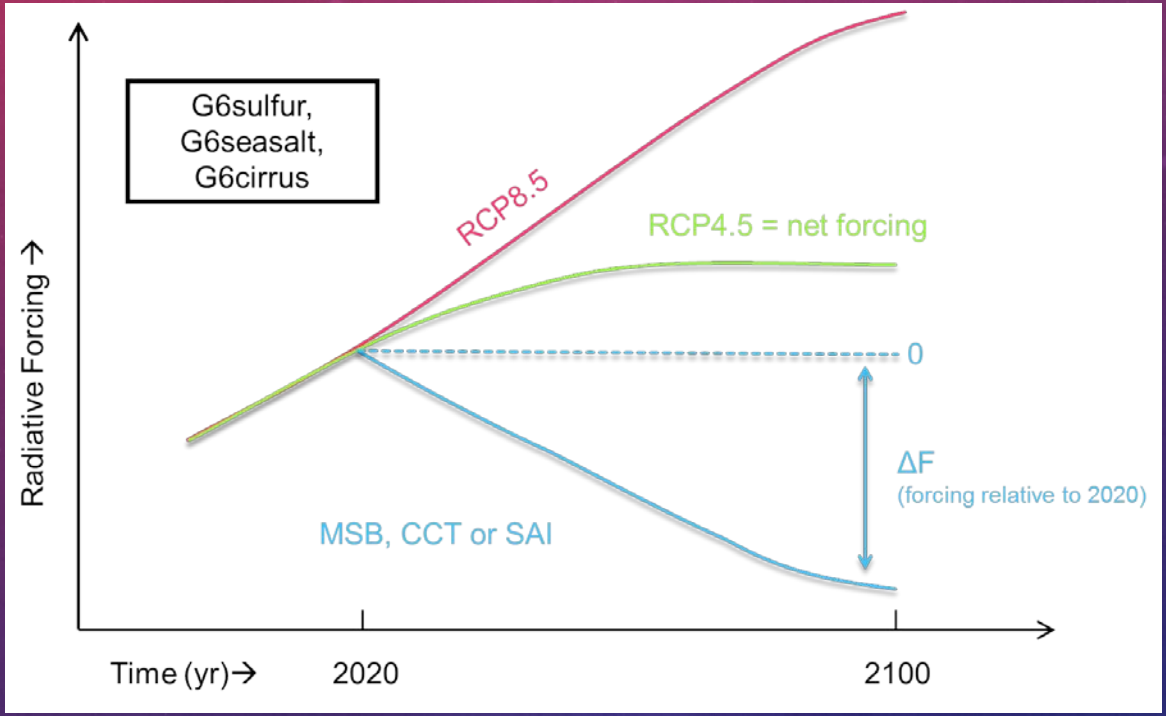
# EXPECT CIRRUS CLOUD THINNING EXPERIMENTS

HELENE MURI

# SCENARIO: RCP8.5 -> RCP4.5 VIA CLIMATE ENGINEERING



After Kravitz et al. (2015).

# ICE SEDIMENTATION

- The ice velocity, $v_i$, is a function only of the effective radius, *Re*, which itself is a function only of *T*.
- For *Re* < 40 × $10^{-6}$ m, the Stokes terminal velocity equation for a falling sphere is used:

$$v_i = \frac{2}{9}\frac{\rho_w g R_e^2}{\eta}$$

- *Re* > 40 × $10^{-6}$ m, the Stokes formula is no longer valid and a linear dependence of $v_i$ on $r = 10^{-6} \times Re$ is used:

$$v_i(r) = v_i(40) + (r - 40)\frac{v_{400} - v_i(40)}{400 - 40}$$

  - $v_{400}$ = 1.0 m/s : the assumed velocity of a 400 micron sphere, after Locatelli and Hobbs [1974].

# ICE EFFECTIVE RADIUS AND TERMINAL VELOCITY

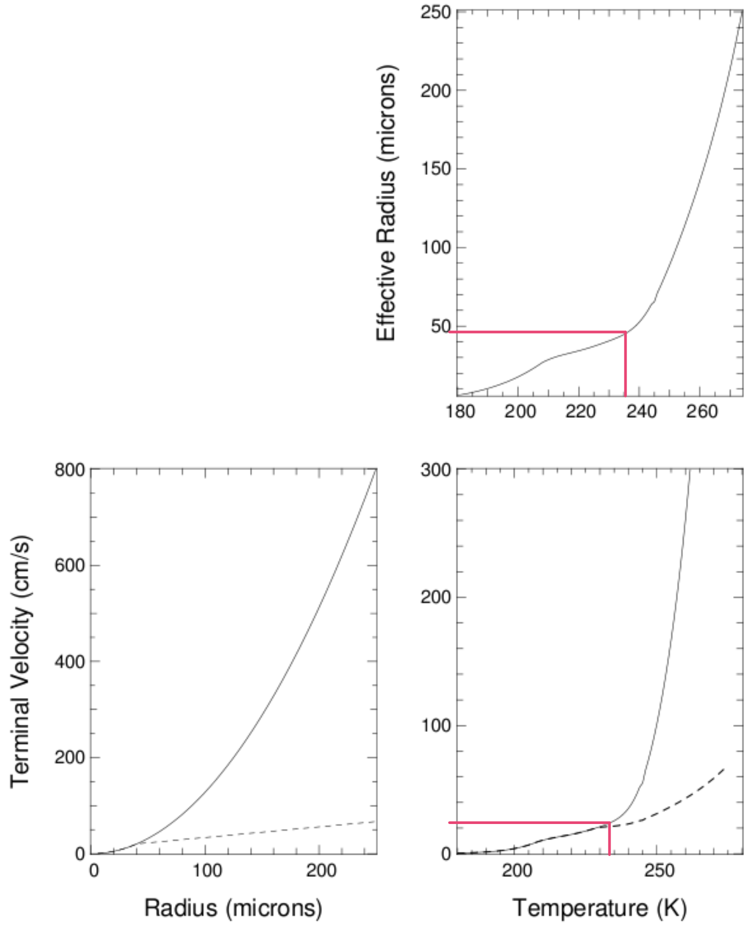
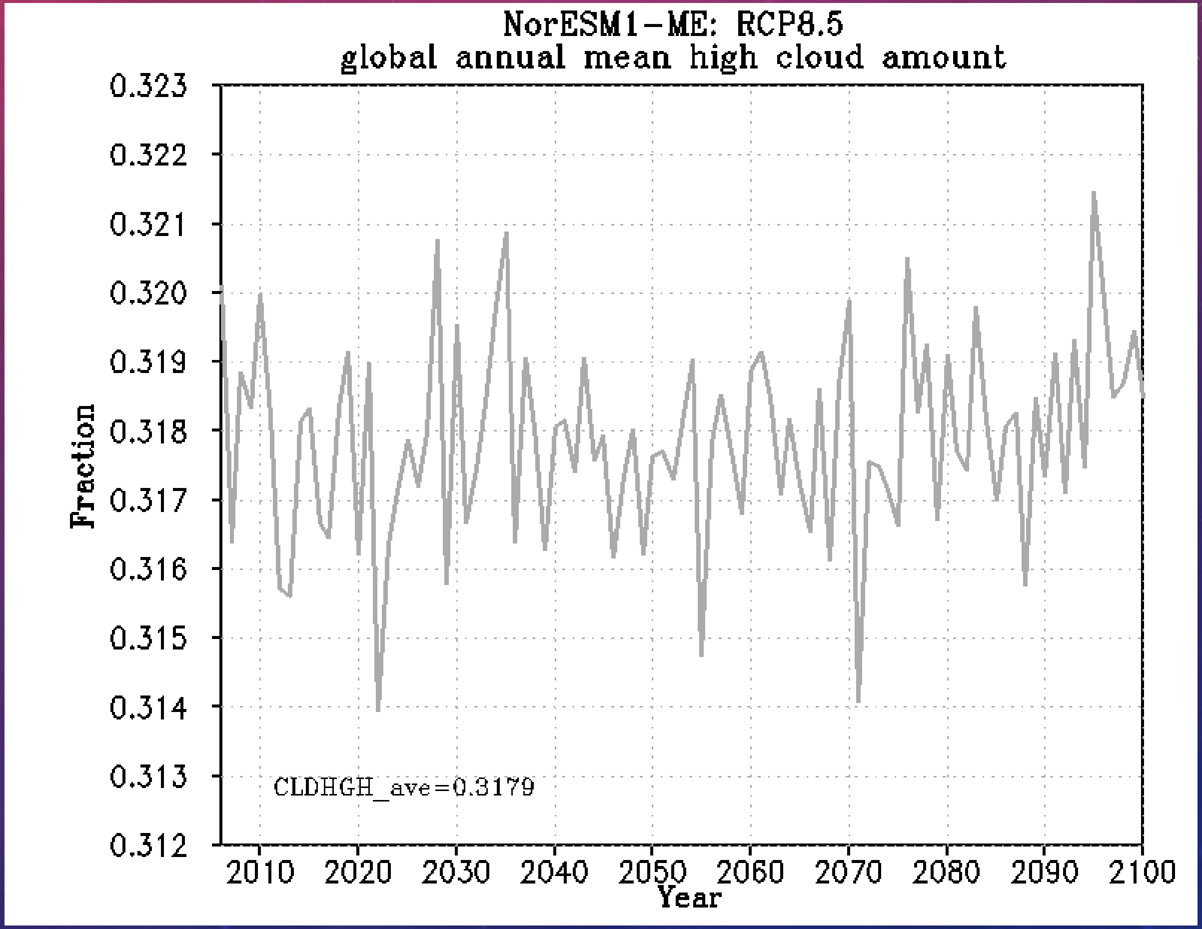
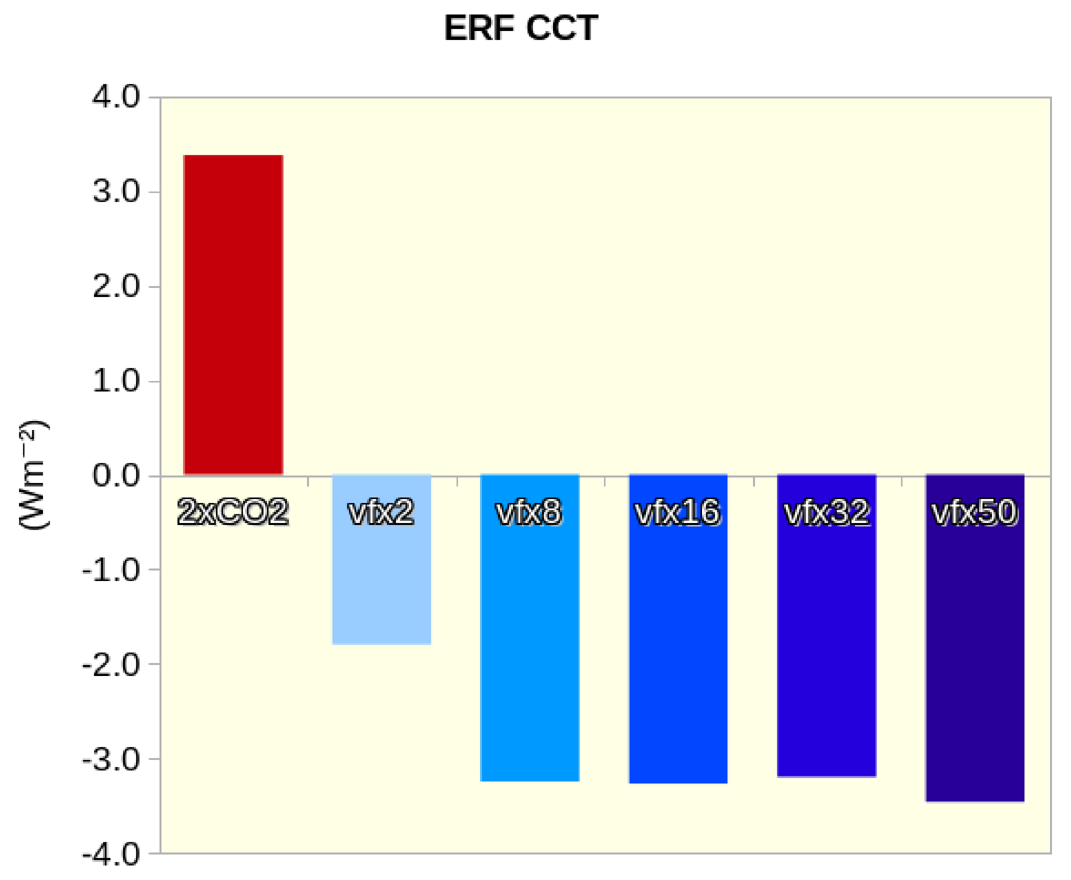


Figure 4.2: Ice effective radius and terminal velocity. Top, ice effective radius versus temperature. Bottom, ice velocity versus radius (left) and temperature (right); the Stokes terminal velocity is solid and the actual velocity is dashed.

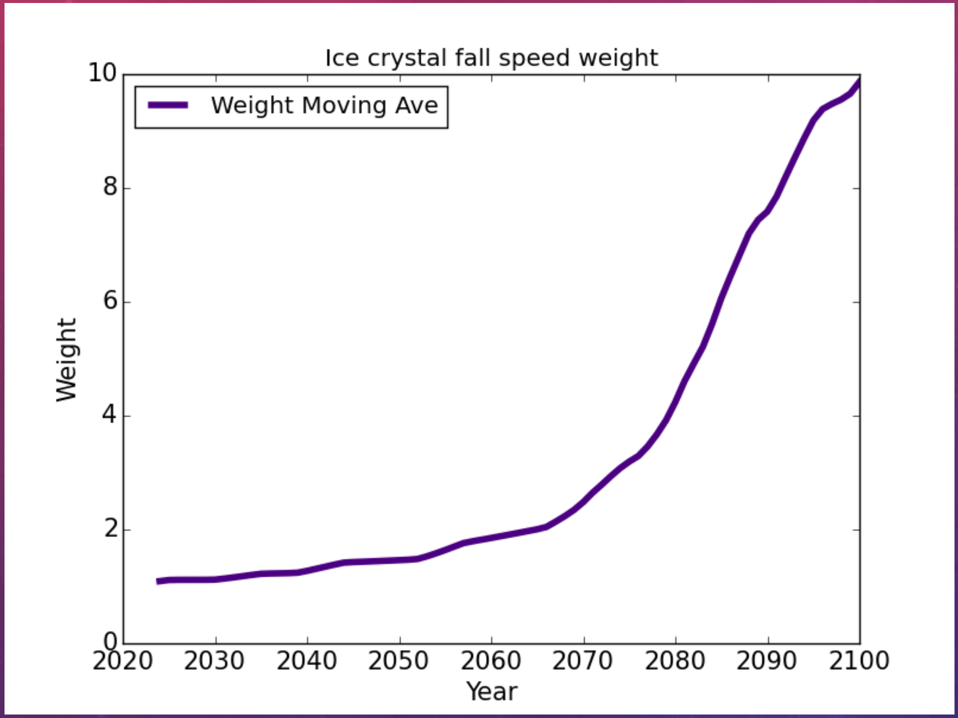
# NORESM1-ME RCP8.5 VERTICALLY INTEGRATED HIGH CLOUD AMOUNT



# FIXED SST RUNS TO ESTIMATE EFFECTIVE RADIATIVE FORCING:

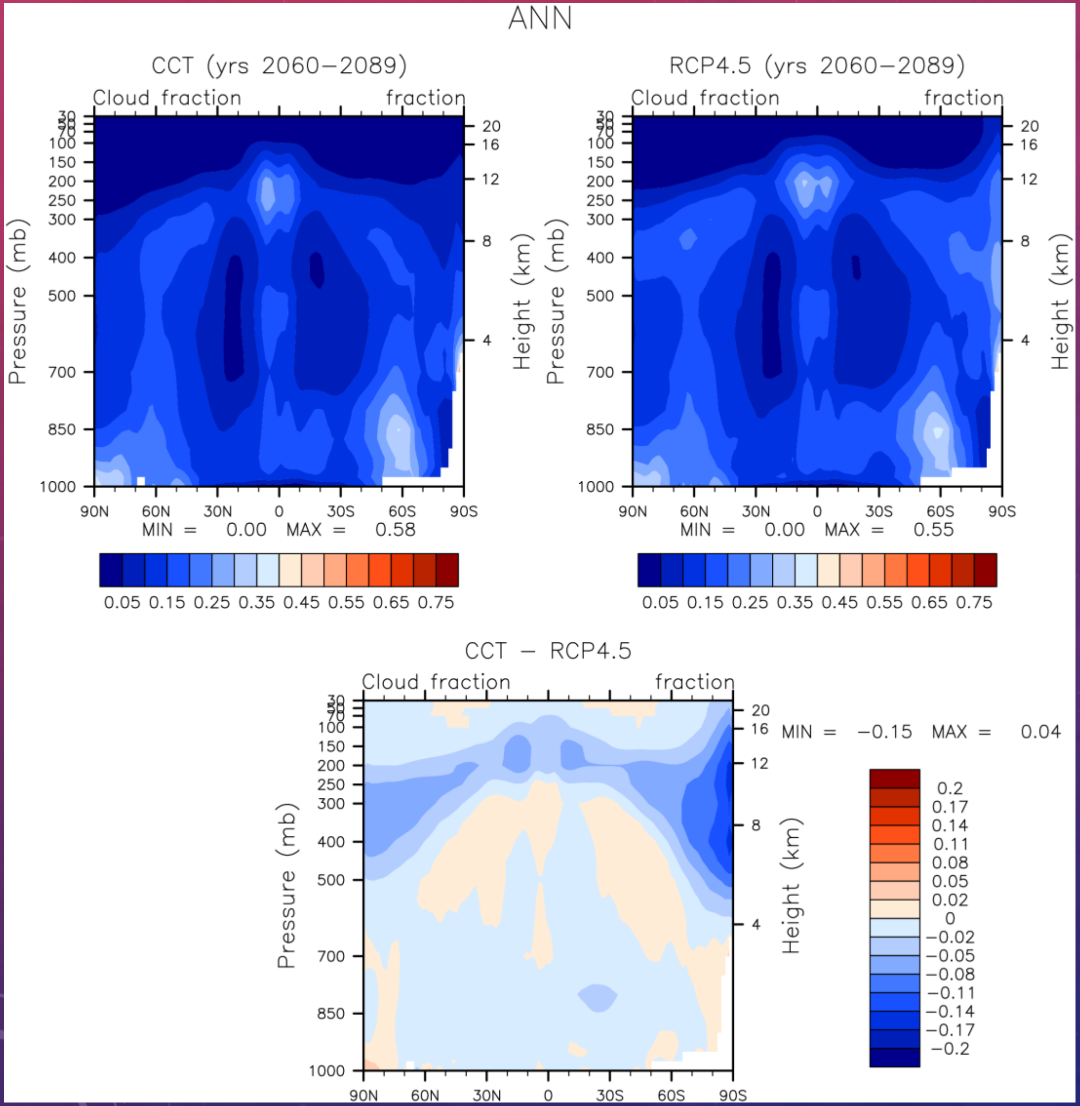


# ICE CRYSTAL FALL SPEED WEIGHTS.



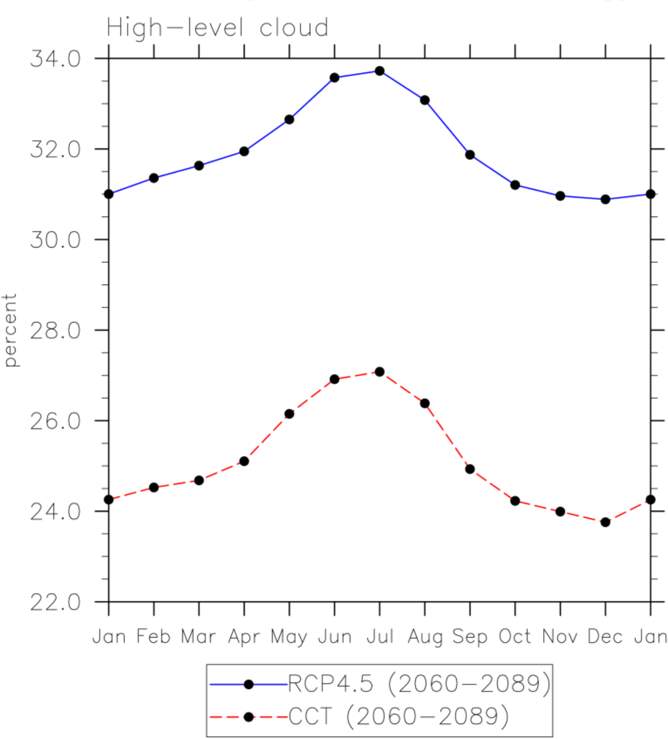
- Multiplication factor for ice crystals at temperatures colder than 235 K.

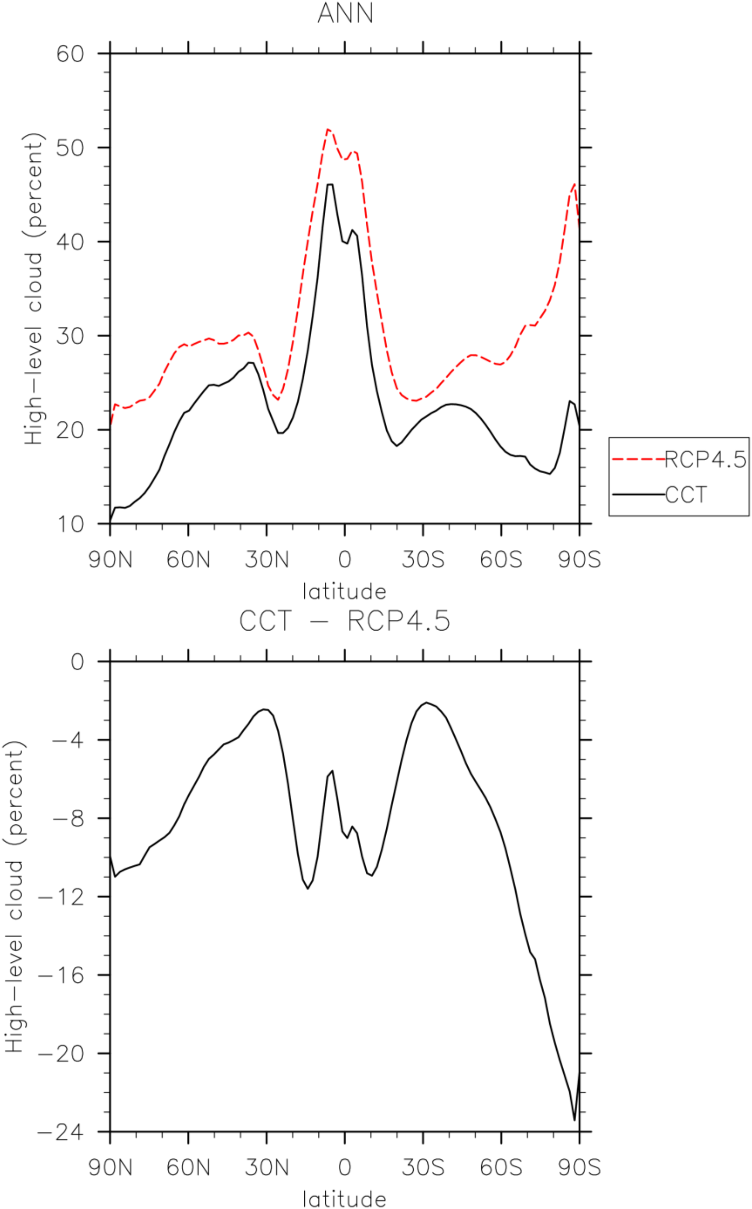
# CCT vs. RCP4.5

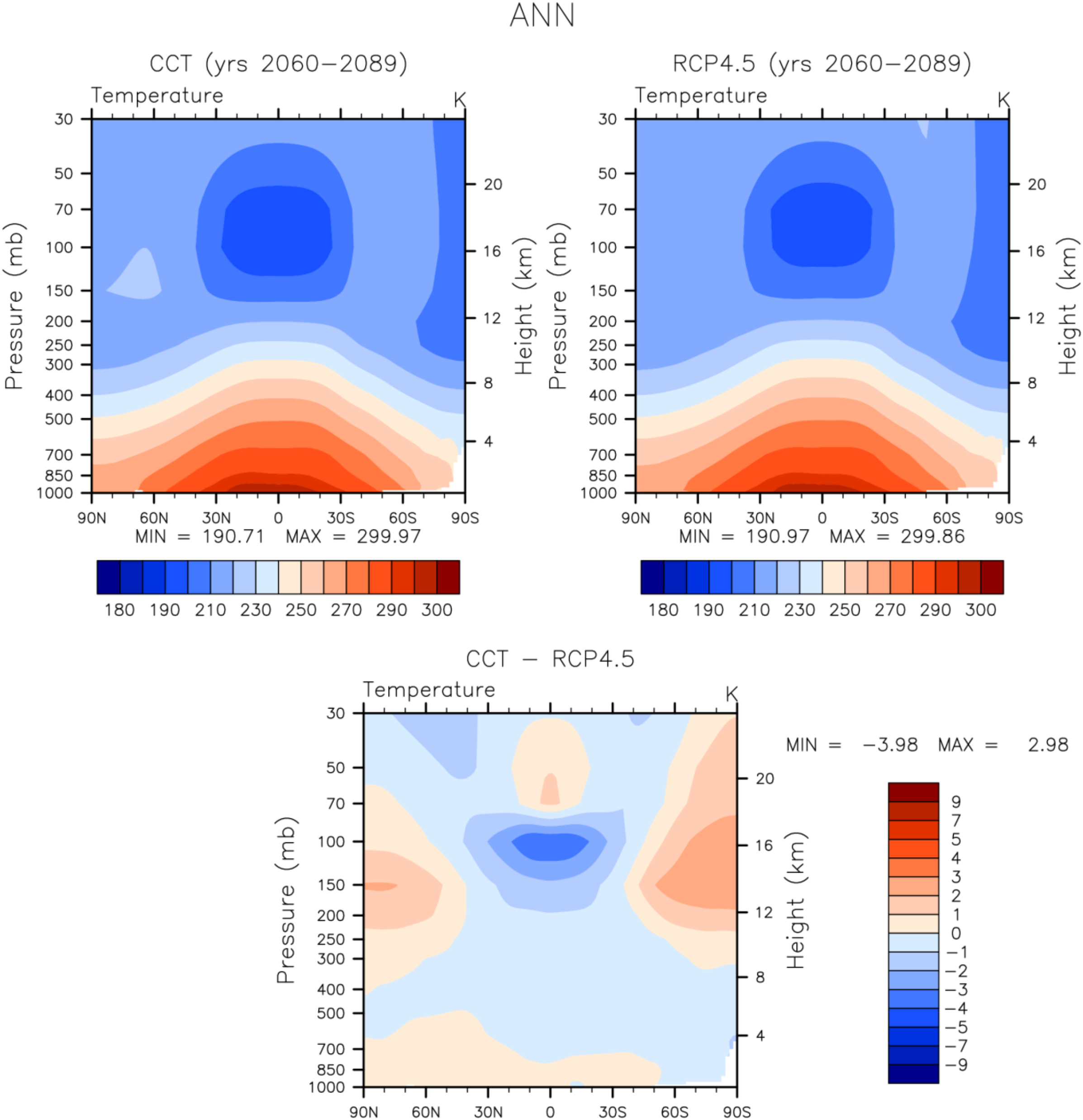


- Cloud fraction, zonal mean. Annual mean over 2060 – 2089.
- Largest change in SH, towards poles.

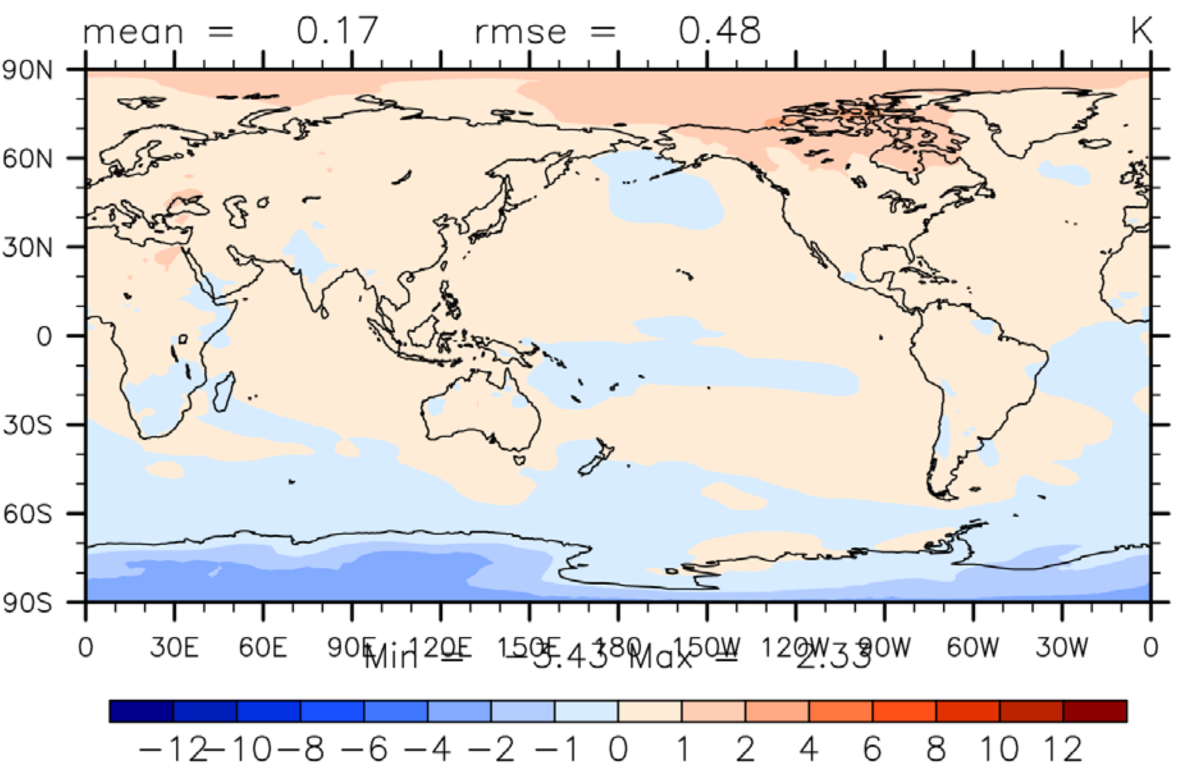
# HIGH LEVEL CLOUD



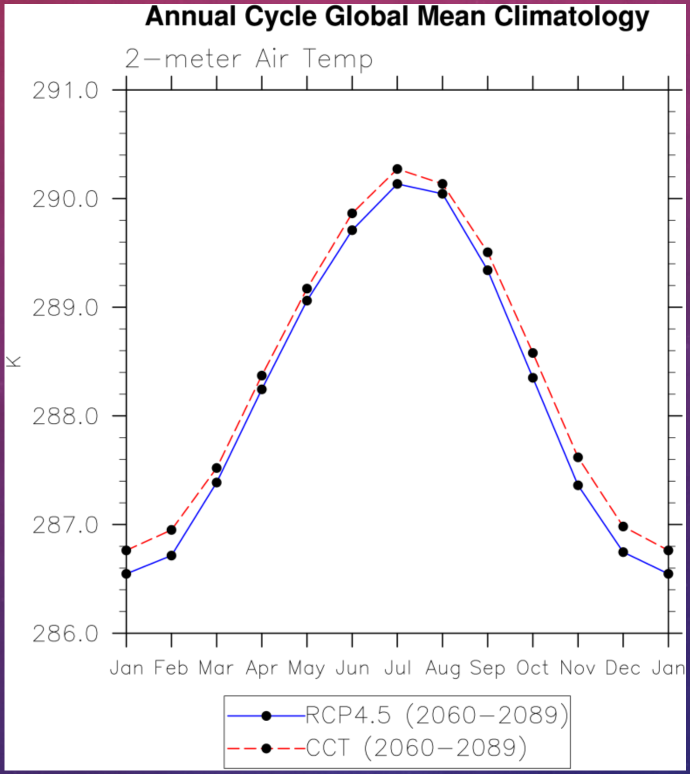



ANN
CCT (yrs 2060–2089)
Temperature
K
30
50
70
100
150
200
250
300
400
500
700
850
1000
Pressure (mb)
Height (km)
20
16
12
8
4
90N
60N
30N
0
30S
60S
90S
MIN = 190.71 MAX = 299.97
180 190 210 230 250 270 290 300
RCP4.5 (yrs 2060–2089)
Temperature
K
MIN = 190.97 MAX = 299.86
180 190 210 230 250 270 290 300
CCT – RCP4.5
Temperature
K
MIN = –3.98 MAX = 2.98
9
7
5
4
3
2
1
0
–1
–2
–3
–4
–5
–7
–9

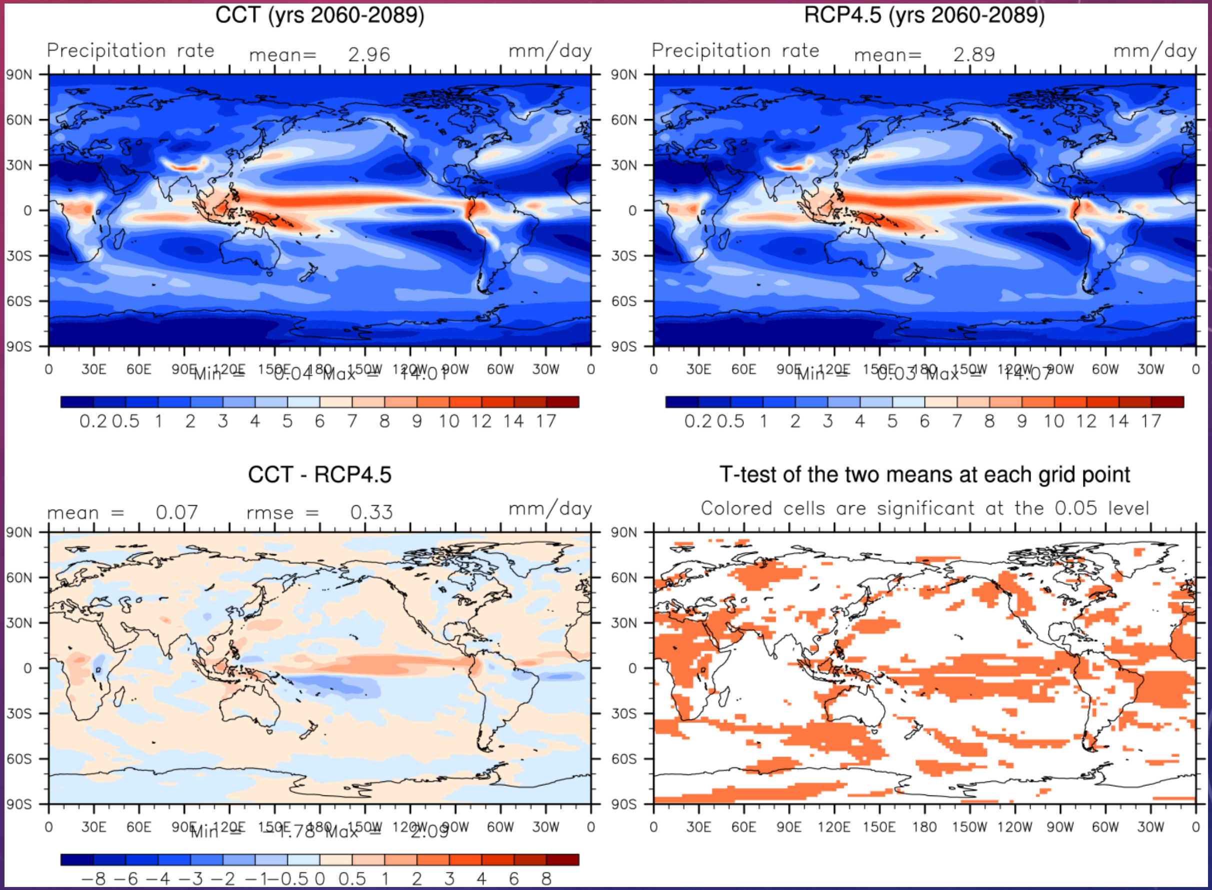
# TAS, ANNUAL MEAN



# TAS – ANNUAL CYCLE (K)

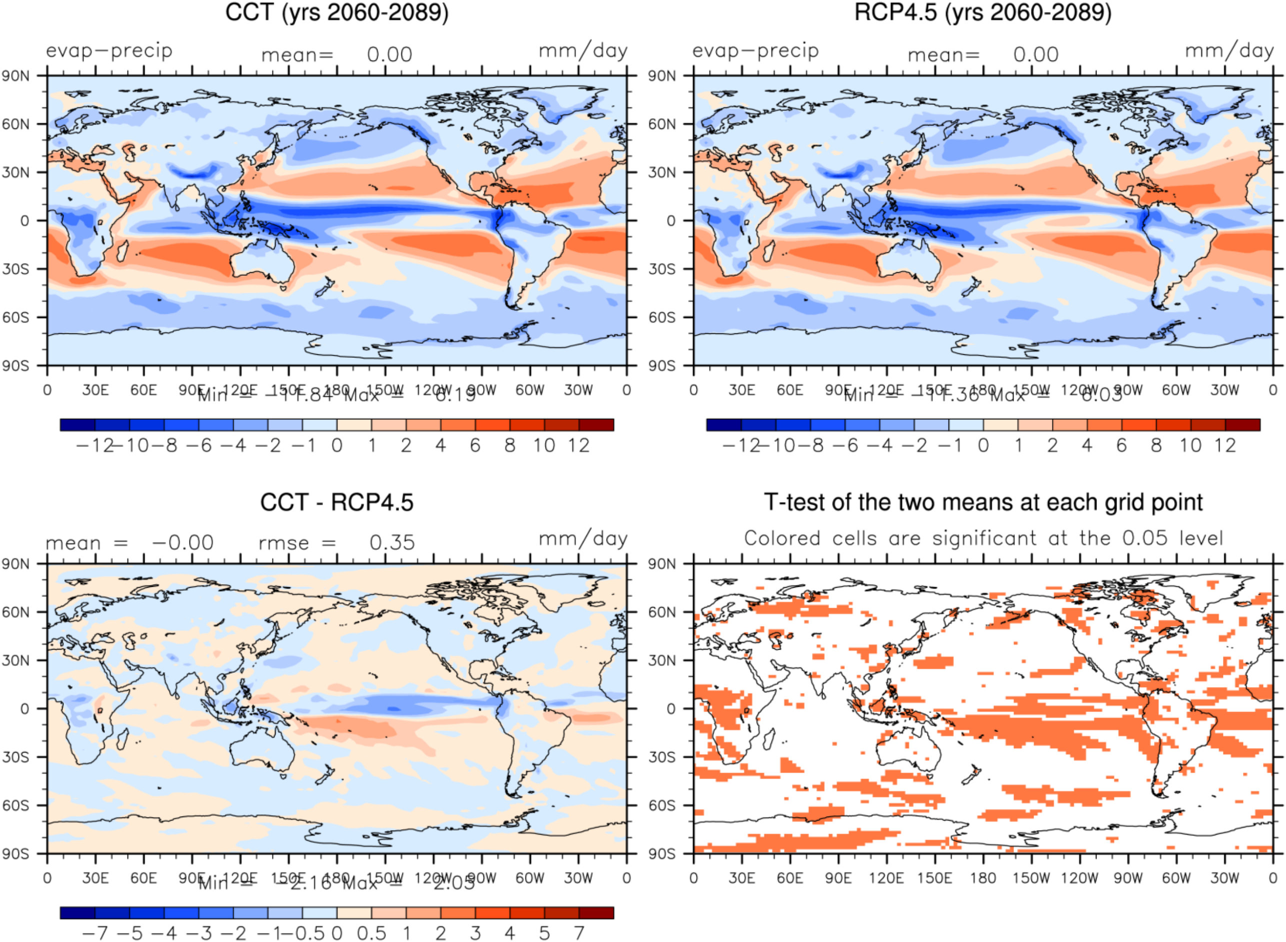


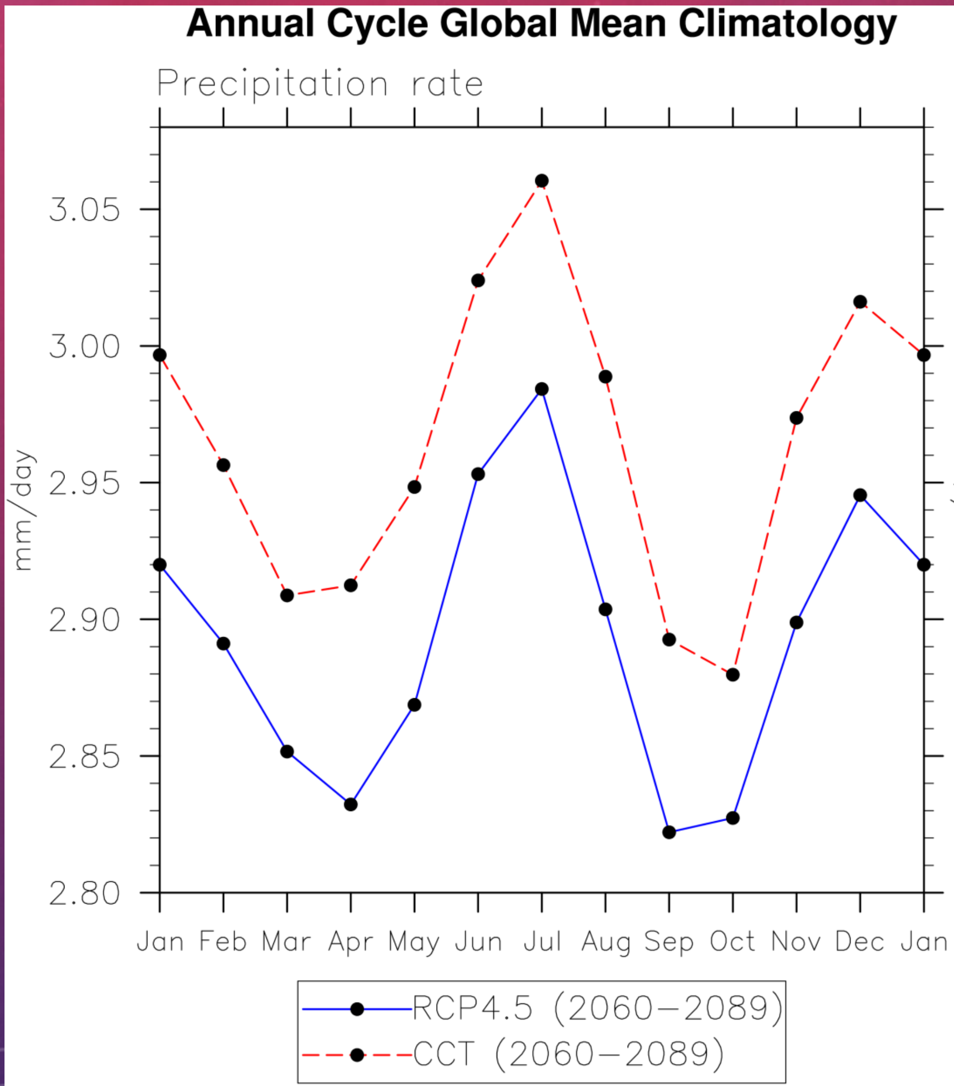
# ANNUAL MEAN PRECIPITATION RATE (MM/DAY)



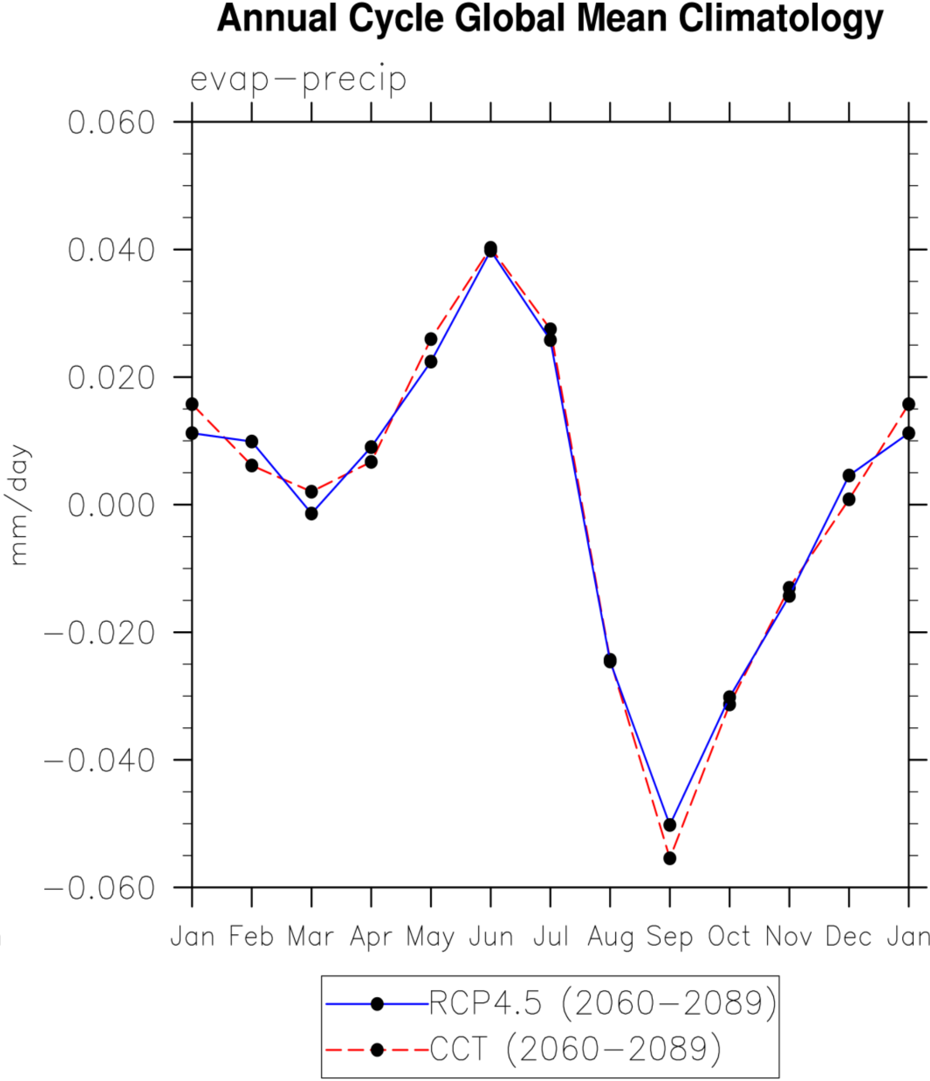
| **Variable** | **CCT** | **RCP4.5** | **CCT-RCP4.5** | **RMSE** |
|---|---|---|---|---|
| *PRECT_LAND* | 2.454 | 2.369 | 0.086 | 0.263 |
| *PRECT_OCEAN* | 3.311 | 3.241 | 0.070 | 0.373 |

# EVAPORATION – PRECIPITATION (MM/DAY), ANNUAL MEAN



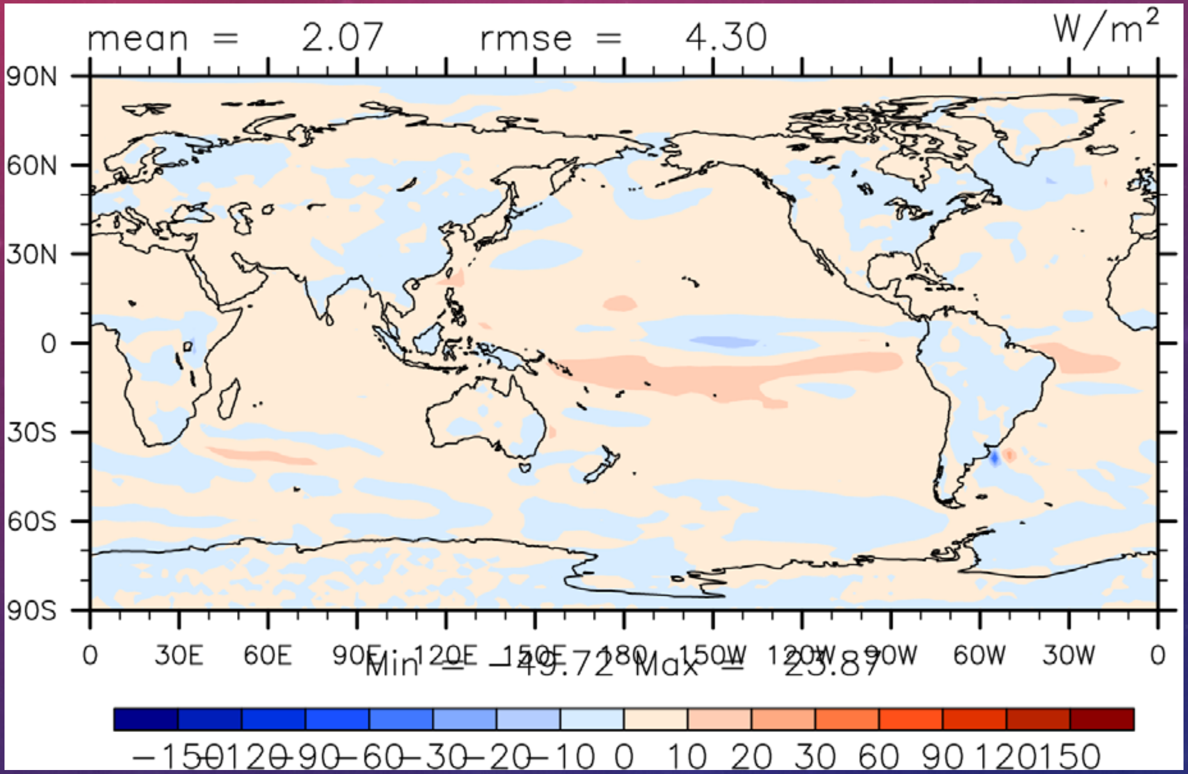


Annual Cycle Global Mean Climatology

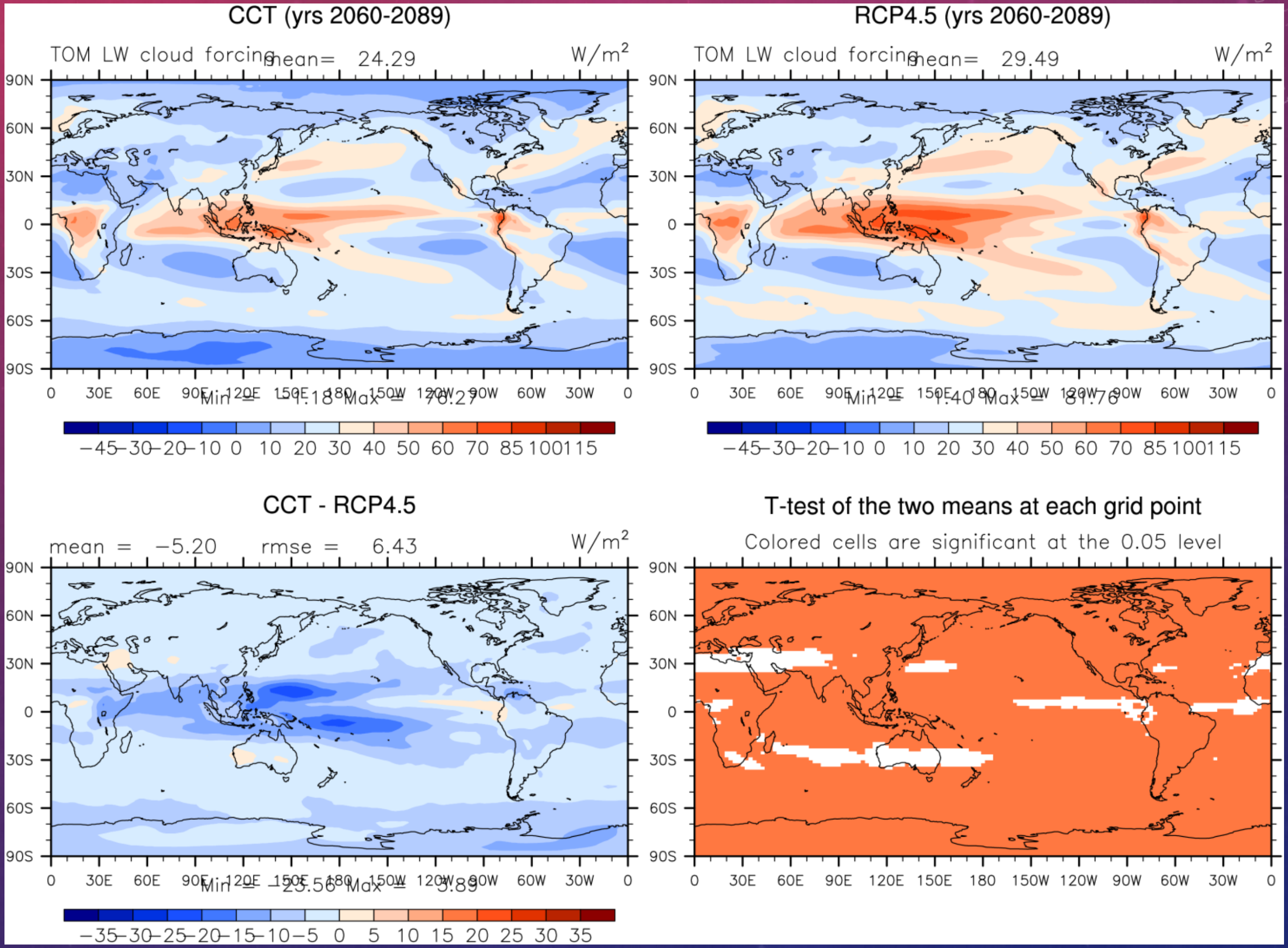


Annual Cycle Global Mean Climatology

# LATENT HEAT FLUX.



# LWCF



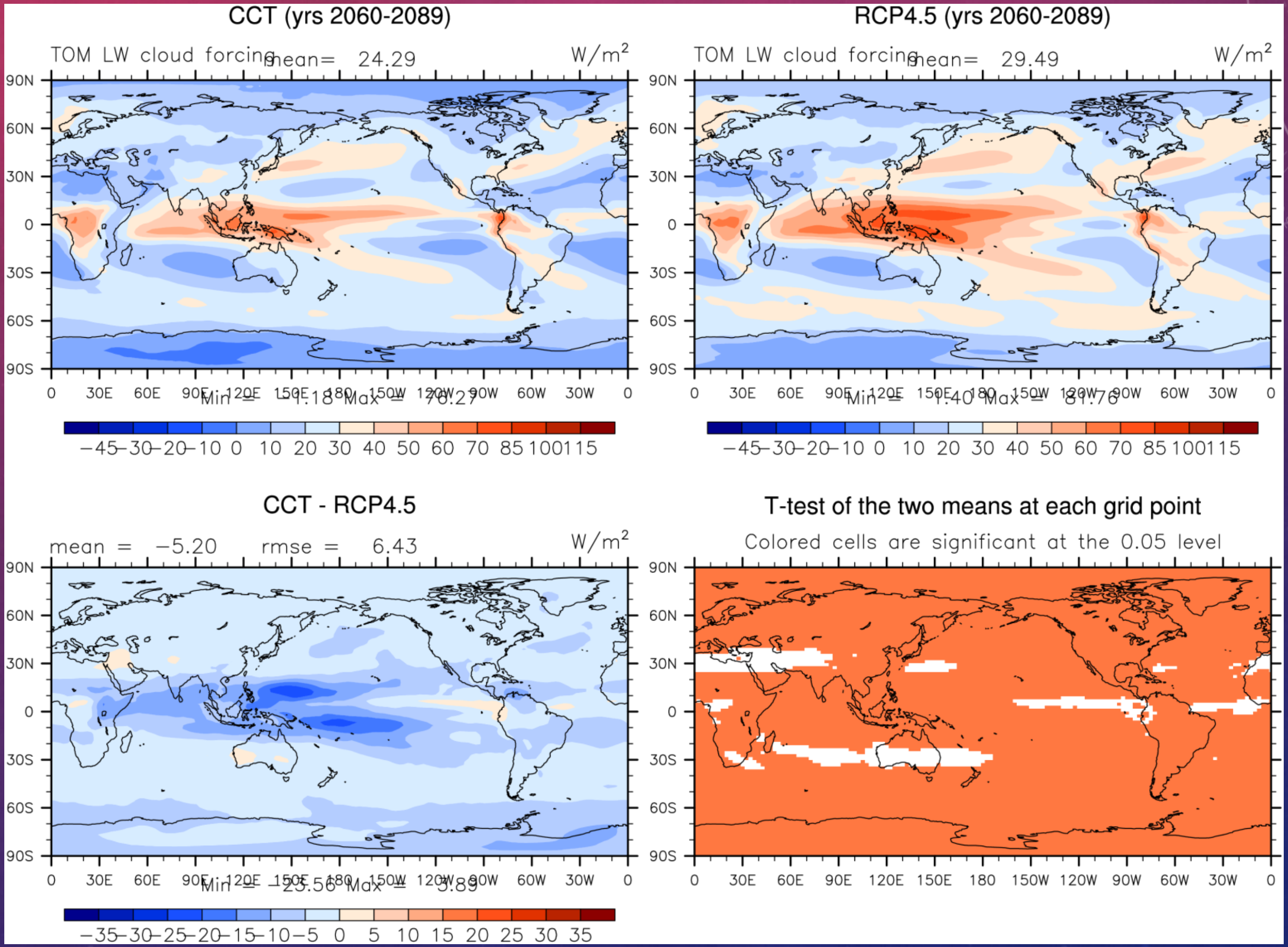
CCT (yrs 2060-2089)

RCP4.5 (yrs 2060-2089)

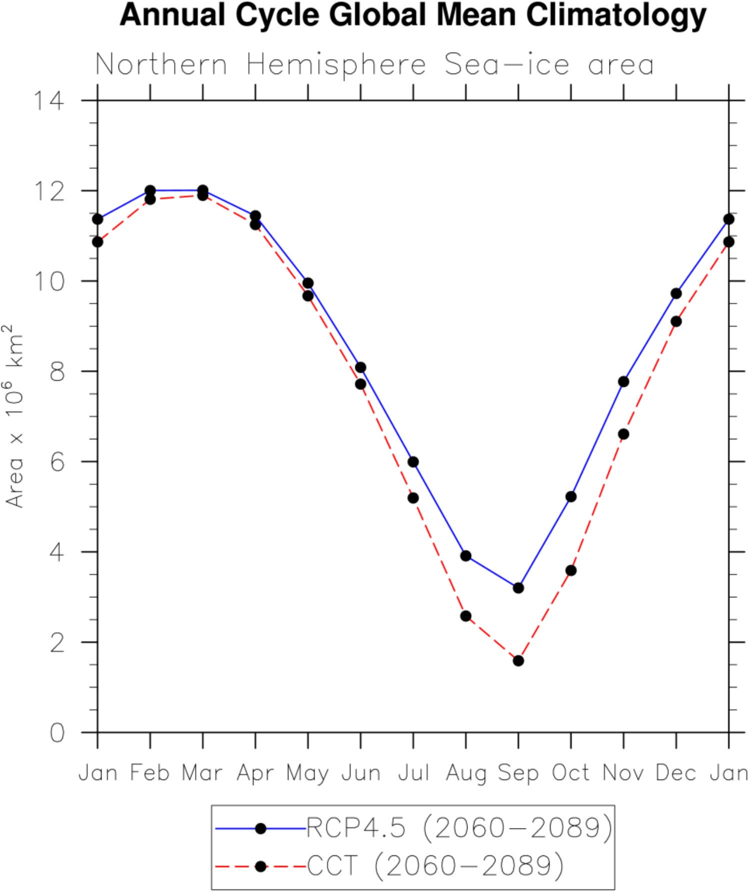
CCT - RCP4.5

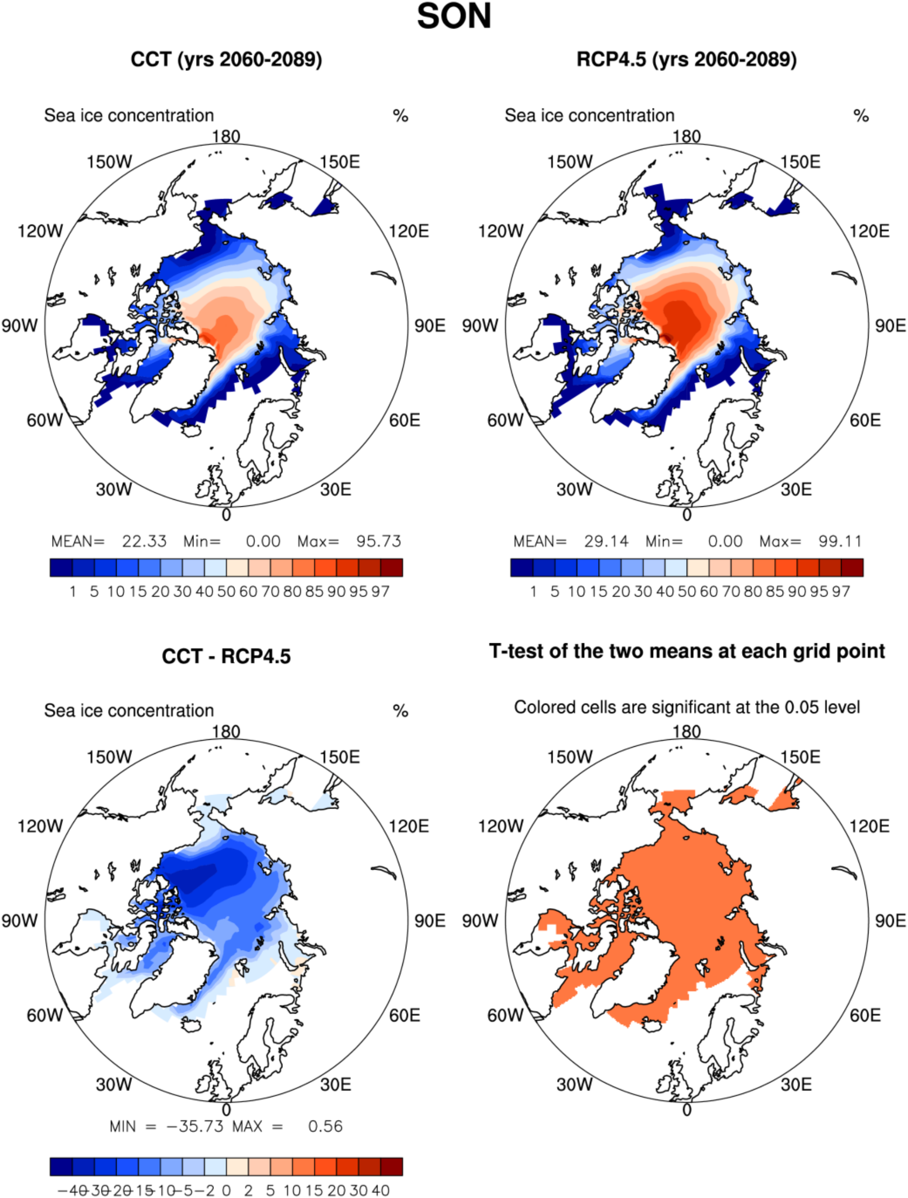
T-test of the two means at each grid point

# SWCF


CCT (yrs 2060-2089)
TOM LW cloud forcing
mean= 24.29
W/m$^2$
Min = 1.18 Max = 76.27
−45 −30 −20 −10 0 10 20 30 40 50 60 70 85 100 115
RCP4.5 (yrs 2060-2089)
TOM LW cloud forcing
mean= 29.49
W/m$^2$
Min = 1.40 Max = 81.76
−45 −30 −20 −10 0 10 20 30 40 50 60 70 85 100 115
CCT - RCP4.5
mean = −5.20
rmse = 6.43
W/m$^2$
Min = −23.56 Max = 3.89
−35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
T-test of the two means at each grid point
Colored cells are significant at the 0.05 level
90N 60N 30N 0 30S 60S 90S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0

# SEA ICE (%)

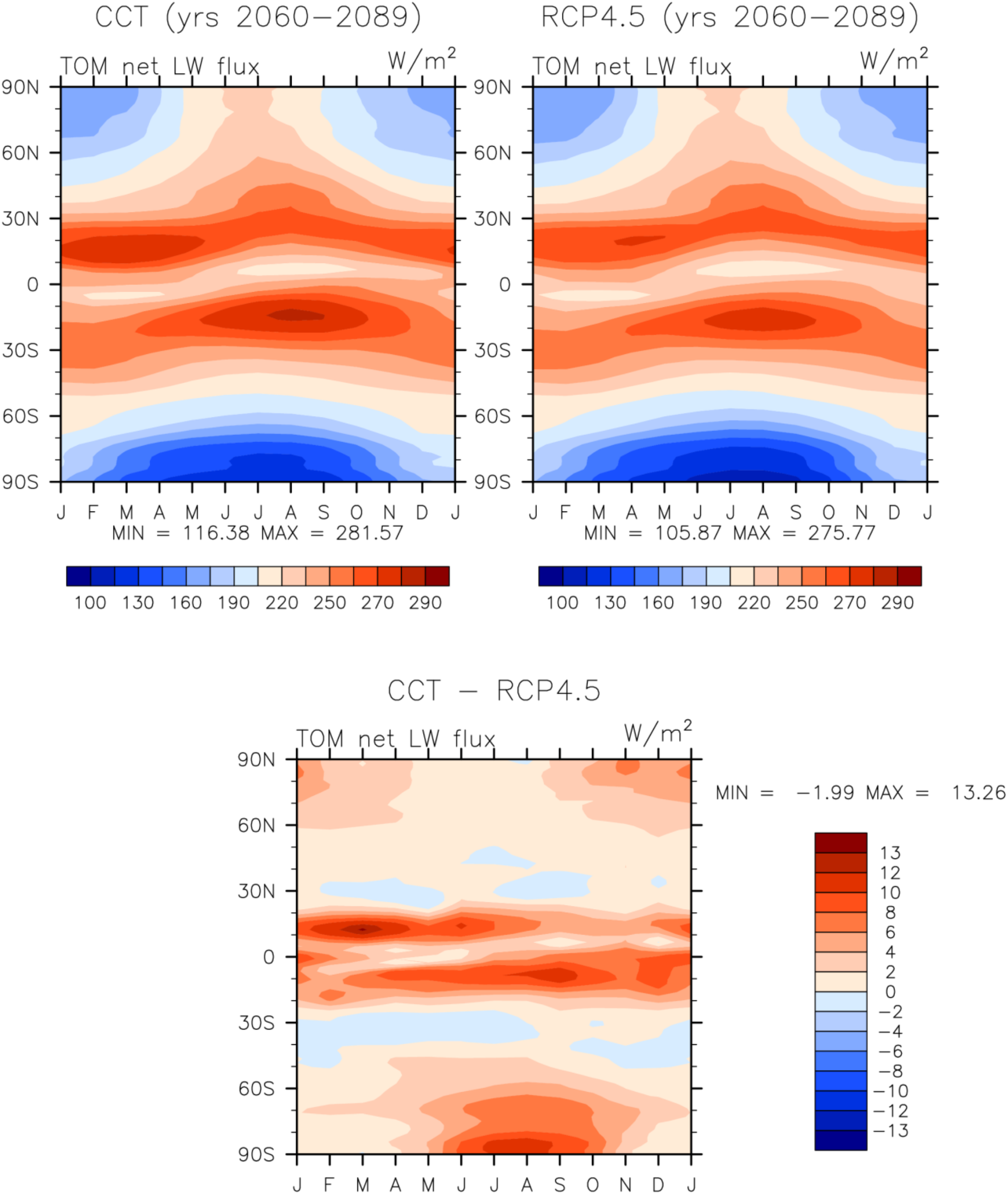

Annual Cycle Global Mean Climatology
Northern Hemisphere Sea−ice area
Area x 10$^6$ km$^2$
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
RCP4.5 (2060−2089)
CCT (2060−2089)


SON
CCT (yrs 2060-2089)
RCP4.5 (yrs 2060-2089)
Sea ice concentration
%
180
150W
150E
120W
120E
90W
90E
60W
60E
30W
30E
0
MEAN= 22.33 Min= 0.00 Max= 95.73
MEAN= 29.14 Min= 0.00 Max= 99.11
1 5 10 15 20 30 40 50 60 70 80 85 90 95 97
CCT - RCP4.5
T-test of the two means at each grid point
Colored cells are significant at the 0.05 level
MIN = −35.73 MAX = 0.56
−40 −30 −20 −15 −10 −5 −2 0 2 5 10 15 20 30 40

# SUMMARY

- ICE FALL SPEED SATURATION EFFECT AT AROUND 8 X FALL SPEED.
- MAX ERF ~ -3.3 $WM^{-2}$.
- LARGEST FORCING IN SH,
  - Over-cooling, increasing thermal gradient between hemispheres,
  - northwards push of ITCZ.

# FLNT SEASONAL CYCLE



# SEDIMENTATION SCHEME

- pkg_cld_sediment.F90
- Based on MATCH-MPIC version 2.0 (Lawrence and Crutzen, Tellus, 1998), adapted by Rasch and Boville, 1998 – 2003.
- Stoke's terminal velocity for < 40 microns.
- Cloud liquid and ice particles are allowed to sediment using independent settling velocities.

# SEDIMENTATION SCHEME

- Sedimenting particles evaporate if they fall into the cloud free portion of a layer.
- No bound is applied to prevent supersaturation of the layer. This will be accounted for in the subsequent cloud condensate tendency calculation.
- Maximum overlap is assumed for stratiform clouds, so particles only evaporate if the cloud fraction is larger in the layer above.