THE EFFECTS OF CONVECTIVE SHIELDS AND CUMULUS-SCALE VERTICAL VELOCITIES ON THE GENERAL CIRCULATION

Leo Donner, GFDL, Princeton University

Donner (1993, *J. Atmos. Sci.*) cumulus parameterization includes convective shields explicitly, using a sub-grid distribution function for cumulus-scale vertical velocity to drive microphysical loading for the shields.

I. How important are the convective shields to the general circulation? (GCM answer)

II. How important are the vertical velocity distributions, *i.e.*, why should they be parameterized? (GCM answer)

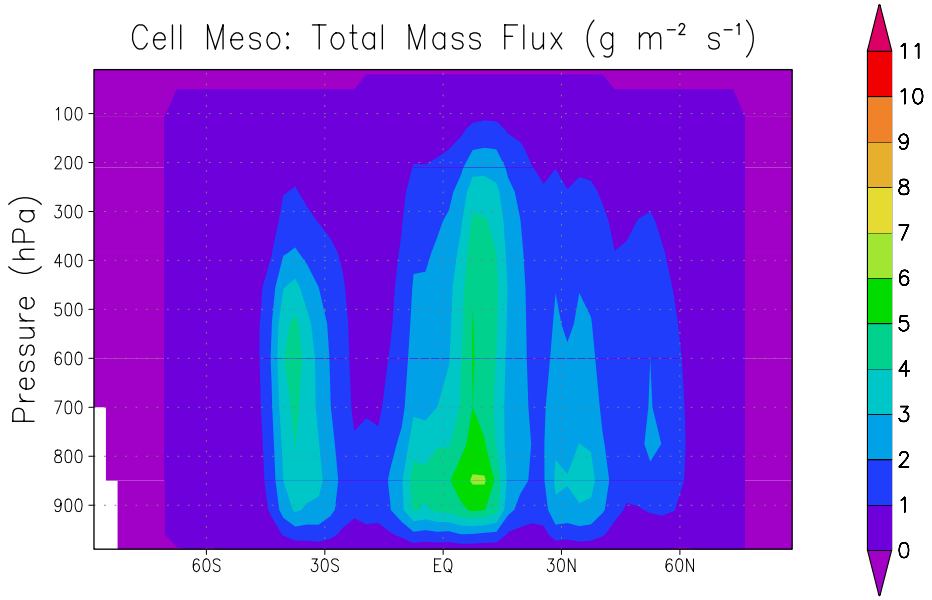
III. Is there a "reality check" on the sub-grid GCM distributions? (Meteostat, GOES, GMS ISCCP B3 answer)

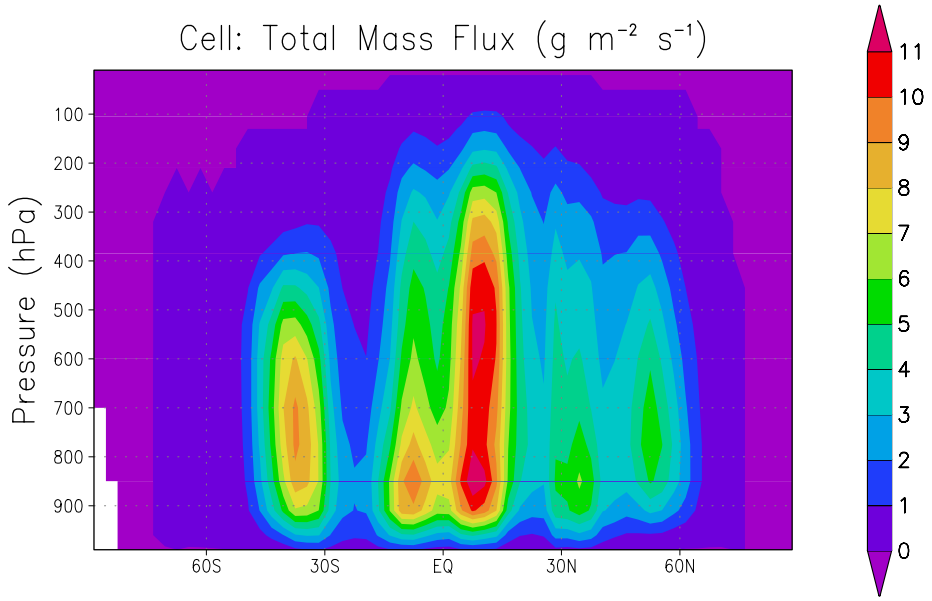
EXPERIMENTS

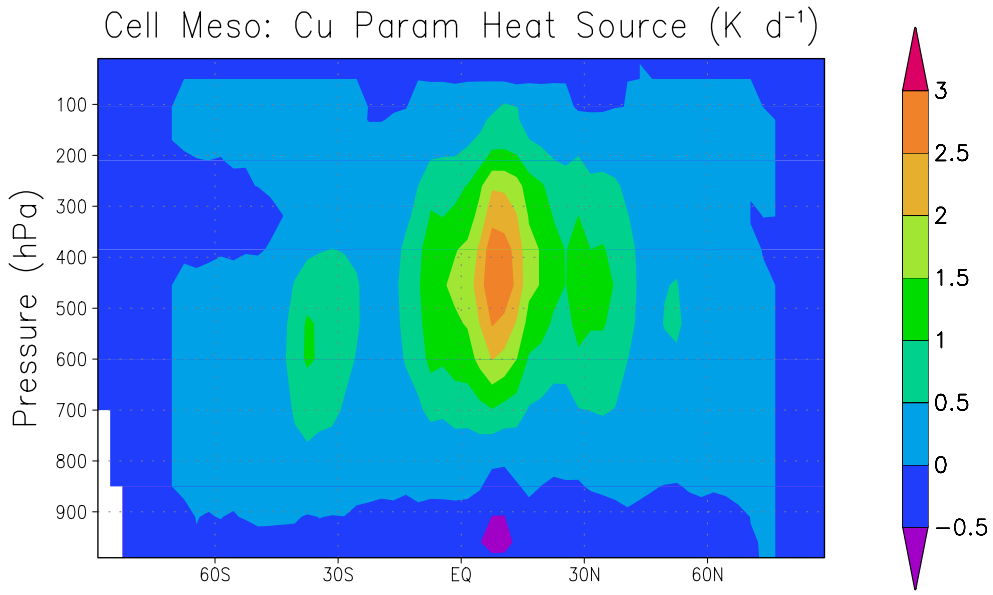
I. Cell Meso: Donner (1993, *J. Atmos. Sci.*) with both deep convective cells and mesoscale stratiform circulations (dinlco).

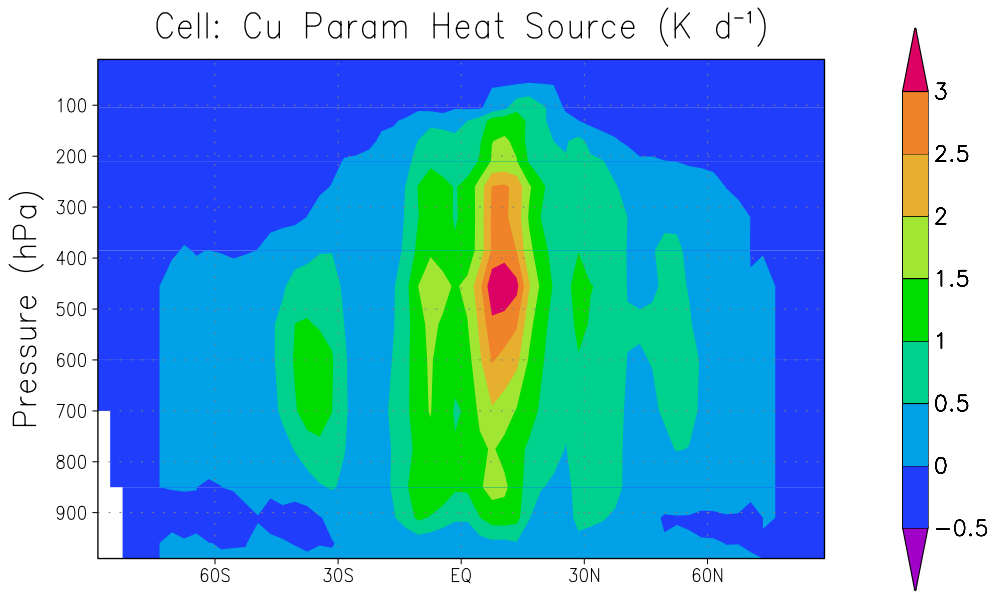
II. Cell: Donner (1993, *J. Atmos. Sci.*) with deep convective cells only (nomesa).

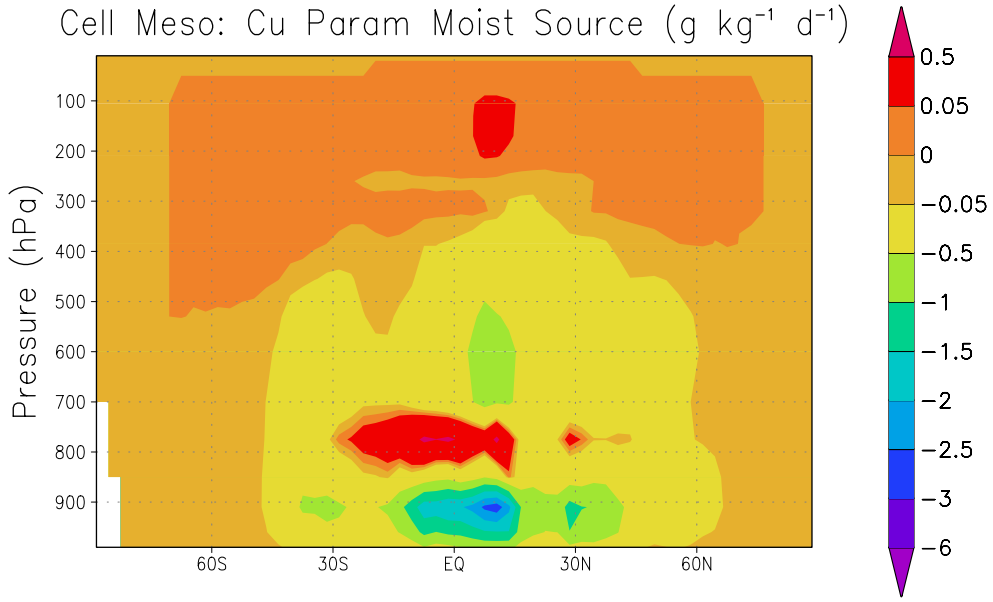
III. Fixed *w*: Donner (1993, *J. Atmos. Sci.*) with both deep convective cells and mesoscale stratiform circulation but no geographical or vertical variation in cumulus vertical velocity. (Only variation is according to sub-ensemble.) (nlconc)

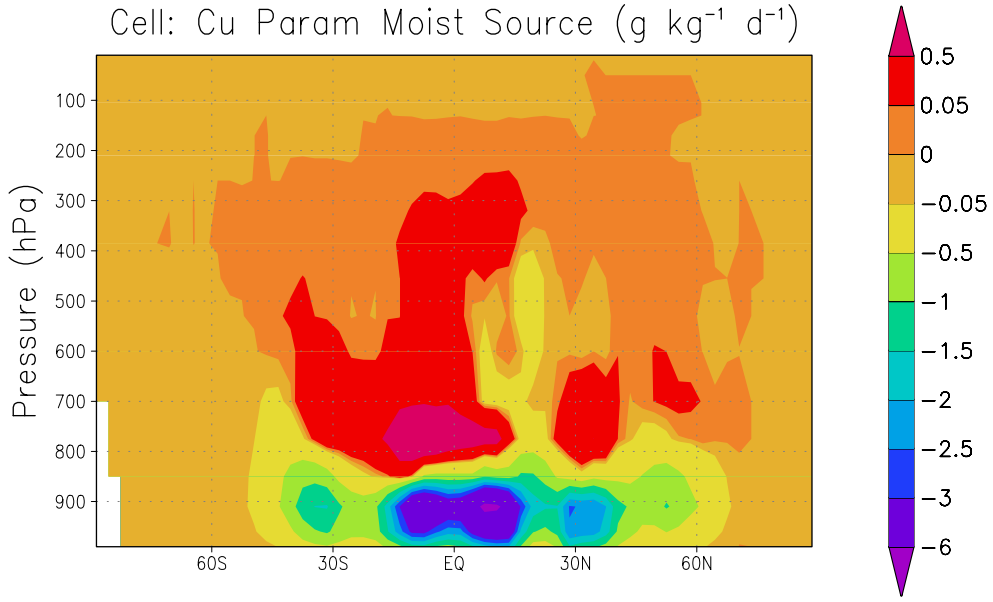

Cell Meso: Total Mass Flux (g m⁻² s⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
11
10
9
8
7
6
5
4
3
2
1
0

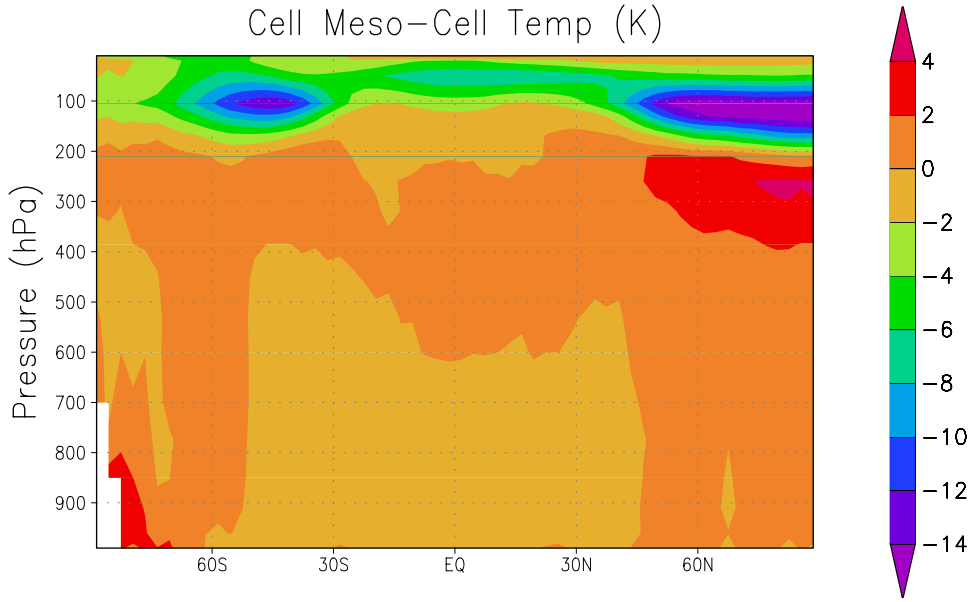

Cell: Total Mass Flux (g m⁻² s⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
11
10
9
8
7
6
5
4
3
2
1
0

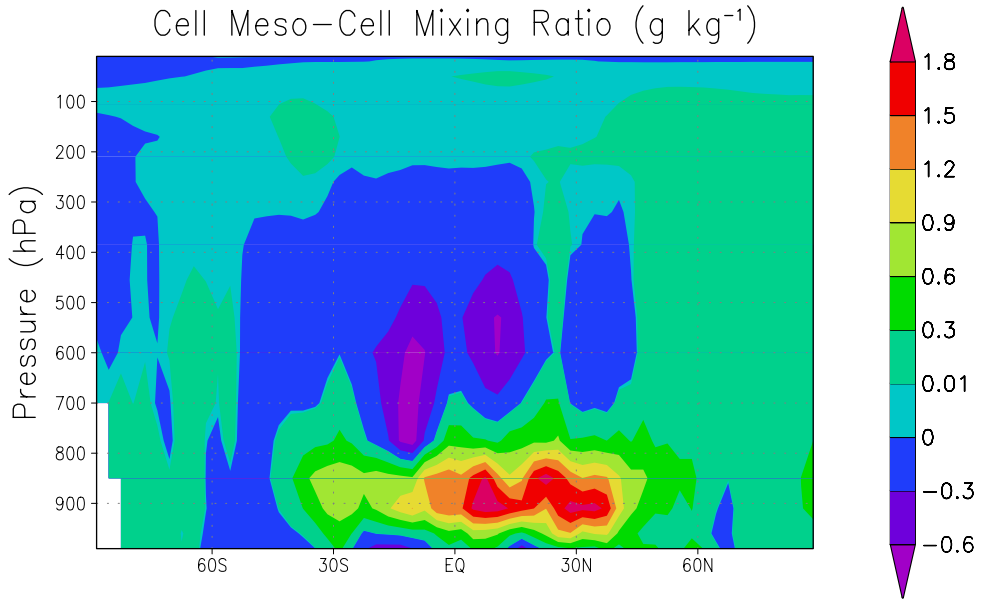

Cell Meso: Cu Param Heat Source (K d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
3
2.5
2
1.5
1
0.5
0
−0.5

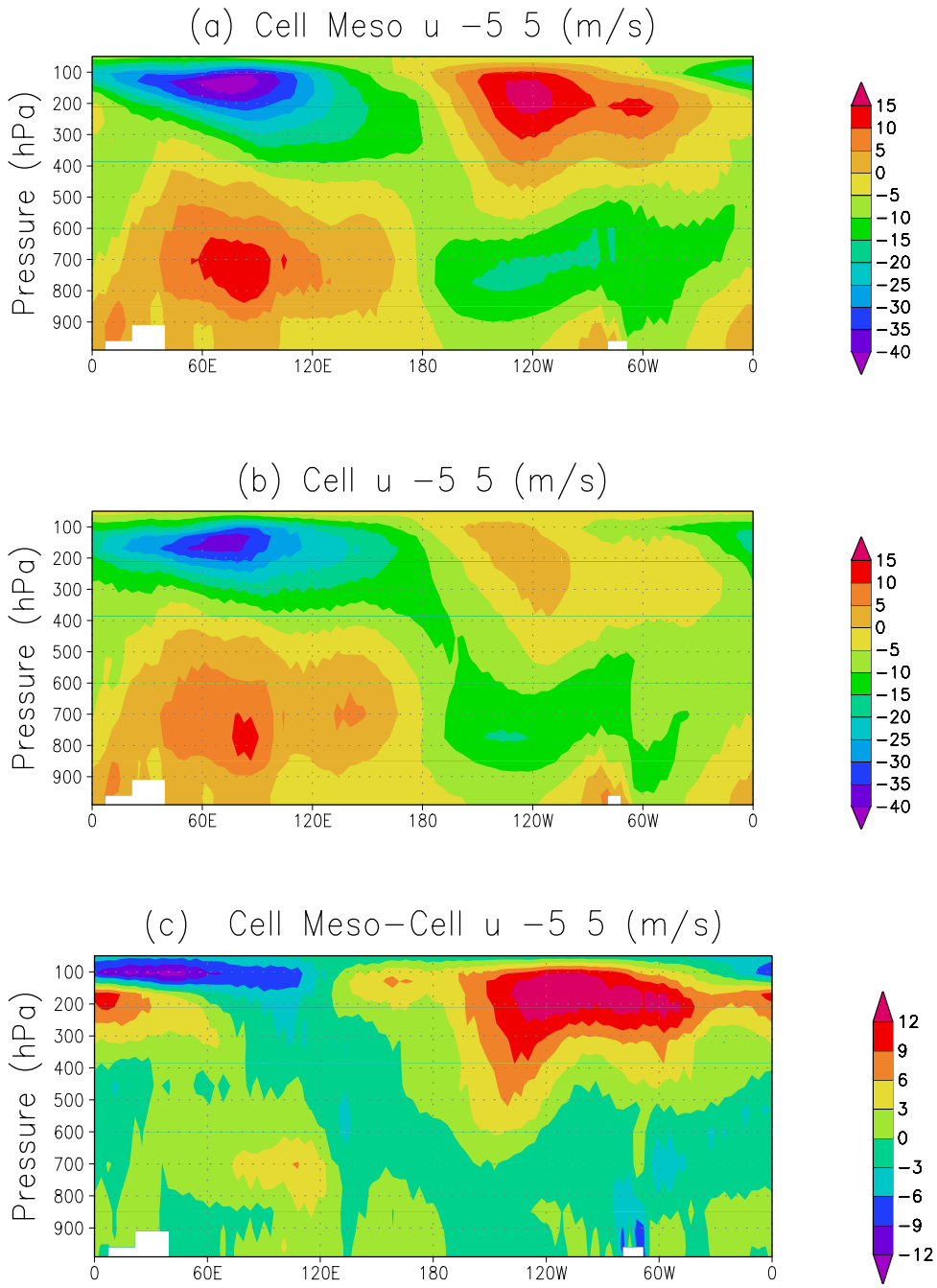

Cell: Cu Param Heat Source (K d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
3
2.5
2
1.5
1
0.5
0
−0.5


Cell Meso: Cu Param Moist Source (g kg⁻¹ d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0.5
0.05
0
−0.05
−0.5
−1
−1.5
−2
−2.5
−3
−6

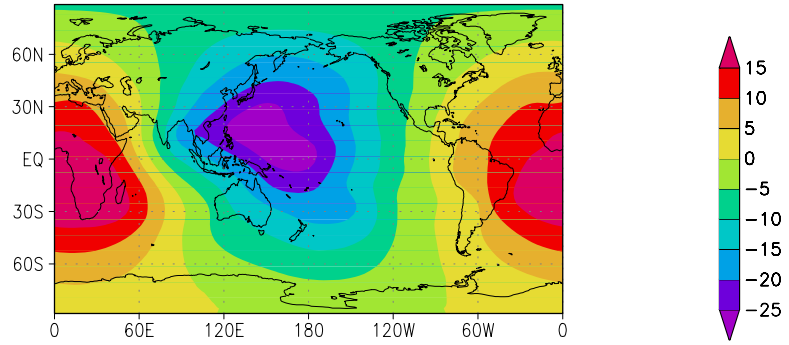

Cell: Cu Param Moist Source (g kg⁻¹ d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0.5
0.05
0
−0.05
−0.5
−1
−1.5
−2
−2.5
−3
−6


Cell Meso−Cell Temp (K)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
4
2
0
−2
−4
−6
−8
−10
−12
−14

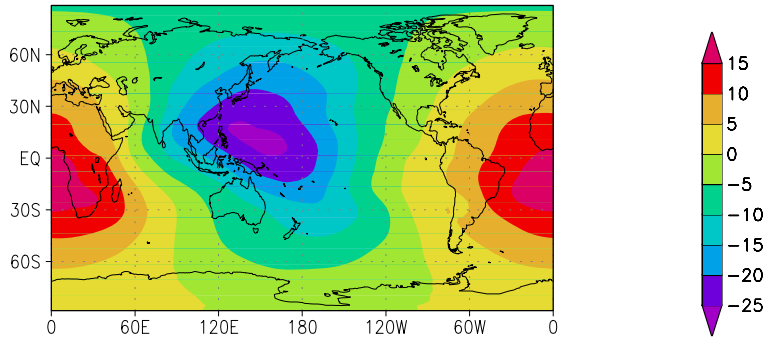

Cell Meso−Cell Mixing Ratio (g kg⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
1.8
1.5
1.2
0.9
0.6
0.3
0.01
0
−0.3
−0.6


(a) Cell Meso u −5 5 (m/s)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
0
60E
120E
180
120W
60W
0
15
10
5
0
−5
−10
−15
−20
−25
−30
−35
−40
(b) Cell u −5 5 (m/s)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
0
60E
120E
180
120W
60W
0
15
10
5
0
−5
−10
−15
−20
−25
−30
−35
−40
(c) Cell Meso−Cell u −5 5 (m/s)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
0
60E
120E
180
120W
60W
0
12
9
6
3
0
−3
−6
−9
−12

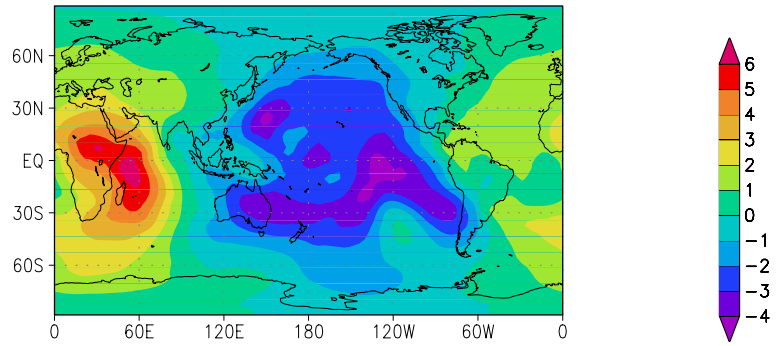
(a) Cell Meso: 210 hPa Vel Pot (10^6 m^2 s^{-1})



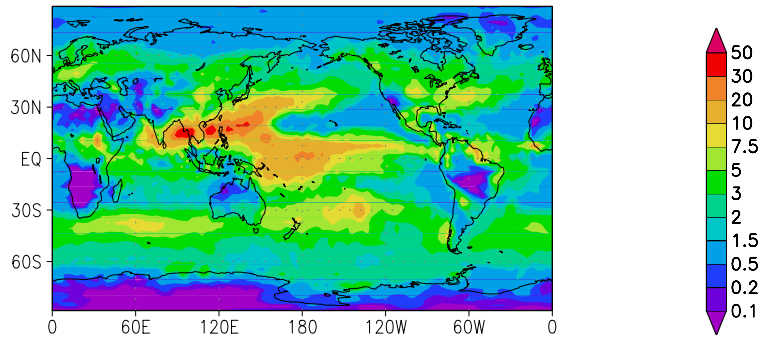
(b) Cell: 210 hPa Vel Pot (10^6 m^2 s^{-1})



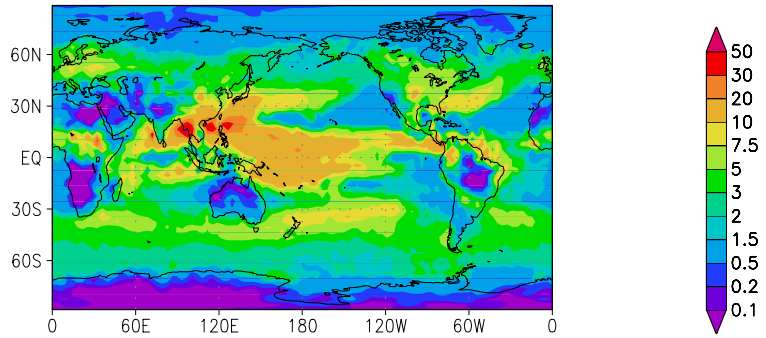
(c) Cell Meso−Cell 210 hPa Vel Pot (10^6 m^2 s^{-1})



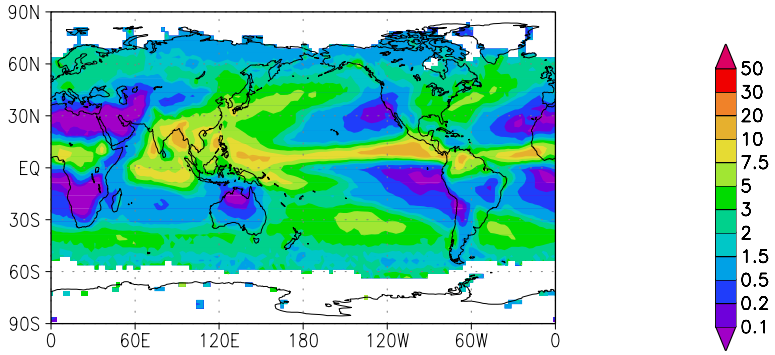
(a) Cell Meso: Total Precip (mm d^{-1})

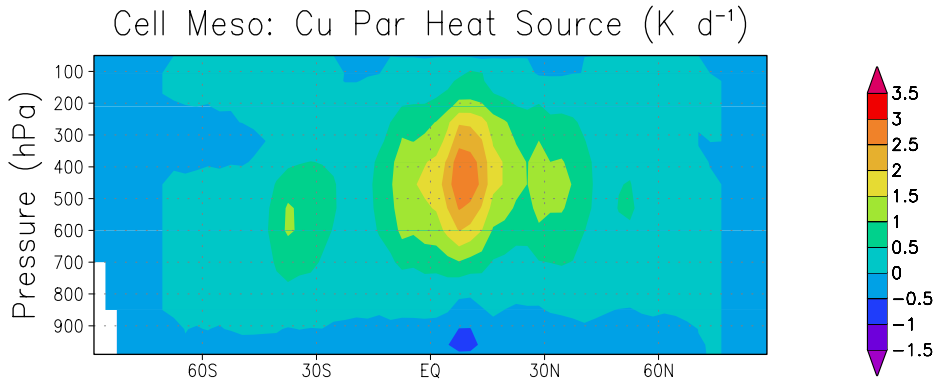


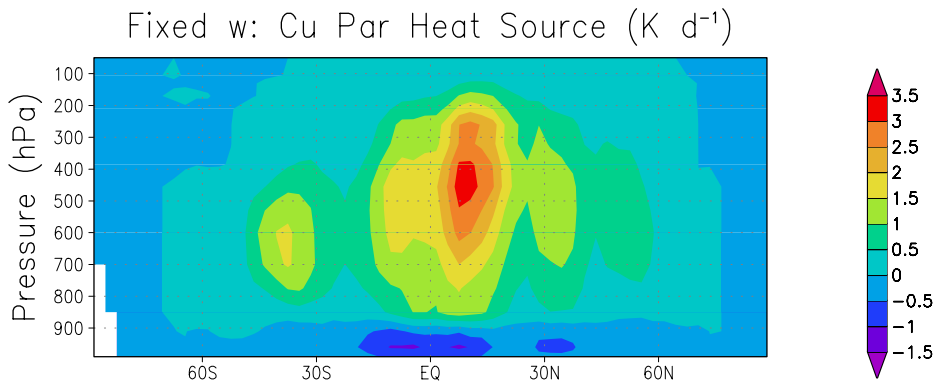
(b) Cell: Total Precip (mm d^{-1})

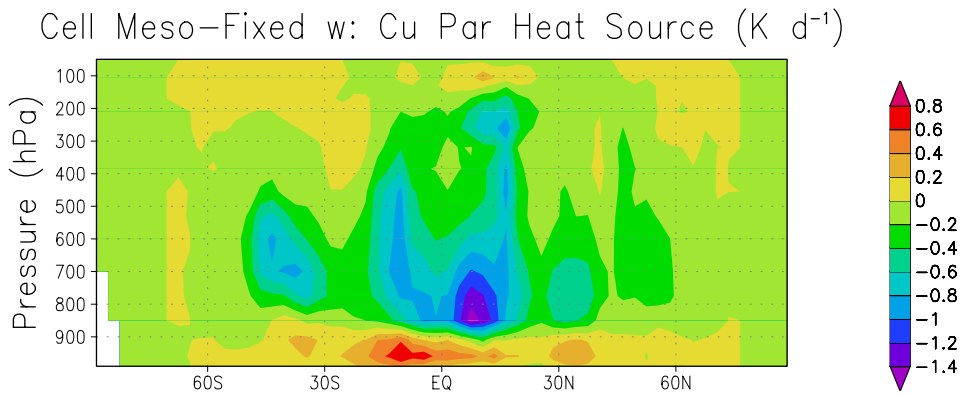


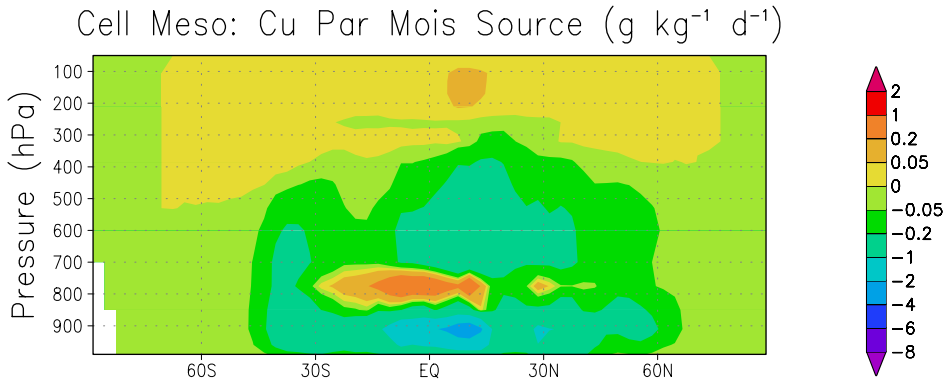
(c) GPCP JJA Precipitation (mm d^{-1})

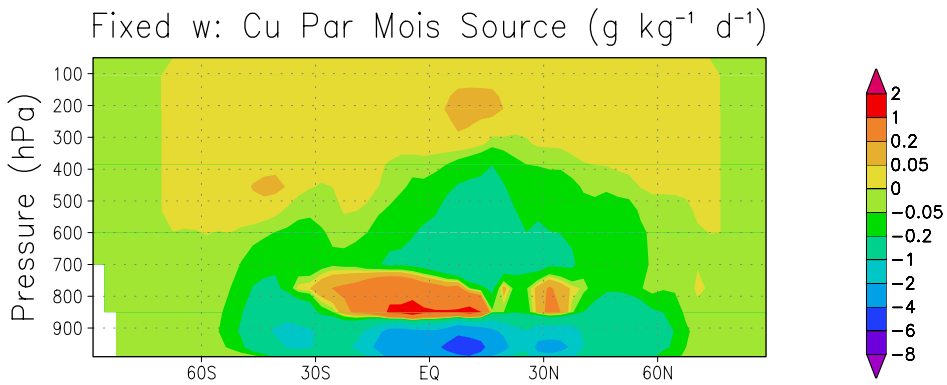


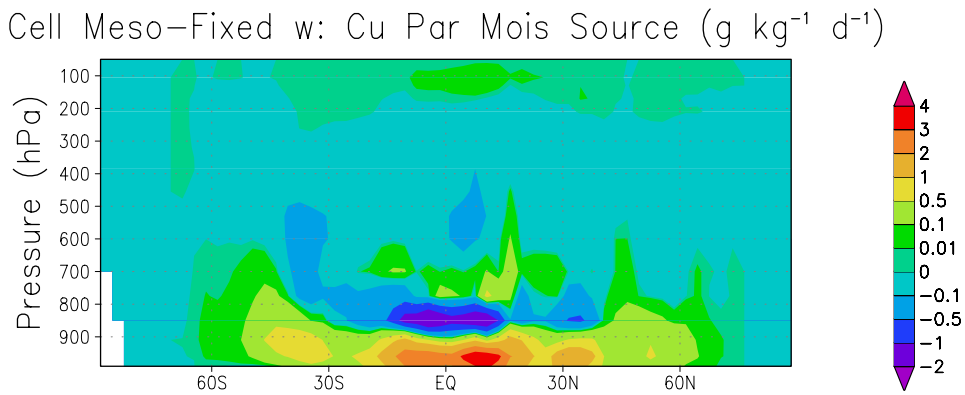

Cell Meso: Cu Par Heat Source (K d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
−1.5

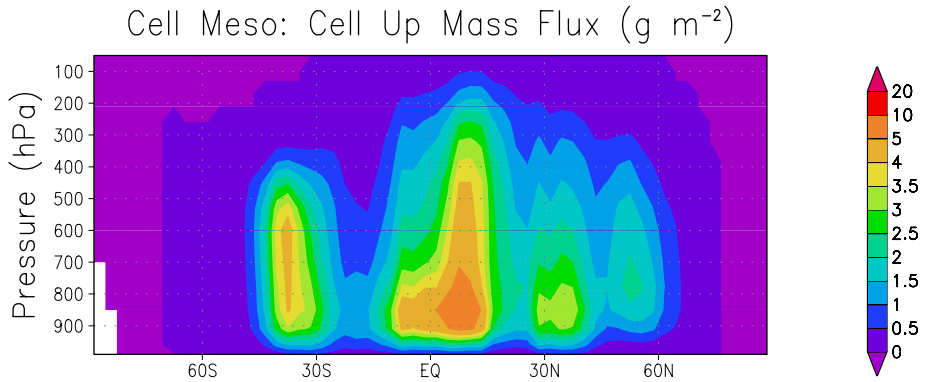

Fixed w: Cu Par Heat Source (K d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
−1.5

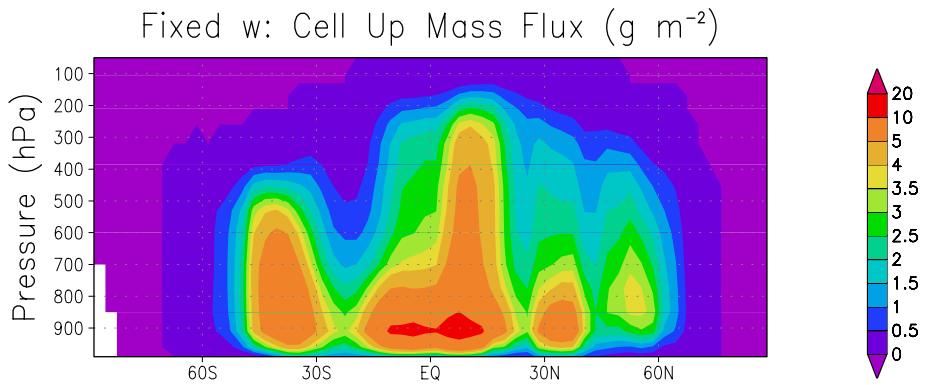

Cell Meso−Fixed w: Cu Par Heat Source (K d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4

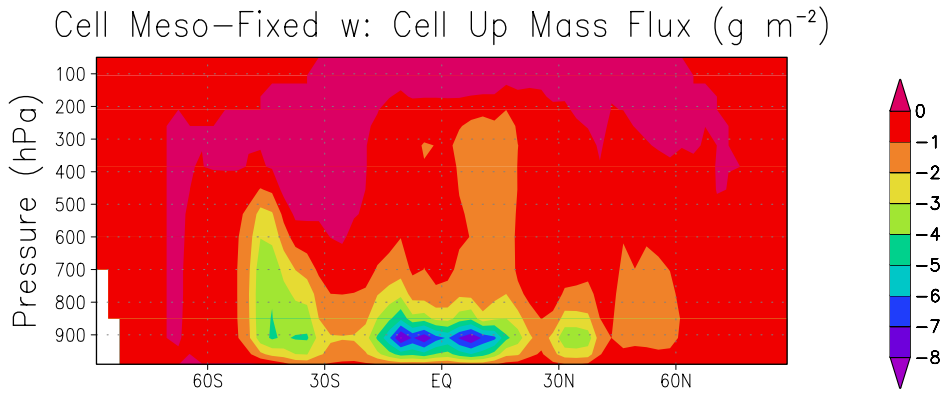

Cell Meso: Cu Par Mois Source (g kg⁻¹ d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
2
1
0.2
0.05
0
−0.05
−0.2
−1
−2
−4
−6
−8

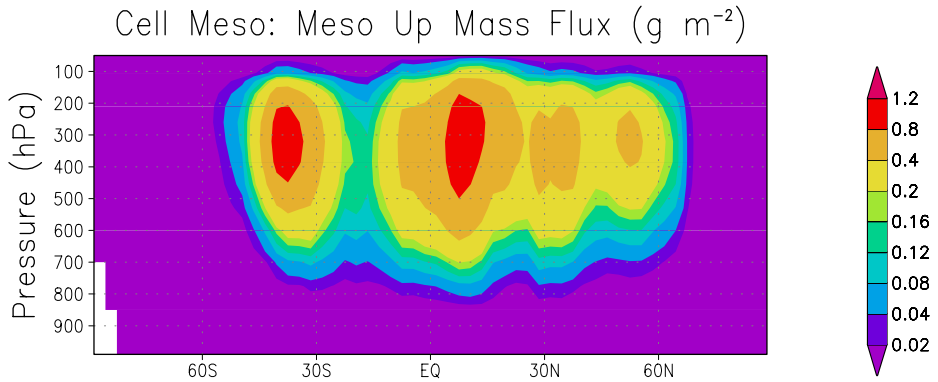

Fixed w: Cu Par Mois Source (g kg⁻¹ d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
2
1
0.2
0.05
0
−0.05
−0.2
−1
−2
−4
−6
−8

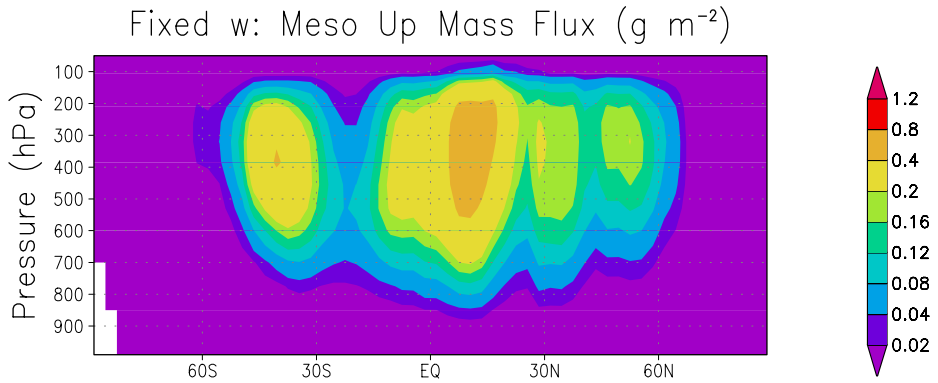

Cell Meso−Fixed w: Cu Par Mois Source (g kg⁻¹ d⁻¹)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
4
3
2
1
0.5
0.1
0.01
0
−0.1
−0.5
−1
−2

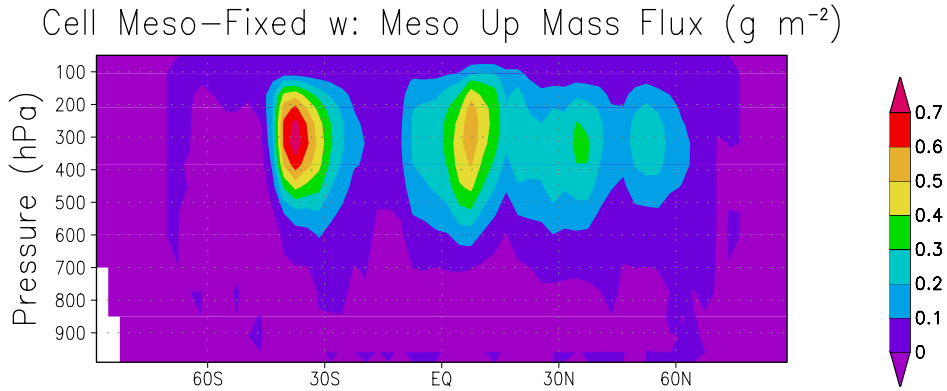

Cell Meso: Cell Up Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
20
10
5
4
3.5
3
2.5
2
1.5
1
0.5
0

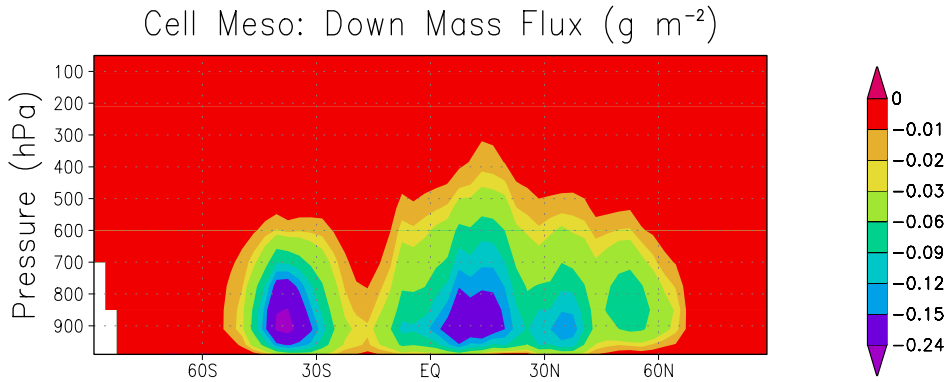

Fixed w: Cell Up Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
20
10
5
4
3.5
3
2.5
2
1.5
1
0.5
0

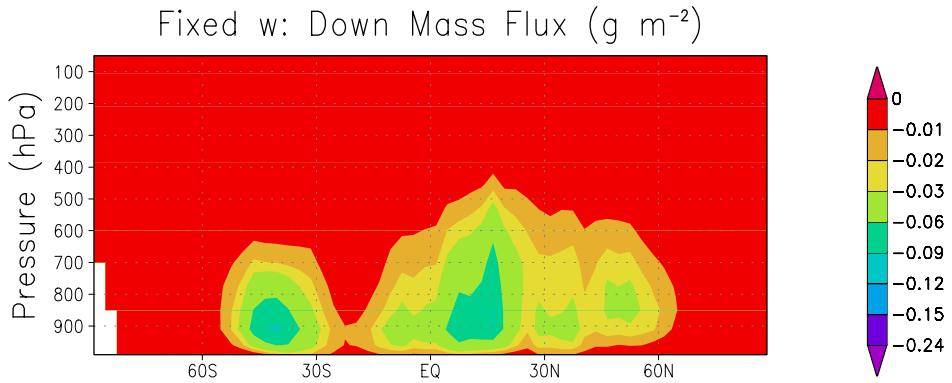

Cell Meso−Fixed w: Cell Up Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0
−1
−2
−3
−4
−5
−6
−7
−8

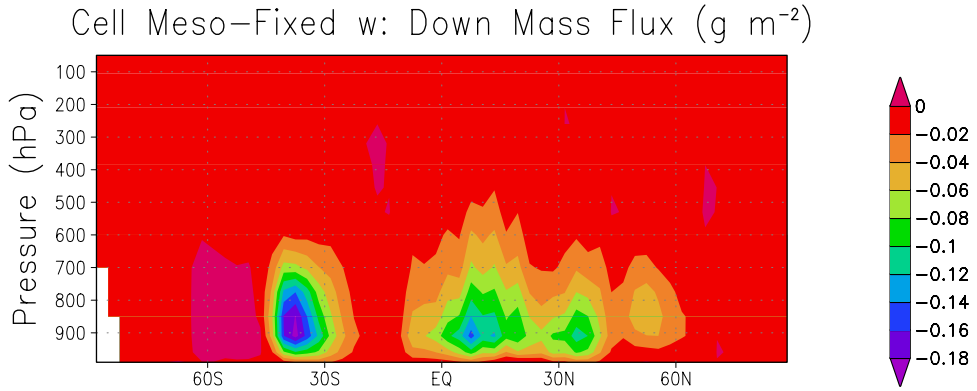

Cell Meso: Meso Up Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
1.2
0.8
0.4
0.2
0.16
0.12
0.08
0.04
0.02

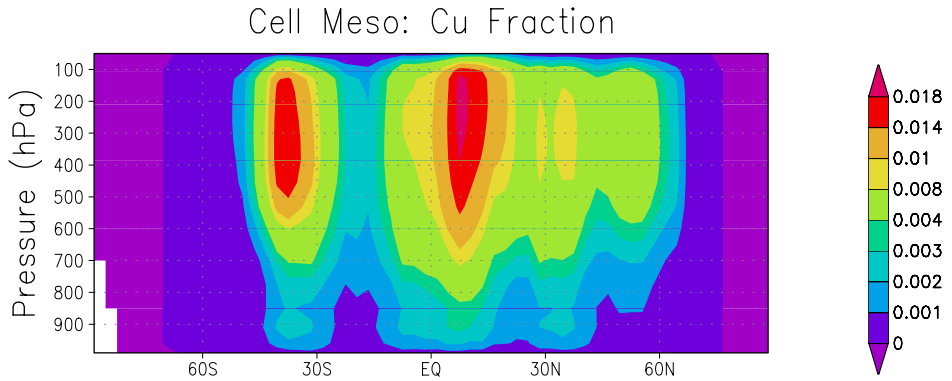

Fixed w: Meso Up Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
1.2
0.8
0.4
0.2
0.16
0.12
0.08
0.04
0.02

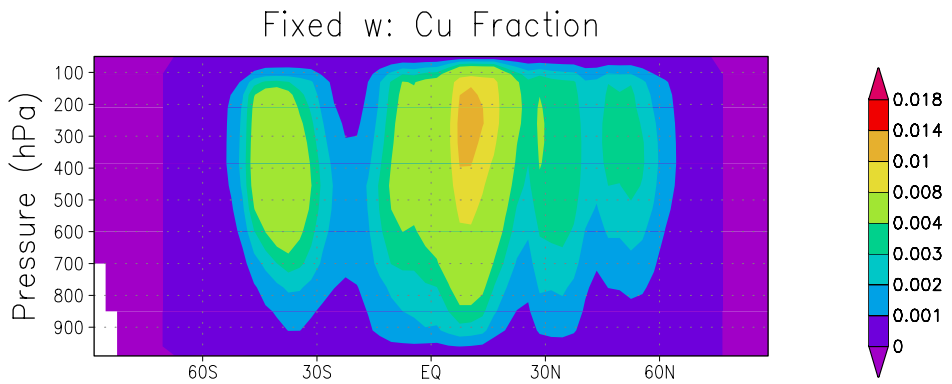

Cell Meso−Fixed w: Meso Up Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

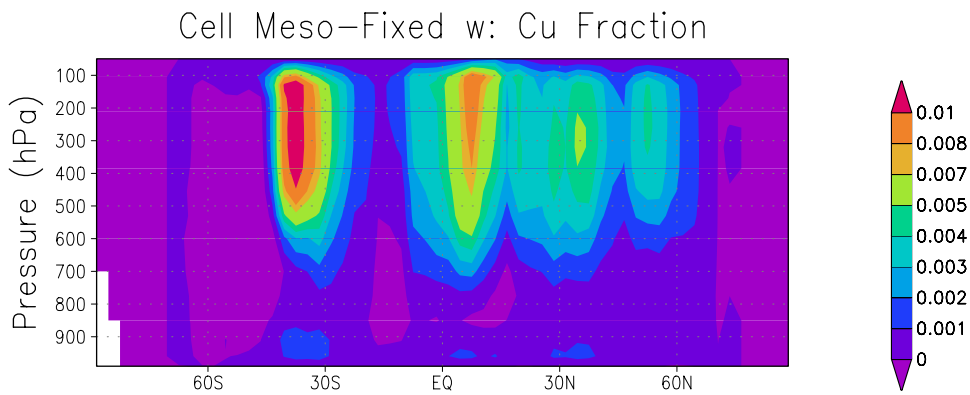

Cell Meso: Down Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0
−0.01
−0.02
−0.03
−0.06
−0.09
−0.12
−0.15
−0.24

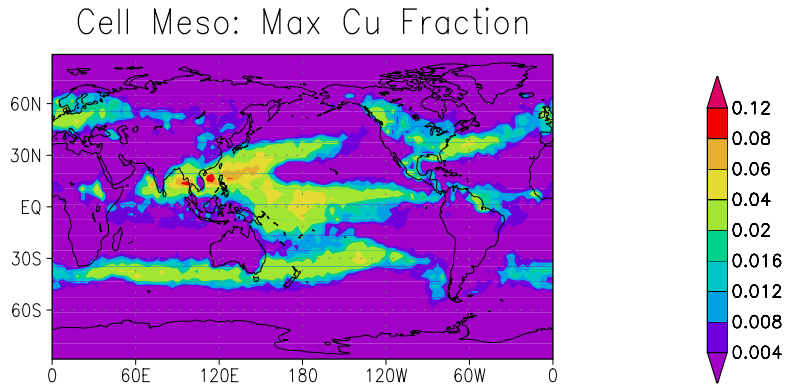

Fixed w: Down Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0
−0.01
−0.02
−0.03
−0.06
−0.09
−0.12
−0.15
−0.24

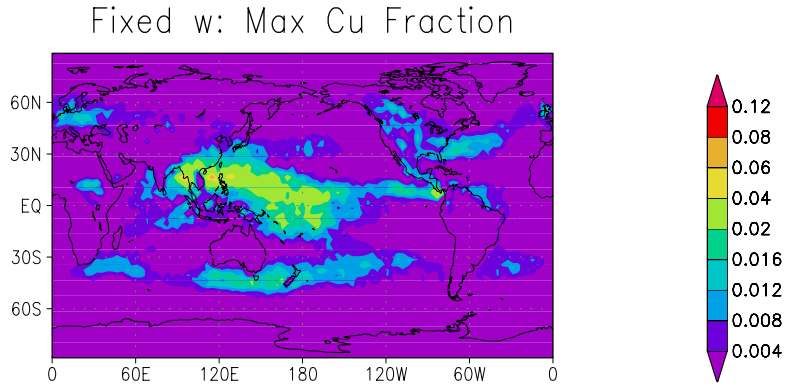

Cell Meso−Fixed w: Down Mass Flux (g m⁻²)
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0
−0.02
−0.04
−0.06
−0.08
−0.1
−0.12
−0.14
−0.16
−0.18

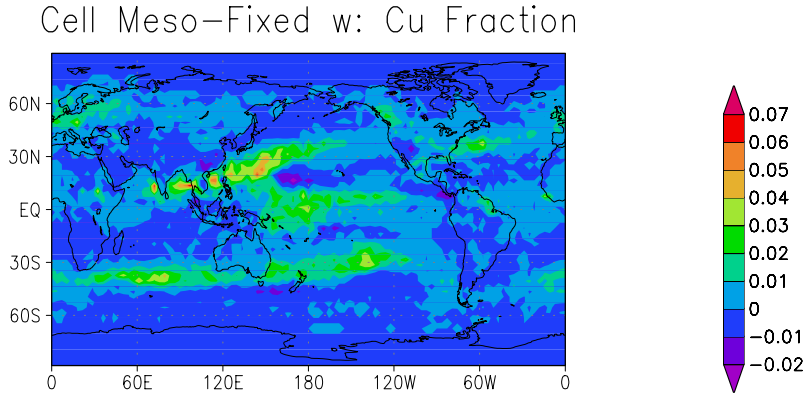

Cell Meso: Cu Fraction
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0.018
0.014
0.01
0.008
0.004
0.003
0.002
0.001
0


Fixed w: Cu Fraction
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0.018
0.014
0.01
0.008
0.004
0.003
0.002
0.001
0

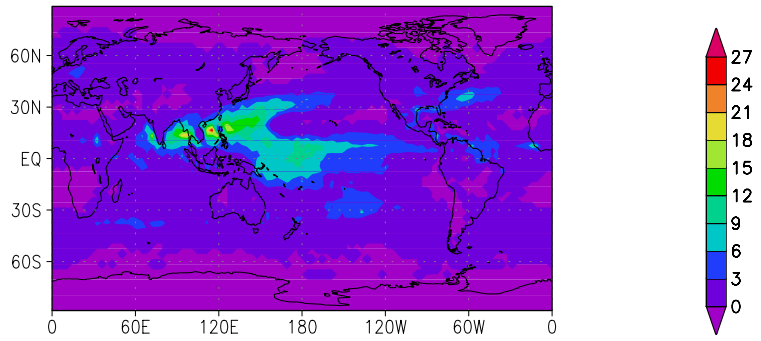

Cell Meso−Fixed w: Cu Fraction
Pressure (hPa)
100
200
300
400
500
600
700
800
900
60S
30S
EQ
30N
60N
0.01
0.008
0.007
0.005
0.004
0.003
0.002
0.001
0


Cell Meso: Max Cu Fraction
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
0.12
0.08
0.06
0.04
0.02
0.016
0.012
0.008
0.004

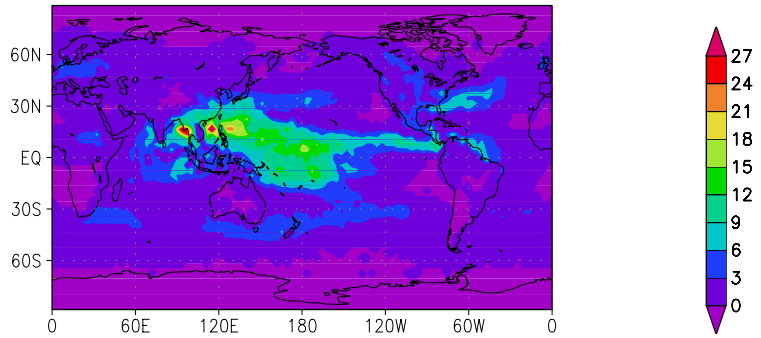

Fixed w: Max Cu Fraction
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
0.12
0.08
0.06
0.04
0.02
0.016
0.012
0.008
0.004


Cell Meso−Fixed w: Cu Fraction
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
−0.01
−0.02

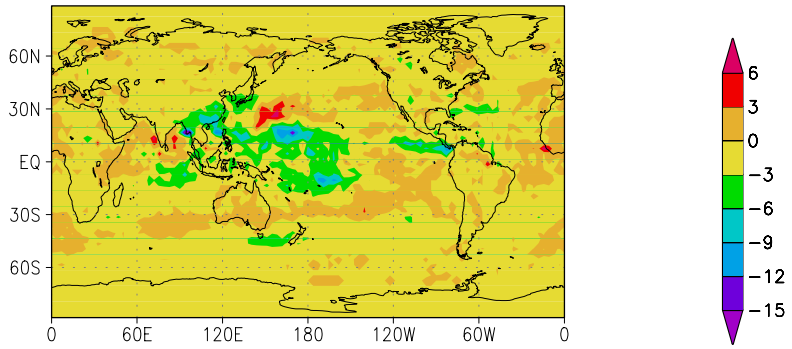
Cell Meso: Con Sys Precip (mm d^{-1})



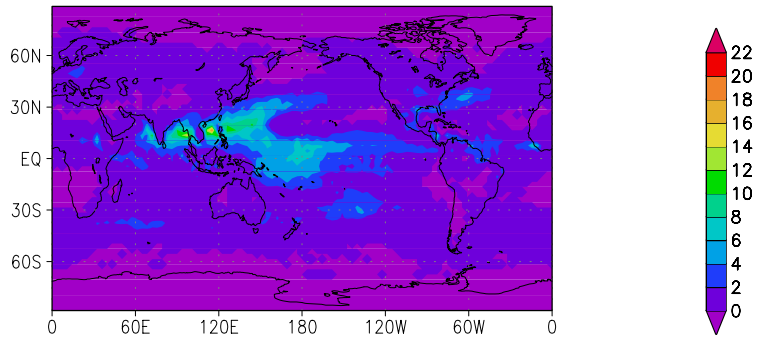
Fixed w: Con Sys Precip (mm d^{-1})



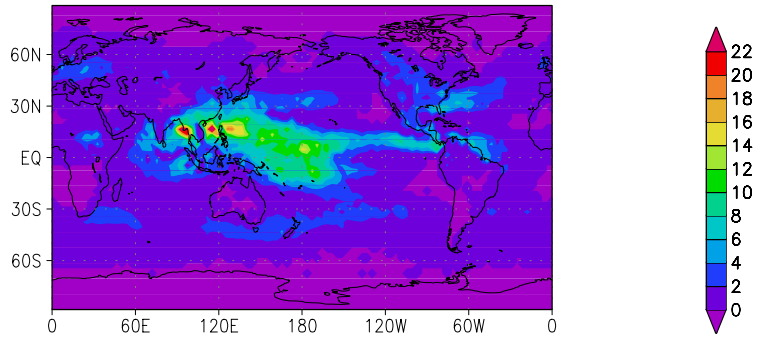
Cell Meso−Fixed w: Con Sys Precip (mm d^{-1})



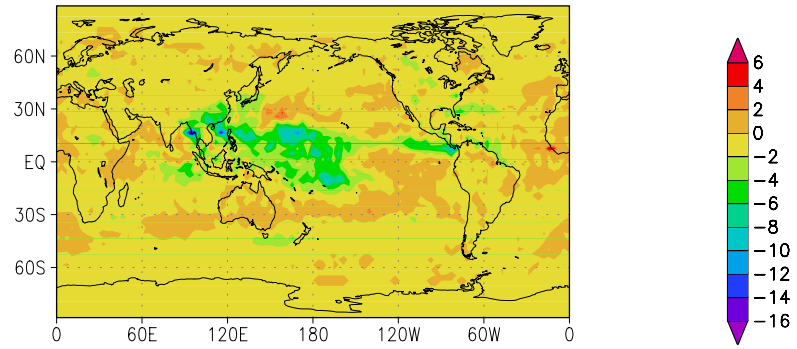
Cell Meso: Cell Precip (mm d^{-1})



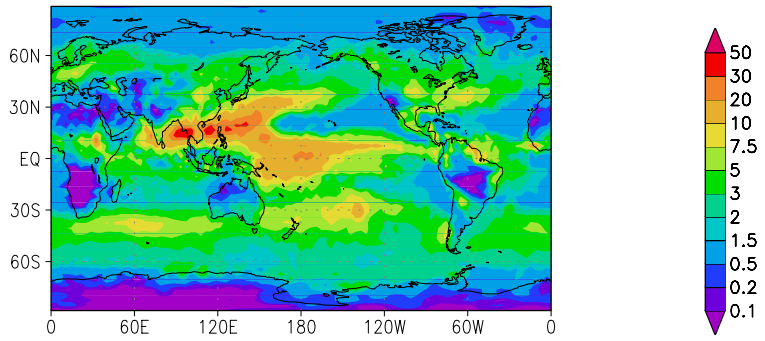
Fixed w: Cell Precip (mm d^{-1})



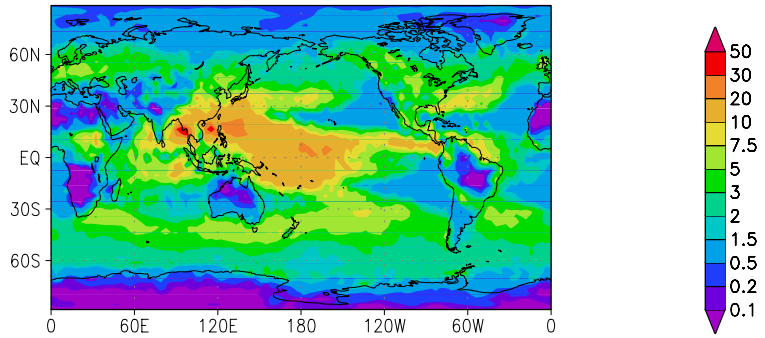
Cell Meso−Fixed w: Con Sys Precip (mm d^{-1})



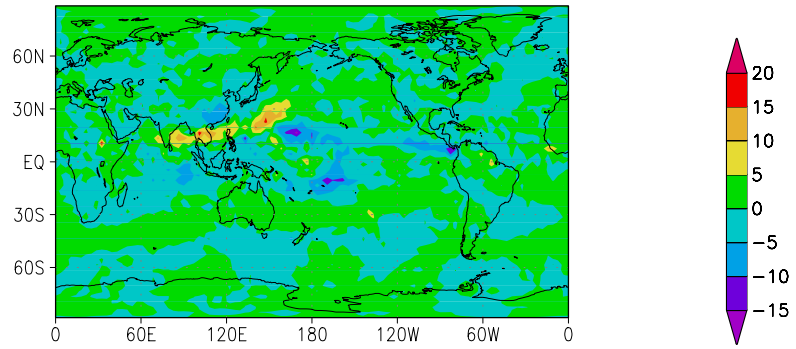
Cell Meso: Total Precip (mm d^{-1})

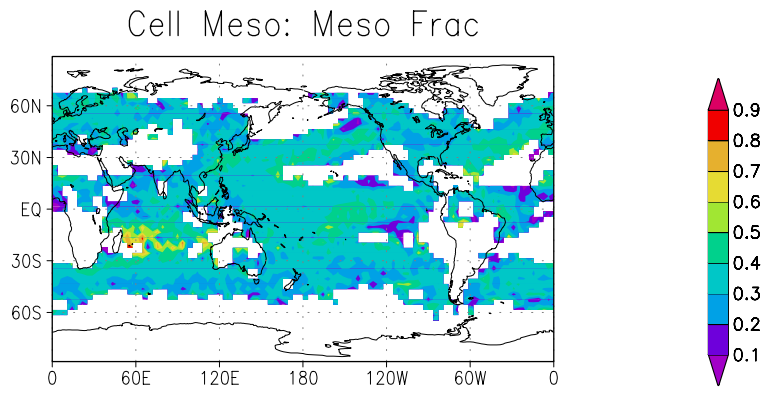


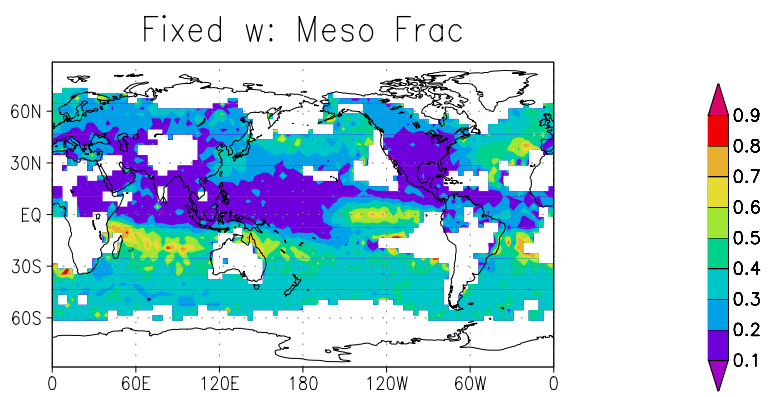
Fixed w: Total Precip (mm d^{-1})

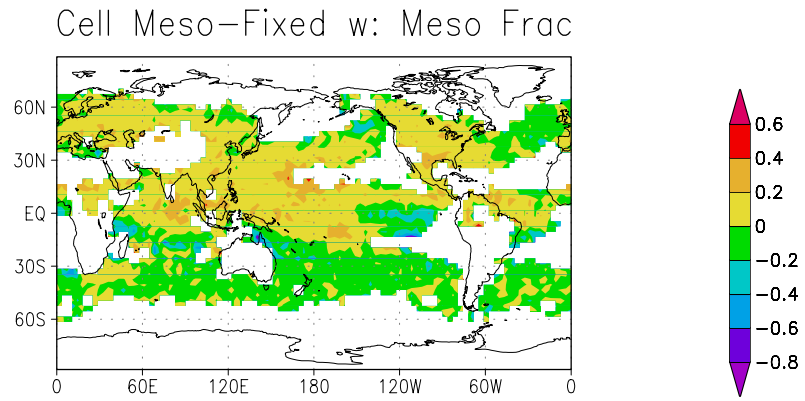


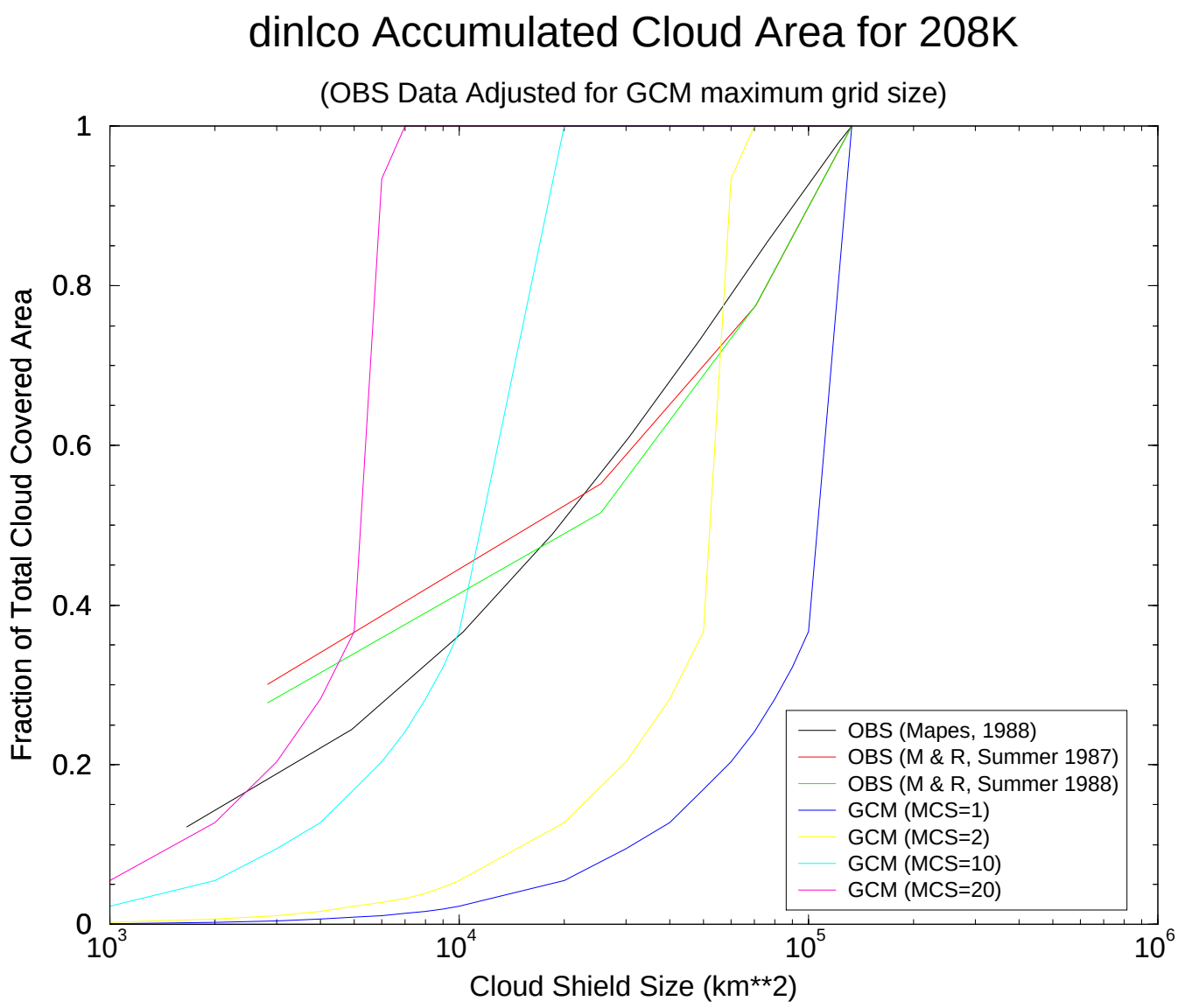
Cell Meso−Fixed w: Con Sys Precip (mm d^{-1})

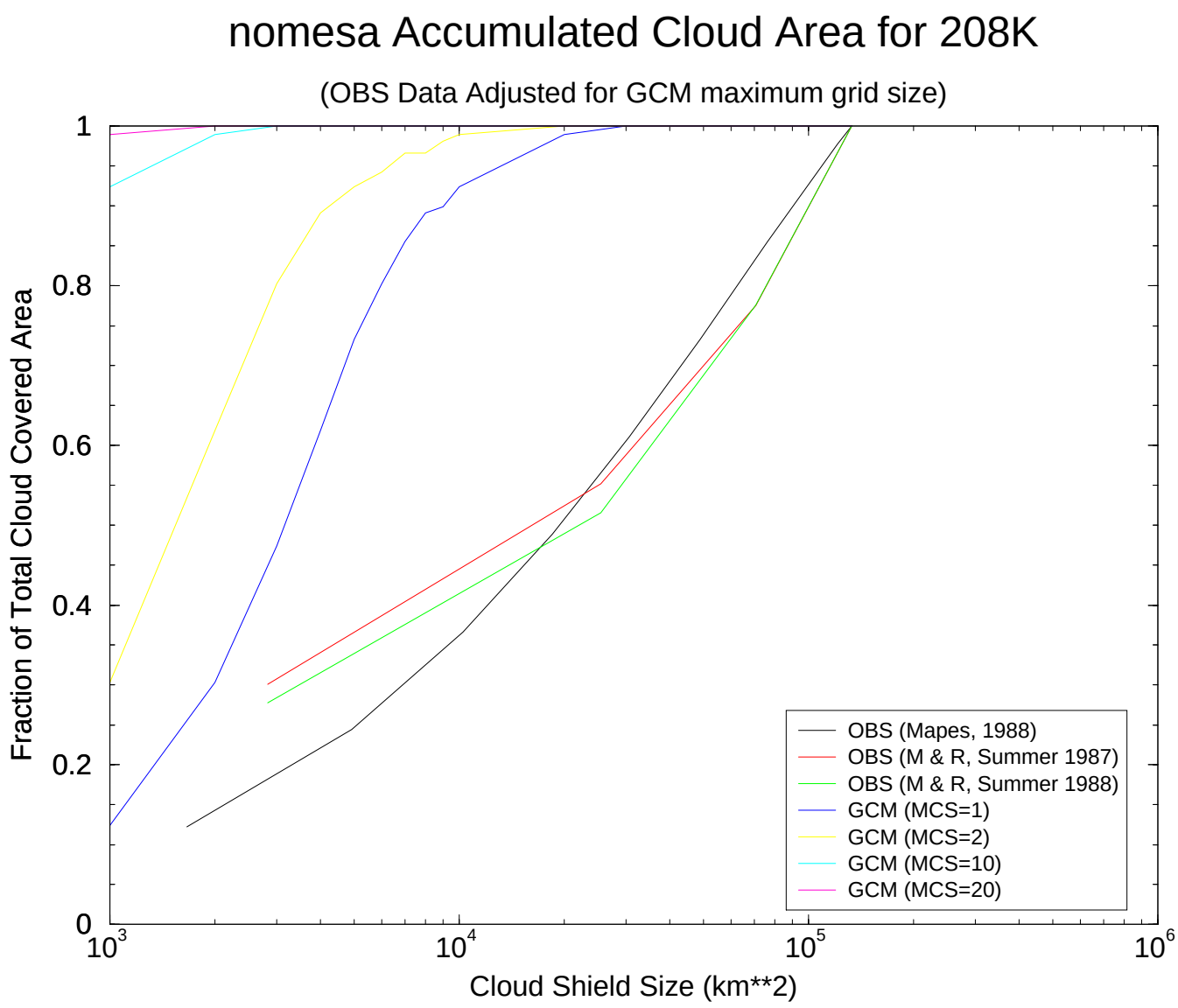



Cell Meso: Meso Frac
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1


Fixed w: Meso Frac
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

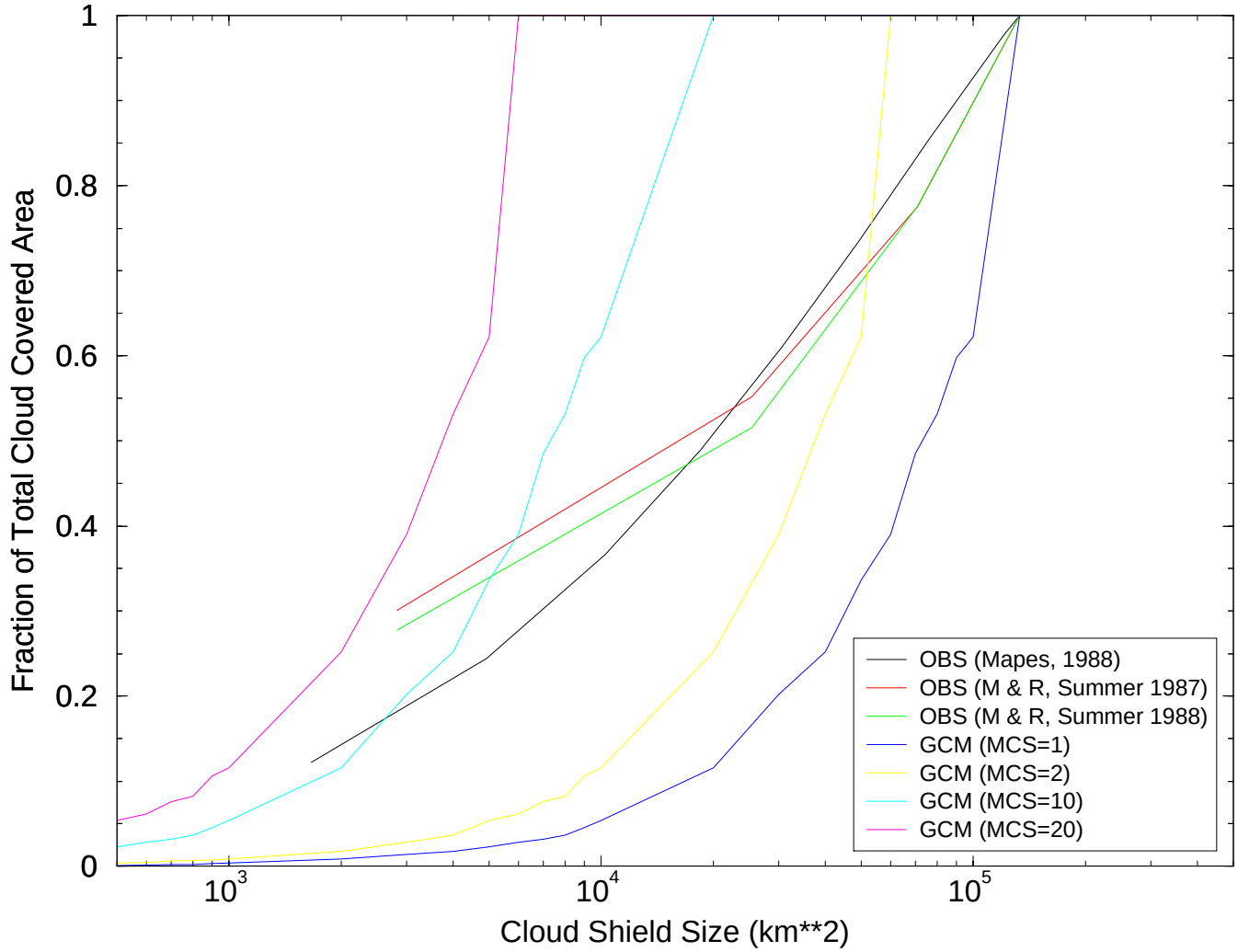

Cell Meso−Fixed w: Meso Frac
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8


dinlco Accumulated Cloud Area for 208K
(OBS Data Adjusted for GCM maximum grid size)
Fraction of Total Cloud Covered Area
Cloud Shield Size (km**2)
0
0.2
0.4
0.6
0.8
1
10^3
10^4
10^5
10^6
OBS (Mapes, 1988)
OBS (M & R, Summer 1987)
OBS (M & R, Summer 1988)
GCM (MCS=1)
GCM (MCS=2)
GCM (MCS=10)
GCM (MCS=20)


nomesa Accumulated Cloud Area for 208K
(OBS Data Adjusted for GCM maximum grid size)
Fraction of Total Cloud Covered Area
Cloud Shield Size (km**2)
0
0.2
0.4
0.6
0.8
1
10^3
10^4
10^5
10^6
OBS (Mapes, 1988)
OBS (M & R, Summer 1987)
OBS (M & R, Summer 1988)
GCM (MCS=1)
GCM (MCS=2)
GCM (MCS=10)
GCM (MCS=20)

nlconc Accumulated Cloud Area for 208K

(OBS Data Adjusted for GCM maximum grid size)



SUMMARY

Effects of Mesoscale Circulations:

I. More middle-troposphere detrainment and less tracer transport to upper troposphere.

II. Heating concentrated at higher altitudes.

III. Moister upper troposphere.

IV. Stronger Walker circulation.

V. Sub-grid distribution of convective-system sizes realistic.

Effects of Variable Cumulus Vertical Velocity:

I. Heating concentrated at higher altitudes.

II. More moistening in PBL and upper troposphere.

III. Less mesoscale activity.

IV. Convective systems larger in spatial extent, larger cloud forcing.