Cloud regimes from joint histograms of passive retrievals and their potential applications

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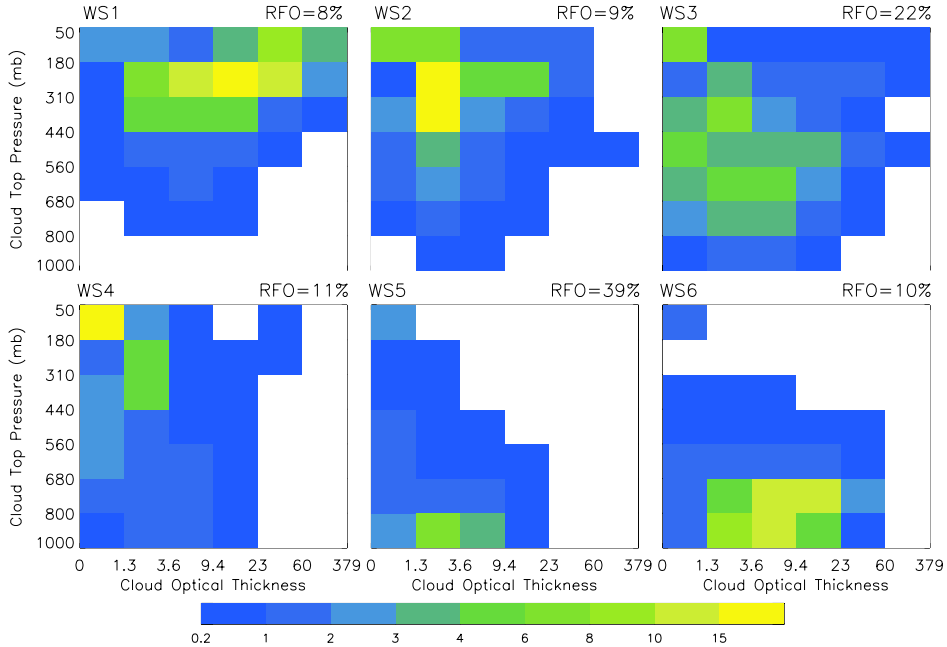
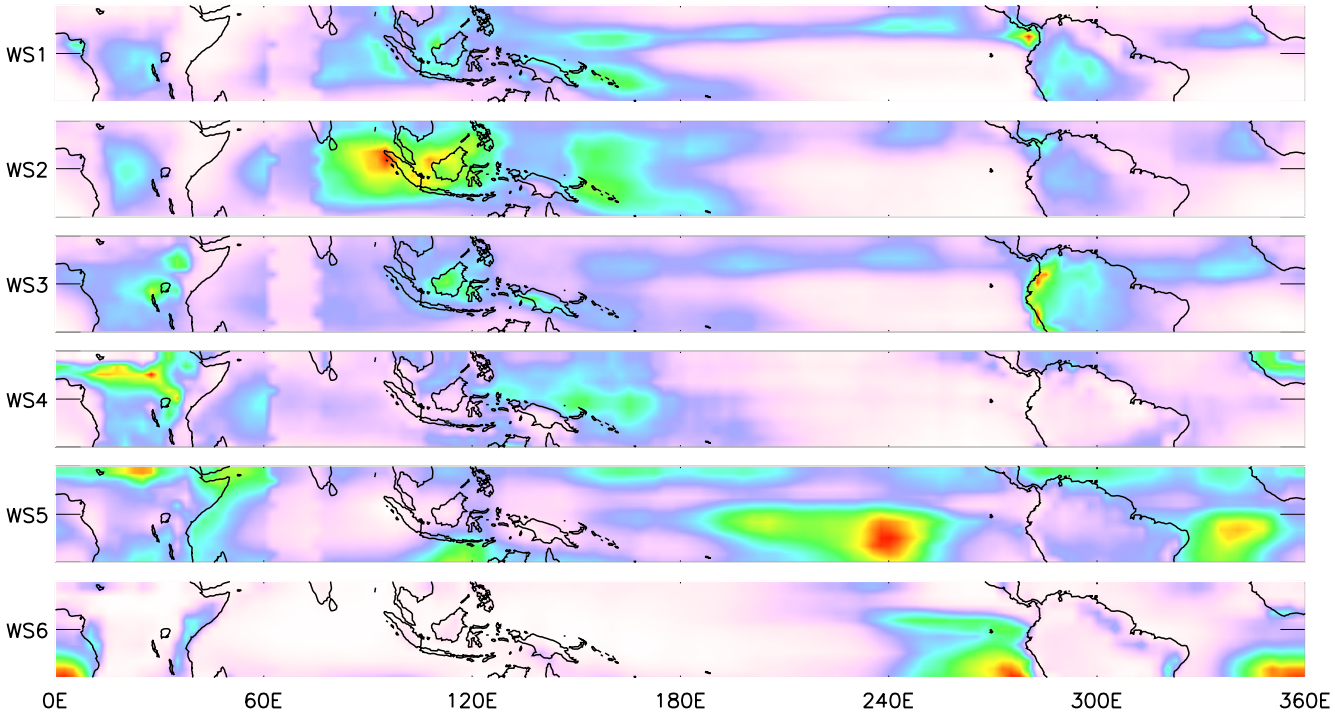
Acknowledgement: NASA MAP and CloudSat/CALIPSO programs

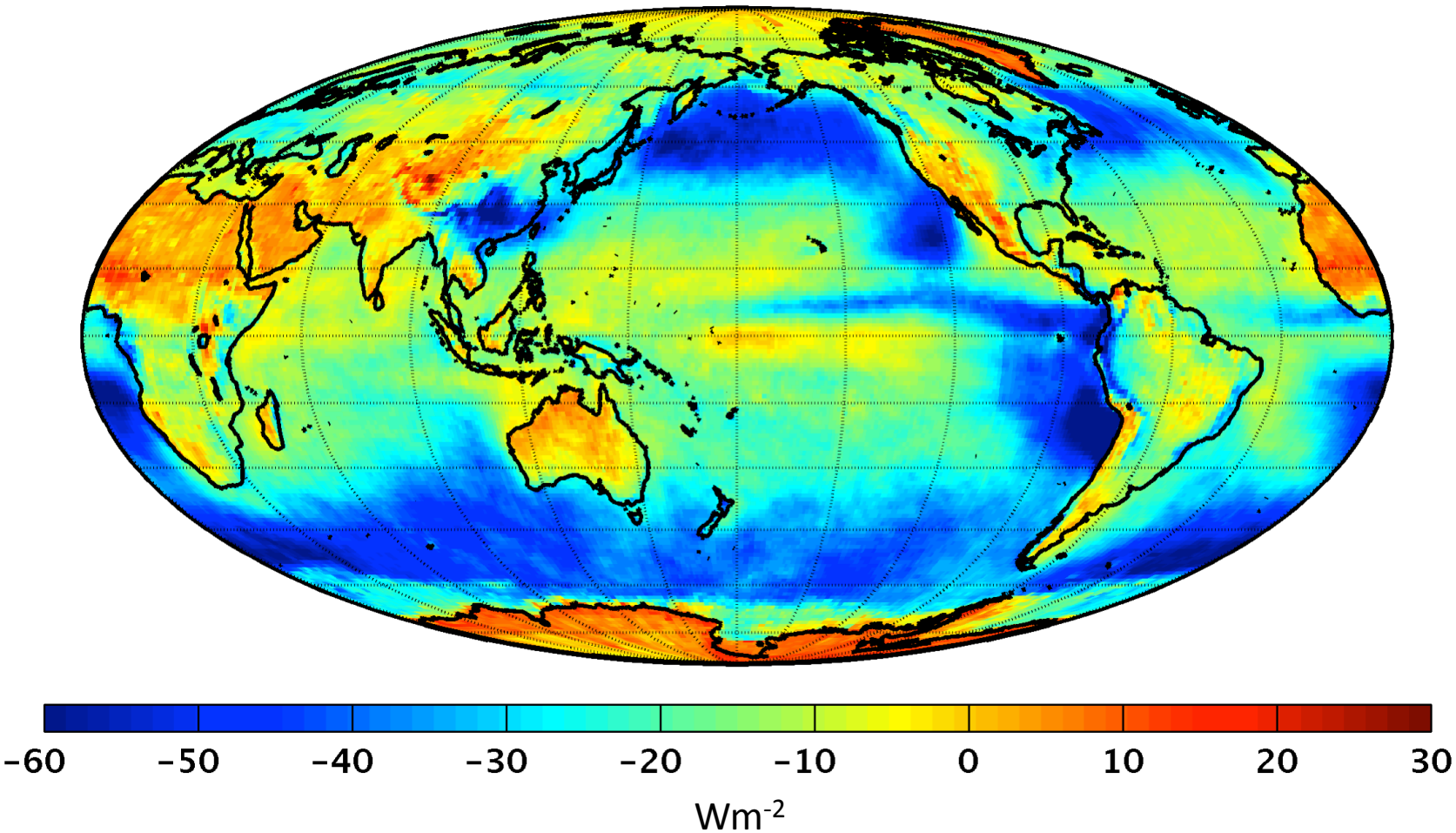
“Weather states” (Rossow et al. 2005), often referred to as cloud regimes



- Patterns of cloud property joint distributions at mesoscale (cloud type mixtures or cloud regimes) that may indicate distinct states of the tropical atmosphere.
- These patterns can be used as the basis for multi-scale, multi-variate compositing of other observations to understand how different cloud regimes affect the atmospheric diabatic heating.
- Distinct values of the diabatic heating of the atmosphere by radiation, precipitation and surface fluxes can be associated with these regimes



Application 1: CRE attribution to cloud regimes



Net TOA CRE from CERES

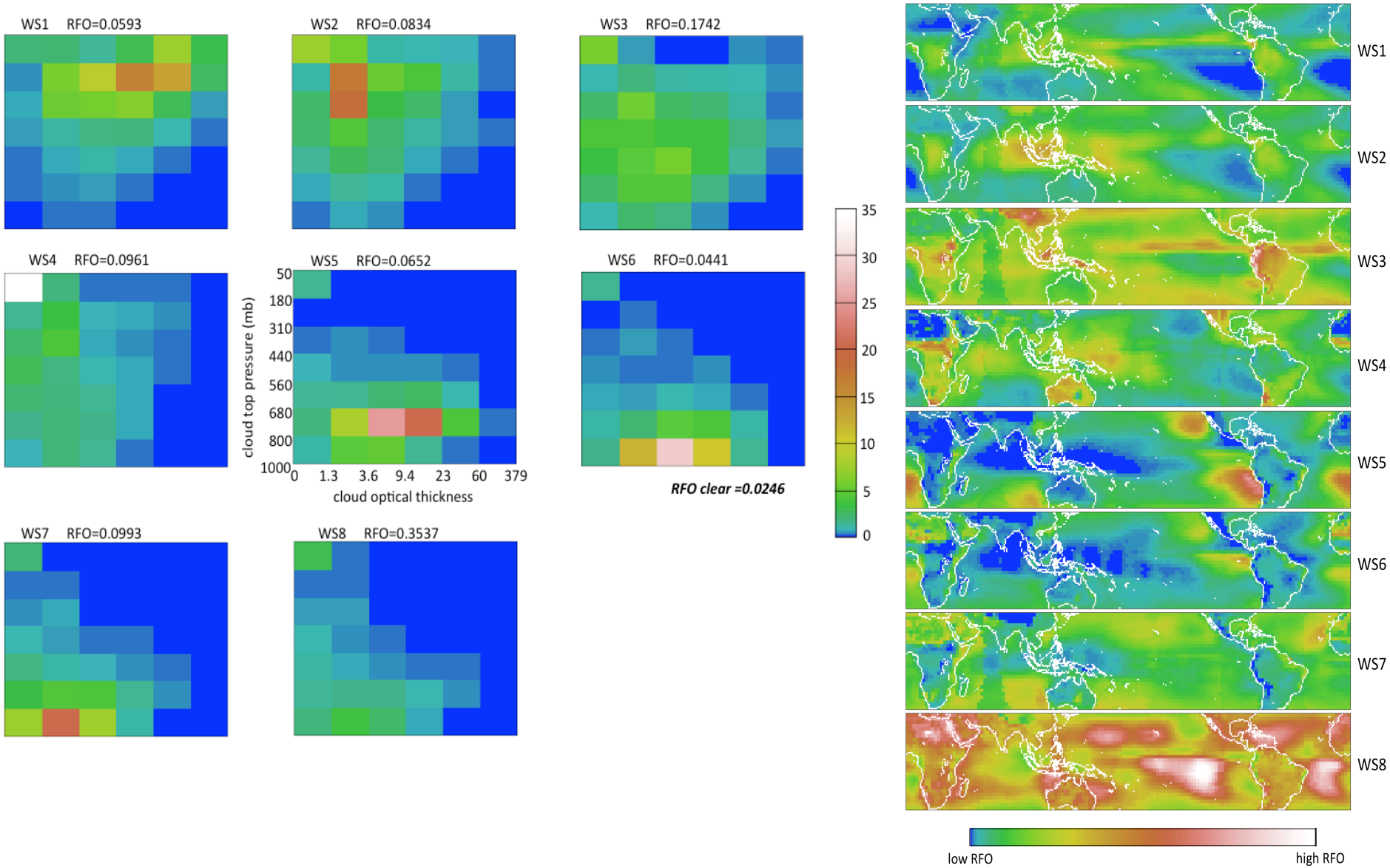
(Courtesy of Norman Loeb)

Application 1: CRE attribution to cloud regimes

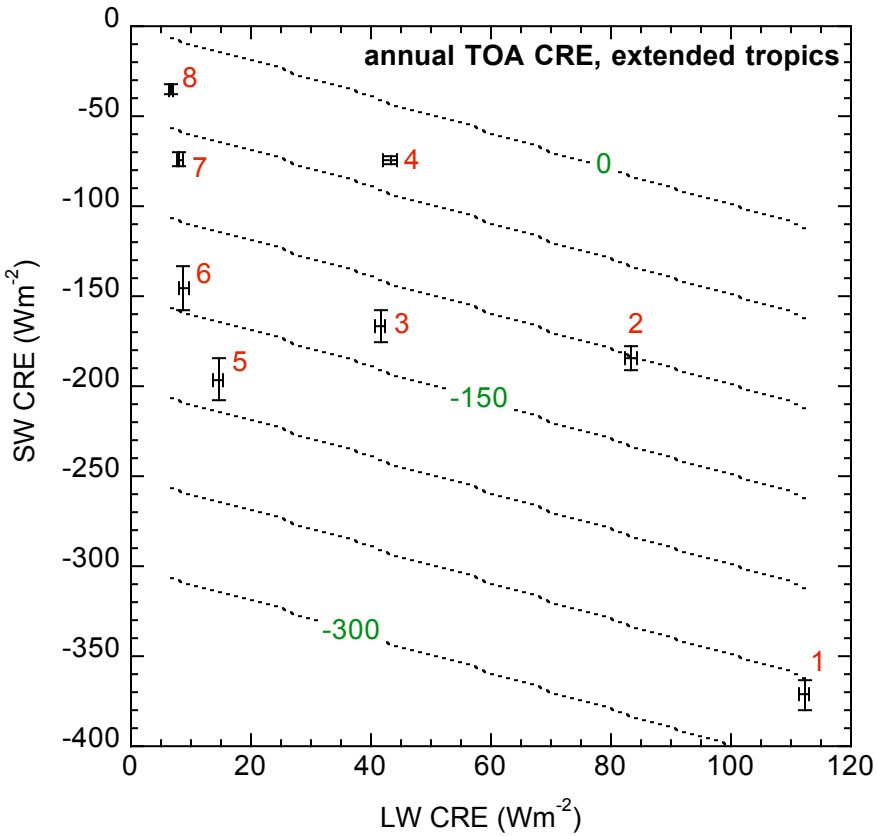
$$CRE = CF\left[F_{clr} - F_{ovc}(p_c, \tau_c)\right]$$

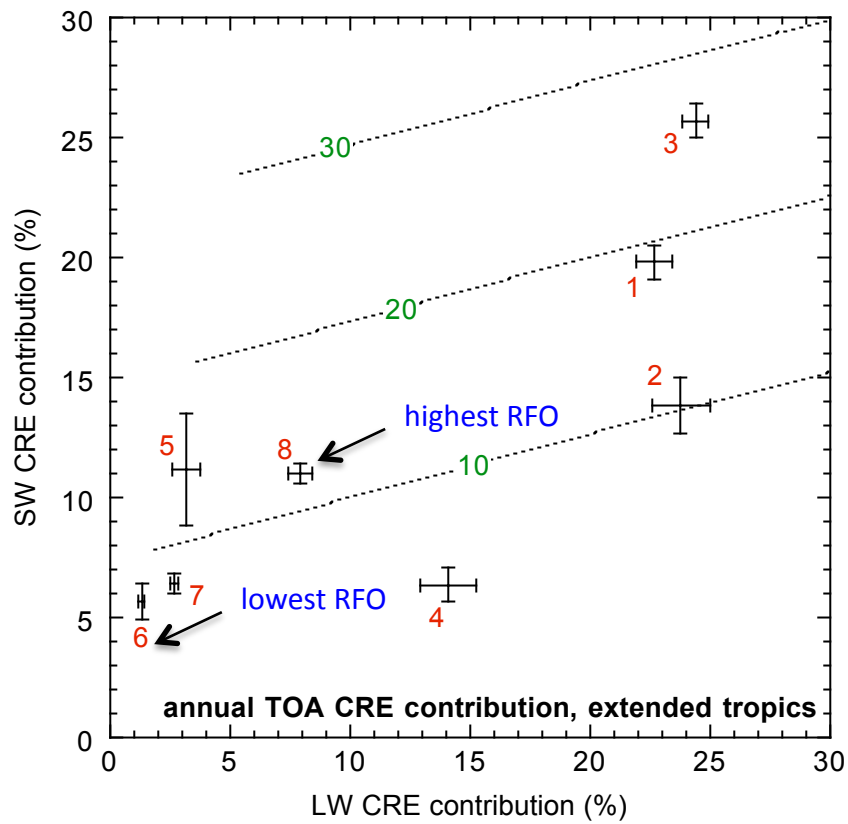
- What are their CREs (LW/SW, TOA/SFC) when they occur?
- Which are the most/least important radiatively (max/min % contributors to total CRE)?
- Are the WS well-separated (distinct) radiatively?
- CRE comes from ISCCP FD dataset
- Evaluation tool for assessing GCM CRE realism
- Oreopoulos and Rossow (JGR, 2011)

ISCCP extended tropics weather states

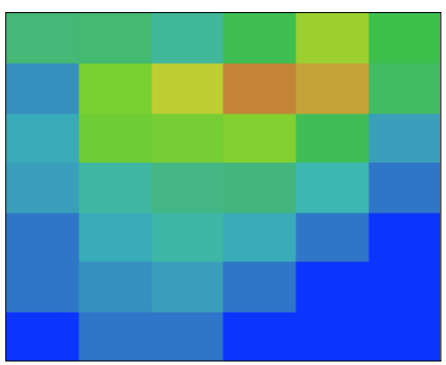


TOA CRE, extended tropics (8 WS)

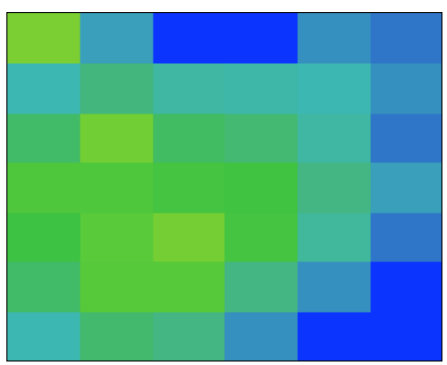




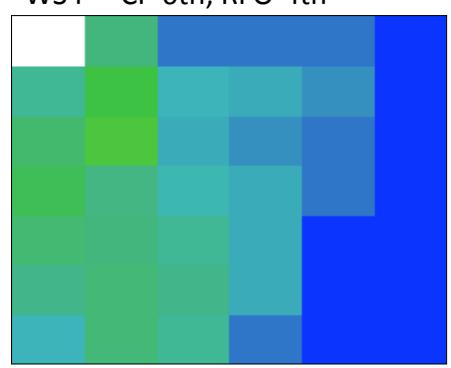
WS1 CF-1st, RFO-7th



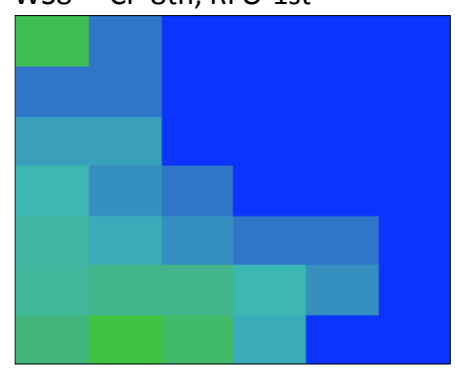
WS3 CF-4th, RFO-2nd



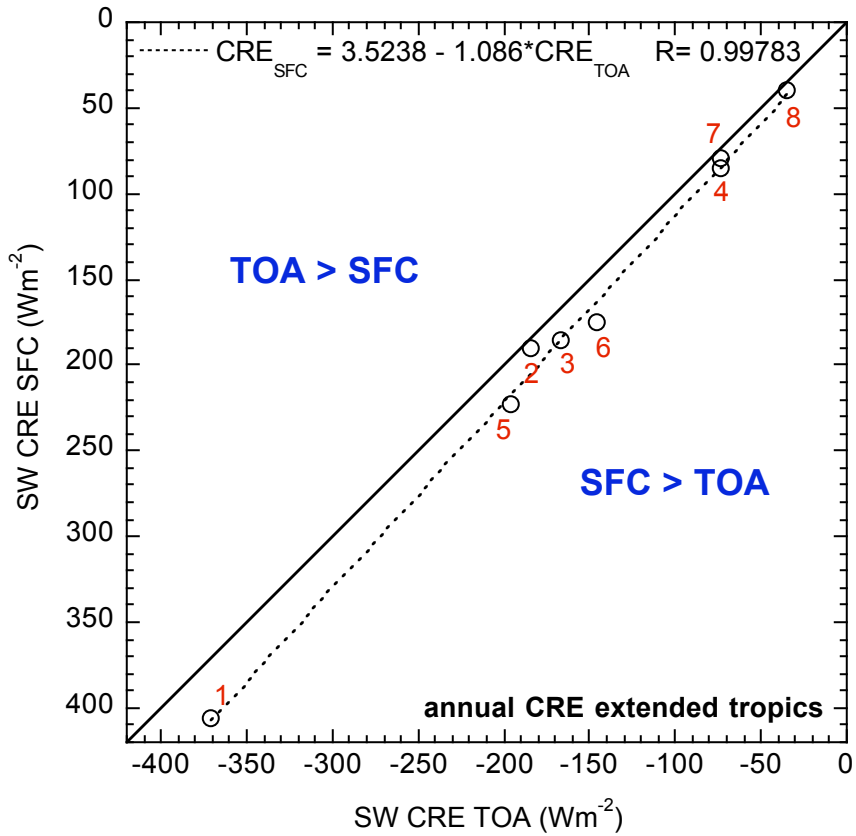
WS4 CF-6th, RFO-4th



WS8 CF-8th, RFO-1st

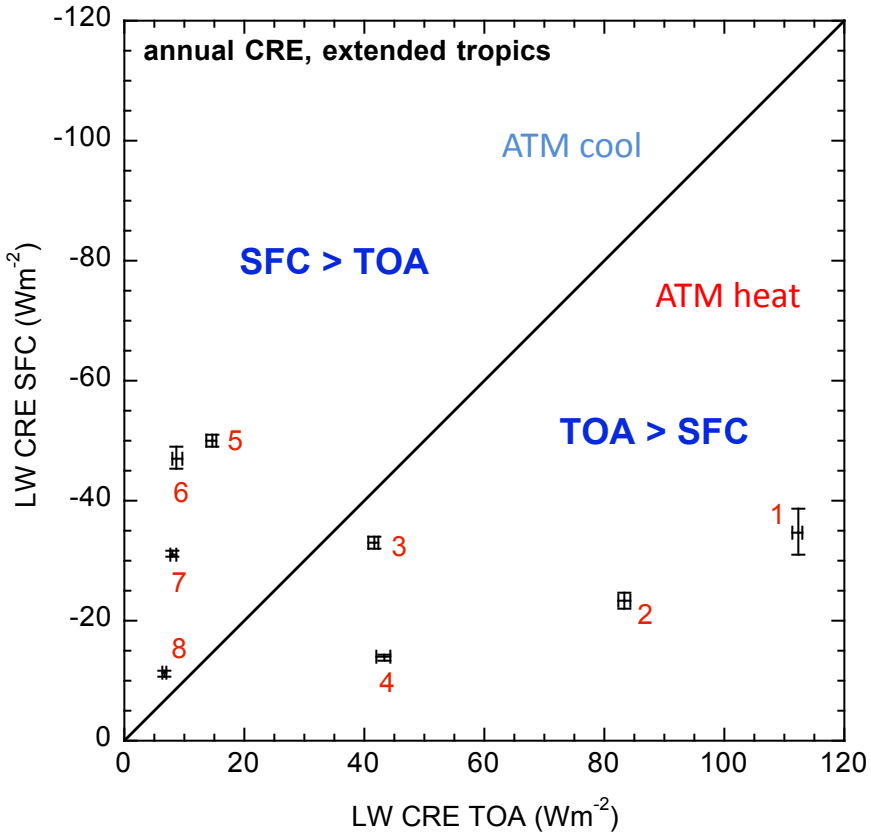


SFC vs TOA SW CRE, extended tropics

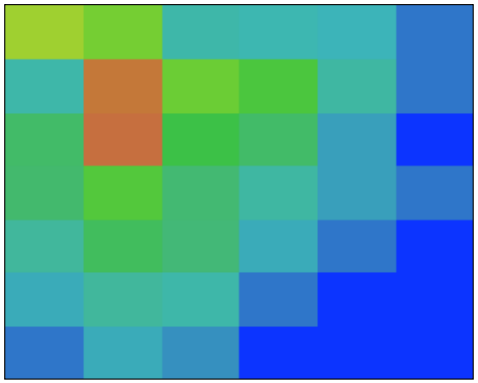


predictably linear and not very interesting!

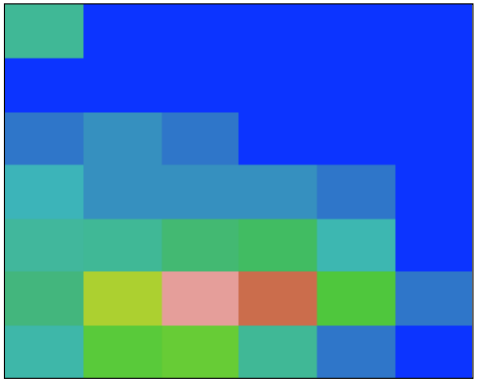
SFC vs TOA LW CRE, extended tropics



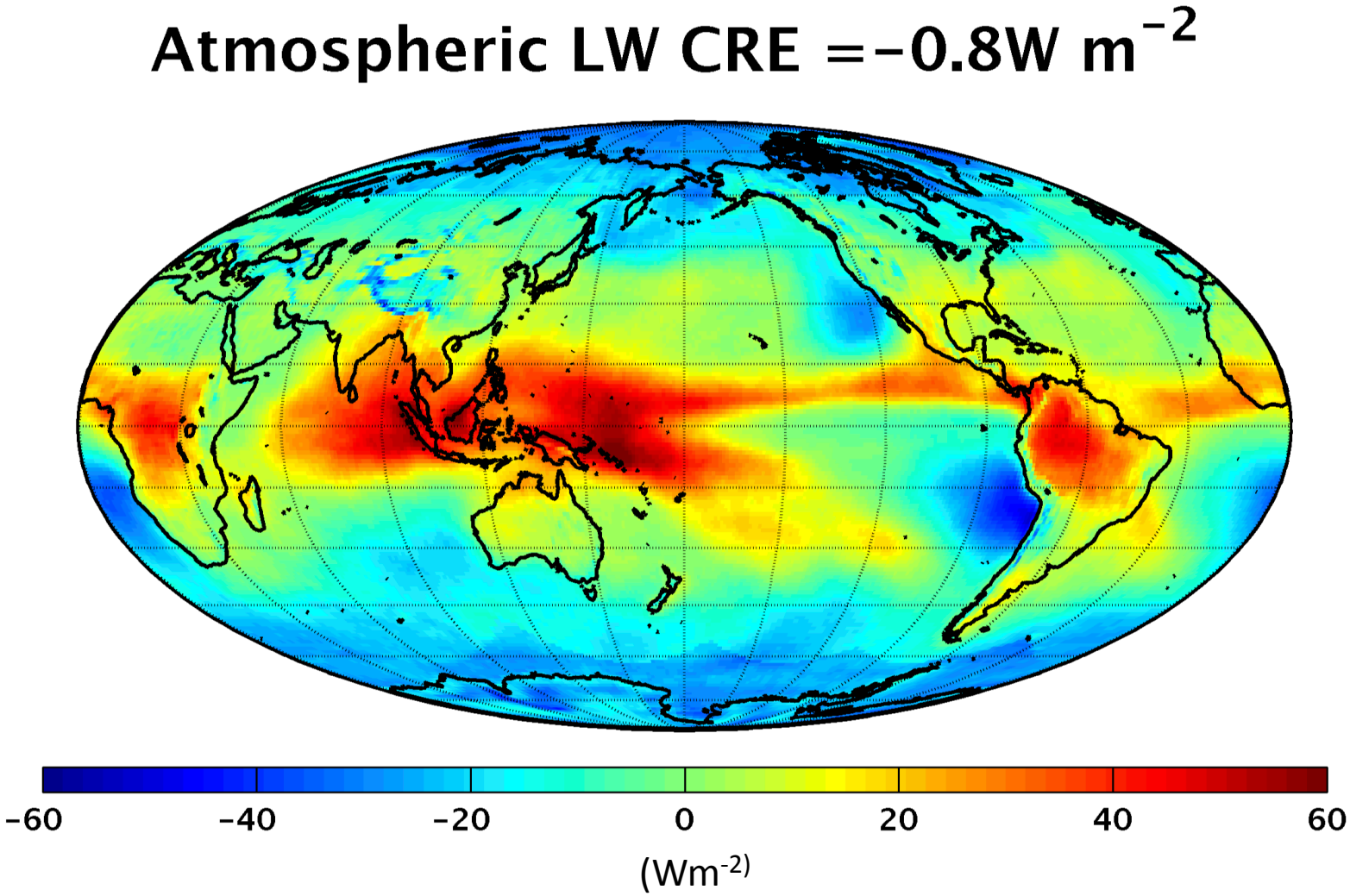
WS2



WS5



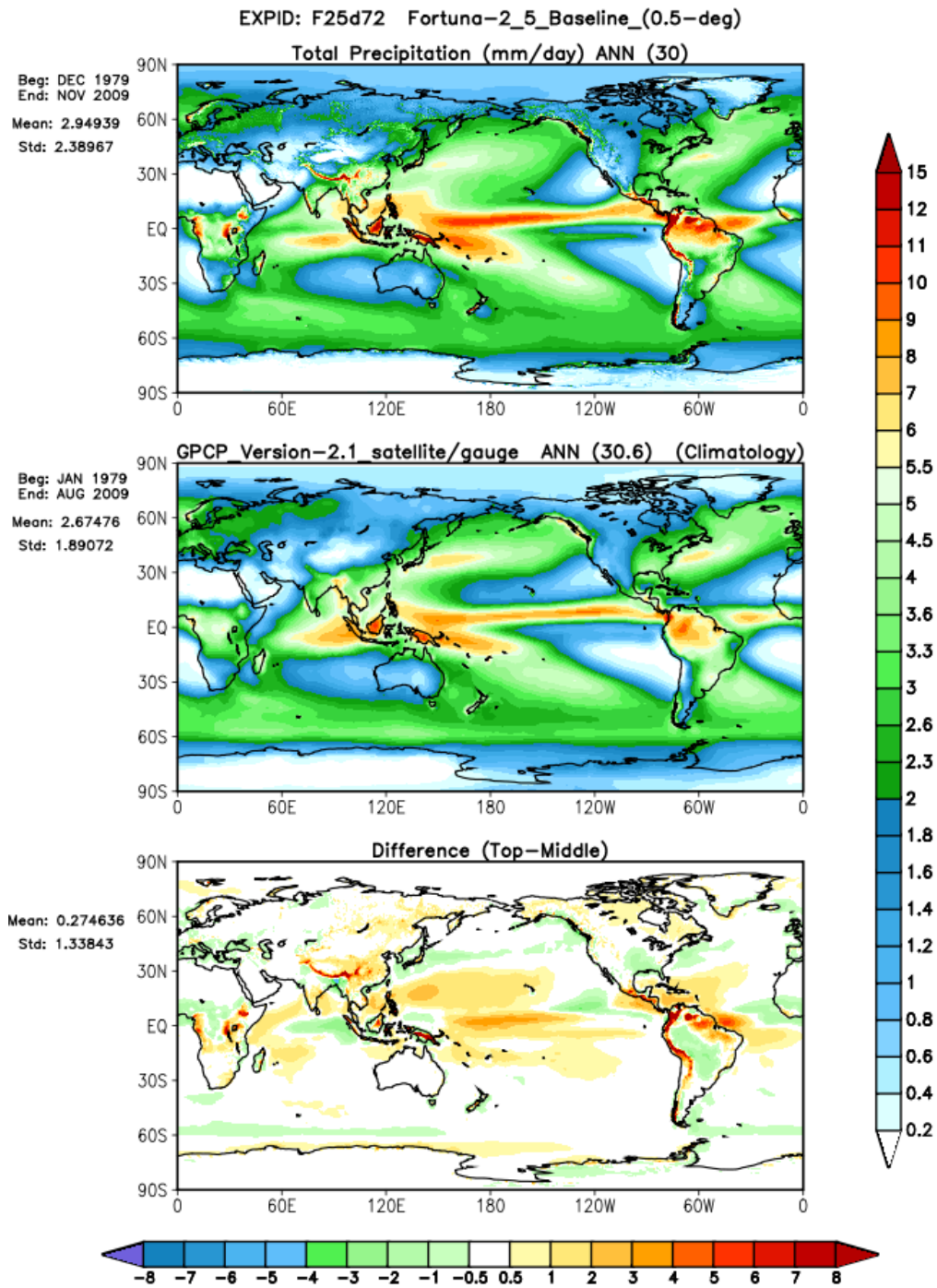
Atmospheric LW CRE from CERES



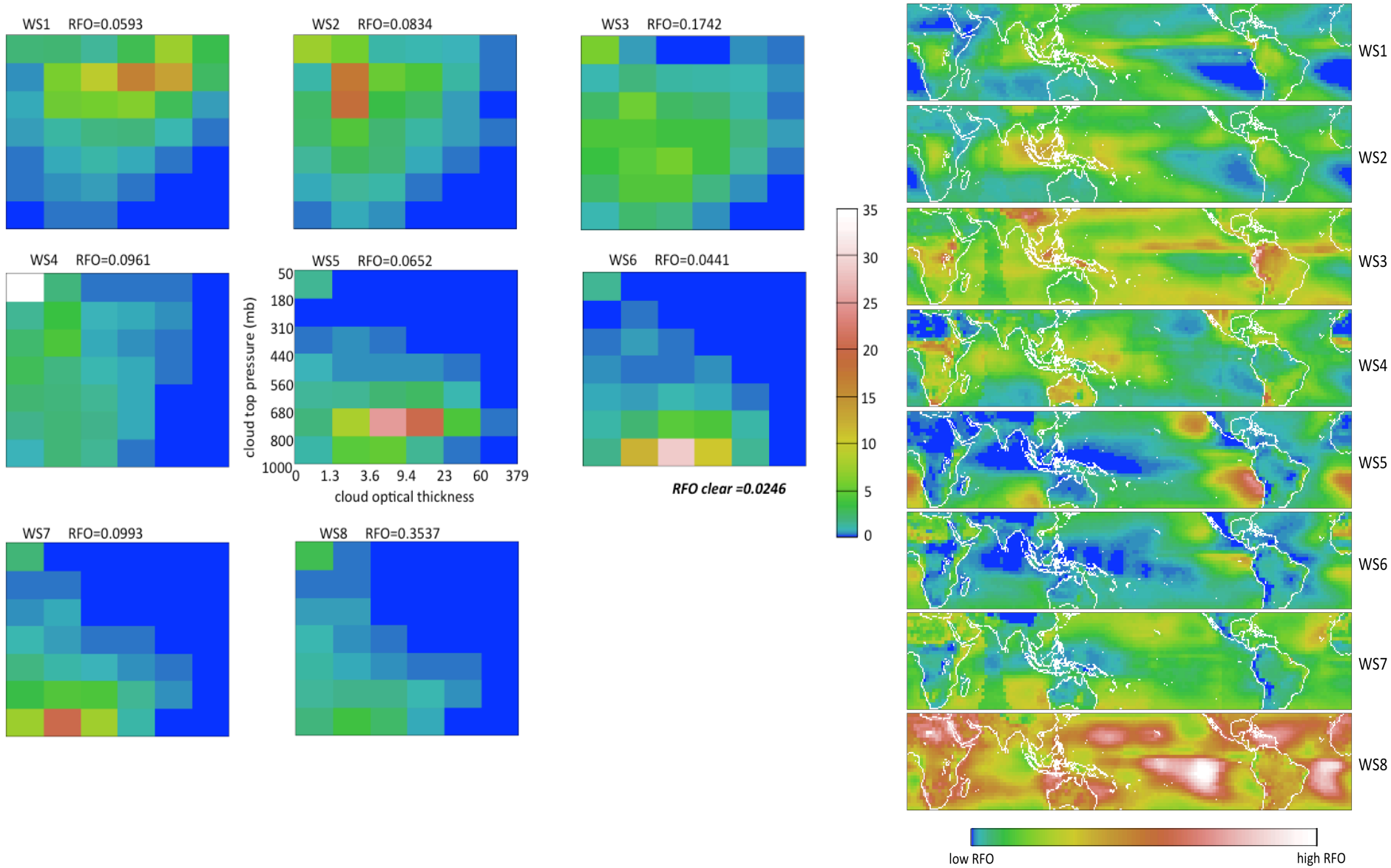
(Courtesy of Norman Loeb)

Application 2: Attribution of tropical precipitation to cloud regimes

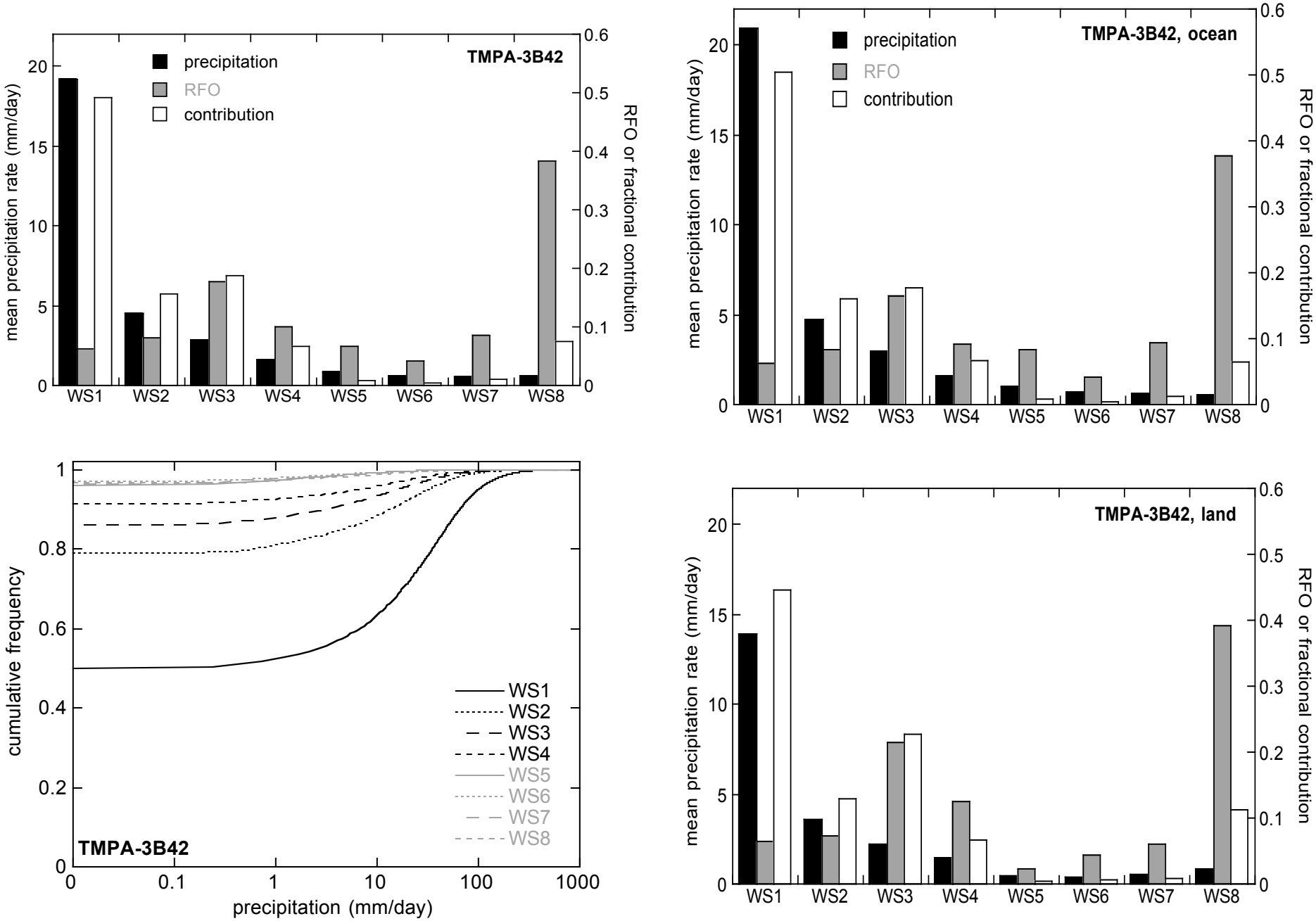
Lee et al. (2012)



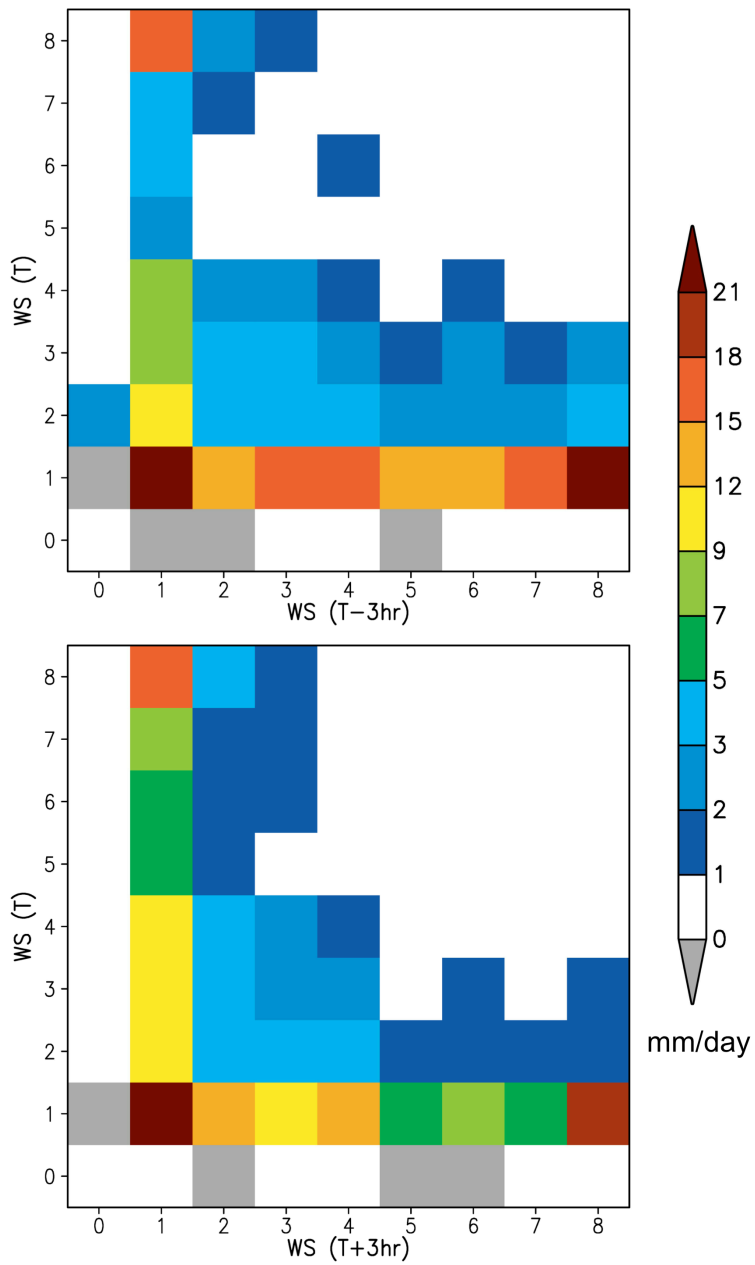
ISCCP extended tropics weather states



WS1 dwarfs the precipitation of the other cloud regimes



Precipitation rates are greater when in temporal proximity to WS1



Lessons and future applications

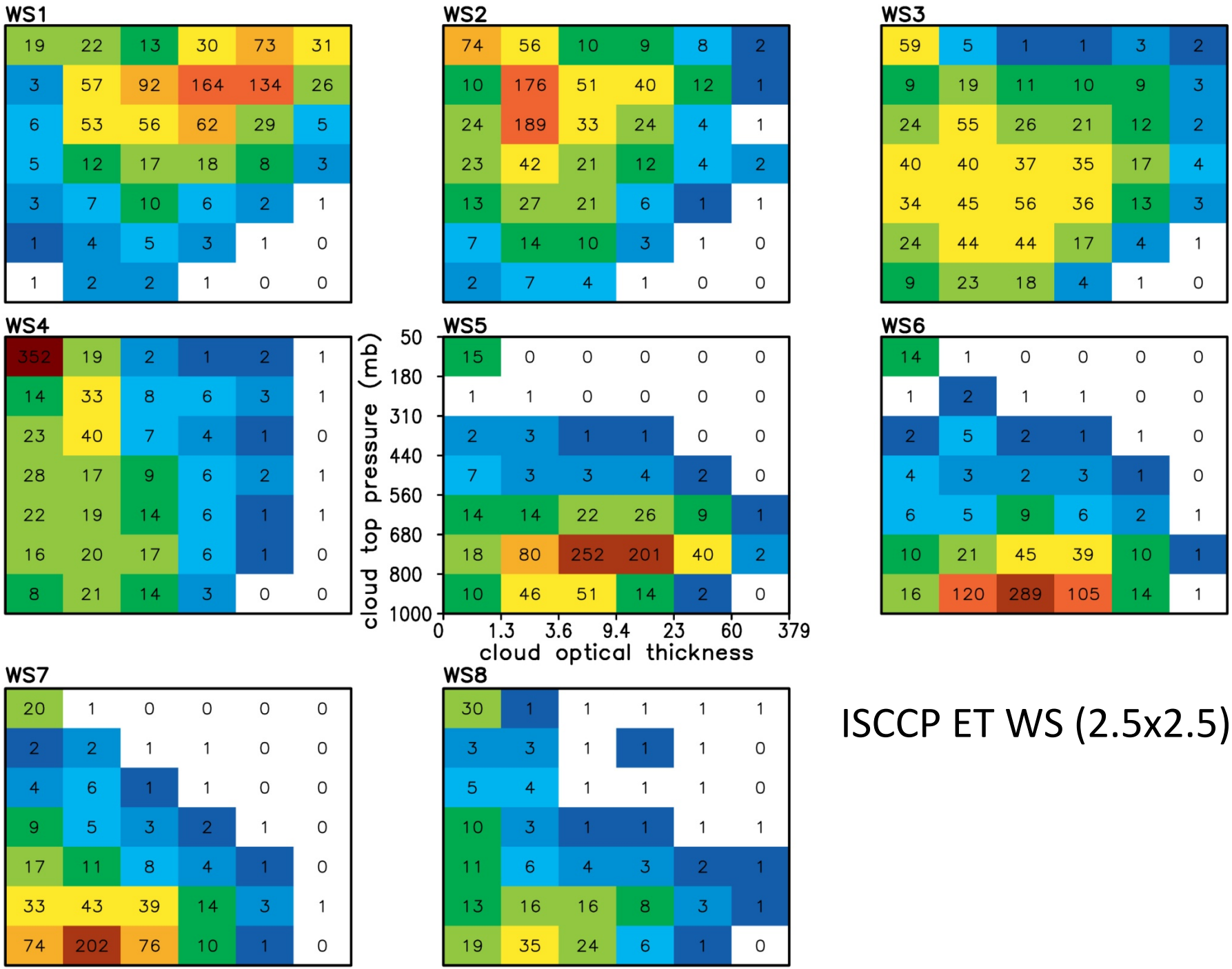
• Cloud radiative effects and precipitation can be partitioned by cloud regimes; this can in principle be done globally.

• The ISCCP cloud regimes are indeed radiatively distinct in terms of CRE and hydrologically distinct in terms of precipitation

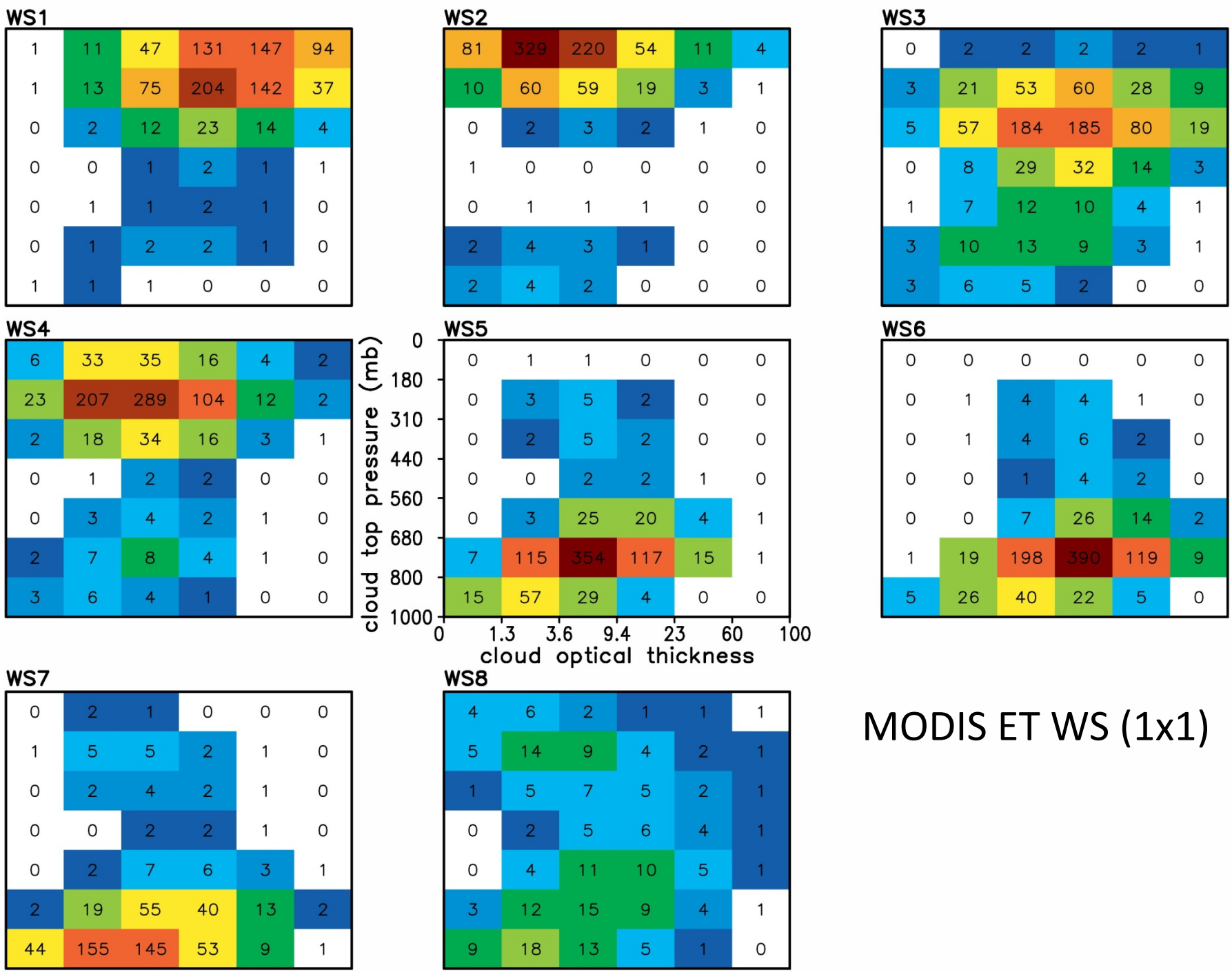
• The radiative or hydrological importance of a cloud regime depends not only on instaneous strength but also on frequency of occurrence.

• With ISCCP cloud simulator similar analysis for GCMs possible, potentially a great validation tool.

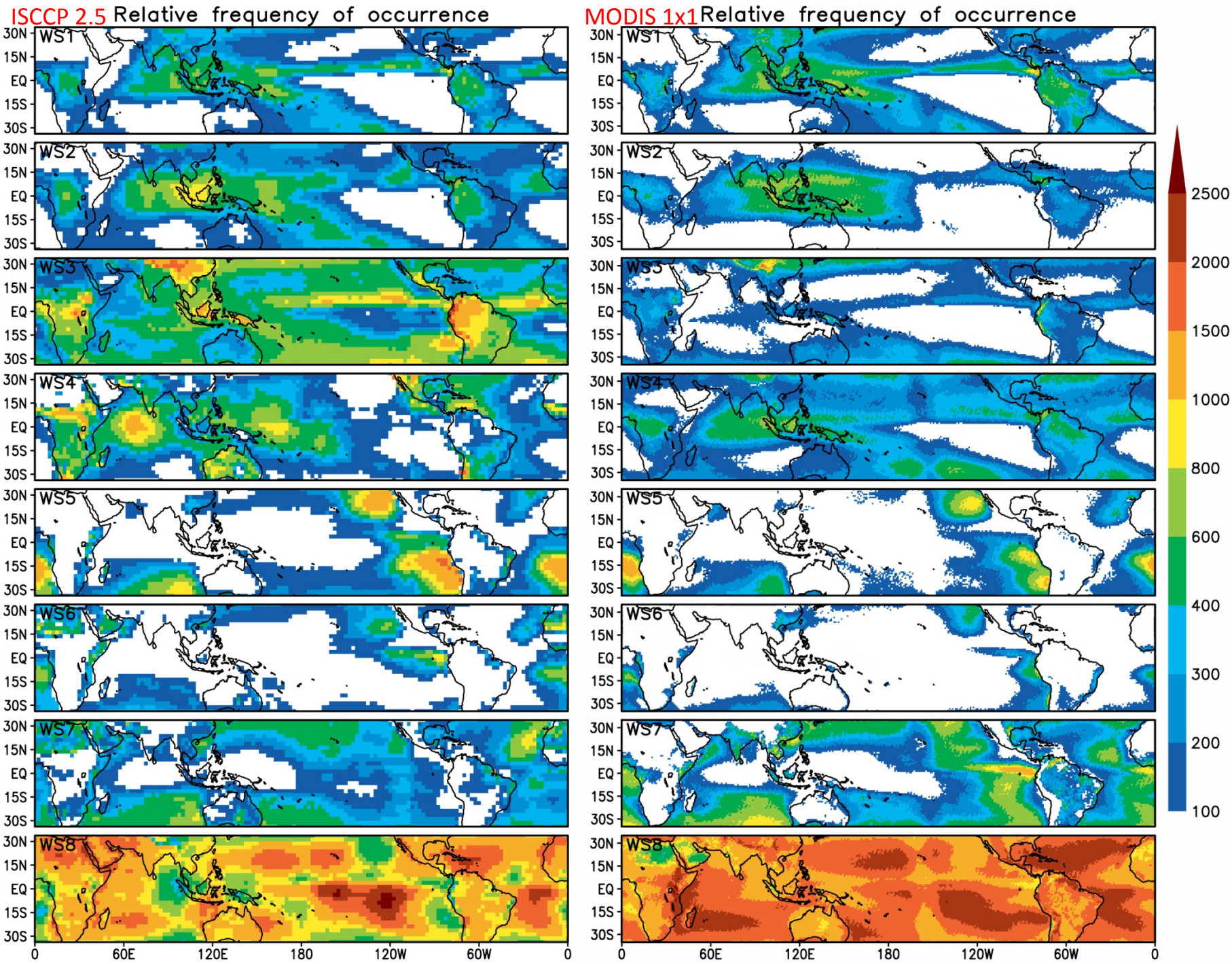
• Extending cloud regime analysis to MODIS-Aqua offers many A-Train compositing opportunities (e.g., AIRS, CALIPSO, CLOUDSAT, CERES).

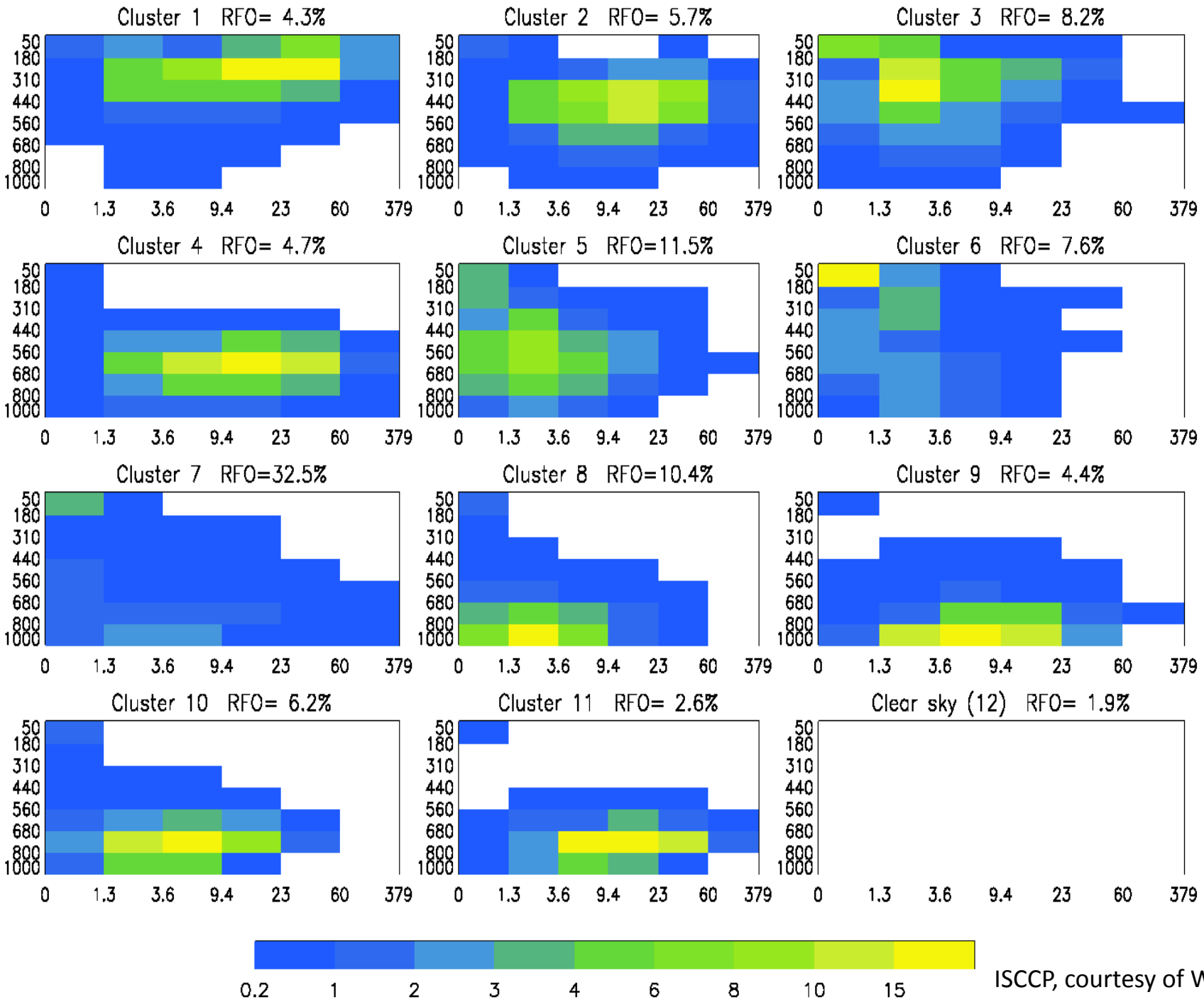


ISCCP ET WS (2.5x2.5)

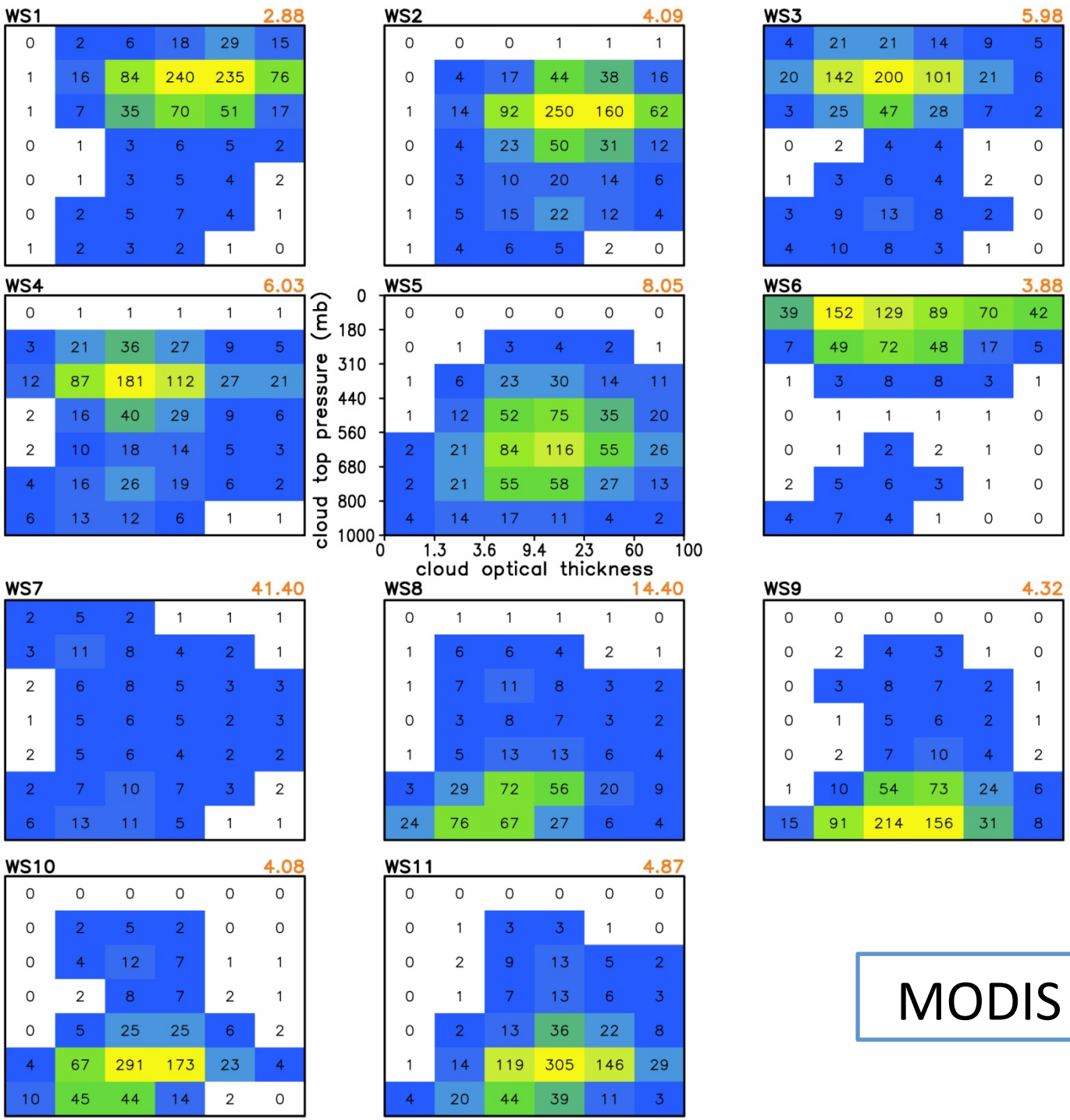


MODIS ET WS (1x1)


ISCCP 2.5 Relative frequency of occurrence
MODIS 1x1 Relative frequency of occurrence
WS1
WS2
WS3
WS4
WS5
WS6
WS7
WS8
30N
15N
EQ
15S
30S
0
60E
120E
180
120W
60W
0
2500
2000
1500
1000
800
600
400
300
200
100

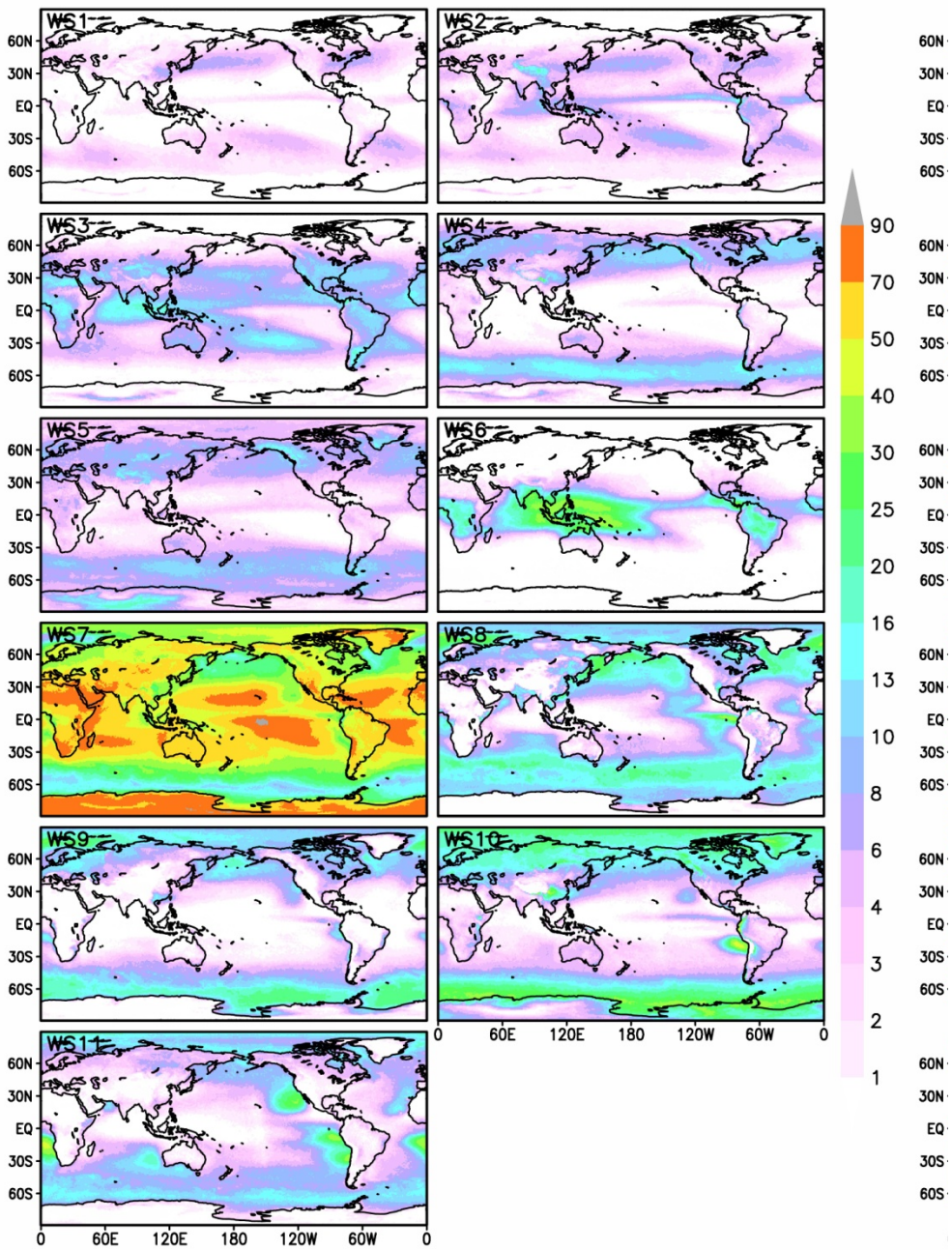


ISCCP, courtesy of W. B. Rossow

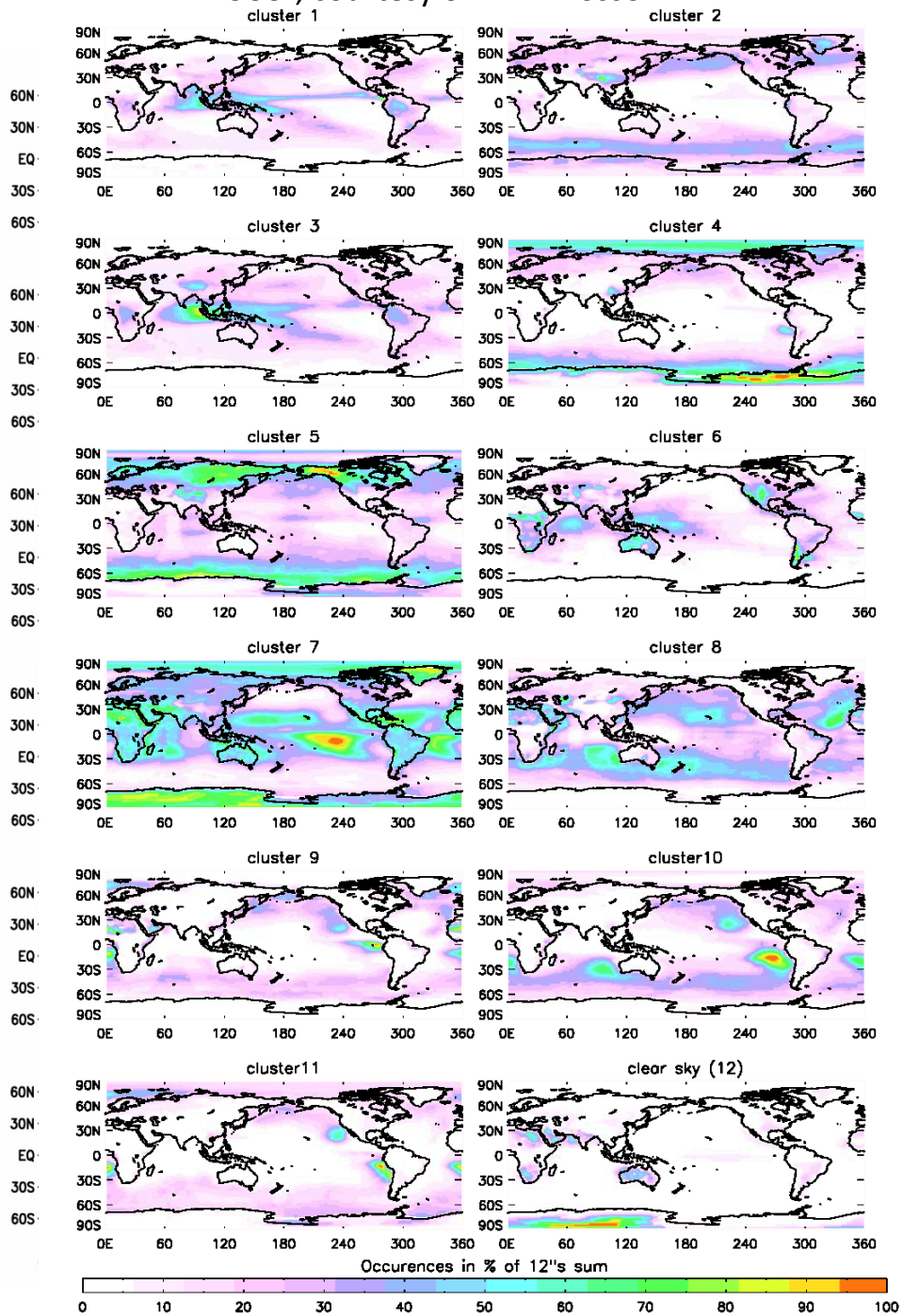

WS1 2.88
0 2 6 18 29 15
1 16 84 240 235 76
1 7 35 70 51 17
0 1 3 6 5 2
0 1 3 5 4 2
0 2 5 7 4 1
1 2 3 2 1 0
WS2 4.09
0 0 0 1 1 1
0 4 17 44 38 16
1 14 92 250 160 62
0 4 23 50 31 12
0 3 10 20 14 6
1 5 15 22 12 4
1 4 6 5 2 0
WS3 5.98
4 21 21 14 9 5
20 142 200 101 21 6
3 25 47 28 7 2
0 2 4 4 1 0
1 3 6 4 2 0
3 9 13 8 2 0
4 10 8 3 1 0
WS4 6.03
0 1 1 1 1 1
3 21 36 27 9 5
12 87 181 112 27 21
2 16 40 29 9 6
2 10 18 14 5 3
4 16 26 19 6 2
6 13 12 6 1 1
WS5 8.05
0 0 0 0 0 0
0 1 3 4 2 1
1 6 23 30 14 11
1 12 52 75 35 20
2 21 84 116 55 26
2 21 55 58 27 13
4 14 17 11 4 2
WS6 3.88
39 152 129 89 70 42
7 49 72 48 17 5
1 3 8 8 3 1
0 1 1 1 1 0
0 1 2 2 1 0
2 5 6 3 1 0
4 7 4 1 0 0
cloud top pressure (mb)
0
180
310
440
560
680
800
1000
0 1.3 3.6 9.4 23 60 100
cloud optical thickness
WS7 41.40
2 5 2 1 1 1
3 11 8 4 2 1
2 6 8 5 3 3
1 5 6 5 2 3
2 5 6 4 2 2
2 7 10 7 3 2
6 13 11 5 1 1
WS8 14.40
0 1 1 1 1 0
1 6 6 4 2 1
1 7 11 8 3 2
0 3 8 7 3 2
1 5 13 13 6 4
3 29 72 56 20 9
24 76 67 27 6 4
WS9 4.32
0 0 0 0 0 0
0 2 4 3 1 0
0 3 8 7 2 1
0 1 5 6 2 1
0 2 7 10 4 2
1 10 54 73 24 6
15 91 214 156 31 8
WS10 4.08
0 0 0 0 0 0
0 2 5 2 0 0
0 4 12 7 1 1
0 2 8 7 2 1
0 5 25 25 6 2
4 67 291 173 23 4
10 45 44 14 2 0
WS11 4.87
0 0 0 0 0 0
0 1 3 3 1 0
0 2 9 13 5 2
0 1 7 13 6 3
0 2 13 36 22 8
1 14 119 305 146 29
4 20 44 39 11 3

MODIS 3°x3°

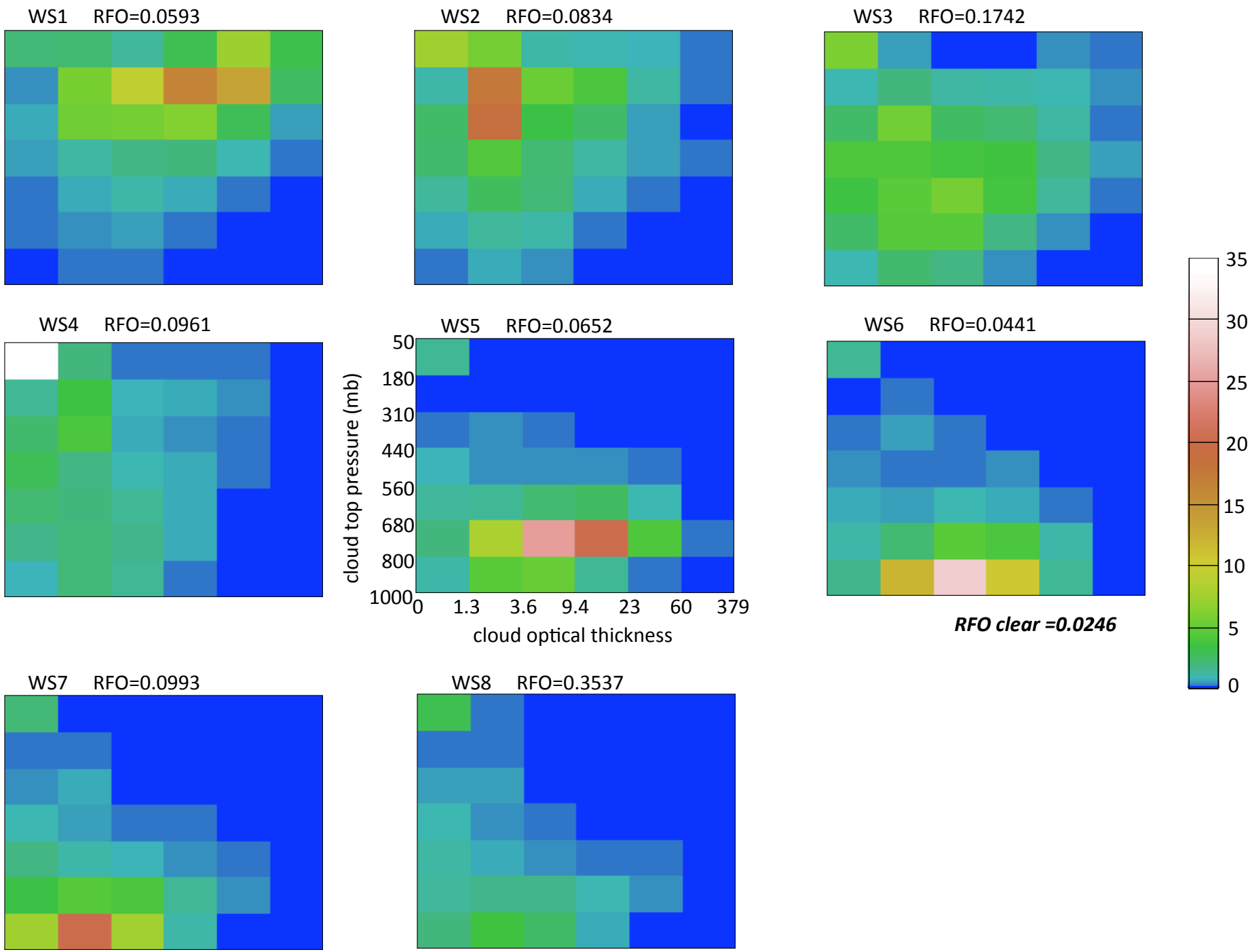
MODIS-Aqua (3°x3°)

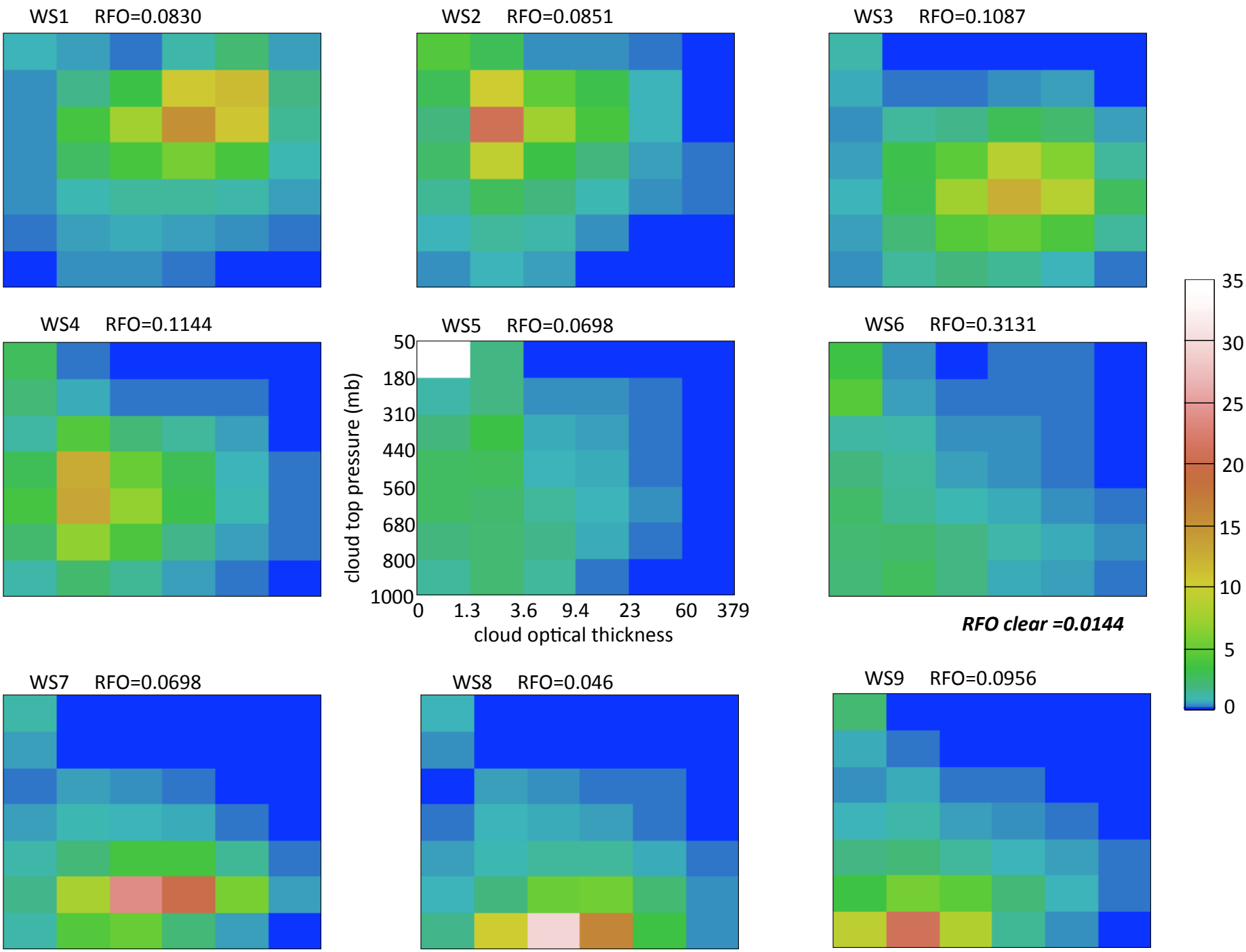


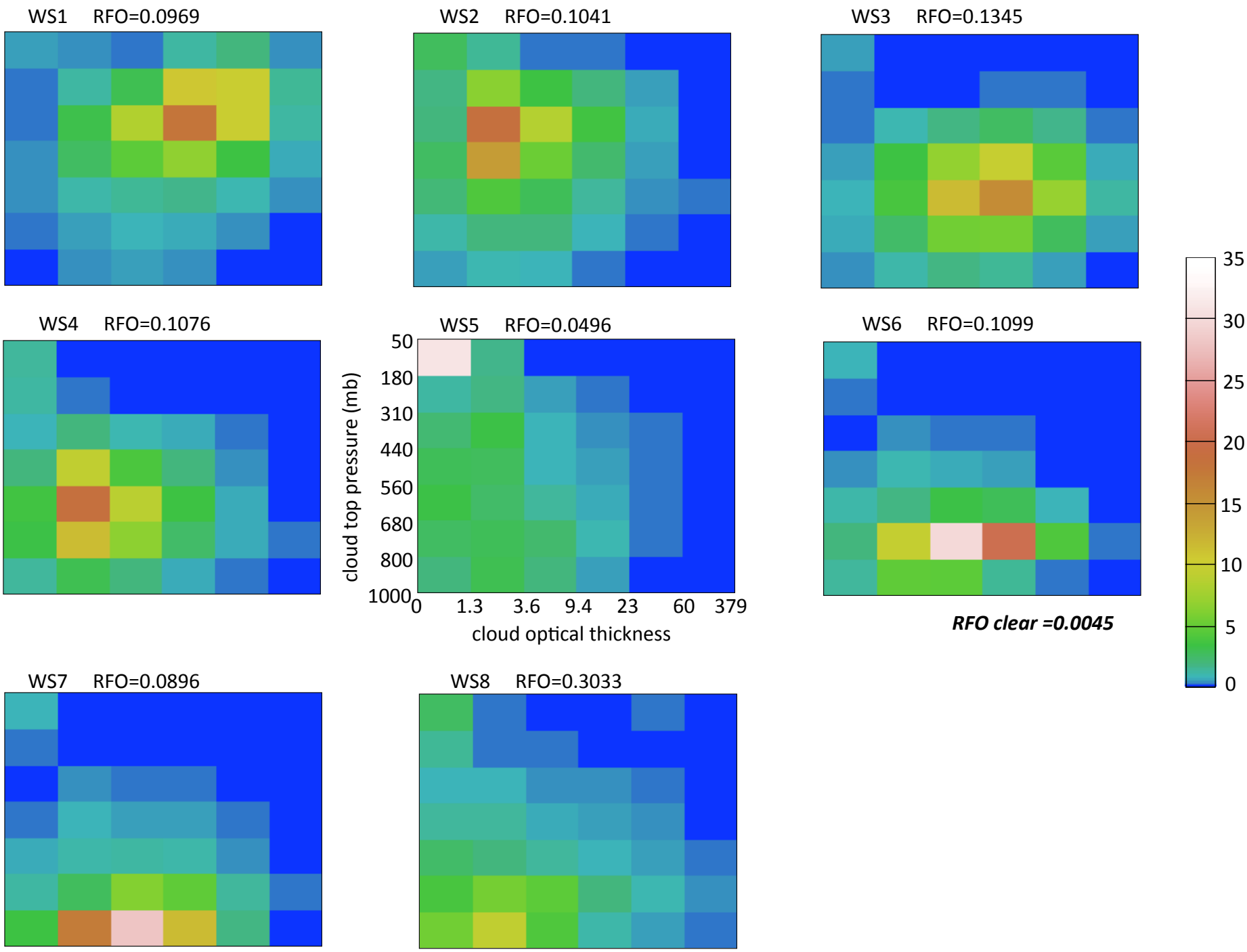
ISCCP, courtesy of W. B. Rossow

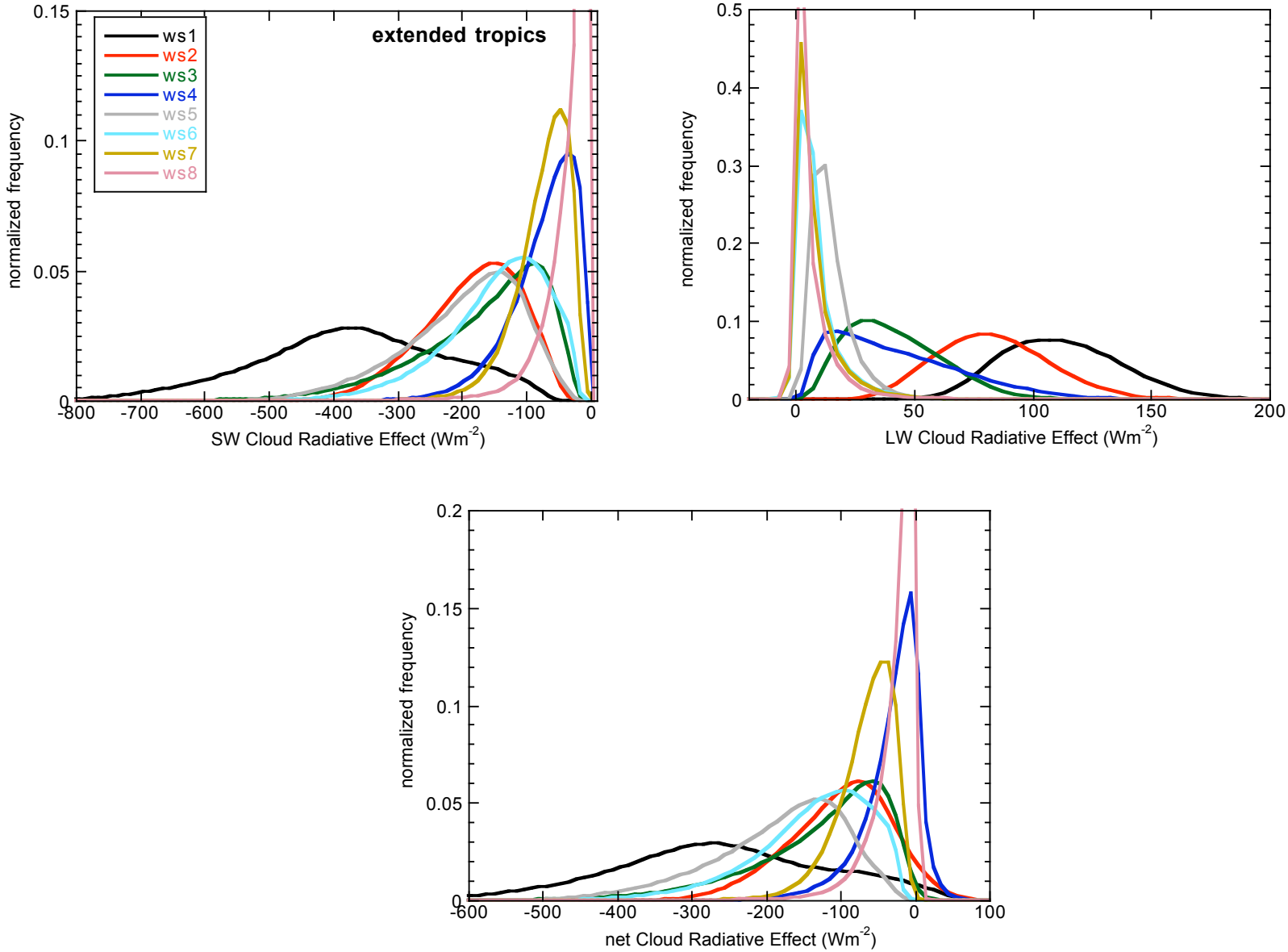


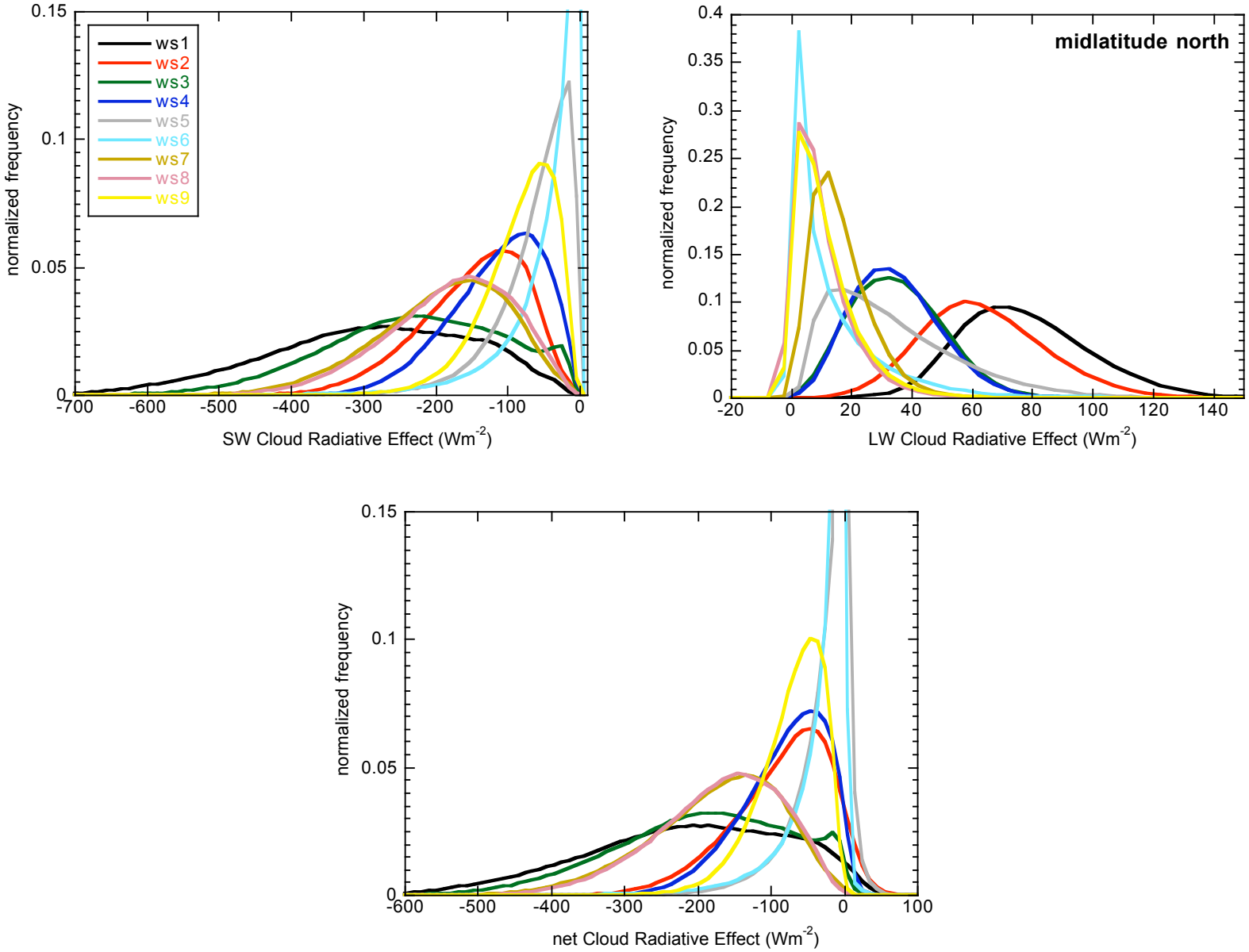
Additional slides

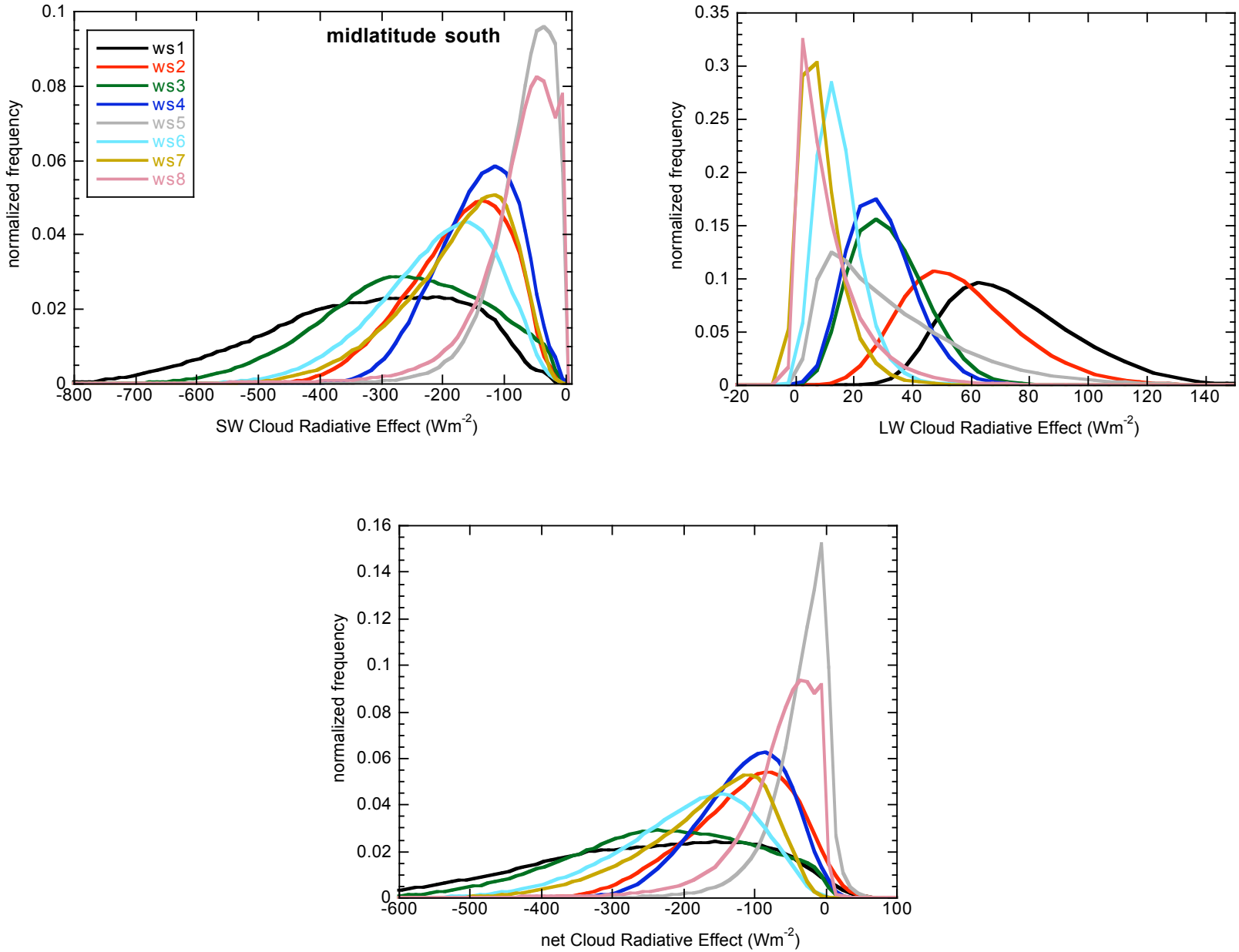

WS1 RFO=0.0593
WS2 RFO=0.0834
WS3 RFO=0.1742
WS4 RFO=0.0961
WS5 RFO=0.0652
WS6 RFO=0.0441
WS7 RFO=0.0993
WS8 RFO=0.3537
cloud top pressure (mb)
50
180
310
440
560
680
800
1000
0
1.3
3.6
9.4
23
60
379
cloud optical thickness
RFO clear =0.0246
35
30
25
20
15
10
5
0

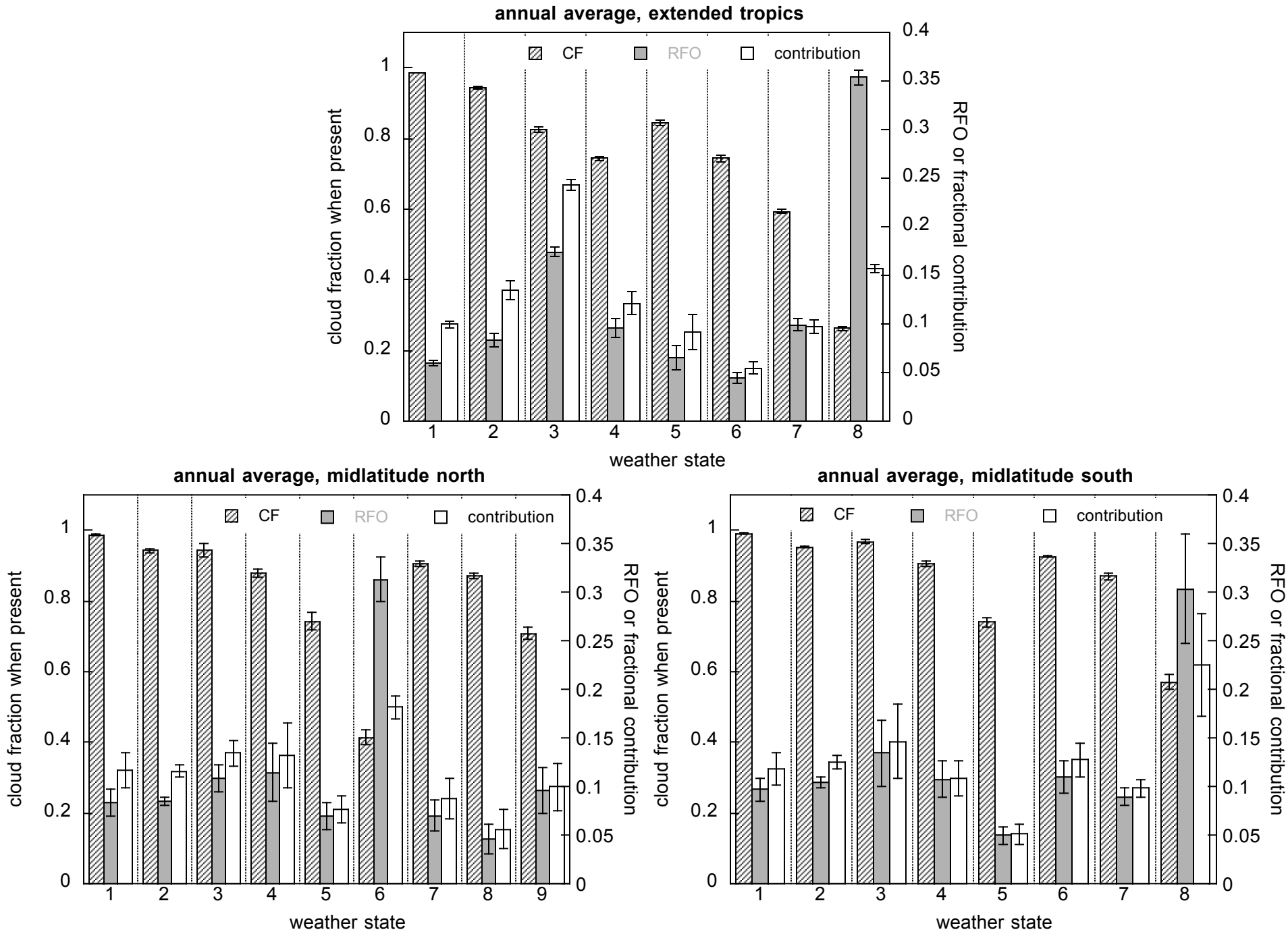

WS1 RFO=0.0830
WS2 RFO=0.0851
WS3 RFO=0.1087
WS4 RFO=0.1144
WS5 RFO=0.0698
WS6 RFO=0.3131
WS7 RFO=0.0698
WS8 RFO=0.046
WS9 RFO=0.0956
cloud top pressure (mb)
50
180
310
440
560
680
800
1000
0
1.3
3.6
9.4
23
60
379
cloud optical thickness
RFO clear =0.0144
35
30
25
20
15
10
5
0


WS1 RFO=0.0969
WS2 RFO=0.1041
WS3 RFO=0.1345
WS4 RFO=0.1076
WS5 RFO=0.0496
WS6 RFO=0.1099
WS7 RFO=0.0896
WS8 RFO=0.3033
cloud top pressure (mb)
50
180
310
440
560
680
800
1000
0
1.3
3.6
9.4
23
60
379
cloud optical thickness
RFO clear =0.0045
35
30
25
20
15
10
5
0


extended tropics
ws1
ws2
ws3
ws4
ws5
ws6
ws7
ws8
normalized frequency
SW Cloud Radiative Effect (Wm-2)
LW Cloud Radiative Effect (Wm-2)
net Cloud Radiative Effect (Wm-2)

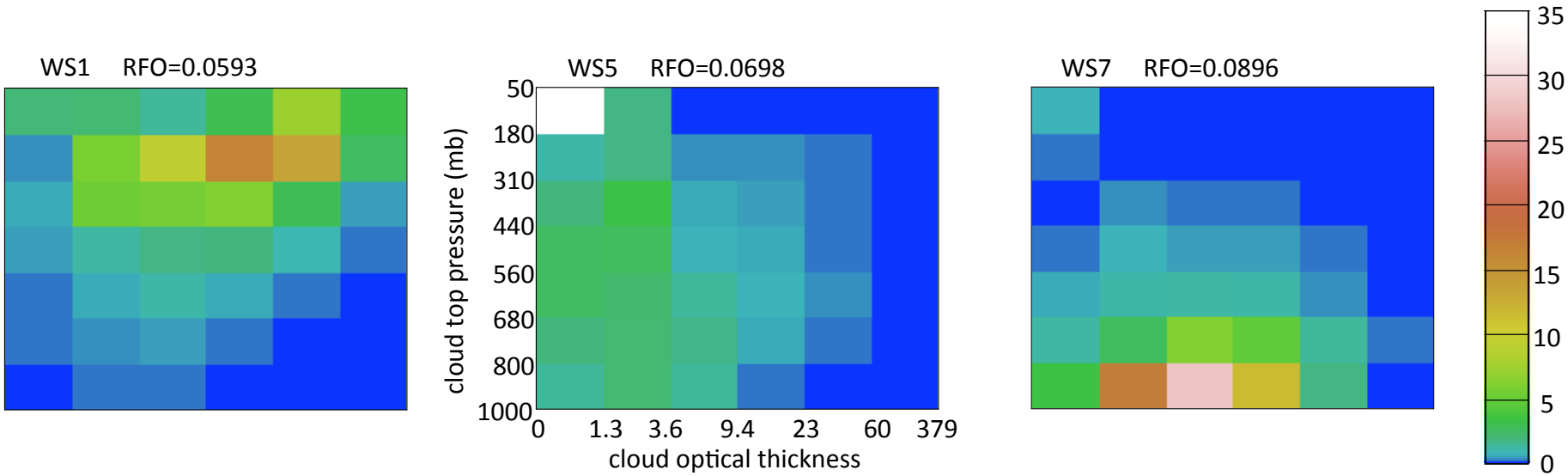

ws1
ws2
ws3
ws4
ws5
ws6
ws7
ws8
ws9
normalized frequency
SW Cloud Radiative Effect (Wm-2)
midlatitude north
LW Cloud Radiative Effect (Wm-2)
net Cloud Radiative Effect (Wm-2)


midlatitude south
ws1
ws2
ws3
ws4
ws5
ws6
ws7
ws8
normalized frequency
SW Cloud Radiative Effect (Wm-2)
LW Cloud Radiative Effect (Wm-2)
net Cloud Radiative Effect (Wm-2)


annual average, extended tropics
CF
RFO
contribution
cloud fraction when present
RFO or fractional contribution
weather state
annual average, midlatitude north
annual average, midlatitude south

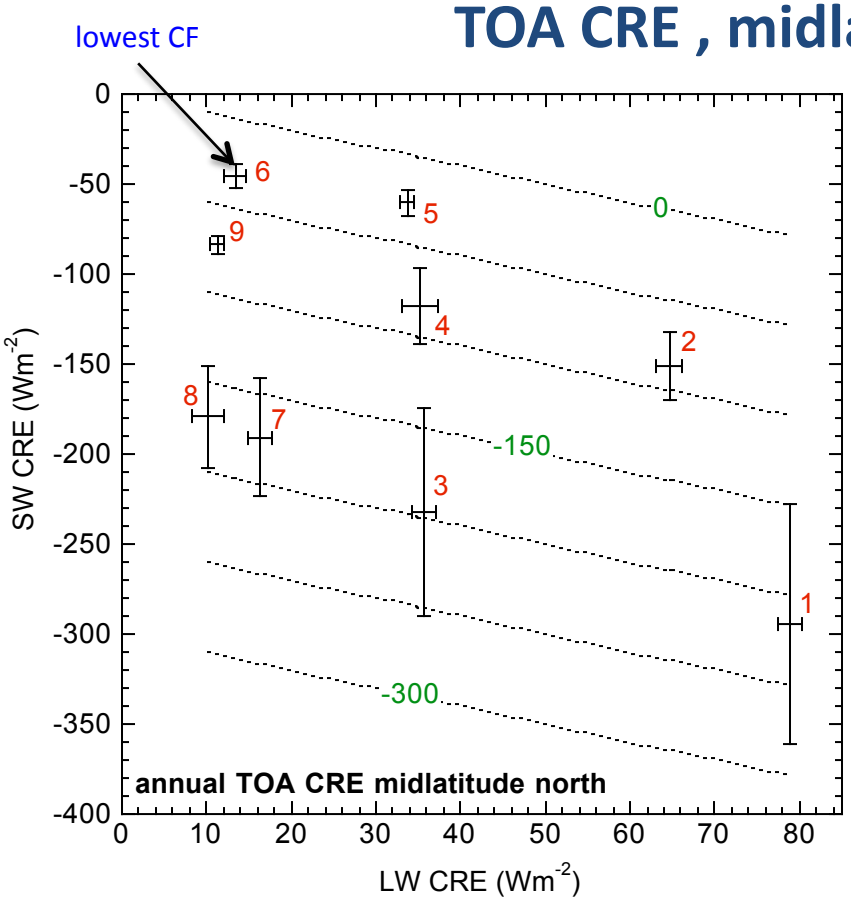
The problem (2)

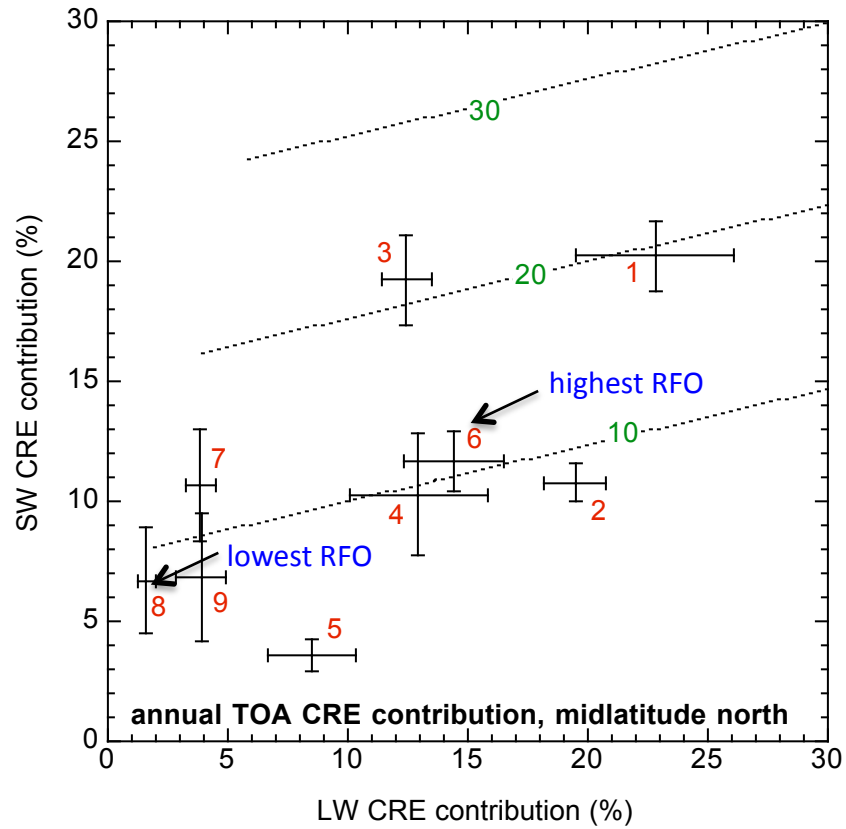
- Here the discussion is in terms of “cloud regimes” or “cloud mixtures” or “weather states” (see Rossow et al., GRL, 2005; Oreopoulos and Rossow 2011)
- WS are the cluster centroids of Cloud Top Pressure – Cloud Optical Thickness histograms according to ISCCP (can be defined differently for other observations)



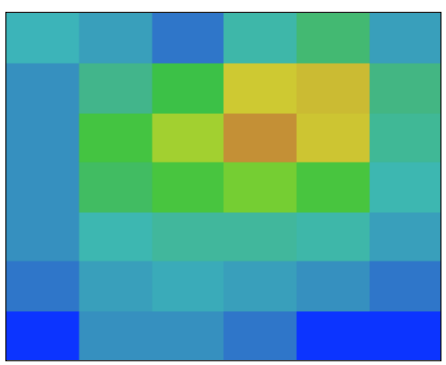
extended tropics (35S to 35N) mid-lat north (35N to 65N) mid-lat south (35S to 65S)

TOA CRE , midlatitude north (9 WS)

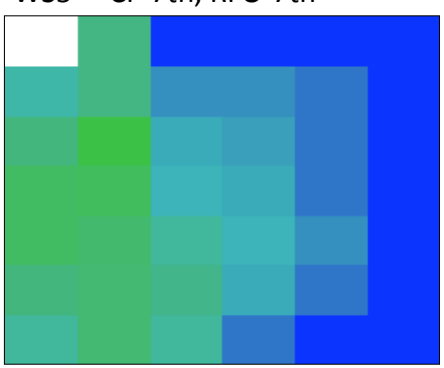




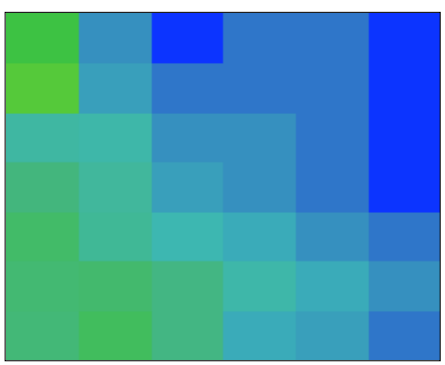
WS1 CF-1st, RFO-5th



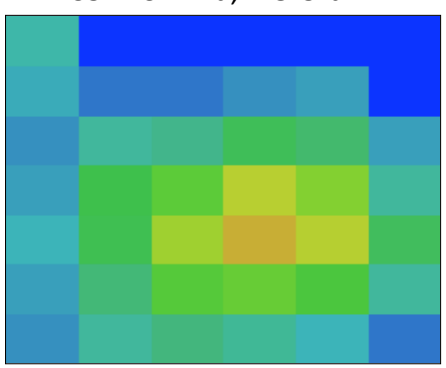
WS5 CF-7th, RFO-7th



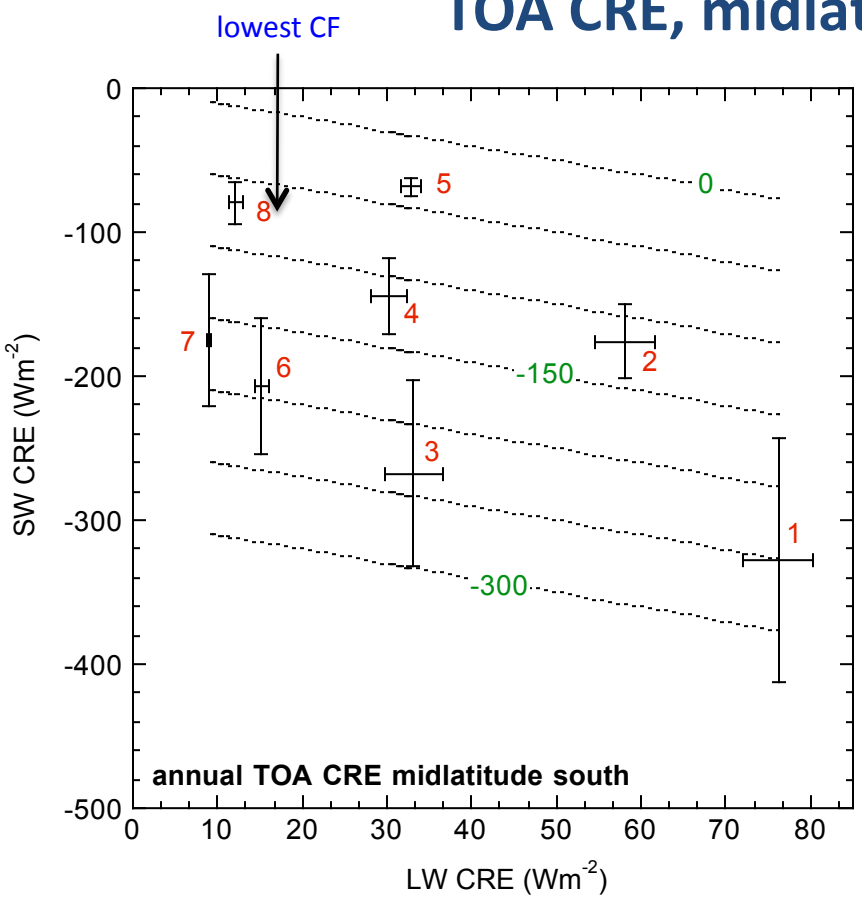
WS6 CF-9th, RFO-1st

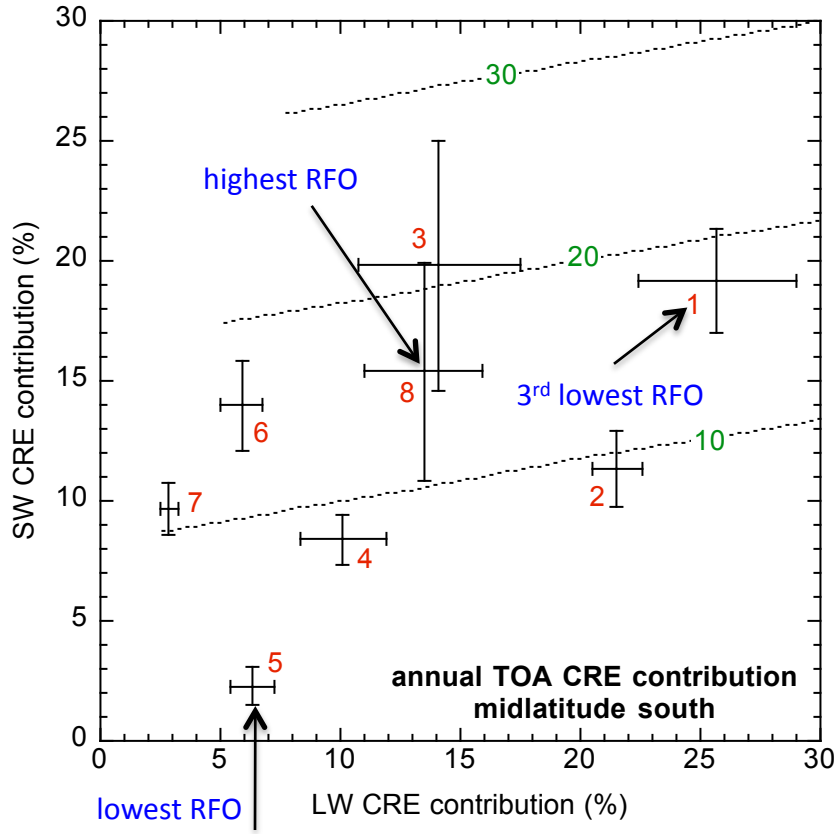


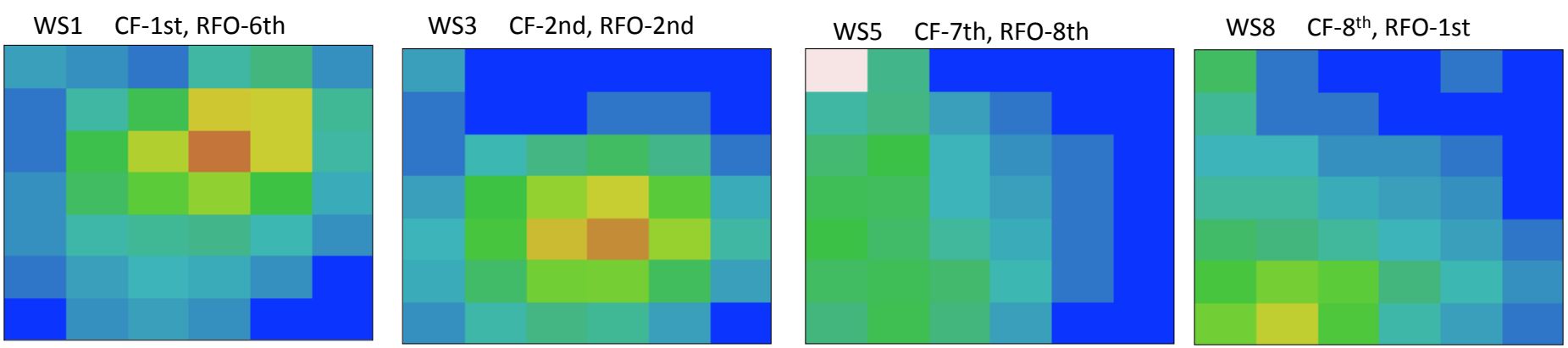
WS3 CF-2nd,RFO-3rd



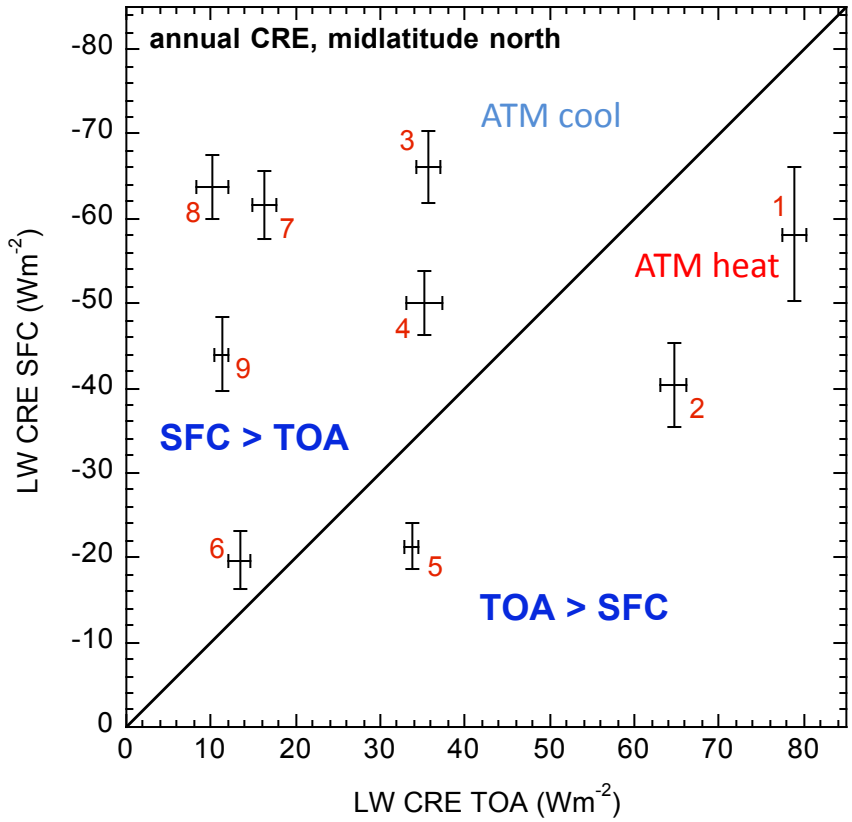
TOA CRE, midlatitude south (8 WS)



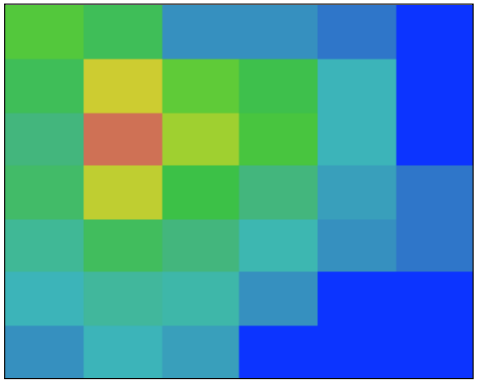




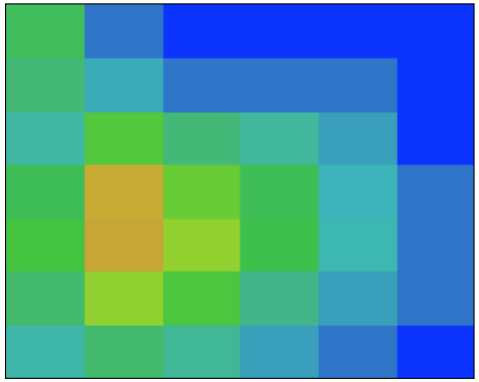
SFC vs TOA LW CRE, midlatitude north



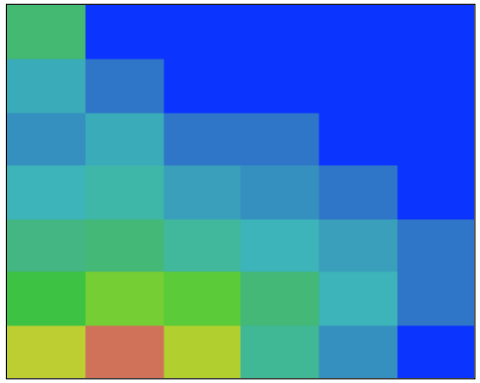
WS2



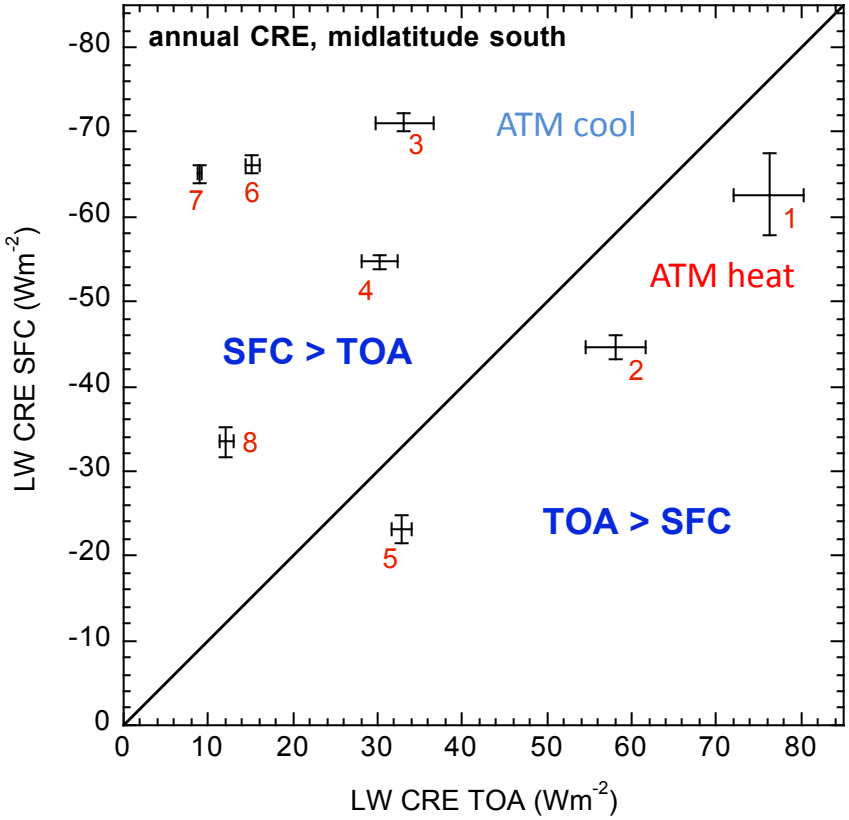
WS4



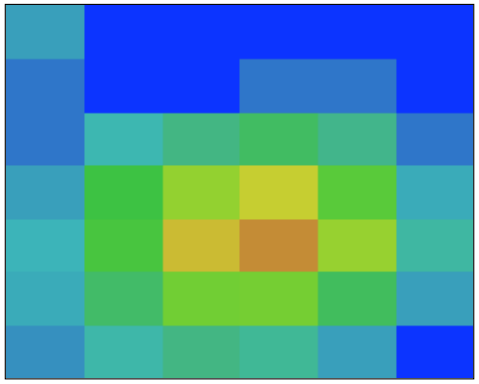
WS9



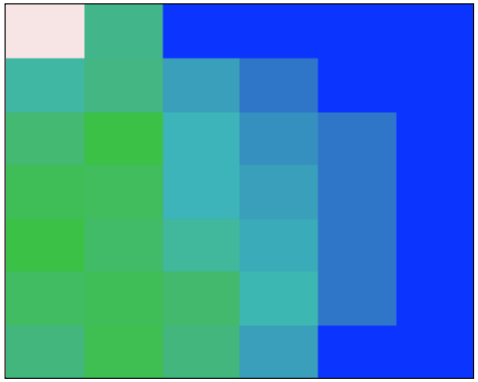
SFC vs TOA LW CRE, midlatitude south



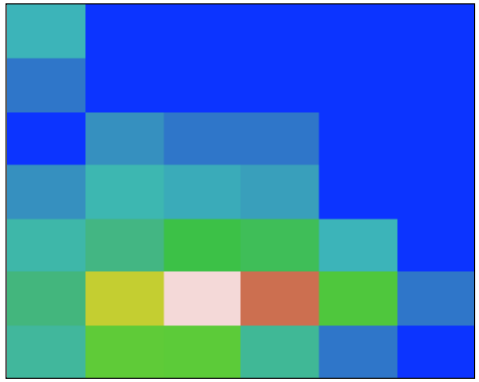
WS3

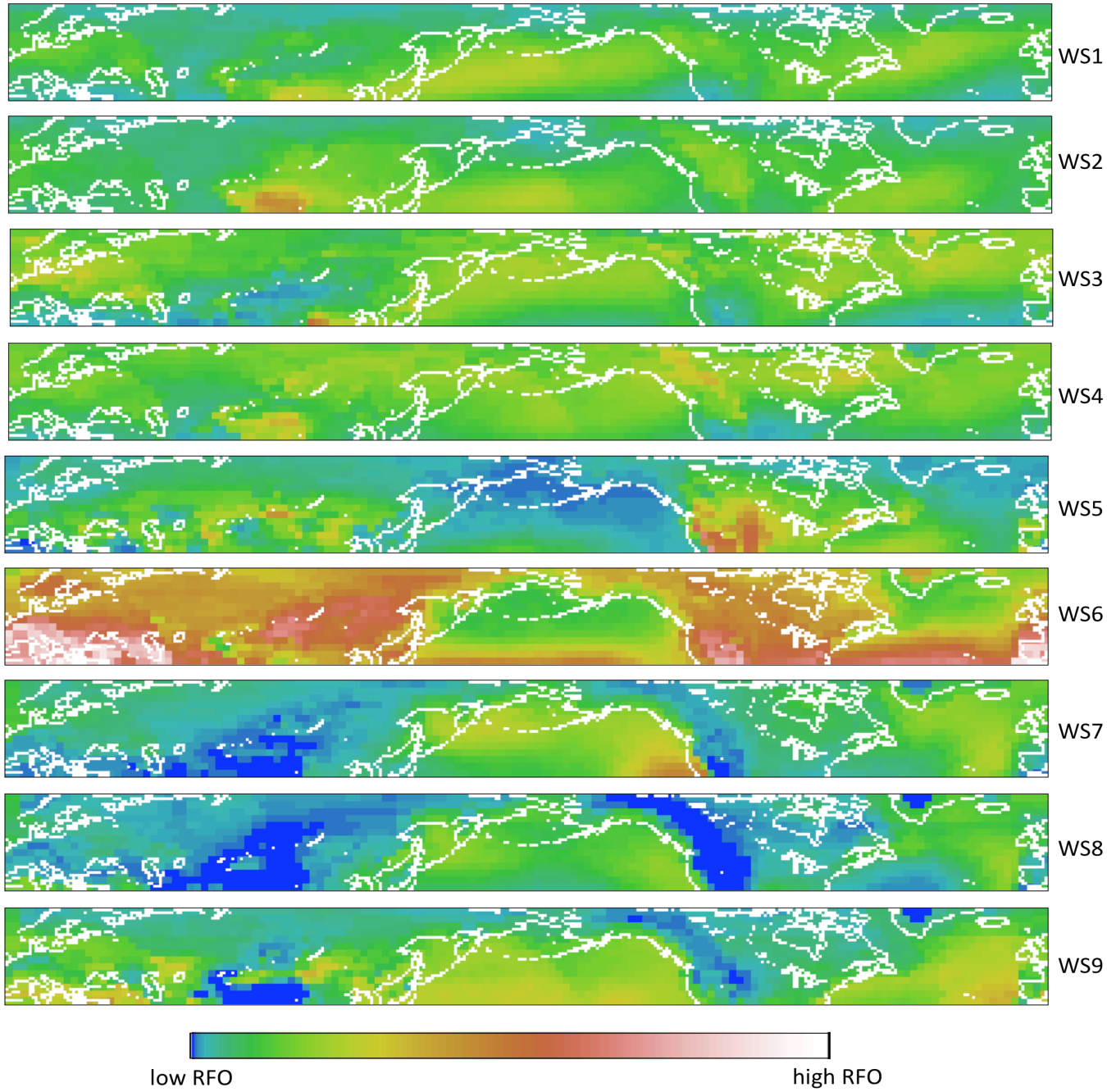


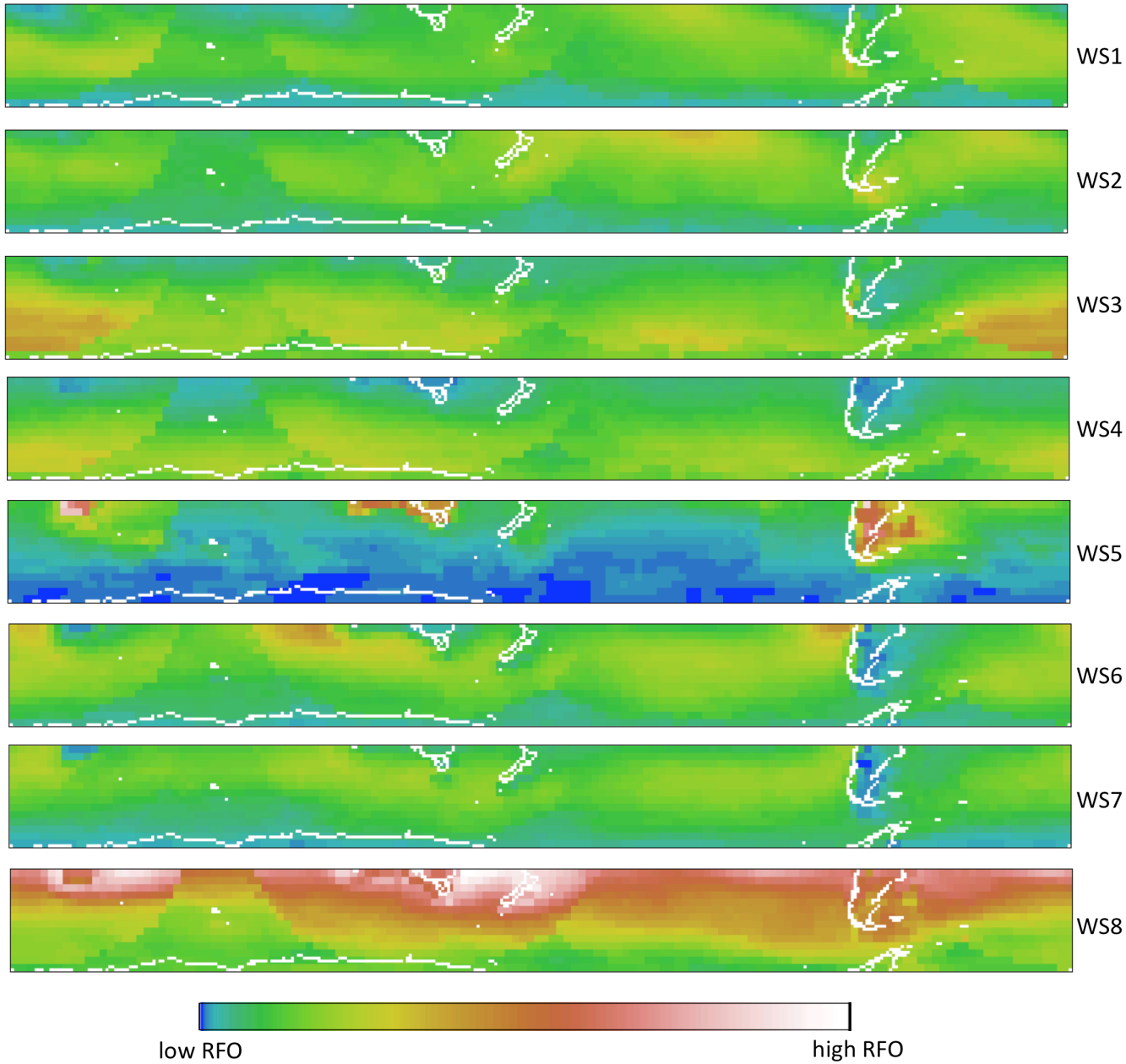
WS5



WS6

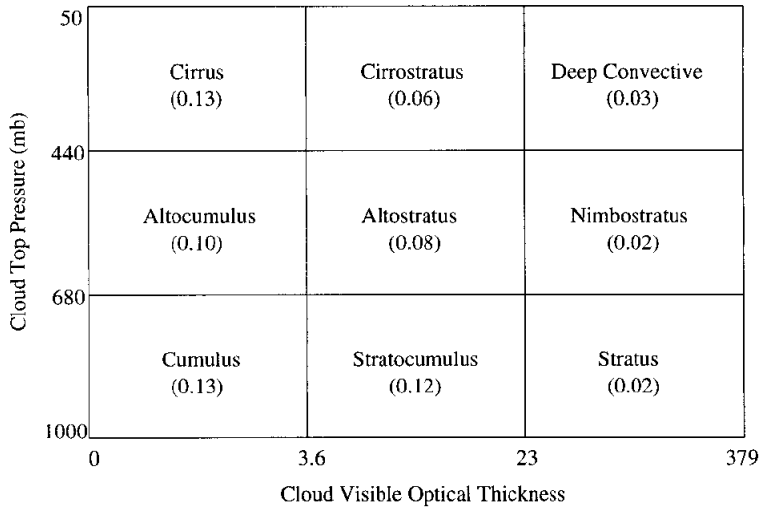



WS1
WS2
WS3
WS4
WS5
WS6
WS7
WS8
WS9
low RFO
high RFO


WS1
WS2
WS3
WS4
WS5
WS6
WS7
WS8
low RFO
high RFO

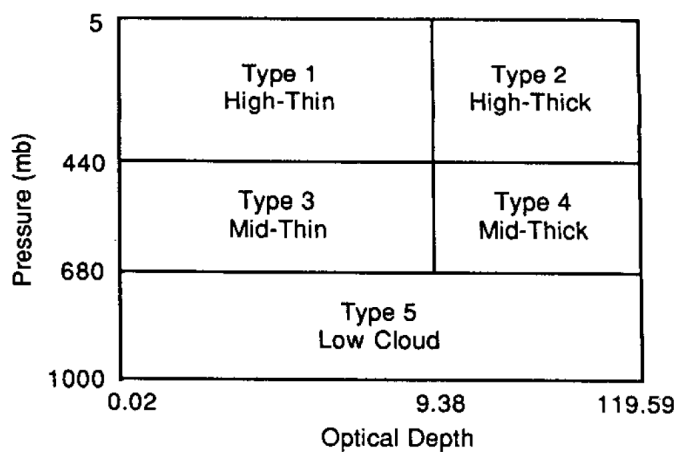
The problem (1)

- Breakdown of Cloud Radiative Effect (aka Cloud Radiative Forcing) by cloud type
- Many ways to define cloud type



Chen et al. 2000

Cloud type	TOA SW	TOA LW	TOA TL
Cirrus	−4.2	5.5	1.3
Cirrostratus	−7.9	5.5	−2.4
Deep convective	−6.2	2.9	−3.3
Altocumulus	−3.2	1.5	−1.7
Altostratus	−8.3	2.0	−6.3
Nimbostratus	−3.4	0.7	−2.7
Cumulus	−5.2	0.6	−4.6
Stratocumulus	−12.7	1.2	−11.5
Stratus	−2.4	0.2	−2.2
Sum (true)	−53.5	20.1	−33.4



Hartmann et al. 1992