Modeling Aerosol-Cloud Interaction in GCMs
and
Simulation of the ADE & AIE over India and Africa

Y. Sud, E. Wilcox, W. Lau, G.K. Walker, L. Oreopoulos , P. S. Bhattacharjee.

Presented by :
Partha S. Bhattacharjee

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Outline

1. Cloud Processes in a GCM
2. McRAS-Algorithms- its Synergy with AIE
3. Synthesis of AIE Modules and Global Budgets
4. Simulation Studies over India and Africa
5. Key Findings

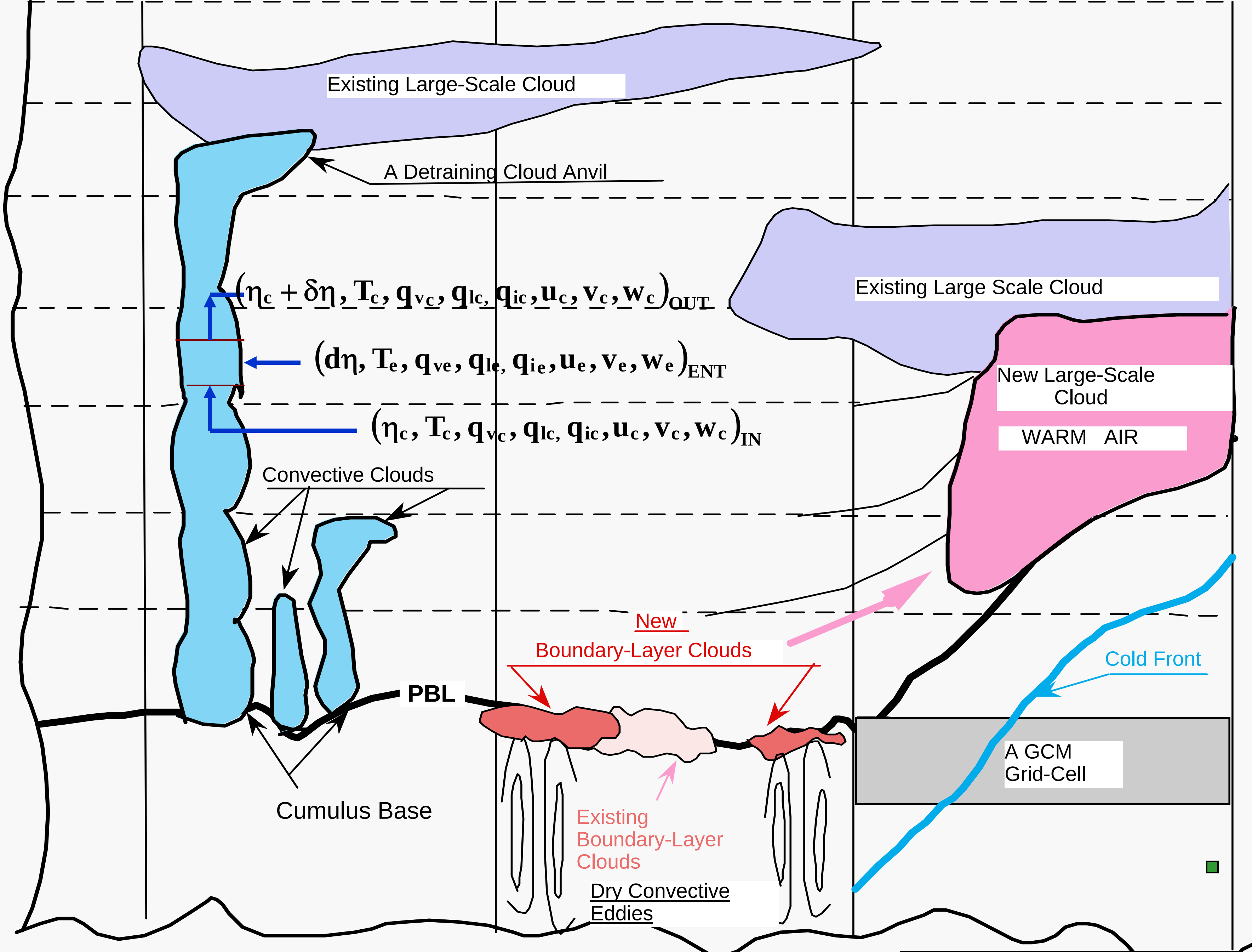
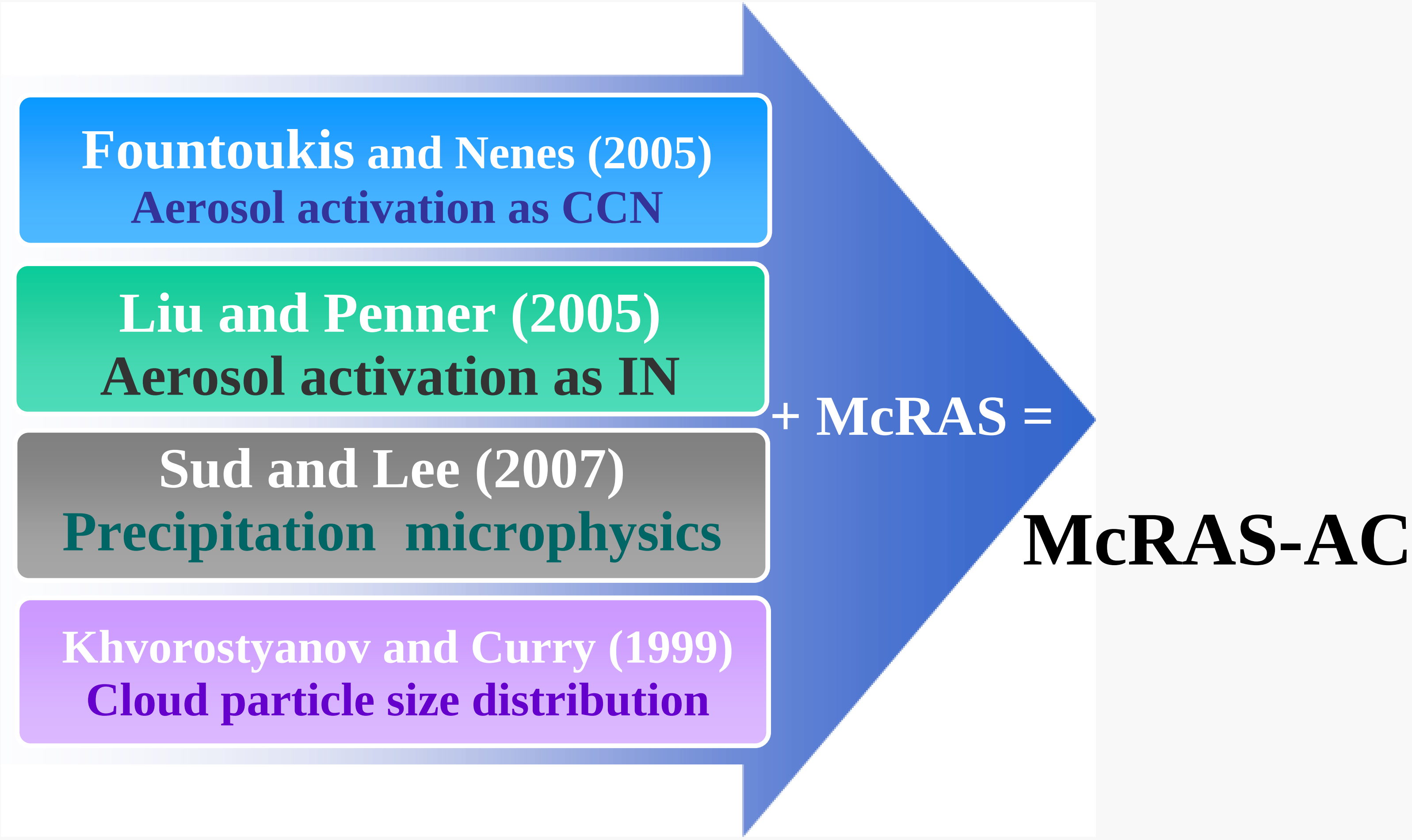


Figure 1a: Schematic Representation of Different Clouds in the GCM

(Sud and Walker, 1999)

Parameterisation of Aerosol Indirect Effect



Fountoukis and Nenes (2005)
Aerosol activation as CCN

Liu and Penner (2005)
Aerosol activation as IN

Sud and Lee (2007)
Precipitation microphysics

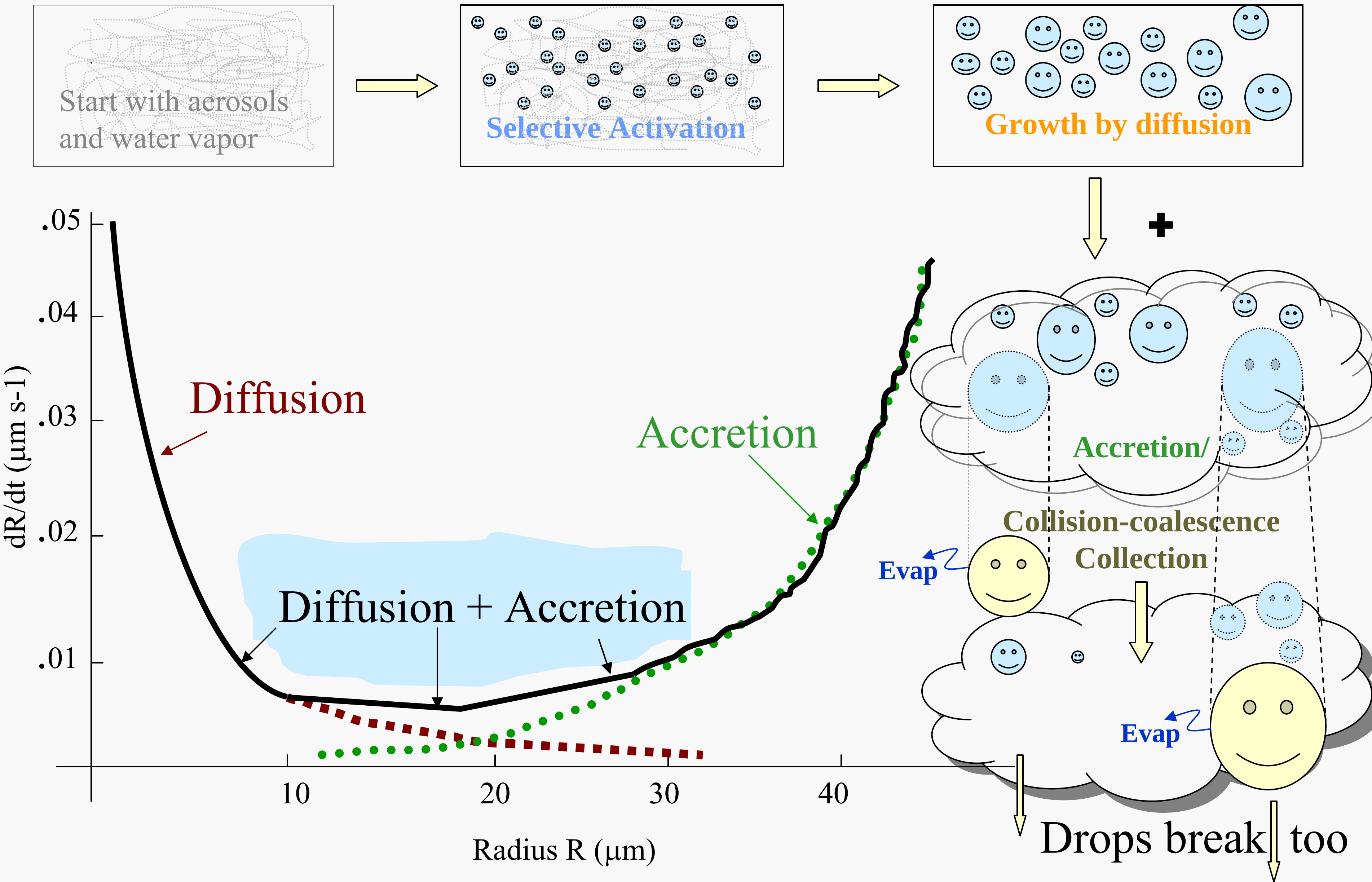
Khvorostyanov and Curry (1999)
Cloud particle size distribution

+ McRAS =

McRAS-AC

Fig 1

From water-vapor/aerosol mix to Cloud-water to Raindrops to ice particles: **A Microcosm of the “Big Bang”**



Start with aerosols and water vapor

Selective Activation

Growth by diffusion

Accretion/ Collision-coalescence Collection

Drops break too

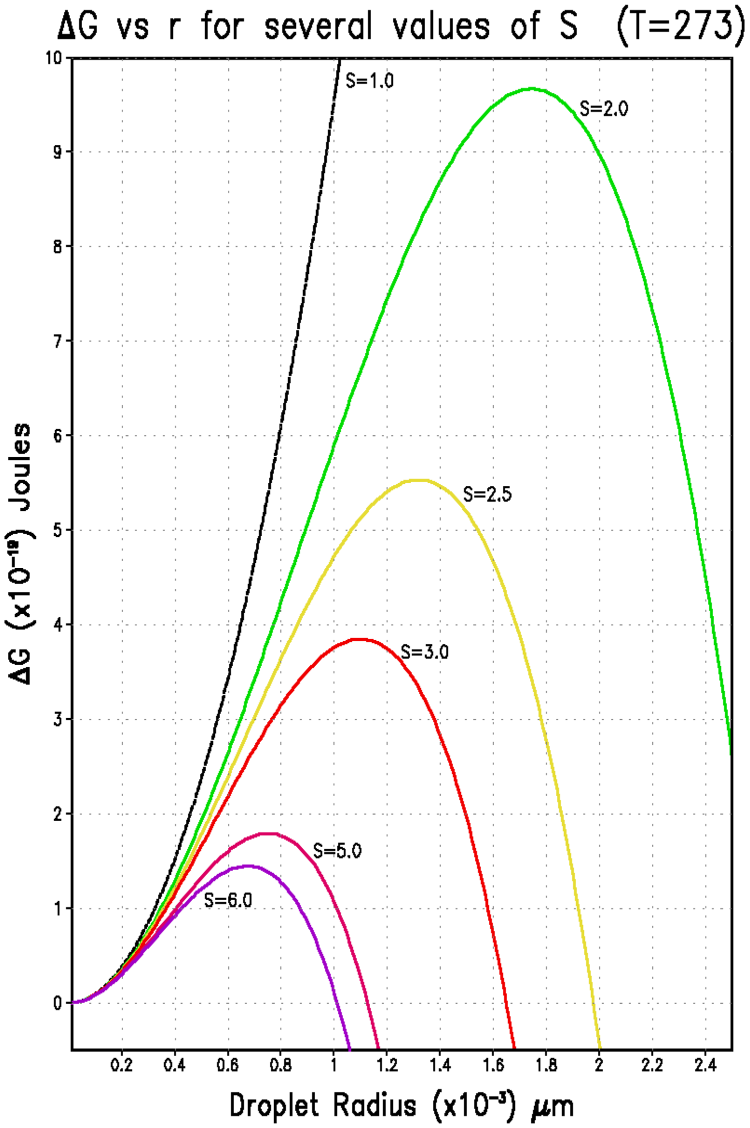
Gibbs Function

The Gibbs function increase enables a minute drop (10^{-3} μm radius range) to grow to its critical radius at an S-value that can be computed from the maxima of:

$$\Delta G = 4\pi r^2 \sigma_{lv} - 4/3\pi r^3 \rho_l R_v \ln \frac{e_s(r)}{e_s}$$

At saturation, the water drop never reaches its critical size and therefore never forms; While at S >> 1.0, the critical sizes can be reached even for very small radii. On the other hand, if hydrophylic aerosols in 1.0 μm size-range are around, the critical size is reached at **S<<1.03** .

Our atmosphere has abundance of aerosols; it rarely reaches S > 1.05. This situation is well represented by Köhler(1936) Theory.



From Byers (1965)

Properties Affecting Droplet Growth

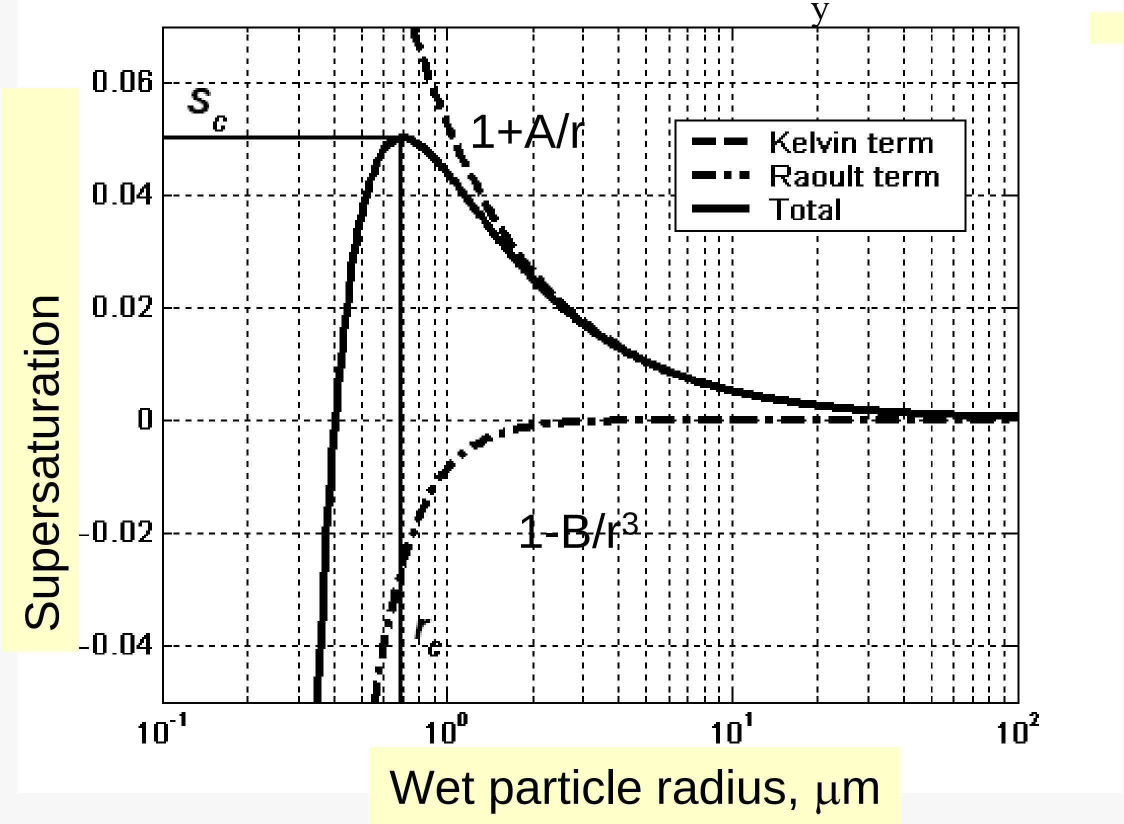
Köhler Equation (1936)

Sfc tension

Molecular wt.

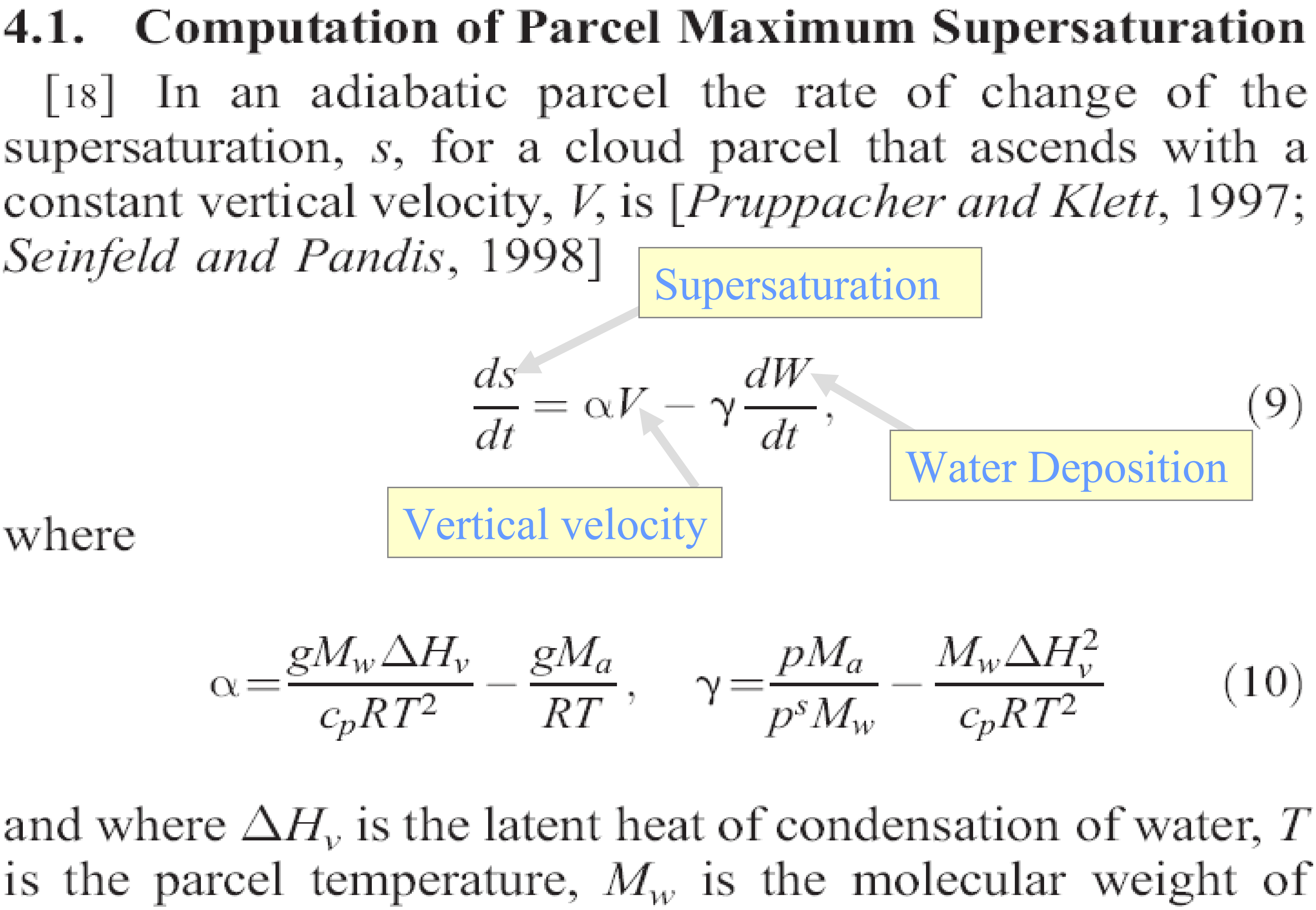
$$S_{eq} \sim \underbrace{\left[\underbrace{\frac{2 M_w \boxed{\sigma_s}}{RT \rho_w r}}_{\text{Kelvin term } A/r} - \underbrace{\frac{3 M_w \cdot m_{solute}}{4\pi r^3 \rho_w \boxed{M_{solute}}} \cdot \boxed{\nu\Phi}}_{Solute\ term\ B/r^3} \right]}_{y}$$

Van't Hoff factor



Particles are 'activated' if $S \geq S_c$

3. Nenes and Seinfeld, 2003



4.1. Computation of Parcel Maximum Supersaturation

[18] In an adiabatic parcel the rate of change of the supersaturation, *s*, for a cloud parcel that ascends with a constant vertical velocity, *V*, is [*Pruppacher and Klett*, 1997; *Seinfeld and Pandis*, 1998]

Supersaturation

$$\frac{ds}{dt} = \alpha V - \gamma \frac{dW}{dt}, \qquad (9)$$

Water Deposition

Vertical velocity

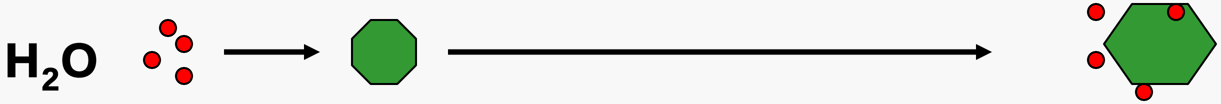
where

$$\alpha = \frac{gM_w \Delta H_v}{c_p R T^2} - \frac{gM_a}{RT}, \qquad \gamma = \frac{pM_a}{p^s M_w} - \frac{M_w \Delta H_v^2}{c_p R T^2} \qquad (10)$$

and where ΔH_v is the latent heat of condensation of water, T is the parcel temperature, M_w is the molecular weight of

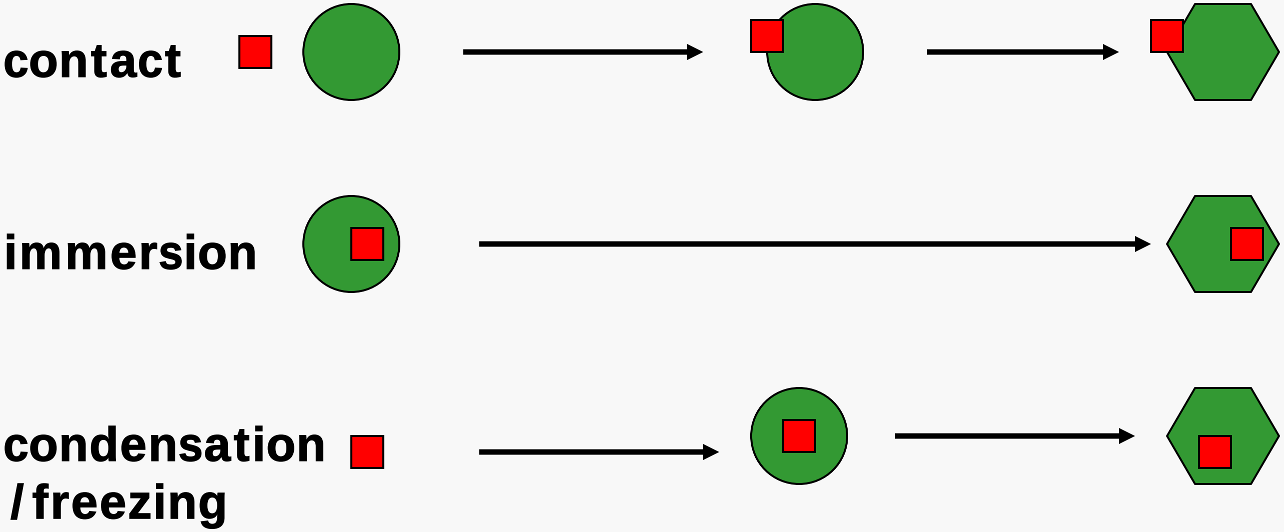
▪ *Heterogeneous nucleation mechanisms*

- Deposition nucleation (deposition nuclei)



H_2O

- Freezing nucleation



contact

immersion

condensation /freezing

From Xiaohong Liu –implemented the NCAR/GSFC

Available at www.ccsm.ucar.edu/working groups/ Atmosphere/Presentations/20040309/24.ppt

Seifert and Beheng (2001, 2005)

Autoconversion:

cloud liquid water (gm/cm3) 9.44×10^{9} width factor of cloud drop size distribution

$$\left.\frac{\partial L_c}{\partial t}\right|_{au} = -\frac{k_c}{20x^*}\frac{(\nu+2)(\nu+4)}{(\nu+1)^2}\Phi'_{au}(\tau)L_c^4N_c^{-2}$$

chosen drop mass, 40 μm universal function number of drop (#/cm3)

Accretion:

$$\left.\frac{\partial L_c}{\partial t}\right|_{ac} = -k_r L_c L_r$$

5.78×10^{3} rain water (gm/cm3)

and

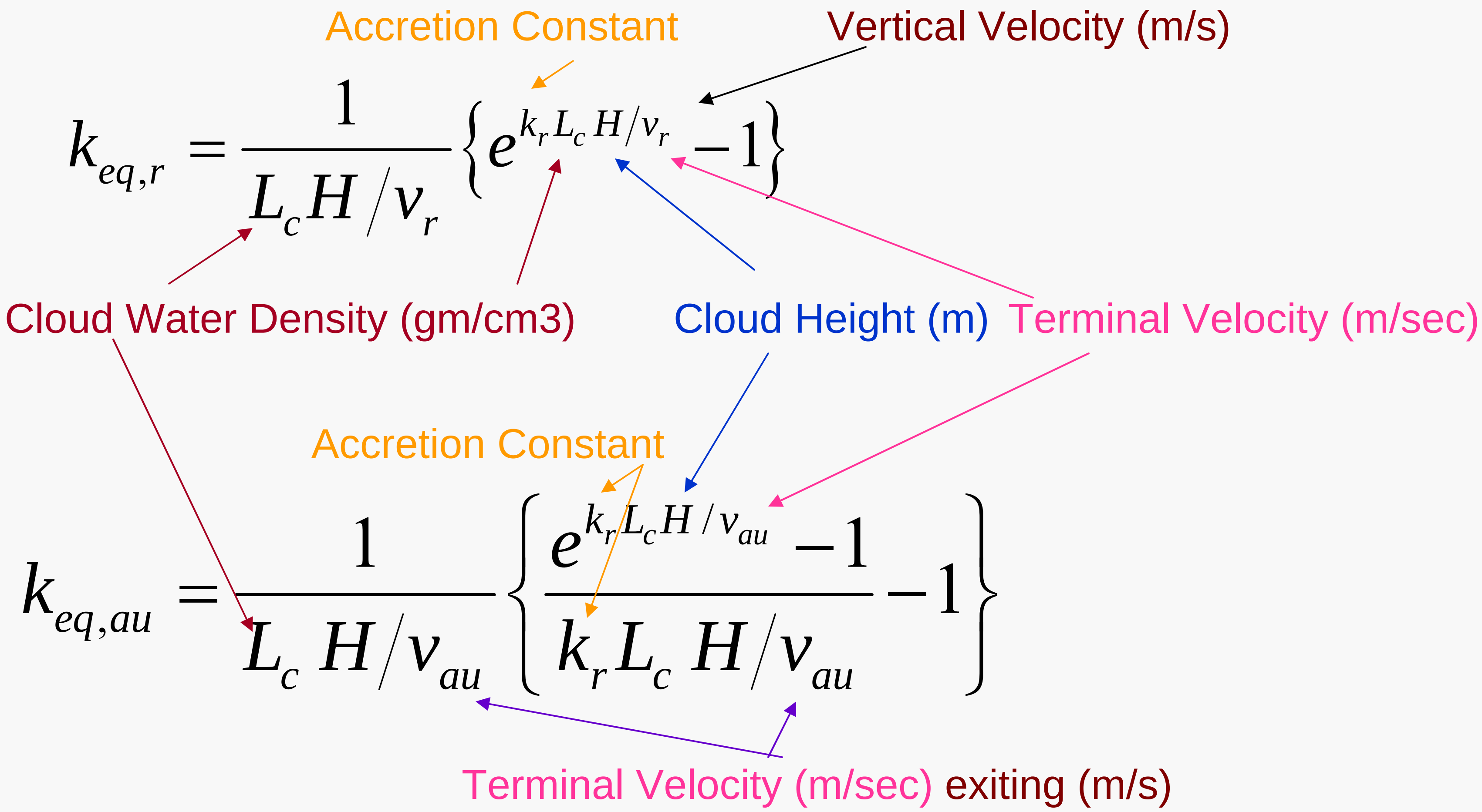
$$\left.\frac{\partial N_c}{\partial t}\right|_{au,ac} = \frac{N_c}{L_c}\left.\frac{\partial L_c}{\partial t}\right|_{au,ac}$$

Self Collection:

$$\left.\frac{\partial N_c}{\partial t}\right|_{sc} = -k_c\frac{(\nu+2)}{(\nu+1)}L_c^2 - \left.\frac{\partial N_c}{\partial t}\right|_{au}$$

k_{eq}

GCM parameterization (Sud and Lee, 2007)



Accretion Constant

Vertical Velocity (m/s)

$$k_{eq,r} = \frac{1}{L_c H / v_r}\left\{ e^{k_r L_c H / v_r} - 1 \right\}$$

Cloud Water Density (gm/cm3)

Cloud Height (m)

Terminal Velocity (m/sec)

Accretion Constant

$$k_{eq,au} = \frac{1}{L_c H / v_{au}}\left\{ \frac{e^{k_r L_c H / v_{au}} - 1}{k_r L_c H / v_{au}} - 1 \right\}$$

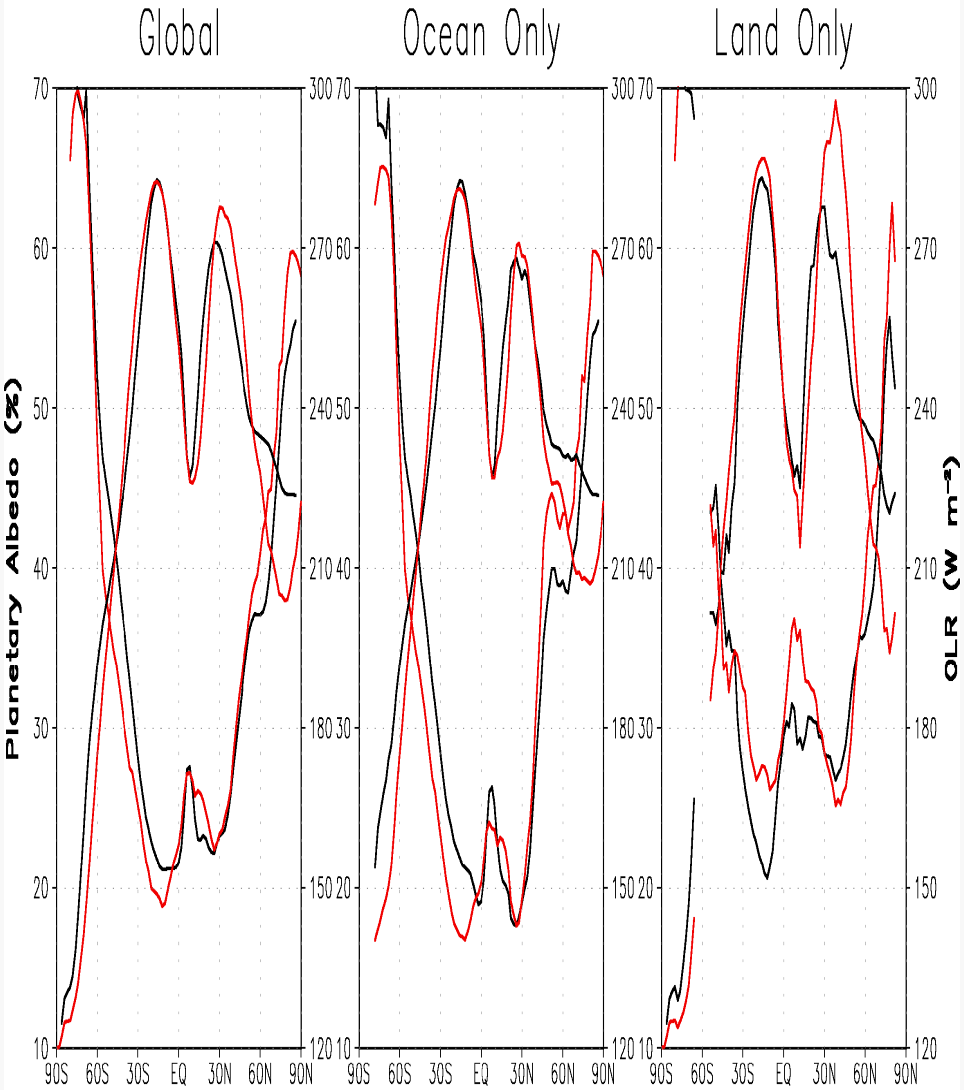
Terminal Velocity (m/sec) exiting (m/s)

$V_{au} = 7.0 \times 10^5 L_c$

Various DSD-Functionals

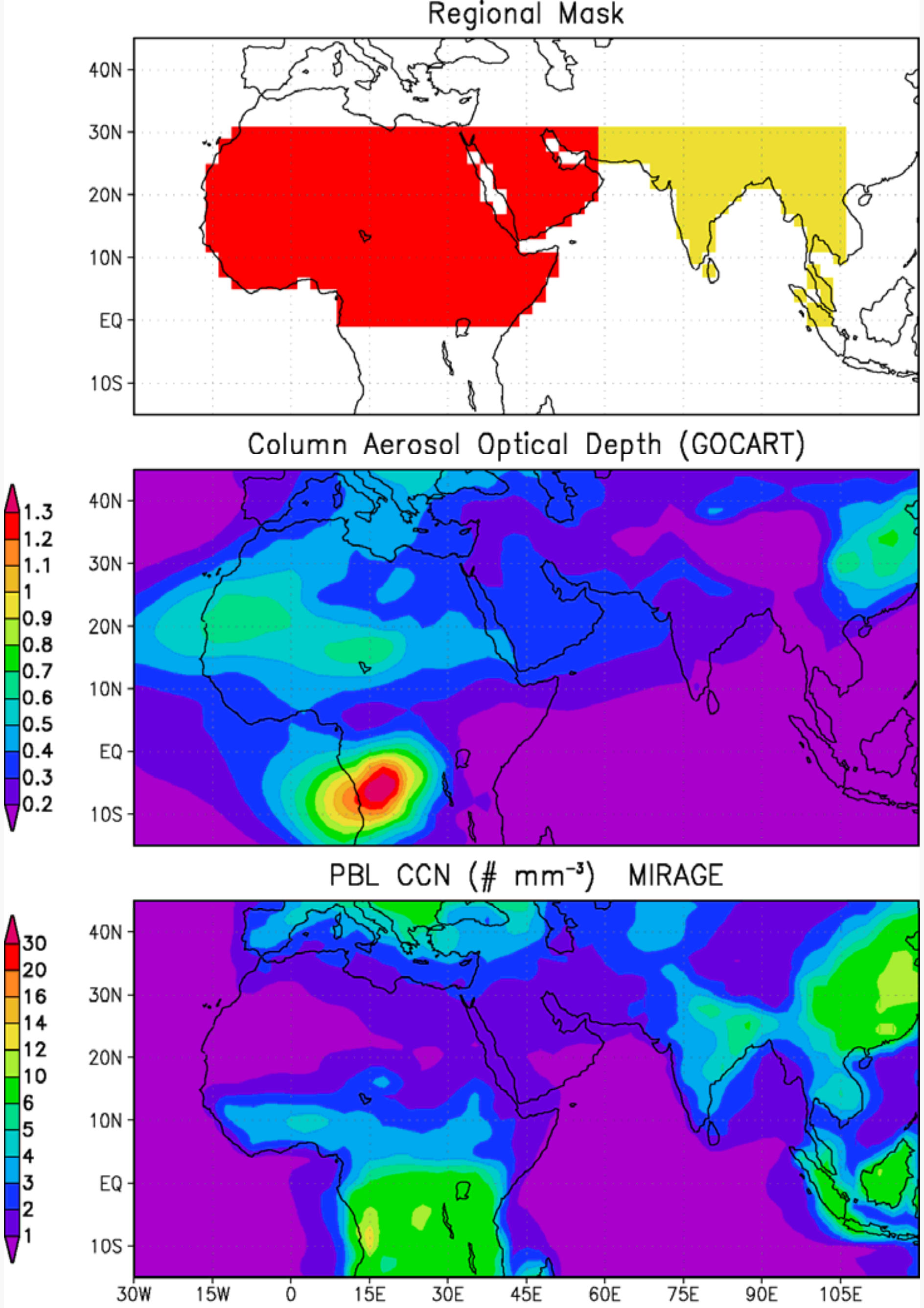
Name of the Distribution	Distribution Function	Ratio r_{eff}/r_{vol}	Approximate Number
Normal	$\frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{(r-\mu)^2}{2\sigma^2}\right]$	$\frac{\left[\mu(\mu^2+3\sigma^2)\right]^{2/3}}{\mu^2+\sigma^2}$	1.1
Half-Normal	$\frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{r^2}{2\sigma^2}\right], r>0$	$\frac{\int_0^\infty r^3\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{r^2}{2\sigma^2}\right)dr}{\int_0^\infty r^2\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{r^2}{2\sigma^2}\right)dr} \Bigg/ \left[\frac{\int_0^\infty r^3\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{r^2}{2\sigma^2}\right)dr}{\int_0^\infty \frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{r^2}{2\sigma^2}\right)dr}\right]^{1/3}$	1.36
Lognormal	$\frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{(\ln r-\mu)^2}{2\sigma^2}\right]$	$\frac{\left[\exp(3\mu+9/2\sigma^2)\right]^{2/3}}{\exp(2\mu+2\sigma^2)}=e^{\sigma^2}$	1~3 (depends on standard deviation)
Marshall-Palmer or Exponential	$\exp\left[-\lambda r\right]$	$\frac{3}{8}r_m \Big/ \frac{1}{4}\sqrt[3]{\frac{3}{4}}r_m$	1.65
Gamma	$r^p\exp\left[-pr/r_m\right]$	$\frac{(p+3)}{\sqrt[3]{(p+1)(p+2)(p+3)}}$	1.09~1.39 (depends on shape factor p)

Zonal Average α_p (%) and OLR (W m^{-2}) JJA



McRAS 1987 simulation (red lines) versus CERES climatology (white lines).

McRAS run 44g. Full AIE Physics. Mirage Int Mixed. 44 + Kauto limit 25



Regional Mask

Column Aerosol Optical Depth (GOCART)

PBL CCN (# mm^{-3}) MIRAGE

Fig 2

Sud et al., Annales Geophysicae , 2009 (accepted)

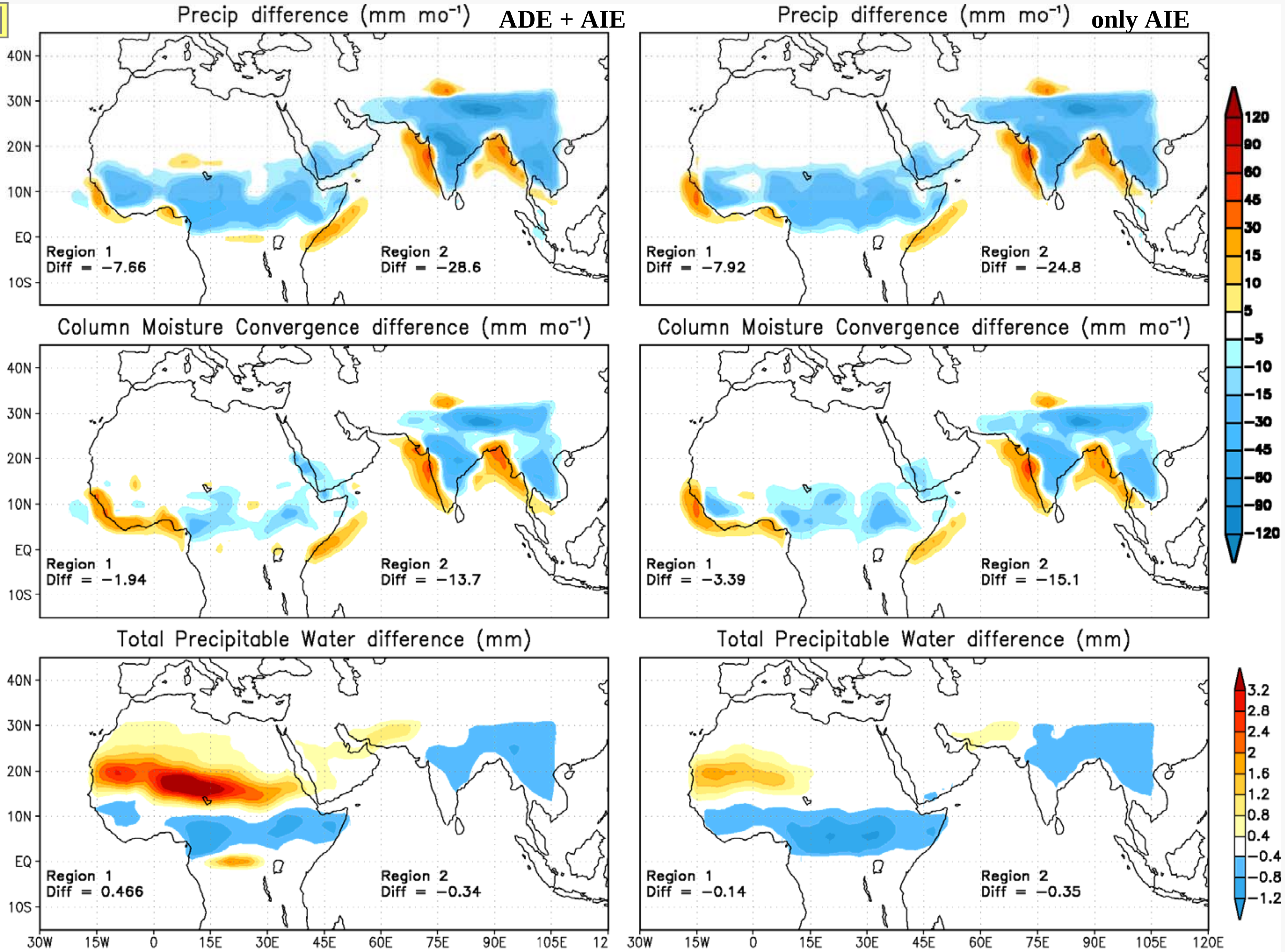

Precip difference (mm mo^{-1})
ADE + AIE
Precip difference (mm mo^{-1})
only AIE
Region 1
Diff = −7.66
Region 2
Diff = −28.6
Region 1
Diff = −7.92
Region 2
Diff = −24.8
Column Moisture Convergence difference (mm mo^{-1})
Column Moisture Convergence difference (mm mo^{-1})
Region 1
Diff = −1.94
Region 2
Diff = −13.7
Region 1
Diff = −3.39
Region 2
Diff = −15.1
Total Precipitable Water difference (mm)
Total Precipitable Water difference (mm)
Region 1
Diff = 0.466
Region 2
Diff = −0.34
Region 1
Diff = −0.14
Region 2
Diff = −0.35
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
120E
120
90
60
45
30
15
10
5
−5
−10
−15
−30
−45
−60
−90
−120
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
−0.4
−0.8
−1.2

Fig 3a

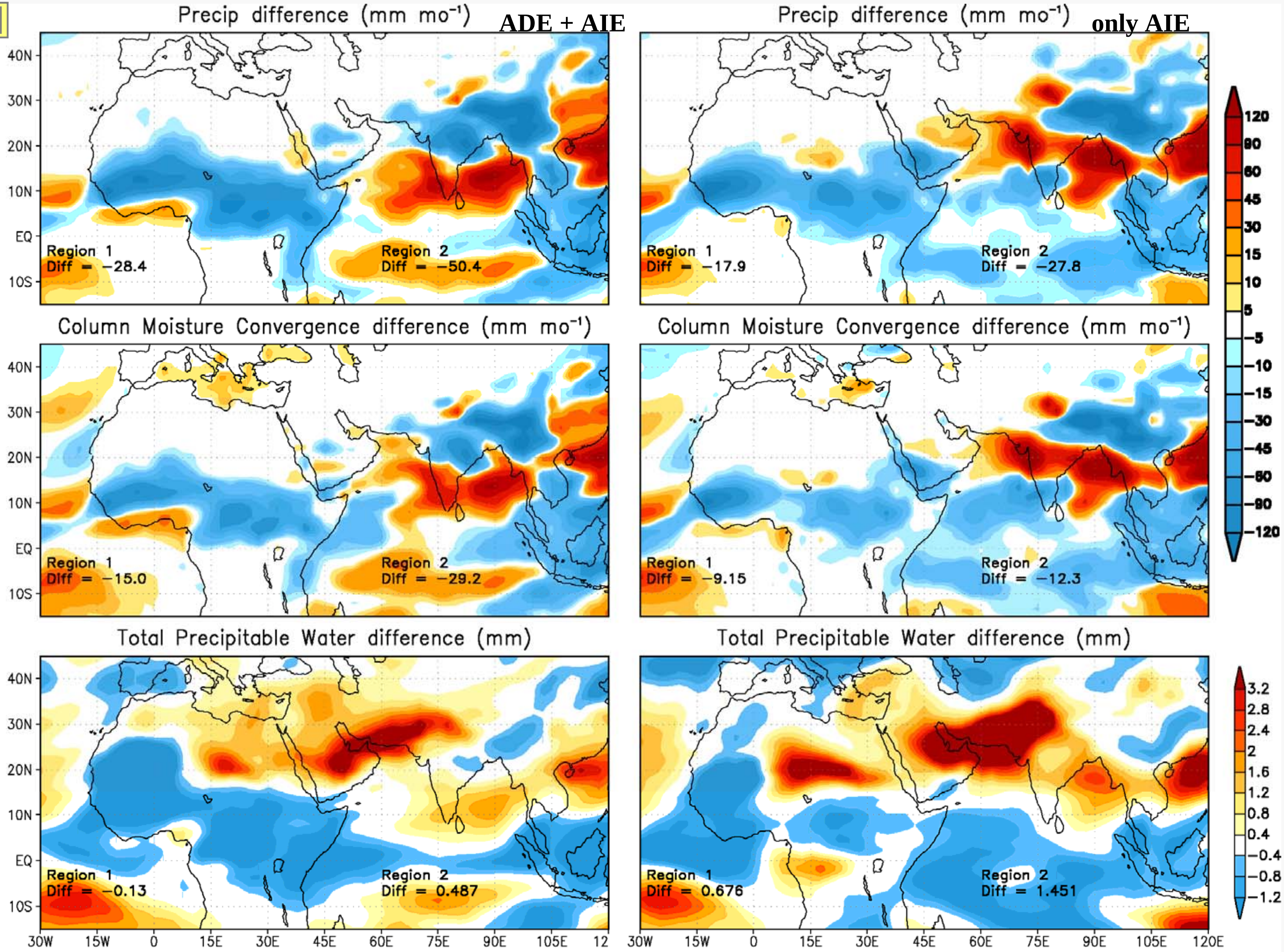

Precip difference (mm mo^{-1})
ADE + AIE
Precip difference (mm mo^{-1})
only AIE
Region 1
Diff = −28.4
Region 2
Diff = −50.4
Region 1
Diff = −17.9
Region 2
Diff = −27.8
Column Moisture Convergence difference (mm mo^{-1})
Column Moisture Convergence difference (mm mo^{-1})
Region 1
Diff = −15.0
Region 2
Diff = −29.2
Region 1
Diff = −9.15
Region 2
Diff = −12.3
Total Precipitable Water difference (mm)
Total Precipitable Water difference (mm)
Region 1
Diff = −0.13
Region 2
Diff = 0.487
Region 1
Diff = 0.676
Region 2
Diff = 1.451
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
120E
120
90
60
45
30
15
10
5
−5
−10
−15
−30
−45
−60
−90
−120
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
−0.4
−0.8
−1.2

Fig 3b

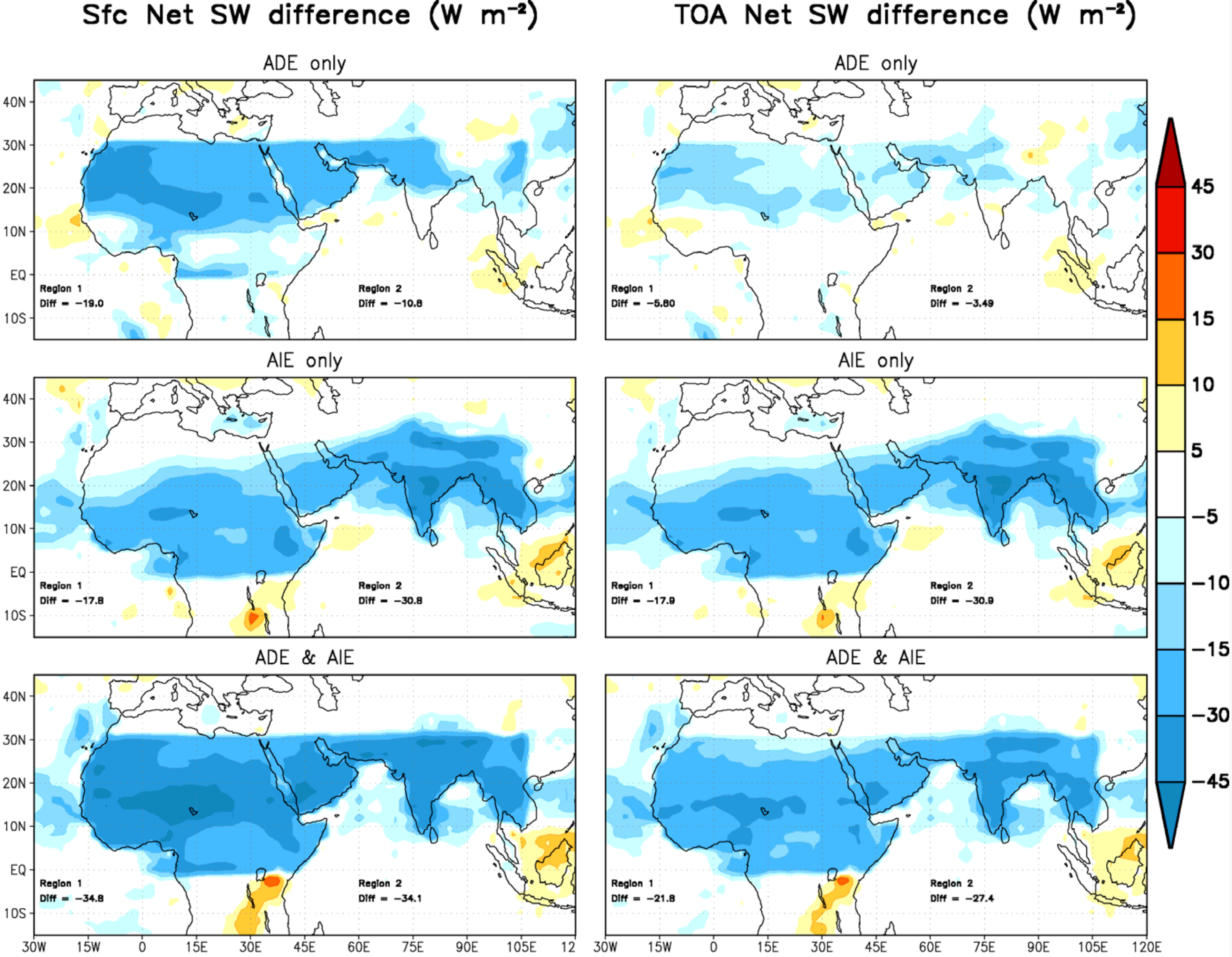

Sfc Net SW difference (W m^{-2})
TOA Net SW difference (W m^{-2})
ADE only
AIE only
ADE & AIE
Region 1
Diff = −19.0
Region 2
Diff = −10.8
Region 1
Diff = −5.80
Region 2
Diff = −3.49
Region 1
Diff = −17.8
Region 2
Diff = −30.8
Region 1
Diff = −17.9
Region 2
Diff = −30.9
Region 1
Diff = −34.8
Region 2
Diff = −34.1
Region 1
Diff = −21.8
Region 2
Diff = −27.4
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
120E
45
30
15
10
5
−5
−10
−15
−30
−45

Fig 6

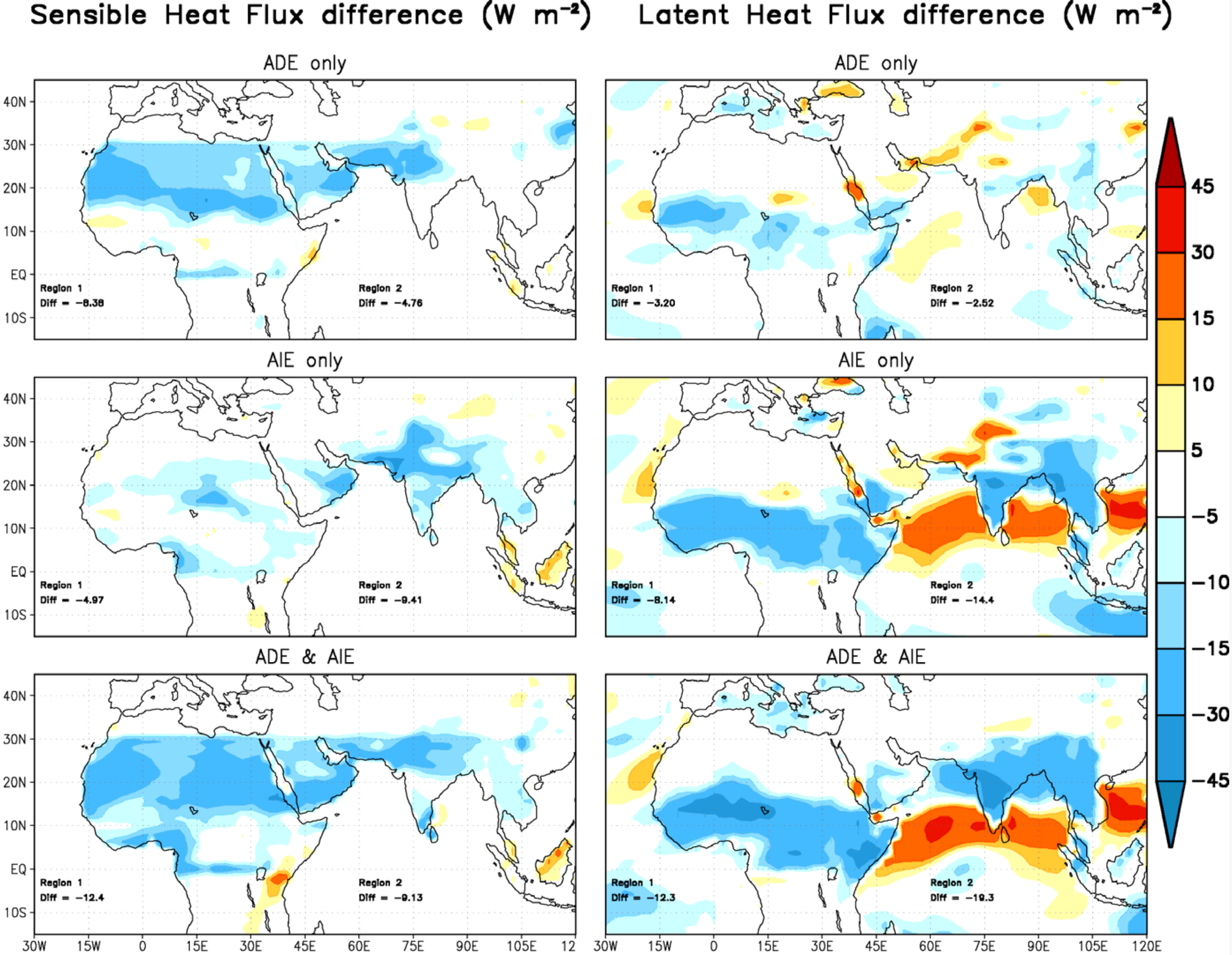

Sensible Heat Flux difference (W m⁻²)
Latent Heat Flux difference (W m⁻²)
ADE only
ADE only
Region 1
Diff = −8.38
Region 2
Diff = −4.76
Region 1
Diff = −3.20
Region 2
Diff = −2.52
AIE only
AIE only
Region 1
Diff = −4.97
Region 2
Diff = −9.41
Region 1
Diff = −8.14
Region 2
Diff = −14.4
ADE & AIE
ADE & AIE
Region 1
Diff = −12.4
Region 2
Diff = −9.13
Region 1
Diff = −12.3
Region 2
Diff = −19.3
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
120E
45
30
15
10
5
−5
−10
−15
−30
−45

Fig 5

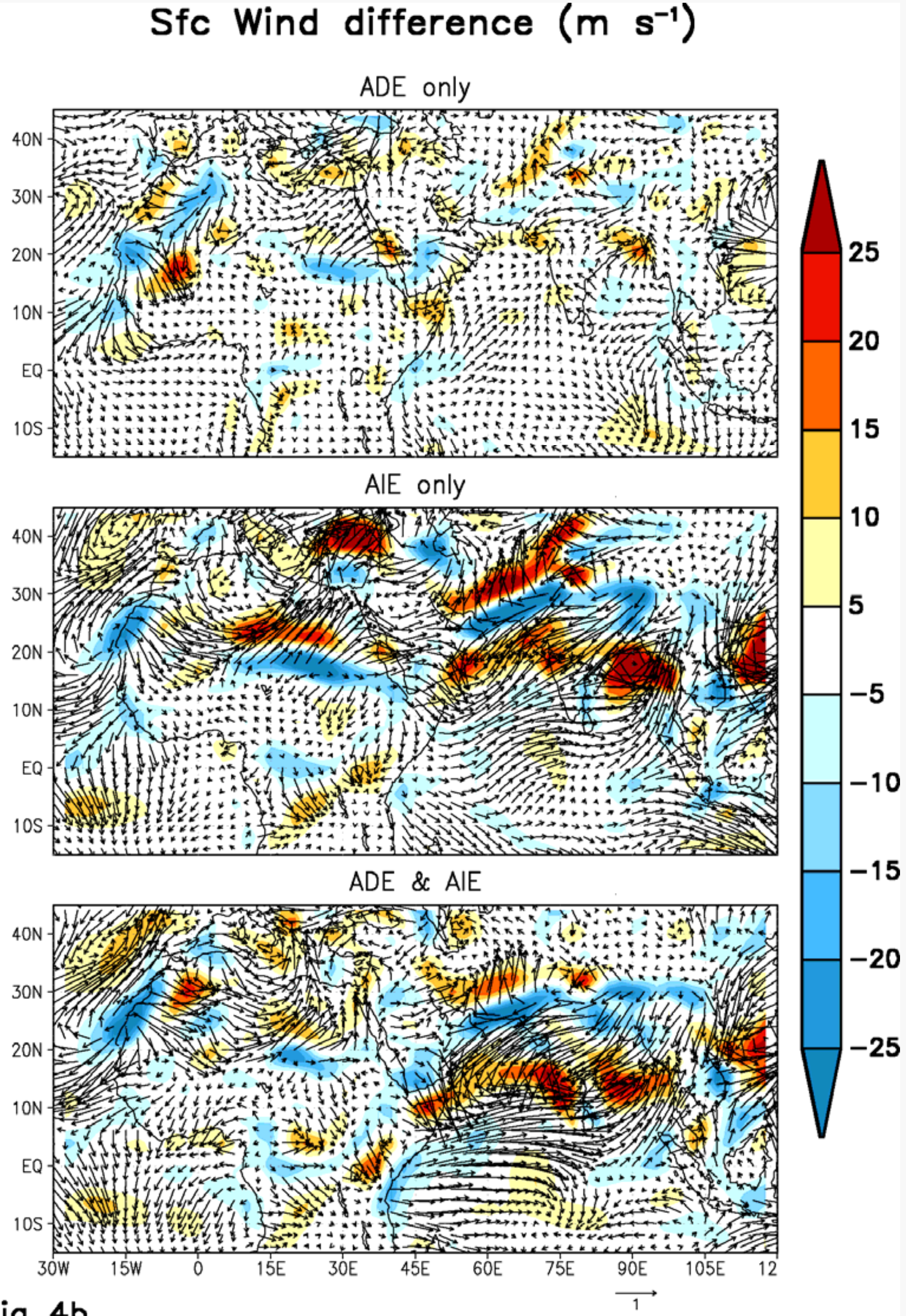

Sfc Wind difference (m s^{-1})
ADE only
AIE only
ADE & AIE
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
12
25
20
15
10
5
−5
−10
−15
−20
−25
1

Fig 4b

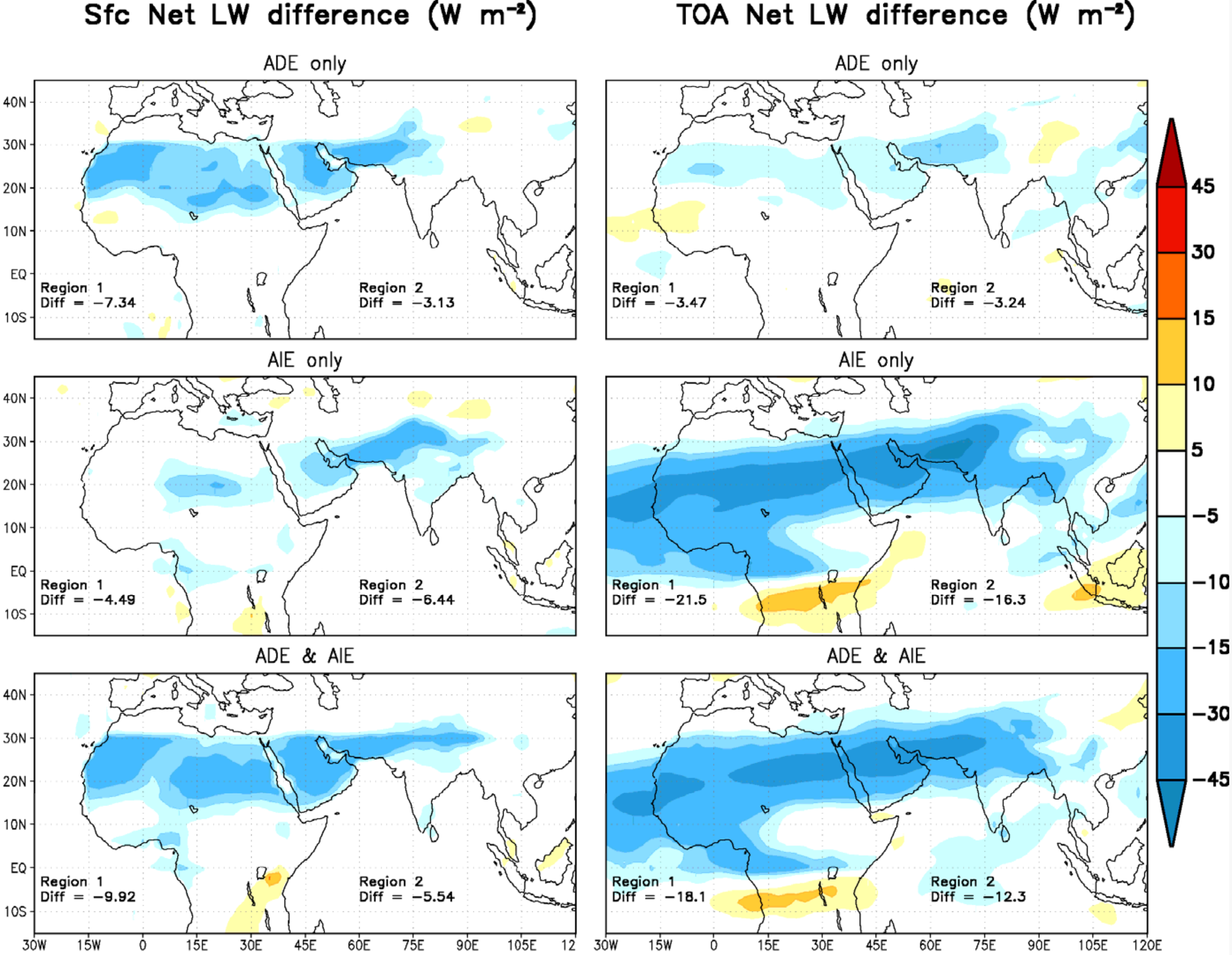

Sfc Net LW difference (W m⁻²)
TOA Net LW difference (W m⁻²)
ADE only
Region 1
Diff = −7.34
Region 2
Diff = −3.13
ADE only
Region 1
Diff = −3.47
Region 2
Diff = −3.24
AIE only
Region 1
Diff = −4.49
Region 2
Diff = −6.44
AIE only
Region 1
Diff = −21.5
Region 2
Diff = −16.3
ADE & AIE
Region 1
Diff = −9.92
Region 2
Diff = −5.54
ADE & AIE
Region 1
Diff = −18.1
Region 2
Diff = −12.3
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
12
120E
45
30
15
10
5
−5
−10
−15
−30
−45

Fig 7a

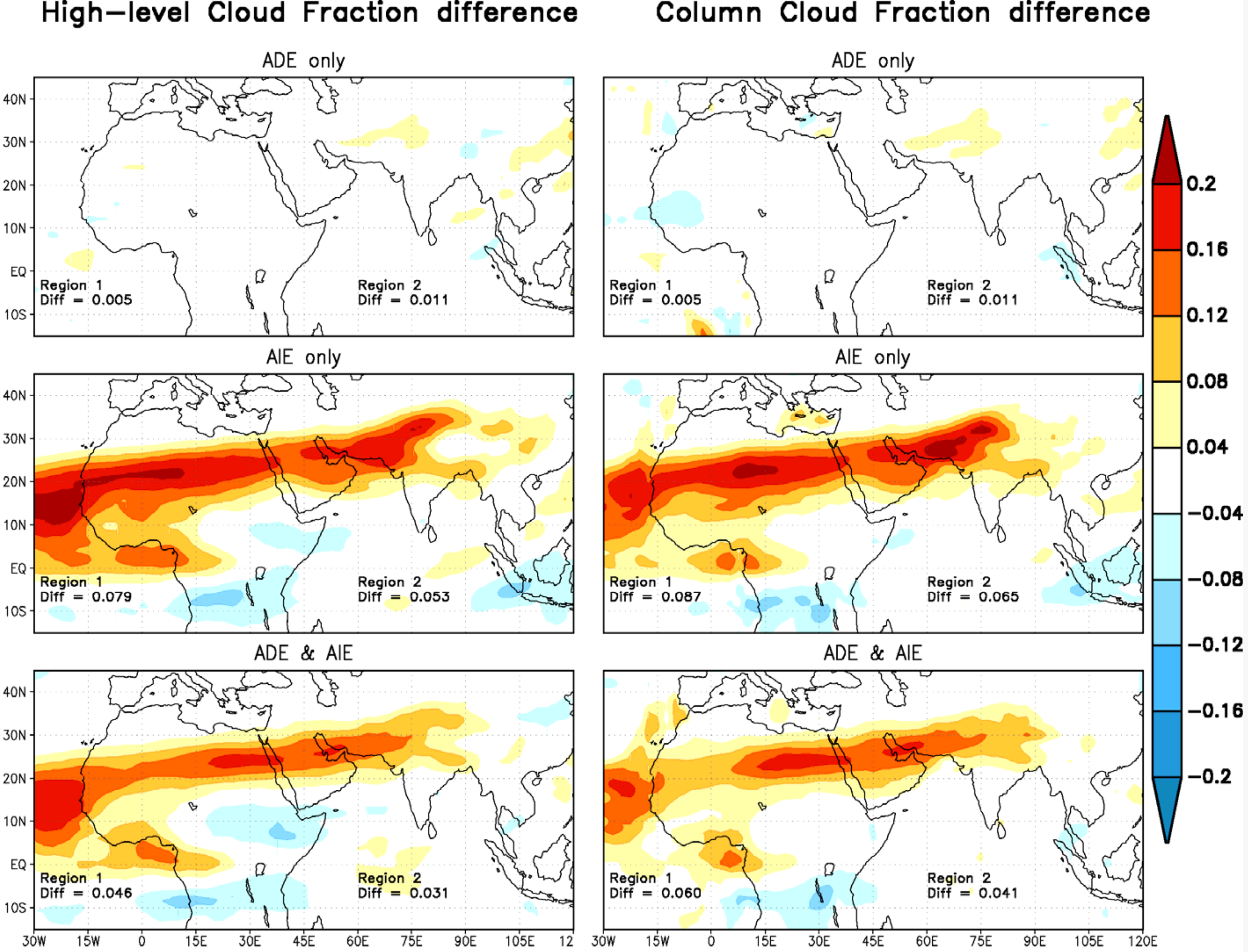

High−level Cloud Fraction difference
Column Cloud Fraction difference
ADE only
ADE only
Region 1
Diff = 0.005
Region 2
Diff = 0.011
Region 1
Diff = 0.005
Region 2
Diff = 0.011
AIE only
AIE only
Region 1
Diff = 0.079
Region 2
Diff = 0.053
Region 1
Diff = 0.087
Region 2
Diff = 0.065
ADE & AIE
ADE & AIE
Region 1
Diff = 0.046
Region 2
Diff = 0.031
Region 1
Diff = 0.060
Region 2
Diff = 0.041
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
12
120E
0.2
0.16
0.12
0.08
0.04
−0.04
−0.08
−0.12
−0.16
−0.2

Fig 7b

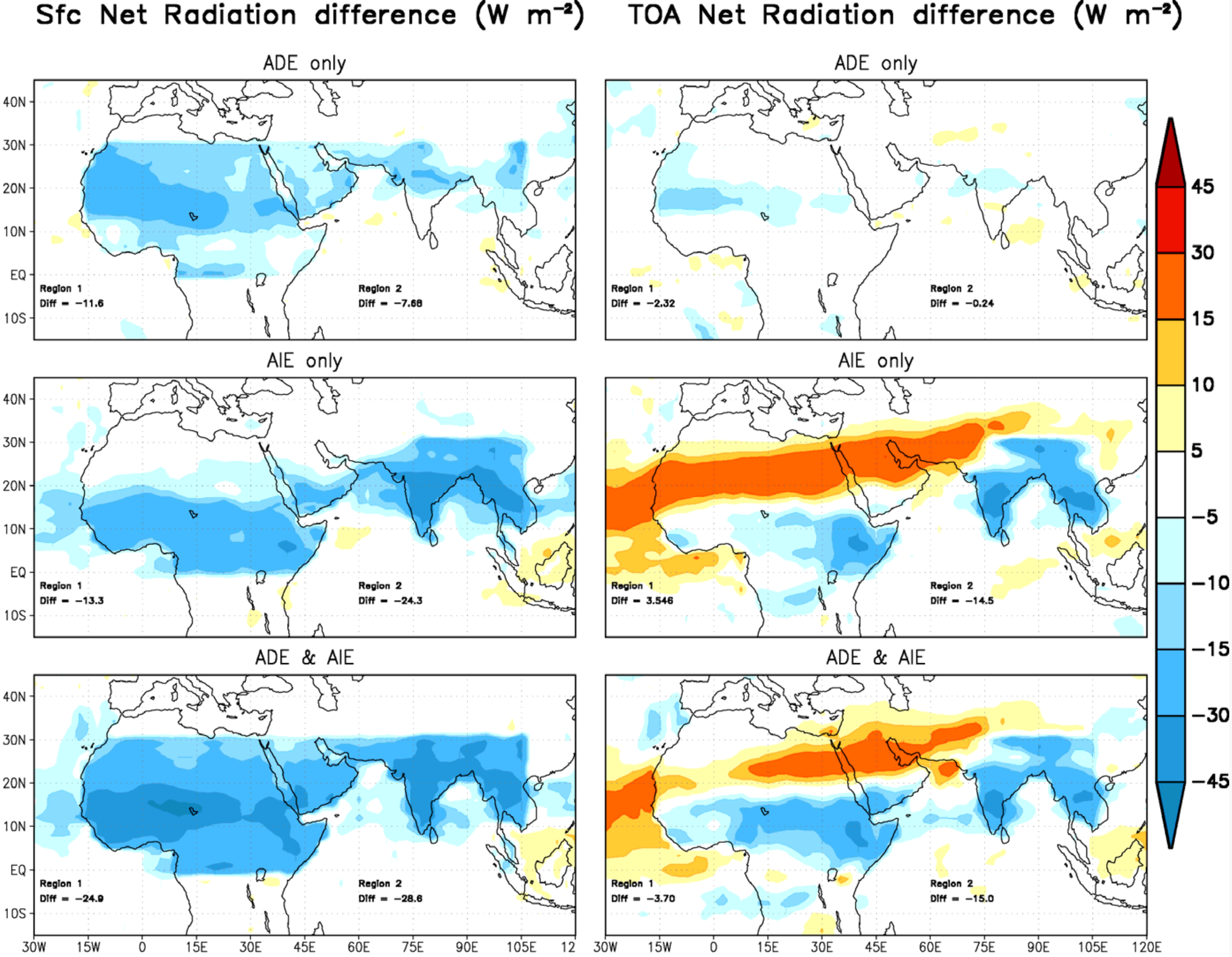
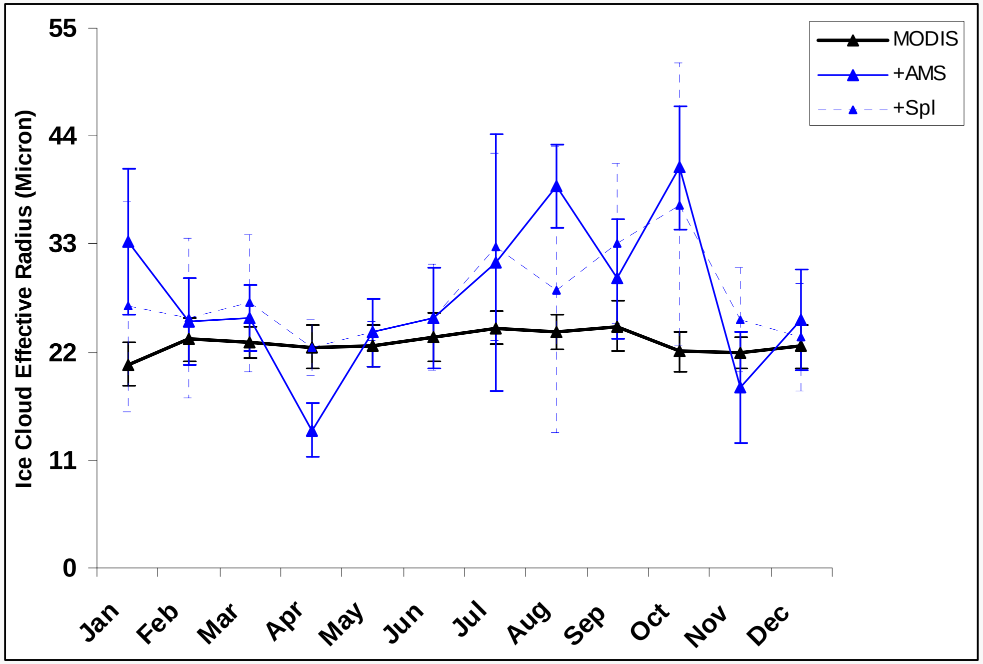

Sfc Net Radiation difference (W m⁻²)
TOA Net Radiation difference (W m⁻²)
ADE only
ADE only
Region 1
Diff = -11.6
Region 2
Diff = -7.68
Region 1
Diff = -2.32
Region 2
Diff = -0.24
AIE only
AIE only
Region 1
Diff = -13.3
Region 2
Diff = -24.3
Region 1
Diff = 3.546
Region 2
Diff = -14.5
ADE & AIE
ADE & AIE
Region 1
Diff = -24.9
Region 2
Diff = -28.6
Region 1
Diff = -3.70
Region 2
Diff = -15.0
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
12
120E
45
30
15
10
5
-5
-10
-15
-30
-45

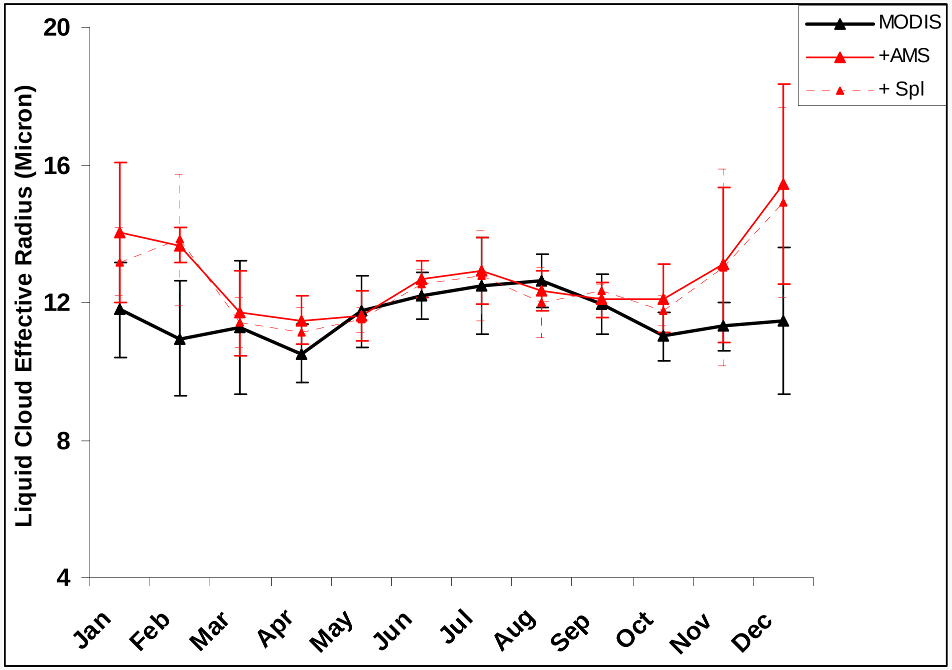
Fig 8

What do we see? (or **CONCLUSIONS**)

1. The existing formulations of aerosol activation for liquid, mixed phase, and ice clouds working with McRAS-AC give reasonable Aerosol-Cloud-Radiation interaction complex for use in GCMs.
2. Regional modeling studies, without a two-way feedback interaction are unable to provide a worthwhile guidance aerosol-climate impacts.
3. Several studies have emphasizes critical importance of the direct effect of aerosols. We show that AIE can be even more important. AIE may exacerbate instead of mitigating global warming .
4. Ice clouds were deficient, and we spent a lot of trying to have a reasonable clouds in the ITCZ; without enough IN's to activated this way impossible ; splintering helps to create IN; but truly Ammonium Sulfate [(NH4)2SO4] is the missing aerosol. It nailed the ice cloud deficiency.

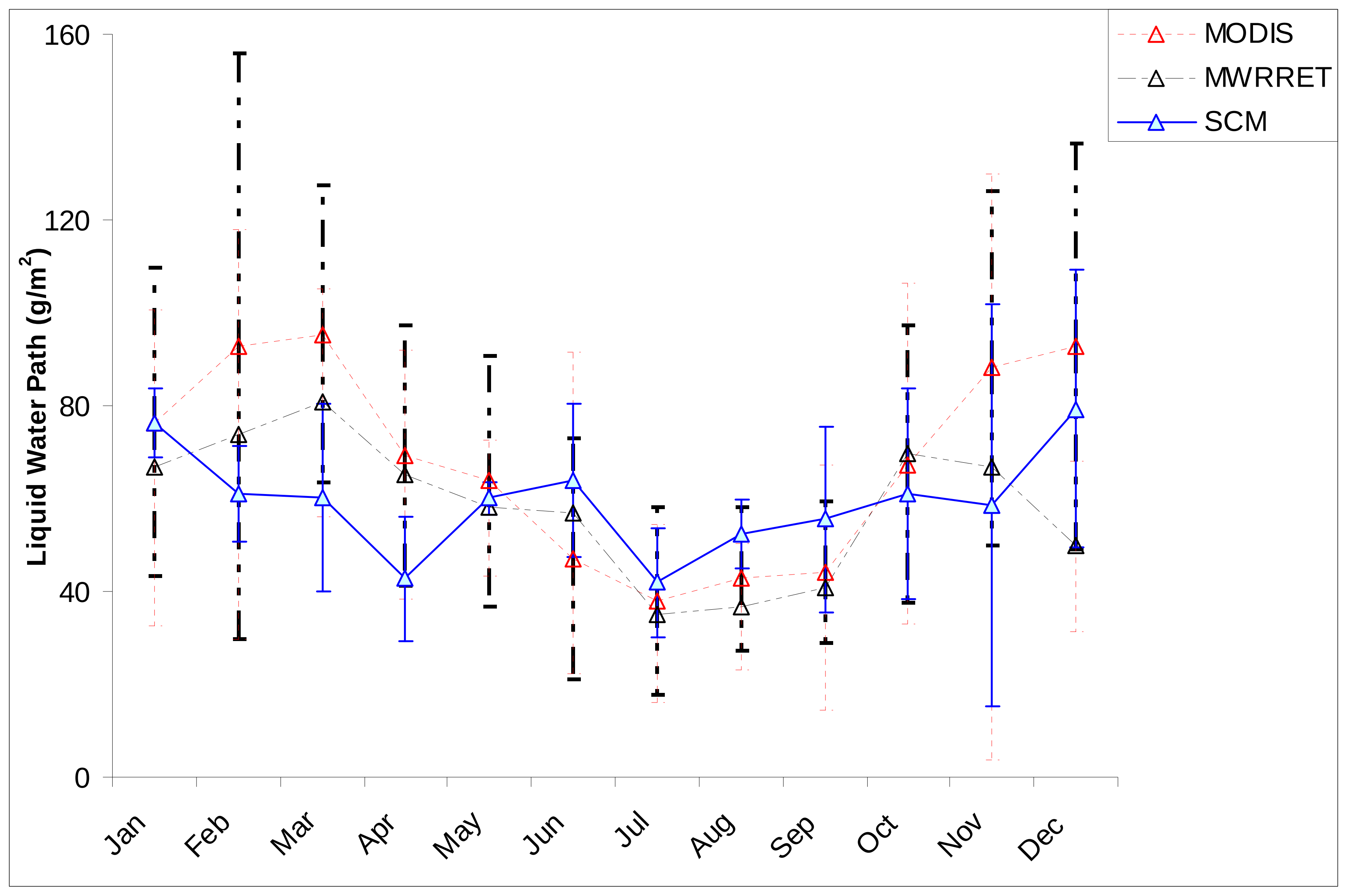
Single Column Model simulation: ARM 3 year case

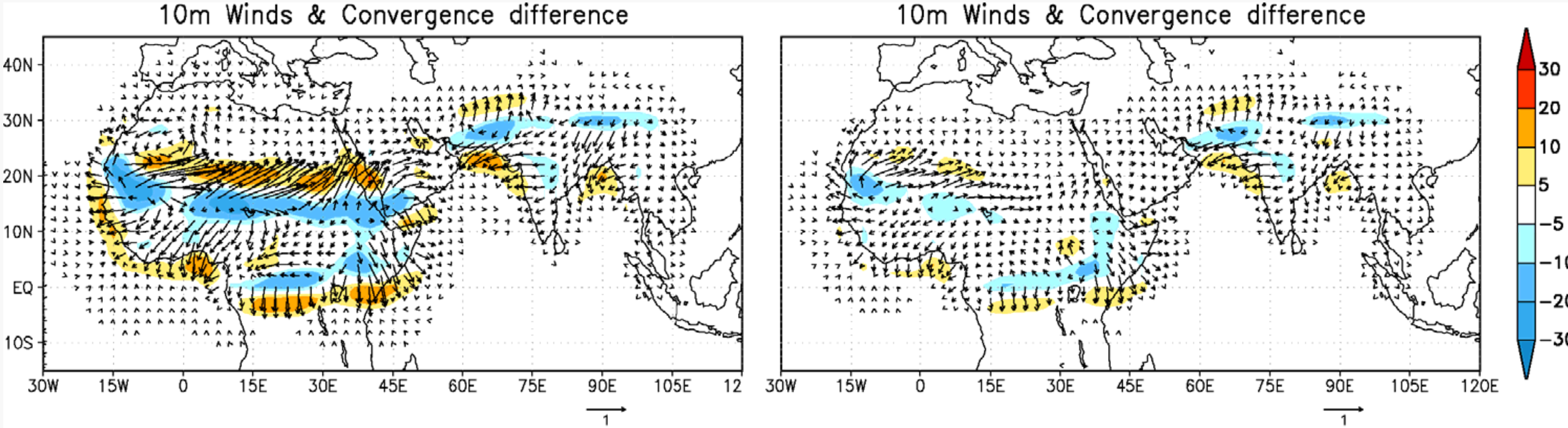




J. Wang, 2008 (JGR) for Ammonium Sulfate data
X. Zeng, 2009 (QJRMS) for Ice splintering

Liquid water path is reasonable in the ARM 3 year case





10m Winds & Convergence difference

10m Winds & Convergence difference

Fig 4a

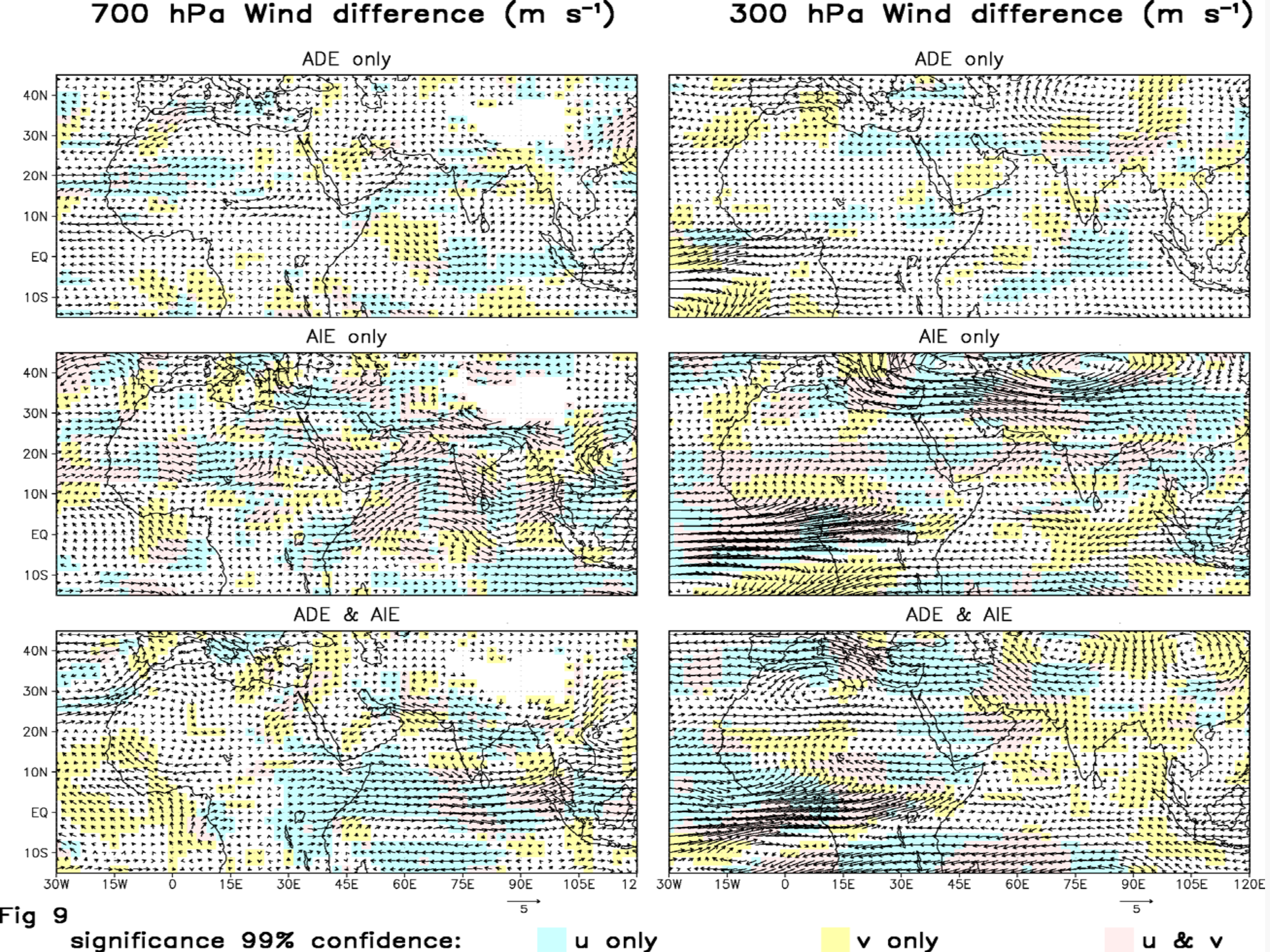

700 hPa Wind difference (m s⁻¹)
300 hPa Wind difference (m s⁻¹)
ADE only
AIE only
ADE & AIE
40N
30N
20N
10N
EQ
10S
30W
15W
0
15E
30E
45E
60E
75E
90E
105E
12
120E
5
significance 99% confidence:
u only
v only
u & v

Fig 9

END

Thanks for Attending