The Abdus Salam International Centre for Theoretical Physics

2148-2

Fifth ICTP Workshop on the Theory and Use of Regional Climate Models

31 May - 11 June, 2010

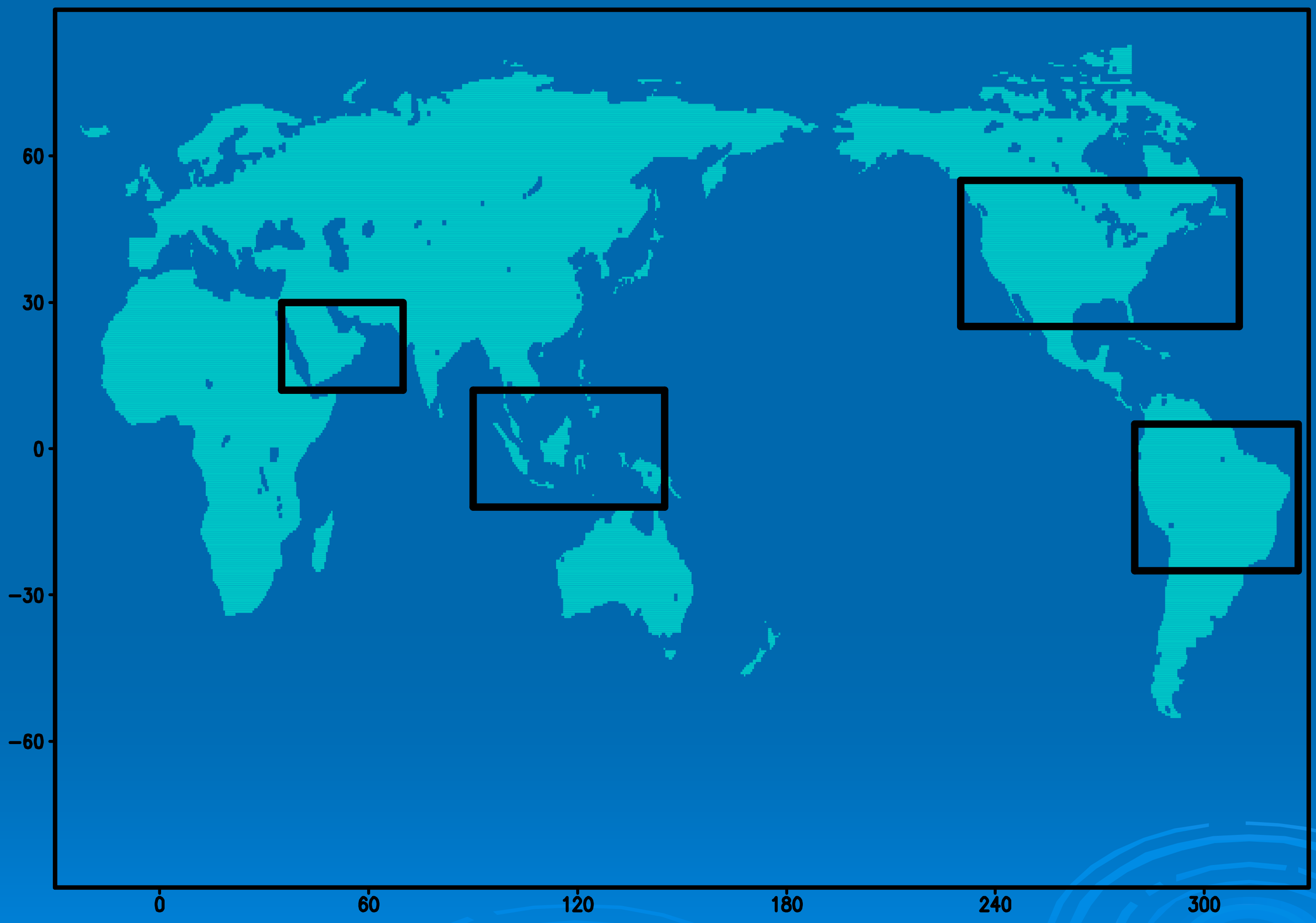
Regional climate studies at MIT using RegCMs

E. Eltahir
MIT
USA

Regional Climate Studies at MIT using RegCMs

Elfatih Eltahir

Jeremy Pal, Jonathan Winter, Marc Marcella, Rebecca Gianotti, Dongfeng Zhang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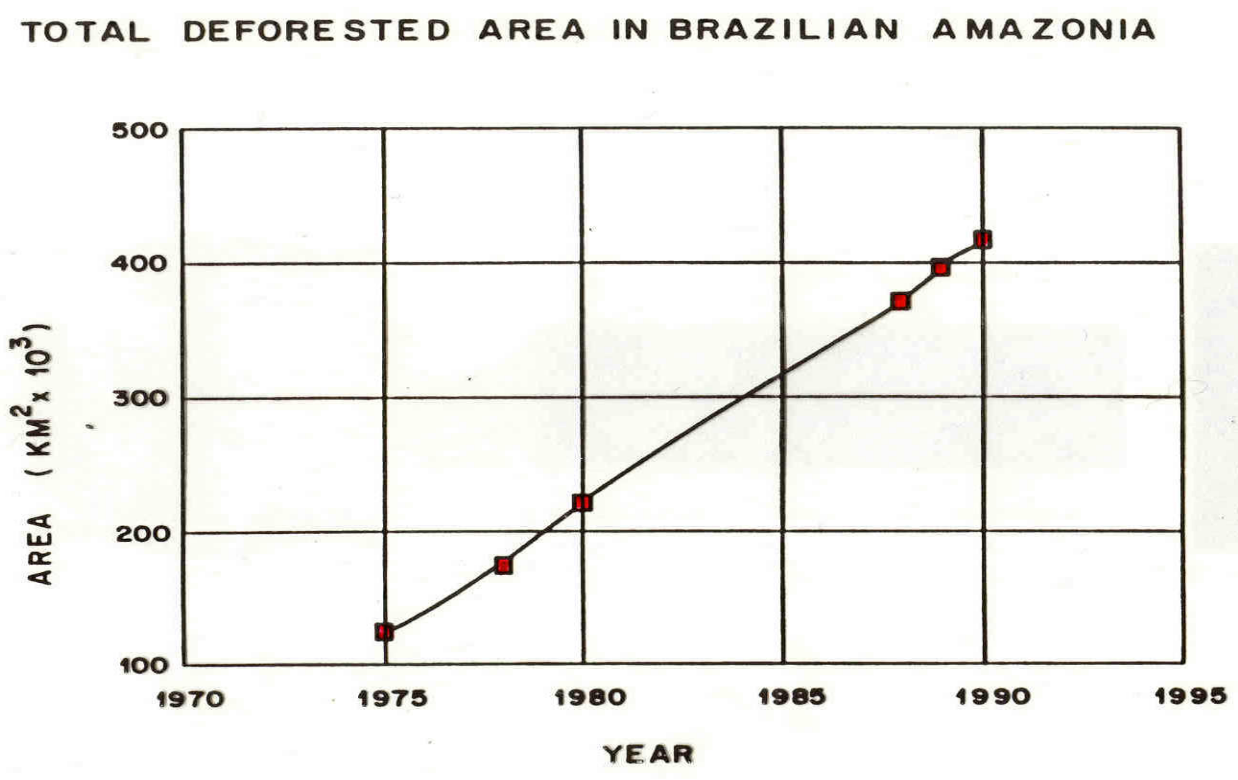
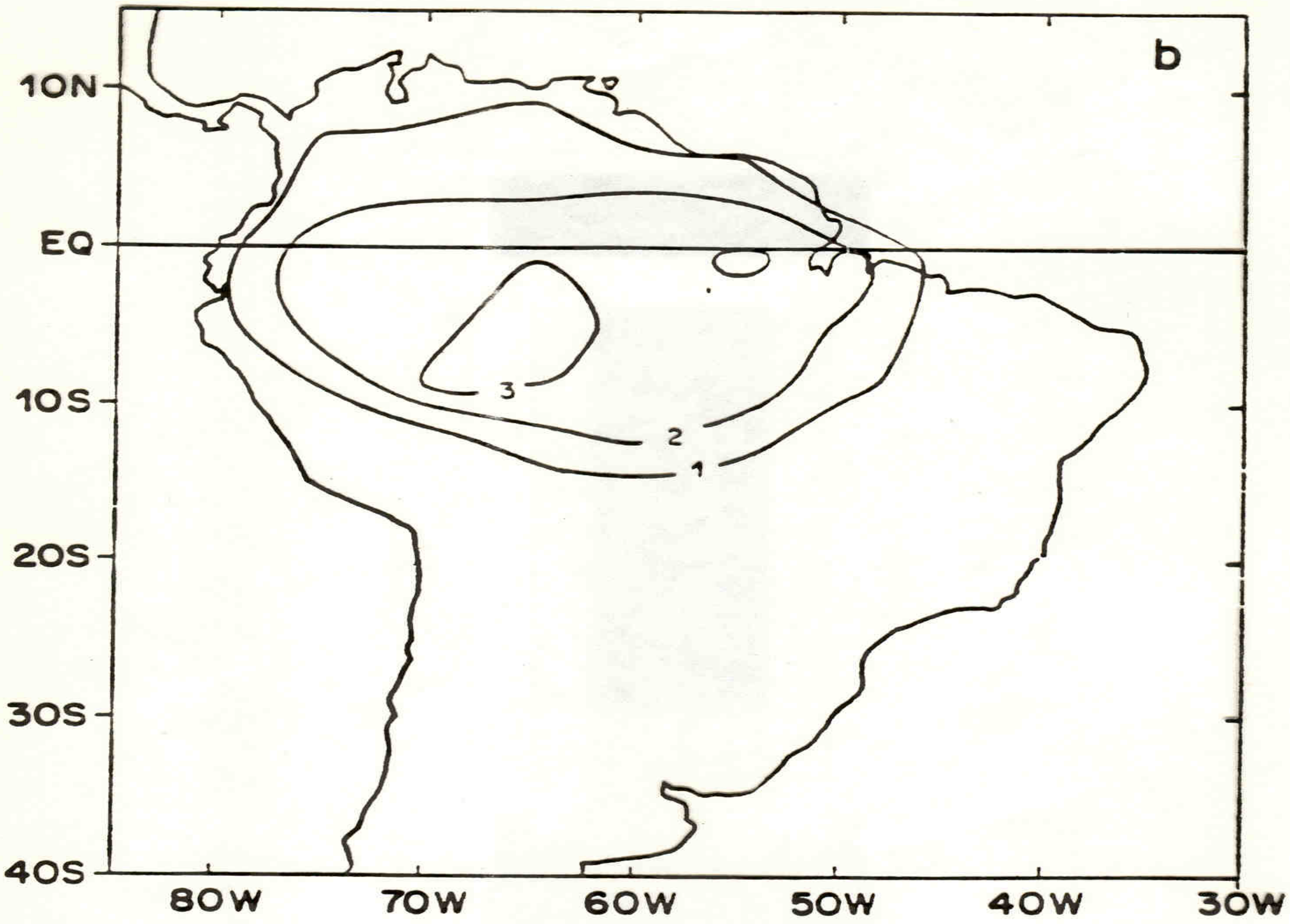
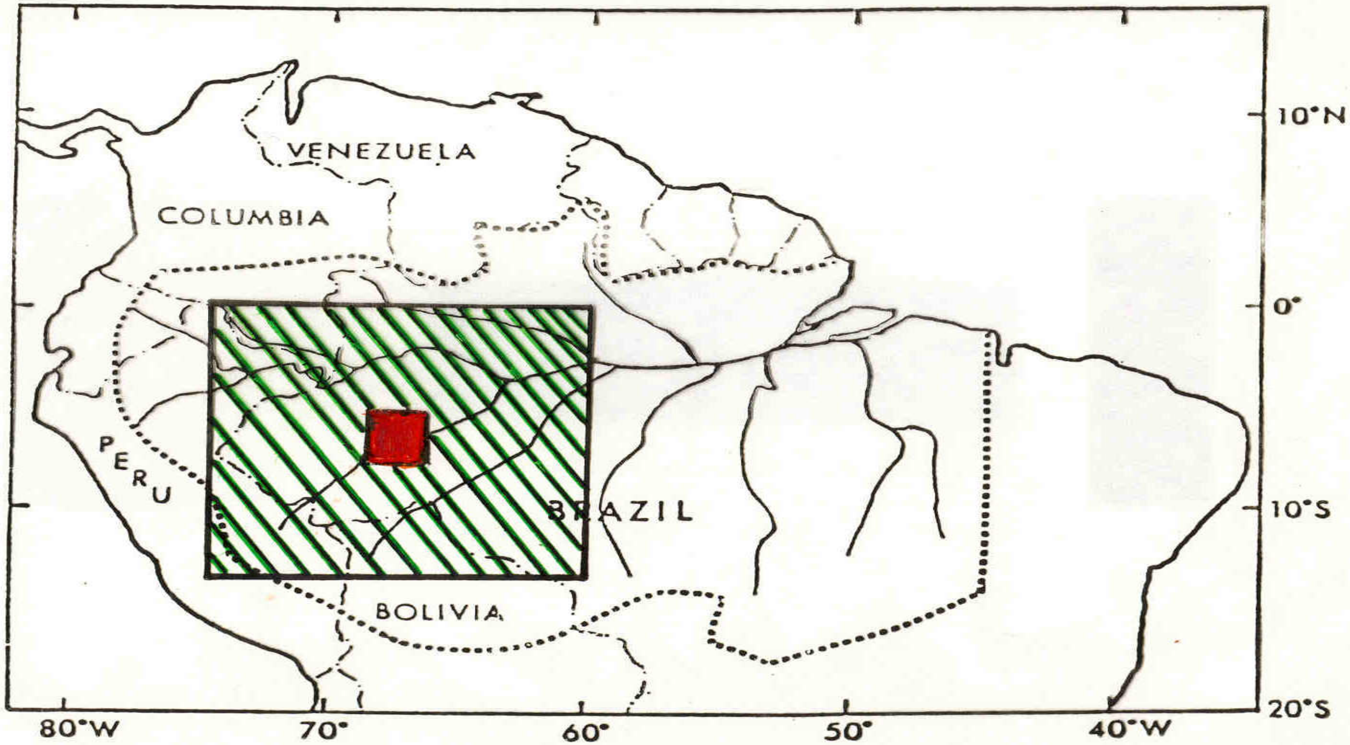


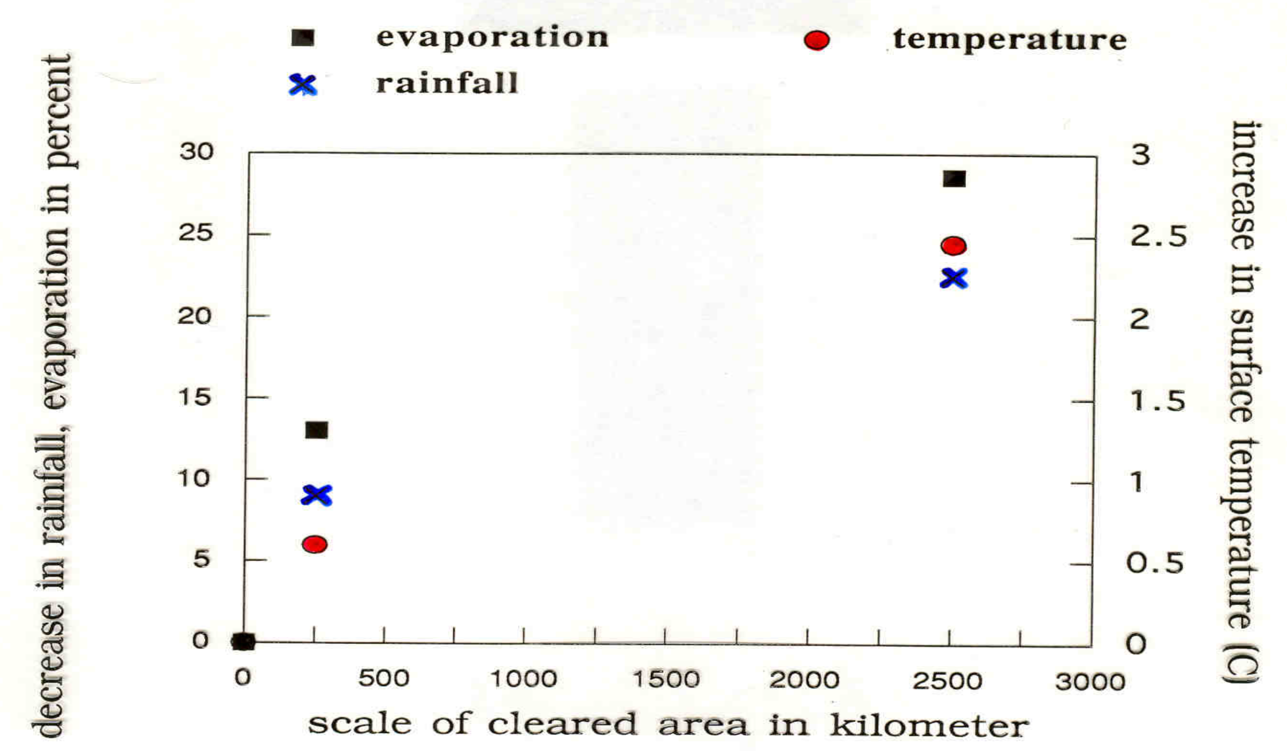
Nobre et al. (1991)

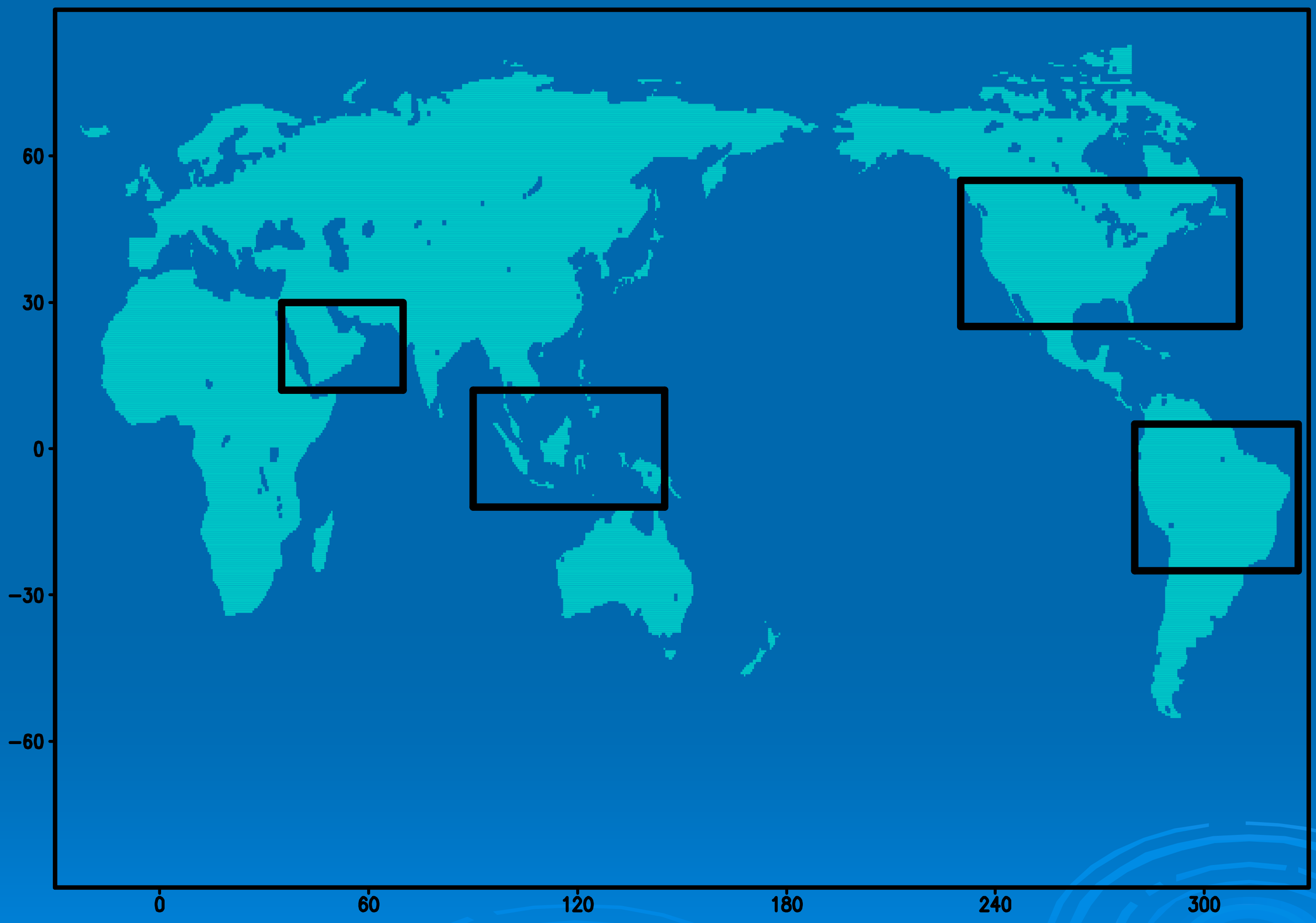


Nobre et al. (1991)



VENEZUELA
COLUMBIA
PERU
BRAZIL
BOLIVIA
10°N
0°
10°S
20°S
80°W
70°
60°
50°
40°W


evaporation
temperature
rainfall
decrease in rainfall, evaporation in percent
increase in surface temperature (C)
30
25
20
15
10
5
0
3
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
scale of cleared area in kilometer



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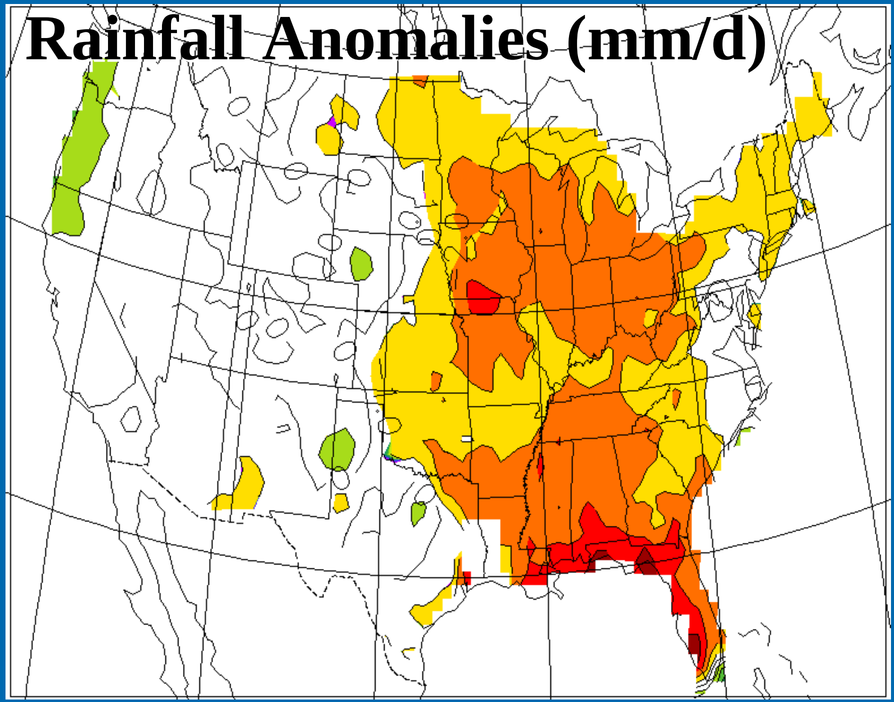
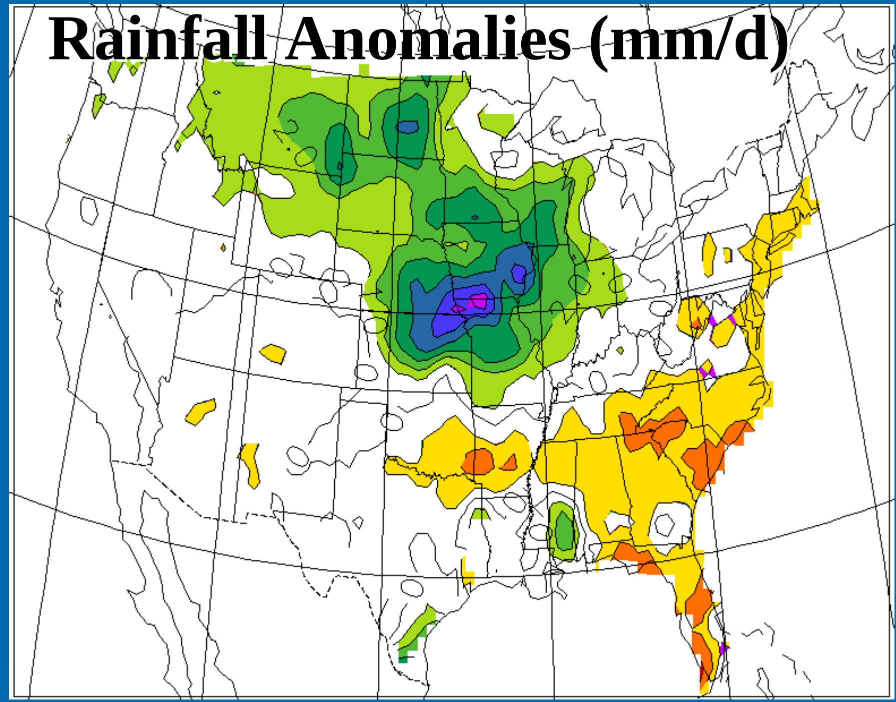
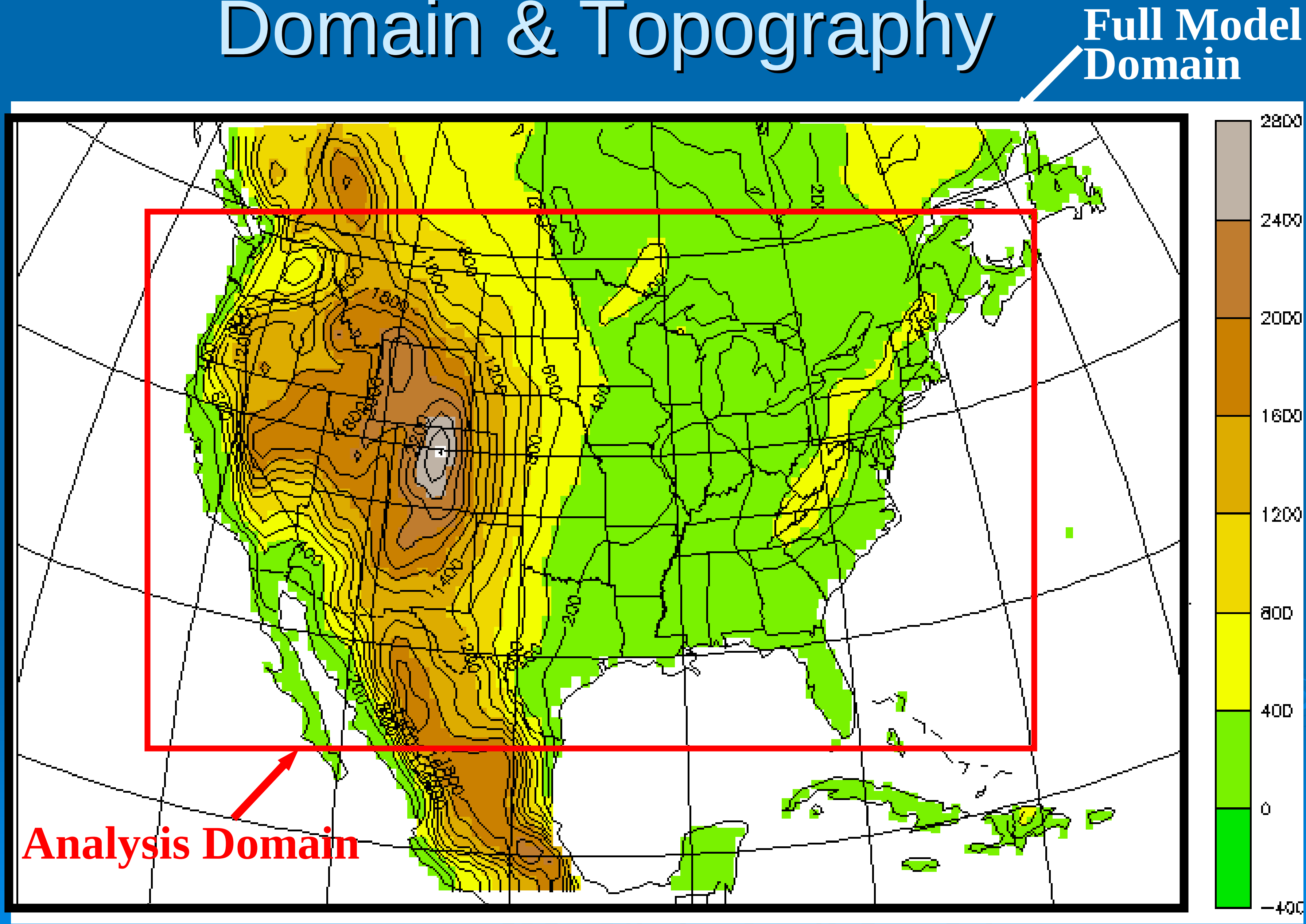


May & June 1988

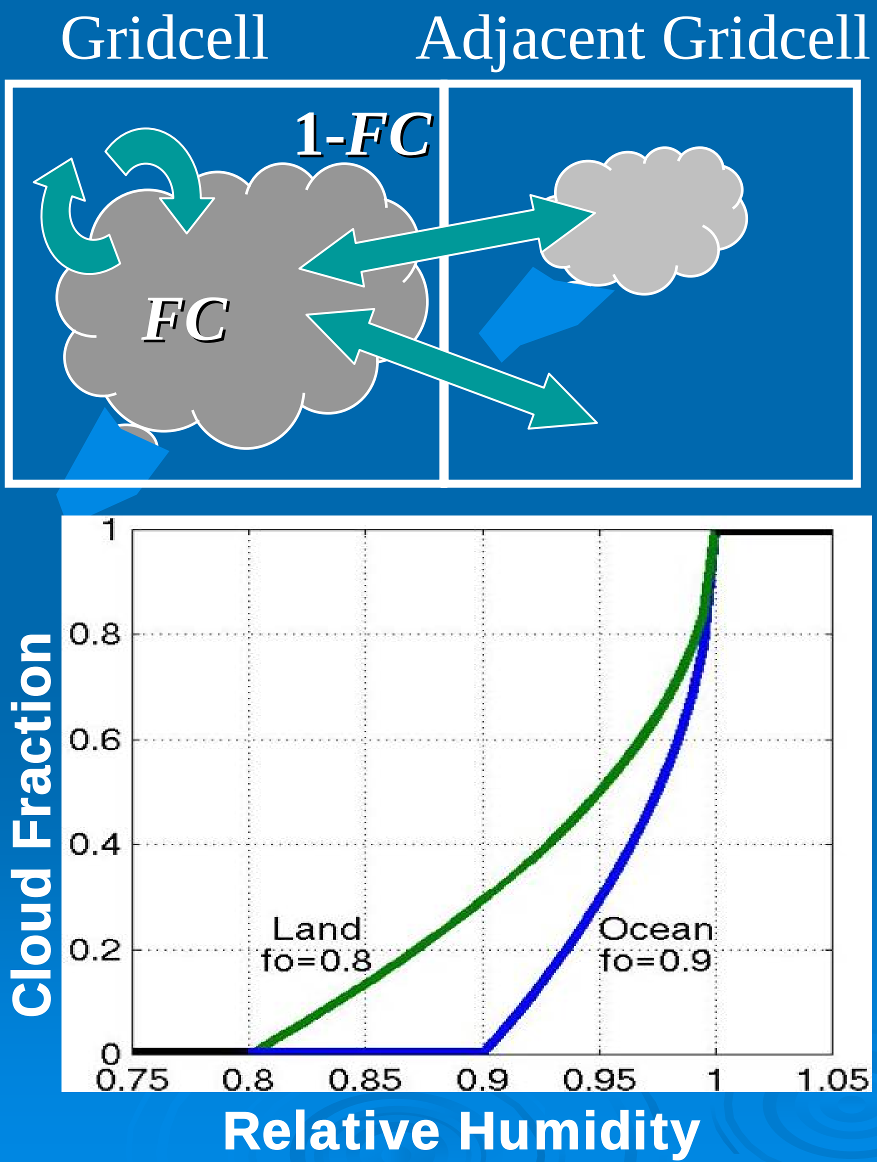


June & July 1993

Domain & Topography



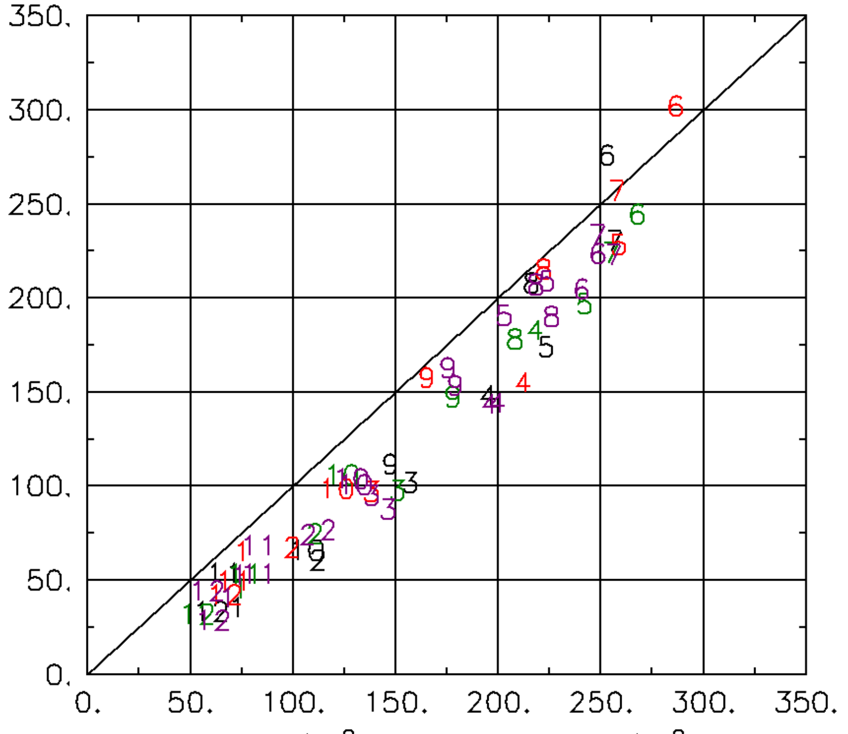
SUBEX



Gridcell
Adjacent Gridcell
1-FC
FC
Cloud Fraction
Land
fo=0.8
Ocean
fo=0.9
0
0.2
0.4
0.6
0.8
1
0.75
0.8
0.85
0.9
0.95
1
1.05
Relative Humidity

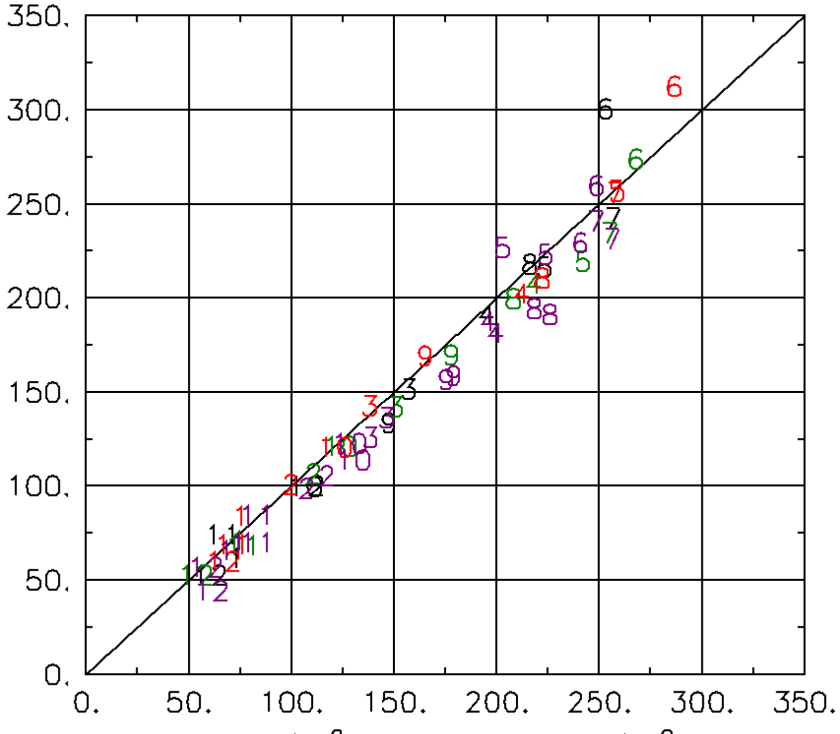
SUBEX: Incident Surface Solar (NASA-SRB)

- Old Model vs Observations



BIAS=−26.2 W/m² RMSE=30.9 W/m² M=1.03

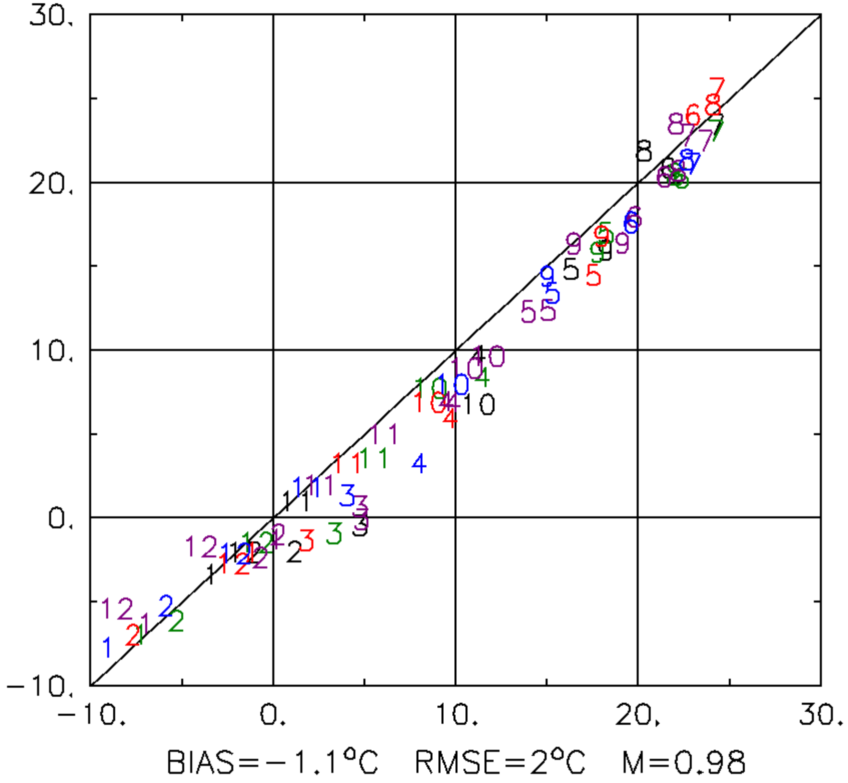
- New Model vs Observations



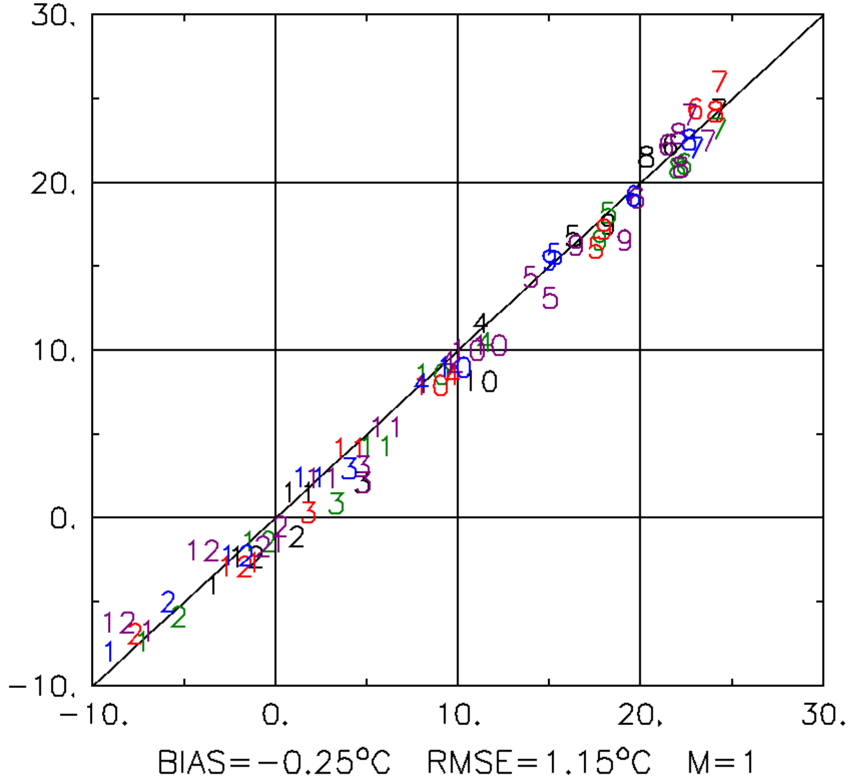
BIAS=−3.9 W/m² RMSE=13.2 W/m² M=1.01

SUBEX: Mean Surface Temperature (USHCN)

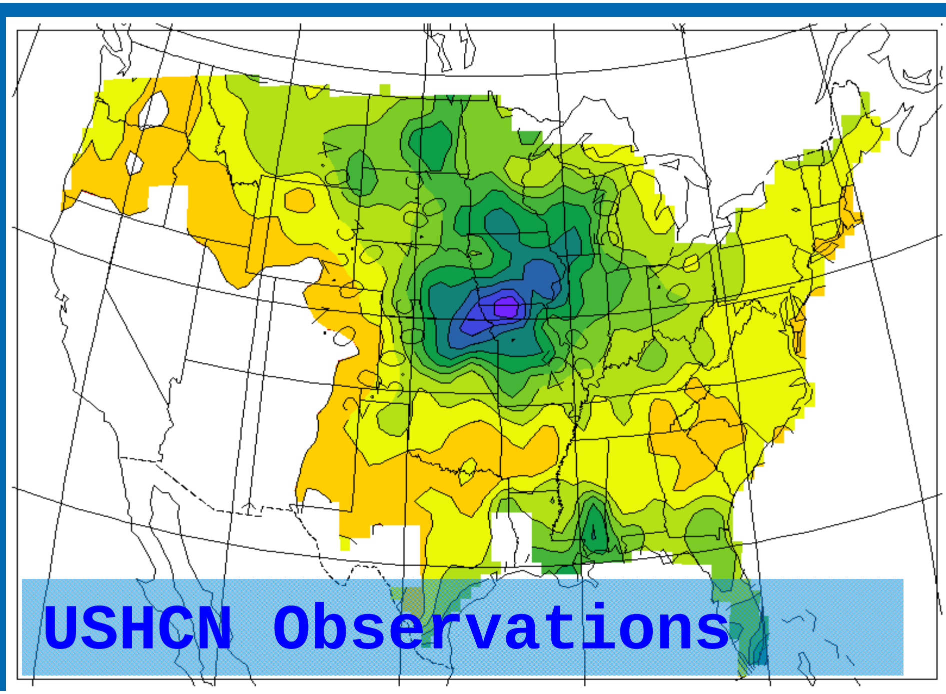
- Old Model vs Observations

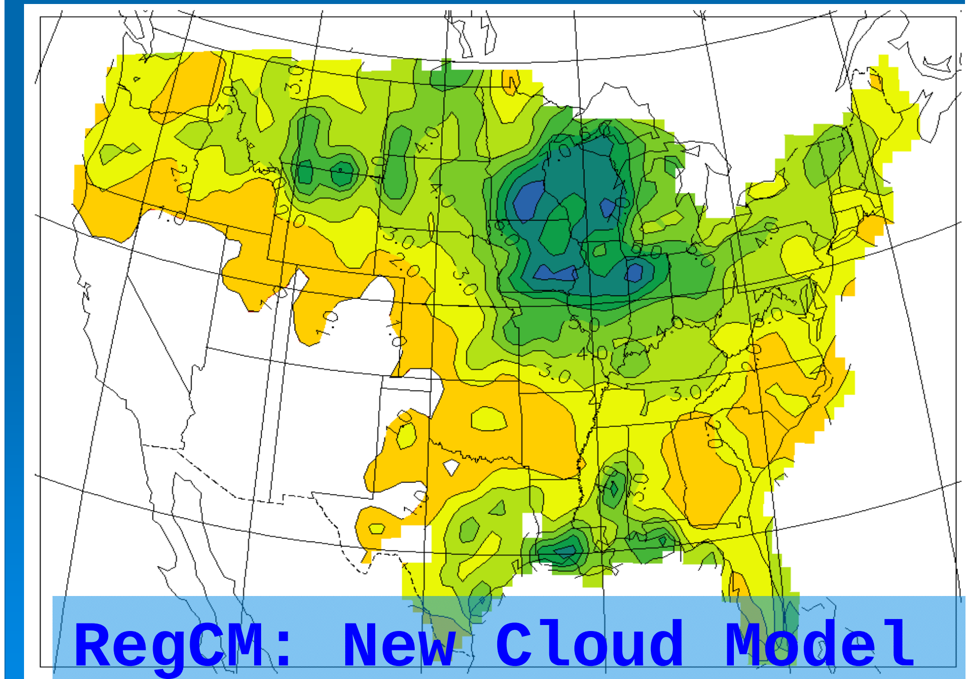


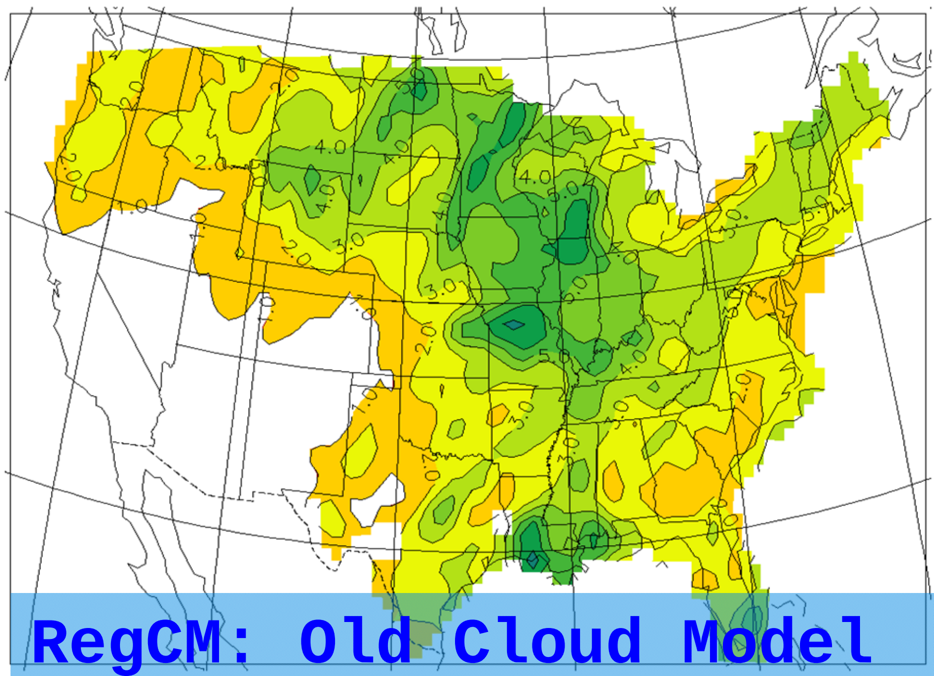
- New Model vs Observations



SUBEX: June & July 1993 Flood







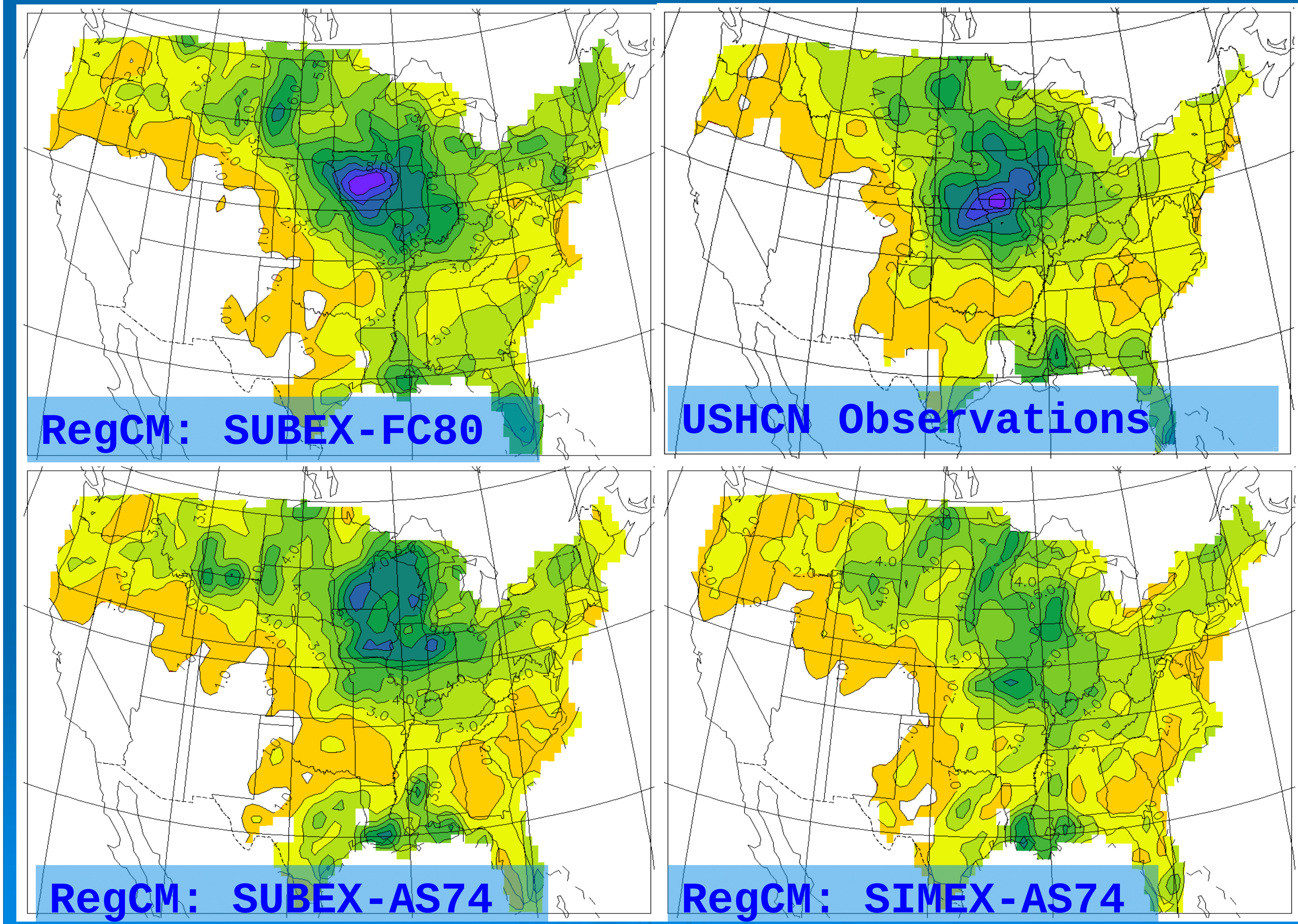
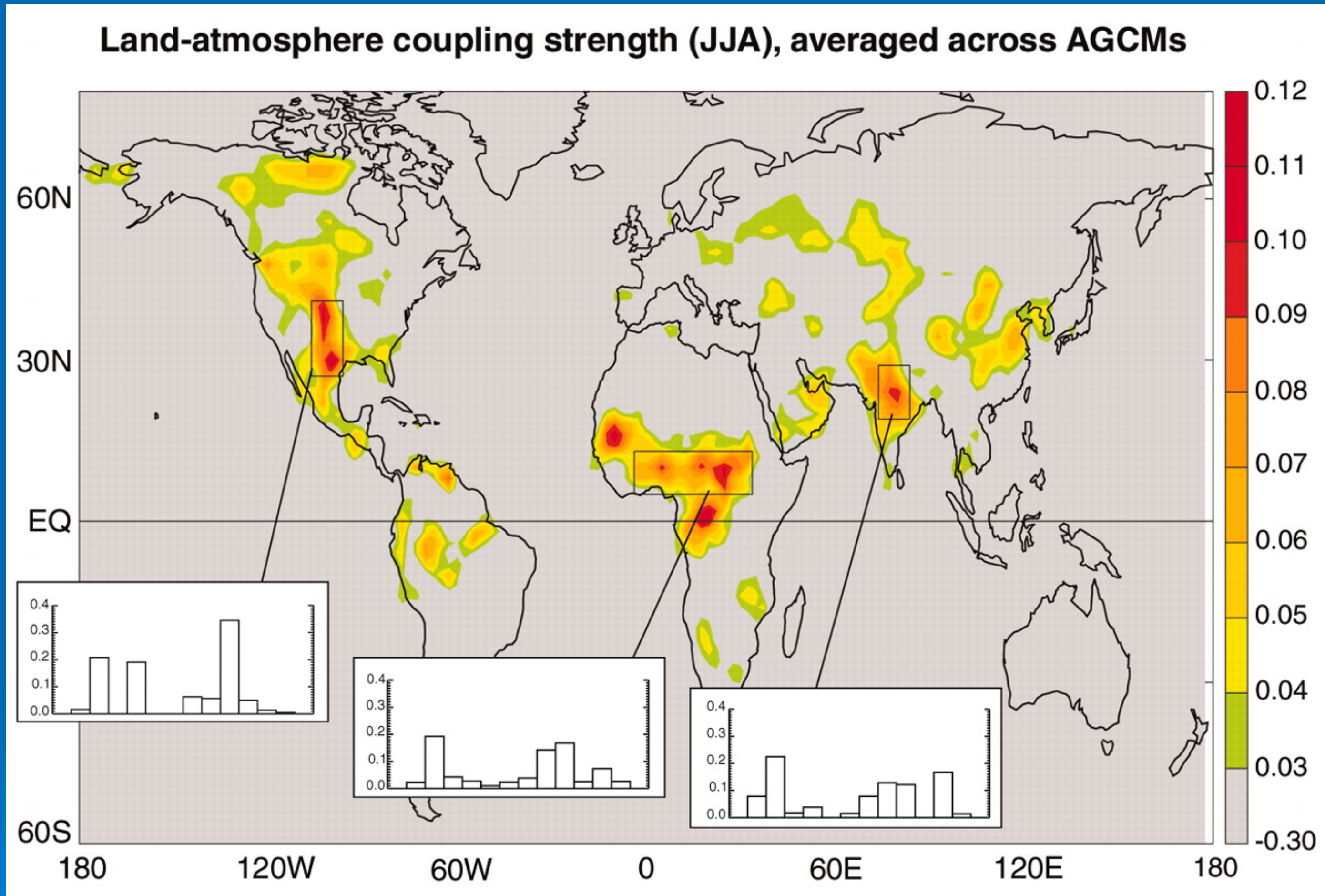

RegCM: SUBEX-FC80
USHCN Observations
RegCM: SUBEX-AS74
RegCM: SIMEX-AS74

Fig. 1. The land-atmosphere coupling strength diagnostic for boreal summer (the {Omega} difference, dimensionless, describing the impact of soil moisture on precipitation), averaged across the 12 models participating in GLACE

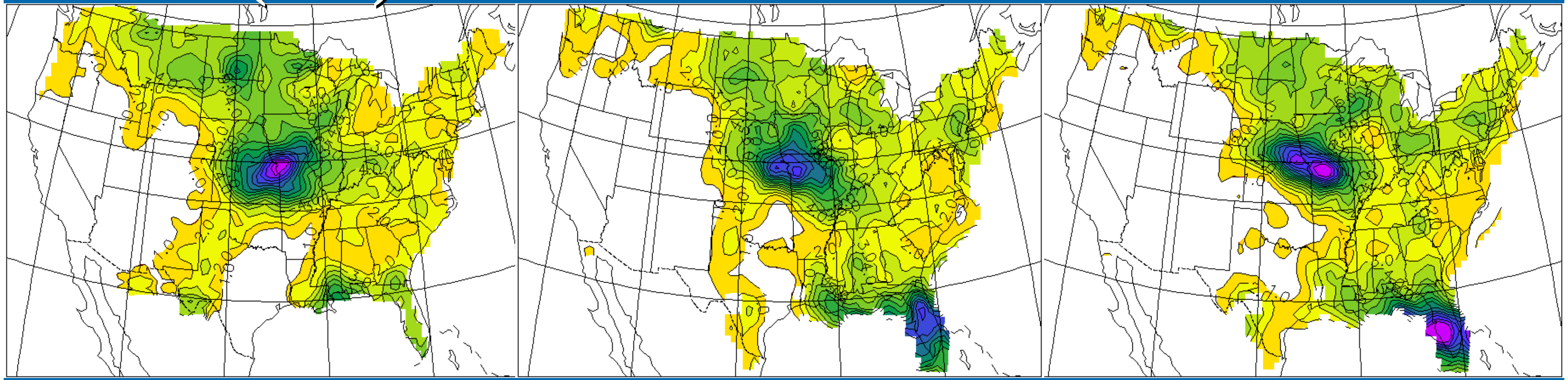


R. D. Koster et al., Science 305, 1138 -1140 (2004)

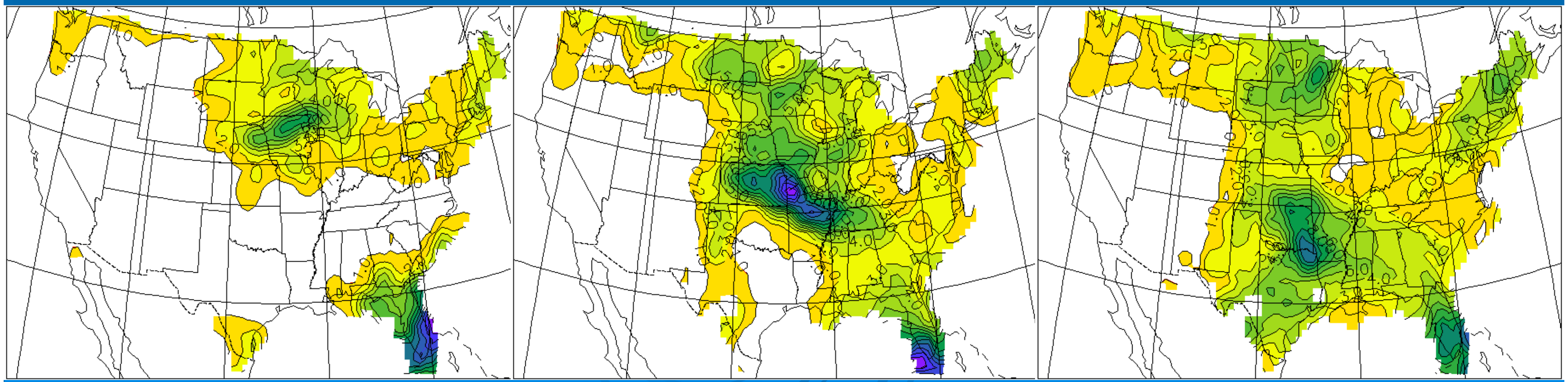
Published by AAAS

Precipitation (U.S. only)

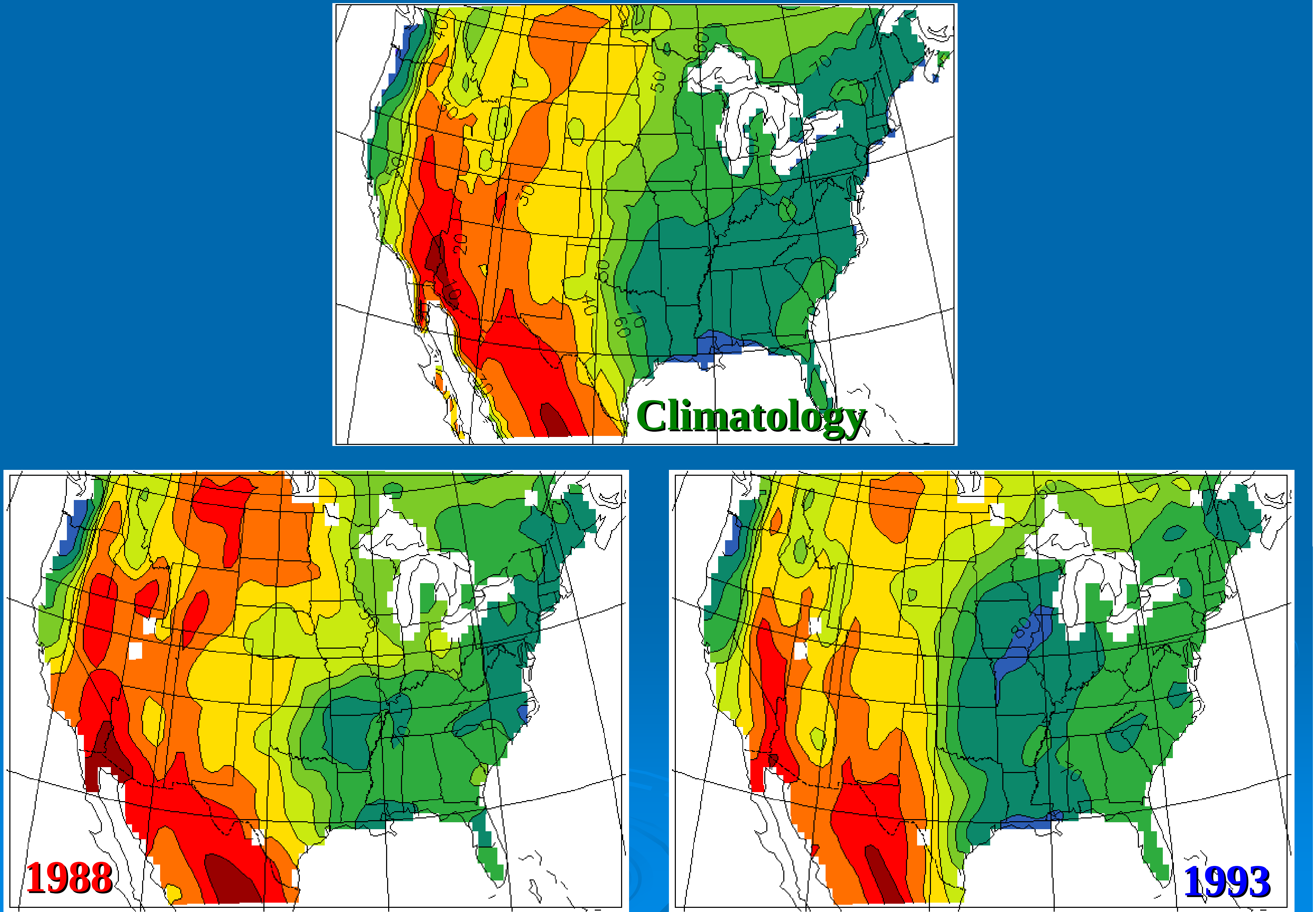
USHCN (Obs) **CTL** **CLM**

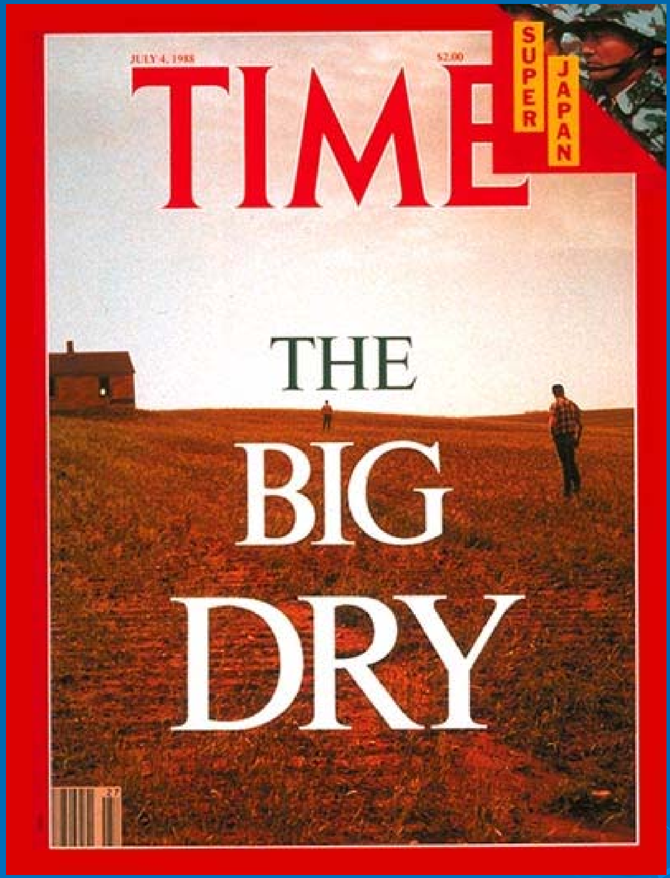


25% **50%** **75%**

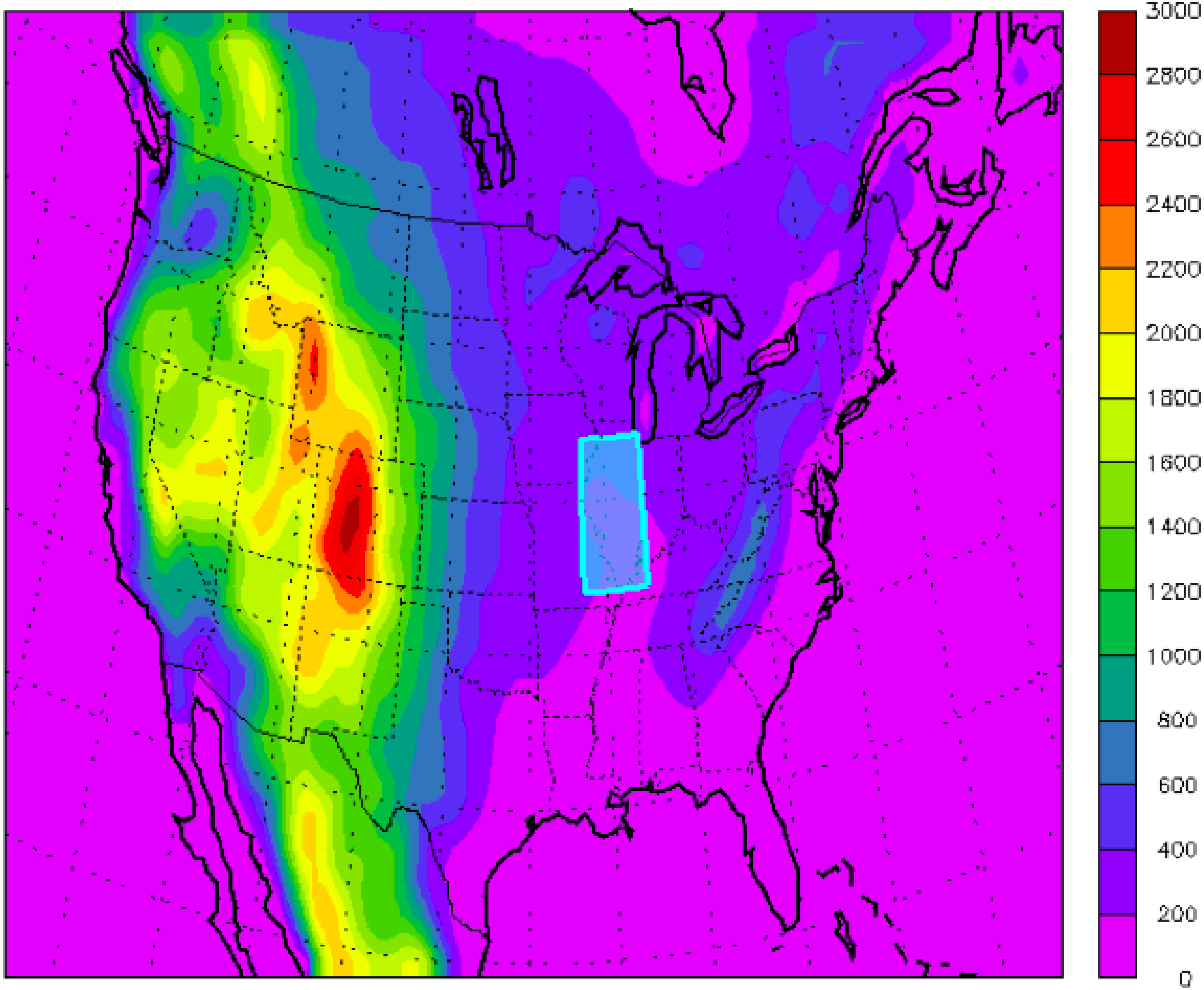


Initial Root Zone Soil Moisture (June 25)





Source: NCDC, Time Magazine, The New York Times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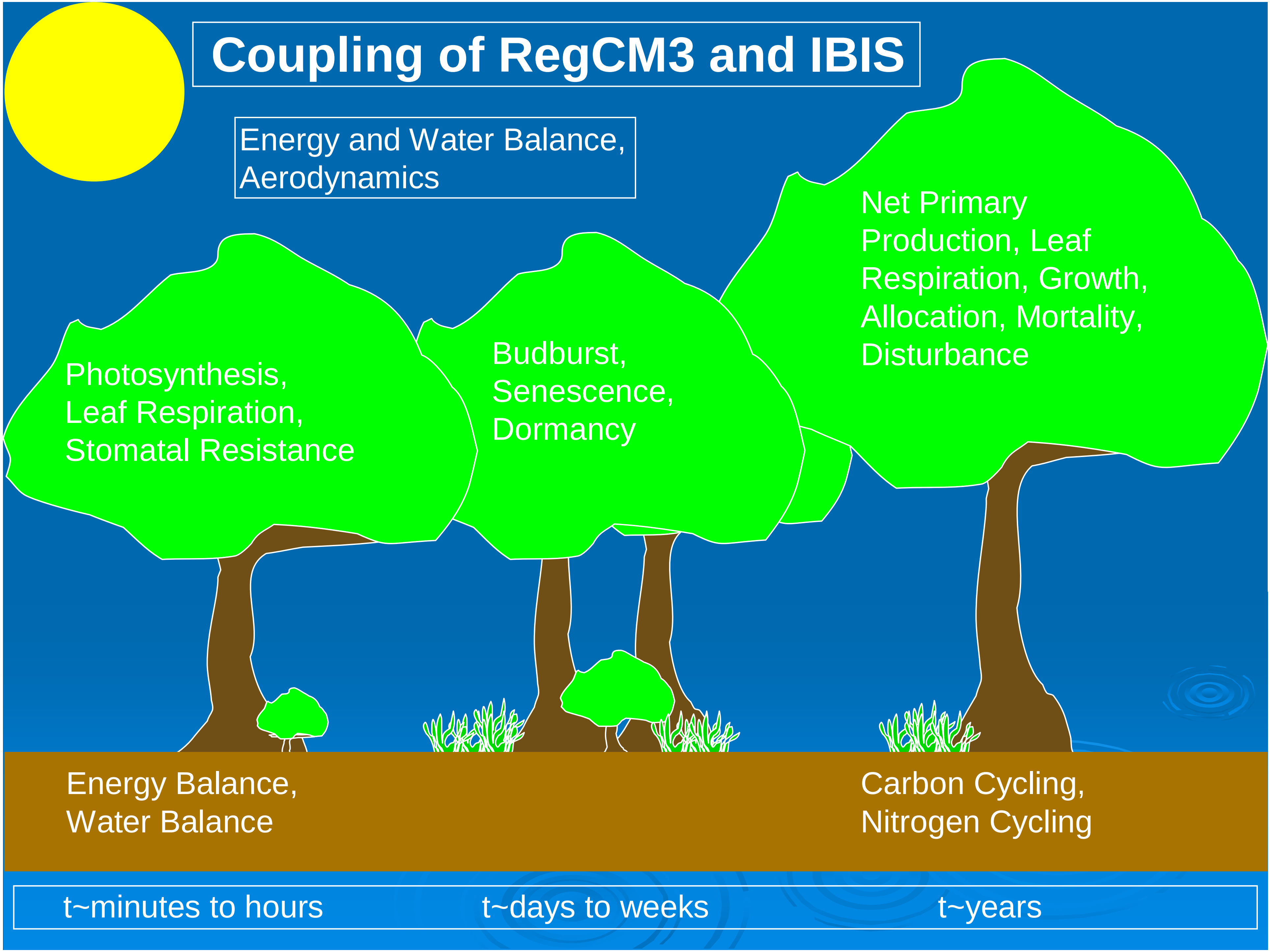
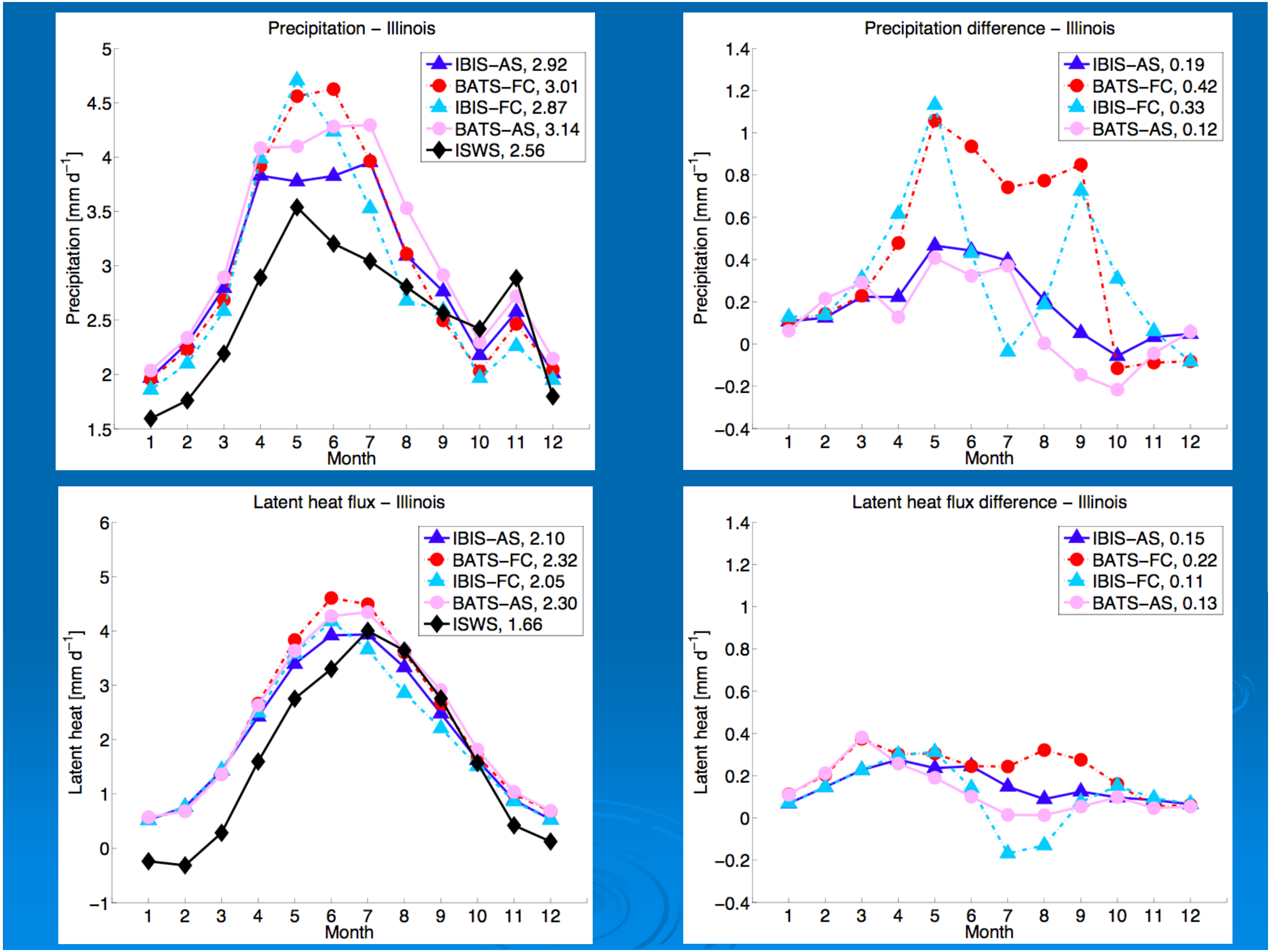
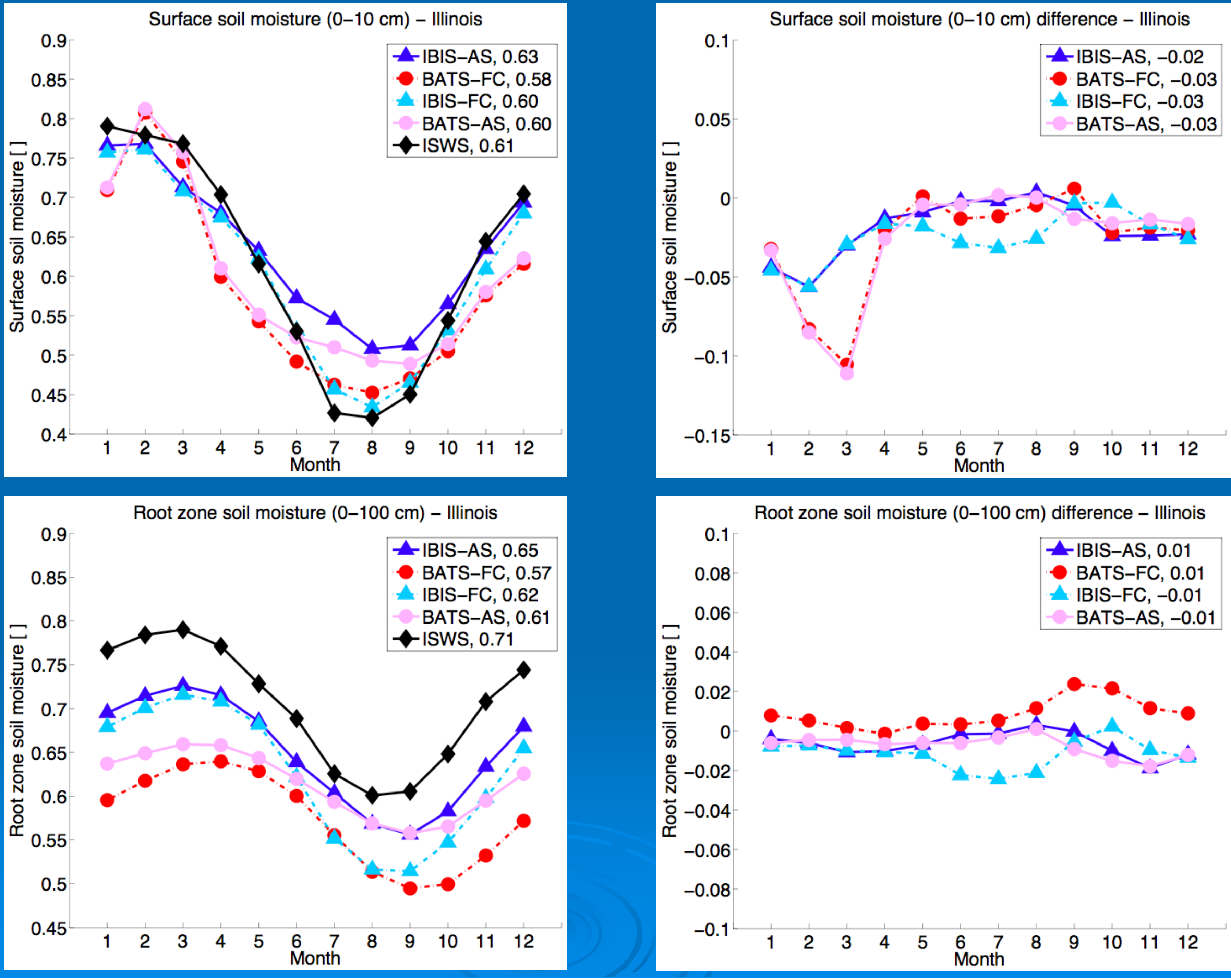

Coupling of RegCM3 and IBIS
Energy and Water Balance, Aerodynamics
Photosynthesis, Leaf Respiration, Stomatal Resistance
Budburst, Senescence, Dormancy
Net Primary Production, Leaf Respiration, Growth, Allocation, Mortality, Disturbance
Energy Balance, Water Balance
Carbon Cycling, Nitrogen Cycling
t~minutes to hours
t~days to weeks
t~years

	NNRP2	NNRP2 +3 °C	EH5OM	EH5OM A1B
IBIS-AS	1984-2005	1984-2005	1984-2005	2080-2099
IBIS-FC	355 ppm	710 ppm	355 ppm	625-700 ppm
BATS-FC	Control Boundary Conditions	Temperature +3 °C; RH unchanged	ECHAM5 GCM 20th Century	ECHAM5 GCM A1B Scenario
BATS-AS	Control SST	SST +3 °C	ECHAM5 SST	ECHAM5 A1B SST



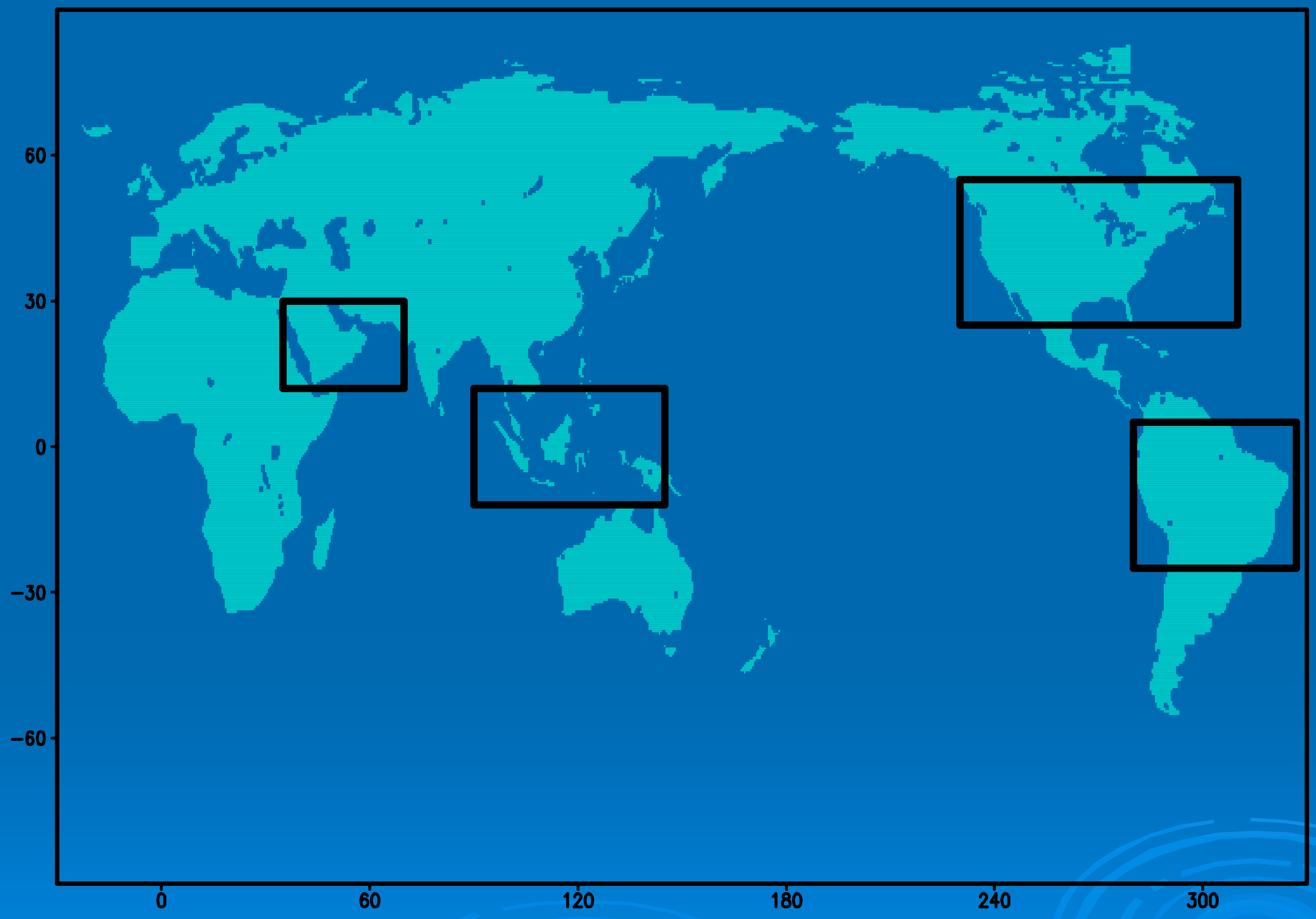
Precipitation – Illinois
IBIS–AS, 2.92
BATS–FC, 3.01
IBIS–FC, 2.87
BATS–AS, 3.14
ISWS, 2.56
Precipitation [mm d⁻¹]
Month
Precipitation difference – Illinois
IBIS–AS, 0.19
BATS–FC, 0.42
IBIS–FC, 0.33
BATS–AS, 0.12
Precipitation [mm d⁻¹]
Month
Latent heat flux – Illinois
IBIS–AS, 2.10
BATS–FC, 2.32
IBIS–FC, 2.05
BATS–AS, 2.30
ISWS, 1.66
Latent heat [mm d⁻¹]
Month
Latent heat flux difference – Illinois
IBIS–AS, 0.15
BATS–FC, 0.22
IBIS–FC, 0.11
BATS–AS, 0.13
Latent heat [mm d⁻¹]
Month



Surface soil moisture (0–10 cm) – Illinois
Surface soil moisture [ ]
Month
IBIS–AS, 0.63
BATS–FC, 0.58
IBIS–FC, 0.60
BATS–AS, 0.60
ISWS, 0.61
Surface soil moisture (0–10 cm) difference – Illinois
Surface soil moisture [ ]
Month
IBIS–AS, −0.02
BATS–FC, −0.03
IBIS–FC, −0.03
BATS–AS, −0.03
Root zone soil moisture (0–100 cm) – Illinois
Root zone soil moisture [ ]
Month
IBIS–AS, 0.65
BATS–FC, 0.57
IBIS–FC, 0.62
BATS–AS, 0.61
ISWS, 0.71
Root zone soil moisture (0–100 cm) difference – Illinois
Root zone soil moisture [ ]
Month
IBIS–AS, 0.01
BATS–FC, 0.01
IBIS–FC, −0.01
BATS–AS, −0.01

Conclusions

- Precipitation is sensitive to both climate change scenarios and increases in all numerical experiments conducted.
- Total runoff increases, removing most all of the difference between the increase in precipitation and the increase in latent heat flux.
- The response of soil moisture to both climate change scenarios is negligible.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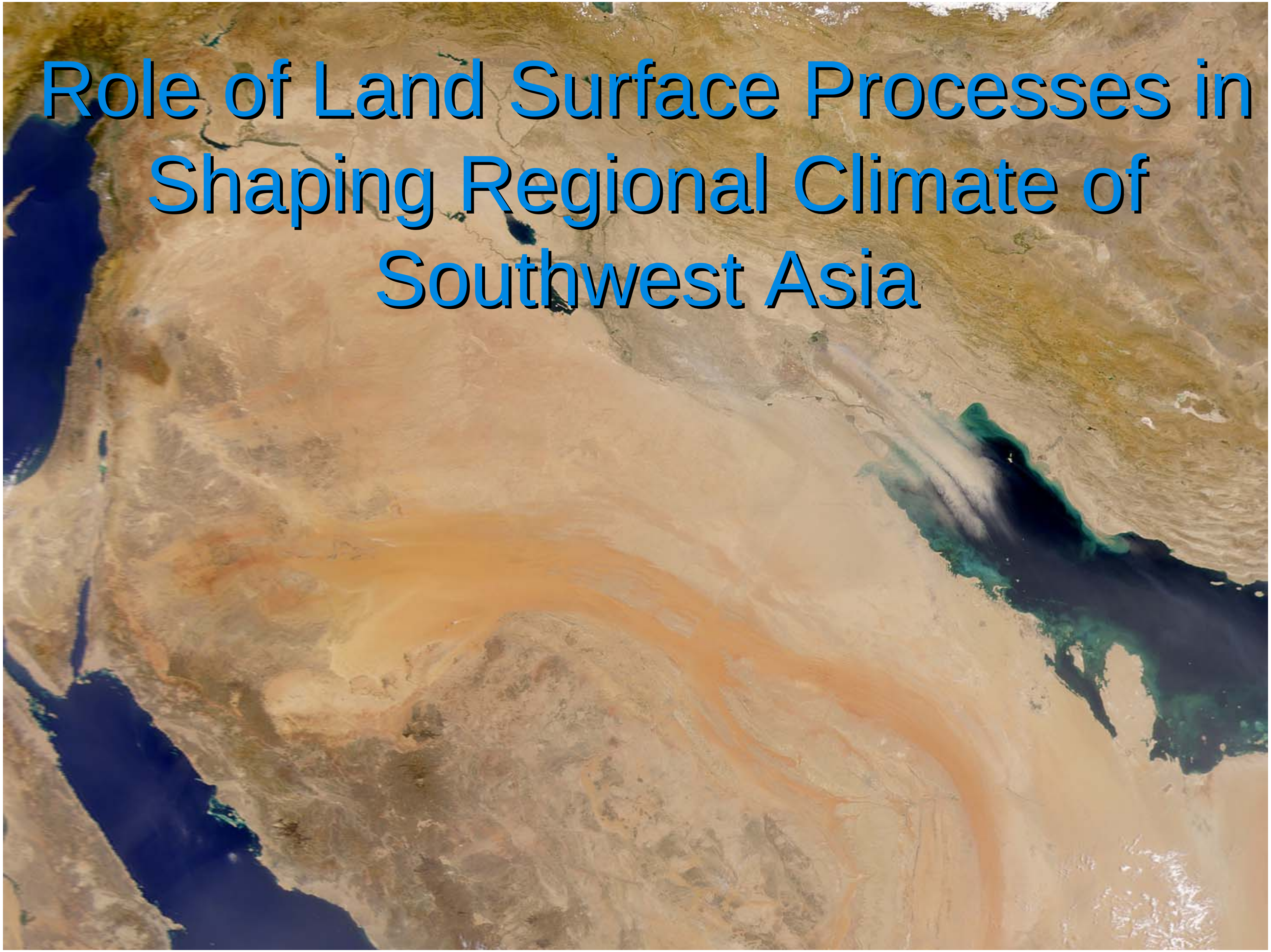
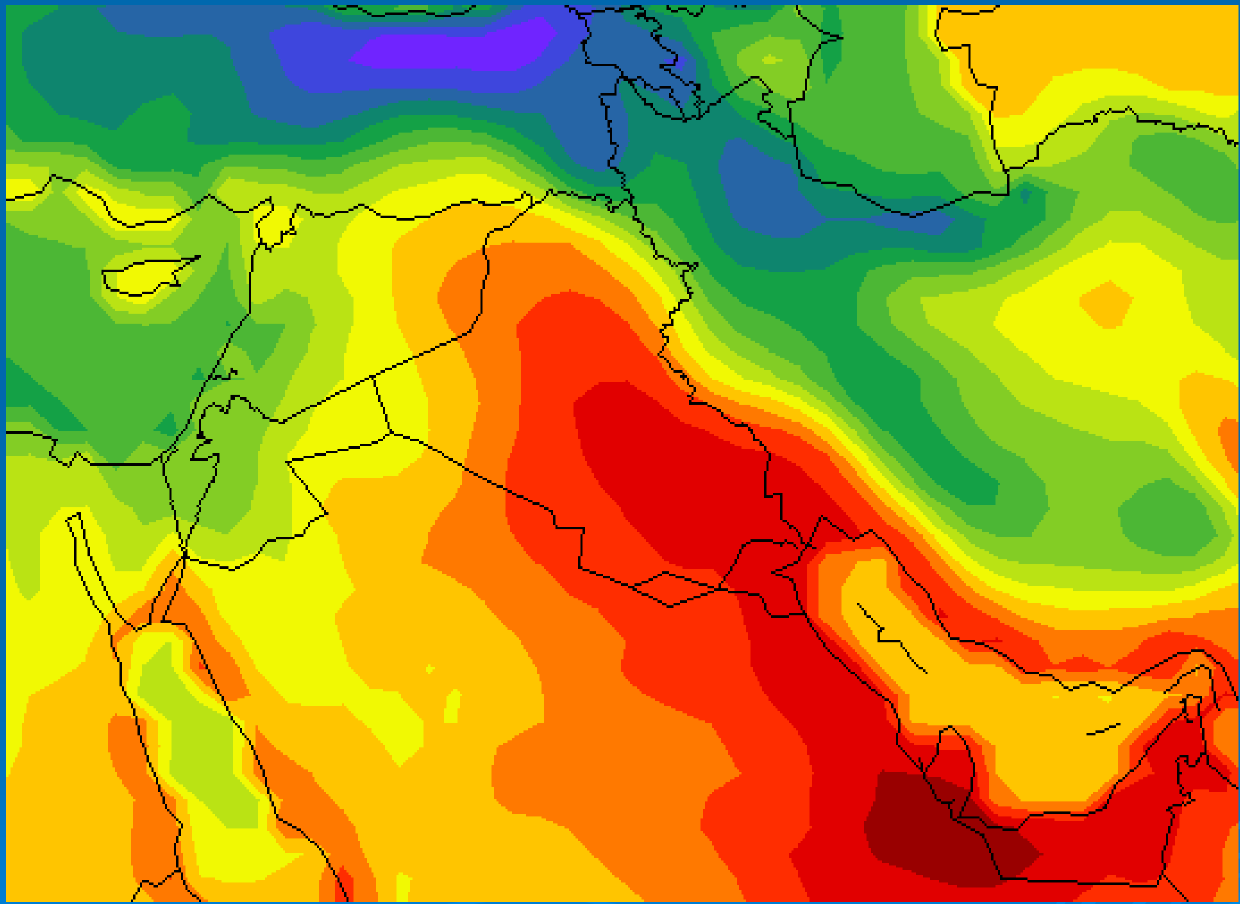
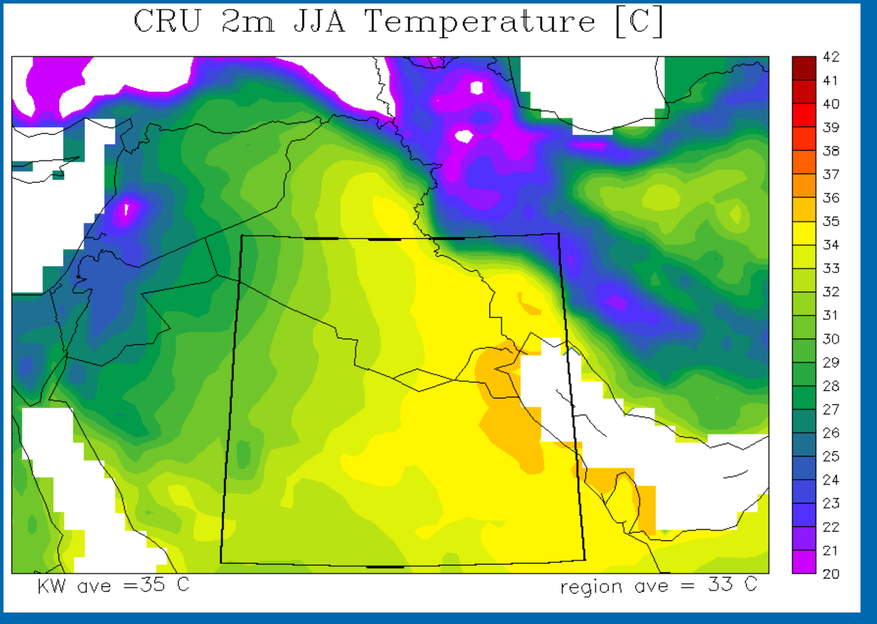
Role of Land Surface Processes in Shaping Regional Climate of Southwest Asia

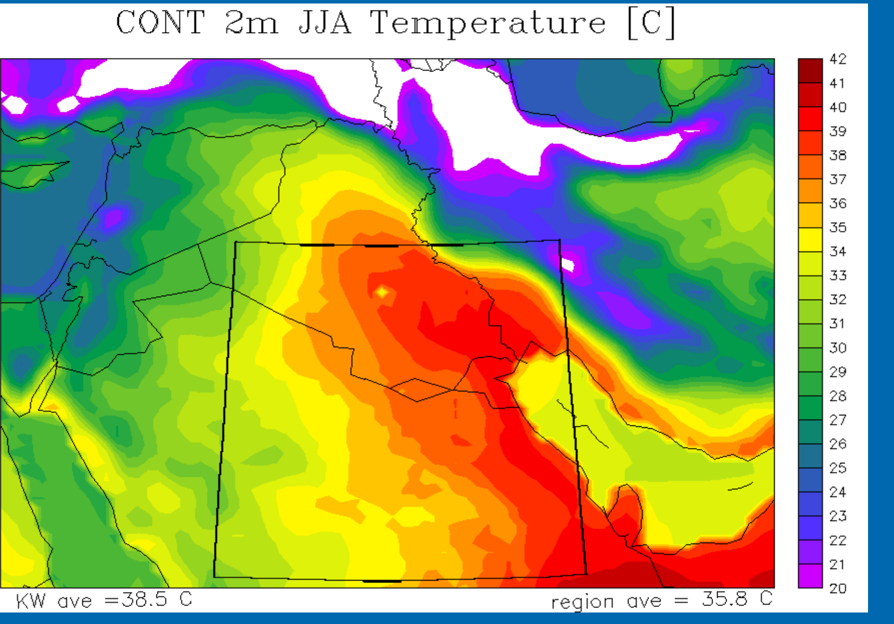


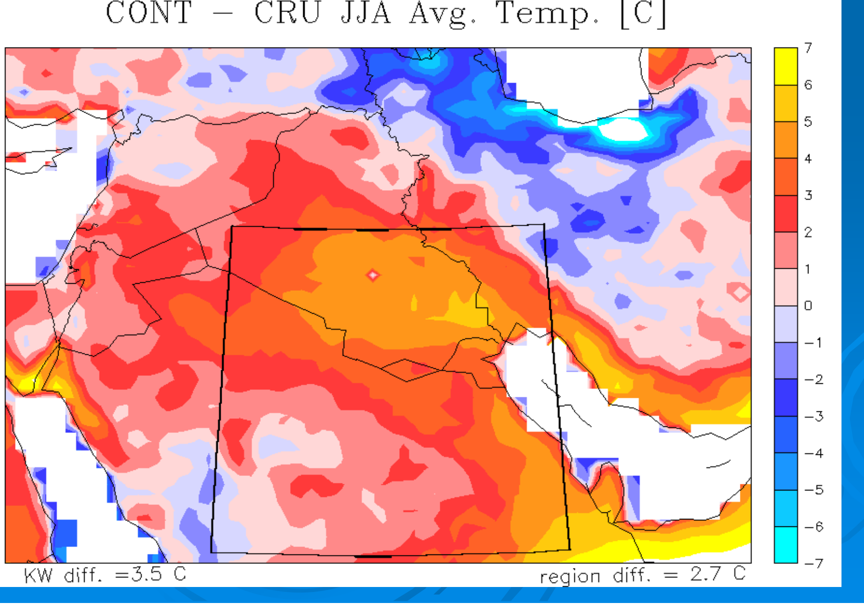
Summer Temperature



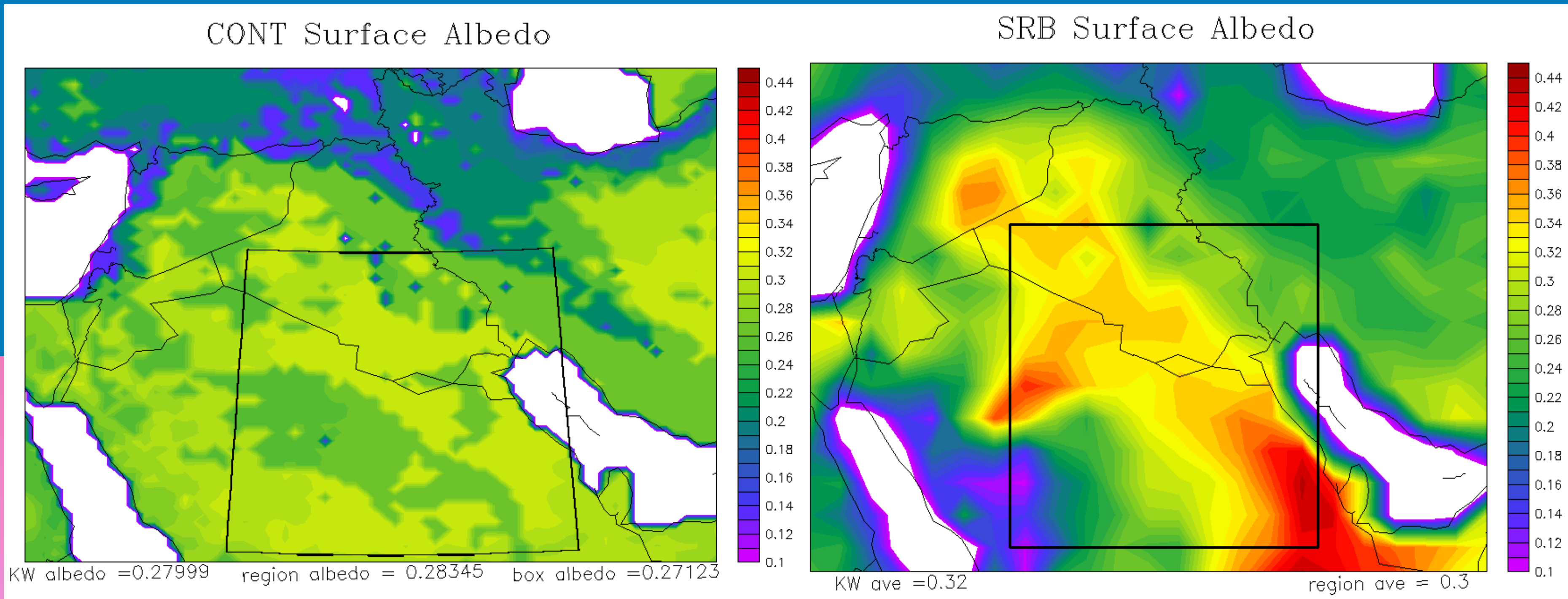
Surface Temperature Bias



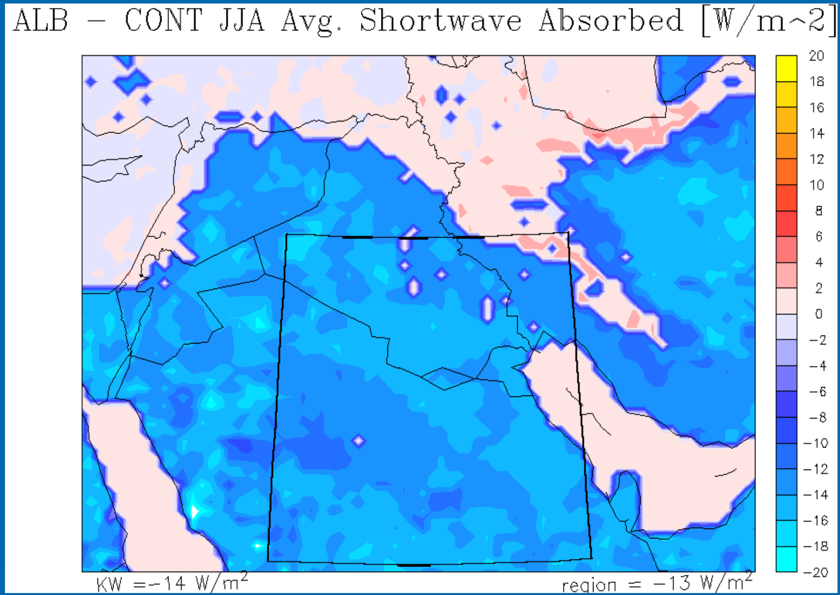


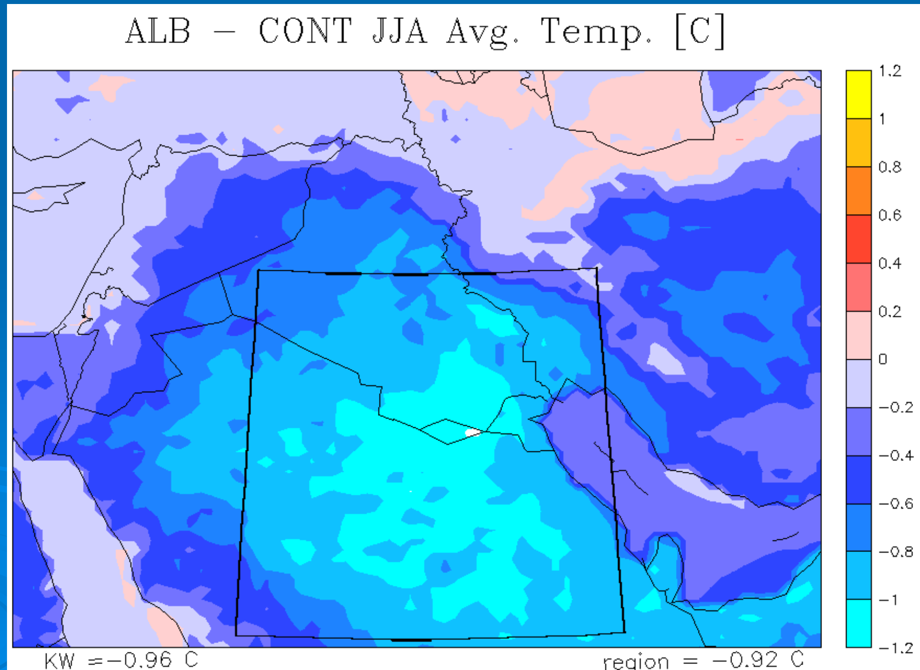


Albedo: Model vs Observations

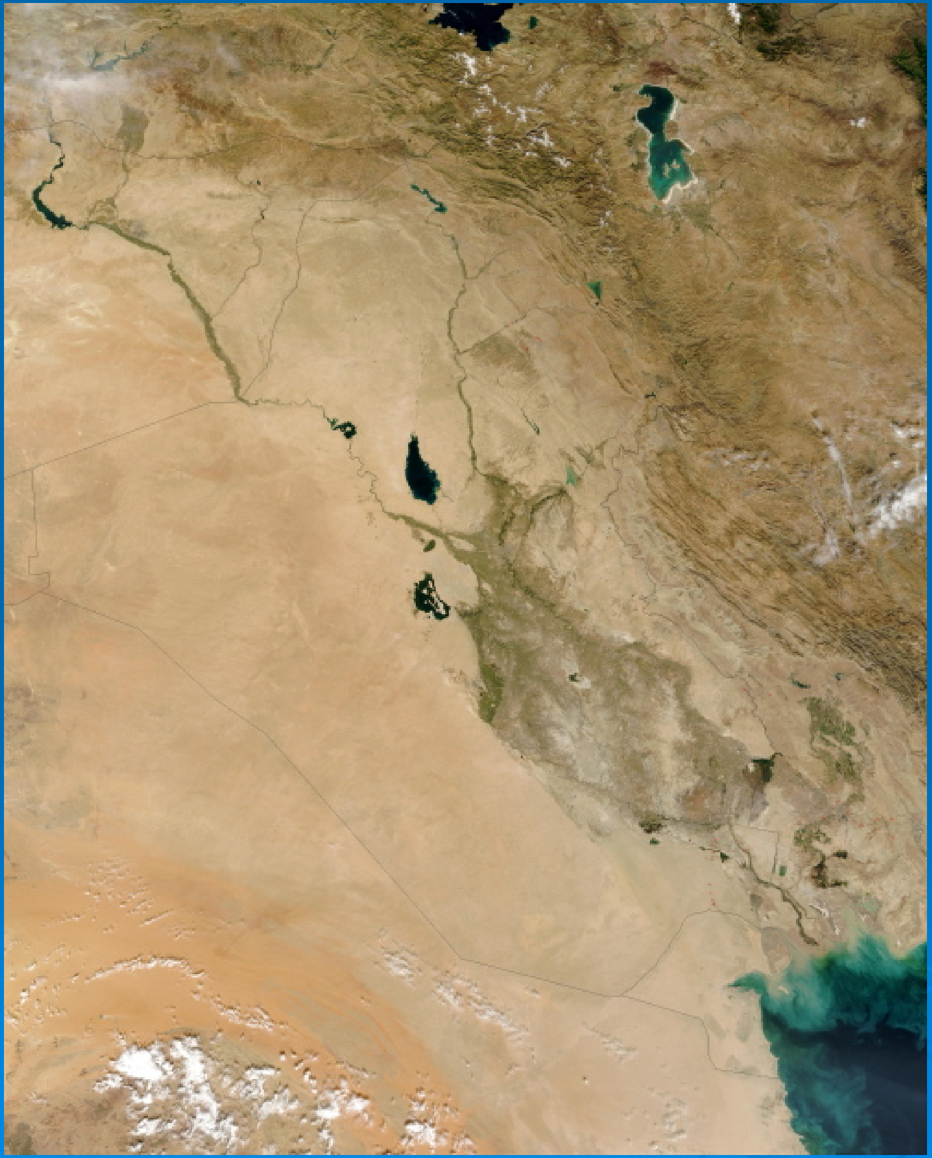


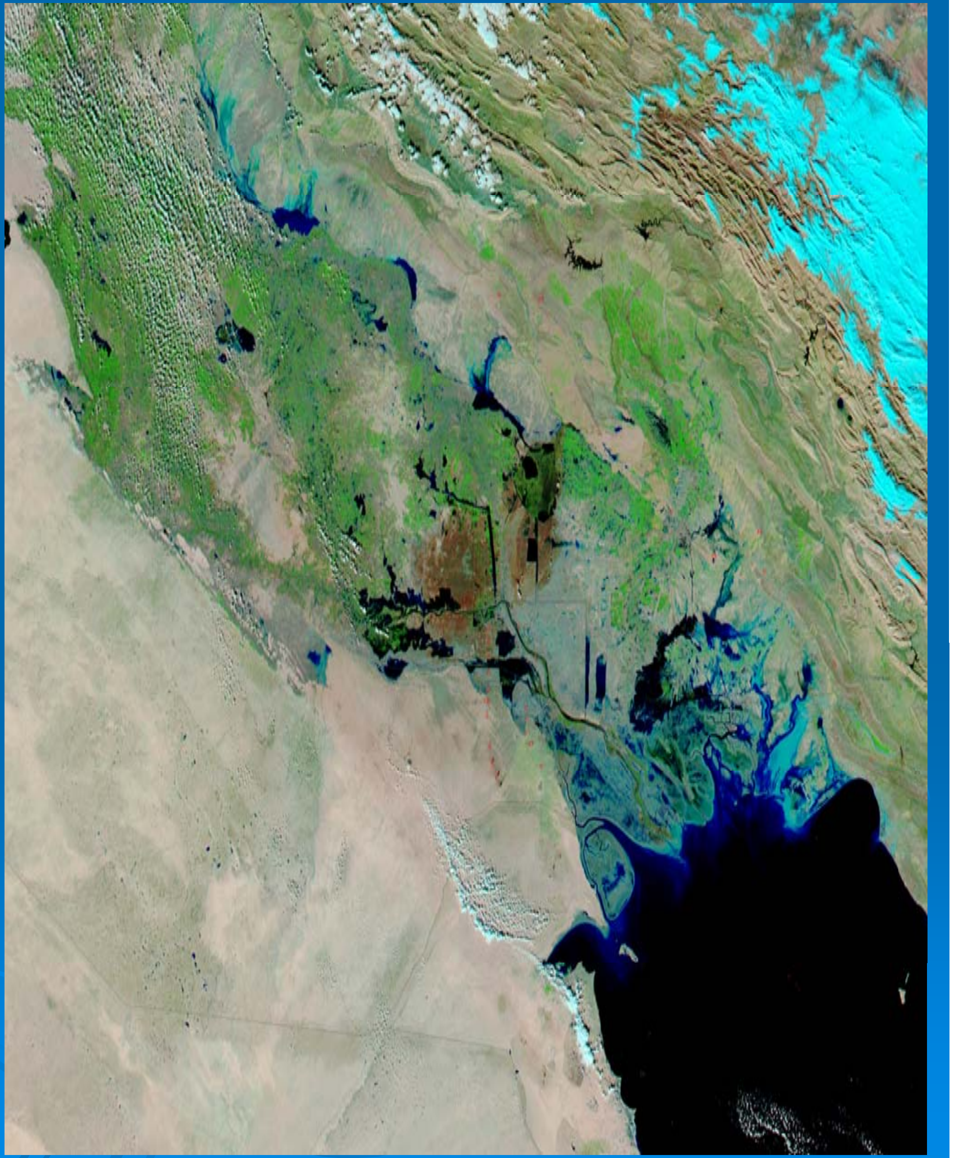
Role of Surface Reflectance



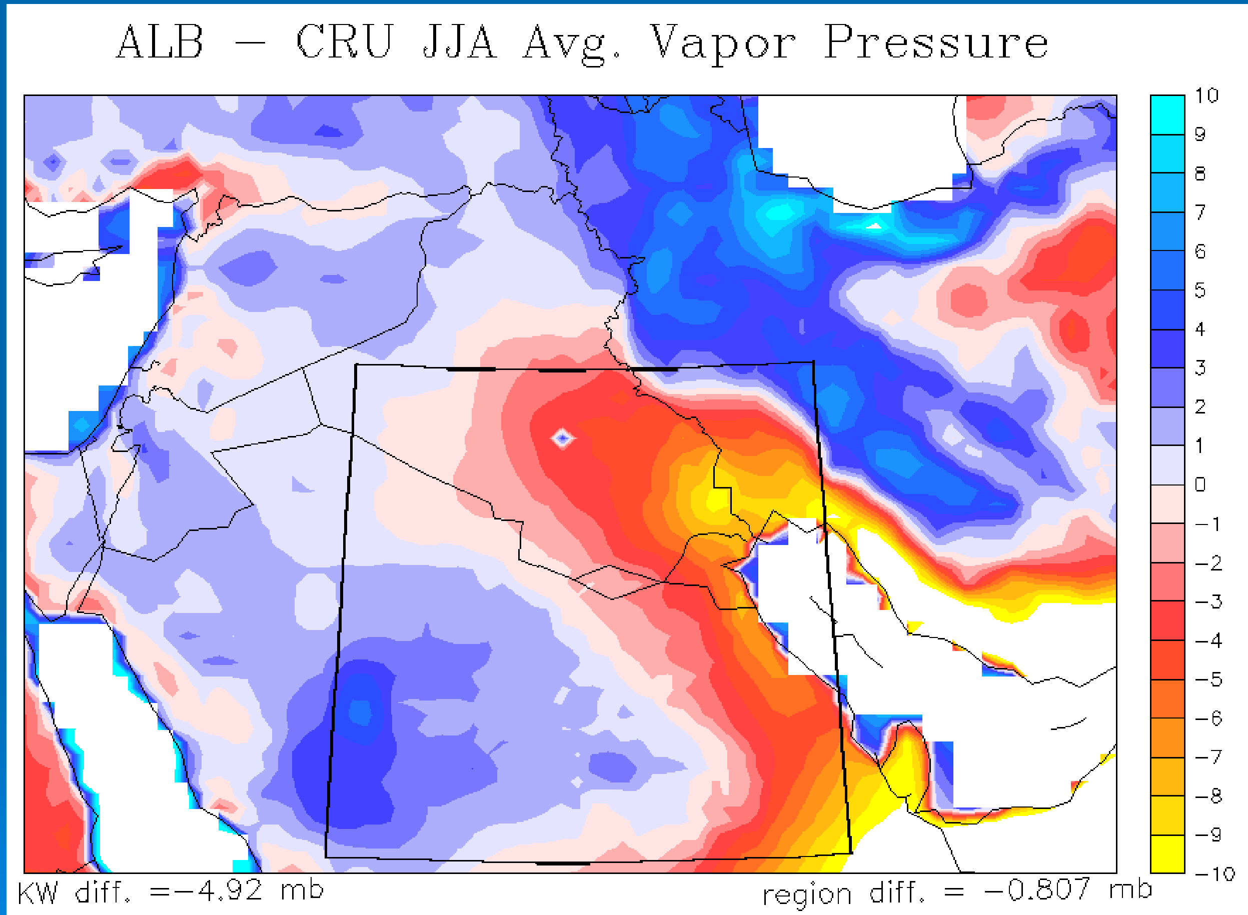


From space…. not only desert..



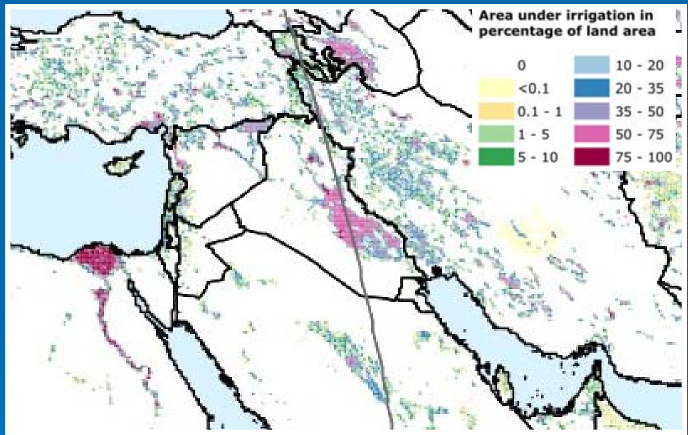


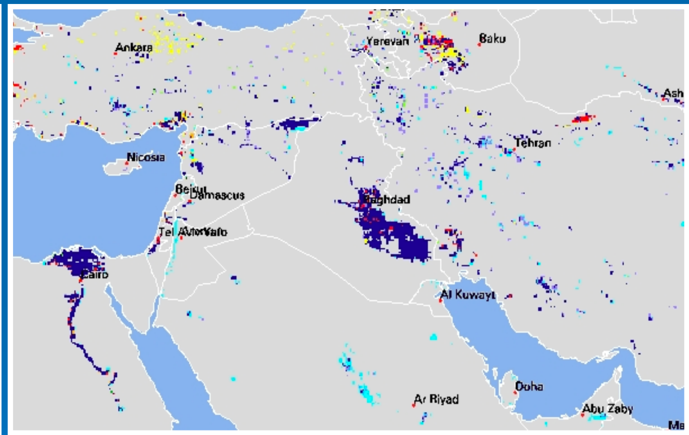
Surface Humidity Bias



Mesopotamian Irrigation and Marshlands

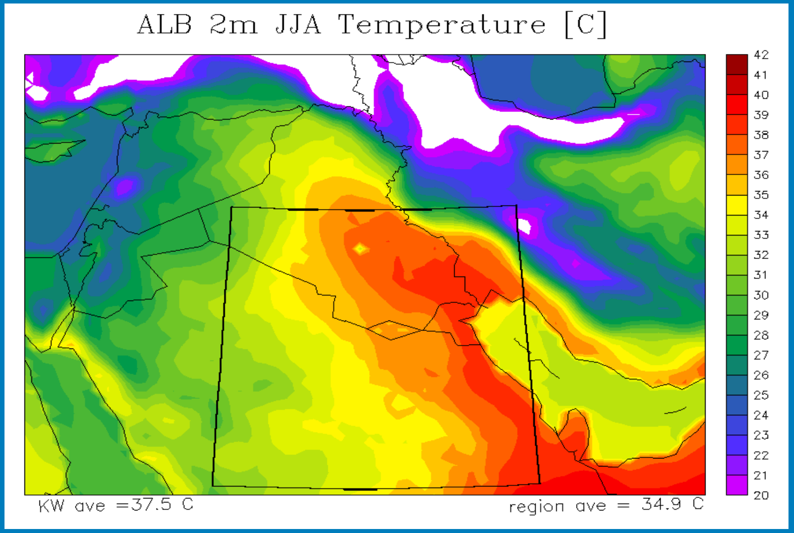
- Nearly 36,000 km^2 of irrigated land in Iraq (FAO & IWMI report-below) used for various crops. AVHRR & country supplied data

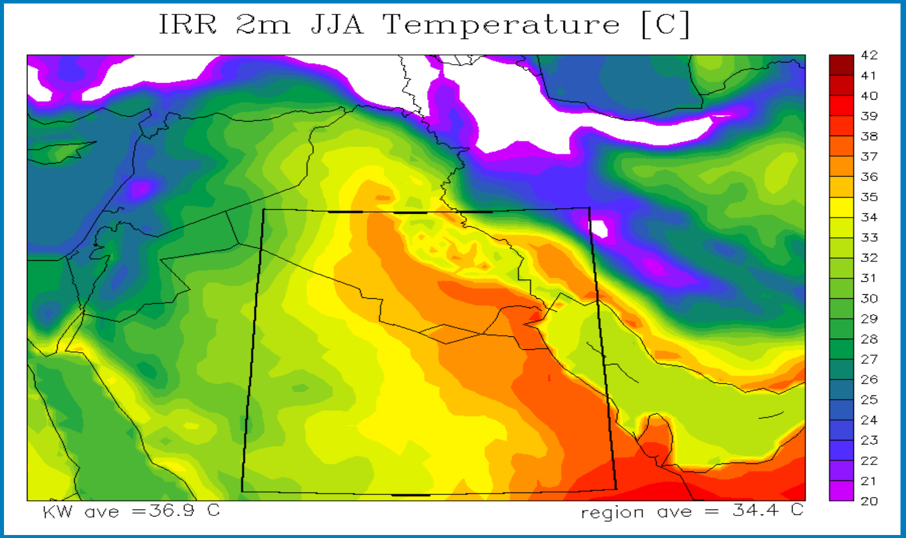


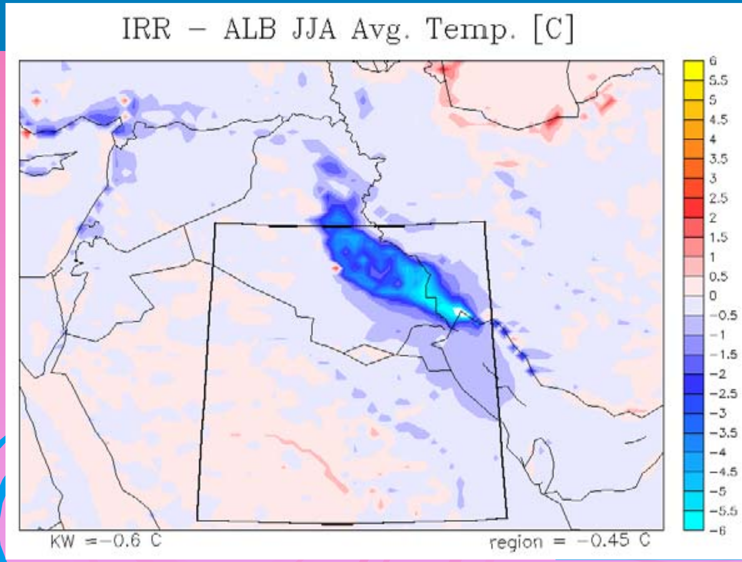


- Nearly 17,000 km^2 of marshlands in Iraq and Iran in the early 1970's, about the size of Kuwait.

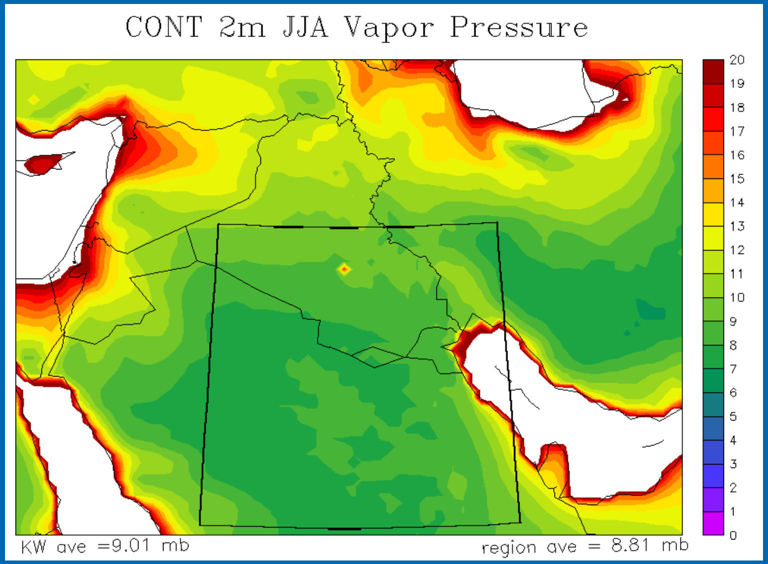
Effects of Irrigation/Marshlands on Temperature

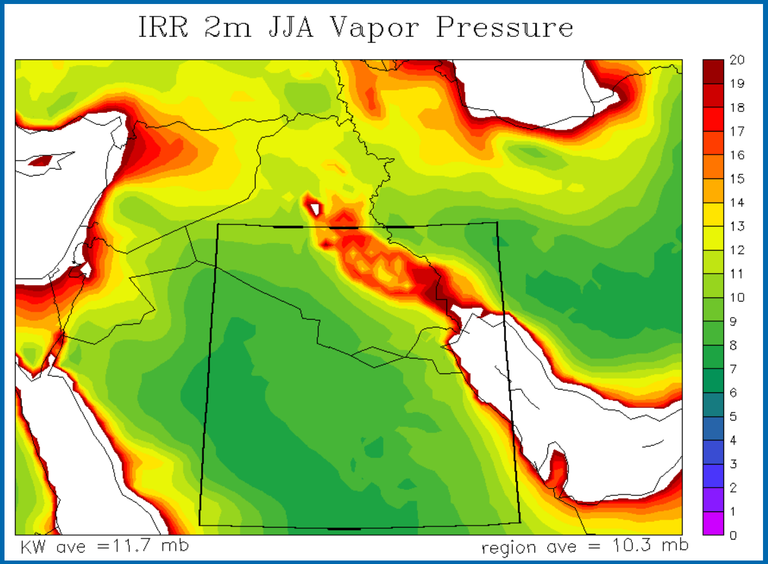


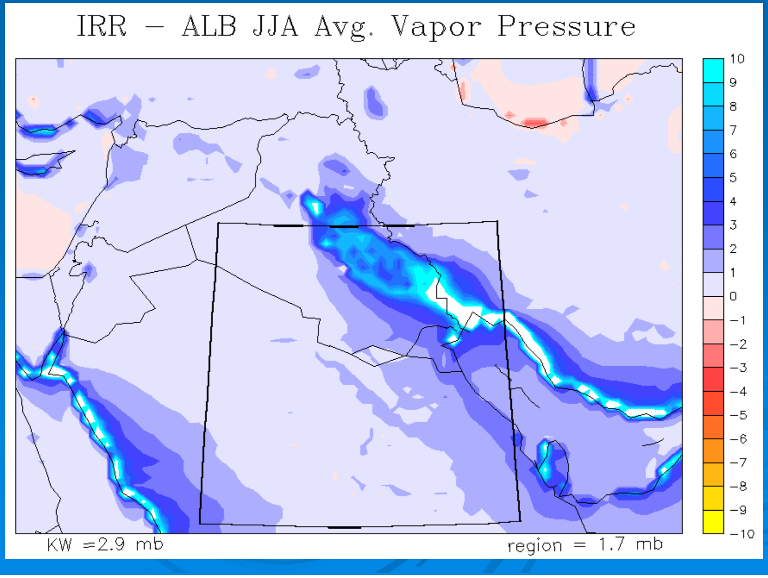




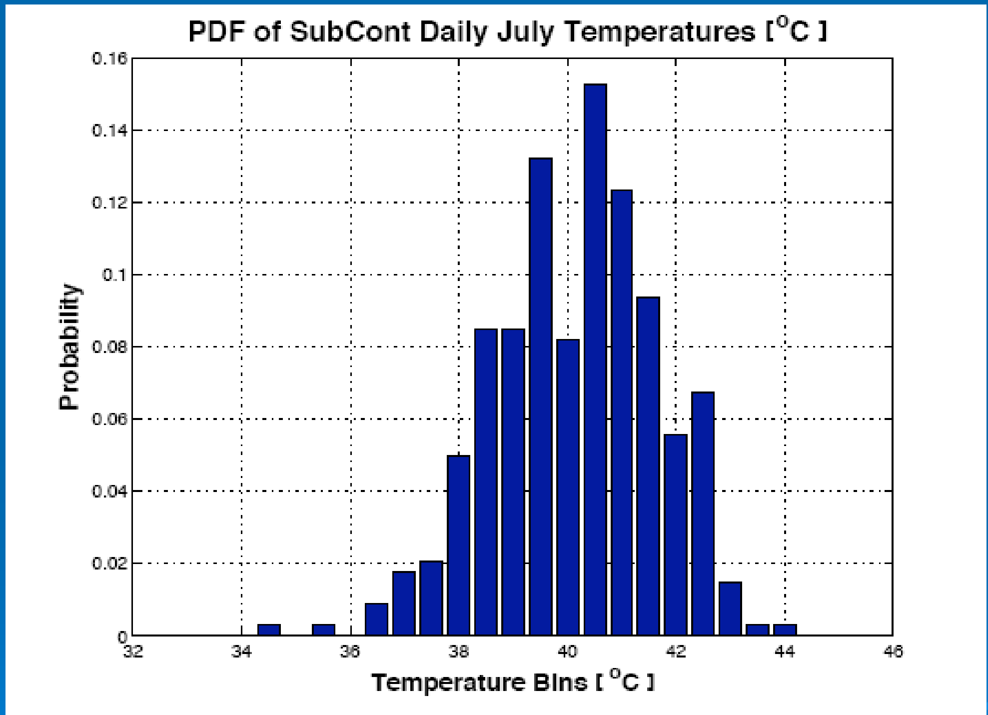
Effects of Irrigation/Marshlands on Surface Humidity



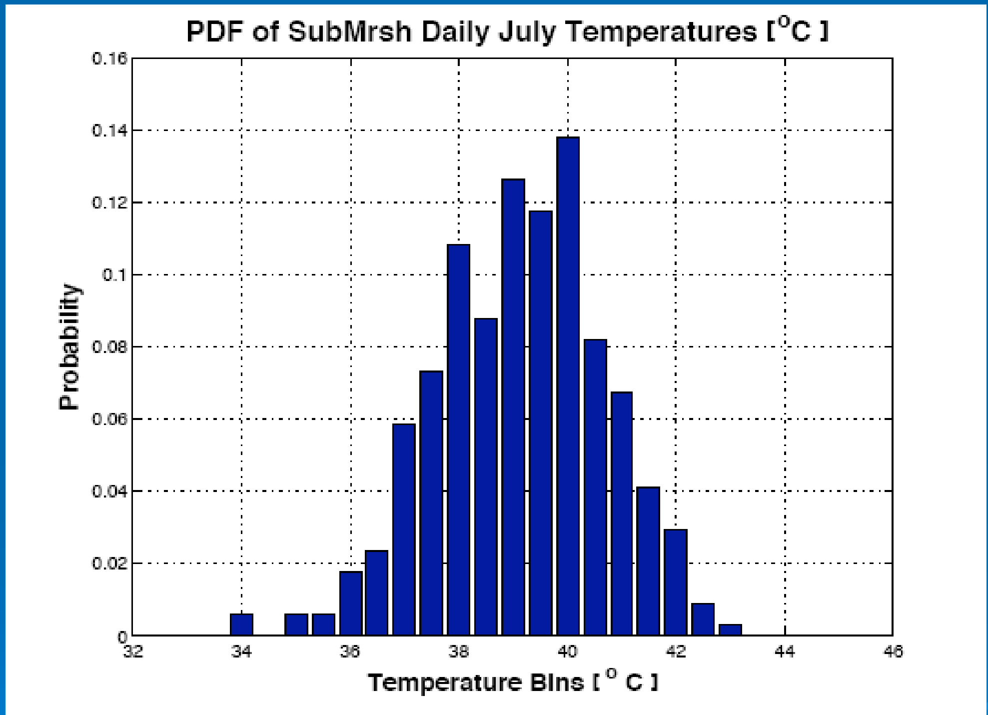




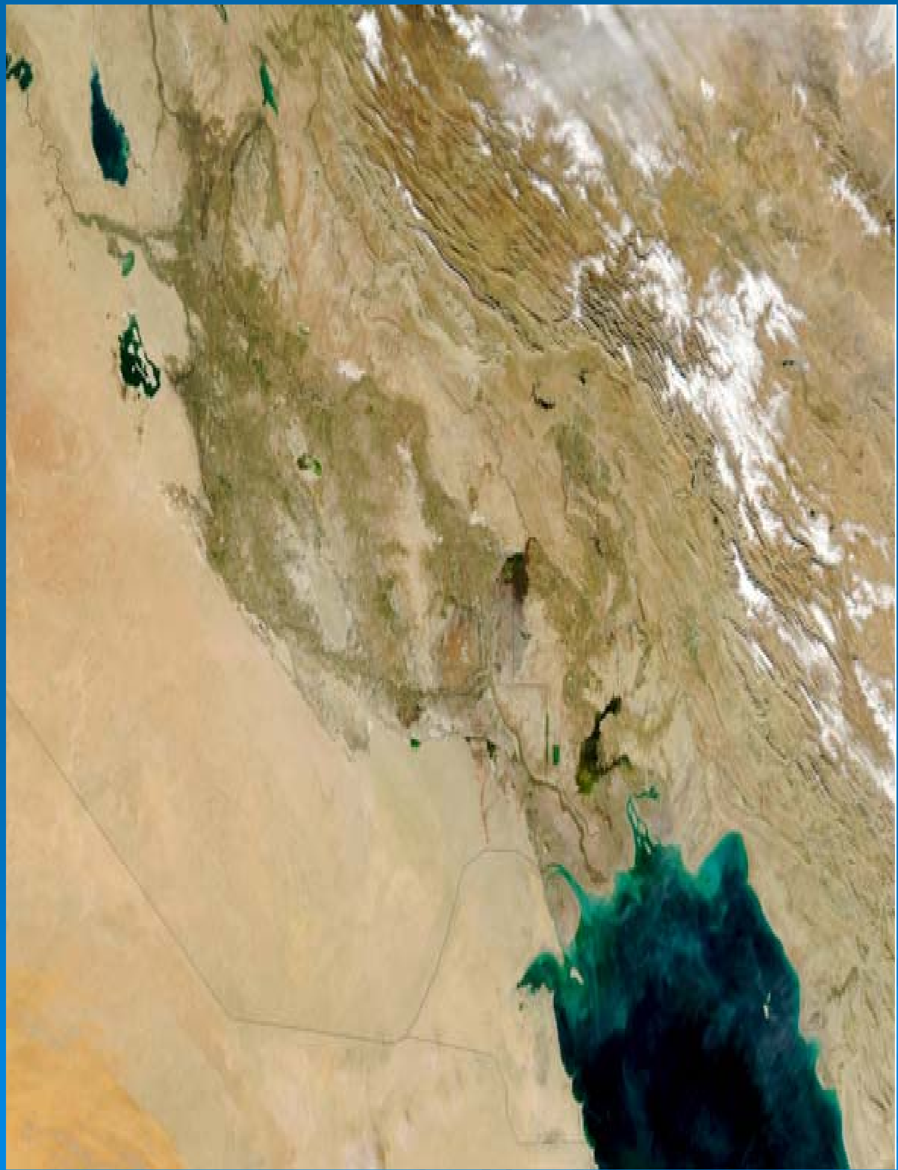
Changes in Extremes: Temperature



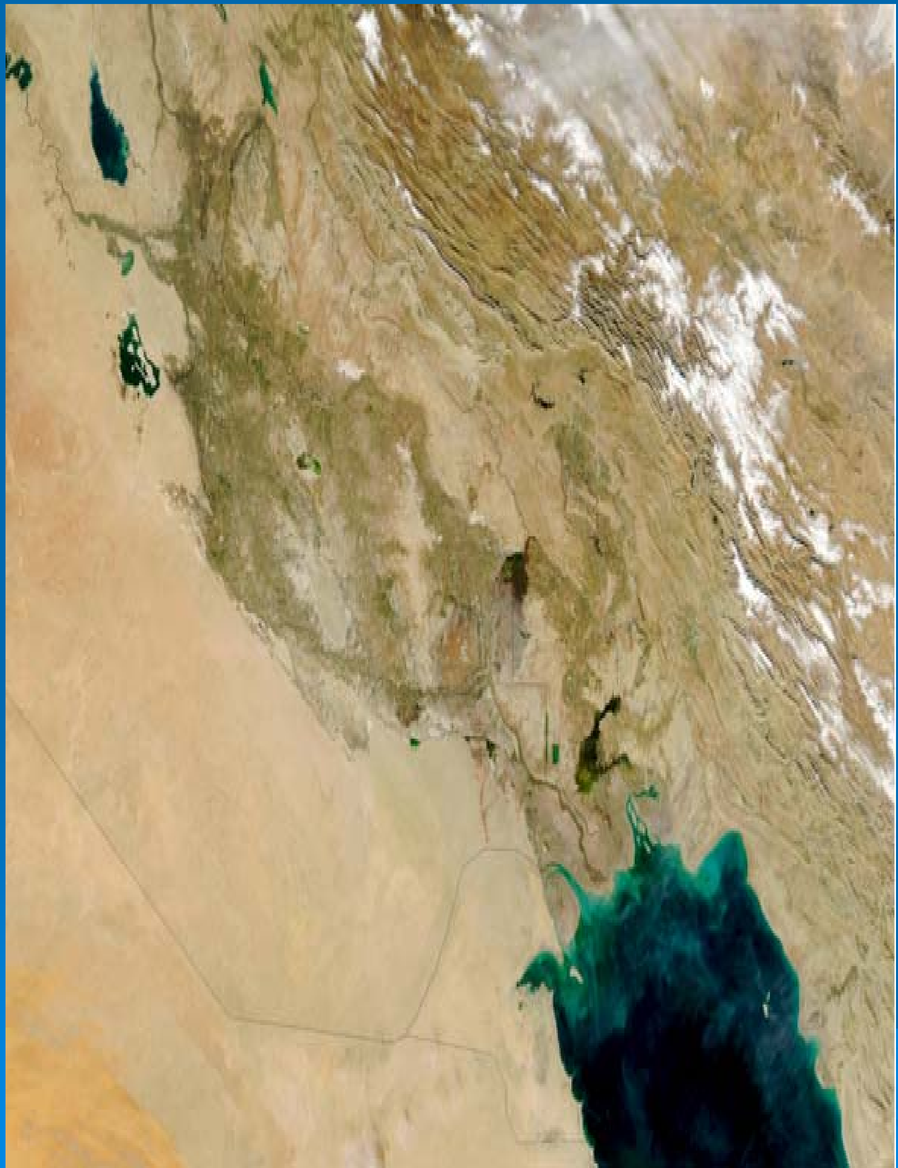
Changes in Extremes: Temperature

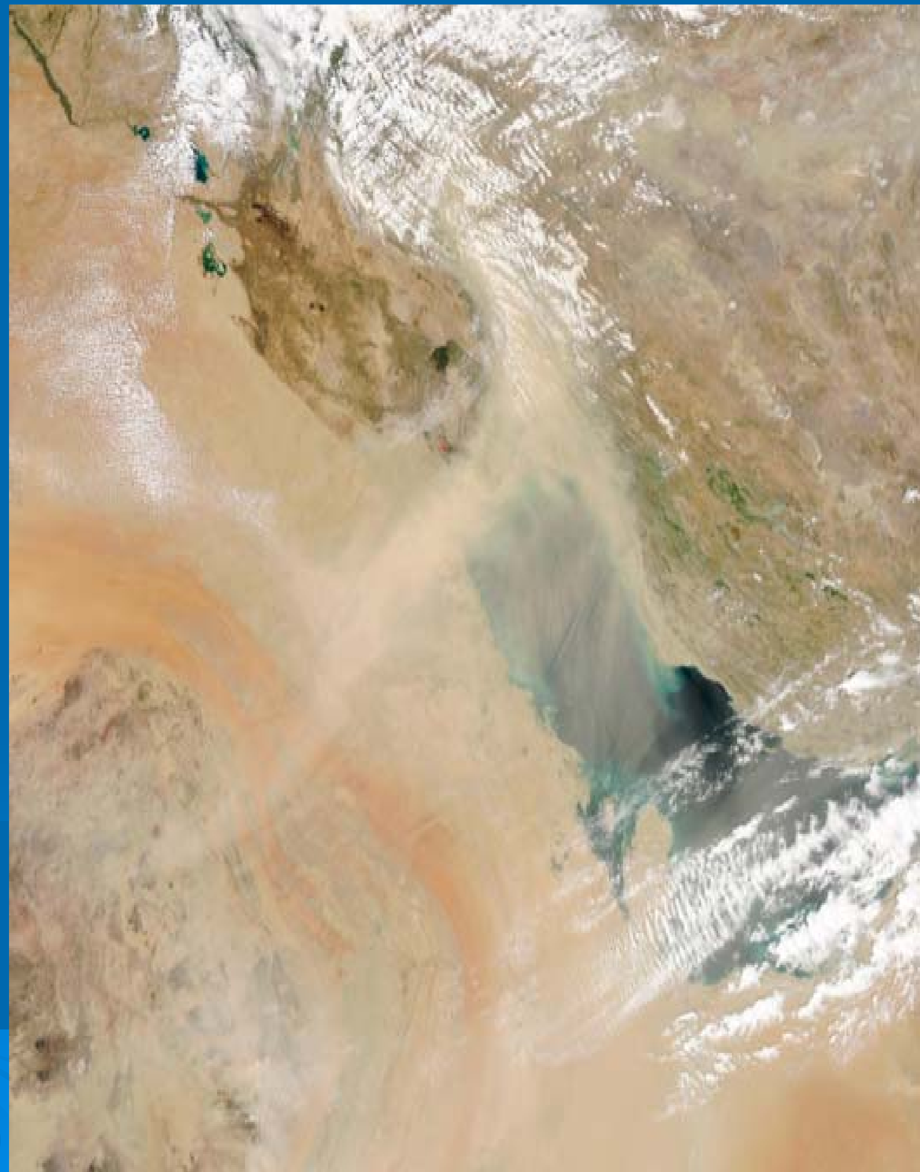


Again… from space

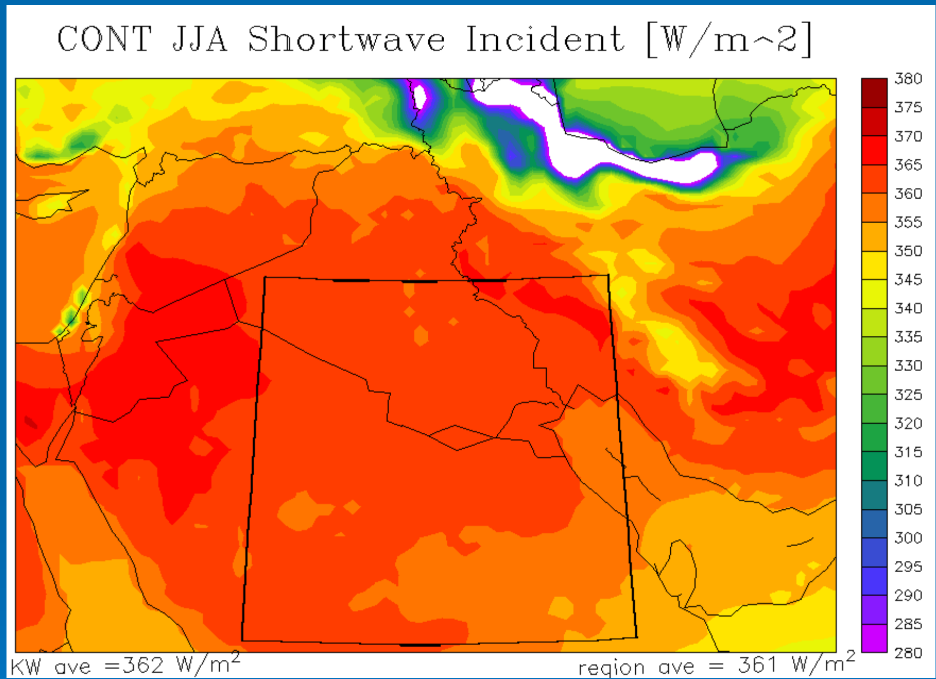


……………………Dust!!

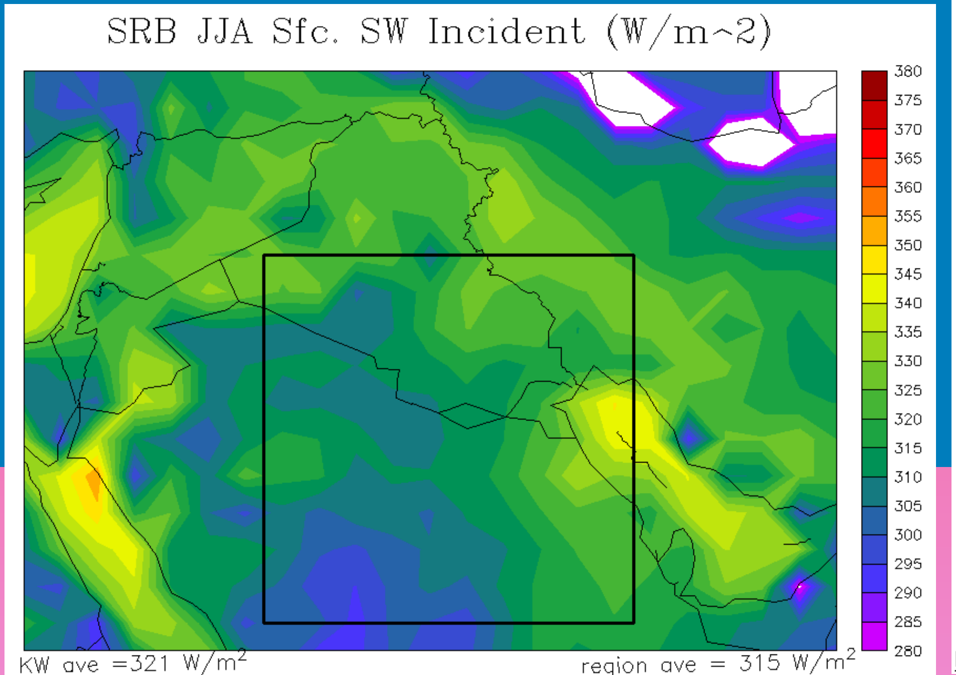


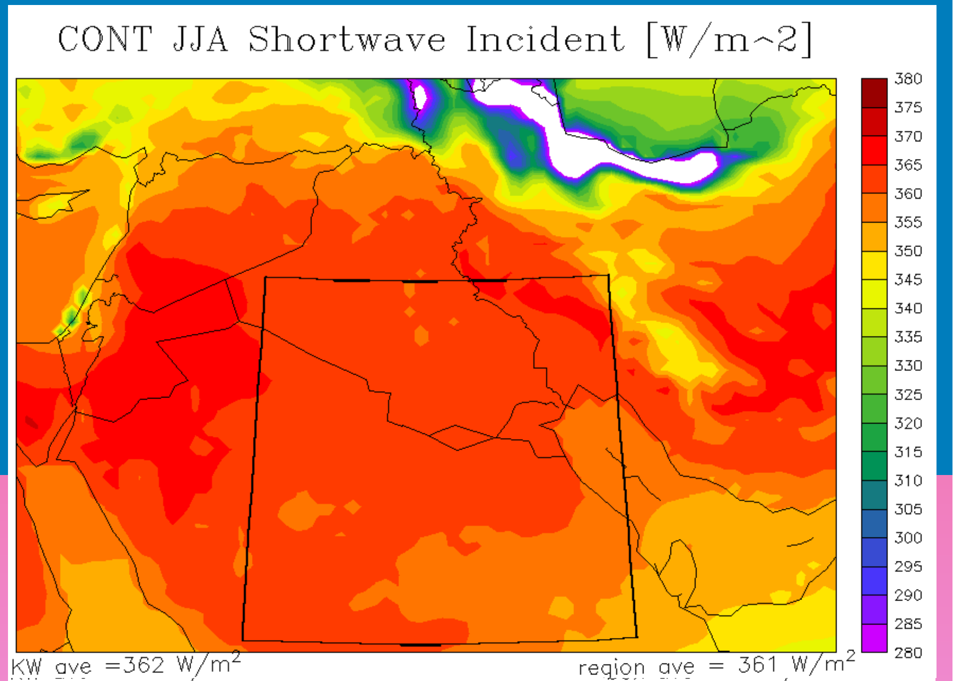


Incoming Shortwave Radiation

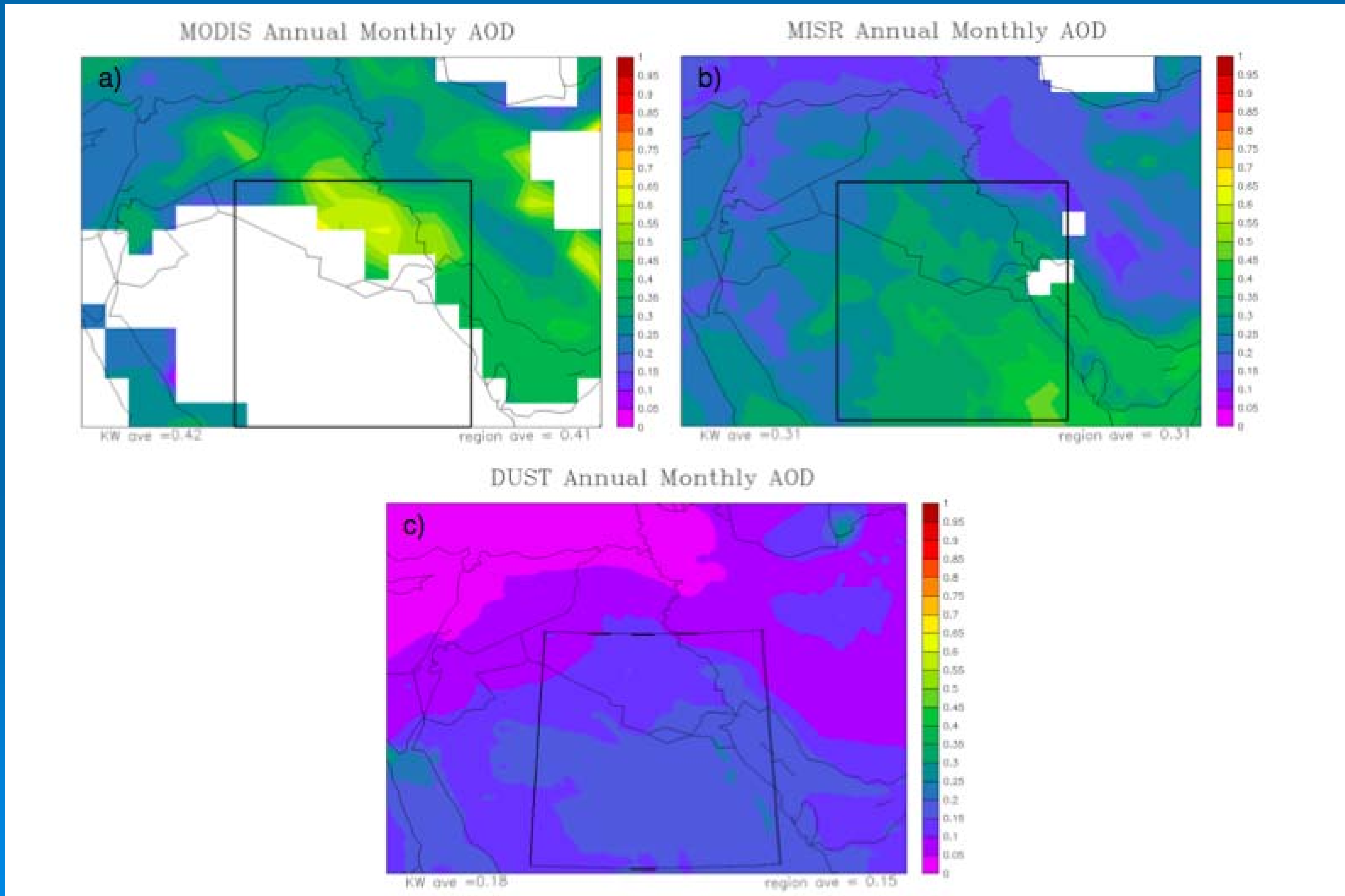


Incoming Shortwave Radiation

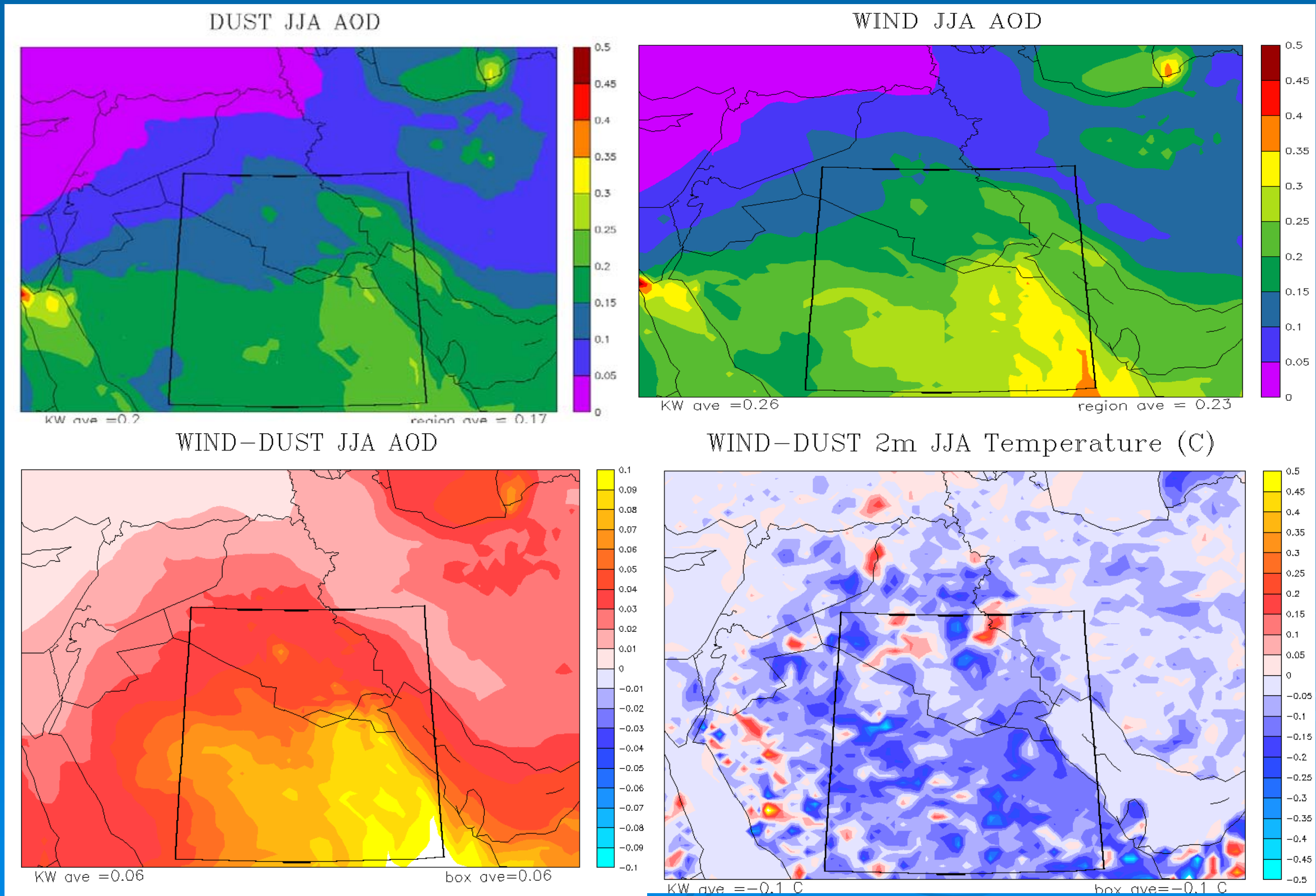




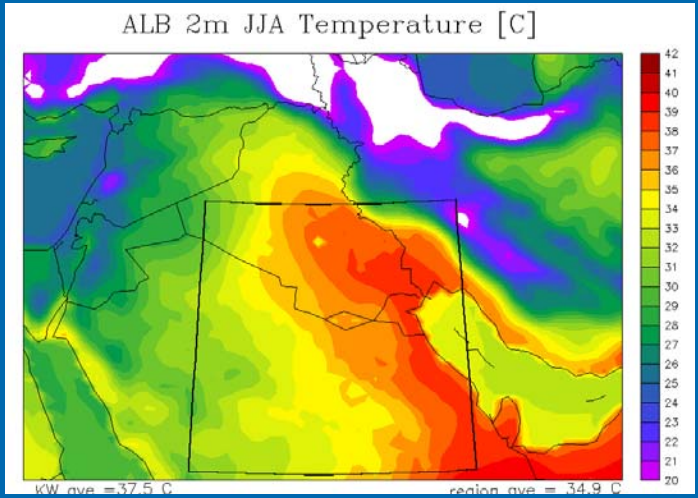
MODIS/MISR: Dust Emissions

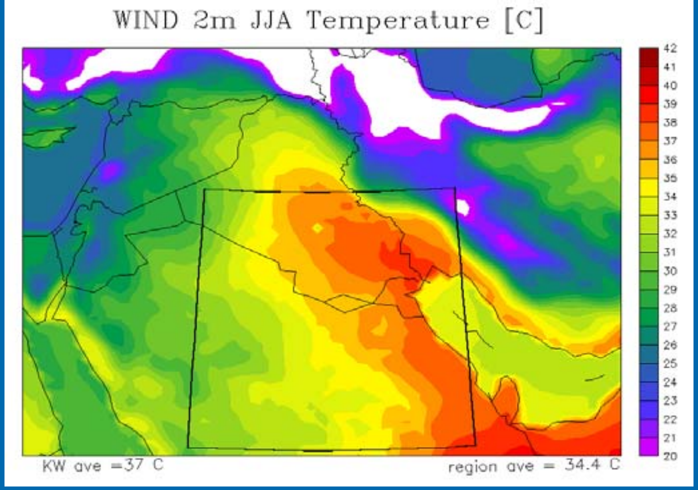


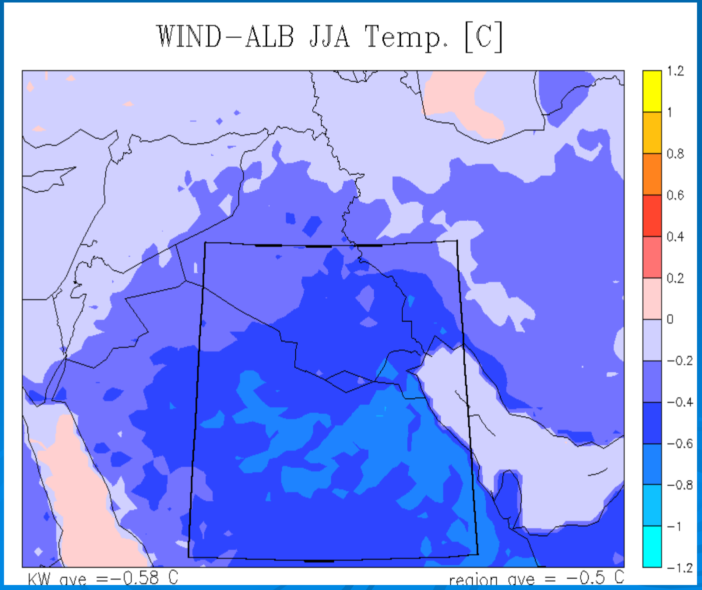
Dust Emissions with Wind Gustiness Included



Effects of Dust on Surface Temperatures







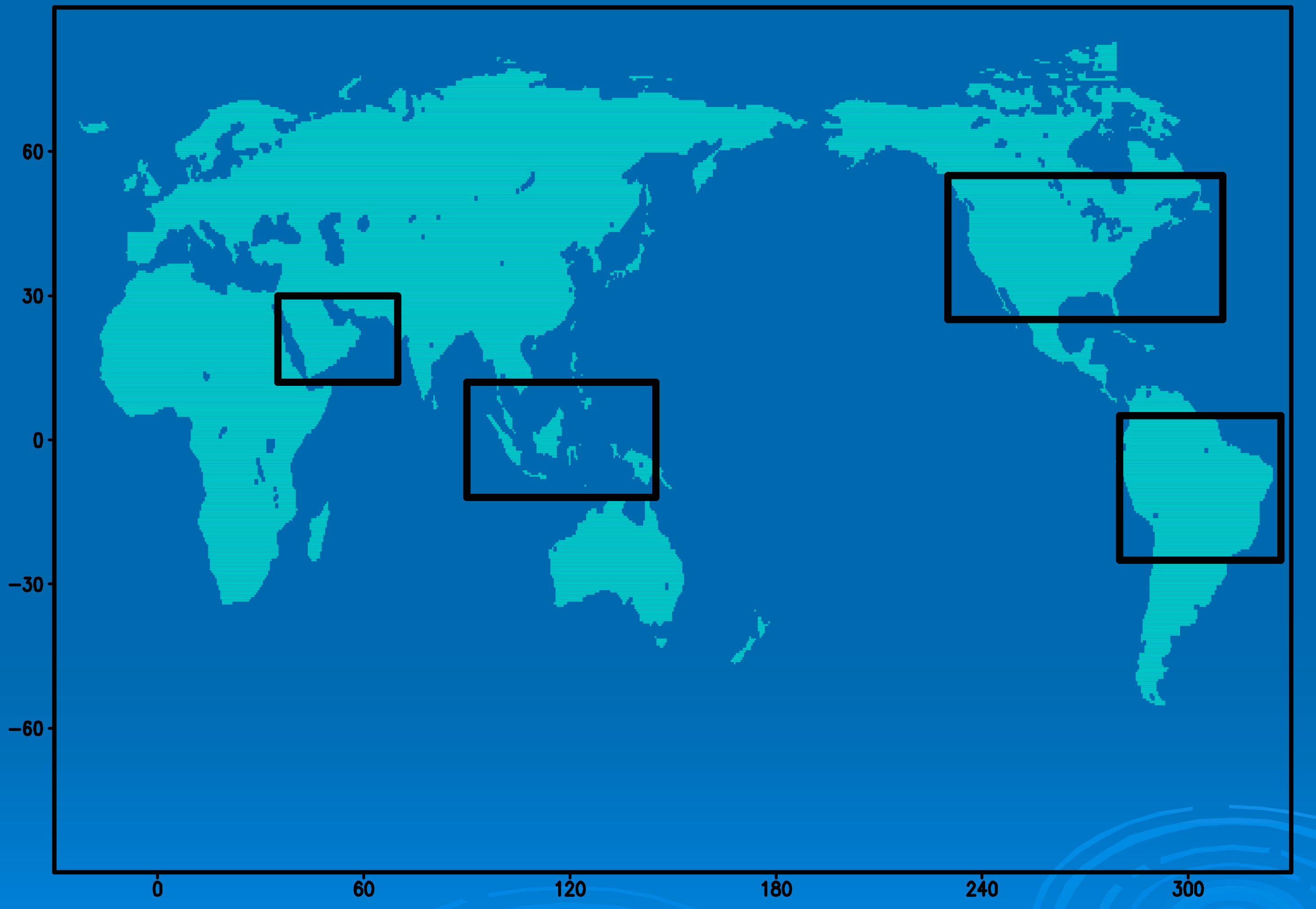
Summary of Effects

Model	KW-TA JJA Bias	Regional-TA JJA Bias
Control	+3.5	+2.7
Albedo adjustment	-1.0	-0.9
Dust (w/subgrid wind)	-0.6	-0.5
Irrigation+Marshlands	-0.6	-0.5
Observational Bias	-0.8	-0.3
Total Expected Bias	+0.5	+0.5

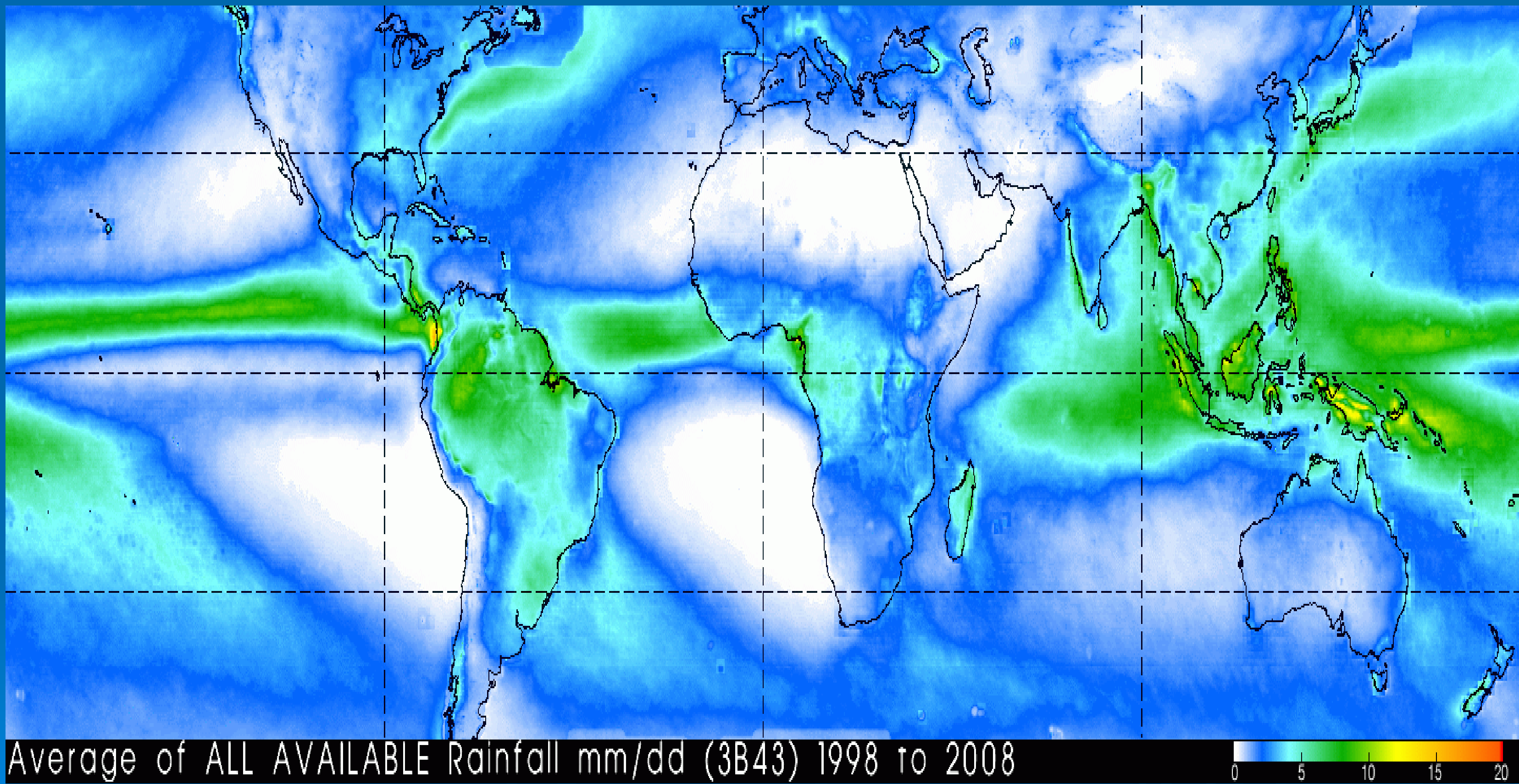
albedo values matching SRB

SWI bias reduced by 20-40 W/m^2

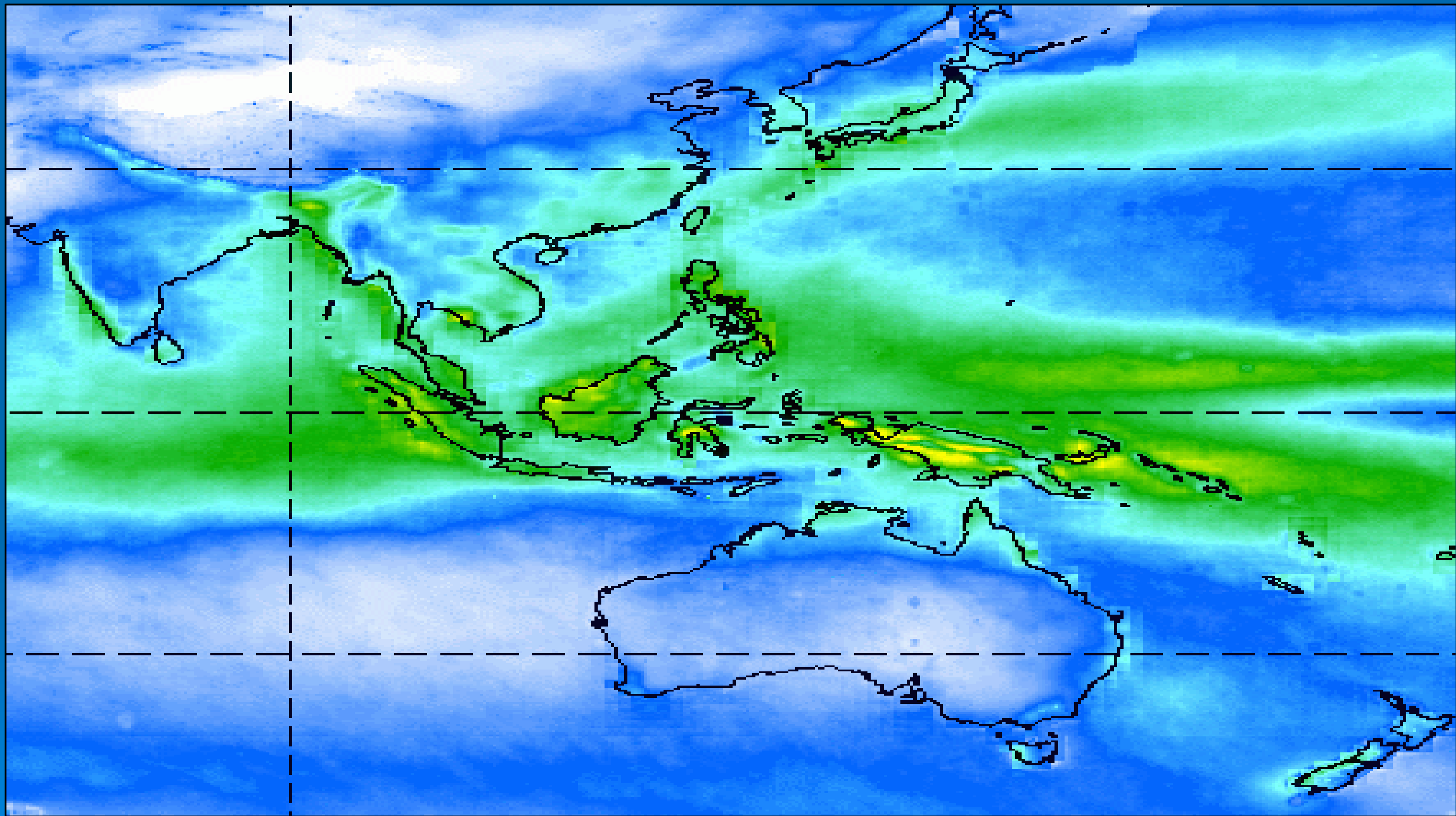
RH bias reduced by 5-10%


60
30
0
−30
−60
0
60
120
180
240
300

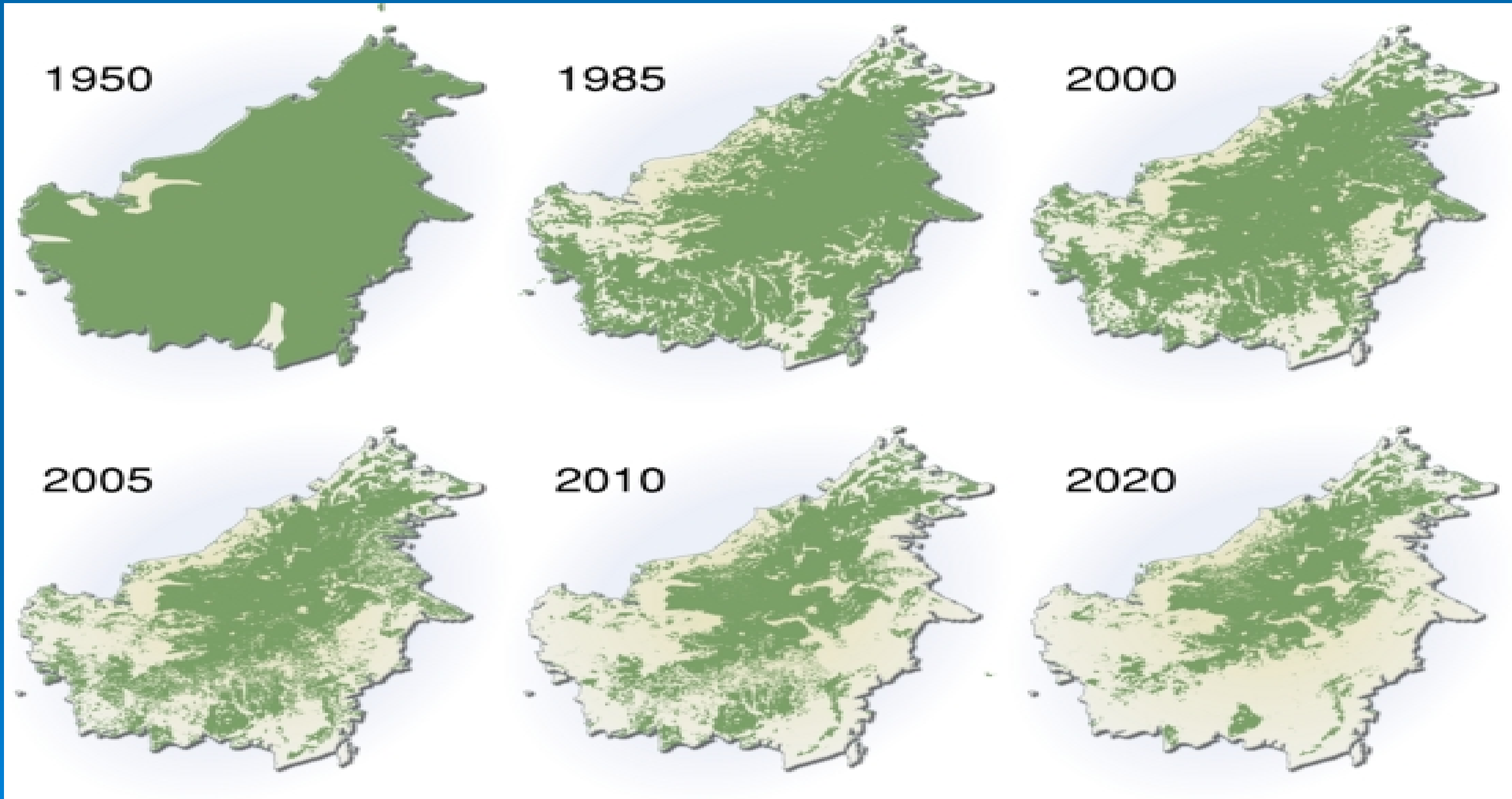
Global Rainfall from Space (TRMM)



Maritime Continent: Rainfall from Space (TRMM)

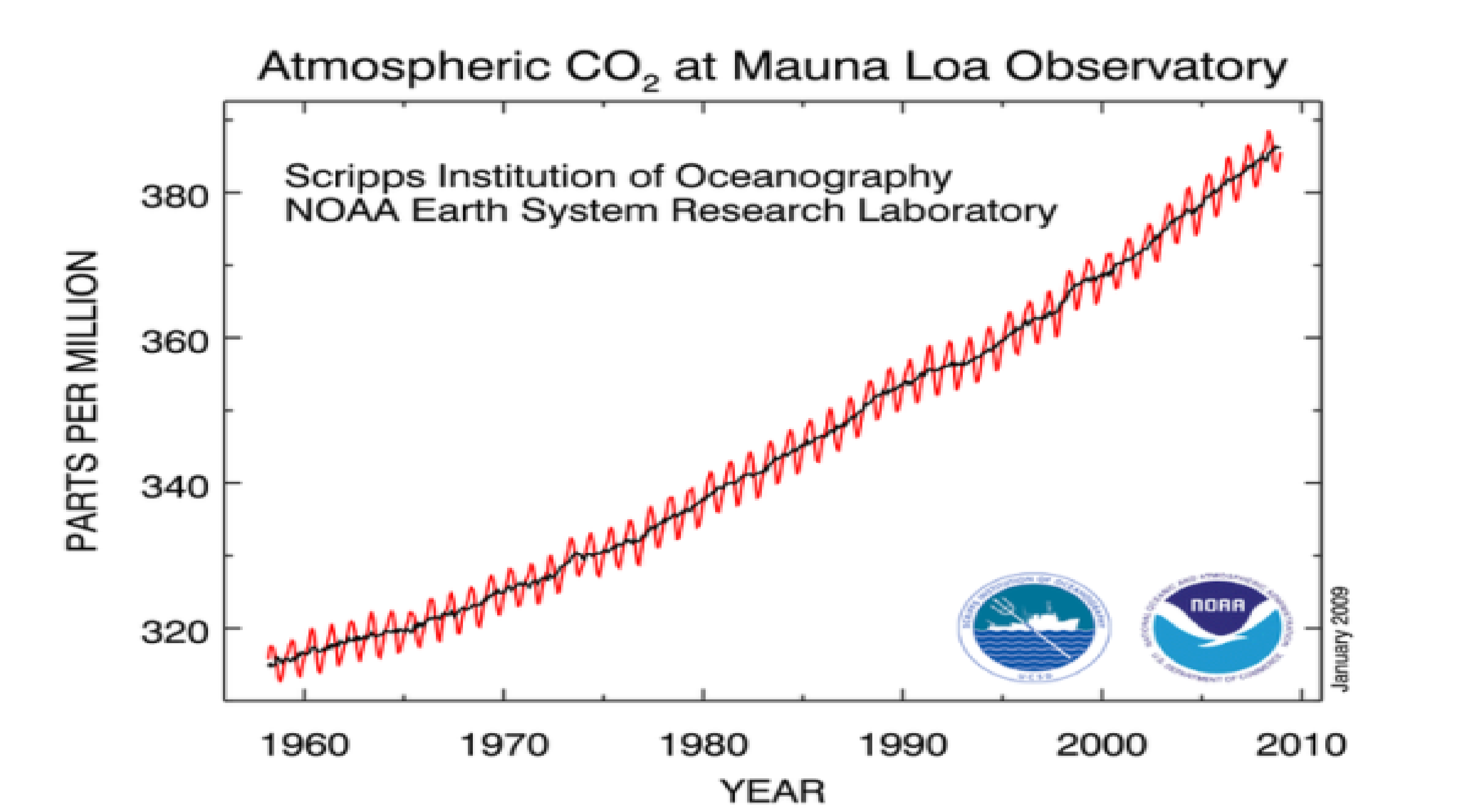


Land Cover Change in Borneo : Observations 1950-2005, projections to 2020



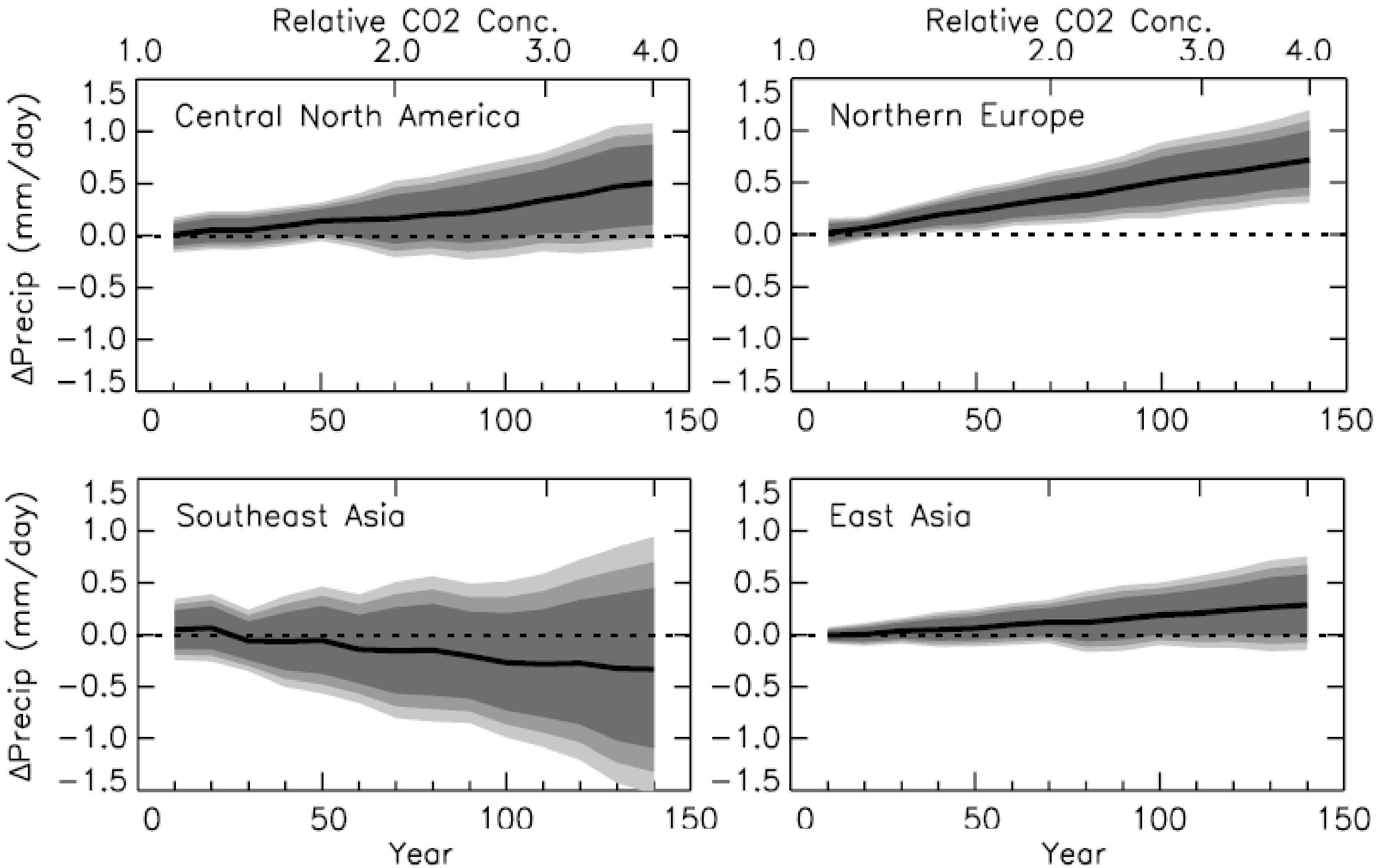
(UNEP/GRID-Arendal 2007)

Global Climate Change



Comparison to other regions

Supplementary Material Figure S11.37, IPCC Report 2007 Chapter 11

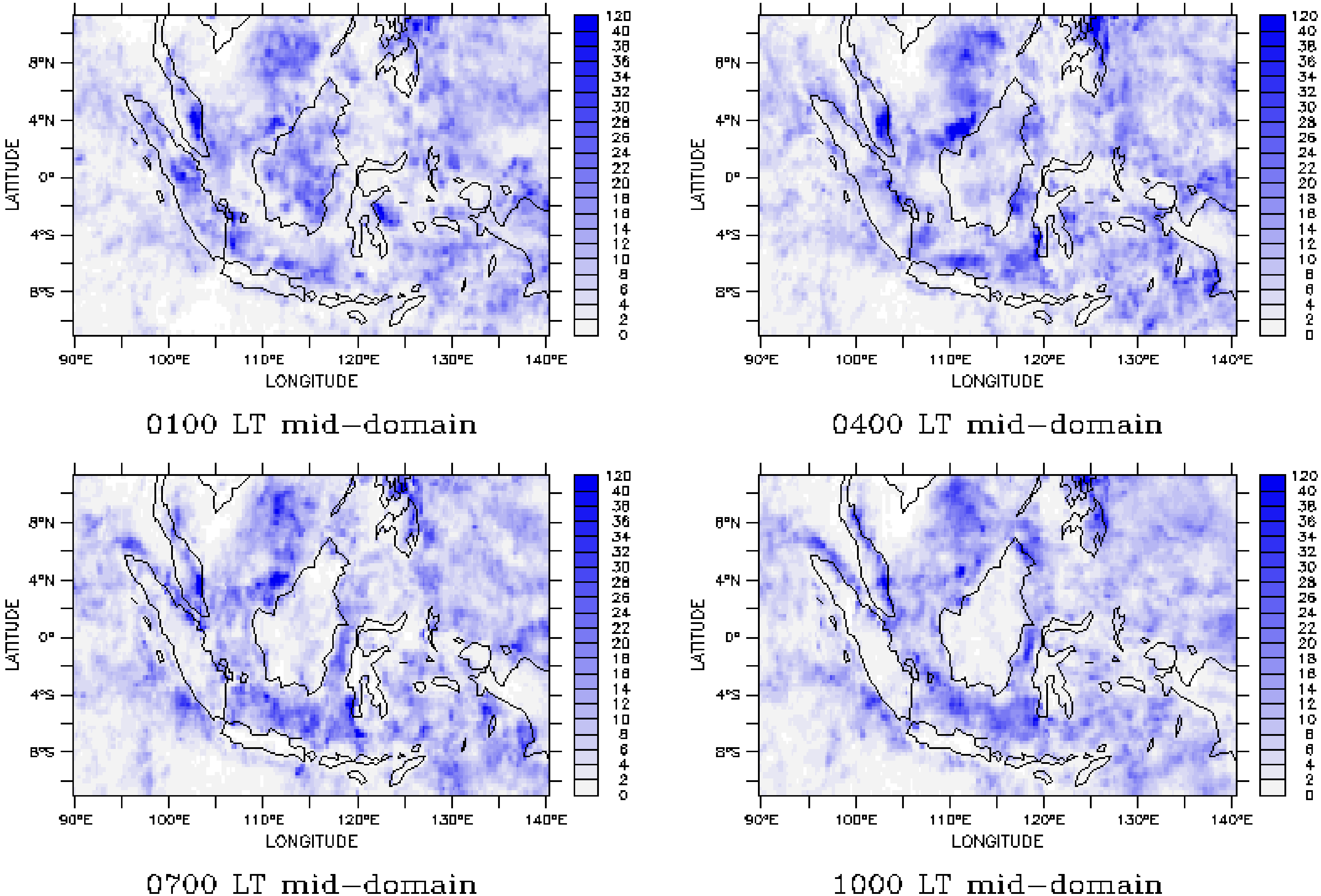


Objectives

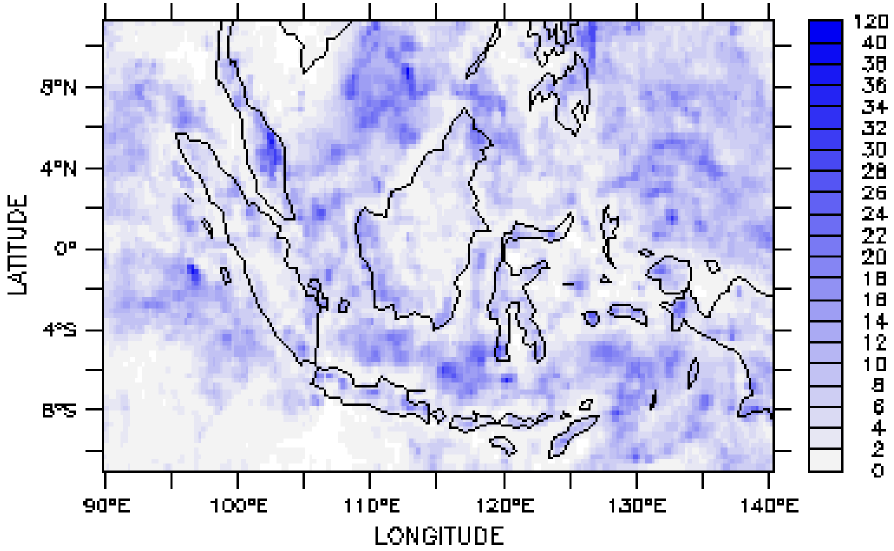
→ Improve ability to simulate climate over Maritime Continent

→ Improve understanding of the role of land surface processes / characteristics in shaping regional climate

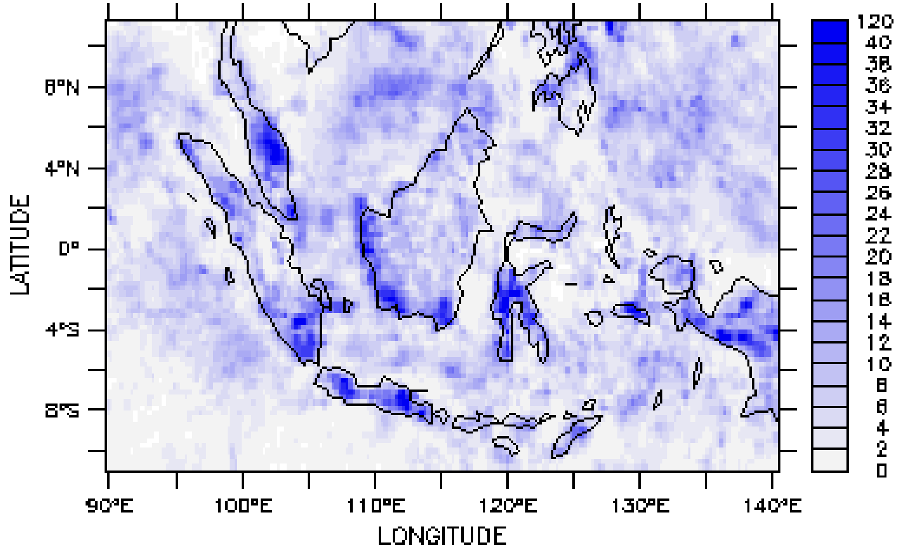
Diurnal cycle of rainfall, average 1998-2001, from TRMM (3-hourly, 0.25º x 0.25º)
Rainfall in mm/day



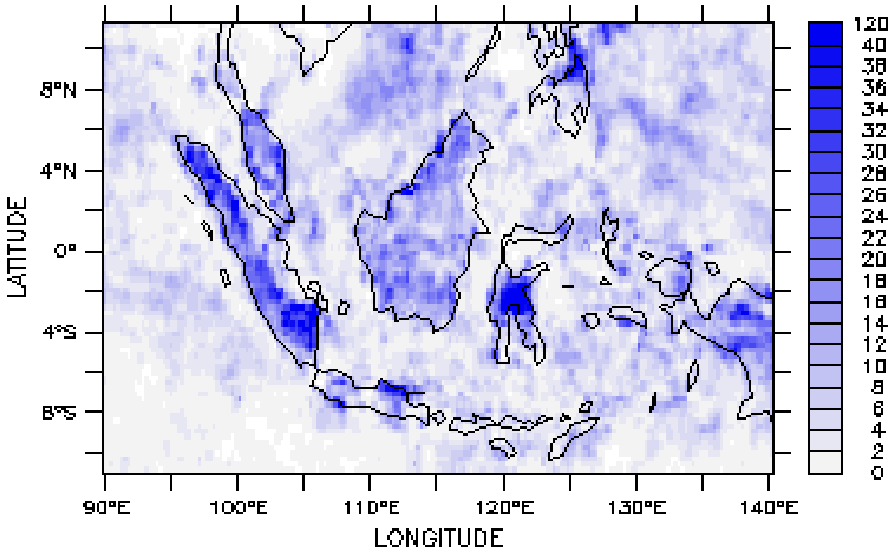
Diurnal cycle of rainfall, average 1998-2001, from TRMM (3-hourly, 0.25º x 0.25º)
Rainfall in mm/day



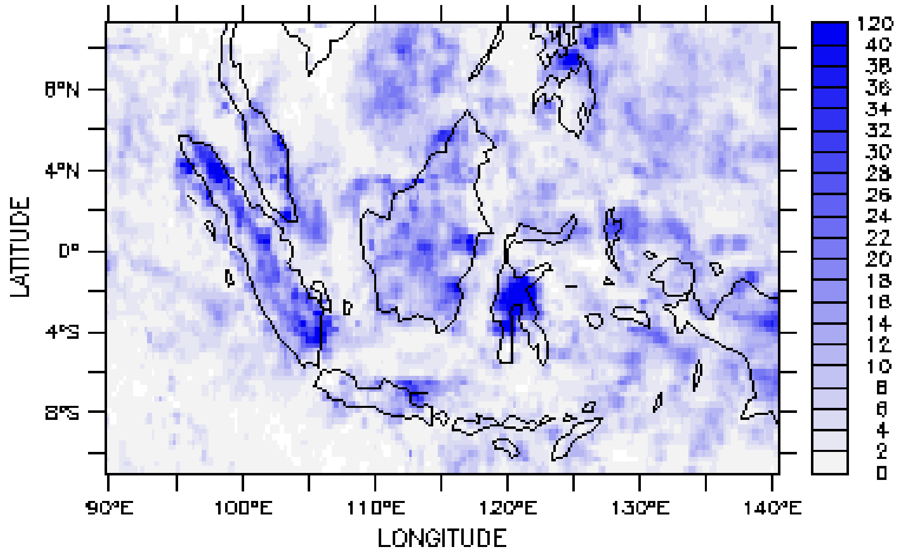
1300 LT mid–domain



1600 LT mid–domain



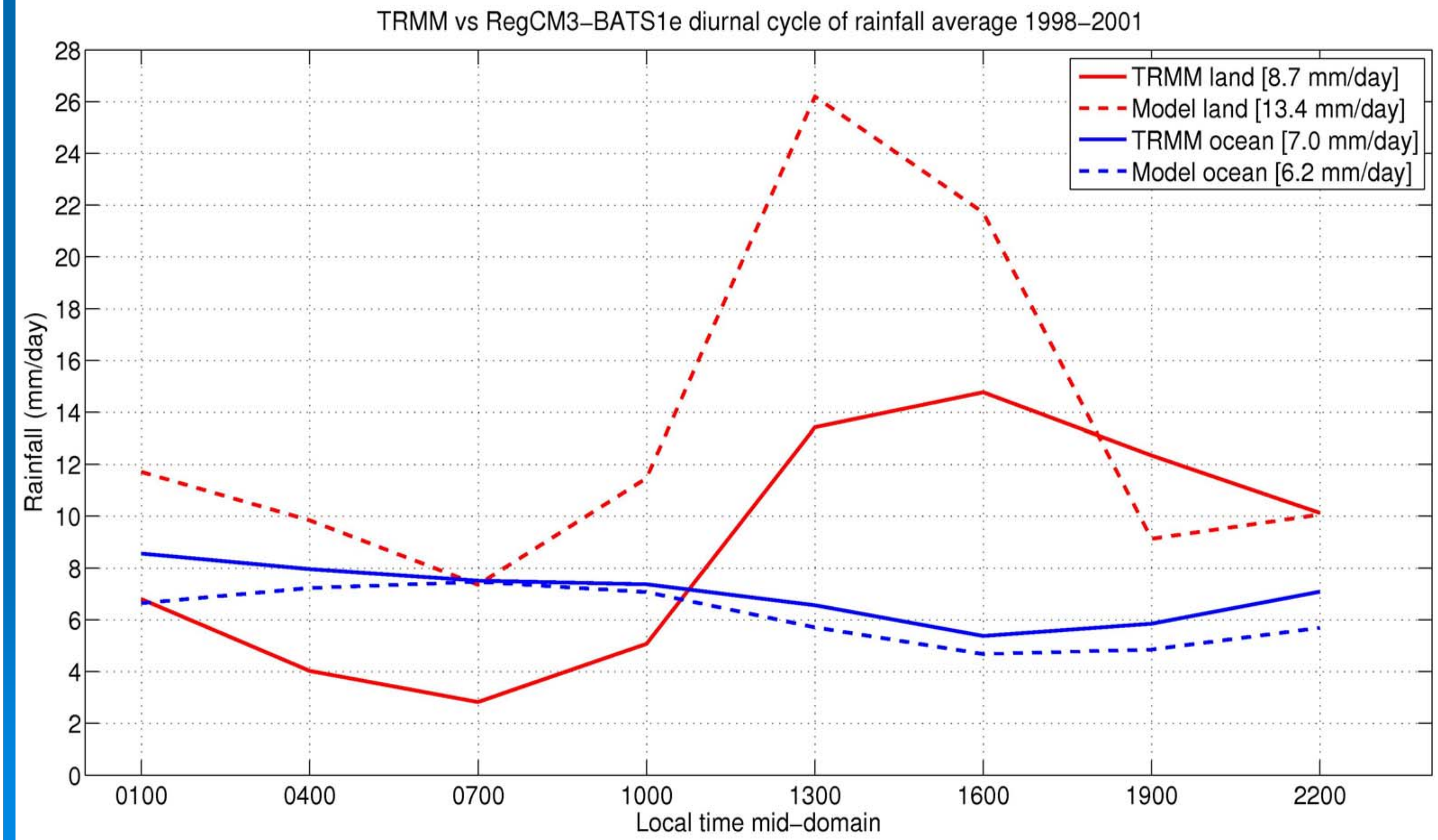
1900 LT mid–domain



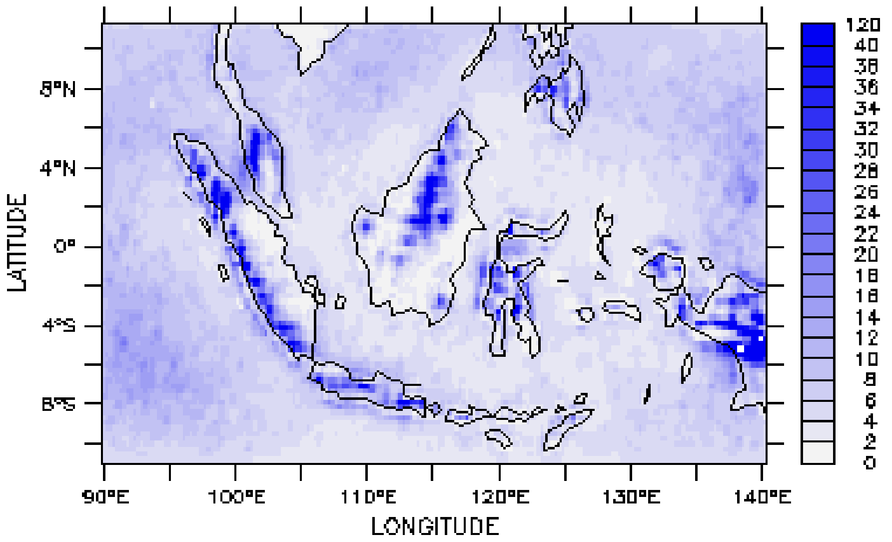
2200 LT mid–domain

Model errors: - over land - wet bias (~4.5 mm/day), diurnal peak too high, too early - common RCM error (e.g. Wang *et al.* 2007)

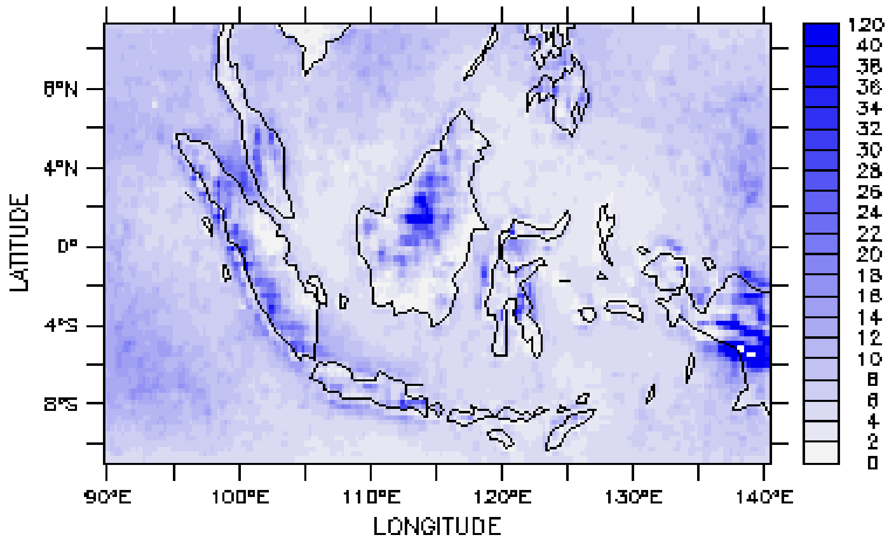
- over ocean - dry bias (~1 mm/day)



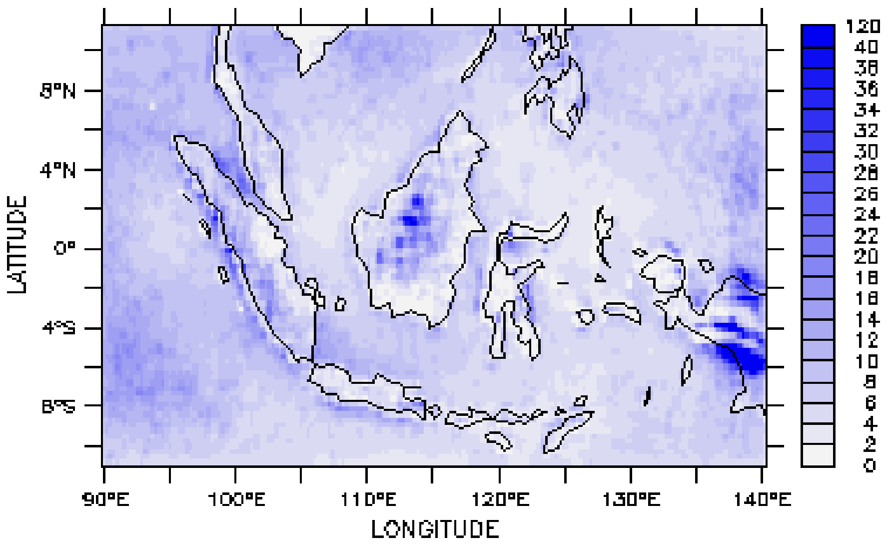
Diurnal cycle of rainfall, average 1998-2001, from RegCM3-BATS1e (DTMAX=0)
Rainfall in mm/day



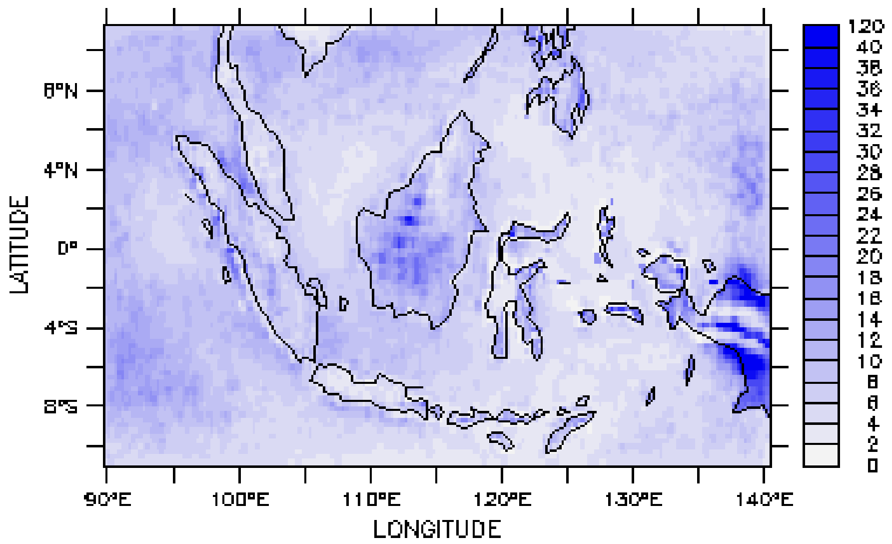
0100 LT mid−domain



0400 LT mid−domain

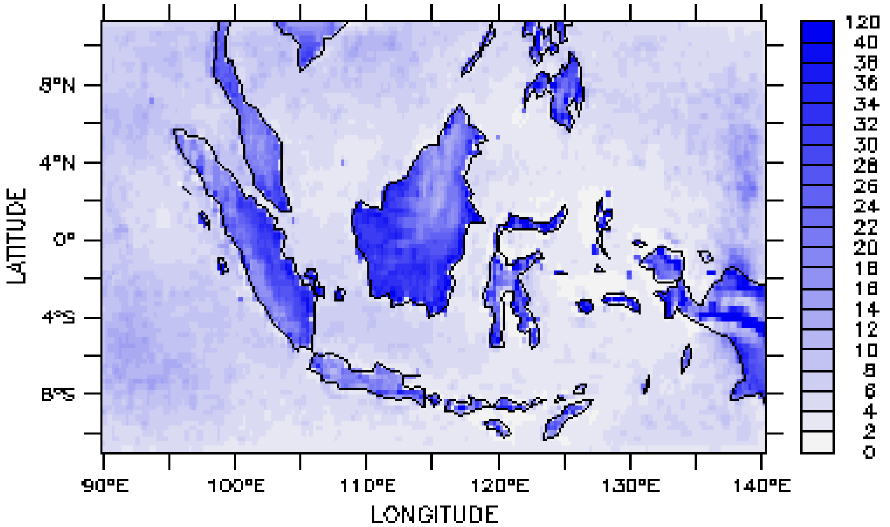


0700 LT mid−domain

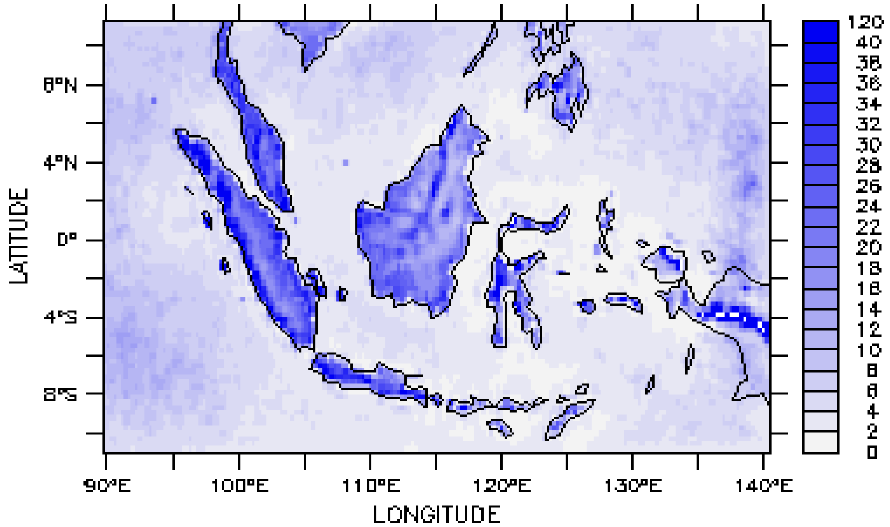


1000 LT mid−domain

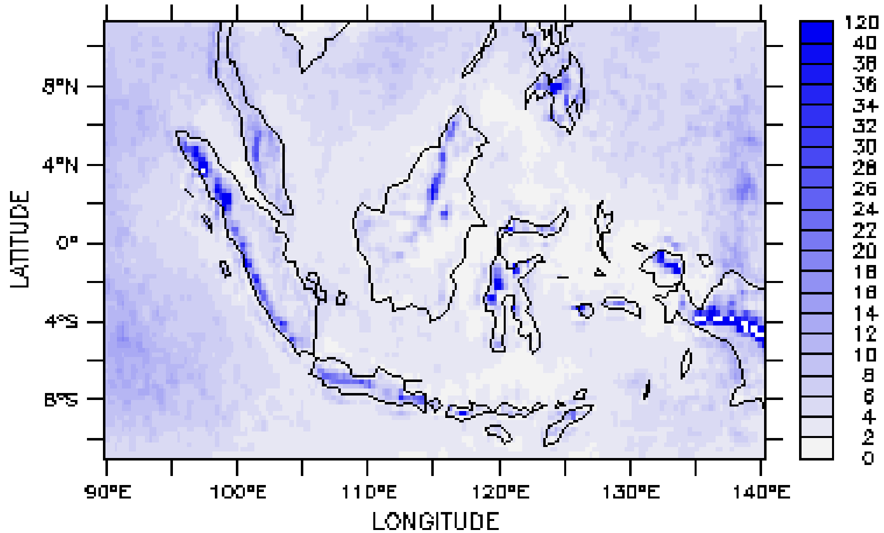
Diurnal cycle of rainfall, average 1998-2001, from RegCM3-BATS1e (DTMAX=0)
Rainfall in mm/day



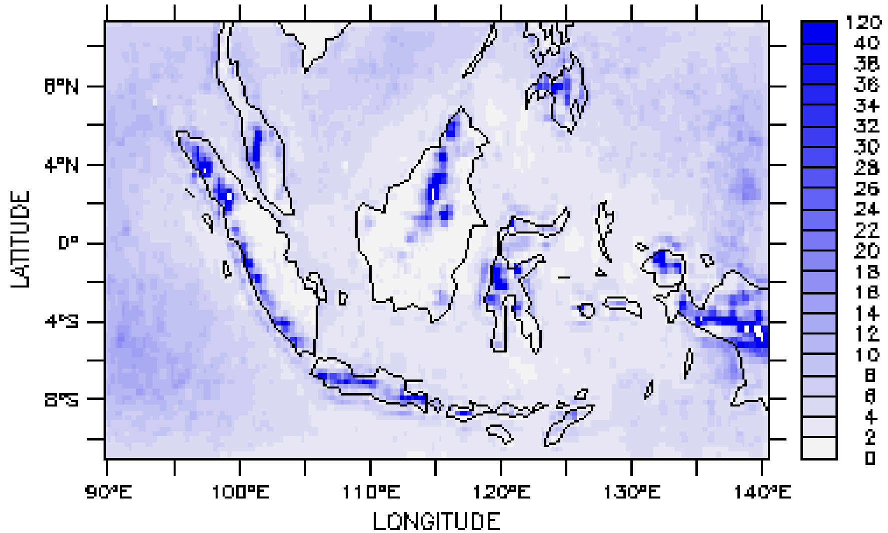
1300 LT mid–domain



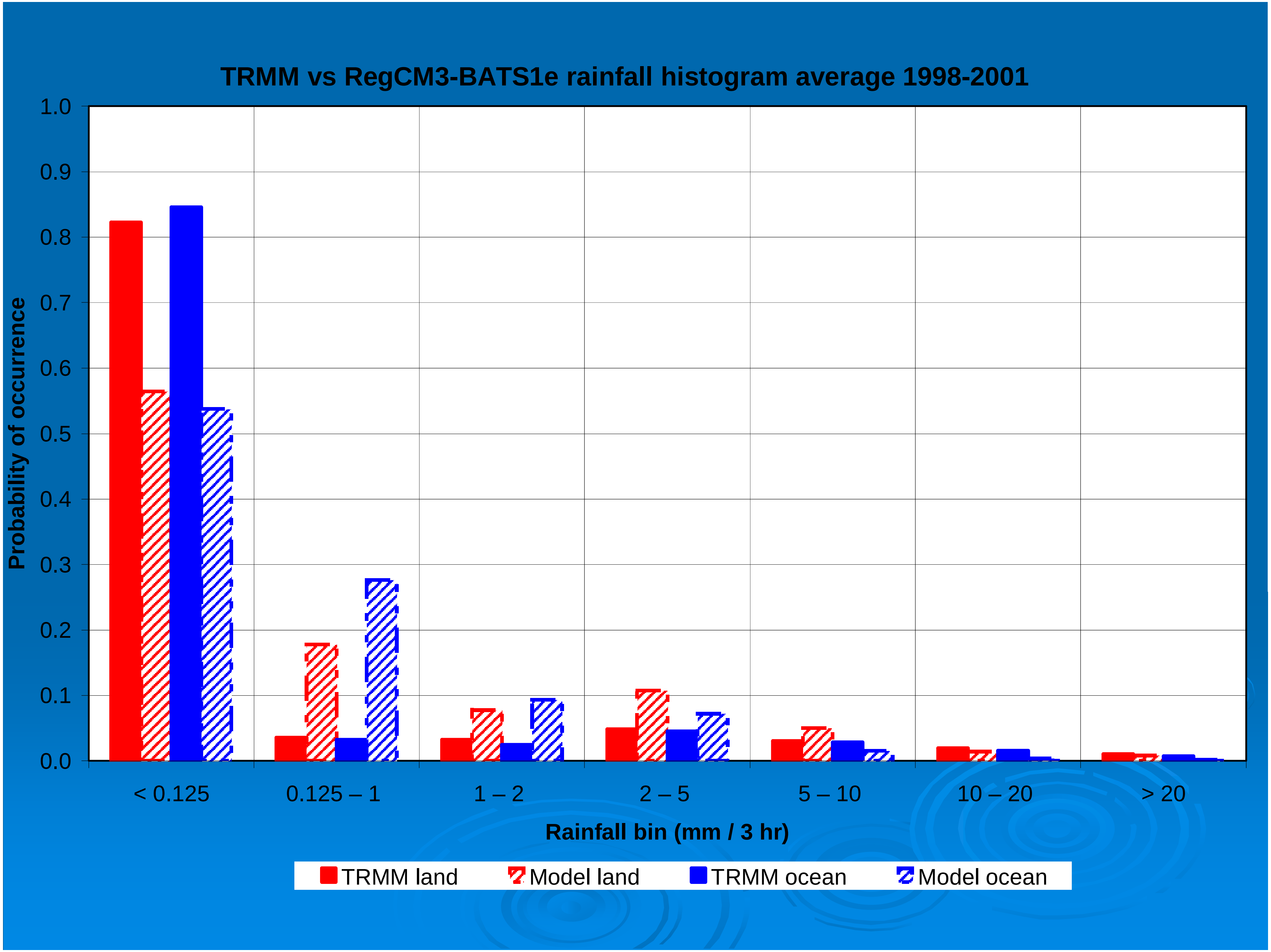
1600 LT mid–domain



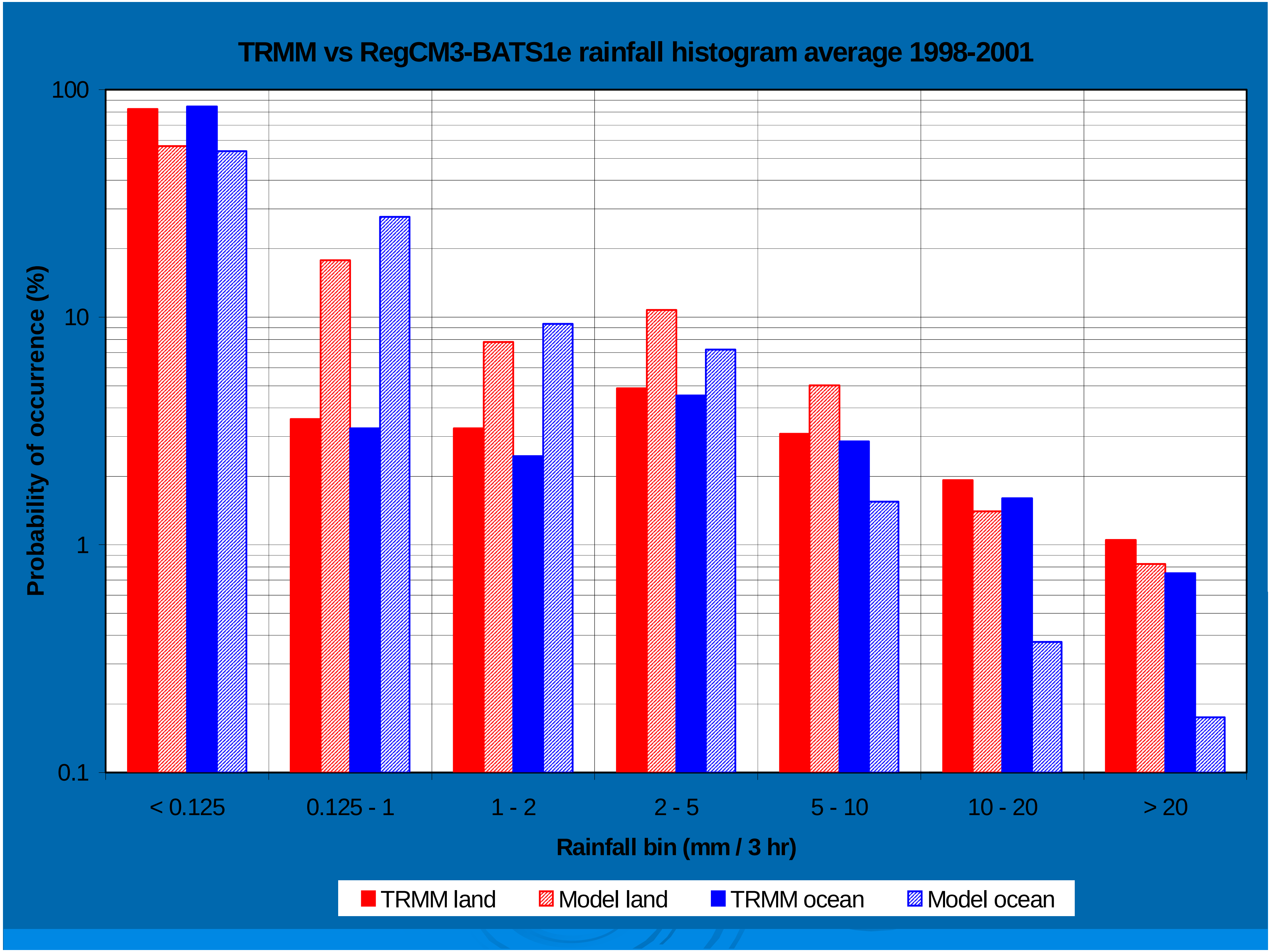
1900 LT mid–domain



2200 LT mid–domain



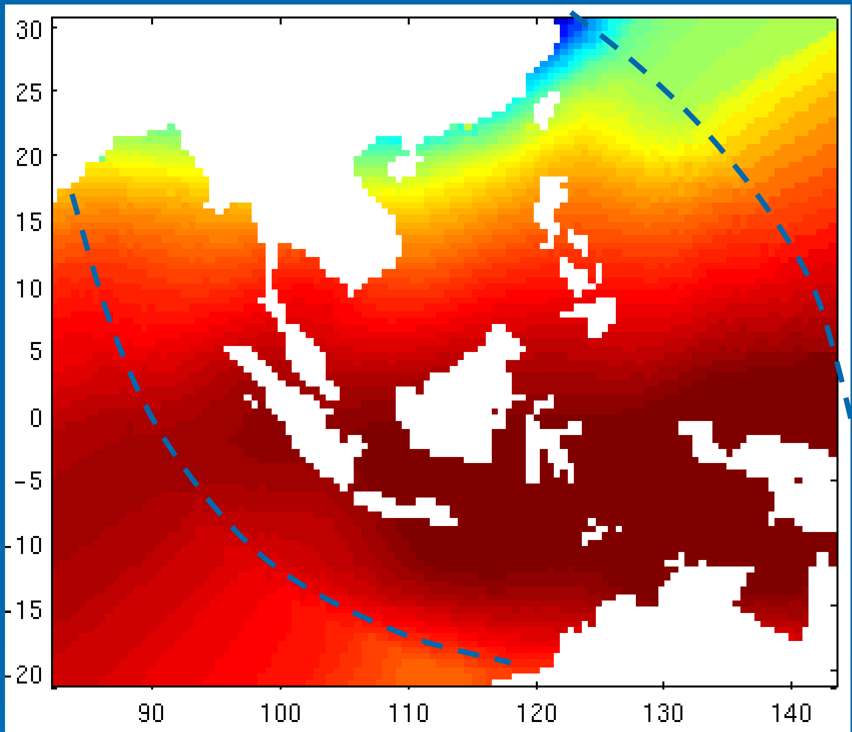
TRMM vs RegCM3-BATS1e rainfall histogram average 1998-2001
Probability of occurrence
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
< 0.125
0.125 – 1
1 – 2
2 – 5
5 – 10
10 – 20
> 20
Rainfall bin (mm / 3 hr)
TRMM land
Model land
TRMM ocean
Model ocean


TRMM vs RegCM3-BATS1e rainfall histogram average 1998-2001
Probability of occurrence (%)
100
10
1
0.1
< 0.125
0.125 - 1
1 - 2
2 - 5
5 - 10
10 - 20
> 20
Rainfall bin (mm / 3 hr)
TRMM land
Model land
TRMM ocean
Model ocean

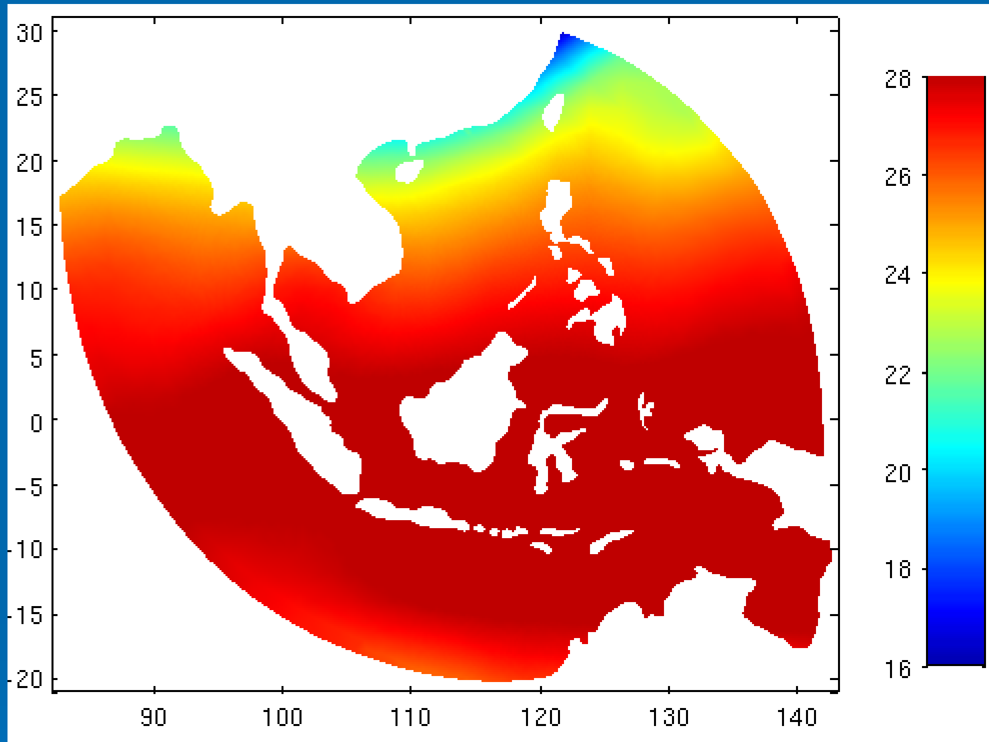
Ongoing Work

- Model performance varies with surface type:
  - Ocean surface fluxes (sensible, latent heat) and rainfall are close to observations
  - But land surface rainfall and ET 50% too high, and vertical profiles indicate too much convection
- Current avenues of investigation:
  - Land surface scheme
  - Criterion for trigger of convective adjustment

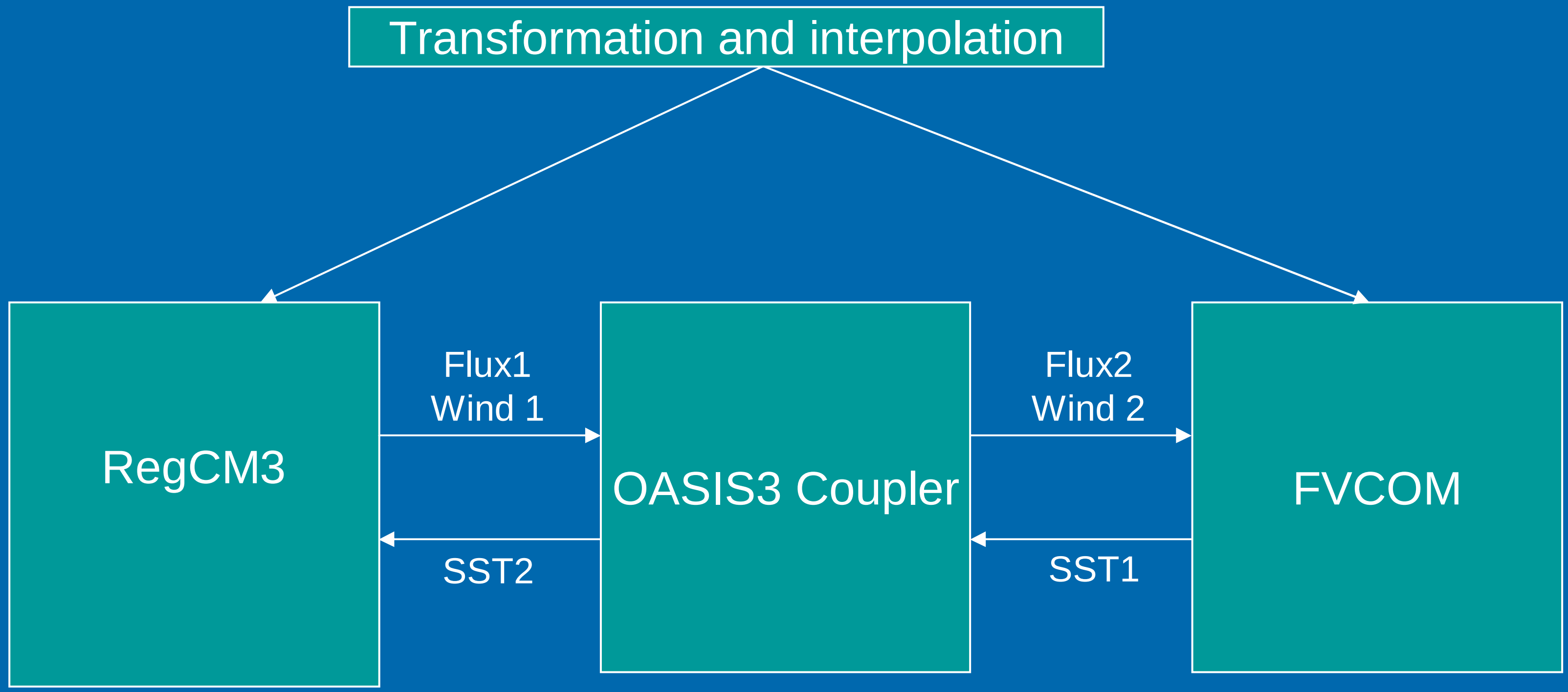
SST



RegCM3

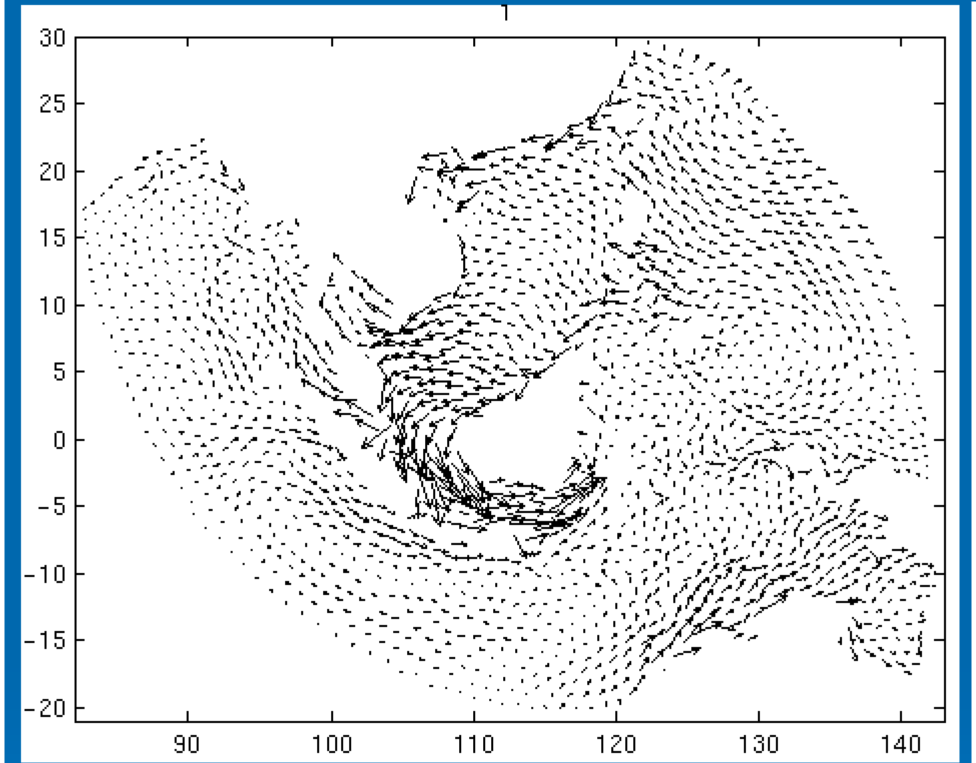


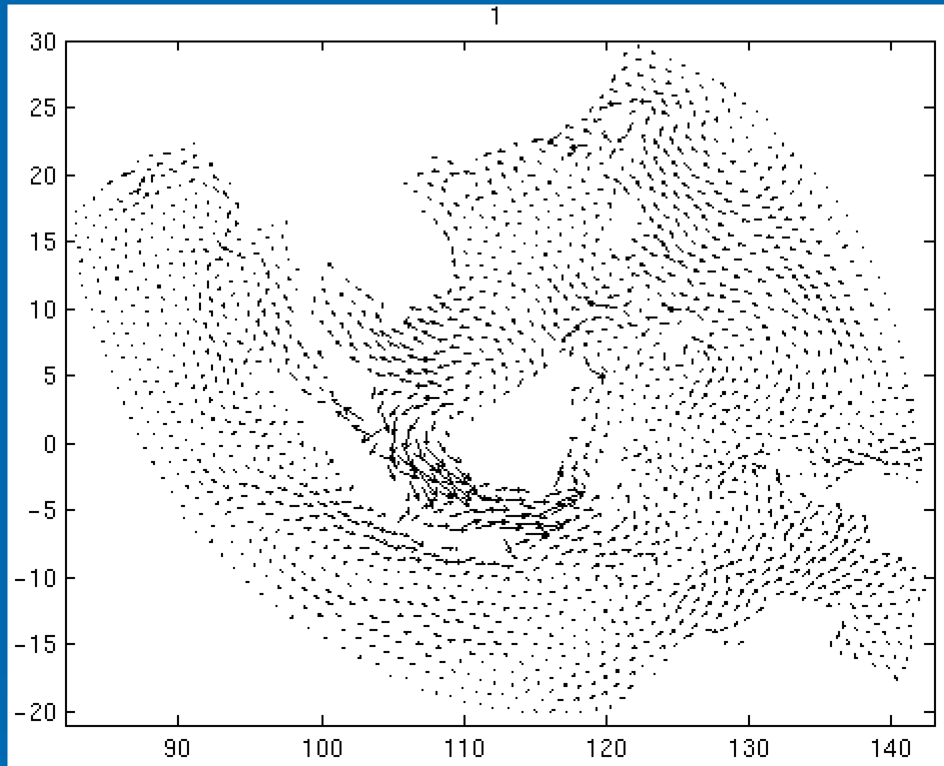
FVCOM



SST and Wind: distance weighted interpolation
Flux: conservative remapping scheme interpolation
(From SCRIP software package)

Velocity field





FVCOM

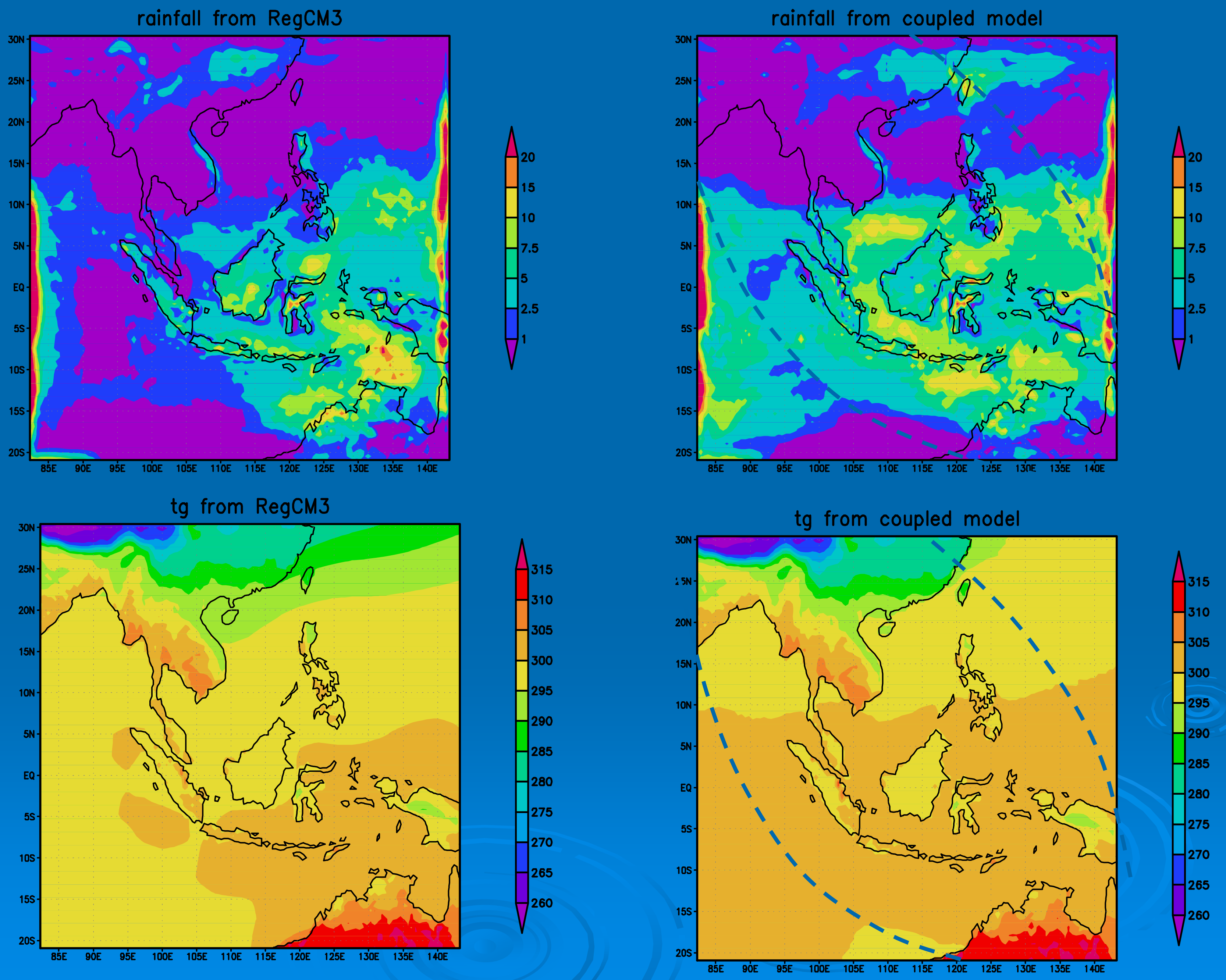
Coupled model

Summary

(i) Our research is problem driven;

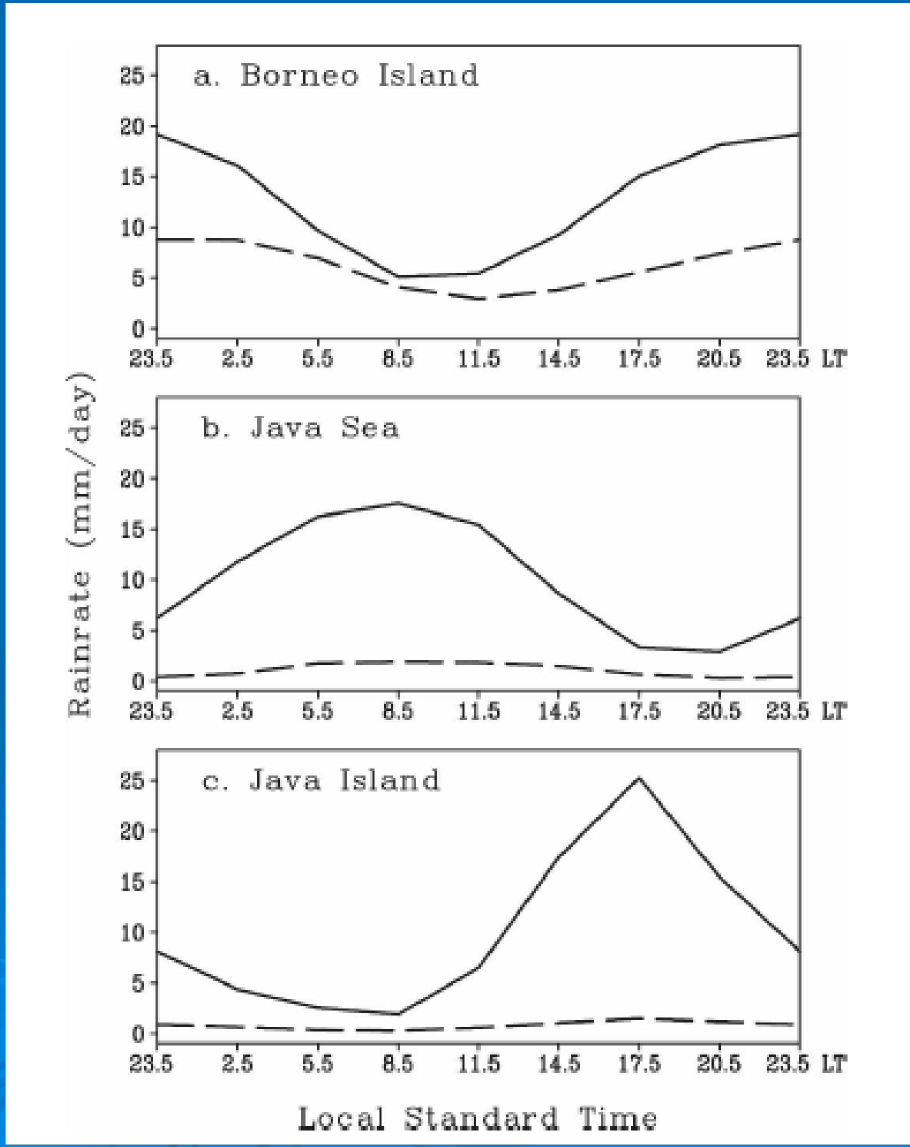
(ii) Significant contributions to model development;

(ii) Extensive testing and validation against field and satellite observations.

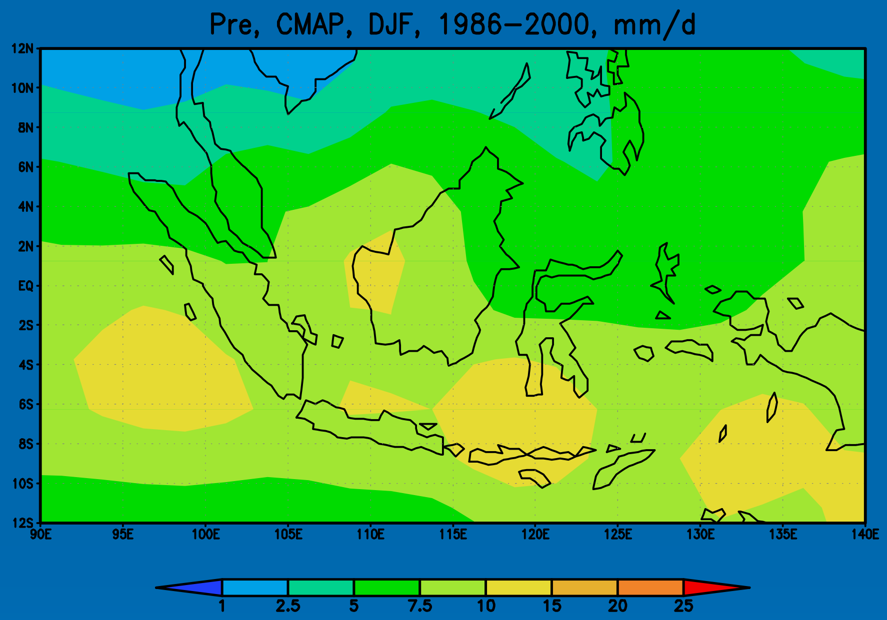

rainfall from RegCM3
rainfall from coupled model
tg from RegCM3
tg from coupled model
20 15 10 7.5 5 2.5 1
315 310 305 300 295 290 285 280 275 270 265 260
30N 25N 20N 15N 10N 5N EQ 5S 10S 15S 20S
85E 90E 95E 100E 105E 110E 115E 120E 125E 130E 135E 140E

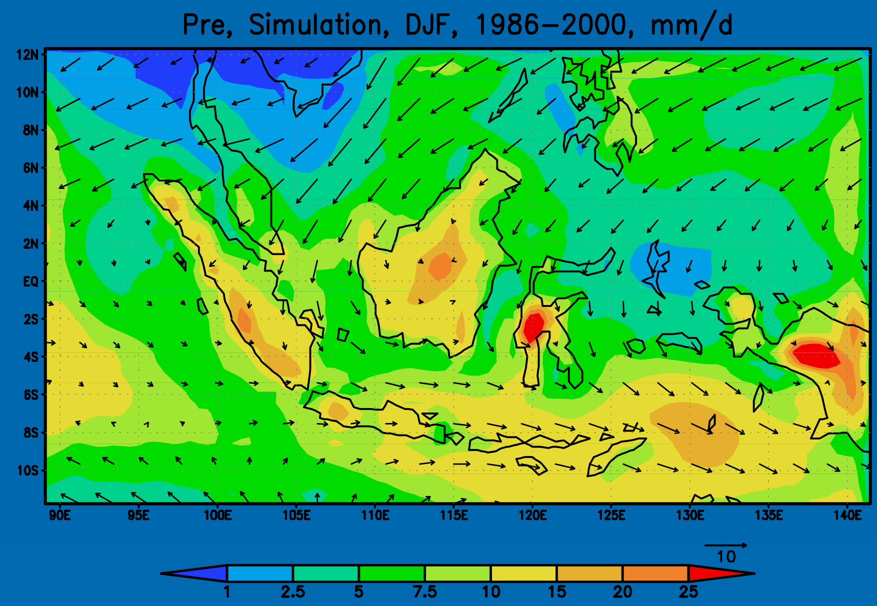
Maritime Continent: Diurnal Cycle of Rainfall

- **Diurnal Cycle of Rainfall during Wet (D, J, F) and Dry (J, J, A) seasons, based on CEMORPH satellite data, Qian (2008)**

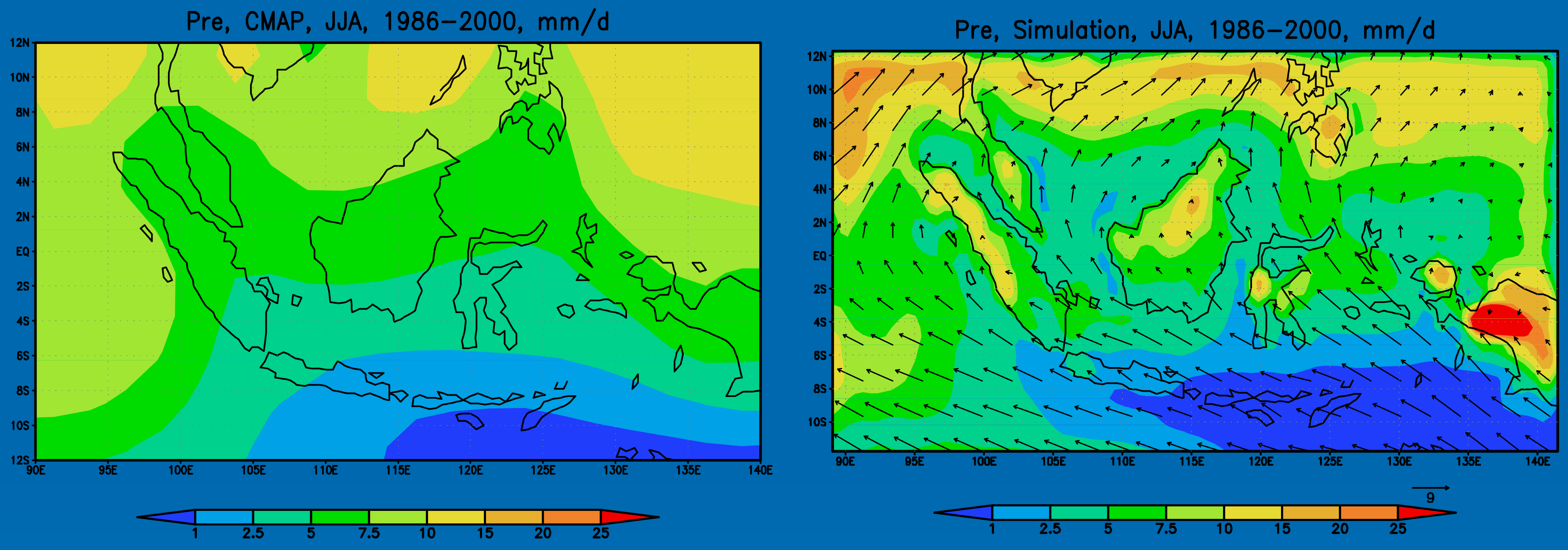


Precipitation-DJF

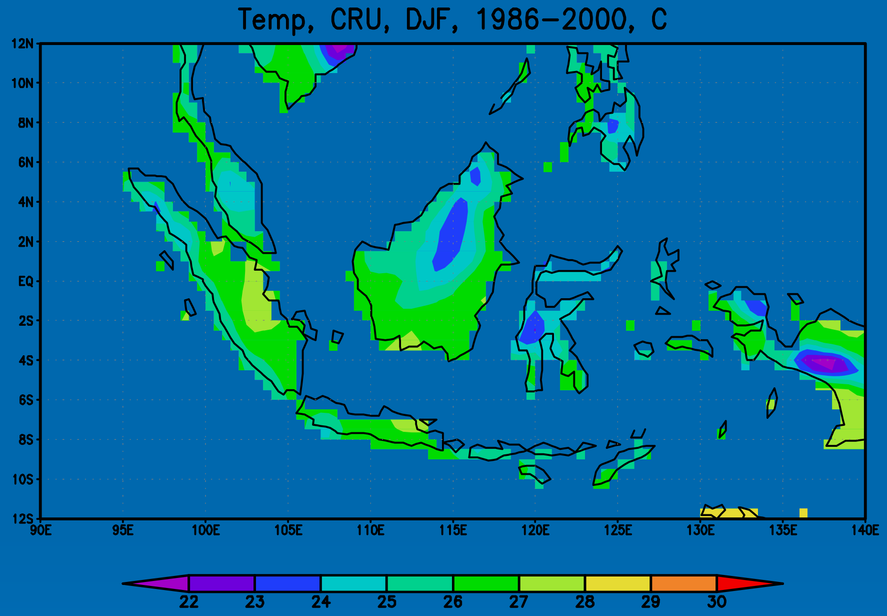


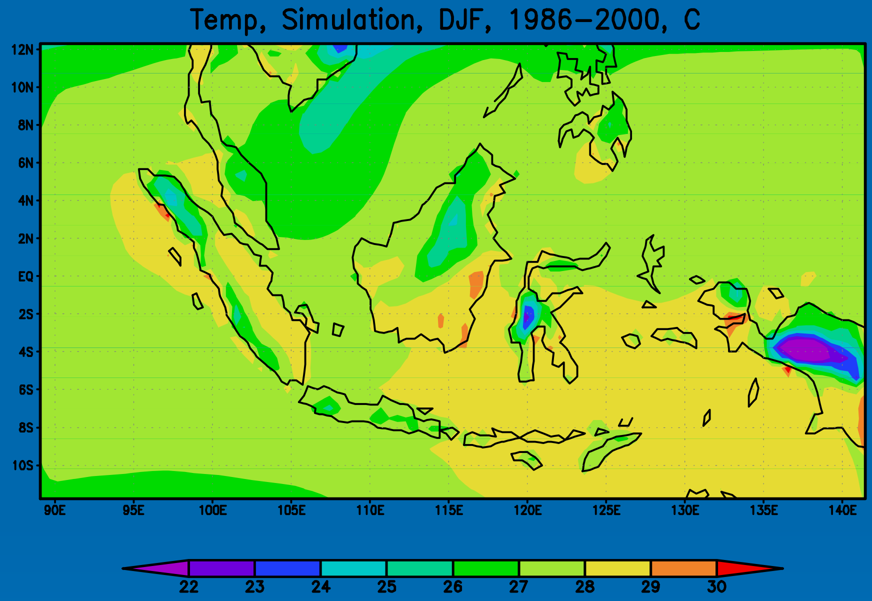


Precipitation-JJA

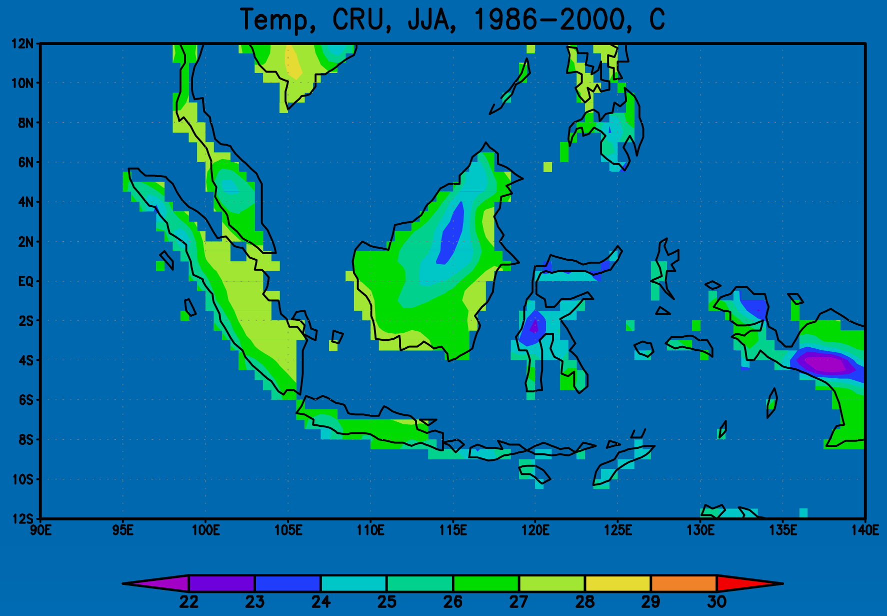


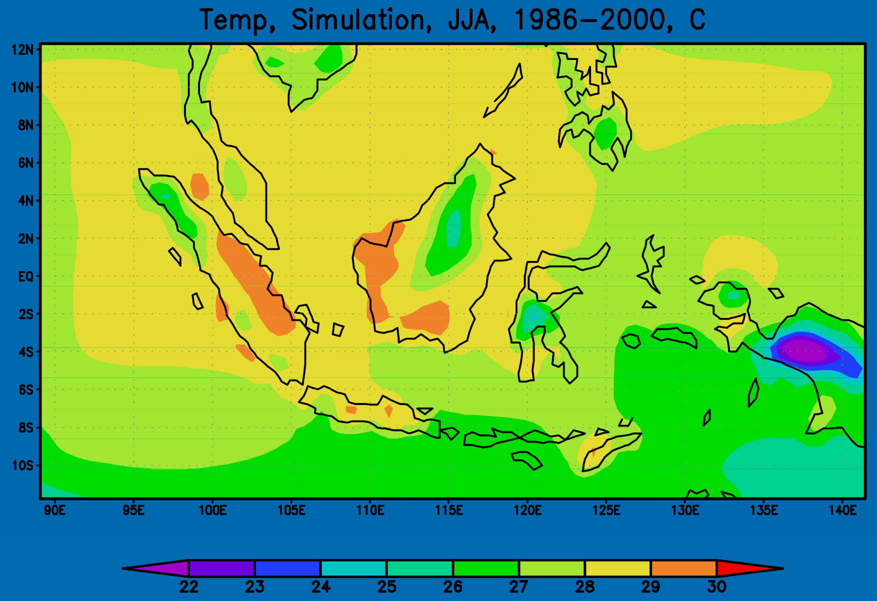
Temperature-DJF



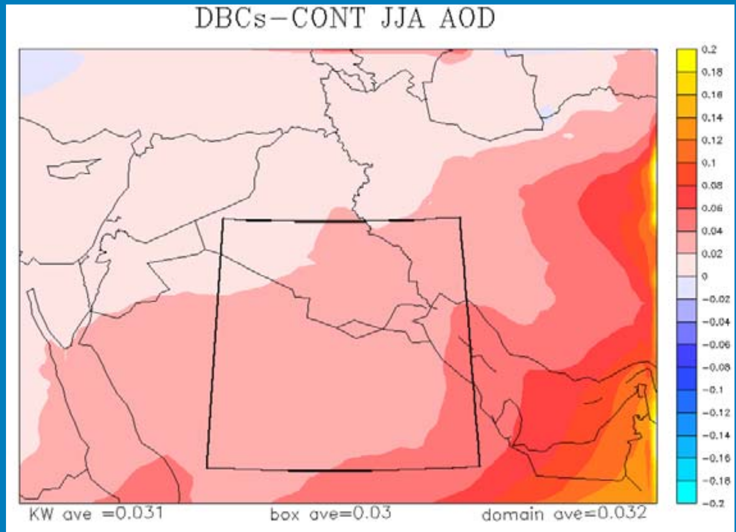


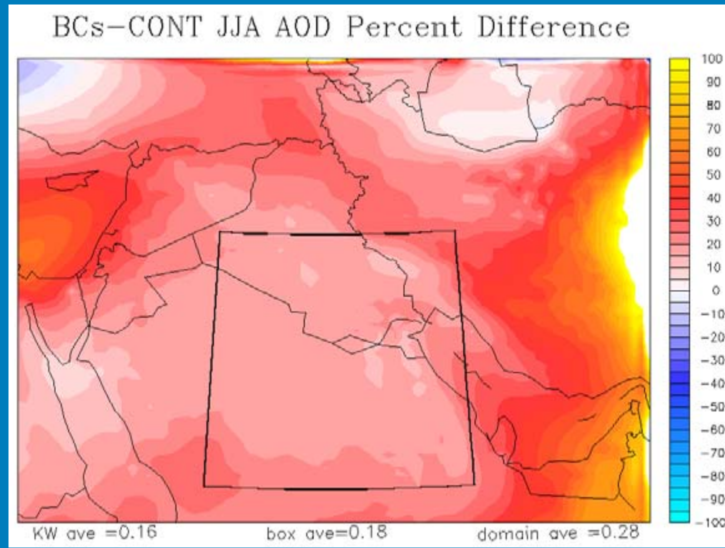
Temperature-JJA

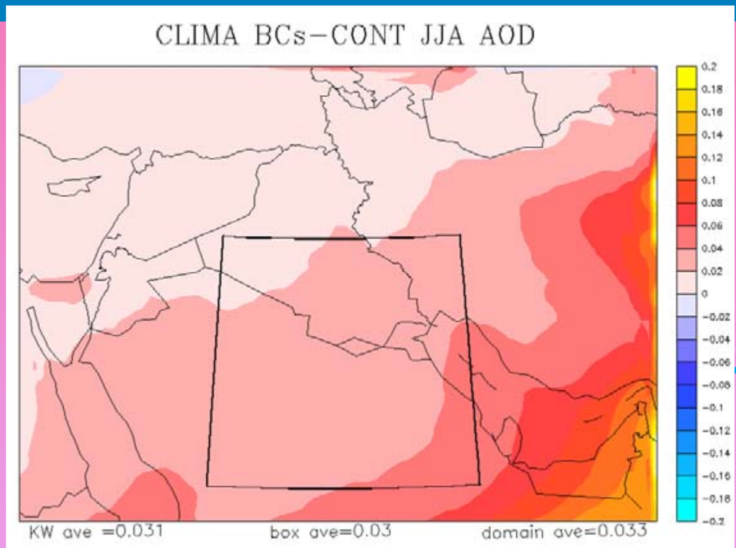


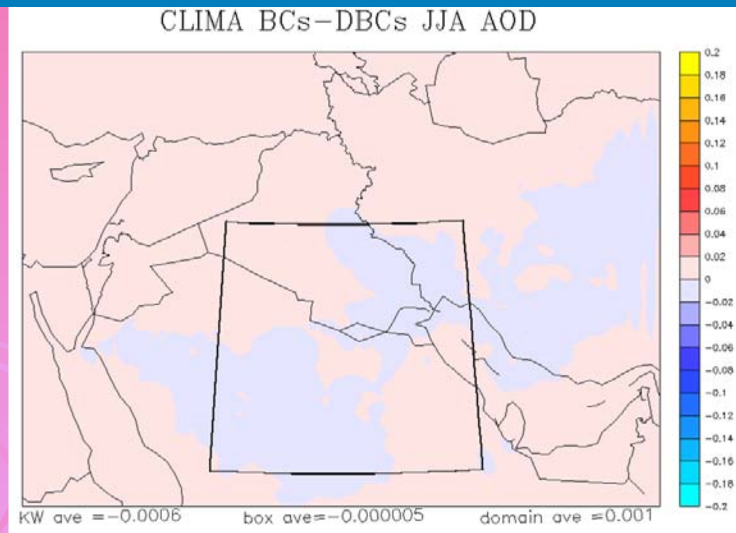


Differences in Mean JJA AOD

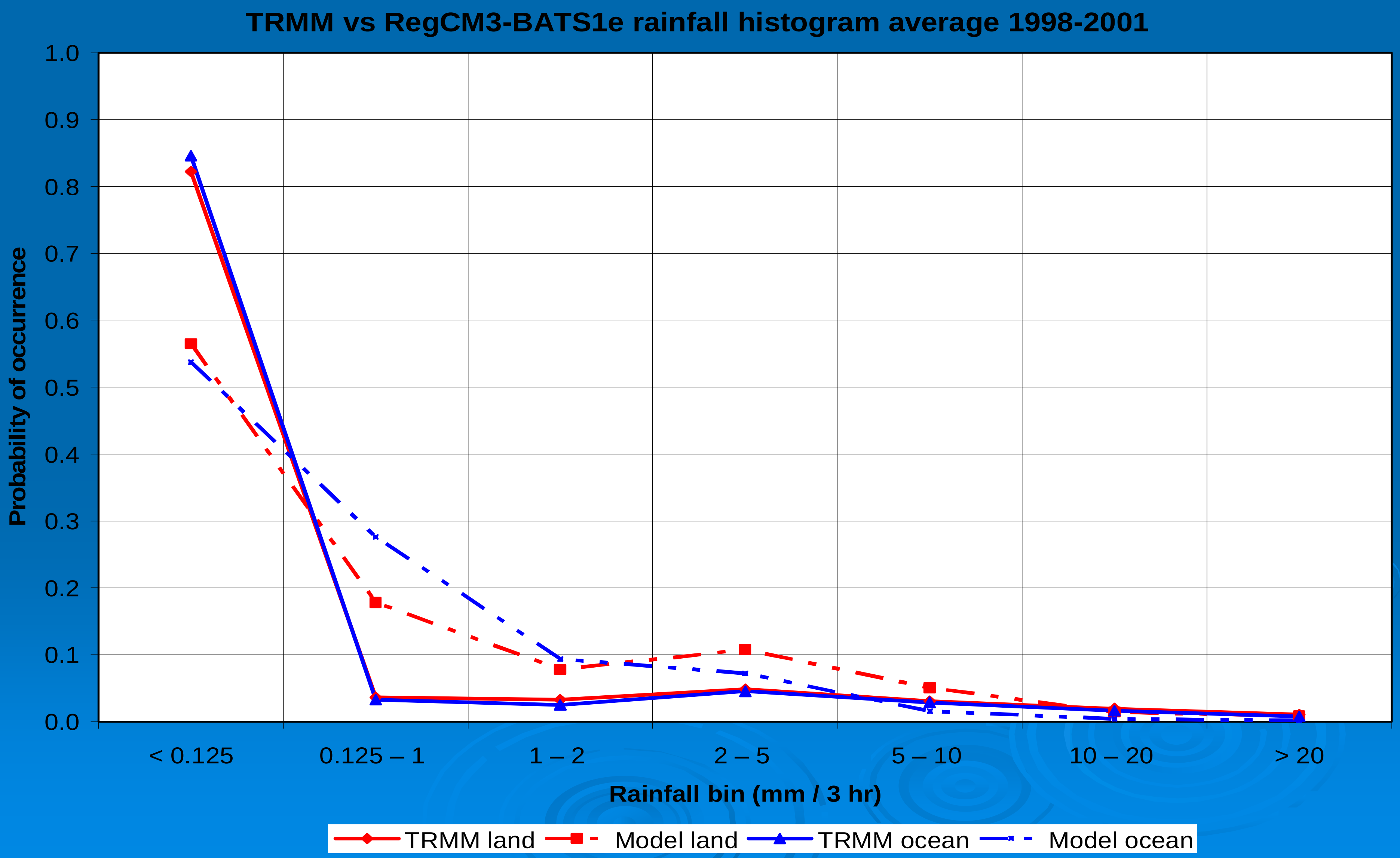


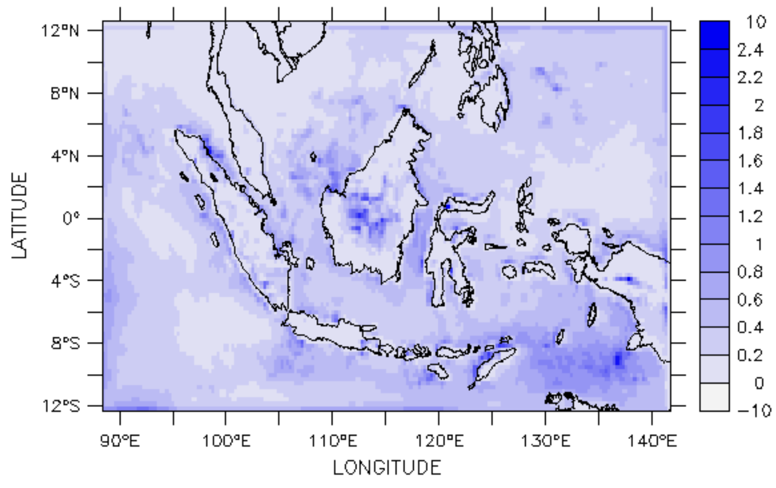




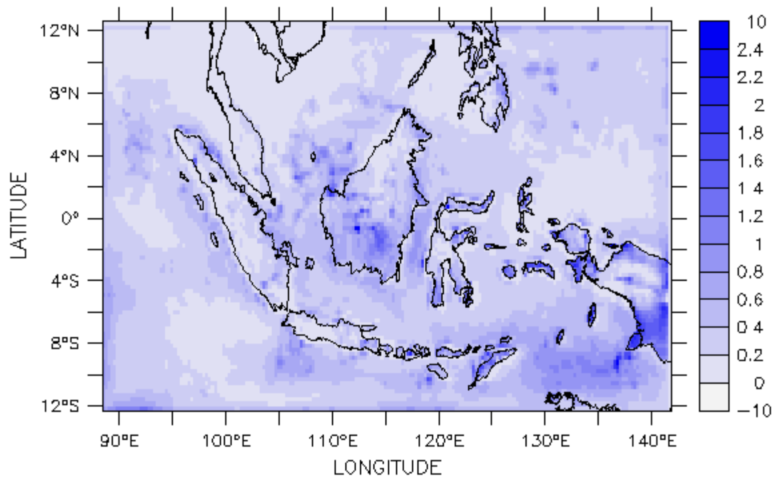


Model errors: - under-representation of dry periods
- over-representation of low-intensity rainfall (< 8 mm/day)
- improvement with increased vertical resolution

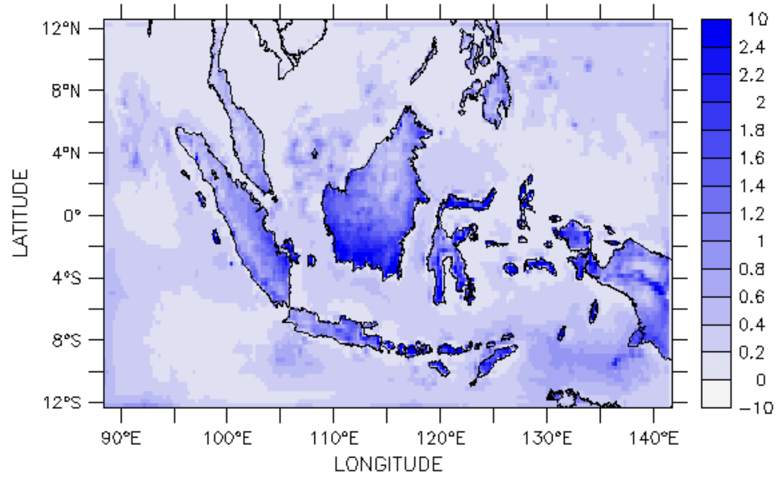




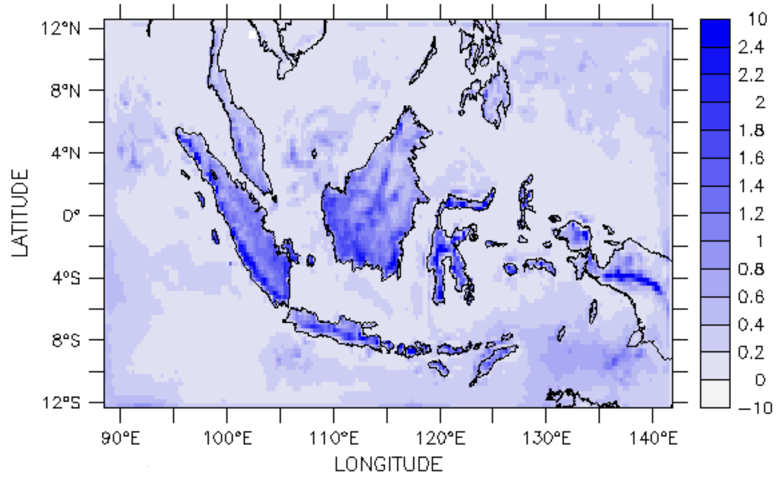
Base case 2002 DJF 0700 LT



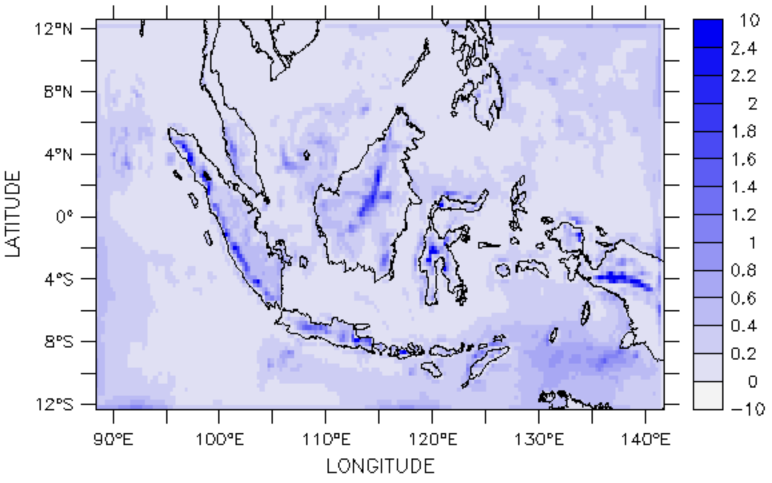
Base case 2002 DJF 1000 LT



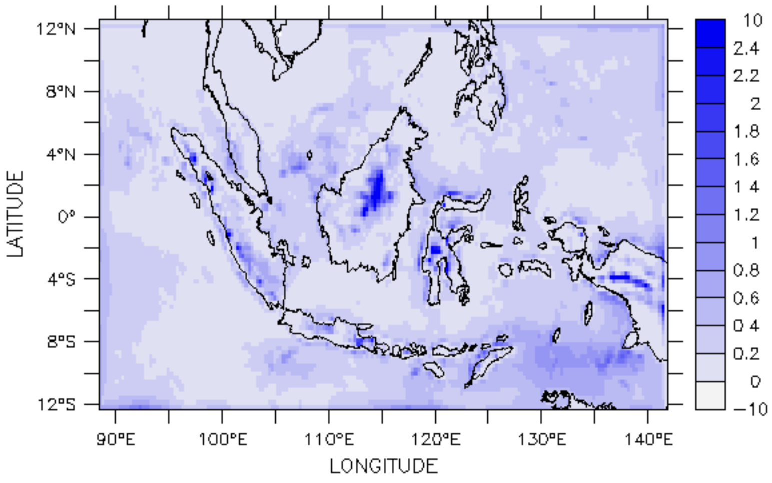
Base case 2002 DJF 1300 LT



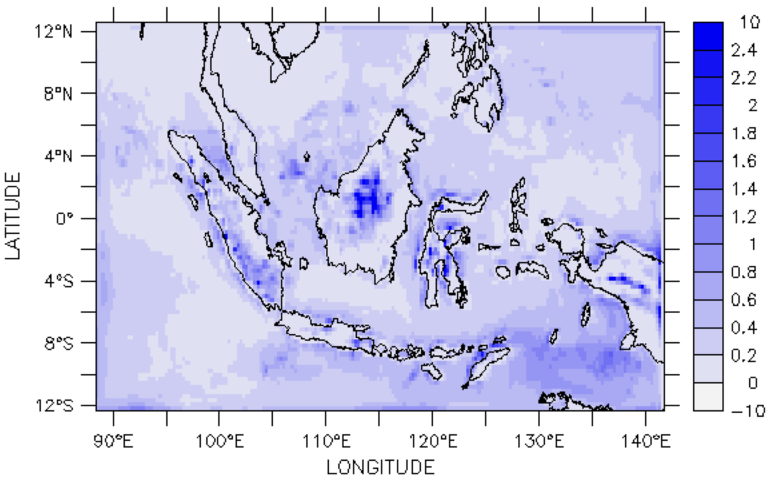
Base case 2002 DJF 1600 LT



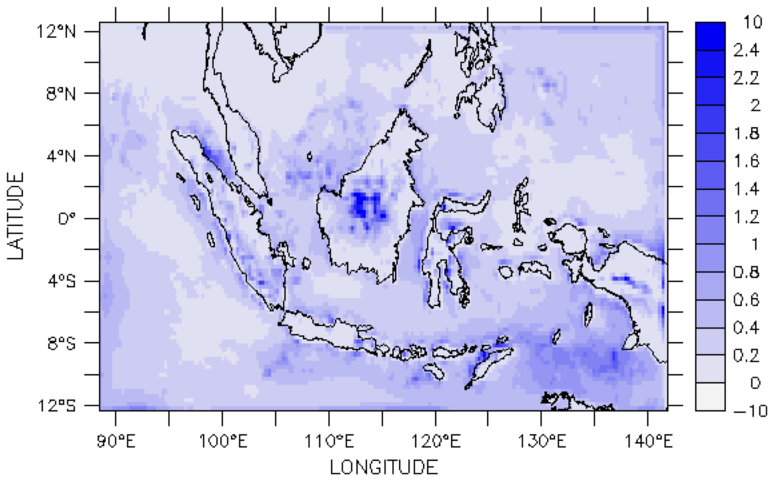
Base case 2002 DJF 1900 LT



Base case 2002 DJF 2200 LT



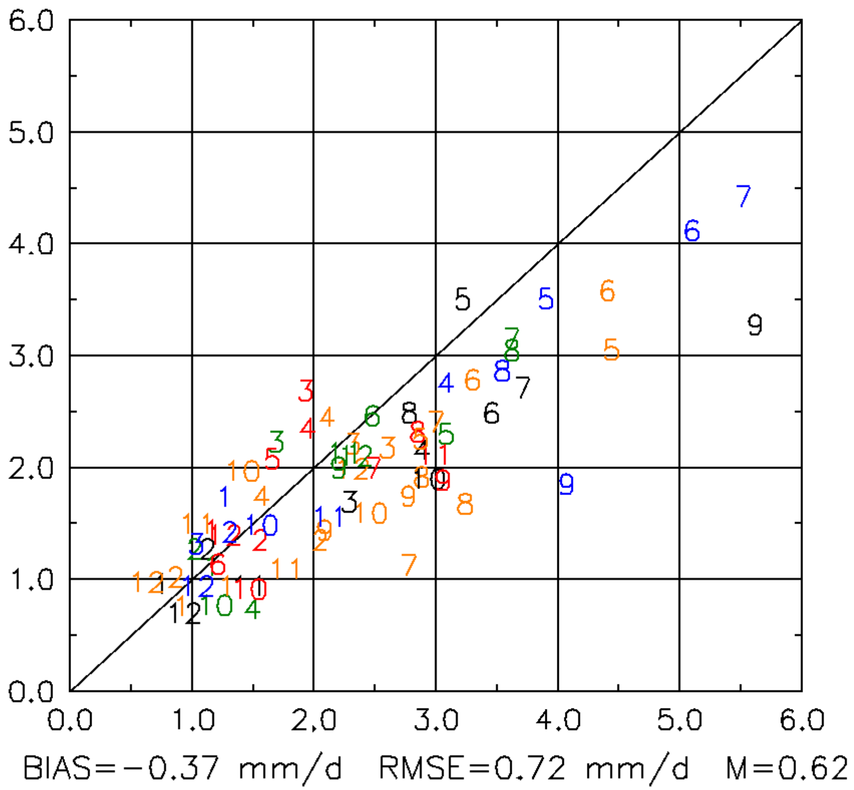
Base case 2002 DJF 0100 LT



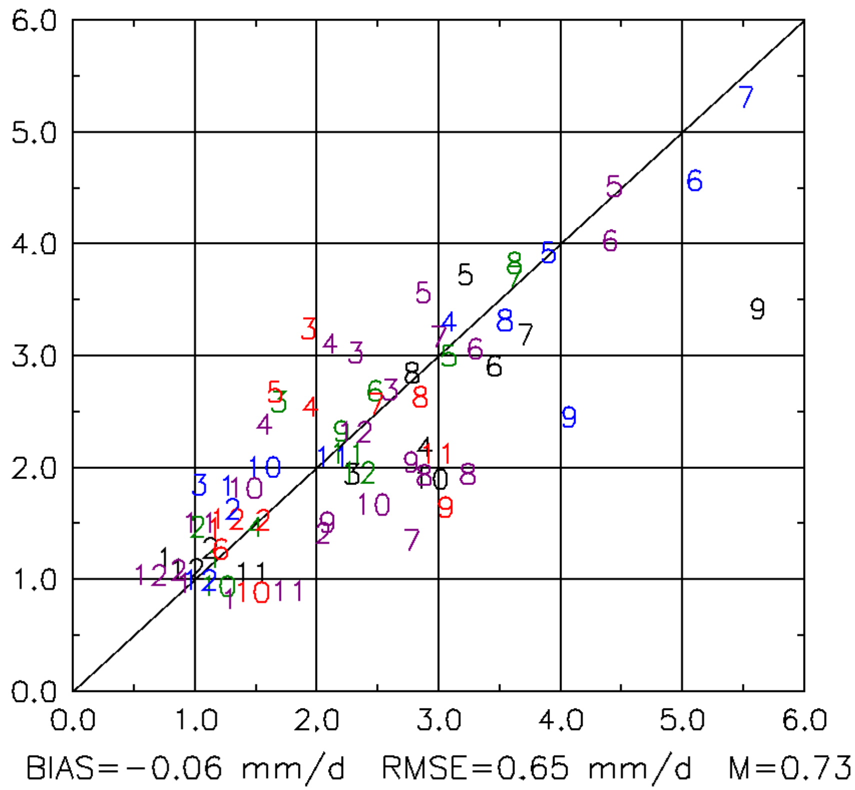
Base case 2002 DJF 0400 LT

SUBEX: Precipitation (USHCN)

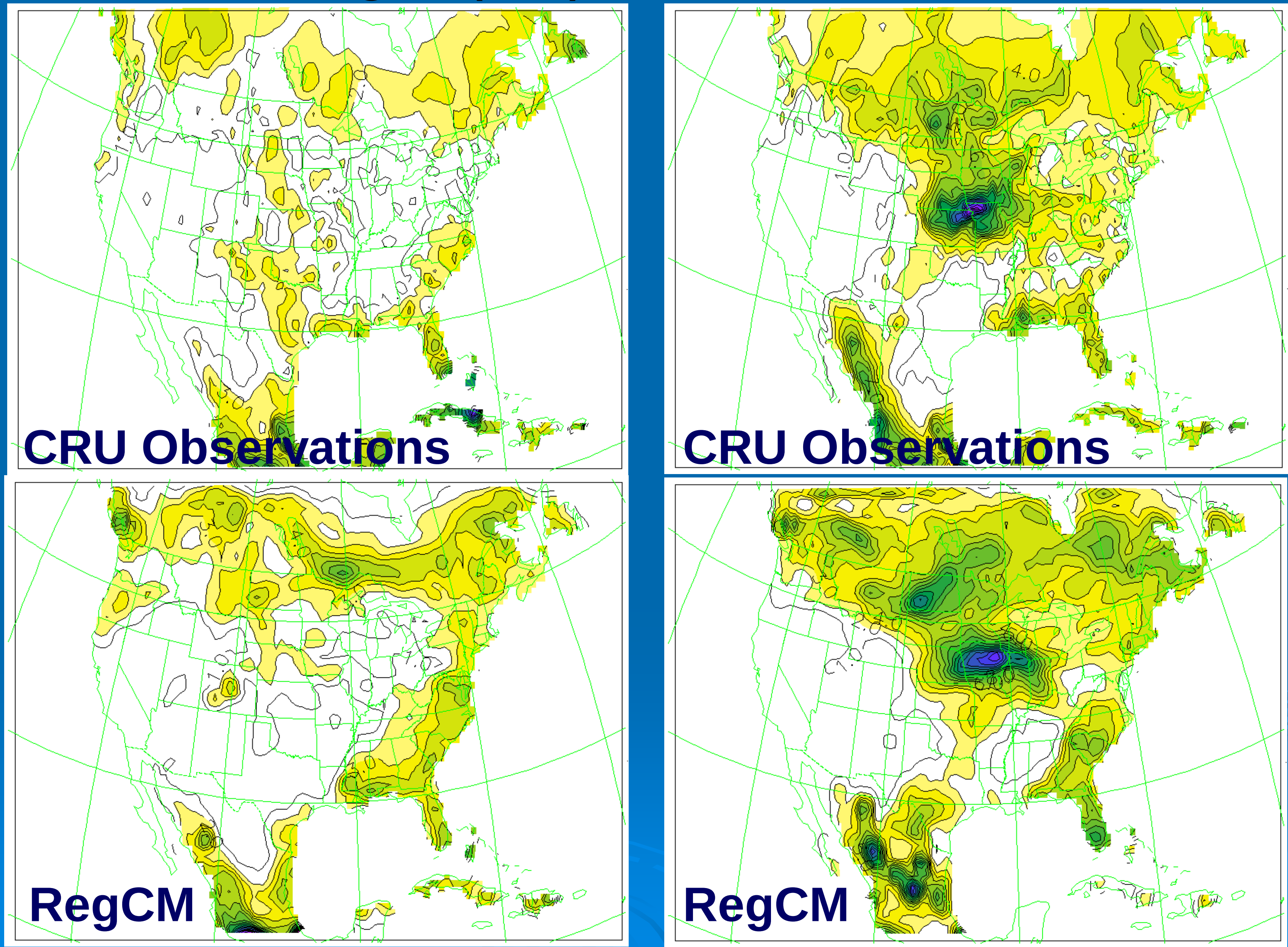
- Old Model vs Observations



- New Model vs Observations



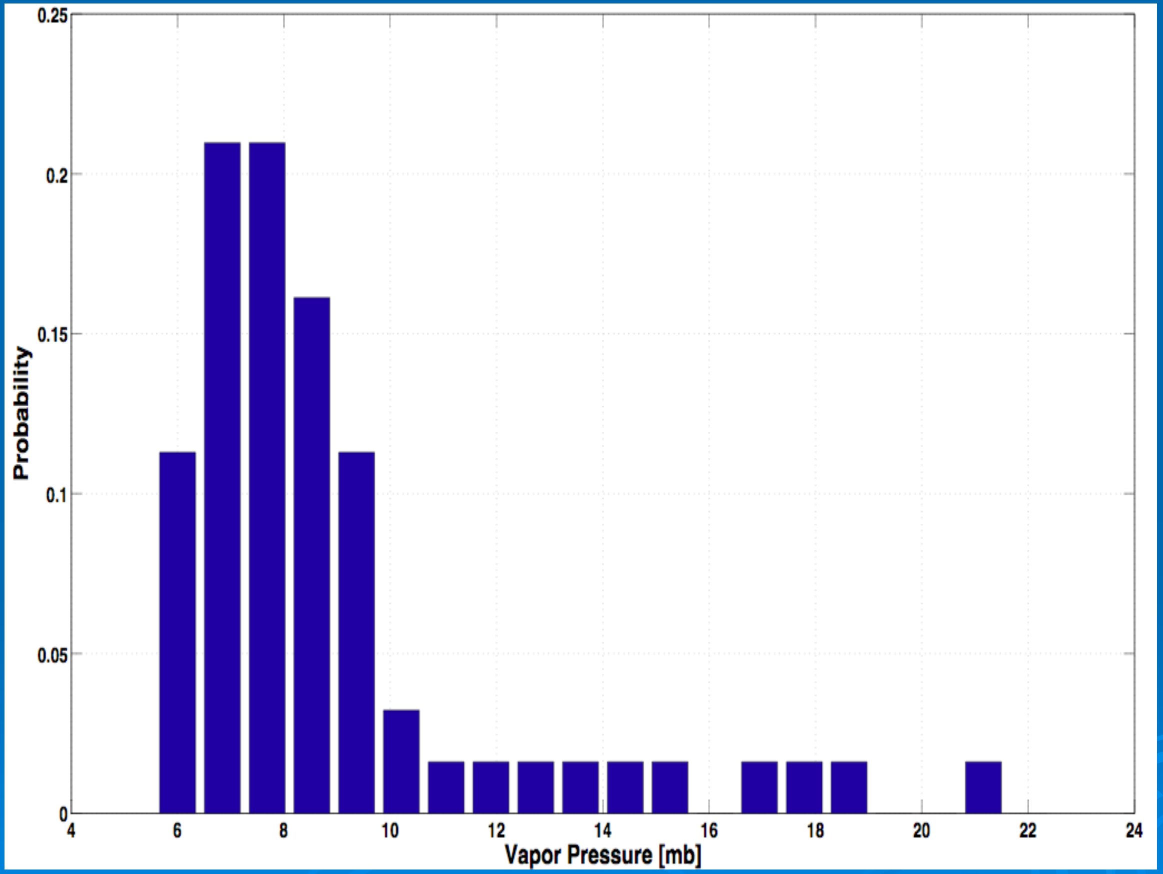
1988 Drought (MJ) | 1993 Flood (JJ)



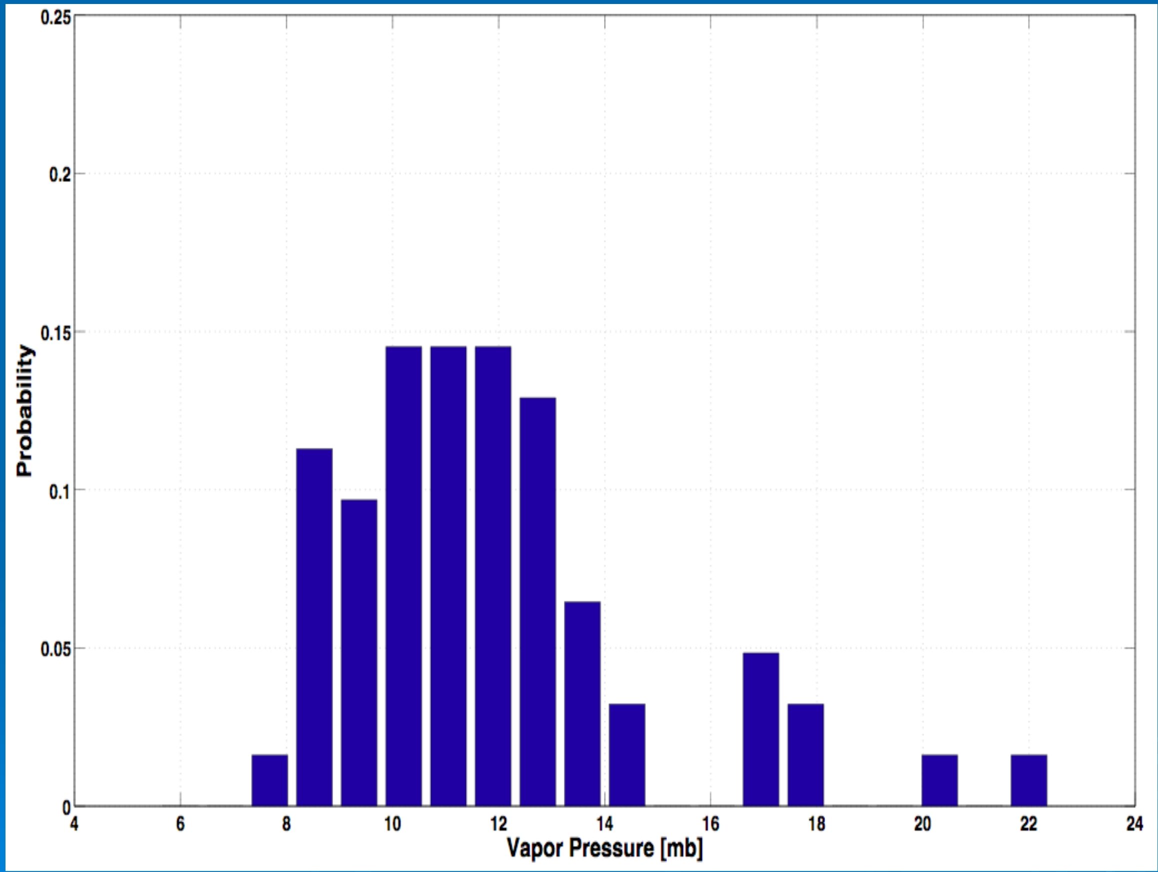
(Pal & Eltahir 2003)

From the ground

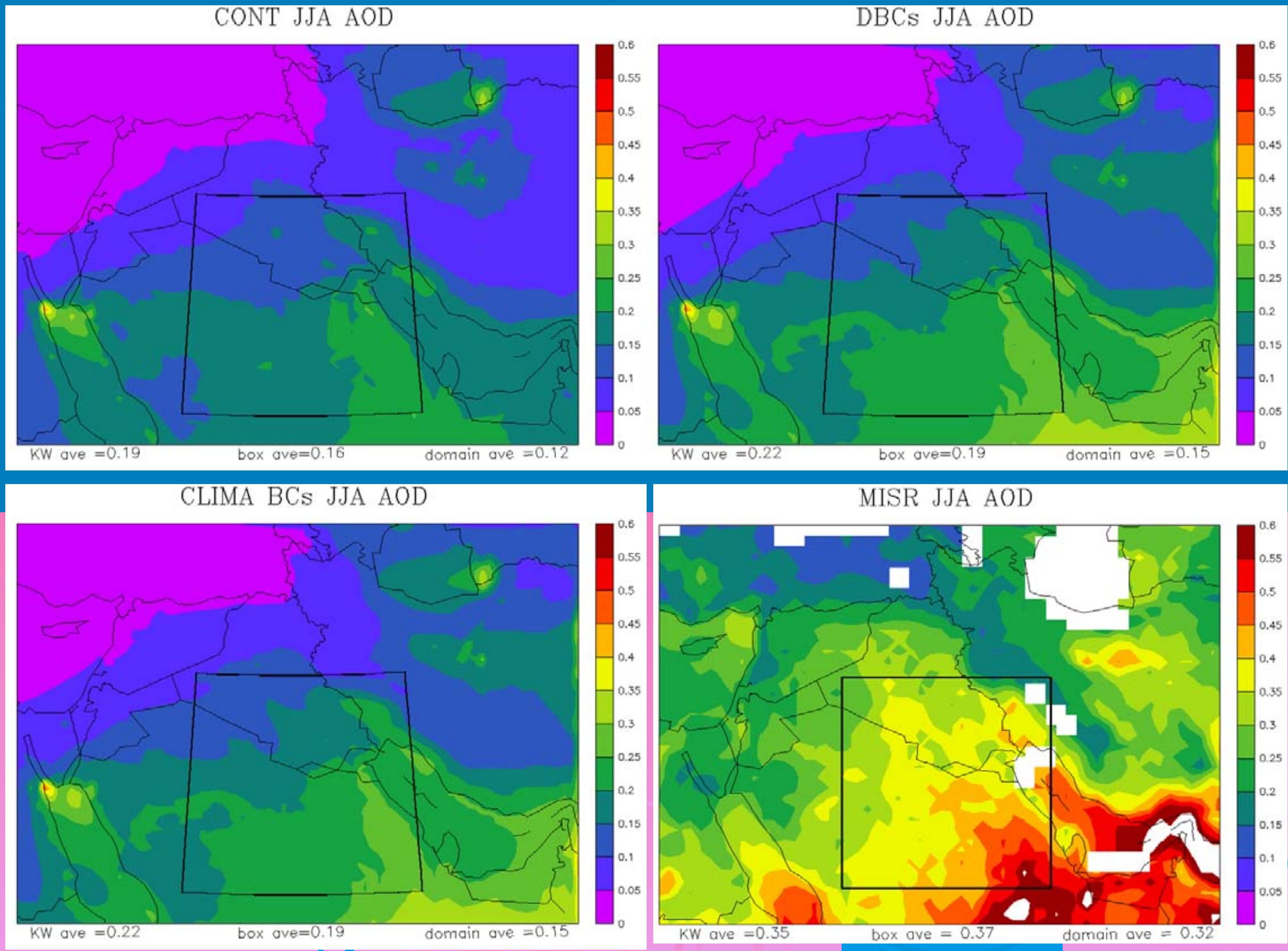
Changes in Extremes: Humidity



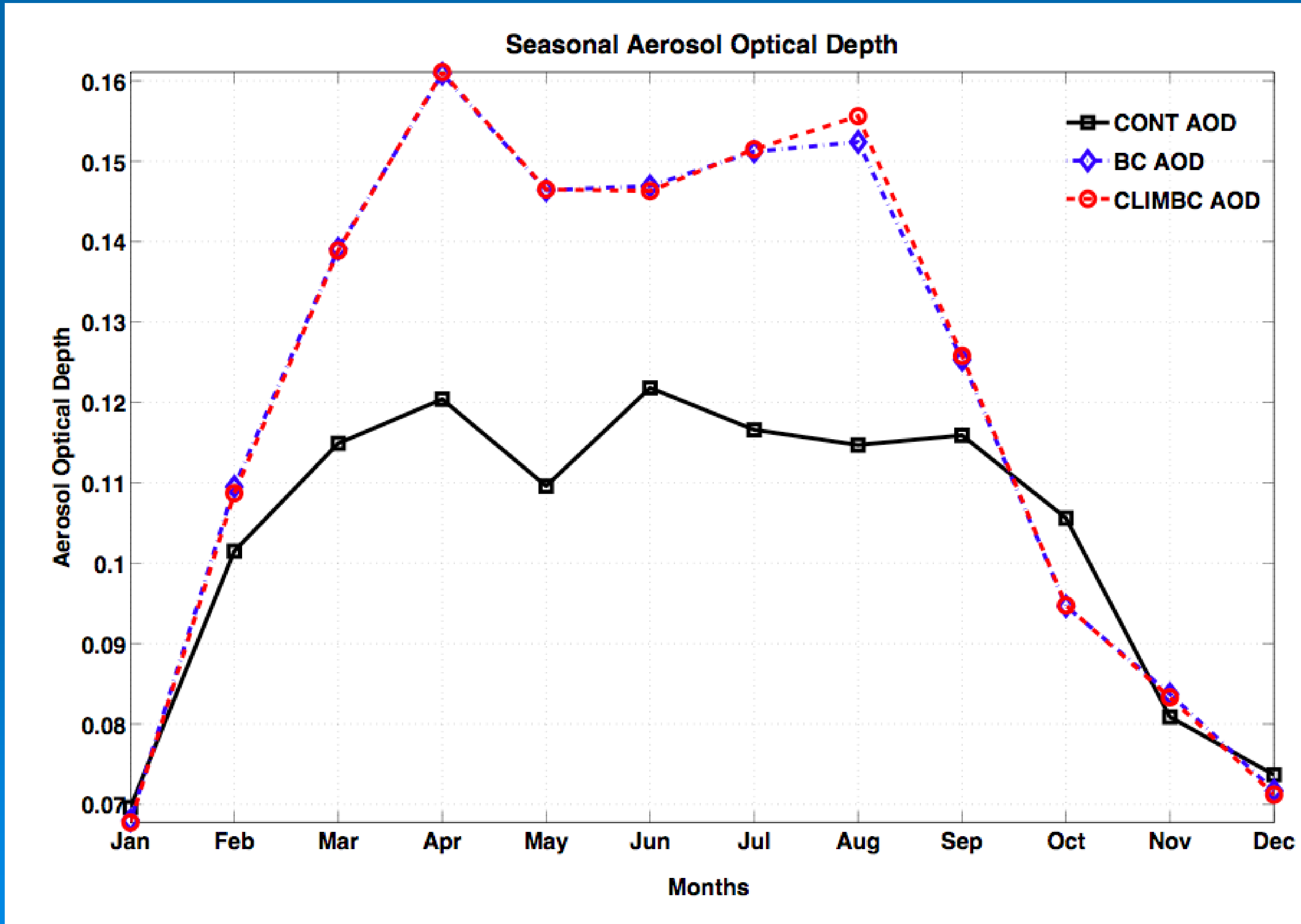
Changes in Extremes: Humidity

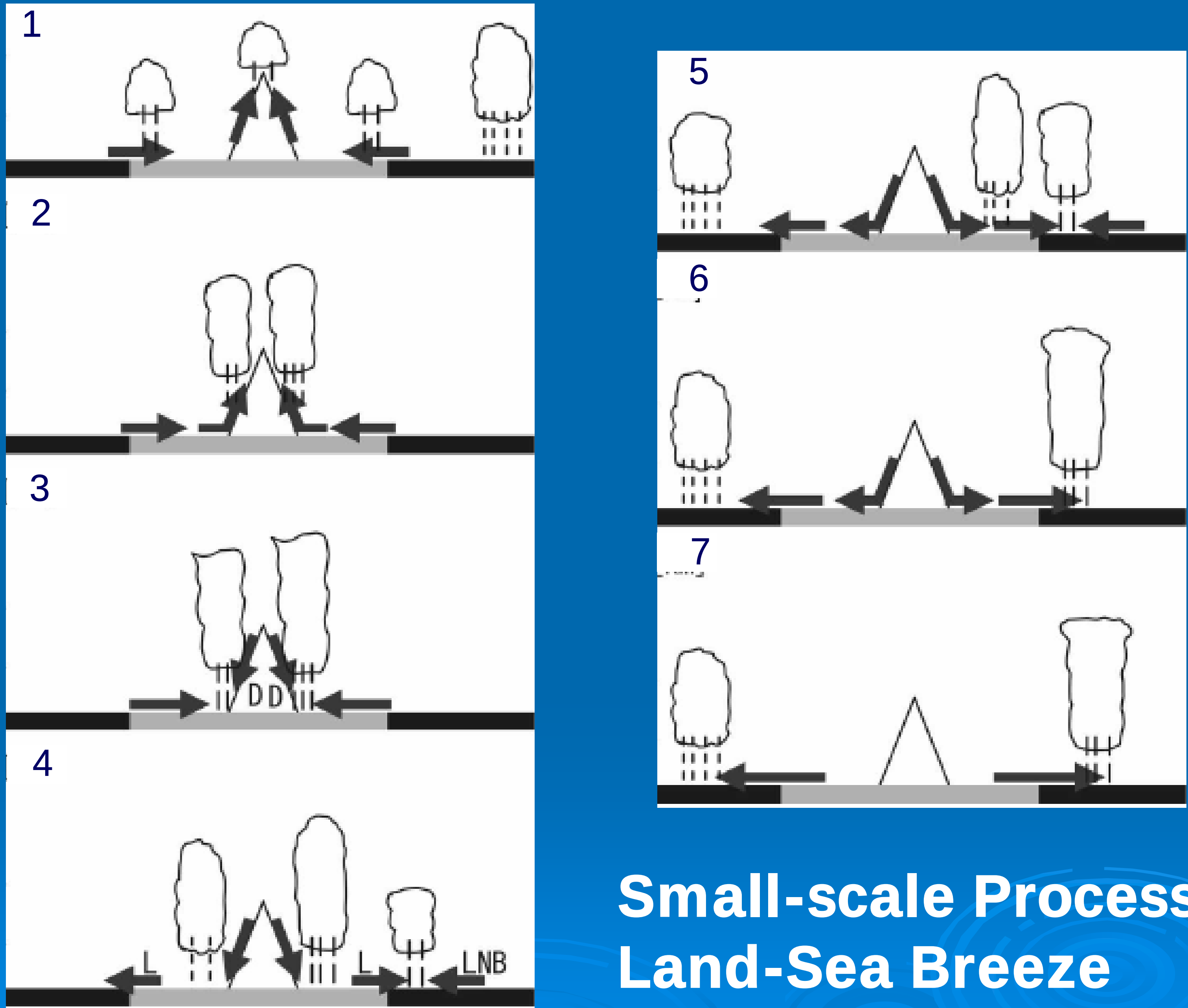


Mean Summertime (JJA) Aerosol Optical Depth



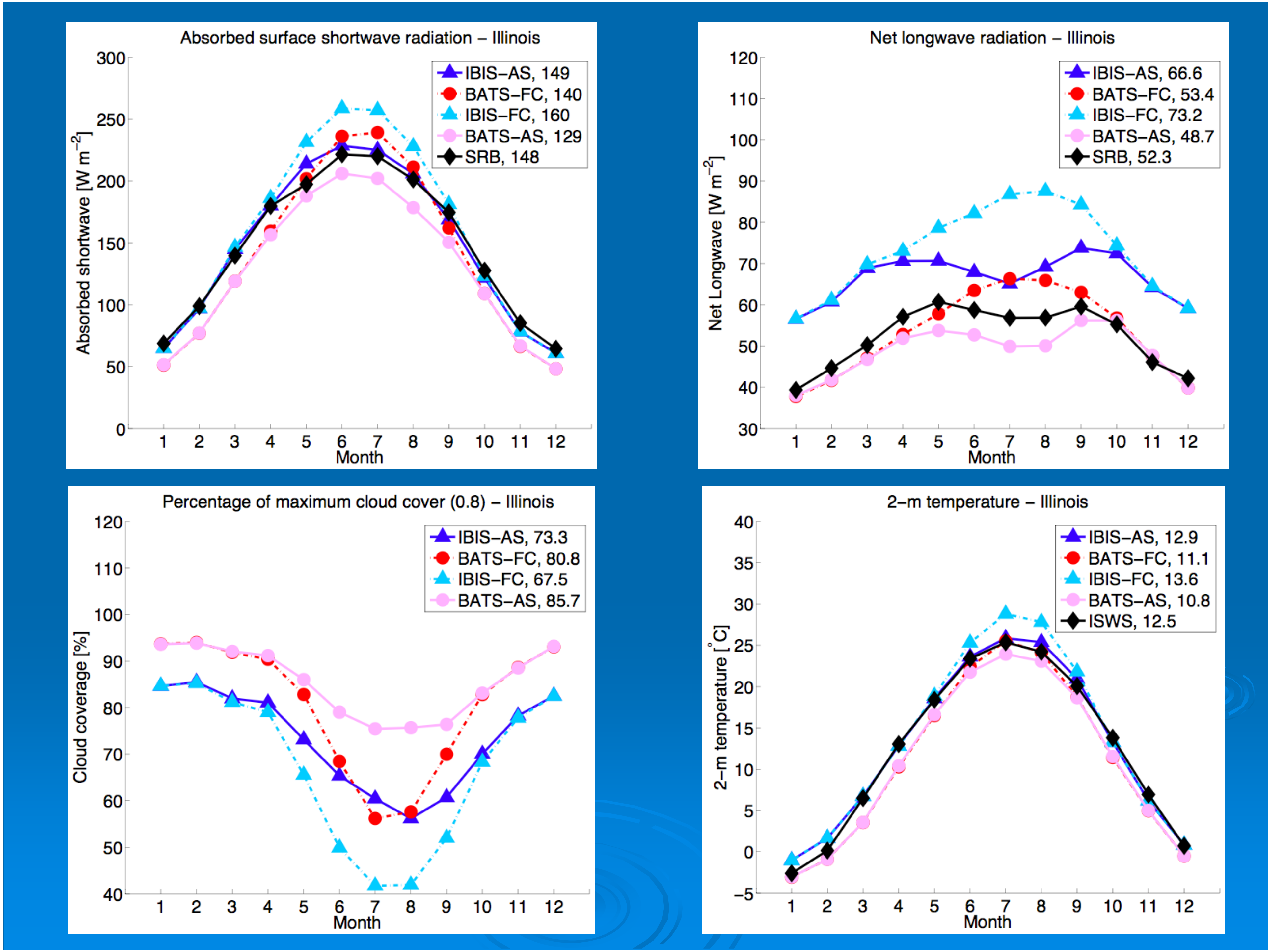
Seasonality Aerosol Optical Depth

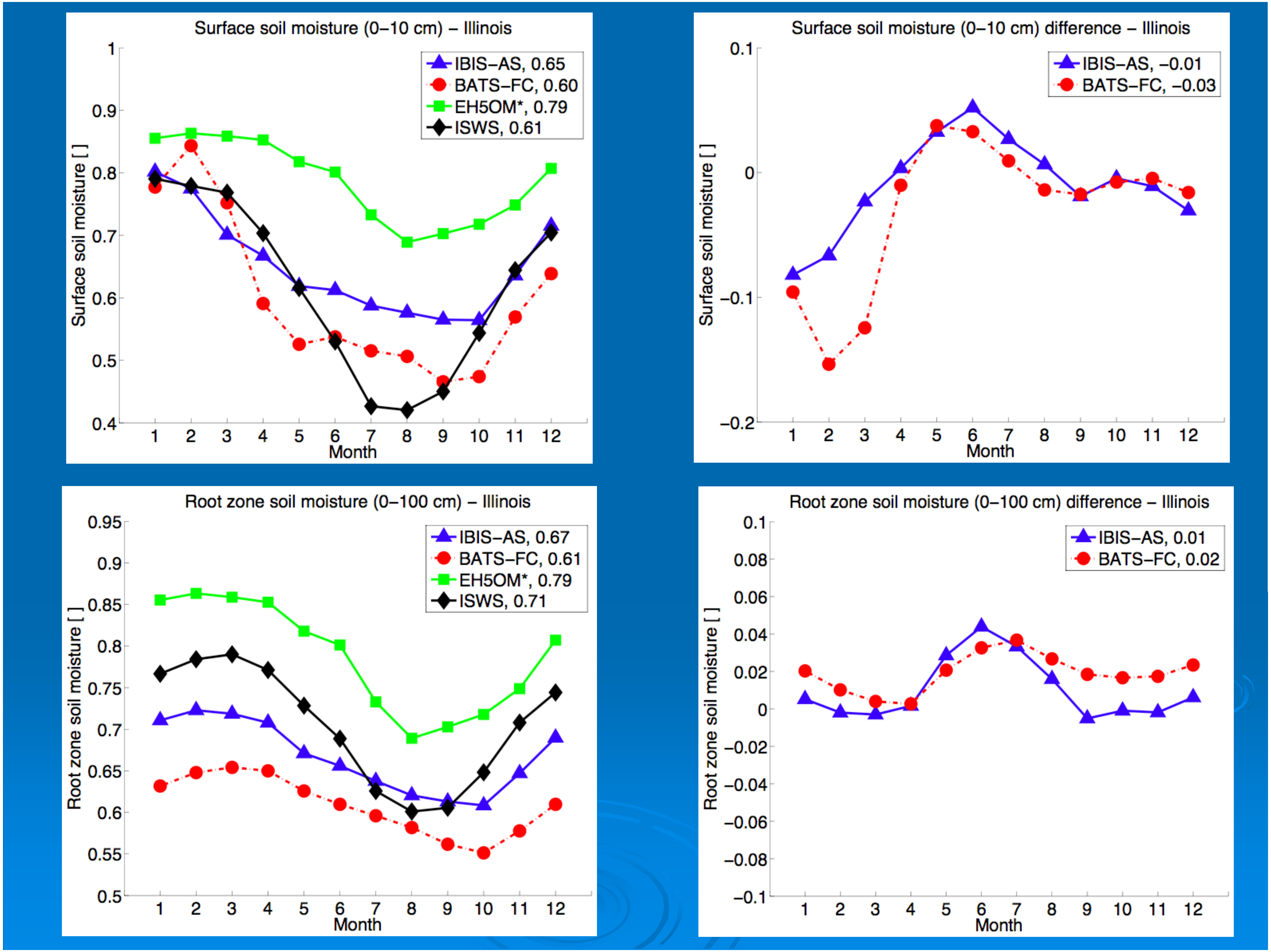




Small-scale Processes: Land-Sea Breeze

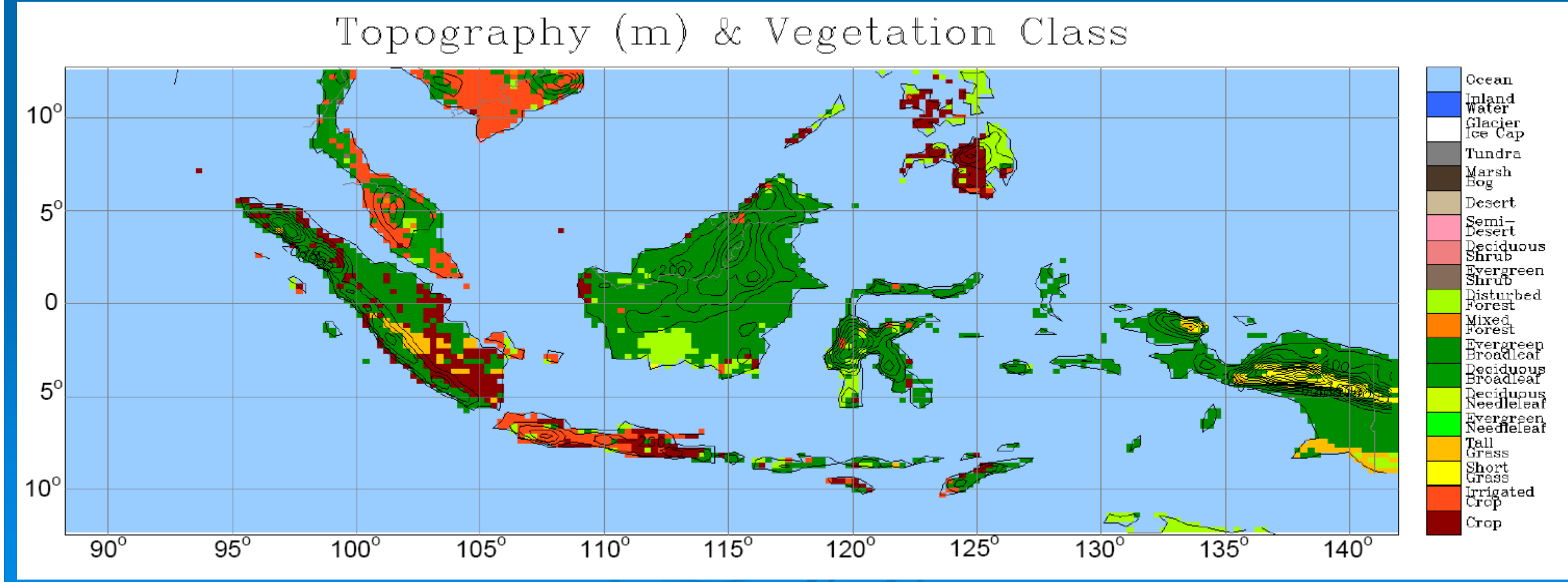
(Ichikawa and Yasunari 2008)


Absorbed surface shortwave radiation – Illinois
Absorbed shortwave [W m^{-2}]
IBIS–AS, 149
BATS–FC, 140
IBIS–FC, 160
BATS–AS, 129
SRB, 148
Month
Net longwave radiation – Illinois
Net Longwave [W m^{-2}]
IBIS–AS, 66.6
BATS–FC, 53.4
IBIS–FC, 73.2
BATS–AS, 48.7
SRB, 52.3
Month
Percentage of maximum cloud cover (0.8) – Illinois
Cloud coverage [%]
IBIS–AS, 73.3
BATS–FC, 80.8
IBIS–FC, 67.5
BATS–AS, 85.7
Month
2–m temperature – Illinois
2–m temperature [°C]
IBIS–AS, 12.9
BATS–FC, 11.1
IBIS–FC, 13.6
BATS–AS, 10.8
ISWS, 12.5
Month

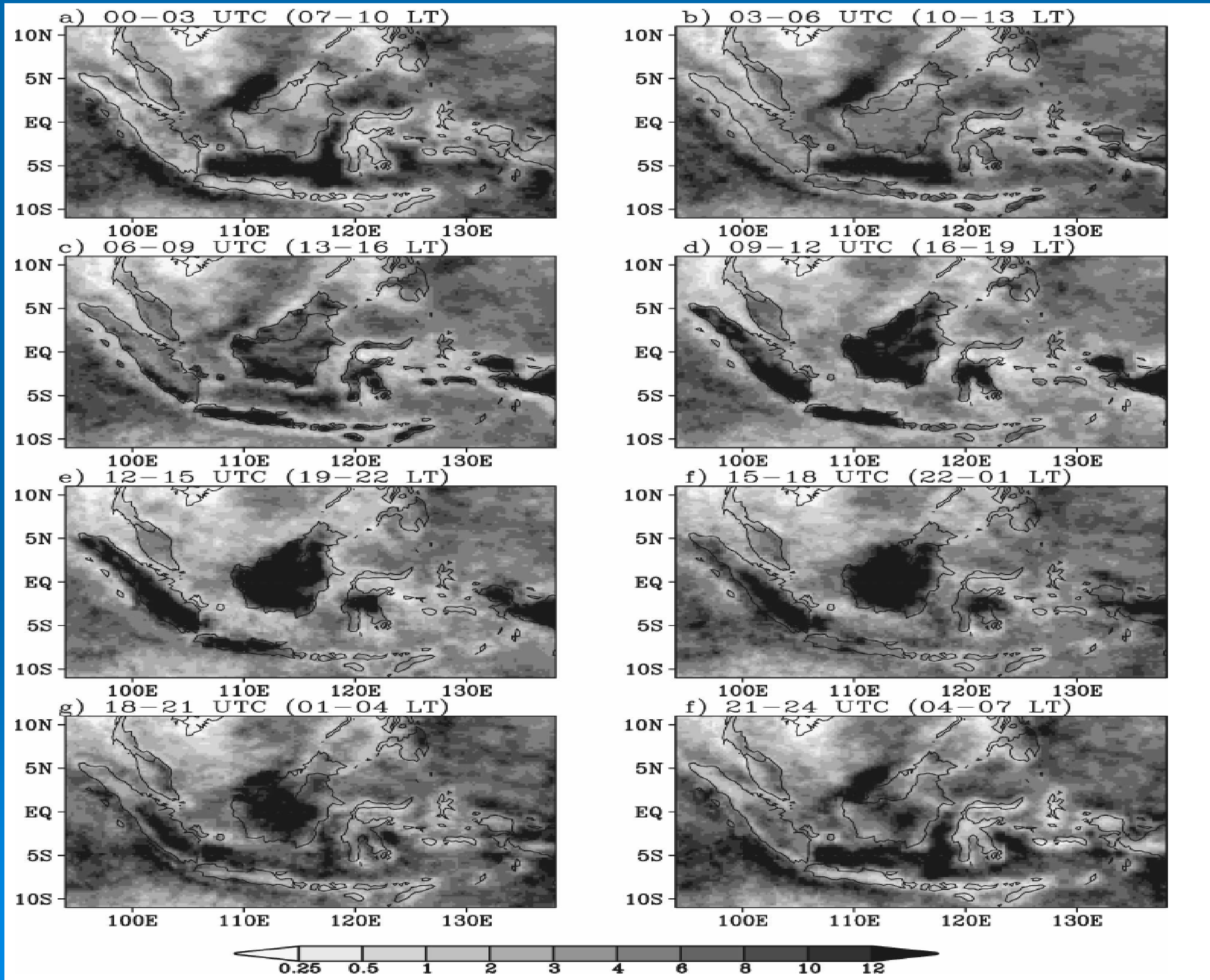

Surface soil moisture (0–10 cm) – Illinois
Surface soil moisture [ ]
Month
1 0.9 0.8 0.7 0.6 0.5 0.4
1 2 3 4 5 6 7 8 9 10 11 12
IBIS–AS, 0.65
BATS–FC, 0.60
EH5OM*, 0.79
ISWS, 0.61
Surface soil moisture (0–10 cm) difference – Illinois
Surface soil moisture [ ]
0.1 0 −0.1 −0.2
IBIS–AS, −0.01
BATS–FC, −0.03
Root zone soil moisture (0–100 cm) – Illinois
Root zone soil moisture [ ]
0.95 0.9 0.85 0.8 0.75 0.7 0.65 0.6 0.55 0.5
IBIS–AS, 0.67
BATS–FC, 0.61
EH5OM*, 0.79
ISWS, 0.71
Root zone soil moisture (0–100 cm) difference – Illinois
Root zone soil moisture [ ]
0.1 0.08 0.06 0.04 0.02 0 −0.02 −0.04 −0.06 −0.08 −0.1
IBIS–AS, 0.01
BATS–FC, 0.02

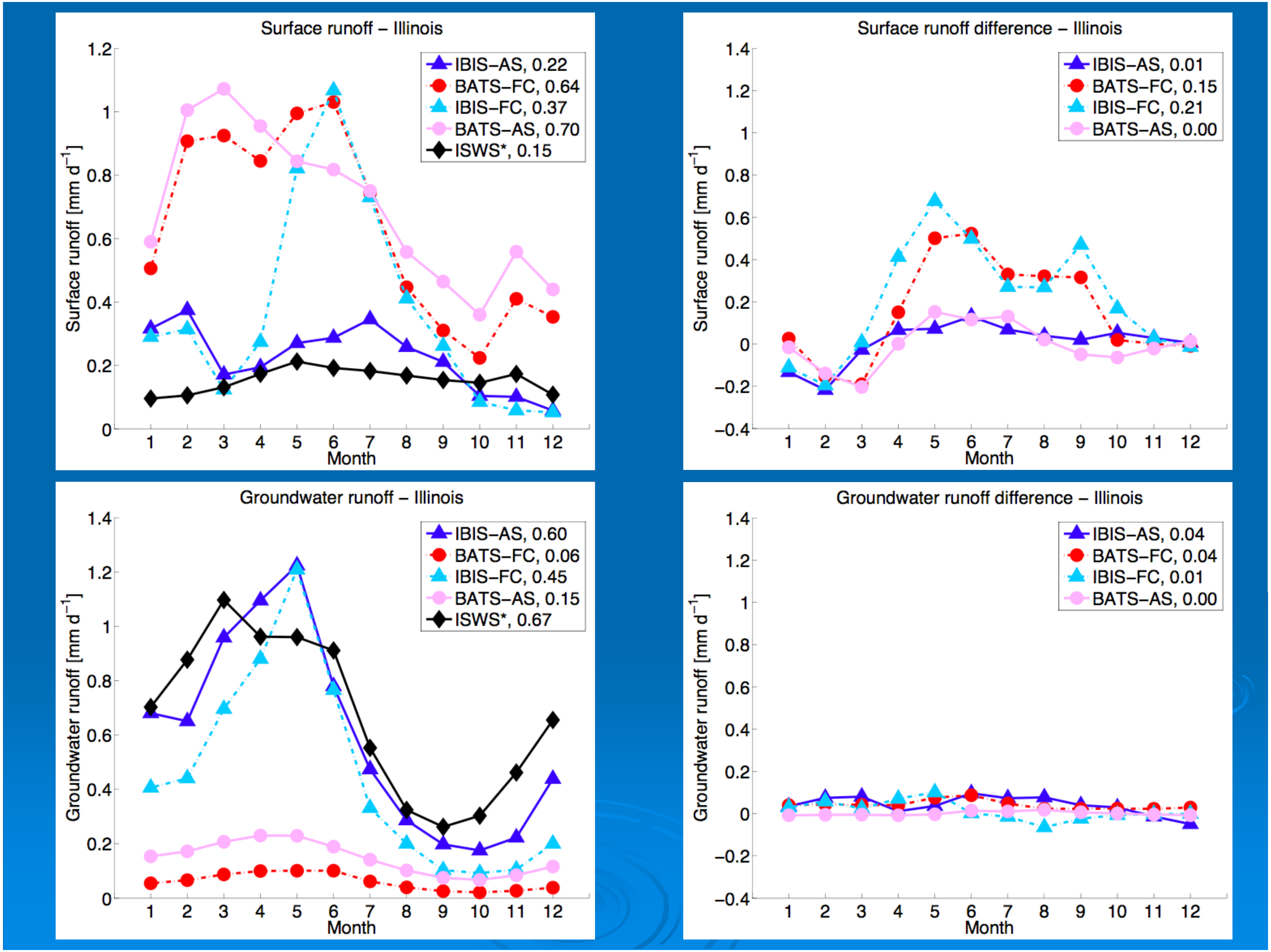
RegCM3-BATS1e over Maritime Continent

- Analyzed period 1998-2001, spin-up July-December 1997
- ERA40 for ICBCs
- Emanuel convection scheme, Zeng ocean flux scheme
- 30 km horizontal resolution, 18 / 29 vertical levels
- Rainfall compared to TRMM (0.25^o 3-hrly), GPCP (1^o daily), Changi airport meteorological station



Maritime Continent: Diurnal Cycle of Rainfall (Qian (2008))





Surface runoff – Illinois
IBIS–AS, 0.22
BATS–FC, 0.64
IBIS–FC, 0.37
BATS–AS, 0.70
ISWS*, 0.15
Surface runoff [mm d^{-1}]
Month
Surface runoff difference – Illinois
IBIS–AS, 0.01
BATS–FC, 0.15
IBIS–FC, 0.21
BATS–AS, 0.00
Surface runoff [mm d^{-1}]
Month
Groundwater runoff – Illinois
IBIS–AS, 0.60
BATS–FC, 0.06
IBIS–FC, 0.45
BATS–AS, 0.15
ISWS*, 0.67
Groundwater runoff [mm d^{-1}]
Month
Groundwater runoff difference – Illinois
IBIS–AS, 0.04
BATS–FC, 0.04
IBIS–FC, 0.01
BATS–AS, 0.00
Groundwater runoff [mm d^{-1}]
Month