Regional climate modelling using CCAM: simulations for CORDEX

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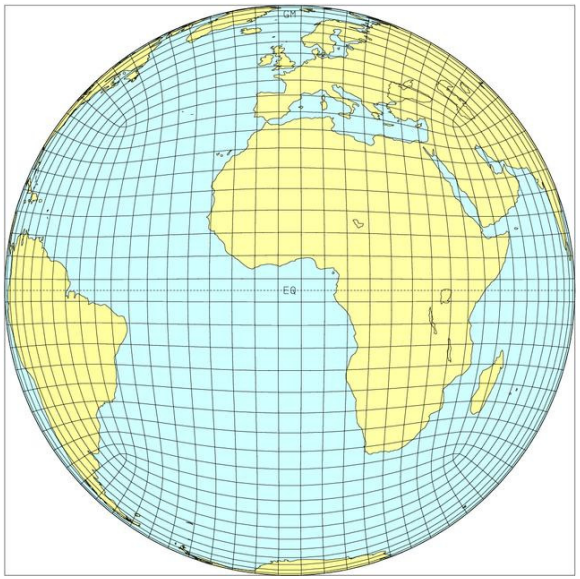
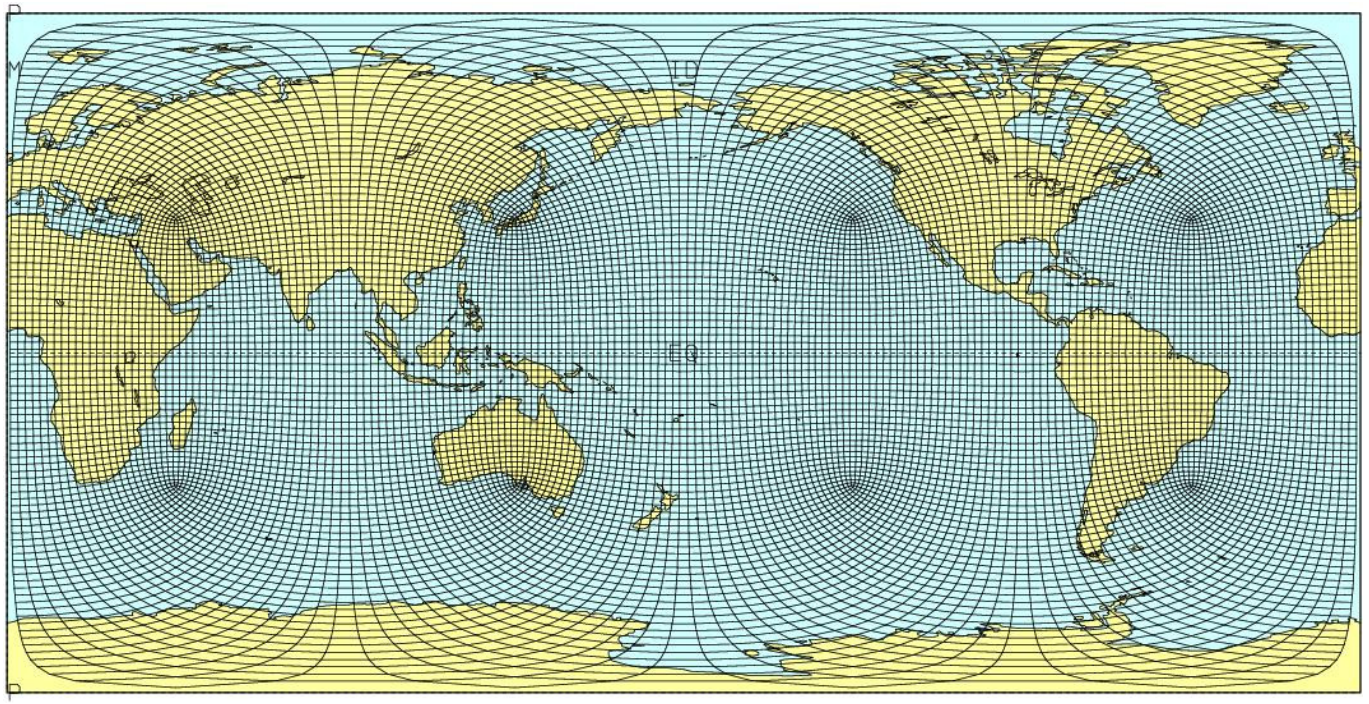
Outline

- CCAM formulation
- Downscaling methodology
- Some downscaled simulations
- Cumulus convection
- CCAM developments

The conformal-cubic atmospheric model

- CCAM is formulated on the conformal-cubic grid
- Orthogonal
- Isotropic





Example of quasi-uniform C48 grid with resolution about 200 km

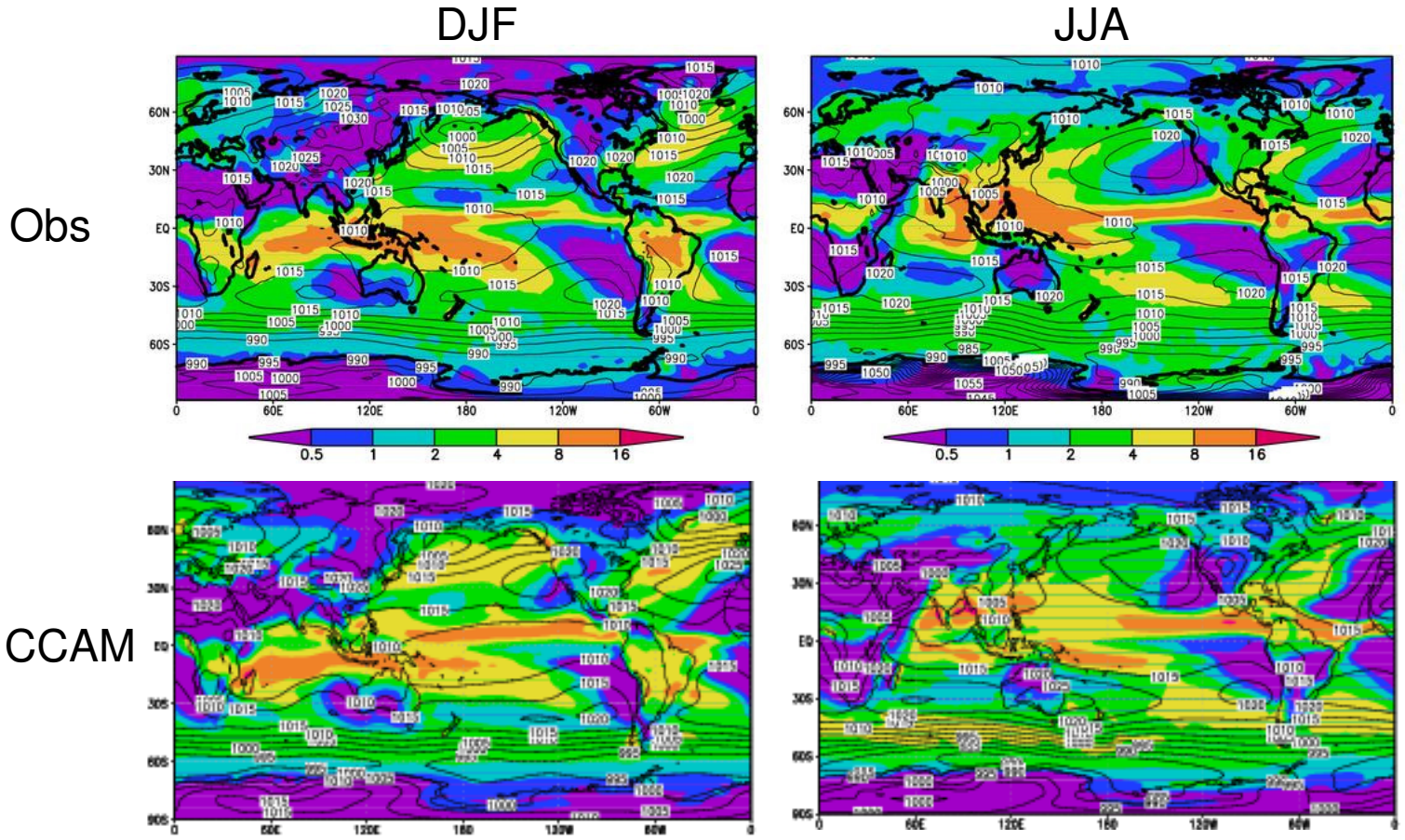
CCAM dynamics

- atmospheric GCM with variable resolution (using the Schmidt transformation)
- 2-time level semi-Lagrangian, semi-implicit
- total-variation-diminishing vertical advection
- reversible staggering
  - produces good dispersion properties
- *a posteriori* conservation of mass and moisture

CCAM physics

- cumulus convection:
  - mass-flux scheme, including downdrafts, entrainment, detrainment
  - up to 3 simultaneous plumes permitted
- includes advection of liquid and ice cloud-water
  - used to derive the interactive cloud distributions (Rotstayn 1997)
- stability-dependent boundary layer with non-local vertical mixing
- vegetation/canopy scheme (Kowalczyk et al. TR32 1994)
  - 6 layers for soil temperatures
  - 6 layers for soil moisture (Richard's equation)
- enhanced vertical mixing of cloudy air
- GFDL parameterization for long and short wave radiation

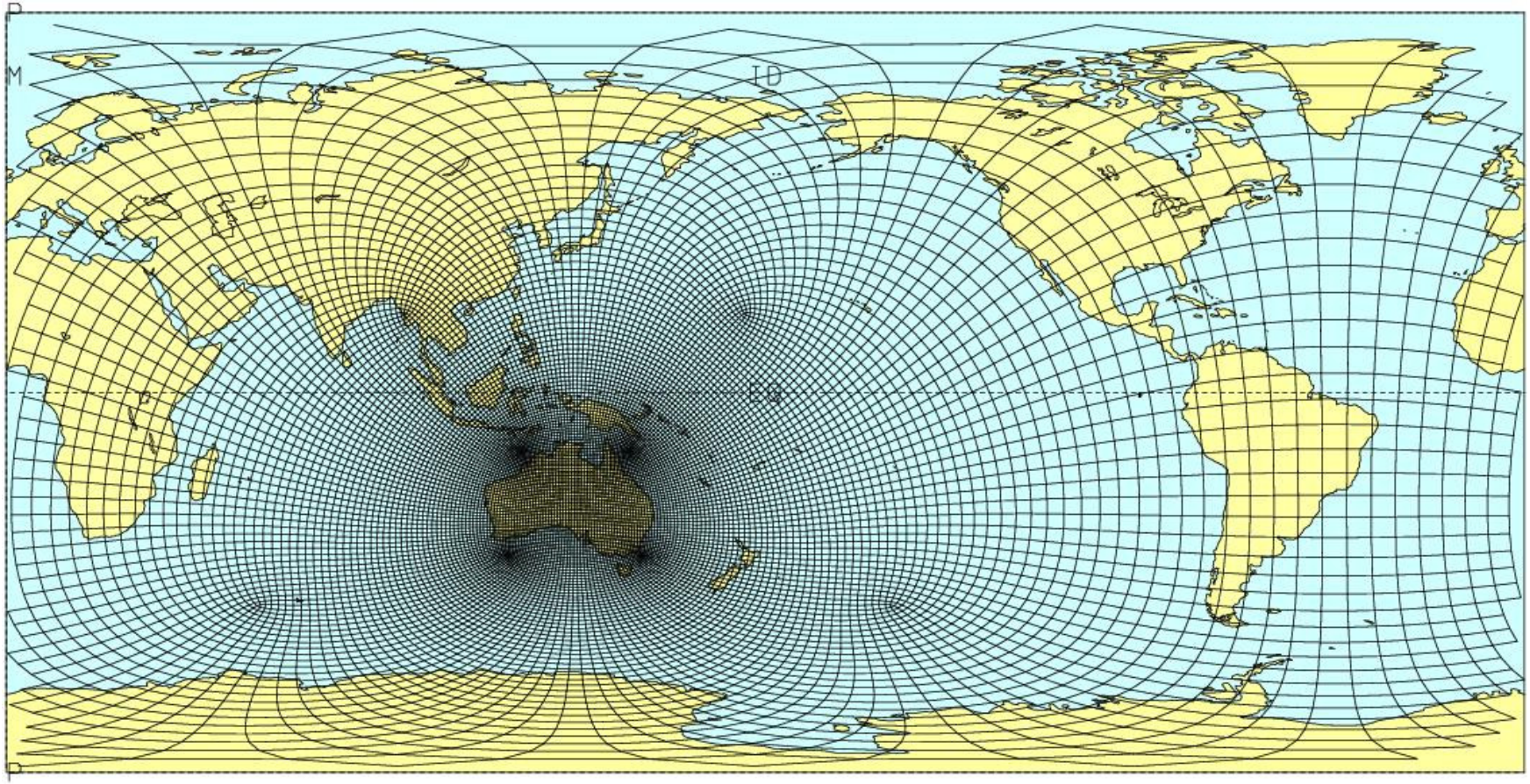
An AMIP run 1979-1995



Tuning/selecting physics options:

- In CCAM, done with 200 km AMIP runs, especially paying attention to Australian monsoon, Asian monsoon, Amazon region
- No special tuning for stretched runs

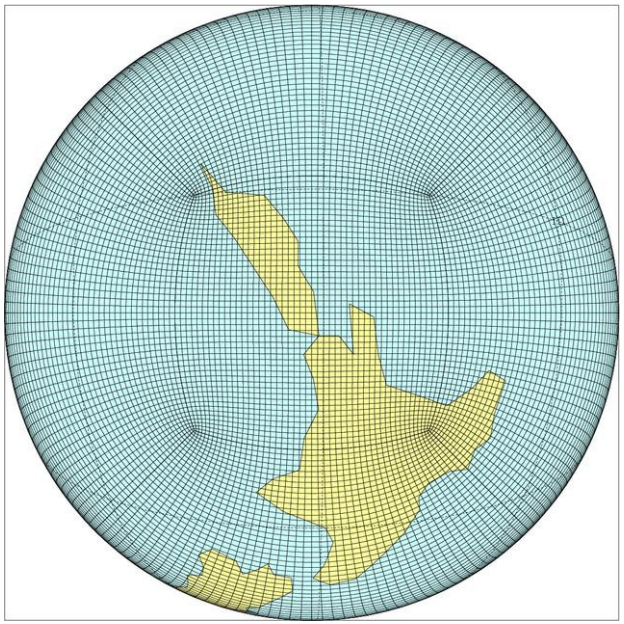
Conformal-cubic C48 grid used for Australian simulations, Schmidt = 0.3



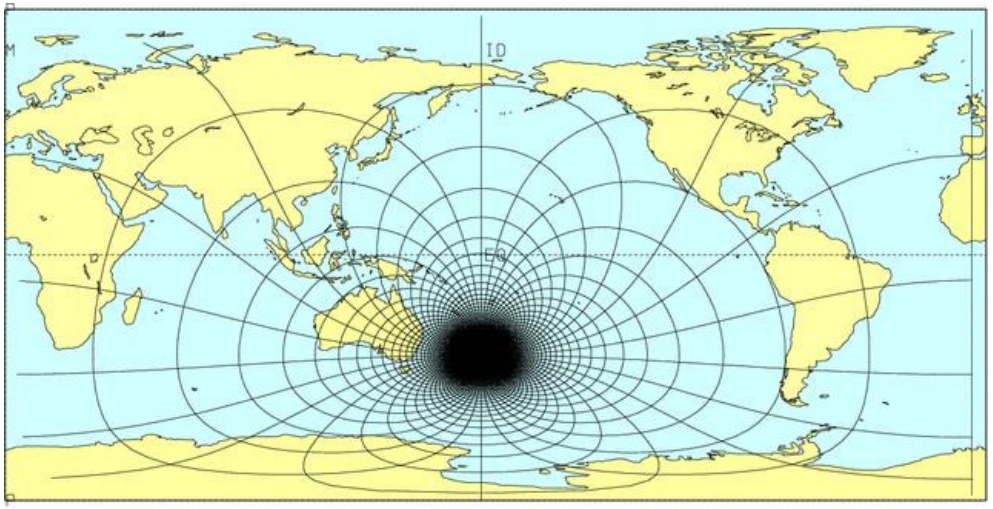
Resolution over Australia is about 60 km

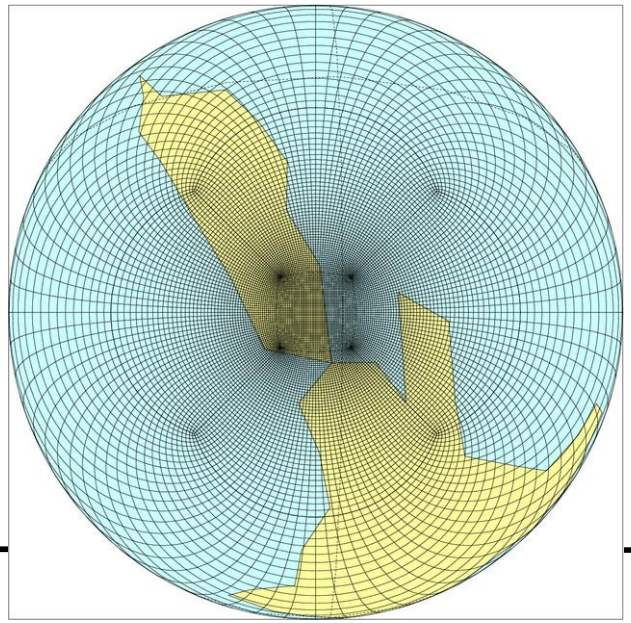
Schmidt transformation can be used to obtain even finer resolution

Grid configurations used to support Alinghi in America's Cup

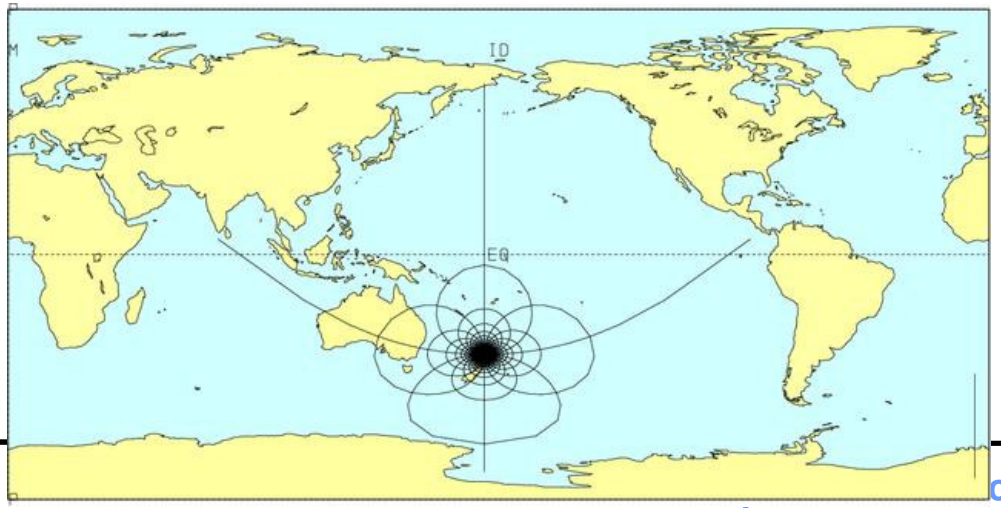


C48 8 km grid over New Zealand



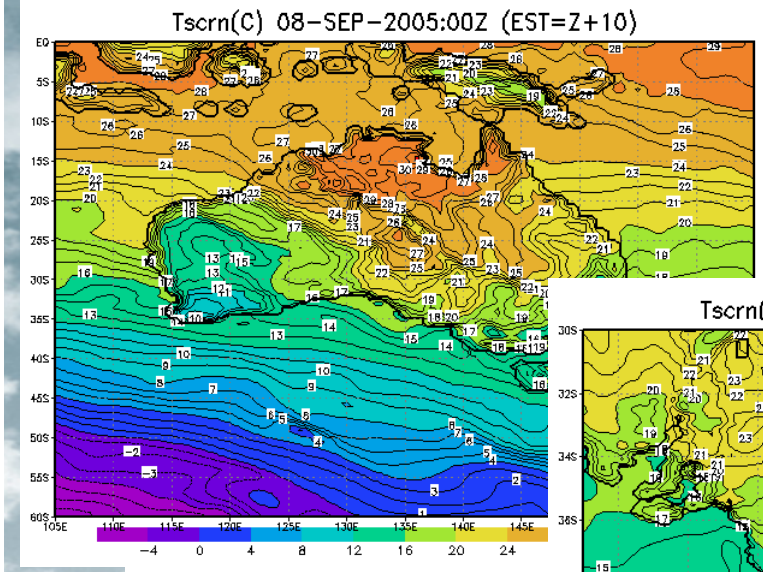


C48 1 km grid over New Zealand

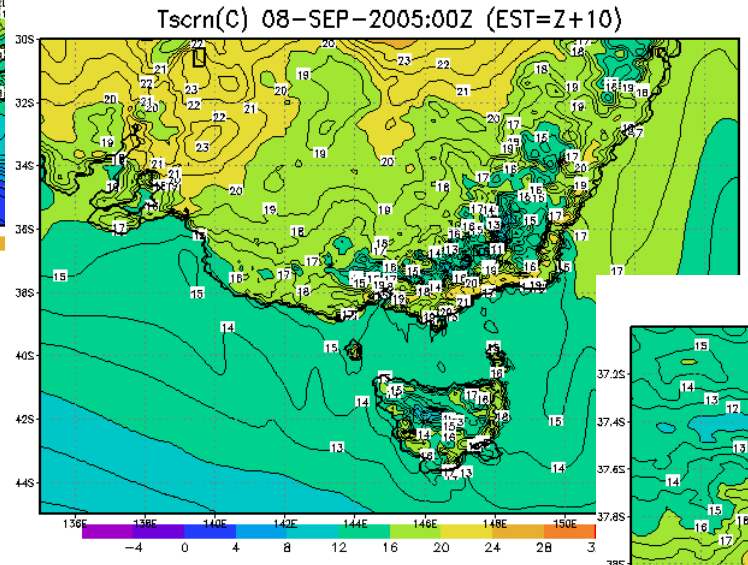


Downscaled forecasts

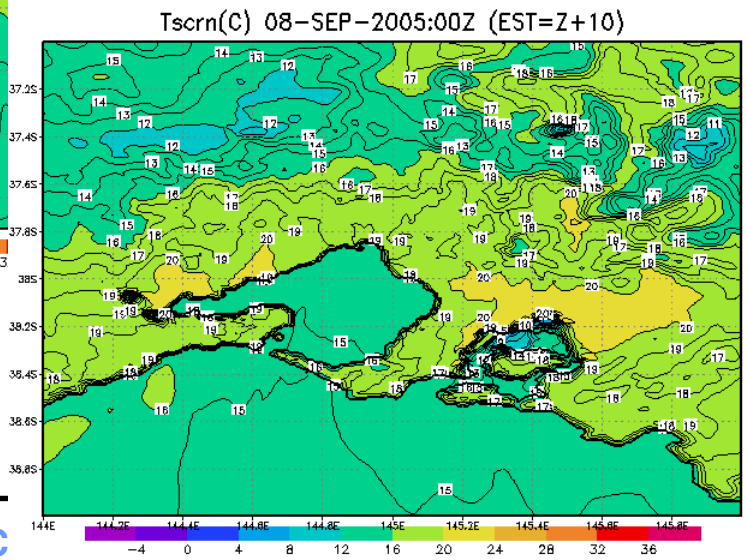
60 km



8 km

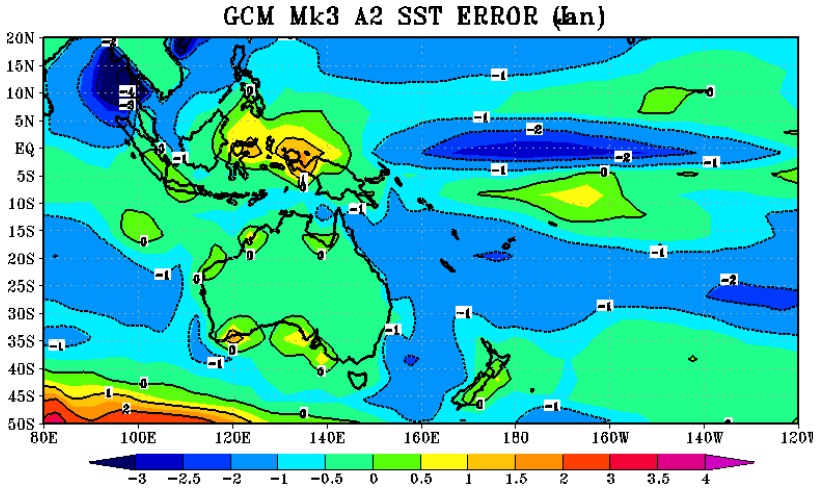


1 km

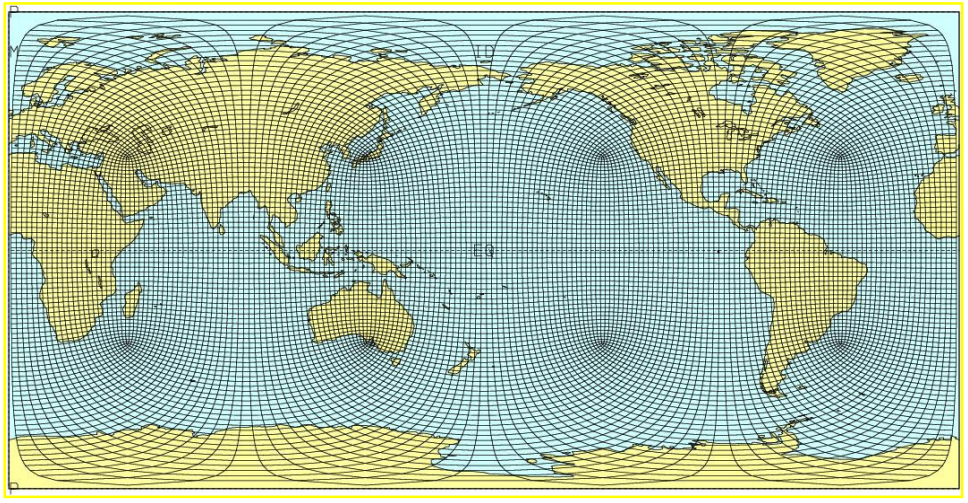


- What do we trust most from coupled GCMs?
  - probably their changes, much more than their absolute values
  - especially SST changes
- How do we cope with the biases of the coupled GCMs?
  - we choose to use just the bias-corrected SSTs (and sea-ice) from CGCMs
  - similar philosophy used by other global modelling groups (Arpege, LMDZ, MRI)

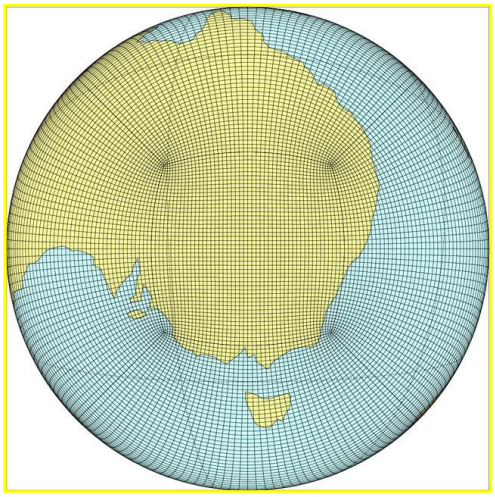
Preferred CCAM downscaling methodology



- Coupled GCMs have coarse resolution, but also possess Sea Surface Temperature (SST) biases
- A common bias is the equatorial "cold tongue"
- First run a quasi-uniform (e.g. 200 km), or modestly stretched, CCAM run driven by the bias-corrected SSTs
- The 200 km run is then downscaled to 20 km (say) by running CCAM with a stretched grid, but applying a digital filter every 6 h to inherit the large-scale patterns of the 200 km run

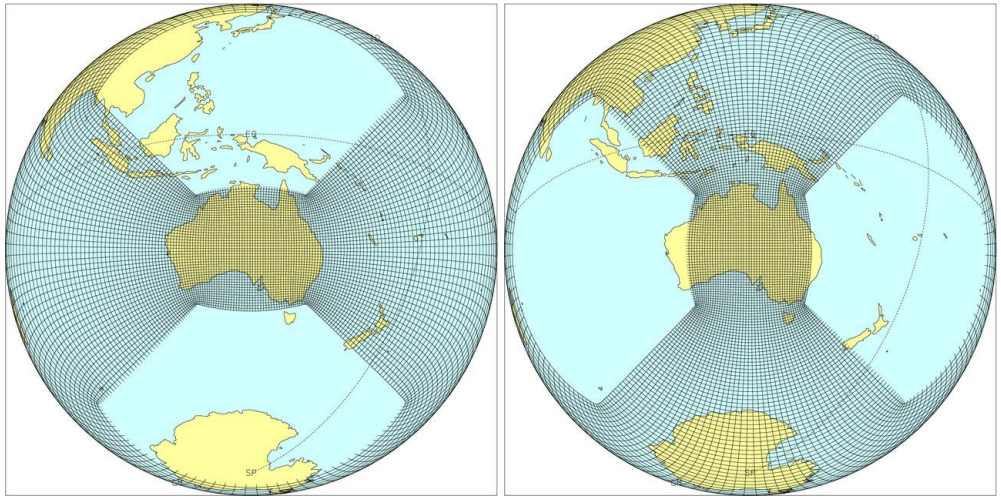


Quasi-uniform C48 CCAM grid with resolution about 200 km



Stretched C48 grid with resolution about 20 km over eastern Australia

Digital-filter downscaling method



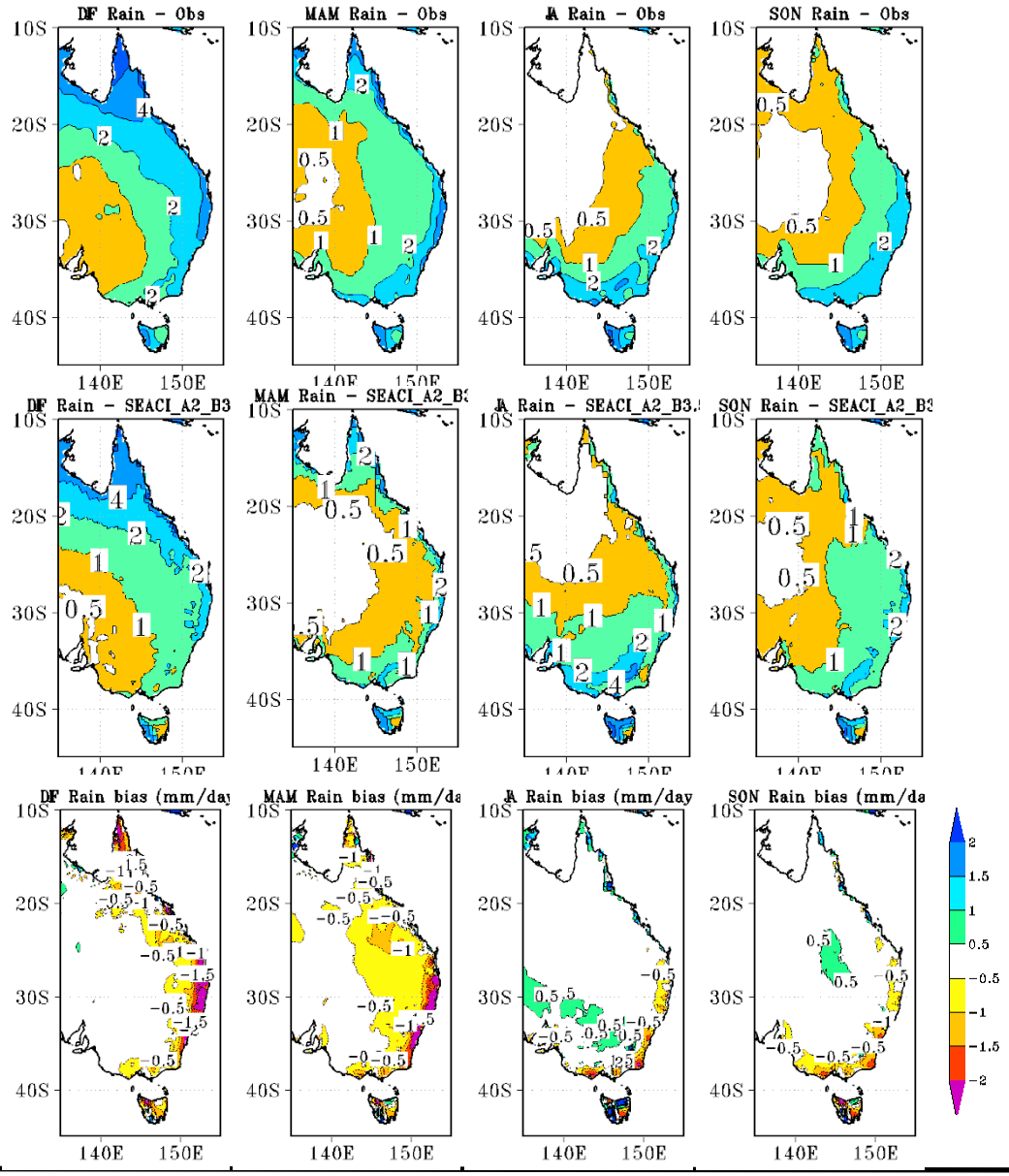
- Uses a sequence of 1D passes over all panels to efficiently evaluate broad-scale digitally-filtered host-model fields (Thatcher and McGregor, MWR, 2009). Very similar results to 2D collocation method.
- These periodically (e.g. 6-hourly or 12-hourly) replace the corresponding broad-scale CCAM fields
- Gaussian filter typically uses a length-scale approximately the width of finest panel
- Suitable for both NWP and regional climate

Present-day rainfall from 20 km simulation downscaling 1961-2000

Obs

20 km

20 km biases



Produces good present-day rainfall with generally small biases

Also good max/min temperatures

(Downscaling from CSIRO Mk3.5)

Rainfall trends 1961-2100 mm/day

Produces similar broad-scale patterns of changes between 200 km and 20 km runs

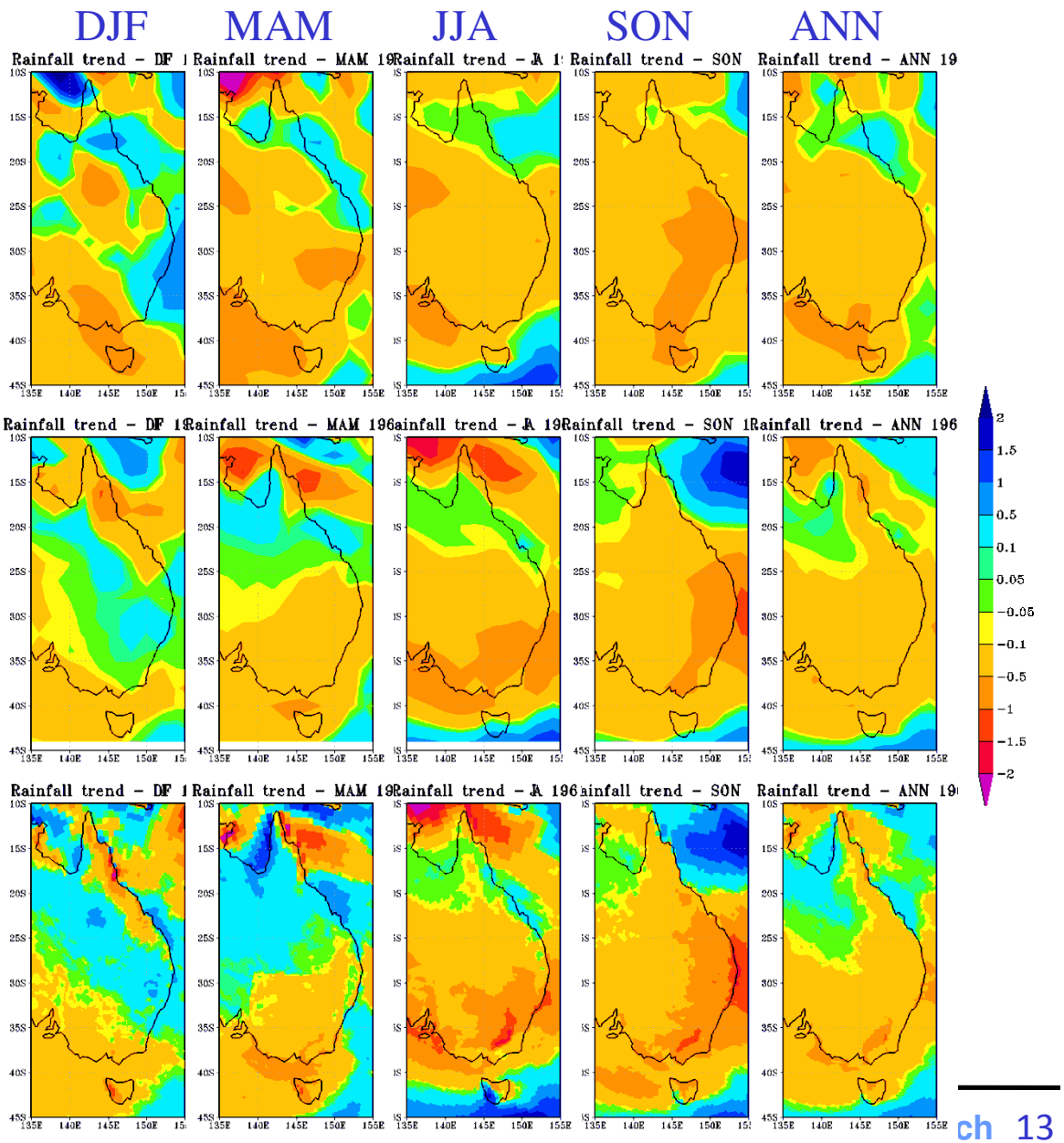
Mk 3.5

Also gives broadly similar changes to Mk 3.5, but less so in tropics in DJF

200 km CCAM

All runs show drying over Murray Darling Basin in most seasons

20 km CCAM



Some recent CCAM climate simulations

1) Ensemble of 60 km C64 runs over Australia for Climate Futures Tasmania project, (1961-2100) – 140 years (14 runs)

- Mk3.5 A2 B1 plus 2 other A2 runs
- GFDL 2.1 A2 B1
- GFDL 2.0 A2 B1
- ECHAM5 A2 B1
- HADCM3 A2 B1
- MIROC-Med A2 B1

2) Ensemble of 14 km C48 runs over Tasmania (1961-2100) – 140 years downscaled from above 60 km CCAM runs

The high-resolution CCAM simulations provide the main climate-change information for a large integrated assessment project for Tasmania

3) Ensemble of simulations over Indonesia (60 km and 14 km)

4) RMIP3 model intercomparison over east Asia downscaling from ECHAM5

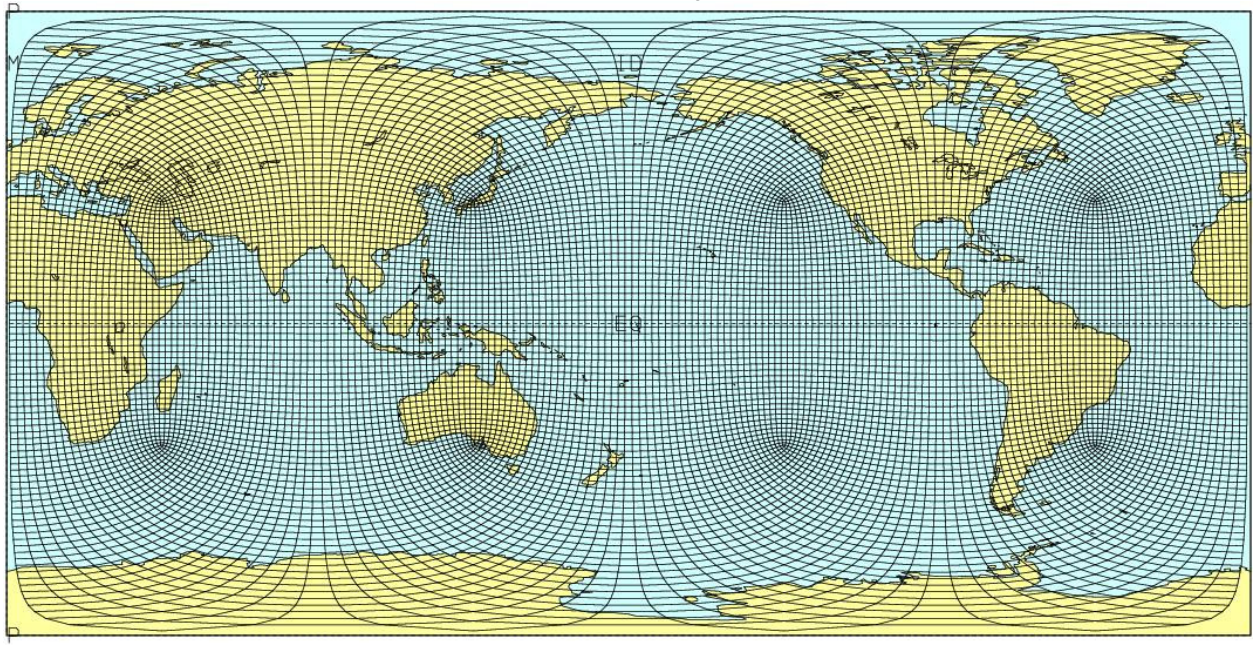
5) PCCSP – very large ensemble of global 60 km runs from 1971-2100 (from 6 GCMs), then downscaled to around 8 km for 7 individual countries

6) Ensembles at 20 km and 14 km resolution over SE Queensland & Cairns

7) New large project starting over Vietnam

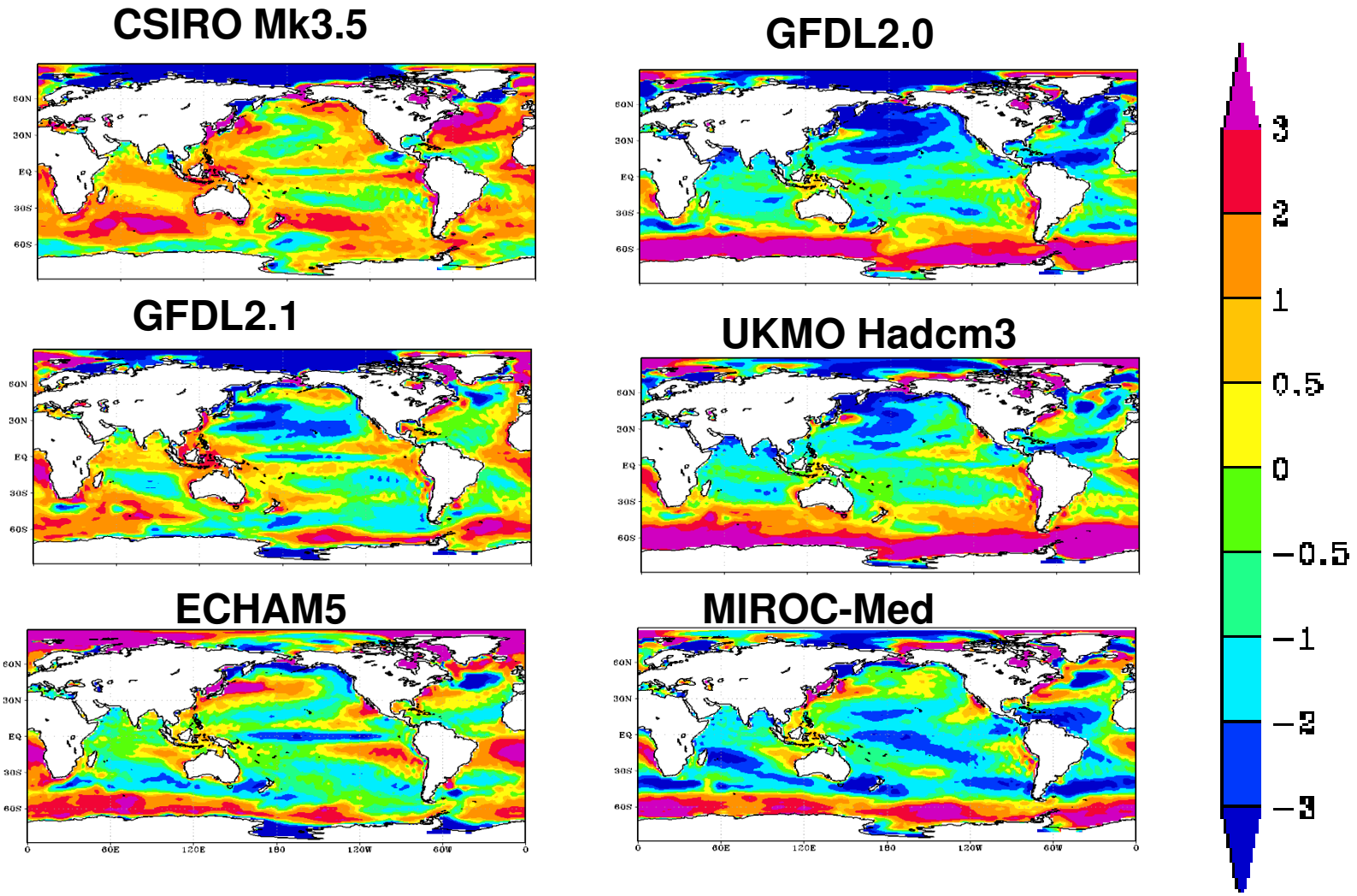
Pacific Climate Change Project (PCCSP)

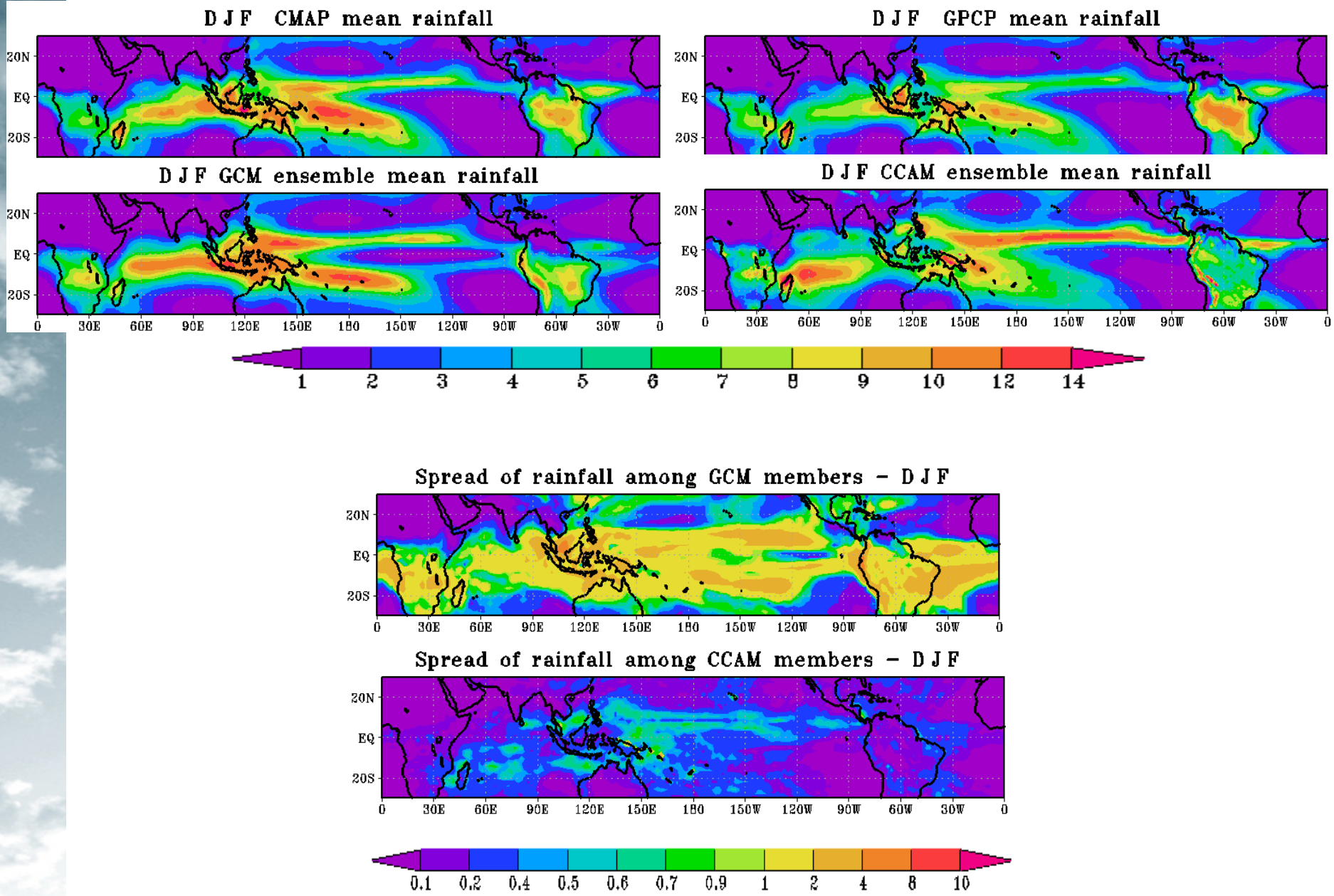
- Similar to CSIRO procedure for CORDEX
- 6 CGCMs and A2 scenario
- Uses monthly bias-corrected SSTs
- Global simulations about 60 km (C160)
- Simulations from 1961-2100 (actually a time-slice run)
- Then downscaled to 8 km over seven islands
  - employing digital filter
- Extra set of runs with mixed-layer ocean

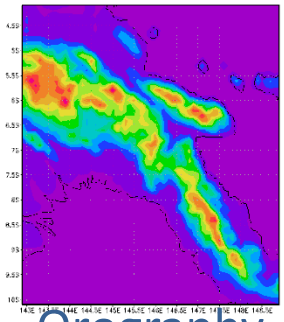


C48 grid - 200 km. Actually used C160 grid – 60 km

January SST biases (°C)



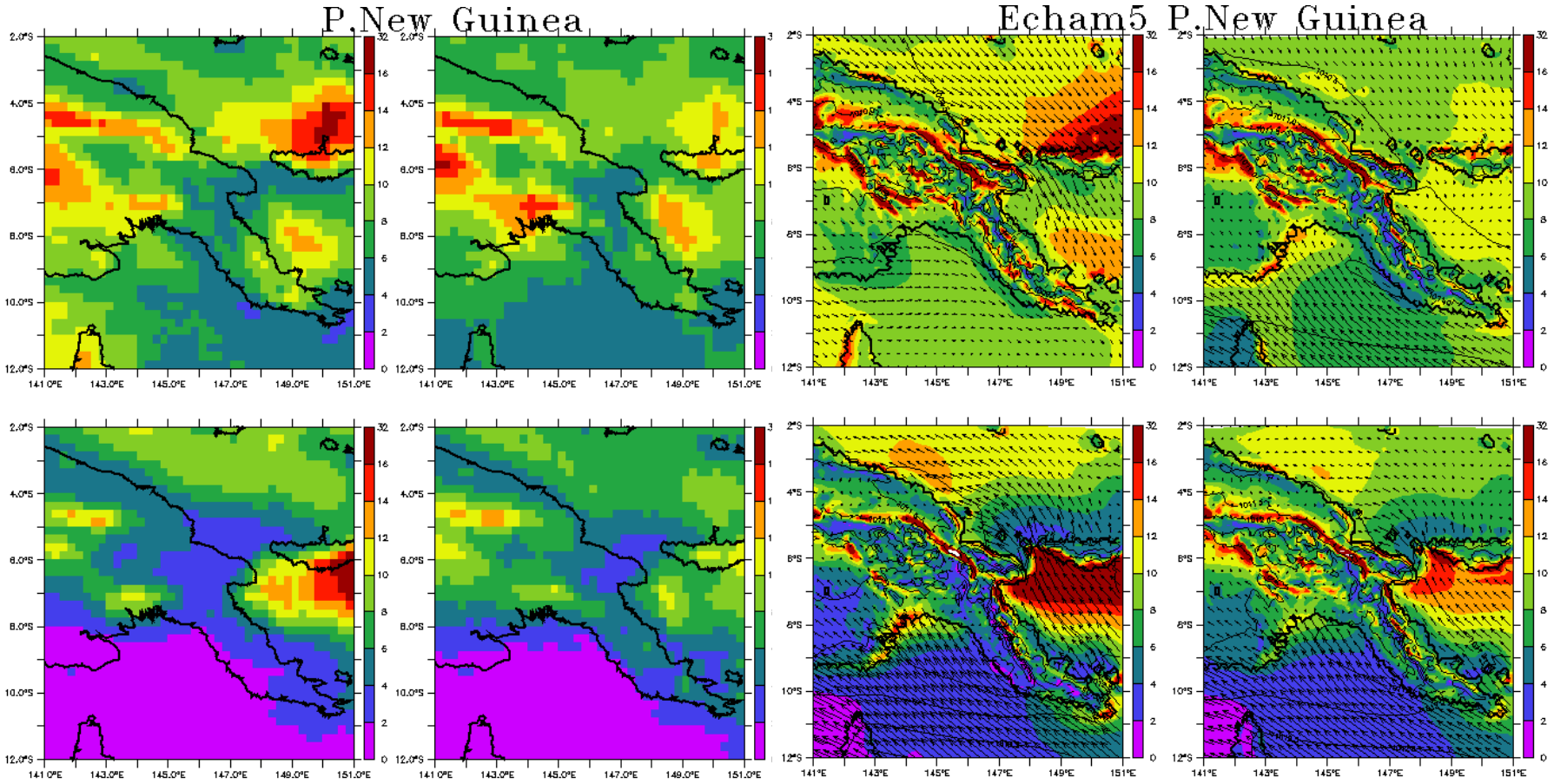

D J F CMAP mean rainfall
D J F GPCP mean rainfall
D J F GCM ensemble mean rainfall
D J F CCAM ensemble mean rainfall
20N
EQ
20S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
1 2 3 4 5 6 7 8 9 10 12 14
Spread of rainfall among GCM members - D J F
Spread of rainfall among CCAM members - D J F
0.1 0.2 0.4 0.5 0.6 0.7 0.9 1 2 4 8 10



Orography

Papua New Guinea

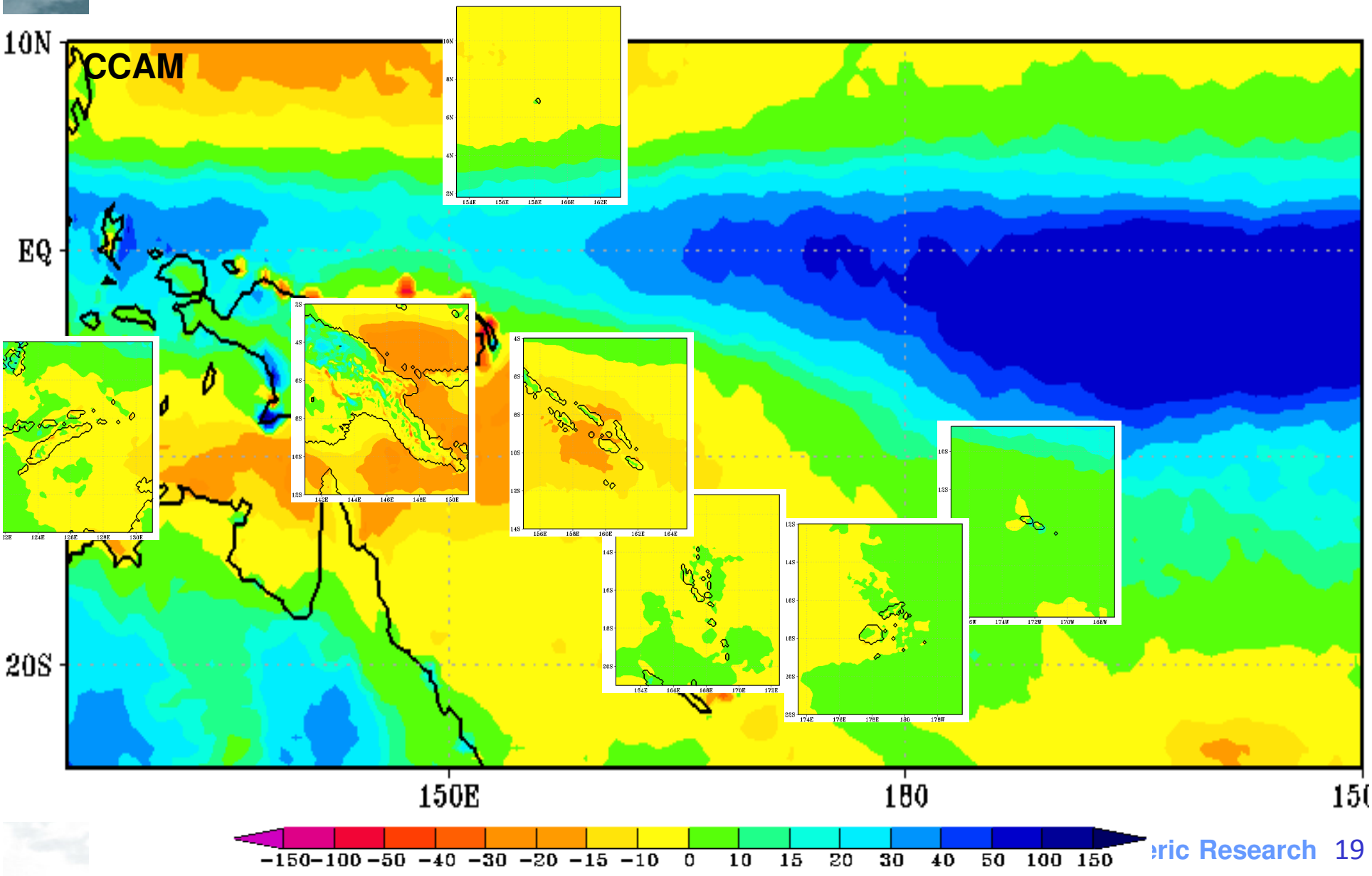
8 km simulation
Rainfall for the 4 seasons



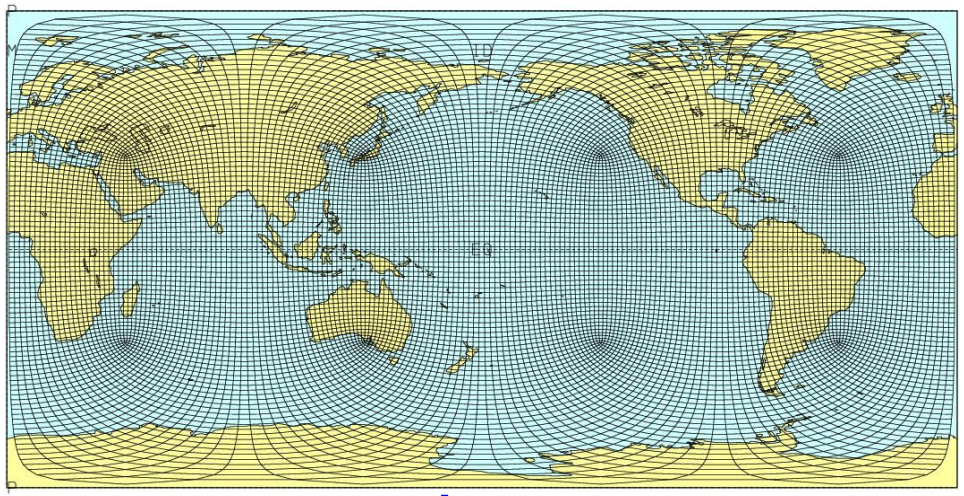
TRMM

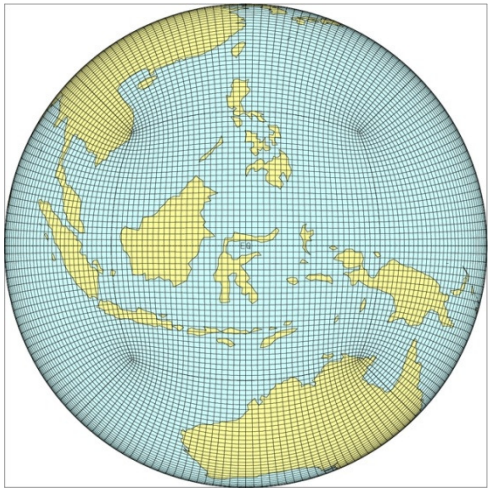
CCAM

Percentage change in ANN rainfall CCAM/ECHAM5



Ensemble of CCAM climate simulations for Indonesia



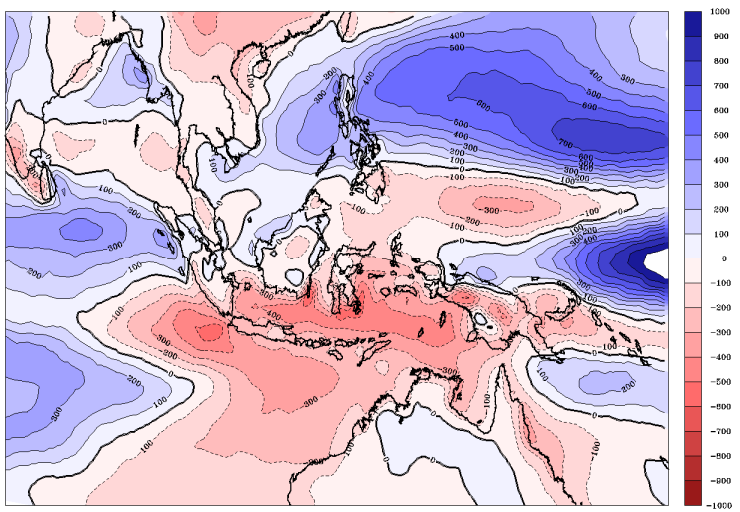


- Fine resolution is needed to simulate good rainfall patterns over the maritime continent
- 6 long simulations were driven by 6 different IPCC AR4 coupled GCMs:- from 1971-2000, 2041-2060, 2081-2100 for the A2 emission scenario
- First ran 200 km quasi-uniform CCAM simulations
- Final grid resolution is about 60 km
  - preserves large-scale fields by using the digital filter
- Then downscaled to 14 km resolution over Lombok/Sumbawa

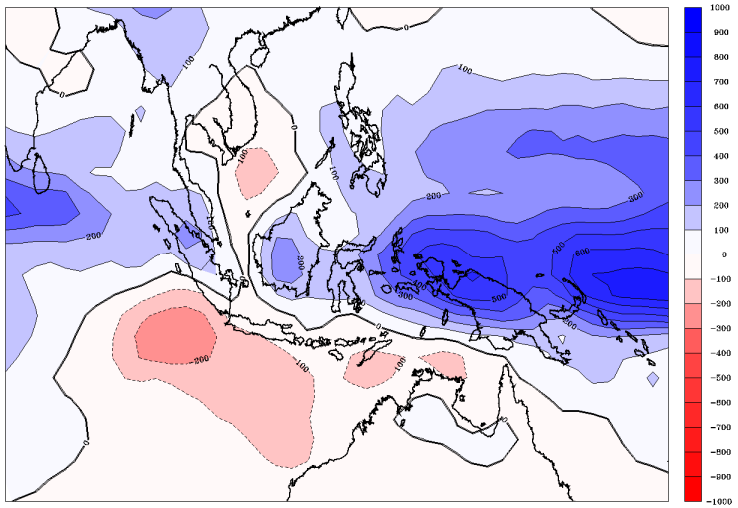
Stretched C48 grid with resolution about 60 km over Indonesia

Rainfall changes 2080-2100 from 1971-2000

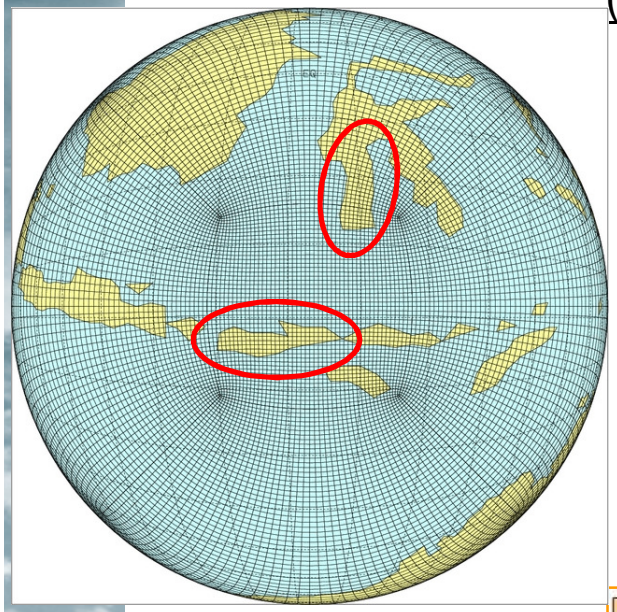
60 km Indon runs



Host GCMs



- tendency to become drier over Java
- tendency to become wetter over Sumatra
- mixed results over Borneo



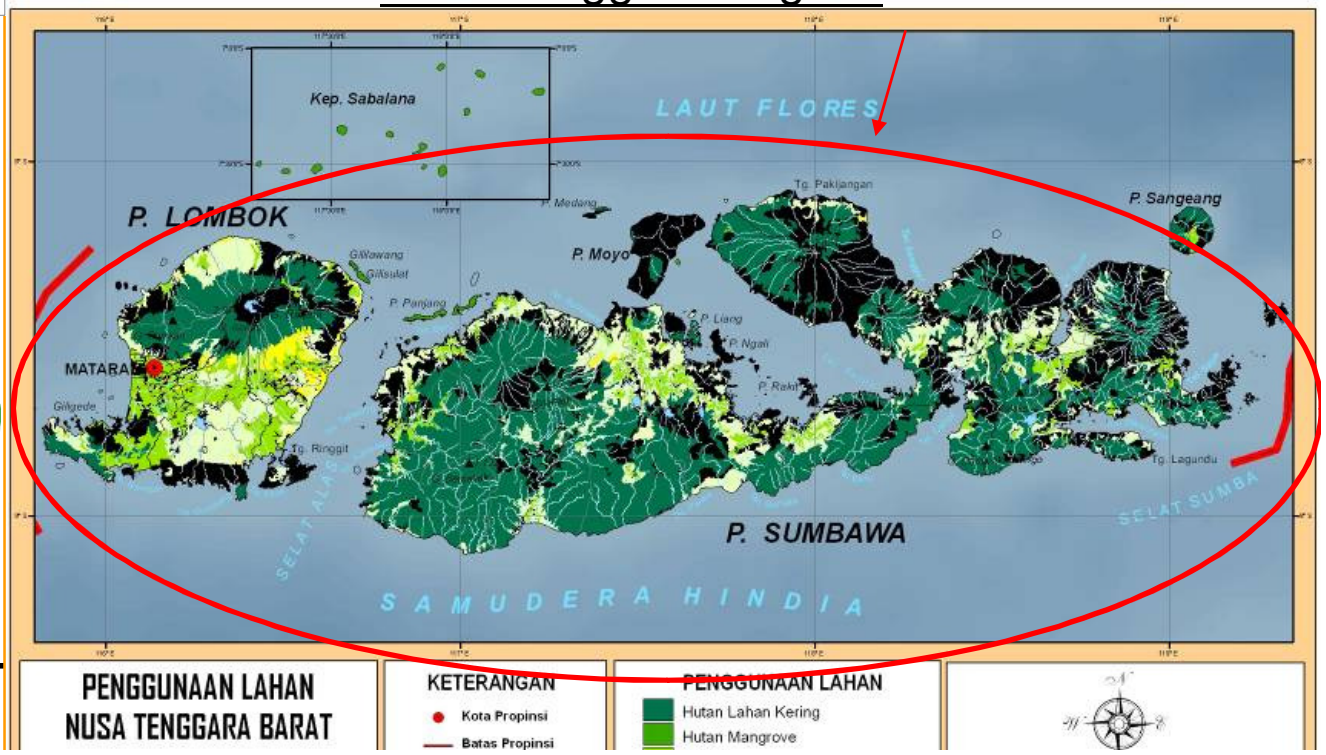
112°E-123°E, 12°S - 4°S

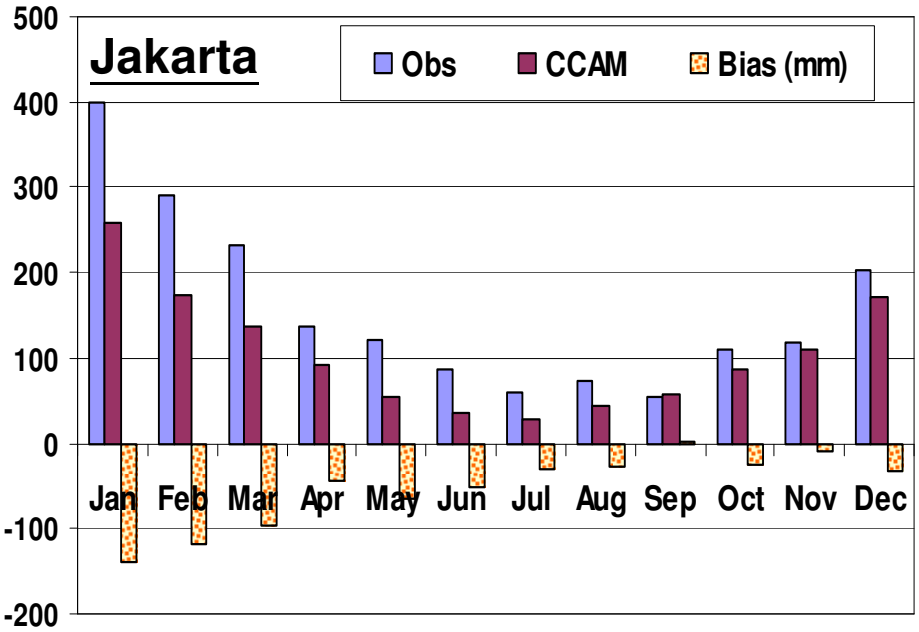
14 km grid

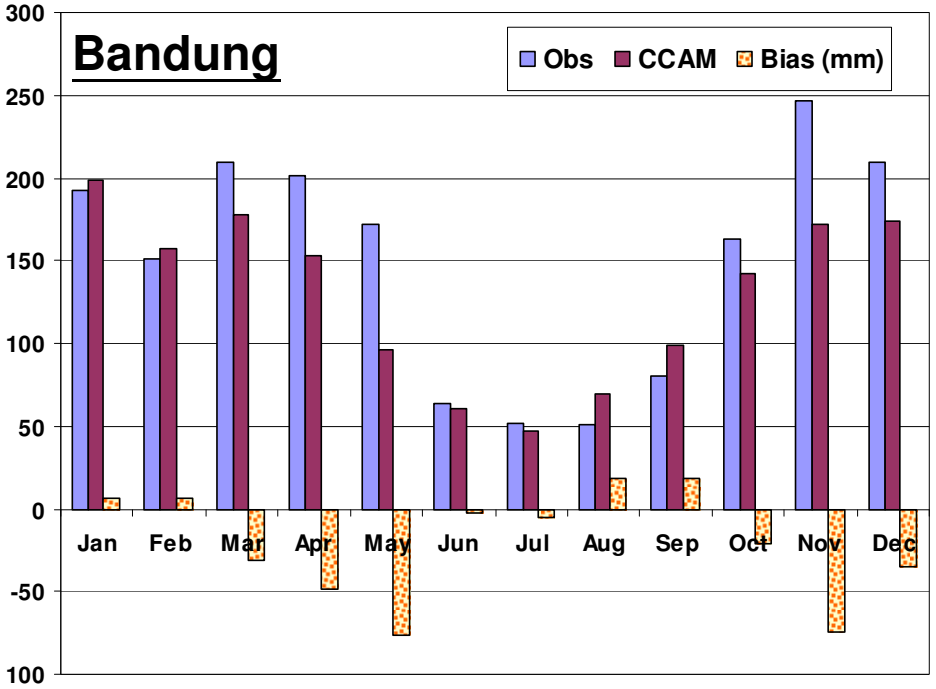
Bali is somewhere here

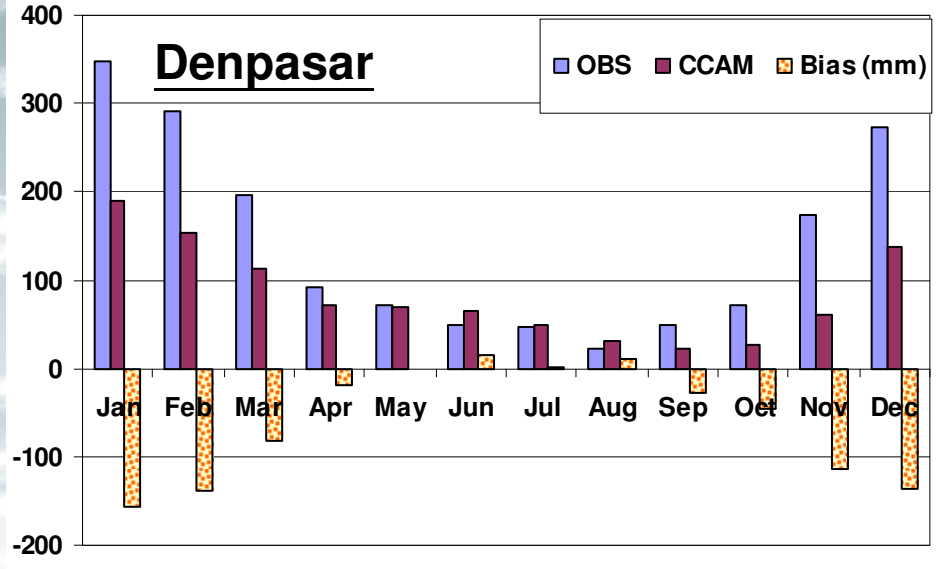
Makassar
(south Sulawesi region)

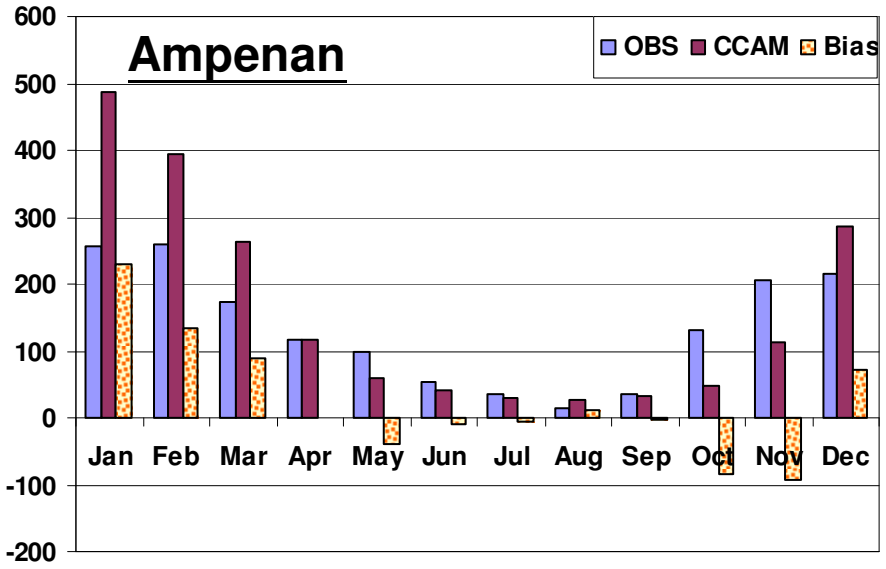
Nusa Tenggara Region





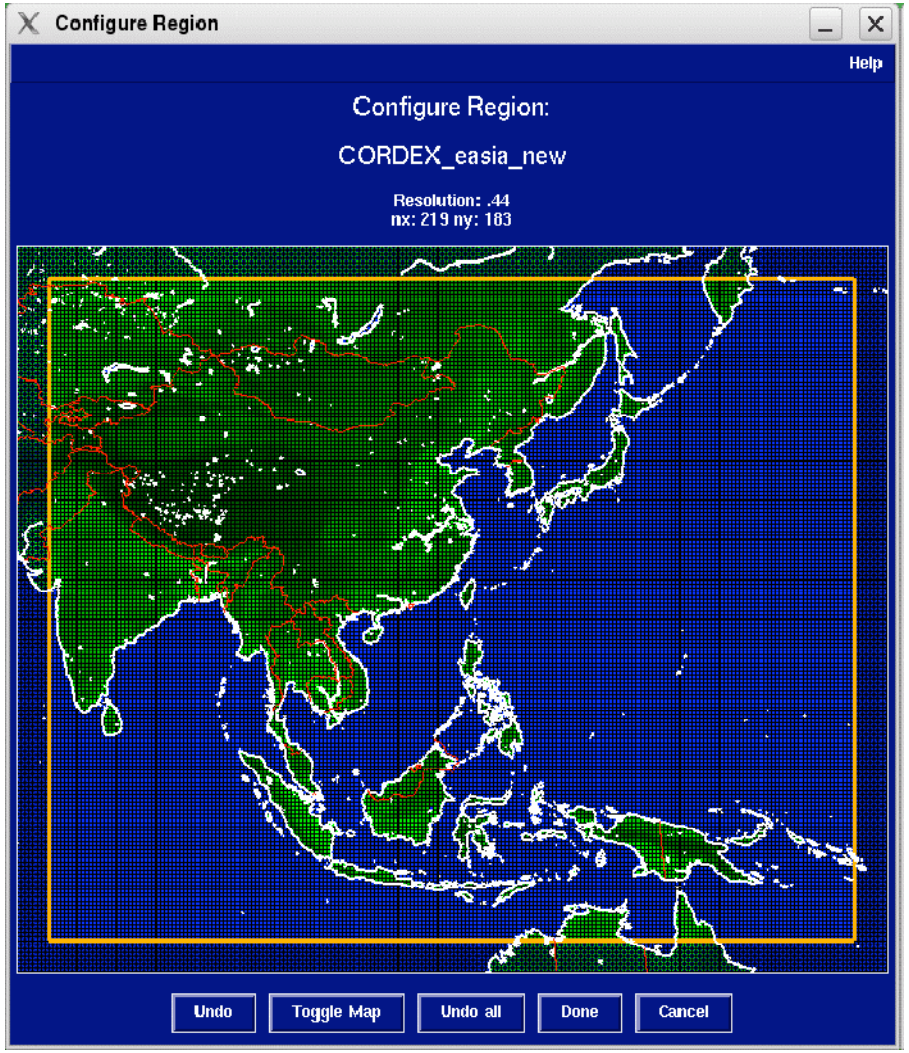




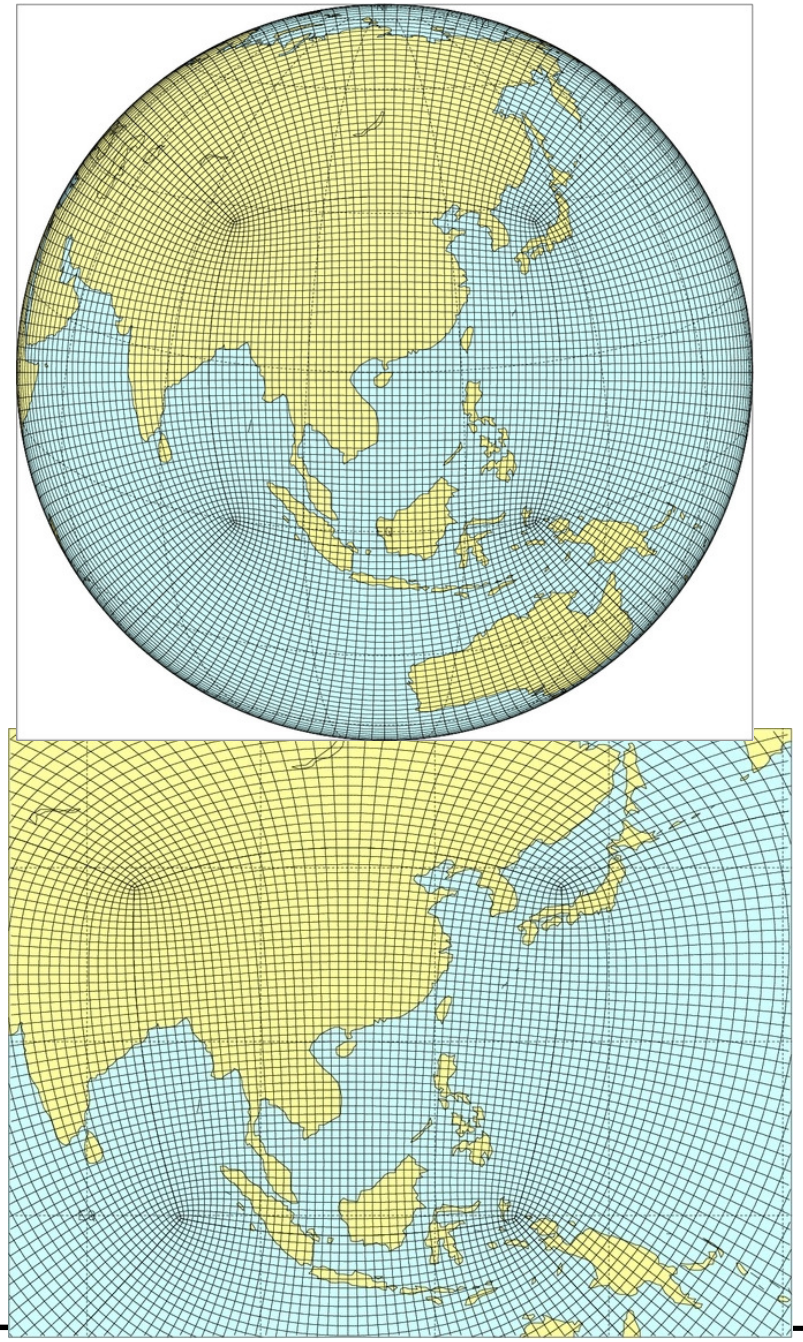


14 km simulations downscaled from NCEP reanalysis SSTs

RMIP3/CORDEX 50 km grid - plotting every 2nd point



Can use C96 stretched or C192 uniform



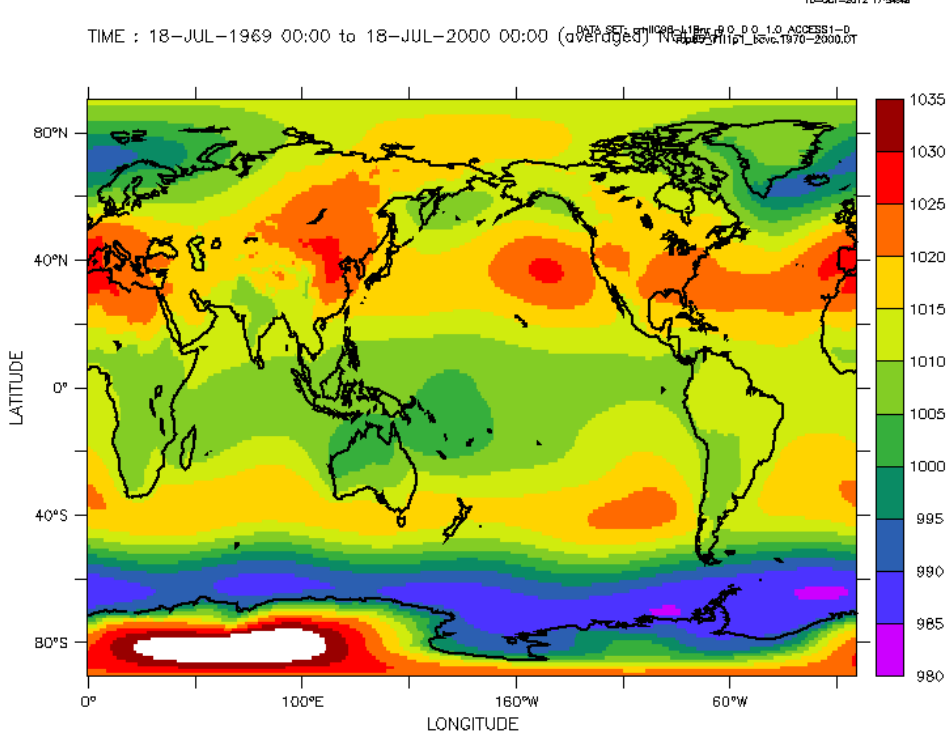
CORDEX runs using CCAM

- Global runs at 50 km, extracting outputs for various CORDEX domains (Africa, Australasia, SE Asia, S Asia)
- Mostly RCP 8.5 and 4.5
- Will try to downscale most of the AR5 CGCMs. About half at 50 km, others at 100 km or 200 km.
- Performing the runs at CSIRO, CSIR (S Africa), and Queensland Climate Centre
- Runs underway

The following results are from our ensemble of downscaled CMIP3 runs at global 60 km for A2 scenario (PCCSP project)

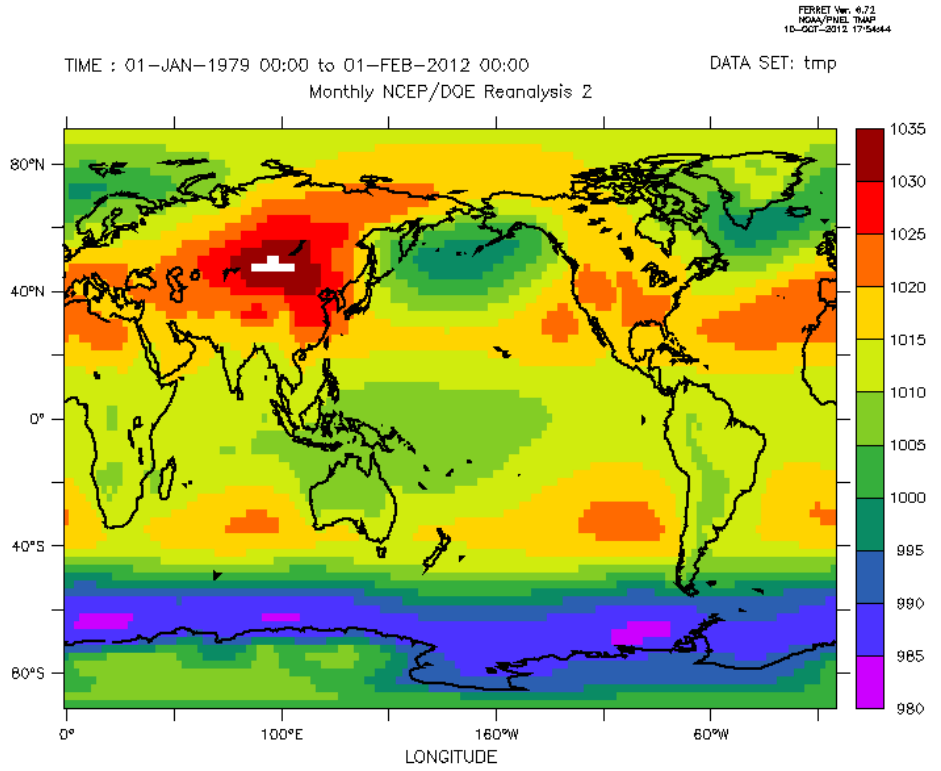
Present-day MSLP

observed

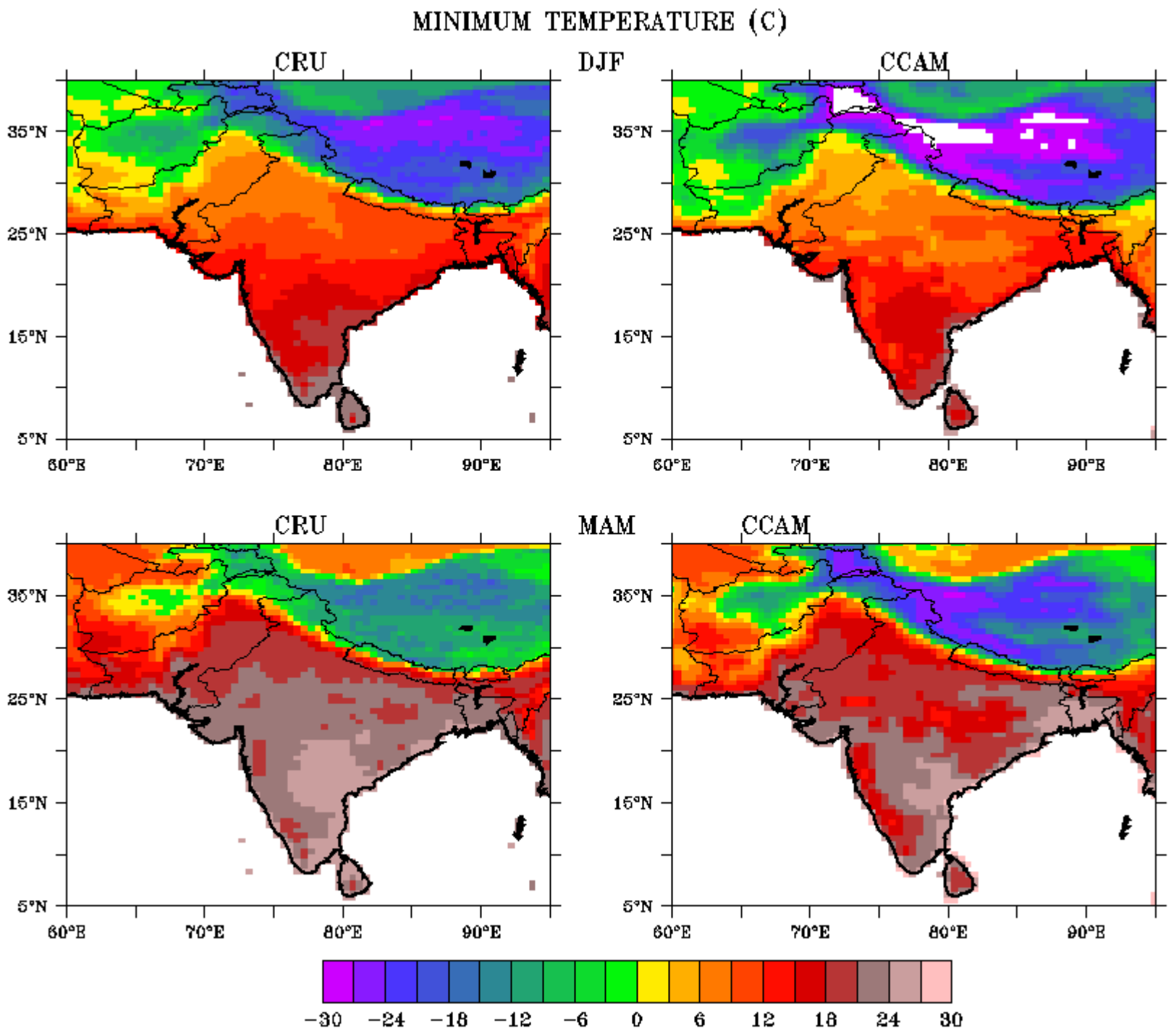


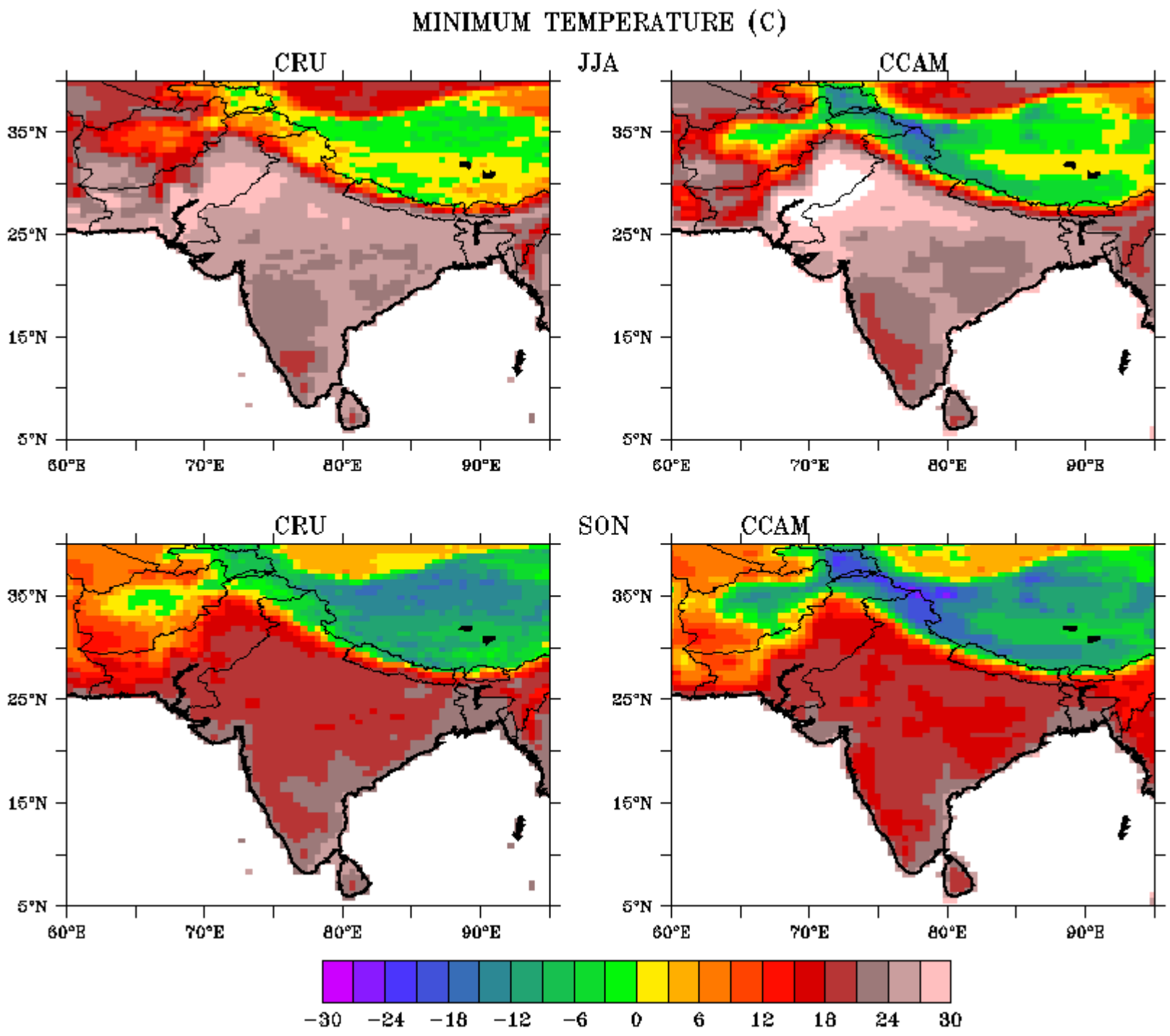
Mean sea level pressure (hPa)

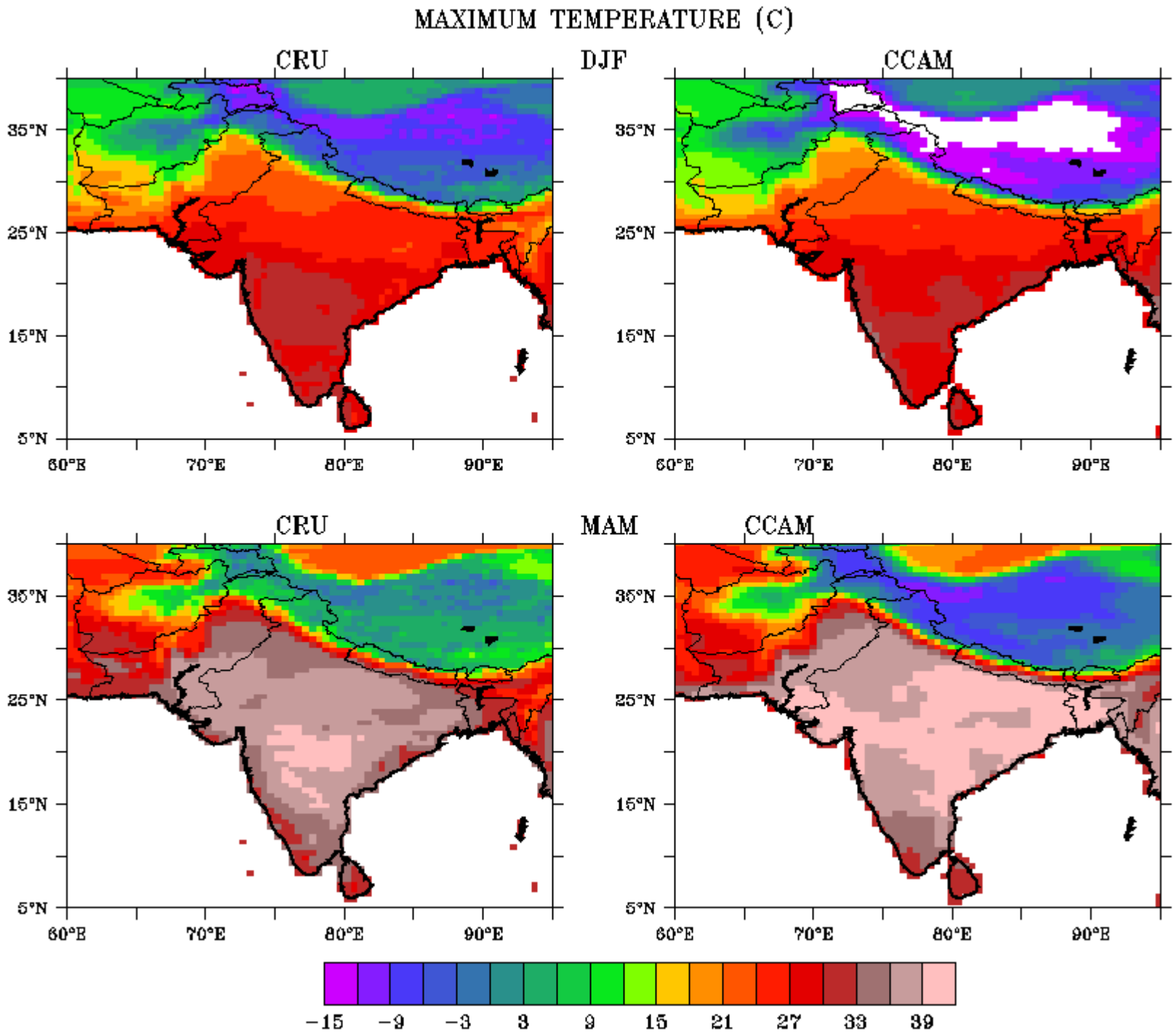
CCAM ensemble



MSLP[L=@AVE]/100


MINIMUM TEMPERATURE (C)
CRU
DJF
CCAM
CRU
MAM
CCAM
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
−30
−24
−18
−12
−6
0
6
12
18
24
30


MINIMUM TEMPERATURE (C)
CRU
JJA
CCAM
CRU
SON
CCAM
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
−30
−24
−18
−12
−6
0
6
12
18
24
30


MAXIMUM TEMPERATURE (C)
CRU
DJF
CCAM
CRU
MAM
CCAM
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
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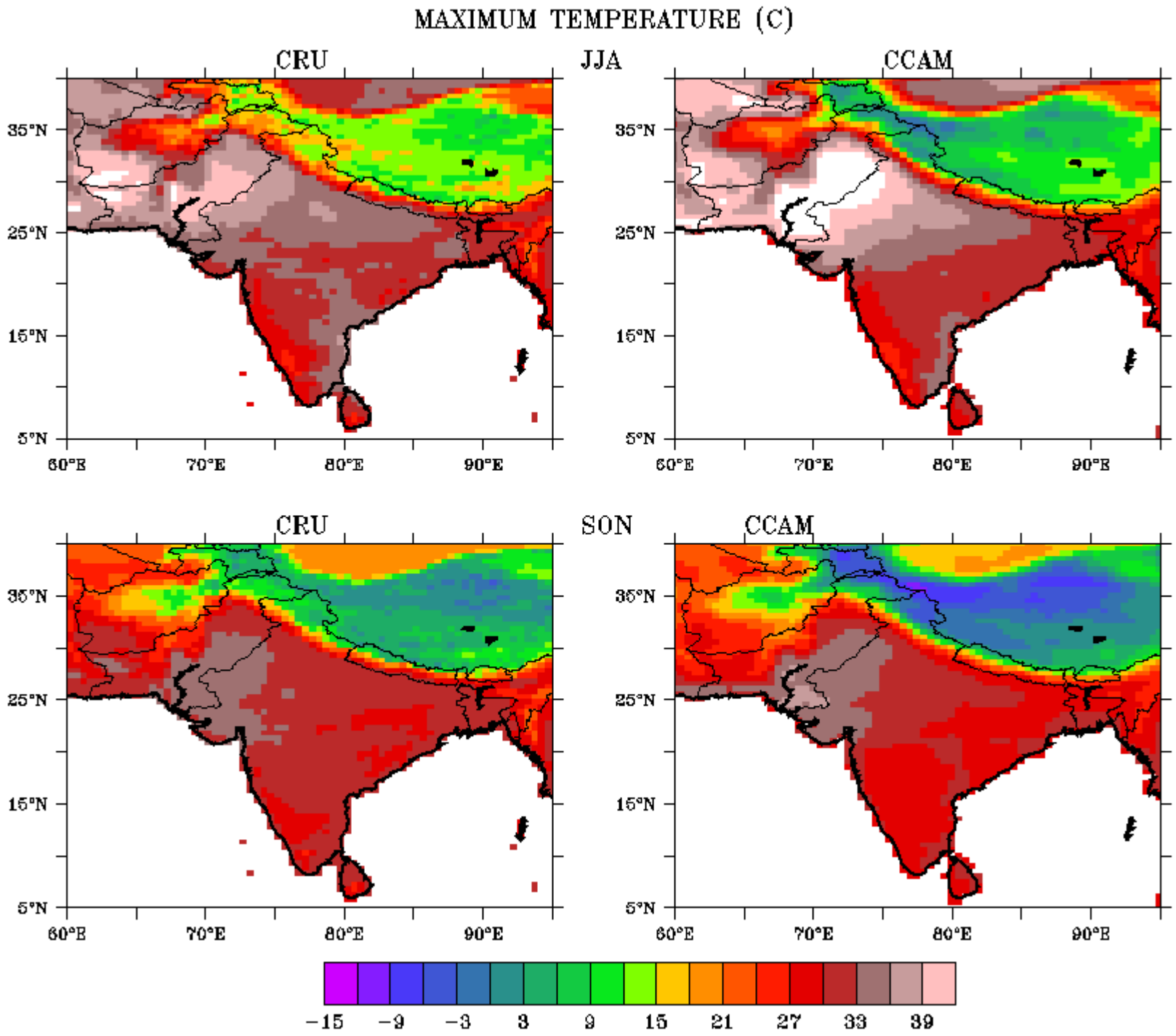
39


MAXIMUM TEMPERATURE (C)
CRU
JJA
CCAM
CRU
SON
CCAM
35°N
25°N
15°N
5°N
60°E
70°E
80°E
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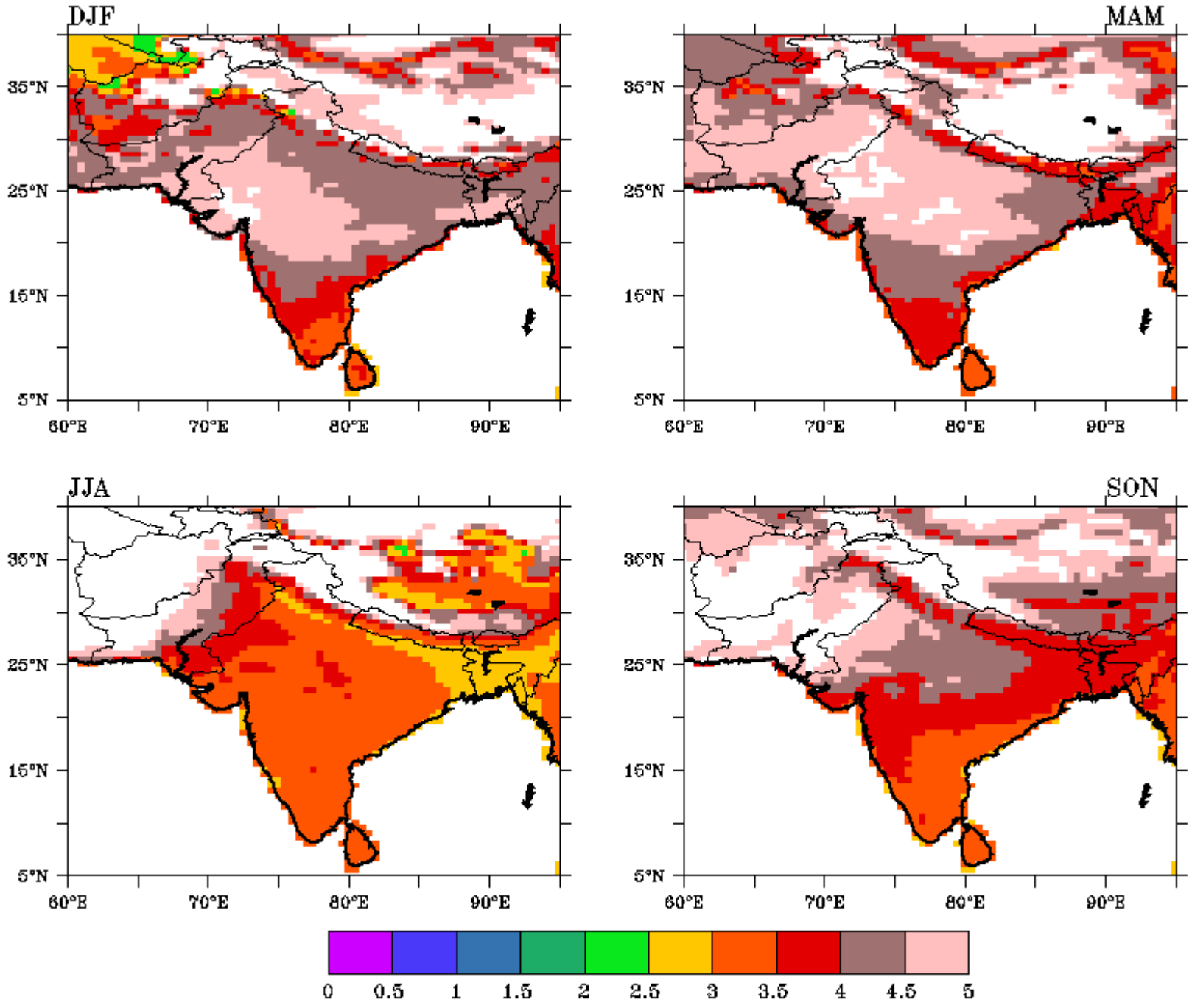
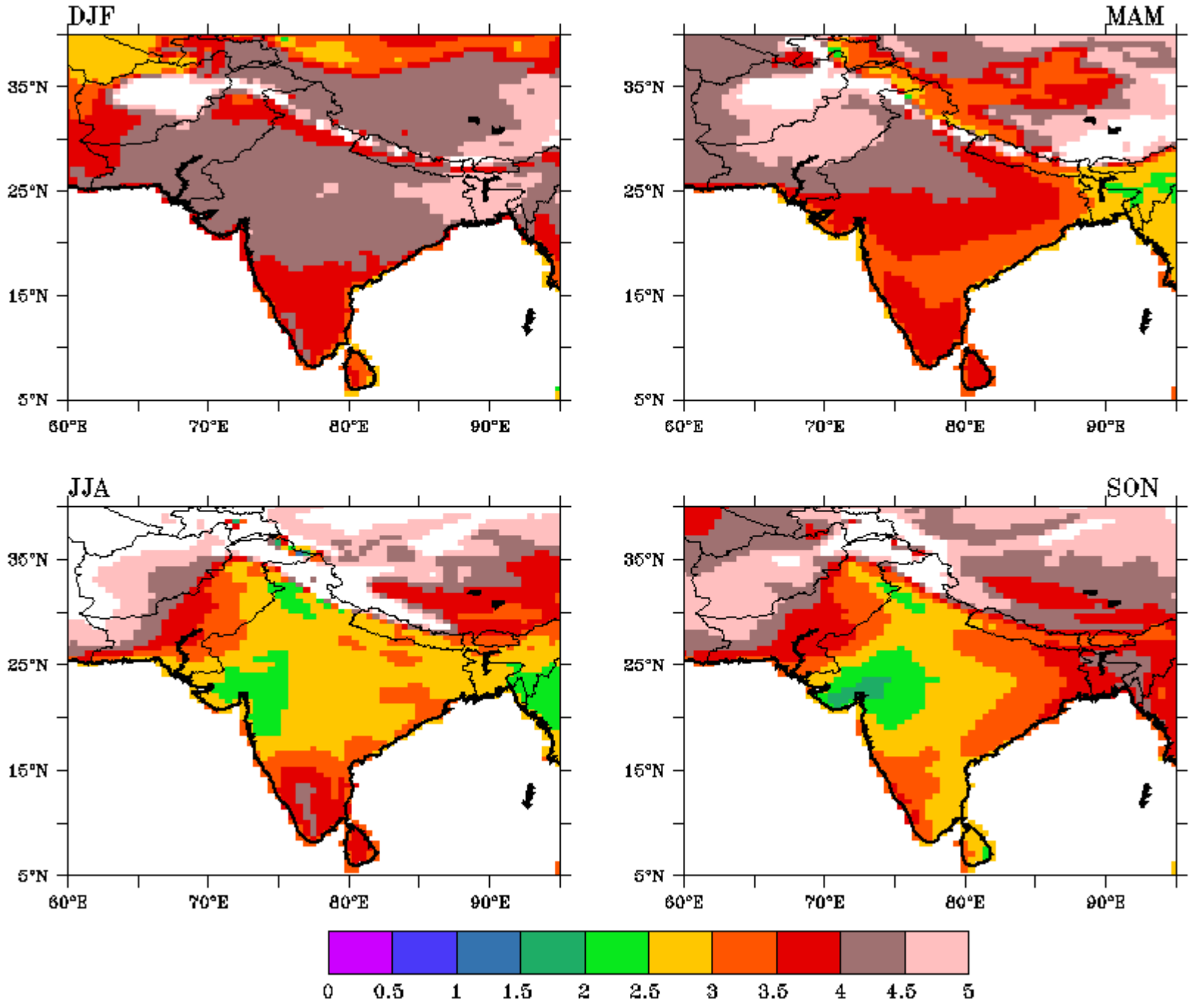
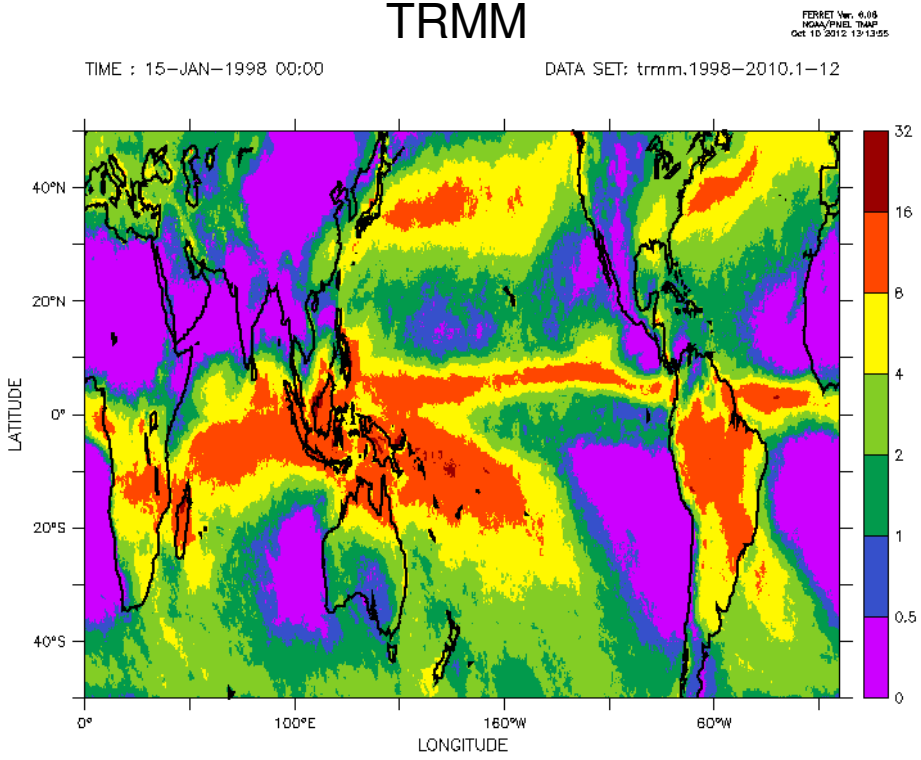

CCAM MINIMUM TEMPERATURE CHANGE (C) – BY 2080
DJF
MAM
JJA
SON
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


CCAM MAXIMUM TEMPERATURE CHANGE (C) – BY 2080
DJF
MAM
JJA
SON
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

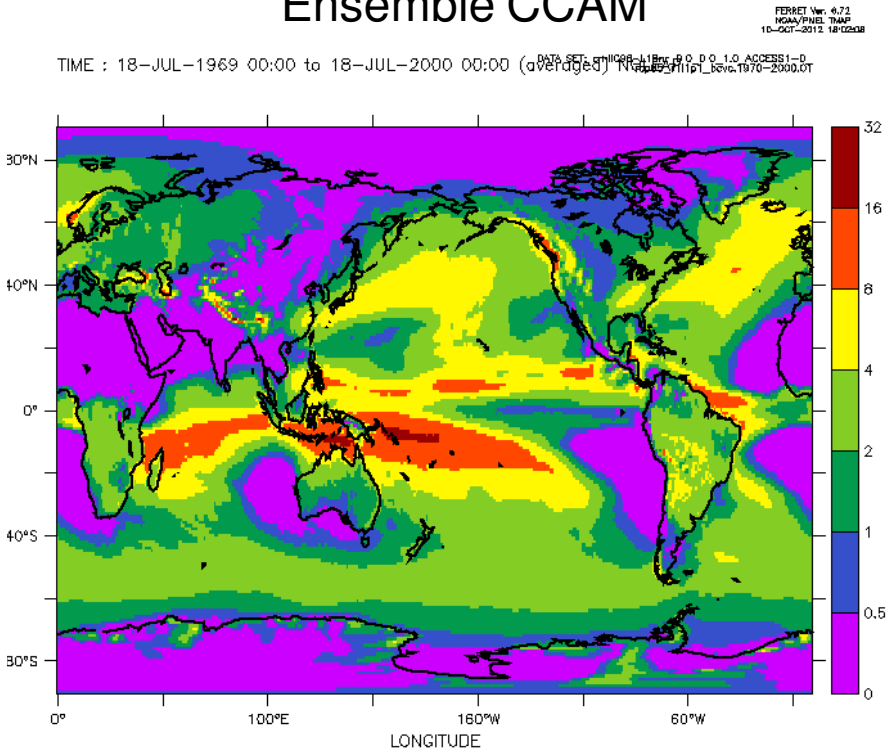
Present-day annual precipitation

TRMM

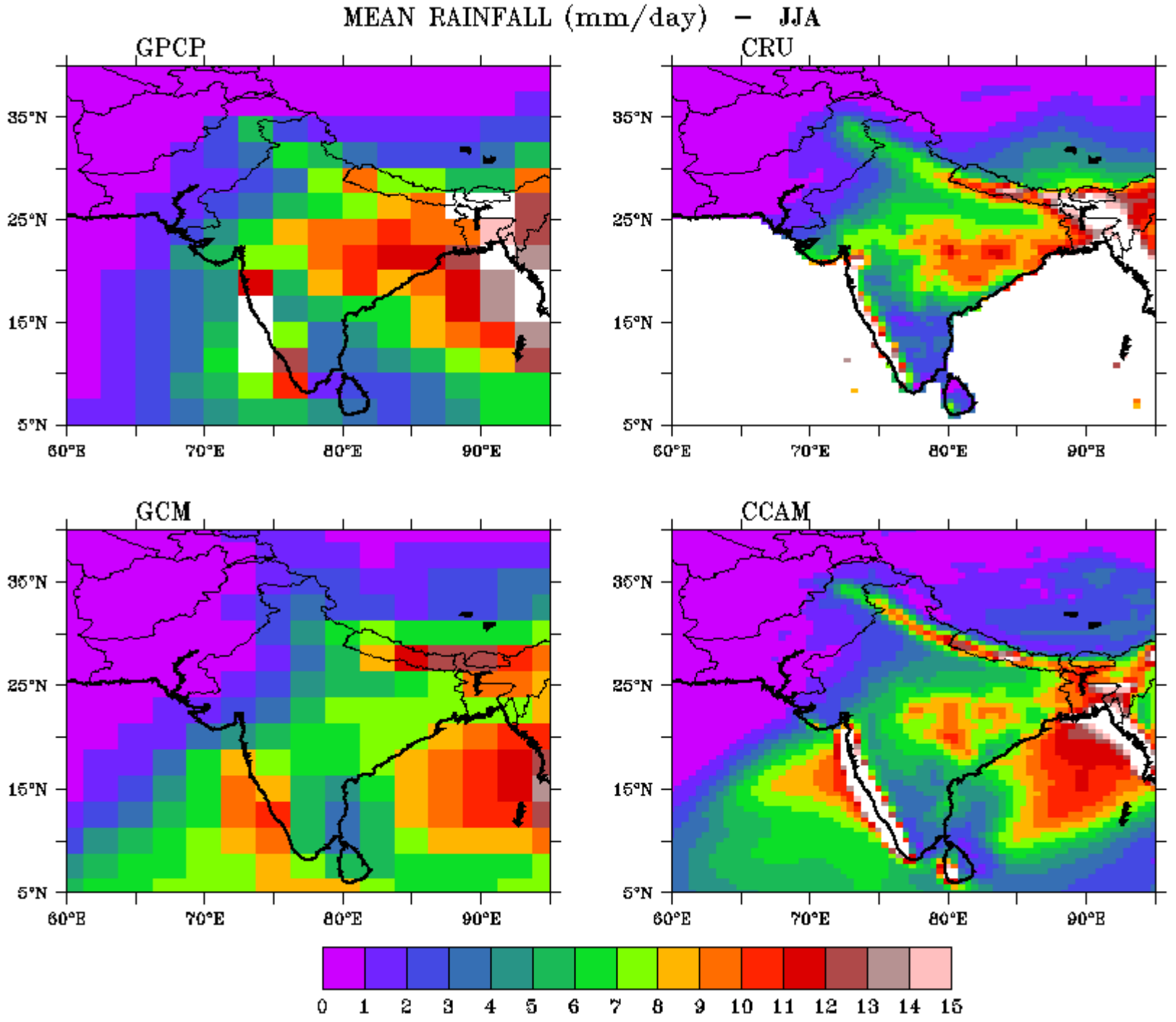


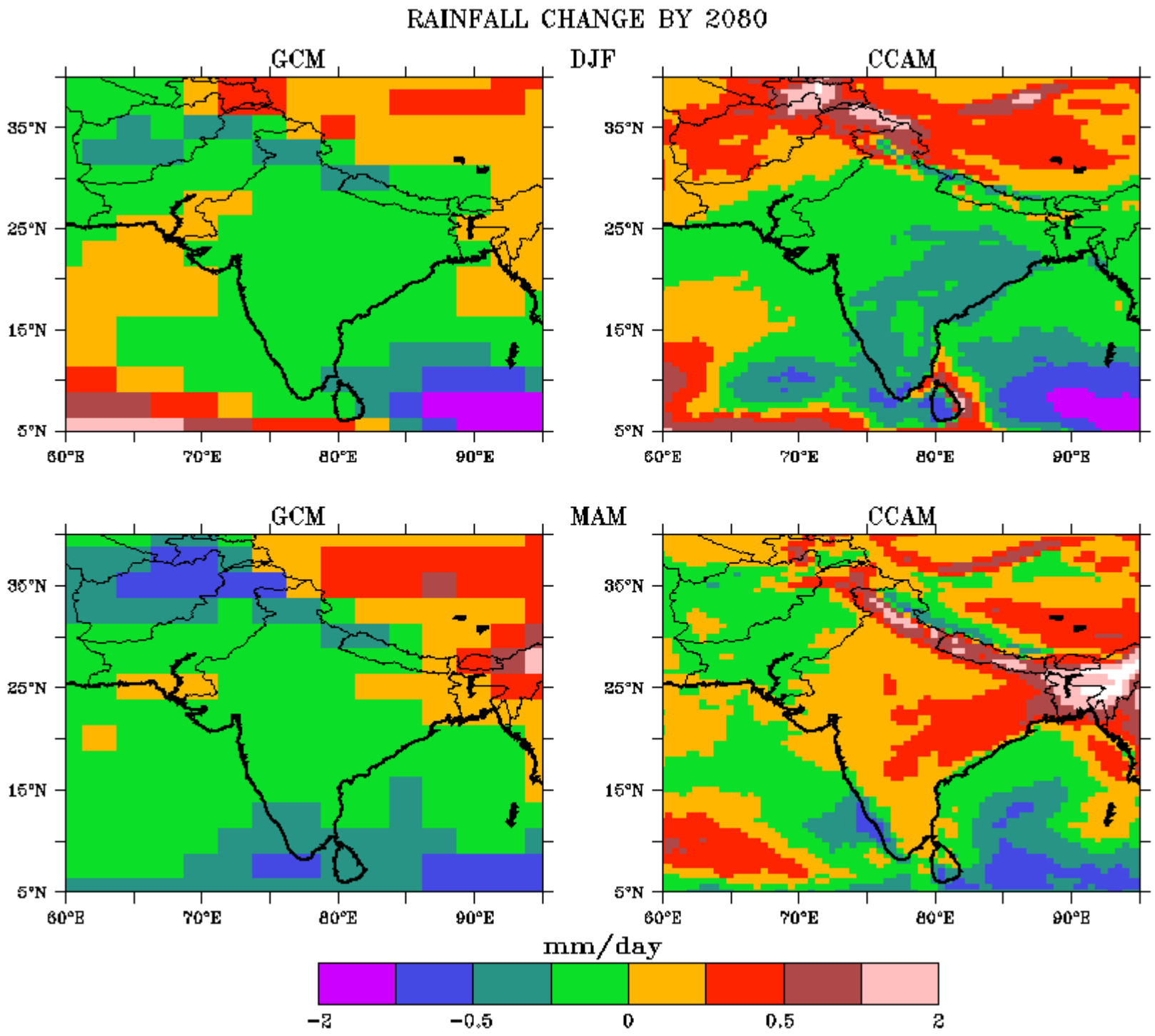
PCP*30.5

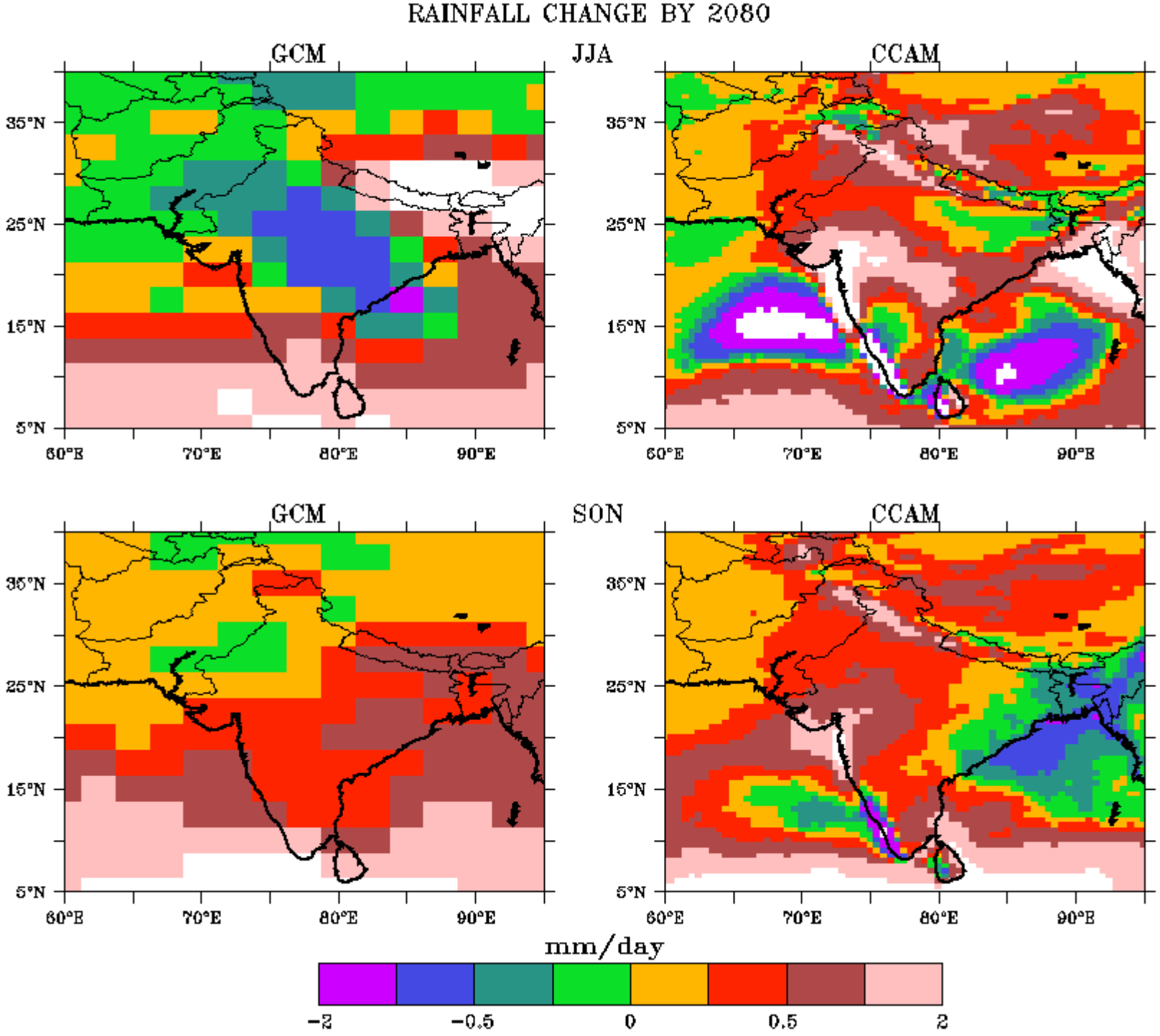
Ensemble CCAM



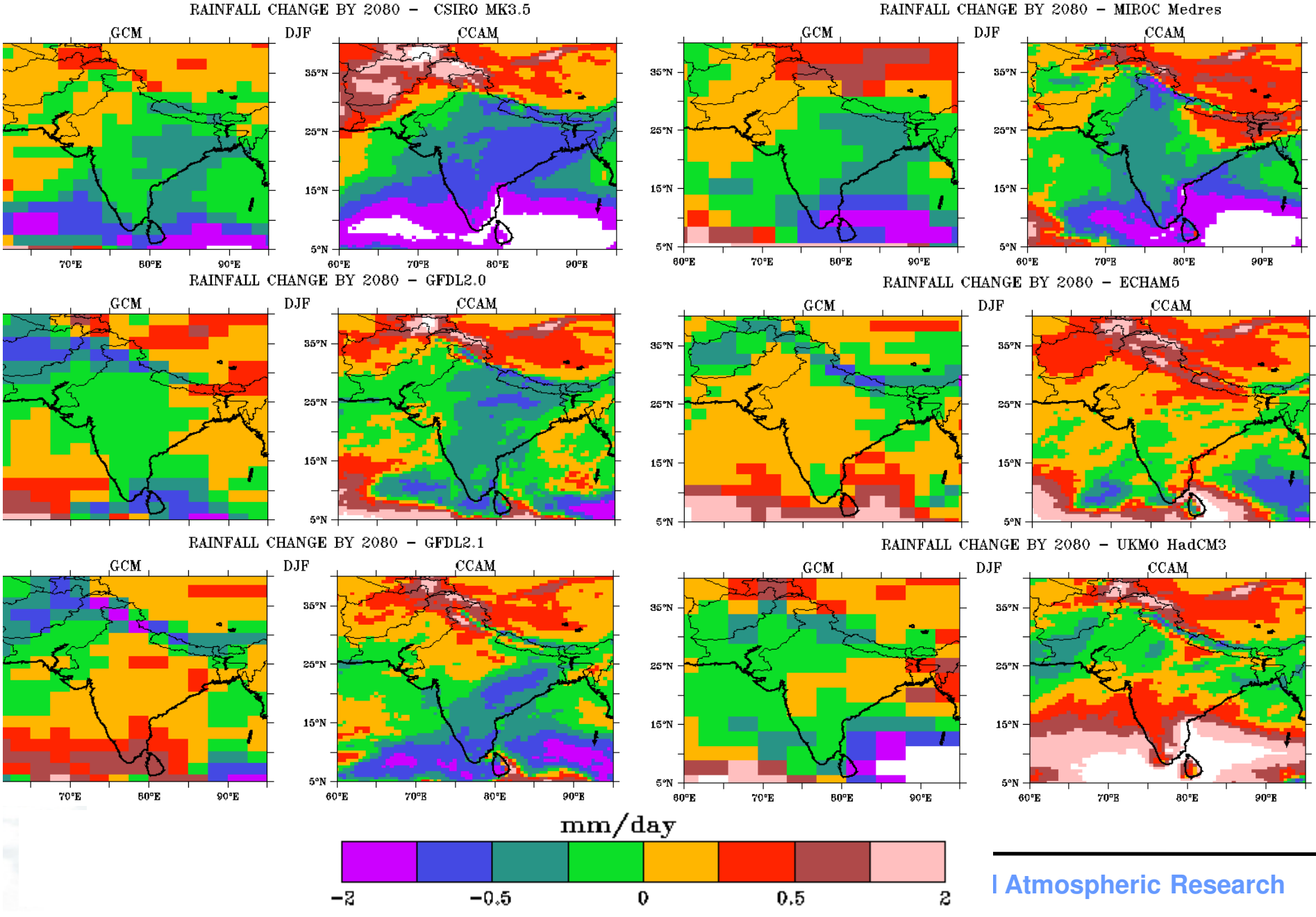
Precipitation (mm/day)


MEAN RAINFALL (mm/day) – JJA
GPCP
CRU
GCM
CCAM
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

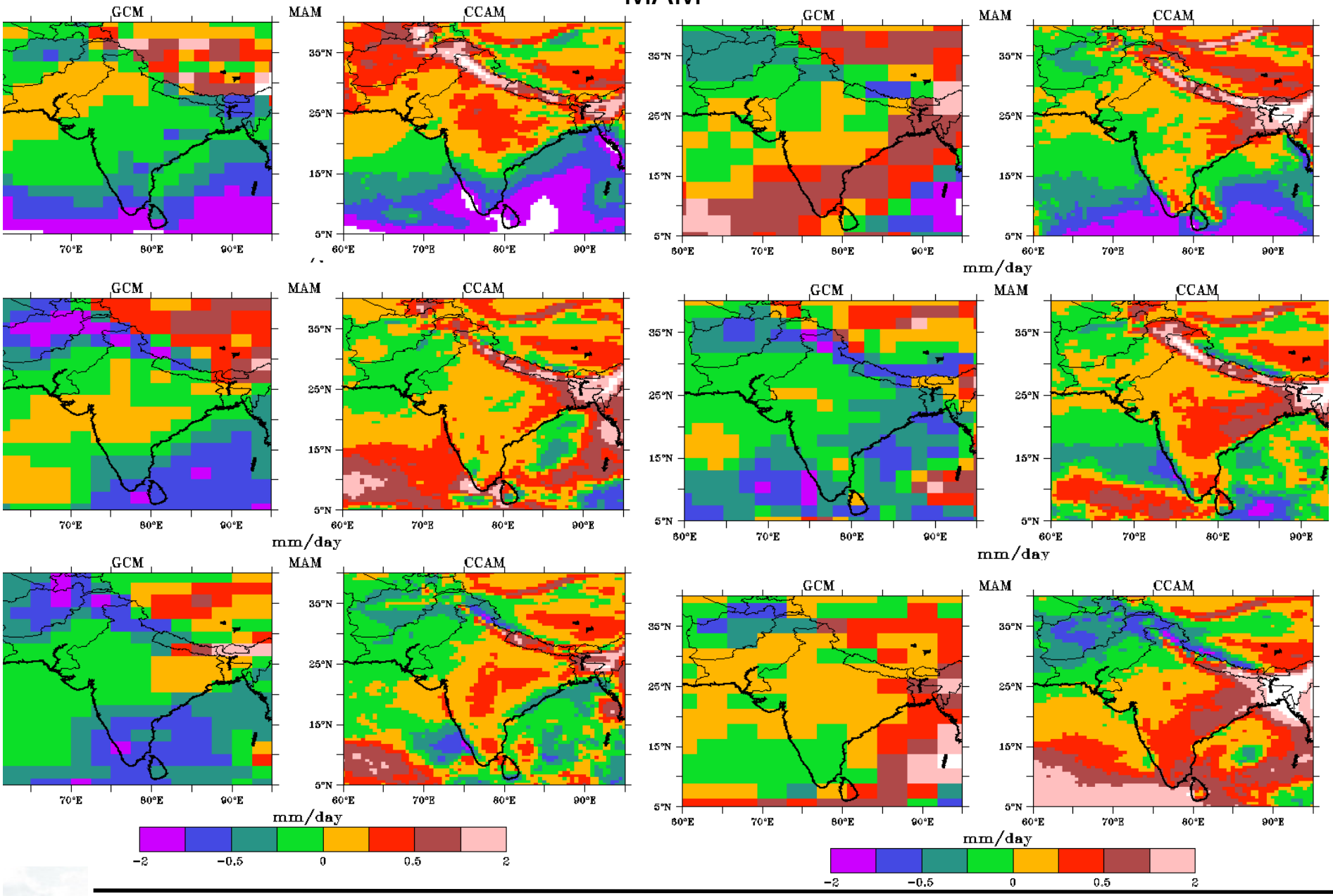

RAINFALL CHANGE BY 2080
GCM
DJF
CCAM
GCM
MAM
CCAM
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
mm/day
−2
−0.5
0
0.5
2


RAINFALL CHANGE BY 2080
GCM
JJA
CCAM
GCM
SON
CCAM
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
mm/day
−2
−0.5
0
0.5
2

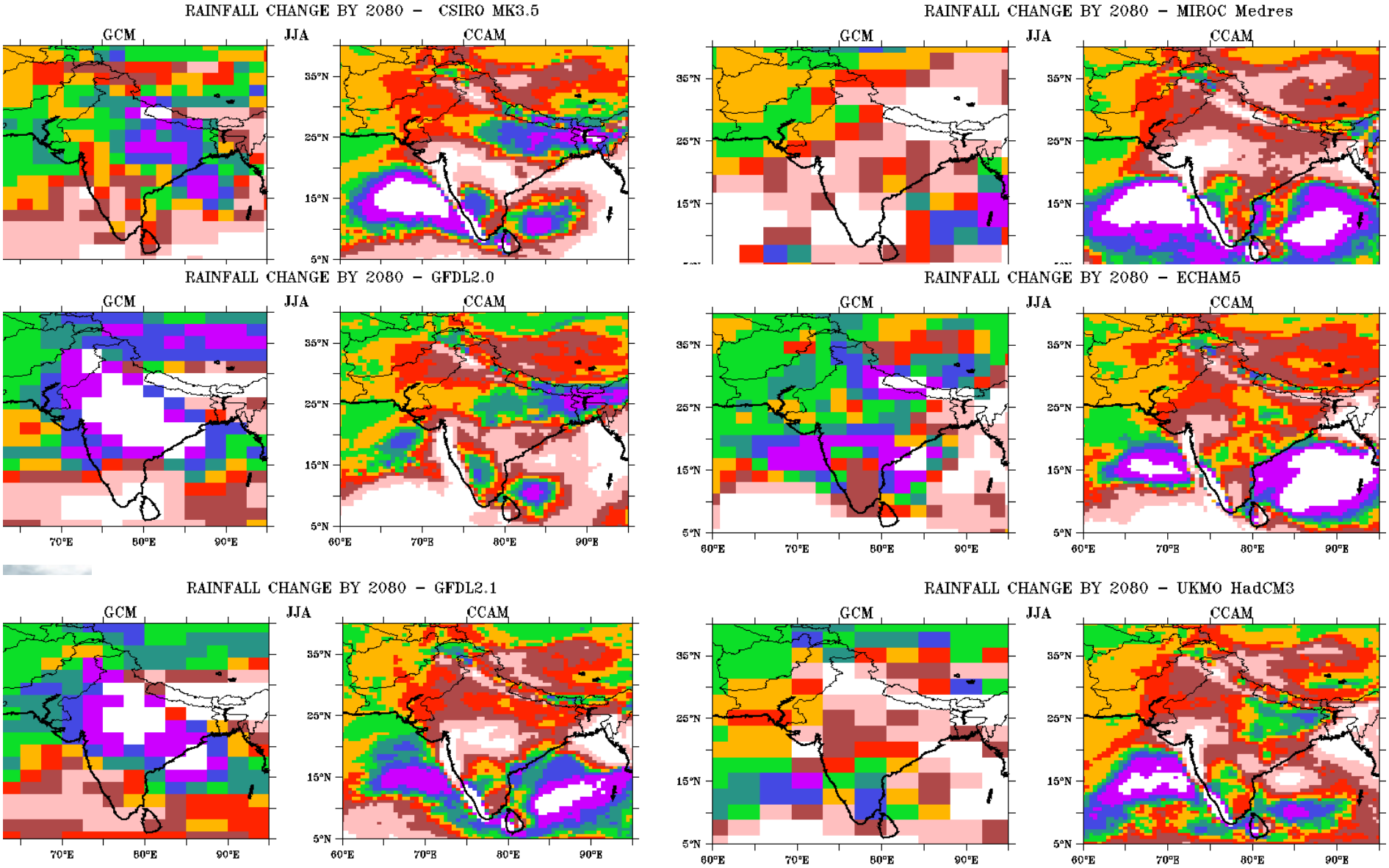
Rainfall change by 2080 mm/d DJF From individual GCMs



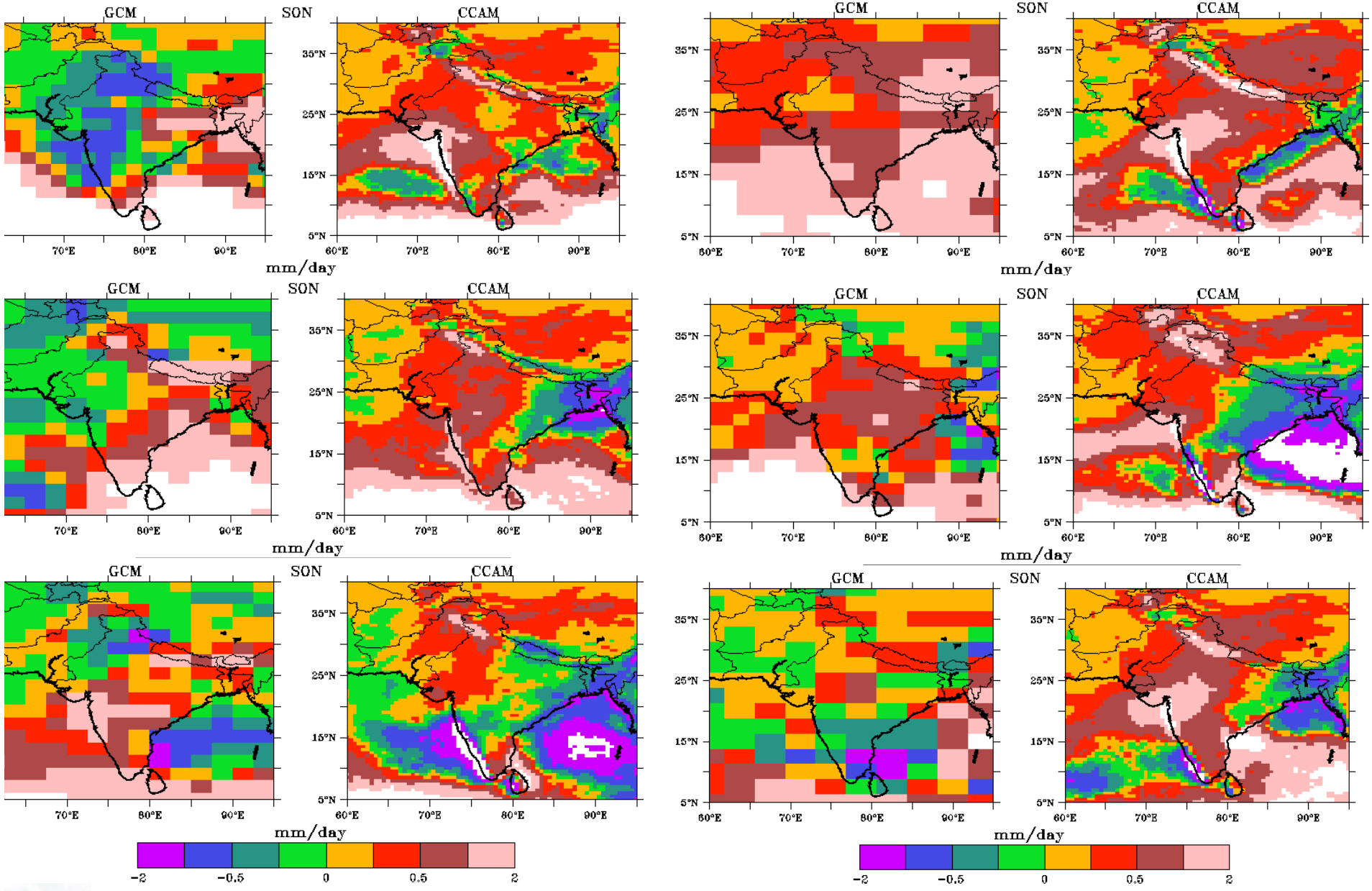
MAM



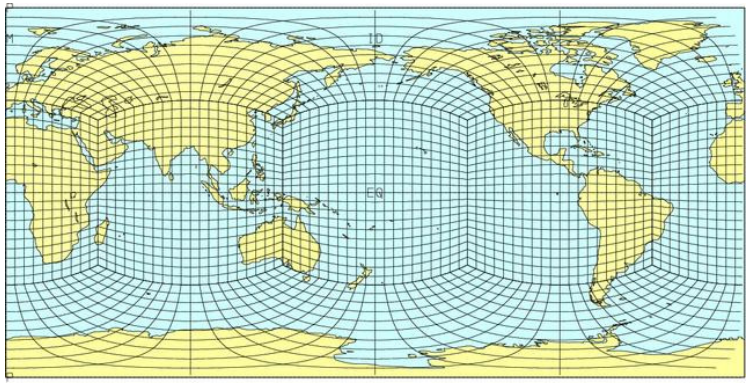
JJA


RAINFALL CHANGE BY 2080 – CSIRO MK3.5
RAINFALL CHANGE BY 2080 – MIROC Medres
RAINFALL CHANGE BY 2080 – GFDL2.0
RAINFALL CHANGE BY 2080 – ECHAM5
RAINFALL CHANGE BY 2080 – GFDL2.1
RAINFALL CHANGE BY 2080 – UKMO HadCM3
GCM
JJA
CCAM
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
mm/day
−2
−0.5
0
0.5
2

SON



Model developments



Equi-angular gnomonic C20 grid

- CABLE canopy/carbon scheme has been included
- mixed-layer-ocean available
- aerosol scheme added
- urban scheme added
- TKE boundary scheme available
- new GFDL radiation scheme available
- new version on gnomonic grid (VCAM), in flux-conserving form (being able to achieve conservation is another advantage of stretched global models) – now working
- coupling to PCOM (parallel cubic ocean model) of Motohiko Tsugawa from JAMSTEC underway

  (3:way: CSIRO+JAMSTEC+CSIR_SouthAfrica)

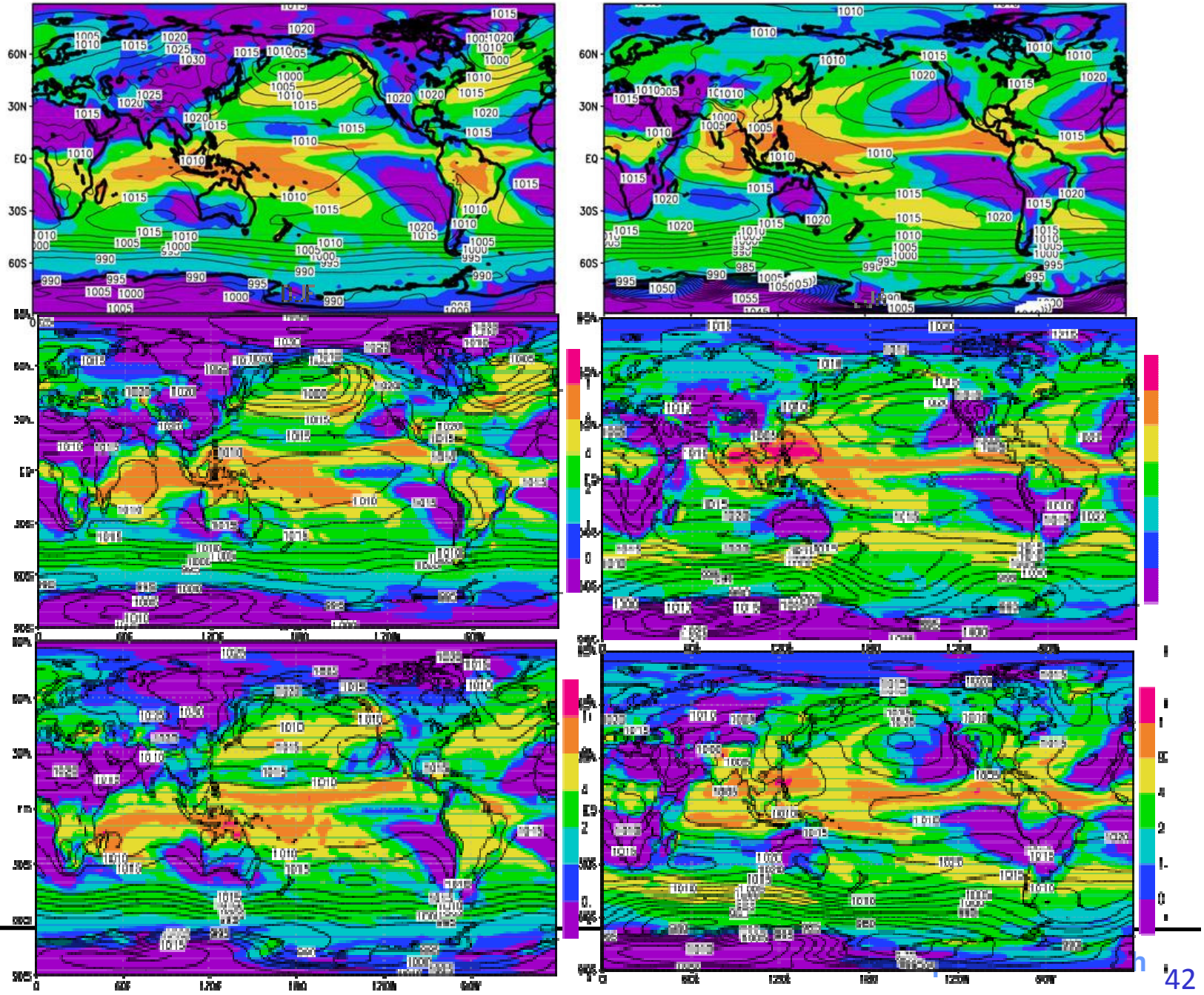
Same physics

DJF JJA

Obs climate

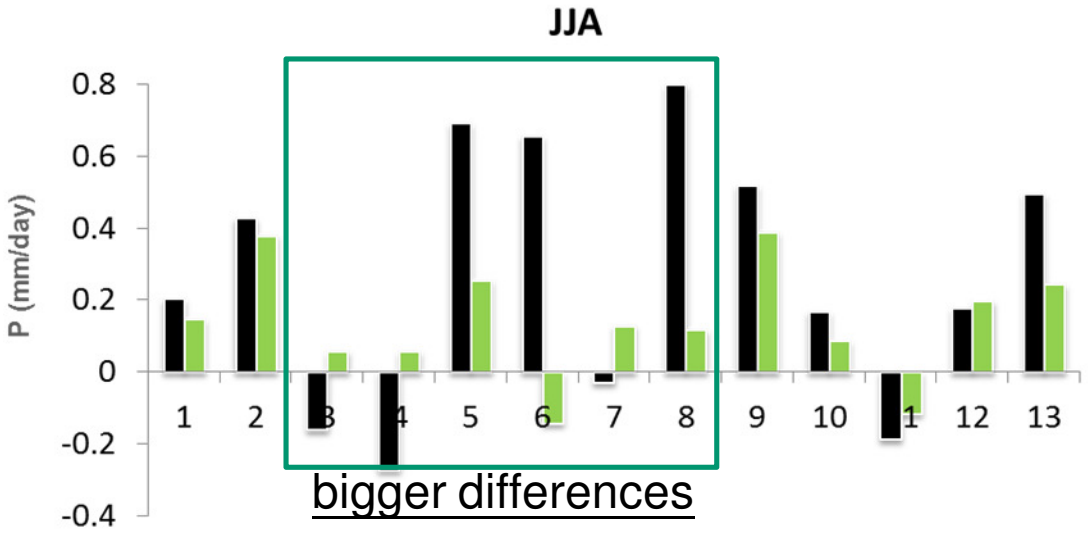
VCAM 1-year

CCAM 1-year



Thank you!

RMIP3 precipitation changes in different sub-regions



bigger differences

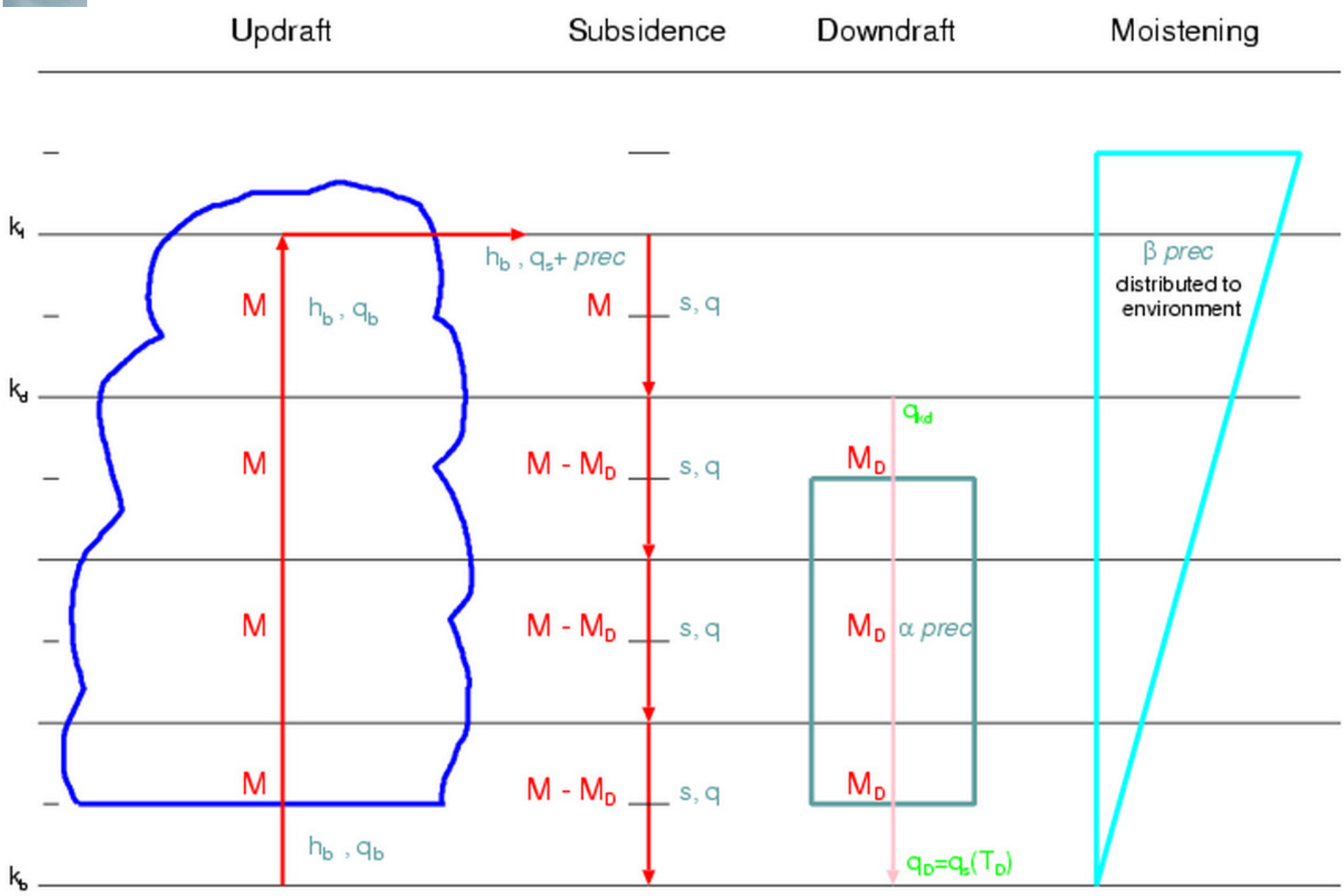
1, Asia
2, Korea/Japan
3, Arid/Semi arid area
4, North China
5, Center China
6, South China
7, Tibet
8, Southeast Asia
9, India
10, North Maritime
11, South Maritime
12, Land
13, Ocean

	ECHAM5	ENSEM.	Uncertainty Range	IV
Arid/semi arid	-0.16	0.06	-0.05~0.34	0.13
North China	-0.27	0.06	-0.18~0.54	0.22
Center China	0.69	0.25	-0.34~0.82	0.40
South China	0.66	-0.14	-0.48~0.27	0.24

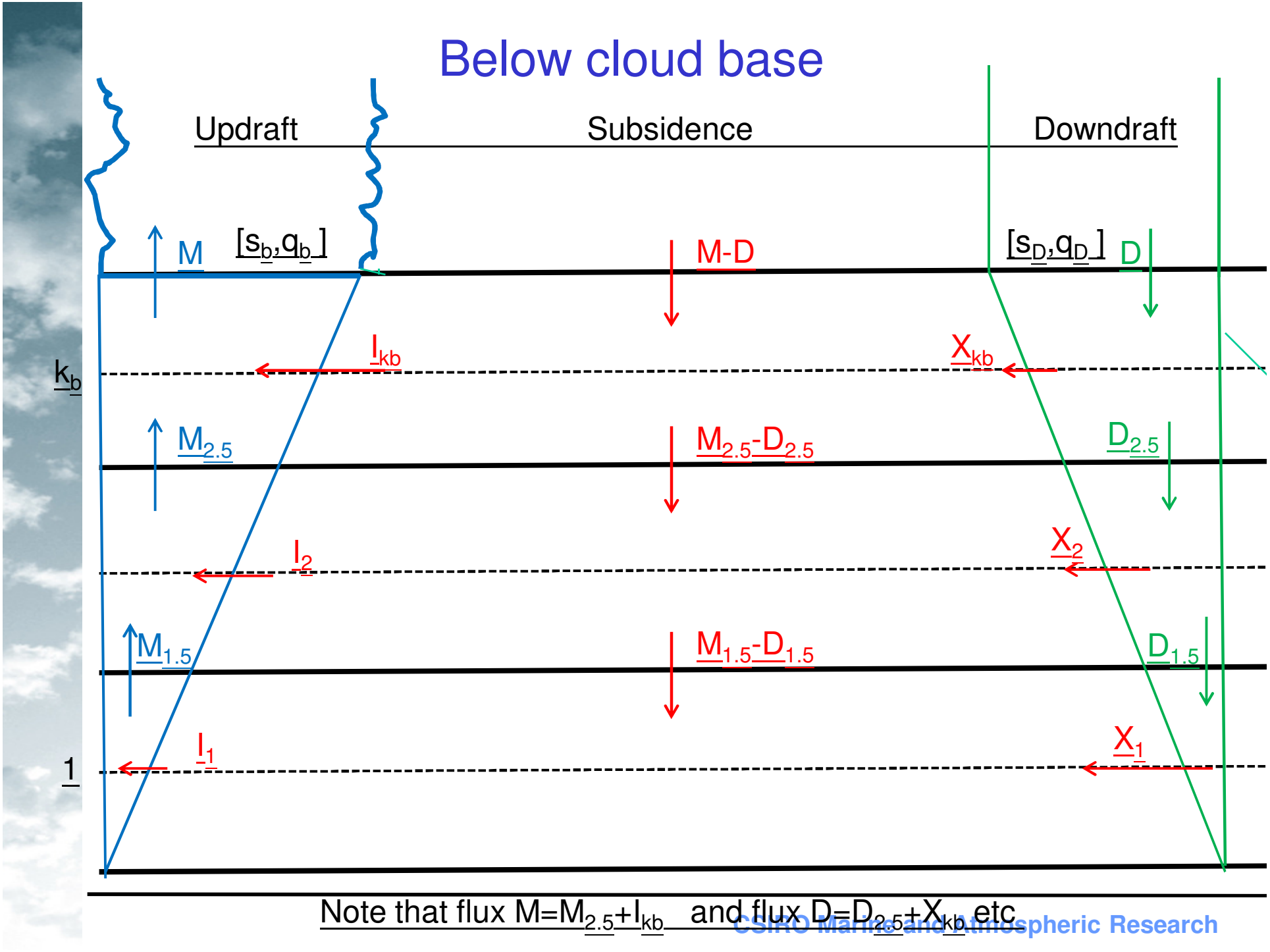
Description of the cumulus parameterization

- In each convecting grid square there is an upward mass flux within a saturated aggregated plume.
- There is compensating subsidence of environmental air.
- Closure is that convection is allowed to continue until the modified environment no longer supports a cumulus plume having the current cloud-base and cloud-top levels. The closure is simply that the mass flux be the minimum flux for which this occurs.

Above cloud base



Below cloud base



Note that flux $M=M_{2.5}+I_{kb}$ and flux $D=D_{2.5}+X_{kb}$ etc