Numerical Simulations of the Effect of Black Carbon Aerosol on Regional Climate in Southeast Asia and Vietnam

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Why is BC considered?

- BC has a significant contribution to global radiative forcing and global climate change.
- BC can mix with other aerosols to form atmospheric brown clouds (ABCs) which absorb incoming solar radiation and prevent it from reaching the surface, warming the atmosphere in the process.
- Clouds contain BC also prevent longwave from leaving the surface, warming the ground.
- BC has a much shorter lifetime compared with CO2 (the most important GRH gas) → control of soot may be the fastest method of slowing warming for a specific period ?


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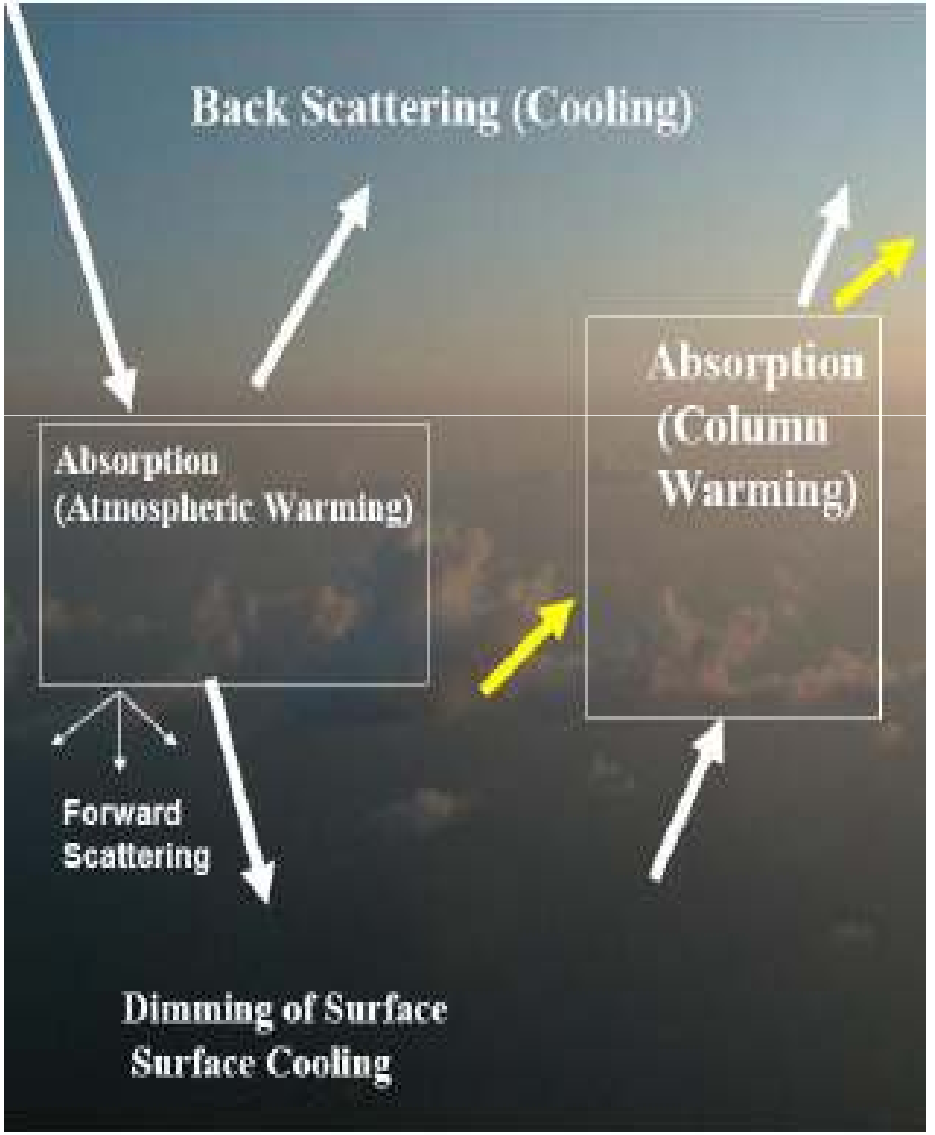
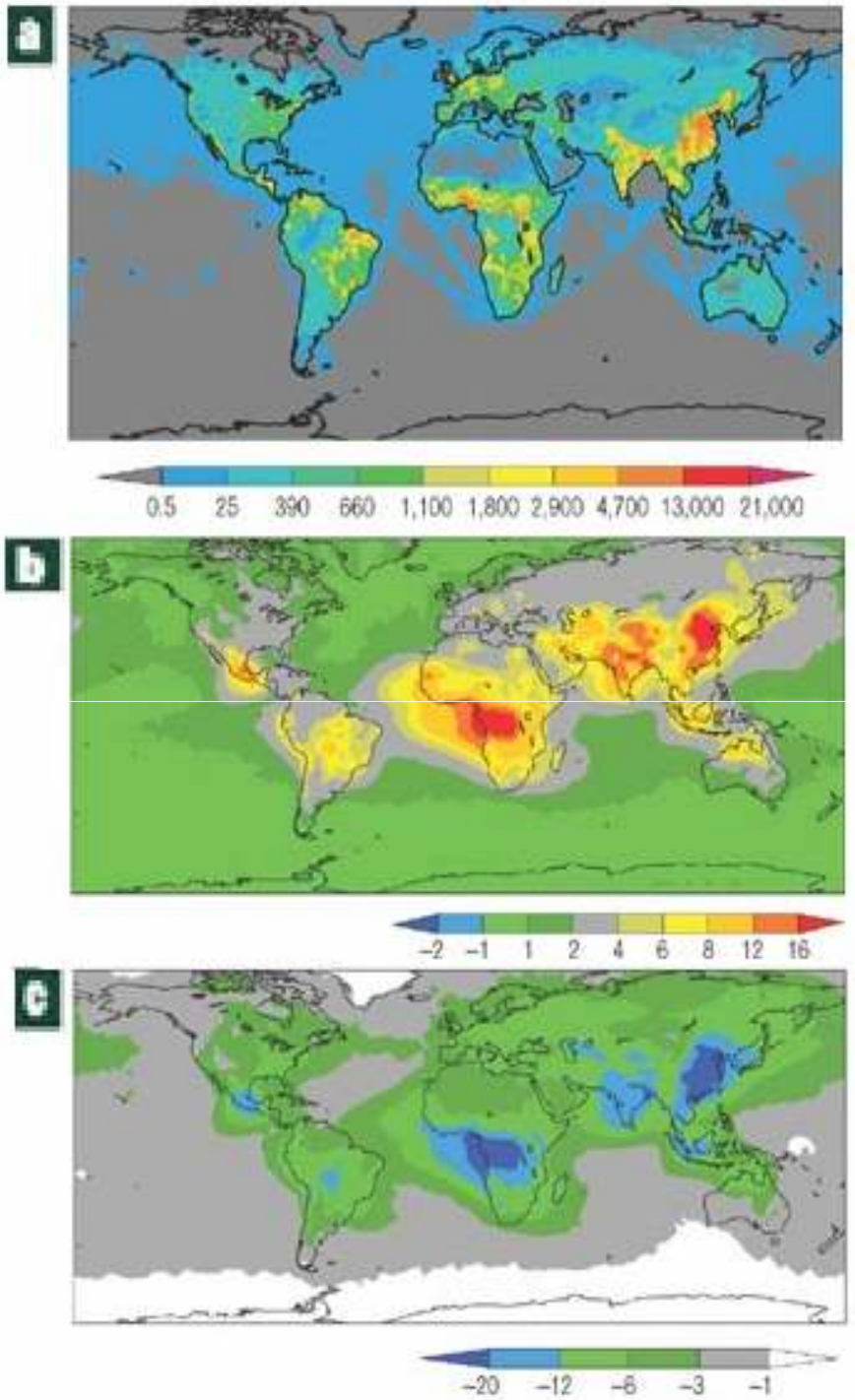
nature
TRAUMATIC BRAIN INJURY
Consciousness raising therapy
VERTEBRATE ORIGINS
Gone fishing
EATING IN THE GREENHOUSE
Are high-CO_2 crops bad for you?
THE HEAT IS ON
Atmospheric brown clouds enhance climate warming
Ramanathan et al, Nature, 448, 2007.


Back Scattering (Cooling)
Absorption (Atmospheric Warming)
Absorption (Column Warming)
Forward Scattering
Dimming of Surface
Surface Cooling

a, BC emission strength (tons year^{-1}) [Bond *et al*.], including emissions from fuel combustion (fossil fuels and biofuels) and open biomass burning (forest fires, savanna burning and outdoor cooking) for the year 1996. The uncertainty in the regional emission is about ± 100% or more.

b, Atmospheric solar heating due to BC [Chung *et al*.] for the 2001 to 2003 period. This study integrates satellite aerosol data, surface network of aerosol remote sensing instruments and field observations with an aerosol-transport-chemical model and a radiative transfer model to obtain the forcing Uncertainty in the forcing is ±30%.

c, As in **b**, but for surface dimming due to ABCs: the reduction in absorbed solar radiation at the surface by all anthropogenic aerosols (BC and non-BC) in ABCs.



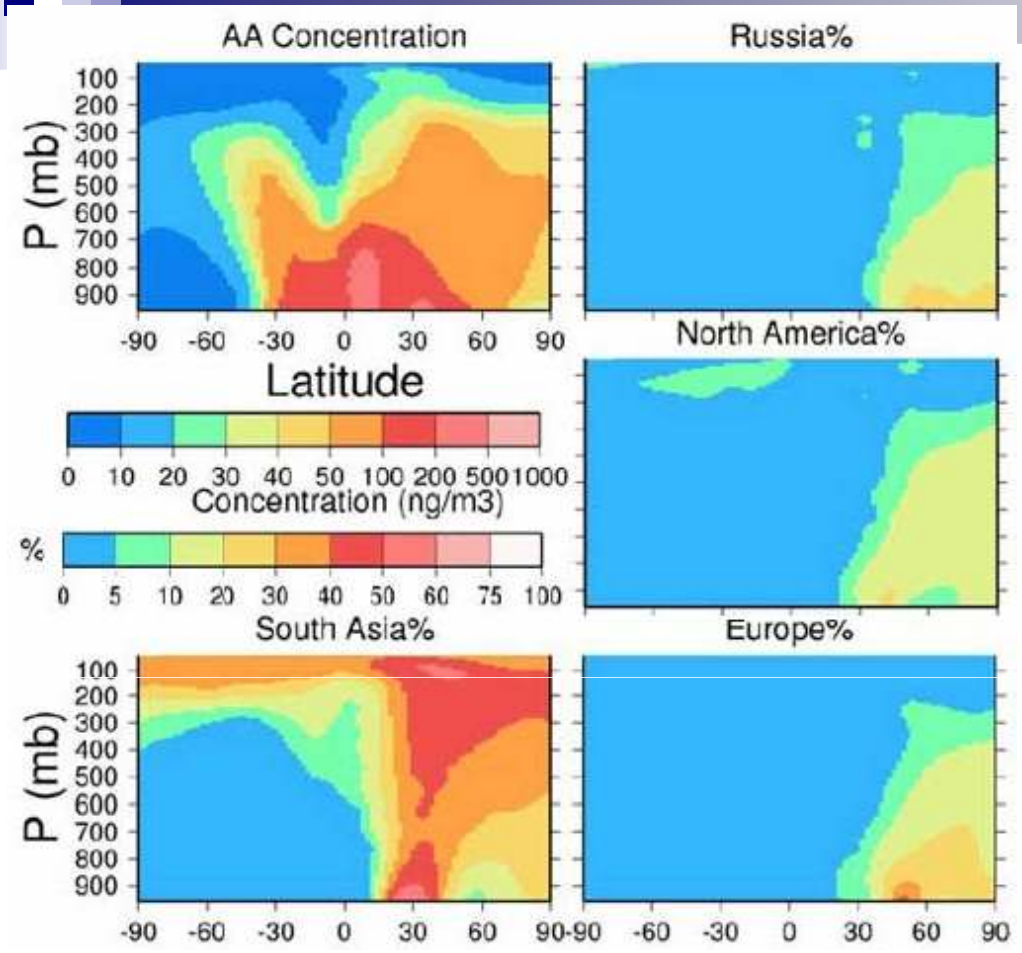


Fig. 1: Regional Concentrations of Black Carbon: (top left) Annual zonal mean black carbon concentration and percent contributions from regional experiments. Credit: NASA/GISS: http://www.nasa.gov/centers/goddard/news/topstory/2005/arctic_soot.html

Aims

1. To numerical simulate the possible impact of Black Carbon (BC) aerosol on climate using a Regional Climate Model (RegCM3)
2. To understand the effect of BC on climate of Southeast Asia and Vietnam

Why is Southeast Asia focused on?

- Emissions from China and India alone account for 25 to 35% of global BC emissions → the regional climate responses to BC are expected to be large.
- BC emissions from China in 2006 have doubled since 2000 (newest estimated).
- The majority of soot emission in South Asia is due to biofuel cooking, whereas in East Asia, coal combustion for residential and industrial uses plays a larger role.
- With the economies of China and India expanding with double digit growth rates, Asia can become a much larger source of ABCs.

Why is RegCM3 chosen?

- Compared to global climate models (GCMs), the relatively high-resolution and detailed physical parameterizations offered by RegCM3 (RCMs) are particularly suitable to describe the complexity of aerosol processes.
- BC has a much shorter lifetime compared with CO2 → highly spatial variability determined by local sources, rapid chemical transformations, transport and removal processes → particularly relevant at the regional scale.
- Solmon F. et.al. (2006): RegCM, Europe, Africa
- Y.Liu (2005): RegCM, America

Precipitation and Temperature at 2m-heigh simulated by RegCM3 without Aerosol Impact compared CRU

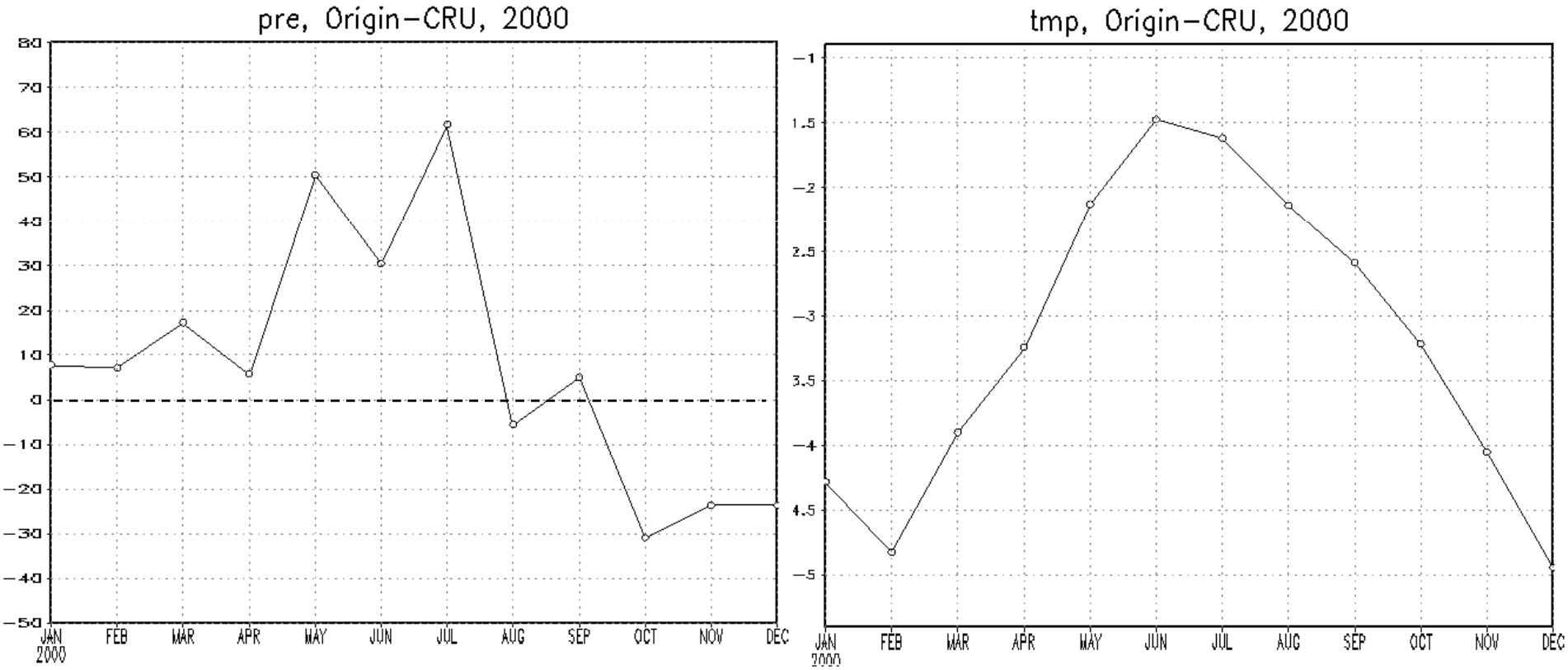
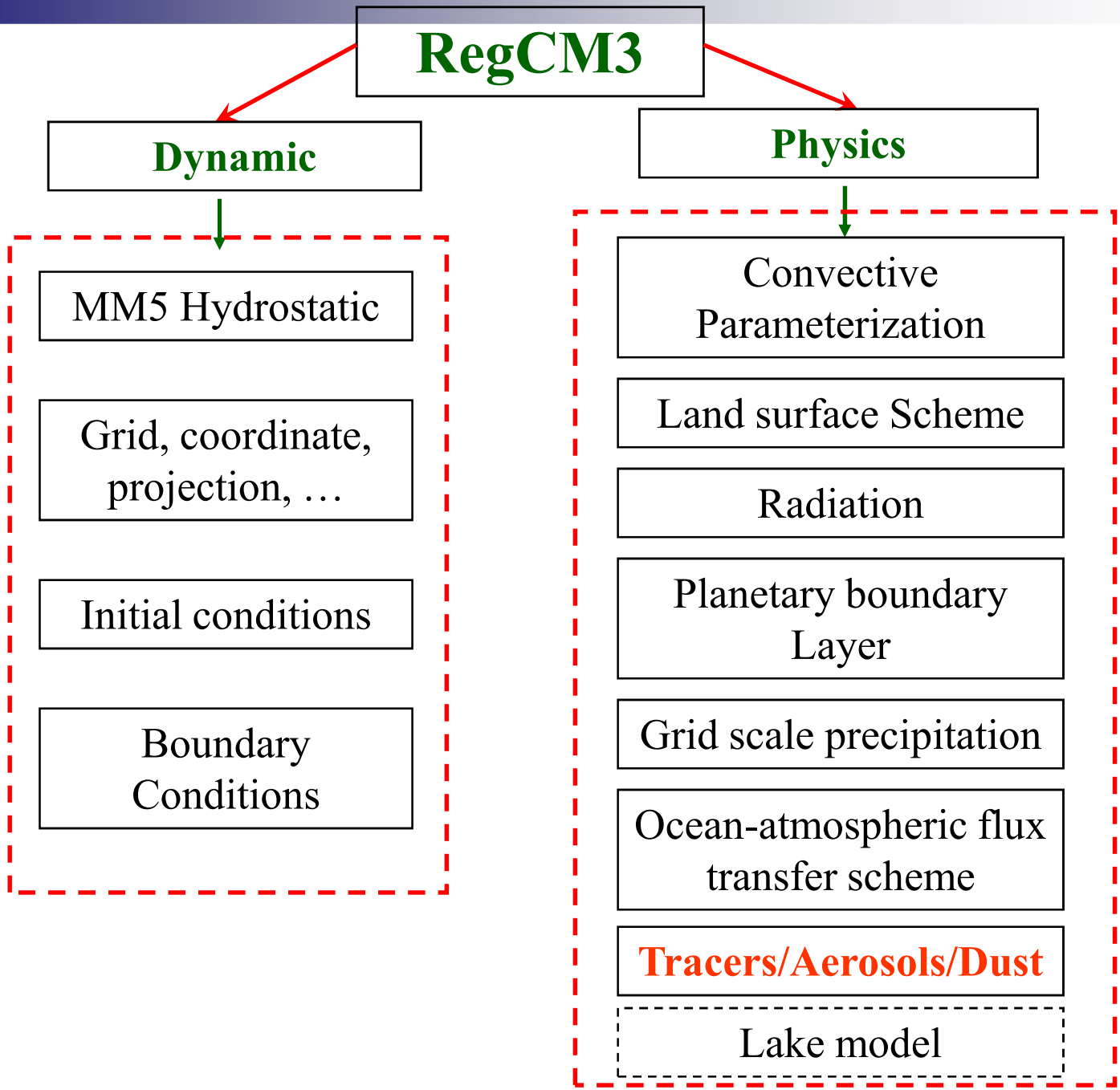


Fig. 3: Precipitation (left) and Temperature at 2m-heigh (right) simulated by RegCM3 without Aerosol Impact compared with CRU.


RegCM3
Dynamic
Physics
MM5 Hydrostatic
Grid, coordinate, projection, …
Initial conditions
Boundary Conditions
Convective Parameterization
Land surface Scheme
Radiation
Planetary boundary Layer
Grid scale precipitation
Ocean-atmospheric flux transfer scheme
Tracers/Aerosols/Dust
Lake model

- Domain: Fig. 2
- Resolution: 54km
- Initial and Boundary Conditions: ECMWF Reanalysis (ERA40)
- Simulation period: 01Jan2000 – 01Jan2001

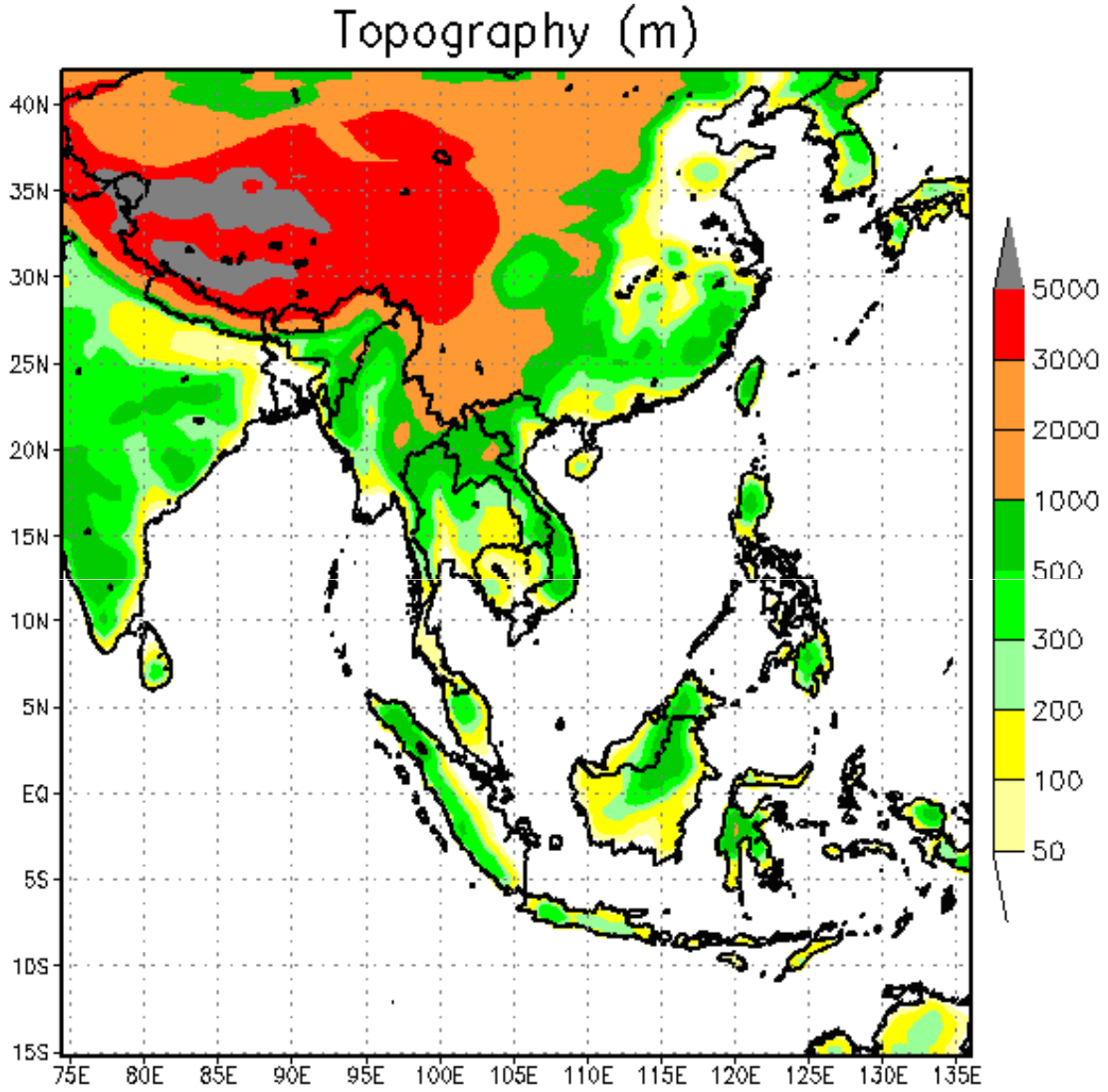
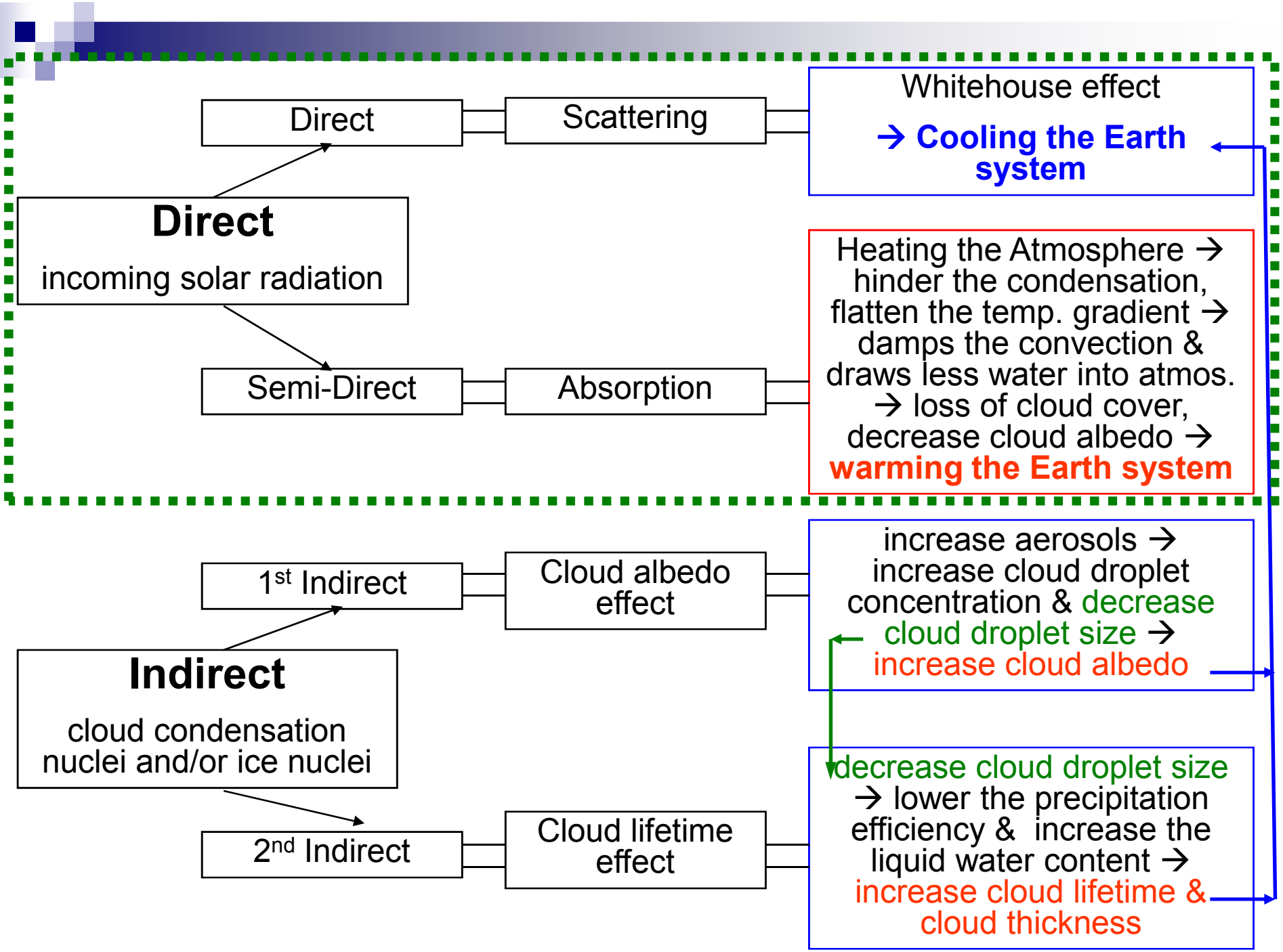


Fig. 2: Integrated domain and topography in meters.


Direct
Scattering
Whitehouse effect
→ Cooling the Earth system
Direct
incoming solar radiation
Semi-Direct
Absorption
Heating the Atmosphere → hinder the condensation, flatten the temp. gradient → damps the convection & draws less water into atmos. → loss of cloud cover, decrease cloud albedo → warming the Earth system
1st Indirect
Cloud albedo effect
increase aerosols → increase cloud droplet concentration & decrease cloud droplet size → increase cloud albedo
Indirect
cloud condensation nuclei and/or ice nuclei
2nd Indirect
Cloud lifetime effect
decrease cloud droplet size → lower the precipitation efficiency & increase the liquid water content → increase cloud lifetime & cloud thickness

Contents

1. The Direct and Feedback Radiative Forcings of BC
2. Impact of Anthropogenic/Industrial BC on climate

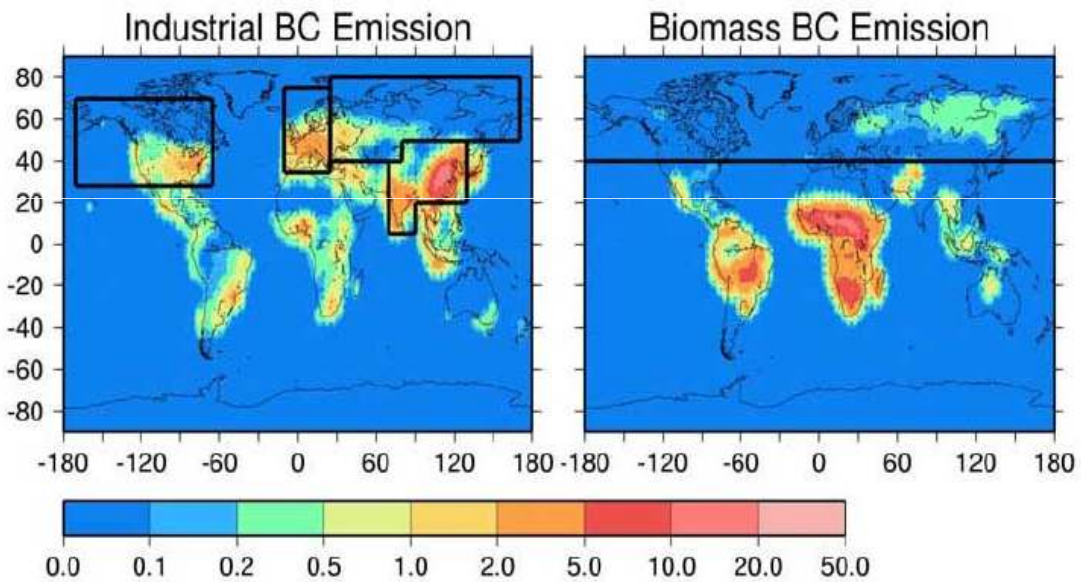
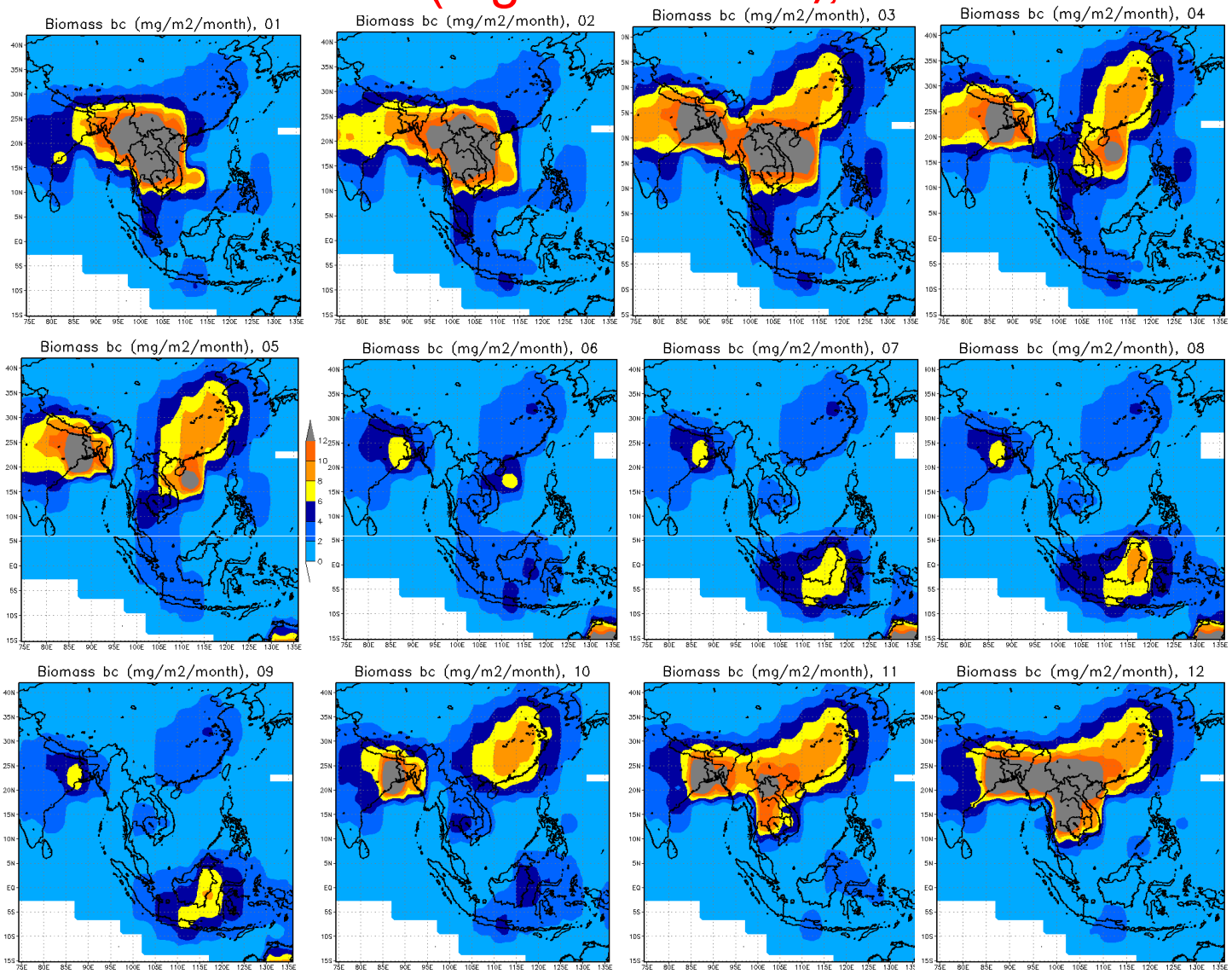


Fig. 4: Black Carbon Emissions: Industrial and biomass black carbon emissions with boxed areas showing regions assumed in the model experiments. Credit: NASA/GISS: http://www.nasa.gov/centers/goddard/news/topstory/2005/arctic_soot.html

BC impact Experiments

Experiments	**Black carbon contribution**
CONT.	Control: RegCM3 without BC
EXP.1	AER**01**D0_***D:*** RegCM3 with the ***direct*** radiative forcing of **biomass burning** BC
EXP.2	AER**01**D0_***F:*** RegCM3 with the ***feedback*** radiative forcing of **biomass burning** BC
EXP.3	AER**11**D0_***F:*** RegCM3 with the ***feedback*** radiative forcing of **both biomass burning and anthropogenic** BC

Biomass BC (mg m^{-2} $month^{-1}$), Observation



Anthropo-genic BC (mg m^{-2} $month^{-1}$)

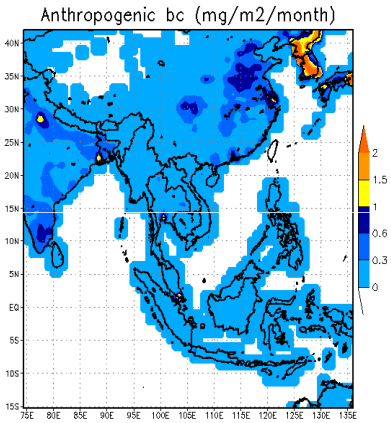


Fig. 5: Monthly (Jan-Dec) black carbon concentration (mg m-2 month-1) from biomass burning (left) and annually black carbon concentration (mg m-2 month-1) from anthropogenic activities (right). [Source: Liousse et al., 1996].

Some Results

Fields analysed

- Top of Atmosphere (TOA) radiation forcing
- Surface (SRF) radiation forcing
- Total Optical Depth (TOD)
- Total Cloud (TCLD)
- Monthly Temperature at 2m-heigh (T2m)
- Monthly Rainfall

1. The Direct and Feedback Radiative Forcings of BC

TOA radiation forcing, EXP.1

TOA radiation forcing, EXP.2

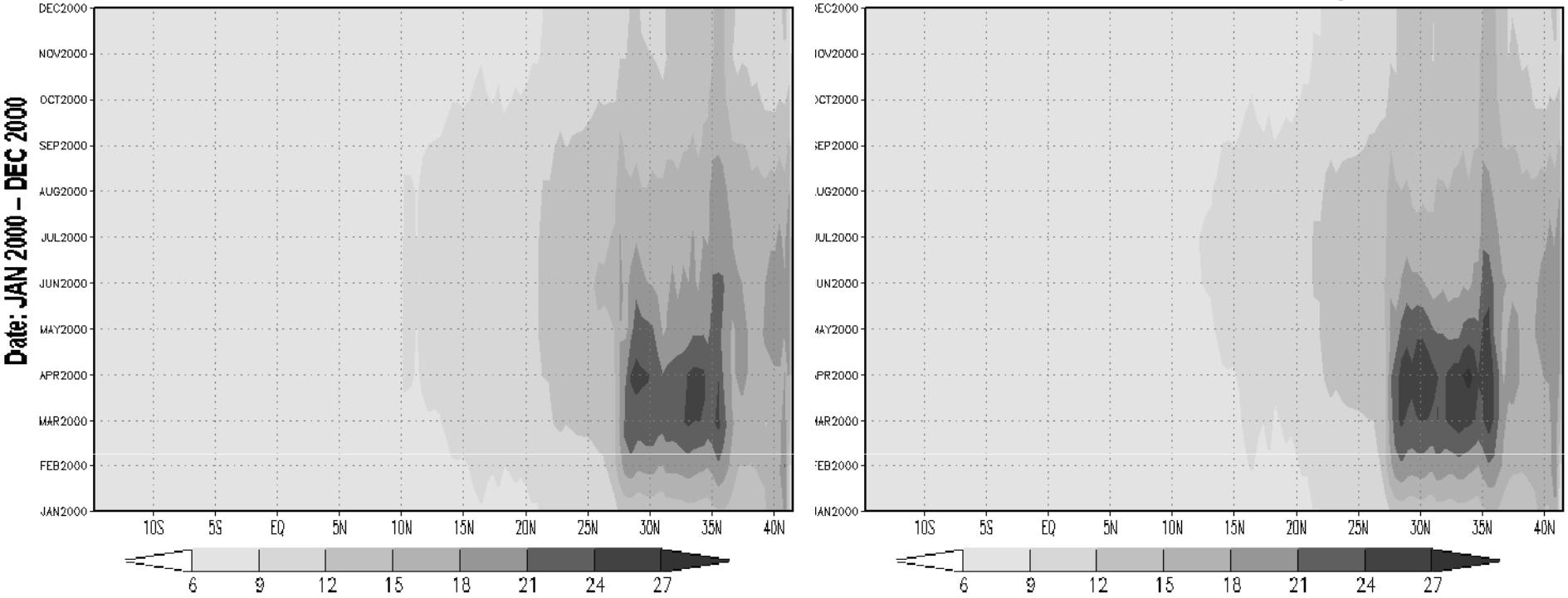
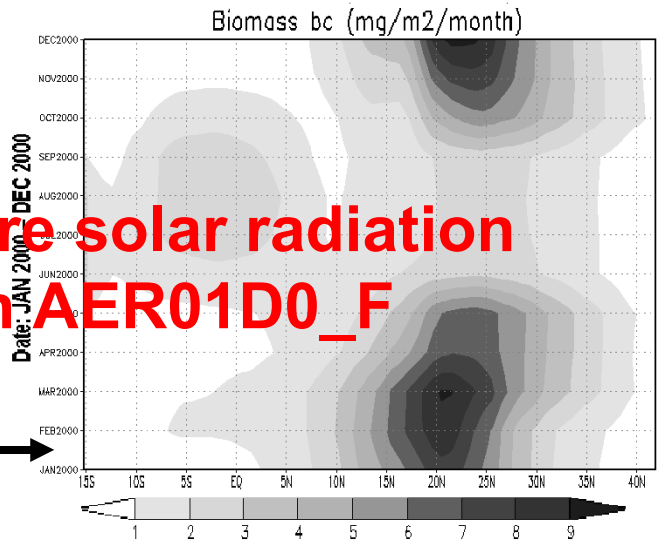


Fig. 7: Latitude – time cross section of monthly radiative forcing (W m-2) at TOA in 2000 of AER01D0_D (left) and AER01D0_F (right)

Positive TOA radiative forcing → more solar radiation is allowed to reach the surface in AER01D0_F

Fig. 8: Latitude – time cross section of monthly black carbon concentration (mg m-2 month-1) (Source: Liousse et al., 1996)



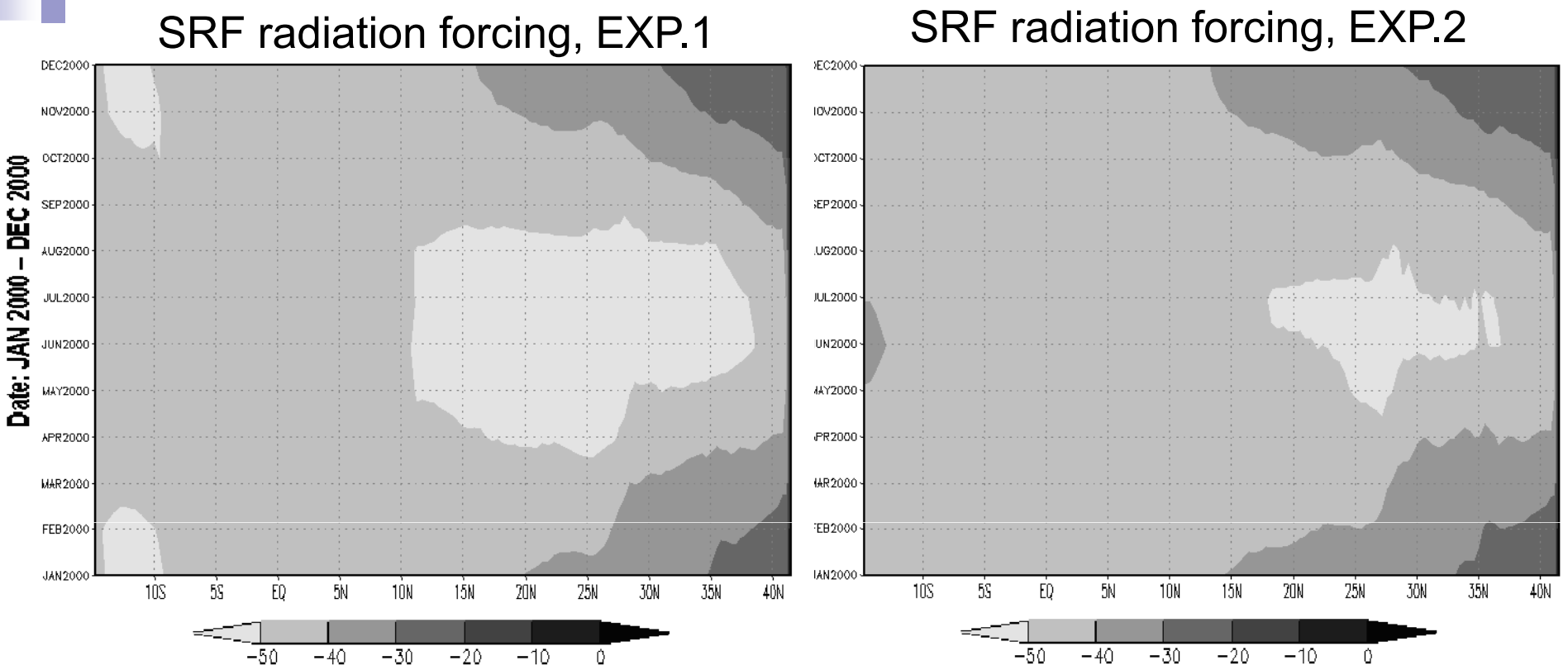


Fig. 9: Latitude – time cross section of monthly radiative forcing (W m-2) at SRF in 2000 of AER01D0_D (left) and AER01D0_F (right)

Negative SRF radiative forcing → less longwave emission leaves surface in AER01D0_F

Positive TOA & Negative SRF radiative forcing

- Maybe caused:
  - (1) by absorbing the solar radiation reflected by the surface–atmosphere–cloud system → BC reduces the albedo of the planet.
  - (2) soot deposited over snow and sea ice can decrease the surface albedo;
  - (3) soot inside cloud drops and ice crystals can decrease the albedo of clouds by enhancing absorption by droplets and ice crystals.

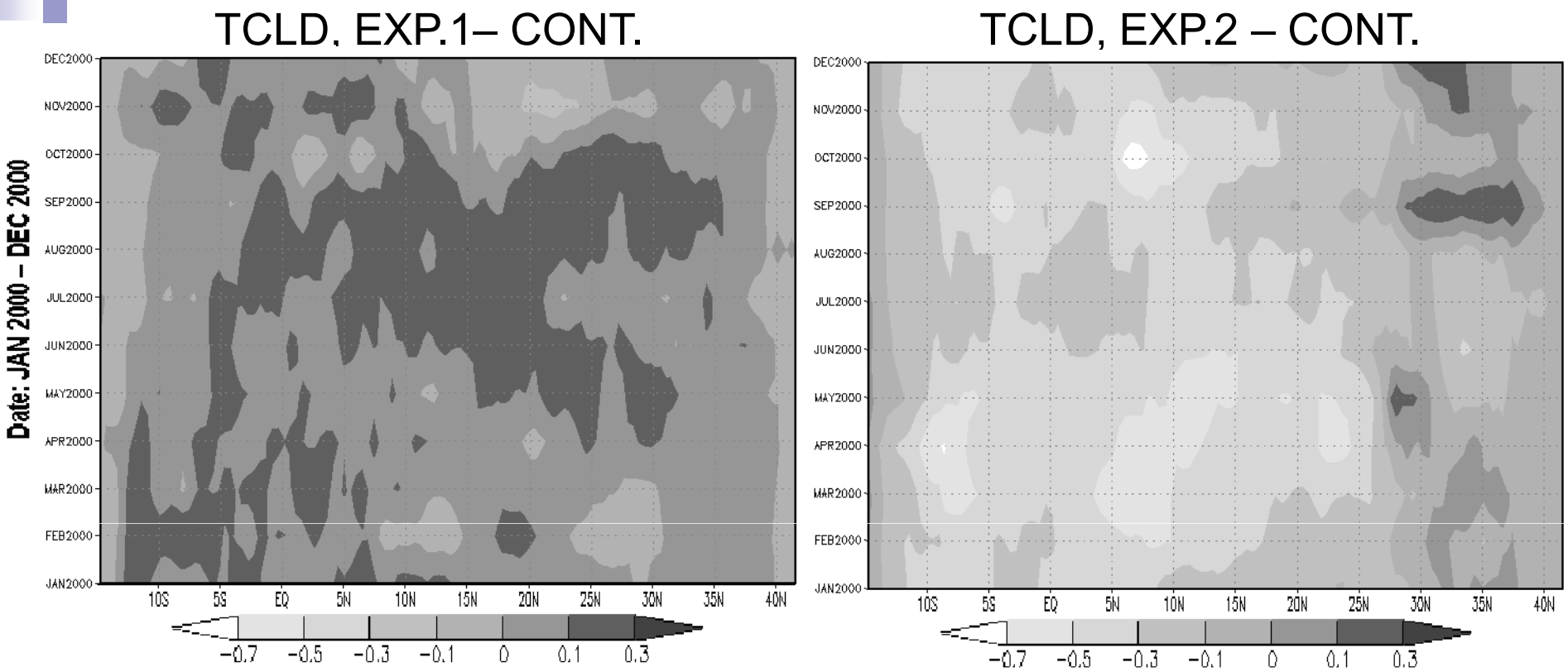


Fig. 10: Latitude – time cross section of monthly TCLD in 2000 of AER01D0_D (left) and AER01D0_F (right)

- BC solar heating can decrease the relative humidity of the cloud layer → drops the evaporation of cloud → decreases low cloud fraction and albedo.
- Decrease cloud fraction → decrease total optical depth TOD.

TOD, EXP.1

TOD, EXP.2

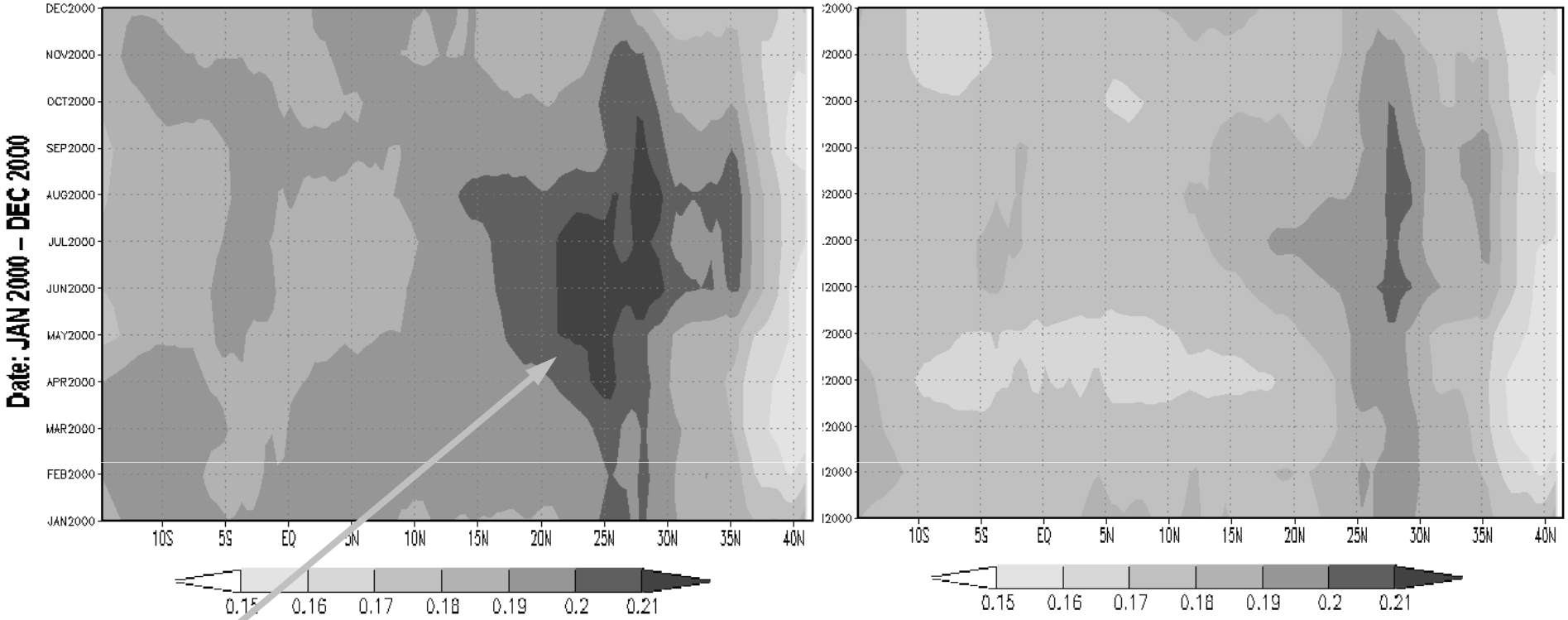


Fig. 11: Latitude – time cross section of monthly TOD in 2000 of AER01D0_D (left) and AER01D0_F (right)

Particles from burning biomass are less oily and contain a much lower BC fraction than fossil fuel soot particles → 'global dimming' effect.

Decrease cloud fraction and albedo and total optical depth TOD → This semi-direct effect can enhance the positive climate forcing by BC.

T2m, EXP.1 – CONT.

T2m, EXP.2 – CONT.

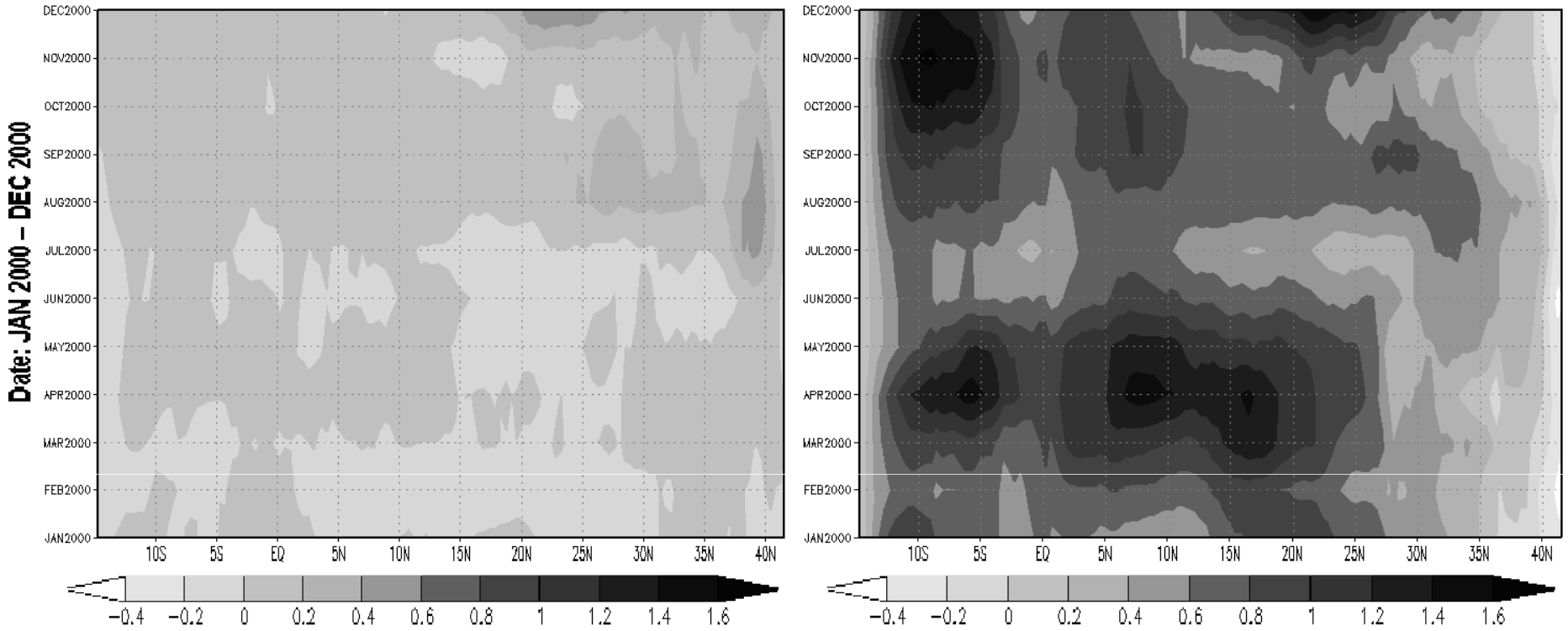


Fig. 12: Latitude – time cross section of monthly T2m (°C) in 2000 of AER01D0_D (left) and AER01D0_F (right).

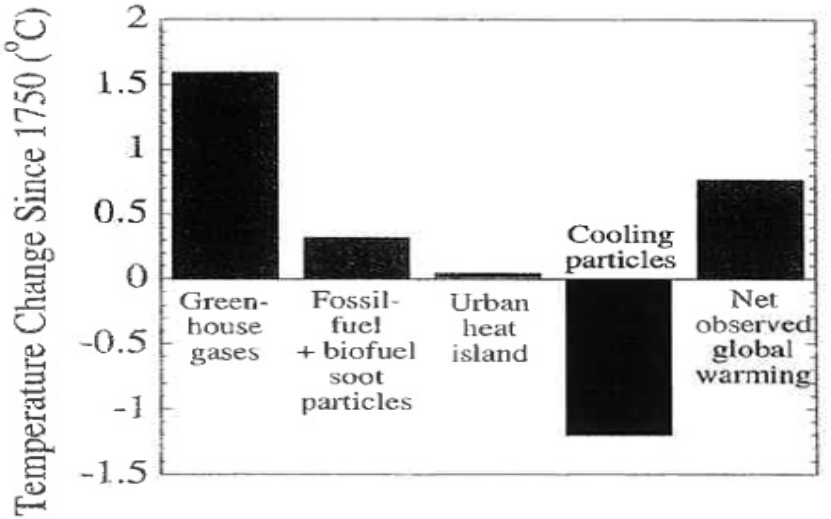


Fig. 13: Temperature Change (°C) since 1750 [www.treehugger.com/black%20carbon%20figure.jpg]

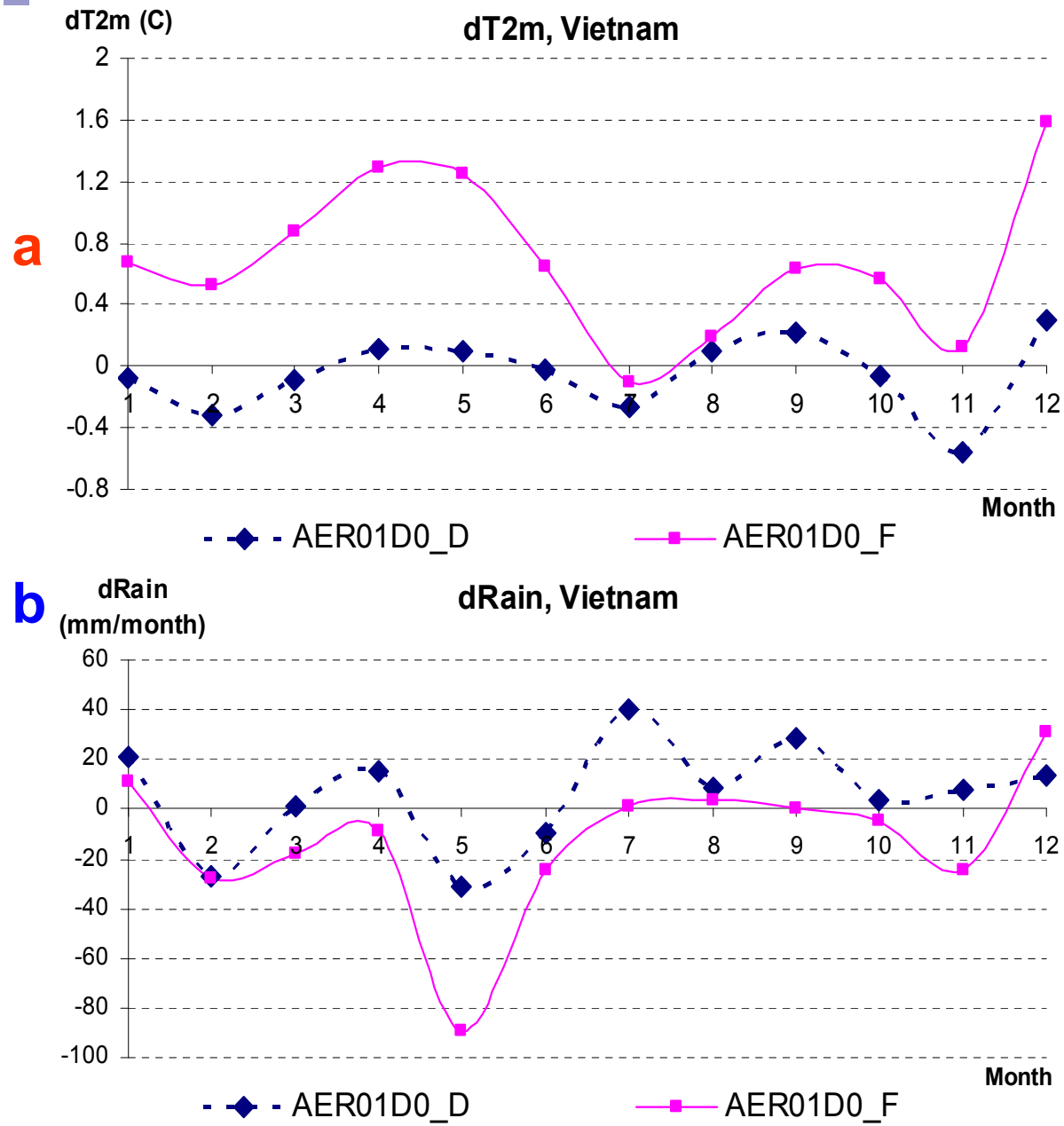


Fig. 14: Difference of monthly T2m (a) and rainfall (b) in 2000 of AER01D0_D and AER01D0_F compared with CONT. over Vietnam.

- *AER01D0_F increasesT2m but decreases rainfall*
- *Strength of impact is high in Feb - May*

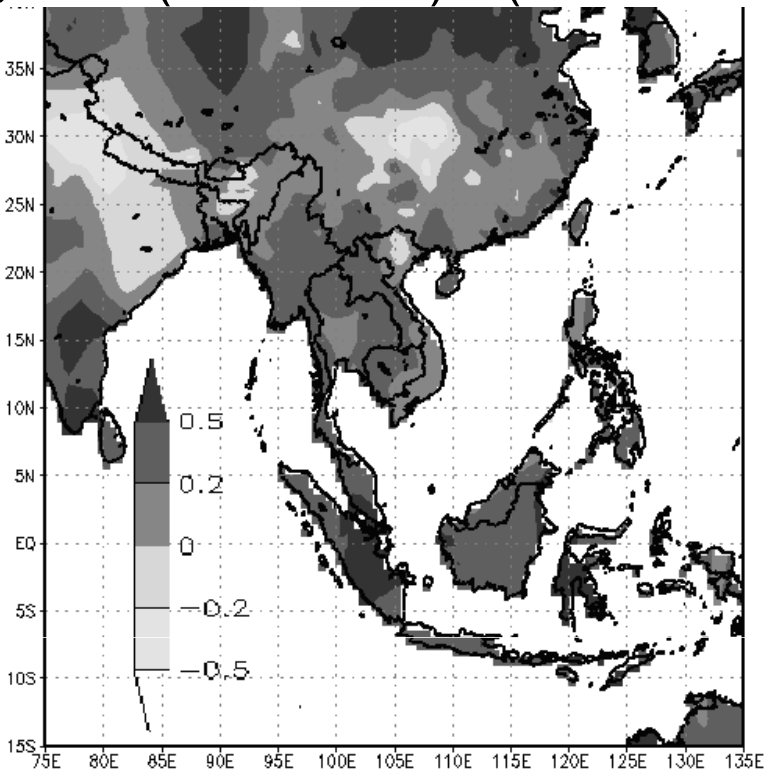
Summary

- BC aerosol can have important effects on climate, especially at the regional scale.
  - **The direct BC effect** generates a negative solar forcing at the surface and positive solar forcing at the top of atmosphere.
  - **The feedback radiative forcing of BC** increases the positive atmospheric forcing and reduces the negative forcing at surface.
  - **The feedback radiative forcing** produces an increase in the surface air temperature and results a very large precipitation reduction.

- By allowing for climate aerosol feedbacks, the precipitation reduction and surface temperature increase by the BC effect simulated in the fully-coupled model could be more agreement with theory.

2. Impact of Anthropogenic BC on climate

T2m, CRU (1981-1998) – (1951-1980)



T2m (EXP.3 – EXP.2)

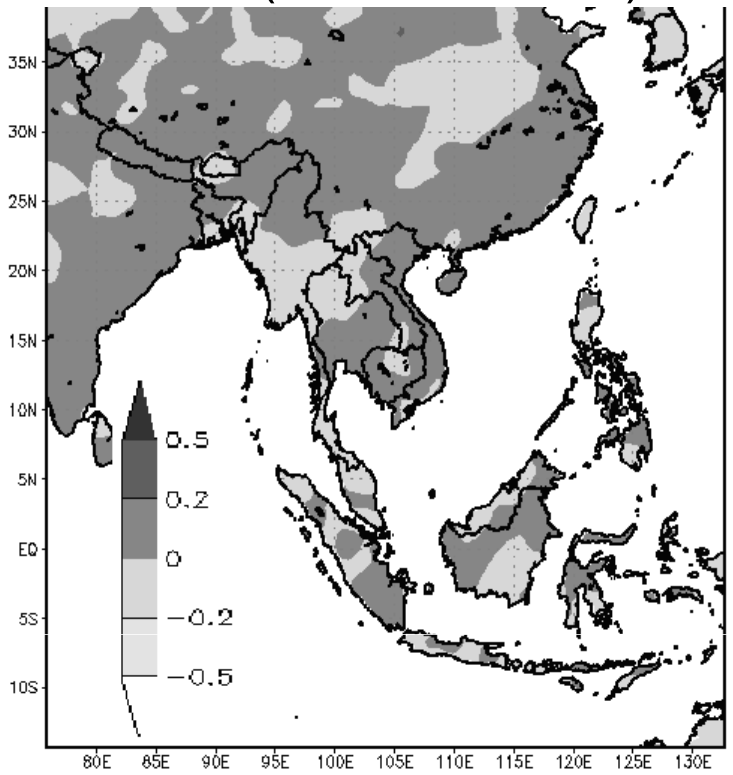


Fig. 15: Difference of monthly T2m (°C) of CRU between period of 1981-1998 and period of 1951-1980 (left, top) and of AER11D0_F – AER01D0_F (right, top).

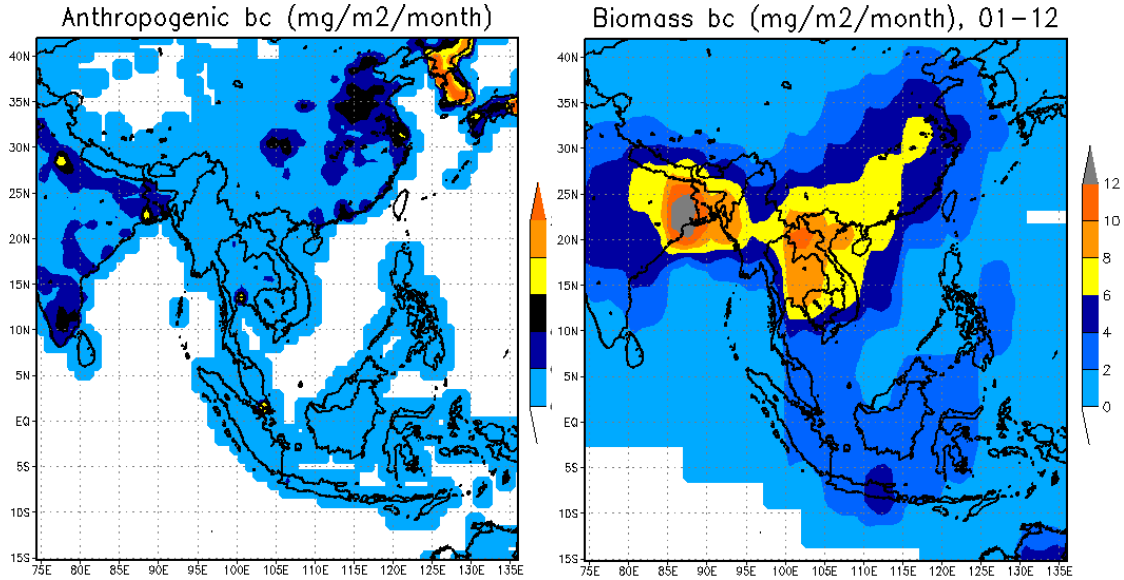
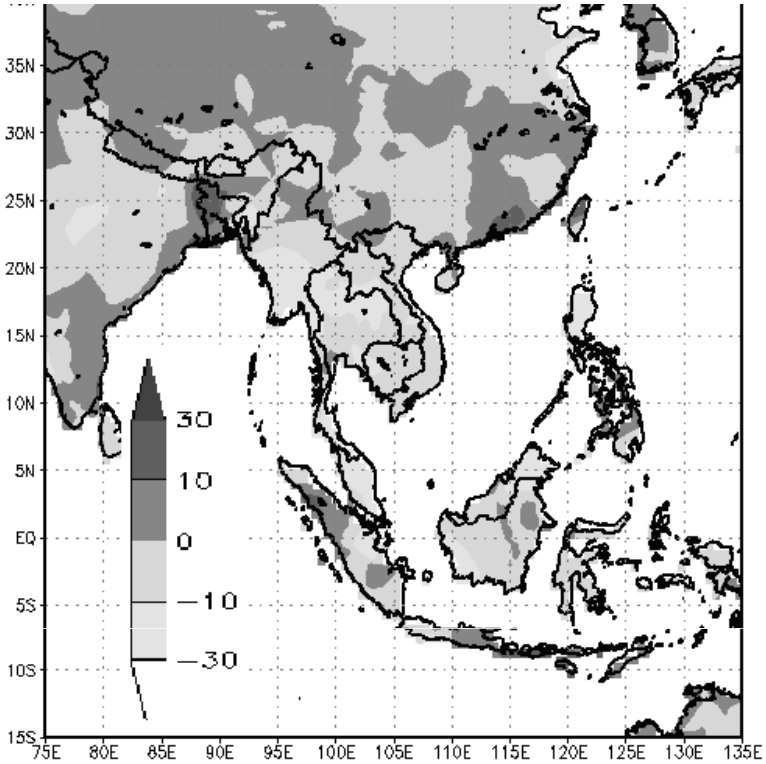
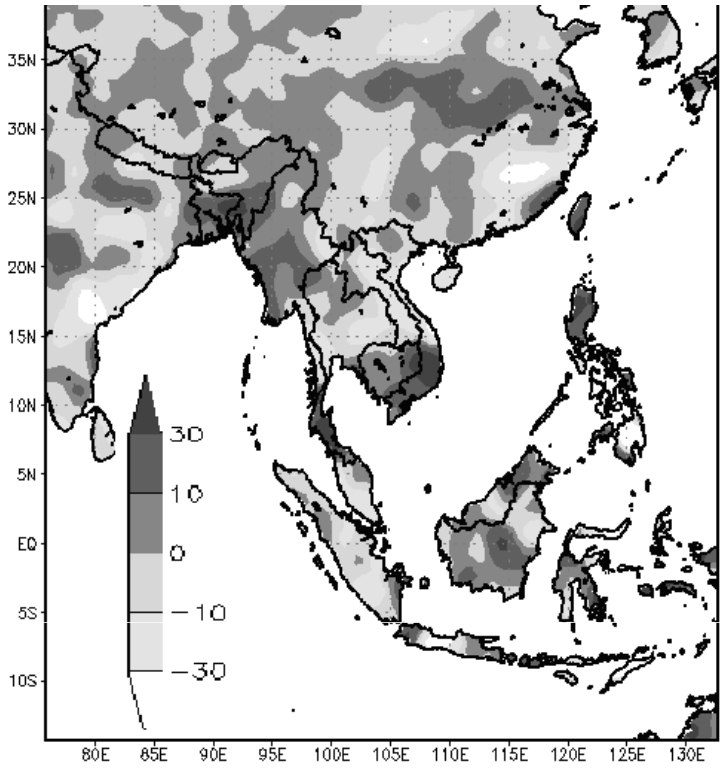


Fig. 16: Anthropogenic BC (mg m-2 month-1) (left, bottom) and annually black carbon concentration (mg m-2 month-1) from biomass burning (right, bottom) [Source: Liousse et al., 1996].

Rain, CRU (1981-1998) – (1951-1980)



Rain (EXP.3 – EXP.2)



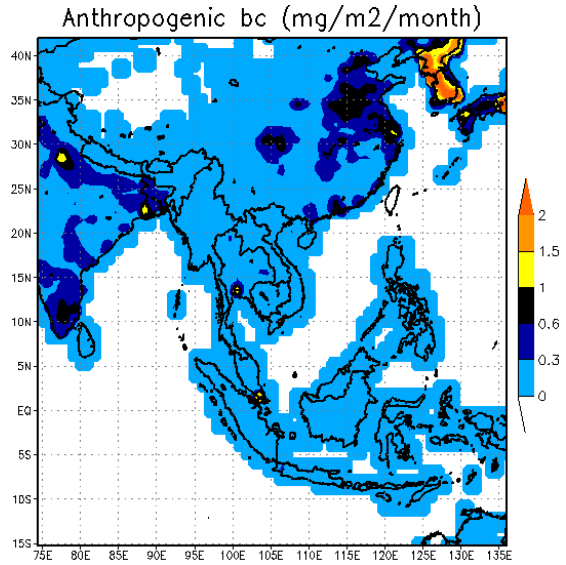


Fig. 17: Difference of monthly rainfall (mm month-1) of CRU between period of 1981-1998 and period of 1951-1980 (left, top) and of AER11D0_F – AER01D0_F (right, top).

Difference between Precipitation / T2m simulated by EXPS. and CRU

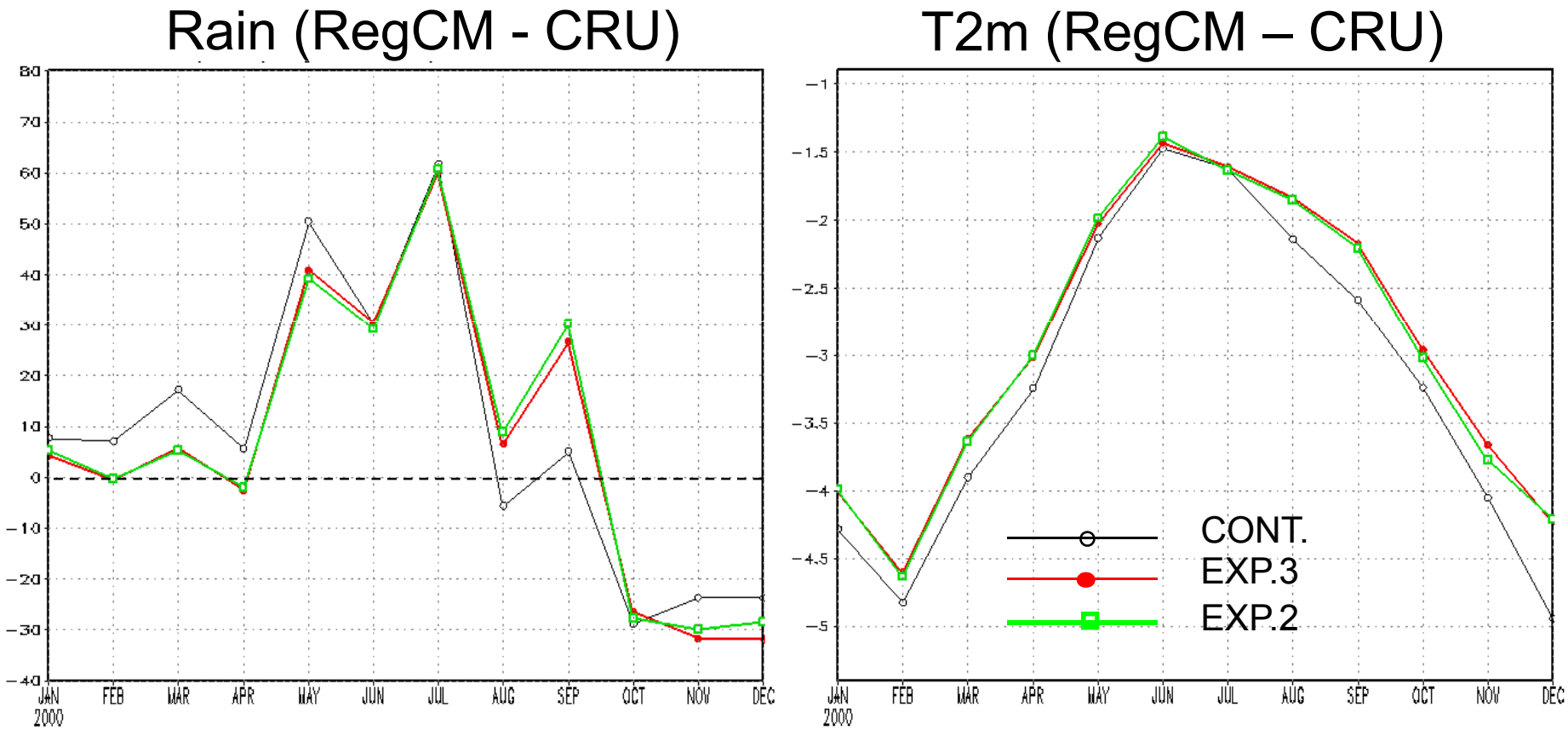
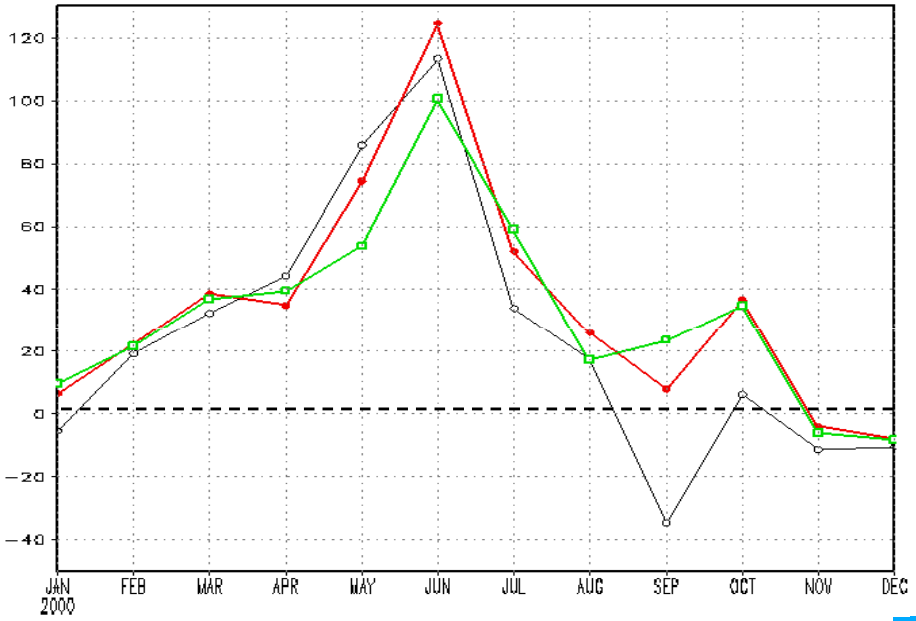


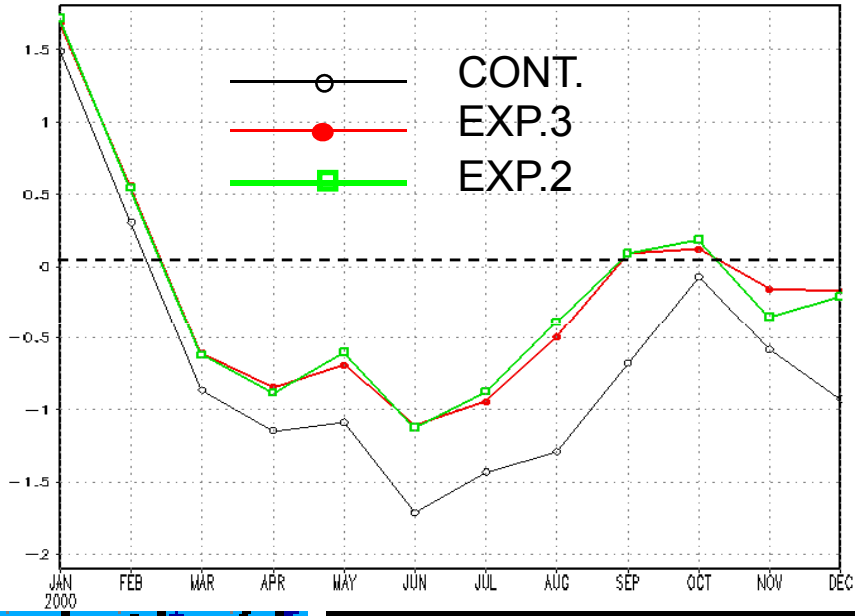
Fig. 18: Precipitation (mm month^{-1}, left) and T2m (^{o}C, right) simulated by EXPS of RegCM3 compared with CRU

Difference between Precipitation / T2m simulated by EXPS. and CRU, China

Rain (RegCM - CRU)



T2m (RegCM – CRU)



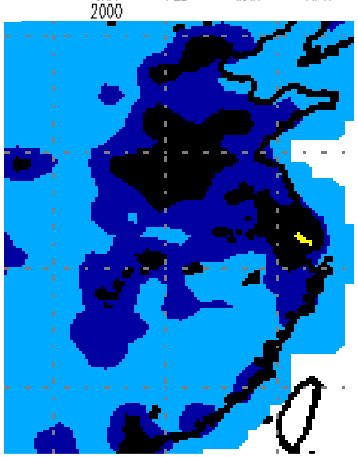


Fig. 19: Precipitation (mm month^{-1}, left) and T2m (°C, right) simulated by EXPS of RegCM3 compared with CRU over China

Summary

- Anthropogenic BC have a significant impact on the surface climate of Southeast Asia and Vietnam
  - Surface warming in almost region except China and India
  - Precipitation decrease in winter and Precipitation increase in summer, especially over China and India.
- With the anthropogenic BC accounted, the variation of temperature and rainfall is close to the reality (CRU).

Some Remarks

- The role of BC impact on climate is really important.
- Regional climate models are useful tools to study aerosol effects.
- BC effects on temperature as expected but rainfall is impacted in complex ways.
- Regions of the same high BC loading are influenced in different ways and in count-intuitive situation.
- The indirect effect of BC is needed to add in RegCM3.
- More experiments and longer simulation period is necessary to get the more exactly conclusion.

Thanks for your attention !