# Climate Response to Aerosol Effects and Their Influence on Hydrological Cycle

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# Scientific questions that motivate this study

- **Forcings vs. Feedbacks**

**Can aerosol indirect effect (a feedback) hold up in coupled models?**

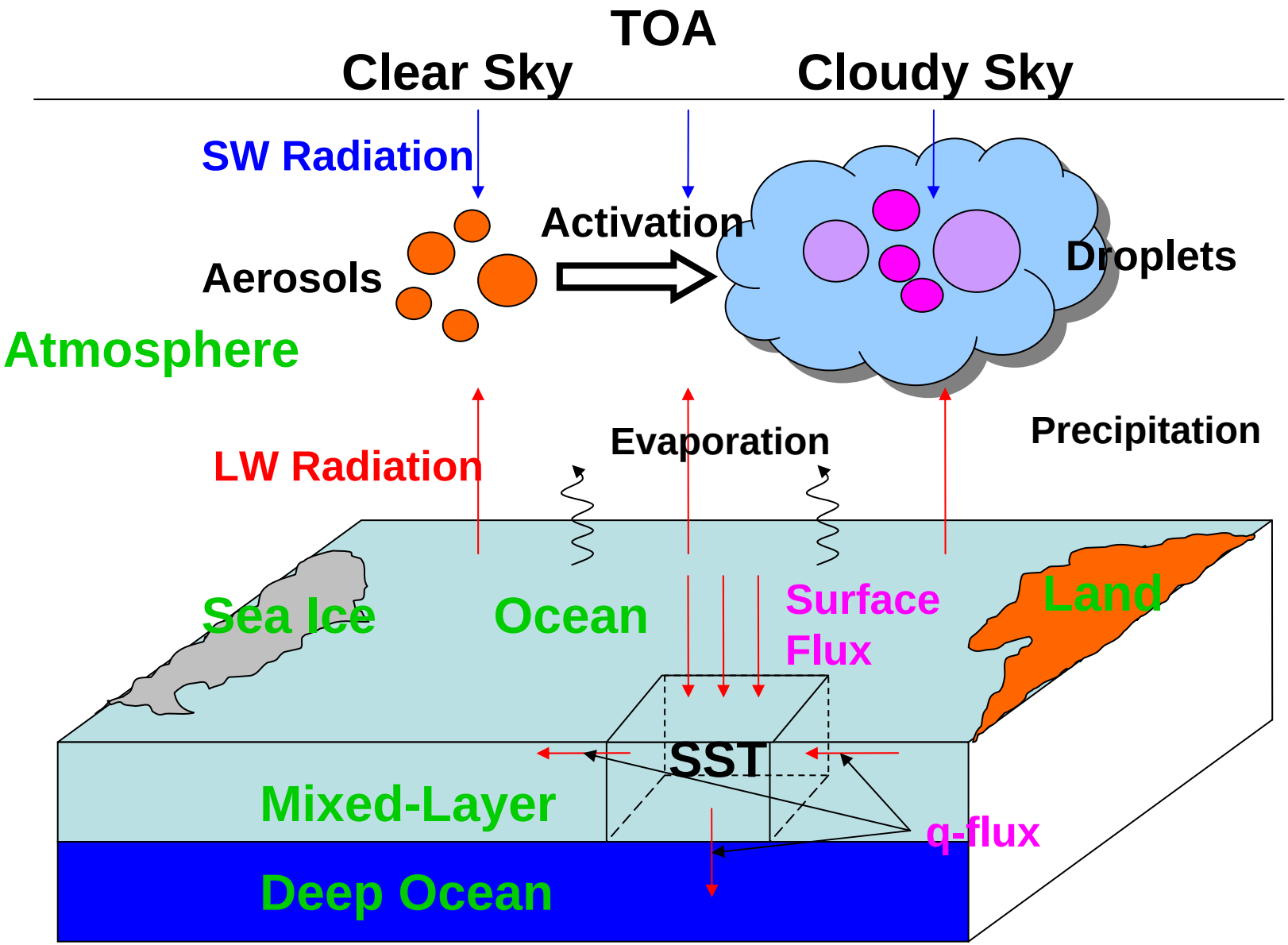
- **Amplification vs. Dampening**

**How do model feedbacks shape climate response?**

- **Global vs. Regional**

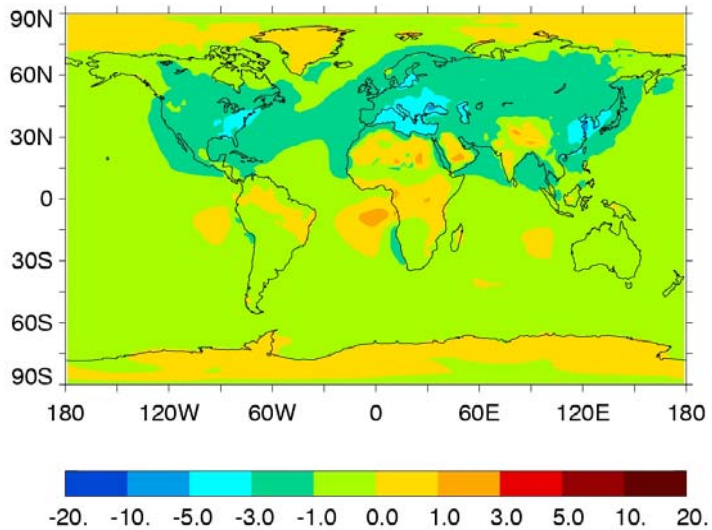
**Are the responses to well-mixed greenhouse gases (WMGG) and to aerosols linearly additive?**

# A coupled atmosphere – mixed-layer ocean general circulation model

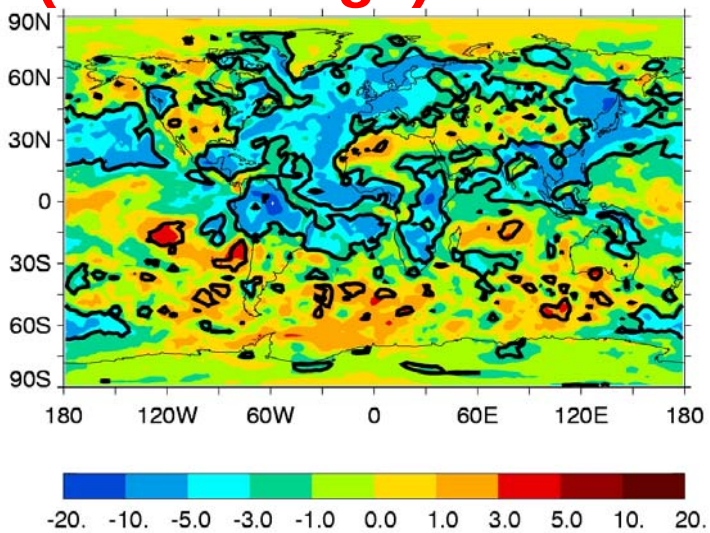


# Model Perturbations

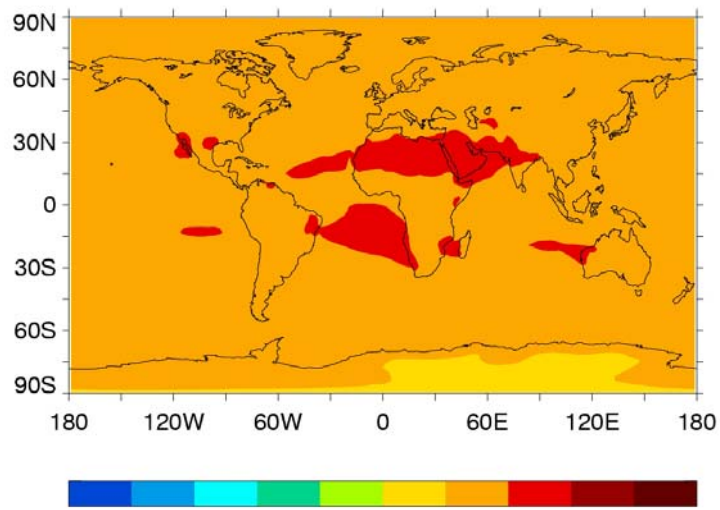
## Aerosol direct effect (forcing)




## Aerosol indirect effect (flux change)

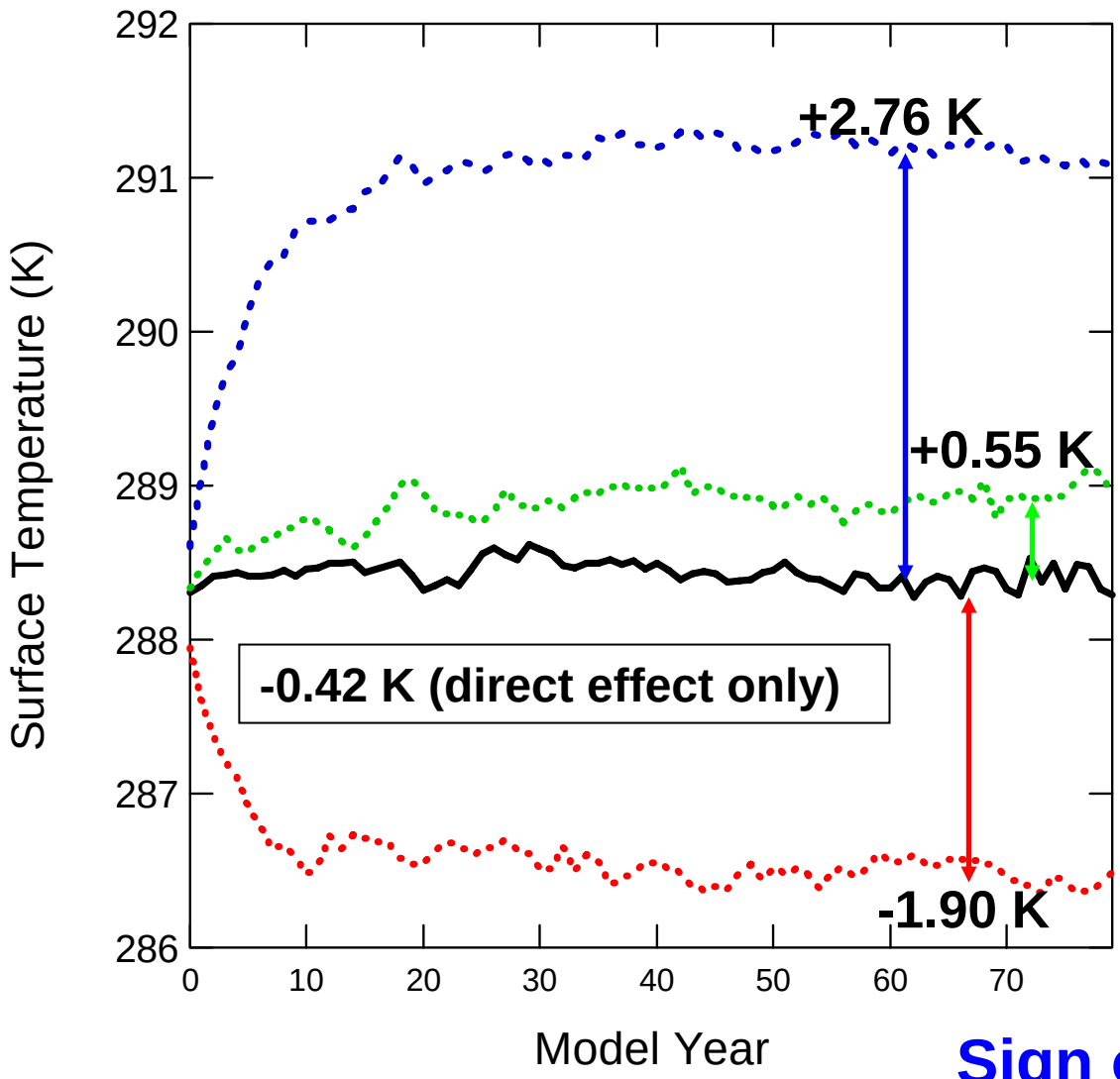



## WMGG (forcing)




| | |
|---|---|
| **Aerosol direct effect** | -0.57 W $m^{-2}$ |
| **Aerosol indirect effect** | -1.7 W $m^{-2}$ |
| **WMGG** | +2.3 W $m^{-2}$ |

# Design of Experiments

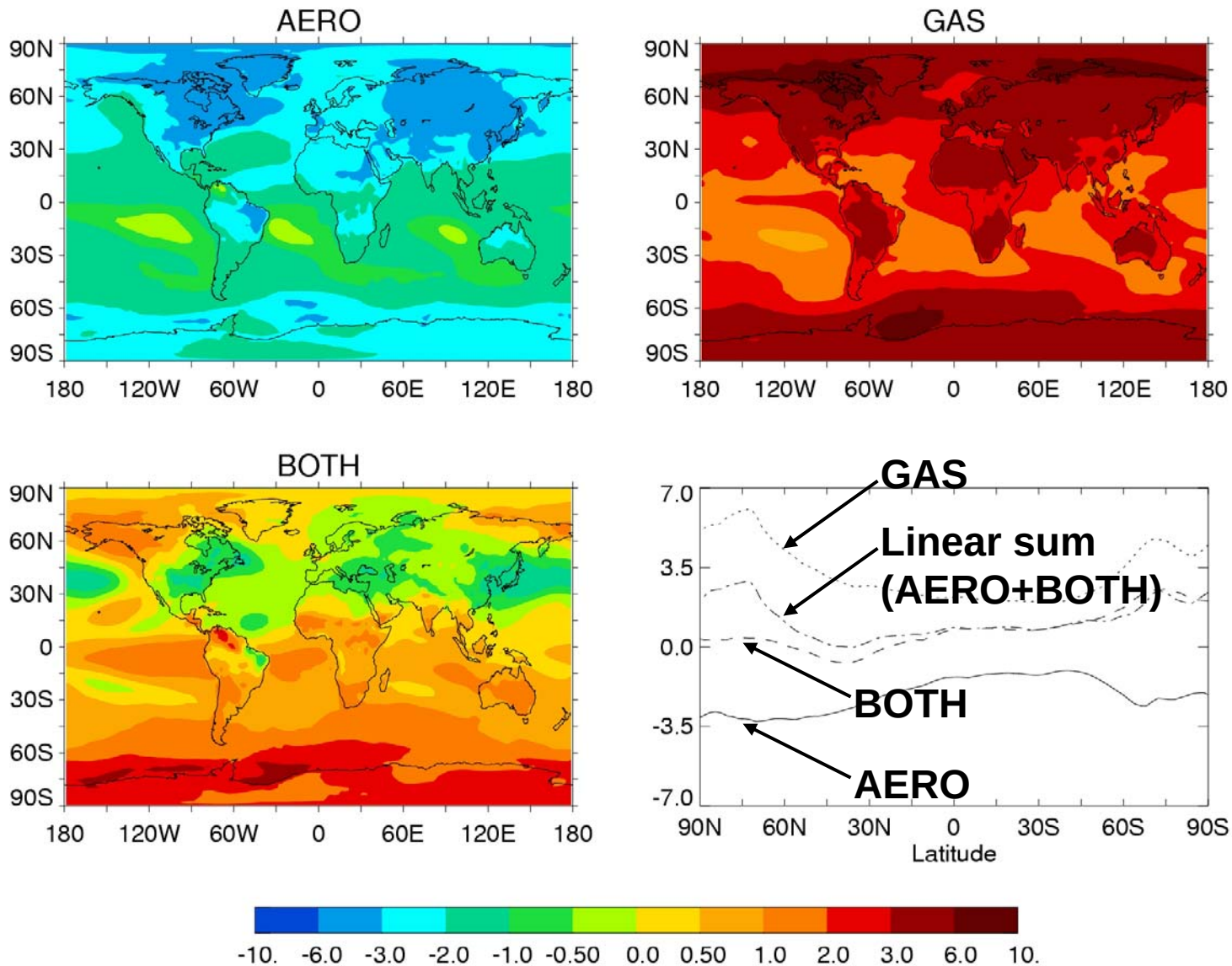



| | Aerosol | WMGG |
|---|---|---|
| GAS | PI | PD |
| BOTH | PD | PD |
| Control | PI | PI |
| AERO | PD | PI |

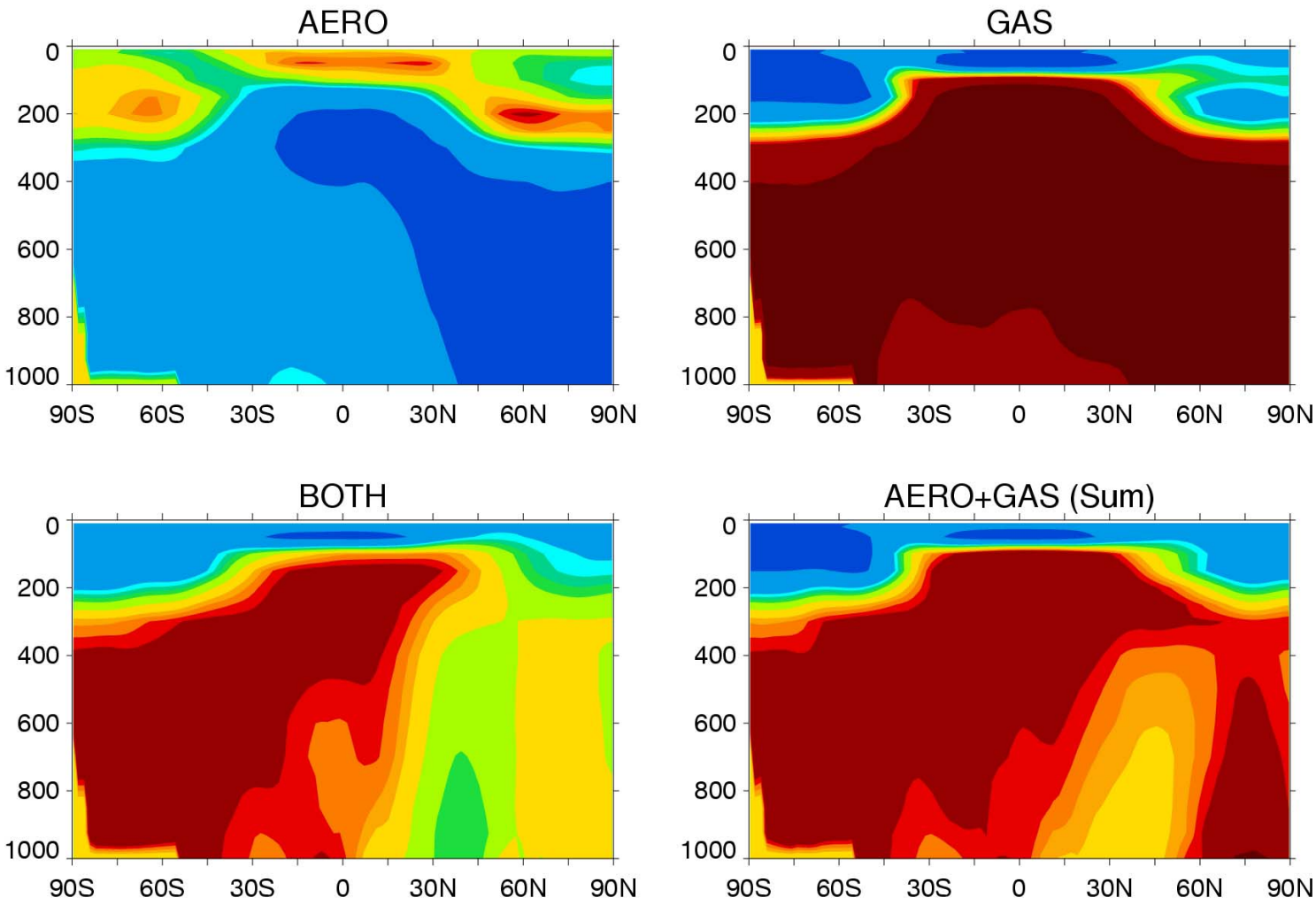
**Sign of nonlinearity:**

**BOTH (0.55 K) < AERO + GAS (0.86 K)**

# Thermal Response: Surface Air Temperature (K)

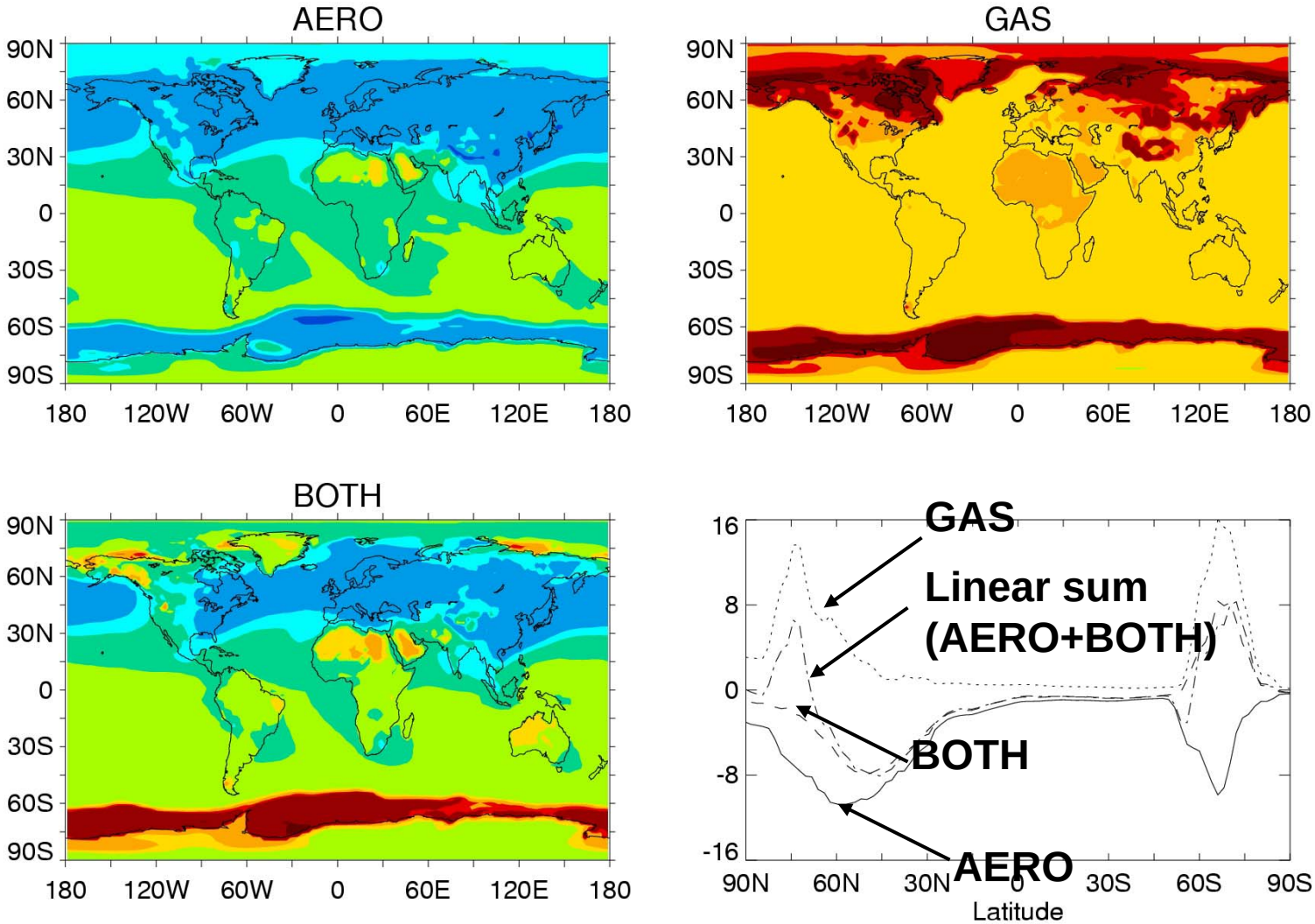


# Vertical Distribution of Thermal Response (K)

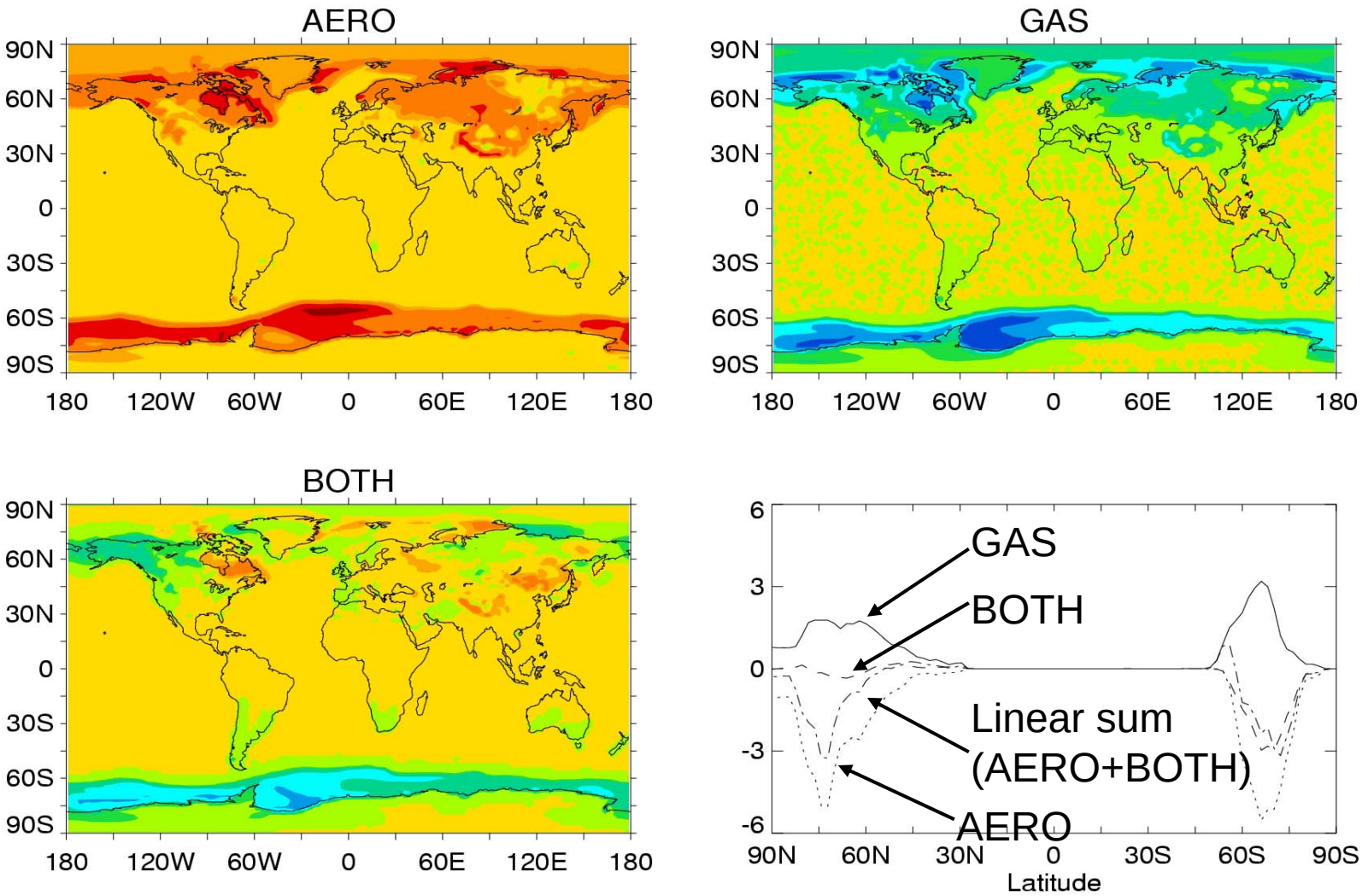


# Radiation: TOA Clear-sky SW (W m$^{-2}$)

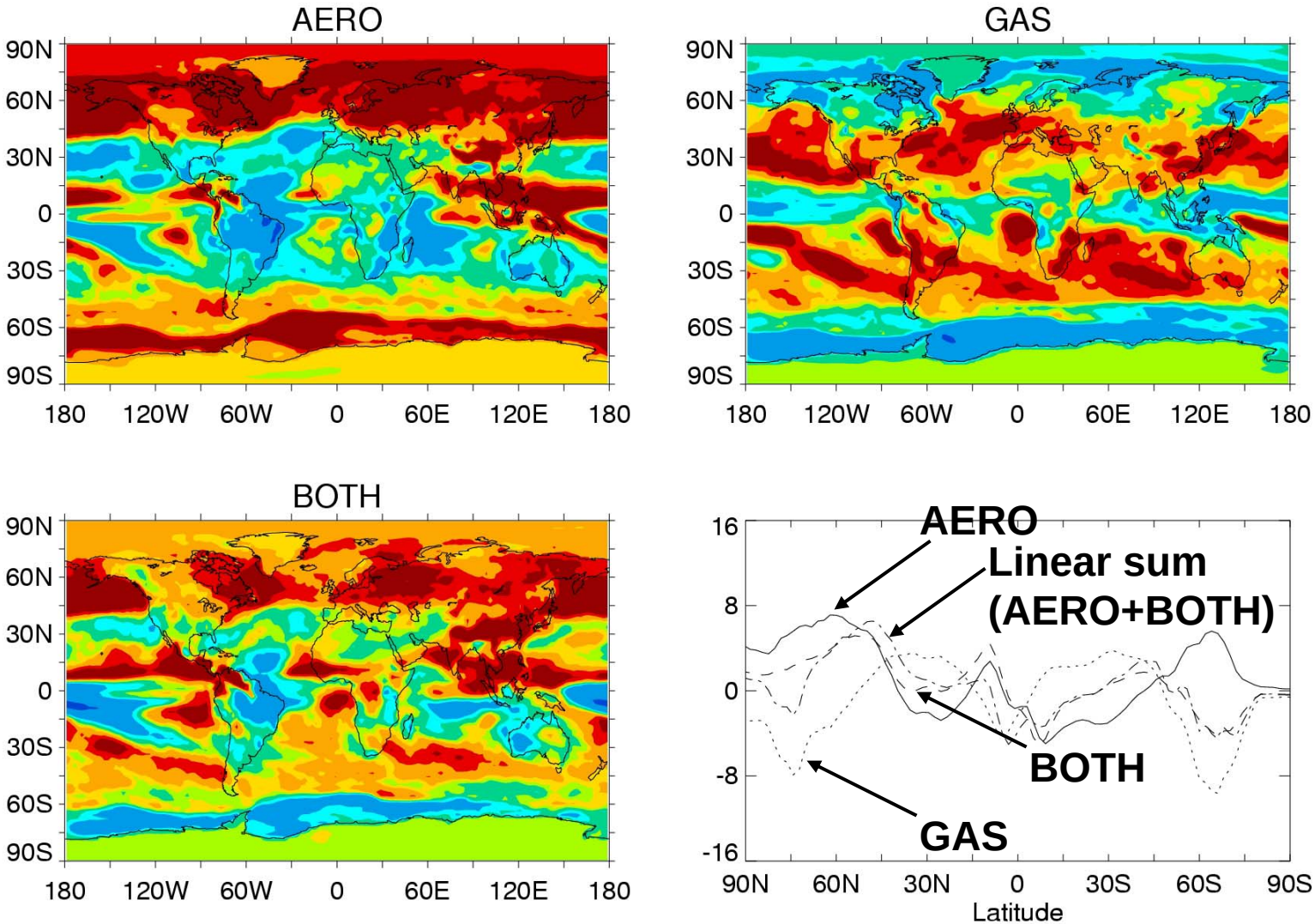
Downward (incoming) is defined as positive



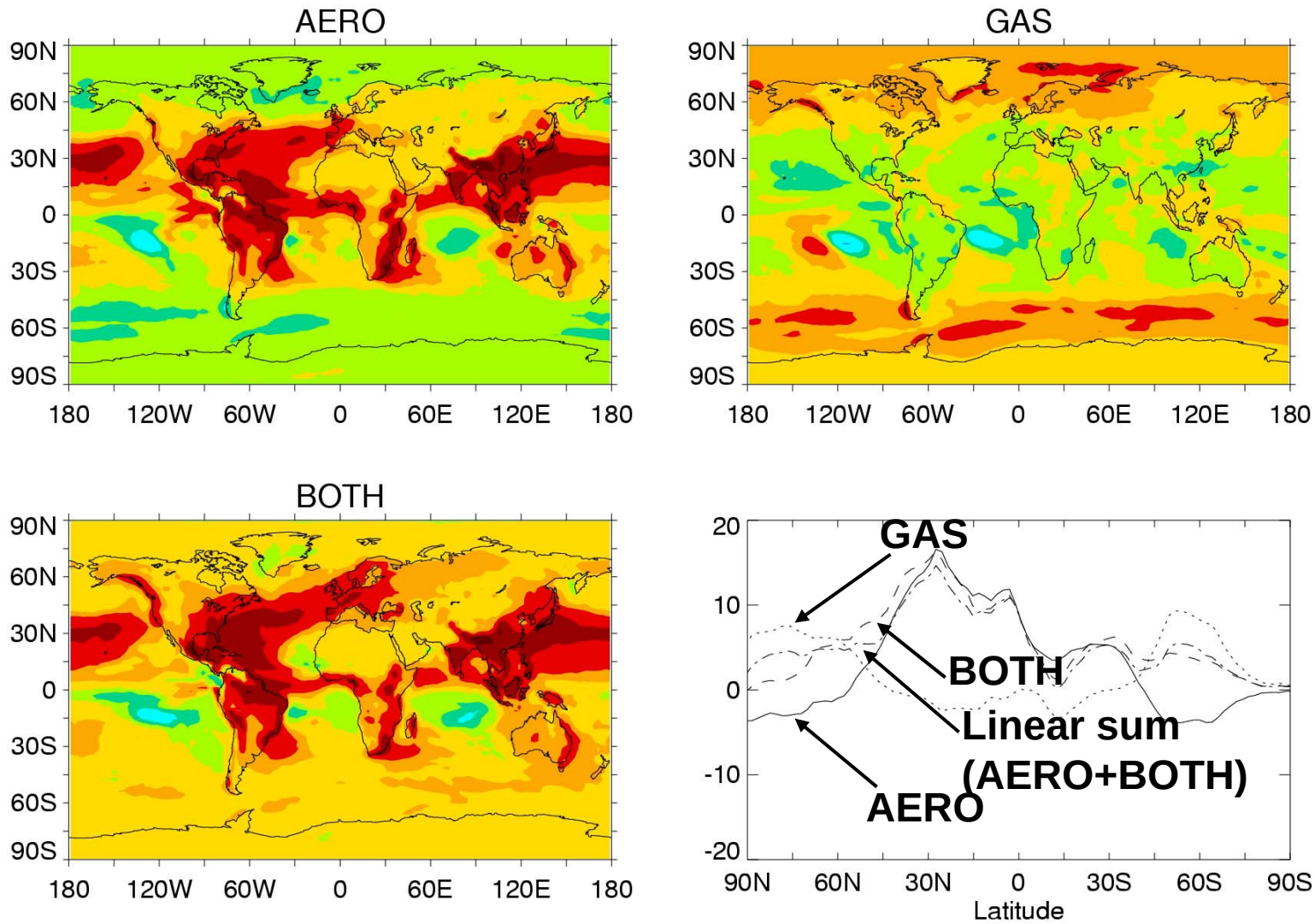
# Surface Albedo (%)



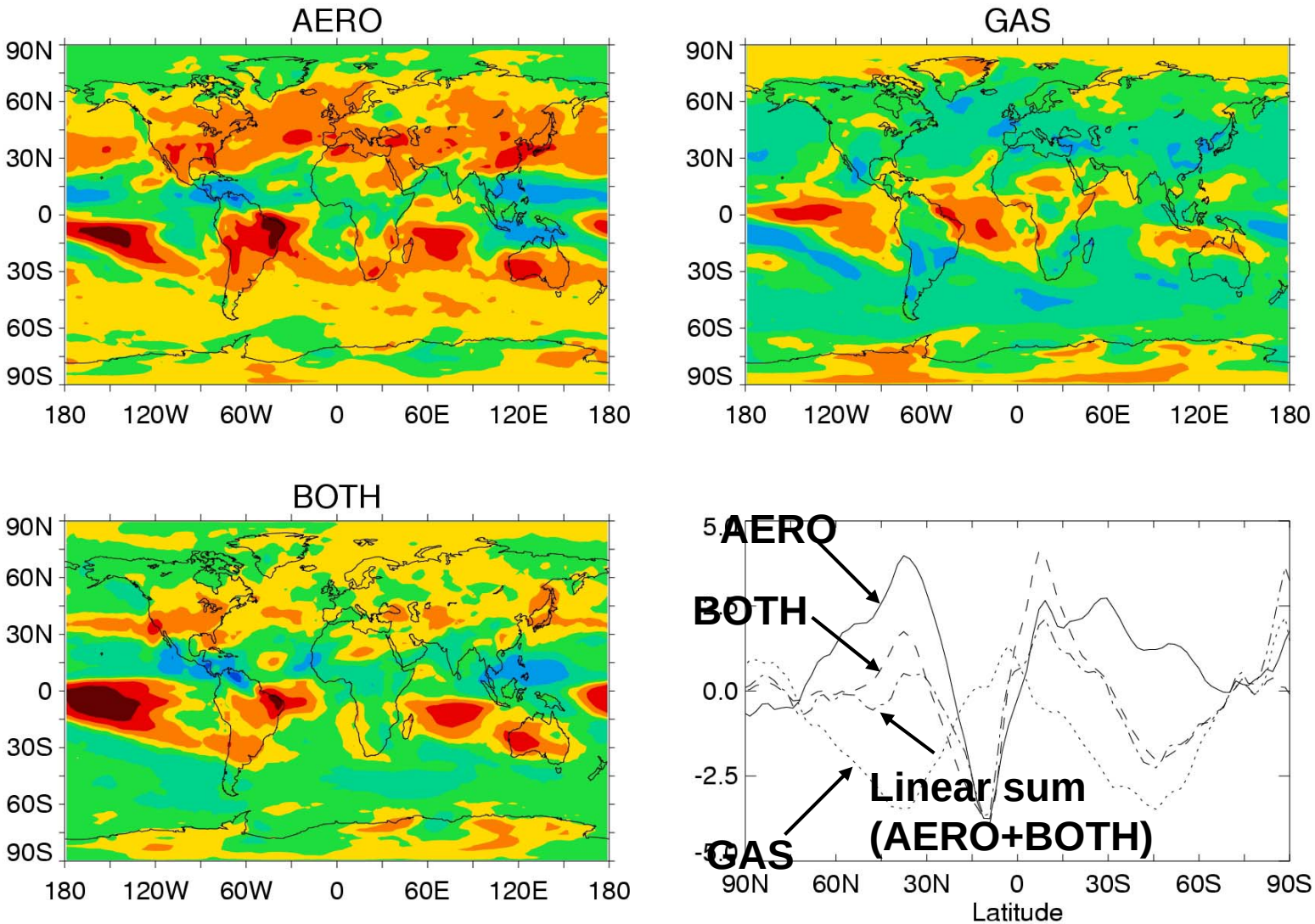
# Radiation: TOA Cloudy-sky SW (W m$^{-2}$)



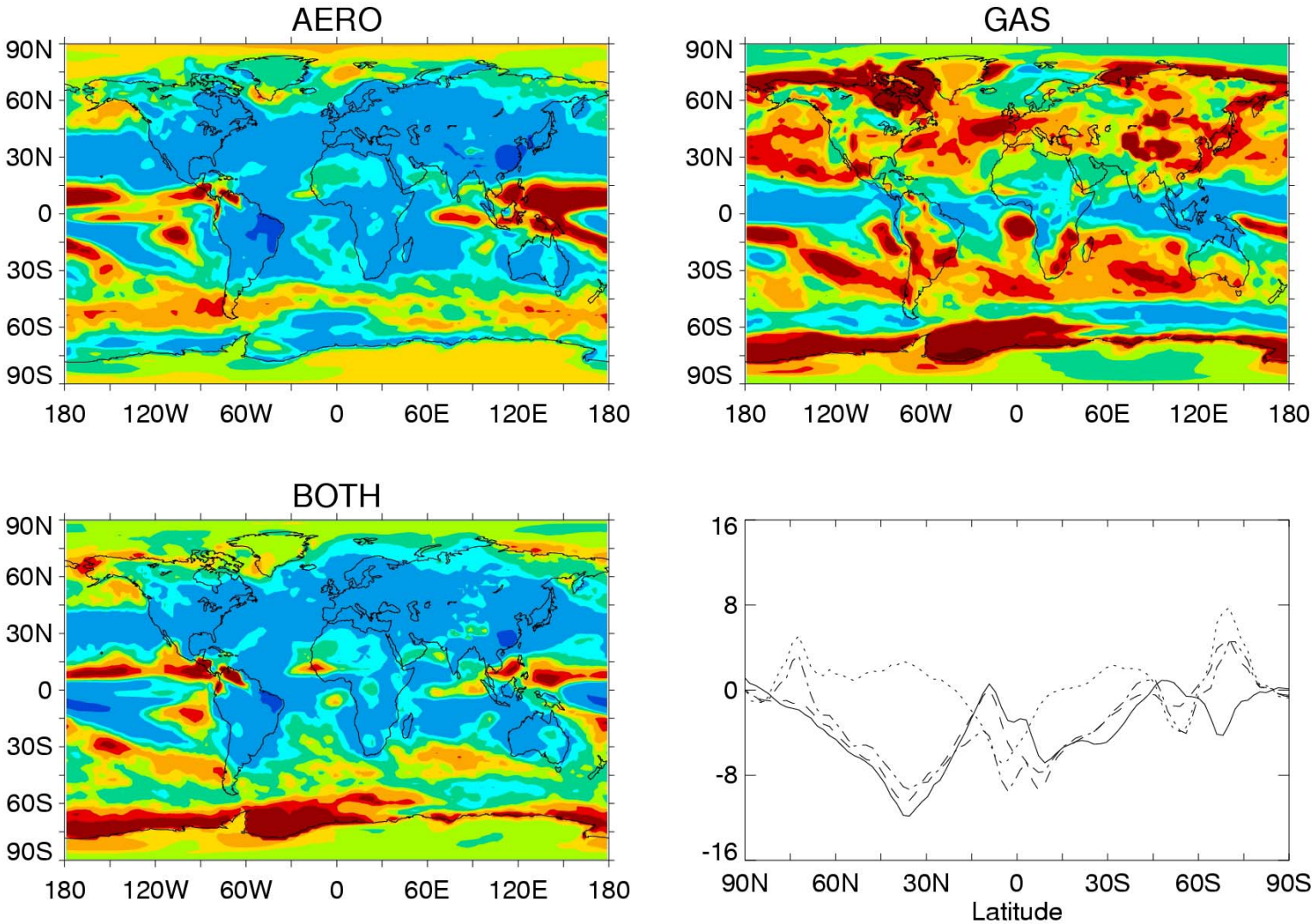
# Clouds: Liquid Water Path (LWP) (mg $m^{-2}$)



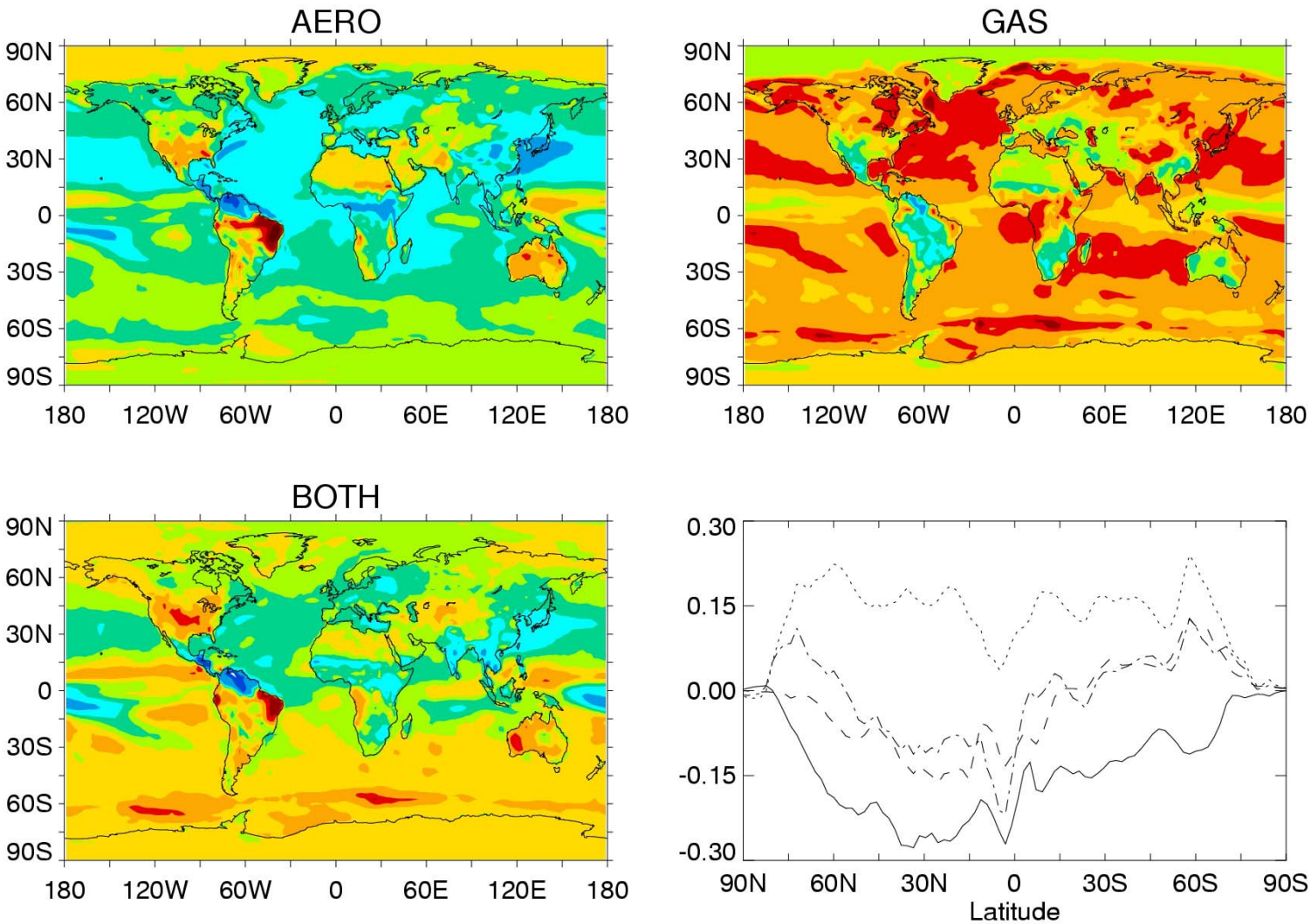
# Clouds: Cloud Cover (%)



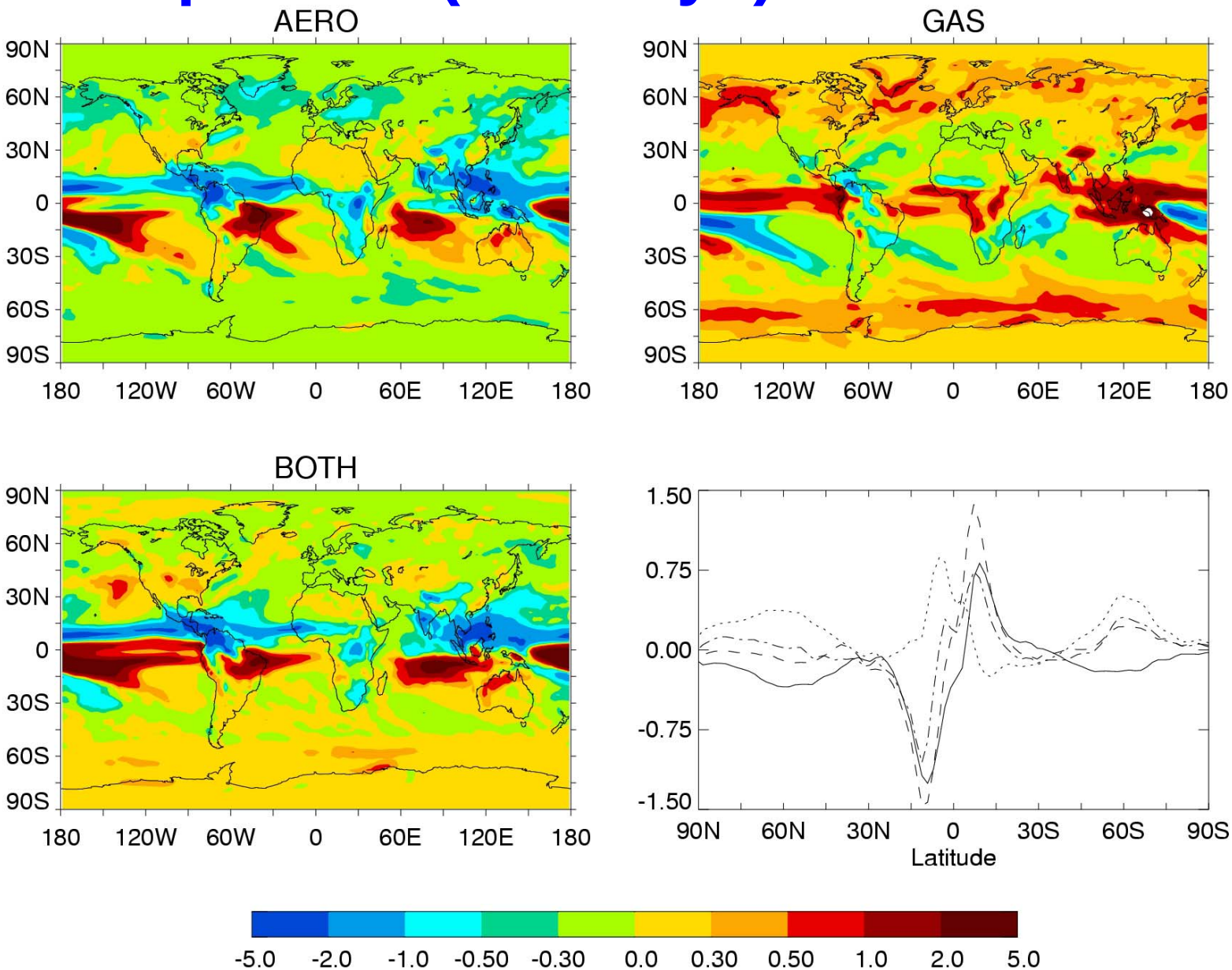
# Radiation: Surface All-sky SW (W $m^{-2}$)



# Evaporation (mm day$^{-1}$)



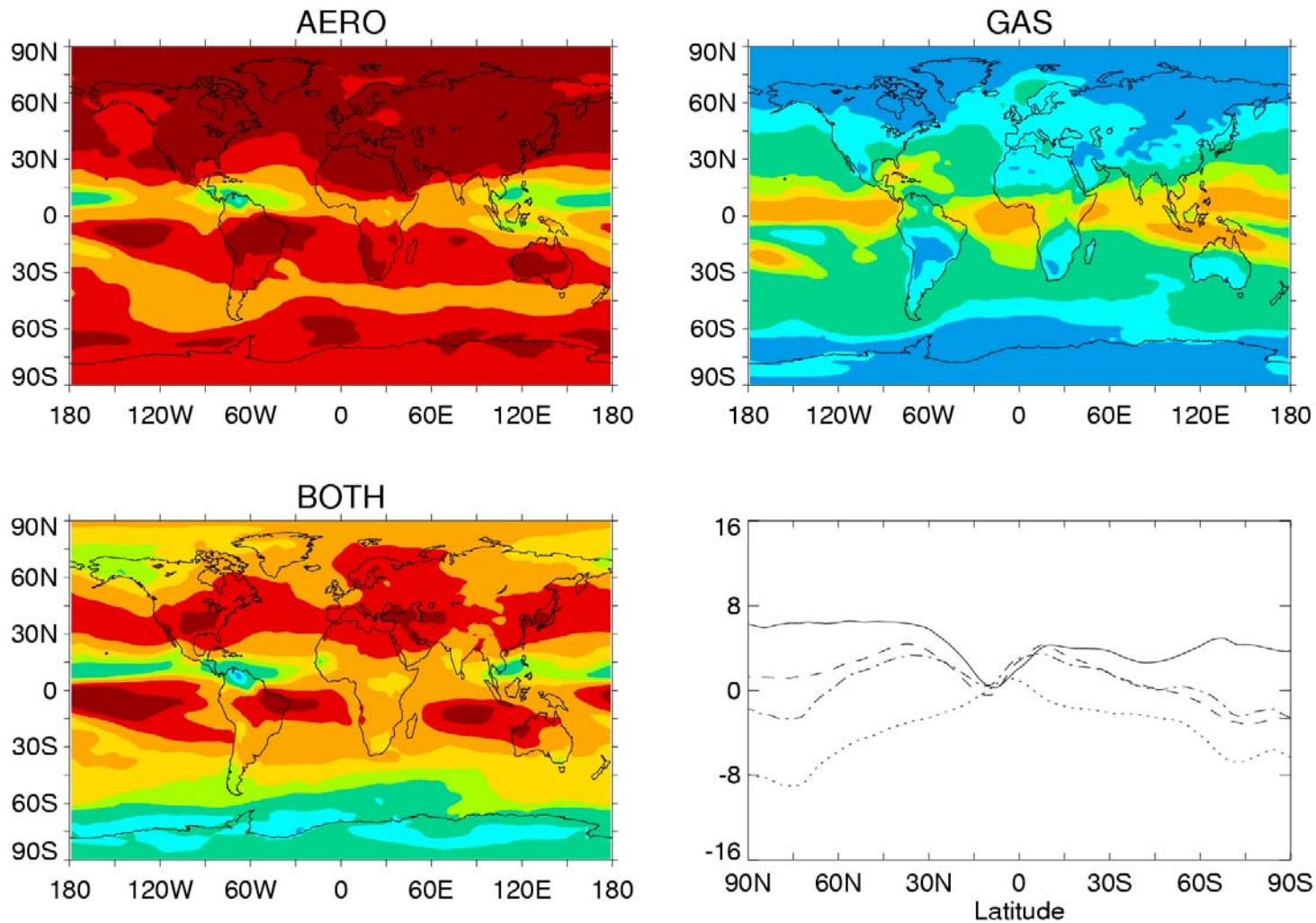
# Precipitation (mm day$^{-1}$)



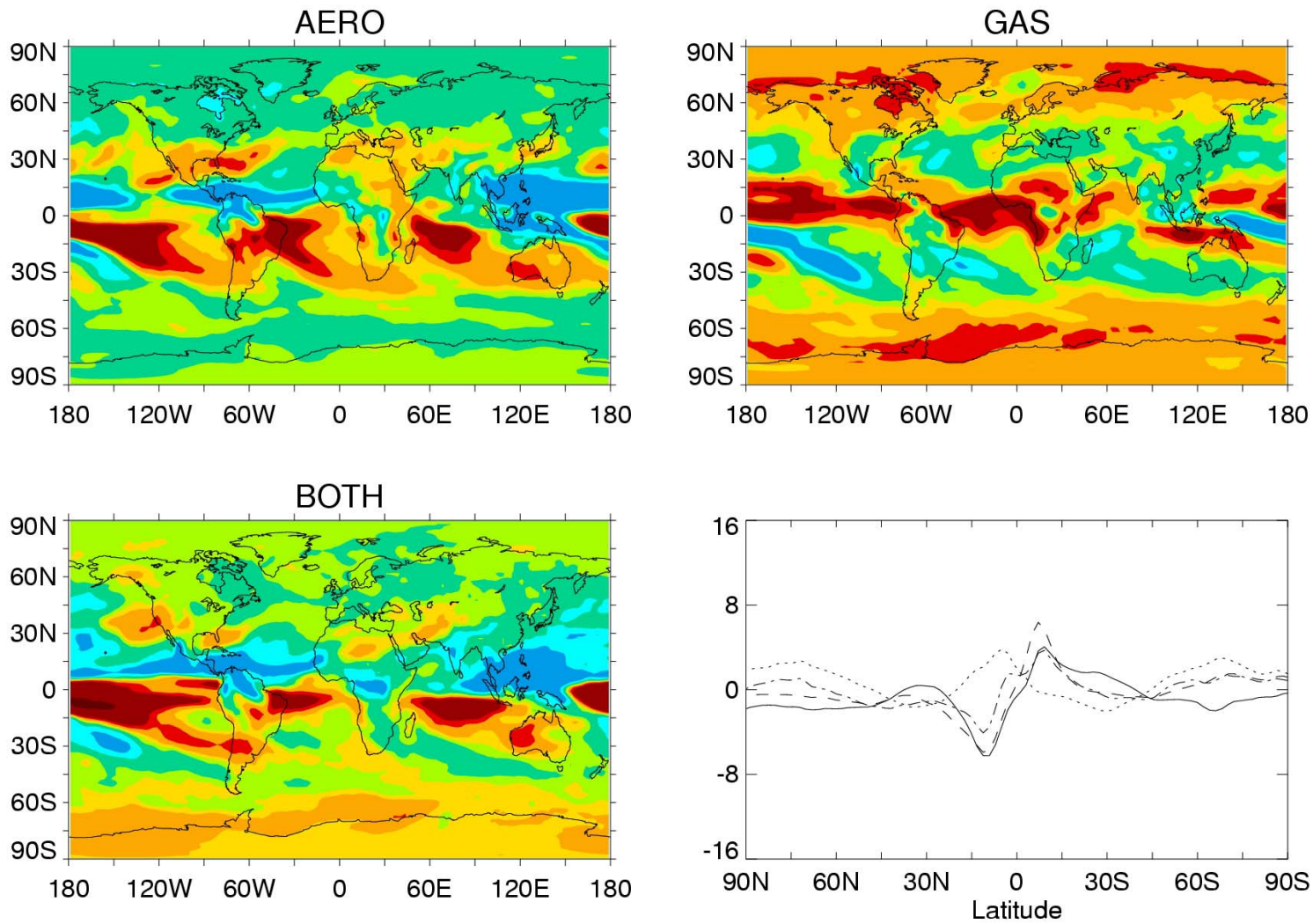
# Conclusions

- **Despite its nature of feedback, aerosol indirect effect is effective in cooling the climate (0.8 K $m^2$ $W^{-1}$ for aerosols and 1.2 K $m^2$ $W^{-1}$ for WMGG);**
- **Nonlinear aspects of the model response result mainly from the inherent nonlinearity in the surface albedo and cloud feedbacks;**
- **Aerosols affect the hydrological cycle not only by reducing surface SW flux but also by altering atmospheric circulation.**

# Radiation: TOA Clear-sky LW (W m$^{-2}$)



# Radiation: TOA Cloudy-sky LW (W m$^{-2}$)



# How is surface albedo formulated in the GCM?

$$a = a_{snow-free}\frac{D^*}{D^*+D_{snow}} + a_{deep-snow}\frac{D_{snow}}{D^*+D_{snow}}$$