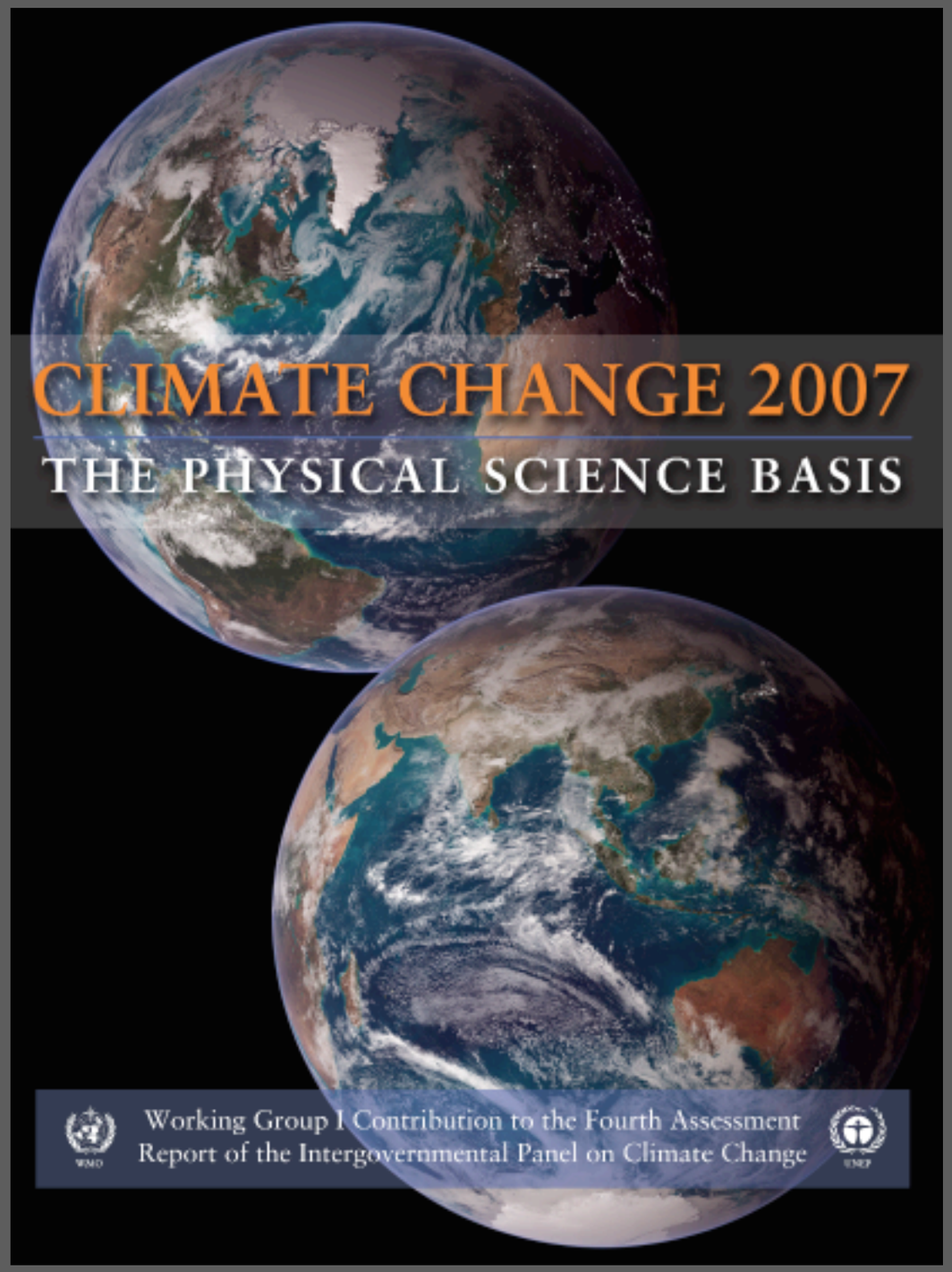
What the Heck are Low-Cloud Feedbacks?

Takanobu Yamaguchi
Rachel R. McCrary
Anna B. Harper

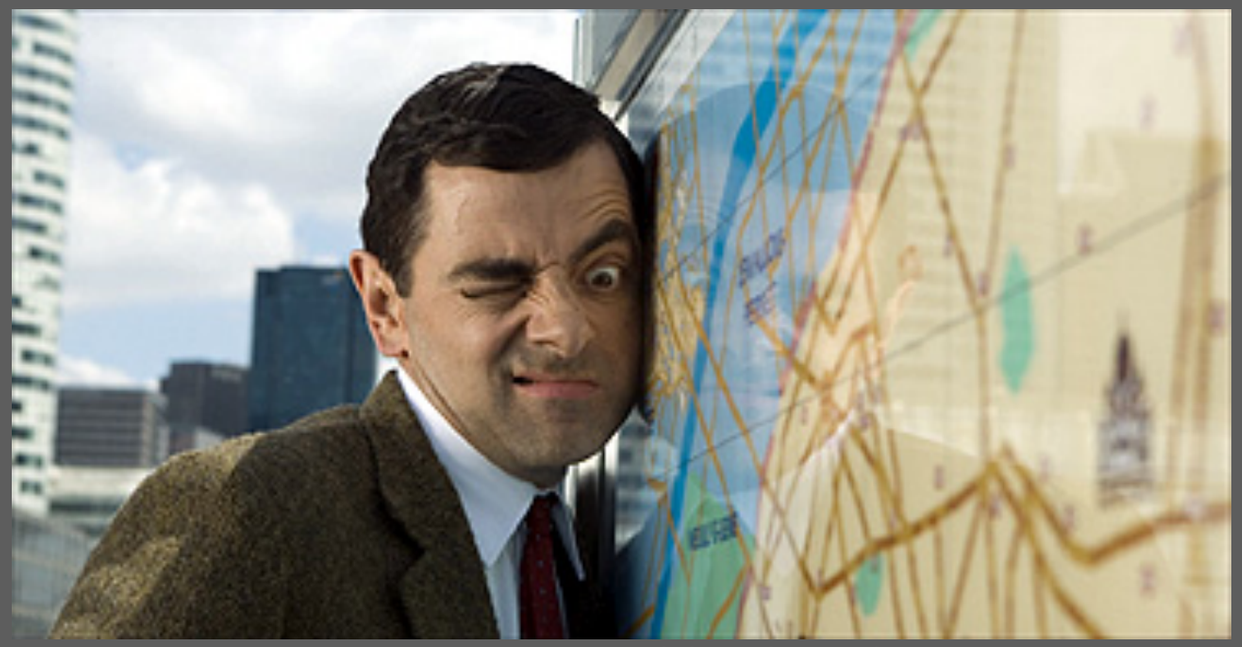
IPCC



"Cloud feedbacks remain the largest source of uncertainty."

Roadmap

1. Low cloud primer
2. Radiation and low clouds
3. What the heck are feedbacks?
4. Low clouds and climate change
5. IPCC ... again
6. Low clouds in models
7. Low clouds at CMMAP
8. Take-home messages



"Mr. Bean's Holiday" obtained at www.guardian.co.uk

Cool low clouds

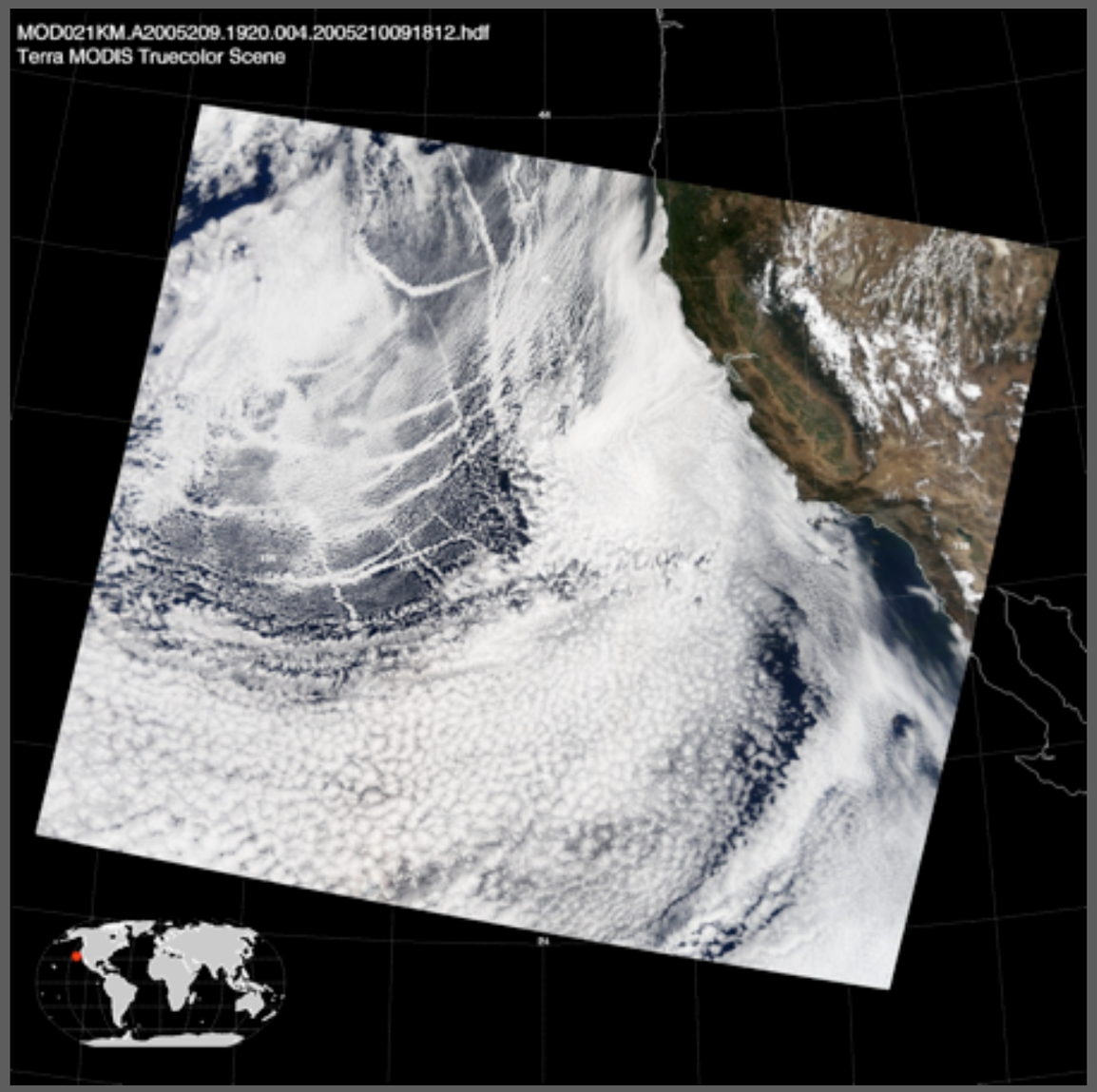
Cool low clouds

Cool low clouds

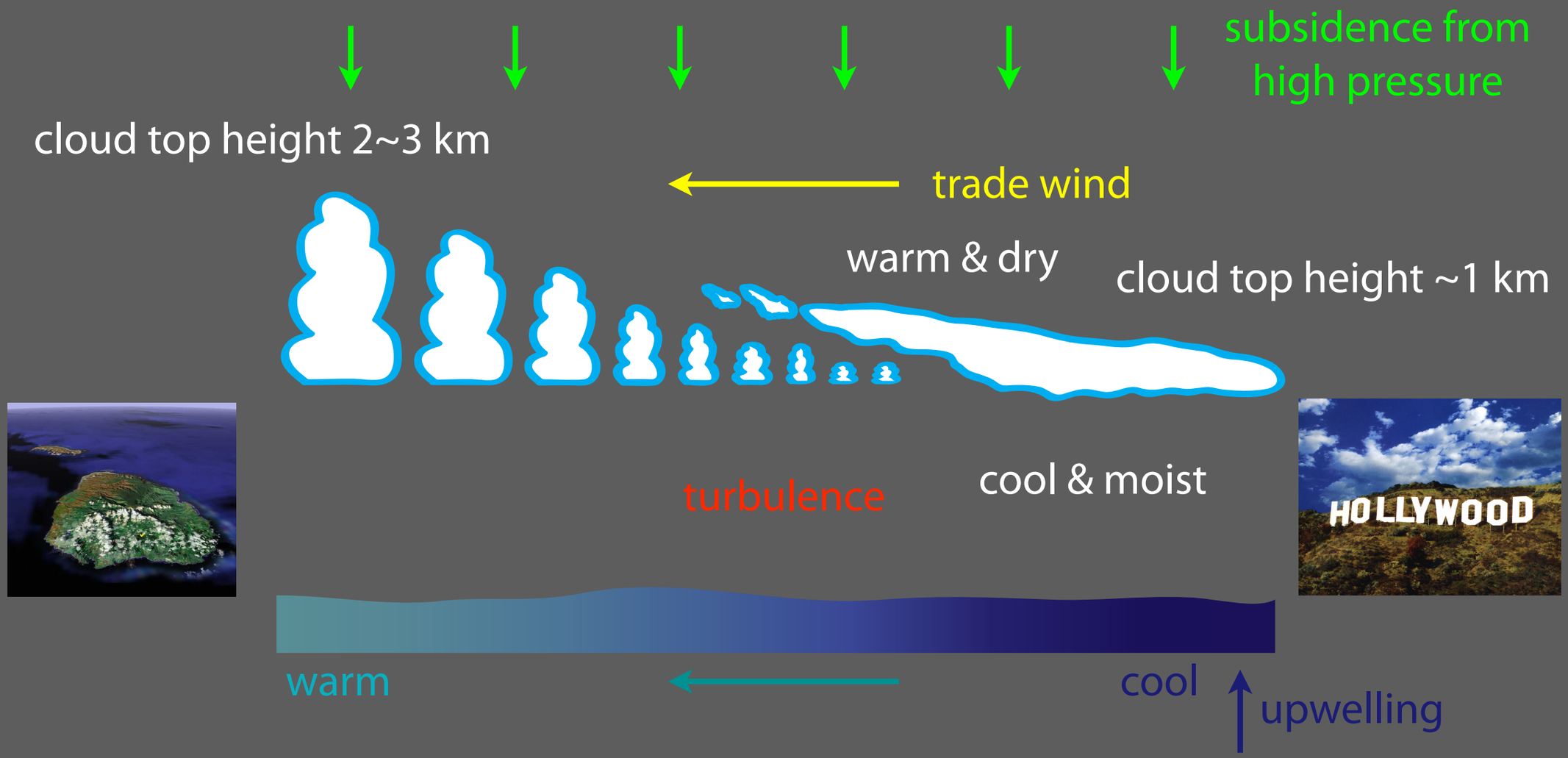
Cool low clouds

Cool low clouds

Cool low clouds



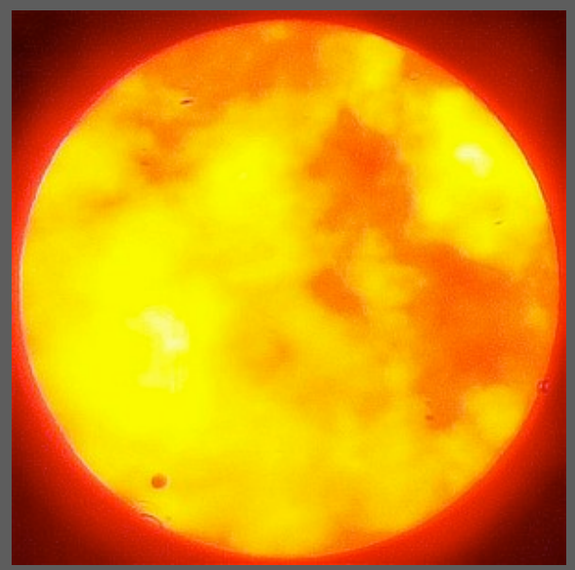
Low clouds



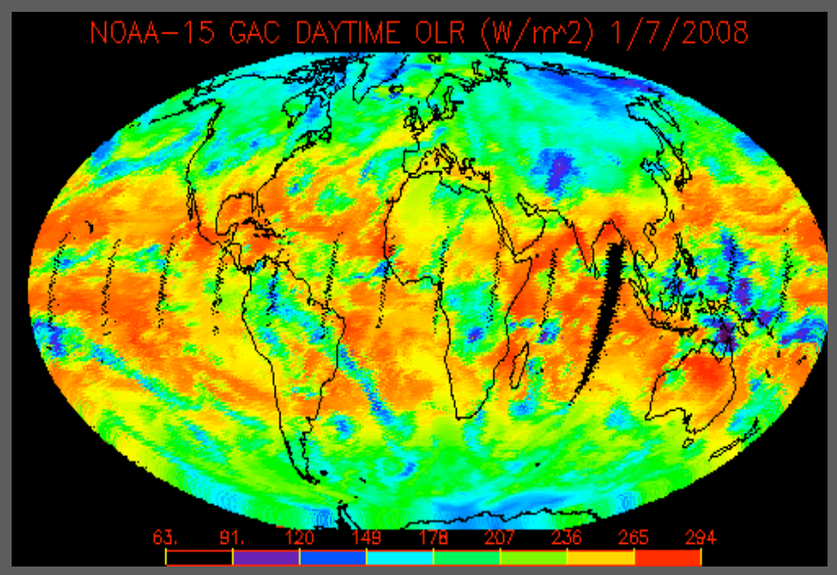
- Low clouds cover a large fraction of the tropics and subtropics.
- Low clouds have a strong negative cloud radiative effect (CRE).

Radiation

- All objects emit radiation at a rate proportional to their temperature.
- Solar radiation peaks in the visible wavelengths
  - ➡ "shortwave radiation" (SW)
- Earth's radiation peaks in the infrared wavelengths
  - ➡ "longwave radiation" (LW) or "infrared radiation" (IR)



Sun ~6000 K



Earth ~288 K

Clouds and Radiation

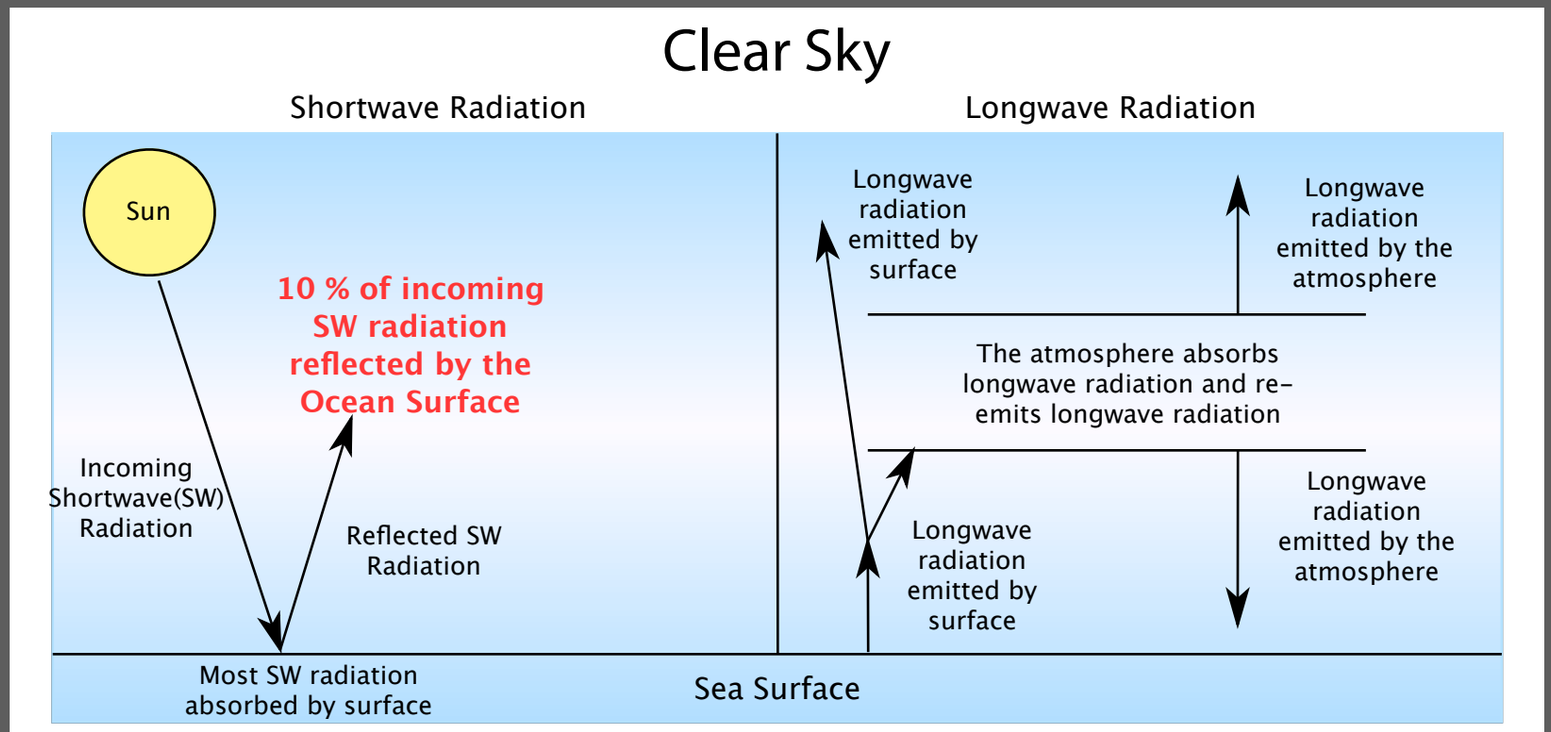
Tiny liquid cloud droplets are excellent absorbers and emitters of infrared radiation. However, they don't absorb solar radiation, instead they reflect it.

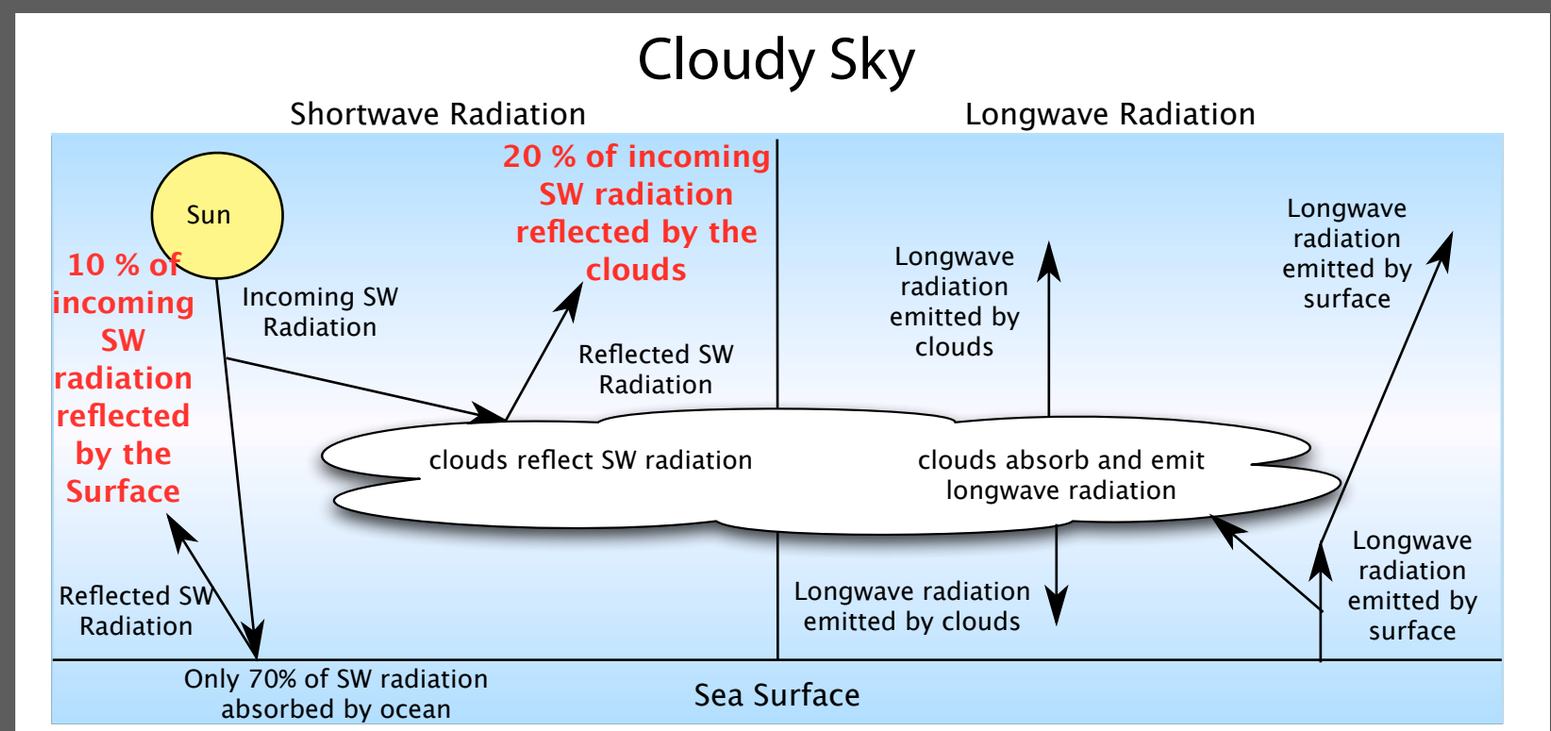
Albedo

Albedo is the amount of radiation reflected by a surface.

SURFACE	ALBEDO
fresh snow	75-95%
thick clouds	60-90%
thin clouds	30-50%
ice	30-40%
avg. Earth & atmosphere	30%
ocean	10%

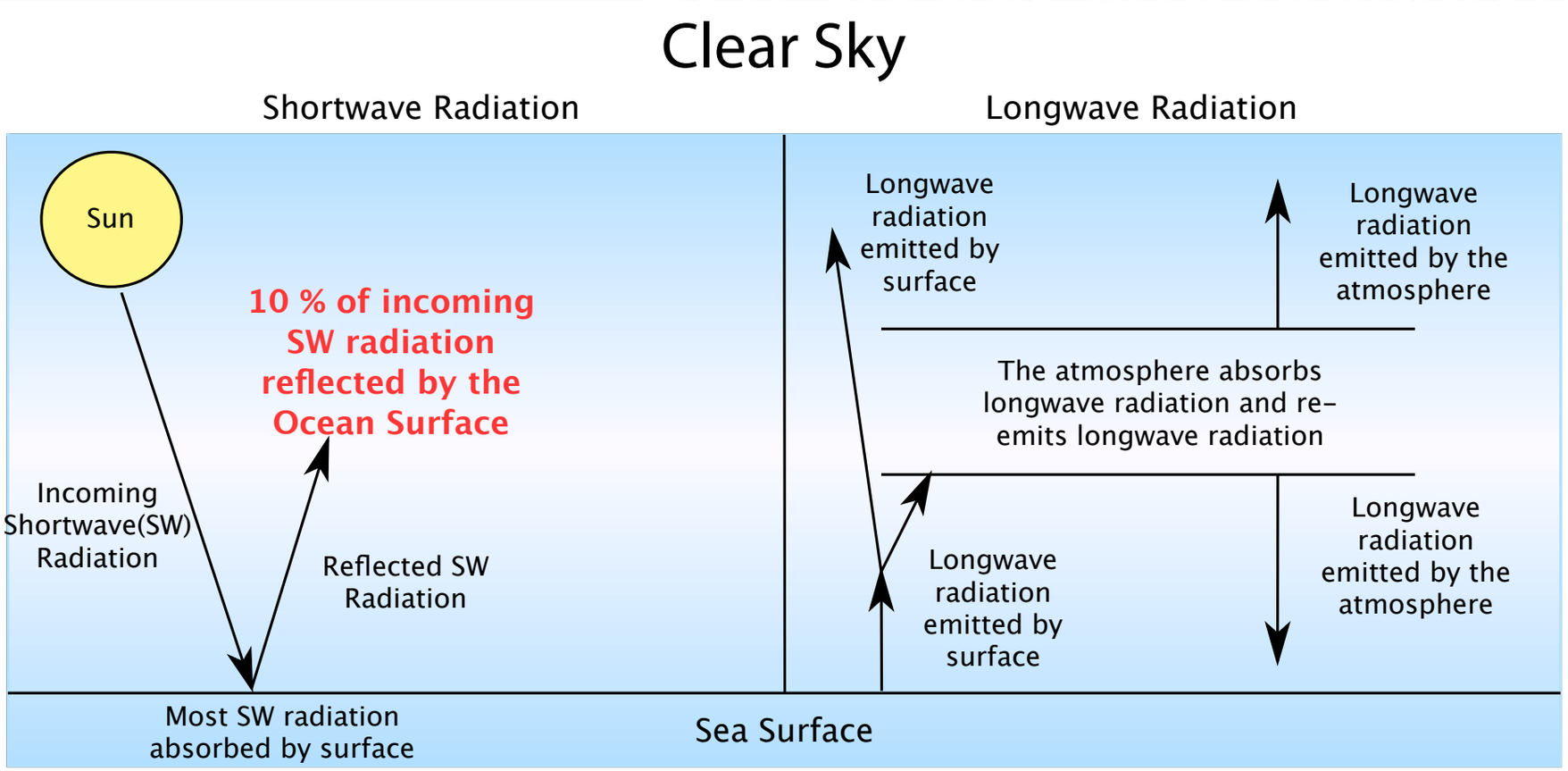
Low clouds and radiation

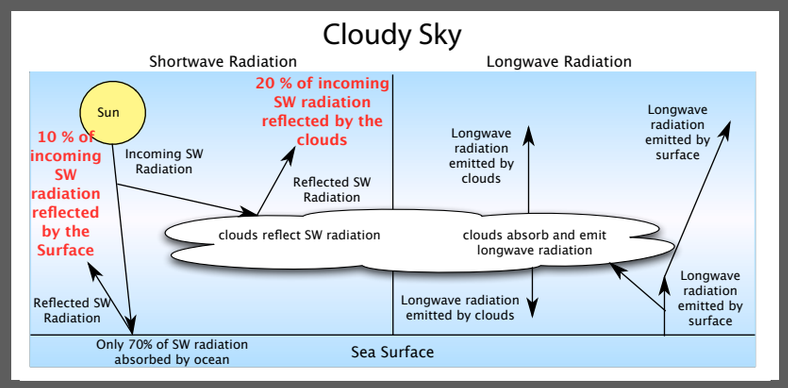




- Clear sky planetary albedo - 10%
- Cloudy sky planetary albedo - 30%
- Low clouds act to cool the earth/ atmosphere system

Low clouds and radiation



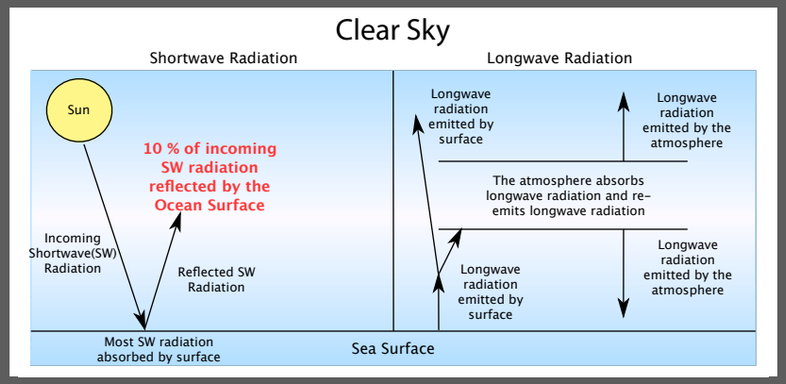


Clear sky planetary albedo - 10%

Cloudy sky planetary albedo - 30%

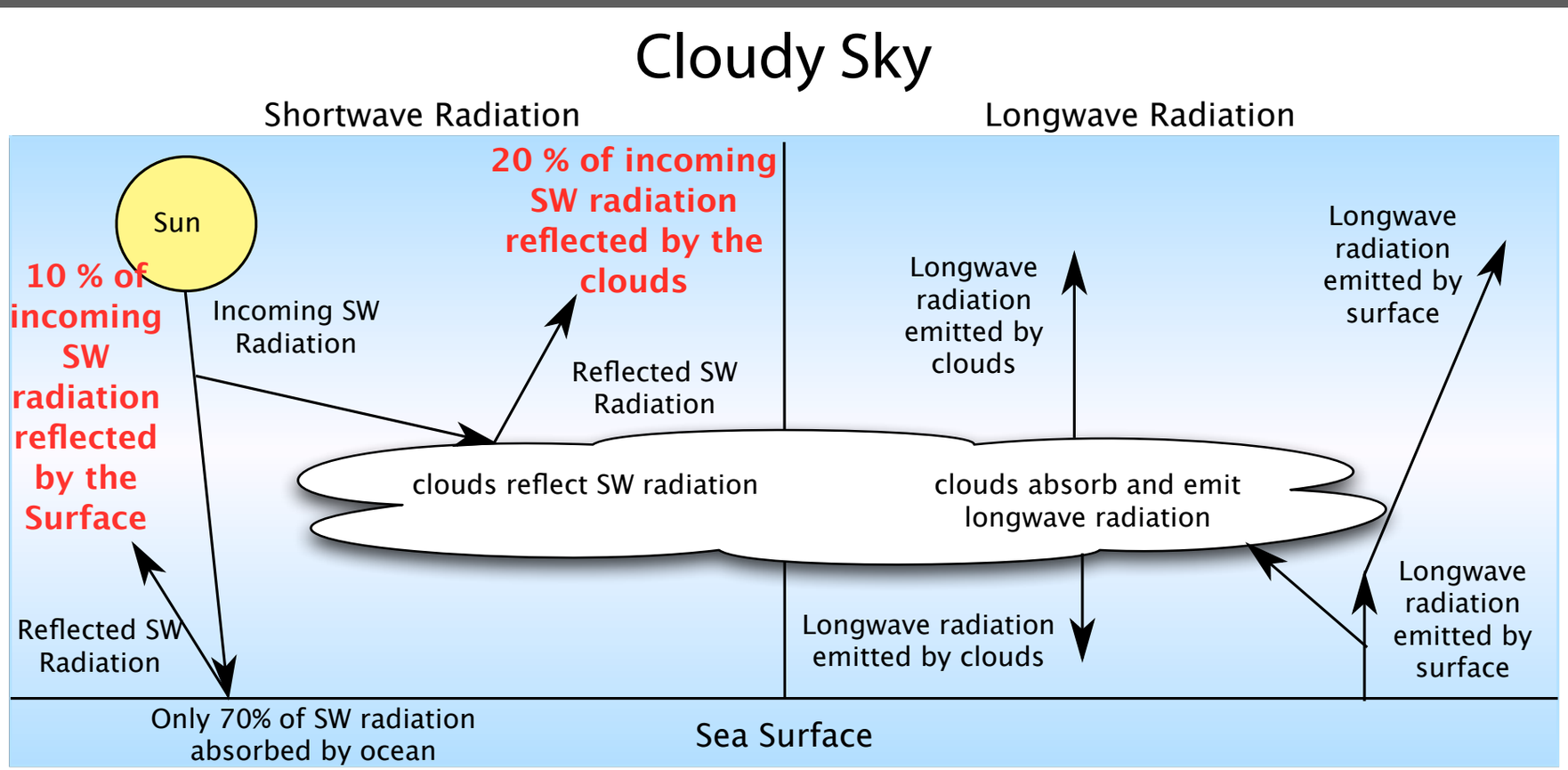
Low clouds act to cool the earth/ atmosphere system

Low clouds and radiation

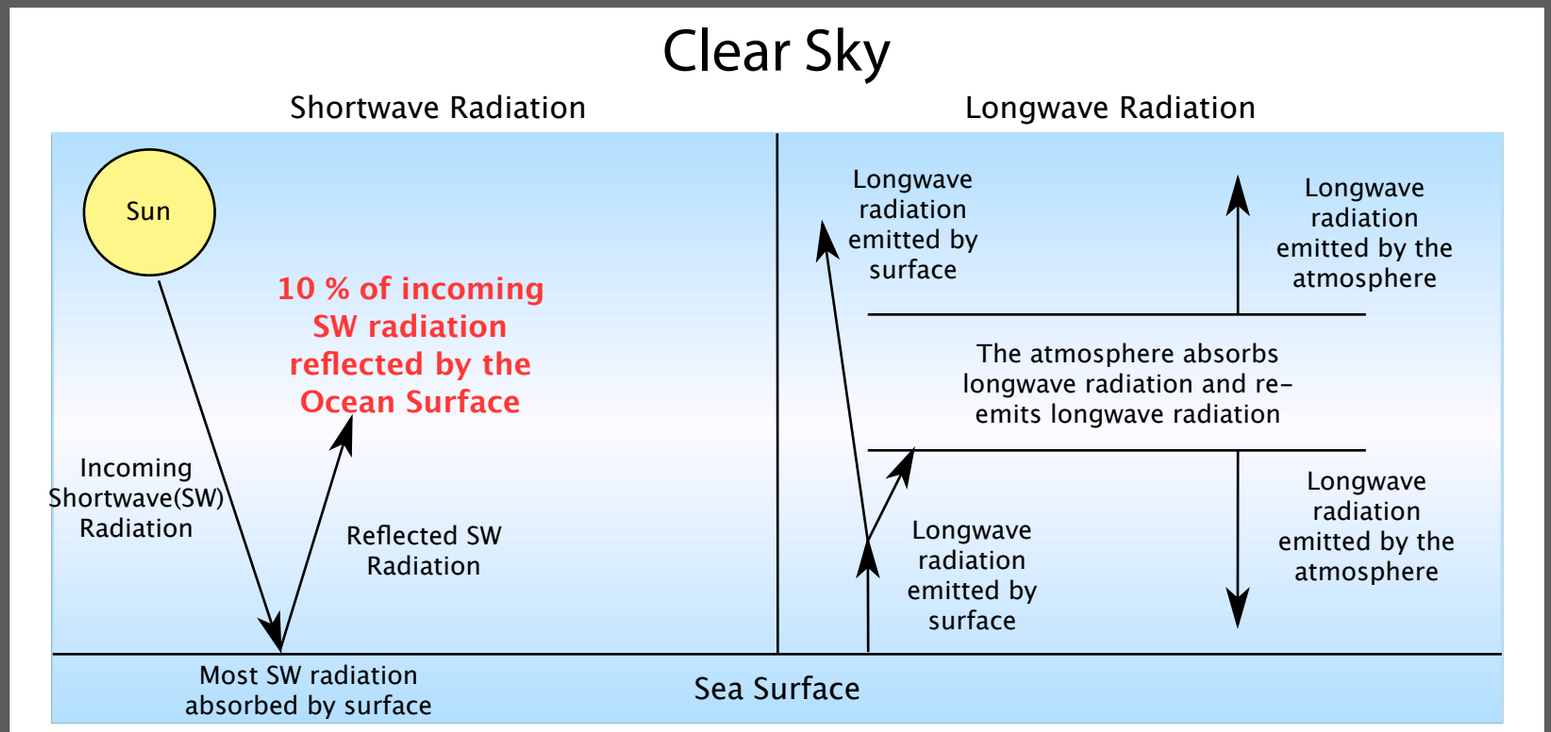


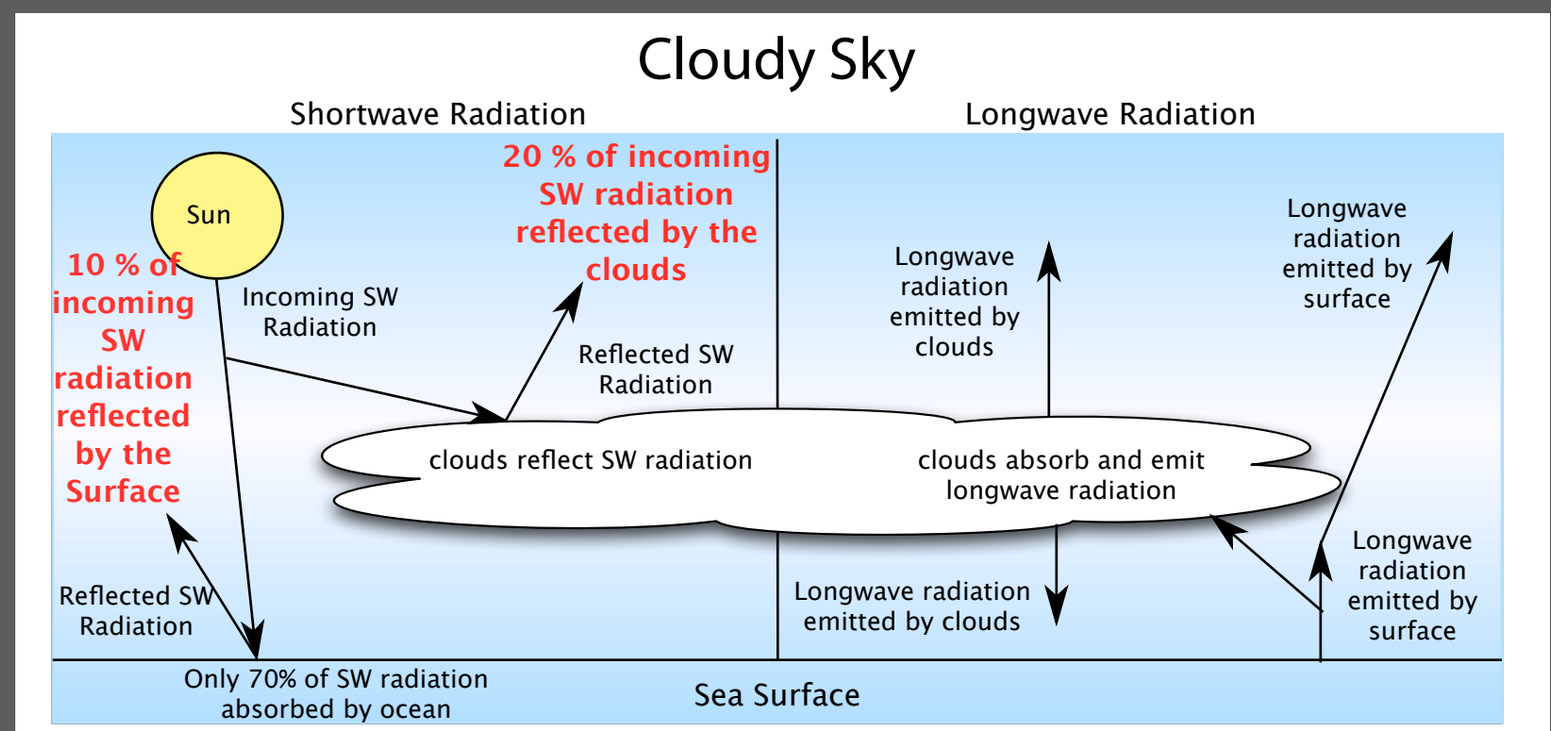
- Clear sky planetary albedo - 10%
- Cloudy sky planetary albedo - 30%

Low clouds act to cool the earth/ atmosphere system



Low clouds and radiation





- Clear sky planetary albedo - 10%
- Cloudy sky planetary albedo - 30%
- Low clouds act to cool the earth/ atmosphere system

What is a feedback?

- A feedback is a mechanism that tends to either amplify or damp a process.
- Feedbacks in climate change act to either amplify or damp the effects of greenhouse warming on the surface temperature.

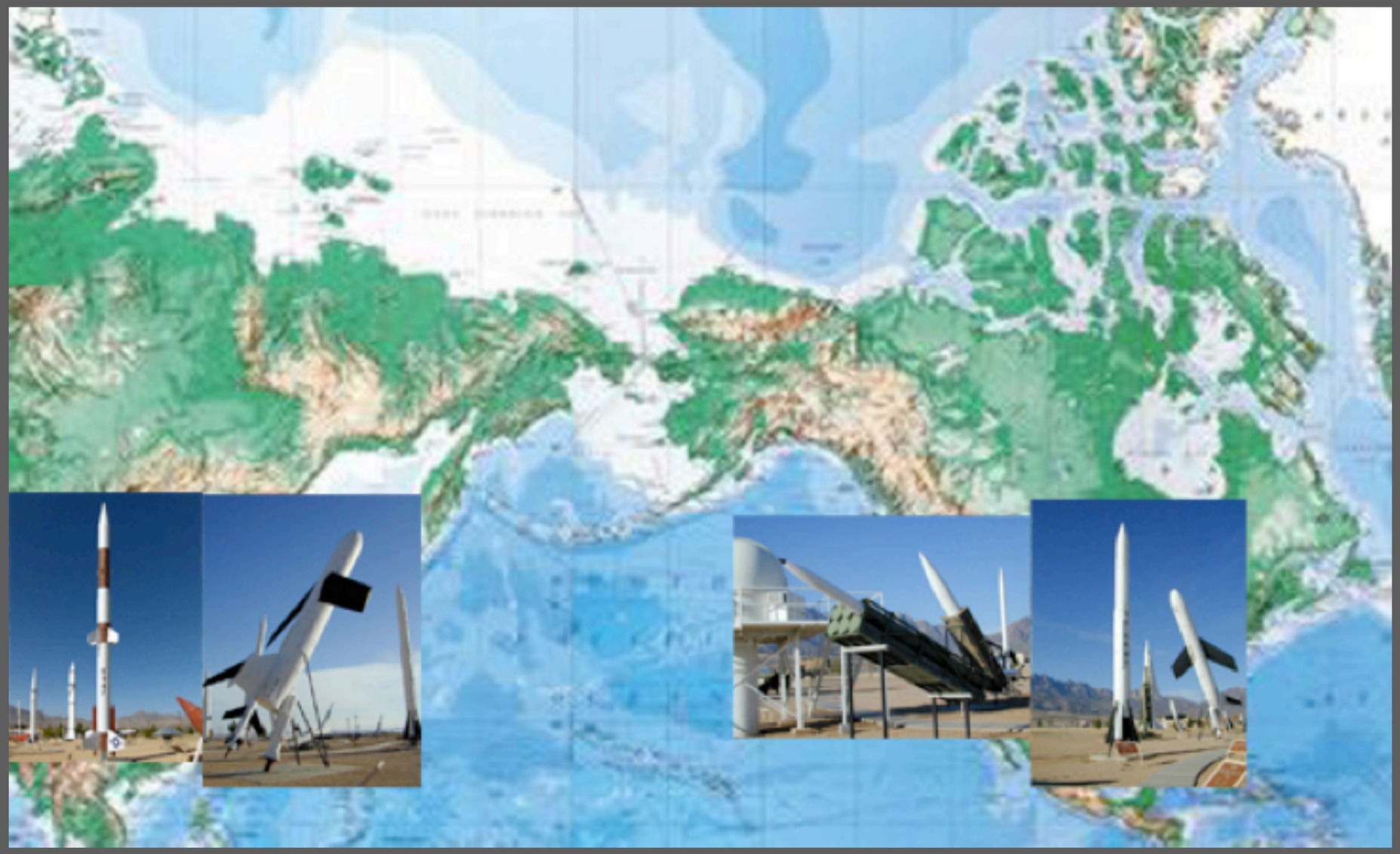
Feedbacks example - The Cold War

Feedbacks example - The Cold War

Feedbacks example - The Cold War

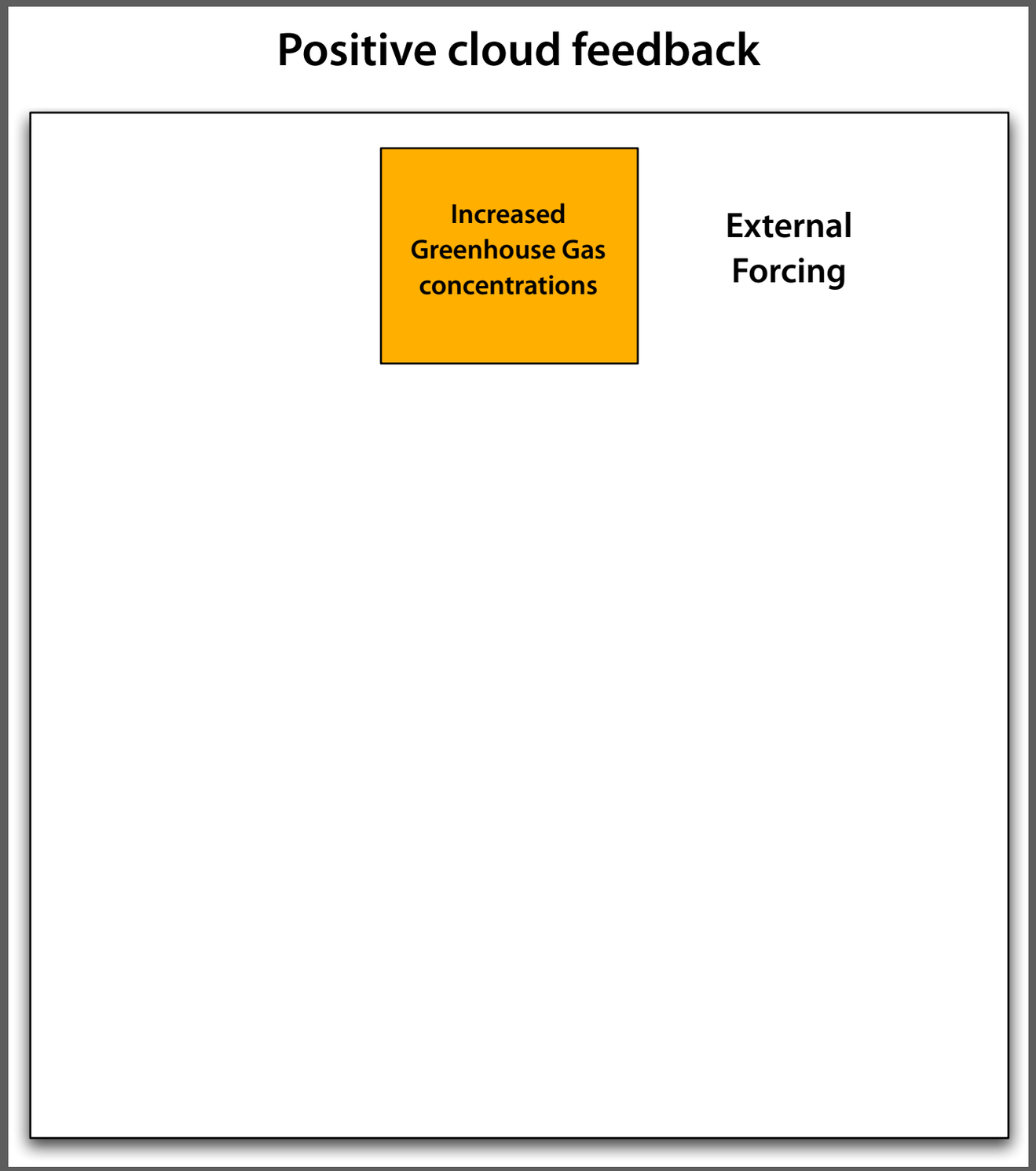
Feedbacks example - The Cold War

Feedbacks example - The Cold War

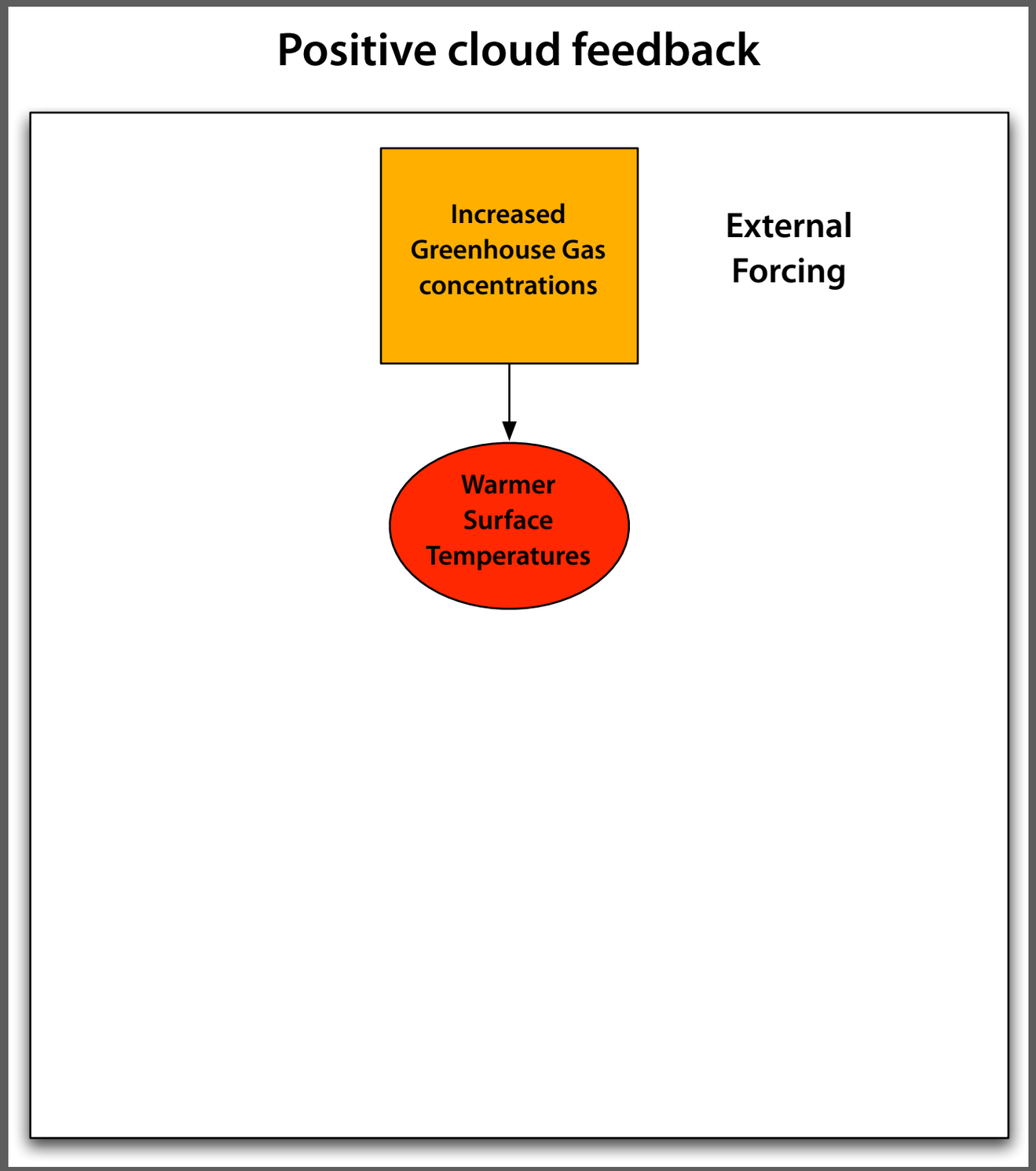


Feedbacks example - The Cold War

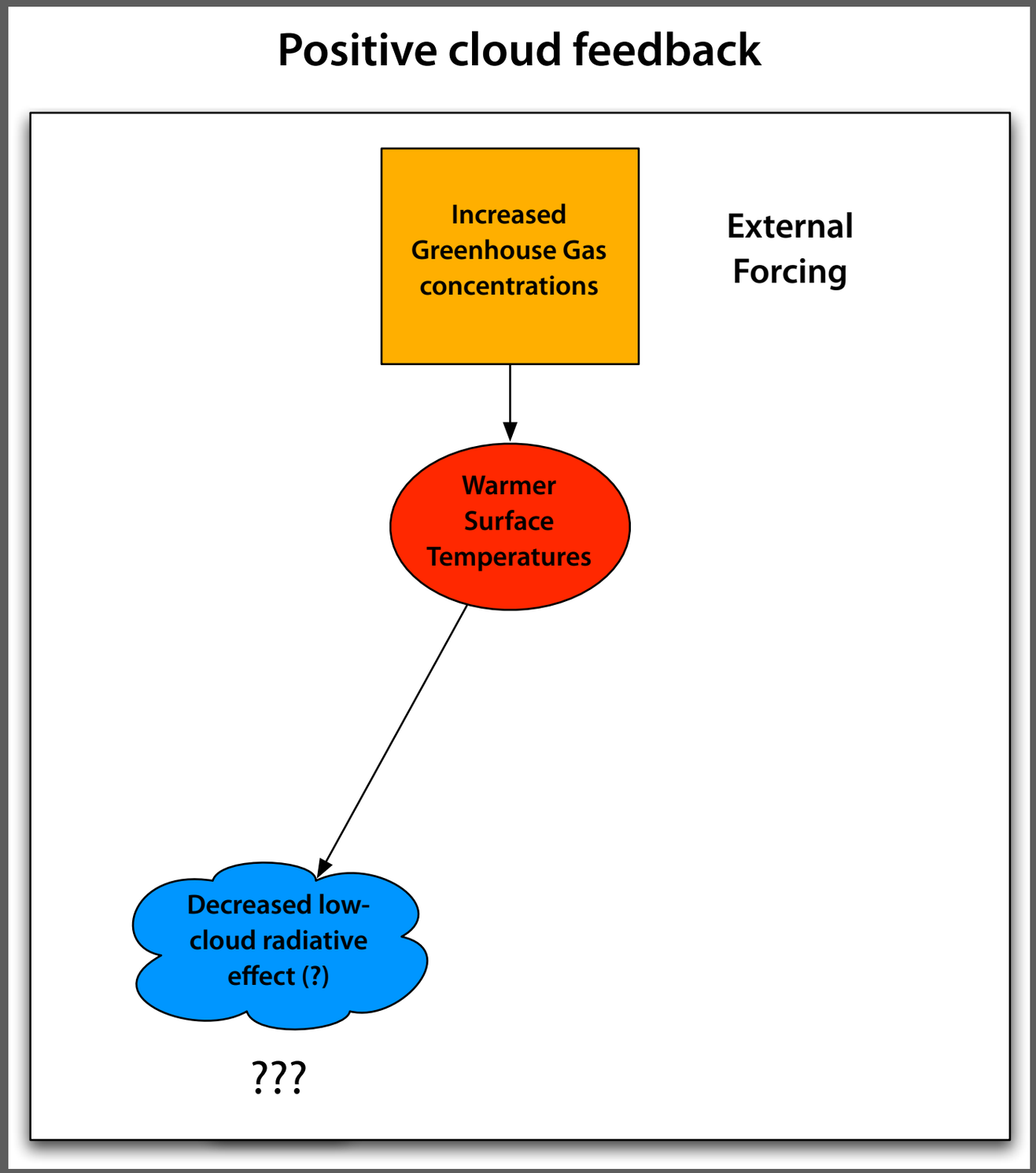
Possible low cloud feedbacks



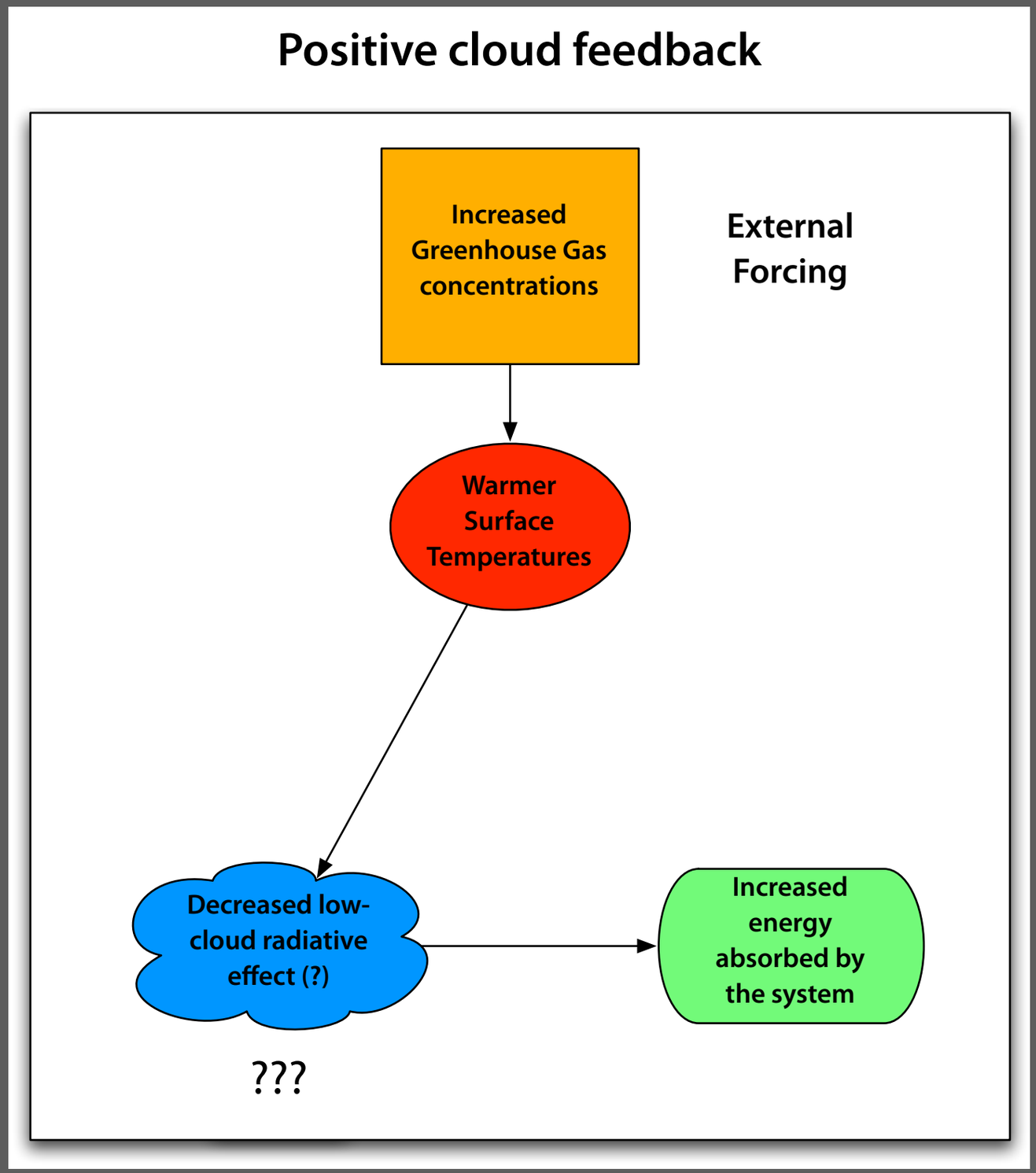
Possible low cloud feedbacks



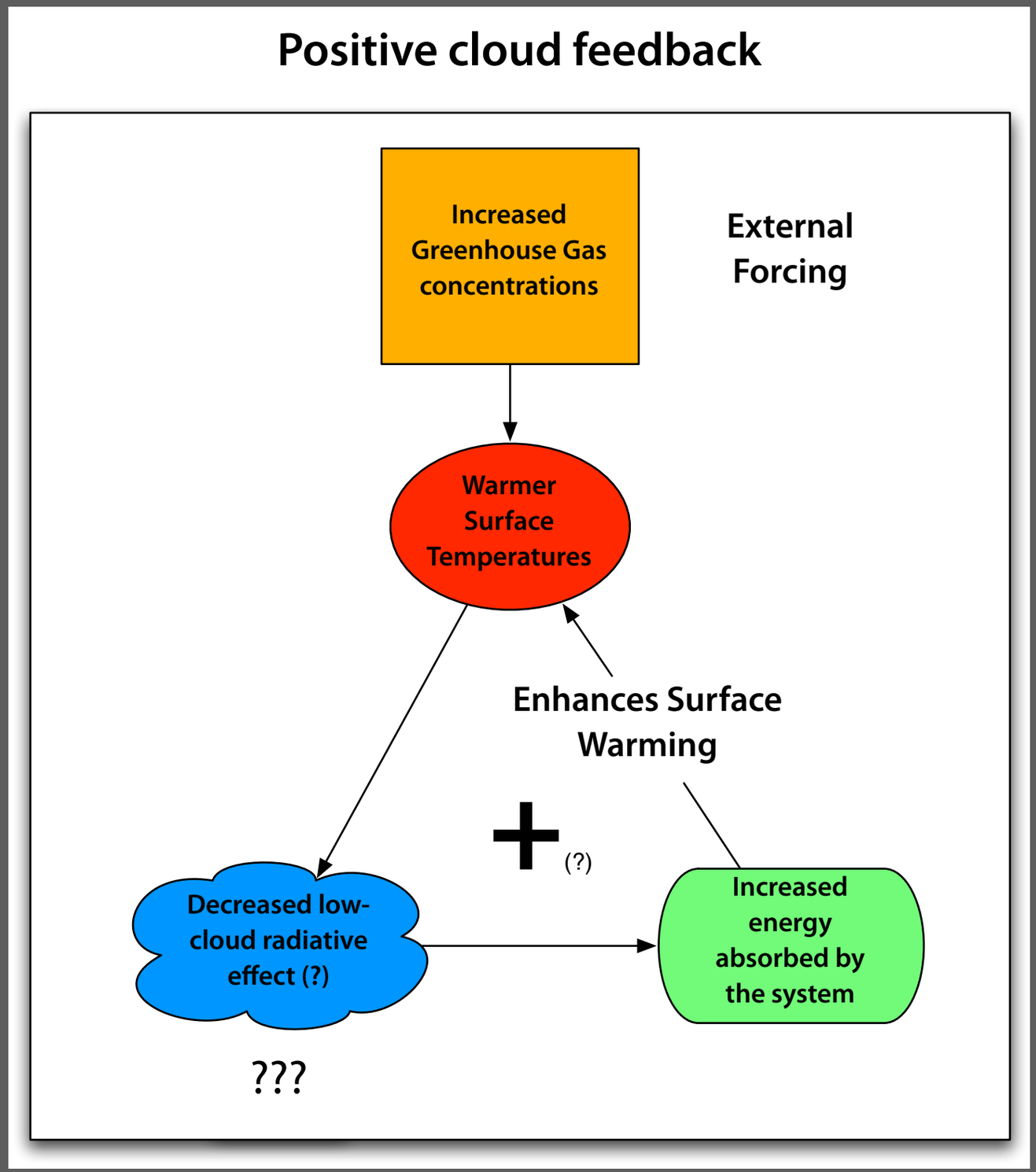
Possible low cloud feedbacks



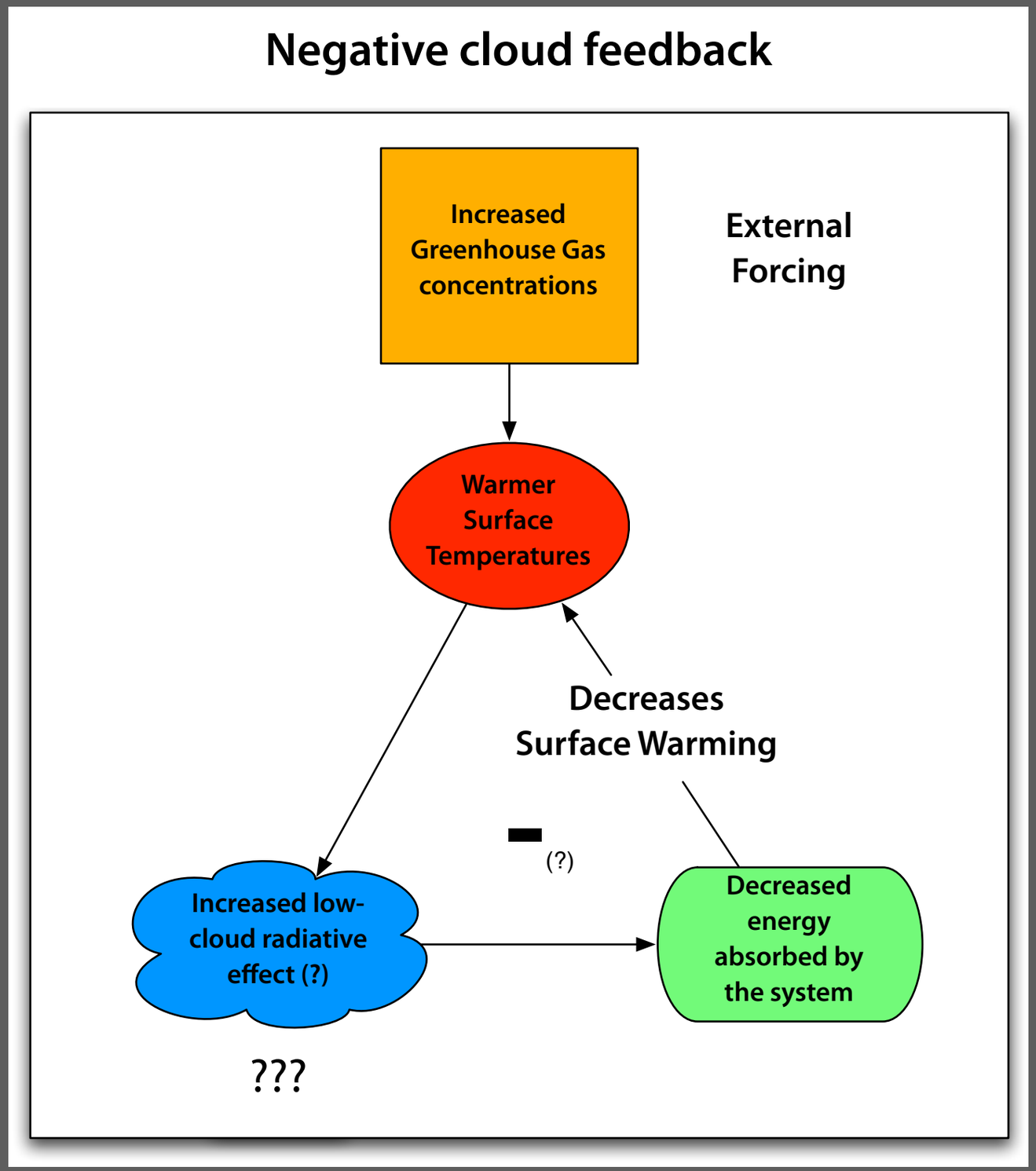
Possible low cloud feedbacks



Possible low cloud feedbacks



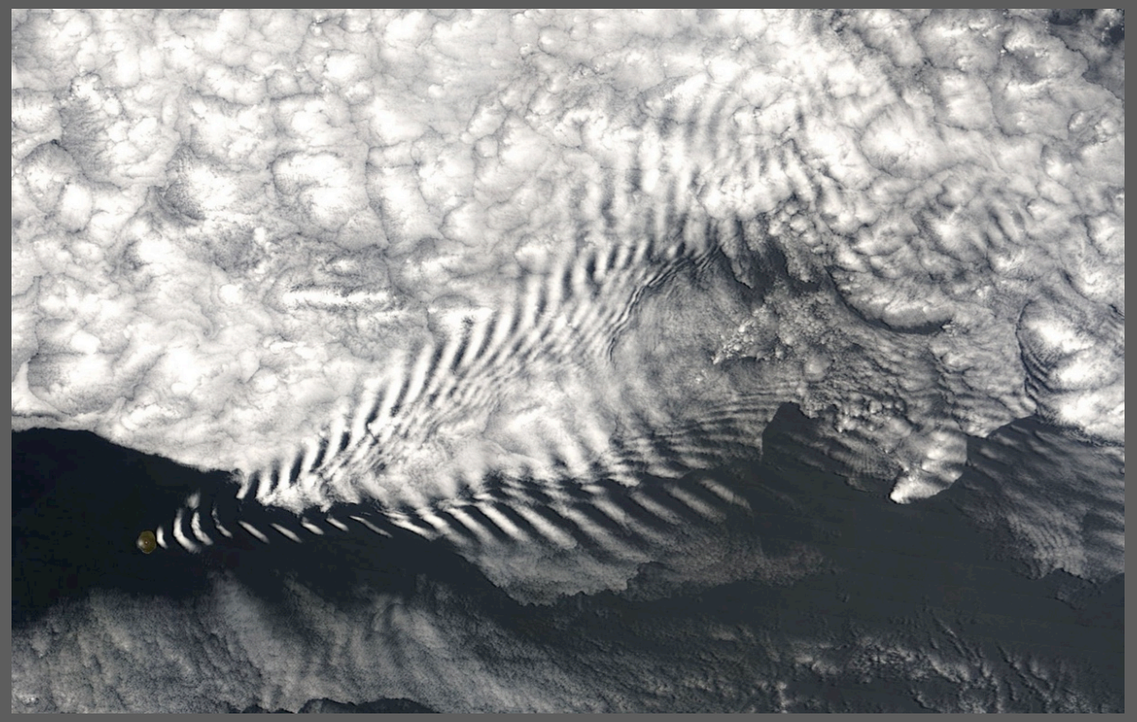
Possible low cloud feedbacks

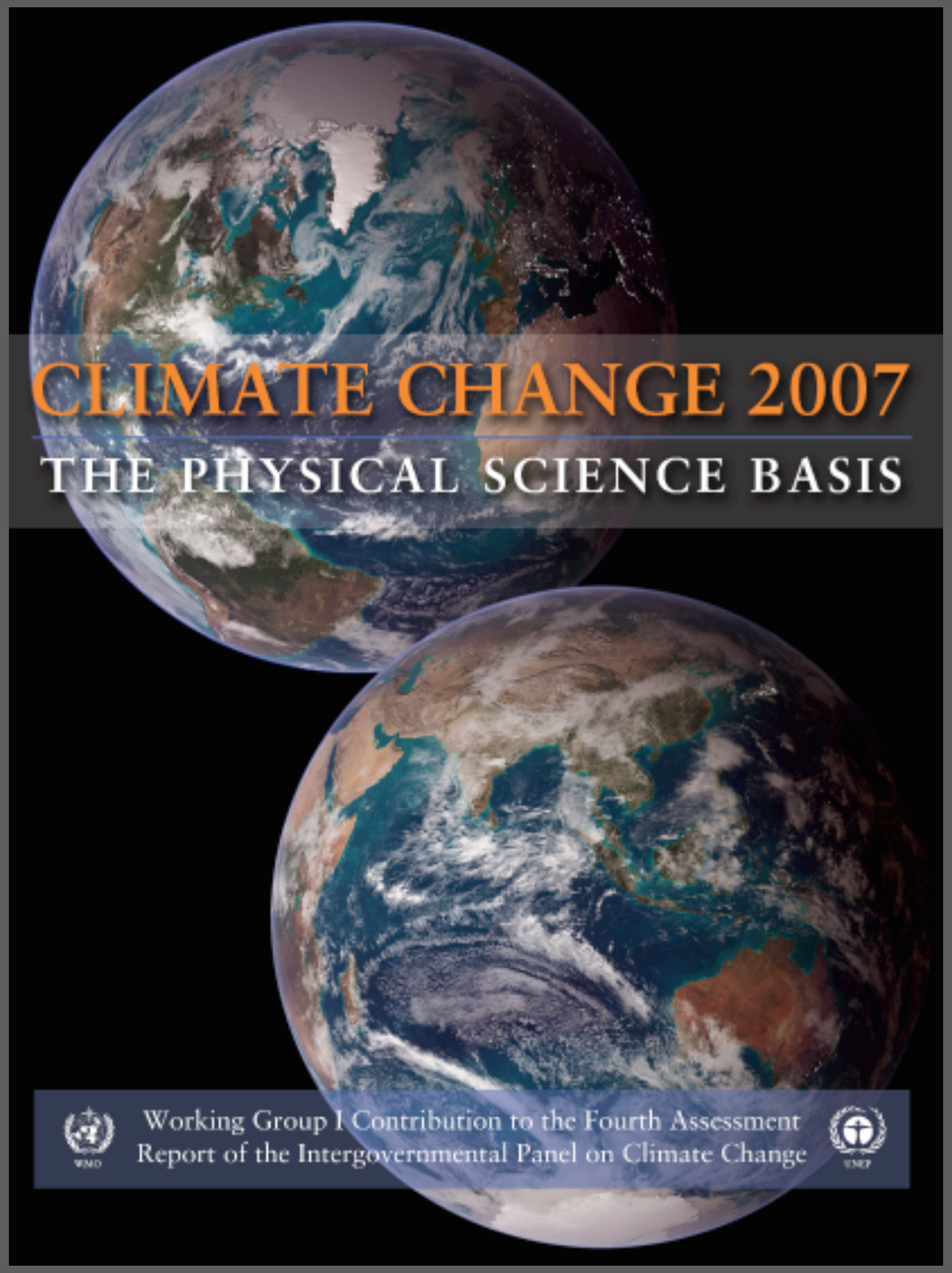


Low clouds and climate change

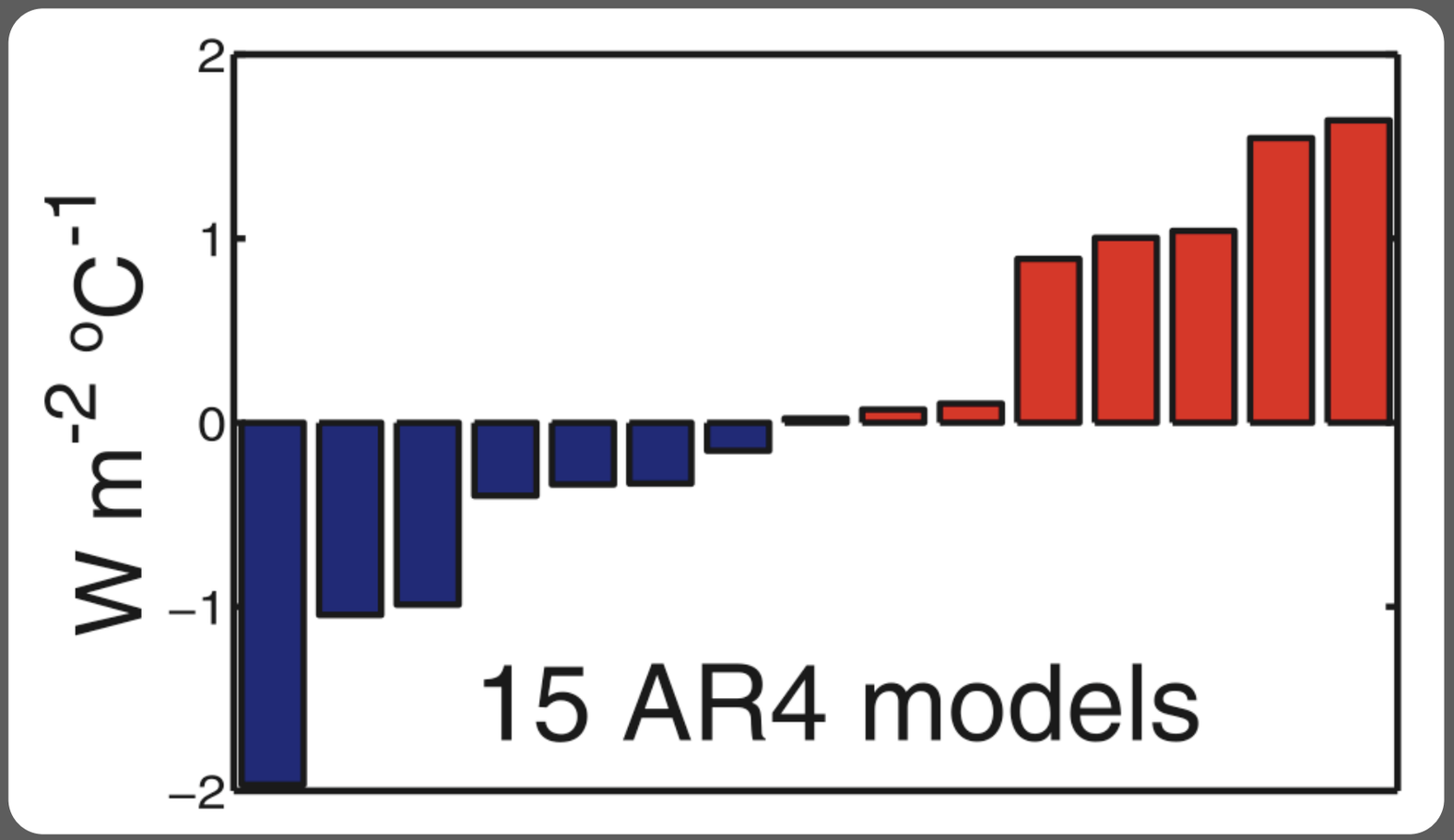
As our climate changes the characteristics of low clouds may change in many ways:

- Total low cloud cover
- Cloud type
- Physical characteristics
  - Liquid water content
  - Cloud drop size
- Aerosols??



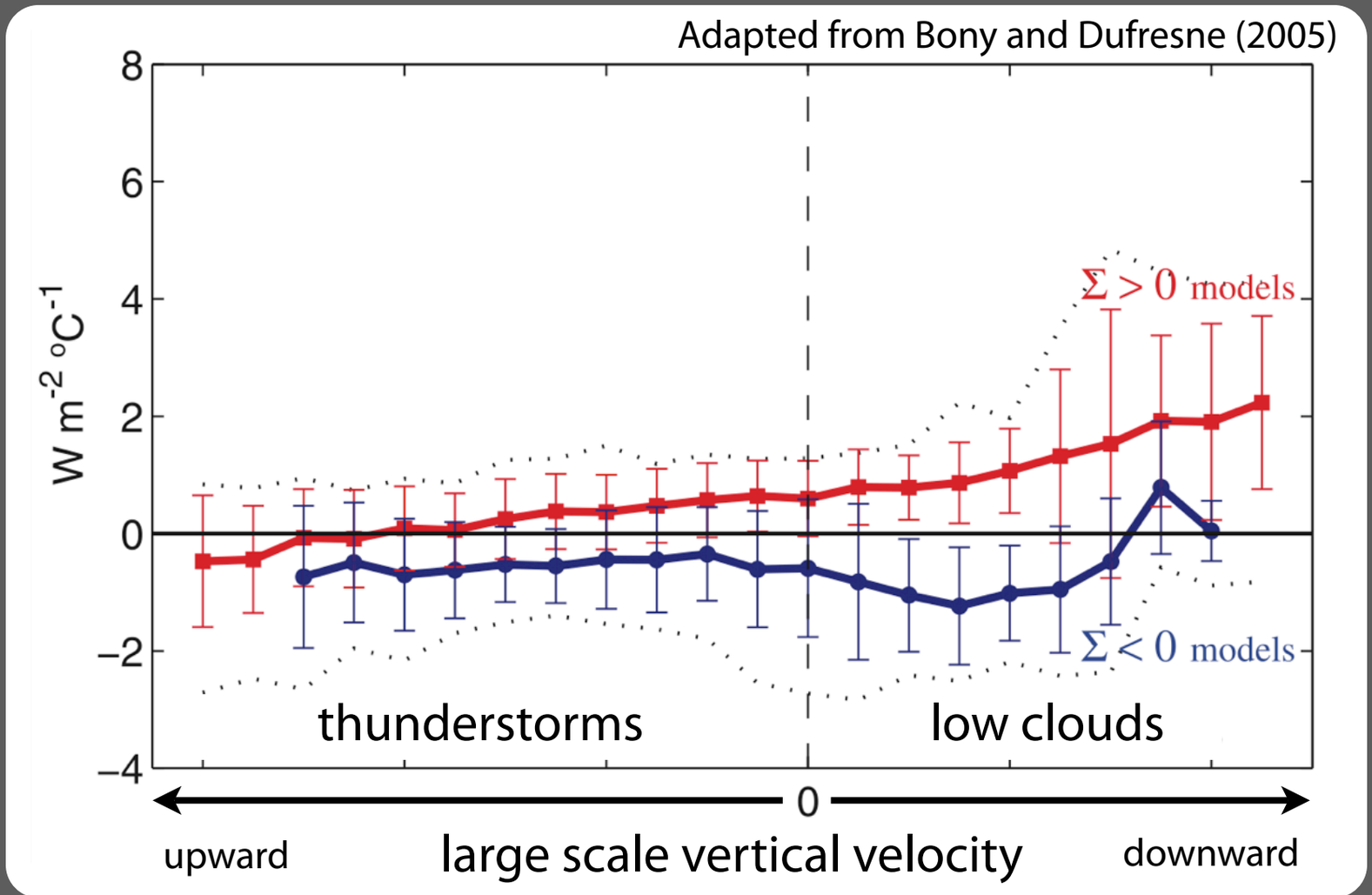

CLIMATE CHANGE 2007
THE PHYSICAL SCIENCE BASIS
Working Group I Contribution to the Fourth Assessment
Report of the Intergovernmental Panel on Climate Change

Cloud radiative effect predicted by GCMs



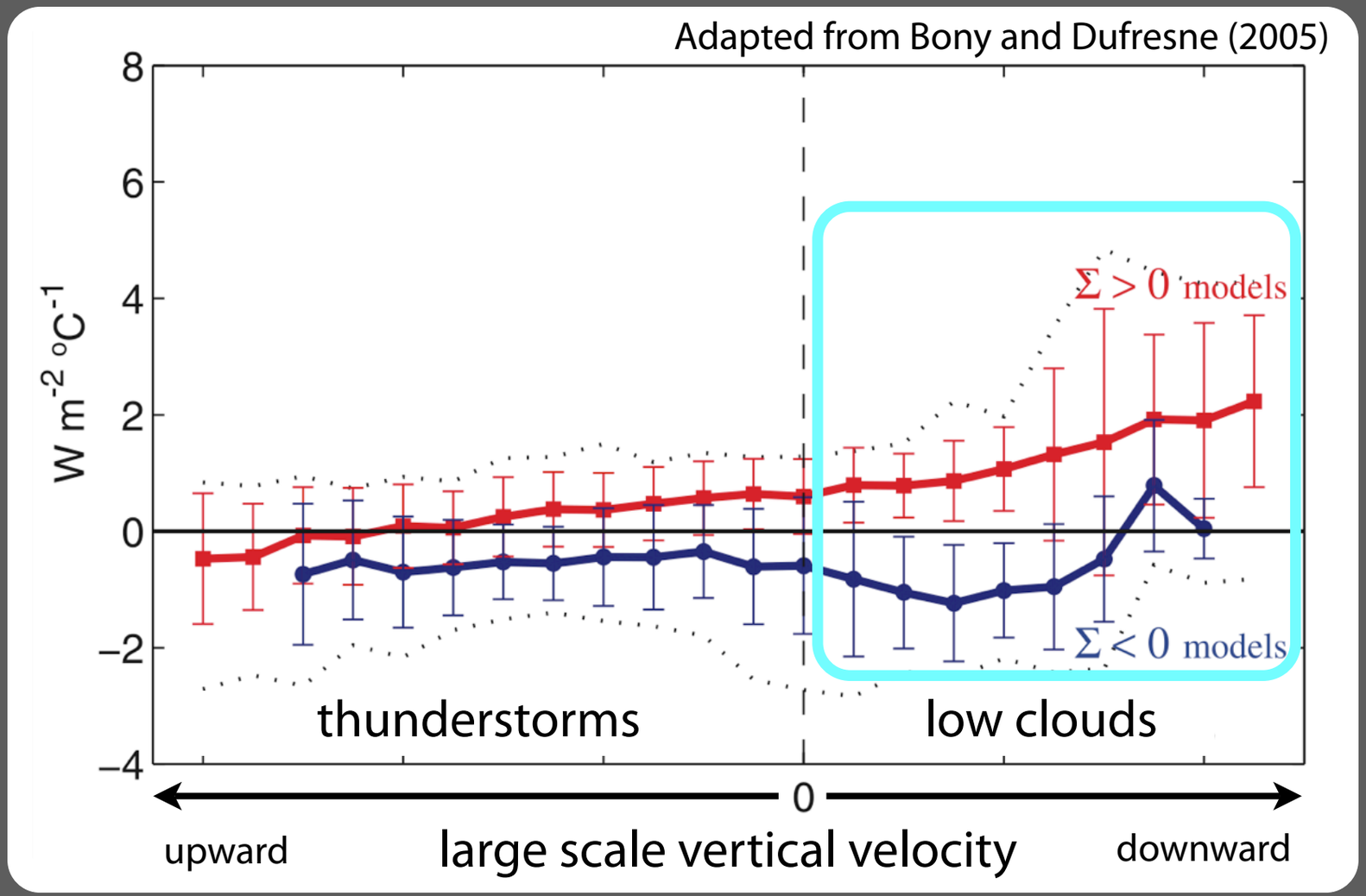
Sensitivity of tropical net CRE to SST changes:
8 models predict negative, 7 models predict positive.

Largest discrepancy in low clouds



➡ The spread of tropical cloud feedbacks among the models primarily arises from inter-model differences in low cloud feedbacks.

Largest discrepancy in low clouds



➡ The spread of tropical cloud feedbacks among the models primarily arises from inter-model differences in low cloud feedbacks.

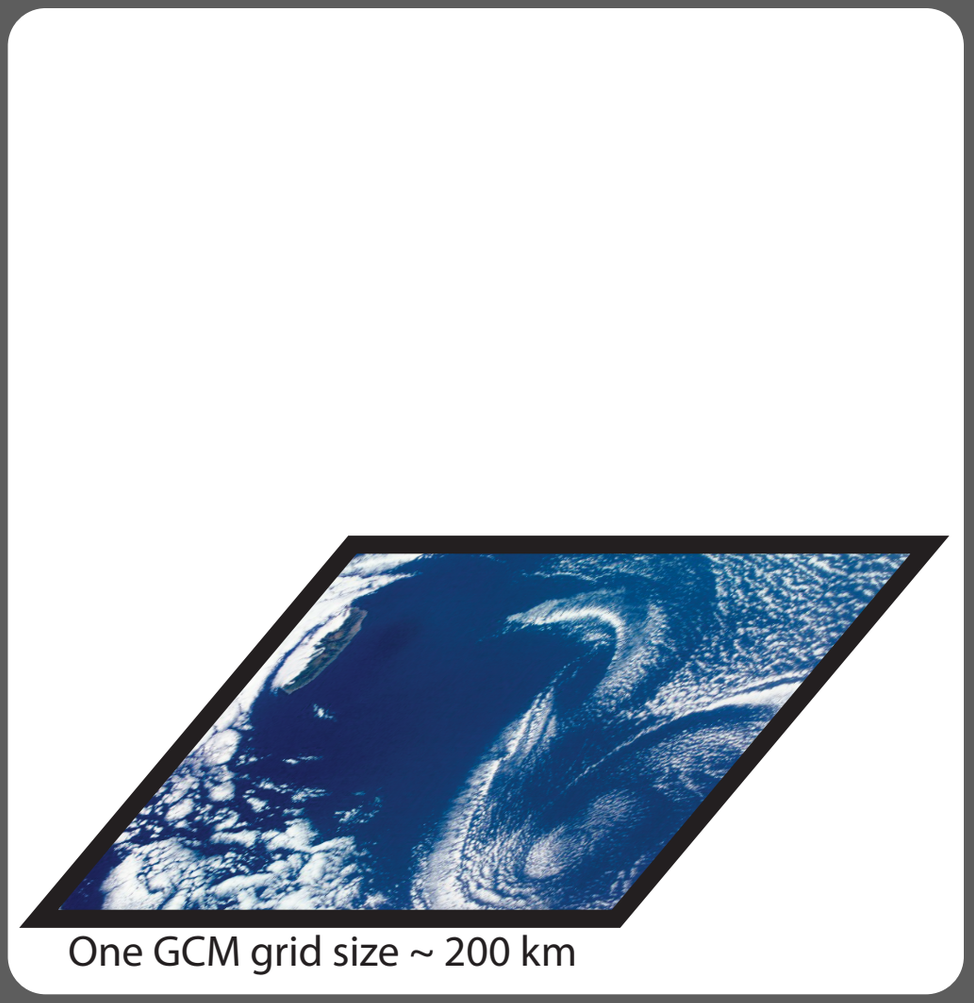
Why are low clouds a problem for some models?

- Clouds are a subgrid scale (SGS) process in GCM. CRM resolves big clouds but not small clouds like low clouds.

➡ Clouds have to be parameterized.

- Processes in the clouds are not well understood.

➡ Turbulence, aerosols, drizzle, precipitation, radiation, etc.



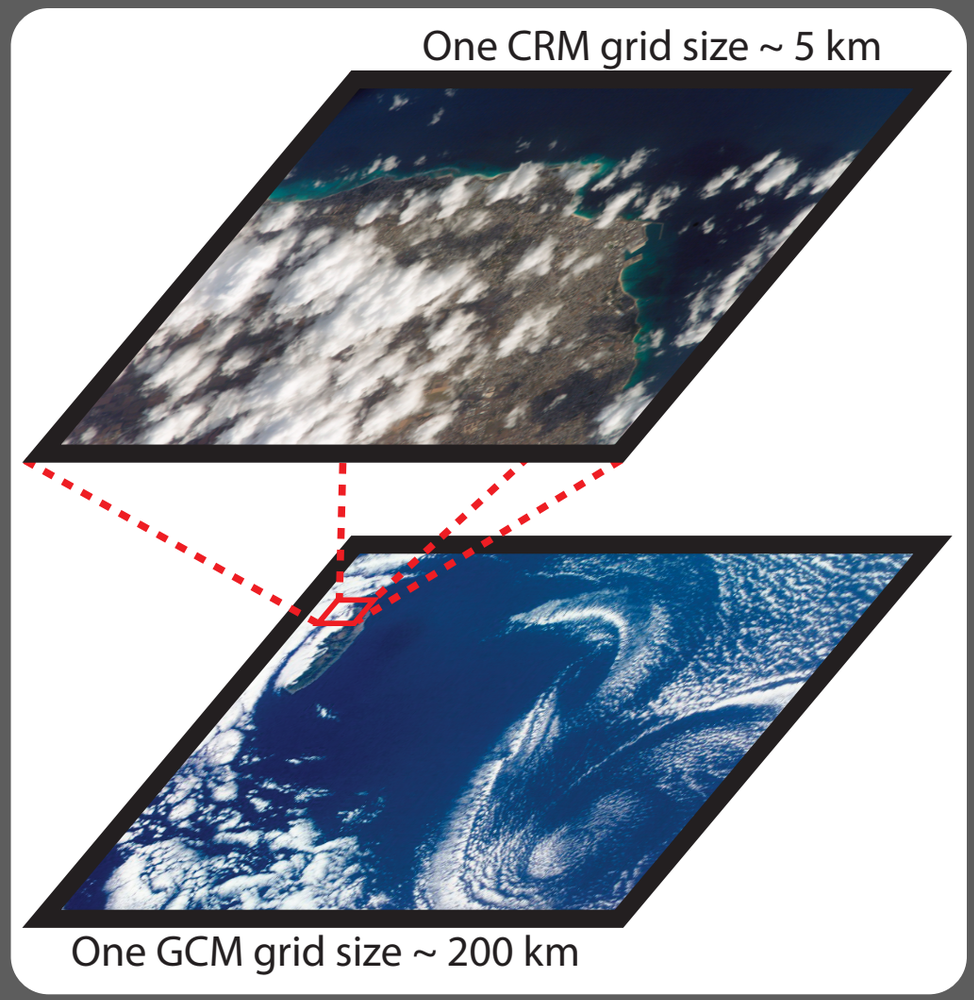
Why are low clouds a problem for some models?

- Clouds are a subgrid scale (SGS) process in GCM. CRM resolves big clouds but not small clouds like low clouds.

➡ Clouds have to be parameterized.

- Processes in the clouds are not well understood.

➡ Turbulence, aerosols, drizzle, precipitation, radiation, etc.

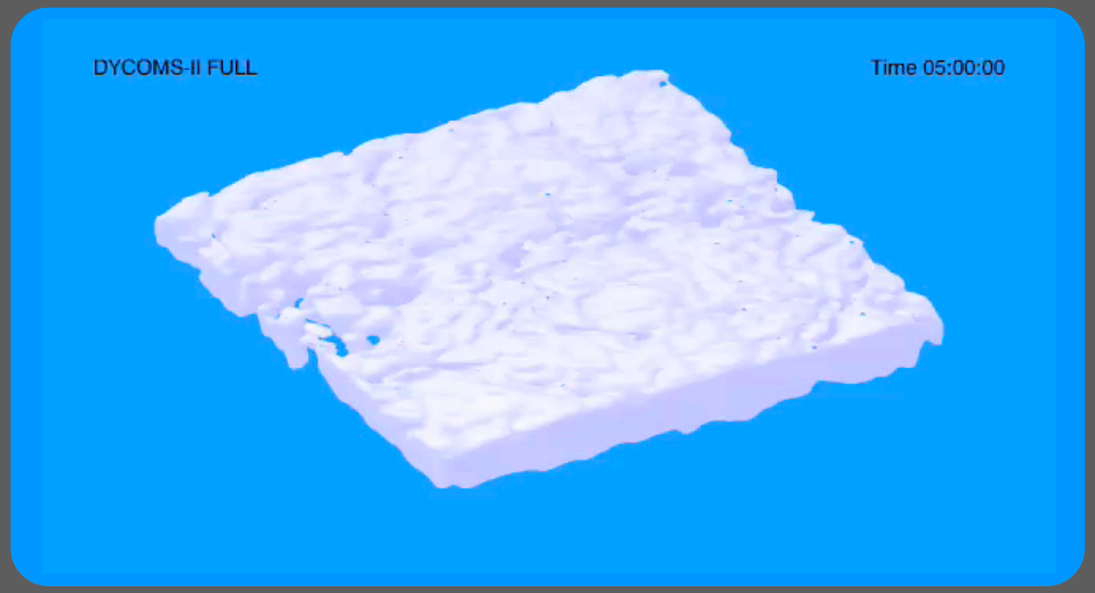


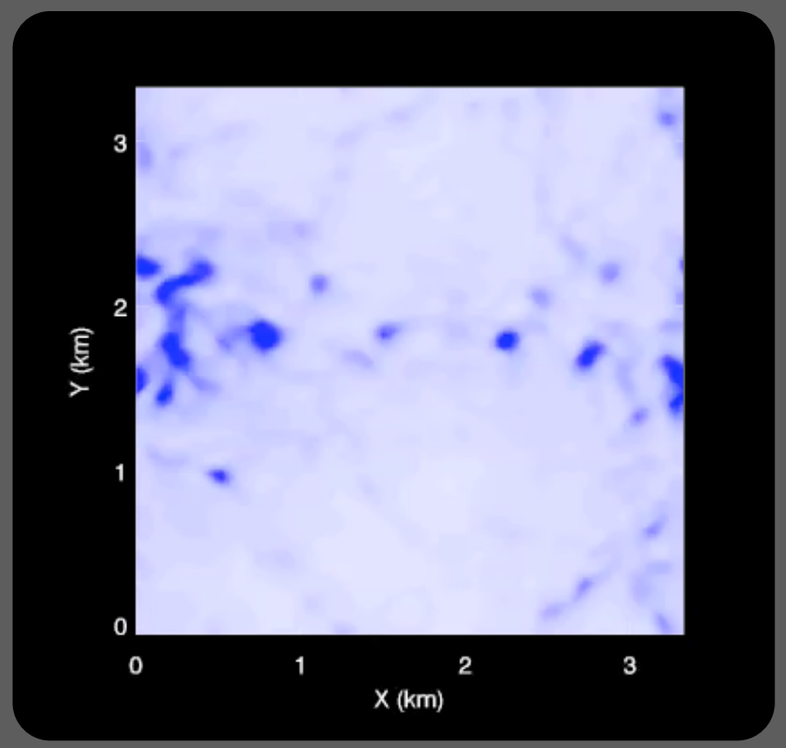
Large eddy simulation

- Large eddy simulation (LES) model resolves clouds with ~50 m or finer grid size.
- Useful tool to study cloud-scale processes

➡ Test parameterizations used in GCM and CRM.

- Problems: expensive for large domain and/or higher resolution, LES still requires parameterizations.

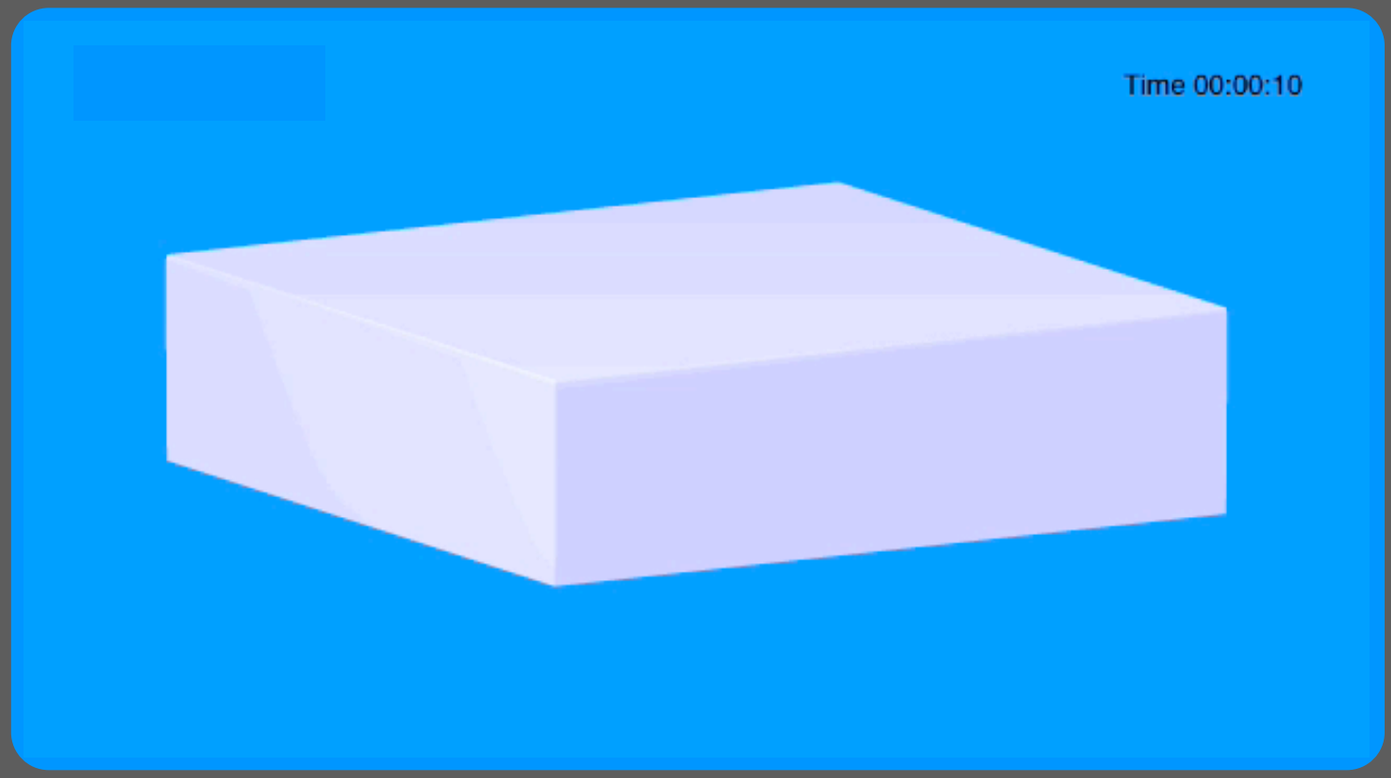




Example

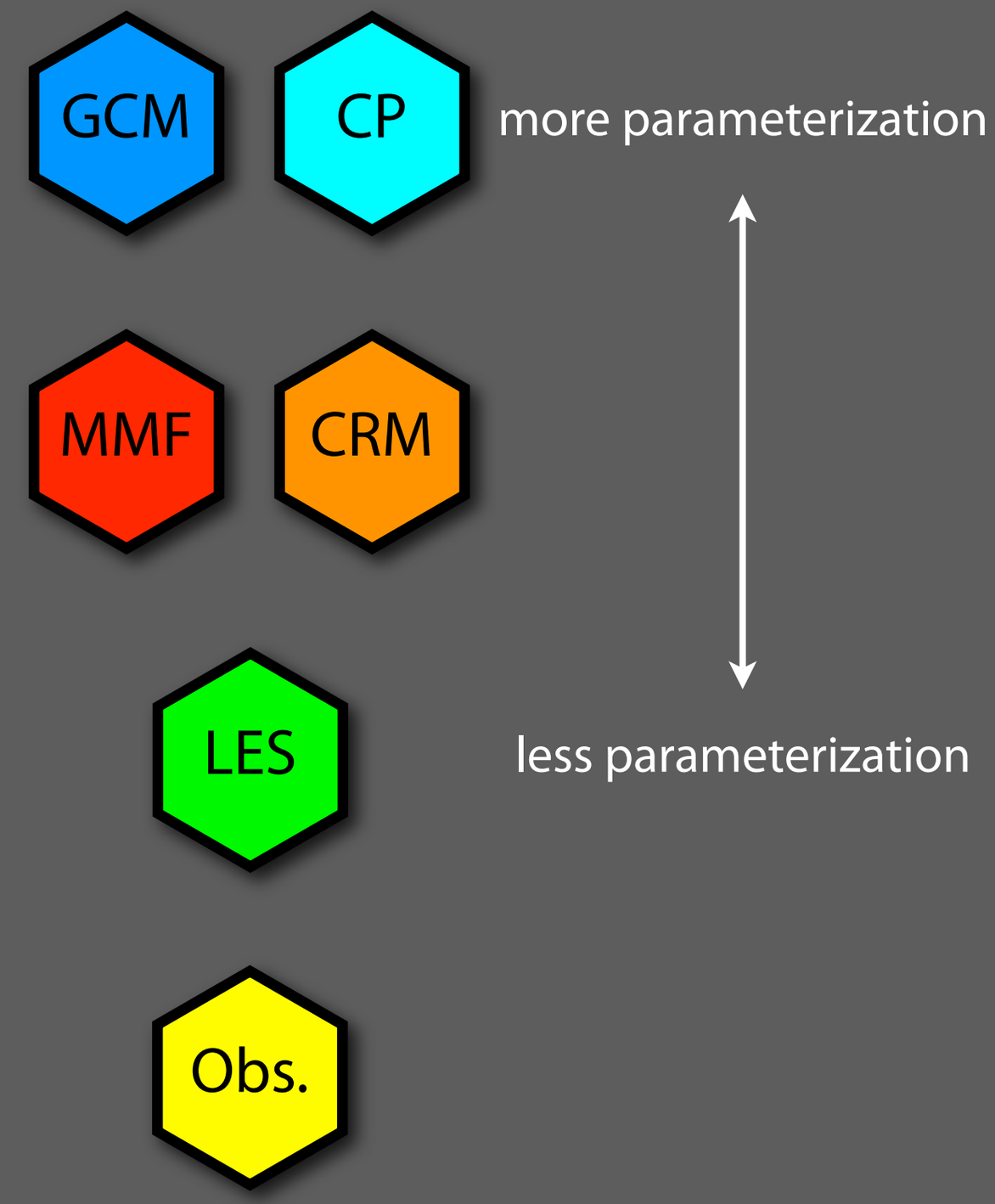
- LESs can be used to test hypotheses with realistic & idealized conditions.
- Right: What happens if dry air is entrained into marine stratocumulus clouds under an idealized condition?

➡ Idealized 3D LES with 5 m isotropic grid and 3.2 km horizontal domain



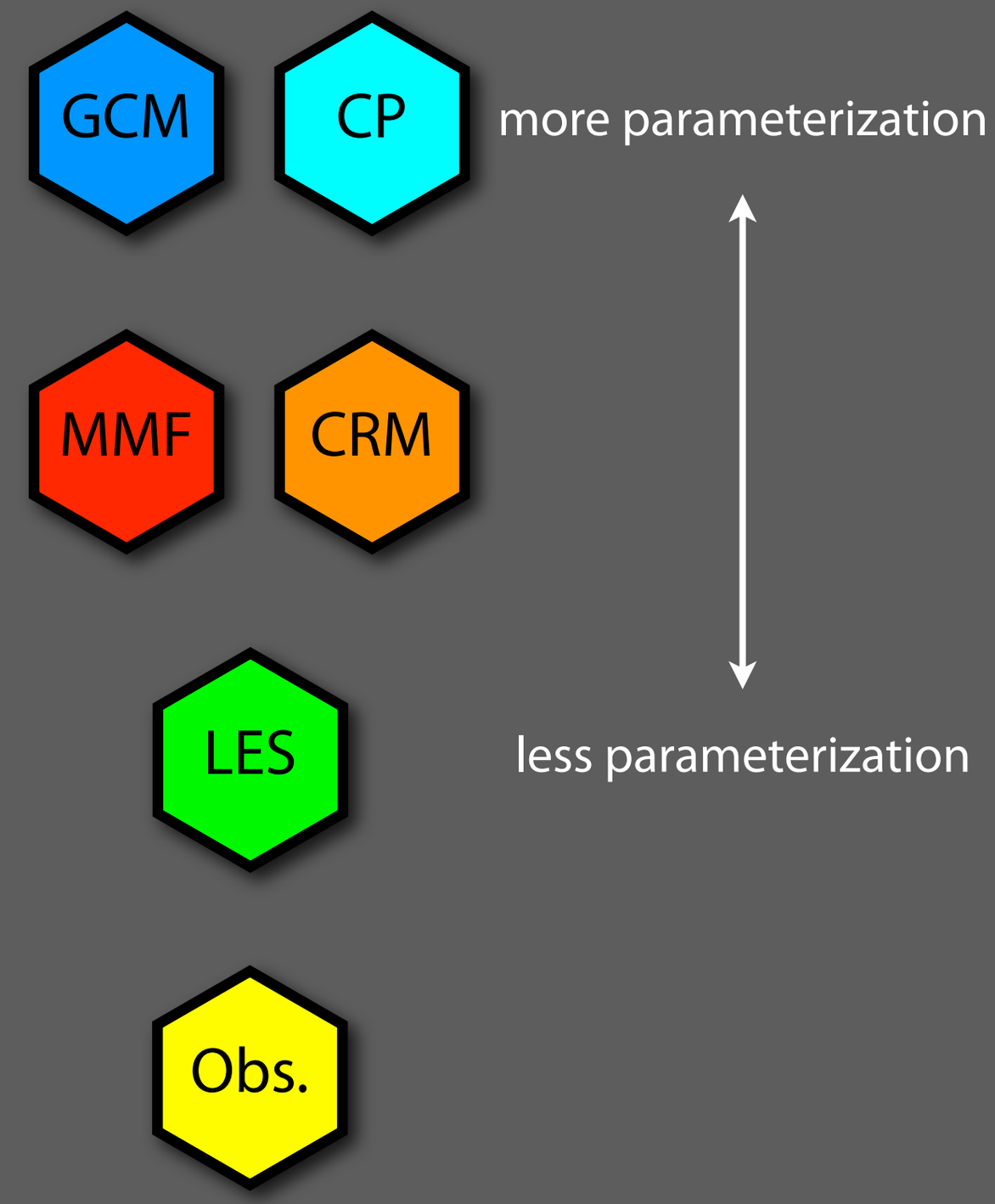
Tools

- GCM - uses conventional parameterization (CP)
- MMF - CRM is embedded in each GCM grid, super parametrization
- LES - very high resolution
- Observations - satellite, field studies



Tools

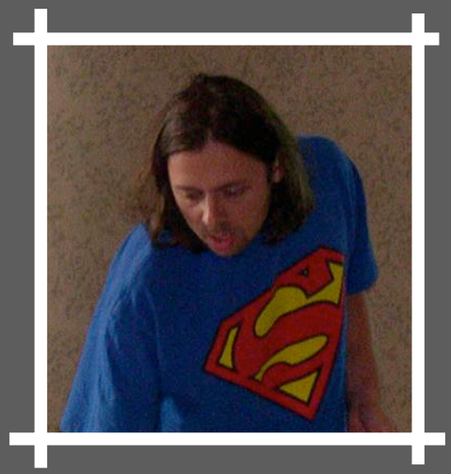
- GCM - uses conventional parameterization (CP)
- MMF - CRM is embedded in each GCM grid, super parametrization
- LES - very high resolution
- Observations - satellite, field studies



Low cloud feedbacks @ CMMAP.org

- Develop improved conventional parameterization of low clouds
- Understand low cloud feedback in the MMF
- Improve the ability of CRMs to simulate low clouds
- Collaboration with Cloud Feedback Intercomparison Project

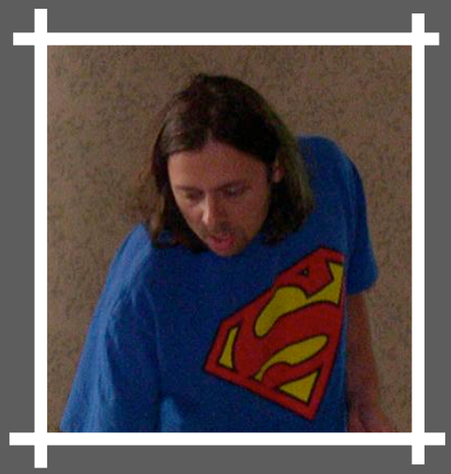
Low cloud feedbacks @ CMMAP.org



Our theme leaders

- Develop improved conventional parameterization of low clouds
- Understand low cloud feedback in the MMF
- Improve the ability of CRMs to simulate low clouds
- Collaboration with Cloud Feedback Intercomparison Project

Low cloud feedbacks @ CMMAP.org



Our theme leaders

- Develop improved conventional parameterization of low clouds
- Understand low cloud feedback in the MMF
- Improve the ability of CRMs to simulate low clouds
- Collaboration with Cloud Feedback Intercomparison Project

Develop improved CP of low clouds

Different GCMs

aqua-planet

Develop improved CP of low clouds

Different GCMs

aqua-planet

simulate with the same boundary conditions

How is the cloud response of each aqua-planet GCM?

Develop improved CP of low clouds

Different GCMs

aqua-planet

simulate with the same boundary conditions

How is the cloud response of each aqua-planet GCM?

- The different global cloud responses among different GCMs mainly come from the different responses of the low clouds.

Develop improved CP of low clouds

Different GCMs

aqua-planet

simulate with the same boundary conditions

How is the cloud response of each aqua-planet GCM?

- The different global cloud responses among different GCMs mainly come from the different responses of the low clouds.
- The different representations of shallow clouds contribute to the disagreement among GCMs.

Develop improved CP of low clouds

Different GCMs

aqua-planet

simulate with the same boundary conditions

How is the cloud response of each aqua-planet GCM?

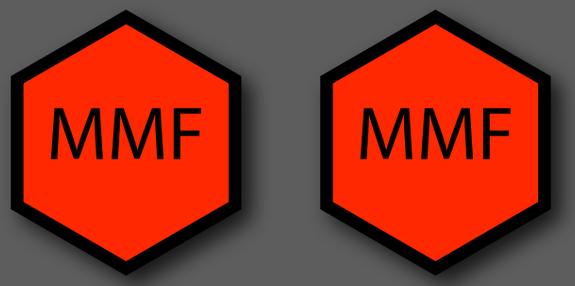
Develop improved parameterization

Further studies with CP, CRM and LES

- The different global cloud responses among different GCMs mainly come from the different responses of the low clouds.
- The different representations of shallow clouds contribute to the disagreement among GCMs.

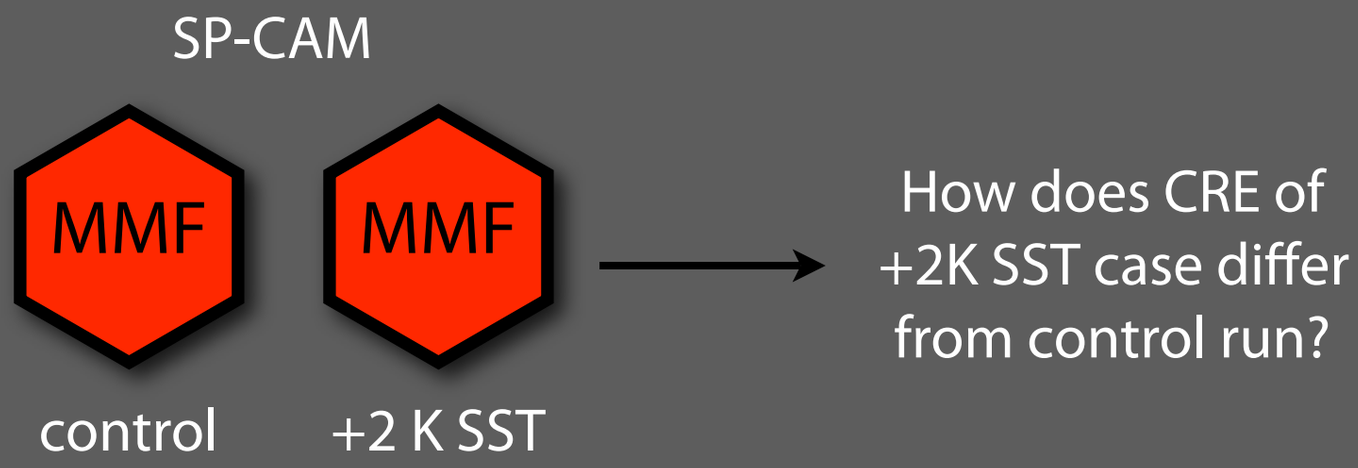
Understand low cloud feedback in the MMF

SP-CAM



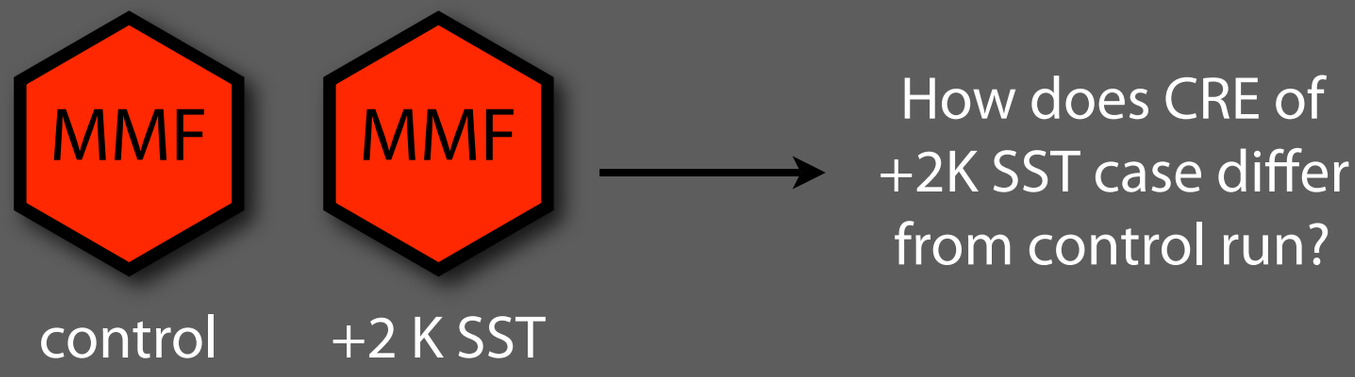
control +2 K SST

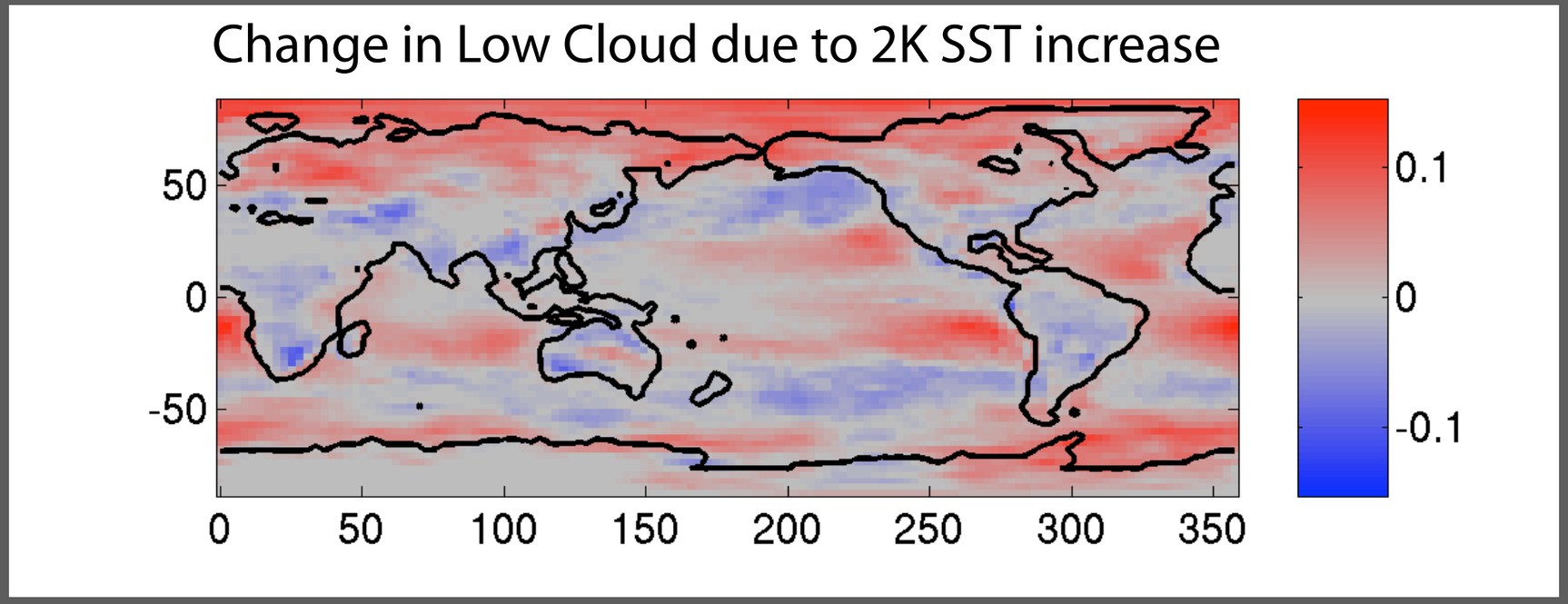
Understand low cloud feedback in the MMF



Understand low cloud feedback in the MMF

SP-CAM



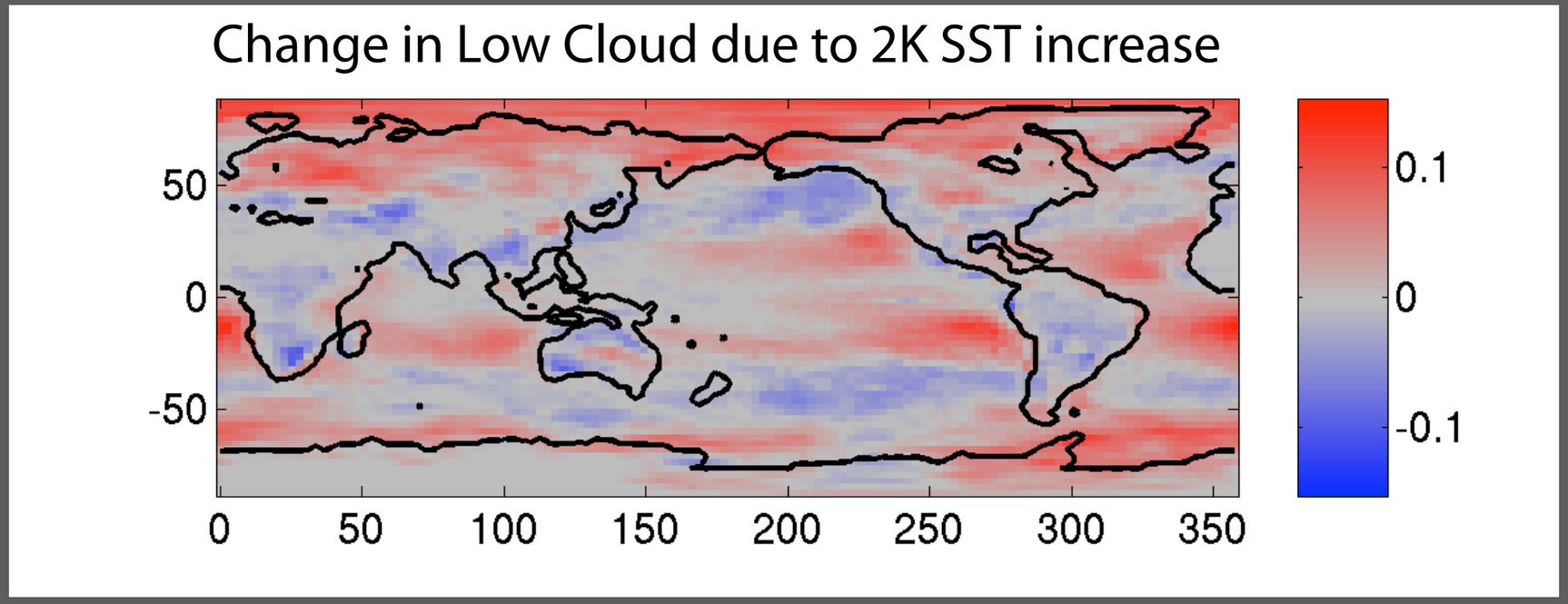


- SP-CAM tropical low cloud cover increases substantially as the climate warms. This has a net cooling effect.

Understand low cloud feedback in the MMF

SP-CAM

How does CRE of +2K SST case differ from control run?

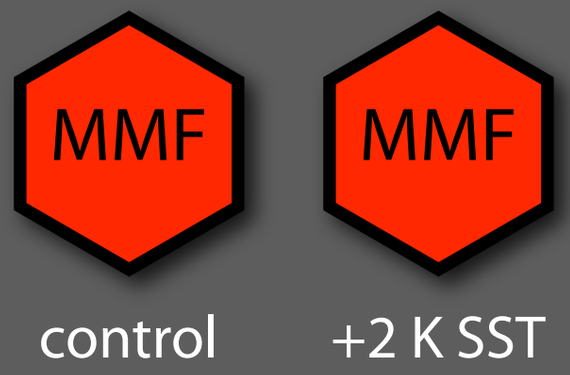


- SP-CAM tropical low cloud cover increases substantially as the climate warms. This has a net cooling effect.

➡ Why do the low clouds increase?

Understand low cloud feedback in the MMF

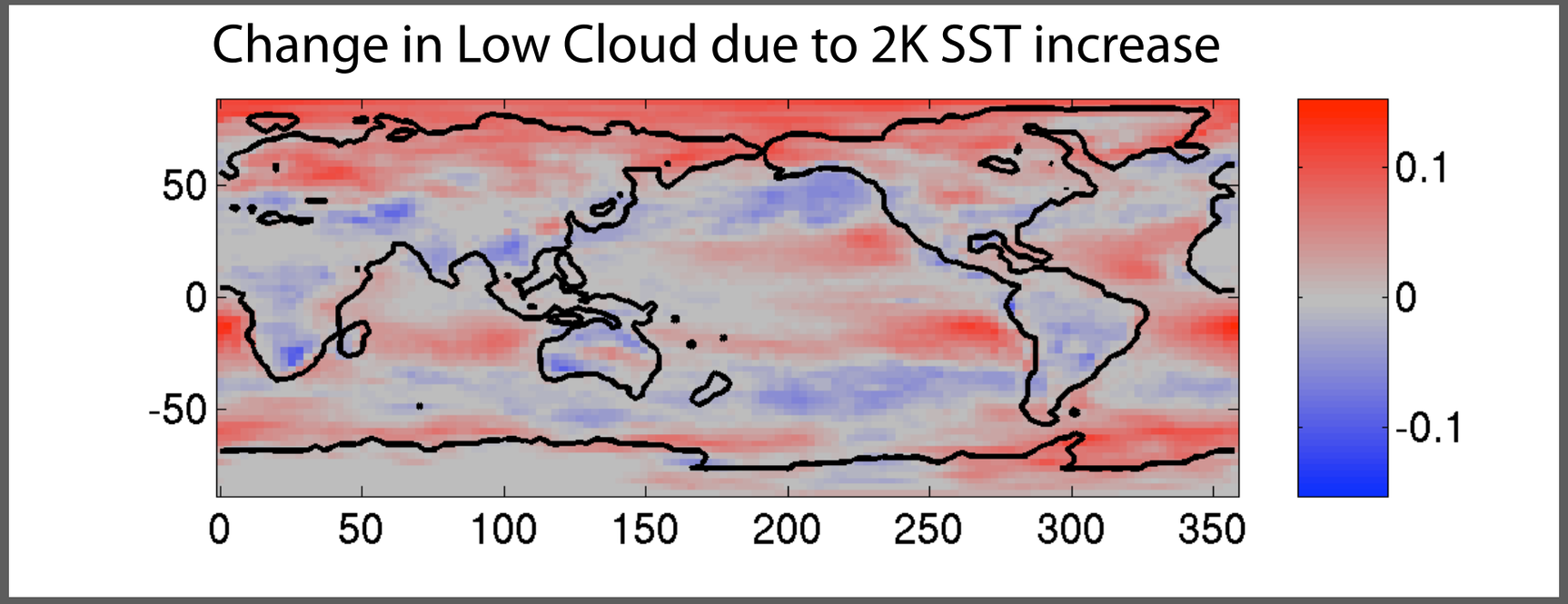
SP-CAM



control +2 K SST

How does CRE of +2K SST case differ from control run?

Further studies with CRM and LES



- SP-CAM tropical low cloud cover increases substantially as the climate warms. This has a net cooling effect.

➡ Why do the low clouds increase?

Take-home messages

- Cloud feedbacks remain the largest source of uncertainty, especially low clouds.
- GCMs disagree with each other due to the low cloud parameterizations.
- Currently we do not understand low cloud feedbacks.
- That's why we are here!

Ask them (not us)

Visit low cloud feedback breakout session
1:15 pm~, Wednesday


questions
Any feedbacks?