IPCC Chapter 7

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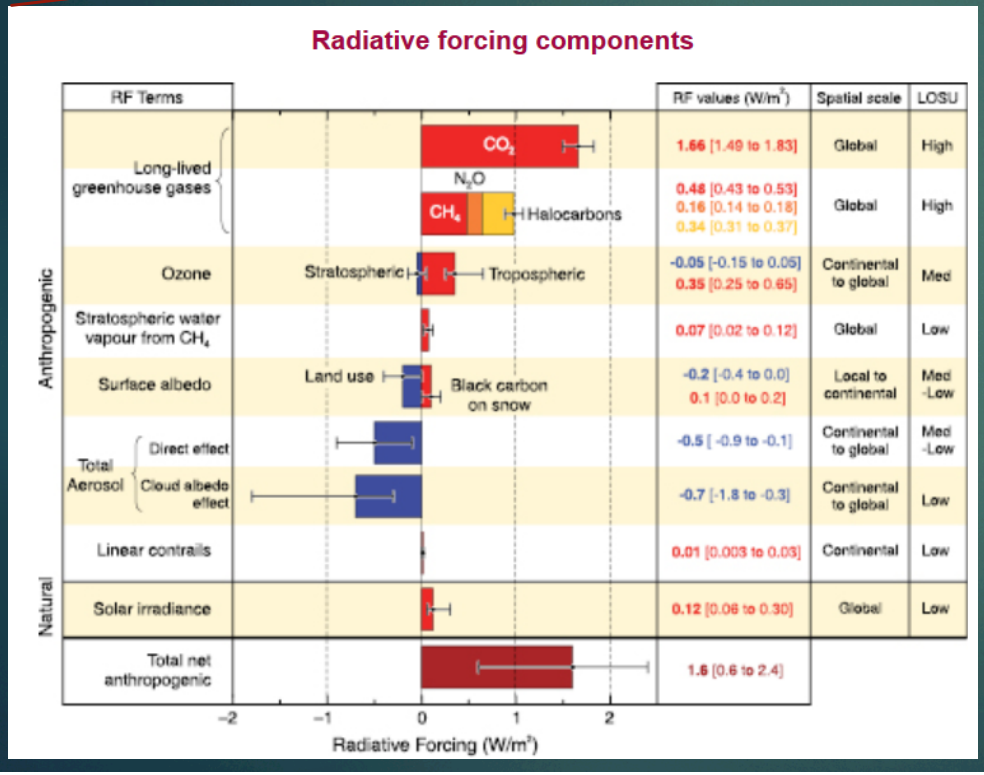
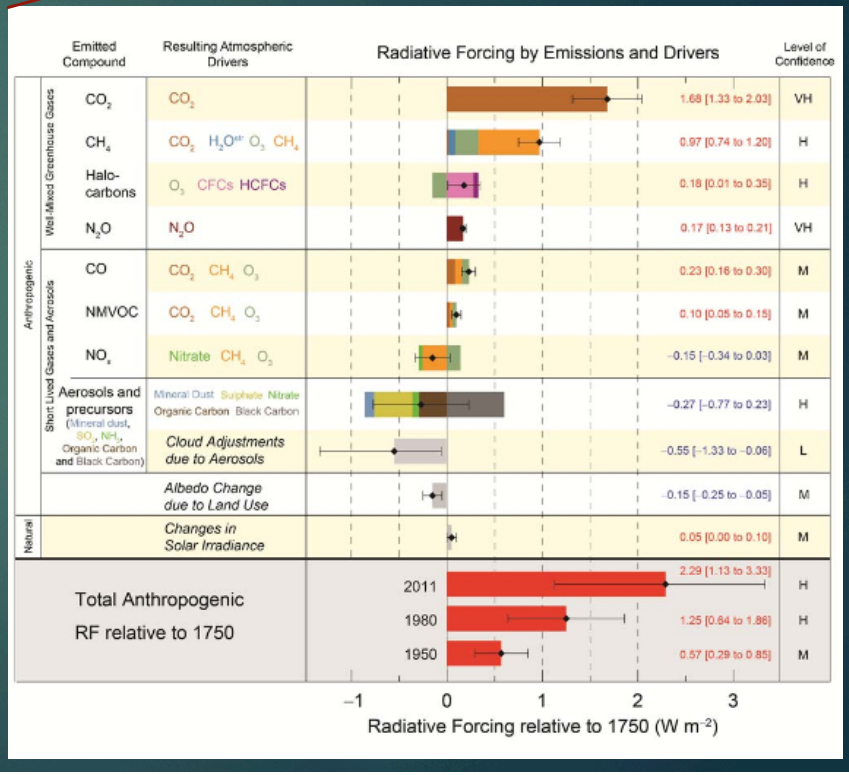
- Cloud and aerosol anthropogenic forcing
  - AR4: -1.2 W/m^2
  - AR5: -0.9 W/m^2

AR4



AR5



Radiative Forcing vs. Effective Radiative Forcing

- What is ERF?
  - It is Radiative Forcing + Rapid Adjustments
- What are Rapid Adjustments?
  - Forcings, not due to ΔT
  - Fast atmospheric and surface changes which can be due to factors such as rise in CO_2.
    - CO_2 can change radiative affects in atmosphere, altering the rising and falling patterns of clouds.
- Newly included since the AR4
- Aerosol radiation interactions
  - i.e. black carbon radiation absorption
- Aerosol cloud interactions
  - i.e. increased CCN for cloud formation

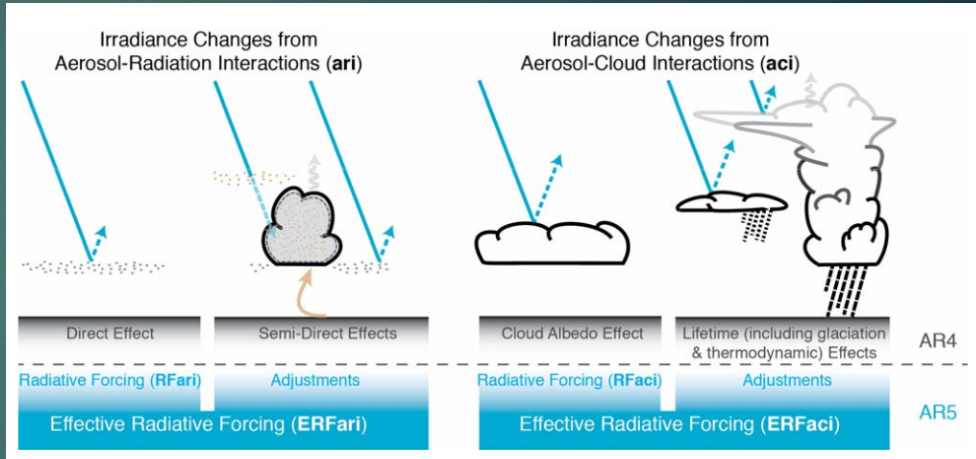
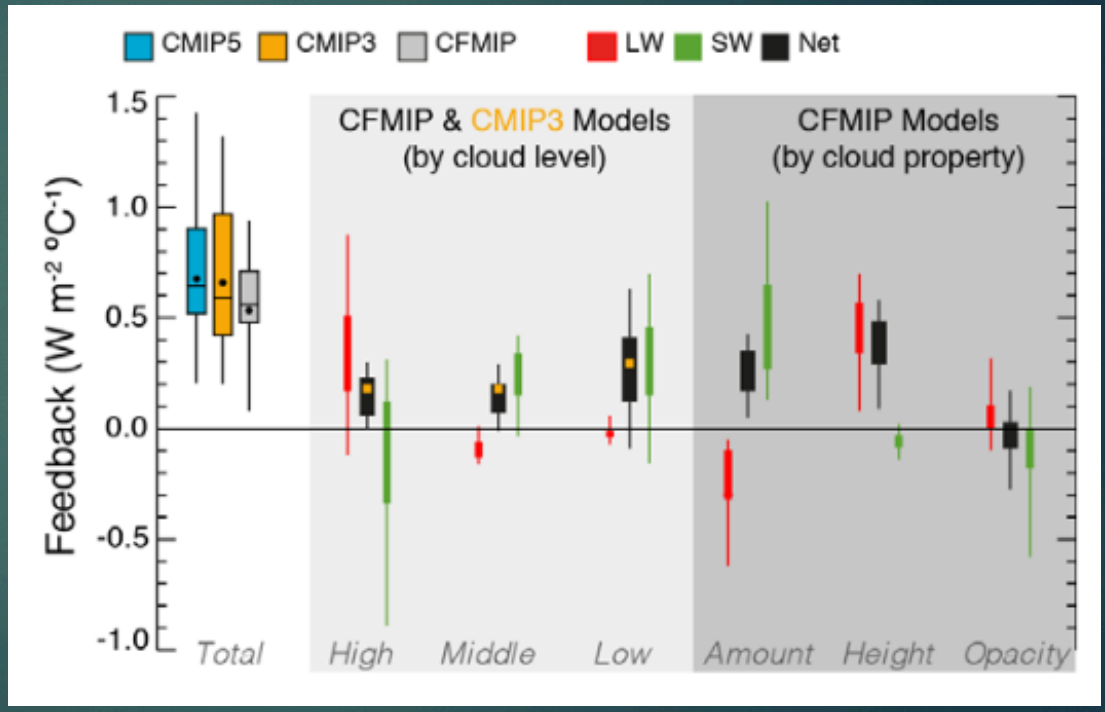


Figure 7.3: Schematic of the new terminology used in this assessment report (AR5) for aerosol-radiation and aerosol-cloud interactions and how they relate to the terminology used in AR4. The blue arrows depict solar radiation, the grey arrows terrestrial radiation, and the brown arrow symbolises the importance of couplings between the surface and the cloud layer for rapid adjustments. See text for further details.

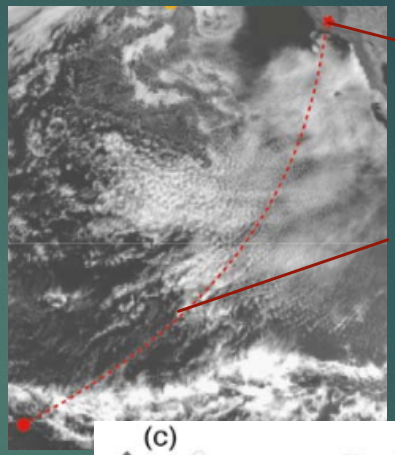
Cloud feedbacks for responses to CO_2 increase (including rapid adjustments)

- All positive feedbacks except for Longwave Radiation in middle-altitude and low-altitude clouds



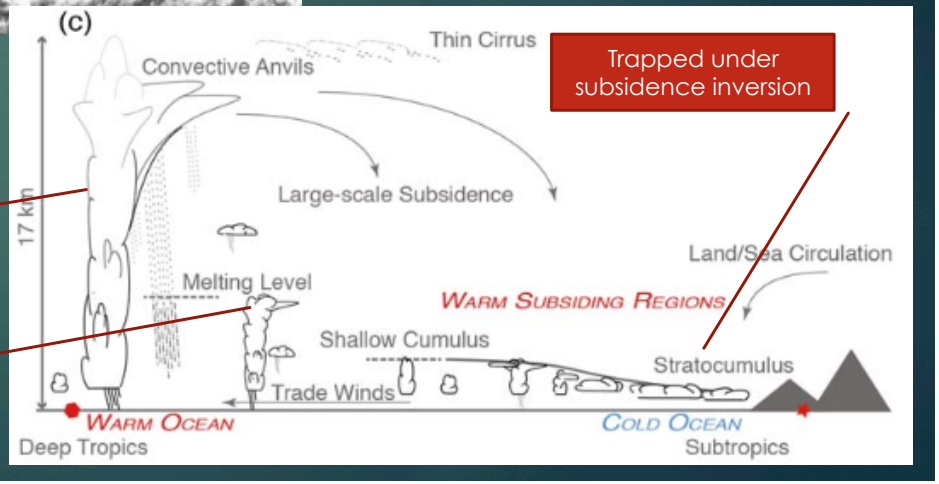
Clouds in Present-Day Climate System

- Cloud systems moving from deep tropics to subtropics
- After the publication of AR4, new remote sensing technologies have allowed more accurate measurements of cloud water vapor content, vertical profiles, and movement.
  - Cloud-profiling radar (CRP) on CloudSat satellite
  - CALIOP LIDAR on the CALIPSO satellite.



Subtropical west coast

Inter-Tropical Convergence Zone (ITCZ)

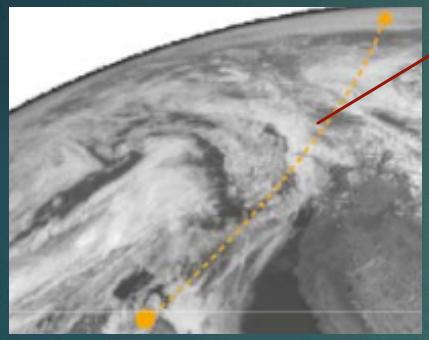


Cirrus anvils due to rising air in ITCZ

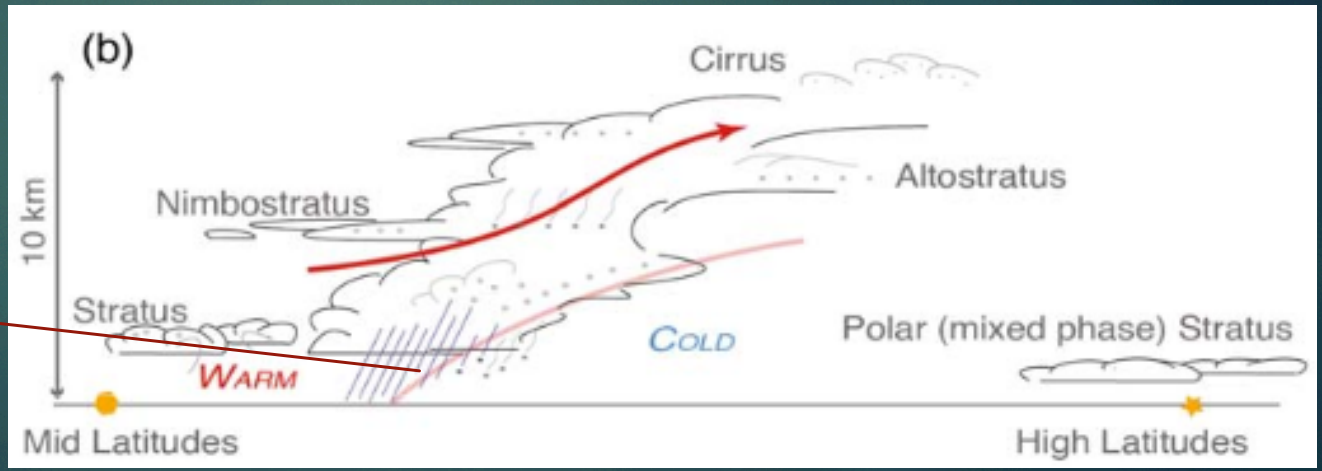
Cumulonimbus precipitating

Clouds in Present-Day Climate System

- Cloud systems in mid-high latitudes



Warm front of cyclone



Clouds release precipitation as it condenses out with cooling

Cloud responses expected from warming due to greenhouse gasses

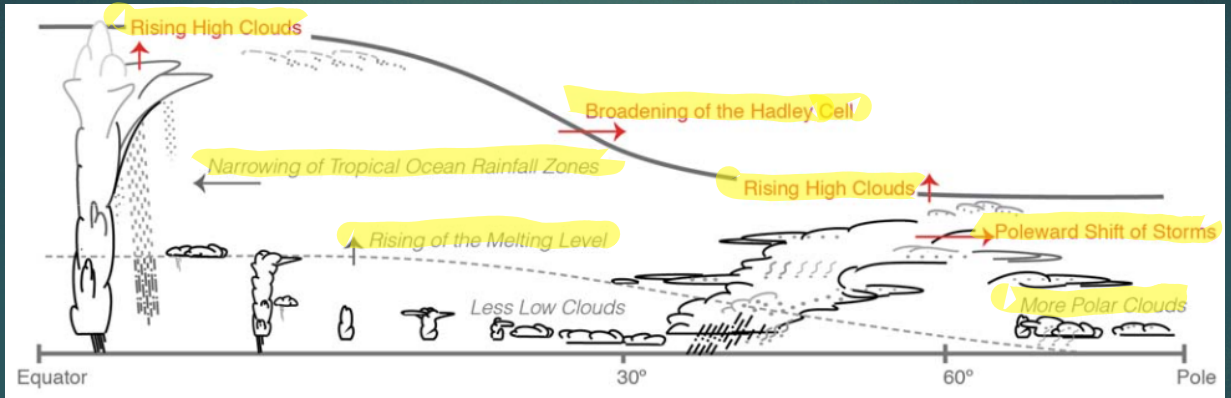
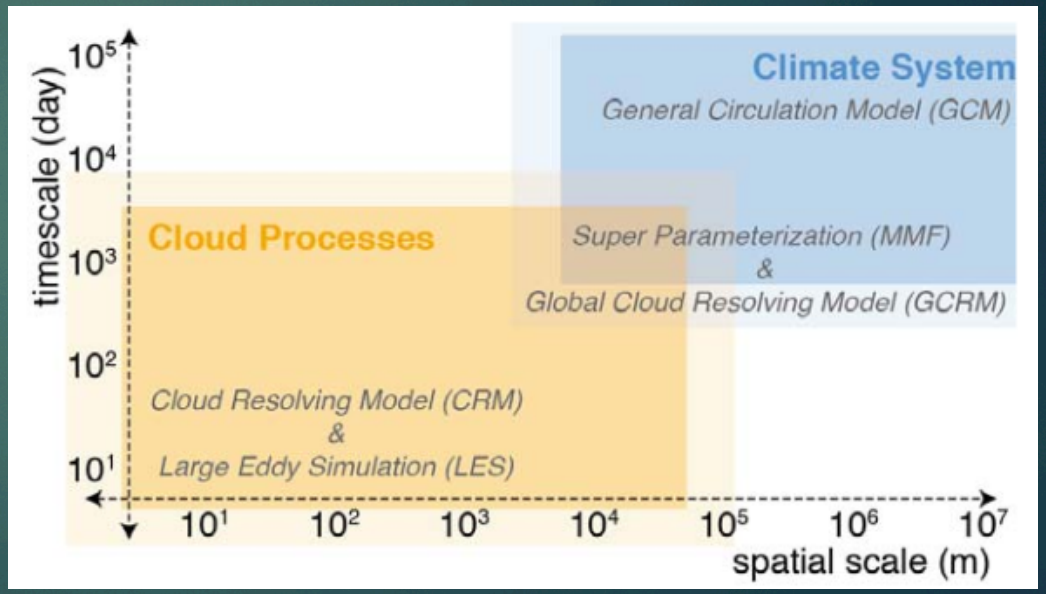


Figure 7.11: Robust cloud responses to greenhouse warming (those simulated by most models and possessing some kind of independent support or understanding). The tropopause and melting level are shown by the thick solid and thin grey dashed lines, respectively. Changes anticipated in a warmer climate are shown by arrows, with red colour indicating those making a robust positive feedback contribution and grey indicating those where the feedback contribution is small and/or highly uncertain. No robust mechanisms contribute negative feedback. Changes include rising high cloud tops and melting level, and increased polar cloud cover and/or optical thickness (*high confidence*); broadening of the Hadley Cell and/or poleward migration of storm tracks, and narrowing of rainfall zones such as the ITCZ (*medium confidence*); and reduced low-cloud amount and/or optical thickness (*low confidence*). Confidence assessments are based on degree of GCM consensus, strength of independent lines of evidence from observations or process models, and degree of basic understanding.

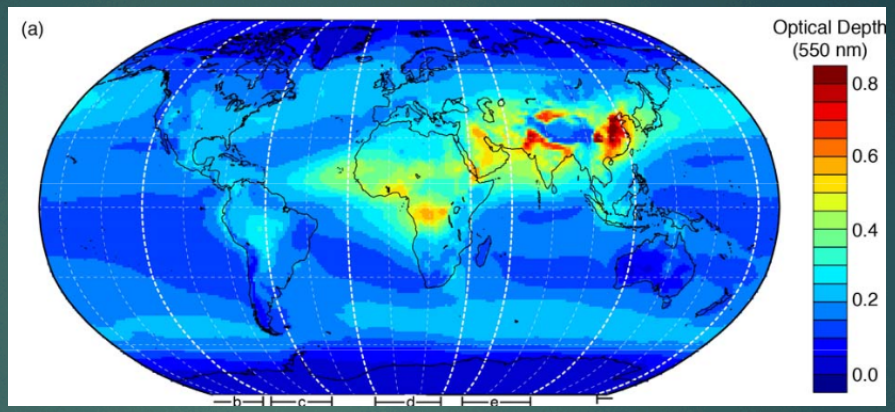
Types of Cloud Models: Scale, Integration, & Application

- High resolution models can explicitly calculate turbulence inside of clouds
  - Applications include:
    - Aerosol transport
    - Aerosol processes
    - Precipitation characteristics
  - Cannot be applied over GCM scales
    - Can be used to aid in parameterizing microphysical processes (turbulence), entrainment, and precip. for GCMs
- Increases in processing power → Global Cloud Resolving Models (GCRMs) and Super Parameterization Models
  - GCRM:
    - Grid spacing 3.5 km
    - Time scales of several months to a couple years
    - Still need to parameterize individual clouds, microphysics, and boundary layer conditions
  - Super Parameterization Models
    - CRM embedded in each grid cell of the GCM
    - CRM replaces some of parameterization (hence the name)
    - More computationally efficient than GCRMs

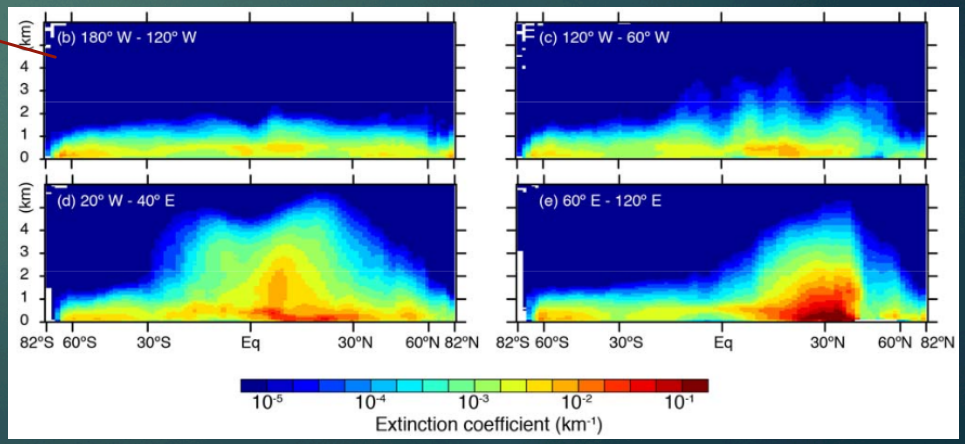


Aerosol Optical Depth (AOD)

- Densest over China and developing parts of India
- Anthropogenic fraction estimated at 20-40% of global mean AOD. Medium Confidence
  - Agreement that anthropogenic aerosol is smaller in size and more adsorbing (i.e. black carbon)
- ¼ to 2/3 of CCN concentrations are of anthropogenic origin

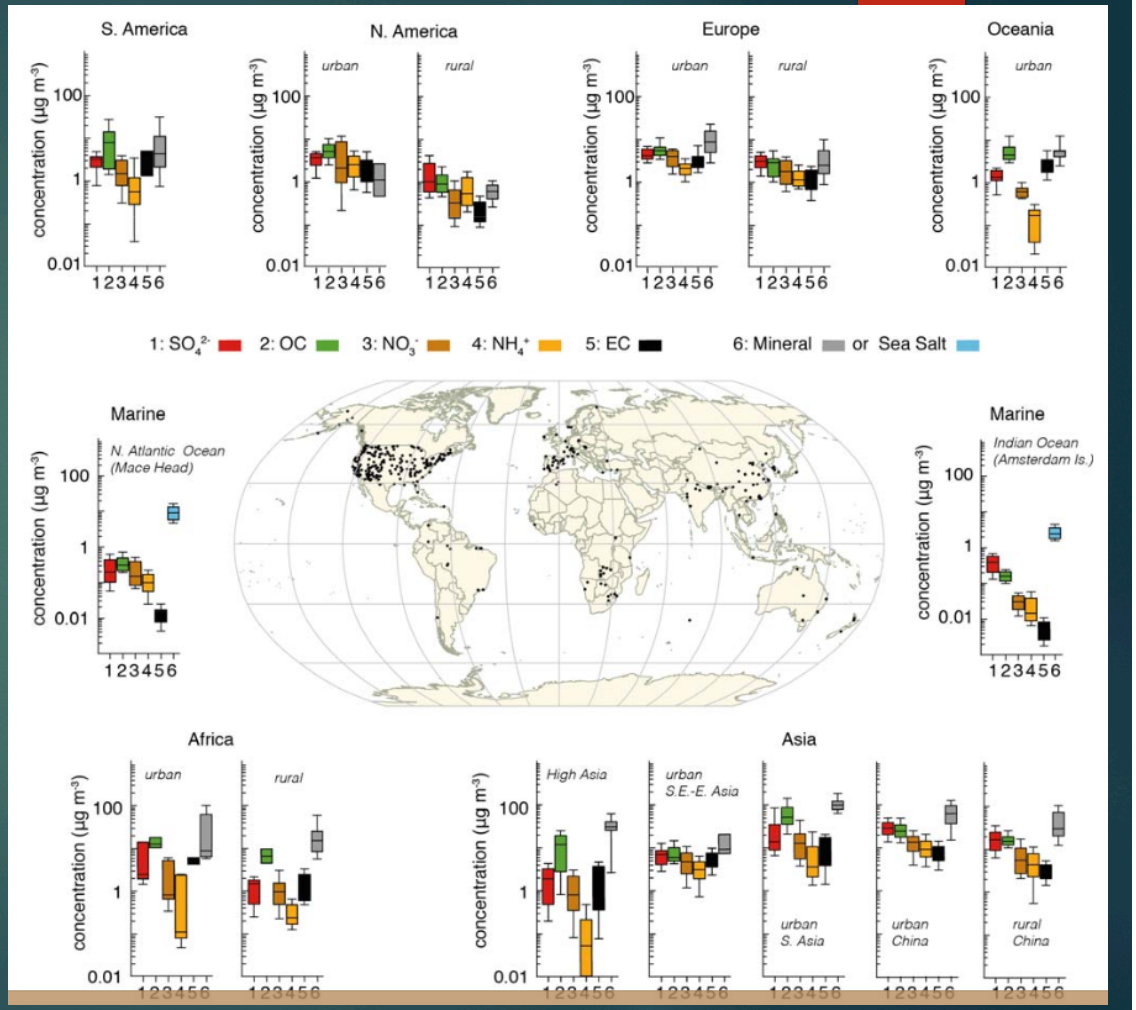


Used CALIOP LIDAR on CALIPSO Satellite



Aerosol concentrations based on location

- High sea salt over "Marine"
- Mineral over Africa (Sahara dust)
- High everything over China & south east Asia



Cloud-aerosol interactions, cosmic rays, & solar radiation management

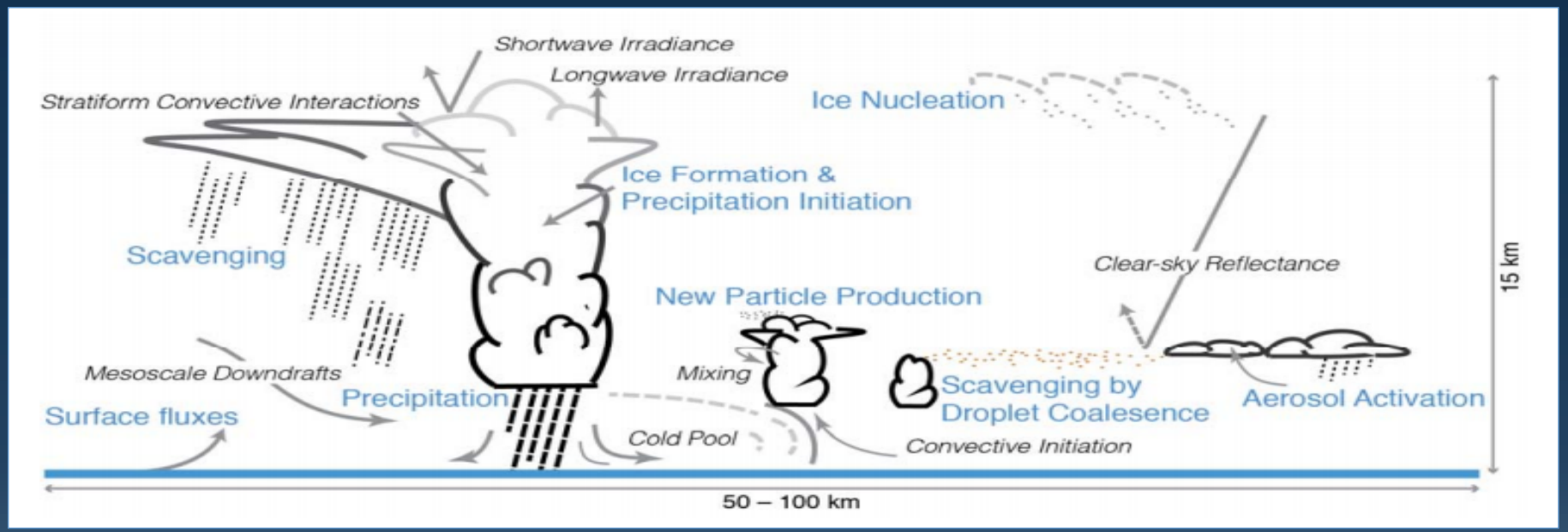
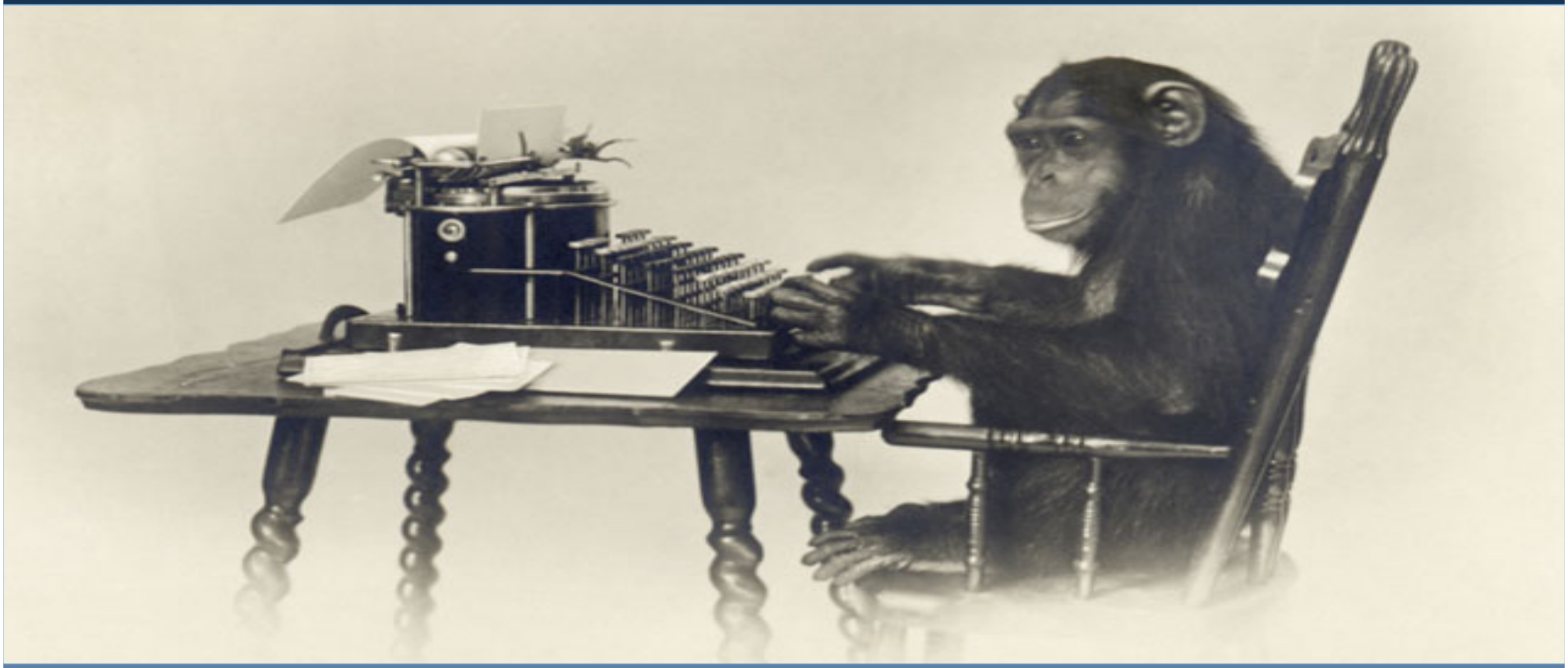


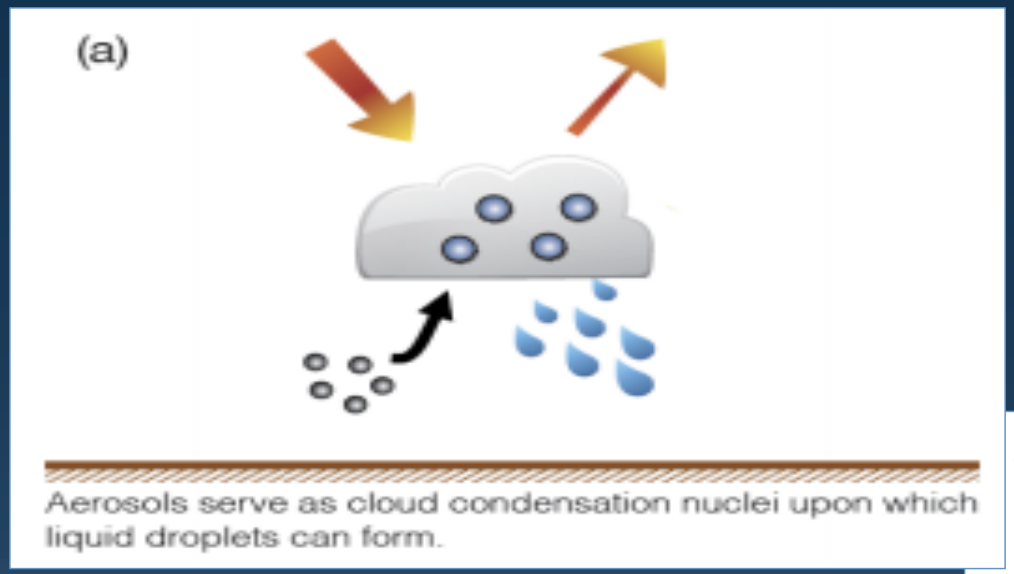
Figure 7.16: Schematic depicting the myriad aerosol-cloud-precipitation related processes occurring within a typical GCM grid box. The schematic conveys the importance of considering aerosol-cloud-precipitation processes as part of an interactive system encompassing a large range of spatial-temporal scales….

"Although advances have been considerable, the challenges remain daunting. The response of cloud systems to aerosol is nuanced…and the representation of both clouds and aerosol-cloud interactions in large-scale models remains primitive."



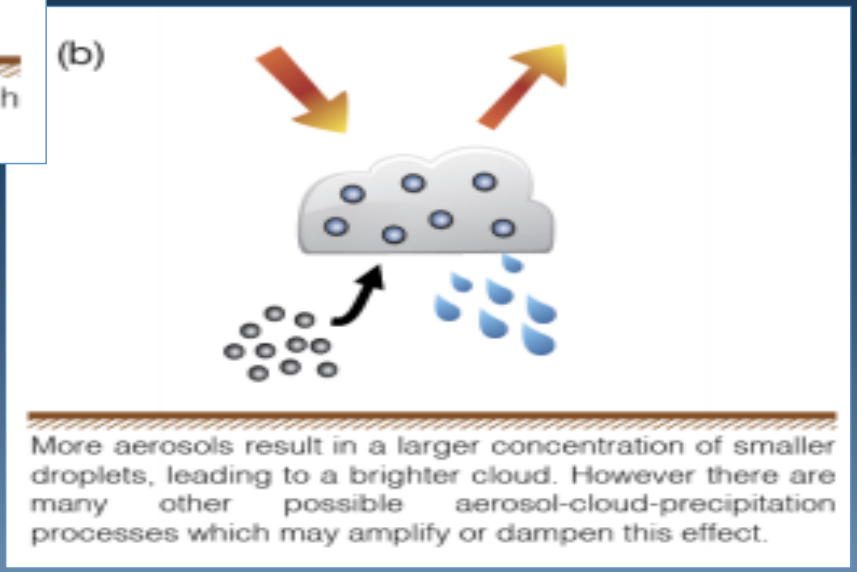
Since AR4

1. Global scale: greater diversity of interactions
2. Observational studies increasingly quantitative
3. Regional scale modeling growing
4. Finer-scale process models (e.g., turbulent mixing) & buffering effect



Aerosols serve as cloud condensation nuclei upon which liquid droplets can form.

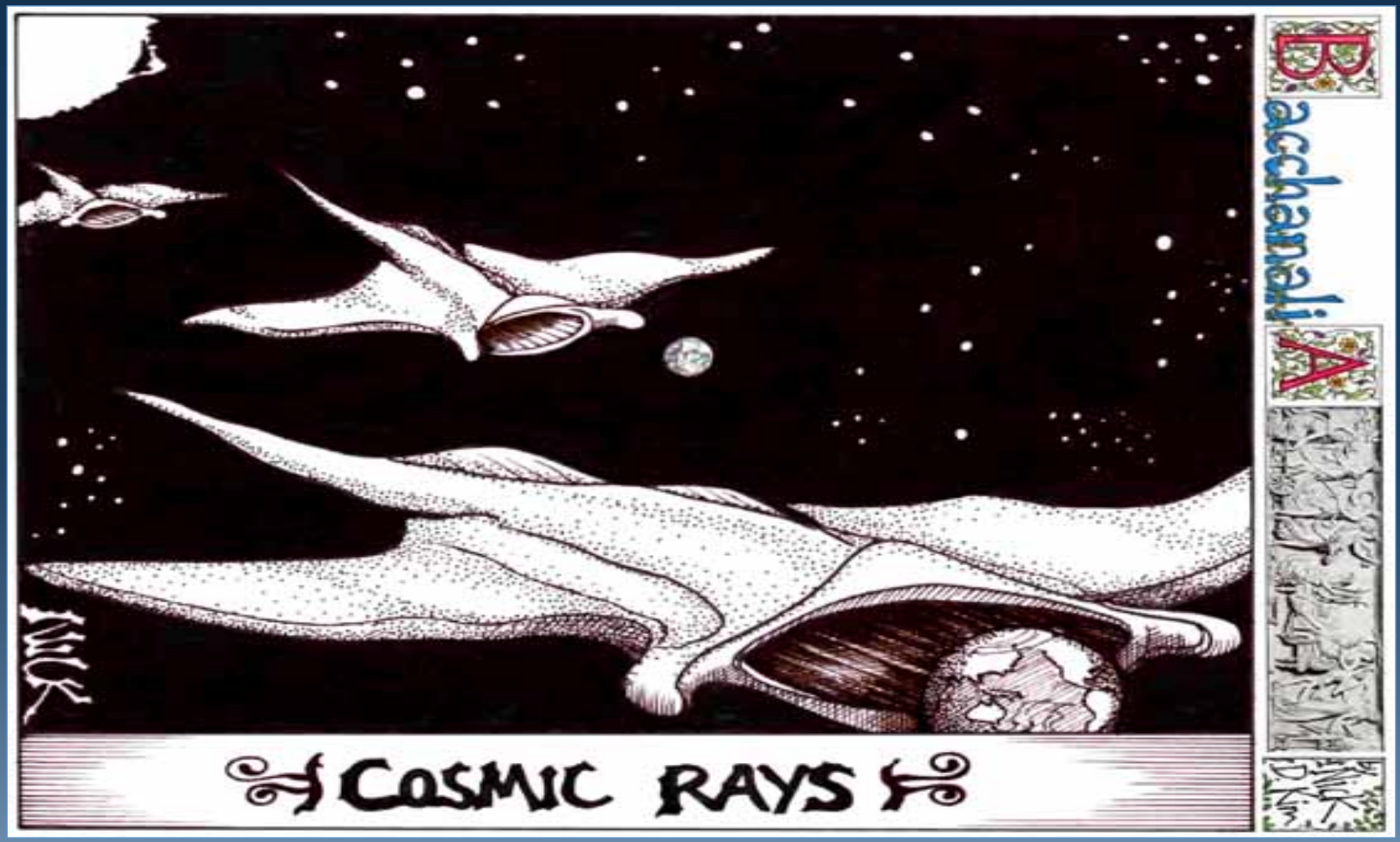
hygroscopy



More aerosols result in a larger concentration of smaller droplets, leading to a brighter cloud. However there are many other possible aerosol-cloud-precipitation processes which may amplify or dampen this effect.

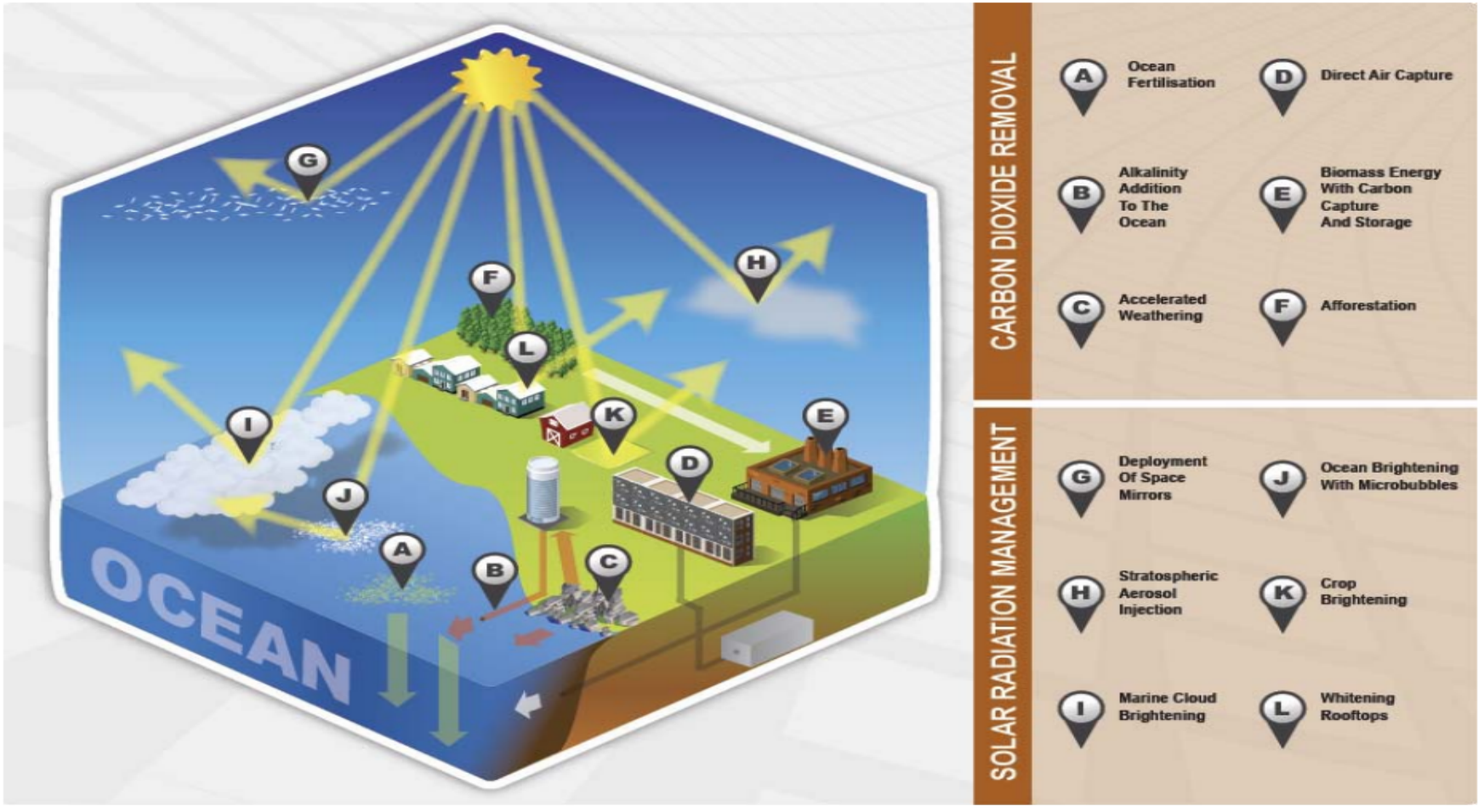
Take-aways:

- Hygroscopic: able to attract & hold water molecules from the air.
- What *really* matters is how much water there is.
- Models generally indicate a net cooling effect due to aerosol-cloud interactions.


Bacchanalia
COSMIC RAYS

Weak/local predictions at best:

- Atmospheric ions from cosmic rays → aerosol nucleation → impact CCN concentrations?
- Charges accumulate at cloud boundaries → conductivity gradients → influences cloud droplet formation and interactions?
- Dargan thinks it's mostly bogus.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CARBON DIOXIDE REMOVAL
A Ocean Fertilisation
D Direct Air Capture
B Alkalinity Addition To The Ocean
E Biomass Energy With Carbon Capture And Storage
C Accelerated Weathering
F Afforestation
SOLAR RADIATION MANAGEMENT
G Deployment Of Space Mirrors
J Ocean Brightening With Microbubbles
H Stratospheric Aerosol Injection
K Crop Brightening
I Marine Cloud Brightening
L Whitening Rooftops

Global concerns?

- Not reducing CO2 → ocean acidification
- Only works during daytime → influences diurnal cycle
- May actually lower rainfall?
- Sulphate aerosol SRM → acid rain?
- Unanticipated consequences…

Potential problems with each method?