# EARTH'S RADIATIVE ENERGY BUDGET
# OR
# A PLANET OUT OF BALANCE


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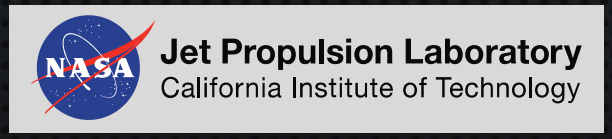
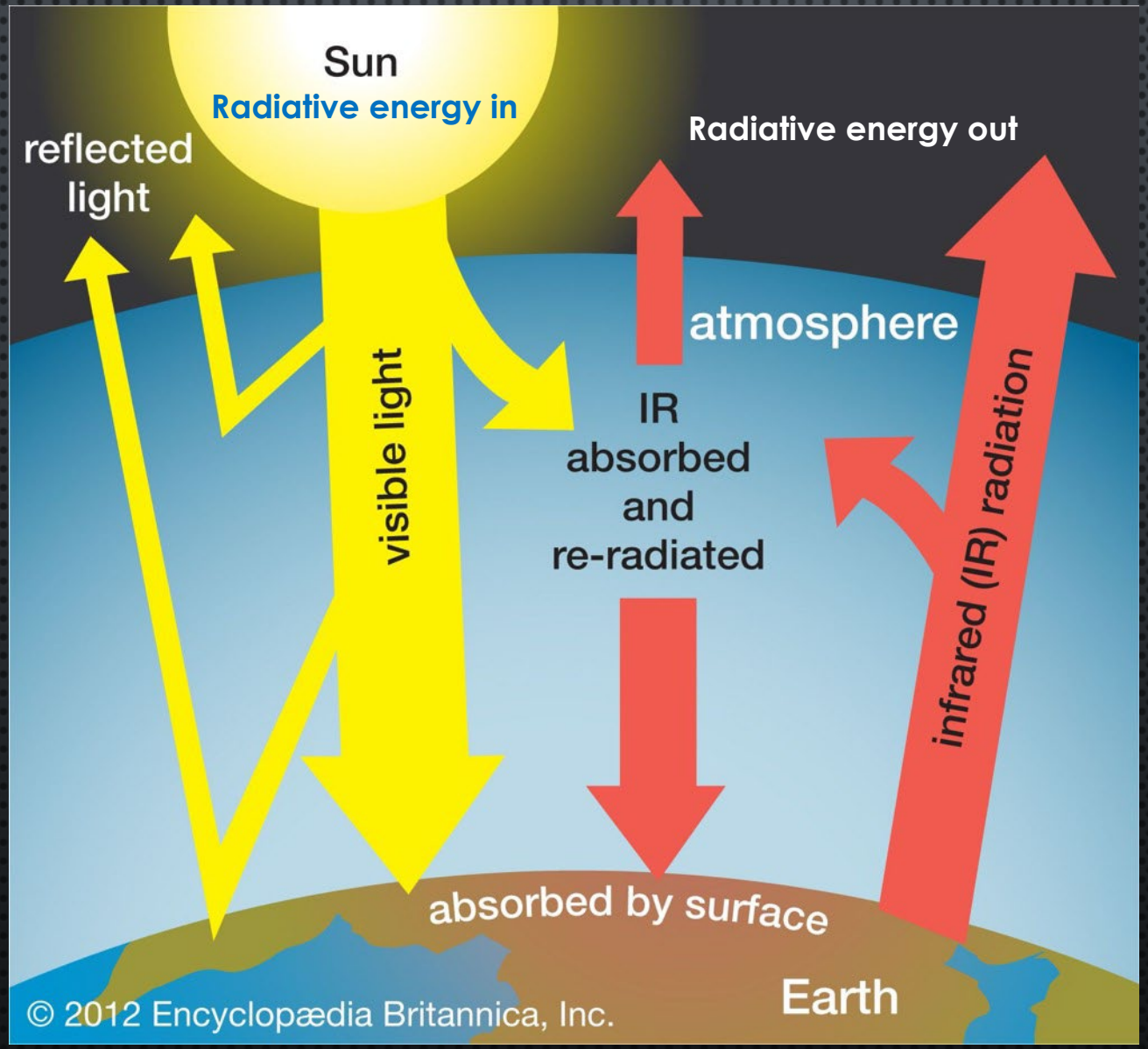
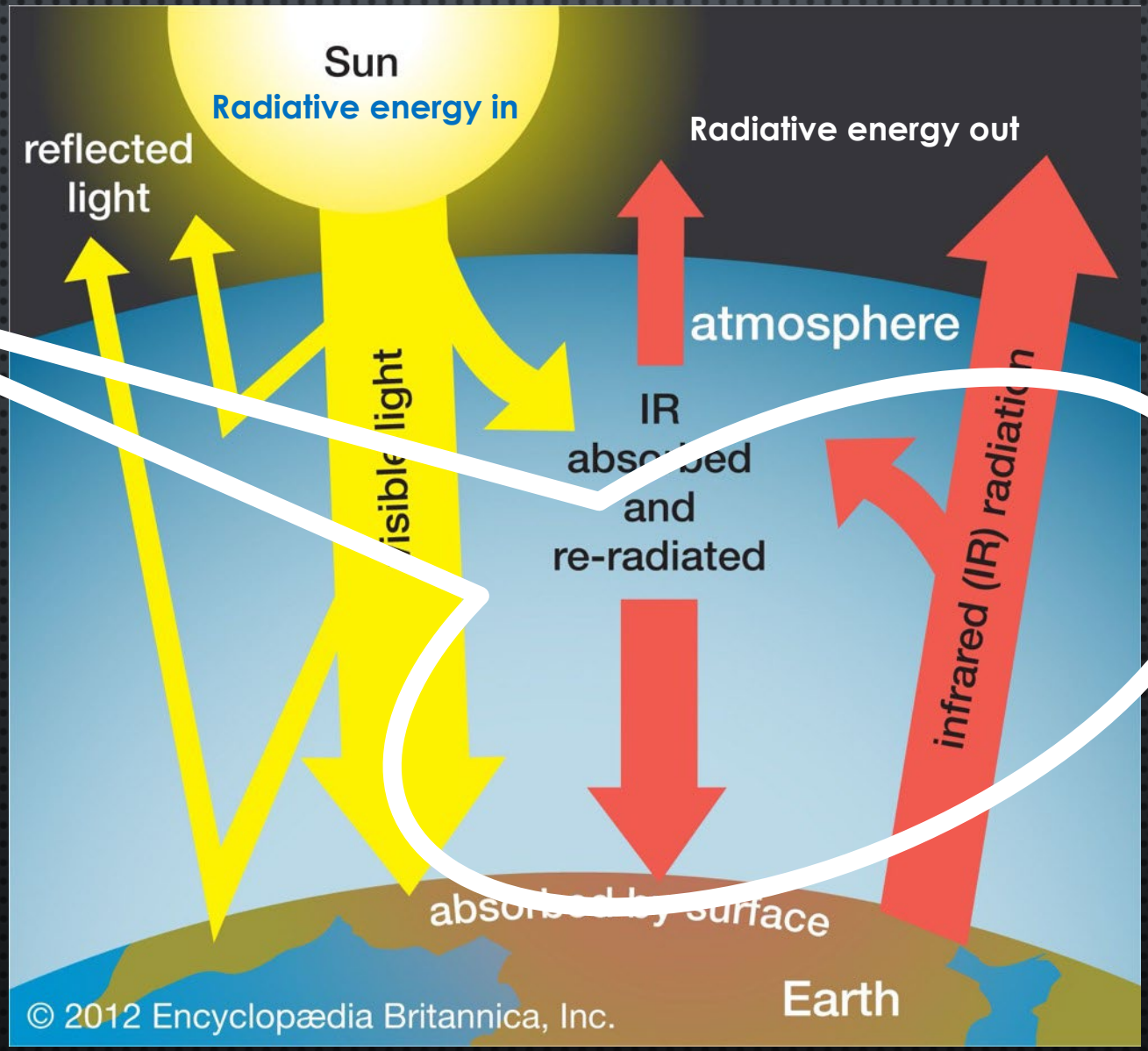


# EARTH'S ENERGY BUDGET



# EARTH'S ENERGY BUDGET

**Global warming through radiative forcing of greenhouse gases (GHG):**
More GHGs absorb and re-emit more infrared radiation back to the surface.



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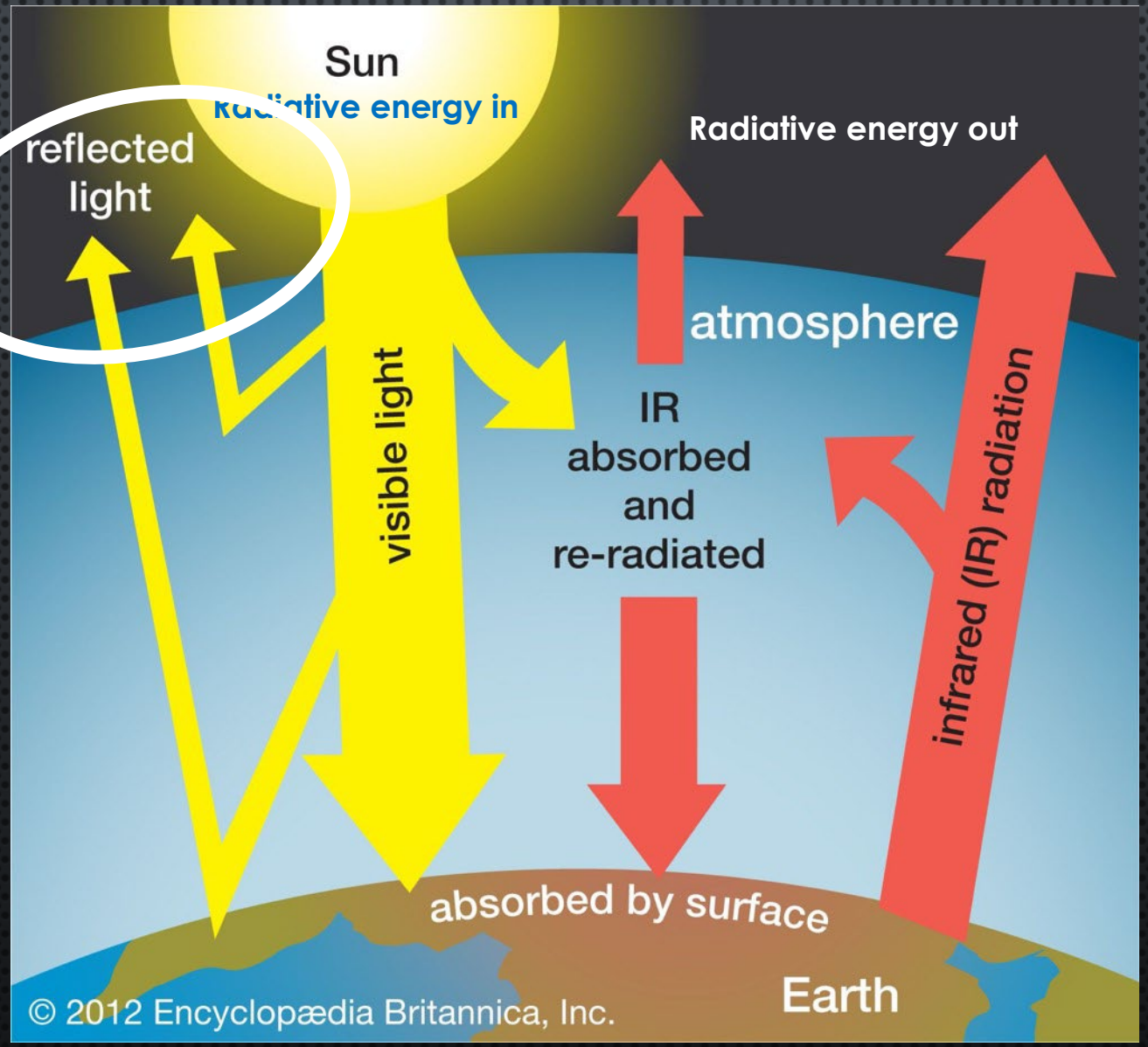
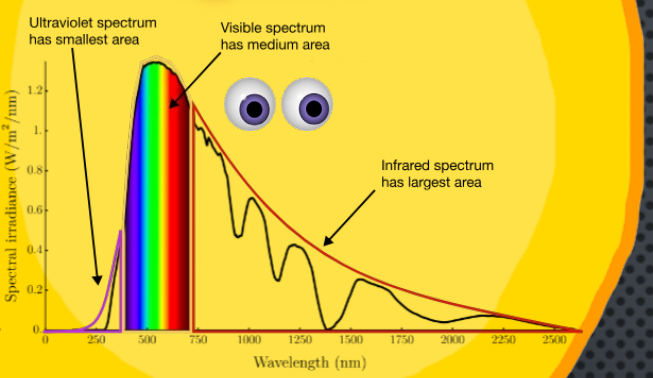



**Albedo** is fraction of sunlight reflected back to space.

2/3 of sunlight is absorbed by surface and atmosphere

9,941°F




# ENERGY FROM SUN RECEIVED BY EARTH:

## 340 W/m²

½ 

/m²

Or:
90,000,000,000,000,000

Distributed across Earth's surface

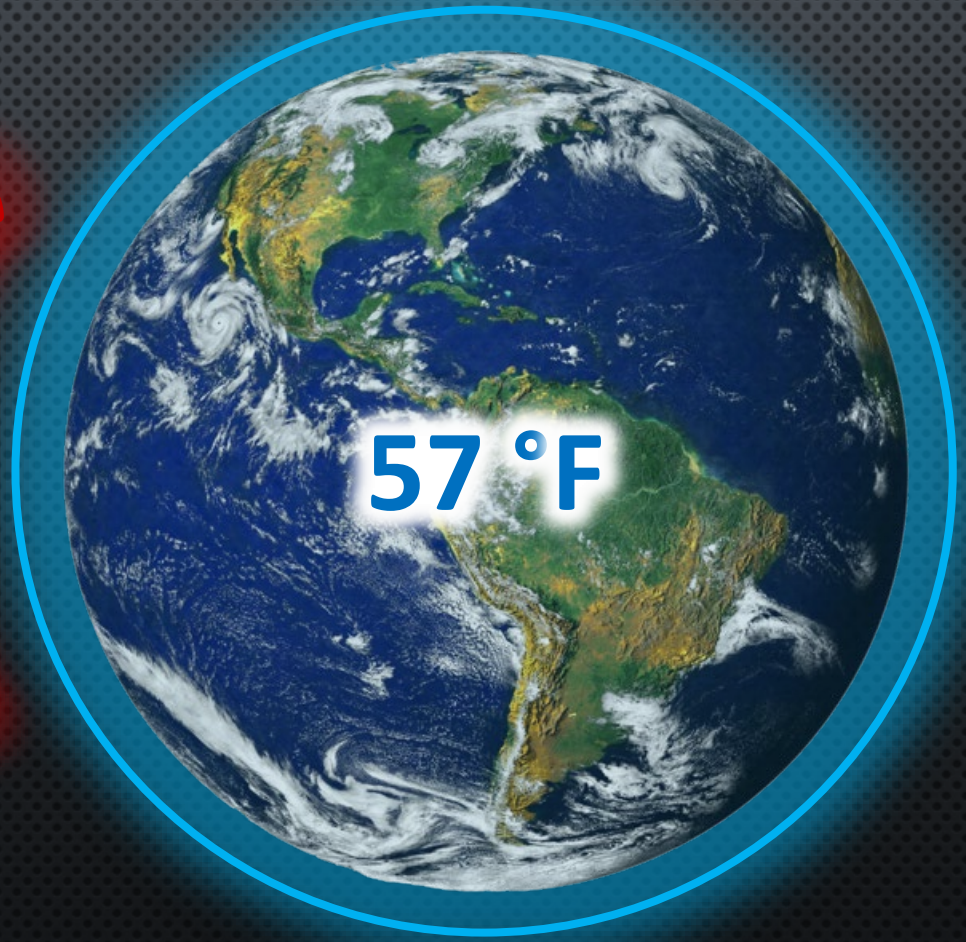
**NASA MISSIONS SORCE & TSIS**

SOLAR RADIATION AND CLIMATE EXPERIMENT

TOTAL AND SPECTRAL *SOLAR* IRRADIANCE SENSOR

# EARTH EMITTED INFRARED (OR LONGWAVE) RADIATION

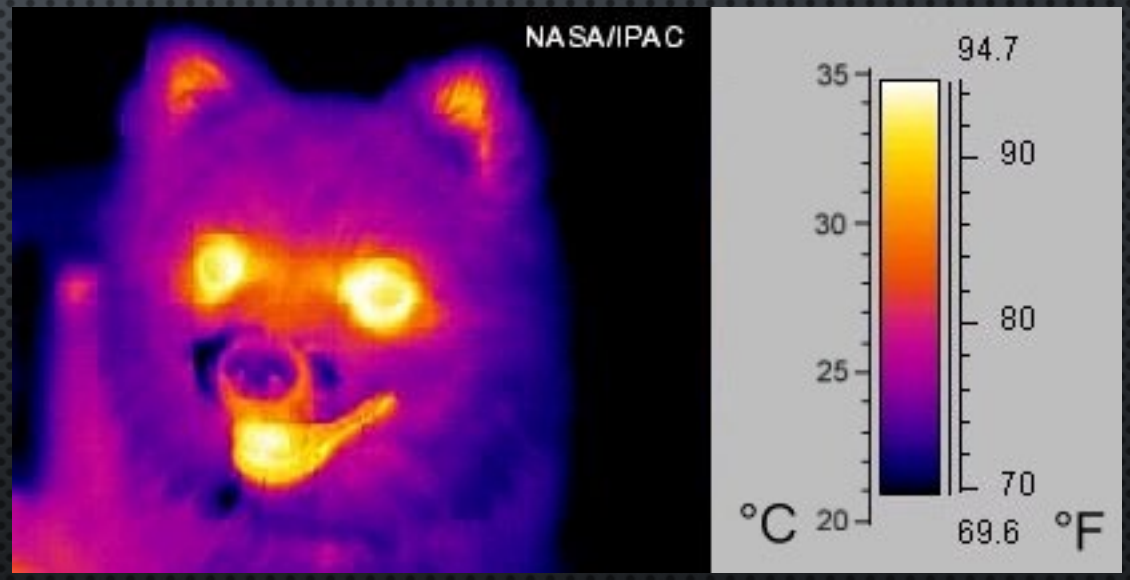
NASA'S *CLOUDS AND EARTH'S RADIANT ENERGY SYSTEM (CERES)*



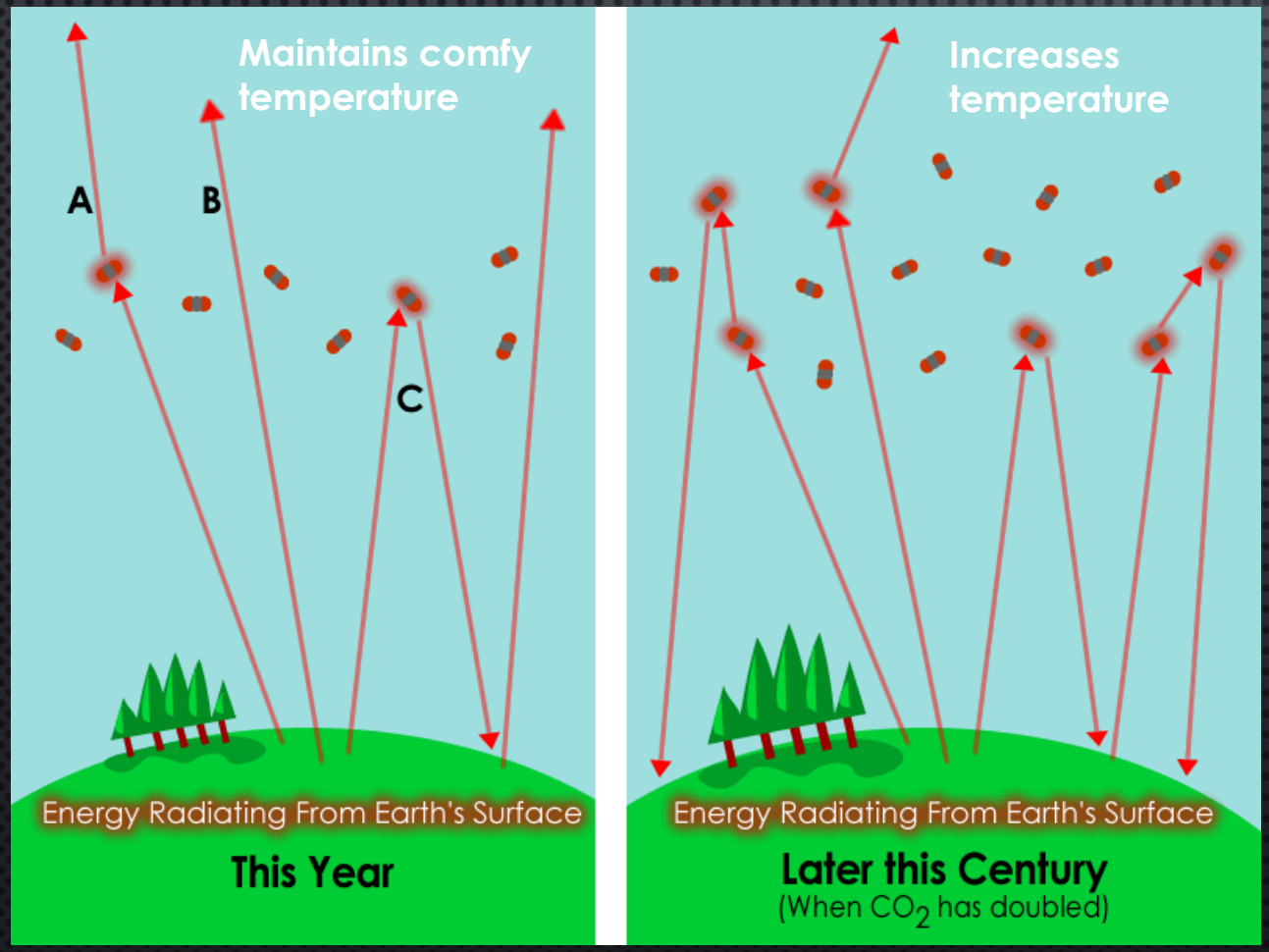

239 W/m²

1/3  /m²

# INFRARED RADIATION IS INVISIBLE UNLESS..



# THE GREENHOUSE EFFECT ACTS LIKE A BLANKET ON A COOL WINTER NIGHT



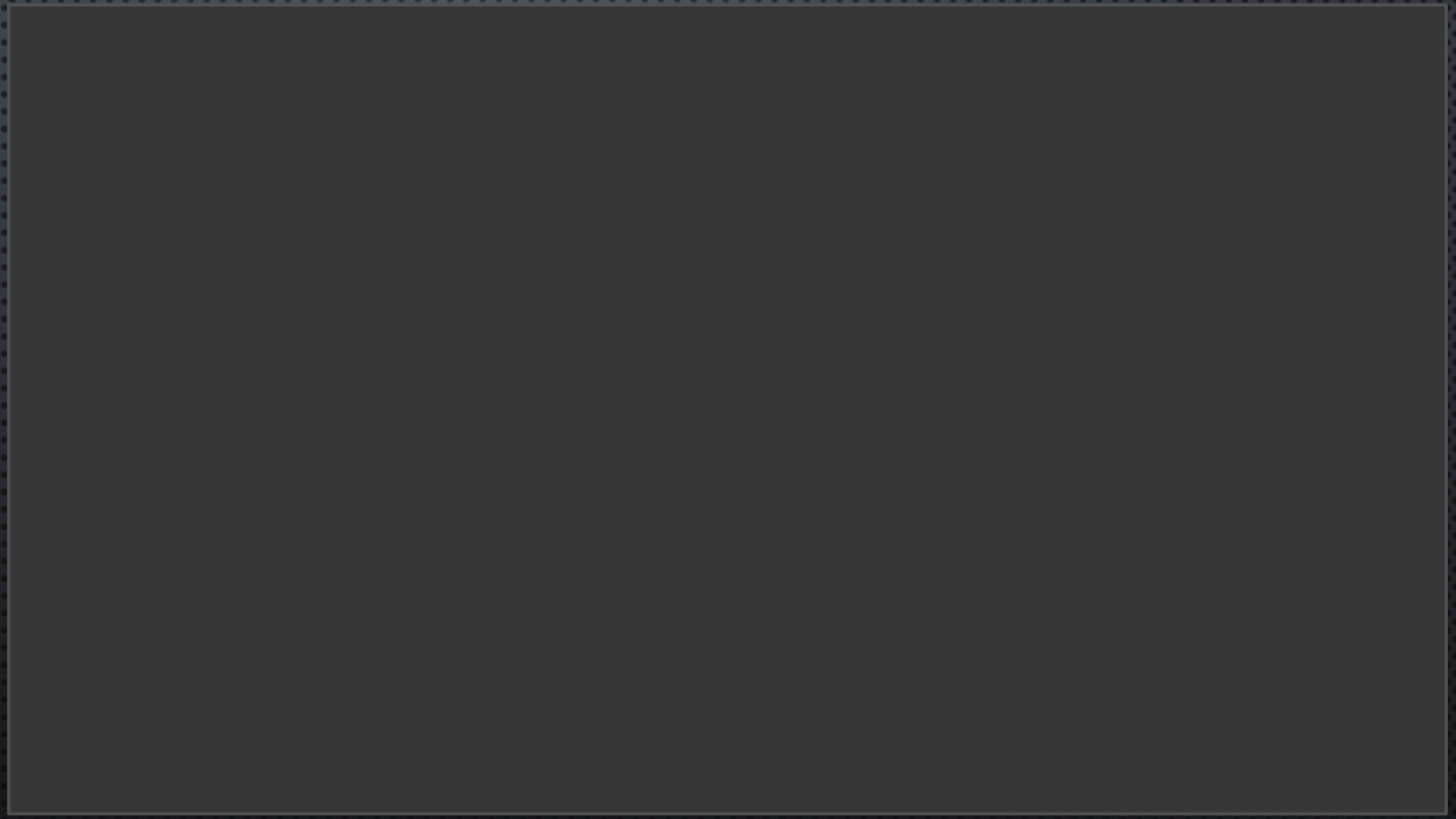

UCAR, Center for Science Education


Credit: NASA/JPL-Caltech

**Without greenhouse effect, Earth would be –0.4˚F cold!**

# EARTH'S ALBEDO = FRACTION OF REFLECTED SUNLIGHT

- No sunlight – no reflection



# EARTH'S ALBEDO = FRACTION OF REFLECTED SUNLIGHT

- No sunlight – no reflection
- Oceans do not reflect much - albedo <0.1


NASA image by Robert Simmon and Jesse Allen, based on MODIS data.

# EARTH'S ALBEDO = FRACTION OF REFLECTED SUNLIGHT

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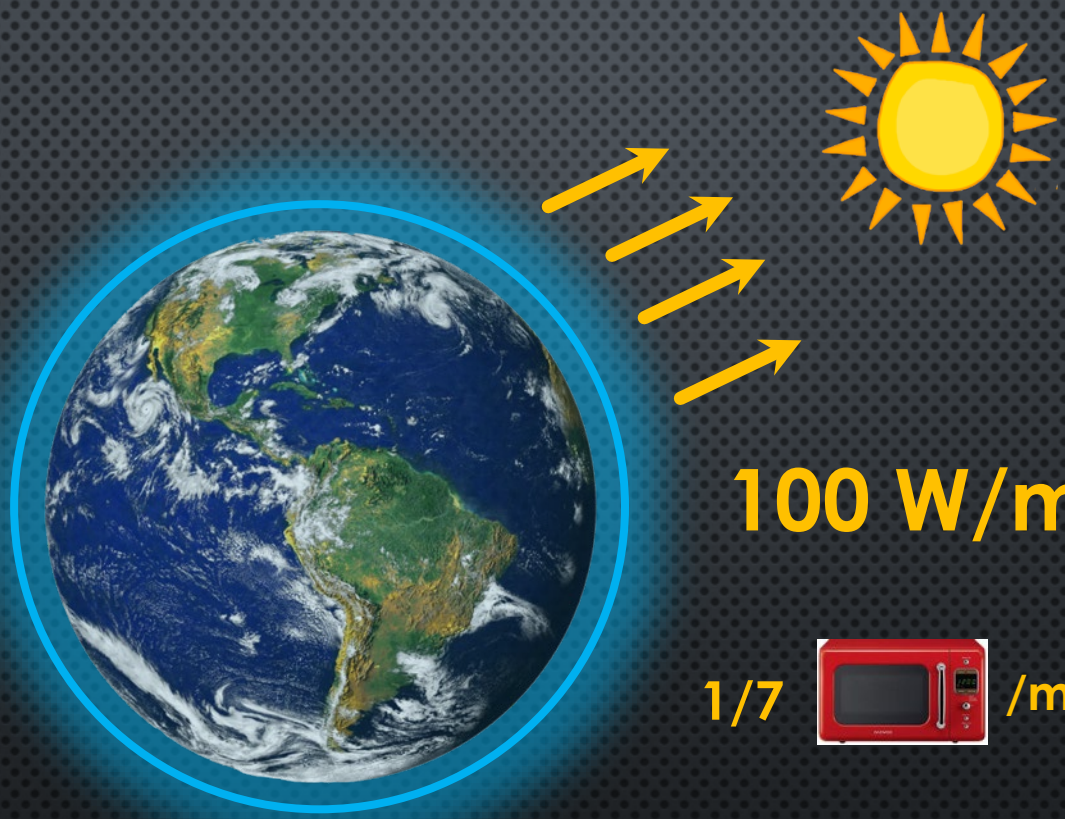
- Snow & ice are very reflective - albedo > 0.8

Credit: NASA LARC

# EARTH'S ALBEDO = FRACTION OF REFLECTED SUNLIGHT

- No sunlight – no reflection
- Oceans do not reflect much - albedo <0.1
- Snow & ice are very reflective - albedo > 0.8
- Clouds are very reflective and cover 70% of Earth's surface
- Earth reflects 30% of incoming sunlight!



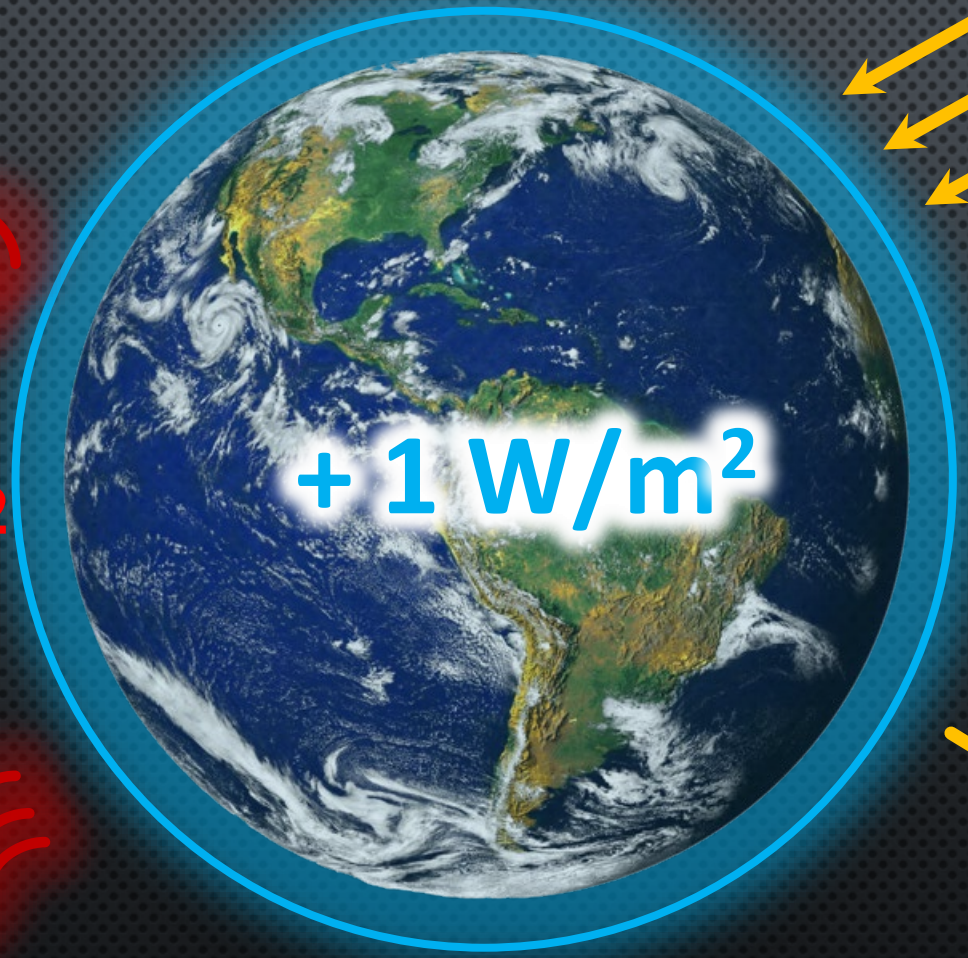
100 W/m$^2$

1/7  /m$^2$

*Credit: NASA GSFC*

*Credit: NASA*

# EARTH'S ENERGY (IM-)BALANCE

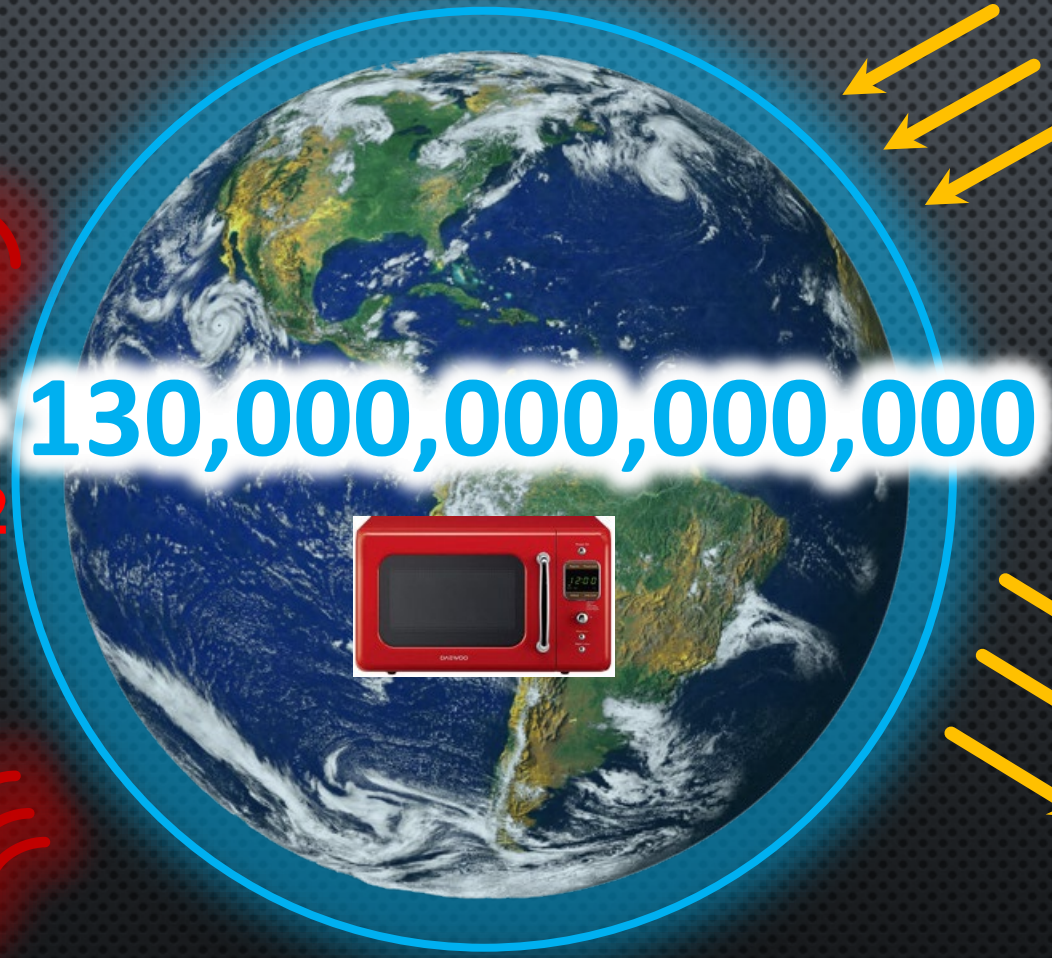



+340 W/m²

-239 W/m²

-100 W/m²

# EARTH'S ENERGY IMBALANCE



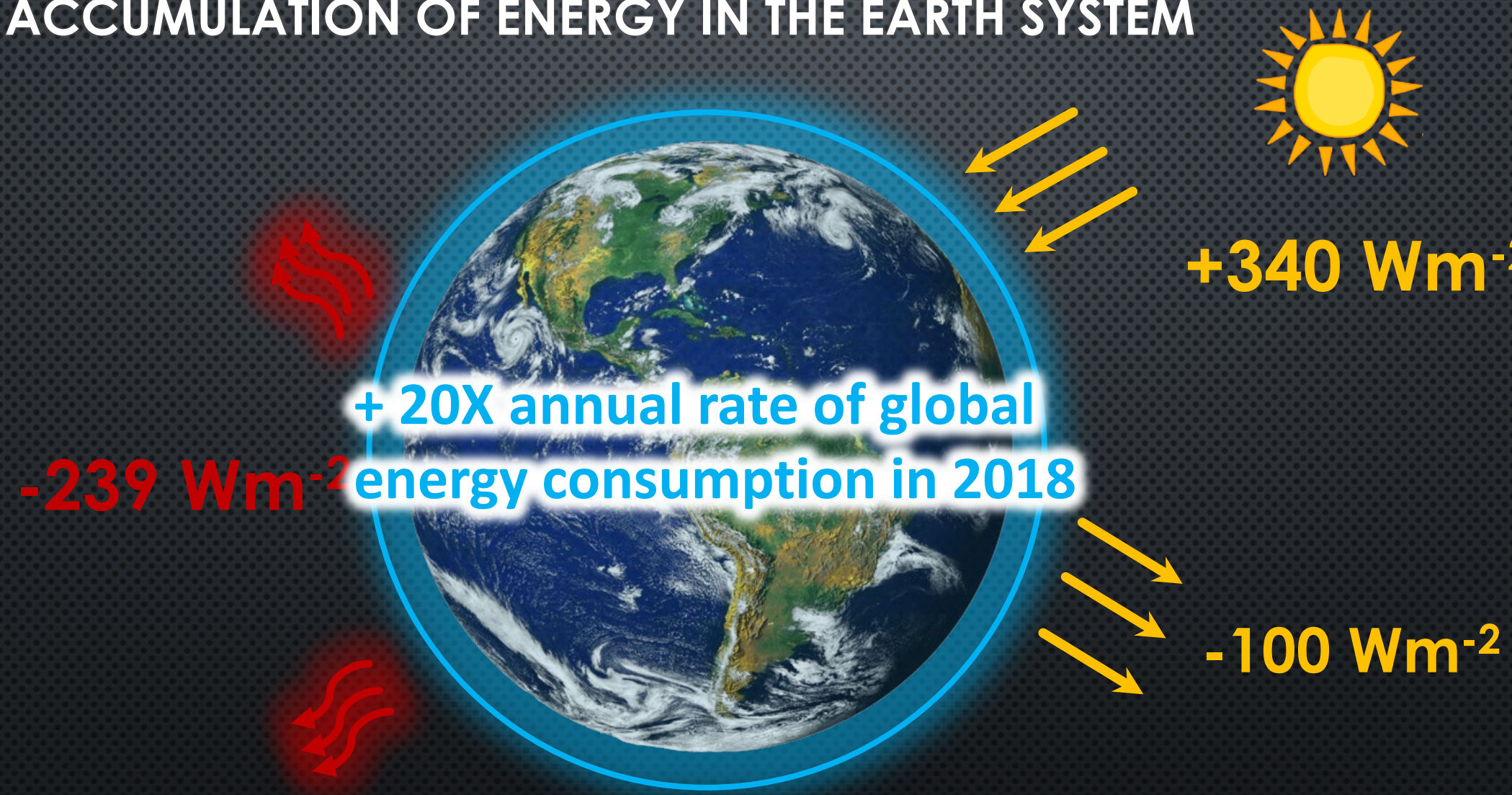
+340 W/m²

-239 W/m²

+ 130,000,000,000,000

-100 W/m²

# POSITIVE ENERGY IMBALANCE = ACCUMULATION OF ENERGY IN THE EARTH SYSTEM



# ENERGY IMBALANCE RESULTS FROM RADIATIVE FORCINGS + FEEDBACKS

- GHG forcing
- Aerosol forcing
- Land use change

**Total RF= ~2 W/m²**

**Earth's energy gain= +1 W/m²**

- Negative feedbacks diminish initial climate response to RF
  - Planck feedback (warmer temperatures = higher emission)
- Positive feedbacks amplify initial climate response
  - Moister atmosphere warms more
  - Ice melt reduces surface albedo
  - Clouds (feedback uncertain)

**Total Feedback = ~ -1 W/m²**

# CLIMATE CHANGE IS A RESPONSE TO RADIATIVE FORCING

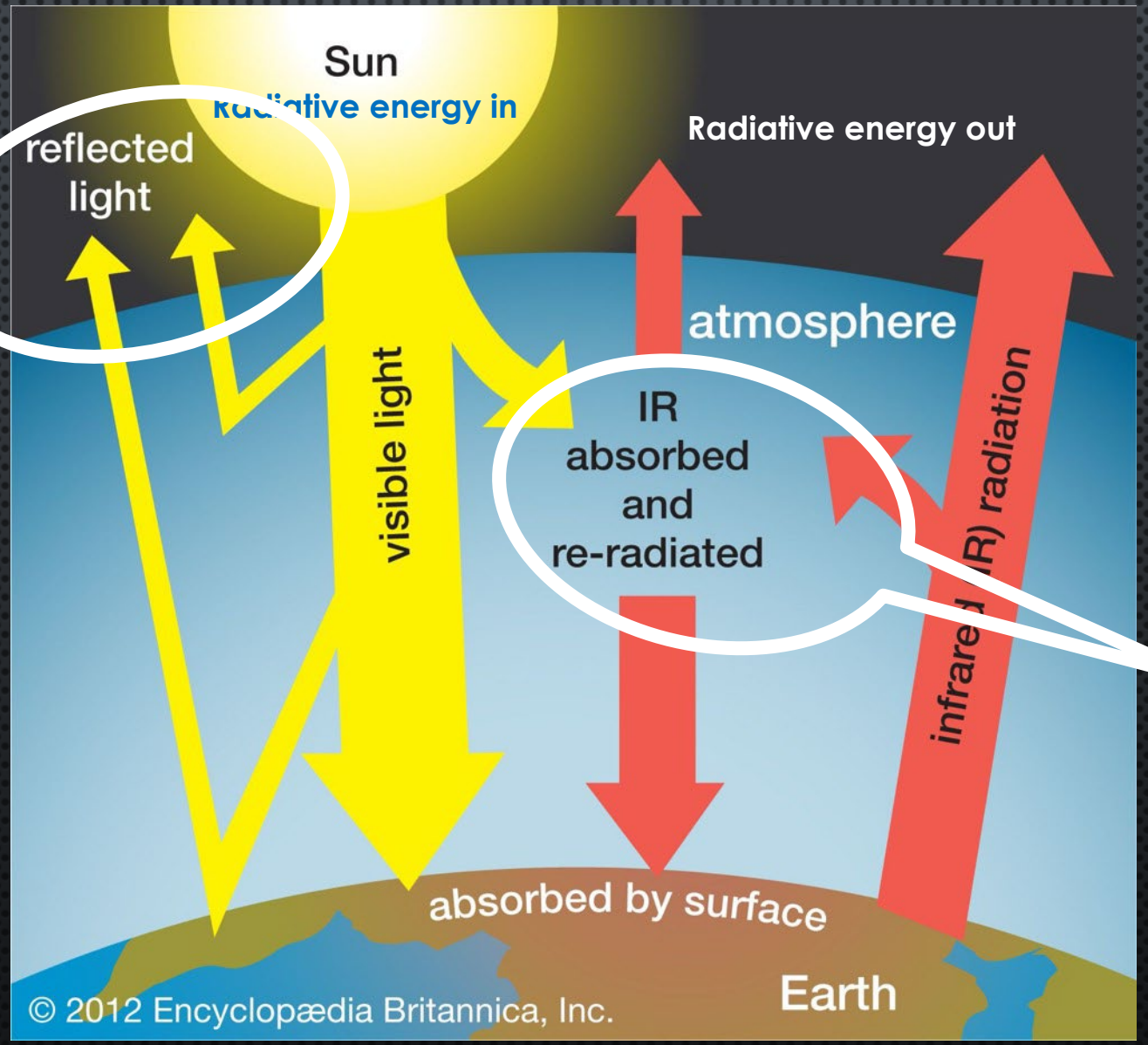
Increase in surface temperature & extreme weather

Increase in global sea level & flooding

Decrease in sea ice with impact on surface albedo

# HOW CAN WE REDUCE THE ENERGY IMBALANCE AND COOL THE PLANET?

Increase albedo
- **Urban management**
- No-till farming
- (cloud brightening)




GHG management to reduce infrared absorption
- Reduce emissions
- Carbon capture & storage
- Reforestation

# THANK YOU FOR YOUR ATTENTION!

## QUESTIONS?

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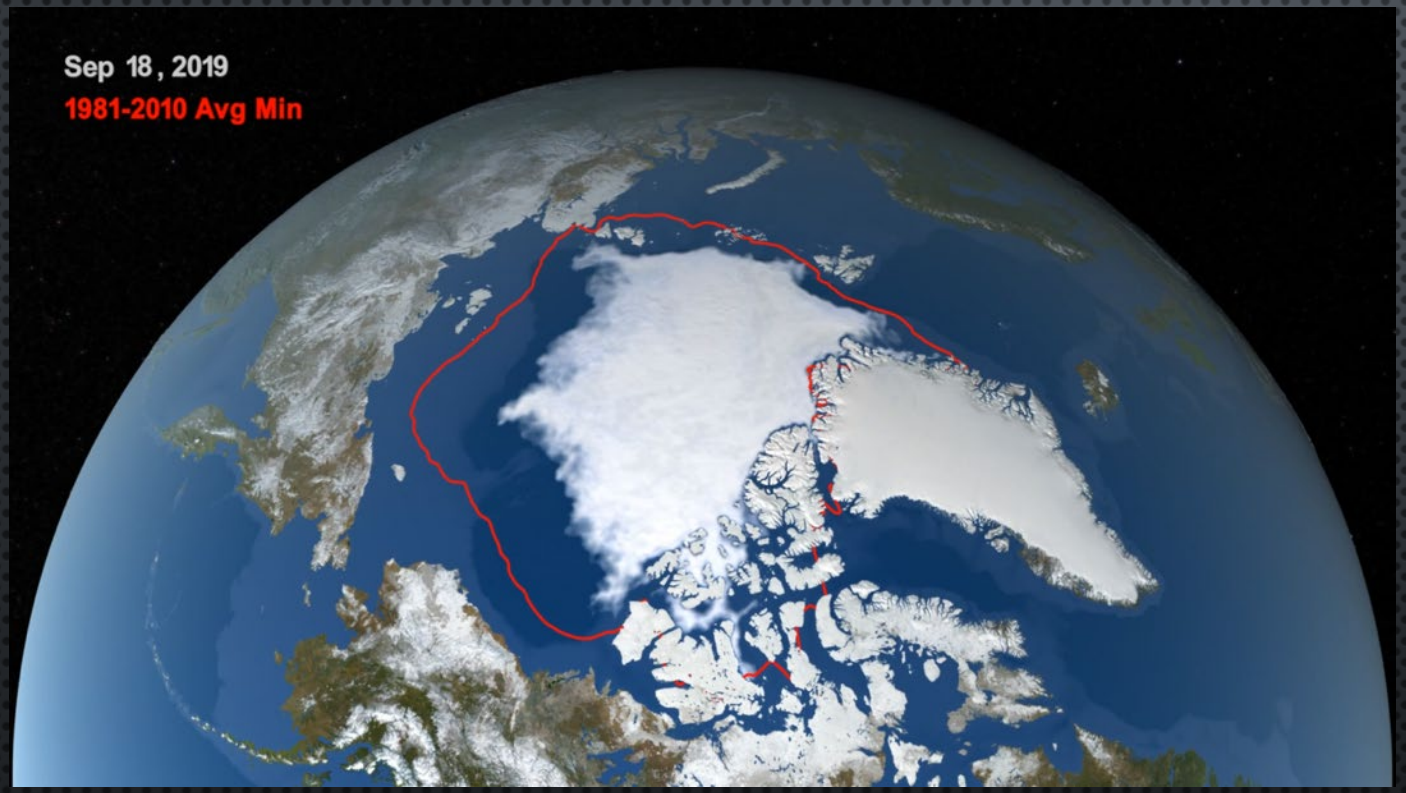
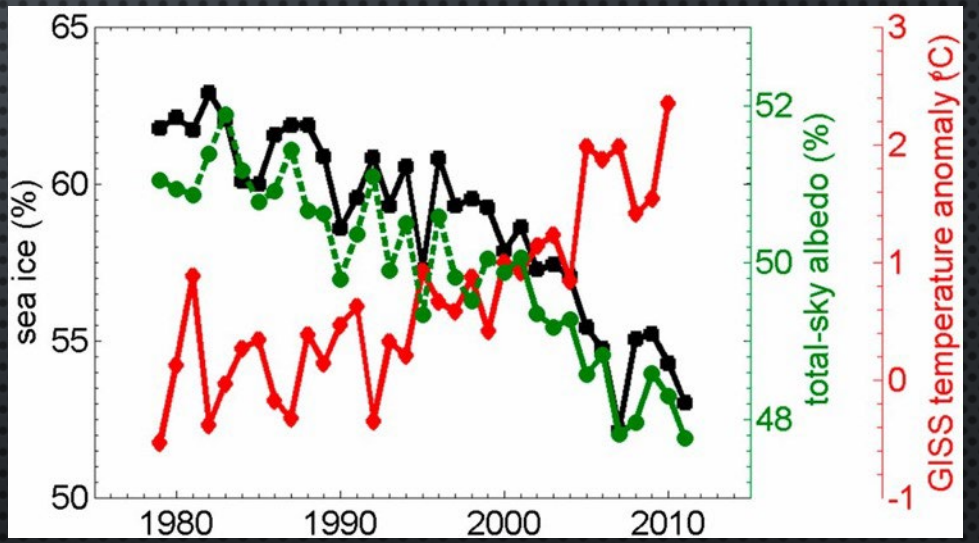
# BACK-UP

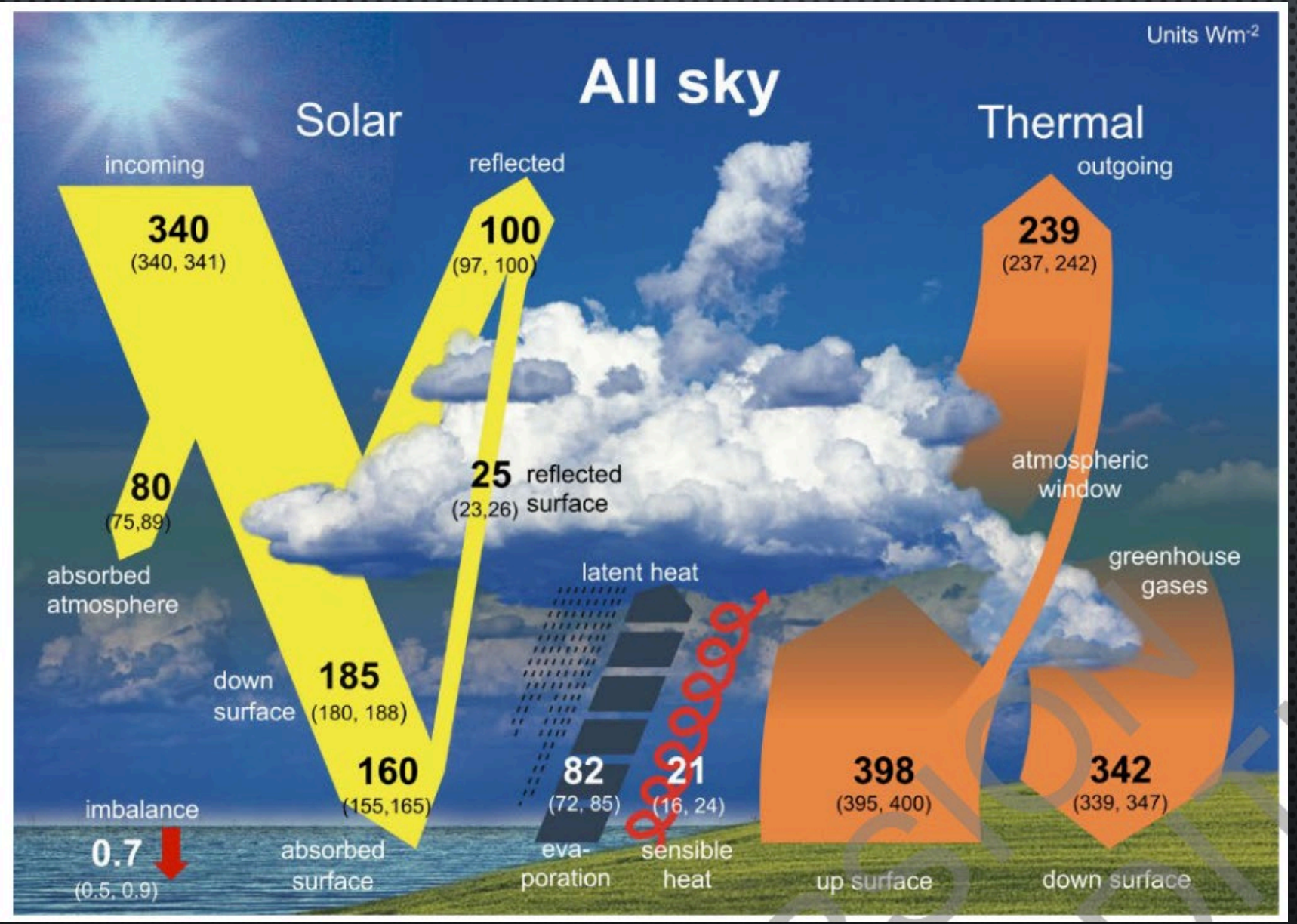
# REDUCTION IN SEA ICE DECREASES REFLECTION OF SUNLIGHT AND YIELDS MORE WARMING = POSITIVE CLIMATE FEEDBACK




NASA/Trent Schindler

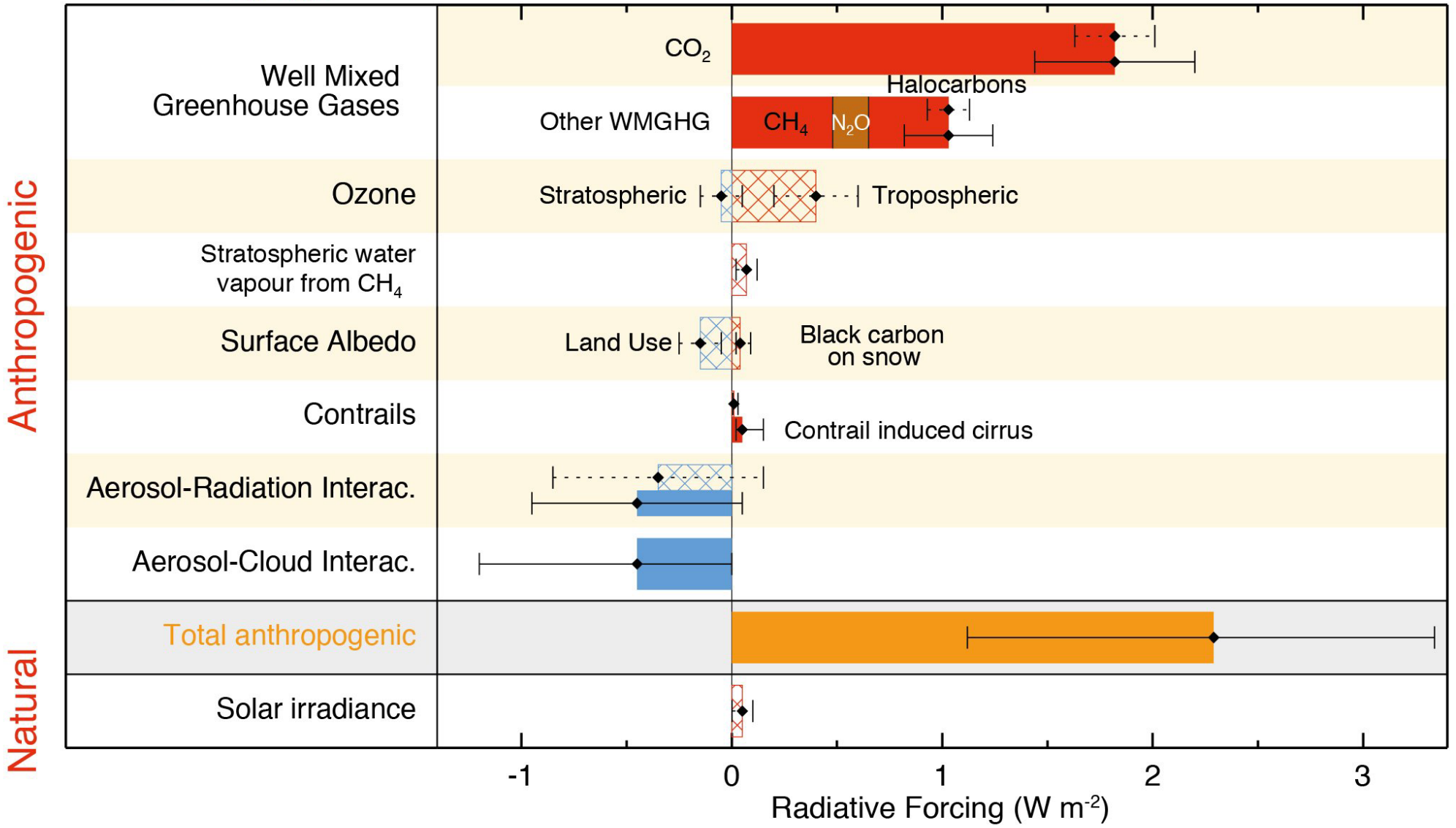



Pistone et al., 2014
https://doi.org/10.1073/pnas.1318201111

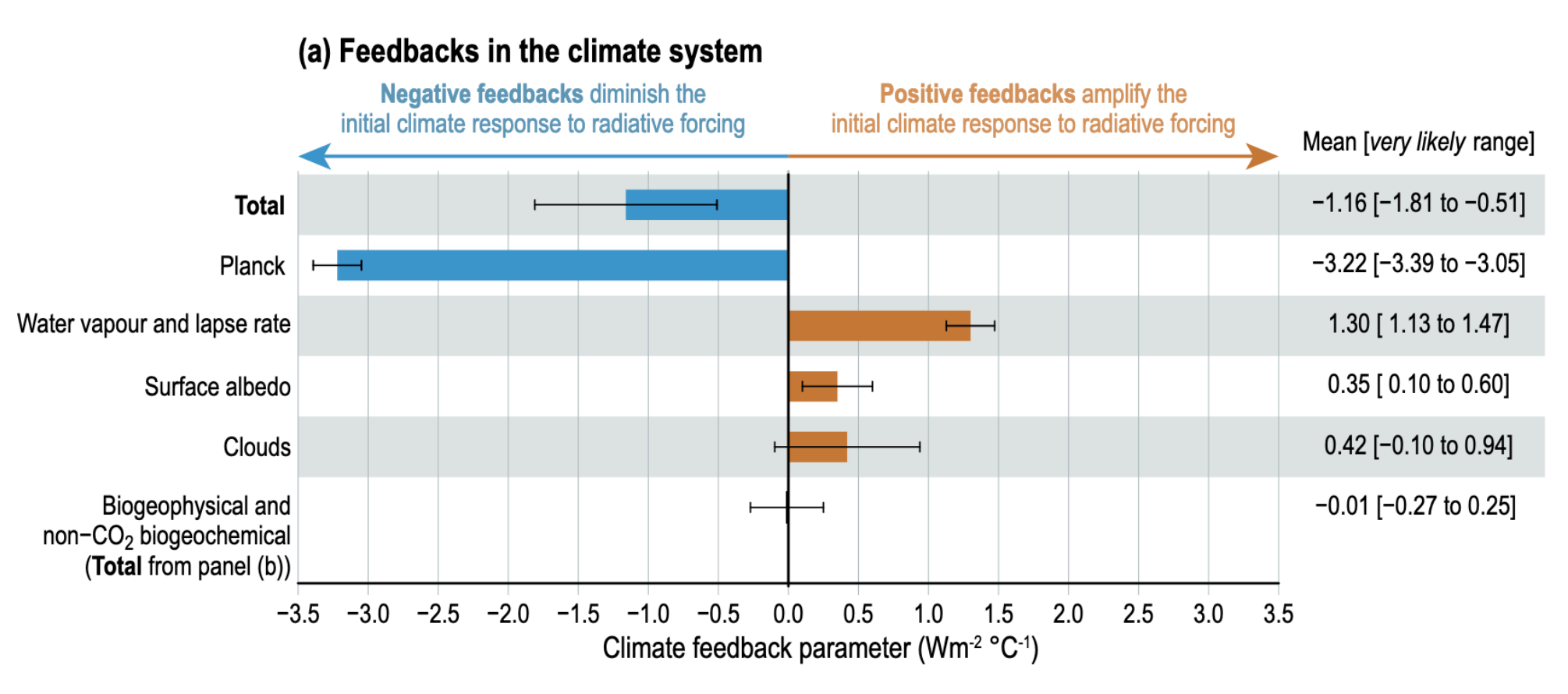



Updated from IPCC AR5 / Wild et al. 2013, 2015 Climate Dynamics

# Radiative forcing of climate between 1750 and 2011




IPCC AR5


(a) Feedbacks in the climate system
Negative feedbacks diminish the initial climate response to radiative forcing
Positive feedbacks amplify the initial climate response to radiative forcing
Mean [very likely range]
Total
Planck
Water vapour and lapse rate
Surface albedo
Clouds
Biogeophysical and non−CO2 biogeochemical (Total from panel (b))
−1.16 [−1.81 to −0.51]
−3.22 [−3.39 to −3.05]
1.30 [ 1.13 to 1.47]
0.35 [ 0.10 to 0.60]
0.42 [−0.10 to 0.94]
−0.01 [−0.27 to 0.25]
−3.5 −3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Climate feedback parameter (Wm-2 °C-1)

IPCC AR6