# Climate Sensitivity controls global precipitation hysteresis in a changing $CO_2$ pathway

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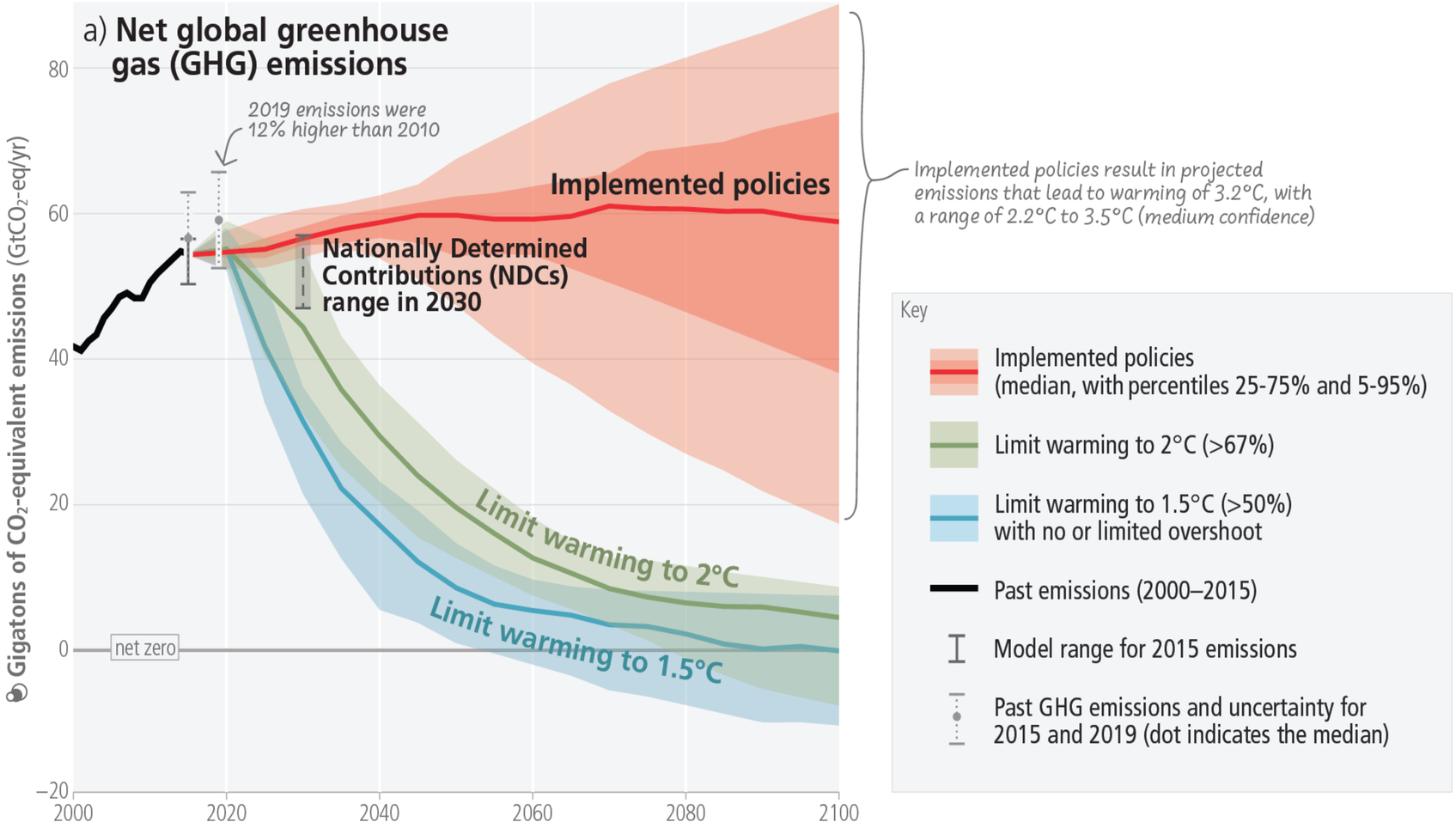
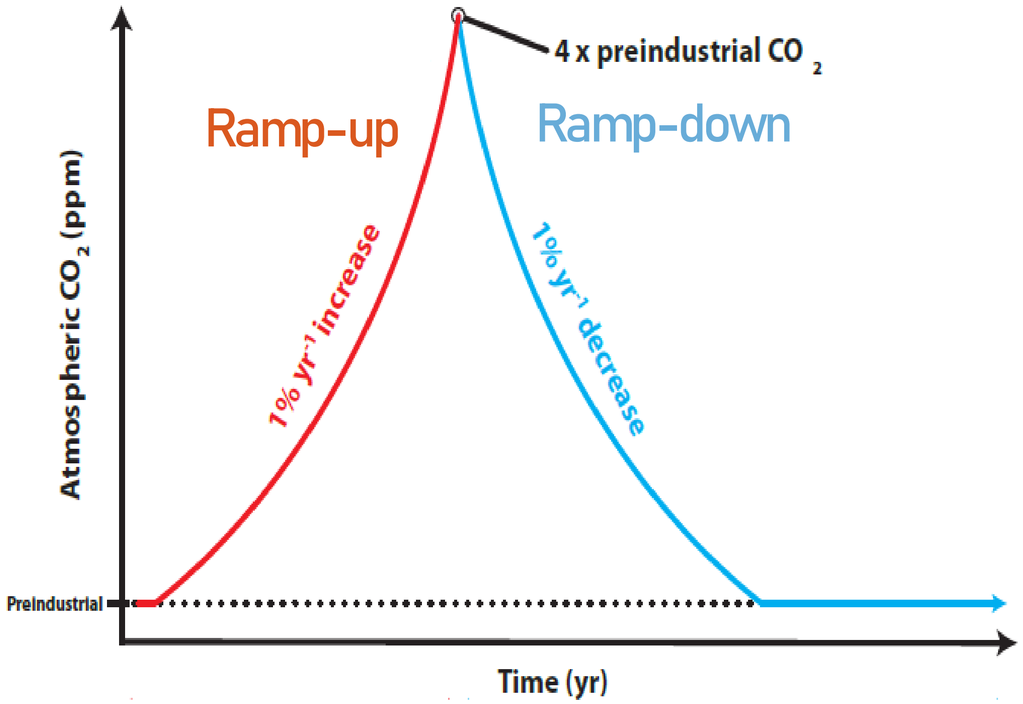
# Limiting warming to 1.5°C and 2°C involves rapid, deep and in most cases immediate greenhouse gas emission reductions

Net zero $CO_2$ and net zero GHG emissions can be achieved through strong reductions across all sectors

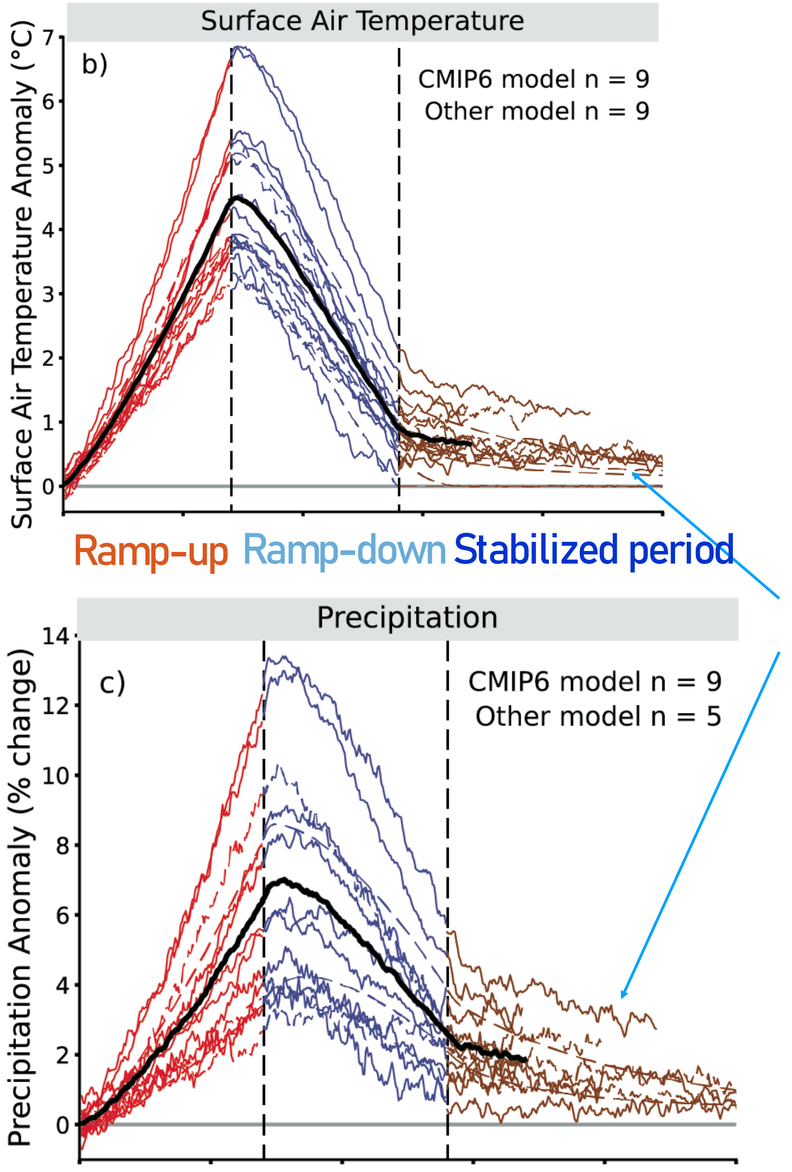


# Carbon Dioxide Removal (CDR) scenario

CMIP6 Carbon Dioxide Removal Model Intercomparison Project (CDRMIP) - To explore the potential impacts of CDR on the climate system




Keller et al. (2018)




IPCC AR6 Chapter 4

However, the CDR response simulated by the ESMs is highly uncertain.

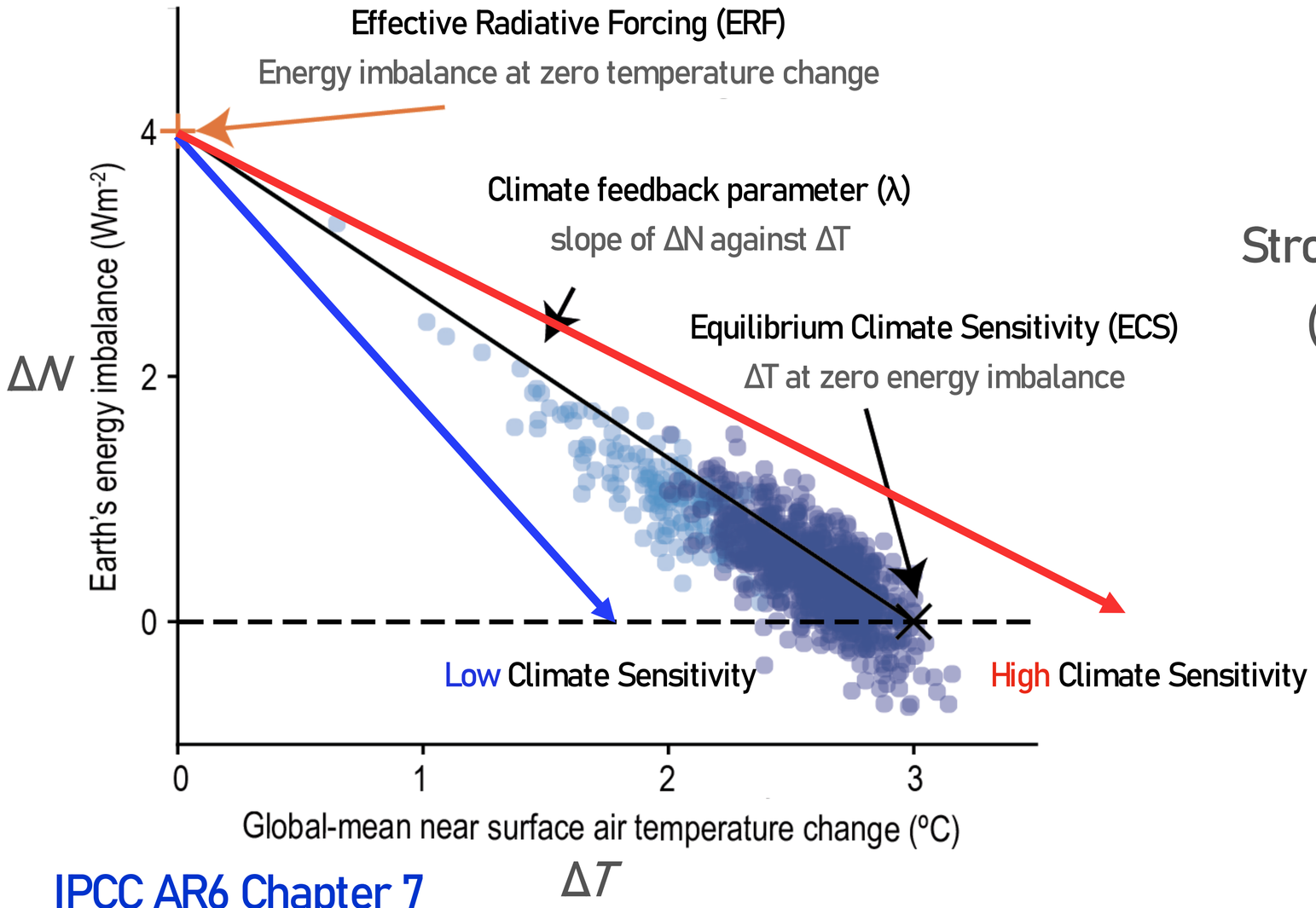
# Scientific Question

What causes such an inter-model diversity in precipitation changes in response to varying $CO_2$ concentrations?

Climate sensitivity in each climate model controls global precipitation hysteresis in a changing $CO_2$ pathway

# Equilibrium Climate sensitivity (ECS)

- Earth's energy budget $\Delta N = \Delta F + \lambda \Delta T$

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**High** Climate Sensitivity Model

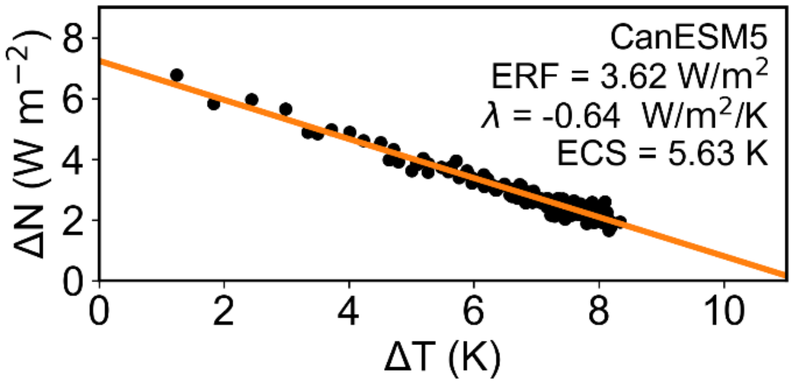
Strong negative climate feedback parameter

(= Less warming is required to restore the climate system to equilibrium)

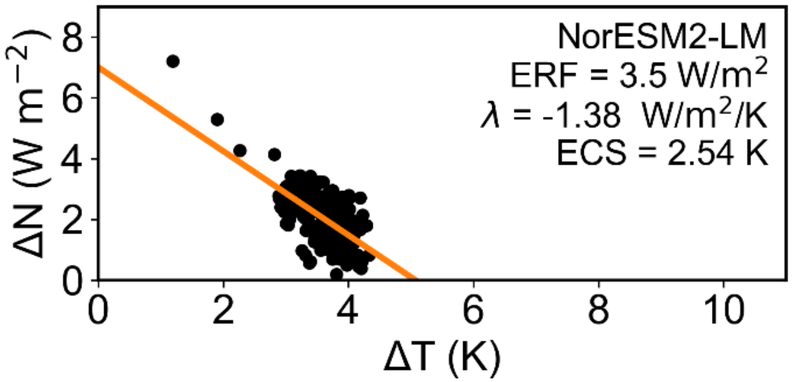
**Low** Climate Sensitivity Model

# ECS from eight CMIP6 CDRMIP ESMs

## High Climate Sensitivity Model



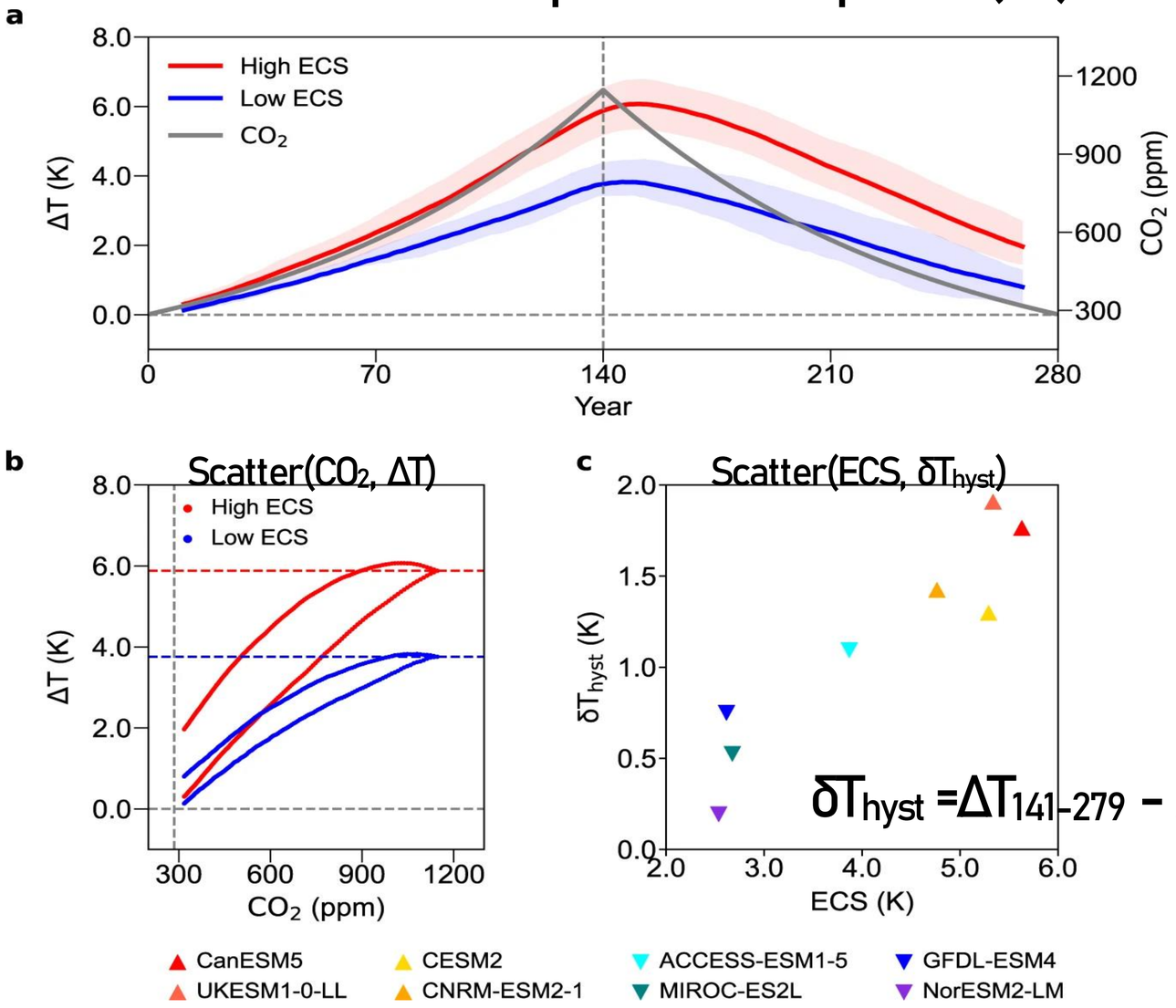

## Low Climate Sensitivity Model




| | Model | ERF (W m$^{-2}$) | $\lambda$ (W m$^{-2}$ K$^{-1}$) | ECS (°C) |
|---|---|---|---|---|
| 1 | CanESM5 | 3.62 | -0.64 | 5.63 |
| 2 | UKESM1-0-LL | 3.63 | -0.68 | 5.34 |
| 3 | CESM2 | 3.23 | -0.62 | 5.18 |
| 4 | CNRM-ESM2-1 | 2.99 | -0.63 | 4.76 |
| 5 | ACCESS-ESM1-5 | 2.84 | -0.73 | 3.87 |
| 6 | MIROC-ES2L | 4.05 | -1.51 | 2.68 |
| 7 | GFDL-ESM4 | 3.92 | -1.50 | 2.62 |
| 8 | NorESM2-LM | 3.50 | -1.38 | 2.54 |
| | Multi-model average | 3.47 | -0.96 | 4.08 |

# CDRMIP ECS and Global warming hysteresis

## Global mean temperature response (ΔT)



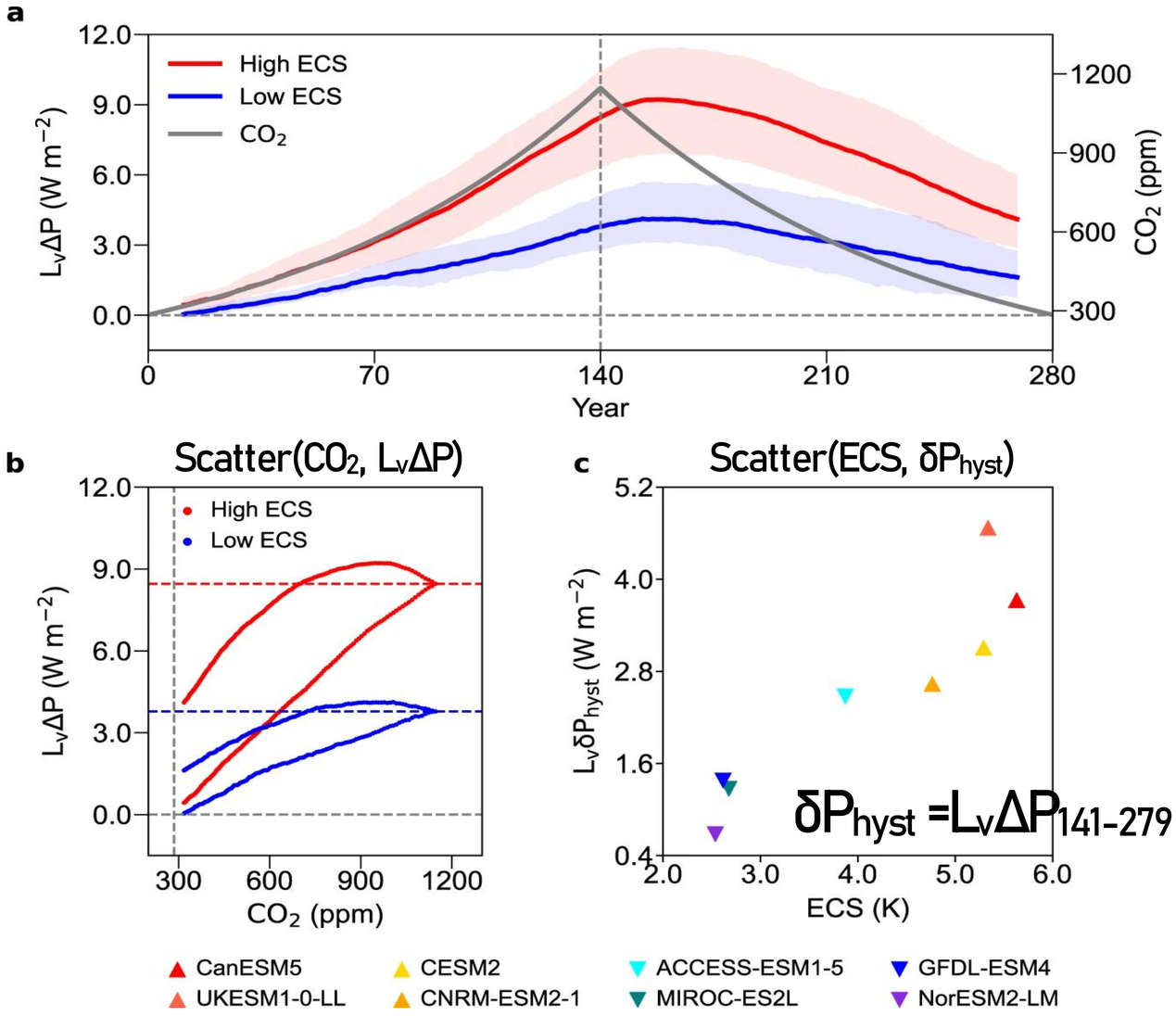

Increasing ΔT hysteresis with higher ECS

weak λ - less efficient restoring feedback

(Jeltsch-Thömmes et al. 2020; Song et al. 2023)

# CDRMIP ECS is a key factor controlling the global precipitation hysteresis

## Global precipitation response ($L_v\Delta P$)




Higher ECS with a larger ΔT hysteresis simulate a greater degree of ΔP hysteresis

→ How does ECS control ΔP hysteresis?

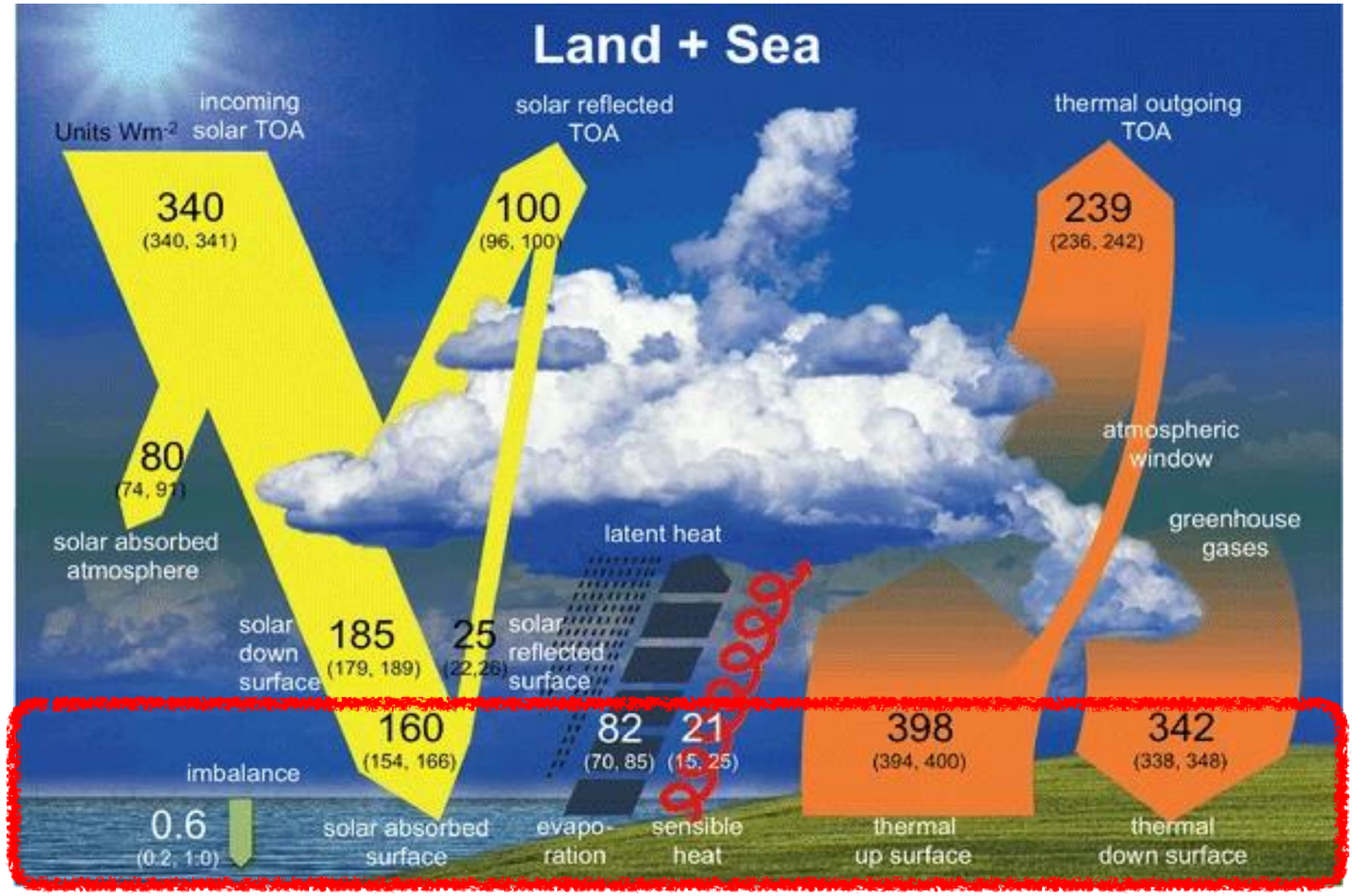
$\delta P_{hyst} = L_v\Delta P_{141\text{-}279} - L_v\Delta P_{1\text{-}139}$

# Surface energy balance constraints on global precipitation

## Surface energy balance constraints

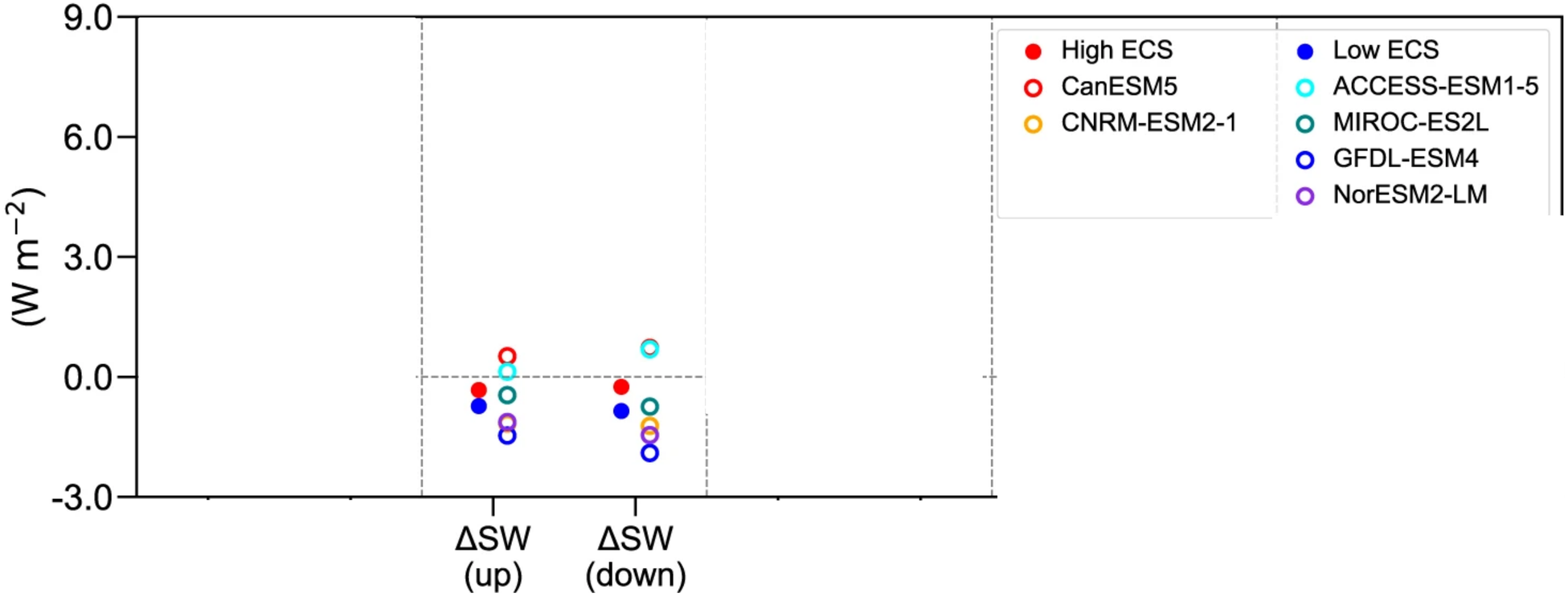
$$L_v \Delta P = \Delta SW + \Delta LW - \Delta SH - \Delta N$$

(surface available energy for precipitation)



# CDRMIP Asymmetrical response of the surface energy budget terms

## Surface energy budget response during ramp-up (1-139 yrs) & -down (141-279 yrs)



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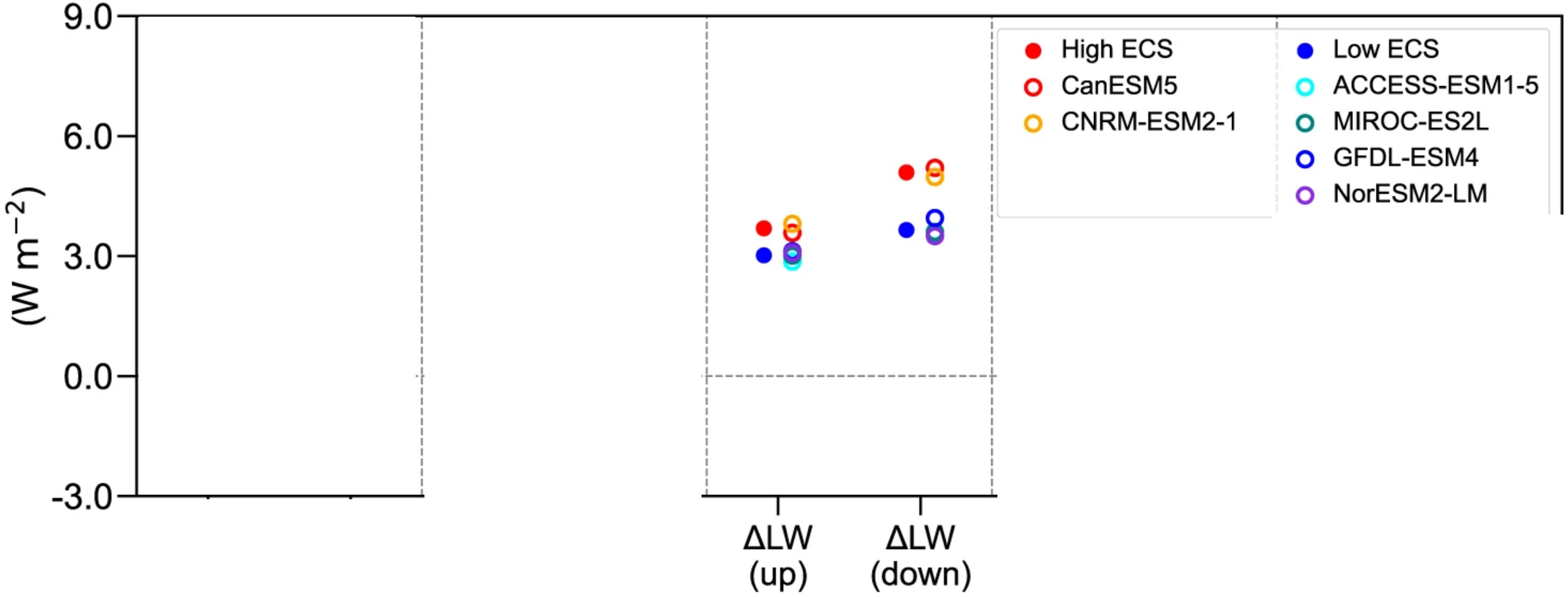

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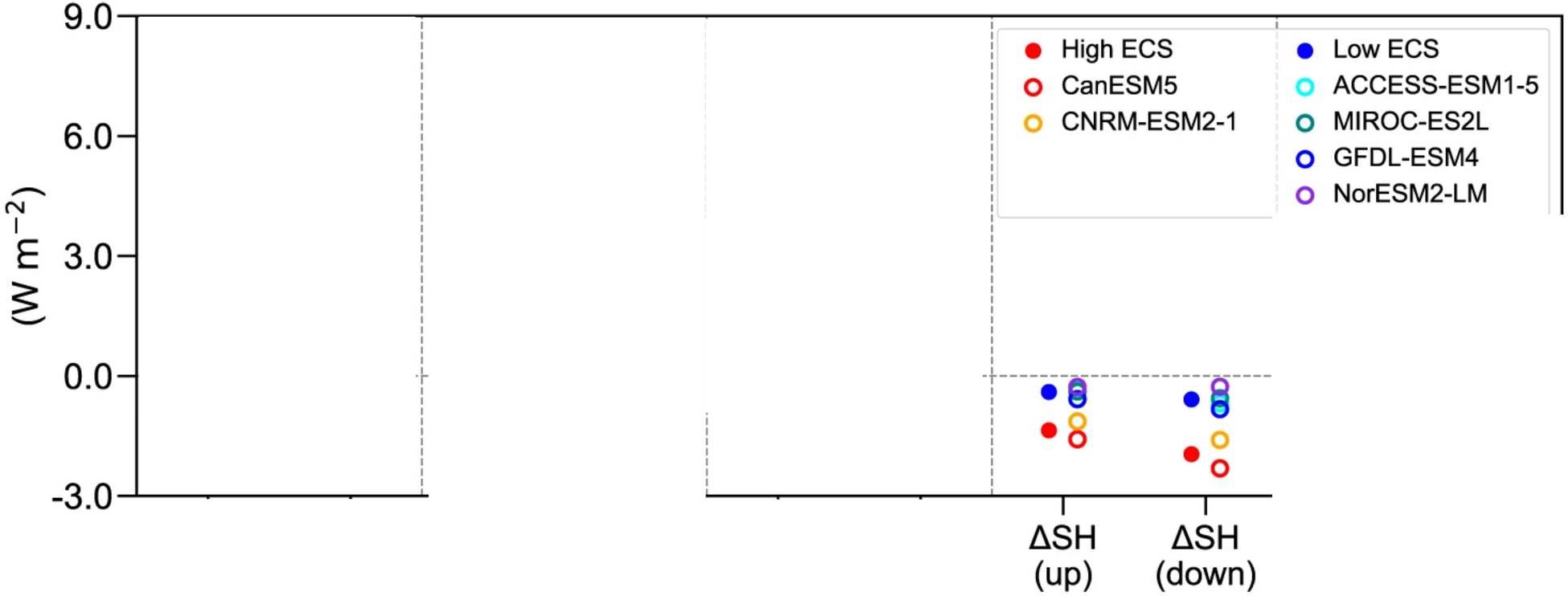

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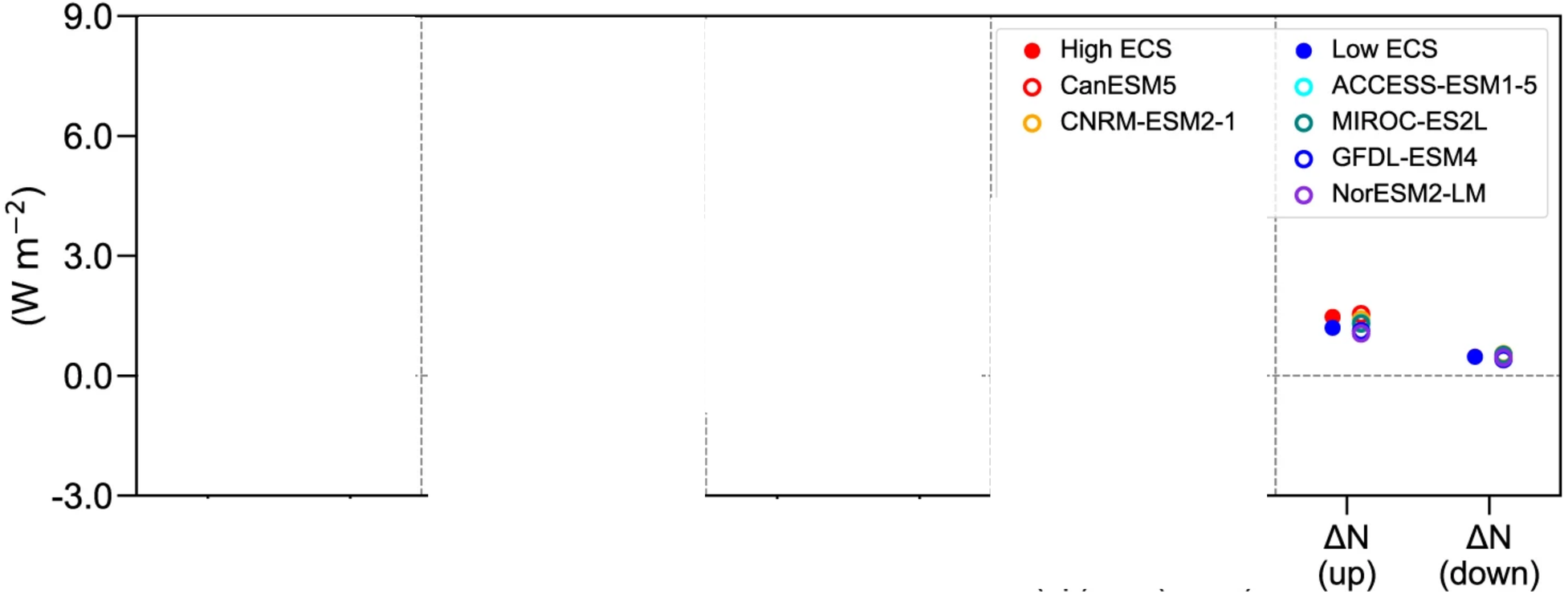

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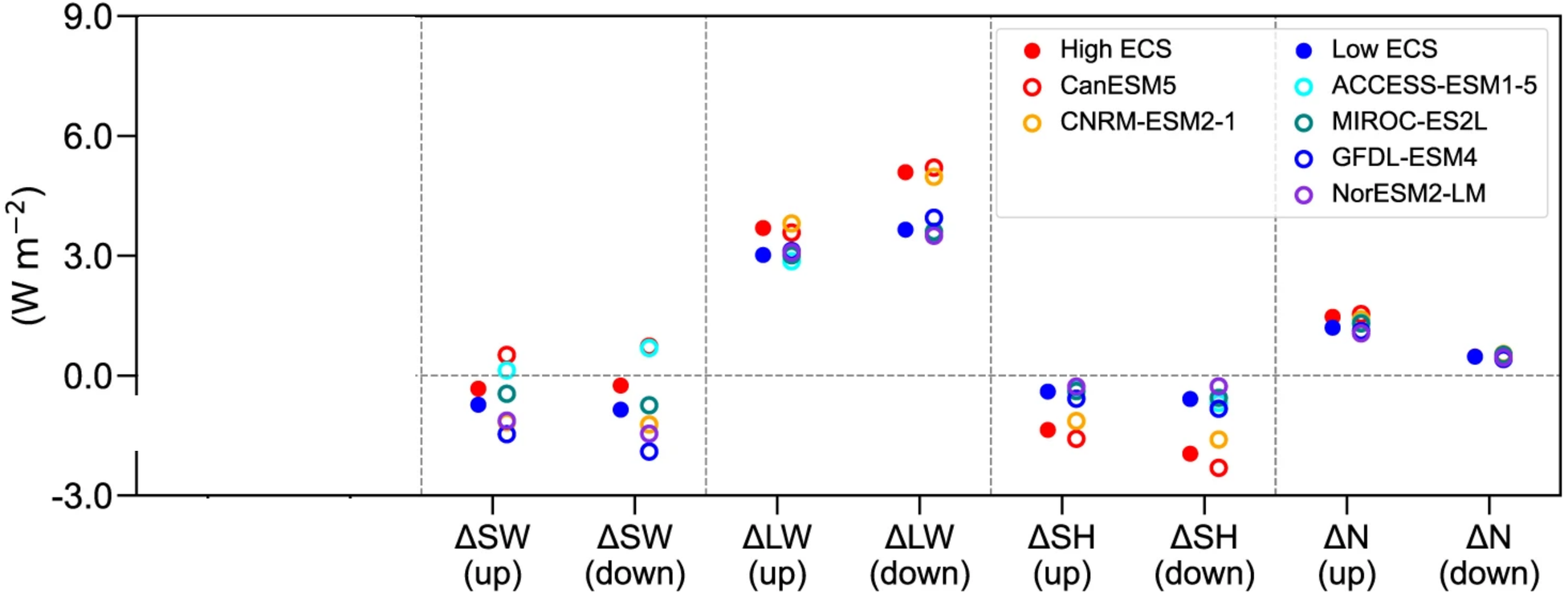


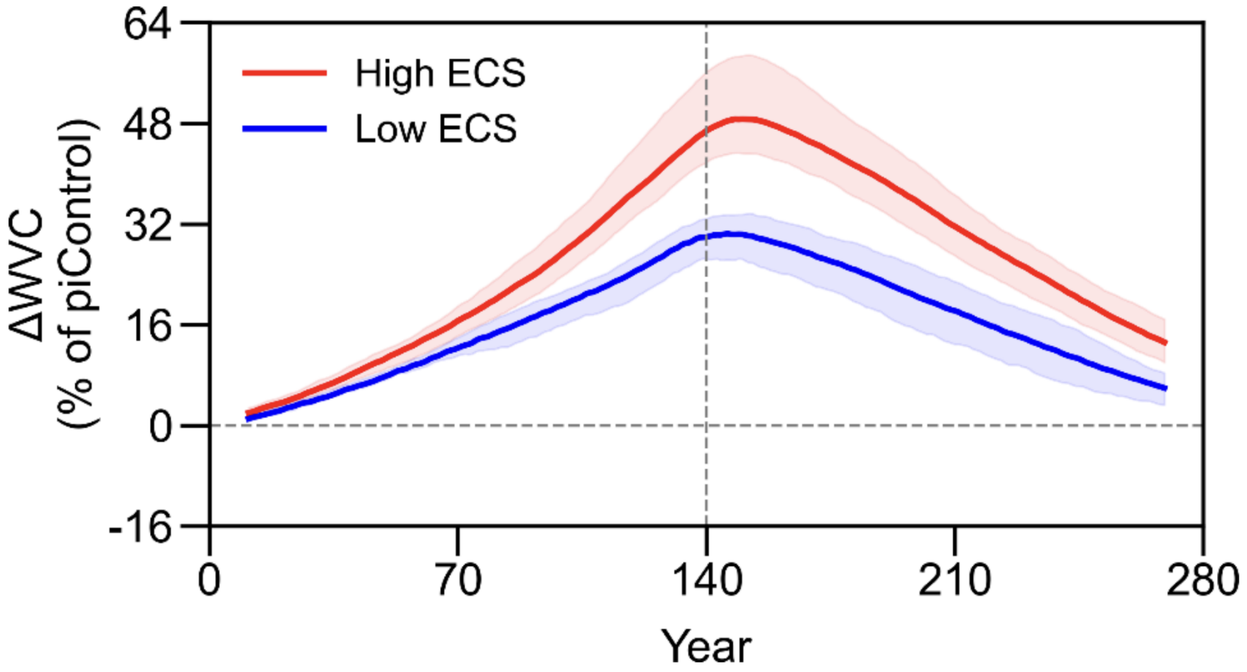

Asymmetrical response of ΔLW and ΔN in High ECS models account for 44% and 31% of the global ΔP hysteresis, respectively.

# CDRMIP Higher ECS simulate a larger asymmetric water vapor feedback response

## Where the asymmetric response of ΔLW in High and Low ECS climate models comes from ?

- ΔLW – water vapor feedback

Atmospheric water vapor content response (ΔWVC)



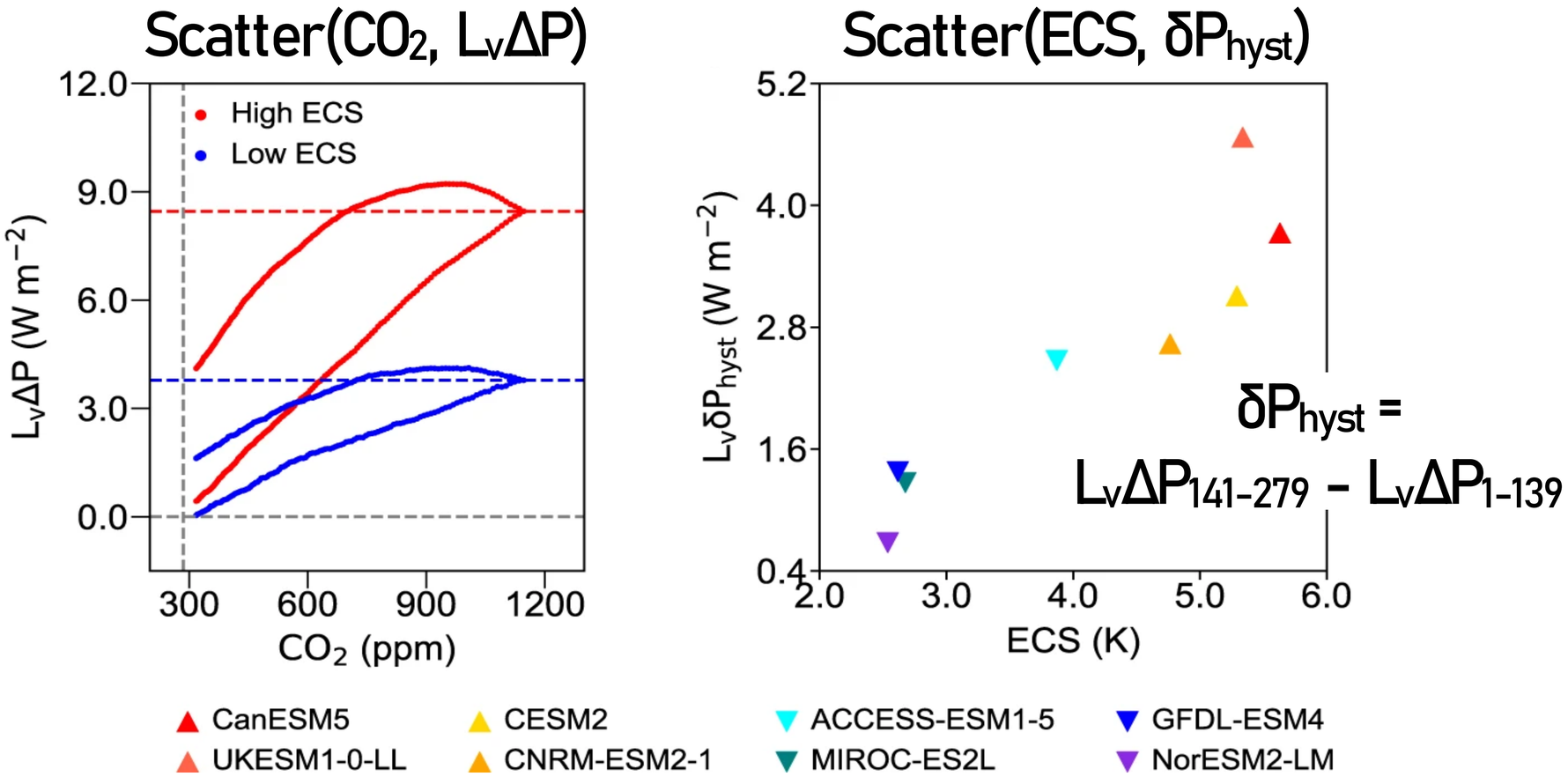

Larger asymmetric ΔWVC in High ECS,
due to a larger ΔT hysteresis,
leads to greater asymmetry in ΔLW
(Clausius-Clapeyron relationship)

# Summary

Higher ECS with a larger ΔT hysteresis simulates

more pronounced asymmetry in feedback response of ΔLW & ΔN,

resulting in a greater degree of ΔP hysteresis.



# Thank you