Explaining the spread in global mean thermosteric sea level rise in CMIP5 simulations of 20th and 21st centuries

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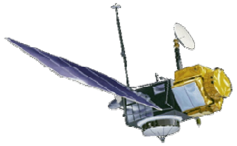
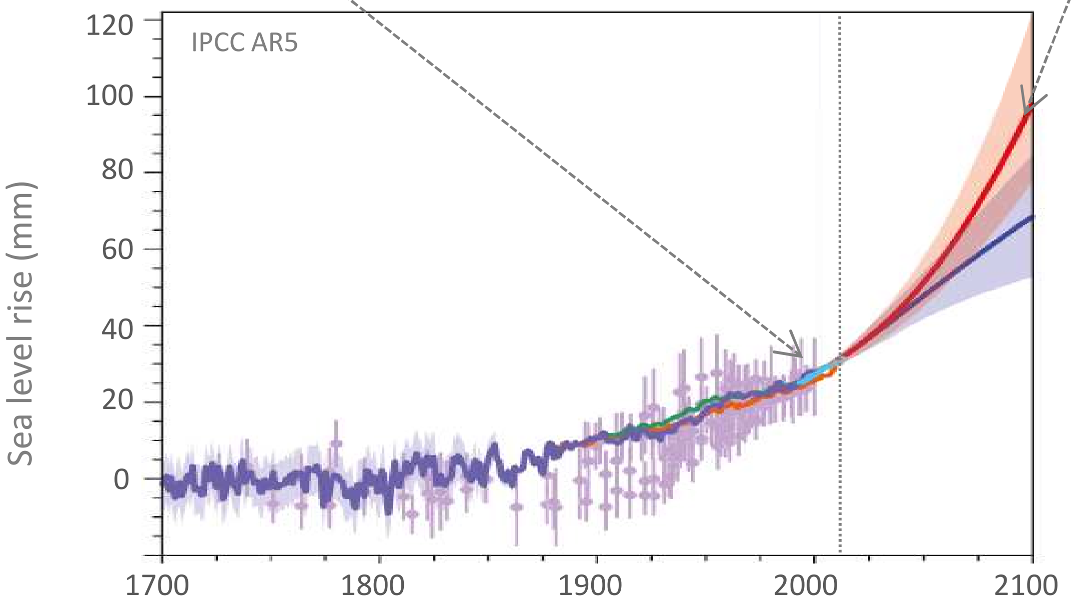
Thermosteric sea level and sea level rise

Sea level rise 1993-2015
Altimetry : 3.3 mm/yr
(source : AVISO)

Sea level rise 2081-2100
Climate models RCP8.5 : 11.2 mm/yr
(source IPCC AR5)





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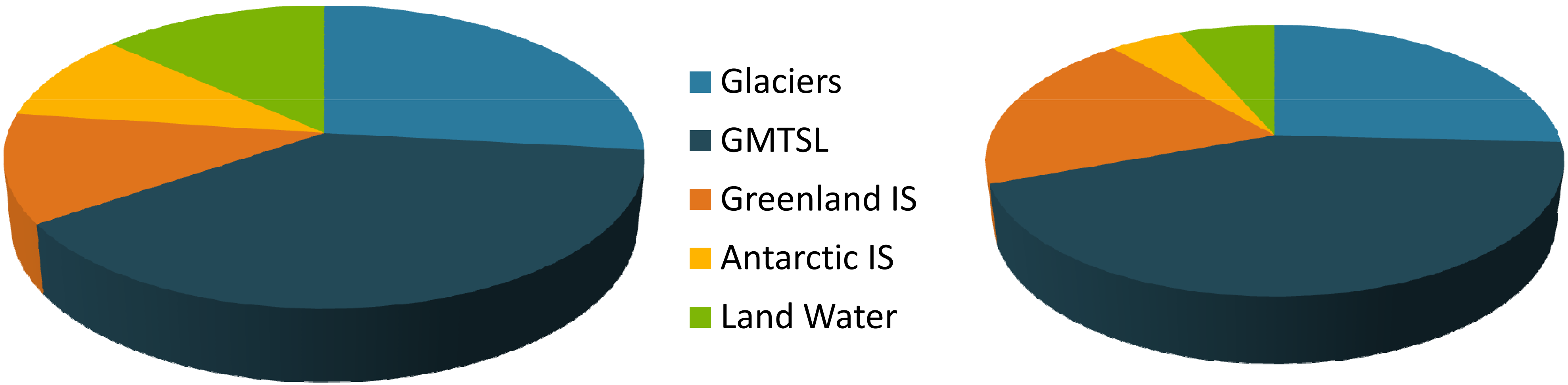
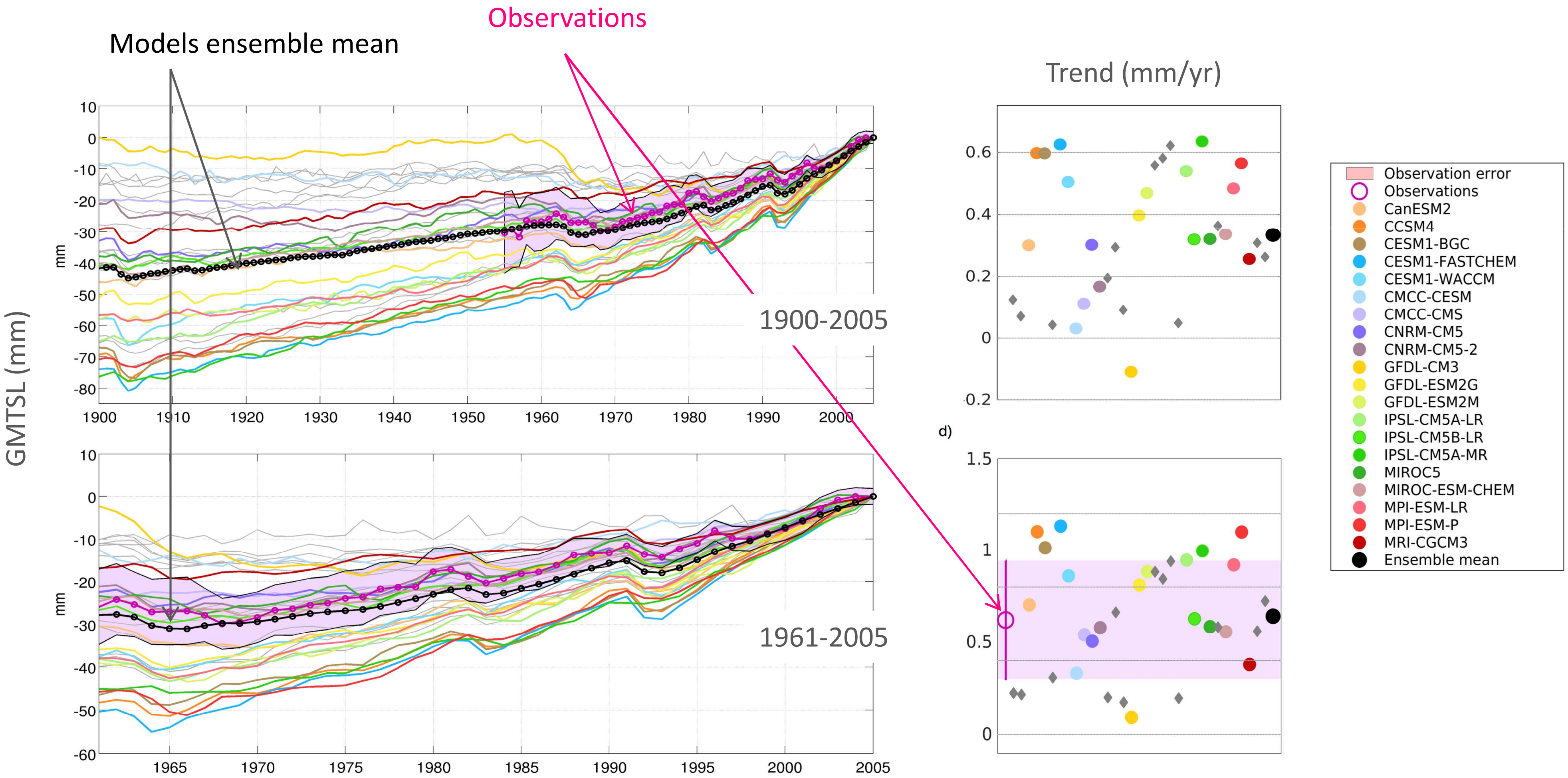


Thermosteric sea level rise is and is expected to remain the primary contributor to global mean sea level rise during the 21st century

Thermosteric sea level and sea level rise

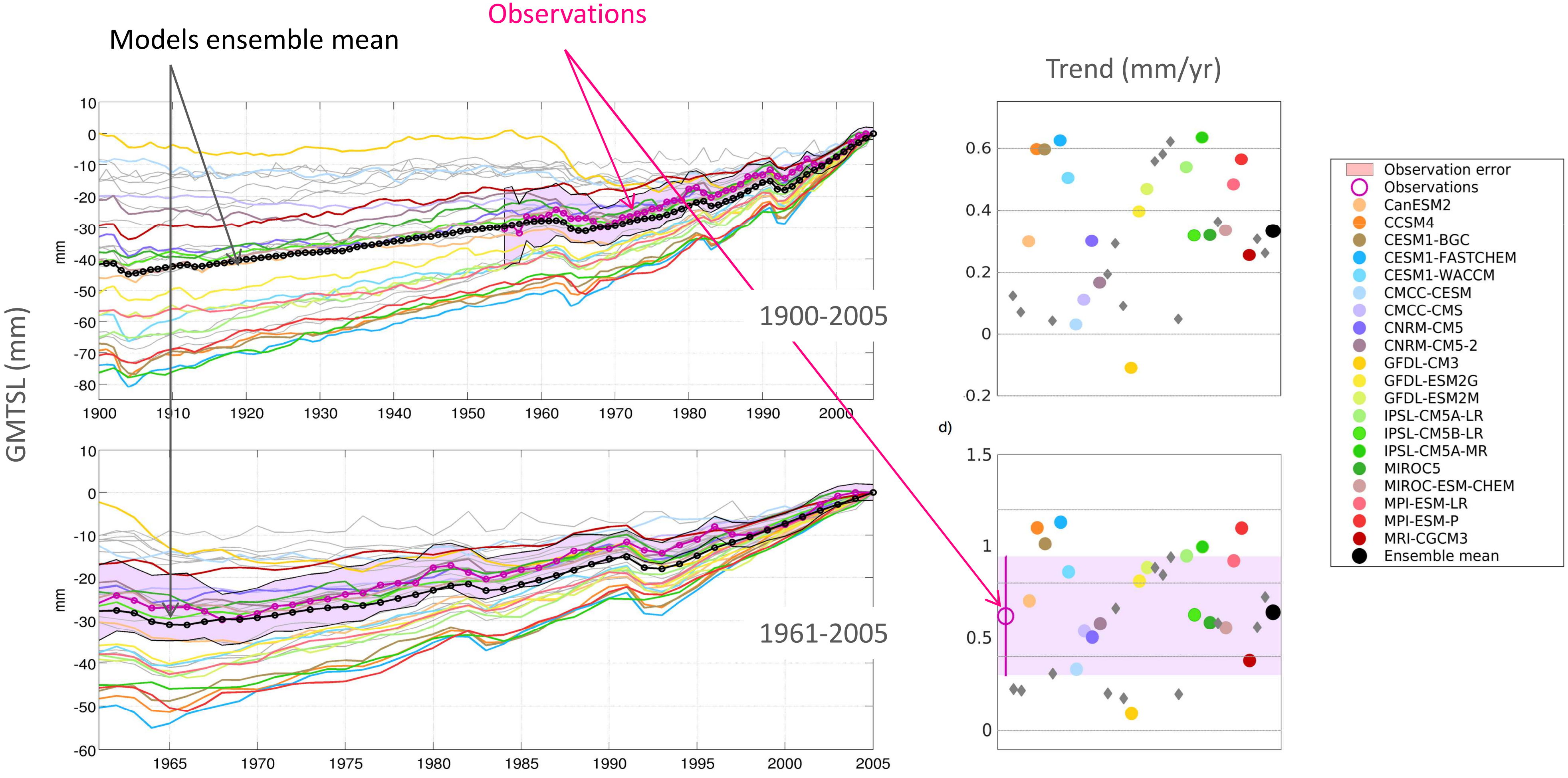
Global mean thermosteric sea level (GMTSL) in CMIP5 climate models



Thermosteric sea level and sea level rise

Global mean thermosteric sea level (GMTSL) in CMIP5 climate models

Ensemble mean consistent with observations but **large spread** over the 20th century



Thermosteric sea level and sea level rise

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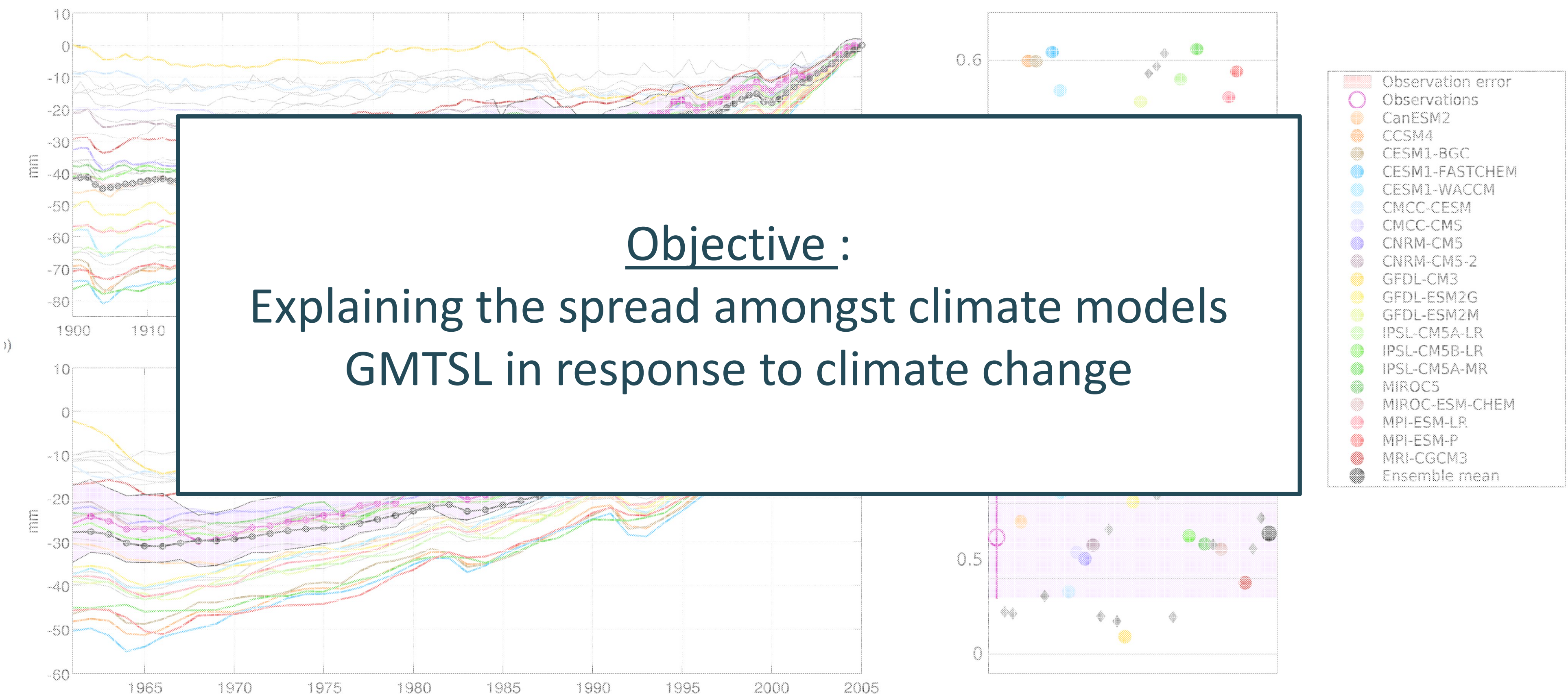
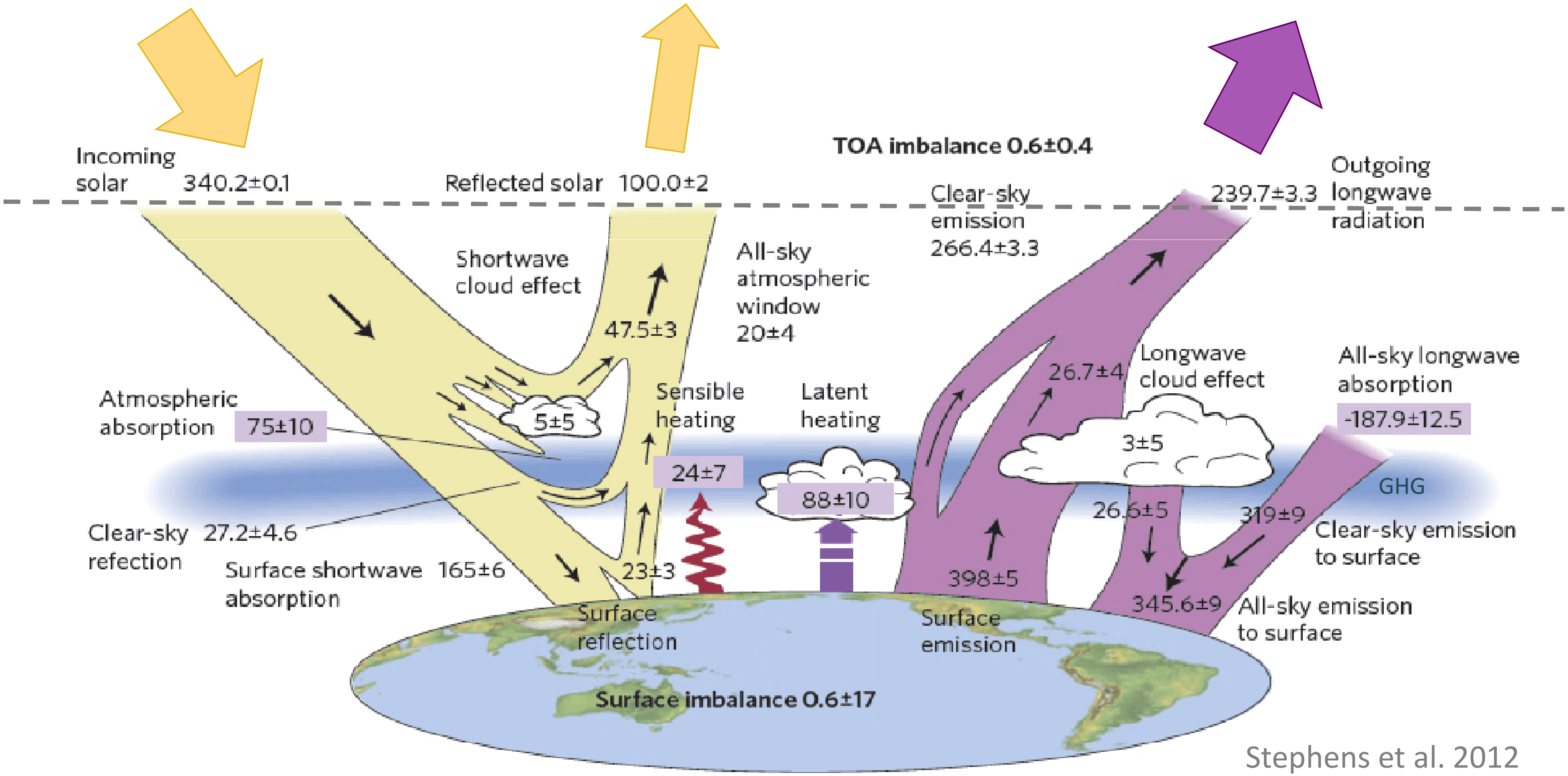


Objective :

Explaining the spread amongst climate models GMTSL in response to climate change

Relating ΔGMTSL to the radiative forcing imbalance

Climate change ⟷ Radiative forcing imbalance (N) at the top-of-atmosphere

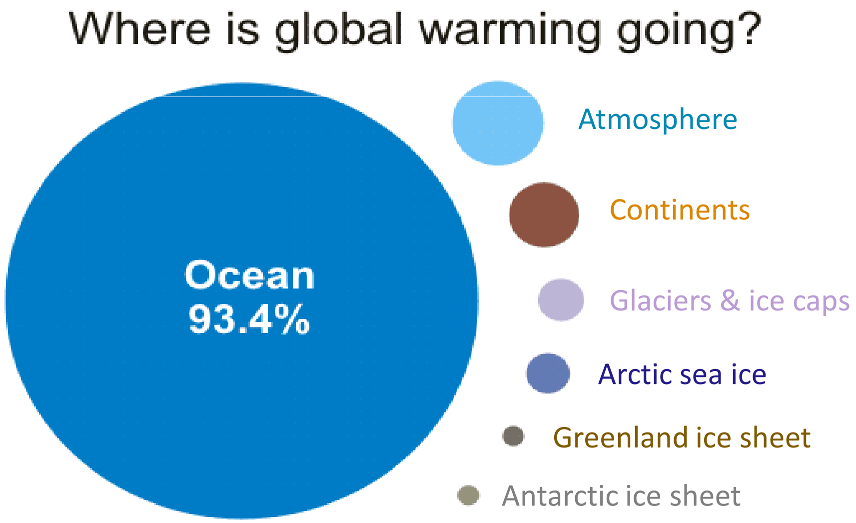


Stephens et al. 2012

Relating ΔGMTSL to the radiative forcing imbalance

Climate change ⟷ Radiative forcing imbalance (N) at the top-of-atmosphere

Physics : N > 0, energy accumulates in the climate system



Levitus et al. 2005, Church et al. 2011

Increase of the ocean heat content (OHC)

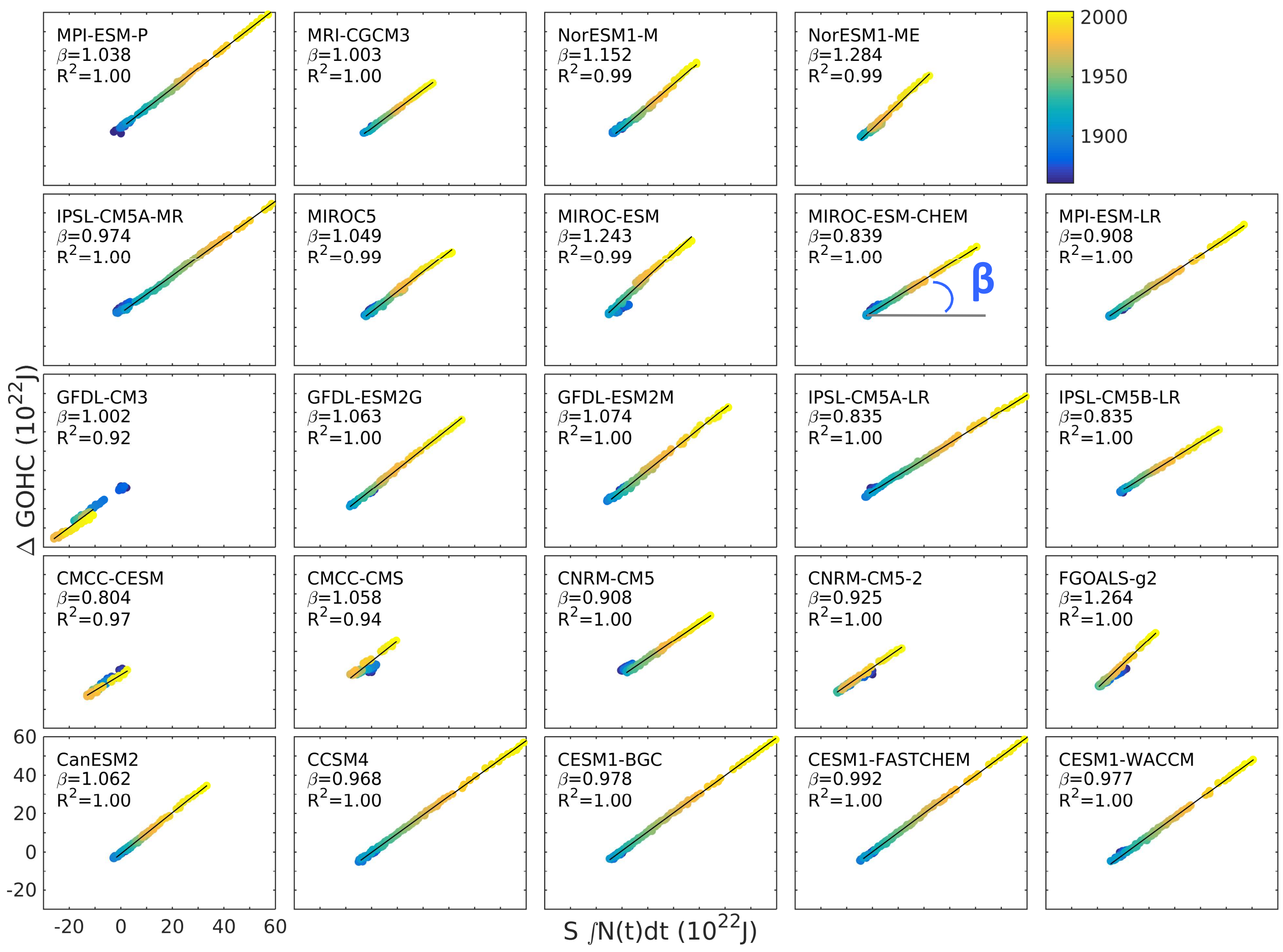
$$\Delta GOHC = \beta S \int N(t)dt$$

β : fraction of the energy excess stored in the ocean

S : Earth's surface

Relating ΔGMTSL to the radiative forcing imbalance

Climate change ⟷ Radiative forcing imbalance (N) at the top-of-atmosphere



Verification in climate models :

Excellent linear relationship

Values of β :

<u>Climate models</u>: β = 0.93 ± 0.2

<u>Observations</u>:

Levitus et al. 2005 : β = 0.85

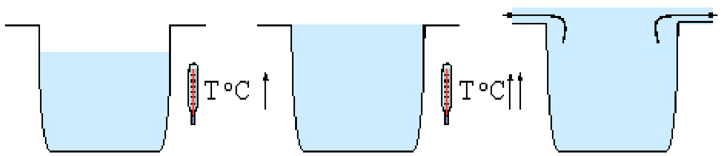
Church et al. 2011 : β = 0.93

IPCC 2013 : β = 0.94

3 out of 24 models with β ≠ 0.93 ± 0.2 -> disregarded

Relating ΔGMTSL to the radiative forcing imbalance

Physics : Increased GOHC induces ocean warming and thermal expansion



$$\Delta GMTSL = \varepsilon \, \Delta GOHC$$

ε : expansion efficiency of heat in m J^{-1}
-> Depends on the heat pattern

Relating ΔGMTSL to the radiative forcing imbalance

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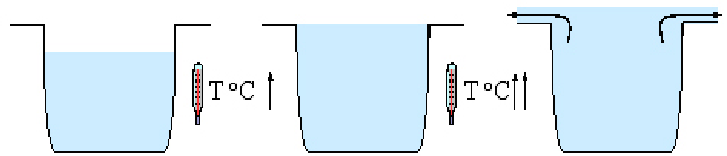

$$\Delta GMTSL = \varepsilon \, \Delta GOHC$$

ε : expansion efficiency of heat in m J^{-1}

-> Depends on the heat pattern

Verification in climate models:

Excellent linear relationship

Values of ε:

Climate models: ε = 0.12 ± 0.02 m YJ^{-1}

Observations:

Levitus et al. (2005): ε = 0.12 ± 0.01 m YJ^{-1}

Church et al. (2011): ε = 0.15 ± 0.03 m YJ^{-1}

Relating ΔGMTSL to the radiative forcing imbalance

Physics : Increased GOHC induces ocean warming and thermal expansion

$$\Delta GOHC = \beta S \int N(t)dt$$

$$\Delta GMTSL = \varepsilon \, \Delta GOHC$$

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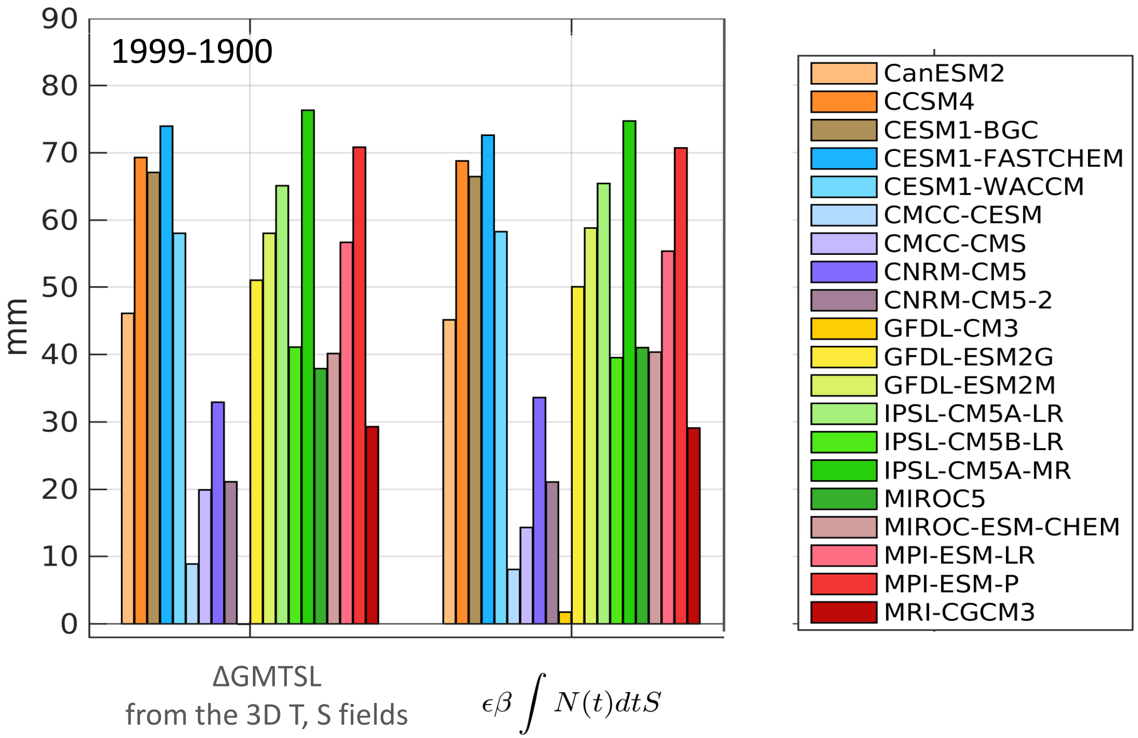


Relationship verified in climate models

Across model spread due to spread in N

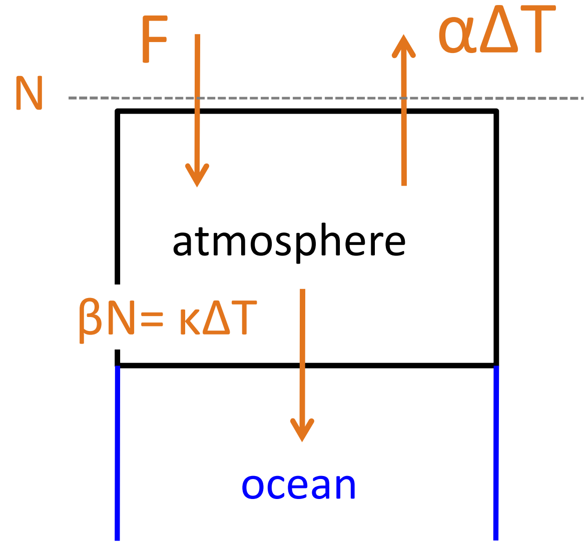
Relating ΔGMTSL to the radiative forcing

Going further...

Physics : Radiative imbalance = Radiative forcing – climate system retroactions

$$N = F - \alpha \Delta T$$

α : climate feedback parameter (W m^{-2} K^{-1})



and… Observations + models show that:

$$F = \rho \Delta T$$

ρ : climate resistance (W m^{-2} K^{-1})
Radiative forcing needed to rise the Earth surface temperature by 1K

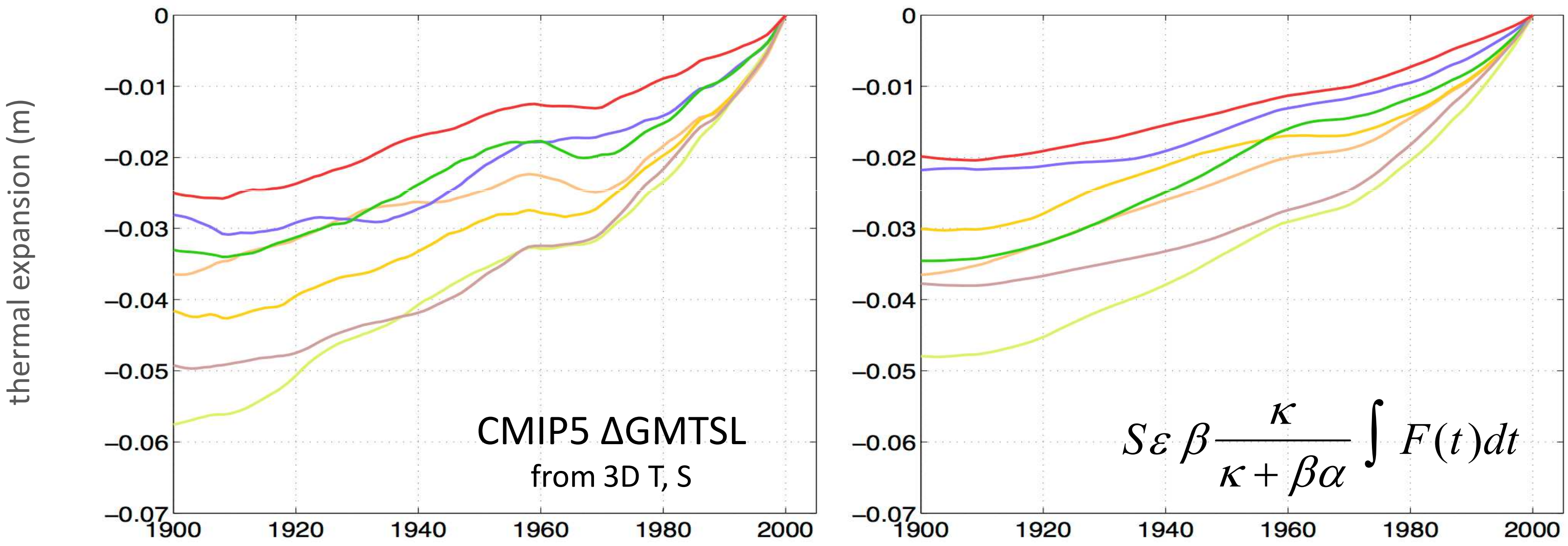
$$N = \frac{\kappa}{\kappa + \beta\alpha} F$$

$$\Delta GMTSL = \varepsilon \beta S \frac{\kappa}{\kappa + \beta\alpha} \int F(t)dt$$

κ: ocean heat uptake efficiency (W m^{-2} K^{-1})

Relating ΔGMTSL to the radiative forcing

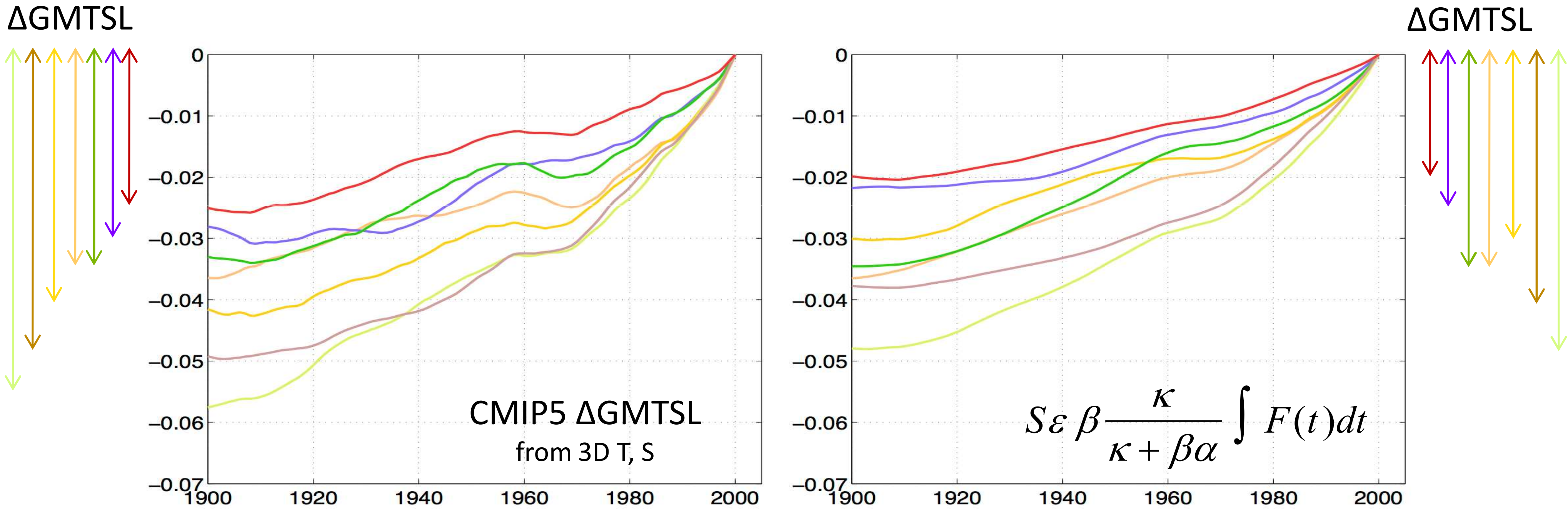
$$\Delta GMTSL = \varepsilon \beta S \frac{\kappa}{\kappa + \beta\alpha} \int F(t)dt$$



Climate models verify these physical mechanisms

Relating ΔGMTSL to the radiative forcing

$$\Delta GMTSL = \varepsilon\, \beta S \frac{\kappa}{\kappa + \beta\alpha} \int F(t)\,dt$$



Climate models verify these physical mechanisms
Use that relationship to explain the spread in GMTSL

Relating ΔGMTSL to the radiative forcing

$$\Delta GMTSL = \underbrace{\varepsilon\, \beta S \frac{\kappa}{\kappa + \beta\alpha}}_{\mu} \int F(t)\,dt$$

transient thermosteric sea level
response of the climate system

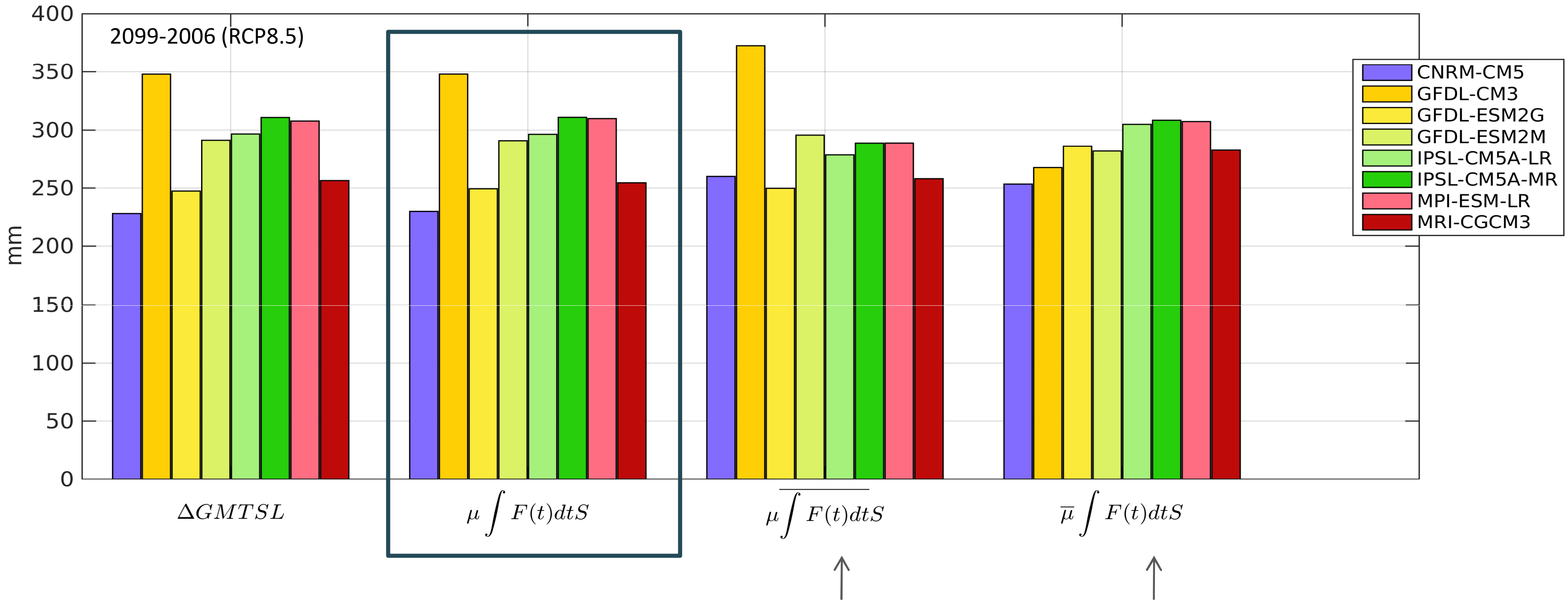
Across models
spread in GMTSL because of

Across models
spread in μ

Across models
spread in F

Which one dominates ?

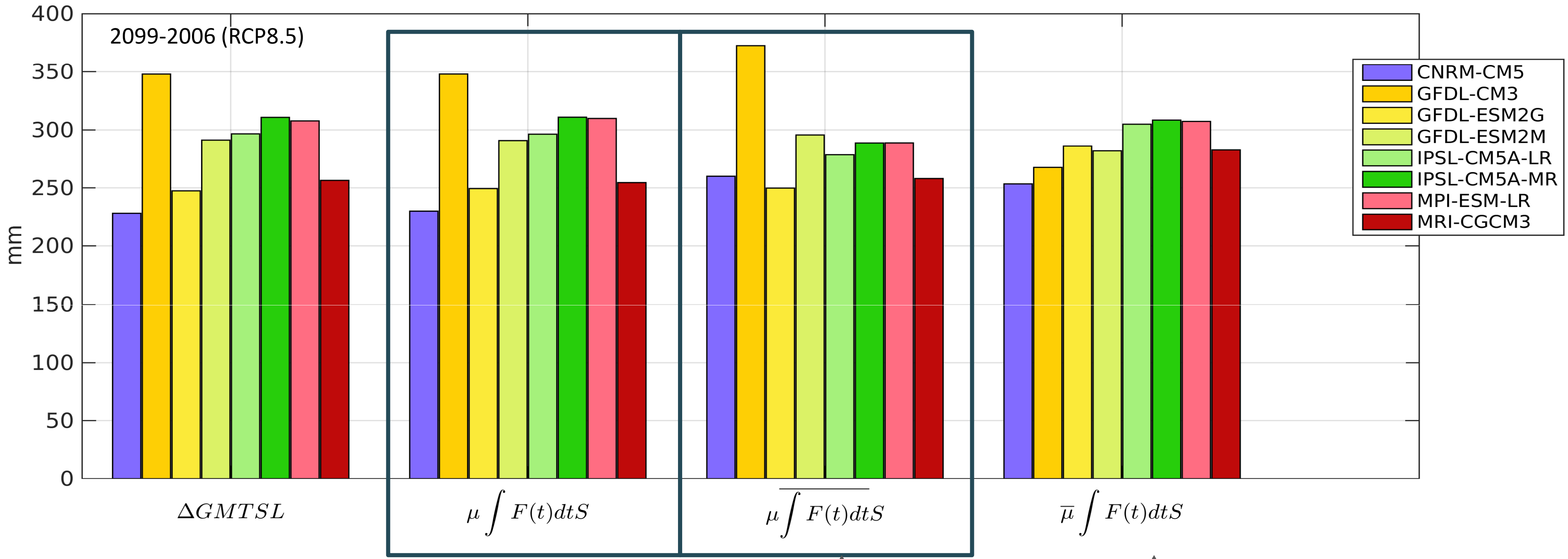
Explaining the spread in climate models spread in GMTSL



Hold ∫F to its ensemble mean value
Across model spread in µ only

Across model spread in ∫F only
Hold µ to the ensemble mean value

Explaining the spread in climate models spread in GMTSL

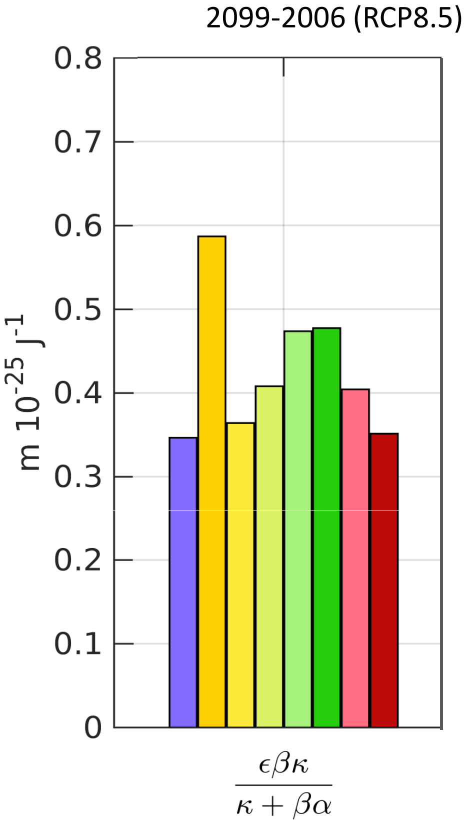


Hold ∫F to its ensemble mean value
Across model spread in μ only

Across model spread in ∫F only
Hold μ to the ensemble mean value

Thermal expansion different across models mostly because they don't have the same transient thermosteric sea level response to climate change

Explaining the spread in climate models spread in GMTSL



Expected from physics:

$$\mu = \varepsilon\, \beta S \frac{\kappa}{\kappa + \beta\alpha}$$

Across model spread in μ because of

spread in ε

spread in β

spread in κ

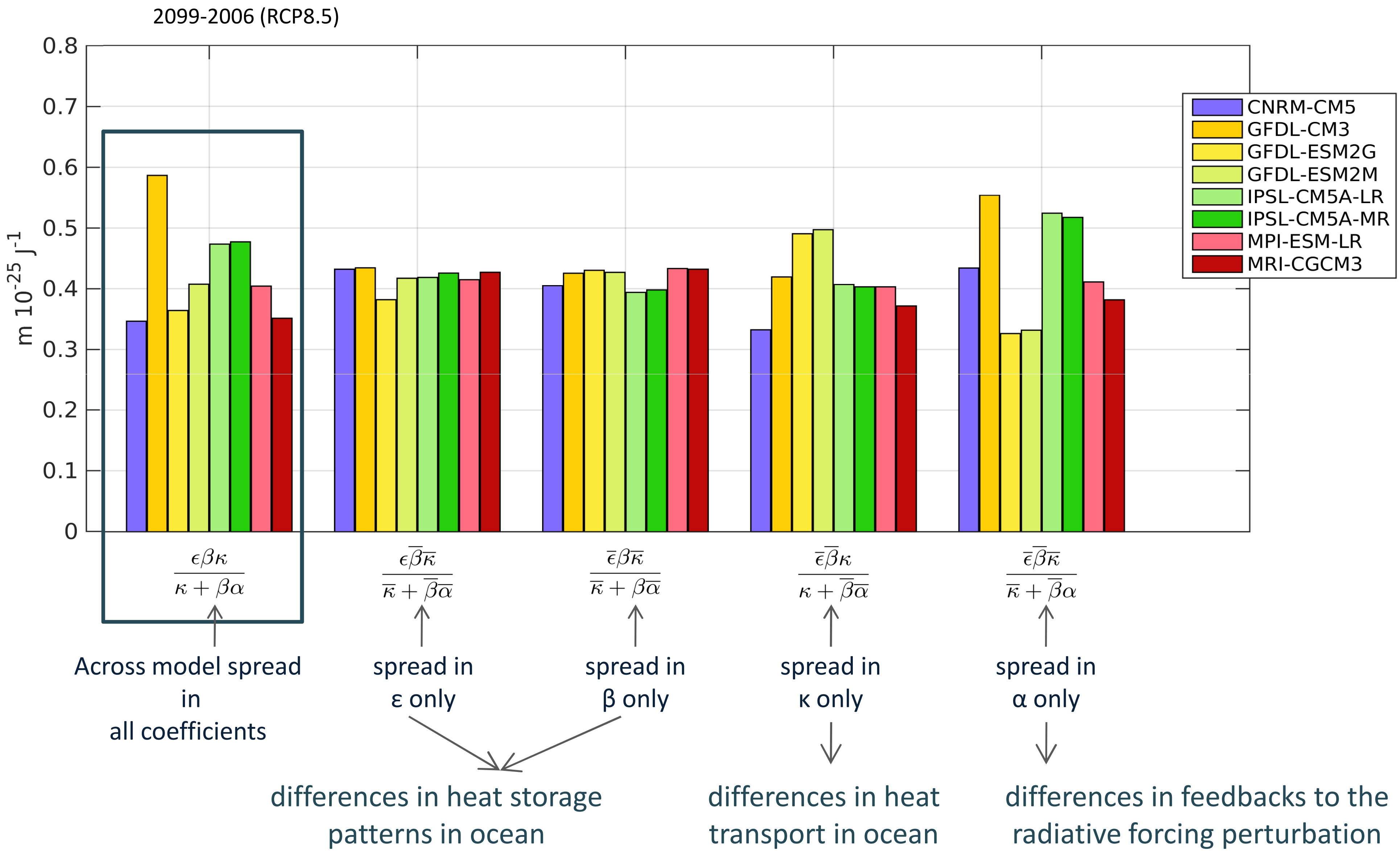
spread in α

differences in heat storage patterns in ocean

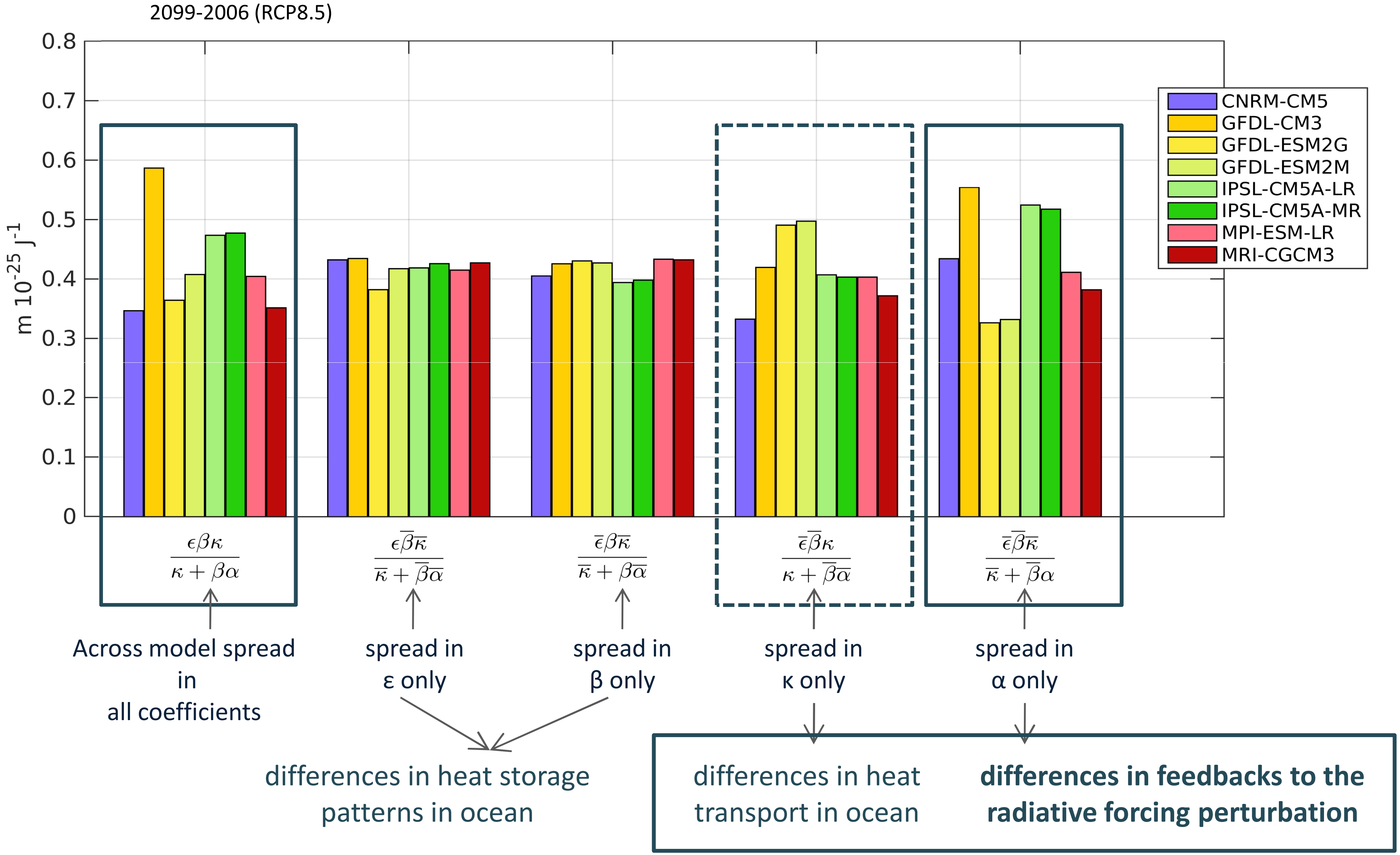
differences in heat transport in ocean

differences in feedbacks to the radiative forcing perturbation

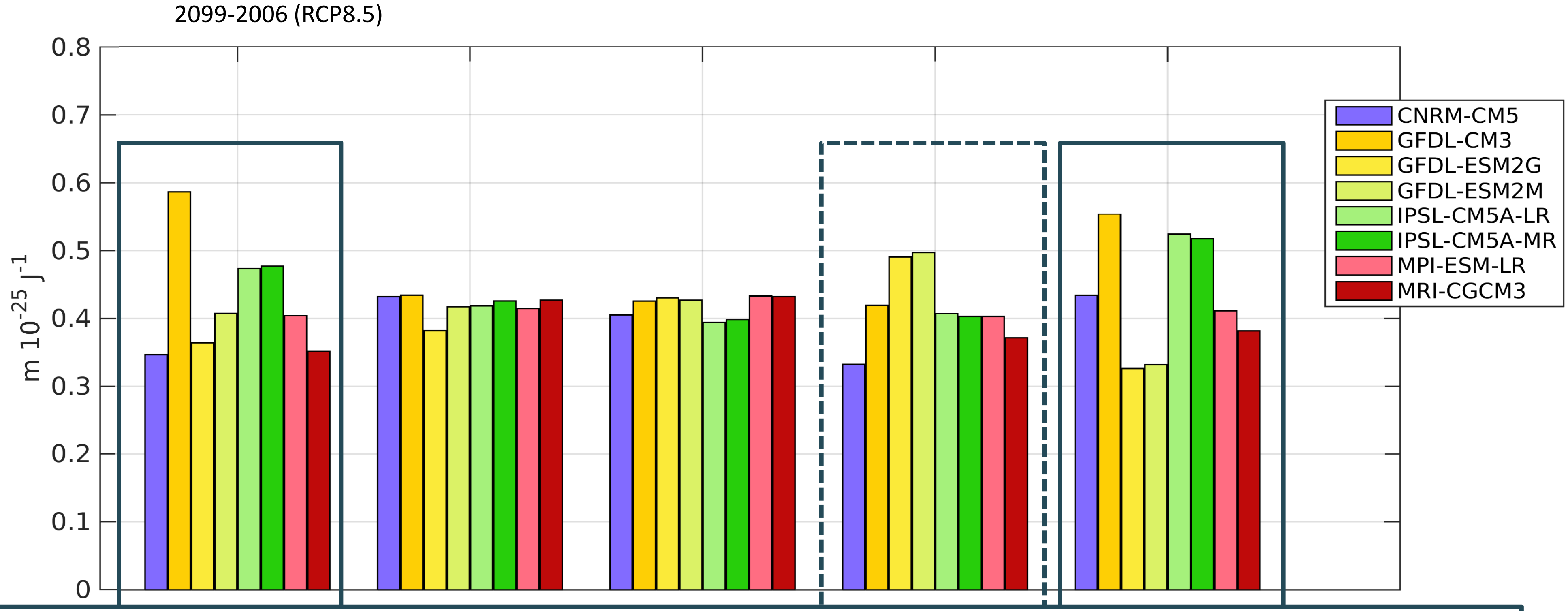
Explaining the spread in climate models spread in GMTSL



Explaining the spread in climate models spread in GMTSL



Explaining the spread in climate models spread in GMTSL



To reduce the spread (or uncertainties) in climate models GMTSL, we have to reduce: the spread due to processes transporting the heat in the ocean (calls for better eddies and vertical diffusion parameterizations)
and the spread due to processes leading to feedbacks of the Earth to radiative forcing peturbation (calls for better representation of cloud physics)

Conclusions

• Under transient climate change, the global mean thermosteric sea level rise linearly depends on the time-integrated radiative forcing at the top-of-the-atmosphere (F).

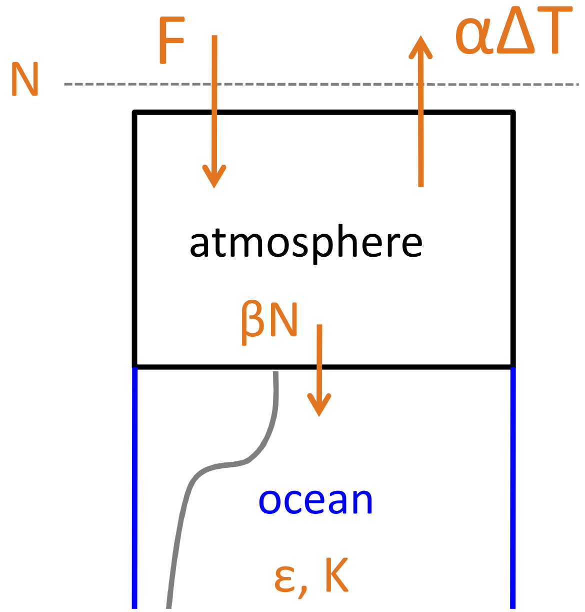
$$\Delta GMTSL = \mu \int F(t)dt = \varepsilon \, \beta S \frac{\kappa}{\kappa + \beta\alpha} \int F(t)dt$$

• The constant of proportionality represents the transient thermosteric sea level response of the climate system.

• μ ~ constant over centennial time-scales
-> knowing μ (from historical simulations) and future F can give a good approximation of next century global mean thermosteric sea level rise !

• The spread in μ across climate models explains most of the spread in global mean thermosteric sea level rise over the 20th and 21st centuries and is mostly due to feedbacks to the radiative forcing perturbation.

• Observational constraint on μ would help reducing uncertainties in ΔGMTSL in climate models.



More in **Melet and Meyssignac, 2015, Journal of Climate**

Relating ΔGMTSL to the radiative forcing

Physics : Increased GOHC induces ocean warming and thermal expansion

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