



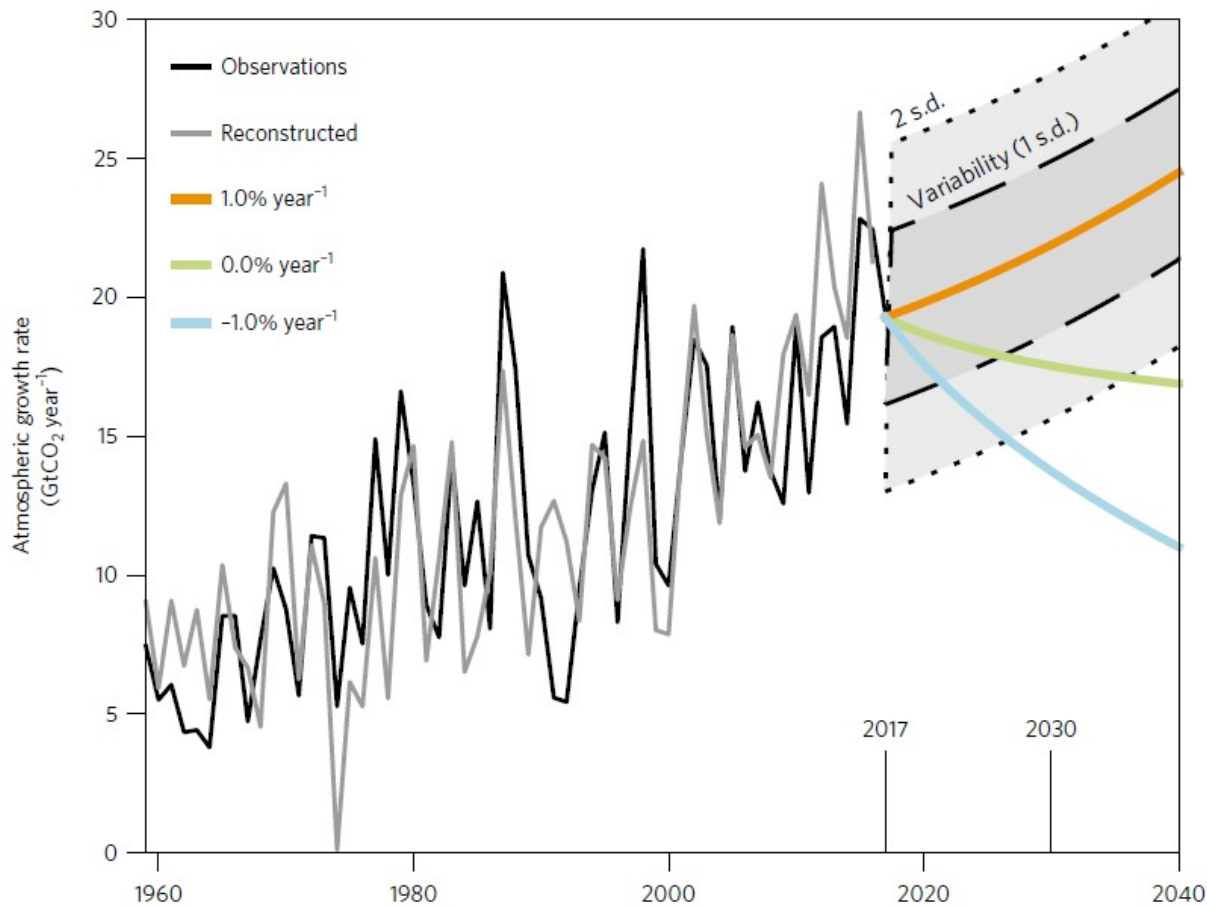
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# The role of ENSO in the interannual variability of the atmospheric CO<sub>2</sub> concentration based on CMIP6 Earth System Models

Verónica Martín-Gómez, Yohan Ruprich-Robert, Raffaele Bernardello, Etienne Tourigny, Markus Donat, Arndt Meier, Valentina Sicardi, Pablo Ortega and Margarida Samsó

# Introduction



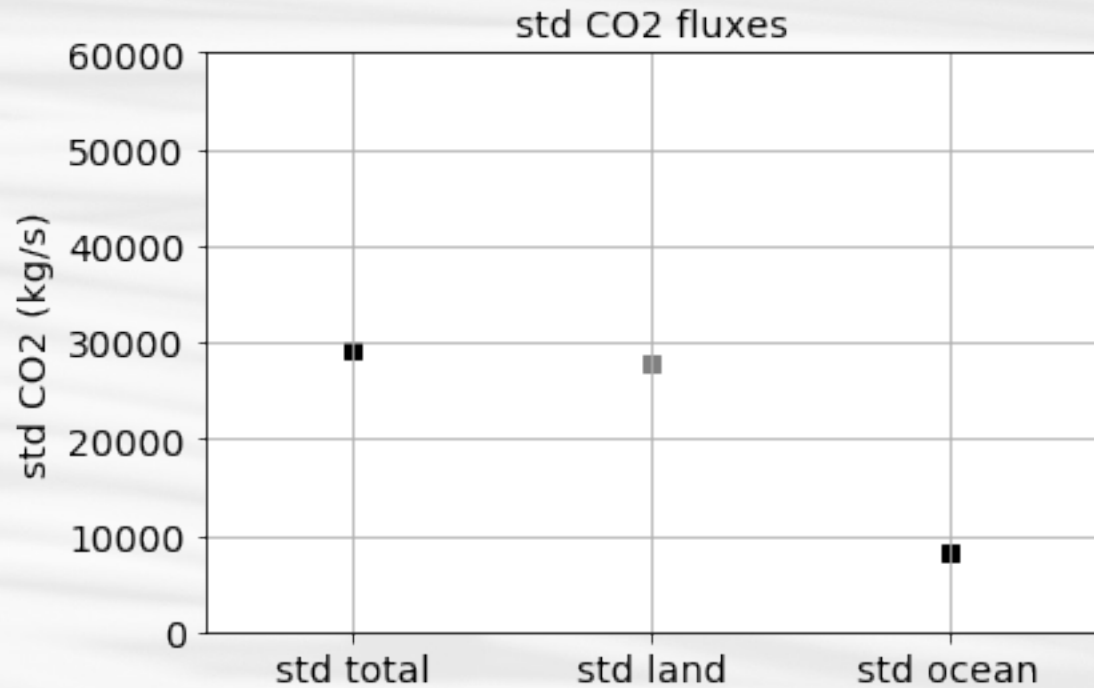
Atmospheric growth rate (Peters et al., 2017)

- Atmospheric growth rate CO<sub>2</sub>
  - Positive trend
  - Large interannual variability
    - Natural processes in the Earth System (main reason)
    - Changes in the anthropogenic CO<sub>2</sub> emissions (small)
- Mismatch between reconstruction and observations
  - Related to natural processes that changes CO<sub>2</sub> in atm
  - $\text{std}(\text{observations} - \text{reconstruction}) \rightarrow$  uncertainty interval.
- Paris Agreement 2015:  
*Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels.*
- Ability to verify global CO<sub>2</sub> emissions: number of years required to detect a change in the trend of the atm CO<sub>2</sub> concentration
- Improve ability verifying global CO<sub>2</sub> emissions  $\rightarrow$  reduce the uncertainty interval by improving the understanding of the:
  - Internal variability of the the atm CO<sub>2</sub> concentration
  - Origin of the uncertainties

# Objectives

- Internal variability of the atmospheric CO<sub>2</sub> concentration is driven by the CO<sub>2</sub> fluxes over the land and ocean
- Analyze the internal variability of the atmospheric CO<sub>2</sub> concentration understanding:
  - the relative role of the CO<sub>2</sub> fluxes over the land and ocean on the atmospheric CO<sub>2</sub> concentration.  
Which one of these two is the most important triggering natural changes in the atmospheric CO<sub>2</sub> concentration?
  - the main drivers for this internal variability
  - the origin of the uncertainties of the CO<sub>2</sub> fluxes in CMIP6 models
- We consider the piControl CMIP6-ESMs for which all variables are available (22 models in total)

# Variability CO2 fluxes in observations

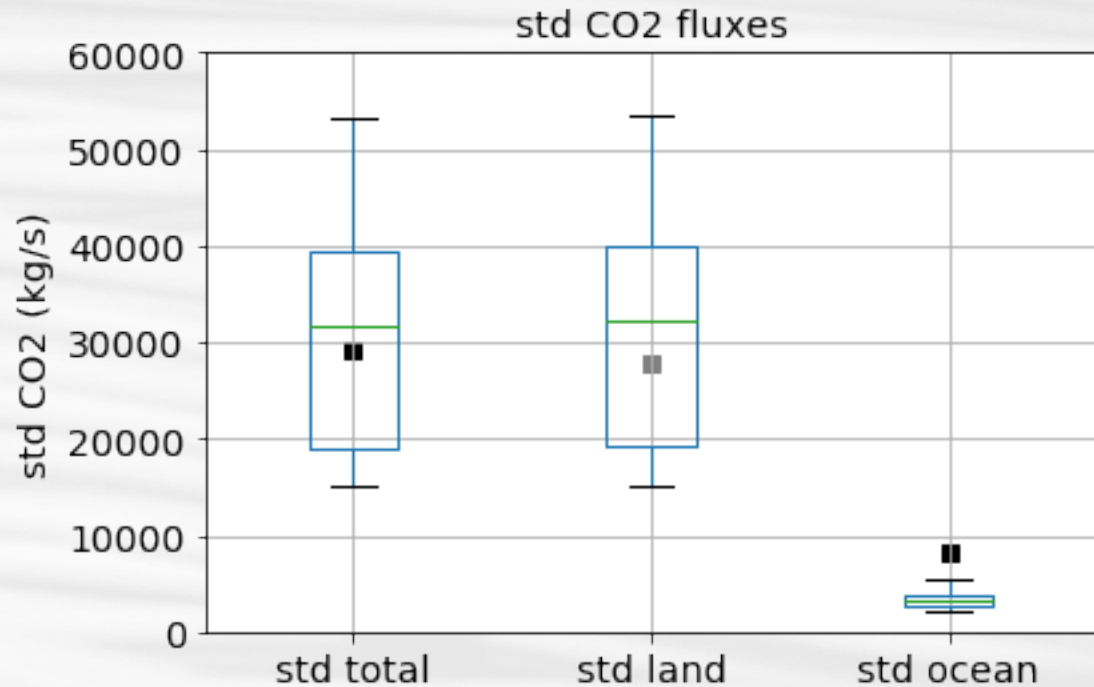


Black point: direct observed co2 flux  
Grey point: estimated co2 flux

**In observations, main contributor to the natural variations in the atmospheric CO2 concentration are the global land CO2 fluxes**

Std total estimated from observed atmospheric CO2 growth rate from NOAA  
Std ocean observed CO2 flux from Landschuetzer

# Variability CO2 fluxes in CMIP6 piControl



Black point: direct observed co2 flux

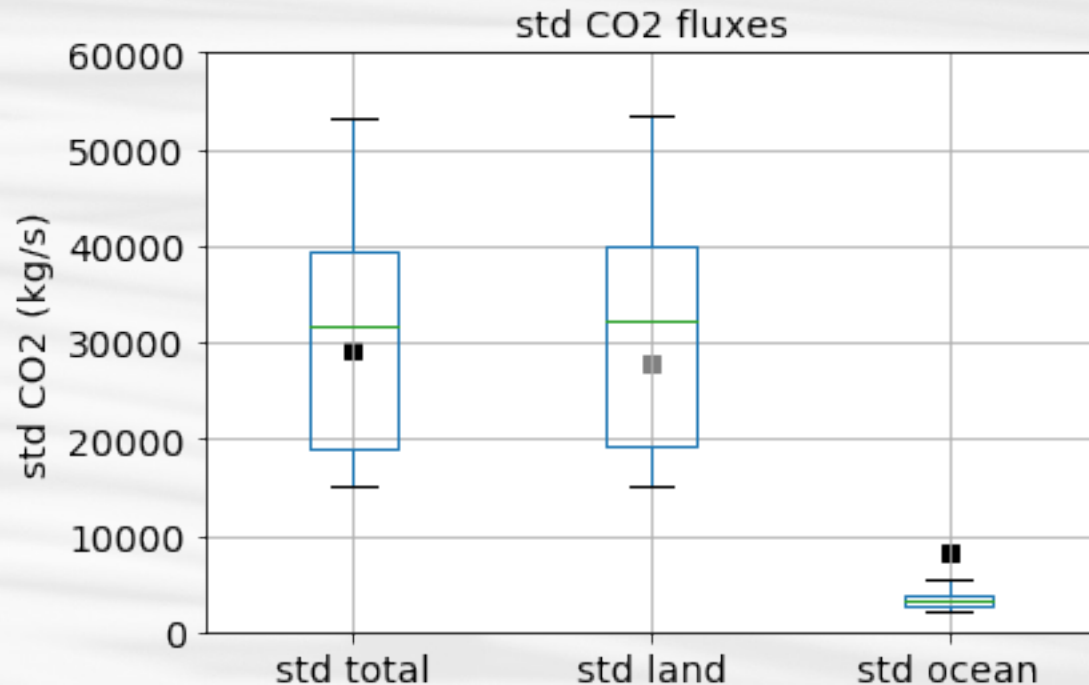
Grey point: estimated co2 flux

Boxplot: results from piControl CMIP6-ESMs

- **CMIP6-ESMs reproduce this observed relative contribution of the ocean and land in the total CO2 fluxes, however there is a large spread in the variability of the total CO2 fluxes coming mainly from the land part fluxes.**

- **Models underestimate the variability of the global CO2 fluxes over ocean.**

# Variability CO2 fluxes in CMIP6 piControl



Black point: direct observed co2 flux  
Grey point: estimated co2 flux  
Boxplot: results from piControl CMIP6-ESMs

- **CMIP6-ESMs reproduce this observed relative contribution of the ocean and land in the total CO2 fluxes, however there is a large spread in the variability of the total CO2 fluxes coming mainly from the land part fluxes.**

- **Models underestimate the variability of the global CO2 fluxes over ocean.**

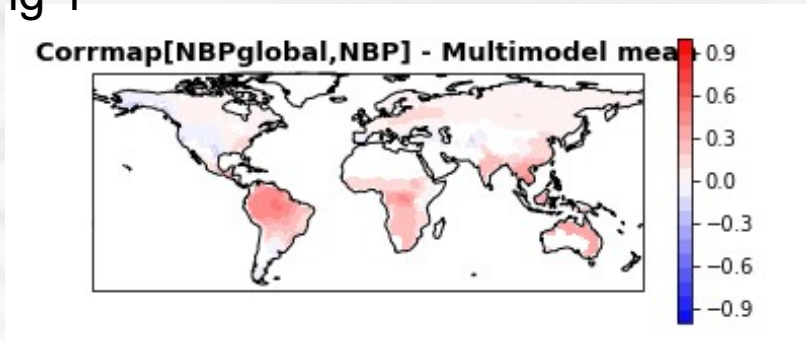
**Focusing on the main source of CO2 variability in the atmosphere (land CO2 fluxes):**

- (1) Is there any potential predictor which could drive the variability in CO2 fluxes over land?**
- (2) From where is coming the large uncertainty in models?**

# Variability CO2 fluxes in CMIP6 piControl

Main regions contributing the most to this Co2 fluxes over land

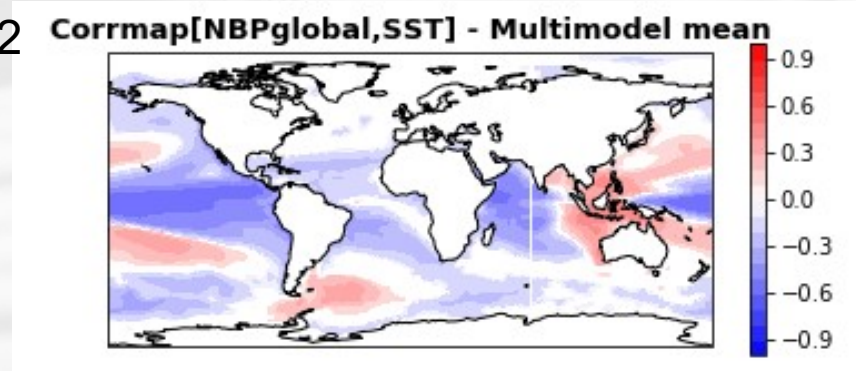
Fig 1



corrmap(global land CO2 fluxes, CO2 fluxes land)  
Multimodel mean

(1) Is there any potential predictor which could drive the variability in the CO2 fluxes over the land?

Fig2



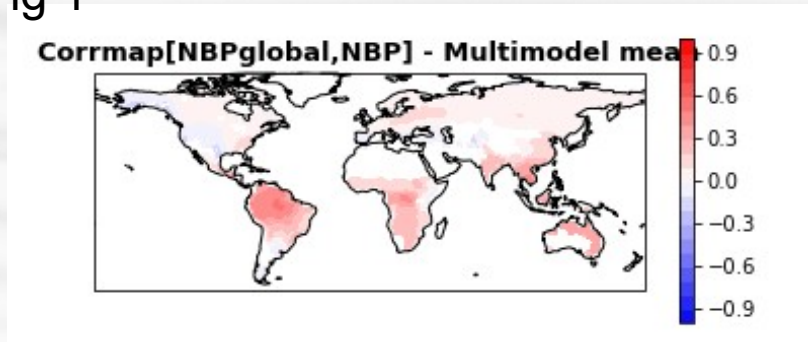
corrmap(global land Co2 fluxes, SST)  
Multimodel mean

**ENSO main driver of the global land CO2 fluxes in models**

# Variability CO2 fluxes in CMIP6 piControl

Main regions contributing the most to this Co2 fluxes over land

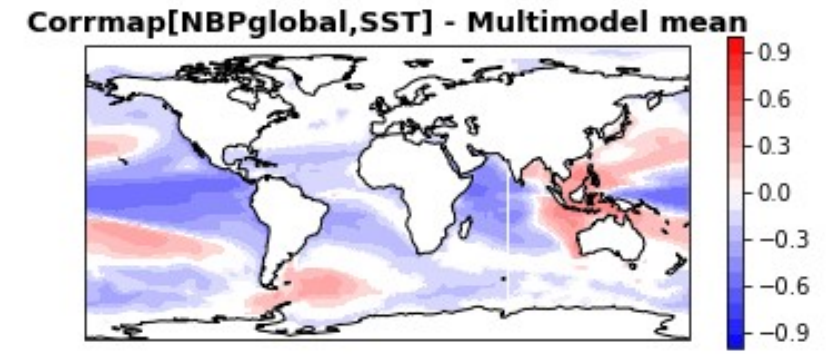
Fig 1



corrmap(global land CO2 fluxes, CO2 fluxes land)  
Multimodel mean

(1) Is there any potential driver of the CO2 fluxes over the land?

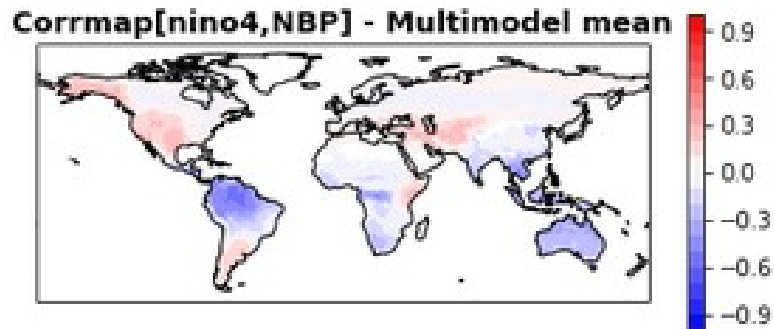
Fig2



corrmap(global land Co2 fluxes. SST)  
Multimodel mean

## Influence of ENSO on the CO2 fluxes over land

Fig 3



corrmap(Nino4, CO2 fluxes land)  
Multimodel mean

Fig 4

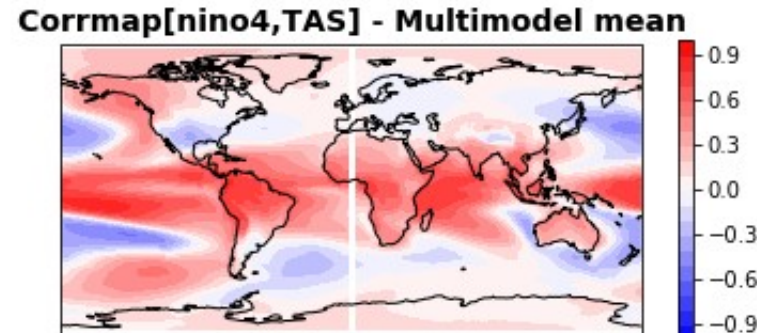
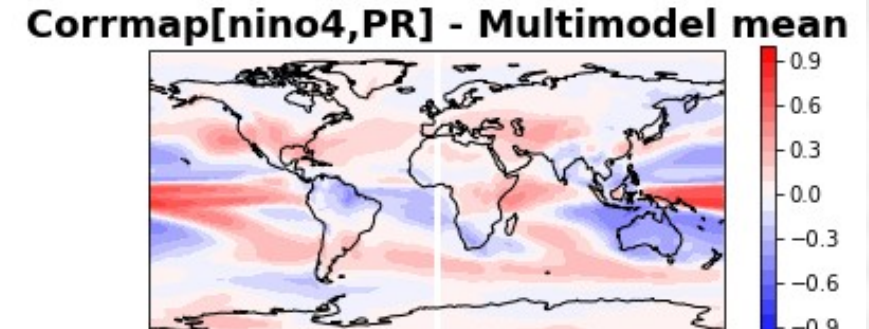


Fig 5

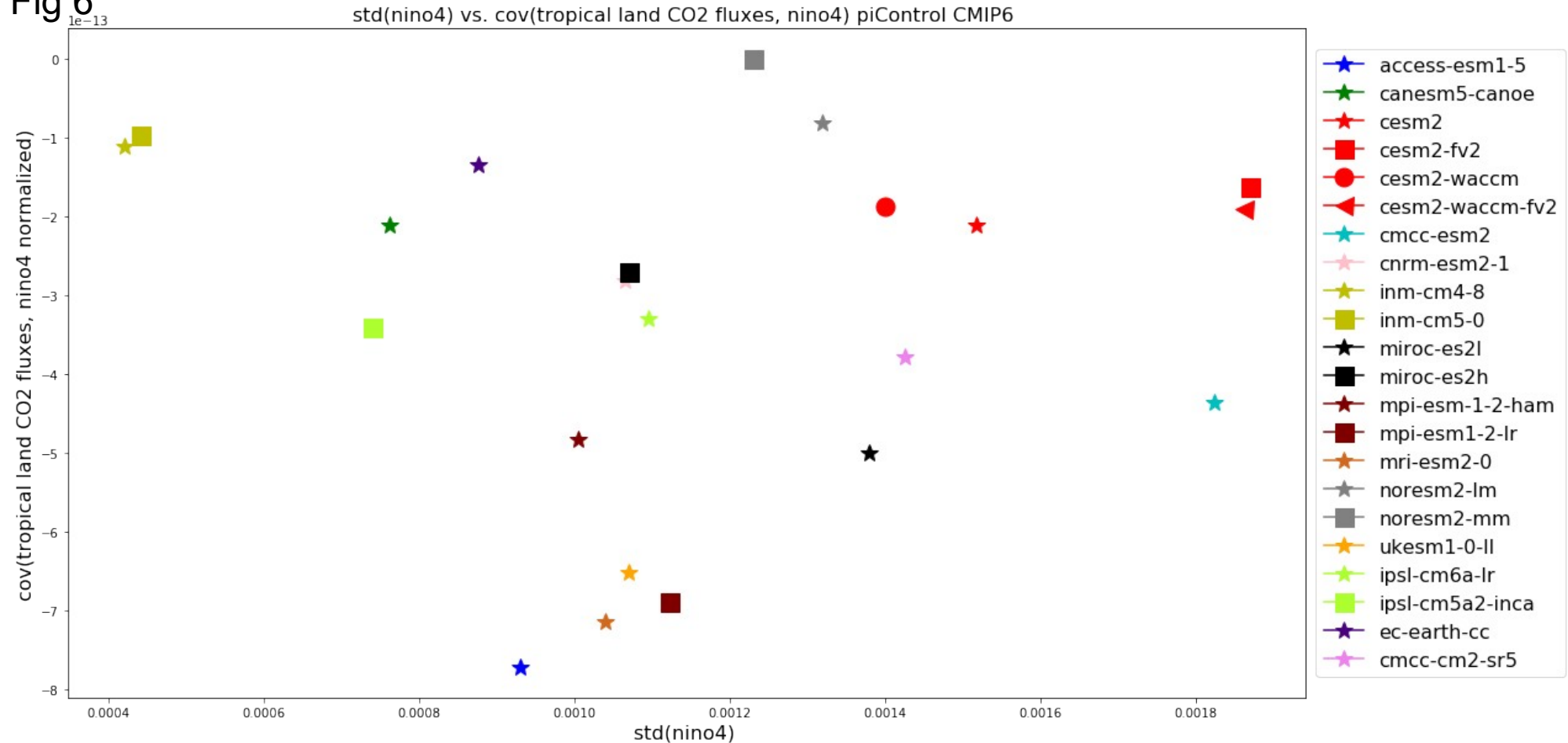




# Uncertainty in the ENSO impacts on the land CO2 fluxes

## Covar(CO2 land fluxes, nino4) vs. std(nino4)

Fig 6



Large intermodel uncertainty from:

- Different ENSO patterns in models
- Different ENSO teleconnections in models
- Different land vegetation models

# Origin of the uncertainty in cmip6 models

Fig 7

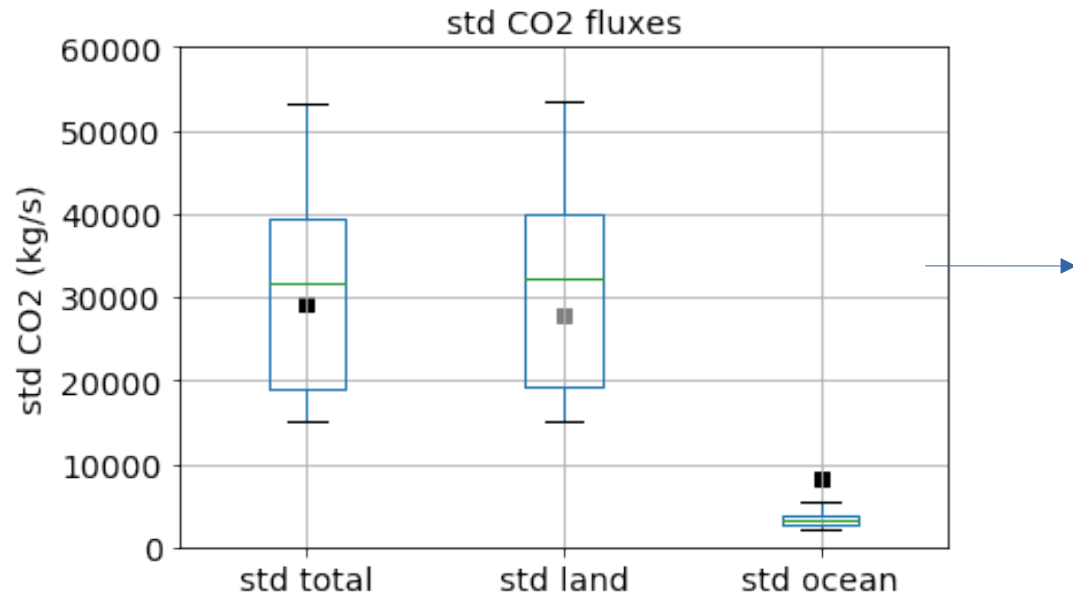
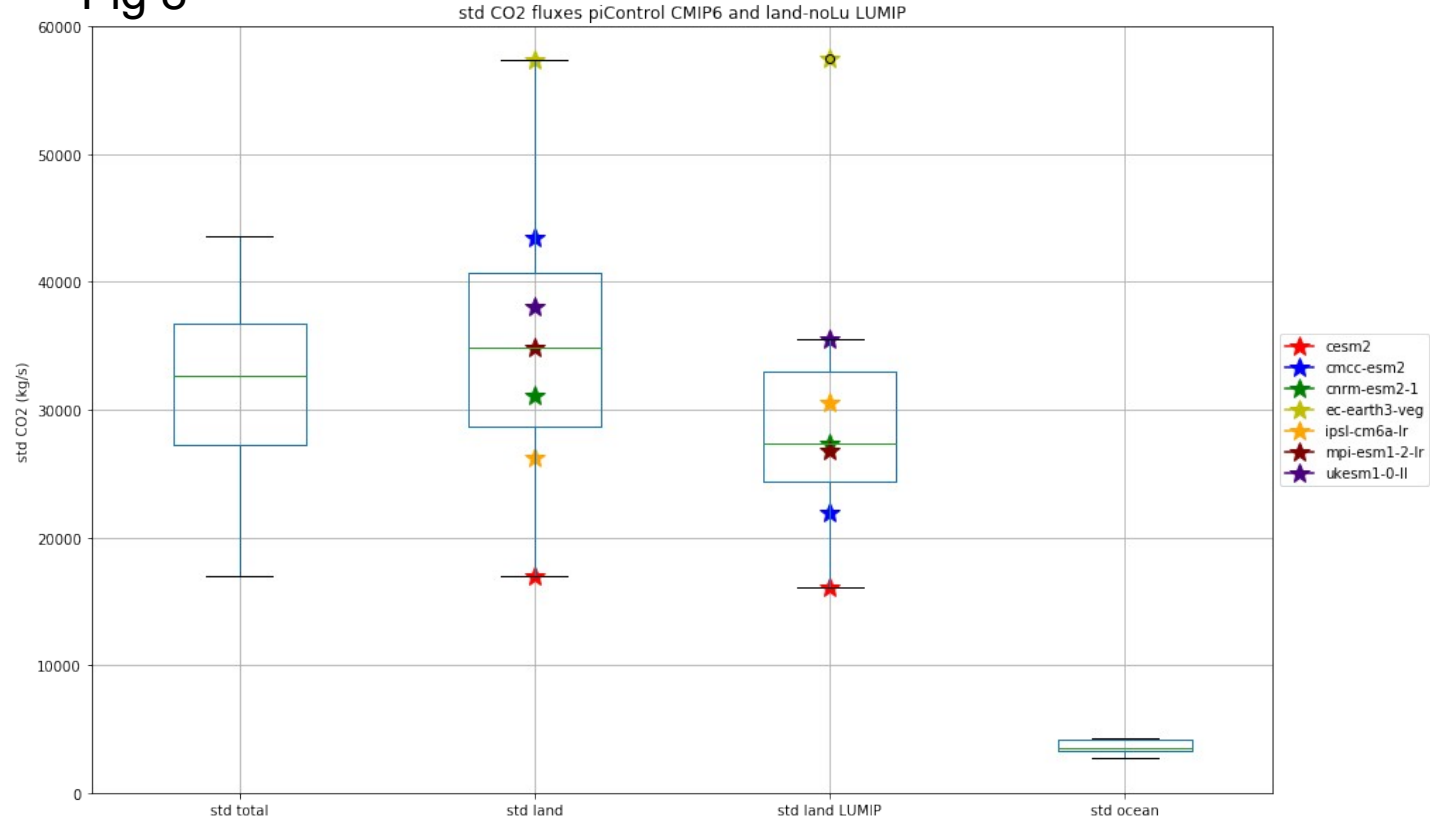


Fig 8



Main intermodel uncertainty is coming from land vegetation models

# General conclusions

- The main source of internal variability of the atmospheric CO<sub>2</sub> concentration comes from global land CO<sub>2</sub> fluxes (tropical areas)
- CMIP6 models reproduce this observed behavior
- For all models, ENSO is main driver of the interannual variability of the global land CO<sub>2</sub> fluxes although there is a large uncertainty in the land CO<sub>2</sub> fluxes response to ENSO
- Main intermodel uncertainty is coming from land vegetation models
- **We need to improve the land vegetation models in order to**
  - **Better constrain the reconstructions of CO<sub>2</sub> → reduce the uncertainty interval**
  - **Have robust estimation of the natural changes in the atmospheric CO<sub>2</sub> growth rate and be able to attribute the changes in the atmospheric growth rate to mitigation measures or natural processes**

# Thank you!

[veronica.martin@bsc.es](mailto:veronica.martin@bsc.es)

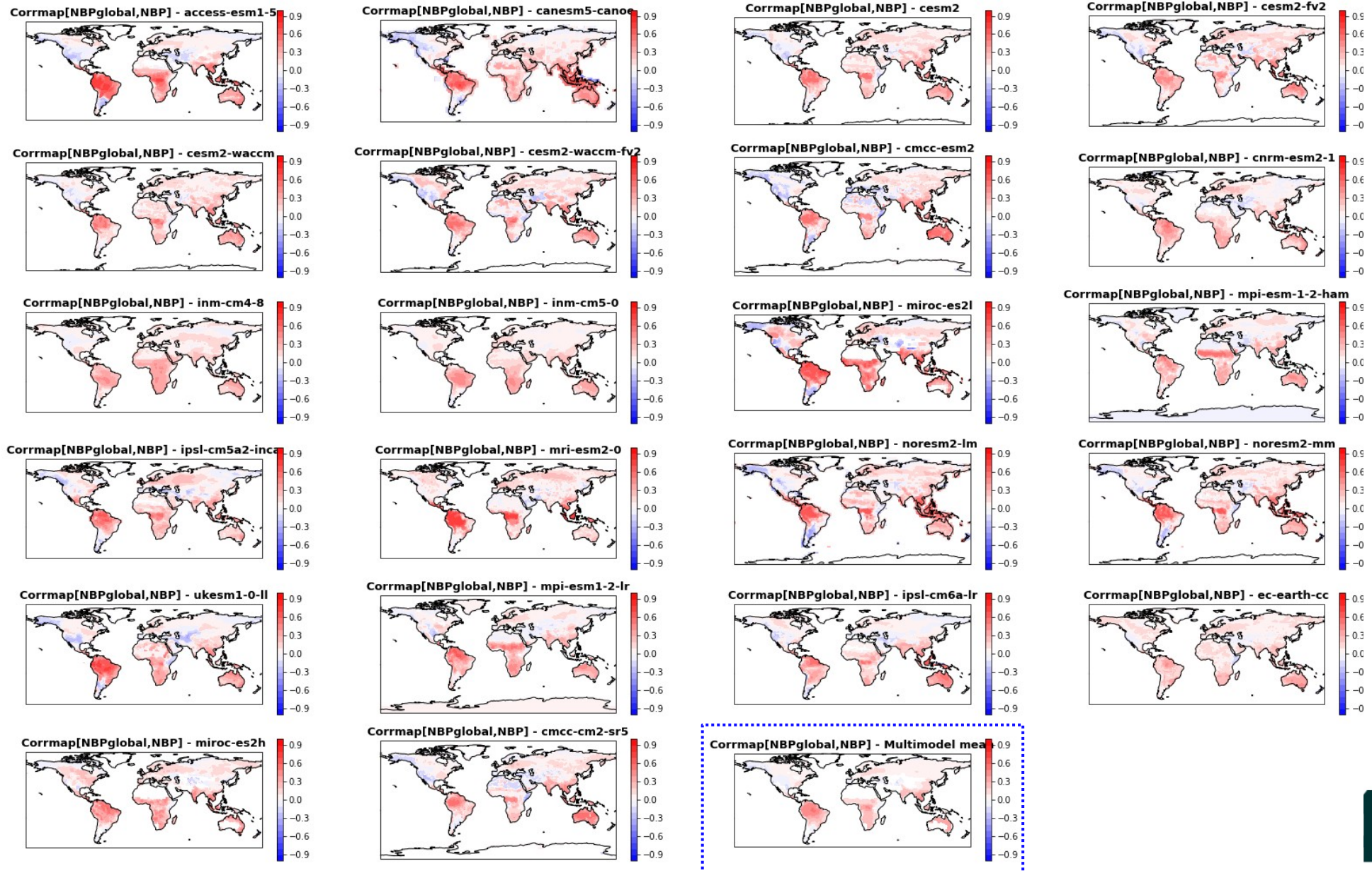


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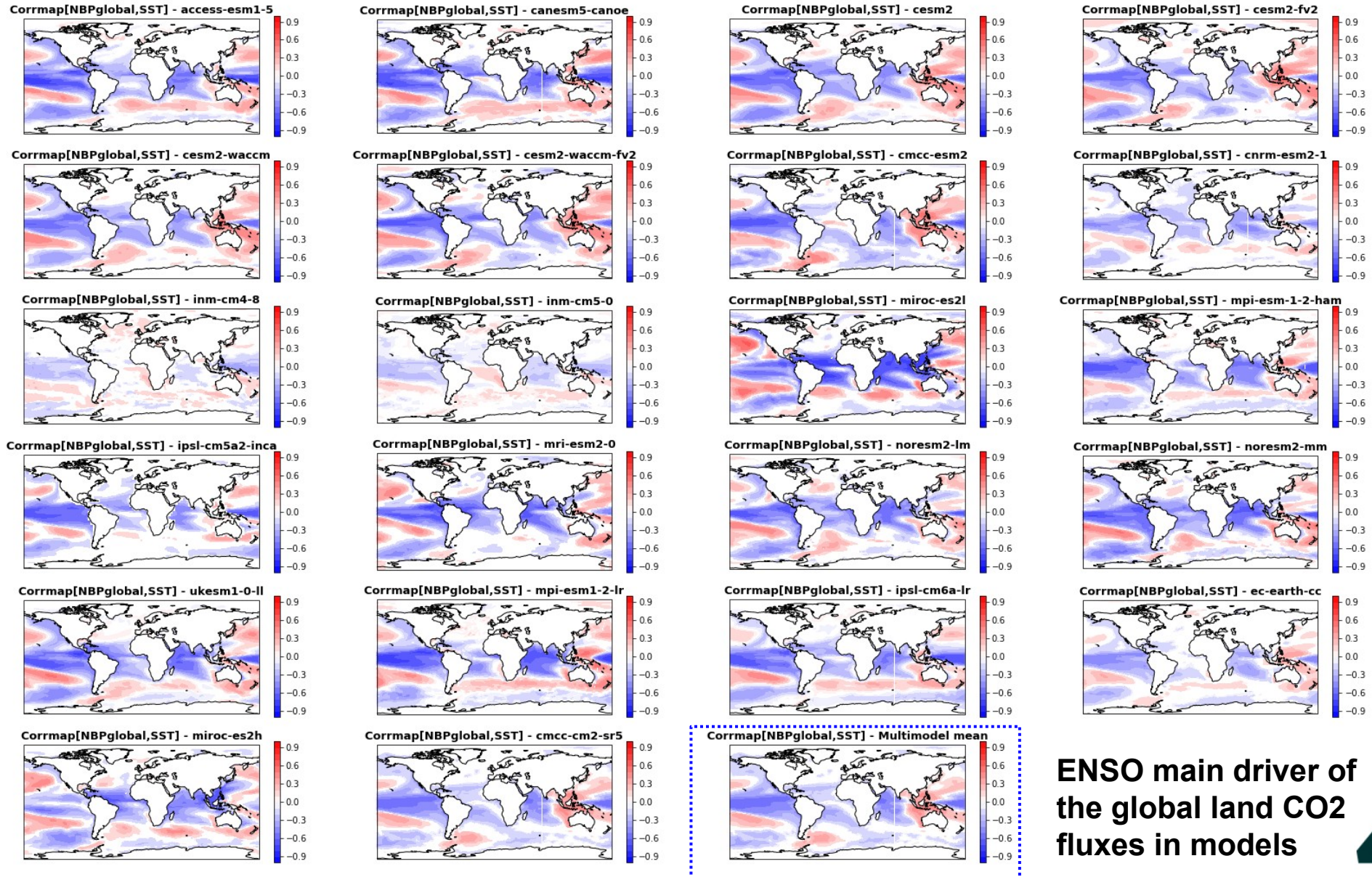
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# (1) Which are the main regions contributing the most to the global land CO2 fluxes?



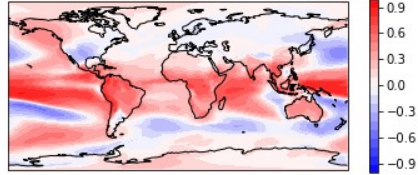
# (2) Is there any potential driver for the land CO2 fluxes?



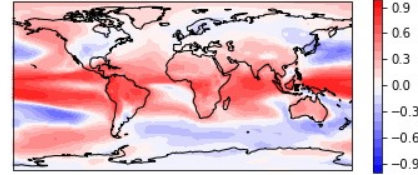
**ENSO main driver of the global land CO2 fluxes in models**

# Correlation maps (nino4, TAS)

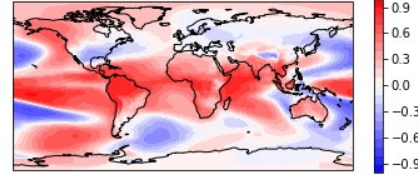
Corrmap[nino4,TAS] - access-esm1-5\*



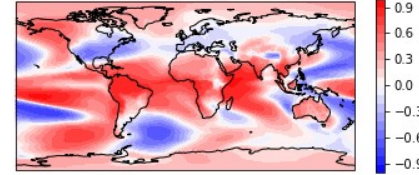
Corrmap[nino4,TAS] - canesm5-canoe\*



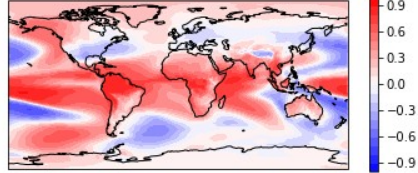
Corrmap[nino4,TAS] - cesm2



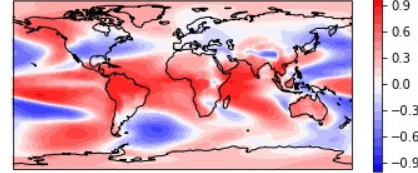
Corrmap[nino4,TAS] - cesm2-fv2



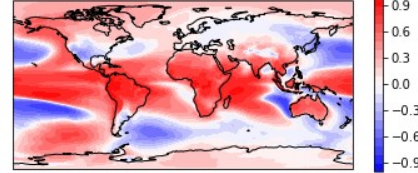
Corrmap[nino4,TAS] - cesm2-waccm



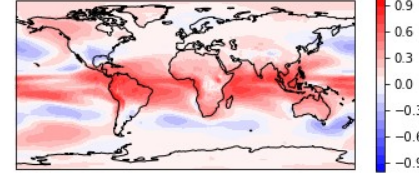
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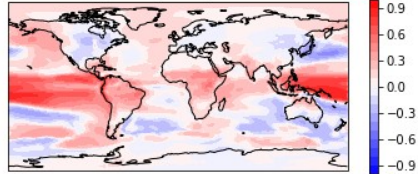
Corrmap[nino4,TAS] - cmcc-esm2



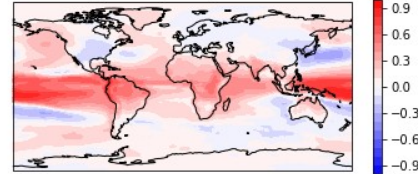
Corrmap[nino4,TAS] - cnrm-esm2-1



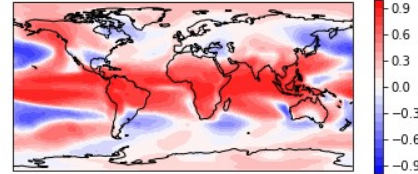
Corrmap[nino4,TAS] - inm-cm4-8\*



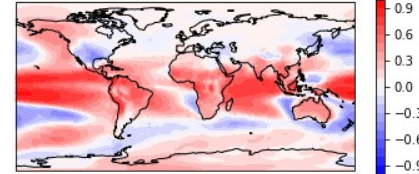
Corrmap[nino4,TAS] - inm-cm5-0\*



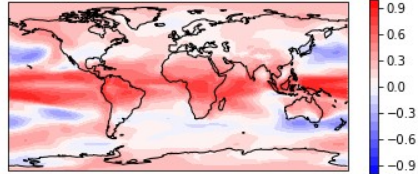
Corrmap[nino4,TAS] - miroc-es2l\*



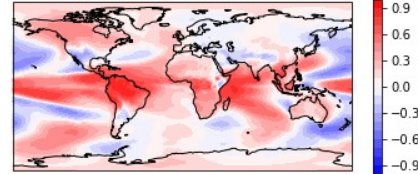
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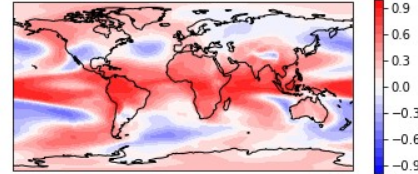
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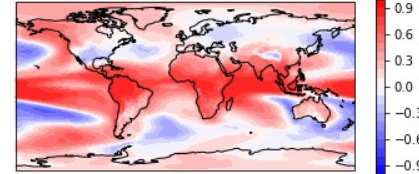
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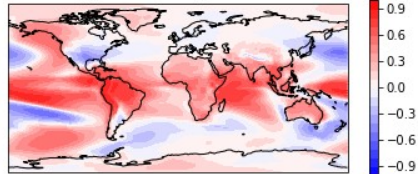
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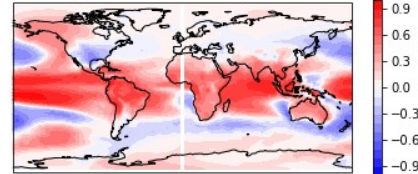
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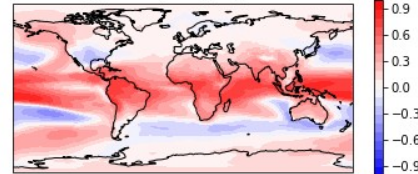
Corrmap[nino4,TAS] - ukesm1-0-ll\*



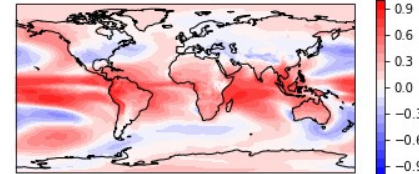
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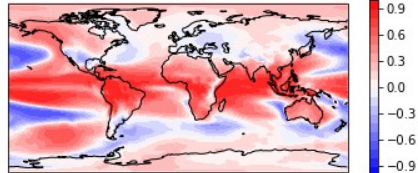
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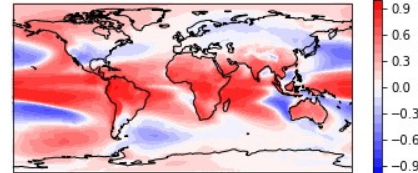
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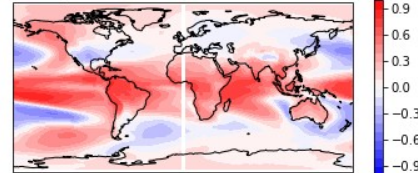
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Corrmap[nino4,TAS] - cmcc-cm2-sr5\*

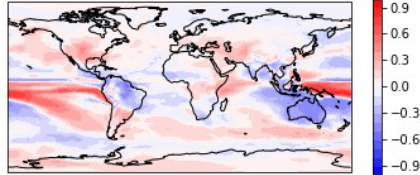


Corrmap[nino4,TAS] - Multimodel mean

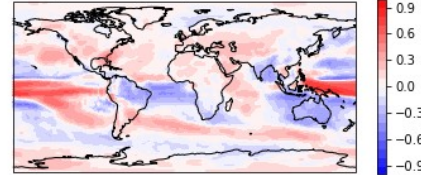


# Correlation maps (nino4, Precipitation)

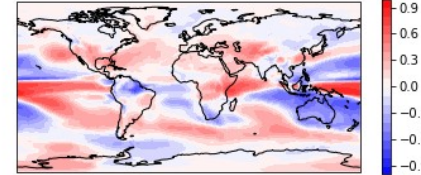
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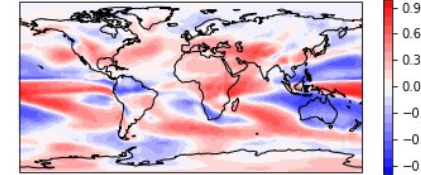
Corrmap[nino4,PR] - canesm5-canoe\*



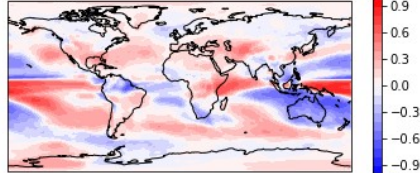
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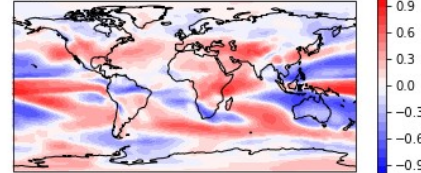
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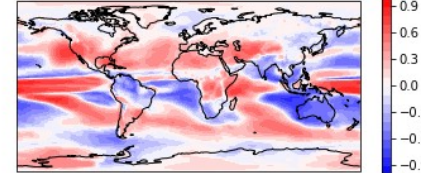
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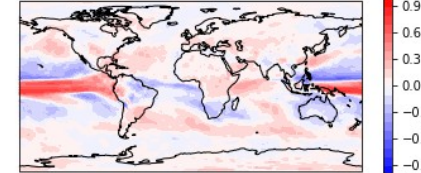
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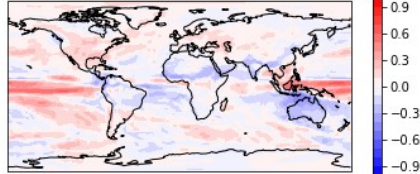
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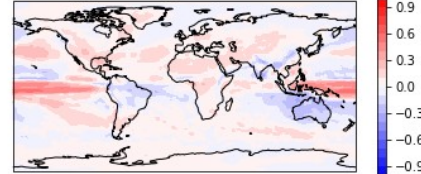
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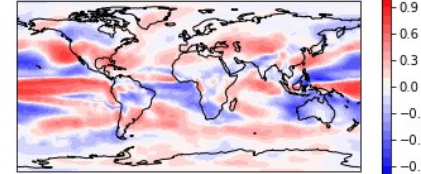
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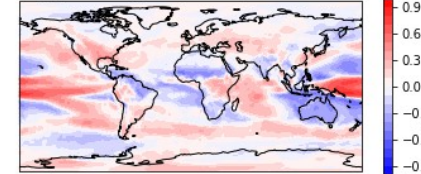
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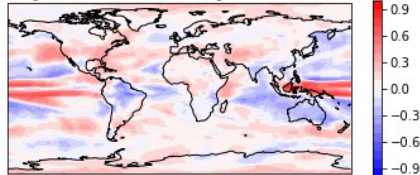
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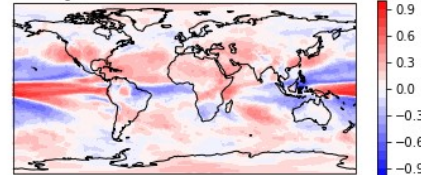
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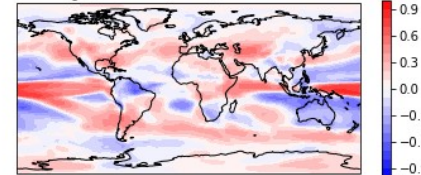
Corrmap[nino4,PR] - ipsl-cm5a2-inca\*



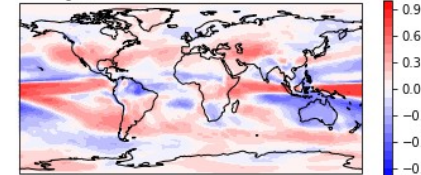
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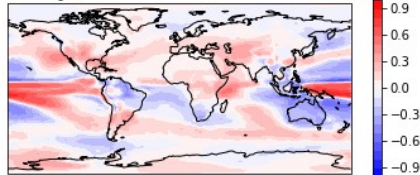
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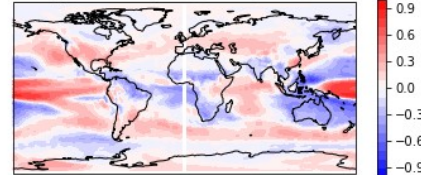
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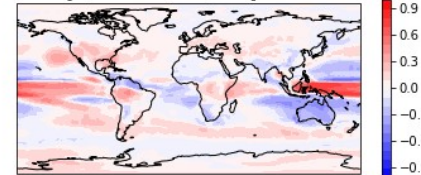
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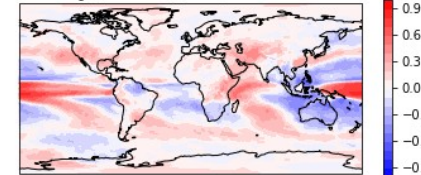
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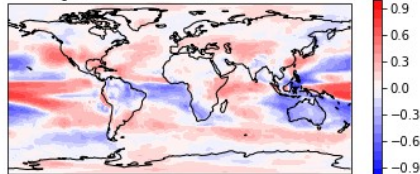
Corrmap[nino4,PR] - ipsl-cm6a-lr\*



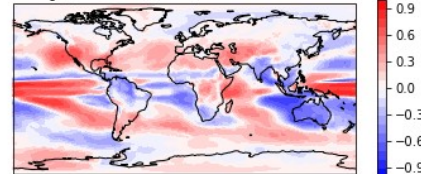
Corrmap[nino4,PR] - ec-earth-cc



Corrmap[nino4,PR] - miroc-es2h\*



Corrmap[nino4,PR] - cmcc-cm2-sr5\*



Corrmap[nino4,PR] - Multimodel mean

