Ensemble approaches to enhance climate prediction

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Francois Counillon, Mao-Lin Shen, Francine Schevenhoven, Shuo Wang, Shunya Koseki, Gregory Duane, and many others

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Hybrid Workshop on Societally-Relevant Multi-Year Climate Agenda, March 29, 2022

Persistent model biases

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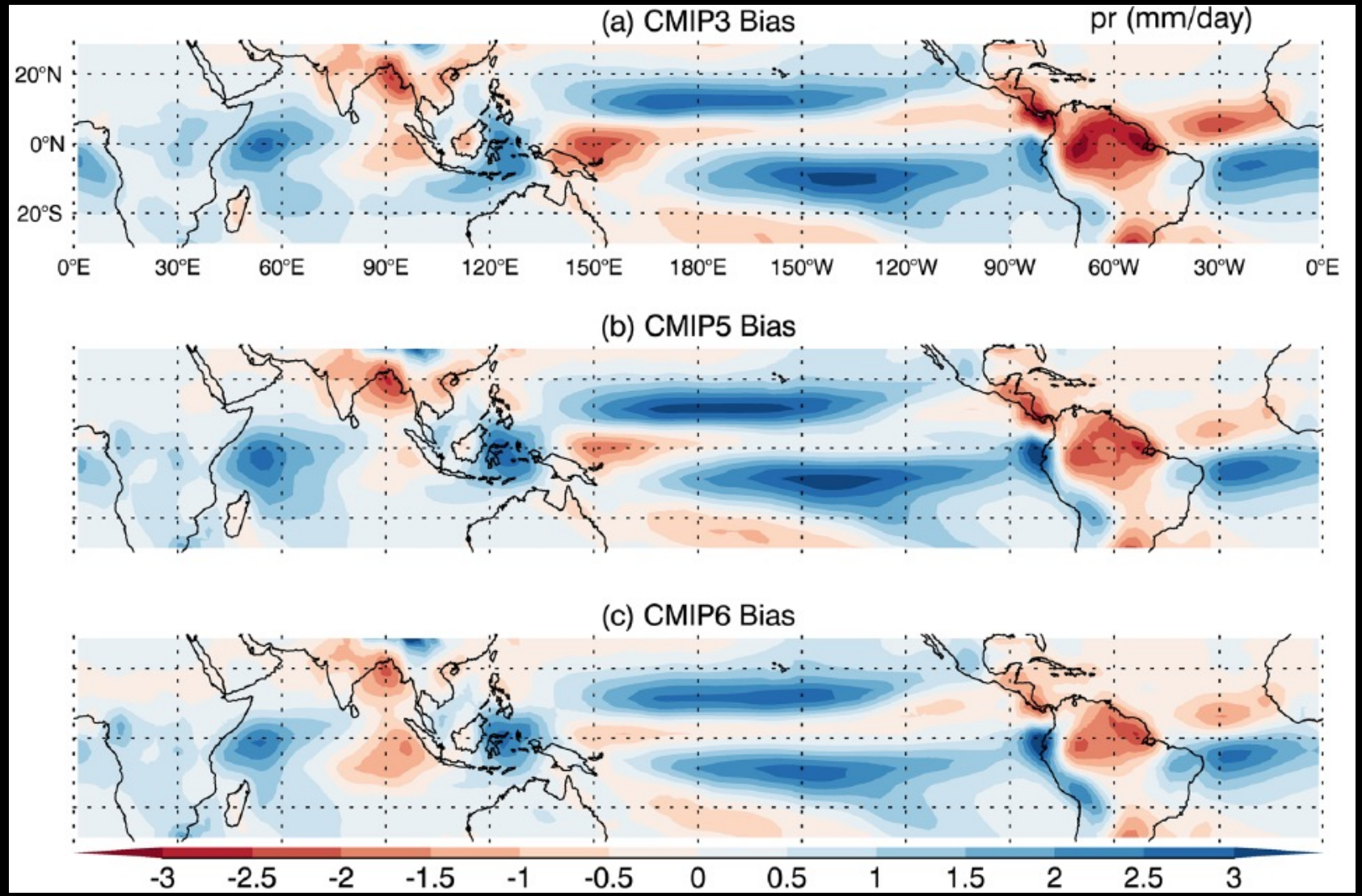
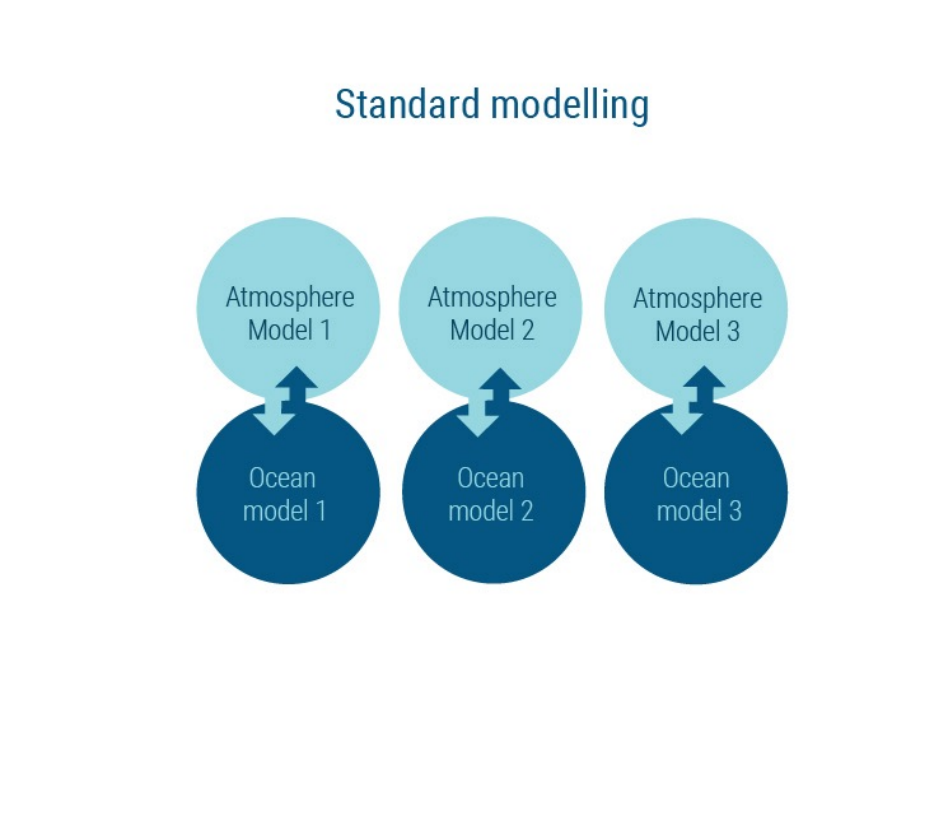
Multi-model precipitation biases across model generations



Tian & Dong 2020

Bias is often larger than the signal we analyze or predict

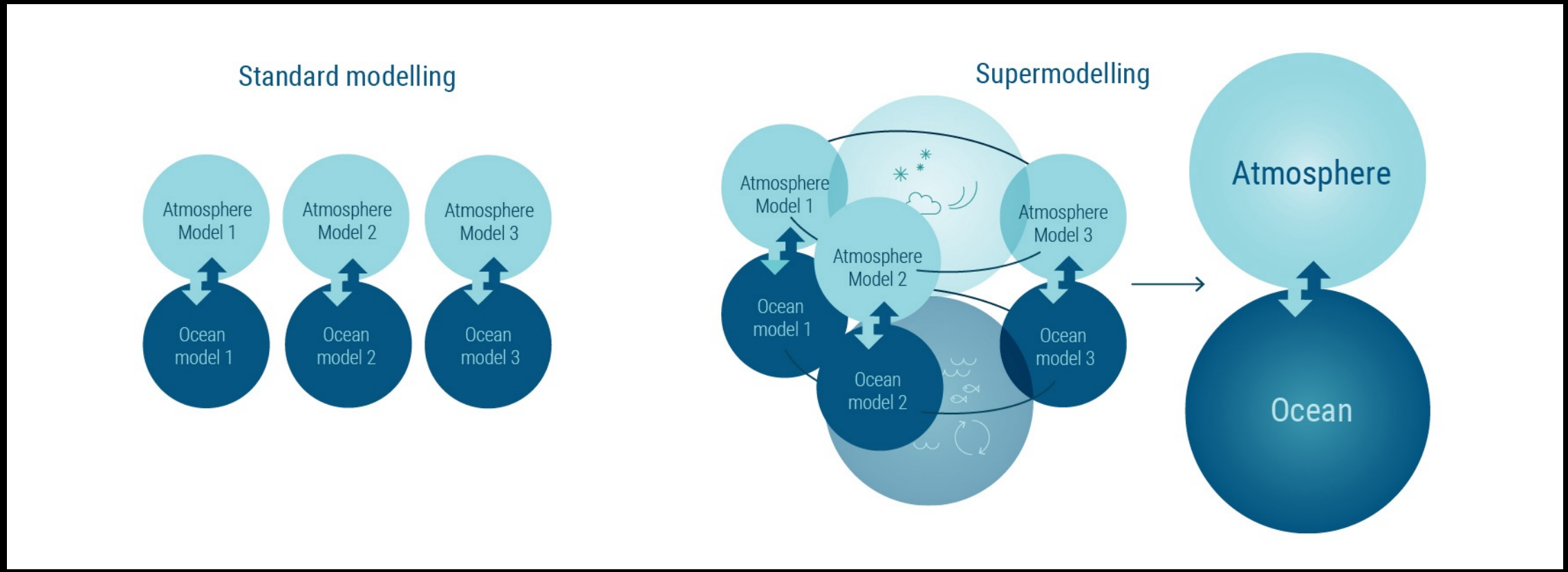
Standard approaches to deal with model error – unconnected multi-model ensemble



Long-term strategy – improve models to represent key processes, through e.g., increasing resolution

Current practical solution – combine outputs of different models in large-ensembles

A smarter ensemble approach – the supermodel

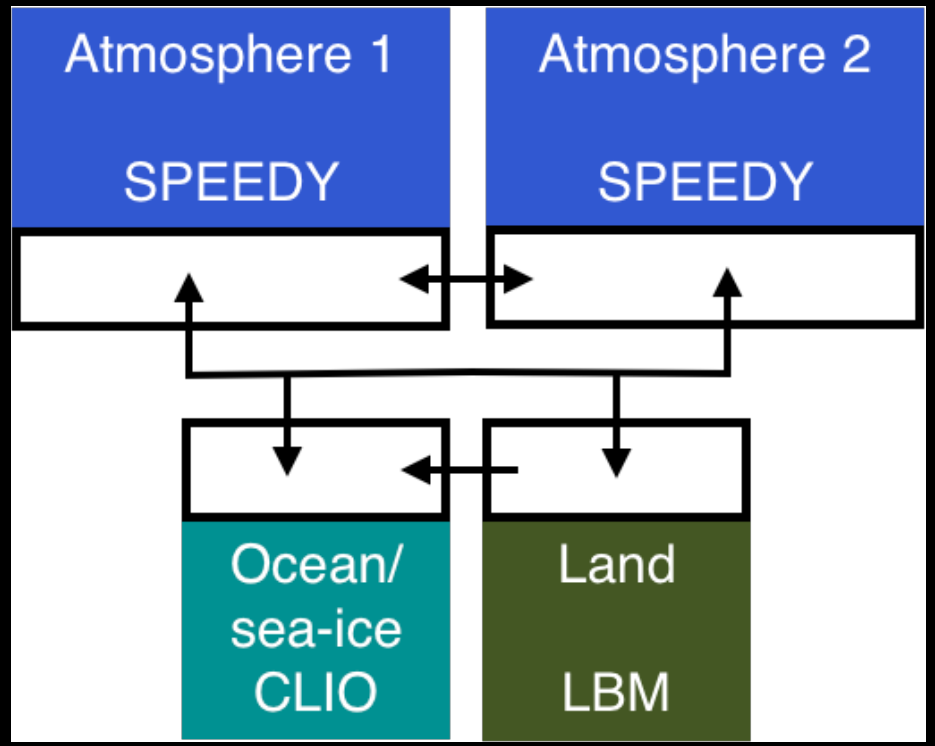


A supermodel is an optimal dynamical combination of models that is superior to its individual constituent models

Two different supermodel implementations

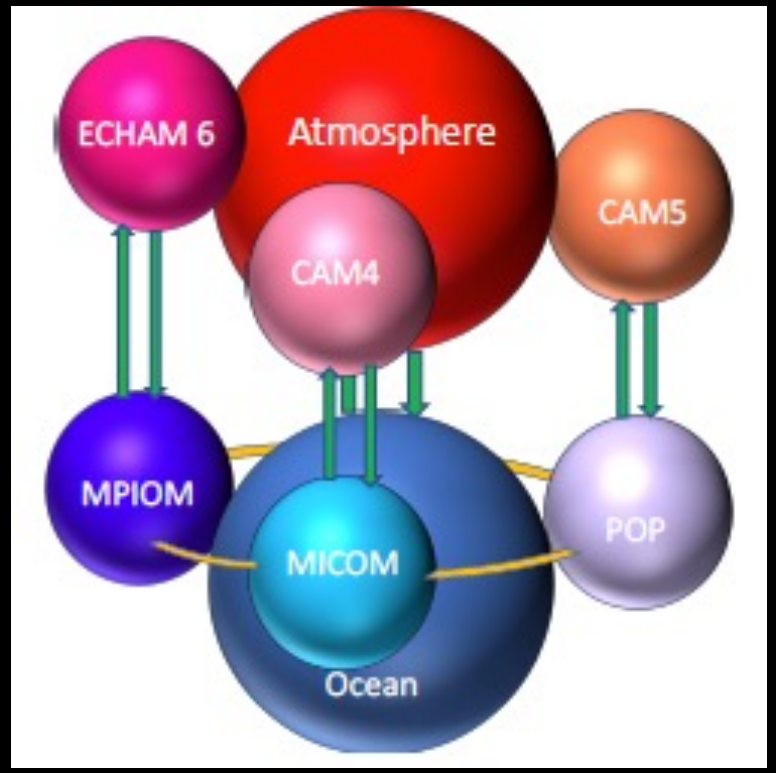
Multiple “imperfect” models are connected via atmospheric components and trained to reproduce a “true” model

Based on the SPEEDO intermediate climate model



Schevenhoven et al. 2019

Three state-of-the-art ESM are connected via ocean components and trained to reproduce observations



Counillon et al. in prep.

Supermodel improves weather forecasts

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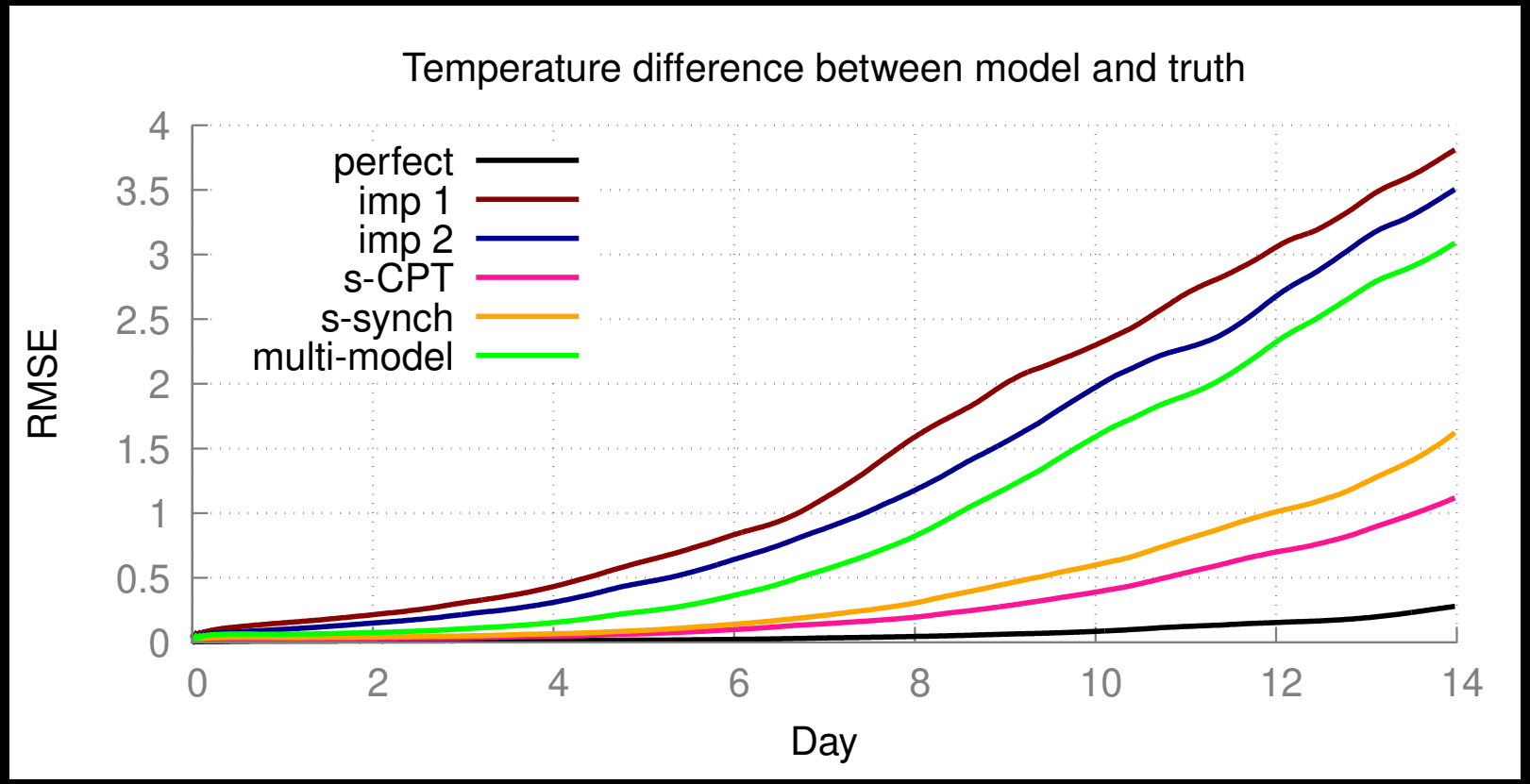
Results from intermediate complexity GCM super model
SPEEDO model with horizontal resolution of 3.75º

RMSE for 2-week forecasts of surface temperature, 25 forecasts

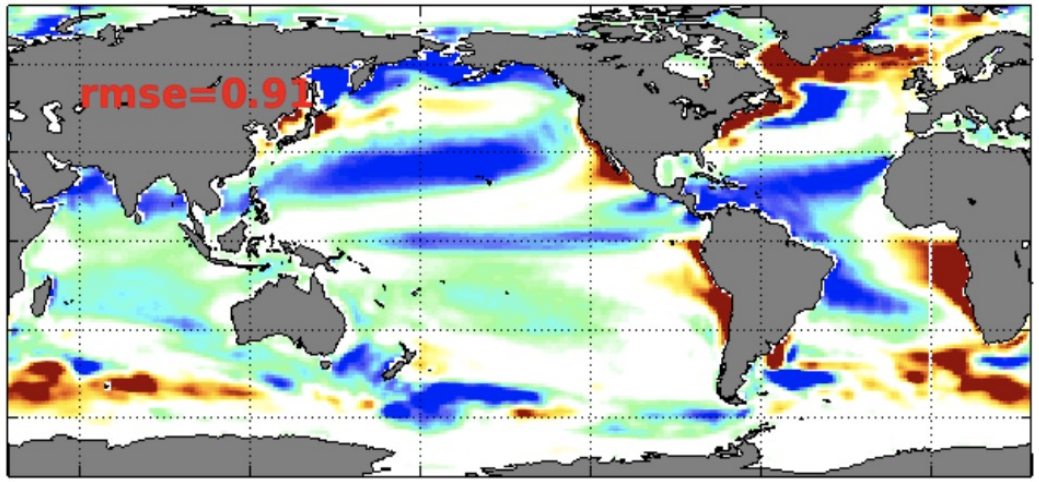


Schevenhoven et al. 2019

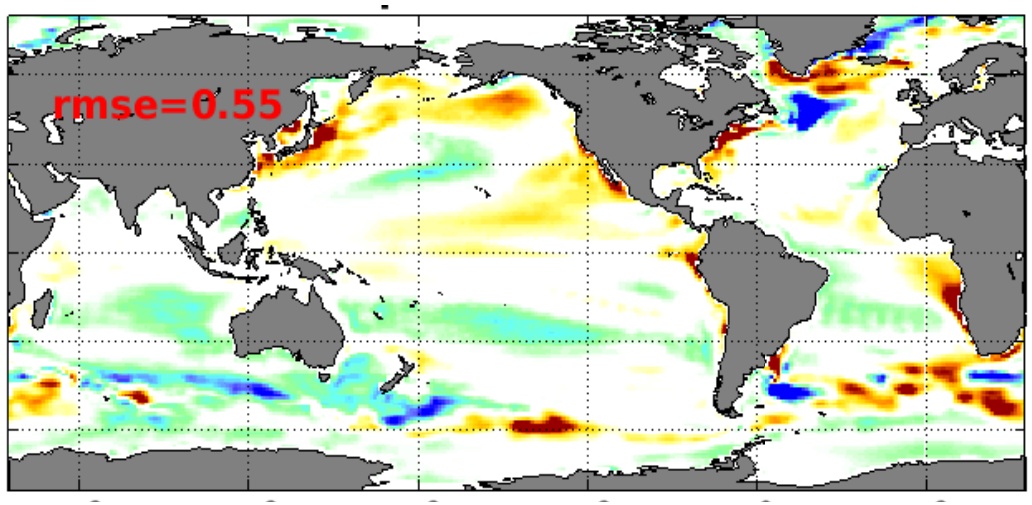
Supermodel reduces SST biases

NorESM-MPIESM-CESM supermodel
connected by assimilating optimally weighted model SST
25 years of simulation

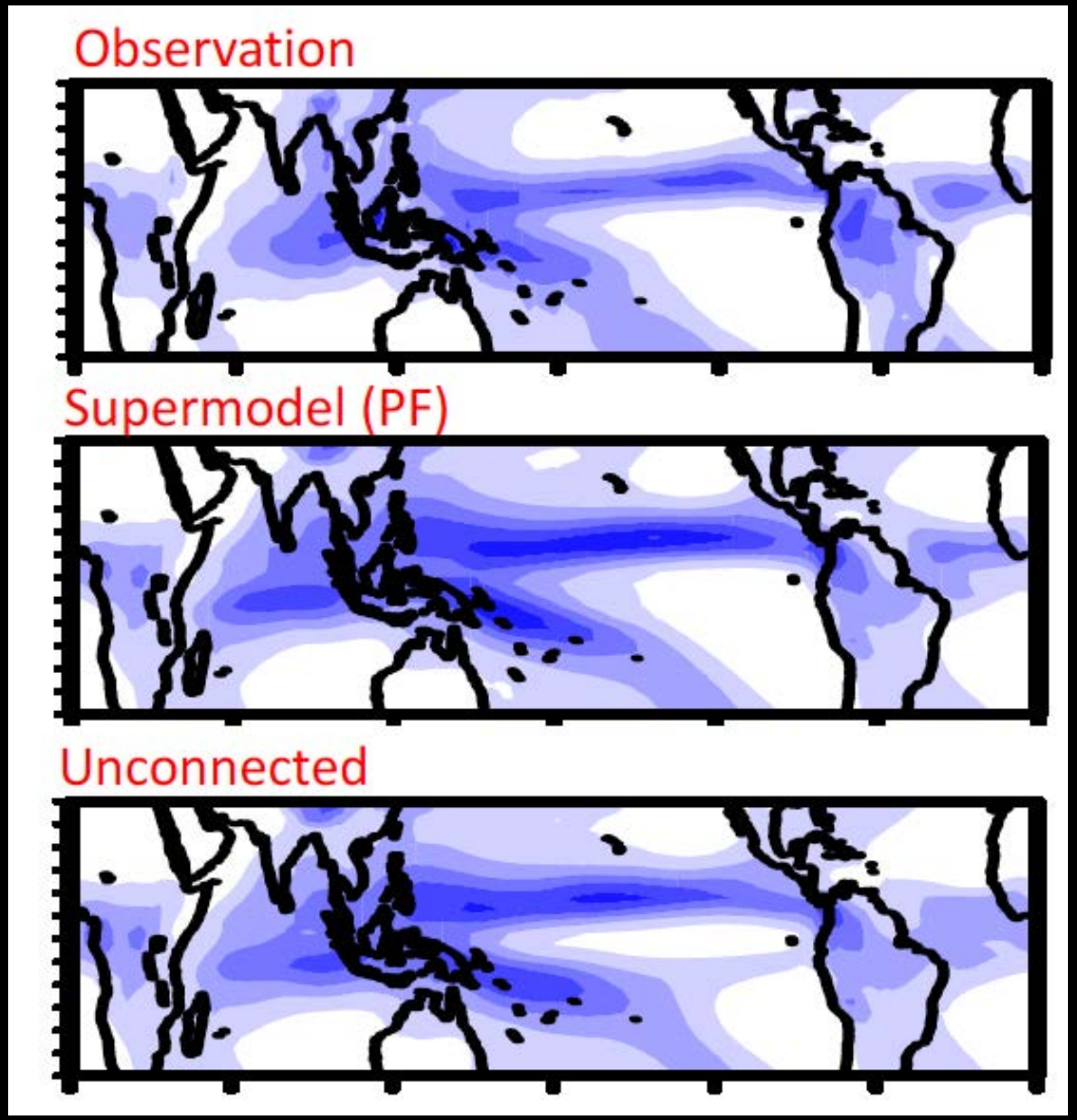
SST bias – standard ensemble average



SST bias – supermodel



Francois Counillon, Shuo Wang, Shunya Koseki
STERCP project (https://stercpproject.w.uib.no/)



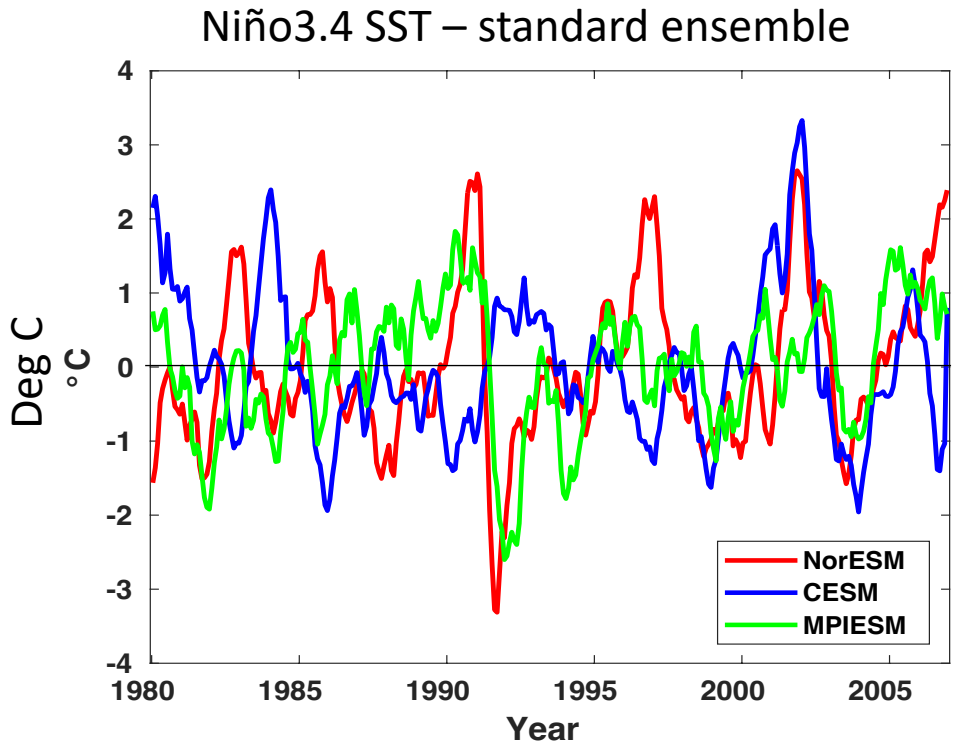
Rainfall climatology for the period 1980-2005

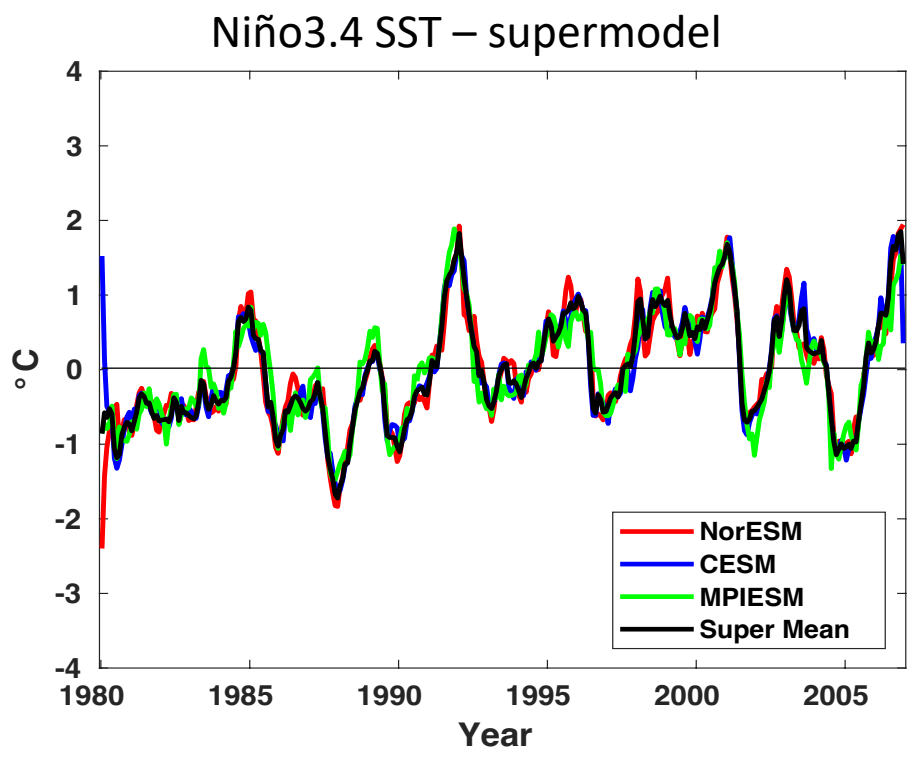
Rainfall patterns in the tropics are improved using optimal weights

Improvement beyond standard multi-model mean

Supermodel leads to synchronized ENSO variability

NorESM-MPIESM-CESM supermodel
connected by assimilating optimally weighted model SST
25 years of simulation





Francois Counillon, Shuo Wang, Shunya Koseki

SPEEDO supermodel better captures response to CO_2 doubling

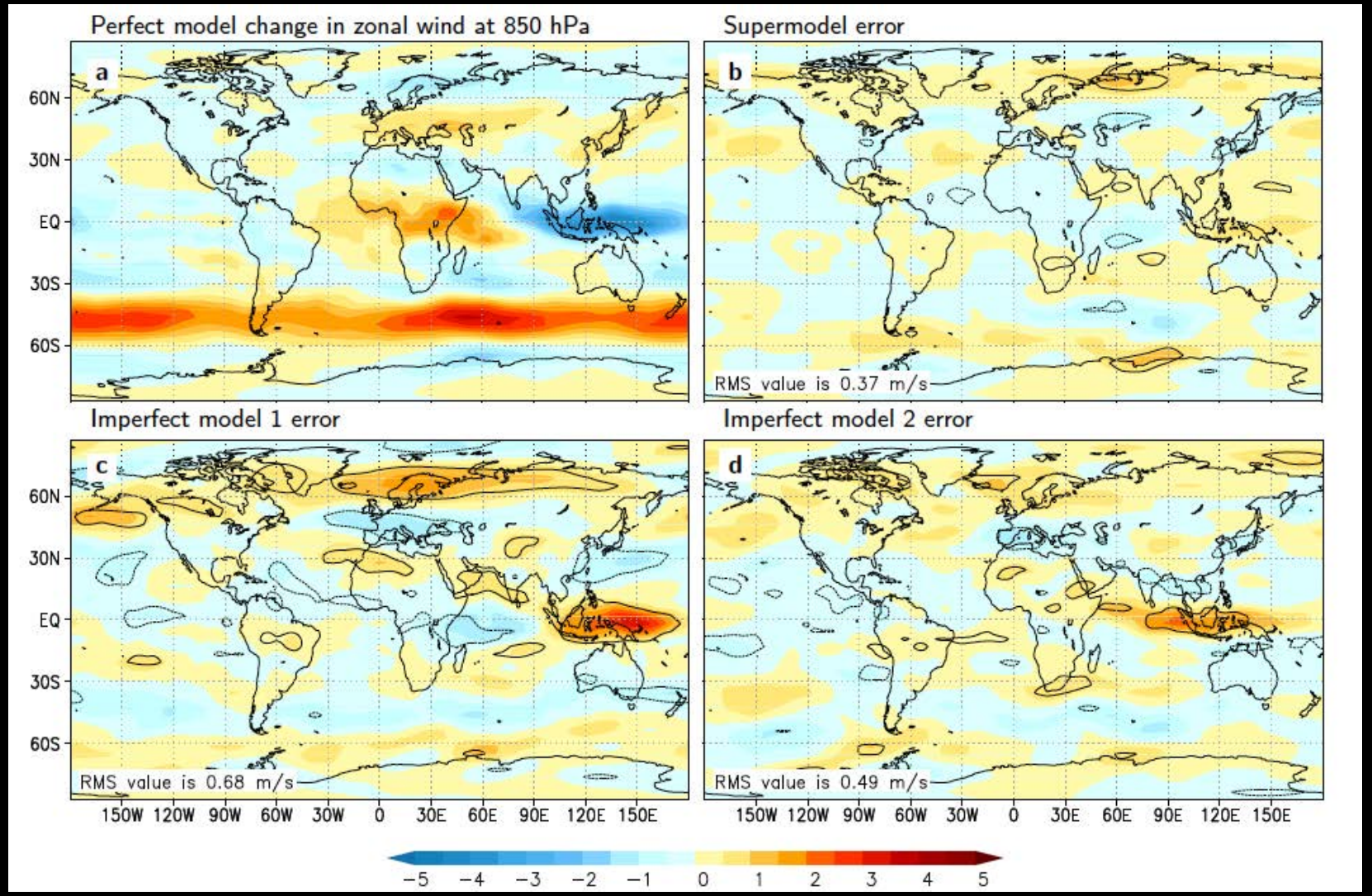
Climatological 850 hPa zonal wind (m/s)

Perfect model response

Error of supermodel

Error or imperfect model 1

Error or imperfect model 2



Selten et al. 2017

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New avenue to improve climate prediction

- Supermodelling – interactive combination of models
- Compensating errors at early stage can reduce structural errors, which would otherwise be enhanced by non-linearity
- *Improvements greater than the standard ensemble approaches*
- *Can improve short-term and long-term predictions*

Thank you for your attention

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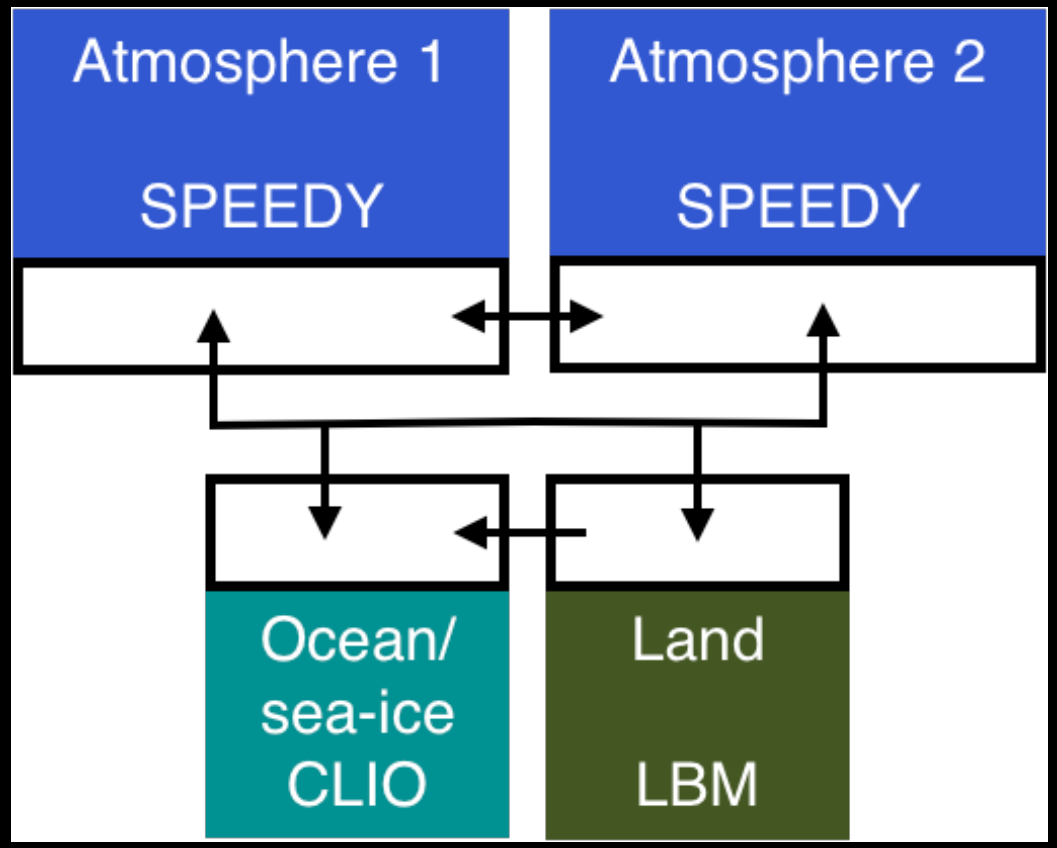
Methods

Supermodel with connected atmospheres – perfect model case

Two imperfect models are trained to reproduce a "true" model

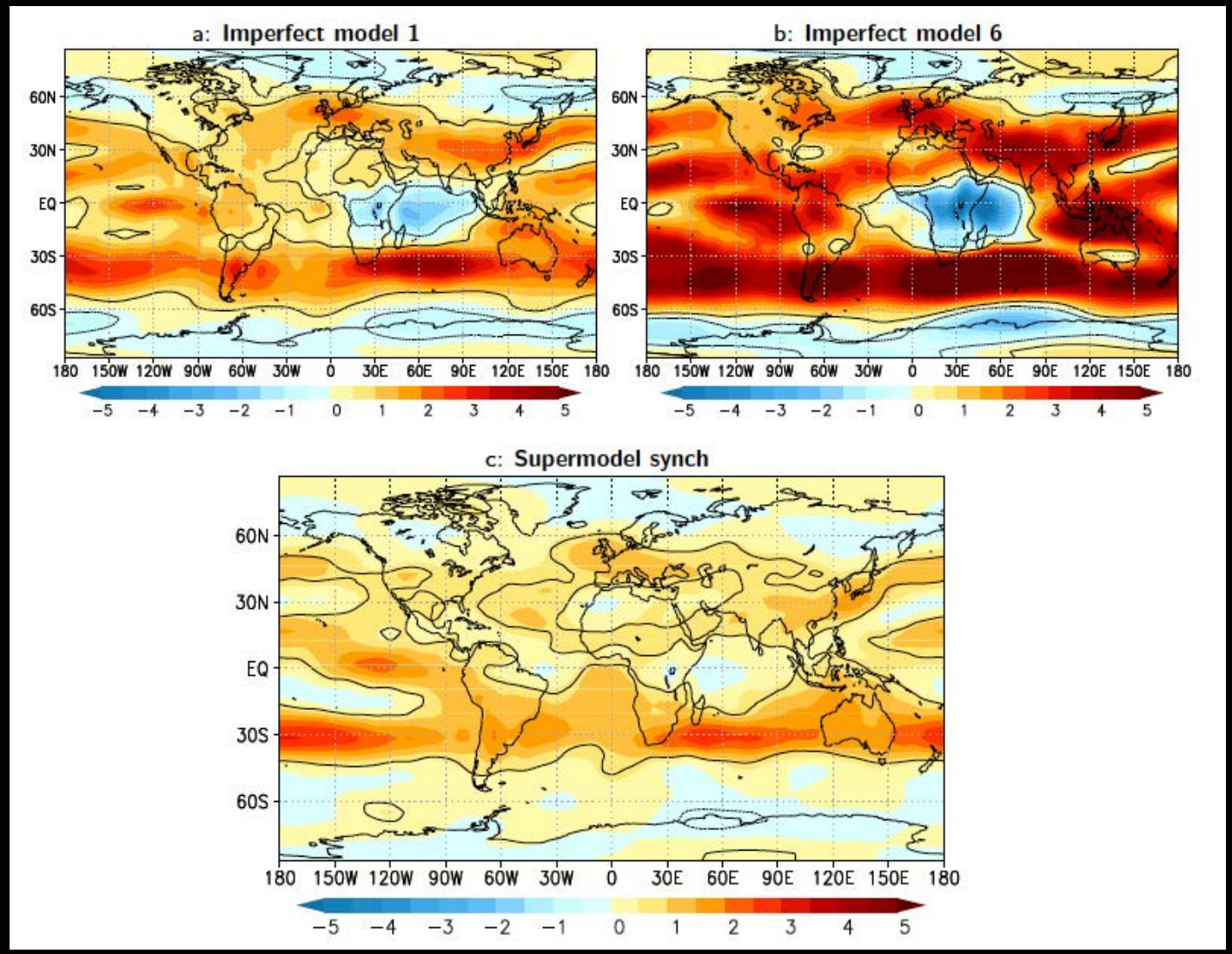


Schevenhoven et al. 2019

- Intermediate complexity climate model with ~4x4º horizontal grid (SPEEDO)
- Connected by 3D states of temperature, vorticity and divergence every 15 minute timestep
- Global connections one value per field, per model
- Interactive ensemble with one ocean and multiple atmosphere (up to 4)
- Perfect model experiments, with imperfect models differing in parameters related to atmospheric convection
- Two new training (machine learning) methods: cross pollination in time, and synchronized based learning

Supermodel also improves climate simulations

Climatological error in 850 hPa zonal wind (m/s)



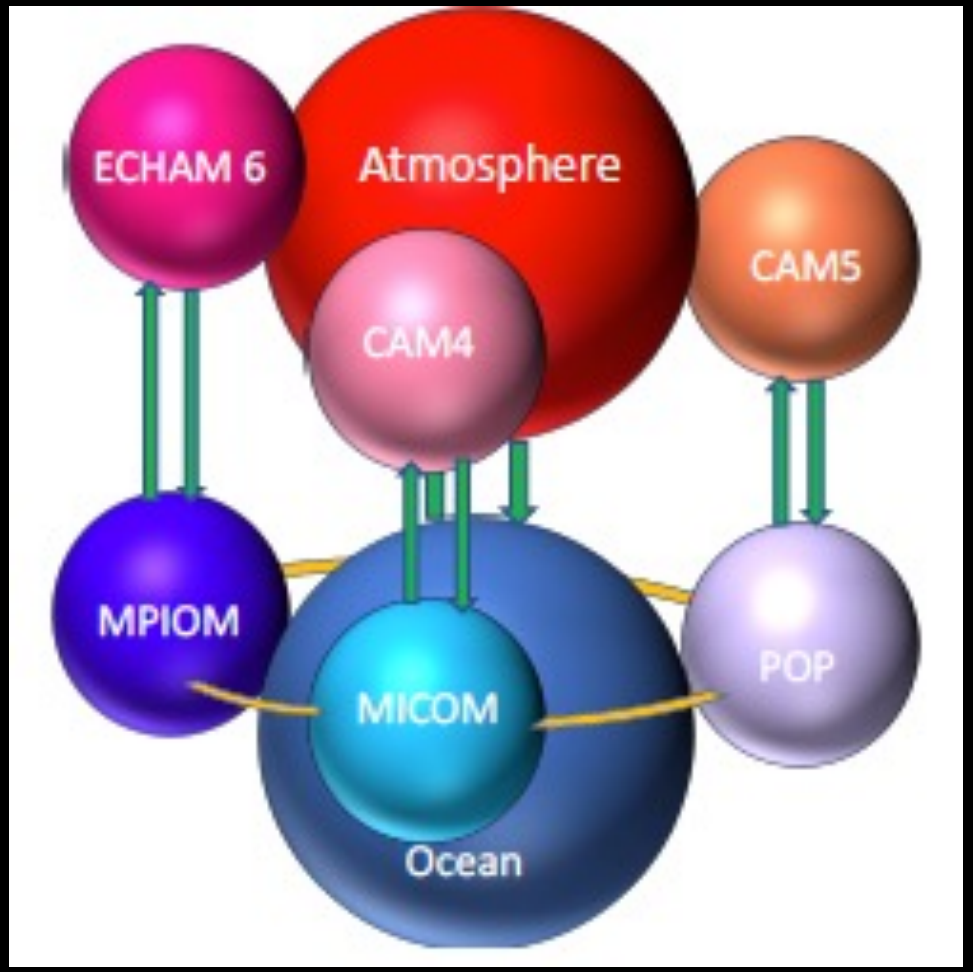
← Imperfect models

← Supermodel

Contours indicate were errors significant at 95% confidence level

Schevenhoven et al. 2019

An ocean connected super-ESM – real world case



- Generate pseudo-observations from the three individual CMIP5/6 ESM
- Assimilate pseudo-observations back into each models every month (SST only)
- The three models are then propagated forward
- Several different offline approaches tested to train supermodel using observed SST data (all improve performance)
- Some results here for 25-year long simulations, training from one-month forecasts
- ~10 years per day, 11 nodes 1408 cpu

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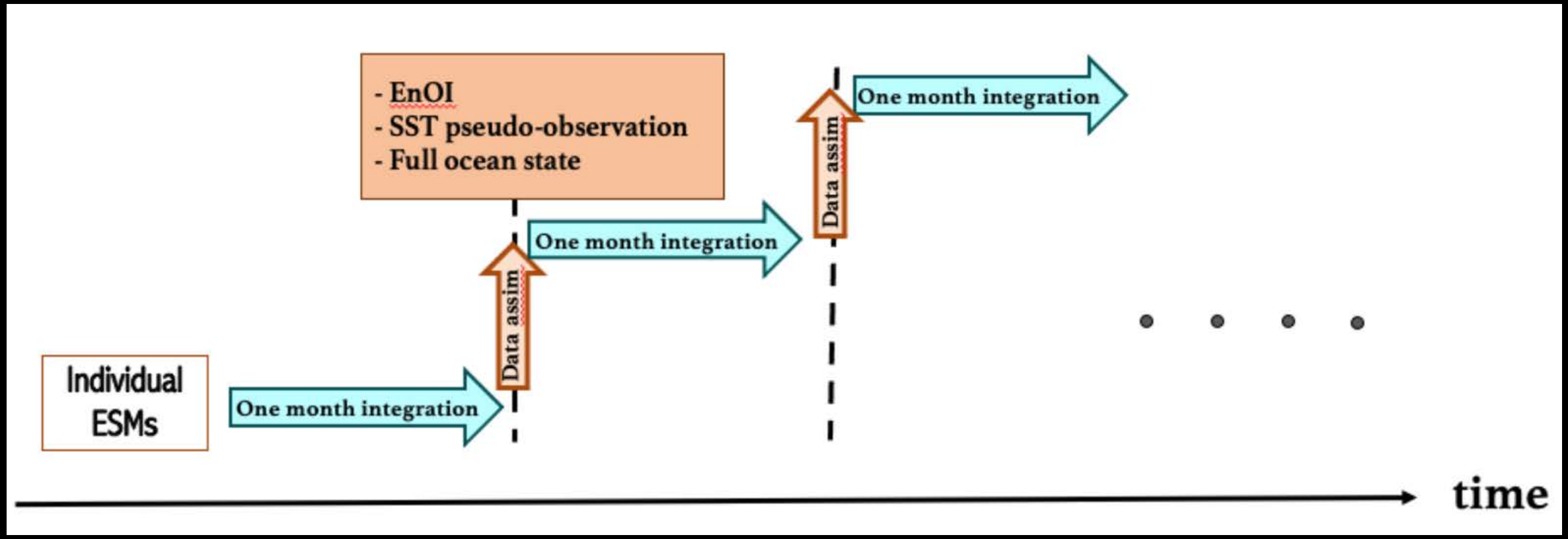
STERCP project (https://stercpproject.w.uib.no/)

Connecting the ocean components of ESM



Psuedo-observations = a weitghed combination of the individual model simulations