Idealized Atlantic Multidecadal Variability Experiments with the Community Earth System Model (CESM)

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AMV climate impacts
Motivation and Goals

Our primary goals are to

- document climate impacts of sea surface temperature (SST) anomalies related to the Atlantic Multidecadal Variability (AMV);
- investigate the associated physical mechanisms

We follow a common experimental protocol (developed at GFDL) to the extend possible and perform suites of idealized AMV SST perturbation experiments using CESM1 and GFDL CM2.1 fully coupled models.

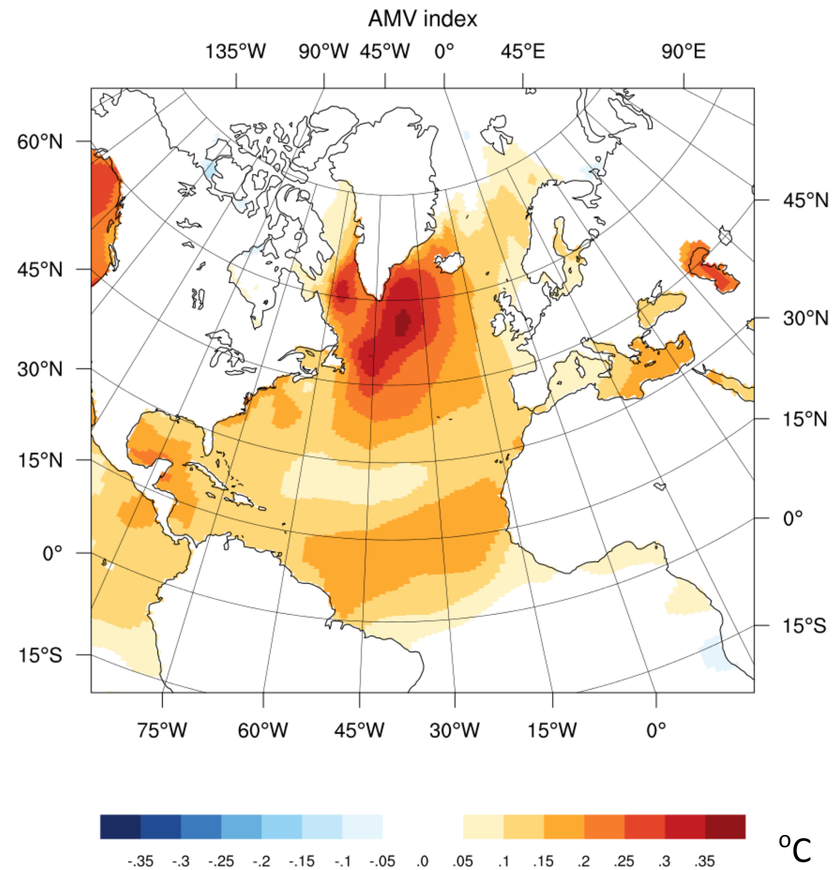
In addition to addressing various science questions, we aim to assess

- robustness of our results across our coupled model simulations, and
- investigate whether tropical or subpolar Atlantic SST anomalies show the largest climate impacts.

AMV climate impacts
AMV SST pattern

Follows an updated version of the Ting et al. (2009) recipe which makes use of models and observations to produce an AMV index:

- A set of coupled model simulations for the 20th century are used together with a signal-to-noise-maximizing EOF analysis to determine a model-based estimate of the forced component in the North Atlantic SST variability
- This forced component is subtracted from the observed North Atlantic SSTs to obtain an AMV index
- Observed SSTs are regressed onto the AMV index to get the SST spatial pattern



AMV pattern on ocean model grid

Models: CMIP5 20th century simulations; multiple ensemble members per model

Observations: NOAA ERSSTv3

Region: 0°-60°N – 7.5°-75°W

Filter: 10-year low-pass

AMV climate impacts
Model & Experimental Procedure

- NCAR experiments use the Community Earth System Model version 1 (CESM1)
- Base code is identical to the version used for the 2200+ -year CESM Large Ensemble pre-industrial control simulation
- 1^{o} horizontal resolution in all components
- Parallel Ocean Program version 2 (POP2); Community Atmospheric Model version 5 (CAM5)

AMV climate impacts
Model & Experimental Procedure

Experimental procedure has been developed at GFDL:

- AMV SST pattern is super-imposed onto the model's own SST climatology
- Over the North Atlantic, the coupled model is restored to the resulting SST patterns; elsewhere the model evolves freely
- A control integration is obtained in which the North Atlantic SSTs are restored to the model's own SST climatology – thus mean state of the control is similar to the sensitivity experiments
- Daily model SST climatology obtained from a 1000-year segment of the control simulation (for years 500 to 1500)
- 5-day SST restoring time scale over the first layer thickness (10 m)
- No restoring under sea ice
- AMV SST pattern is time independent

AMV climate impacts
Experiments

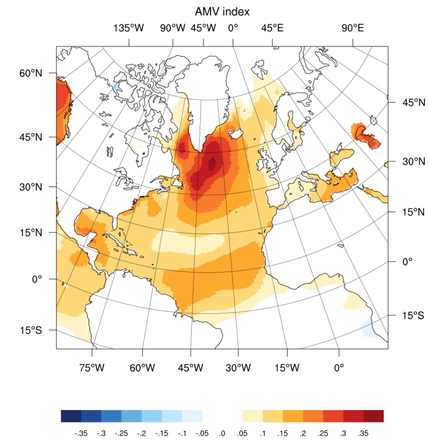
10-year long **ensemble experiments**:

- ◆ **CONT** daily SST climatology (separate for each sensitivity experiment)
- ◆ **AMV+** daily SST climatology + AMV$^+$ pattern
- ◆ **AMV-** daily SST climatology + AMV$^-$ pattern
- ◆ **AMV+_SPNA** daily SST climatology + AMV$^+$ pattern in the subpolar North Atlantic only
- ◆ **3xAMV+_SPNA** daily SST climatology + 3 x AMV$^+$ pattern in the subpolar North Atlantic only
- ◆ **AMV+_TA** daily SST climatology + AMV$^+$ pattern in the tropical Atlantic only

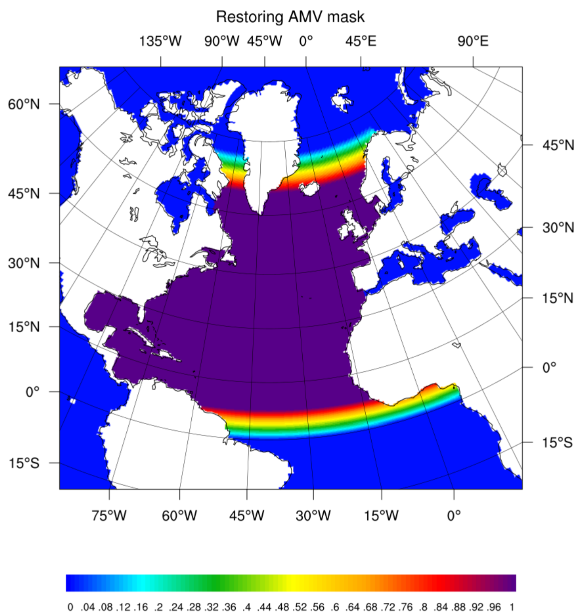
Results are presented as differences from CONT;

Stippled: 95% confidence level (2-tailed t-test)

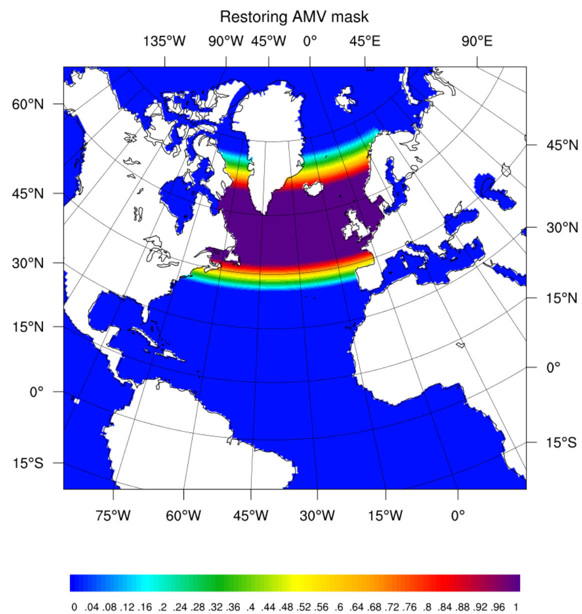
AMV climate impacts
Experimental set up



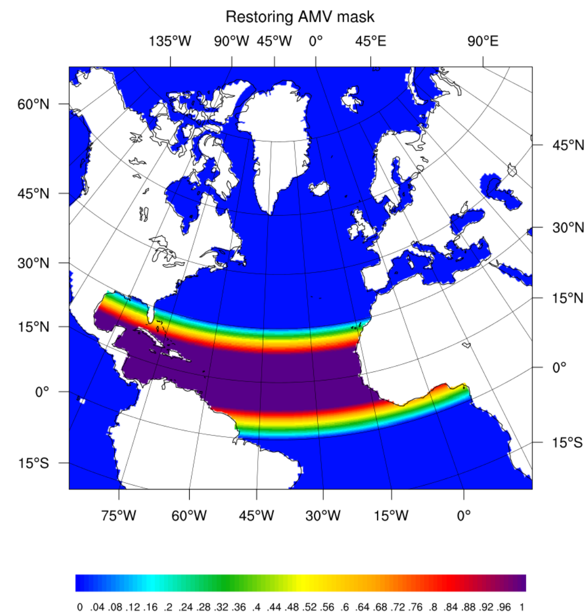
AMV pattern



Full NA restoring



SPNA restoring



TA restoring

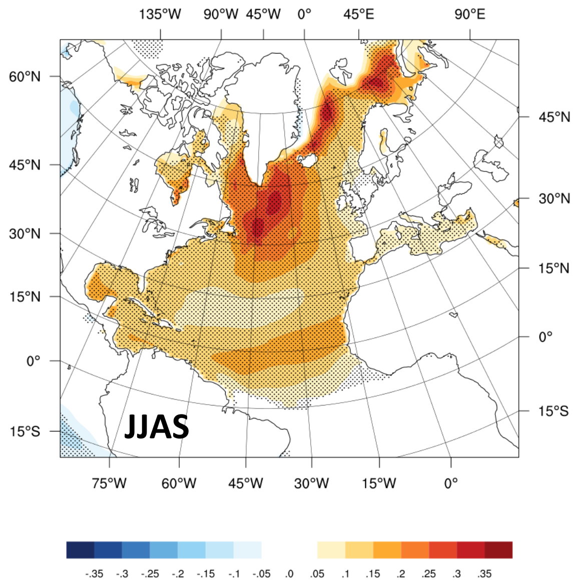
AMV climate impacts
Experimental set up

30 members in each ensemble

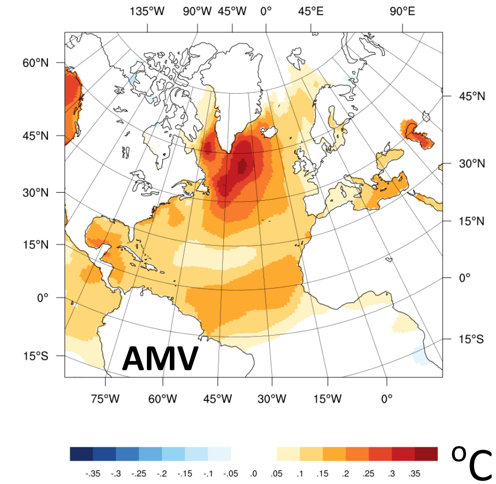
=> combination of MACRO and MICRO perturbations similar to Hawkins et al. (2015)

- **MACRO:** 3 different oceanic initial conditions
- **MICRO:** from each MACRO initial condition,
  10 members are produced using atmospheric initial condition perturbations at round-off level (temperature)

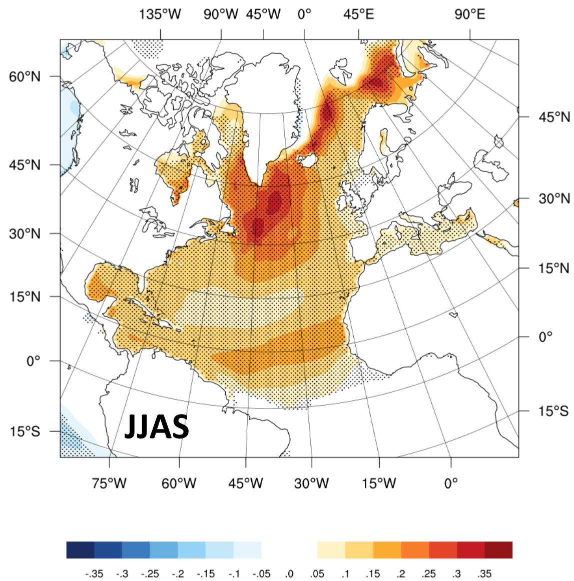
AMV climate impacts
Preliminary results: verification



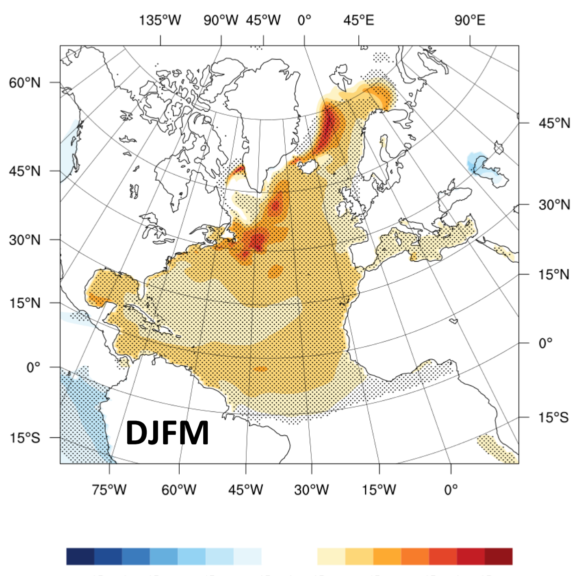
- AMV restoring works very well over summer

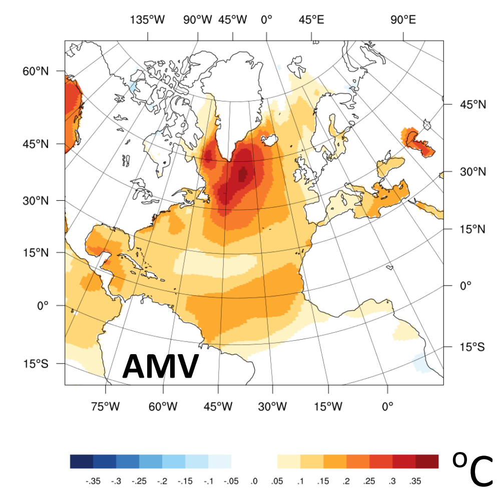


AMV climate impacts
Preliminary results: verification

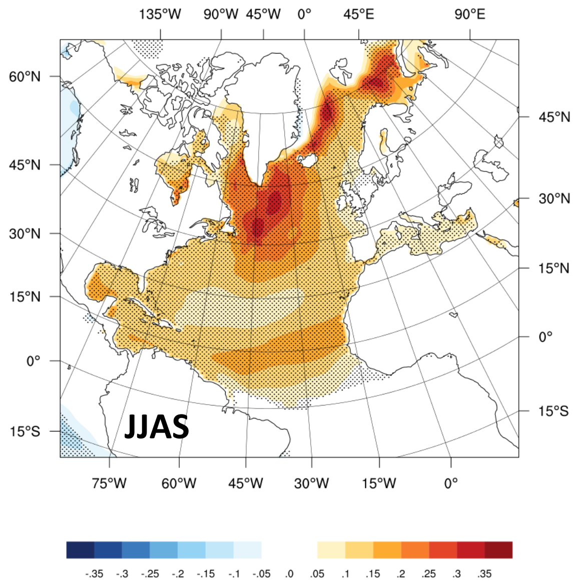


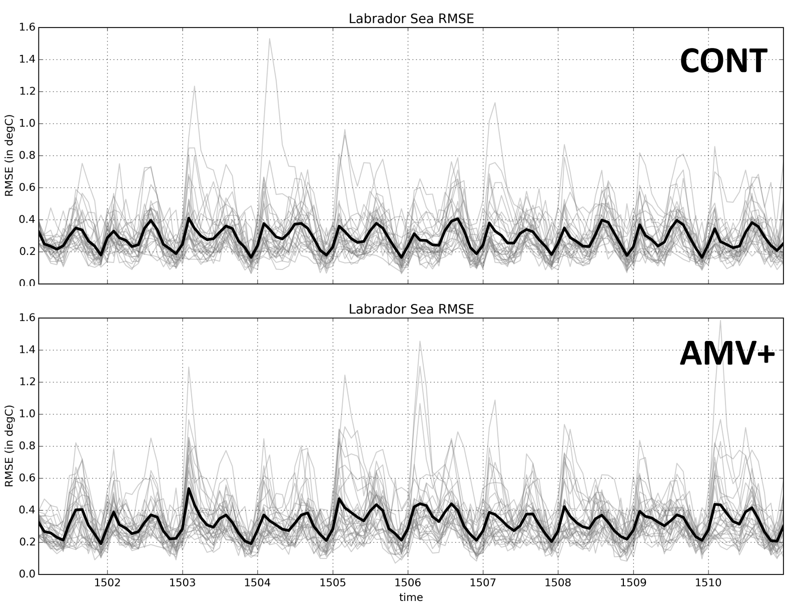
- AMV restoring works very well over summer
- Not as well in winter
  - ⇒ this is probably to be expected:
    - ✧No restoring when sea-ice is present
    - ✧Faster more energetic dynamics in winter





AMV climate impacts
Preliminary results: verification





- AMV restoring works very well over summer
- Not as well in winter
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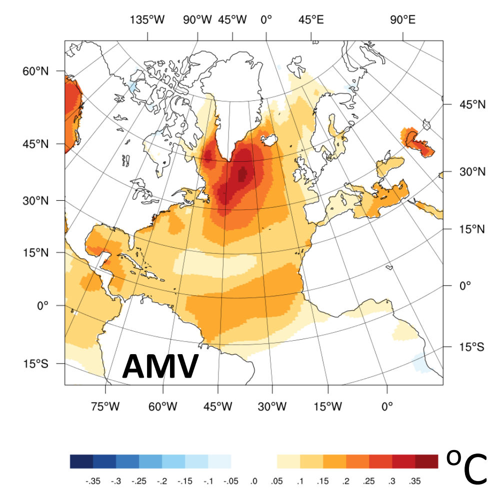
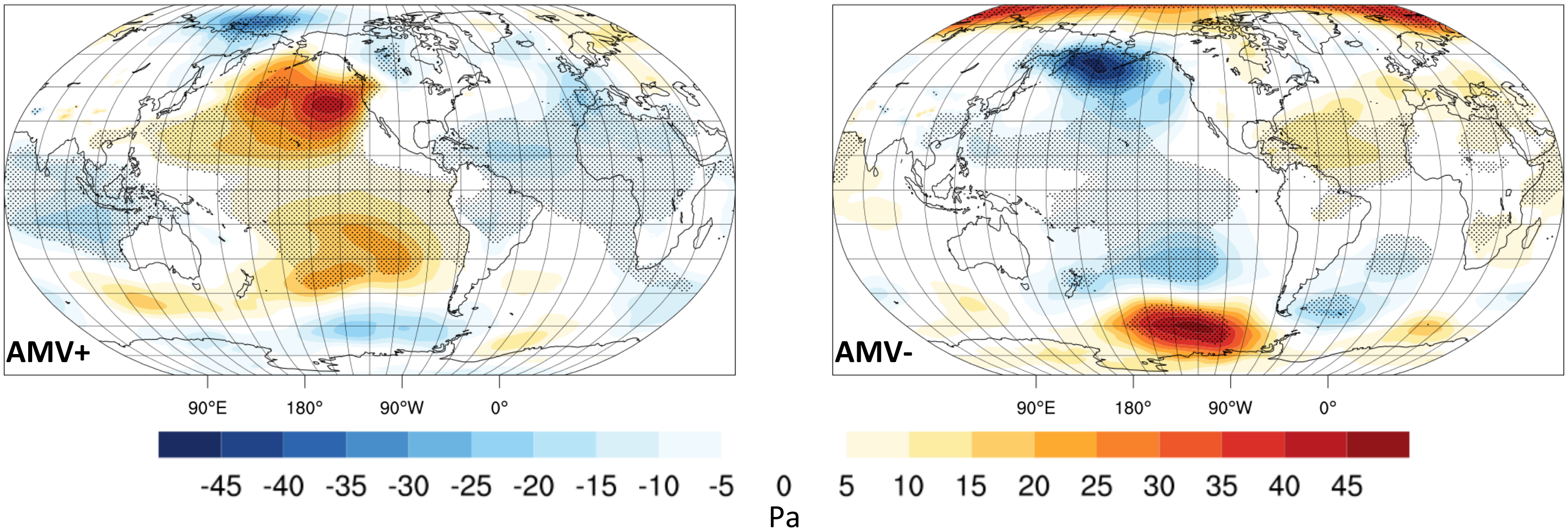
- Seasonality in the RMSE, but NO trend over the 10-year simulation



AMV climate impacts
Preliminary results: AMV+/AMV-

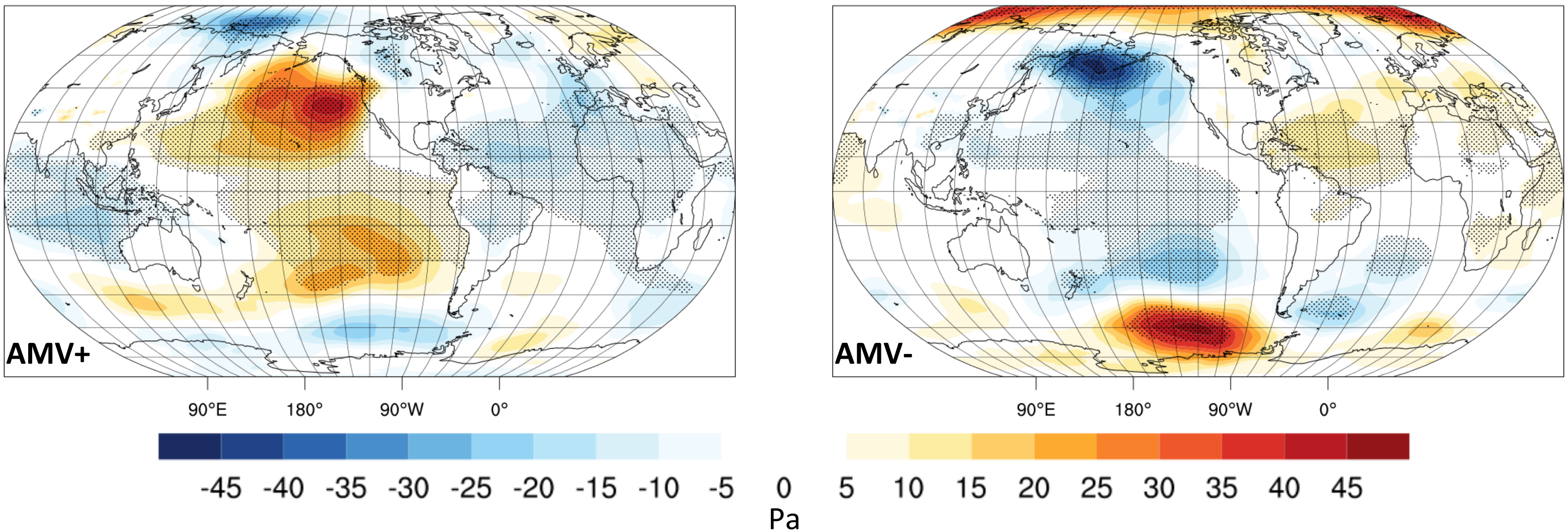
Sea Level Pressure (SLP) 10-year climatological composite (30 members)



- First order response is primarily linear

AMV climate impacts
Preliminary results: AMV+/AMV-

Sea Level Pressure (SLP) 10-year climatological composite (30 members)

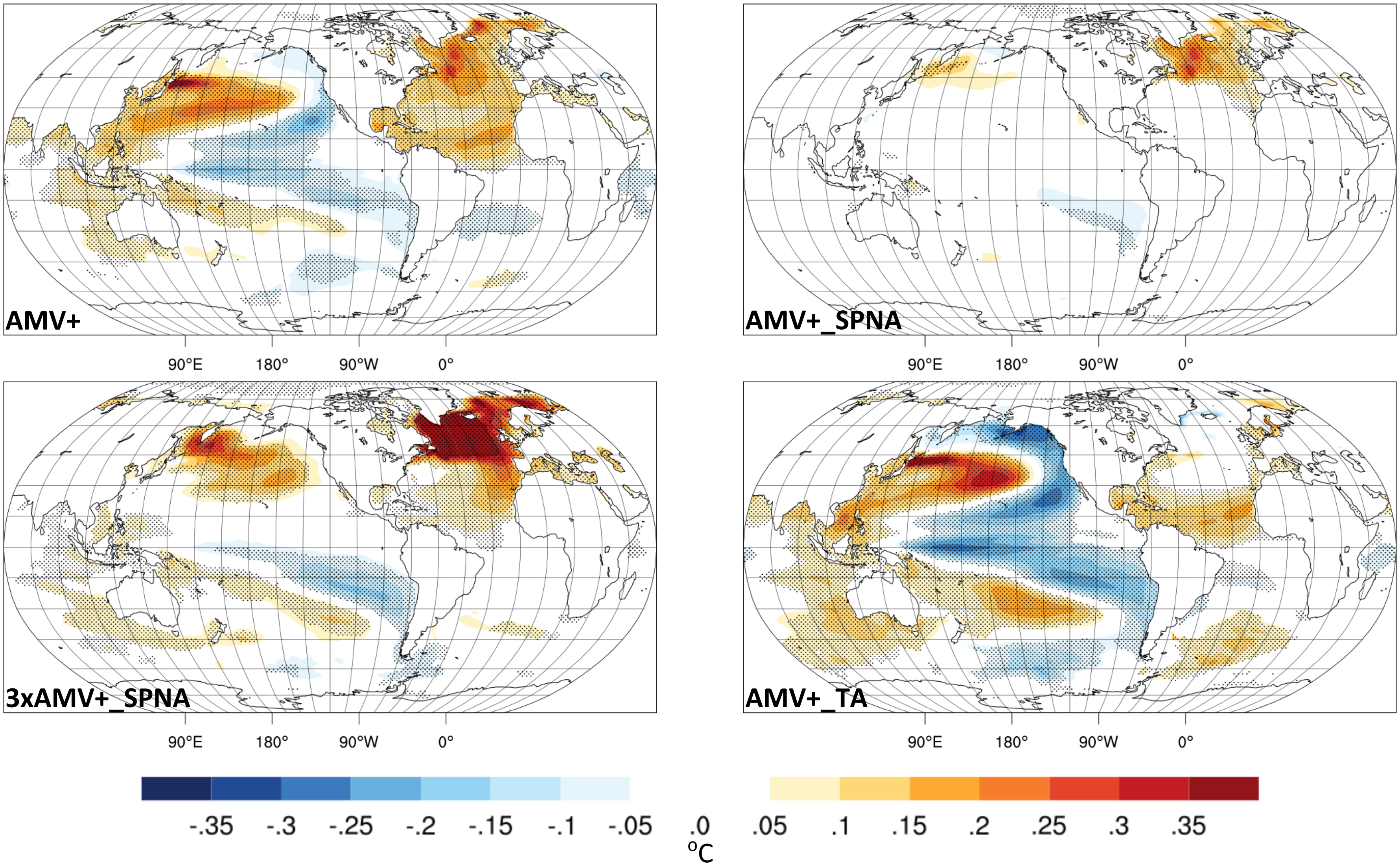


- First order response is primarily linear

  => We are going to focus on the AMV+ response

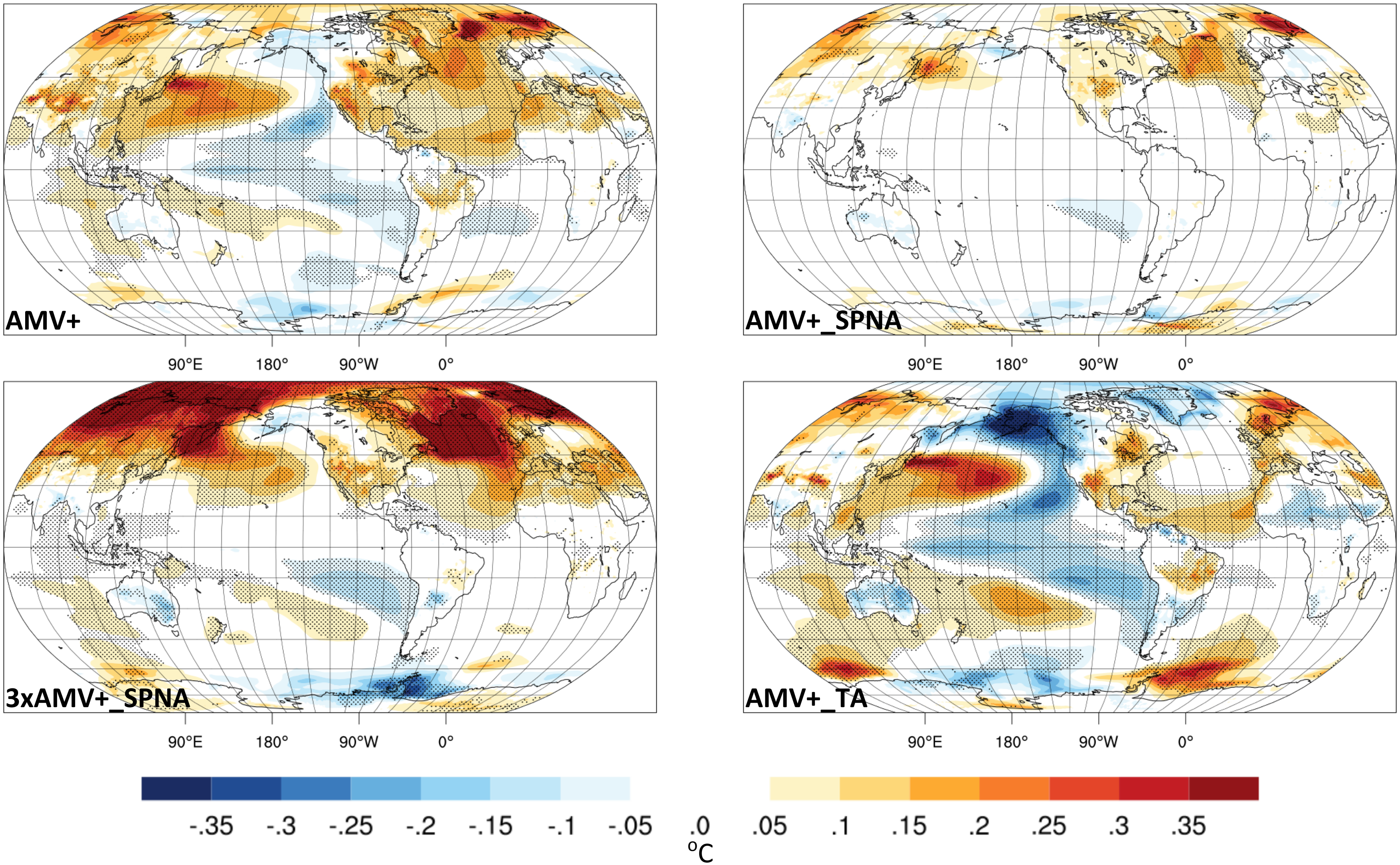
AMV climate impacts
Preliminary results: SST

10-year climatological composite (30 members)



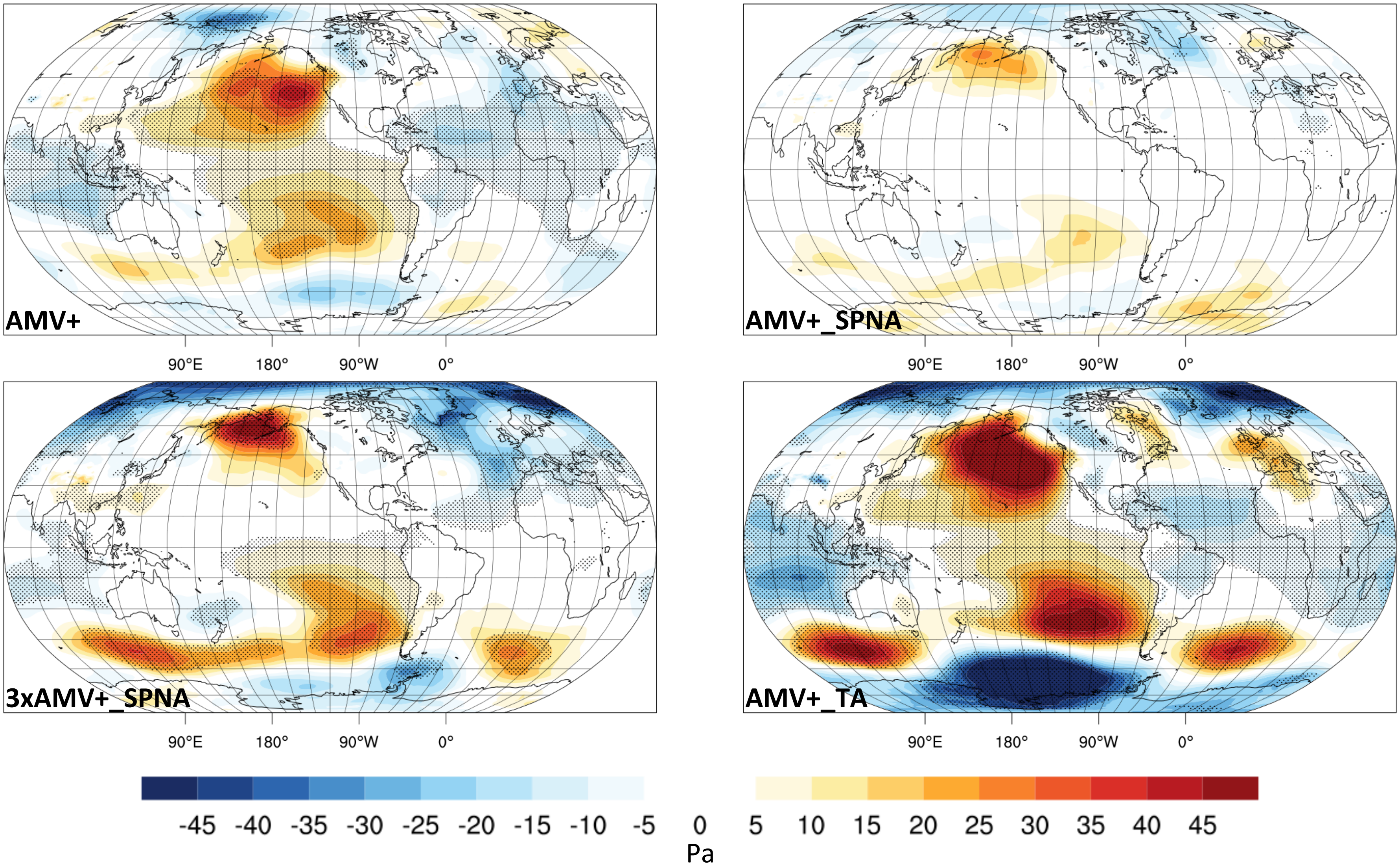
AMV climate impacts
Preliminary results: T2M

10-year climatological composite (30 members)



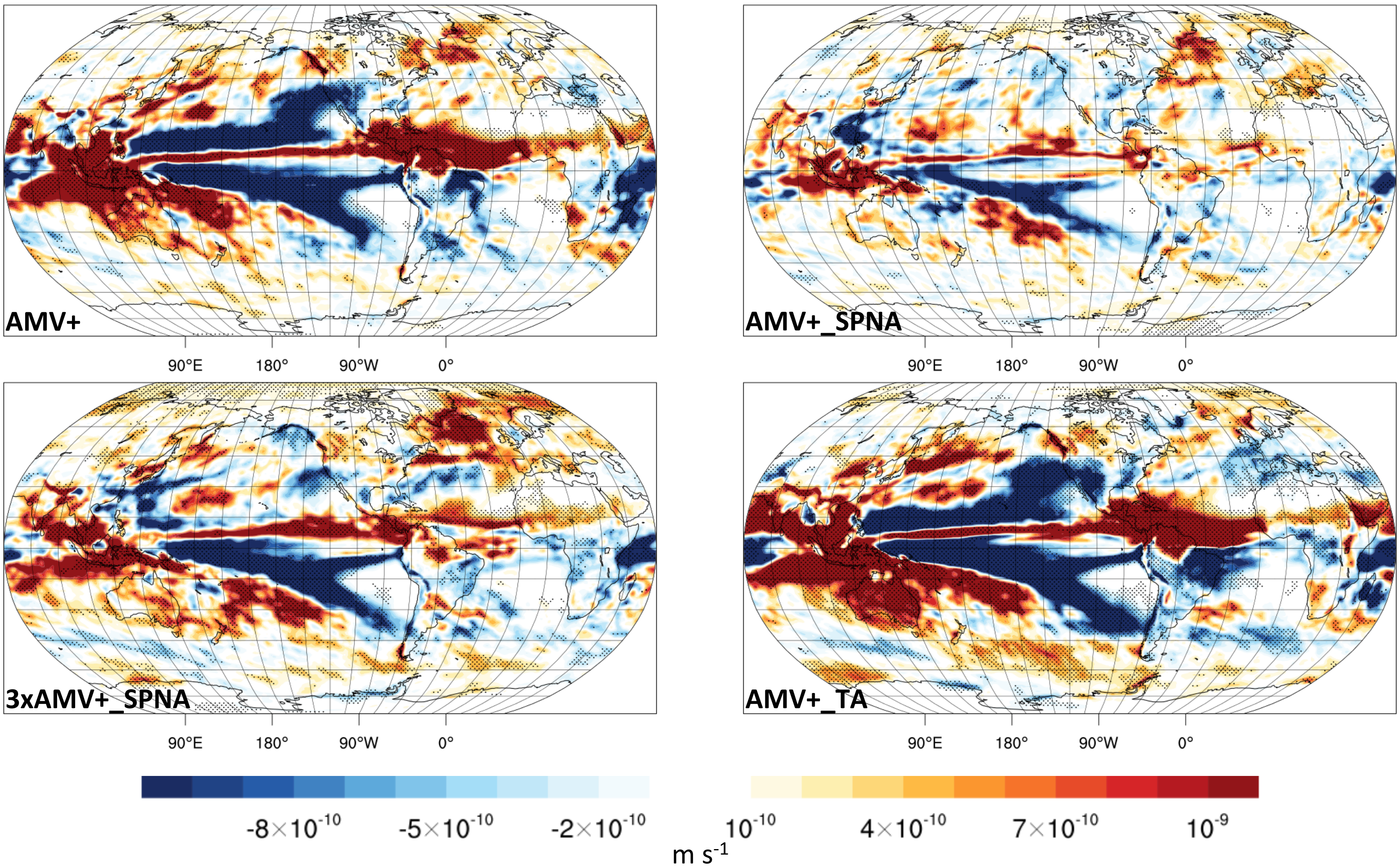
AMV climate impacts
Preliminary results: SLP

10-year climatological composite (30 members)



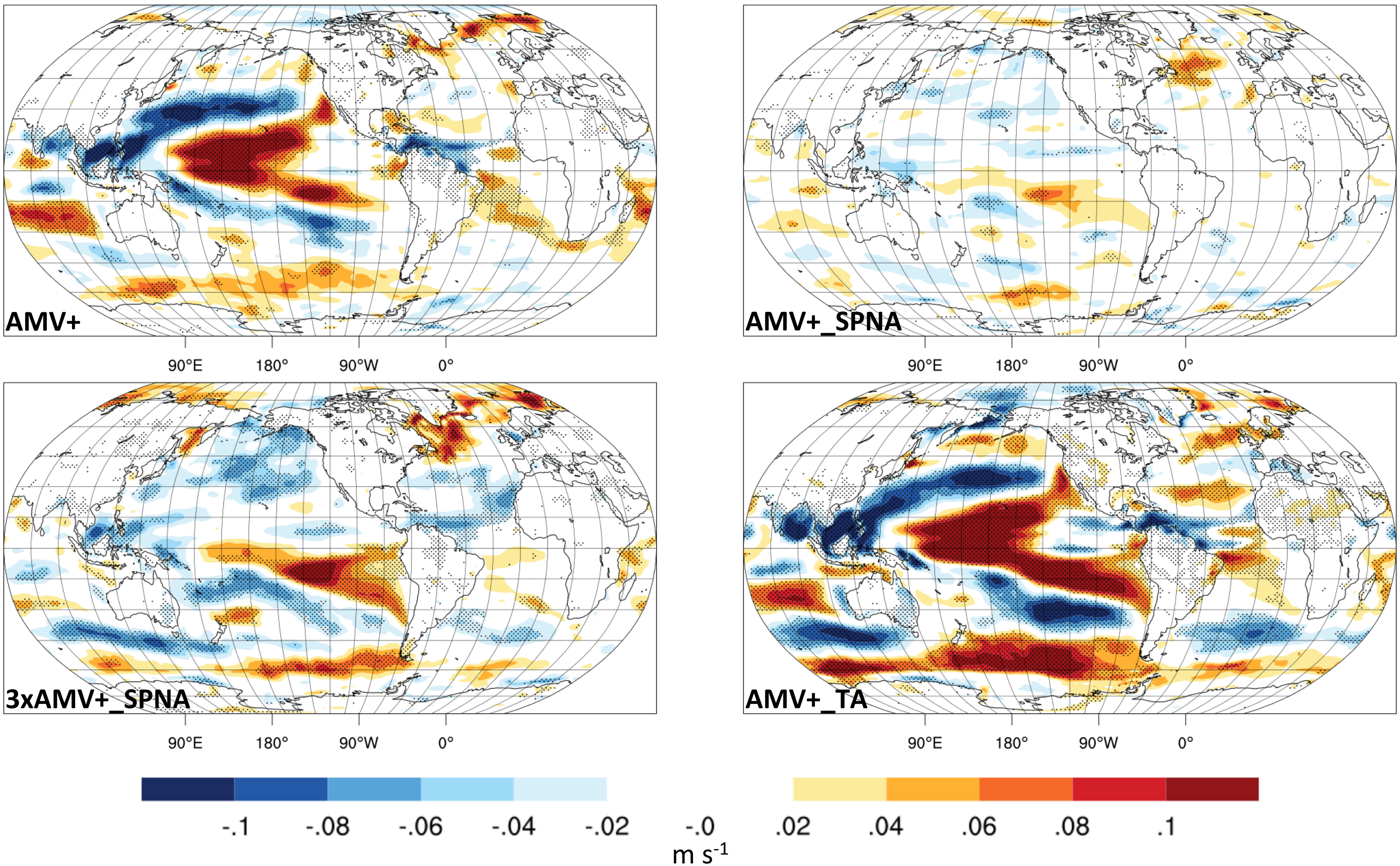
AMV climate impacts
Preliminary results: Precipitation

10-year climatological composite (30 members)



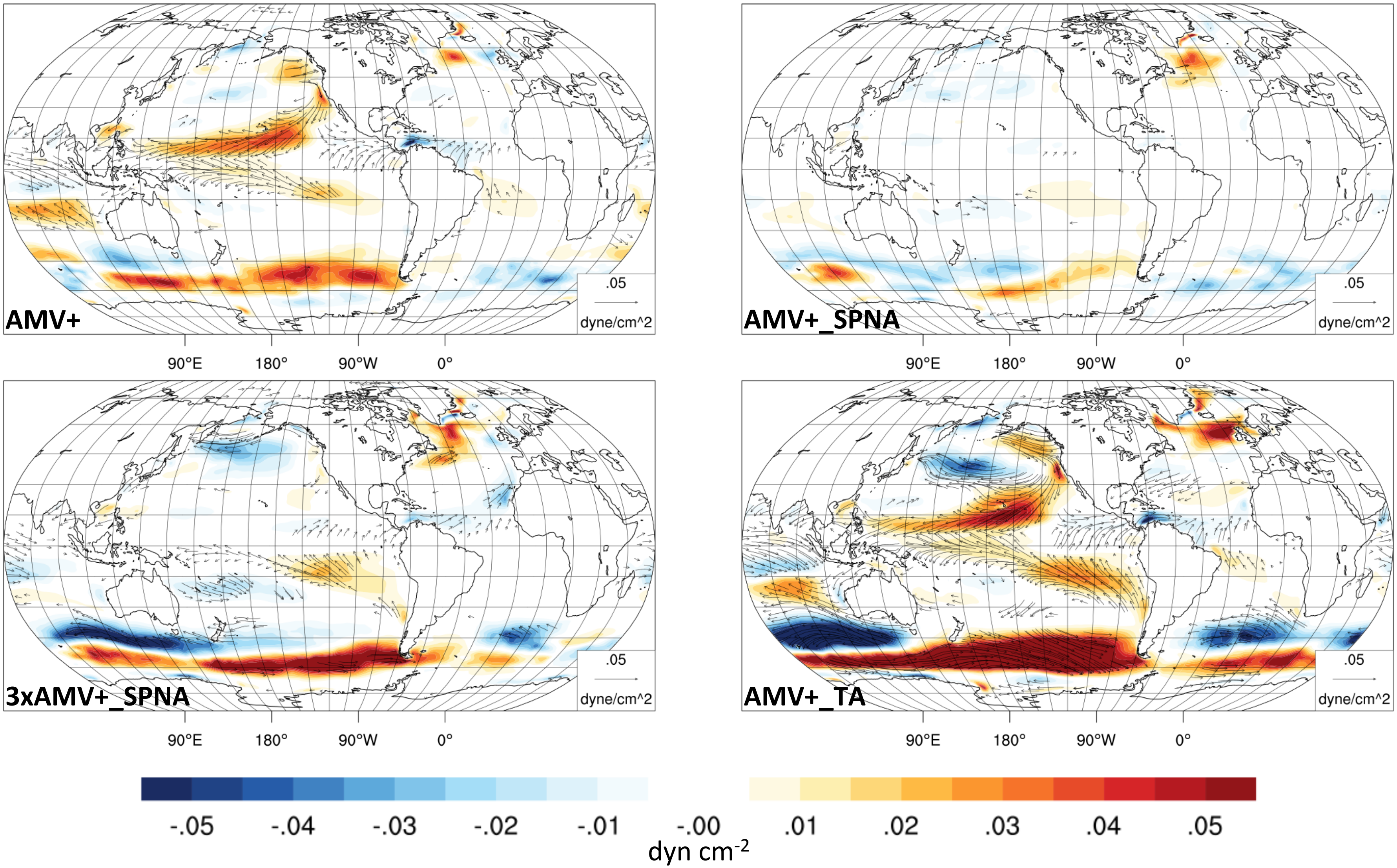
AMV climate impacts
Preliminary results: 10-meter winds

10-year climatological composite (30 members)



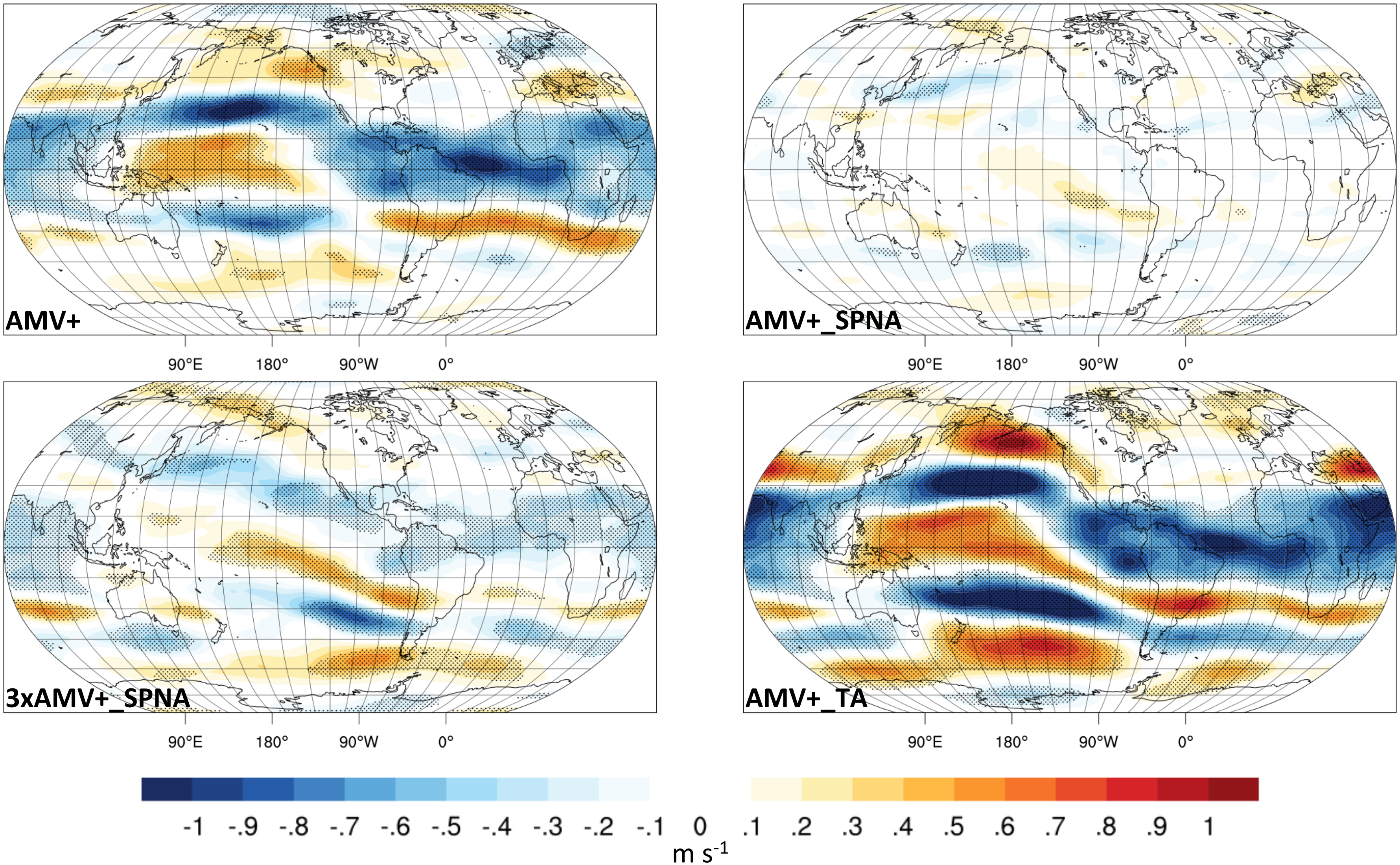
AMV climate impacts
Preliminary results: surface wind stress

10-year climatological composite (30 members)



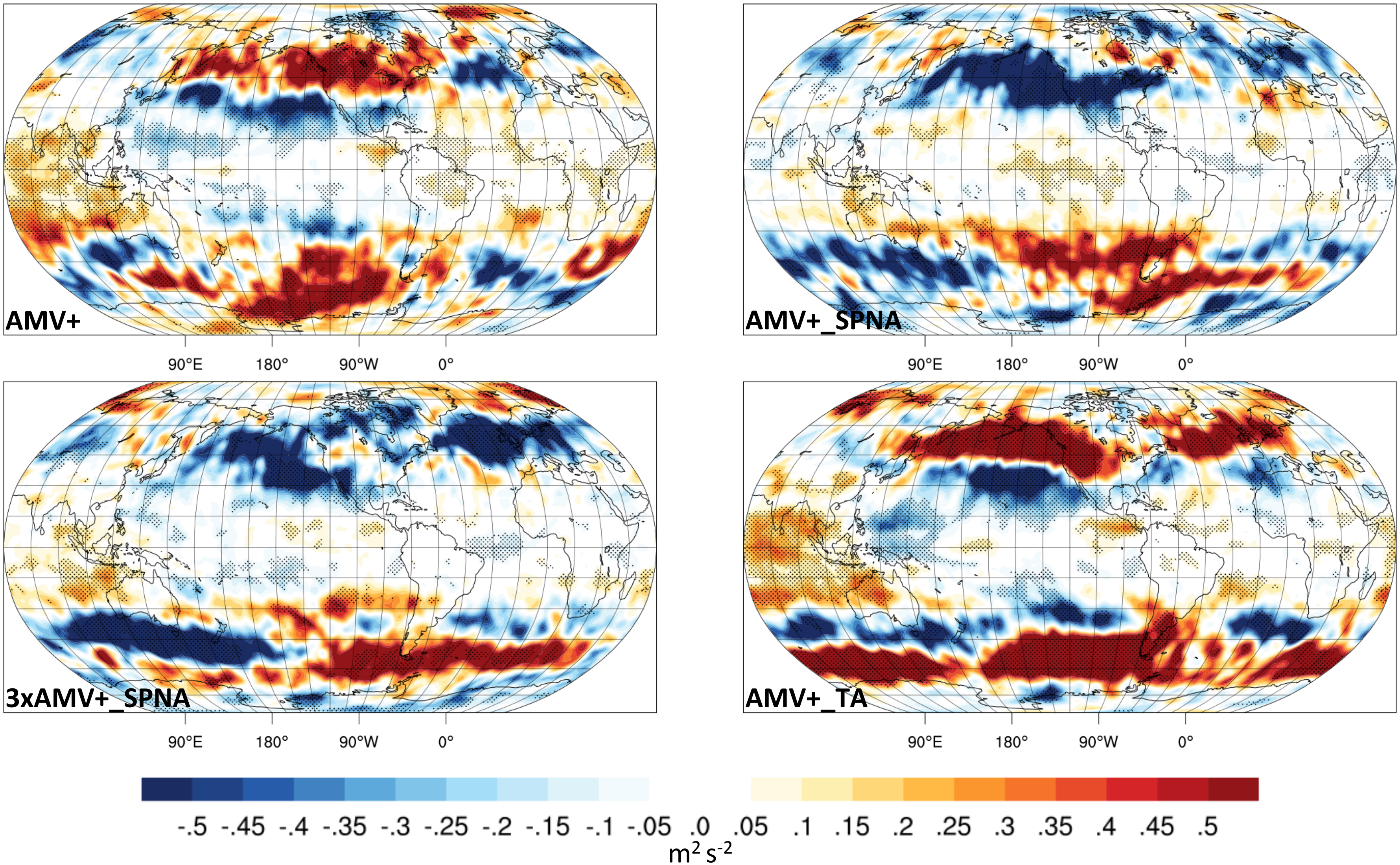
AMV climate impacts
Preliminary results: U200

10-year climatological composite (30 members)



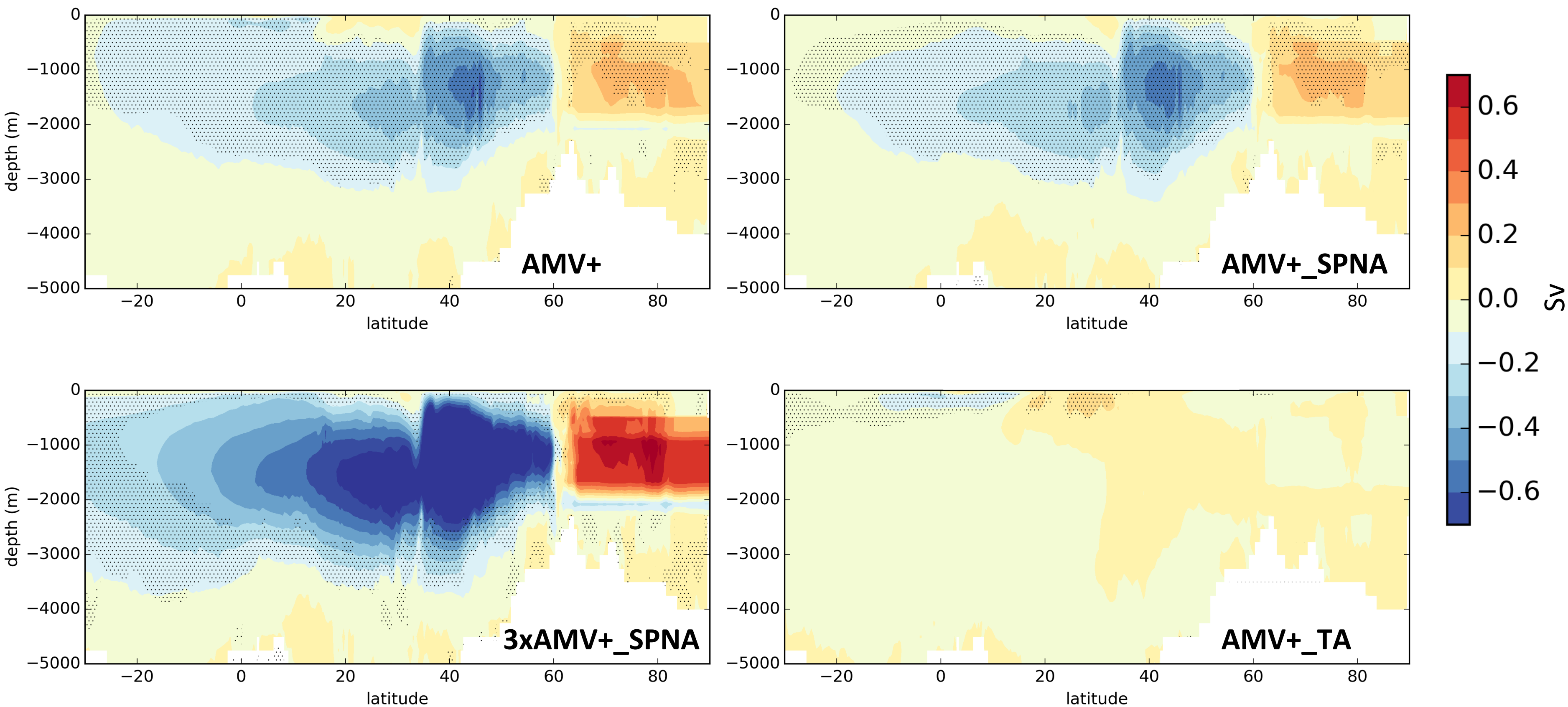
AMV climate impacts
Preliminary results: Storm Track (V'500)

10-year climatological composite (30 members)



AMV climate impacts
Preliminary results: AMOC

10-year climatological composite (30 members)



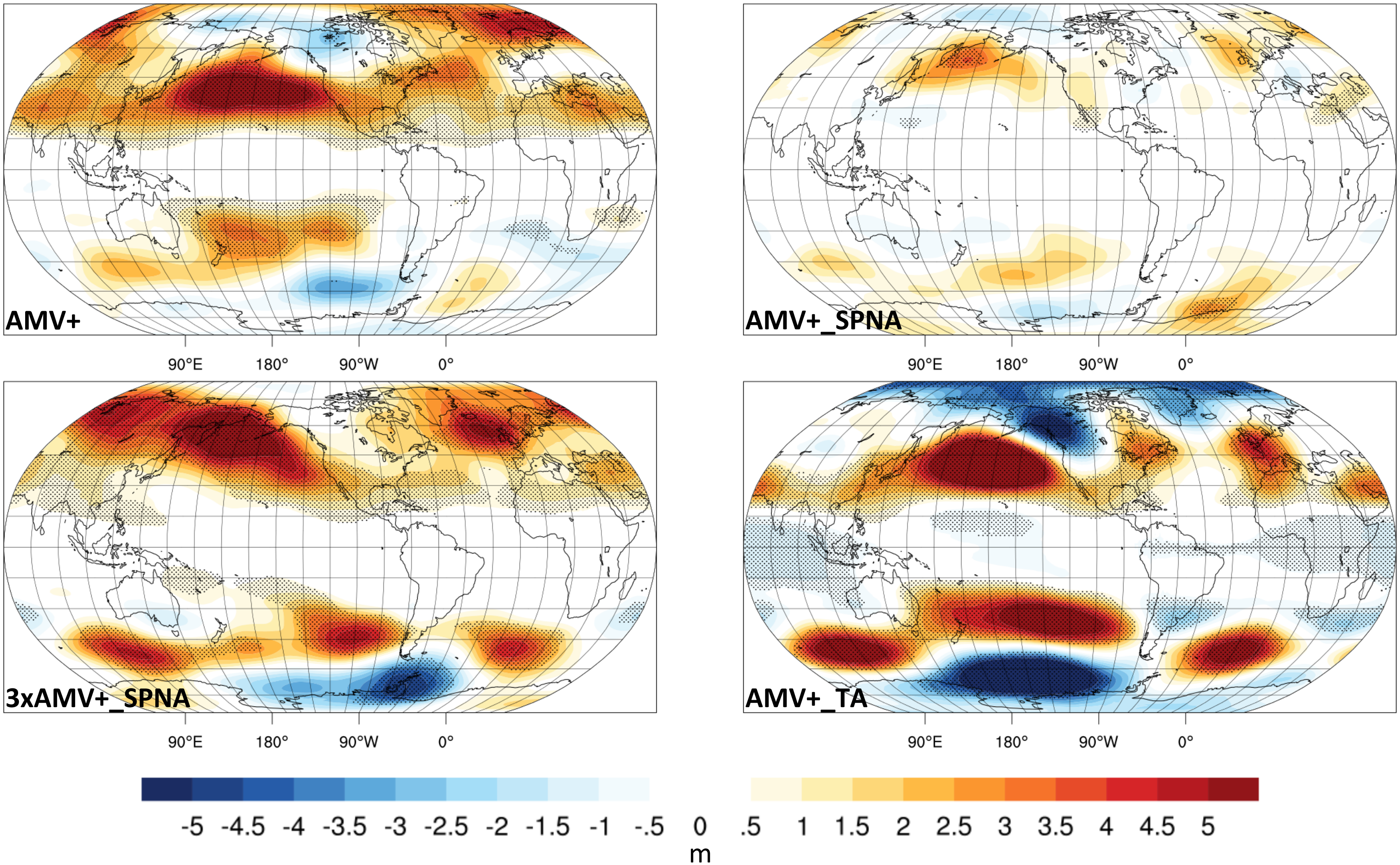
AMV climate impacts
Summary

- We have designed an experimental protocol to assess climate impacts of AMV and to understand the associated physical mechanisms
- Preliminary results:
  - The Tropical Atlantic controls the first order AMV impacts
  - AMV+ (AMV-) lead to a negative (positive) PDV response in the Pacific Ocean
  - Other impacts include poleward shift of tropical precipitation; stronger zonal winds in the Southern Ocean; …
  - AMV impacts results from mechanisms involving atmospheric teleconnections
  - More analysis is underway to identify and better understand the mechanisms at play, e.g., considering seasonal responses

More in Yohan Ruprich-Robert's and Rym Msadek's presentations

AMV climate impacts
Preliminary results: Z500

10-year climatological composite (30 members)



AMV climate impacts
Preliminary results: vertical pressure velocity

10-year climatological composite (30 members)