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FOR COMPUTATIONAL ENGINEERING & SCIENCES

ATMOSPHERIC FORCING-INDUCED UNCERTAINTIES IN THE ECCO STATE ESTIMATE

Yanzhou Wei, Patrick Heimbach, An Nguyen, Helen Pillar
The University of Texas at Austin, TX

https://crios-ut.github.io
https://ecco-group.org

What is Uncertainty Quantification in the context of DA?

Different uses of DA

- Parameter estimation (calibration)
  - **Seek uncertainties in the parameters**
- State estimation / reconstruction / synthesis (interpolation)
  - **Seek uncertainties in the reconstructed state, or in derived quantities / metrics / quantities of interest (QoIs)**
- Forecasting (extrapolation)
  - **Seek uncertainties in the forecast**

Origins of uncertainty in the context of DA:

- **Observations:**
  - measurement error
  - sampling (in space and time)
- **Assimilation scheme:**
  - DA algorithm (and implied approximations)
  - The way how observations are ingested in DA
- **Model:**
  - Parametric uncertainties
  - Structural uncertainties (discretization, model inadequacy)
- **All boundary conditions**
  - external forcing, bathymetry, lateral boundaries
- **Use of prior knowledge** (e.g., error covariances, representation error)

Approaches to quantify uncertainties

- I.C. uncertainties
- Forcing uncertainties
- Parametric uncertainties
  - Stochastic parameterization (see Max Trostel's work)
- Hessian-based UQ for observing system design
  - see Nora Loose's work

Approaches to quantify uncertainties

- **Forcing uncertainties**

Two main goals of this work

1. Investigate structure of forcing adjustments

2. Investigate impact of perturbations to the forcing adjustments(!)
   - Two constraints:
     a) Perturbations should not alter cost function ”too much”
        (seek alternative “acceptable” ECCO solutions)
     b) Perturbations should be applied in a “consistent” manner, i.e., correlations among forcing fields (which indicate physics-based covariability)

ECCO's atmospheric forcing adjustment

$$V_{\mathrm{ERA}}(r, t) + V_{\mathrm{adj}}(r, t) = V_{\mathrm{ECCO}}(r, t)$$

- air temperature at 2 m above the sea surface
- precipitation
- specific humidity at 2 m above the sea surface
- zonal wind stress
- meridional wind stress
- downward longwave radiation
- downward shortwave radiation

Multivariate EOF analysis of atmospheric adjustment fields

- **decompose the space-time field $\boldsymbol{T(r, t)}$** into multiplications of spatial patterns $S_i(r)$ and corresponding principal components $a_i(t)$:

$$T(r, t) = \Sigma\, a_i(t)\, S_i(r)$$

$a_i(t)$ and $S_i(r)$ denote the i-th temporal and spatial EOF modes

- **Atmospheric adjustment fields expressed as**

$$V_{\mathrm{adj}}(r, t) = V_0(r) + V_1(r, t) + V_2(r, t) + \ldots$$

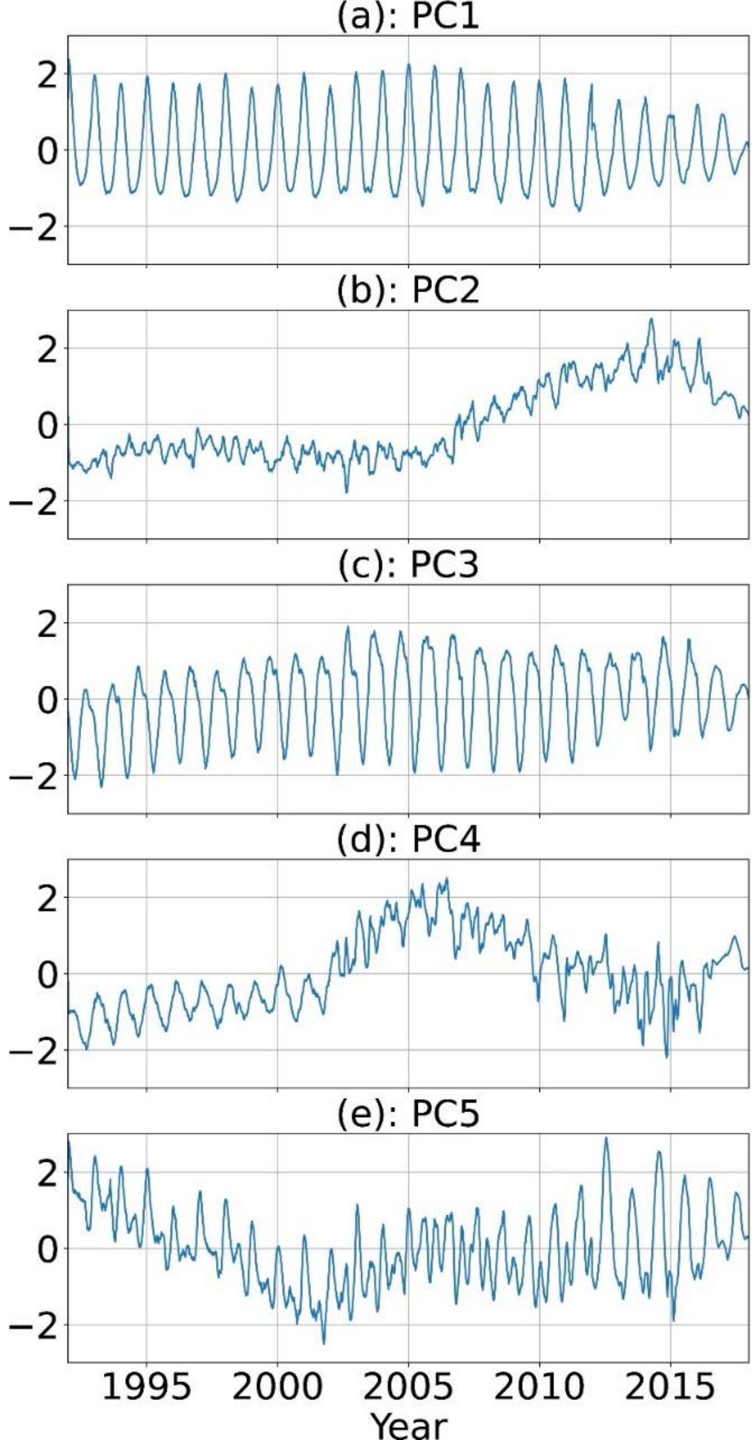
- **Full ECCO fields expressed as**

$$V_{\mathrm{ECCO}}(r, t) = V_{\mathrm{ERA}}(r, t) + V_0(r) + V_1(r, t) + V_2(r, t) + \ldots$$

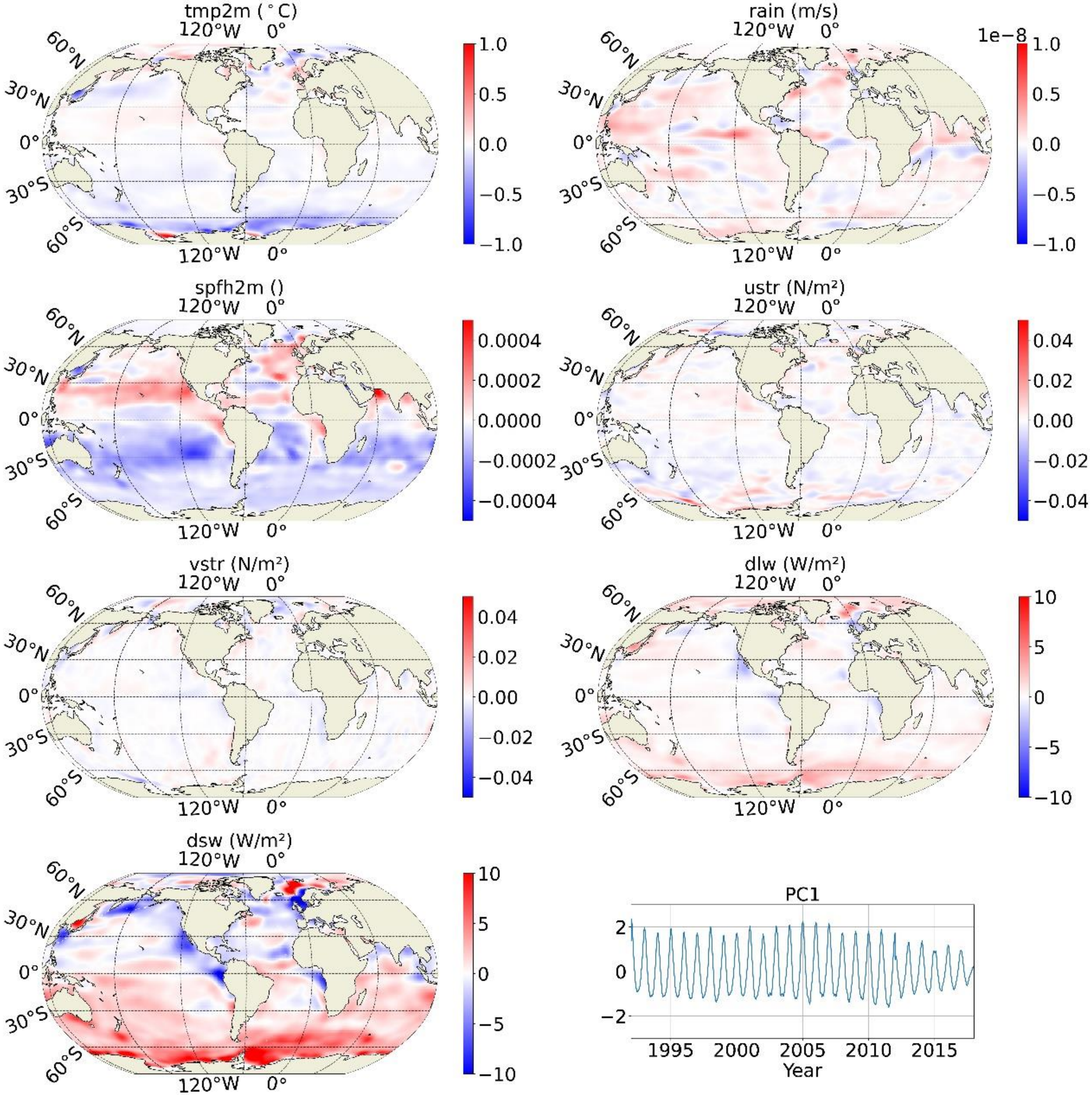
Perturbation experiments

• **EXP_ECCO:**	$V_{\mathrm{ECCO}}(r, t)$	(control run)
• **EXP_ERA:**	$V_{\mathrm{ERA}}(r, t)$	
• **EXP_0:**	$V_0(r)$	(time-mean of adjustment fields)
• EOF Experiments		
– **EXP_1:**	$V_1(r, t)$	(1st multivariate EOF)
– **EXP_2:**	$V_2(r, t)$	
– …		
– **EXP_*i*:**	$V_i(r, t)$	(i-th multivariate EOF)

5 leading principal components of atmospheric adjustments

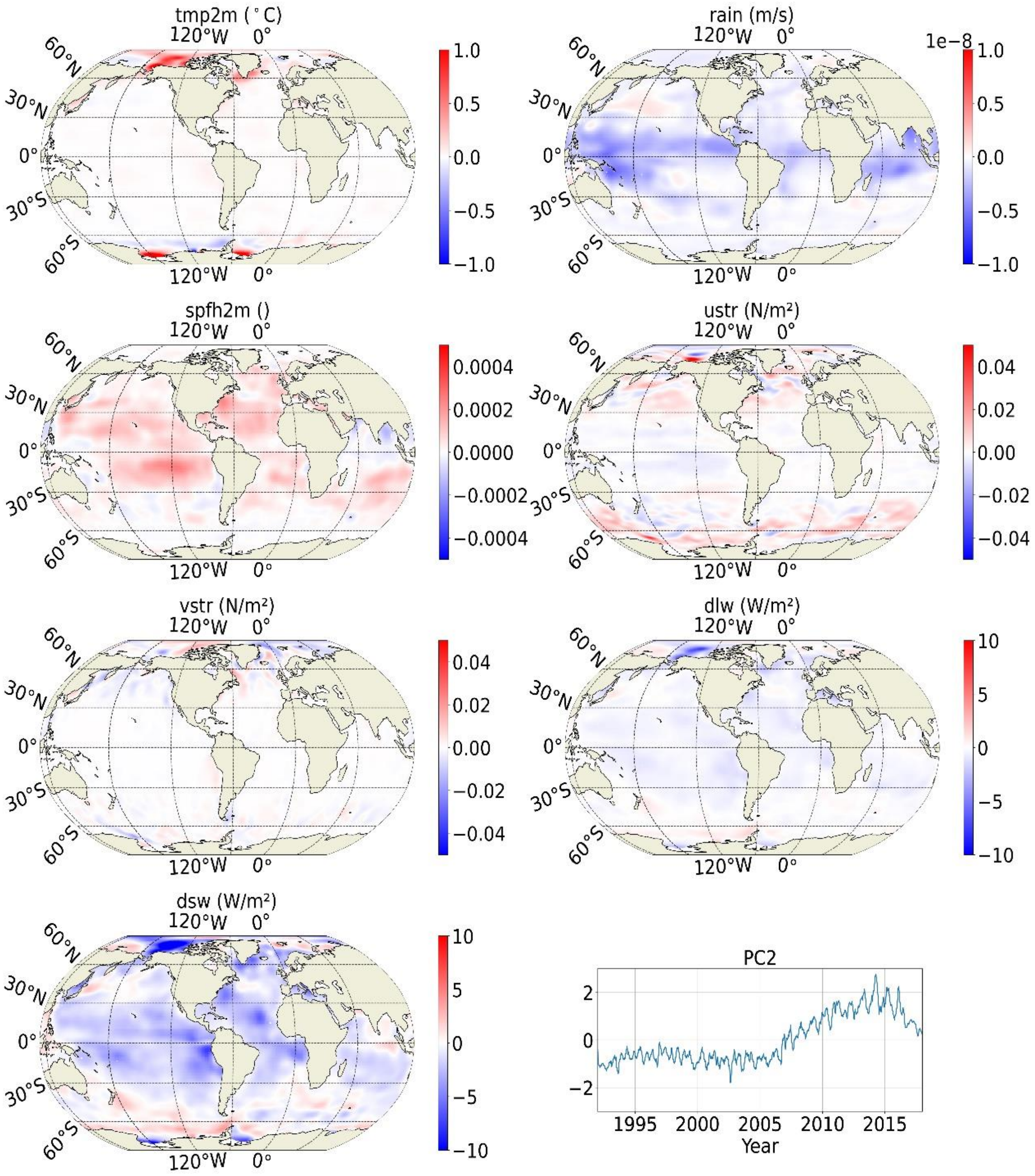


EOF & PC 1

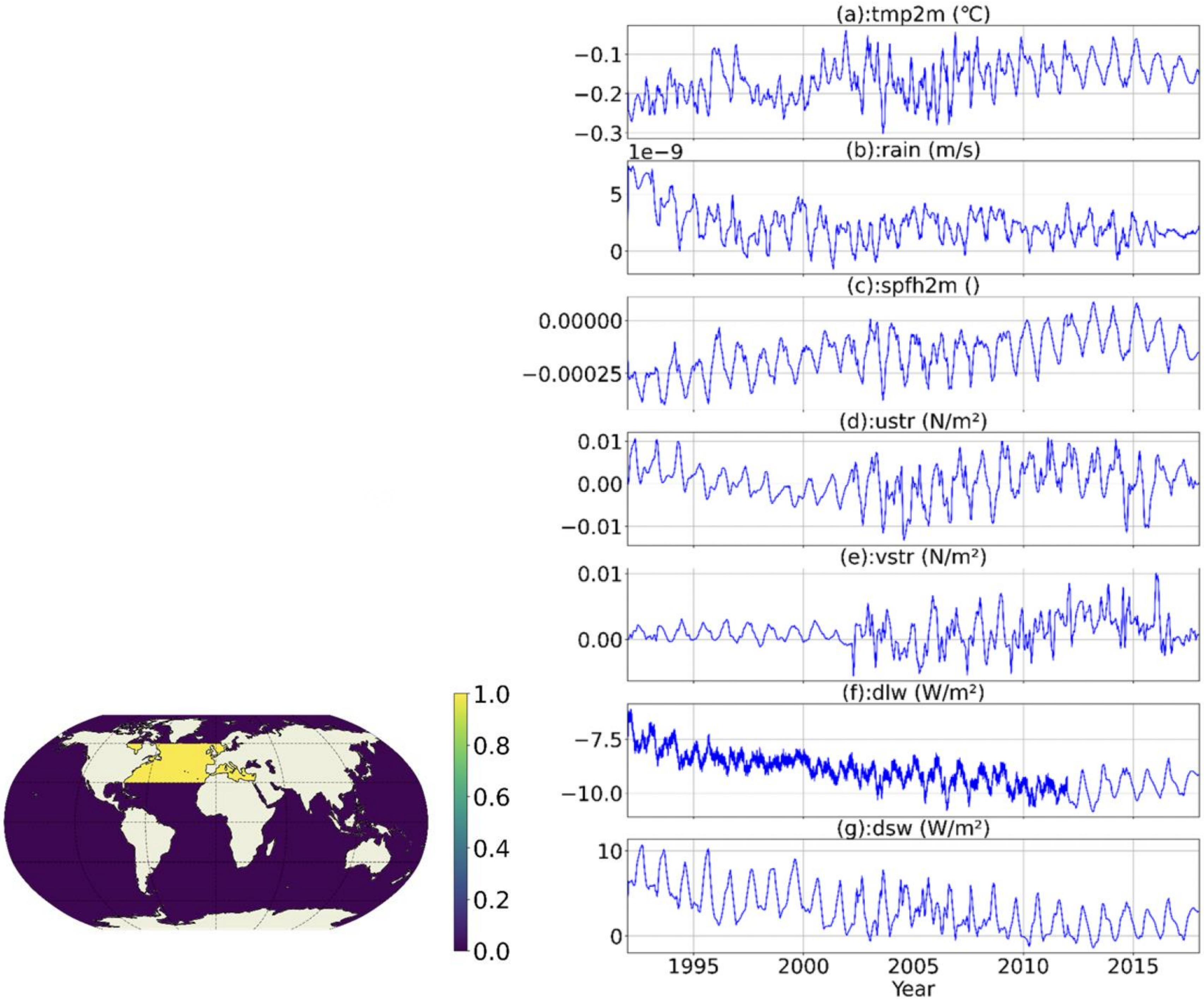


tmp2m (°C)
rain (m/s)
1e−8
spfh2m ()
ustr (N/m²)
vstr (N/m²)
dlw (W/m²)
dsw (W/m²)
PC1
Year

EOF & PC 2



tmp2m (°C)
rain (m/s)
1e−8
spfh2m ()
ustr (N/m²)
vstr (N/m²)
dlw (W/m²)
dsw (W/m²)
120°W
0°
60°N
30°N
0°
30°S
60°S
1.0
0.5
0.0
−0.5
−1.0
0.0004
0.0002
0.0000
−0.0002
−0.0004
0.04
0.02
0.00
−0.02
−0.04
10
5
0
−5
−10
PC2
2
0
−2
1995
2000
2005
2010
2015
Year



1.0
0.8
0.6
0.4
0.2
0.0
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−0.2
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1e−9
(b):rain (m/s)
5
0
(c):spfh2m ()
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−0.00025
(d):ustr (N/m²)
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0.00
−0.01
(e):vstr (N/m²)
0.01
0.00
(f):dlw (W/m²)
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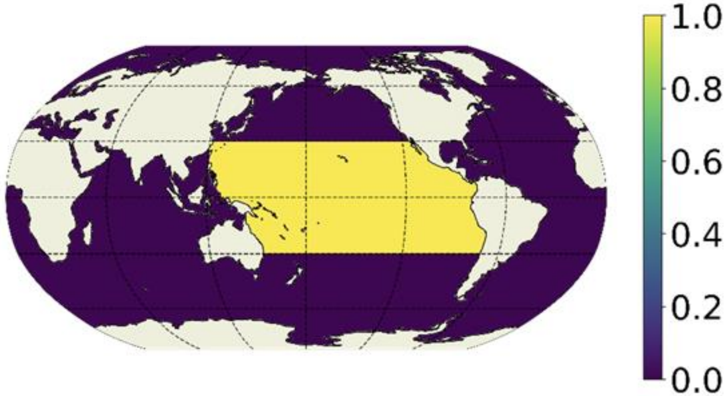
−10.0
(g):dsw (W/m²)
10
0
1995
2000
2005
2010
2015
Year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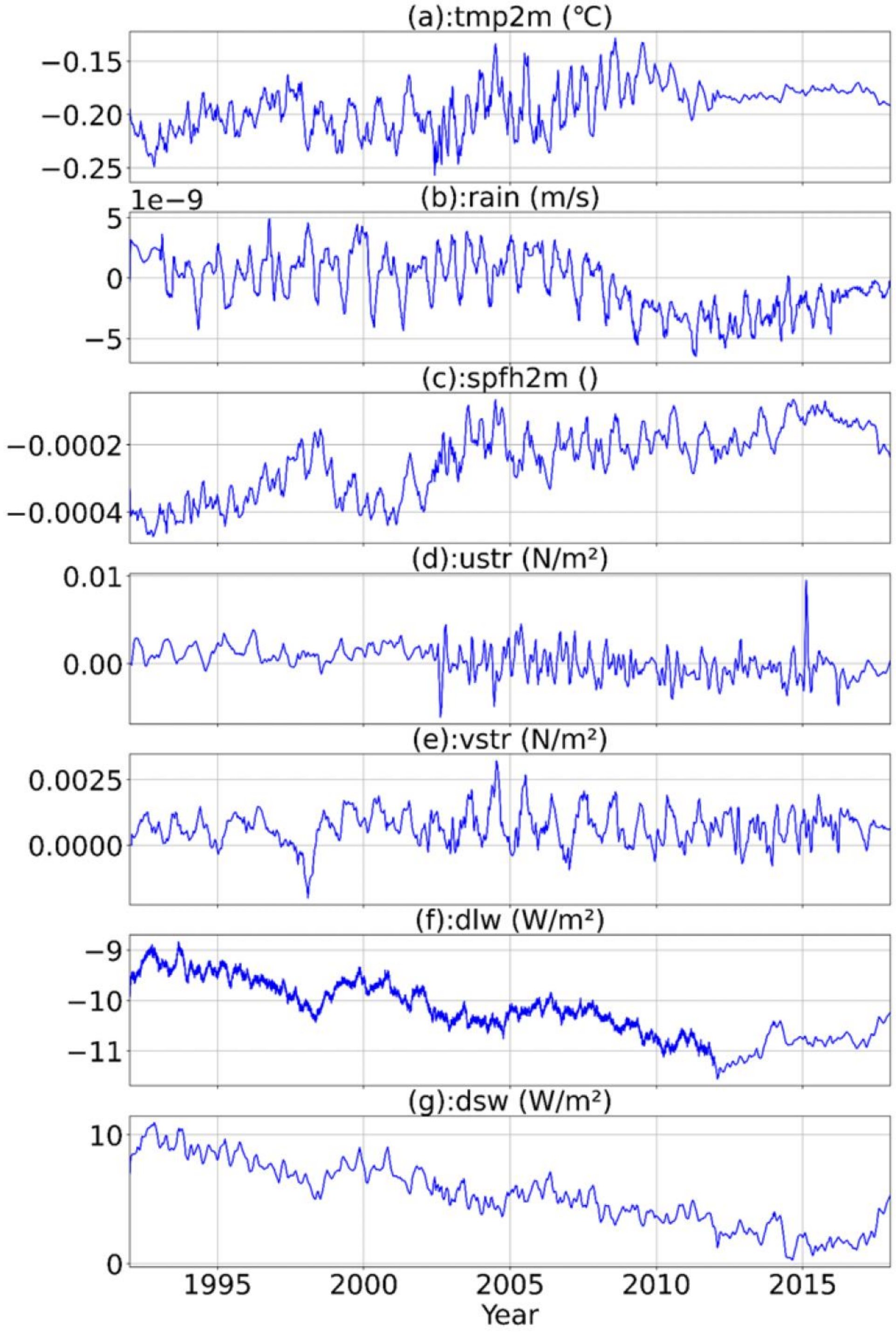
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−0.25
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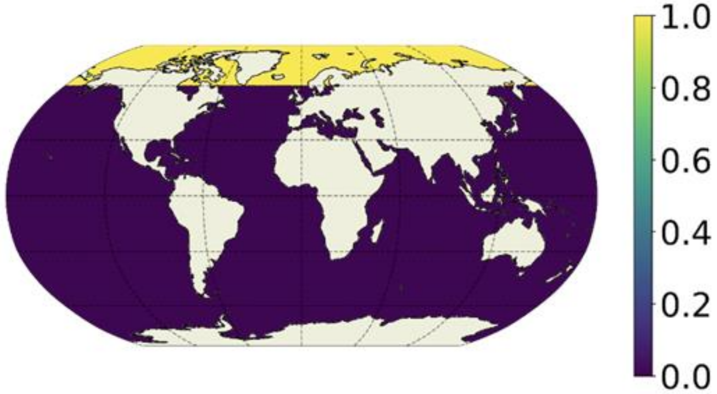
1e−9
5
0
−5
(c):spfh2m ()
−0.0002
−0.0004
(d):ustr (N/m²)
0.01
0.00
(e):vstr (N/m²)
0.0025
0.0000
(f):dlw (W/m²)
−9
−10
−11
(g):dsw (W/m²)
10
0
1995
2000
2005
2010
2015
Year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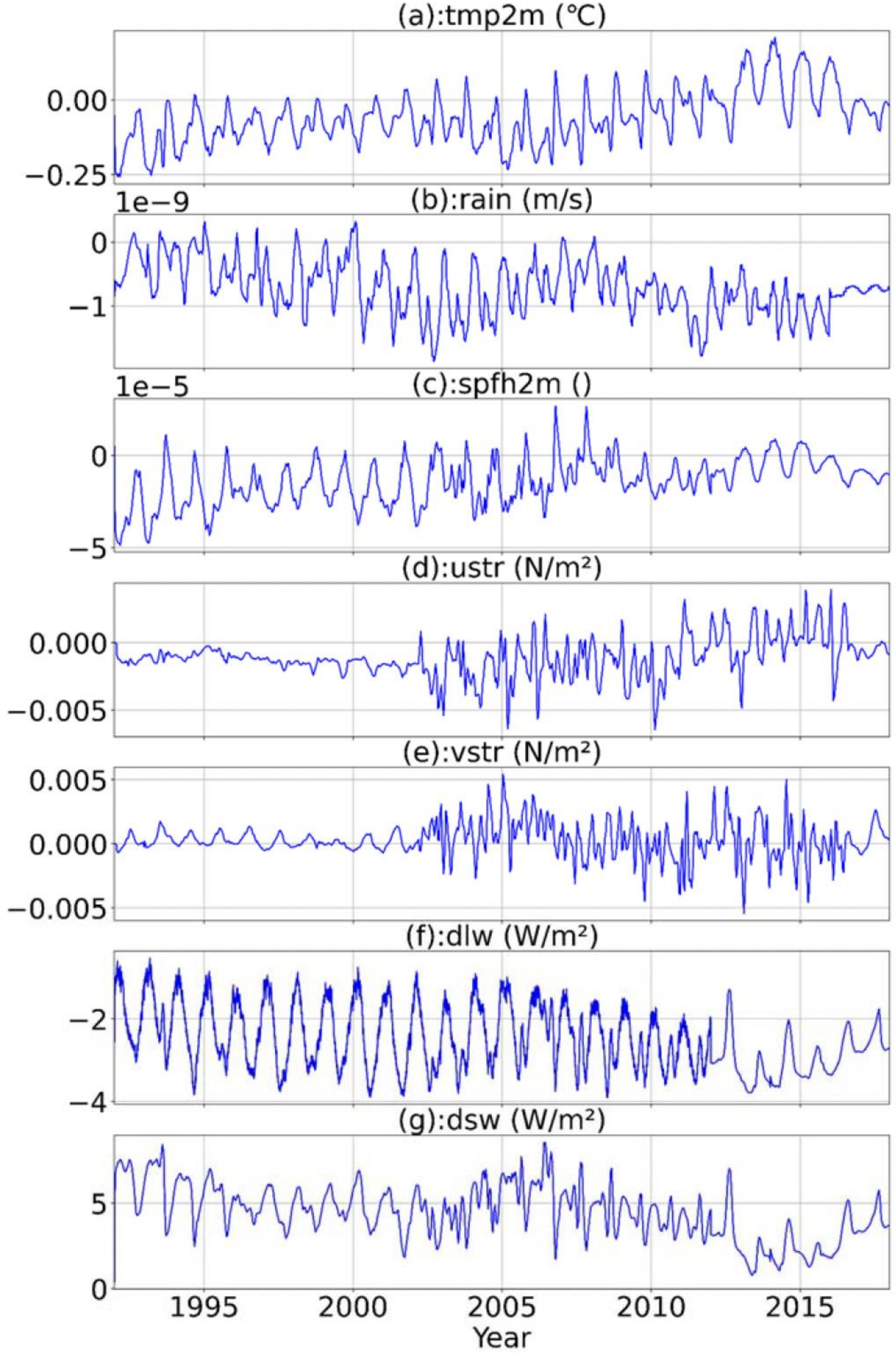
0.6
0.4
0.2
0.0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1e−9
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1e−5
(d):ustr (N/m²)
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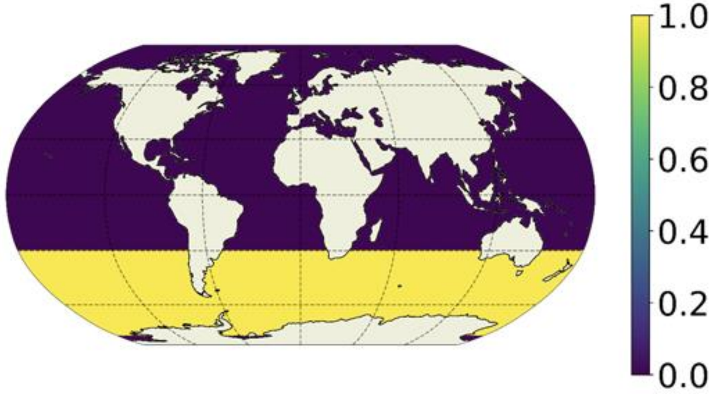
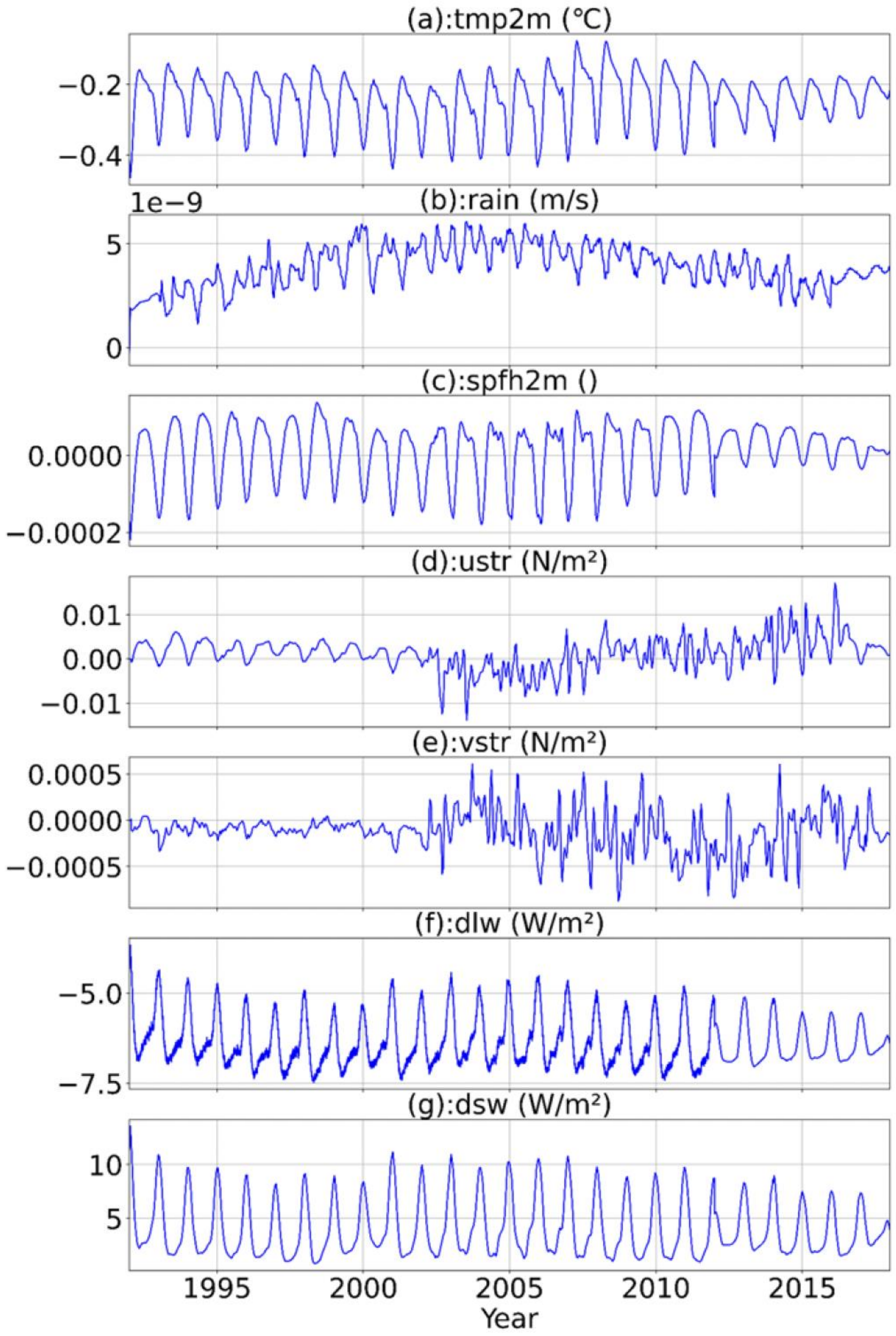
(f):dlw (W/m²)
(g):dsw (W/m²)
Year


1.0
0.8
0.6
0.4
0.2
0.0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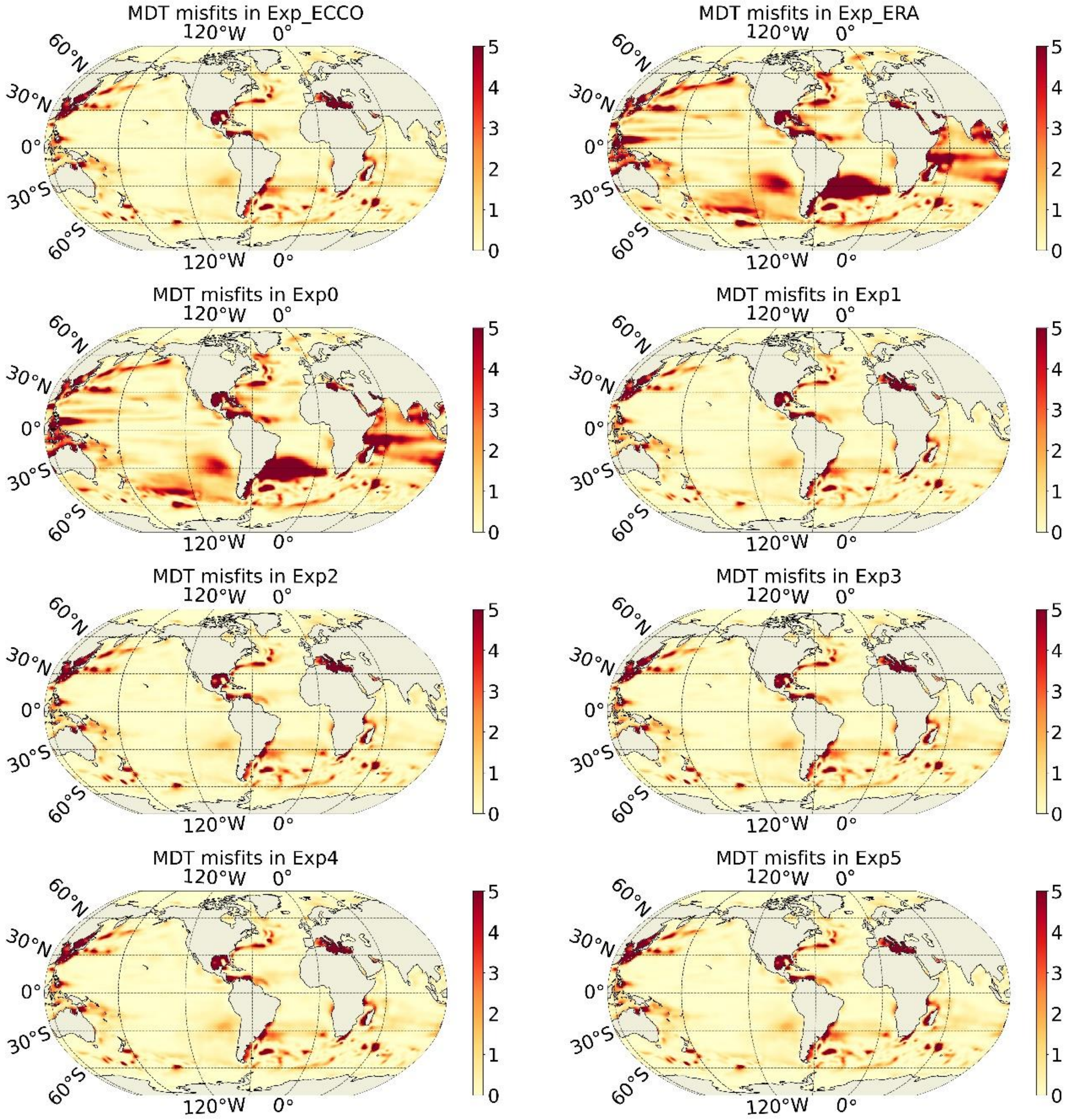
−0.4
1e−9
(b):rain (m/s)
5
0
(c):spfh2m ()
0.0000
−0.0002
(d):ustr (N/m²)
0.01
0.00
−0.01
(e):vstr (N/m²)
0.0005
0.0000
−0.0005
(f):dlw (W/m²)
−5.0
−7.5
(g):dsw (W/m²)
10
5
1995
2000
2005
2010
2015
Year

Cost misfits

Mean Dynamic Topography

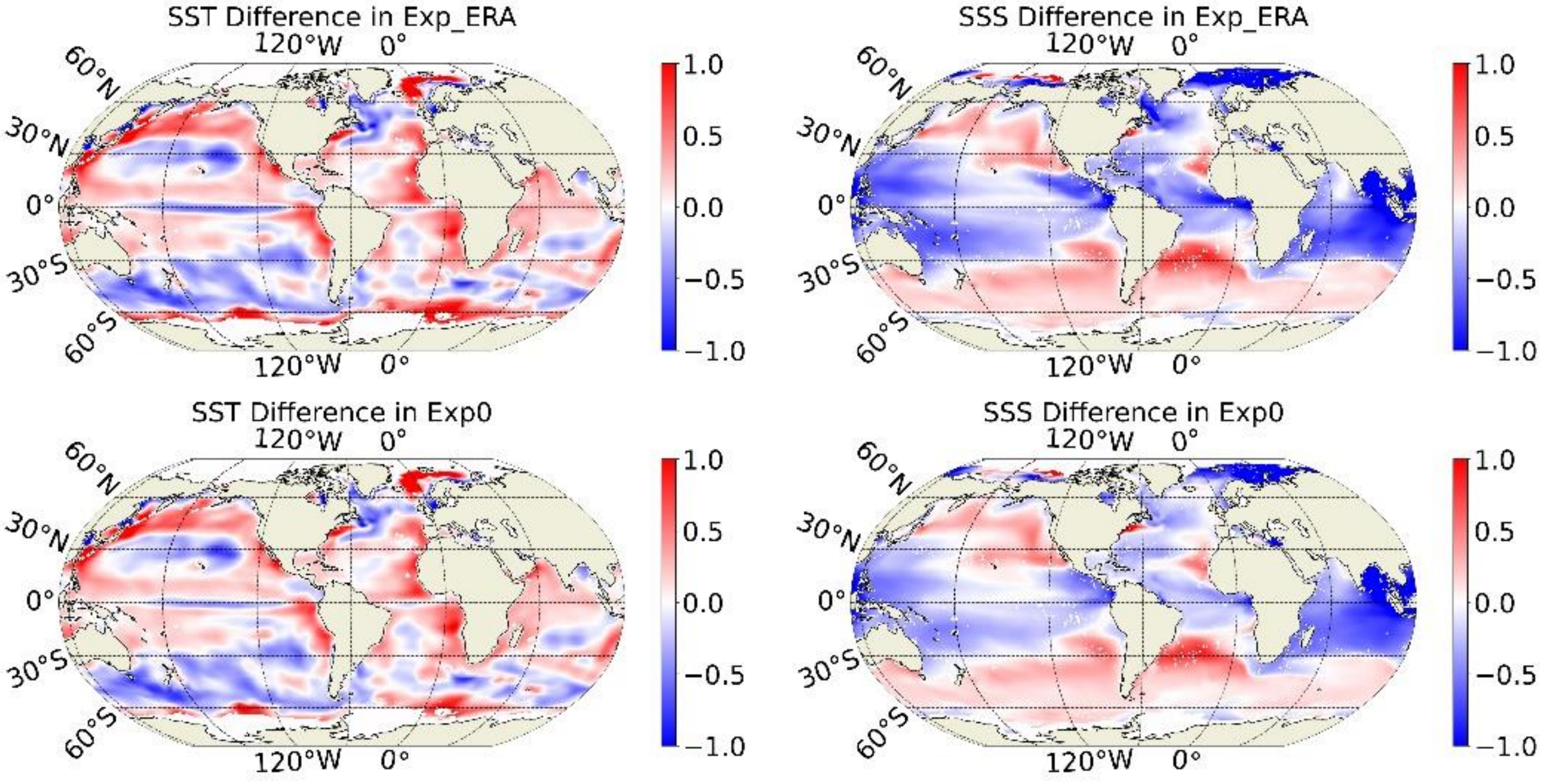
- EXP_ECCO – Control Run
- EXP_ERA
- EXP_0
- EOF Experiments
  - EXP_1
  - EXP_2
  - EXP_3
  - EXP_4
  - EXP_5



Differences between control simulation and perturbation experiments

Left: *SST*

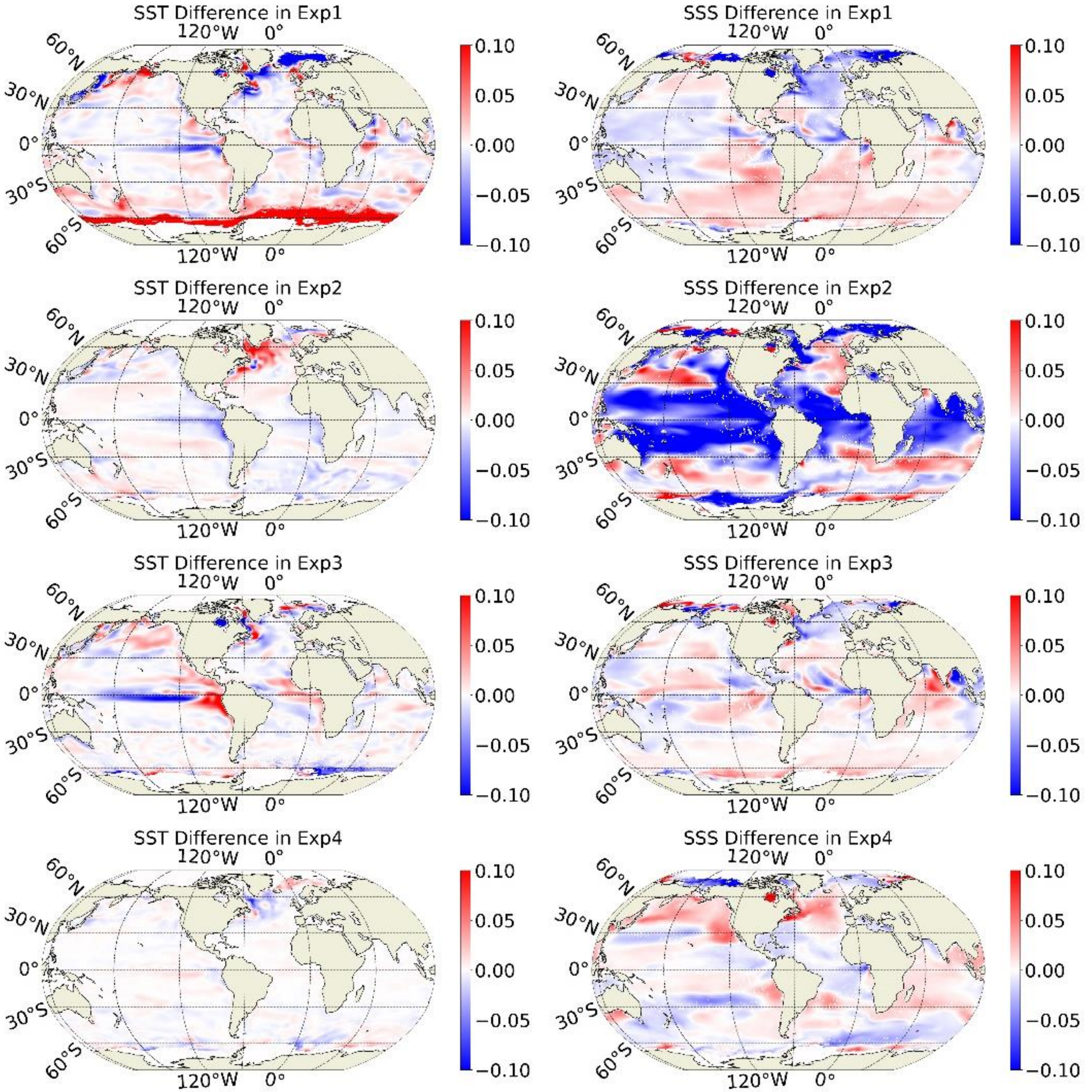
Right SSS



Differences between control simulation and perturbation experiments

Left: ***SST***

Right SSS



Preliminary conclusion

- Structure of adjustment fields is peculiar – warrants more careful look
- Much of the adjustments captured in the time-mean field
- Perturbing state with multivariate EOFs gives only small changes in misfits
  - Are these useful perturbation experiments?
- Haven't considered initial condition perturbations yet