Observationally Based Analysis of Land–Atmosphere Coupling

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Outline

Motivations

- Predictability of climate at seasonal and longer time scales stems from the interaction of the atmosphere with slowly varying components of the climate system: <u>ocean</u> and <u>land surface</u> (ENSO)

- Persistent anomalies in land-surface variables may provide memory to external forcings (volcanic eruptions)

Observational analysis of land-atmosphere coupling

- Datasets
- Methodology
- Results

Conclusions

NEW PAPER PUBLISHED:

- Catalano F., A. Alessandri, M. De Felice, Z. Zhu, and R. B. Myneni, 2016: Observationally based analysis of land–atmosphere coupling. Earth Syst. Dynam. 7, 251-266, doi:10.5194/esd-7-251-2016

Observational datasets

	ET	LAI	SM	PRE
Type	satellite	satellite	satellite	gridded from rain gauges
Version	-	1.0	0.1	2.2
Producer	Univ. Montana	Boston Univ.	ESA	GPCP
Spatial resolution (original)	1° x 1°	8 km x 8 km	0.25° x 0.25°	2.5° x 2.5°
Spatial resolution (after pre-processing)	1° x 1°	0.5° x 0.5°	0.5° x 0.5°	2.5° x 2.5°
Temporal frequency (original)	monthly	15-days	daily	monthly
Temporal frequency (after pre-processing)	seasonal	seasonal	seasonal	seasonal
Units	W m^{-2}	m^2 m^{-2}	m^3 m^{-3}	mm d^{-1}
Period	1983-2006	1982-2010	1979-2010	1979-2010
Reference	Zhang et al. (2010)	Zhu et al. (2013)	Liu et al. (2011, 2012)	Adler et al. (2003)

Pre-processing

- Seasonal-mean interannual anomalies;

  Stratification: JFM (January-February-March), AMJ (April-May- June), JAS (July-August-September), OND (October-November-December);

- Replacement of missing values with climatology for LAI and SM where their total number does not exceed a given threshold (10% for LAI and 30% for SM for similar coverage);

Methodology: the Coupled Manifold

Main assumption

- Two climate fields S and Z may be linked by a linear relation (Navarra and Tribbia, 2005):

$$Z = Z_{for} + Z_{free} = \mathbf{A}S + Z_{free}$$

$$S = S_{for} + S_{free} = \mathbf{B}Z + S_{free}$$

- The technique is applied to the Principal Components (PC) of Z and S
- **A** and **B** are linear operators whose coefficients express the relations between the modes of Z and S
- Data scaled by the covariance matrices: $\begin{cases} \hat{Z} = (ZZ')^{-1/2} Z \\ \hat{S} = (SS')^{-1/2} S \end{cases} \longrightarrow \hat{B} = \hat{A}'$
- Coefficients of the coupling matrices are found by solving the minimization Procrustes problem:

$$\min \| Z - AS \|_F^2 \longrightarrow \hat{A} = \hat{Z}\hat{S}'$$

Each element of the coupling matrices is tested against the null hypothesis of being equal to zero at the **1% significance level** (Cherchi et al., 2007)

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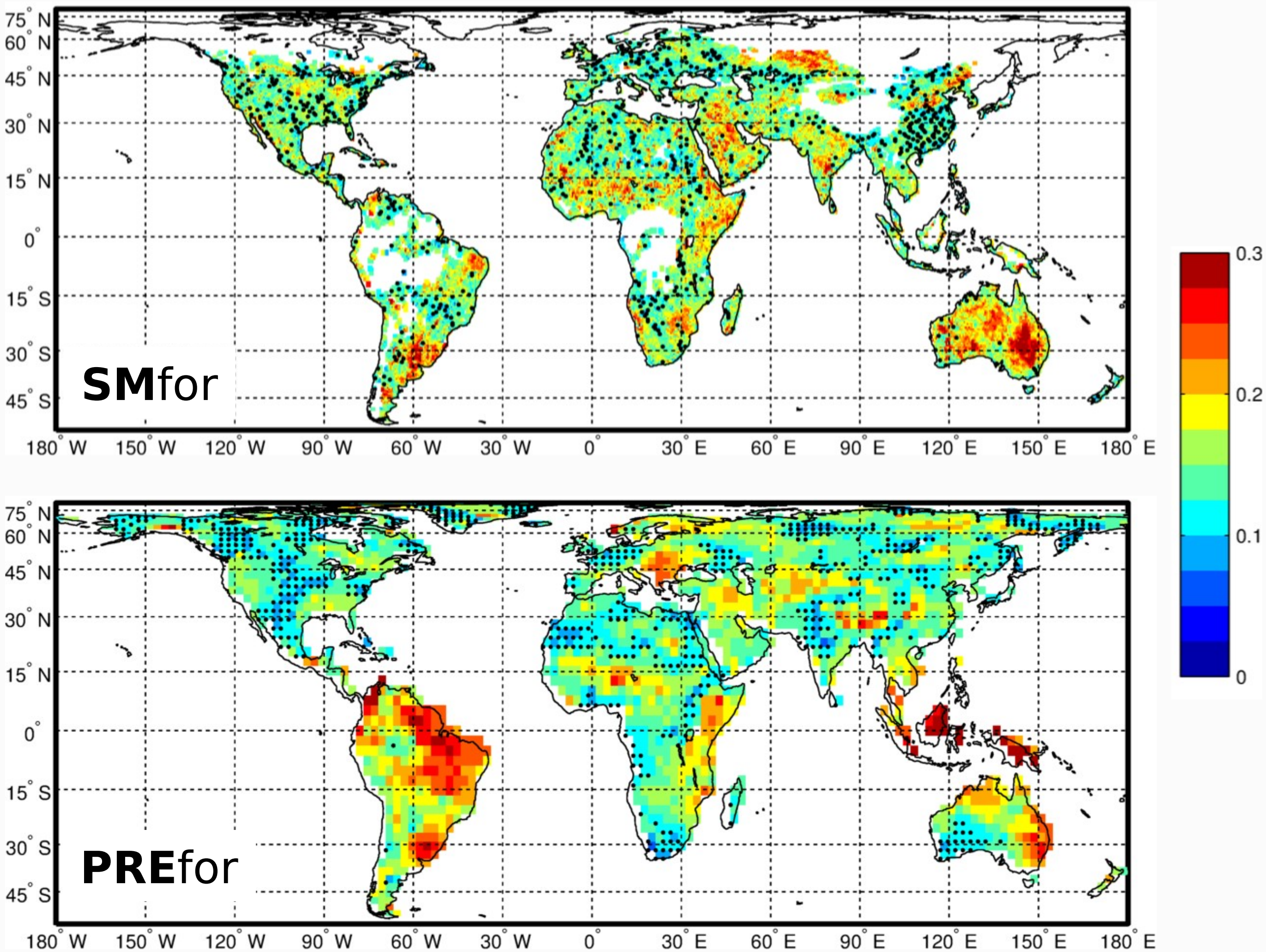
Main advantages of the technique:

- The technique is able to find robust relations between fields in presence of strong background noise
- Detects both local and remote effects of the forcing variable

Soil moisture-precipitation coupling



	Forced	Free
SM	0.17	0.83
PRE	0.19	0.81
ET	0.14	0.86
PRE	0.18	0.82
LAI	0.14	0.86
PRE	0.17	0.83

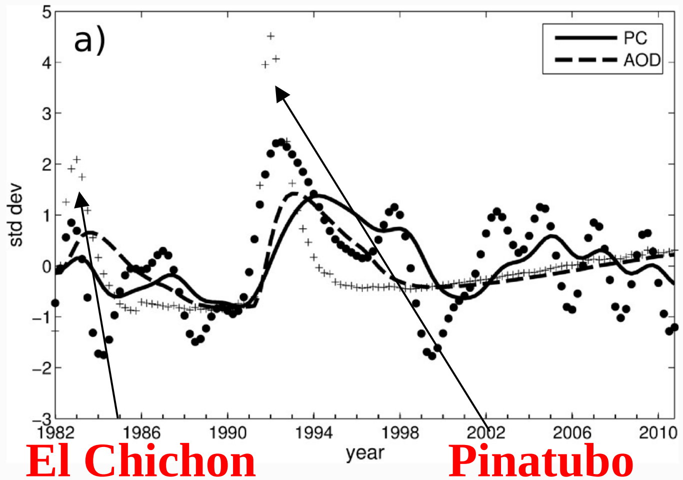
Ratios of the global-scale forced and free variance with respect to the total variance
Significant at the 1% level
(Monte Carlo bootstrap with 1000 repetitions)

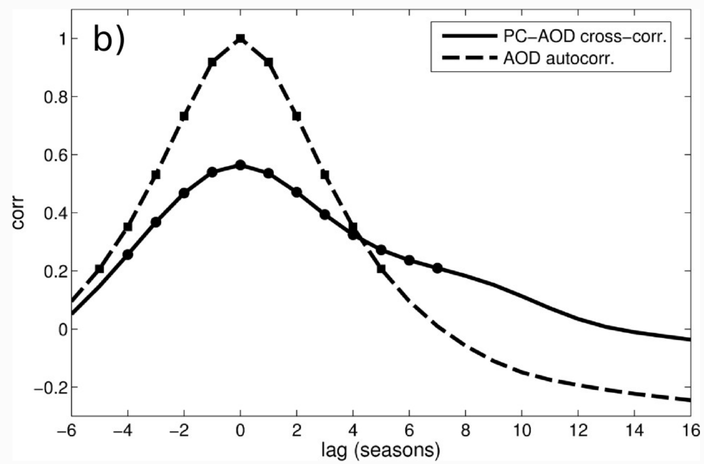
Ratio of the forced variance to the total variance.
(a) SM forced by PRE.
(b) PRE forced by SM.

Dots where variance ratio did not pass significance test at the 1% level
(Monte Carlo bootstrap with 1000 repetitions)

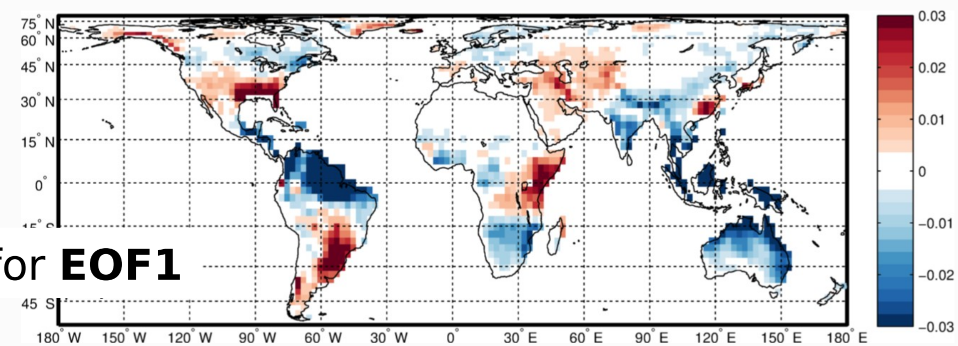
Response to volcanic eruptions

PRE forced by SM **PC1** expl. var.: 26%





PREfor **EOF1**



In 1991, abrupt decrease of PREfor PC1 lasting until 1994.
Dimming effect: reduction of PRE over humid regions: most SH and Asian monsoon region, increase of PRE over arid and semi-arid regions

Significant correlations up to about two years. Persistence of the negative SM anomalies provides the memory of the initial perturbing event (Mt Pinatubo eruption).

(a) First PC of PRE forced by SM (full line and filled circles). Dashed line (cross marks): stratospheric Aerosol Optical Depth (AOD). Lines: 5-years running means, marks: each single season.
(b) Lagged correlations between AOD and PC1 of the forced PRE. Dashed curve: AOD autocorrelation.

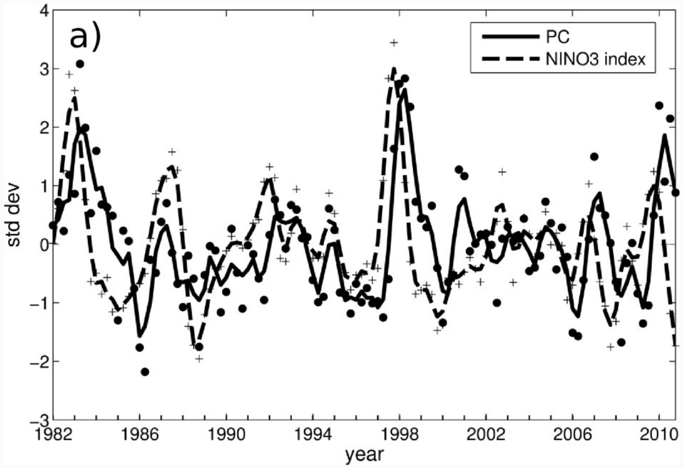
Marks in (b) indicate <u>significance at the 5% level</u>

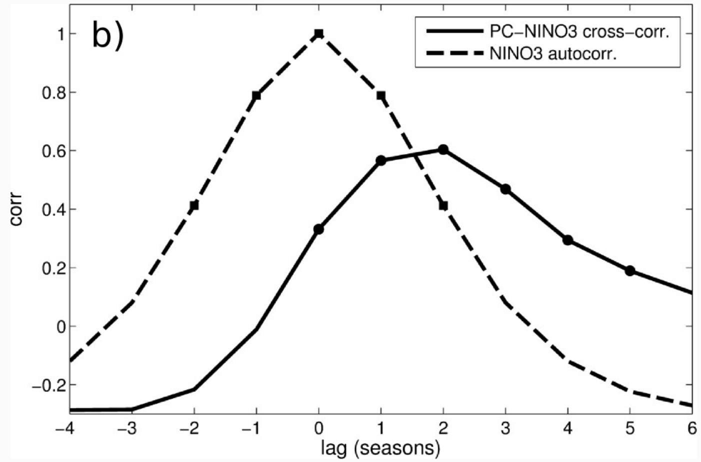
AOD from NASA GISS dataset

Response to ENSO

PRE forced by SM **PC2**

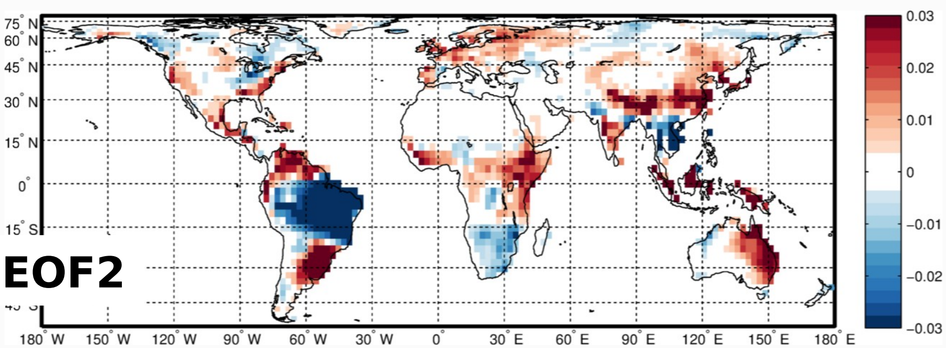
expl. var.: 14%





Large-scale oscillation correlated to ENSO variability. Tripole pattern over South America in EOF2 typical of ENSO teleconnections.

Significant correlations up to more than one year lag. ENSO effects on SM induce a delayed forcing on PRE.



PREfor **EOF2**

(a) Second PC of PRE forced by SM (full line and filled circles). Dashed line (cross marks): NINO3 index. Lines: 3-seasons running means, marks: each single season.
(b) Lagged correlations between NINO3 index and PC1 of forced PRE. Dashed curve: NINO3 autocorrelation.

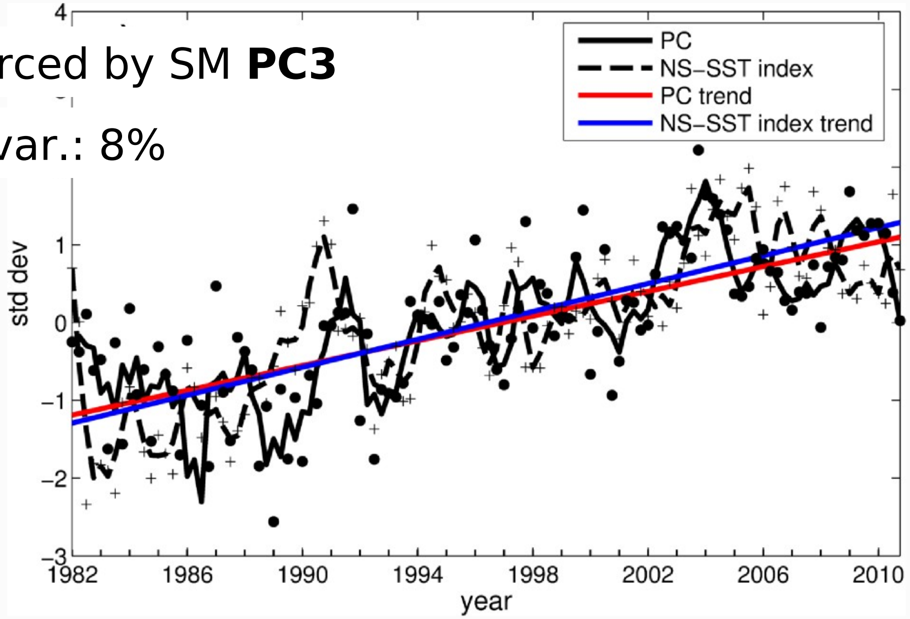
Marks in (b) indicate significance at the 5% level.

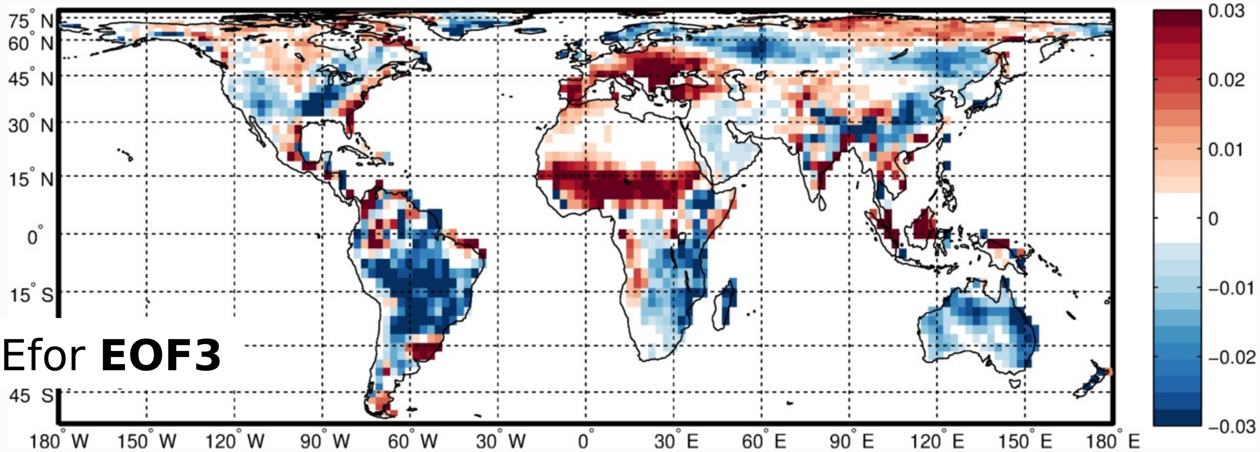
NINO3 index: average of SST in Tropical Pacific region (5S-5N, 210-270E)
SST from HadISST dataset

Trend

PRE forced by SM **PC3**

expl. var.: 8%





PREfor **EOF3**

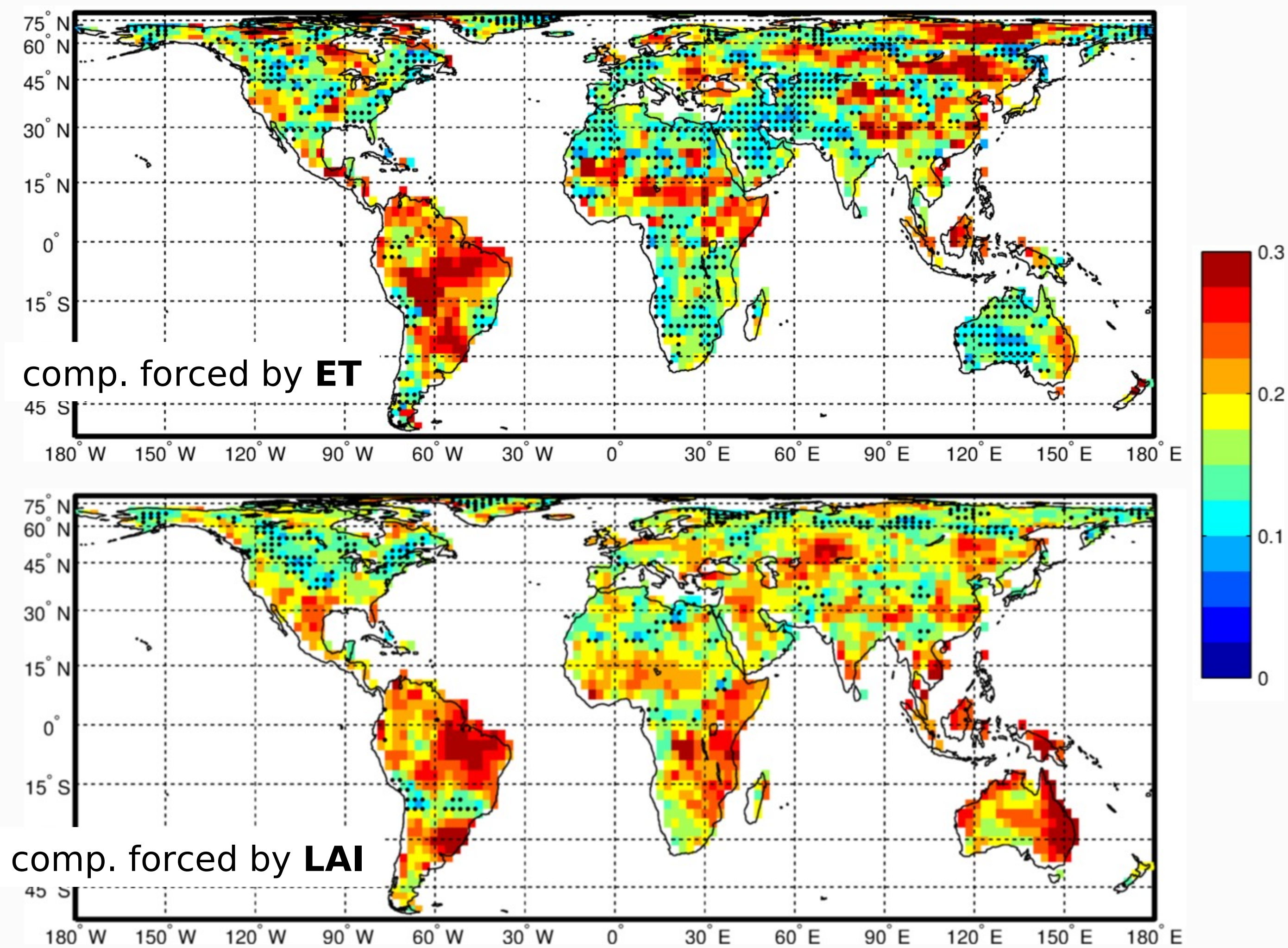
Trend of increasing precipitation over most NH, particularly strong over Sahel. Decreasing precipitation over most SH.
Pattern associated to a larger warming trend in NH with respect to SH, corresponding to an increase of specific humidity in NH (Munemoto and Tachibana, 2012)

Third PC of PRE forced by SM (full line and filled circles). Dashed line (cross marks): NS-SST index. Lines: 3-seasons running means, marks: each single season. Coloured lines: trends

NS-SST index: NH SST annual mean anomalies - SH SST anomalies

ET and LAI mediation of PRE-SM coupling

PREfor by SM



Ratio of the forced variance to the total variance
(a) PREfor by SM - component forced by ET
(b) PREfor by SM – component forced by LAI

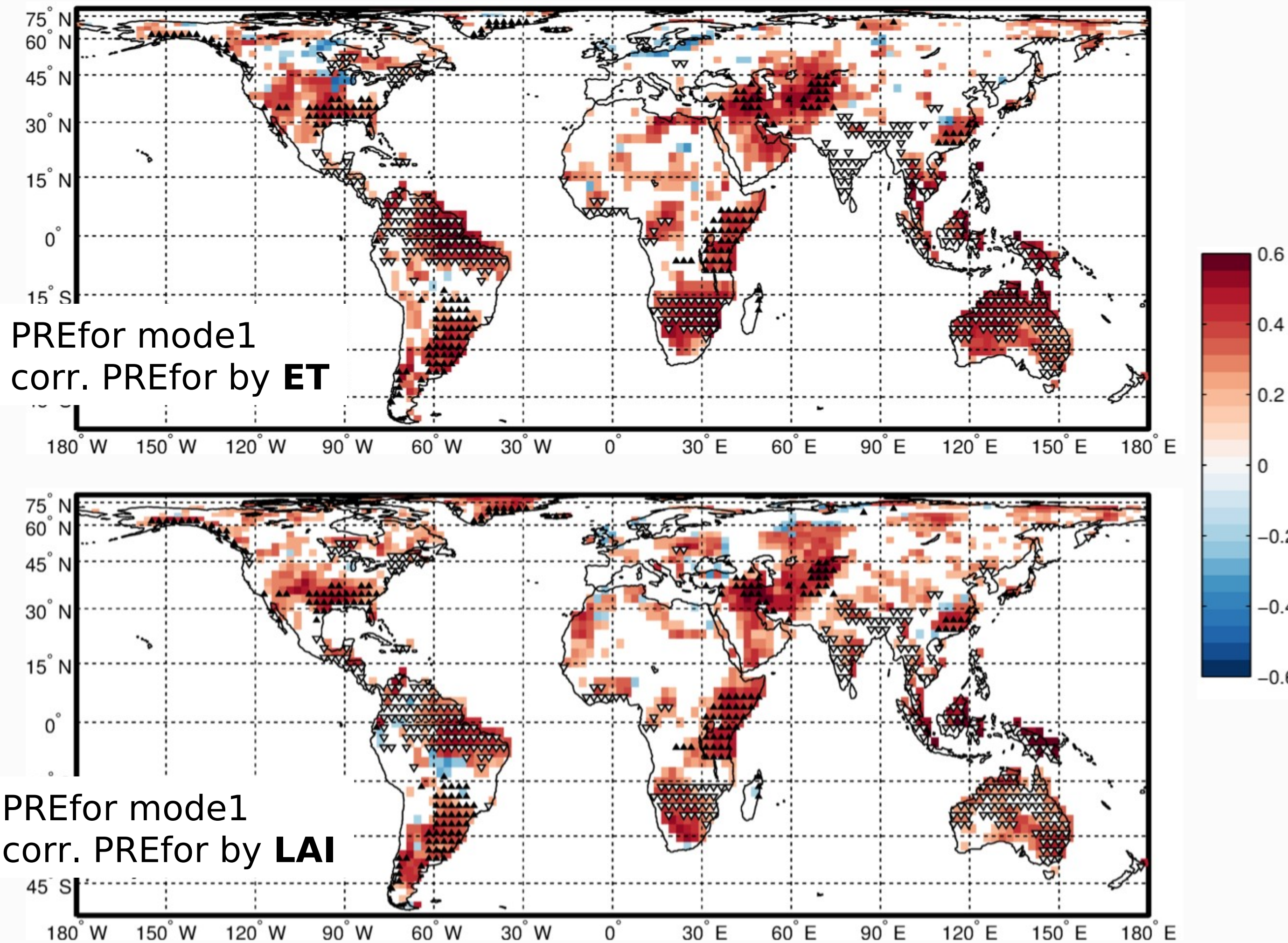
Dots where variance ratio did not pass <u>significance test at the 1% level</u>
(Monte Carlo bootstrap with 1000 repetitions)

	Forced	Free
forced by ET	0.20	0.80
forced by LAI	0.23	0.77

Ratios of the global-scale forced and free variance with respect to the total variance
<u>Significant at the 1% level</u>
(Monte Carlo bootstrap with 1000 repetitions)

Vegetation mediation effect over semi-arid regions not dependent on ET

ET and LAI mediate the volcanic effect on PRE forced by SM



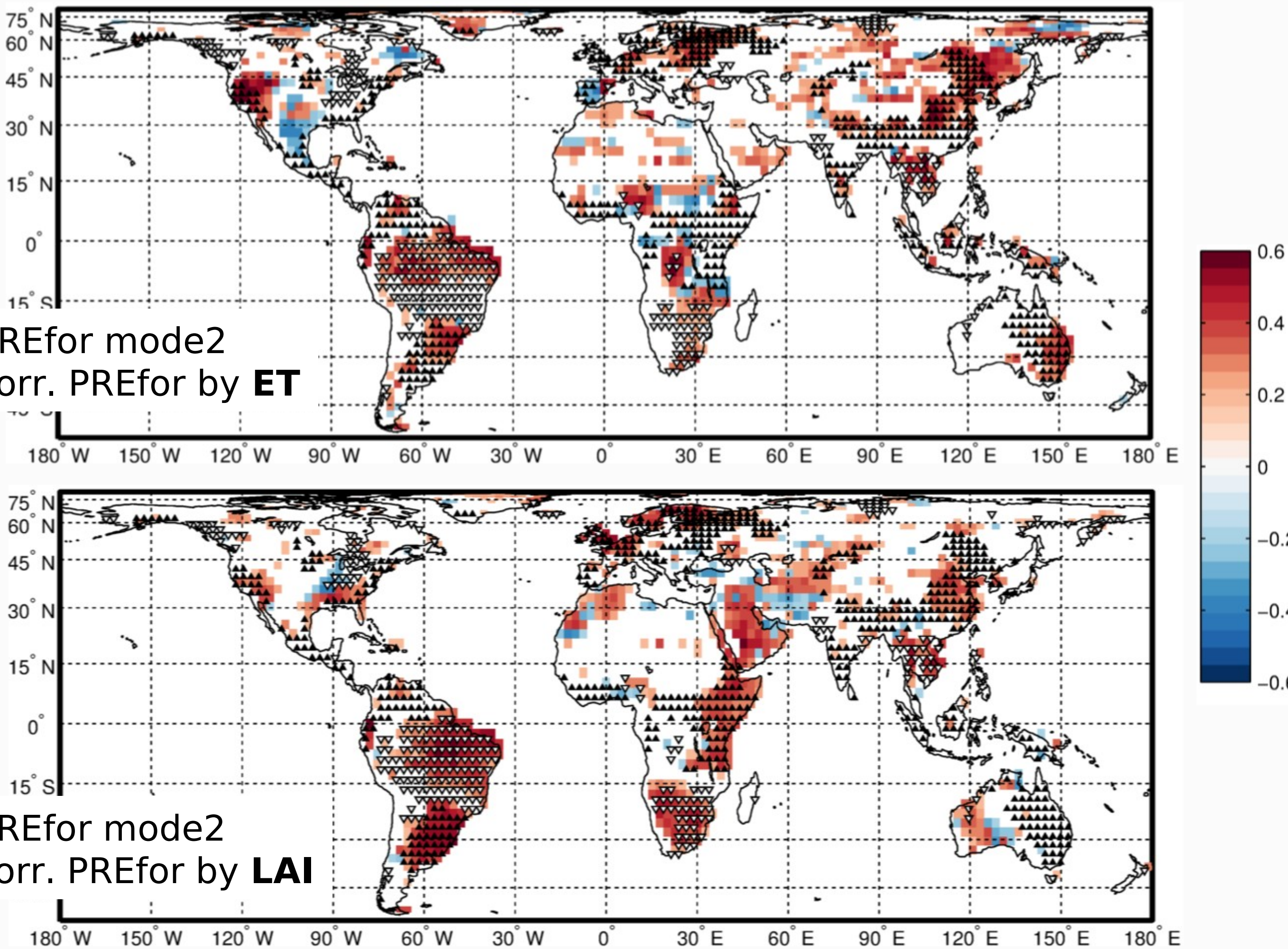
Positive feedback where ET and LAI are radiation limited, similar patterns.

Dimming effect:
-in humid regions rainfall reduction stresses vegetation;
-over arid and semi-arid regions reduced evapotranspiration increases SM, attenuate stress on vegetation and determine a positive effect on PRE

Point-by-point correlation of the first mode of variability of PRE forced by SM with:
(a) PRE forced by ET
(b) PRE forced by LAI
<u>Correlations significant at the 5% level</u>

Black upward (white downward) triangles: positive >0.01 (negative <-0.01) values of the first EOF of PRE forced by SM

ET and LAI mediate the ENSO effect on PRE forced by SM



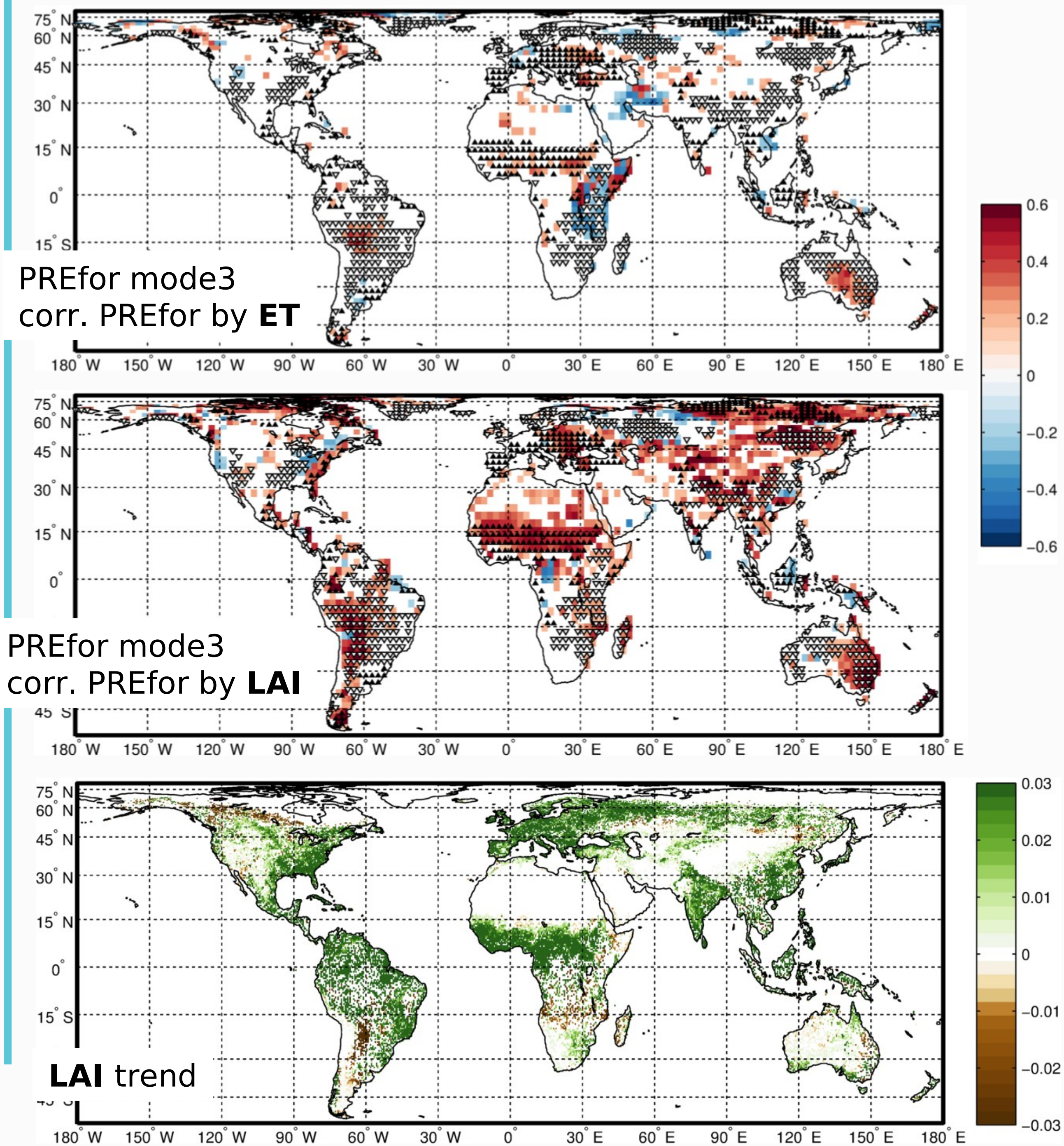
Positive feedback: reduction of PRE over most wet climates, enhancement over most transition and semi-arid climates.

Negative feedback of **ET** over regions where the positive ENSO phase induces wet and cool conditions (i.e. Mexico).

Point-by-point correlation of the second mode of variability of PRE forced by SM with:
(a) PRE forced by ET
(b) PRE forced by LAI
Correlations significant at the 5% level

Black upward (white downward) triangles: positive >0.01 (negative <-0.01) values of the second EOF of PRE forced by SM

Trend: LAI mediates the effects on PRE forced by SM



ET feedbacks non significant over most NH, apart from Sahel, negative feedback over Tanzania

Positive feedback of **LAI**:
-amplification of rainfall response to SST trend
-contribution to reduction of PRE over SH.

<u>Positive (negative) trends of rainfall associated to greening (browning) vegetation trends</u>

Point-by-point correlation of the third mode of variability of PRE forced by SM with:
(a) PRE forced by ET
(b) PRE forced by LAI
(c) LAI trend
<u>Correlations and LAI trend significant at the 5% level</u>

Black upward (white downward) triangles: positive >0.01 (negative <-0.01) values of the second EOF of PRE forced by SM

Conclusions

- Observational analysis revealed a strong land-atmosphere coupling (up to 60% locally and 32% globally), in particular over: Amazon basin, Nordeste, Great Plains, Sahel, Europe, Indian Monsoon region
  - Soil moisture provides a memory of climatic events, like ENSO and intense volcanic eruptions (El Chichon and Pinatubo)
  - ET and LAI provide positive/negative feedbacks on PRE contributing to further enhance or reduce rainfall depending on the regions of the globe, with differences between wet, transition and semi-arid climates.

- Coupling with SM has to be considered un <u>underestimation of real coupling</u> due to incomplete cover of SM dataset.