The complex influence of the Atmospheric Evaporative Demand on Drought severity

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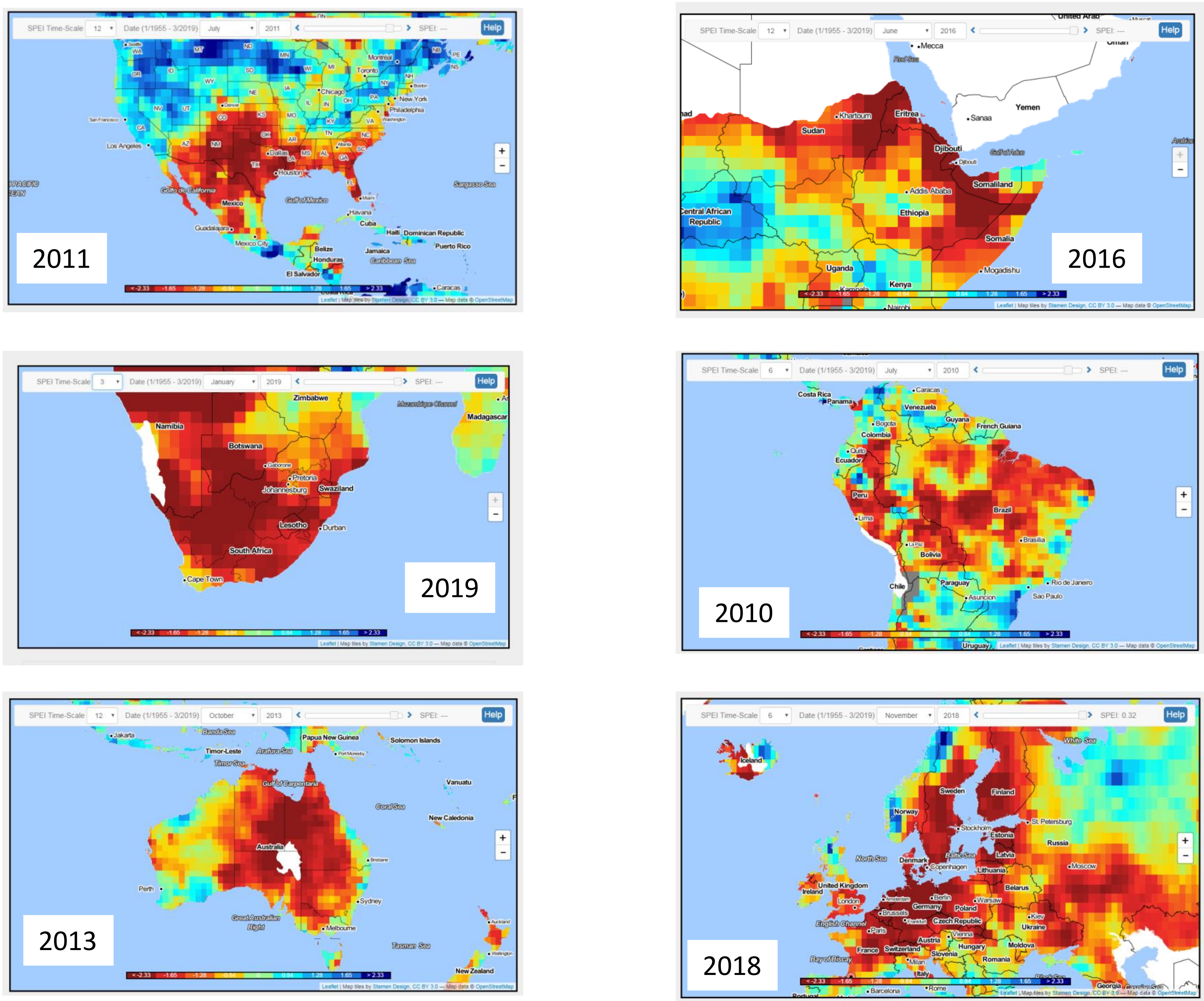
2011
2016
2019
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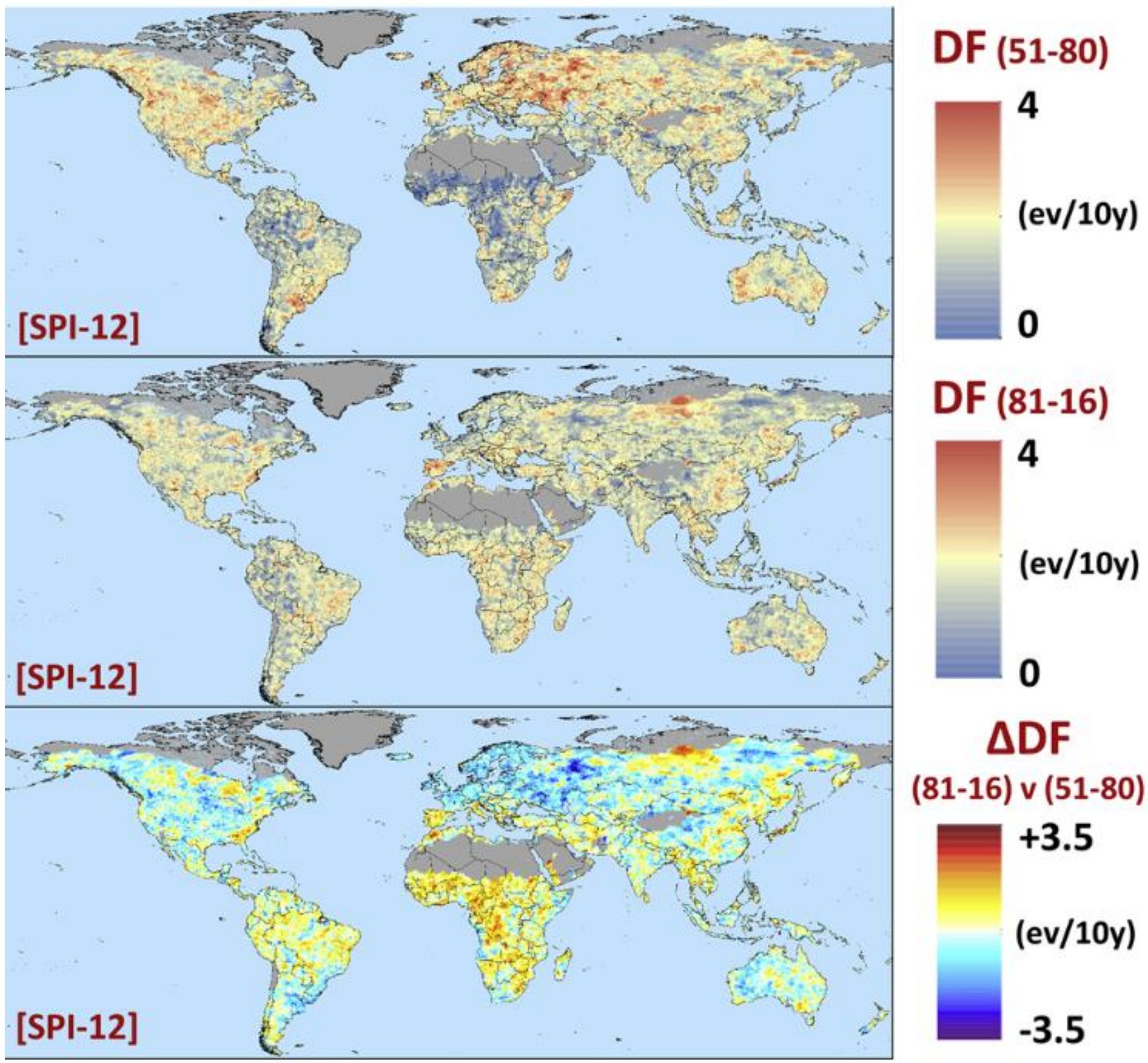
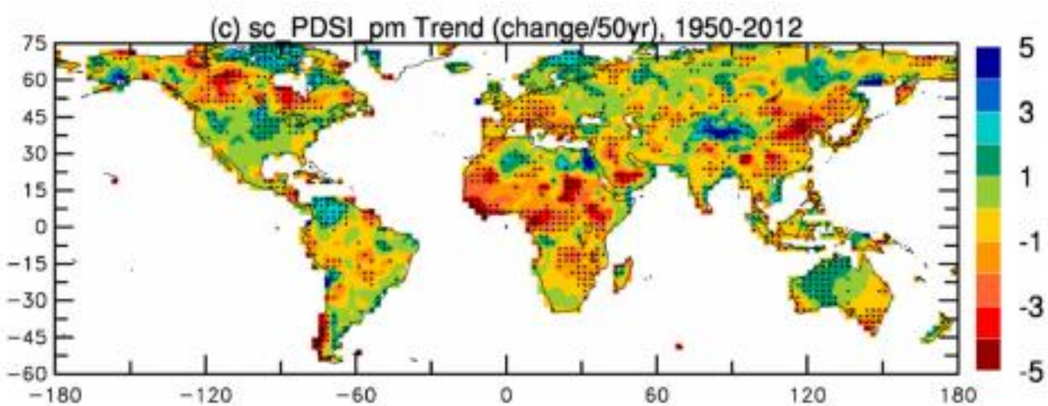
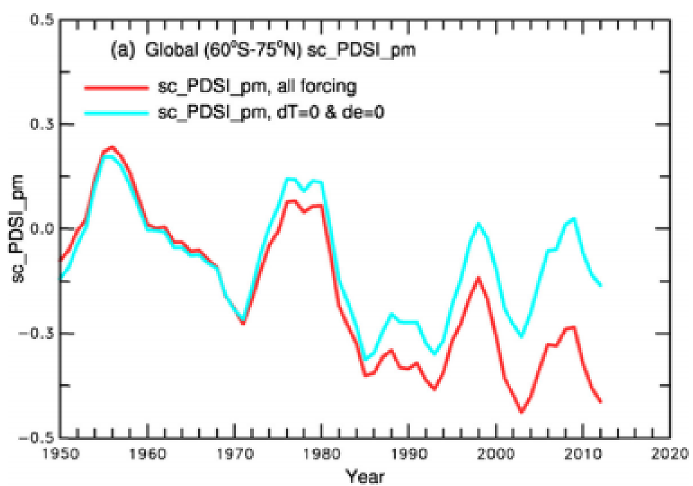
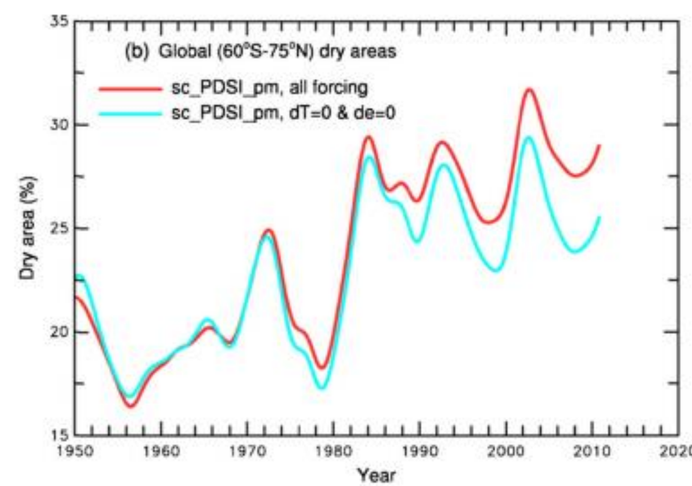
Changes in precipitation droughts



Spinoni et al. 2019

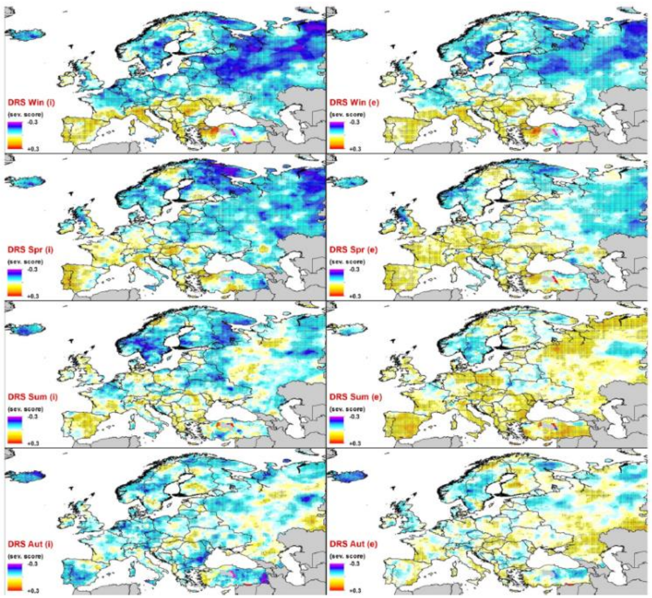




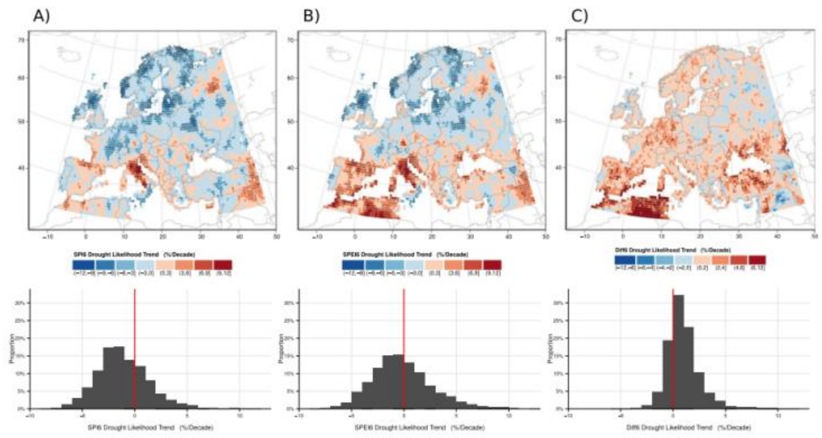


Dai and Zhao, 2017

SPI SPEI



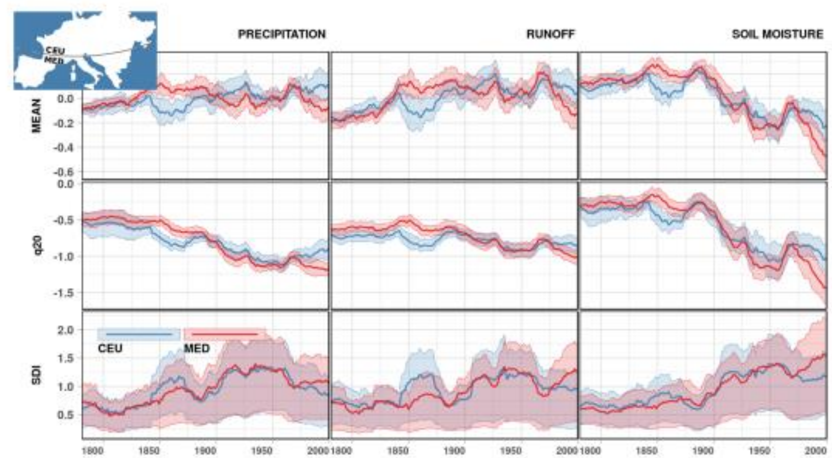
Spinoni et al. 2018



Stagge, J., et al. (2017) Sci. Reports

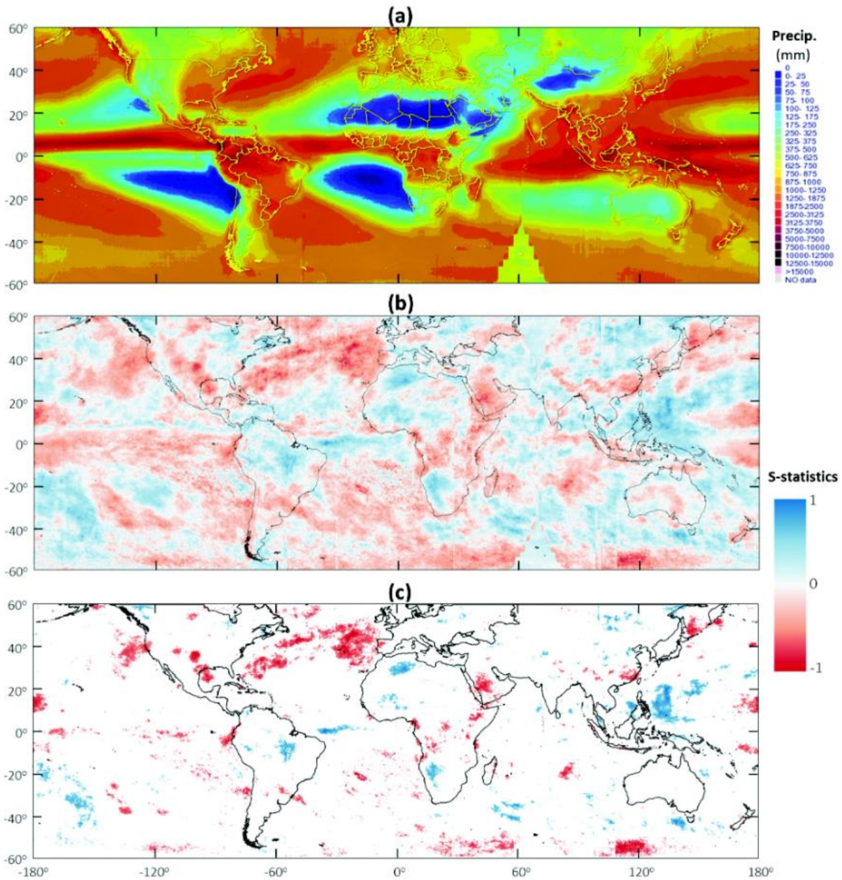
Revisiting the recent European droughts from a long-term perspective

Martin Hanel[1], Oldřich Rakovec[2,1], Yannis Markonis[1], Petr Máca[1], Luis Samaniego[2], Jan Kyselý[1,3] & Rohini Kumar[2]



Global Precipitation Trends across Spatial Scales Using Satellite Observations

Phu Nguyen, Andrea Thorstensen, Soroosh Sorooshian, Kuolin Hsu, Amir Aghakouchak,
Hamed Ashouri, Hoang Tran, and Dan Braithwaite



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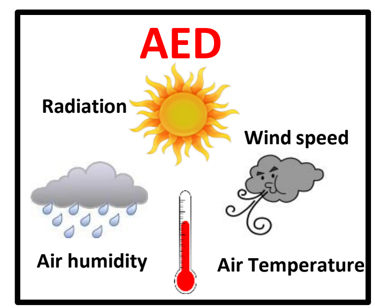
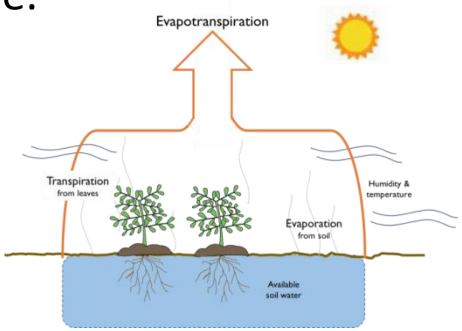
ATMOSPHERIC EVAPORATIVE DEMAND

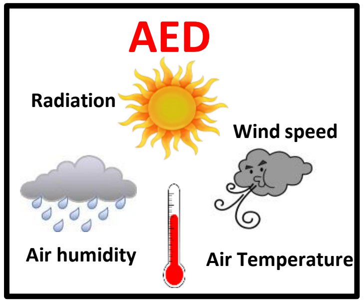


Evapotranspiration vs. **AED**

The **evapotranspiration (ET)** represents a upward water flux from soil, free water and plant leaves to the atmosphere.



The **AED** does not correspond to a land-atmosphere flux but to ***the capacity of the atmosphere to demand water*** (the drying –or evaporating- power of the atmosphere is another common word to refer to the same concept) as a function of its atmospheric condition, including ***radiative*** (determined by the net solar radiation) and ***aerodynamic*** (determined by the air temperature, wind speed and air humidity) components.



The reason of the confusion among these two very different variables is that under the "umbrella" concept of the AED, there are some AED metrics that also contain the term "evapotranspiration". They are the **Potential Evaporation (ETp)**, **the Reference Evapotranspiration (ETo)** and the **pan evaporation (Epan)**, which is a measurement of the AED.

ET_p would correspond to the evaporation from a saturated surface (free water or 100% of humidity in natural vegetation or crops). ETp can be calculated using the Penman equation (Penman, 1948):

$$ET_p = \frac{1}{\lambda}\frac{\Delta(R_n - G) + \rho c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma}$$

There are other procedures to calculate ETp [e.g., the Priestley-Taylor equation, Milly and Dunne, 2016], but they are suboptimal since they do not consider both **radiative** and **aerodynamic** terms of the AED.

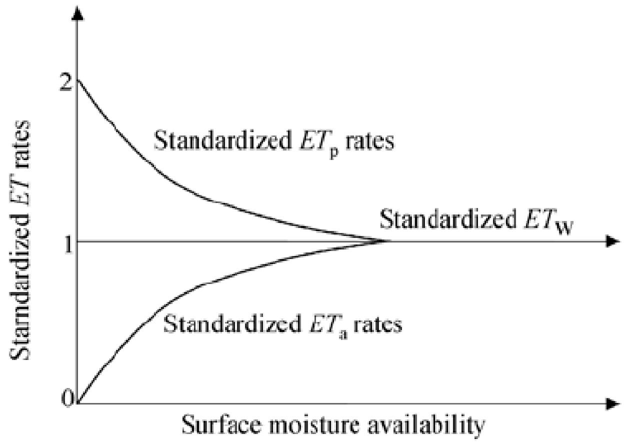
There are other **two terms** that are used to refer to the AED that are **not recommended**:

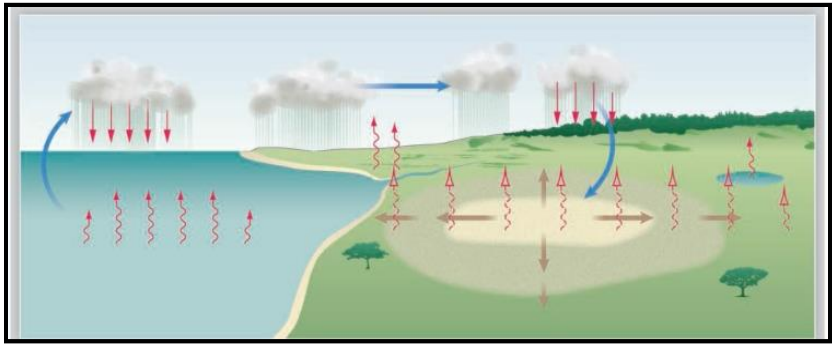
i) the first one is the **saturation Vapour Pressure Deficit (VPD)** e_s-e_a. Under conditions of non-saturated air the actual vapor pressure is lower that the saturation vapor pressure, so the difference among them is an indicator of the evaporative capacity of the air but **it does not fully capture both radiative and aerodynamic components of the AED**. VPD is involved in the calculation of the aerodynamic component, and it is one of the variables used to calculate ETp and ETo,

ii) the second term is the **Potential Evapotranspiration (PET)**. The PET concept cannot be considered a universal concept since it does not represent a climate variable and strongly depends on the characteristics and type of the vegetation and the type of surface. Thus, PET would be close to the agronomic term of "water requirement" under non-limited water conditions, in which differences in vegetation height, leaf anatomy, stomatal characteristics, and even albedo are key variables and they would cause that the requirement differs from ETo under similar atmospheric conditions.

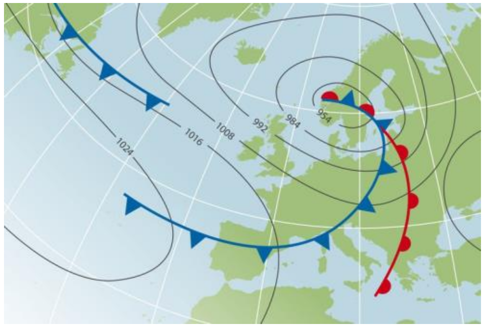
Atmospheric Evaporative Demand is driven by different mechanisms:

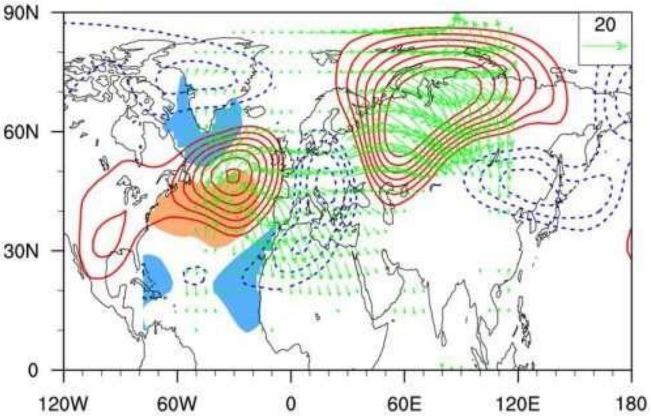
- **Thermodynamic forcing (Bouchet's complementary relationship under low soil moiture and differential warming trend between oceanic and continental regions) connected with increased warming and no constant relative humidity.**



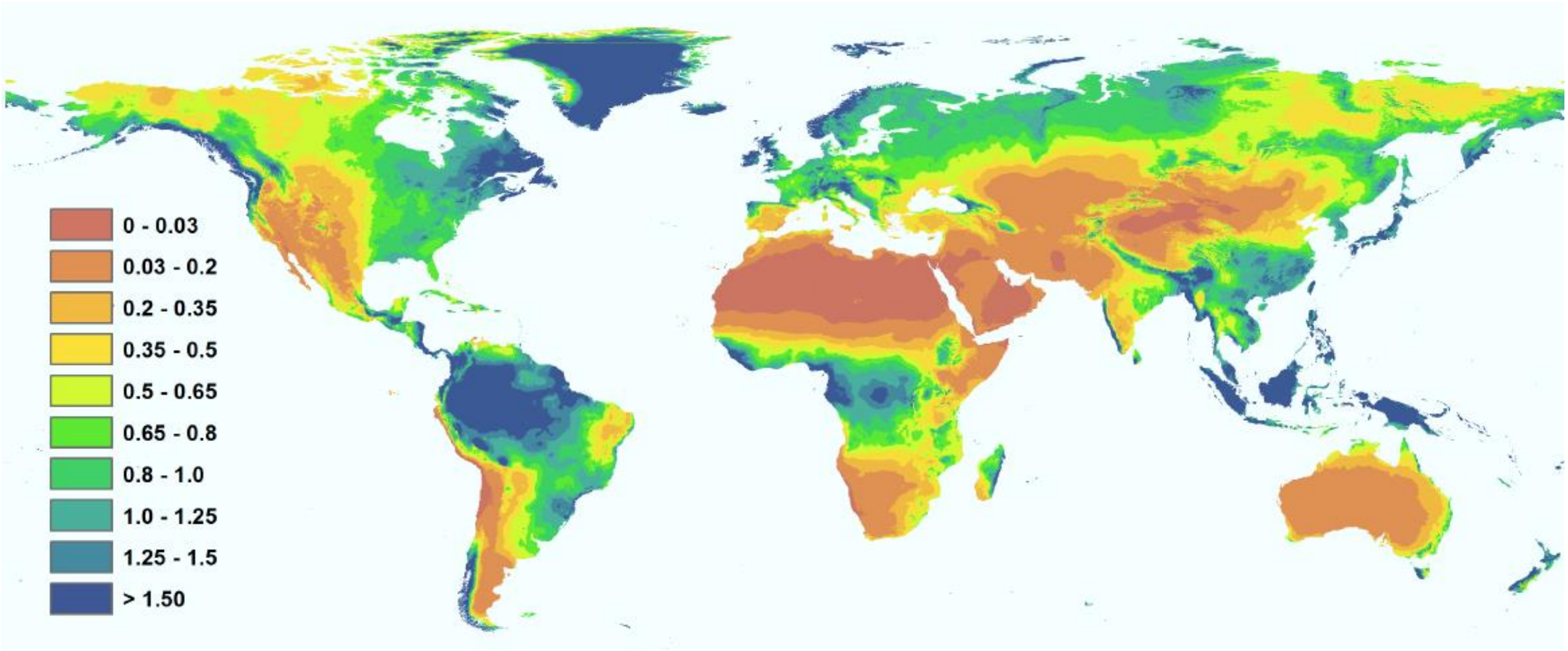


- **Atmospheric circulation**





The role of the AED is different on climate aridity and on drought

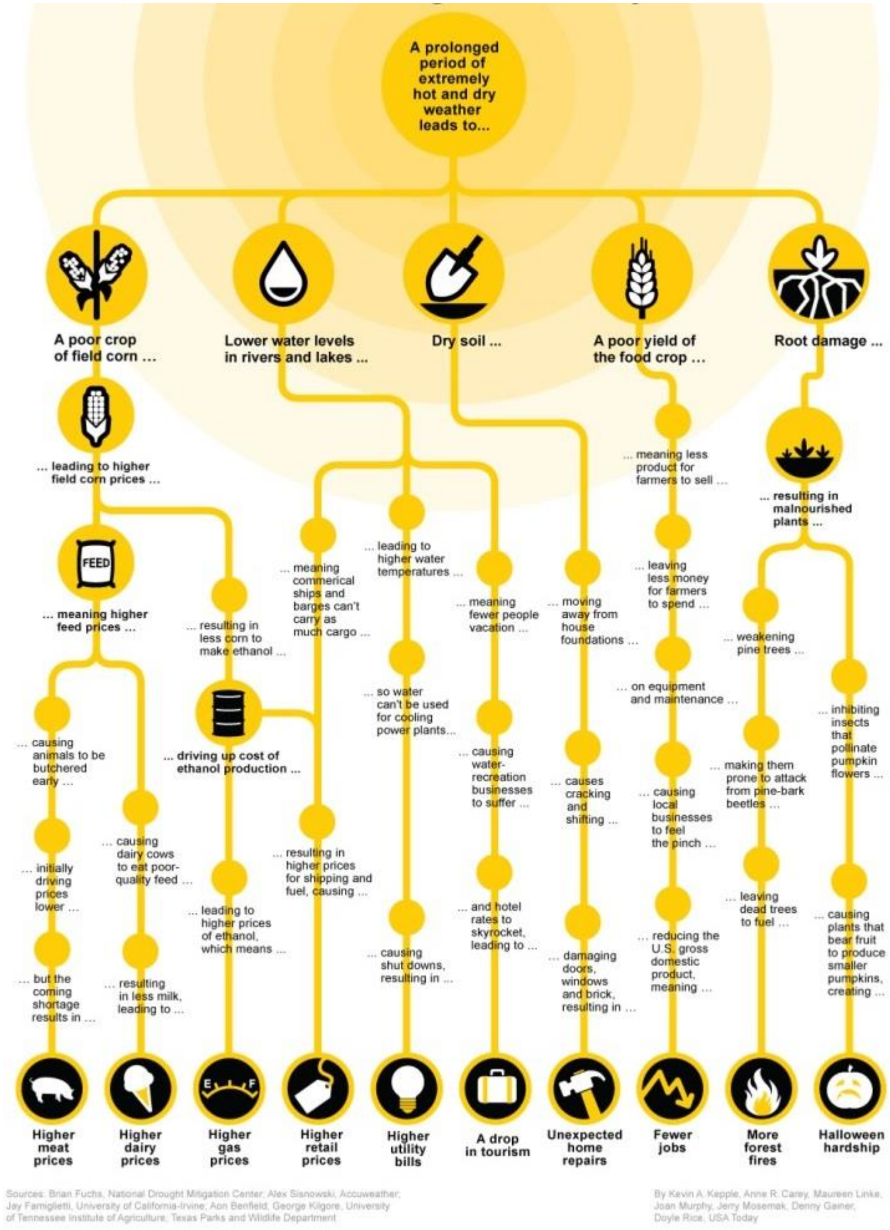


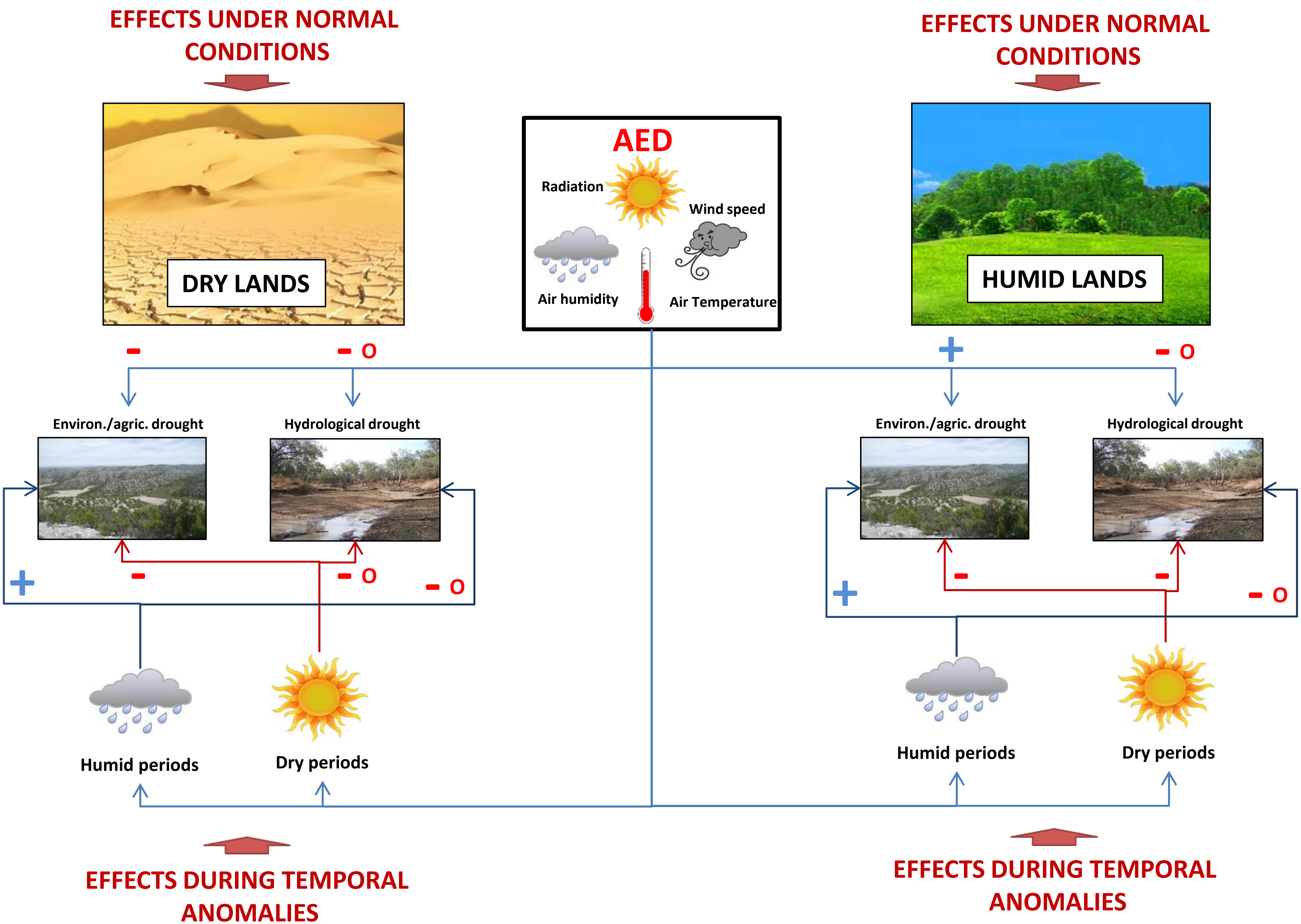
AED will always have a **negative role on the climate aridity**. It has been discussed the use of aridity indices for future climate projections given possible AED regulation by CO2 fertilization (further discussion next slides).

Nevertheless, it is doubtless that **increased AED under constant precipitation will always increase drought severity**.

- **Thus, AED effects on drought severity are extremely complex given <u>different economic sectors and natural systems affected and geographic differences.</u>**

Under an idealized scenario in which precipitation does not show temporal variations, the effect of the AED on drought severity can be completely different **as a function of the precipitation climatology**, and also the **type of drought (hydrological vs. environmental/agricultural)**.

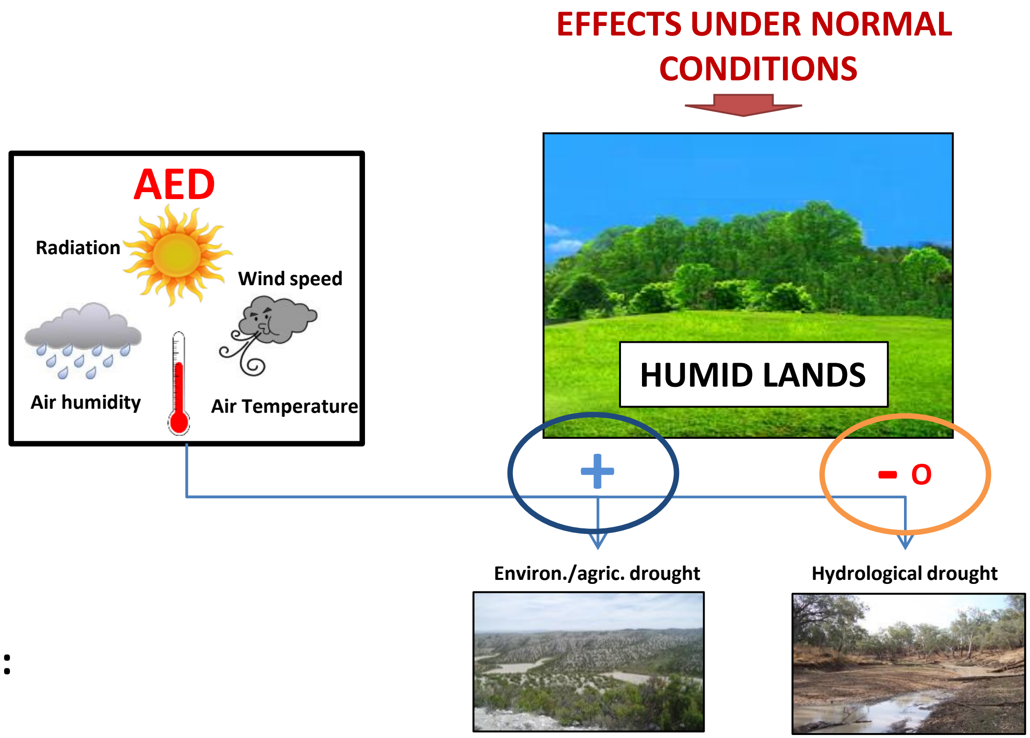




EFFECTS UNDER NORMAL CONDITIONS
DRY LANDS
AED
Radiation
Wind speed
Air humidity
Air Temperature
EFFECTS UNDER NORMAL CONDITIONS
HUMID LANDS
-
- o
+
- o
Environ./agric. drought
Hydrological drought
Environ./agric. drought
Hydrological drought
+
-
- o
- o
+
-
-
- o
Humid periods
Dry periods
Humid periods
Dry periods
EFFECTS DURING TEMPORAL ANOMALIES
EFFECTS DURING TEMPORAL ANOMALIES

POSITIVE ENVIRONMENTAL/AGRICULTURAL:

Under unlimited water availability, AED effect would be positive for plant activity and growth since enhanced AED would favor plant transpiration, plant leaf area and the primary production (NPP).



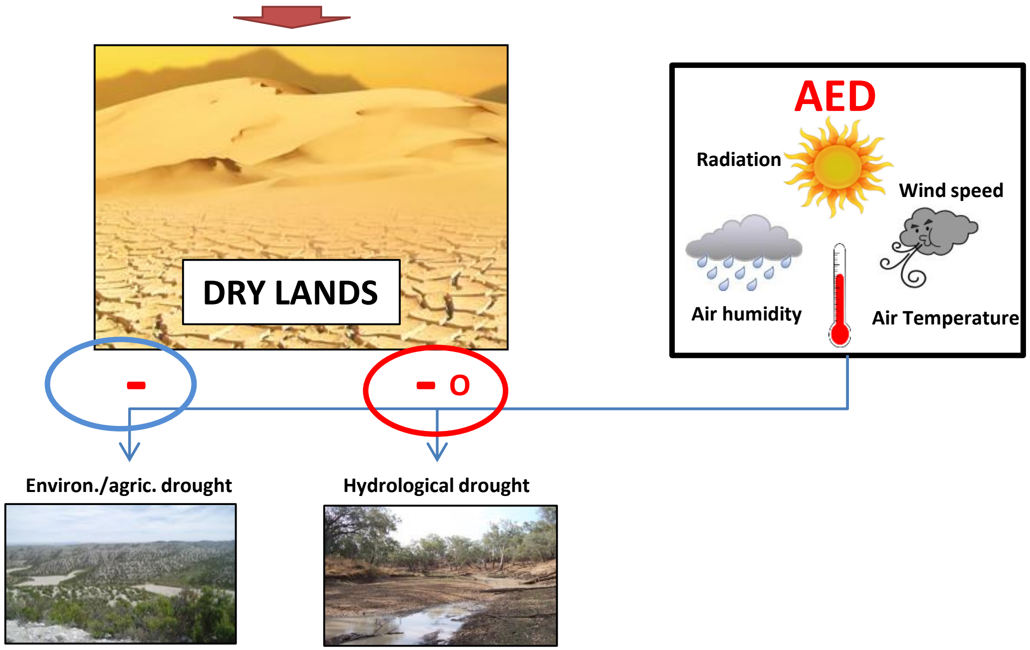
NEGATIVE HYDROLOGICAL INFLUENCE:

DIRECT: evaporation in free water (streams, lakes and reservoirs)
INDIRECT: increase in plant transpiration, which importance is higher than direct evaporation from the soil and water bodies.

During normal or humid periods, although the water losses by enhanced AED can have even a higher magnitude than in dry periods, they would not have relevance given sufficient water availability.

Nevertheless, the effects could increase **downstream**, in areas in which water uses depend on the water resources generated in other areas [**e.g., the Mediterranean region in which the mountain headwater are strongly relevant for urban water supply and irrigation in the lowlands**].

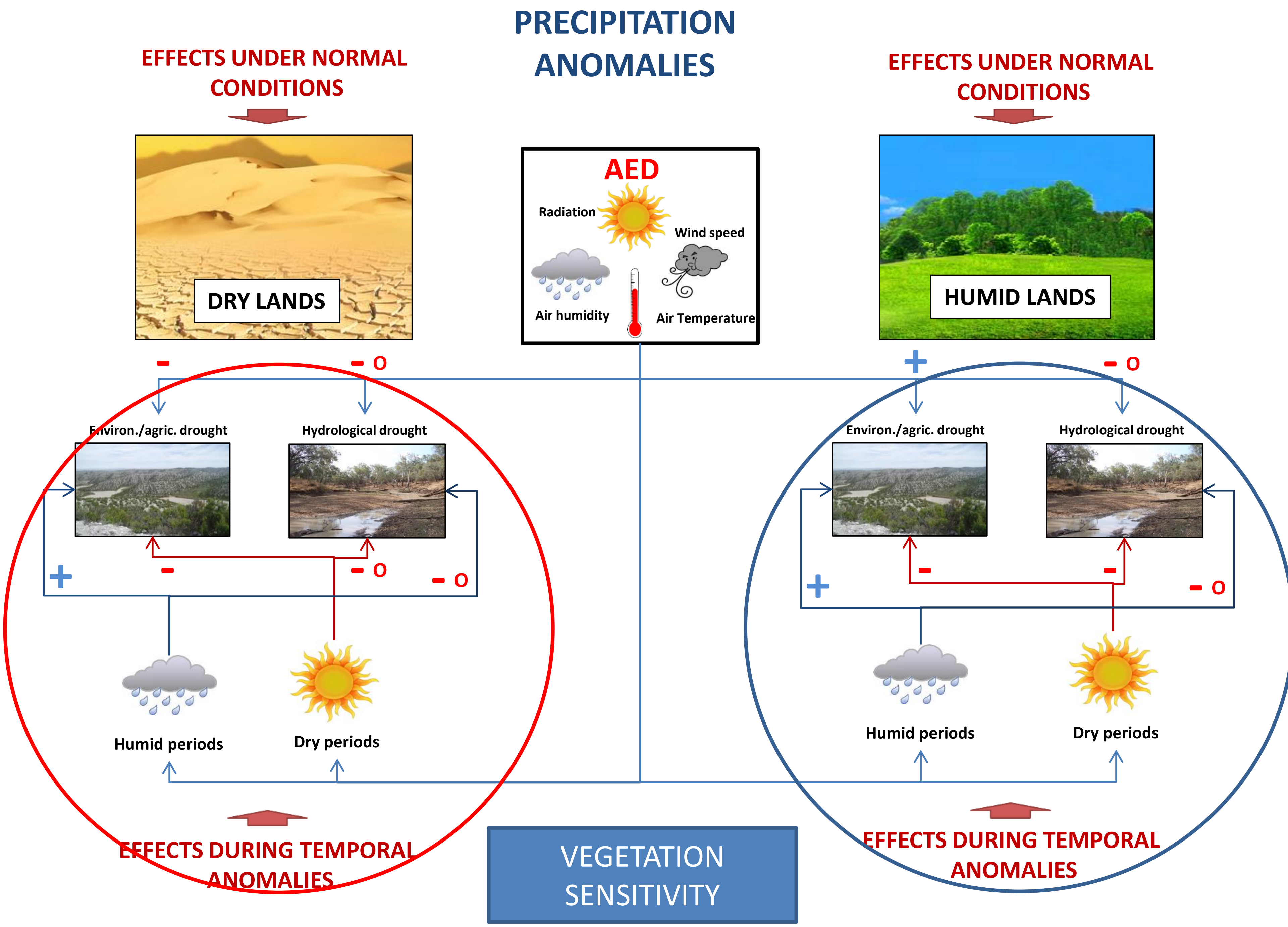
EFFECTS UNDER NORMAL CONDITIONS



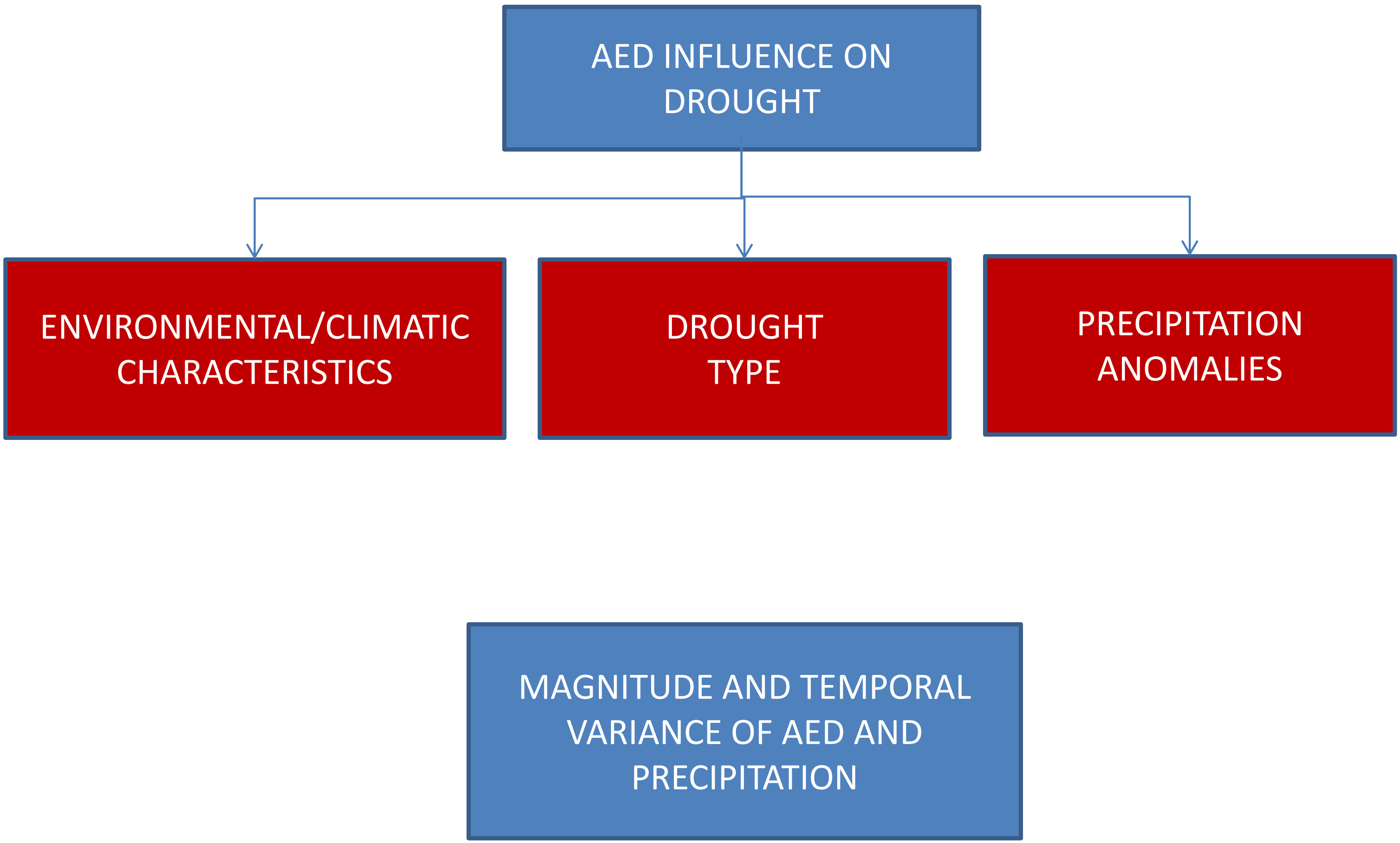
NEGATIVE HYDROLOGICAL INFLUENCE: It is expected that hydrological effects of the AED are small given low available water to evaporate. EXCEPTION: evaporation in big reservoirs and irrigated lands.

VERY NEGATIVE ENVIRONMENTAL/AGRICULTURAL INFLUENCE:

Although AED would not increase ETa in these areas, it increases the water stress by vegetation, causing an **evapotranspiration deficit** (i.e. the difference between the available water for transpiration and the water demand by the atmosphere). **If evapotranspiration deficit is stronger than the tolerated by plants**, it causes **reductions in photosynthesis** and net primary production, aboveground biomass and ultimately cause crop yield failure and forest mortality, as the most evident impacts.



PRECIPITATION ANOMALIES
EFFECTS UNDER NORMAL CONDITIONS
DRY LANDS
AED
Radiation
Wind speed
Air humidity
Air Temperature
EFFECTS UNDER NORMAL CONDITIONS
HUMID LANDS
-
- O
+
- O
Environ./agric. drought
Hydrological drought
Environ./agric. drought
Hydrological drought
+
-
- O
- O
+
-
-
- O
Humid periods
Dry periods
Humid periods
Dry periods
EFFECTS DURING TEMPORAL ANOMALIES
VEGETATION SENSITIVITY
EFFECTS DURING TEMPORAL ANOMALIES


AED INFLUENCE ON DROUGHT
ENVIRONMENTAL/CLIMATIC CHARACTERISTICS
DROUGHT TYPE
PRECIPITATION ANOMALIES
MAGNITUDE AND TEMPORAL VARIANCE OF AED AND PRECIPITATION

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Contribution of precipitation and reference evapotranspiration to drought indices under different climates

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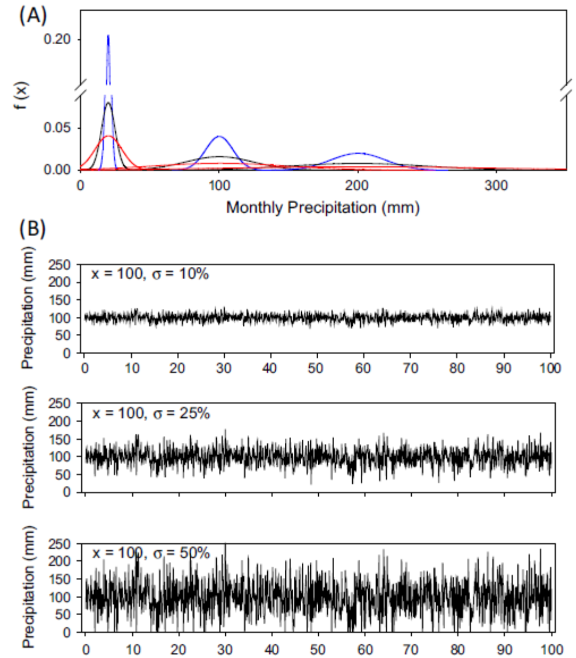
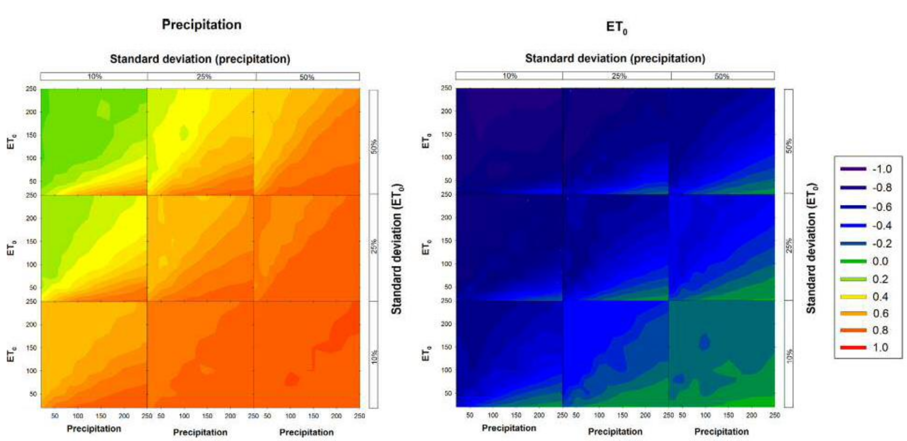
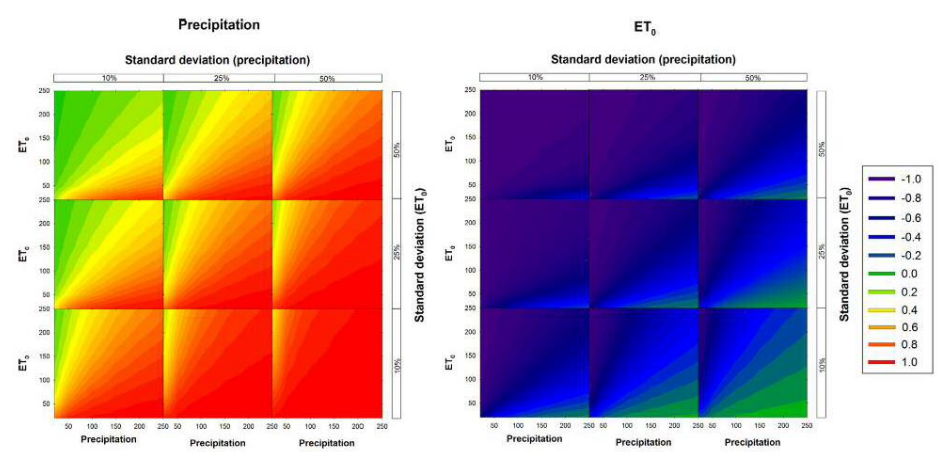
[c] Estación Experimental de Aula Dei (EEAD–CSIC), Zaragoza, Spain

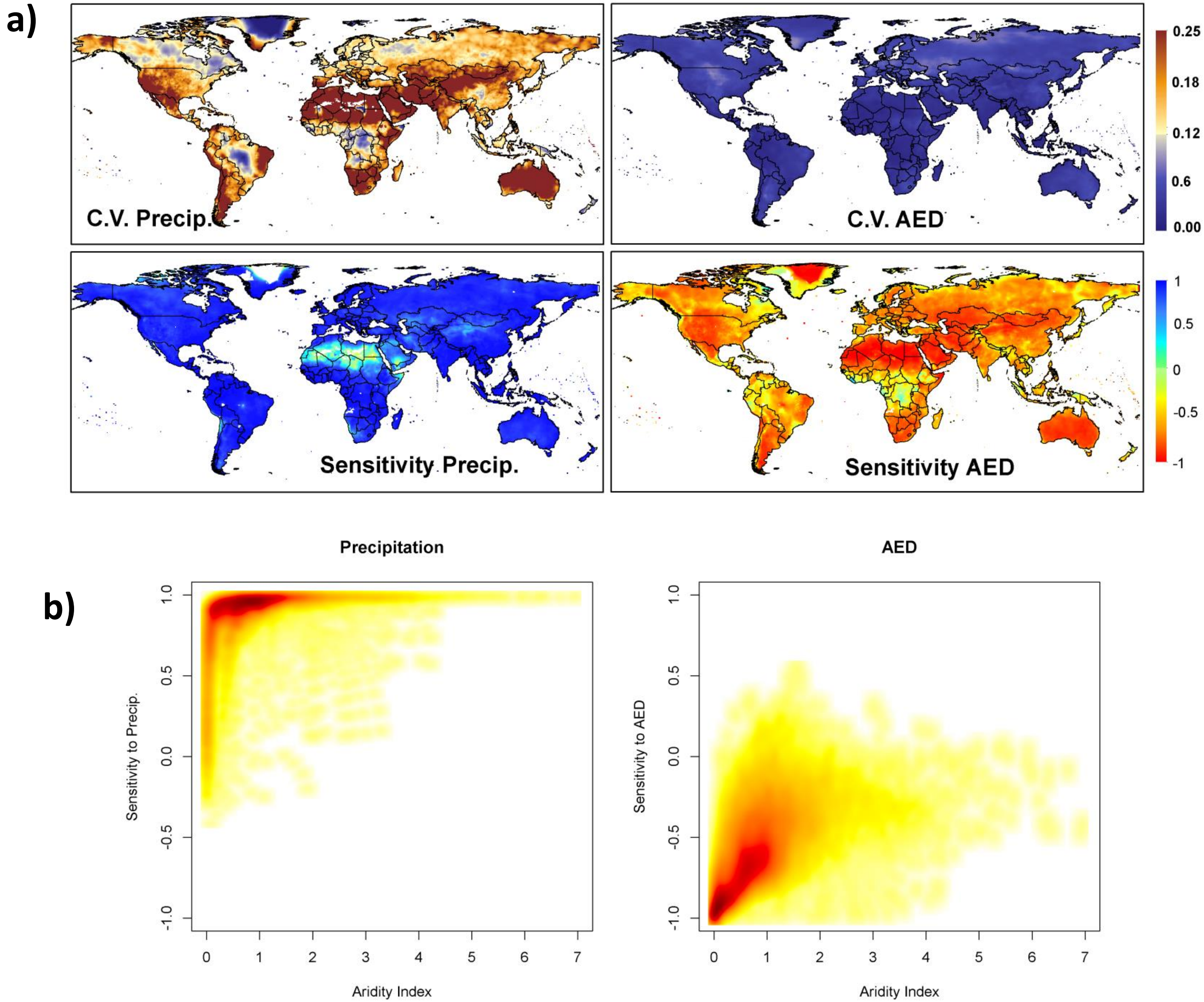


PDSI



SPEI





It is necessary to stress that these general patterns may vary for specific drought events as a consequence of the particular precipitation and/or AED anomalies.

ETa vs. AED

Common confusion: Drought indices are not using AED as substitute of ETa

ETa is suggested to be included in metrics of drought severity

The use of ETa instead AED shows uncertainties to measure drought severity in water limited regions in which ETa is constrained by Precipitation and not by the AED.

In these regions no changes in drought severity would be normally identified under enhanced AED since P – ETa will usually tend to zero, and trends in ETa are strongly driven by trends in precipitation.

The key aspect is to compare the highest possible ETa (or AED) with the current water availability (e.g. the ETa or the soil moisture, ultimately determined by precipitation).

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(wileyonlinelibrary.com) DOI: 10.1002/joc.3887

Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring

Santiago Beguería,[a] Sergio M. Vicente-Serrano,[b*] Fergus Reig[b] and Borja Latorre[a]
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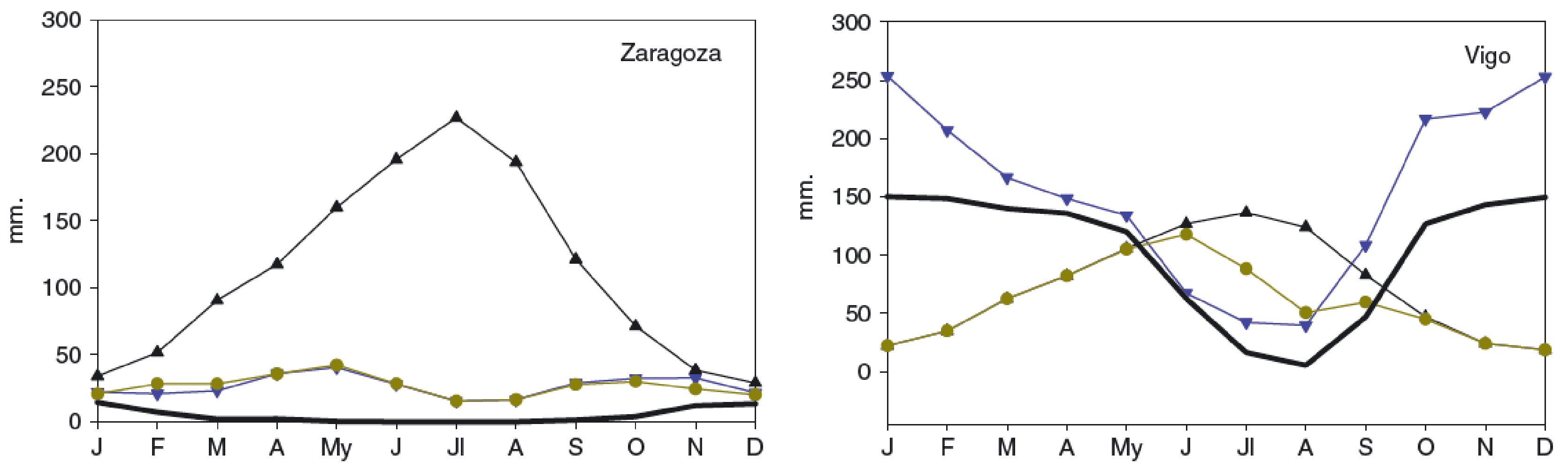


Figure 5. Average soil water content (W) (black line) (1961–2011), precipitation (P) (blue triangles), Reference Evapotranspiration (ET_0) (black triangles) and actual evapotranspiration (ET_a) (circles) in Zaragoza (left) and Vigo (right).

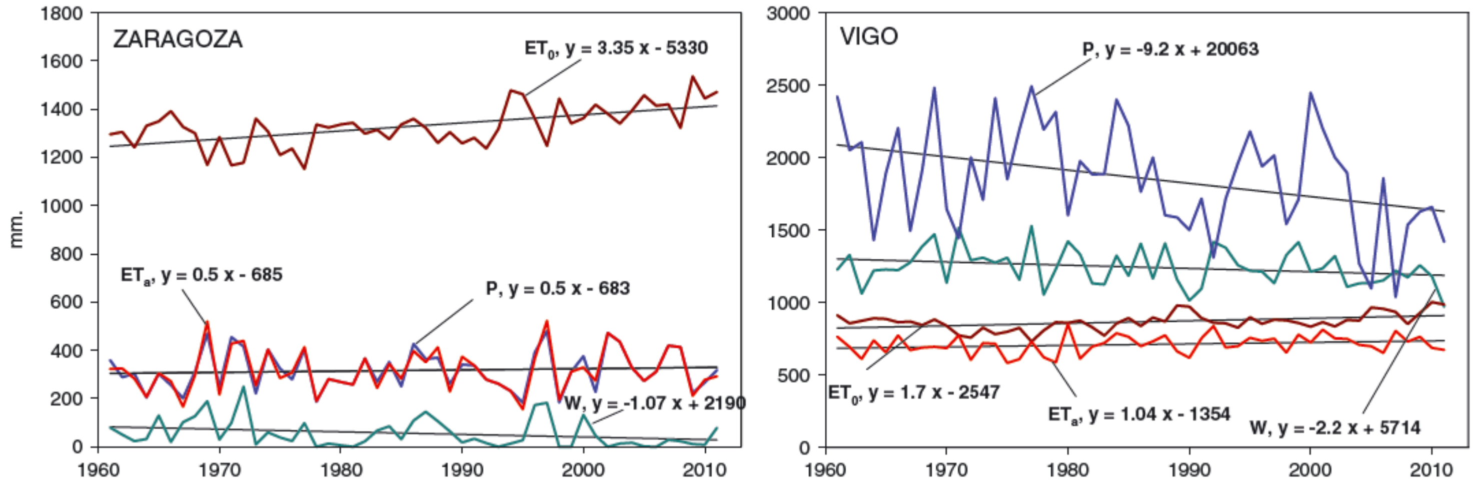
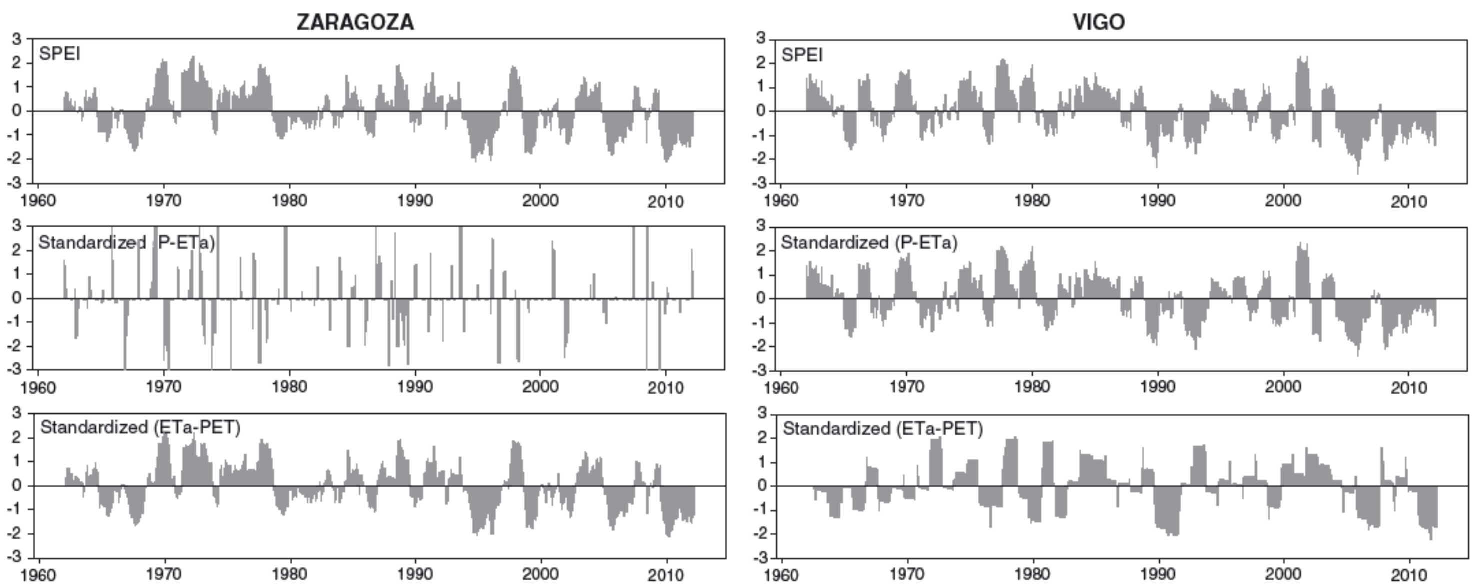


Figure 7. Evolution of annual P, ET_0, "W" and "ET_a" in Zaragoza and Vigo between 1961 and 2011.



- **ETa would make sense as a replacement of precipitation or soil moisture in drought metrics** since it would be better estimator of the amount of water actually used by the vegetation, **but never as a substitute of the AED**.

- The **difference between ETa and AED** could provide more optimal indicator of the environmental and agricultural drought stress than other drought indices. This seems to be an optimal approach to monitor drought severity in vegetation areas under limited moisture conditions since **the ETa is better metric of the real water use by vegetation than precipitation or soil moisture**.

Global Assessment of the Standardized Evapotranspiration Deficit Index (SEDI) for Drought Analysis and Monitoring

SERGIO M. VICENTE-SERRANO,[a] DIEGO G. MIRALLES,[b] FERNANDO DOMÍNGUEZ-CASTRO,[a]
CESAR AZORIN-MOLINA,[c] AHMED EL KENAWY,[a,d] TIM R. MCVICAR,[e,f] MIQUEL TOMÁS-BURGUERA,[g]
SANTIAGO BEGUERÍA,[g] MARCO MANETA,[h] AND MARINA PEÑA-GALLARDO[a]

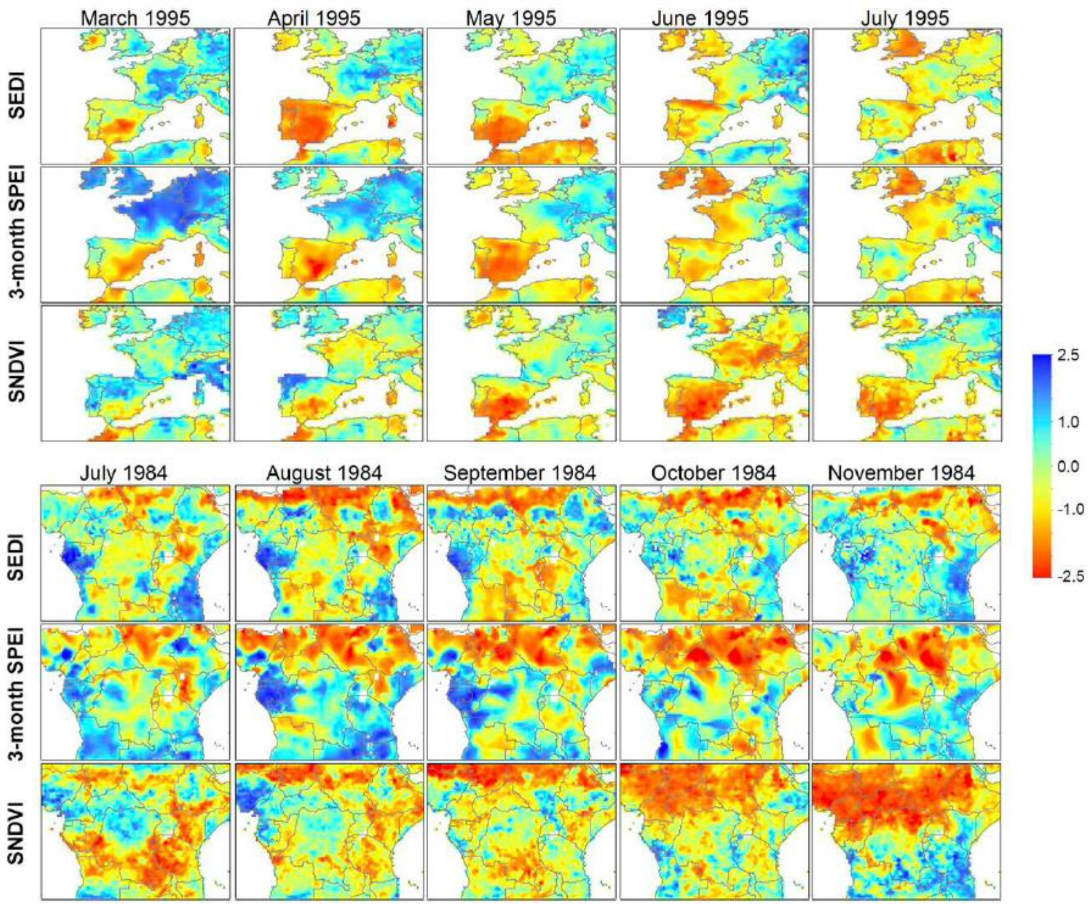
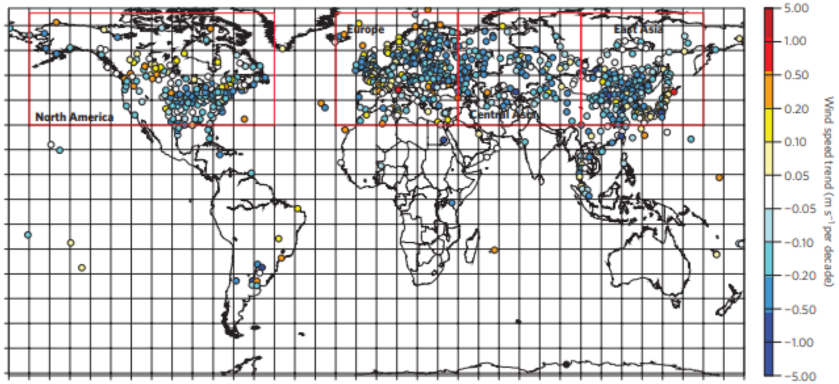


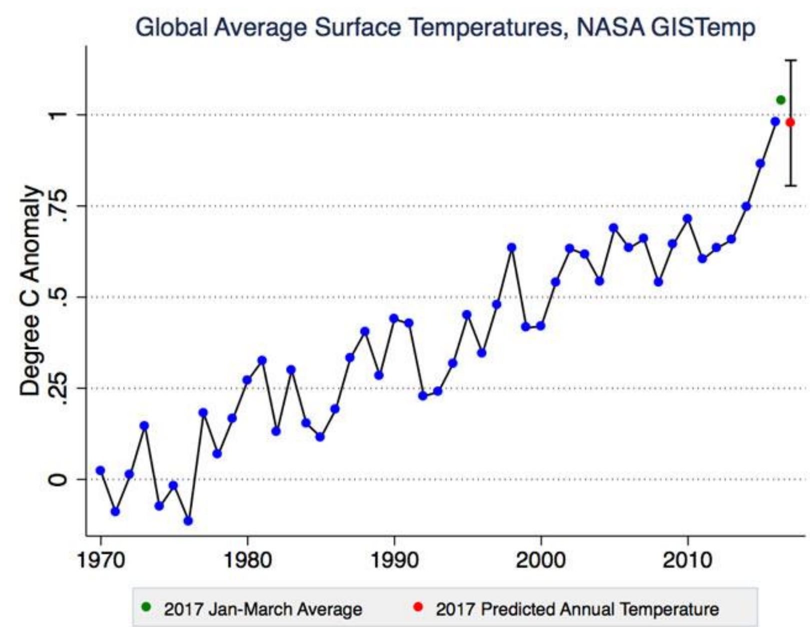
FIG. 12. Spatial distribution of the SEDI, 3-month SPEI, and sNDVI during two extraordinary drought events recorded (top) in 1995 over the Iberian Peninsula and (bottom) in 1984 over the Sahel.

LETTERS
PUBLISHED ONLINE: 17 OCTOBER 2010 | DOI: 10.1038/NGEO979
nature geoscience

Northern Hemisphere atmospheric stilling partly attributed to an increase in surface roughness

Robert Vautard[1]*, Julien Cattiaux[1], Pascal Yiou[1], Jean-Noël Thépaut[2] and Philippe Ciais[1]





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https://doi.org/10.5194/esd-9-915-2018

Earth System Dynamics
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EGU

Recent changes of relative humidity: regional connections with land and ocean processes

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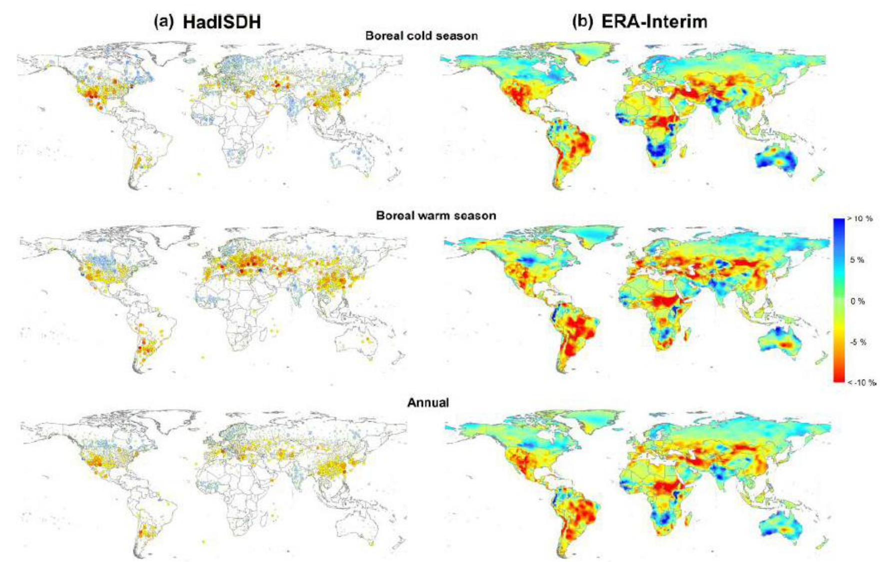

Figure 1. Spatial distribution of the magnitude of change of RH (% per decade) over the period 1979–2014 from the HadISDH (**a**) and ERA-Interim datasets (**b**). Results are provided for the boreal cold (October–March) and warm (April–September) seasons and annually.

Global Atmospheric Evaporative Demand over Land from 1973 to 2008

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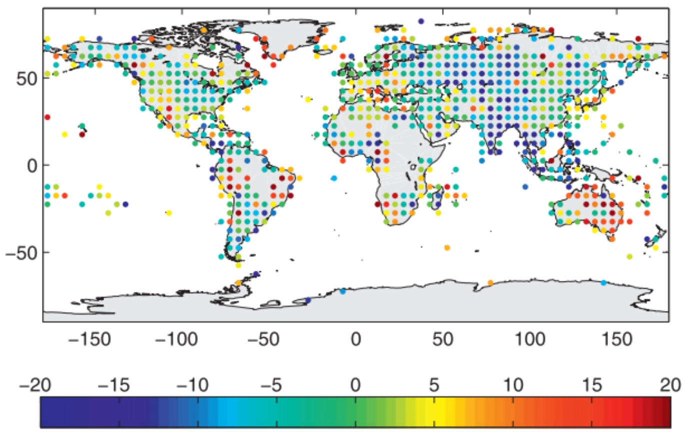
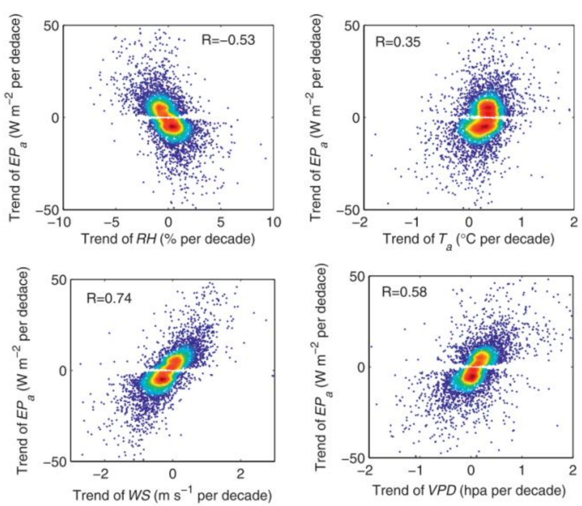


FIG. 8. The normalized linear trend of EP_a from 1973 to 2008 (% decade^{-1}). The trends were calculated where air temperature,



Water Resources Research

RESEARCH ARTICLE
10.1002/2014WR015427

Sensitivity of reference evapotranspiration to changes in meteorological parameters in Spain (1961–2011)

Key Points:
- ETo is sensitive to changes in relative humidity and maximum temperature
- There are spatial gradients in the ETo sensitivity
- Trends in ETo are explained by trends

Sergio M. Vicente-Serrano[1], Cesar Azorin-Molina[1], Arturo Sanchez-Lorenzo[2], Jesús Revuelto[1], Enrique Morán-Tejeda[1], Juan I. López-Moreno[1], and Francisco Espejo[3]

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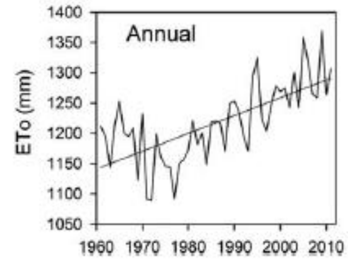
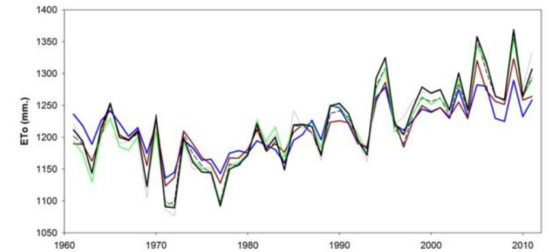
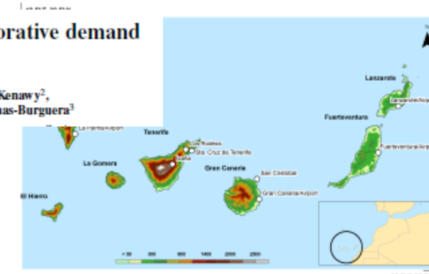




Recent changes and drivers of the atmospheric evaporative demand in the Canary Islands

Sergio M. Vicente-Serrano[1], Cesar Azorin-Molina[1], Arturo Sanchez-Lorenzo[1], Ahmed El Kenawy[2], Natalia Martín-Hernández[1], Marina Peña-Gallardo[1], Santiago Beguería[3], and Miquel Tomas-Burguera[3]



Geophysical Research Letters

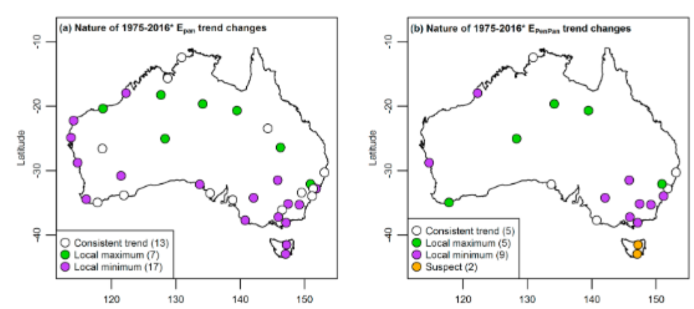
RESEARCH LETTER
10.1029/2018GL079332

Revisiting Pan Evaporation Trends in Australia a Decade on

Clare M. Stephens[1], Tim R. McVicar[2,3], Fiona M. Johnson[1], and Lucy A. Marshall[1]

[1]Water Research Centre, School of Civil and Environmental Engineering, UNSW, Sydney, New South Wales, Australia, [2]CSI Land and Water, Canberra, ACT, Australia, [3]Australian Research Council Centre of Excellence for Climate System Scienc Sydney, New South Wales, Australia

Key Points:
- Pan evaporation decreases between the 1970s and mid-2000s were previously attributed to decreasing



2017 DROUGHT

EN LA MANCOMUNIDAD DEL TORCÓN

La sequía deja las primeras restricciones de agua para consumo humano en Castilla-La Mancha

MEDIO AMBIENTE

España se enfrenta a una de las sequías más destructivas de la historia

España se enfrenta en 2017 a una de las sequías más graves de la historia ¿Por qué ahora? ¿Podemos evitar una sequía igual el futuro?

Le Monde

LES DÉCODEURS

30 départements en état de crise : comprendre la sécheresse qui touche la France

MEDIO AMBIENTE

Radiografía de la sequía extrema en Esp

- Las reservas de agua de los embalses están ahora en el nivel más bajo de los últimos 22 años
- La peor situación está en la zona sureste peninsular (cuencas de los ríos Segura y Júcar) y en la cuenca del

Le Parisien

Sécheresse : 21 départements classés en «crise hydrique»

EL PAÍS ESPAÑA

ANDALUCÍA CATALUÑA C. VALENCIANA GALICIA MADRID PAÍS VASCO MÁS COMUNIDADES TITULARES »

HIDROLOGÍA ›

Retrato de una España atrapada en la sequía

El año hidrológico ha concluido con cifras preocupantes. Estos son los datos que fundamentan la alarma

Siccità, 10 Regioni pronte a chiedere lo stato di calamità e le misure di sostegno per le aziende

Il riconoscimento dell'emergenza sospenderebbe per le imprese il pagamento delle rate di mutuo e dei contributi. Secondo un'analisi Coldiretti, due terzi dell'Italia e delle coltivazioni sono a secco a causa della mancanza di precipitazioni e della scarsità di rifornimento idrico. Il bacino del Garda pieno per un terzo

EL PAÍS ECONOMÍA

MERCADOS MIS AHORROS VIVIENDA MIS DERECHOS FORMACIÓN TITULARES » Retina CincoDías NEGOCIOS

La sequía rebaja los ingresos del campo en 2.500 millones

Los pagos por indemnizaciones previstos por las compañías de seguros para agricultores se estiman en 725 millones

NIEUWS SPORT REGIO SLIMMER LEVEN SHE. MIJN ZON

Droogte van voorjaar 2017 officieel erkend als landbouwramp

Allarme siccità: piogge e consumi d'acqua in Italia

Secondo un'analisi Coldiretti, due terzi dell'Italia e delle coltivazioni sono a secco a causa della mancanza di precipitazioni e della scarsità di rifornimento idrico. Ecco le mappe dei consumi e degli sprechi in Italia

a cura di Paola Cipriani

29 agosto 2017

Ogni italiano consuma in media 89,3 metri cubi di acqua, ossia 245 litri al giorno. La spesa media mensile delle famiglie per l'acquisto di acqua minerale è di circa 11 euro, 13 euro è la spesa media mensile per la fornitura di acqua di uso domestico. Il 3% del volume d'acqua potabile immesso in rete viene sottratto senza autorizzazione o non misurato per imprecisione o malfunzionamento dei contatori.

Volumi di acqua immessa nelle reti comunali

LE FIGARO·fr

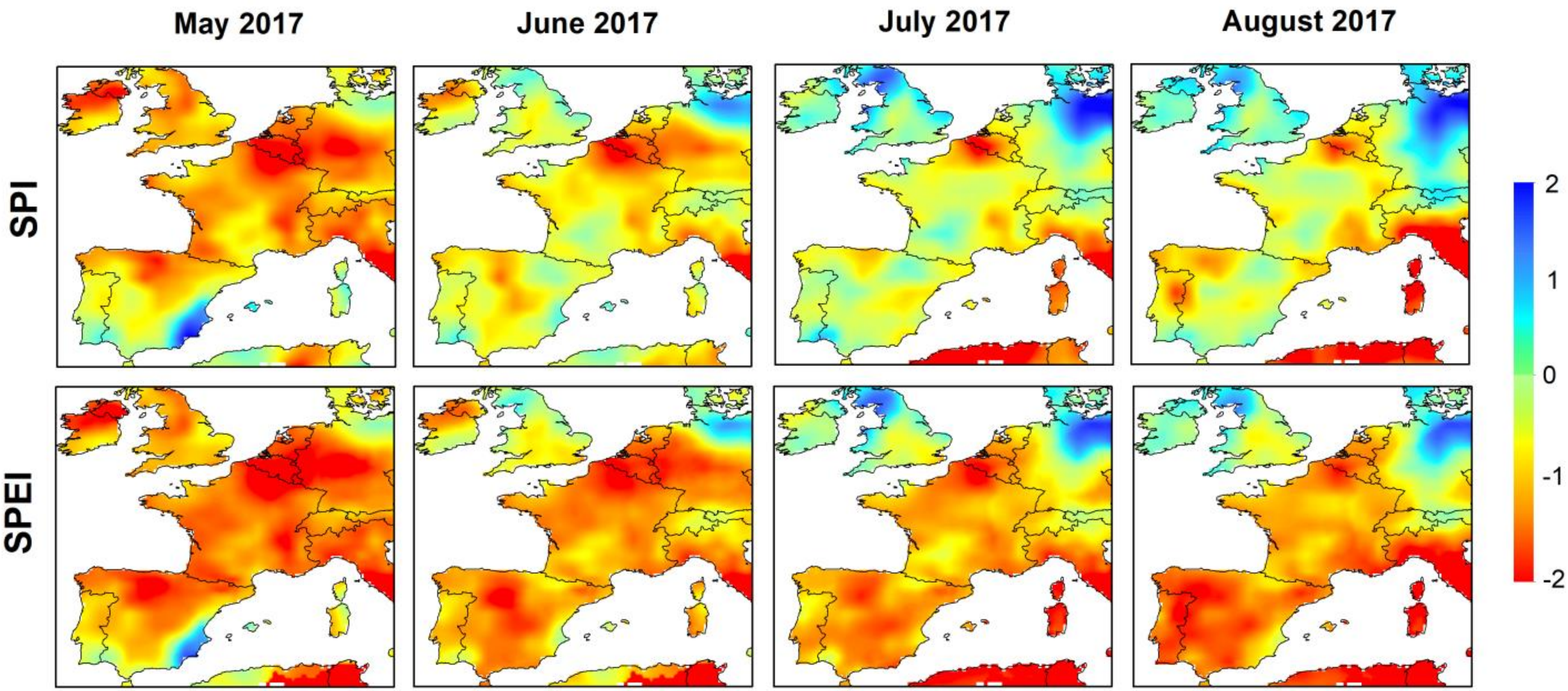
Actualité › Sciences & Environnement

Sécheresse : la France atteint la cote d'alerte

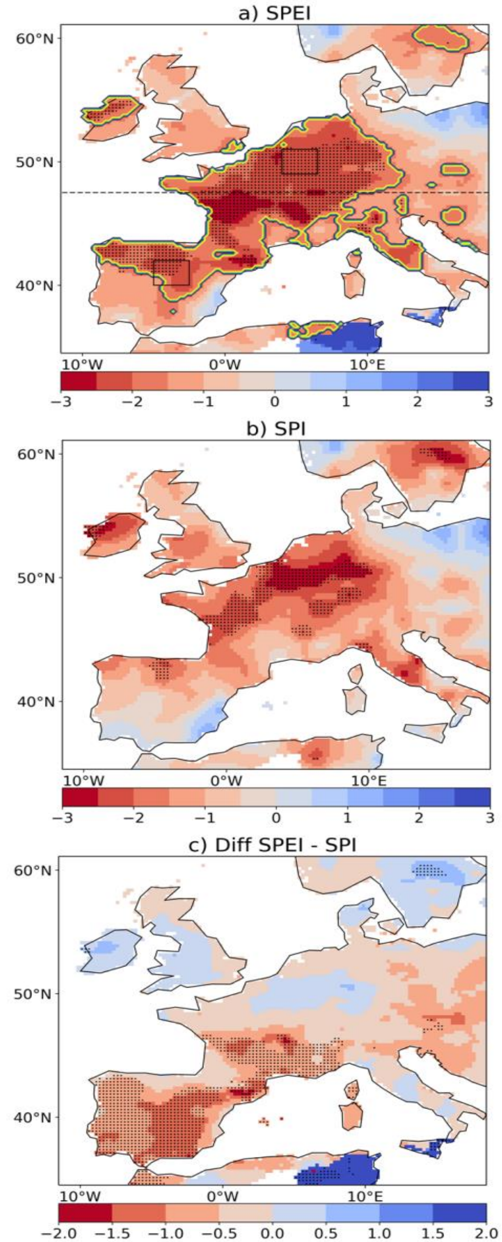
Europe

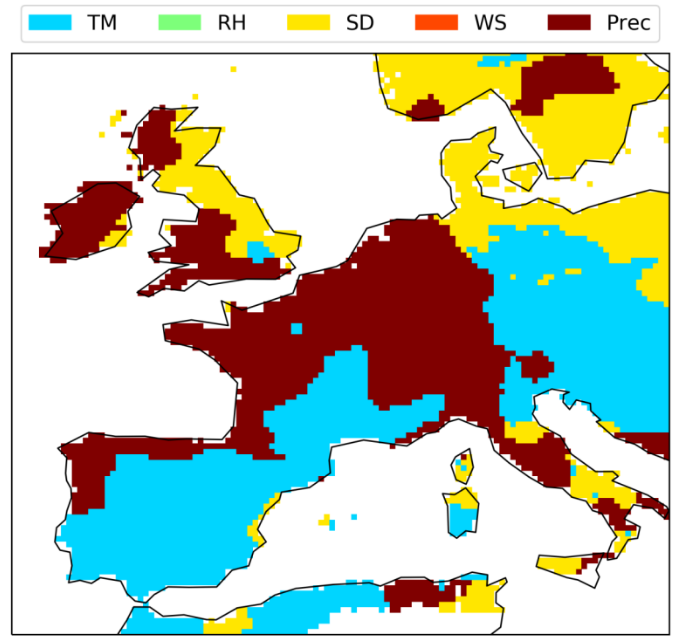
L'Italie frappée par une sécheresse historique, le rationnement de l'eau courante envisagé à Rome

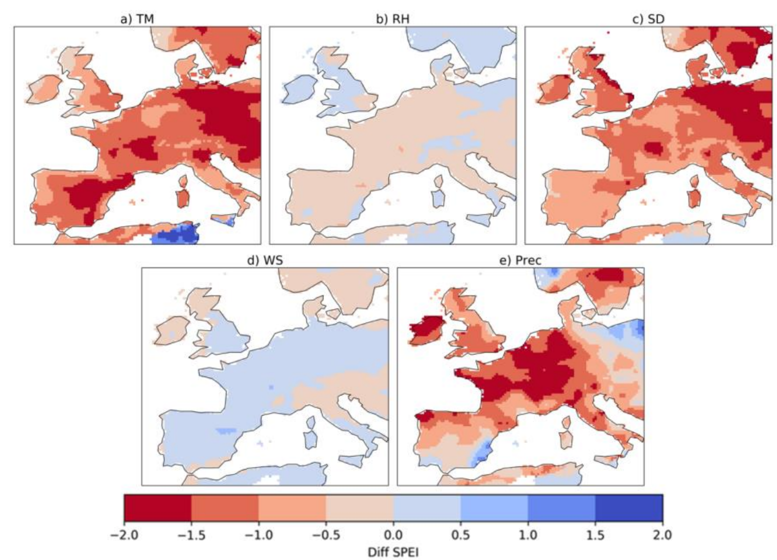
Première publication : 25/07/2017 - 16:24 Dernière modification : 25/07/2017 - 17:05


May 2017
June 2017
July 2017
August 2017
SPI
SPEI
2
1
0
-1
-2

Drought 2016/2017







García-Herrera et al. (2019): Journal of Climate

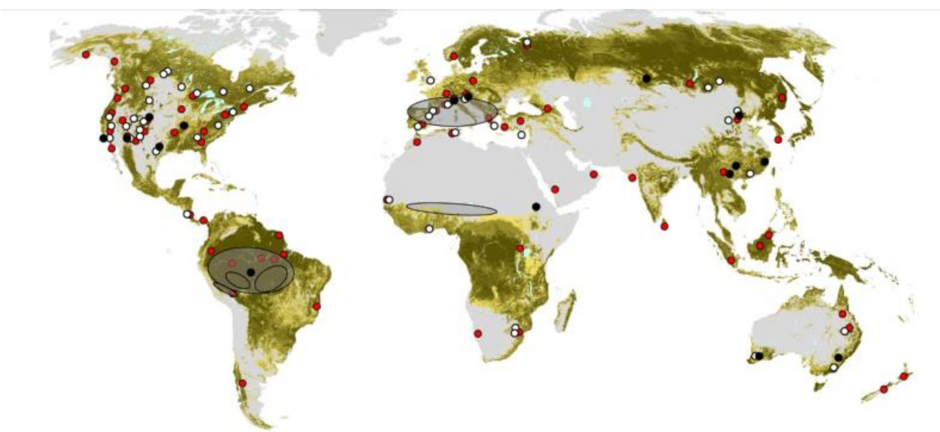
esa ECOSPHERE

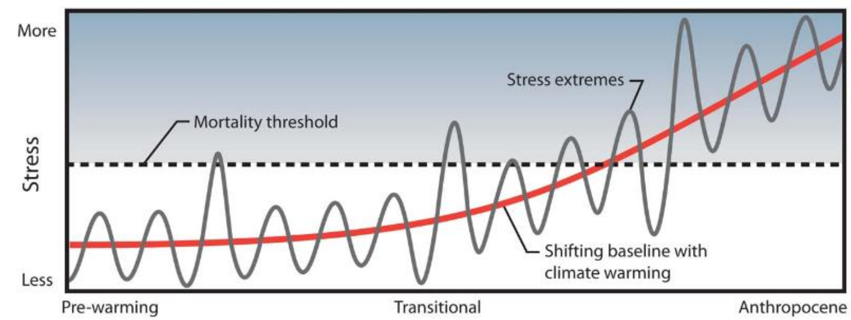
ESA CENTENNIAL PAPER

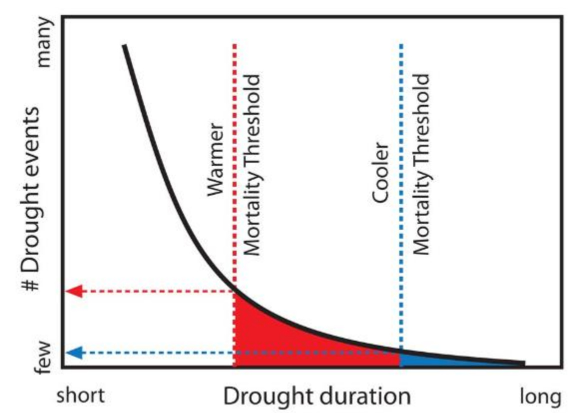
On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene

Craig D. Allen,[1,†] David D. Breshears,[2] and Nate G. McDowell[3]

[1]U.S. Geological Survey, Fort Collins Science Center, Jemez Mountains Field Station, Los Alamos, New Mexico 87544 USA
[2]School of Natural Resources and the Environment, joint with the Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, Arizona 85745 USA
[3]Earth and Environmental Science Division, MS-J495, Los Alamos National Laboratory, Los Alamos, New Mexico 85745 USA







PNAS

CrossMark

Anthropogenic warming has increased drought risk in California

Noah S. Diffenbaugh[a,b,1], Daniel L. Swain[a], and Danielle Touma[a]

[a]Department of Environmental Earth System Science and [b]Woods Institute for the Environment, Stanford University, Stanford, CA 94305

Edited by Jane Lubchenco, Oregon State University, Corvallis, OR, and approved January 30, 2015 (received for review November 22, 2014)

California is currently in the midst of a record-setting drought. The drought began in 2012 and now includes the lowest calendar-year and 12-mo precipitation, the highest annual temperature, and the ... which steered Pacific storms away from California over consecutive seasons (8–11). Although the extremely persistent high pressure is at least a century-scale occurrence (8), anthropogenic ...

Water Resources Research

RESEARCH ARTICLE

10.1029/2018WR023153

On the Causes of Declining Colorado River Streamflows

Mu Xiao[1], Bradley Udall[2], and Dennis P. Lettenmaier[1]

[1]Department of Geography, University of California, Los Angeles, CA, USA, [2]Colorado Water Institute, Colorado State University, Fort Collins, CO, USA

Key Points:

- The naturalized flow of the Colorado River has decreased about 15% over the last 100 years

Water Resources Research

RESEARCH ARTICLE

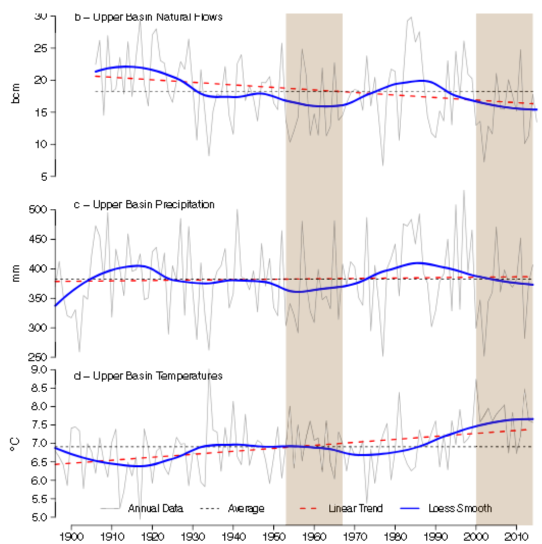
10.1002/2016WR019638

The twenty-first century Colorado River hot drought and implications for the future

Bradley Udall[1,2] and Jonathan Overpeck[2,3]

Key Points:

- Record Colorado River flow

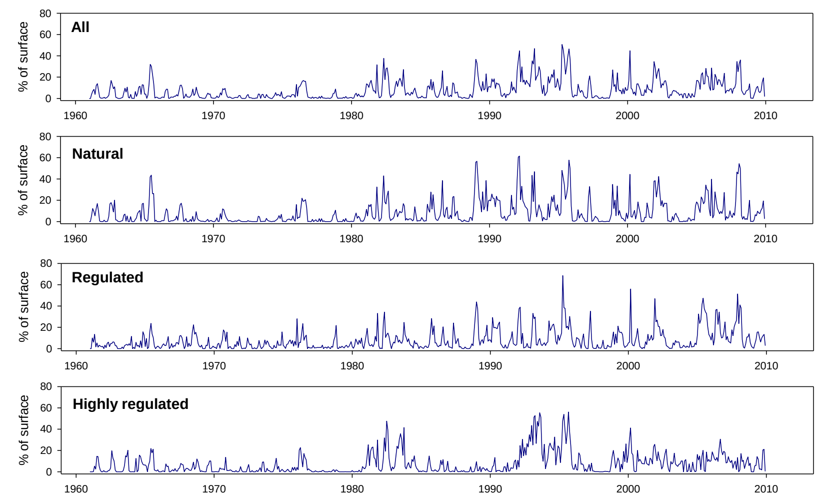


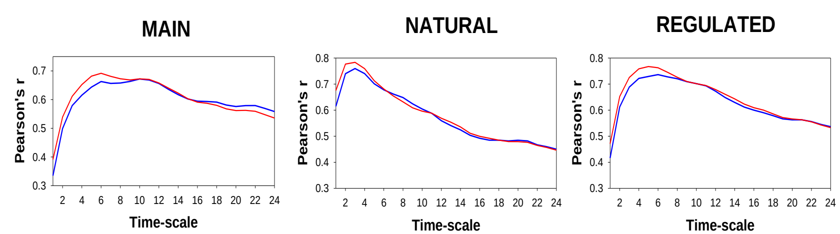
Environ. Res. Lett. 9 (2014) 044001 (9pp)

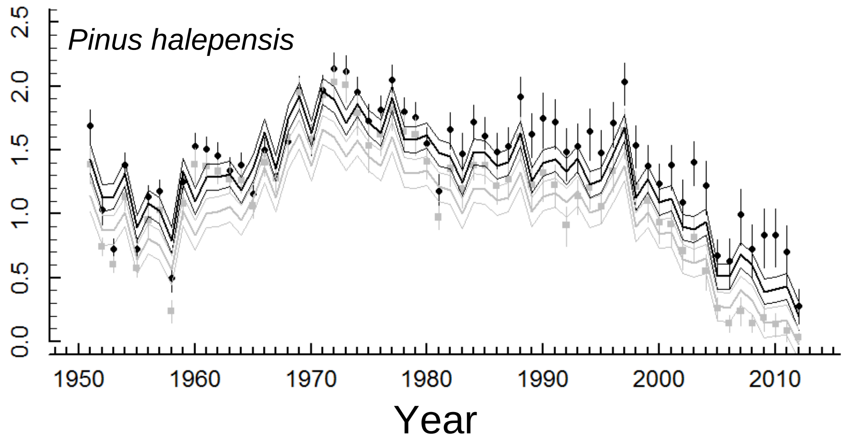
doi:10.1088/1748-9326/9/4

Evidence of increasing drought severity caused by temperature rise in southern Europe

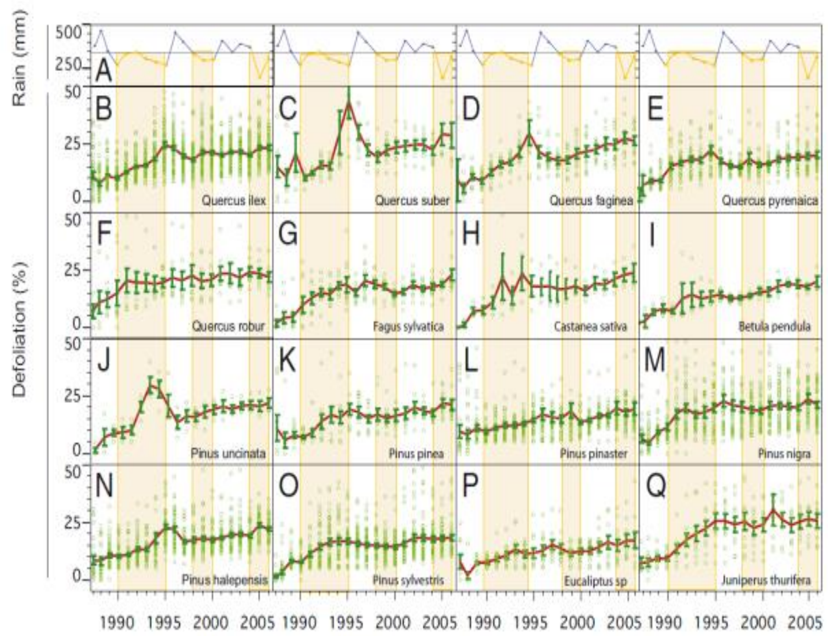
Sergio M Vicente-Serrano[1], Juan-I Lopez-Moreno[1], Santiago Beguería[2], Jorge Lorenzo-Lacruz[1], Arturo Sanchez-Lorenzo[3], José M García-Ruiz[1], Cesar Azorin-Molina[1], Enrique Morán-Tejeda[1], Jesús Revuelto[1], Ricardo Trigo[4], Fatima Coelho[5] and Francisco Espejo[6]





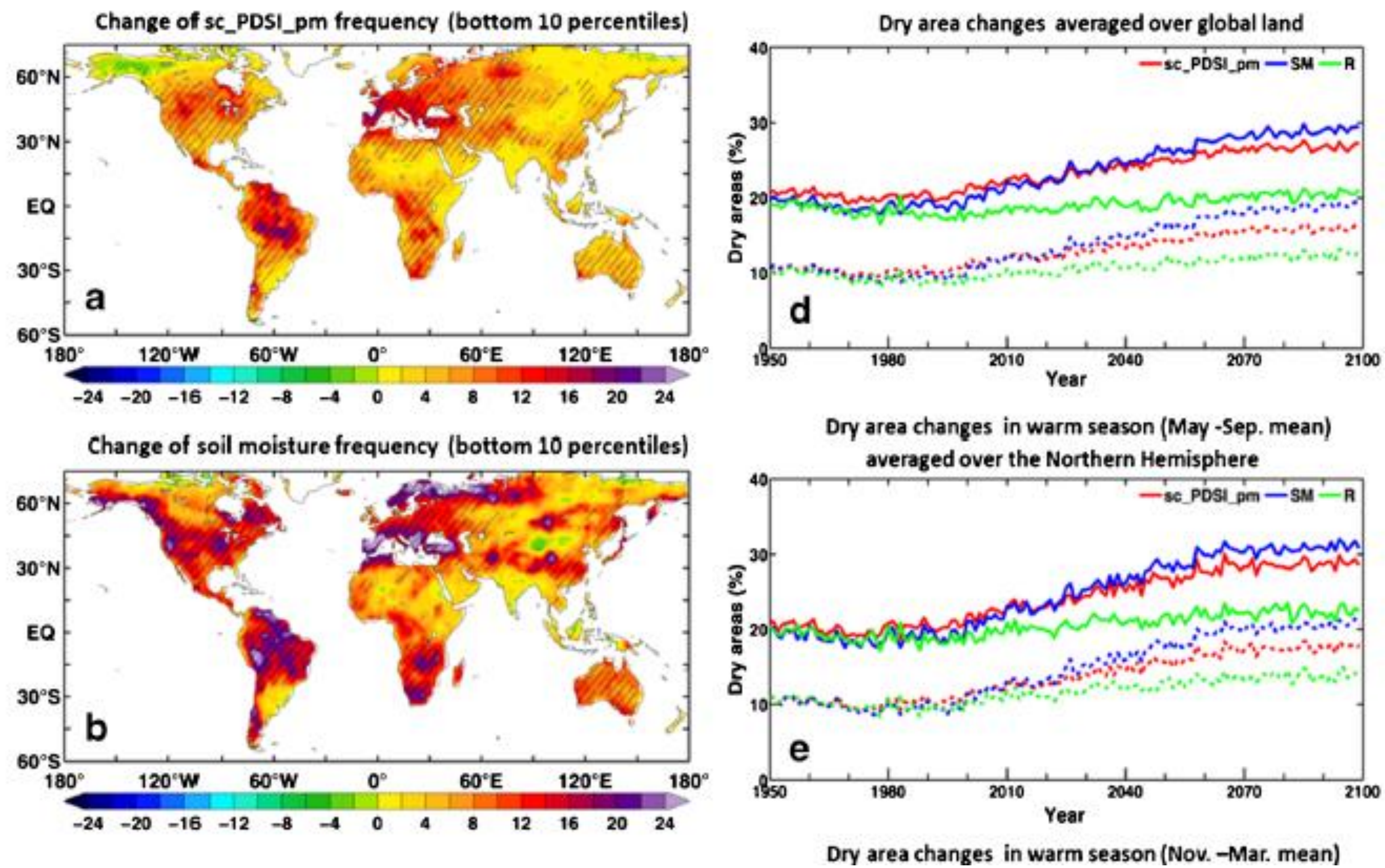


Camarero et al., (2015): Journal of Ecology



Carnicer et al., (2011): PNAS (2011), 108: 1474

FUTURE SCENARIOS?



Dai et al. 2018

AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE

10.1002/2015WR017031

On the assessment of aridity with changes in atmospheric CO_2

Michael L. Roderick[1,2,3], Peter Greve[4], and Graham D. Farquhar[2,3]

4.1. A Flux-Based Approach for Assessing Changes in Aridity

We begin with the usual water balance equation,

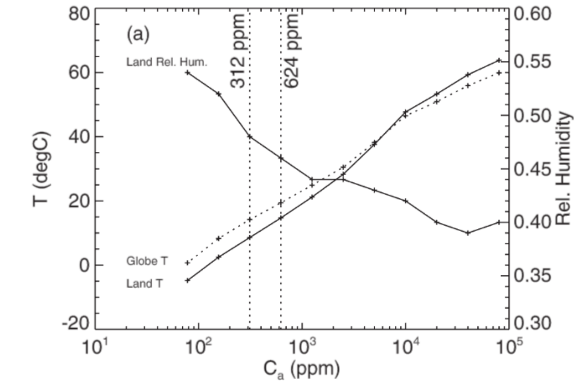
$$\frac{dS}{dt} = P - (E_t + E_s) - Q, \qquad (2)$$

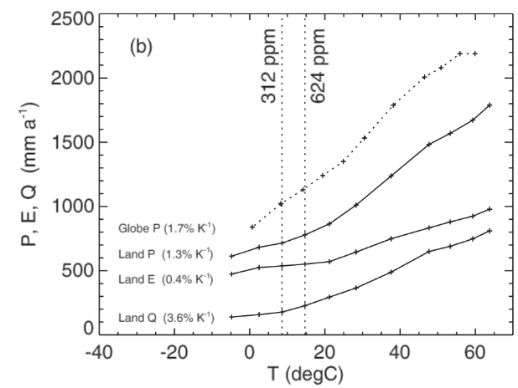
where the rate of change in water storage (dS/dt) is determined by inputs of precipitation (P) and outputs of evaporation (E) and runoff (Q). The total E is separated into two components, (i) transpiration (E_t) and (ii) a residual term that includes all other sources of evaporation (E_s). Note that E_s includes fluxes such as evapo-

$$W = \frac{A}{E_t},$$

the steady state water balance can be rewritten as,

$$P \approx \frac{A}{W} + E_s + Q.$$





Current Climate Change Reports (2018) 4:202–209
https://doi.org/10.1007/s40641-018-0094-1

CLIMATE CHANGE AND DROUGHT (Q FU, SECTION EDITOR)

CrossMark

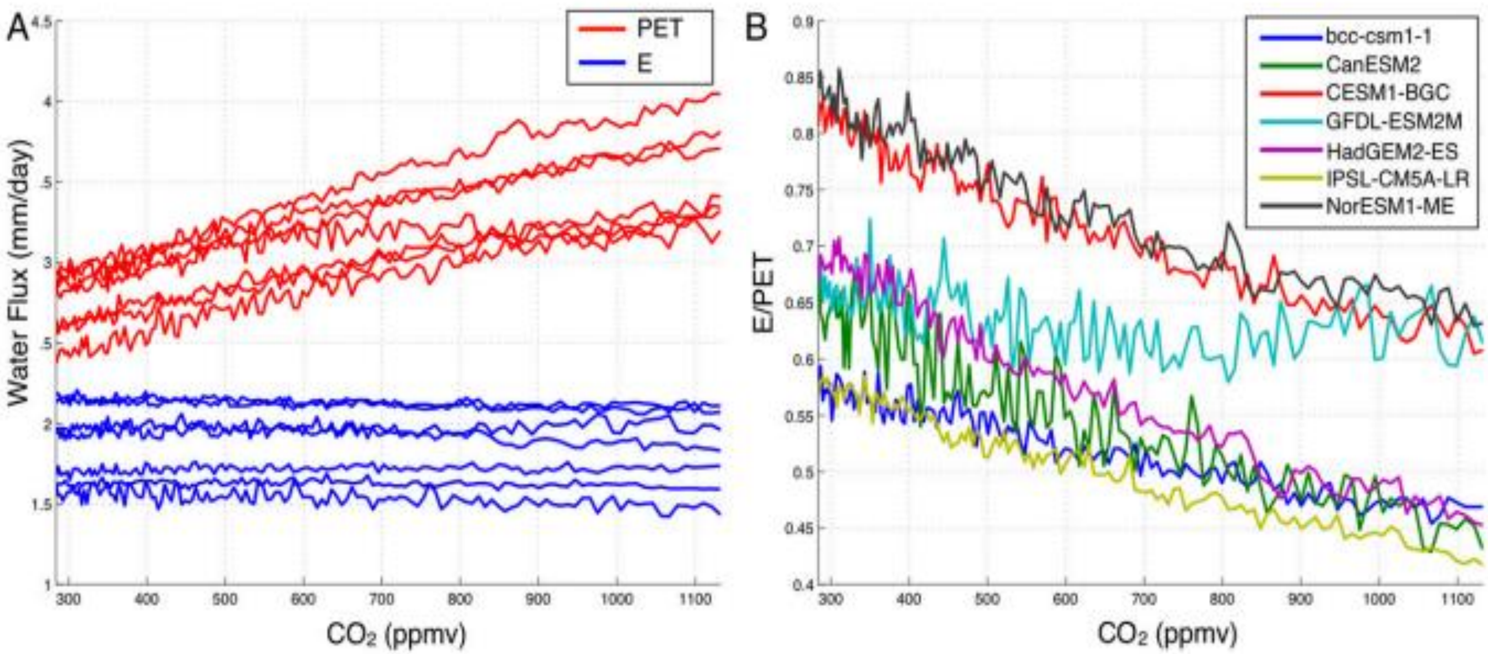
Drought Indices, Drought Impacts, CO_2, and Warming: a Historical and Geologic Perspective

Jacob Scheff[1]

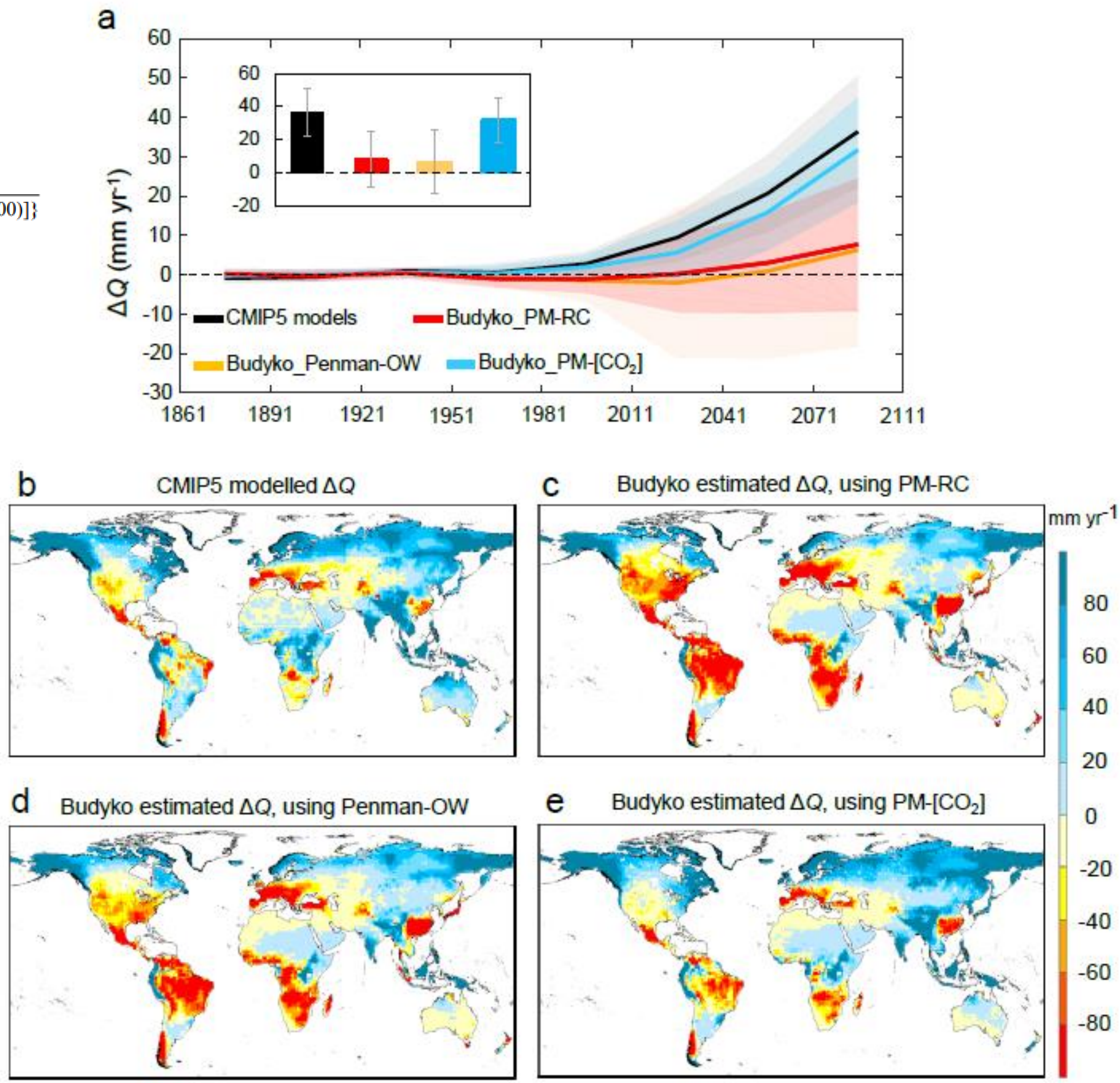
Plant responses to increasing CO_2 reduce estimates of climate impacts on drought severity

Abigail L. S. Swann[a,b,1], Forrest M. Hoffman[c,d], Charles D. Koven[e], and James T. Randerson[f]

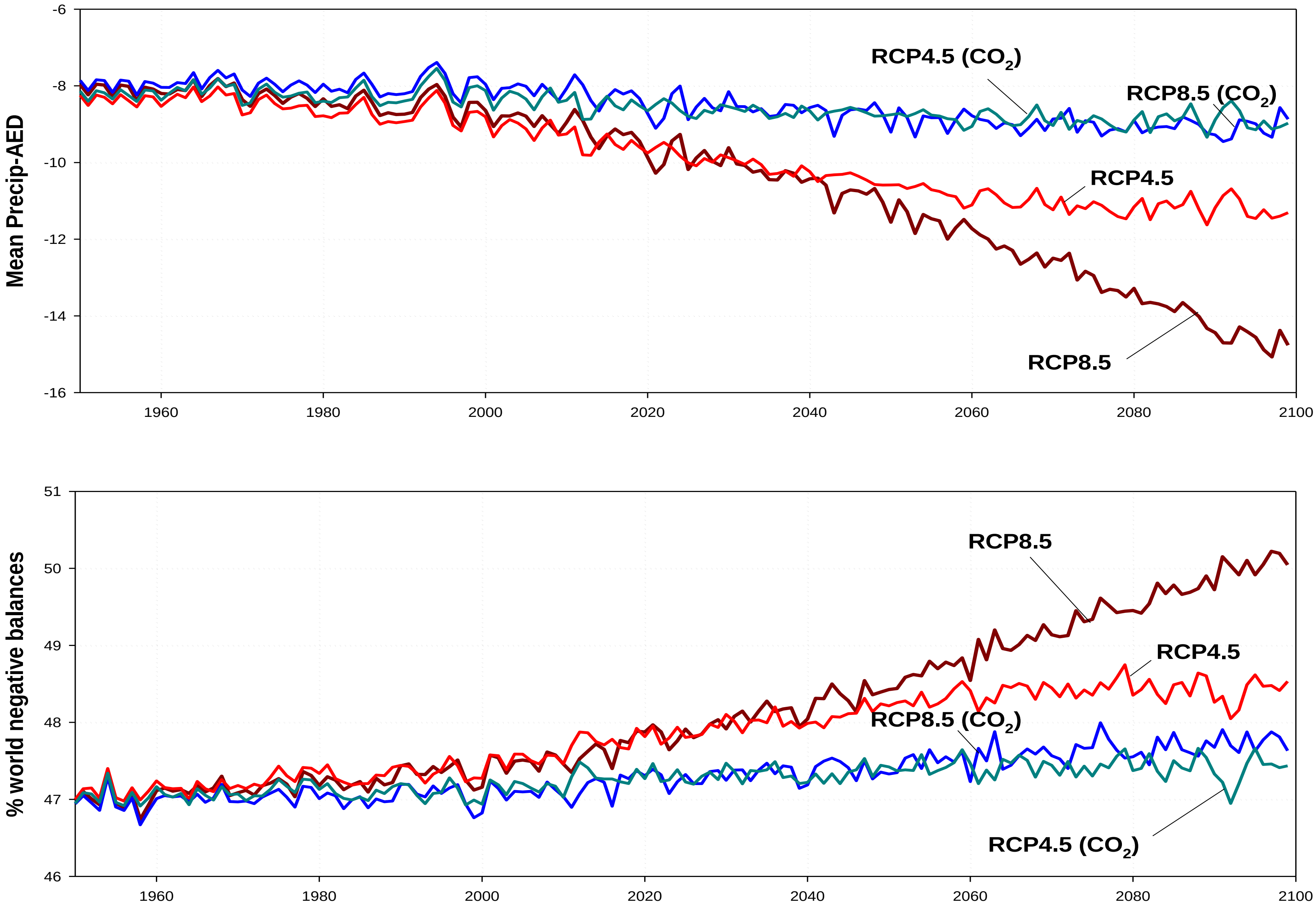
[a]Department of Atmospheric Sciences, University of Washington, Seattle, WA 98195; [b]Department of Biology, University of Washington, Seattle, WA 98195; [c]Computer Science & Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831; [d]Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831; [e]Climate & Ecosystem Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720; and [f]Department of Earth System Science, University of California, Irvine, CA 92697



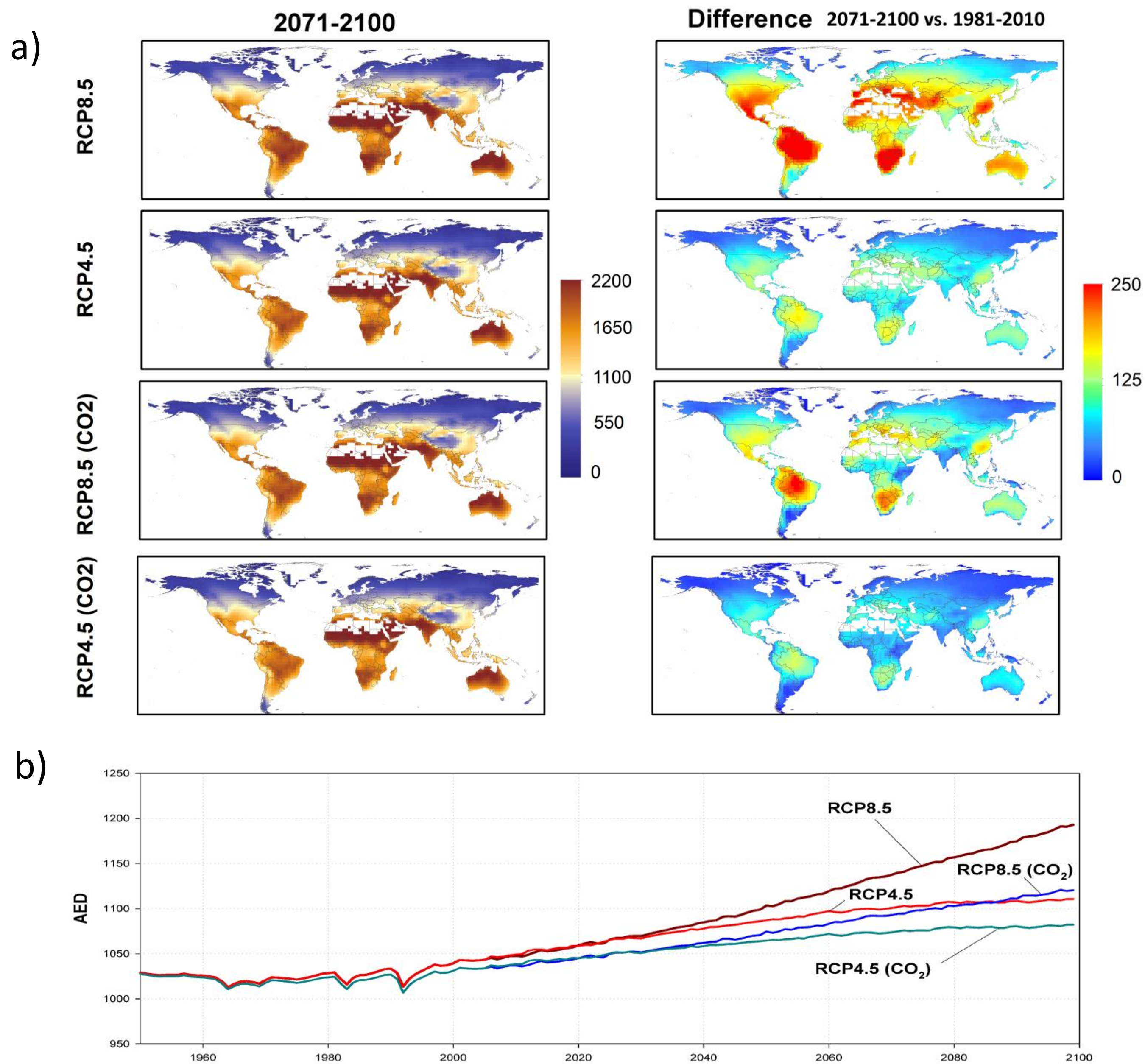
$$E_P = \frac{0.408 s R_n^* + \gamma \frac{900}{T+273} u D}{s + \gamma\{1 + u[0.34 + 2.4 \times 10^{-4}([CO_2] - 300)]\}}$$



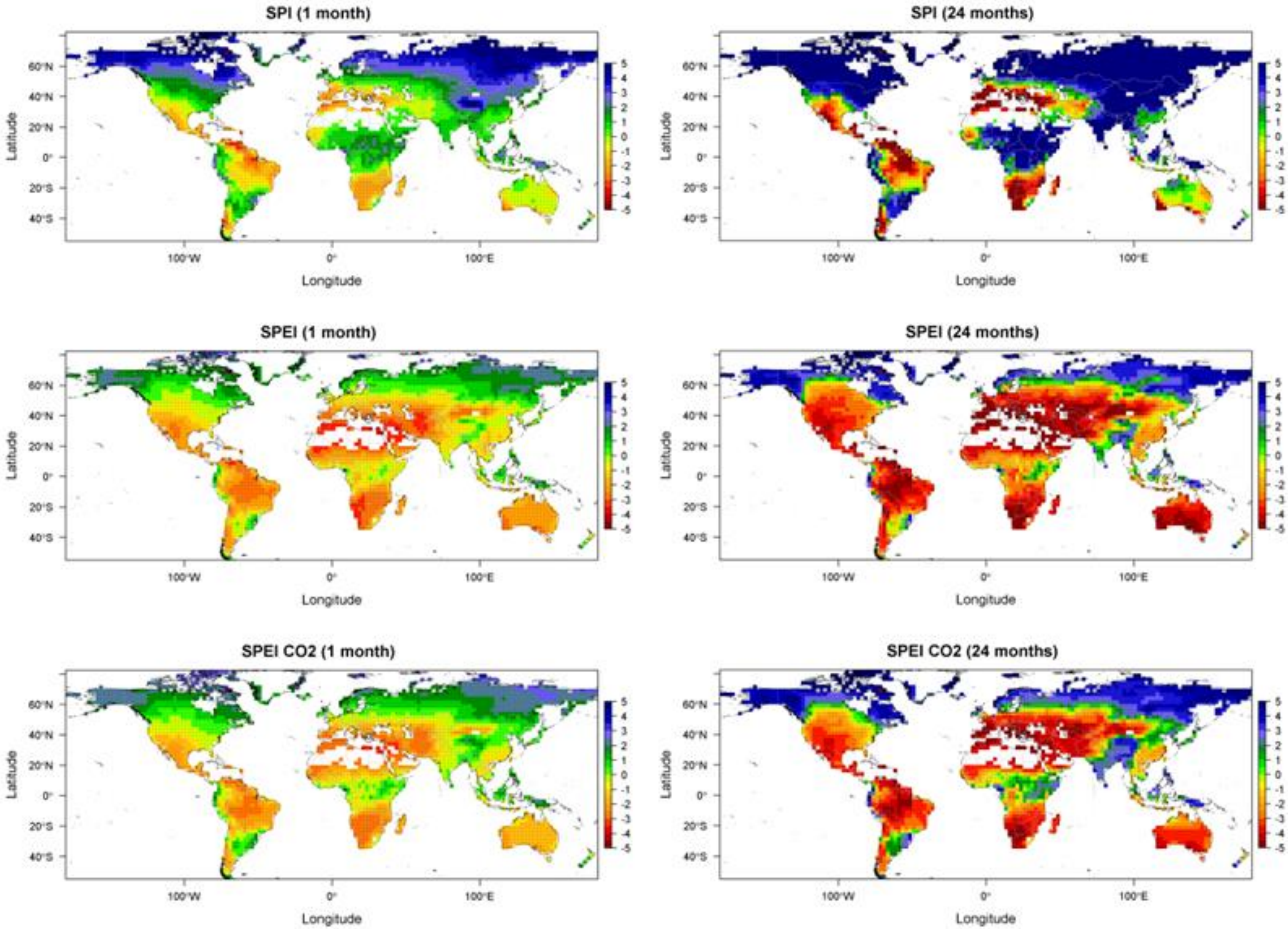
Yang et al. 2019: Nat Clim. Ch.



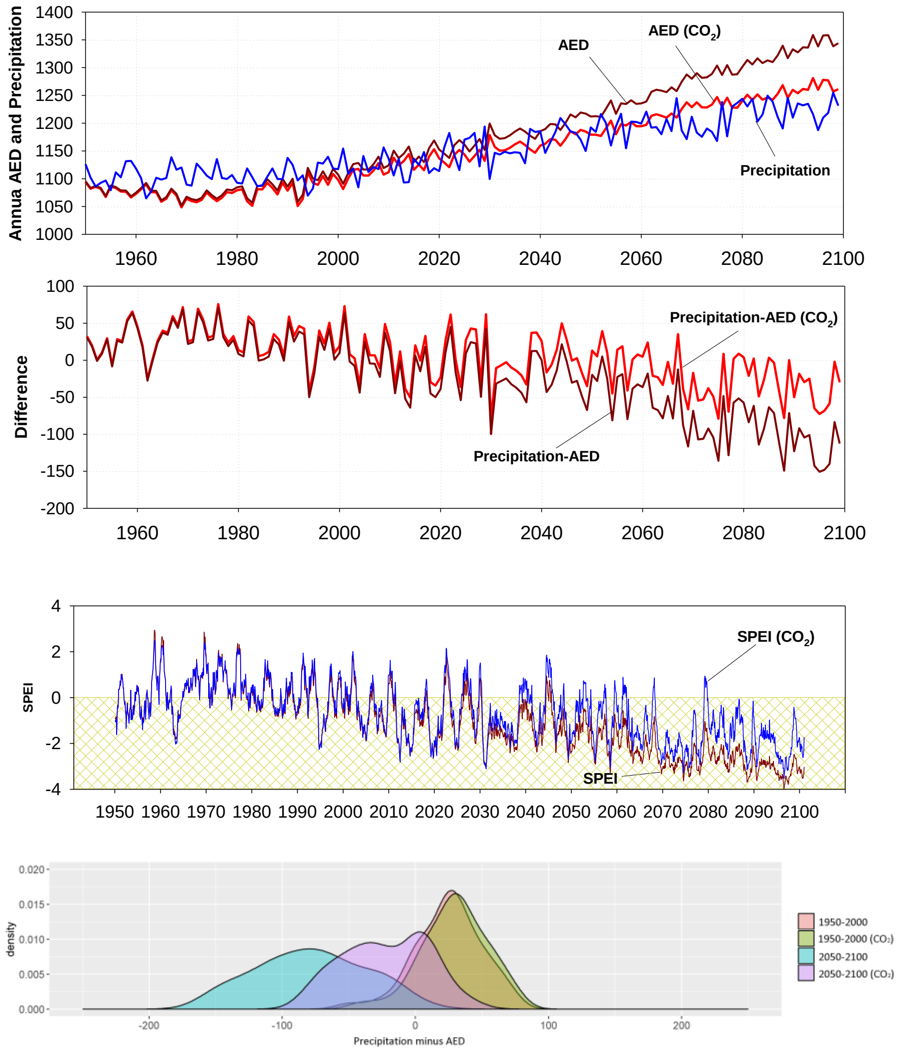
Mean Precip-AED
RCP4.5 (CO_2)
RCP8.5 (CO_2)
RCP4.5
RCP8.5
-6
-8
-10
-12
-14
-16
1960
1980
2000
2020
2040
2060
2080
2100
% world negative balances
RCP8.5
RCP4.5
RCP8.5 (CO_2)
RCP4.5 (CO_2)
51
50
49
48
47
46
1960
1980
2000
2020
2040
2060
2080
2100



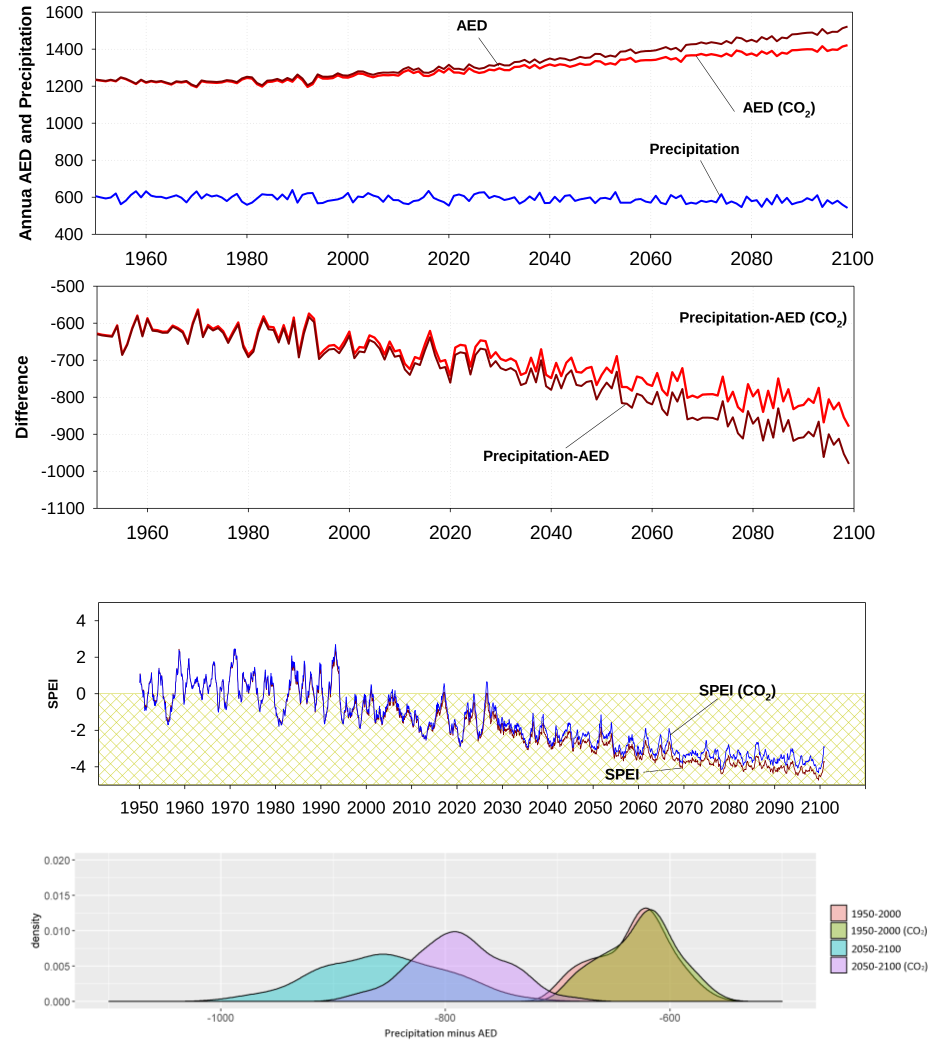
a)
2071-2100
Difference 2071-2100 vs. 1981-2010
RCP8.5
RCP4.5
RCP8.5 (CO2)
RCP4.5 (CO2)
2200
1650
1100
550
0
250
125
0
b)
AED
1250
1200
1150
1100
1050
1000
950
1960
1980
2000
2020
2040
2060
2080
2100
RCP8.5
RCP8.5 (CO2)
RCP4.5
RCP4.5 (CO2)


SPI (1 month)
SPI (24 months)
SPEI (1 month)
SPEI (24 months)
SPEI CO2 (1 month)
SPEI CO2 (24 months)
Latitude
Longitude
60°N
40°N
20°N
0°
20°S
40°S
100°W
0°
100°E
5
4
3
2
1
0
-1
-2
-3
-4
-5

Humid site (East US)



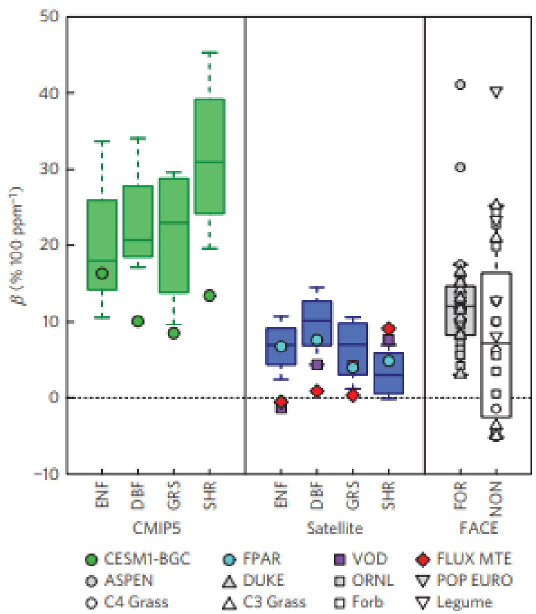
Dry site (West US)



LETTERS
PUBLISHED ONLINE: 7 DECEMBER 2015 | DOI: 10.1038/NCLIMATE2879
nature climate change

Large divergence of satellite and Earth system model estimates of global terrestrial CO_2 fertilization

W. Kolby Smith[1,2]*, Sasha C. Reed[3], Cory C. Cleveland[1], Ashley P. Ballantyne[1], William R. L. Anderegg[4], William R. Wieder[5,6], Yi Y. Liu[7] and Steven W. Running[1]



Chapter 2

CO_2 Fertilization: When, Where, How Much?

Christian Körner · Jack Morgan · Richard Norby

2.1 Carbon a Limiting Plant Resource?

1990; Bowes 19
photosynthesi
known among

Global Change Biology (2007) 13, 2498–2508, doi: 10.1111/j.1365-2486.2007.01467.x

Water savings in mature deciduous forest trees under elevated CO_2

SEBASTIAN LEUZINGER and CHRISTIAN KÖRNER
Institute of Botany, University of Basel, Schönbeinstrasse 6, CH-4056 Basel, Switzerland

10% reduction at 540 p.p.m.

nature climate change
LETTERS
PUBLISHED ONLINE: 11 MAY 2015 | DOI: 10.1038/NCLIMATE2614

Water-use efficiency and transpiration across European forests during the Anthropocene

Increased WUE compensated by:

Legthened growing season
Increased leaf area index
Enhanced AED

- **What about vegetation changes? E.g. the recent Mediterranean trends**

esa ECOSPHERE

ESA CENTENNIAL PAPER

On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene

Craig D. Allen,[1,†] David D. Breshears,[2] and Nate G. McDowell[3]

[1]U.S. Geological Survey, Fort Collins Science Center, Jemez Mountains Field Station, Los Alamos, New Mexico 87544 USA
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[3]Earth and Environmental Science Division, MS-J495, Los Alamos National Laboratory, Los Alamos, New Mexico 85745 USA

3. CO_2 Fertilization & WUE

Sufficient to compensate. CO_2 fertilization and water-use efficiency effects generally compensate for drought and heat stress, fostering increased tree growth and NPP, widespread woody plant expansion in dryland ecosystems, and an overall "greening" observed in many regions.

Effects limited; no benefit during severe drought. Mortality processes associated with growing drought and heat stress already are overcoming CO_2 fertilization and water-use efficiency buffering at times and across extensive regions, with forest "browning" and NPP declines, reductions in forest growth, and markedly greater tree mortality observed in multiple regions of growing water stress in recent decades despite concurrent rising [CO_2].

Correct assessment of the AED effect on drought severity:

Be carefull considering the region of interest,
the drought type
and
the precipitation/soil moisture conditions

Multidisciplinary approaches:

Hydrology
Agronomy
Plant Physiology
Meteorology
…