Effects of greenhouse gases on climate. Evolution of Droughts

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What is a drought?

- Drought is a prolonged absence or marked deficiency of precipitation.
- This deficiency produces water shortage for some activity as agricultural productivity.
- We can distinguish

- agricultural drought which is related to soil moisture deficit

-meteorological drought which is related to a prolonged deficit of precipitation

- hydrological drought (below normal stream flows and ground water levels.

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IPCC AR4

Importance of Droughts

Drought is a natural hazard that can have large damages on regional agriculture.

How will climatic aridity change in the future? Is there a global trend?

In the 2000s, numerous droughts in several continents suggest that an increase of aridity is already occurring.

IPCC

- AR4 (2007): More intense and longer droughts have been observed in wider areas. …Increased drying linked with higher temperature and decreased precipitation has contributed to changes in droughts.
- AR5 (2013) and SYR (2014):Possible overestimation of the increase in regional and global drought

There is ***low confidence*** in observed global- scale trends in droughts, due to lack of direct observations, dependencies of inferred trends on the choice of the definition for drought, and due to geographical inconsistencies in drought trends

Drought Index

- To analyze drought, we need to define it in a quantitative way and this has been done by introducing an appropriate « index »
- An index often used to define drought sustained by farmers is the PDSI (Palmer Drought Severity Index). It is related to the ratio of precipitation rate and potential evapotranspiration (EP)

Generally, precipitation (P) and potential evapotranspiration (EP) are annual or monthly mean values.

Potential Evapotranspiration

- EP is the rate at which evapotranspiration occurs when the surface is well supplied with water.
- Thornwaite Formula: EP is a function of temperature. Although attractive because of its simplicity, it has been known that this formula is based on incorrect physics.

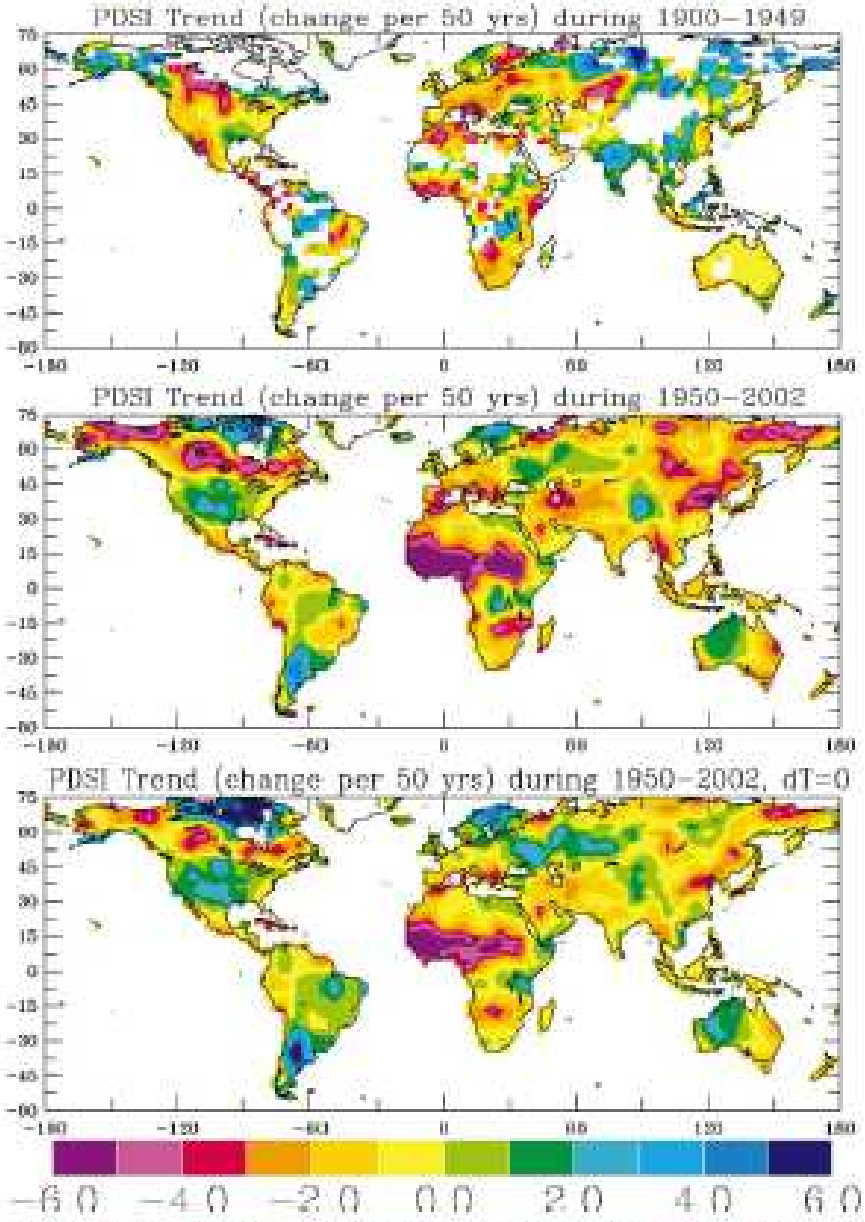


Fig. 7. Maps of linear trends of PDSI (change (50 yr)$^{-1}$, calculated with both precipitation and temperature changes) during (top) 1900–49 and (middle) 1950–2002. (bottom) The trends of PDSI calculated without temperature changes. Red (blue) areas indicate drying (wetting).

Trends of drought index using PDSI using Thornwaite equation for EP.

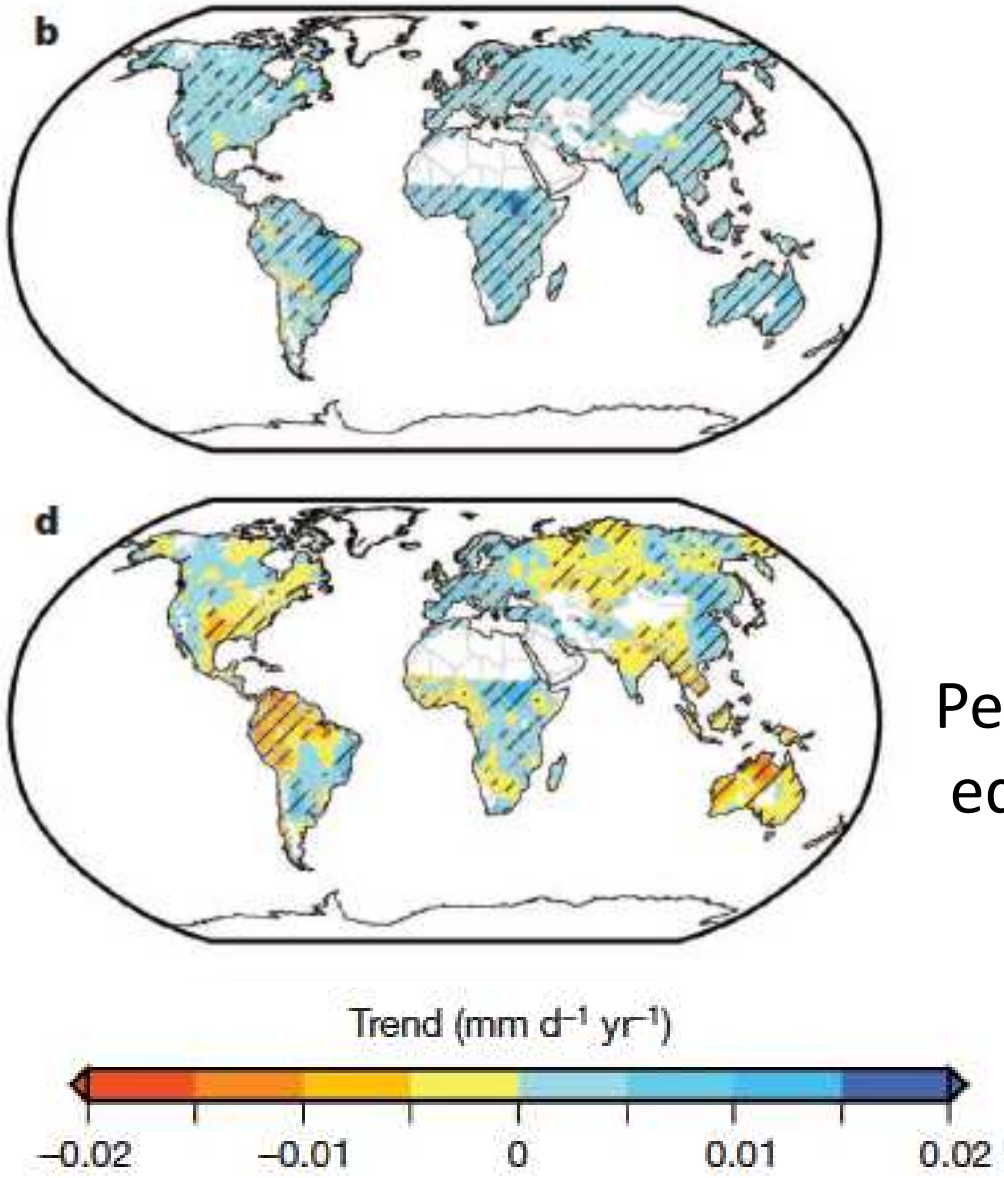
UNEP aridity classification:
Hyper arid: P/EP<0.05
Arid: : 0.05< P/EP <0.20
Semi-arid 0.20 < P/EP < 0.50
Subhumid: 0.50 < P/EP < 0.65

Dai et al, 2004
J. Of Hydrometeorology

Potential Evapotranspiration

- With EP determined only by temperature, an increase in temperature will cause an increase in EP that induce increase in aridity.
- A more physical formula is the Penman-Monteith equation. EP is related to radiative fluxes, to wind and to air humidity.

Trend in Potential Evaporation

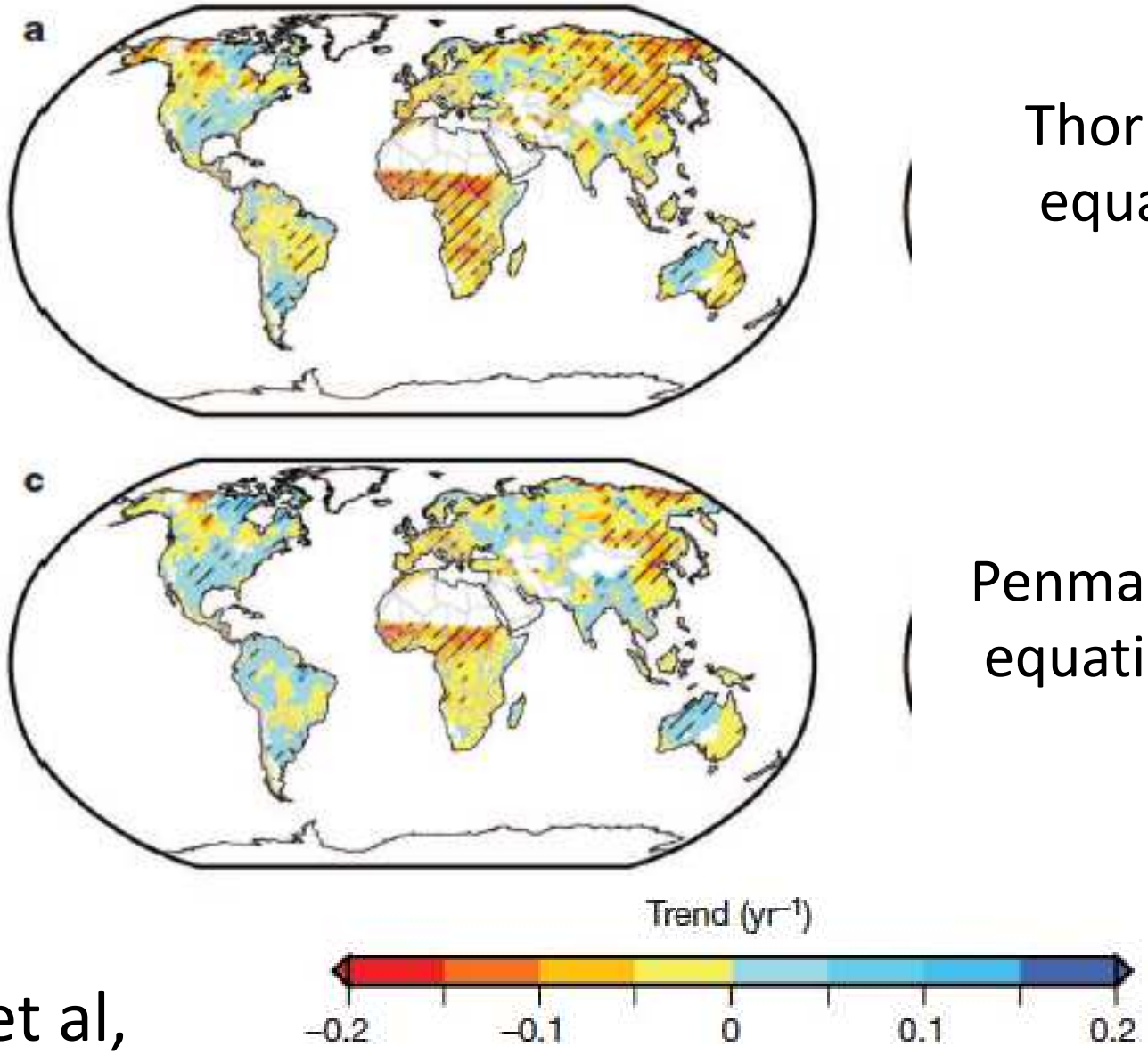


Thornwaite equation

Penman-Monteith equation

Sheffield et al, 2012

PDSI trend



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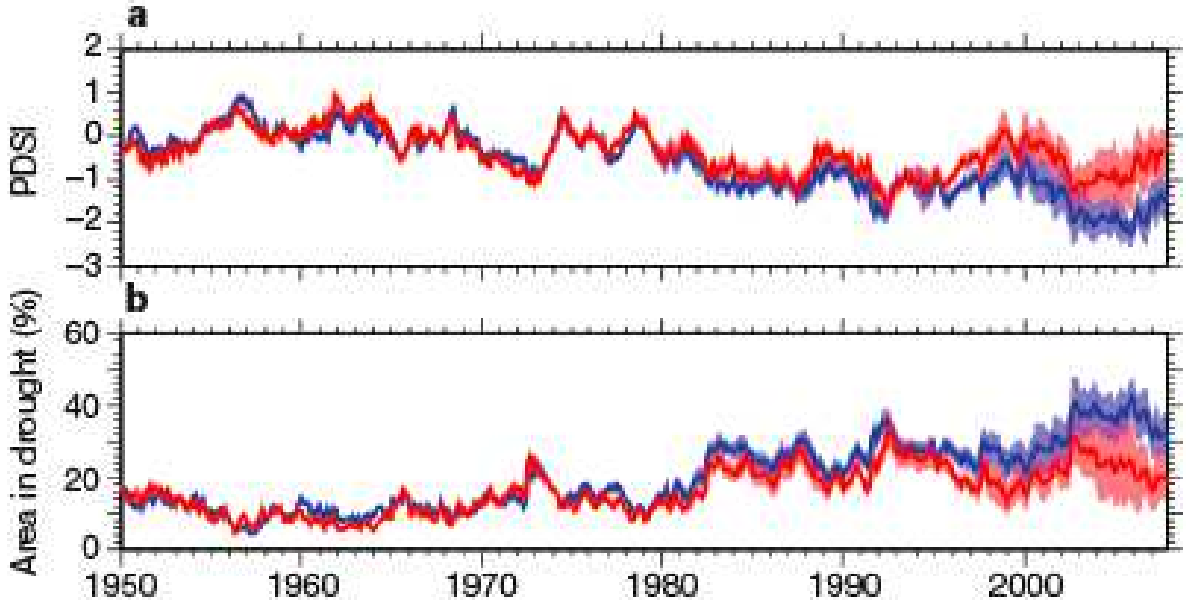


Figure 1 | Global average time series of the PDSI and area in drought. a, PDSI_Th (blue line) and PDSI_PM (red line). b, Area in drought (PDSI <-3.0) for the PDSI_Th (blue line) and PDSI_PM (red line). The shading represents the range derived from uncertainties in precipitation (PDSI_Th and PDSI_PM) and net radiation (PDSI_PM only). Uncertainty in precipitation is estimated by forcing the PDSI_Th and PDSI_PM by four alternative global precipitation data sets. Uncertainty from net radiation is estimated by forcing the PDSI_PM with a hybrid empirical–satellite data set[31] and an empirical estimate. The other near-surface meteorological data are from a hybrid reanalysis–observational data set[31]. The thick lines are the mean values of the different PDSI data sets. The time series are averaged over global land areas excluding Greenland, Antarctica and desert regions with a mean annual precipitation of less than 0.5 mm d^{-1}.

Evaporation rates

- Since 50 years, evaporation rates over land has decreased and not increased.
- “Warmer is more arid”?

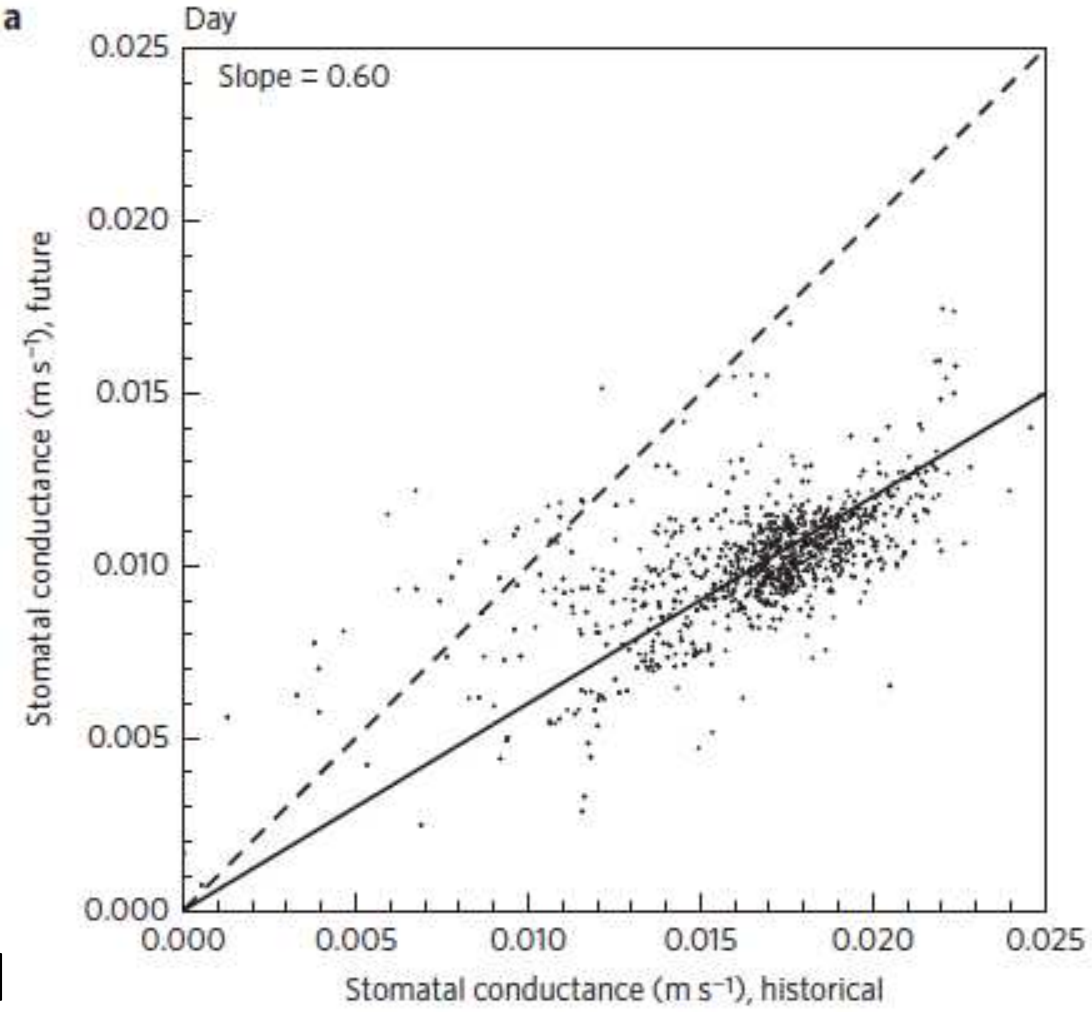
It is a misinterpretation of feedback between tha land and the atmosphere. During drought, evaporation rate decreases;

Less evaporation induces an increase of temperature.

Future Climate and Droughts

- Offline analyses of climate model outputs do not take into account the change of stomatal conductance Cs with atmospheric CO2 concentration.
- EP is computed with a constant bulk Cs
- Milly and Dune (2015) have determined the change of Cs simulated by their Earth Model

Stomatal conductance



Cs is reduced by 40%.
With this decrease, The bias of PE is reduced

Milly and Dunne, 2015

Dought assessment for past and future climate

Inconsistencies

- Evaporation rates have decreased over land since 50 years.
- Precipitation rates will increase with warming.
- Biological impact of increased CO2 influences the evaporation rate.

Conclusion

We know that an increase of the atmospheric CO_2 concentration induces a global warming, and regional increases of land temperature.

The impact on global precipitation is known but it is more difficult to assess the regional changes of precipitation rates.

The impact of global warming on drought is still a matter of research. Improvements in modeling and observations are needed to increase confidence in results.

Thank you