Flash Drought as Captured by MERRA-2:

Disentangling the Contributions of Precipitation Deficit and Excess Energy

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Drought has many flavors:

Meteorological drought: a long-term deficit of precipitation

Agricultural drought: a long-term deficit of soil moisture

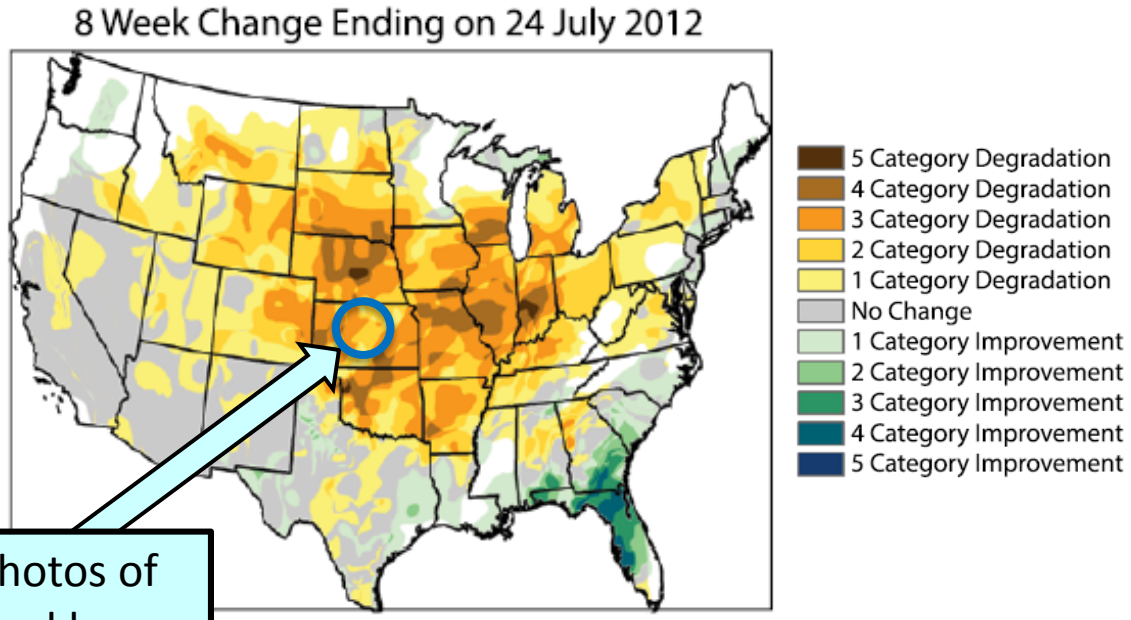
Hydrological drought: a long-term deficit of streamflow, reservoir contents

Socio-economic drought: a deficit of water availability relative to societal need

New to the climate lexicon: the “flash drought”

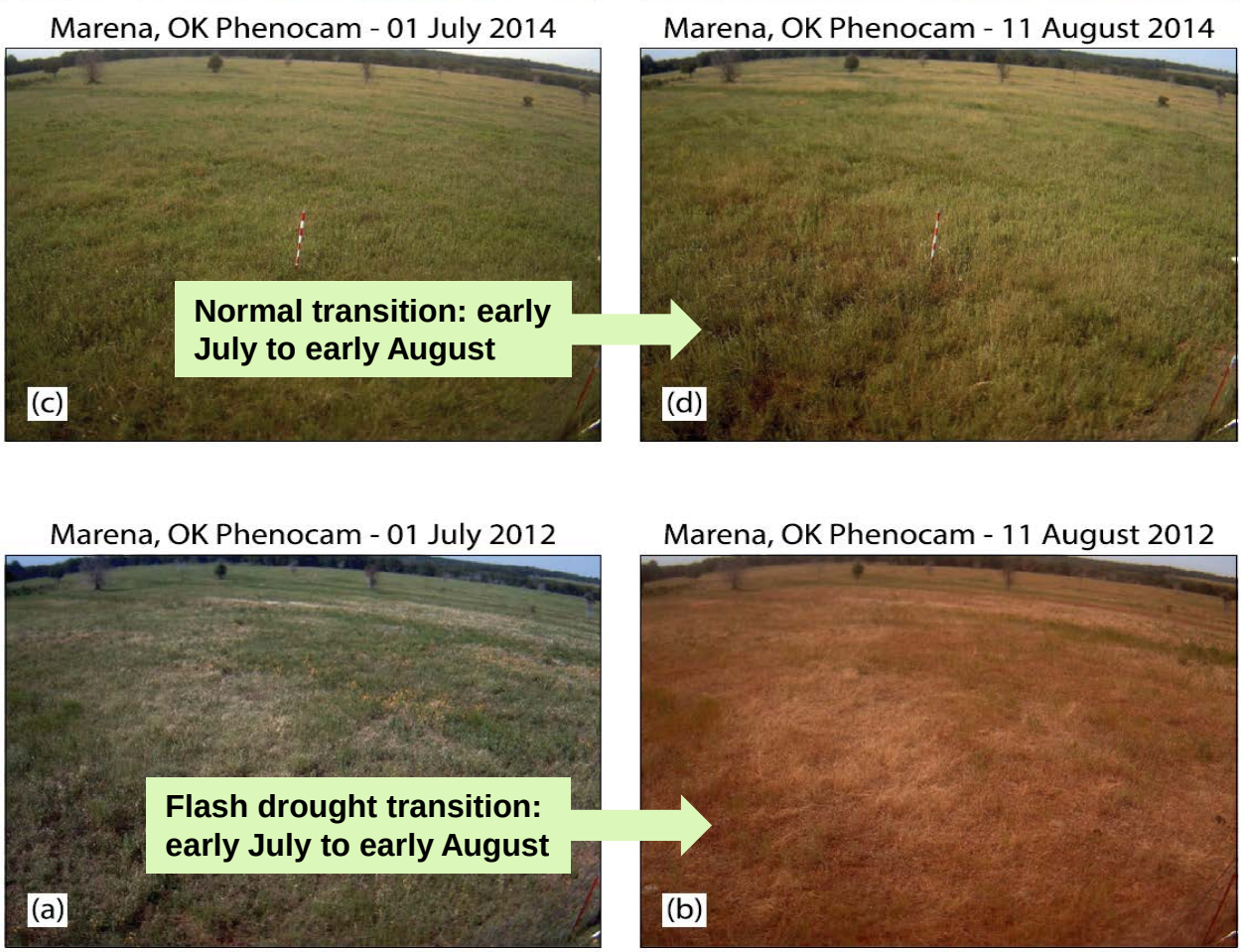
Flash droughts are “distinguished from more conventional slowly developing droughts by their unusually rapid rate of intensification.” (Otkin et al. 2018)

Drought intensification
(from US Drought Monitor)



Next page: photos of what happened here

from Otkin et al. (2018)



from Otkin et al. (2018)

Potential causes of a flash drought (focusing on agricultural drought):

(1) **Precipitation deficit** (Okay, this is obvious.)

(2) **Evaporation excess** (Anomalous drying of the soil due, e.g., to anomalous incident shortwave radiation, air dryness, wind speed, or air temperature)

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(2) Evaporation excess **(Anomalous drying of the soil due, e.g., to anomalous incident shortwave radiation, air dryness, wind speed, or air temperature)**

In the literature, this latter source is often implied to be critical for flash drought. e.g., from Otkin et al (2018): "Though precipitation deficits over some time period are required for drought to develop, their presence alone is unlikely to lead to a flash drought because a lack of precipitation is only one of several factors that can lead to rapid drought intensification…."

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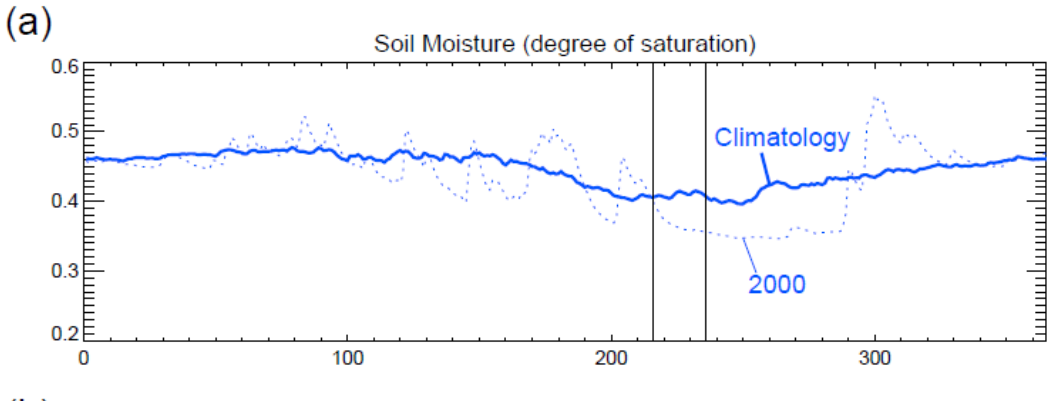
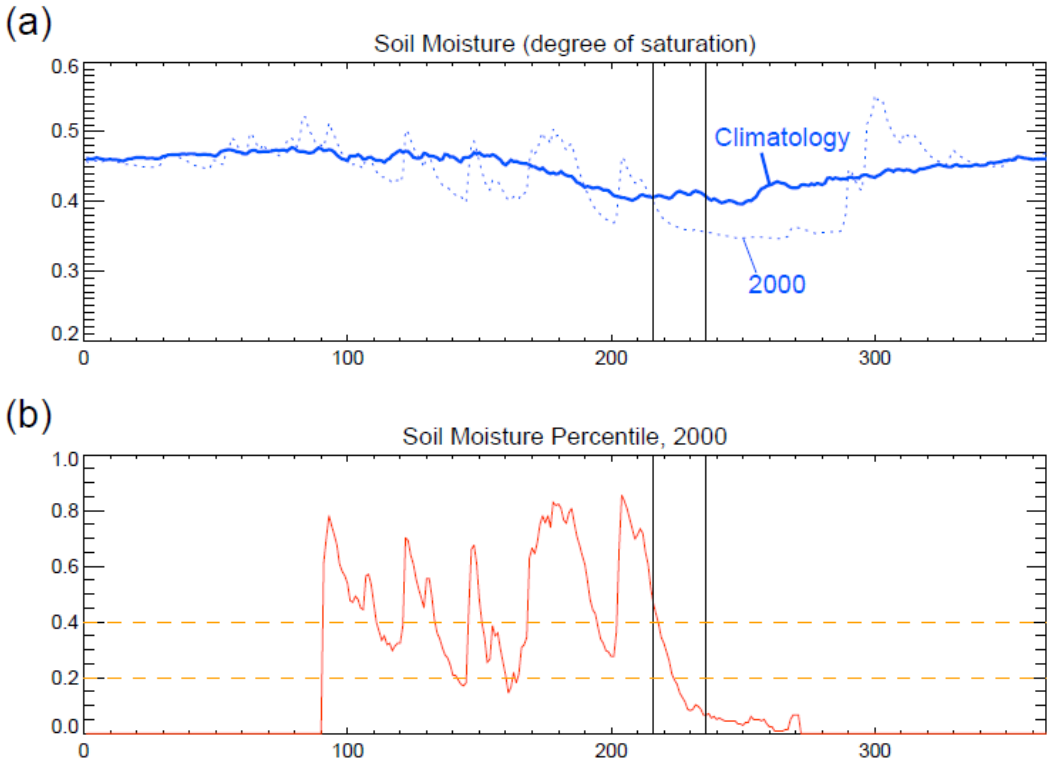
How important is evaporation excess for flash drought production? Use MERRA-2 to find out!

Approach used to identify flash droughts from MERRA-2 data



Step 1: Convert the time series of root zone soil moisture within a given year at a given grid cell…

Approach used to identify flash droughts from MERRA-2 data

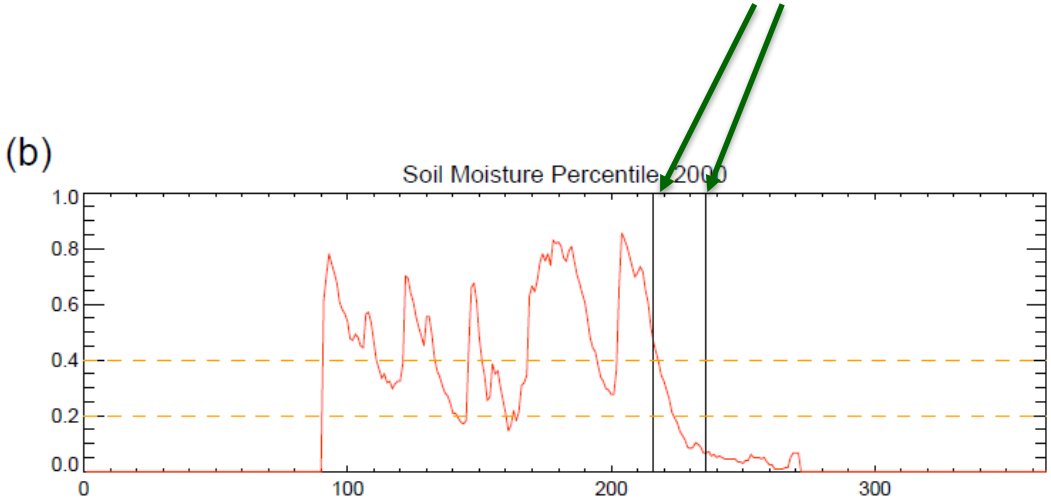


Step 1: Convert the time series of root zone soil moisture within a given year at a given grid cell…

… into a time series of percentiles (focusing on the April-September time period)

Approach used to identify flash droughts from MERRA-2 data

Step 2: Look for a drop from above the 40th percentile to below the 20th percentile within a span of 20 days (an approach suggested by Ford and Labosier 2017).



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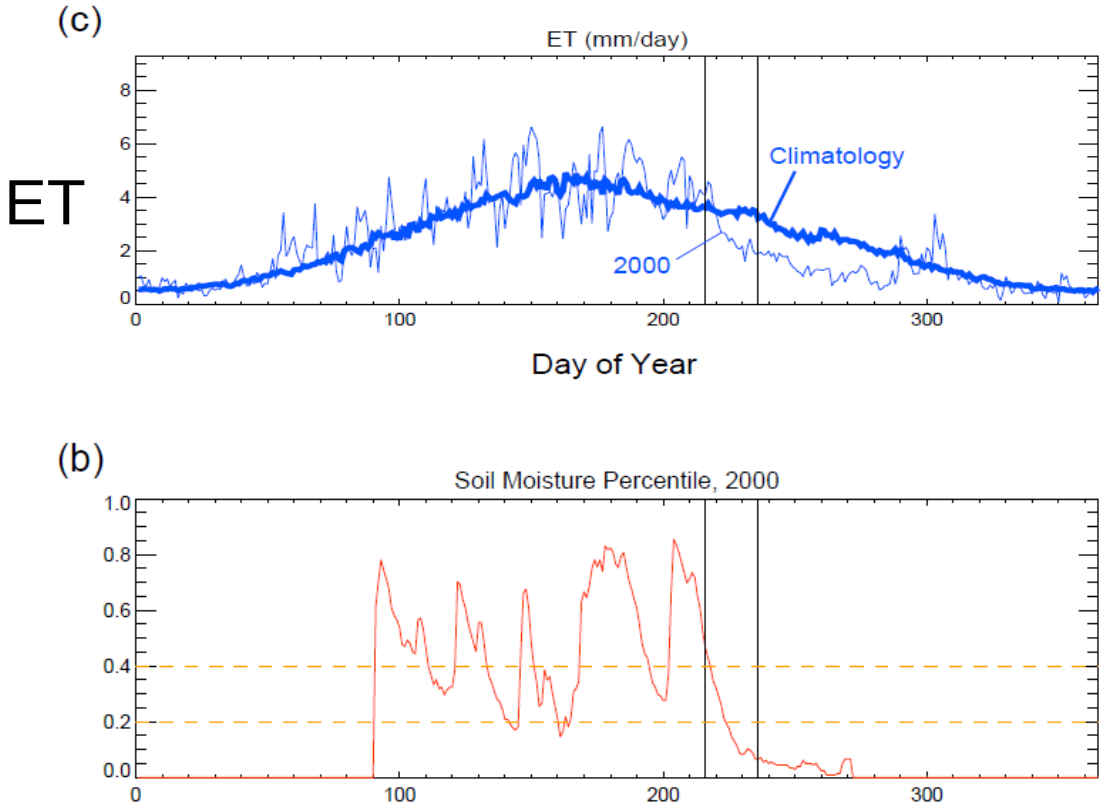

Step 3: Call it a flash drought if it is accompanied by a large change in evapotranspiration.

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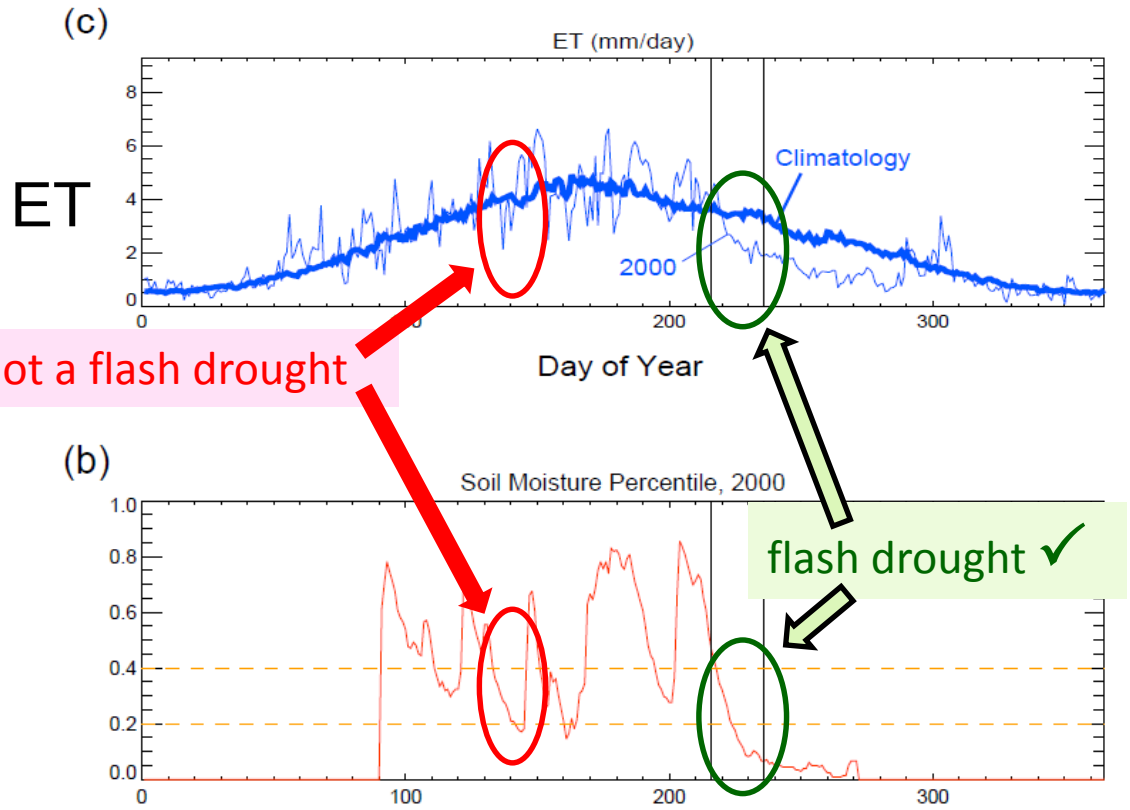

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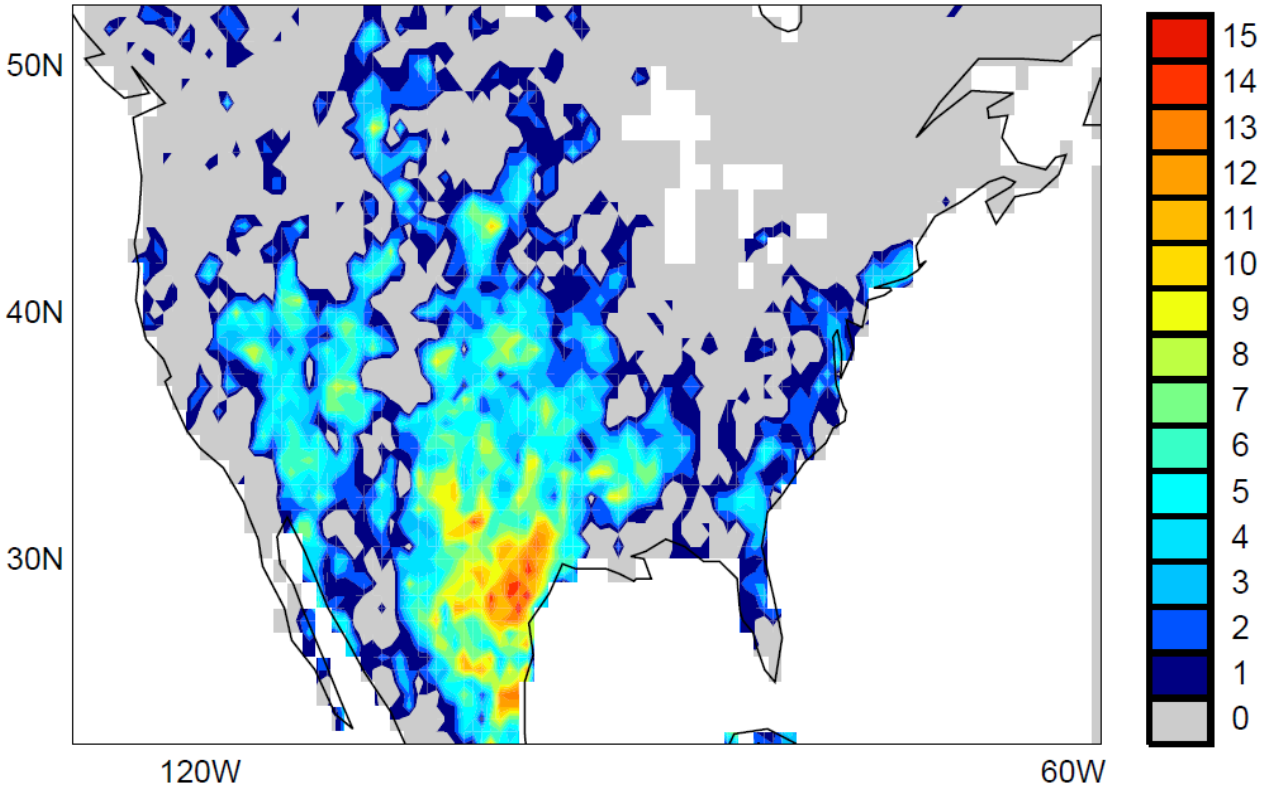
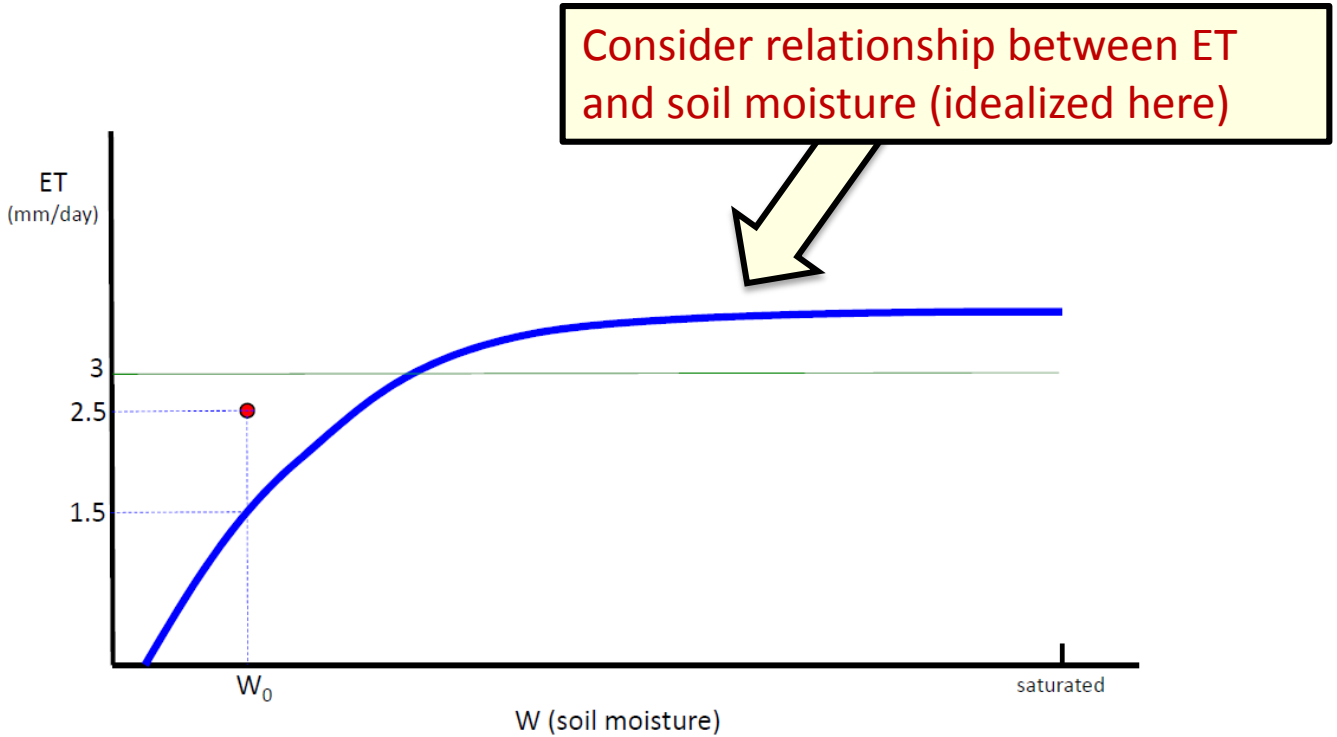
Number of flash droughts occurring during April-September over the MERRA-2 period



Again, what are the relative roles of precipitation and ET anomalies in creating a flash drought?

Does MERRA-2 support the idea that ET anomalies (as induced, e.g., by heatwaves, high winds, etc.) are needed for flash drought production?

Approach used to determine ET contribution to a flash drought



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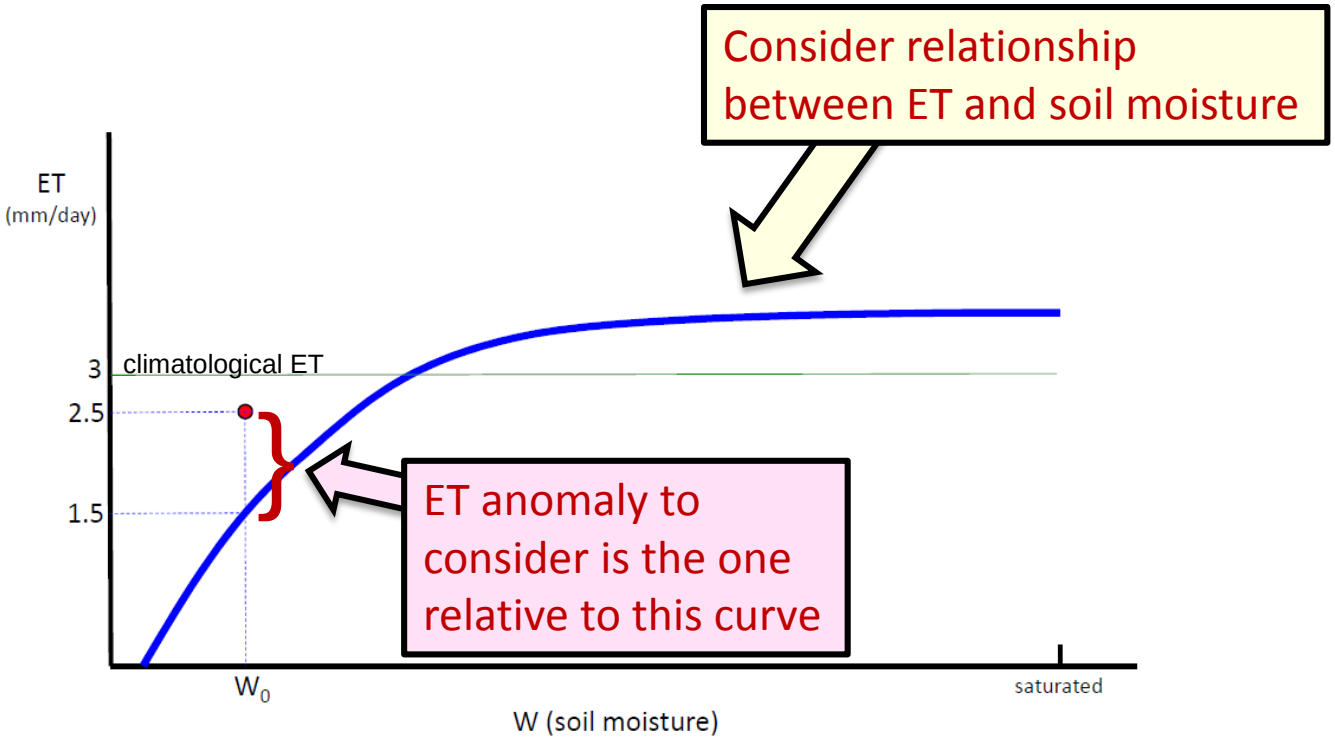
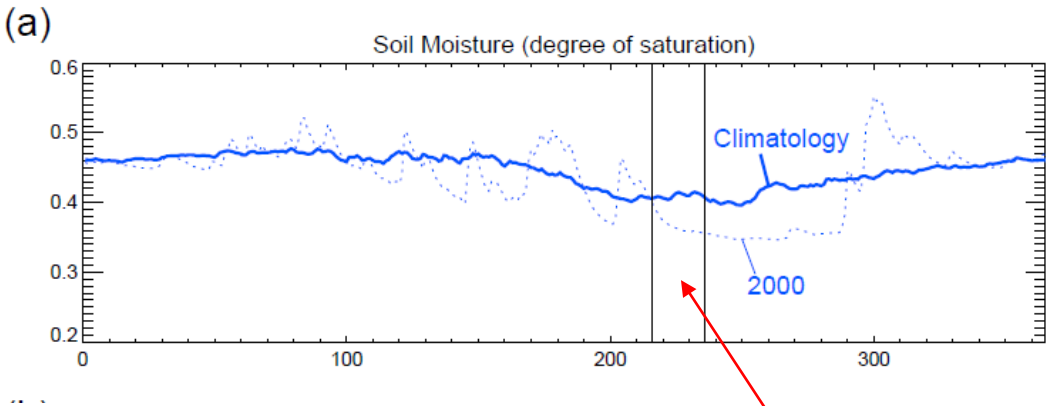
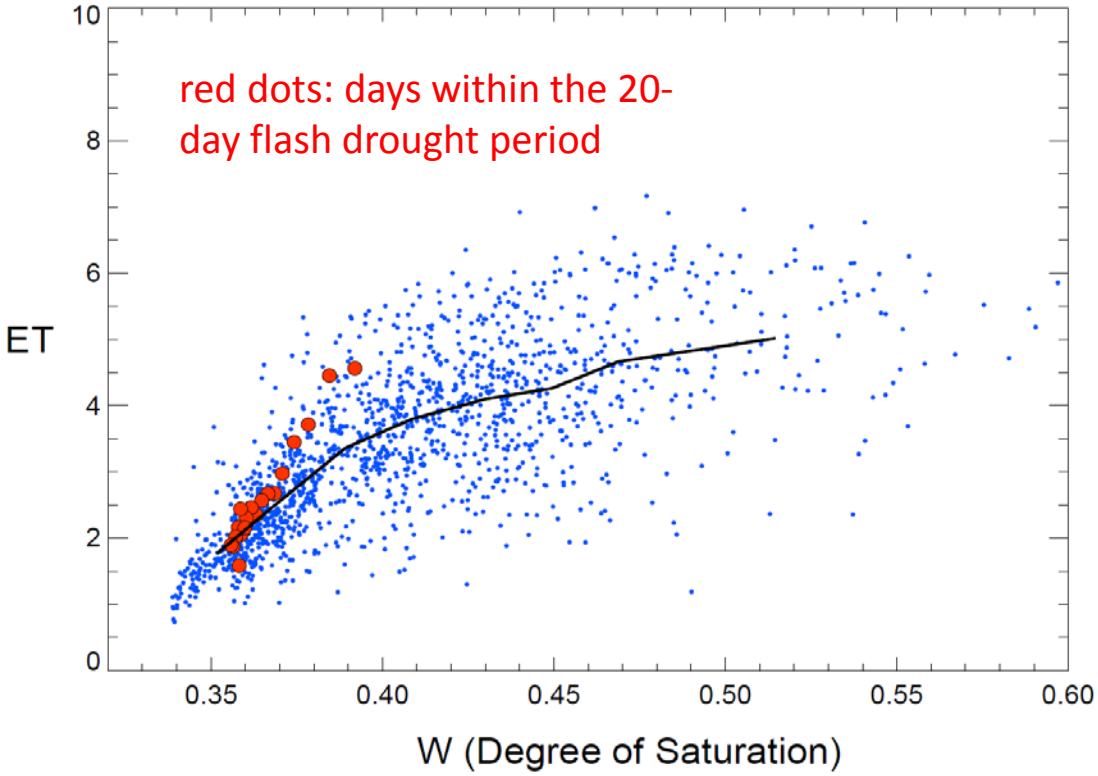




Recall: we identified a flash drought at this Oklahoma grid cell.

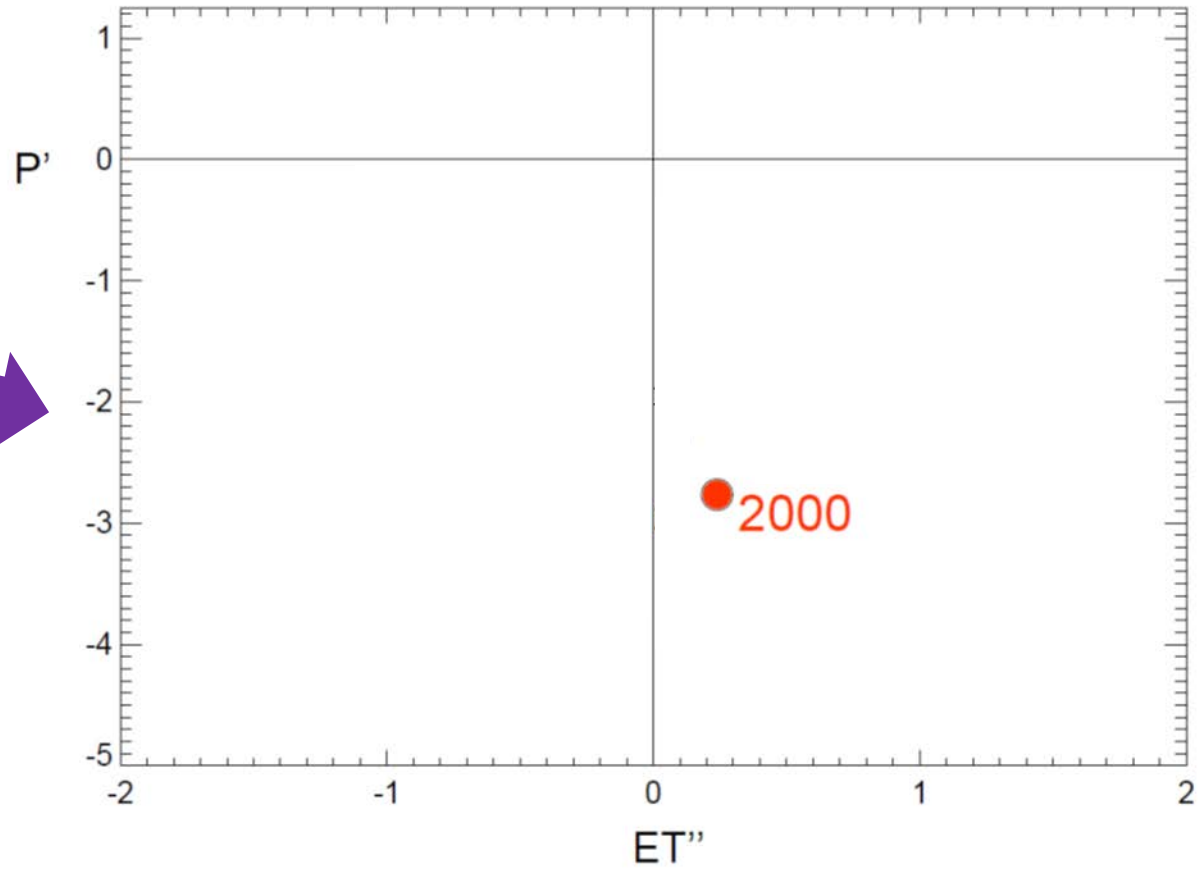
Curve fitted with MERRA-2 data (at a given location and time-of-year):

Each dot corresponds to a single day within the MERRA-2 period.



We sum over the anomalies relative to the fitted black line to get the total ET anomaly for the flash drought.

Plot the resulting 20-day ET anomaly against the concurrent precipitation anomaly



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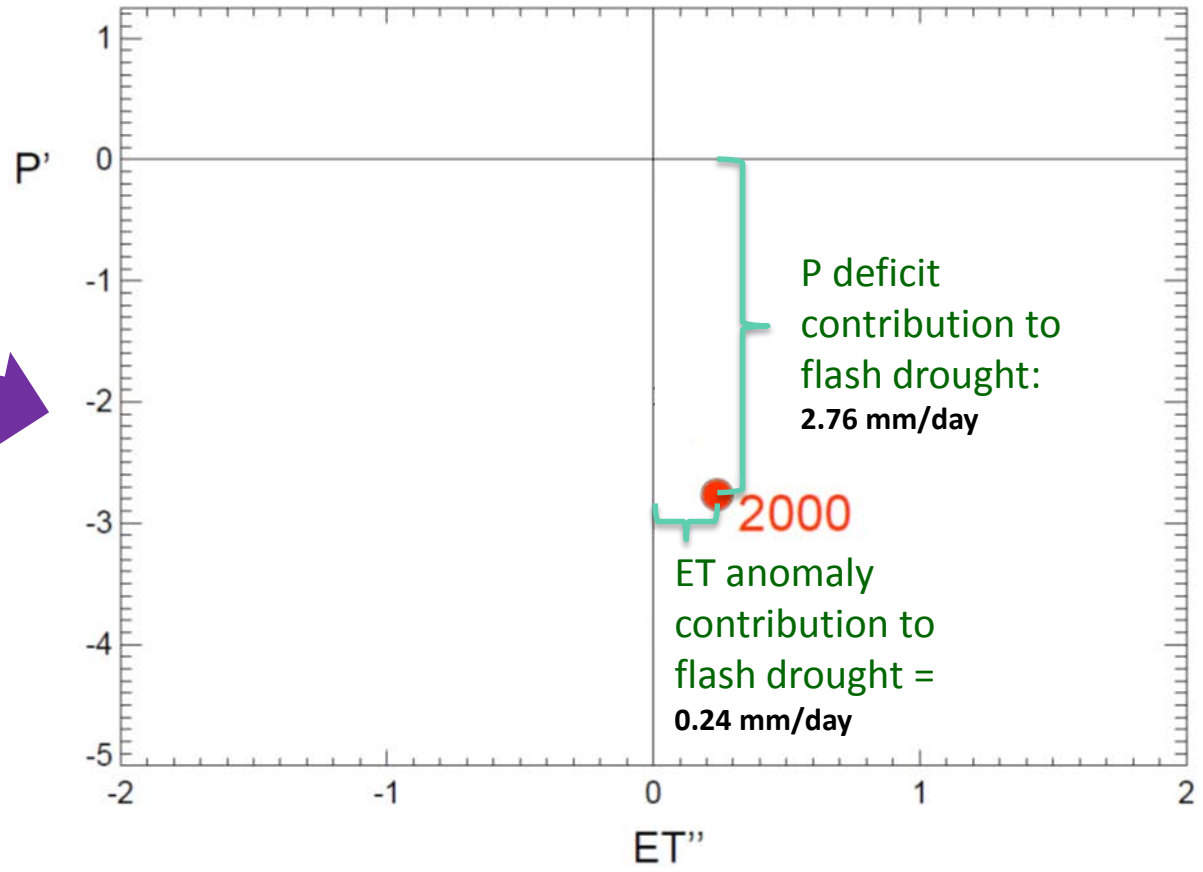

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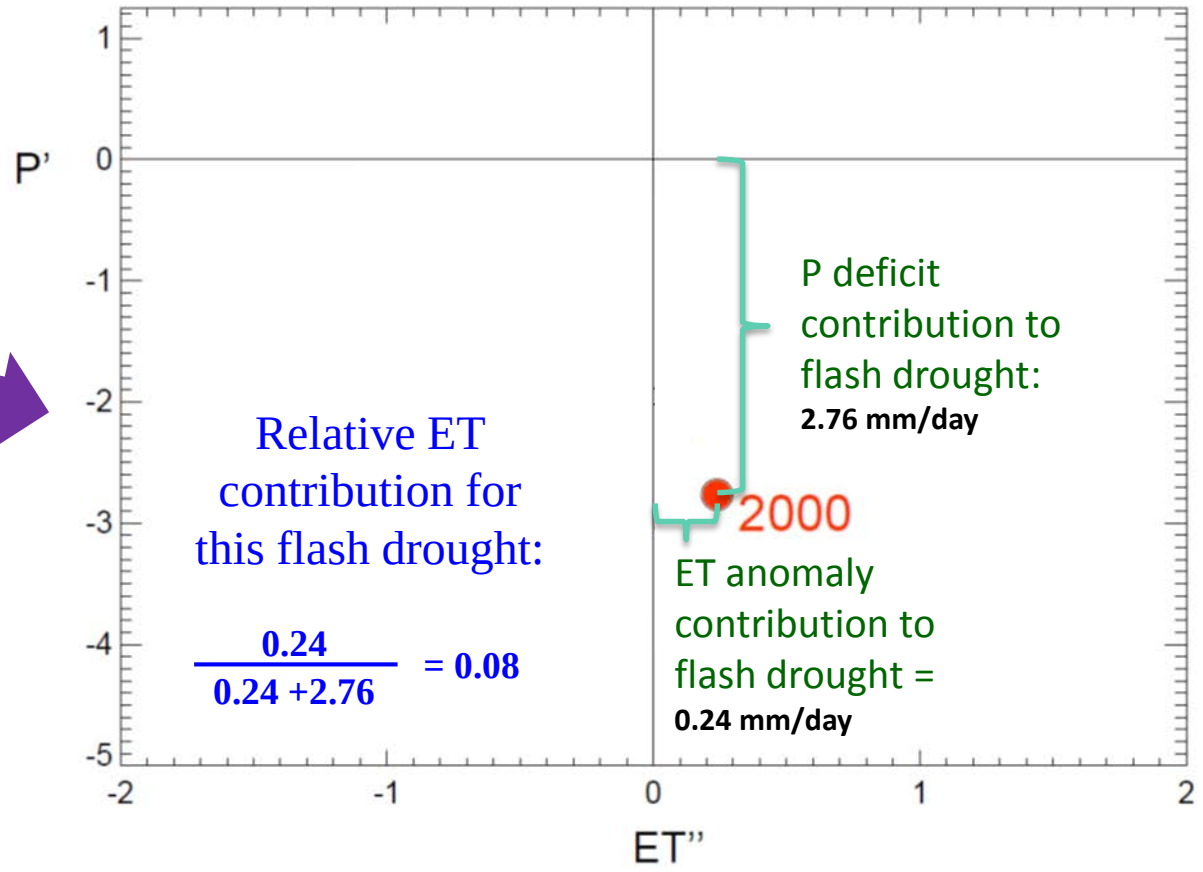
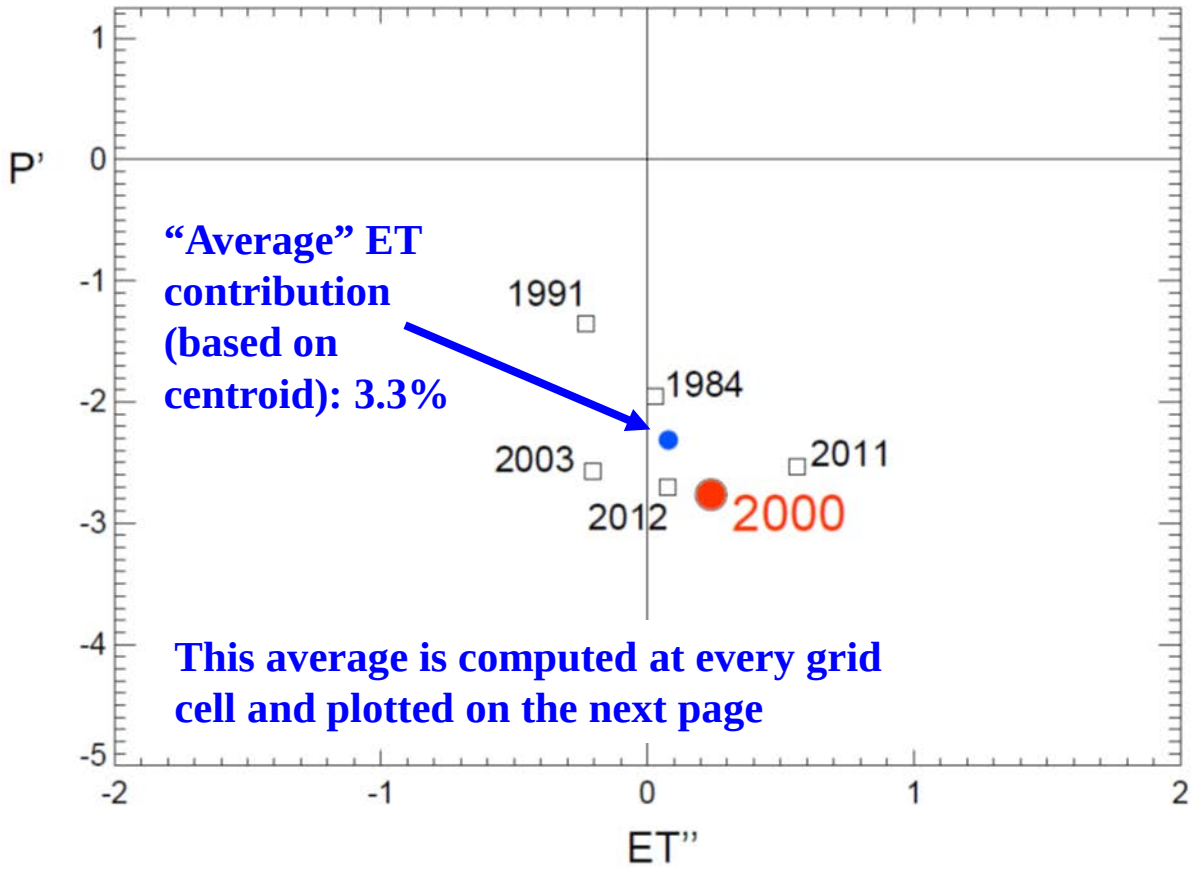
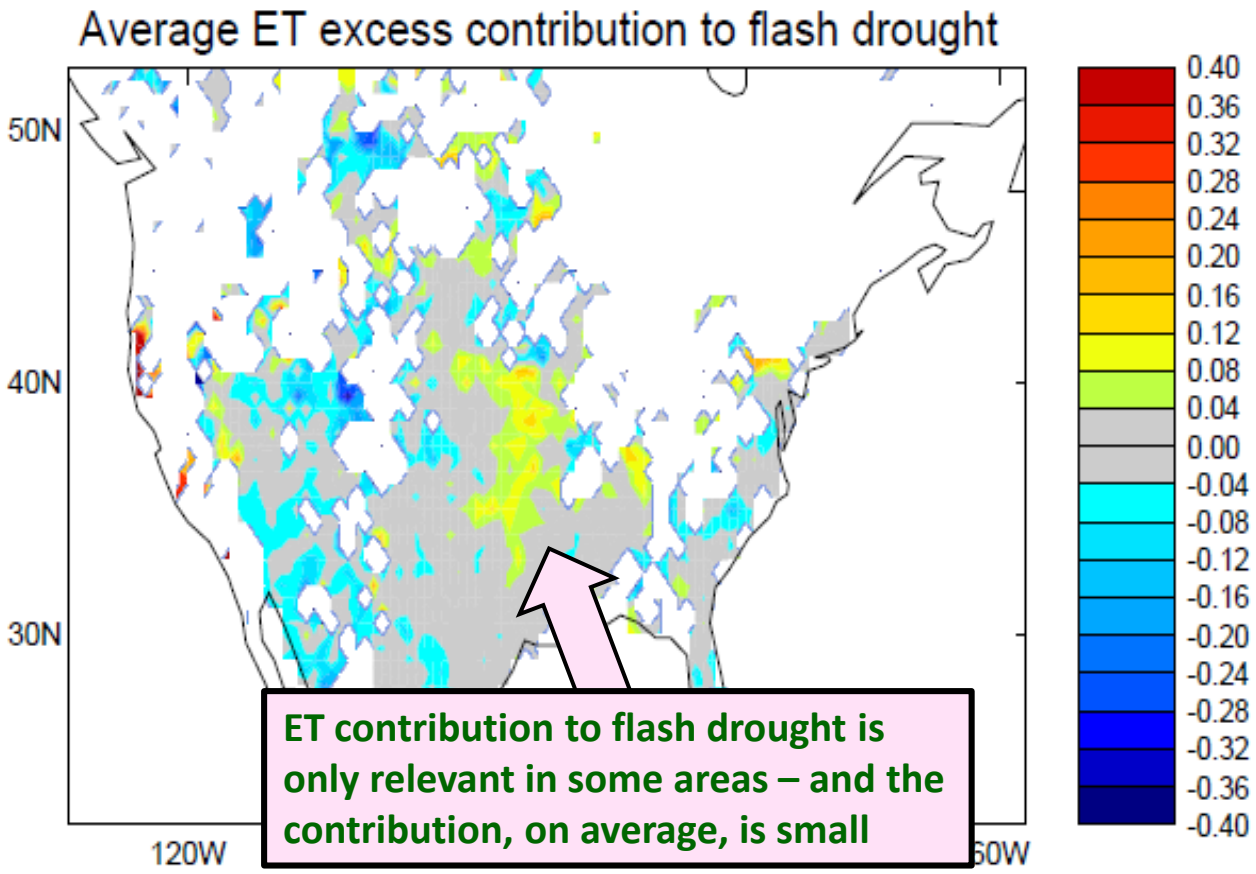
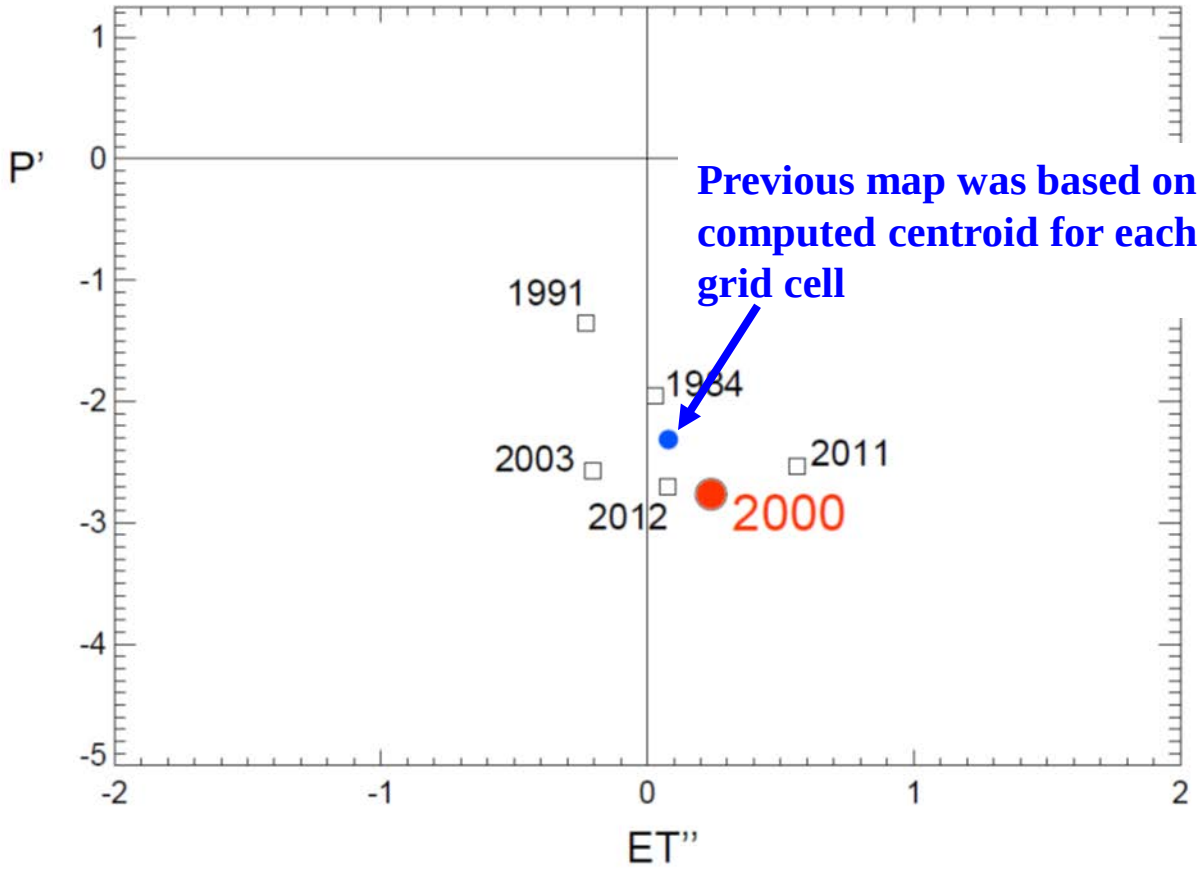
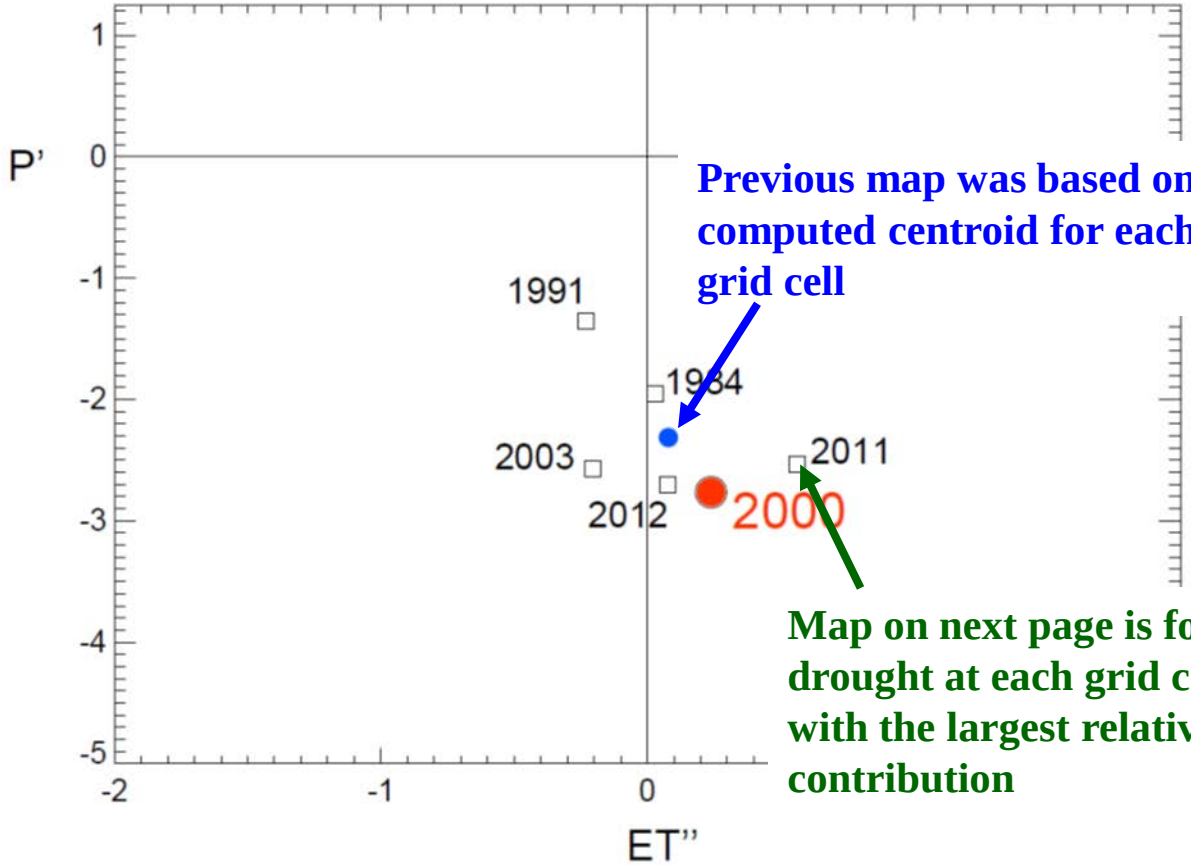


There were, in fact, 6 flash droughts identified at this grid cell.



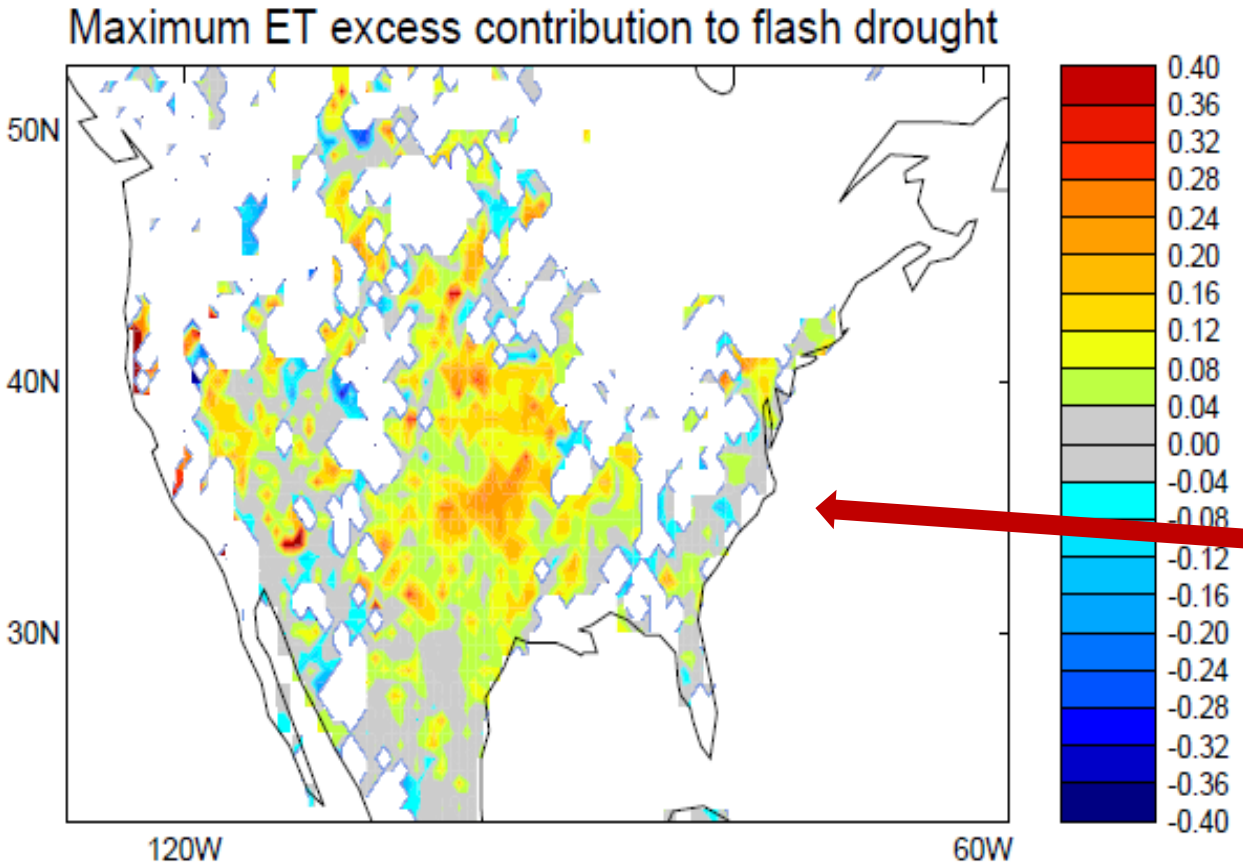

Average ET excess contribution to flash drought
50N
40N
30N
120W
60W
0.40
0.36
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
-0.04
-0.08
-0.12
-0.16
-0.20
-0.24
-0.28
-0.32
-0.36
-0.40
ET contribution to flash drought is only relevant in some areas – and the contribution, on average, is small


P'
ET''
1
0
-1
-2
-3
-4
-5
-2
-1
0
1
2
1991
1994
2003
2011
2012
2000
Previous map was based on computed centroid for each grid cell



Previous map was based on computed centroid for each grid cell

Map on next page is for drought at each grid cell with the largest relative ET contribution



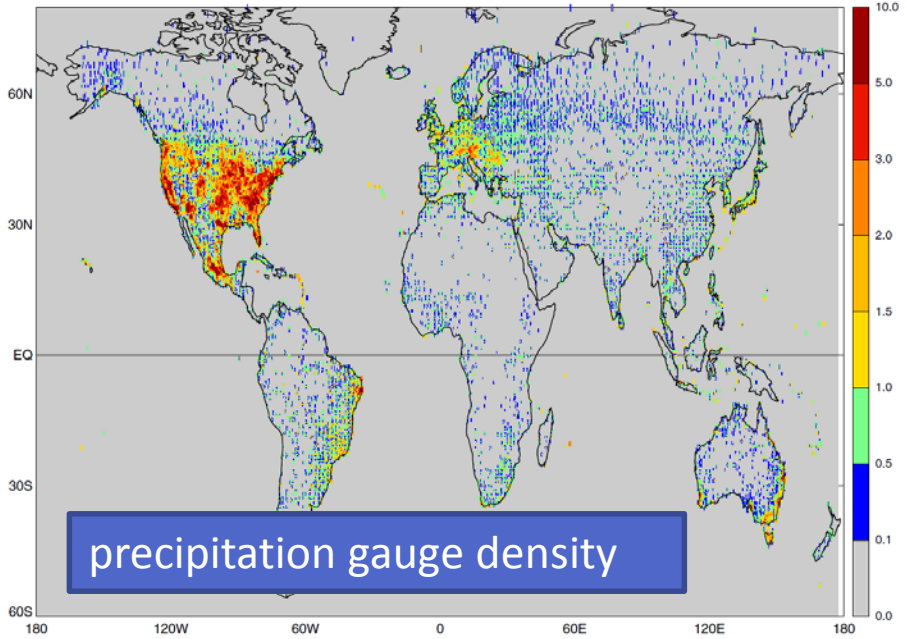
Results for the individual flash drought with the highest relative contribution at each grid cell.

Global Scale Analysis

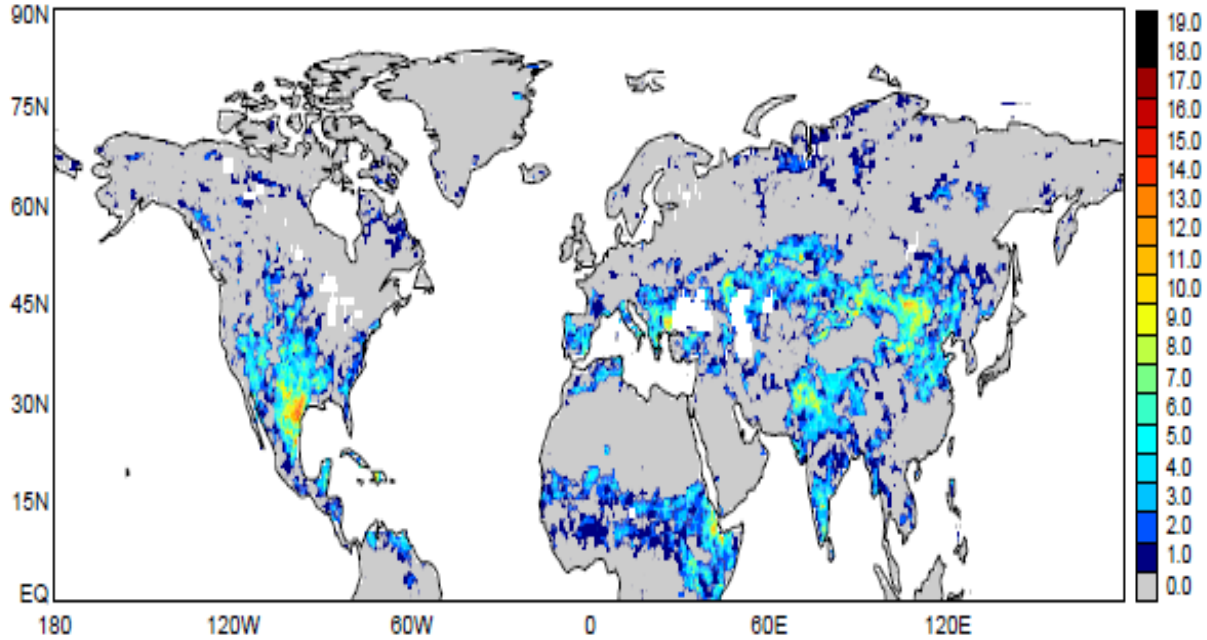
We can repeat this analysis for the globe, but…

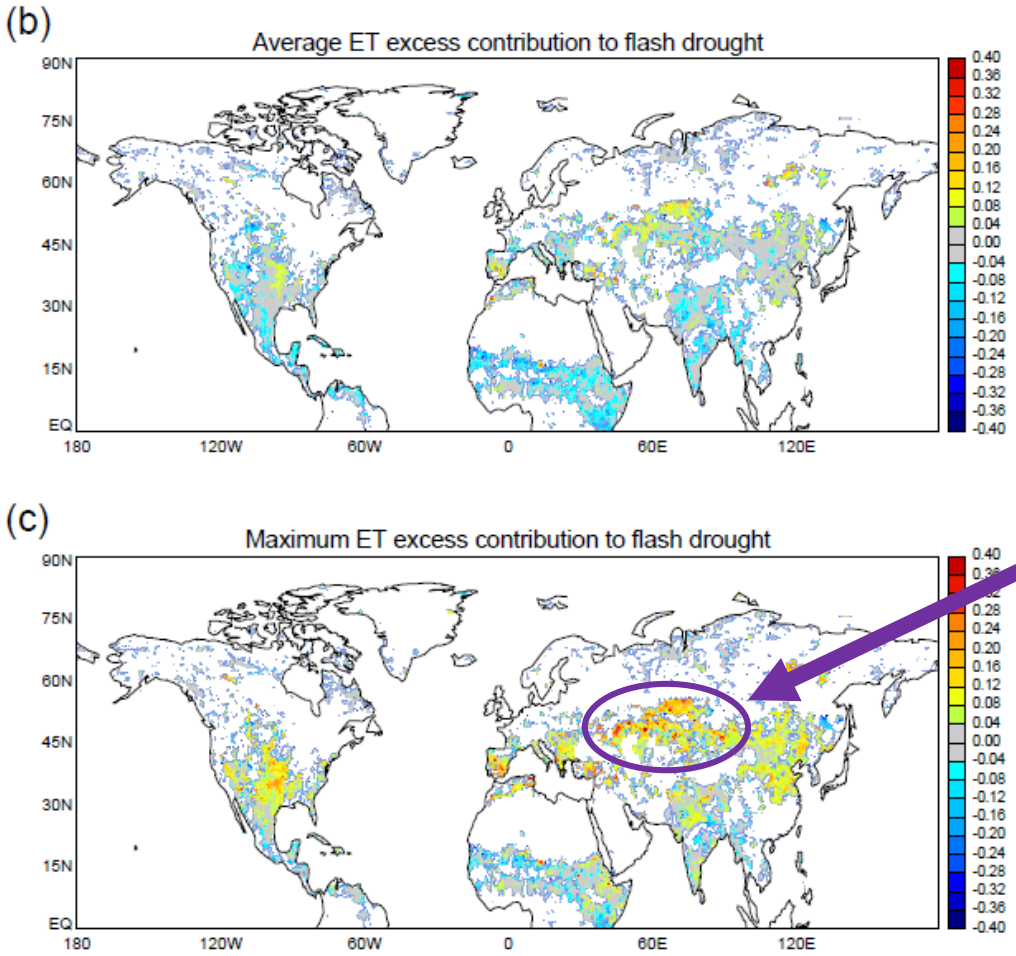
…the quality of the precipitation data driving the land surface model in MERRA-2 is of lesser quality in much of the globe.

⇨ We have less confidence in our soil moisture percentiles and thus in our identification of flash droughts.



of flash droughts during April-September, 1980-2017





Relative contributions of ET to flash droughts

The relative contribution of ET to flash drought formation can be large (~30%) for some droughts in this region, in agreement with literature studies…

Summary

MERRA-2 provides the comprehensive data needed to quantitatively define flash drought occurrences across multiple decades.

In North America, flash droughts appear mostly down the middle of the US and in eastern Mexico. Across the globe, they mostly occur in transition regions – regions that are not too dry (though this is actually prescribed) and not too wet.

In addition, MERRA-2 precipitation, evapotranspiration (ET), and soil moisture data also allow us to isolate the relative contributions of precipitation deficits and ET excesses to flash drought formation…

Recall sentiment in the literature:

> "Though precipitation deficits over some time period are required for drought to develop, their presence alone is unlikely to lead to a flash drought because a lack of precipitation is only one of several factors that can lead to rapid drought intensification…."

Main result of our study: Although ET does have some impact on flash drought formation (up to ~30% for some droughts), the above idea is not supported by the MERRA-2-based analysis.

The "implicit" main result of our study: MERRA-2 is very useful for hydrological analysis!