Causes of Drought in the Great Plains

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What is Drought?

Well, it means *dry conditions* prevail for a period of time. How dry and for what period? It all depends…

- No one definitive definition exists - drought is in the eyes of the beholder, that is, drought is contextual
- Most droughts are defined based on *impacts*, not the underlying weather and climate.

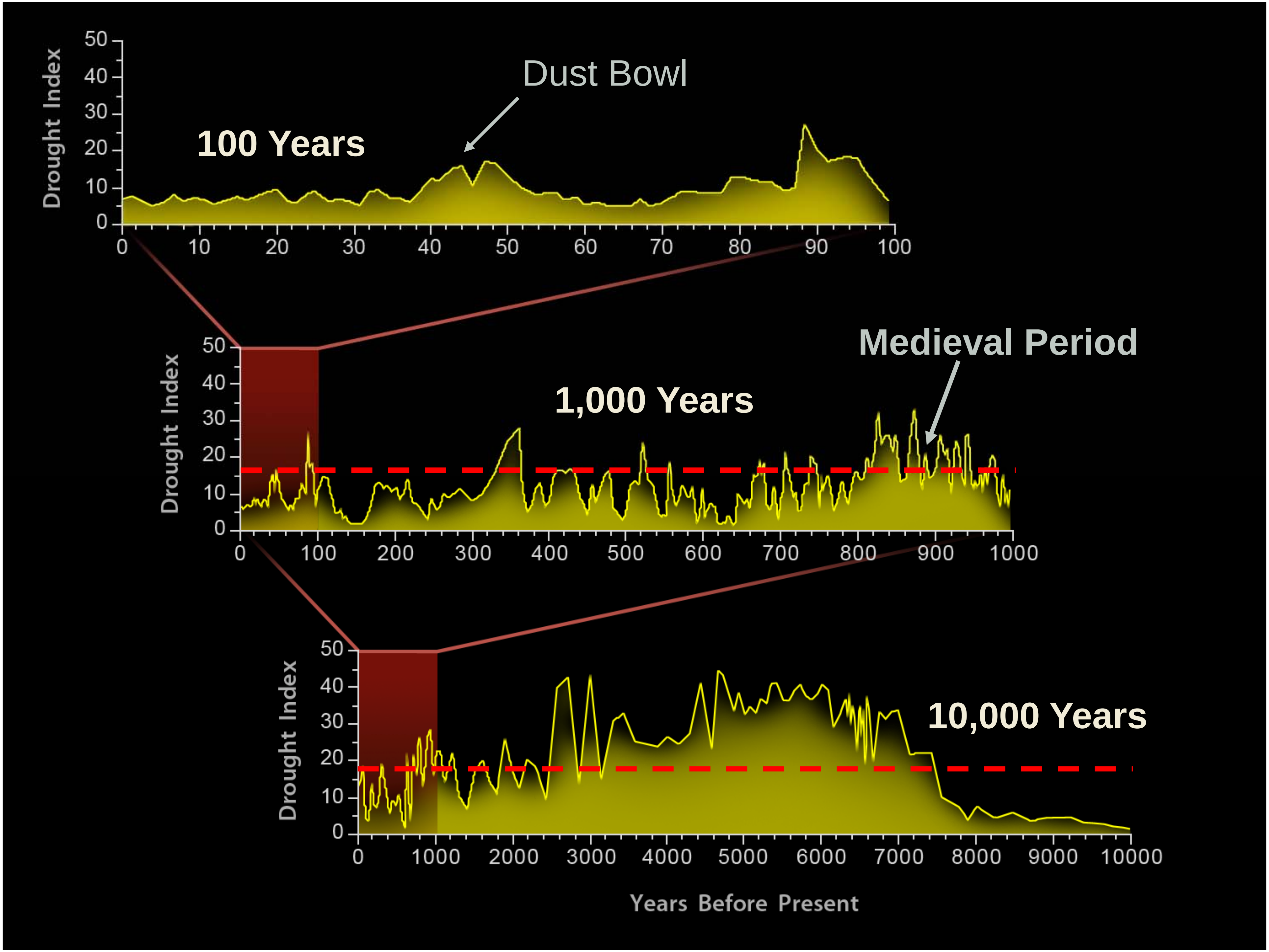
EXAMPLES:

- ***Meteorological drought*** - amount and duration of dryness, and the atmospheric conditions that lead to it

- ***Agricultural drought*** - fairly short-term; crop yields suffer due to insufficient *soil moisture*. Can be as short as a portion of a growing season

- ***Hydrologic drought*** - longer-term; river flows diminish and lake/reservoir levels decrease. Usually takes several years to manifest

- ***Socioeconomic drought*** - when supply of water for human activities does not meet demand



Dust Bowl
100 Years
Drought Index
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Medieval Period
1,000 Years
Drought Index
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
1000
10,000 Years
Drought Index
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Years Before Present

Historic droughts versus prehistoric 'megadroughts' in the Great Plains

Analysis of proxy indicators such as tree rings and lake sediments tell us that drought is an ubiquitous feature of the Great Plains

Furthermore, prehistoric drought periods appear to have lasted much longer than historic ones

Less clear is whether prehistoric droughts were more *intense* than modern ones

Nonetheless, the modern period of settlement appears to have been relatively wet!

OK, so what *causes* drought?

Obviously, insufficient rain and snow, perhaps augmented by increased evaporative stress

But how can this happen?

Remote versus Local Factors

Remote factors refer to phenomena, far-removed from where the drought occurs, that affect the large-scale atmospheric circulation, and hence the tendency for rain and snow

Usually related to fluctuations in ocean temperatures; these vary in where they occur, and the length of their influence

Remote factors are probably responsible for the *initiation* of most droughts

Local factors refer to phenomena such as reduced soil moisture that affect precipitation and evaporation where the drought occurs

Usually don’t induce drought, but may strongly influence the *magnitude* and *duration* of an already occurring drought

Remote Factors

*SST patterns favoring drought for the Great Plains

Two of the best known:

(1) ENSO (tropical Pacific)

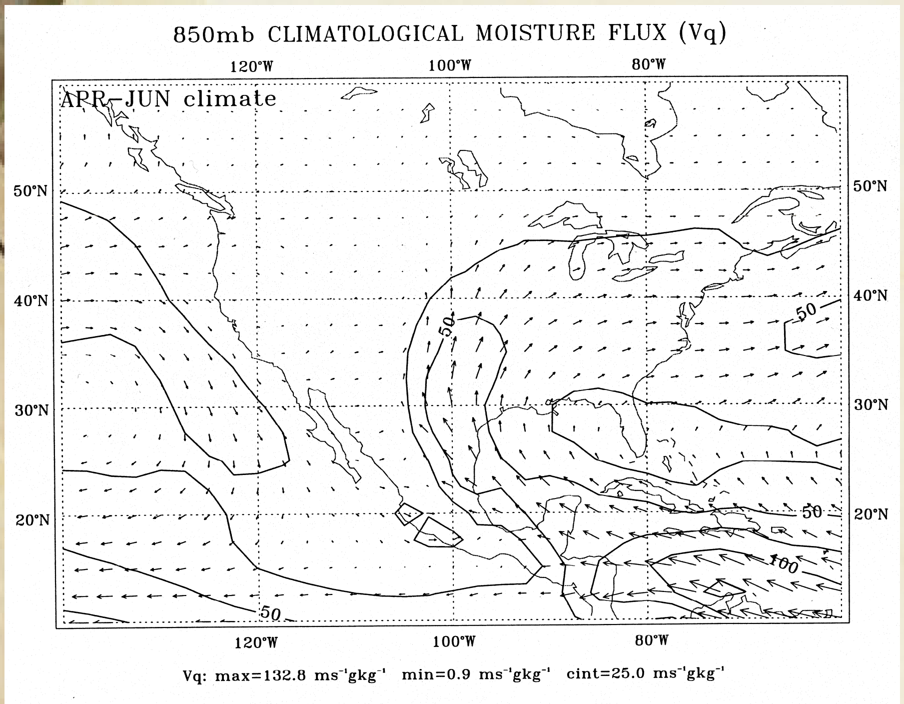
(2) AMO (North Atlantic)

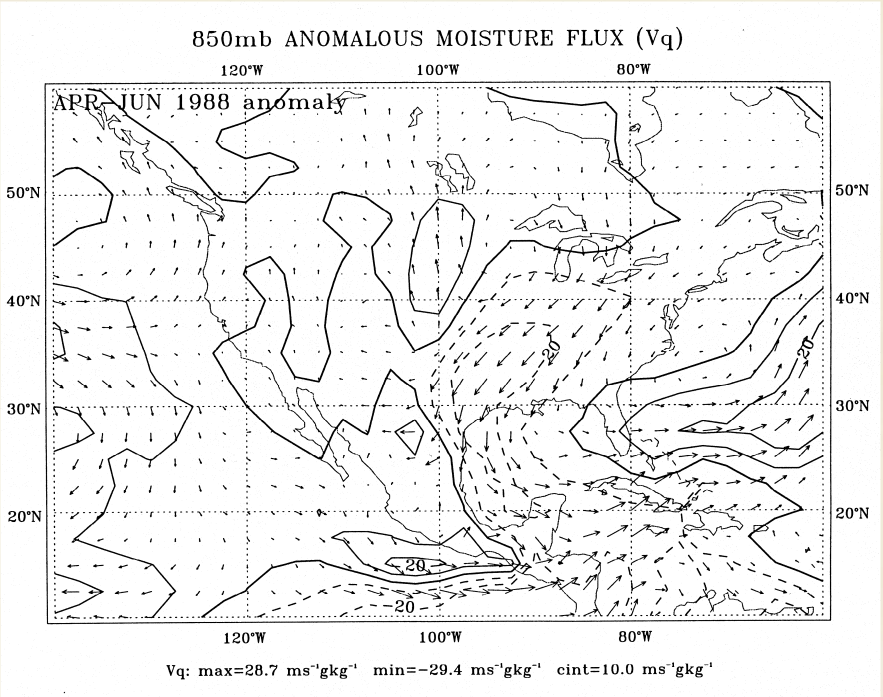
There may be more (e.g., North Pacific; NAO)

Induce drought when an anticyclone (high pressure system) is set-up or enhanced over a region

Reduces moisture transport into the region; inhibits precipitation mechanisms; may increase evaporation

Role of Anomalous Moisture transports: 1988 Drought





850 mb Mean Moisture Flux
(April - June)

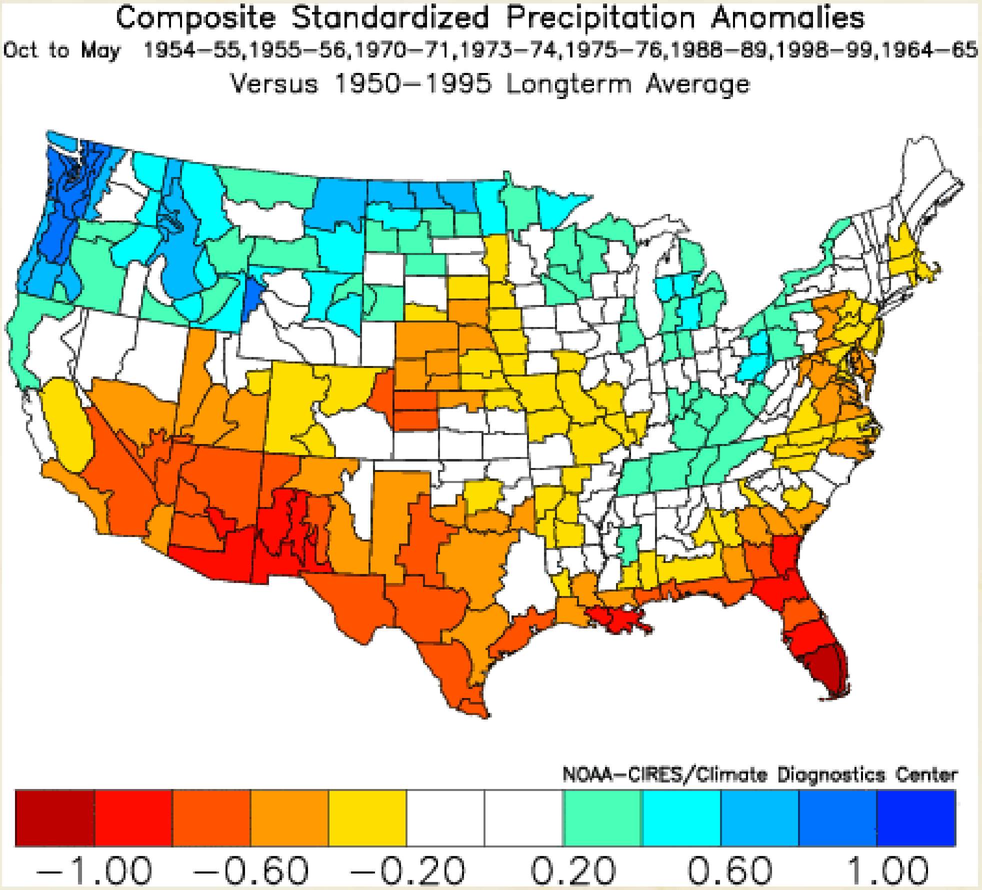
850 mb Anomalous Flux
(April-June, 1998)

(from Lyon and Dole, 1995)

La Niña Effects on U. S. Precipitation

La Niña Composite (Oct.-May)

(created off of CDC web site)



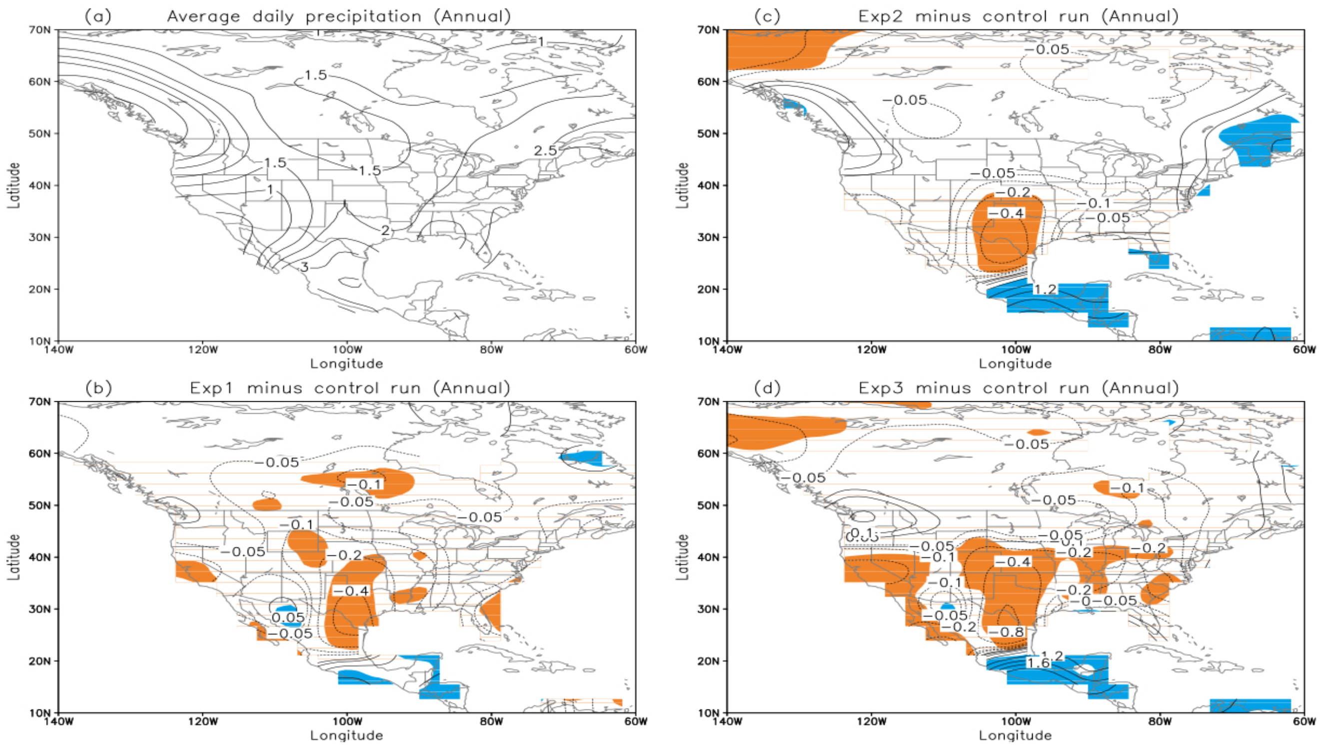


Fig.4: Simulated annual averaged daily precipitation (mm/day). (a) Control run, and (b), (c), and (d), respectively, are the differences between experiments 1-3 and the control run. Shadings indicate the differences are significant at 95% confidence level by two-tailed student-test. For clarity, only the precipitation over the land is shown.

Relative effects of La Nina and the Atlantic Multidecadal Oscillation. Top left - total precipitation in control. Bottom left - precipitation anomaly for La Nina. Top right - for AMO. Bottom right - combined La Nina and AMO

Local Factors

- Usually involve ‘land surface-atmosphere interactions’

- In the Great Plains, reduced soil moisture is probably most important

  --- less moisture locally available through surface evapotranspiration

  --- stabilizes atmospheric column, making it harder for summer thunderstorms to form

- Elsewhere, snow cover may be important (US west) as can deforestation (tropical regions)

Land Surface effects

Why consider?

- **Like SSTs, LS has a "memory" beyond synoptic scales**
- **After SSTs, it is most likely source for seasonal climate predictability.**

- **Influence on T**

- **Influence on P**

Are surface effects such as soil moisture and snow cover simply passive elements or can they affect the evolution of climate on seasonal and longer time scales?

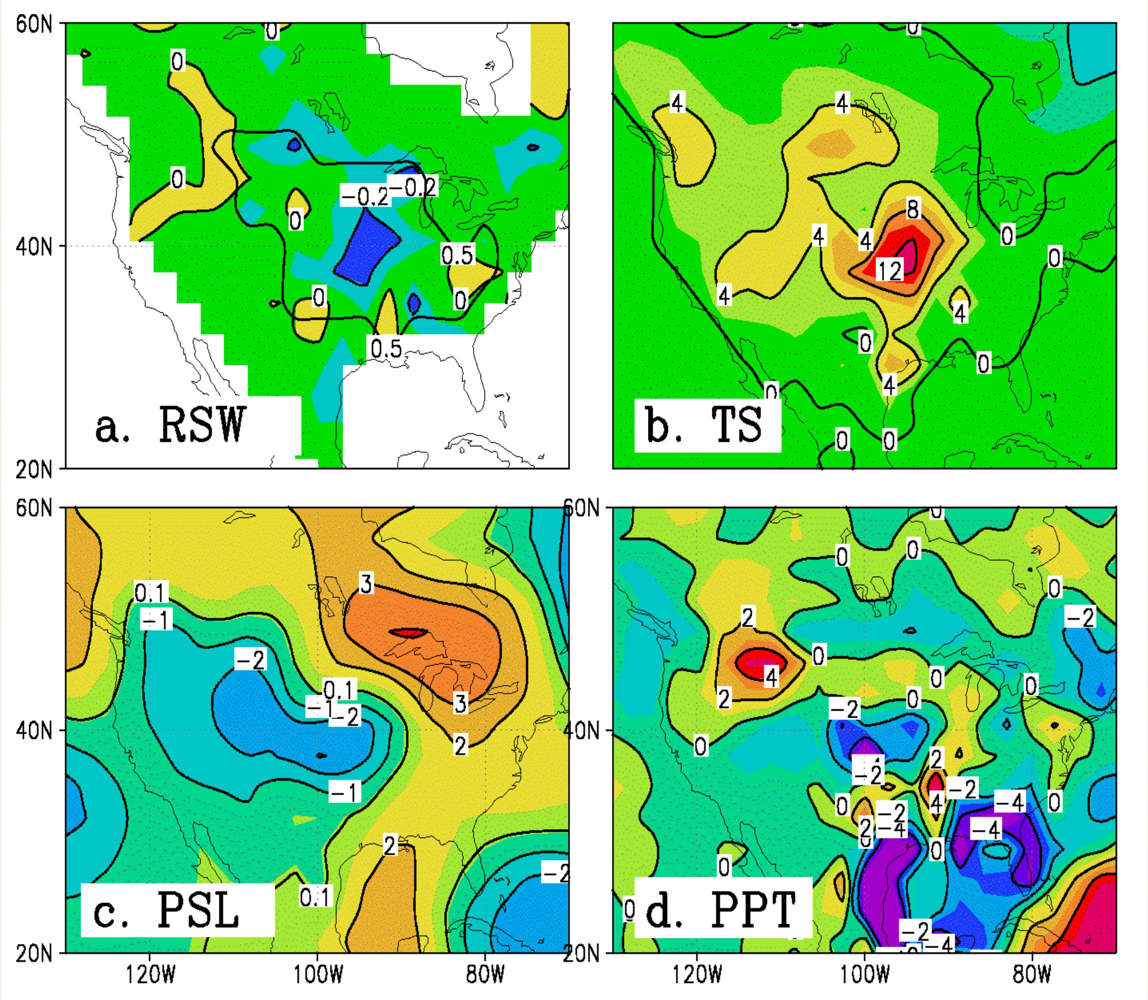
Enabling this potential predictability requires:

(i) Understanding the physical mechanisms involved in this interaction

(ii) Evaluating the importance of these mechanisms relative to all others (e.g., SST anomalies) that can also affect precipitation.

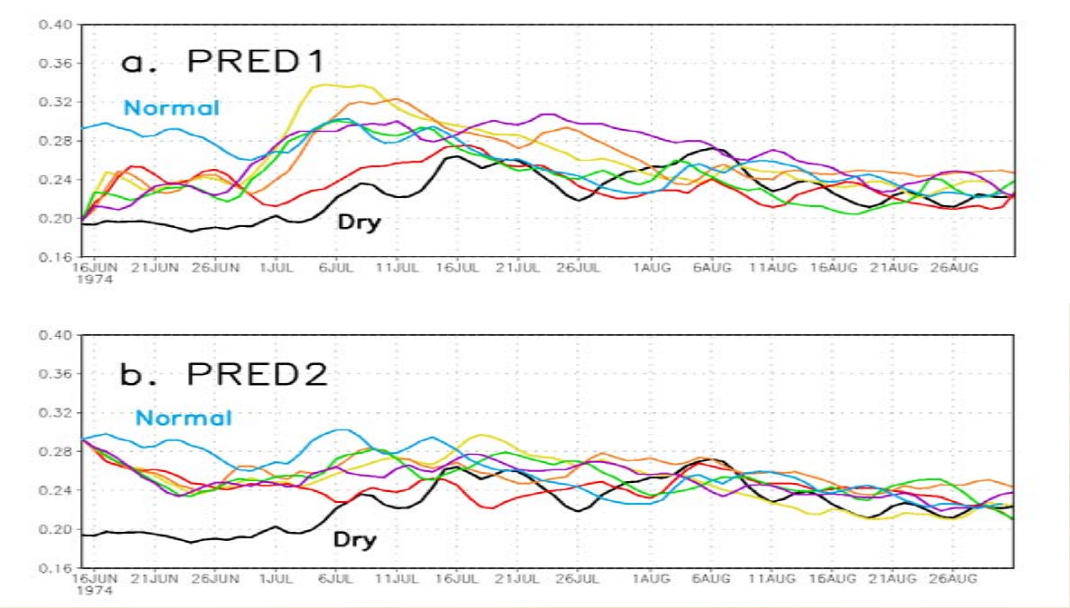
(iii) Evaluation the time scales over which soil moisture and snow cover are most likely to have a predictable effect on precipitation.

Model runs with near-desert conditions imposed initially throughout the soil column showed a much larger effect, with warmer surface temperatures, reduced precipitation, and lower surface pressures. The effects persisted for at least a year.



SOIL MOISTURE (Great Plains Region)

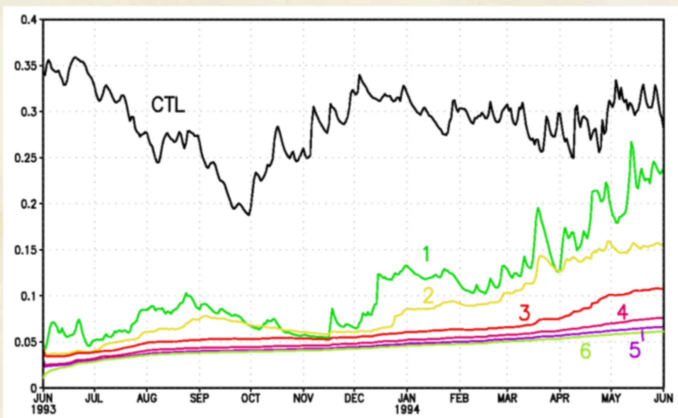
In June, GCM runs show little impact of the initial soil moisture anomalies on the subsequent evolution of soil moisture and other atmospheric parameters

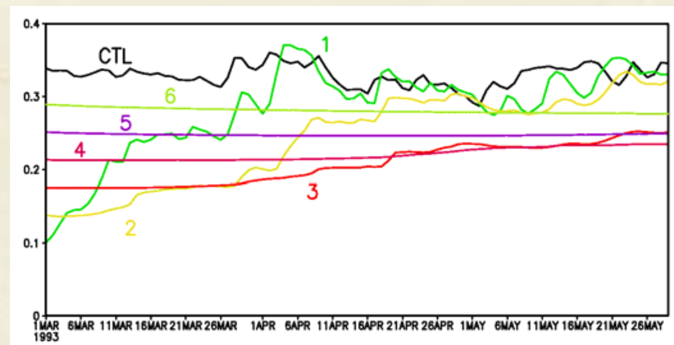


Internal variability is most important, with the initial state of the atmosphere (representing remote effects such as SST anomalies) playing a more secondary role on seasonal and shorter time-scales.

How important is the vertical profile of soil moisture?

Results show that sub-surface dry anomalies can play a large role in the perpetuation of a surface drought.

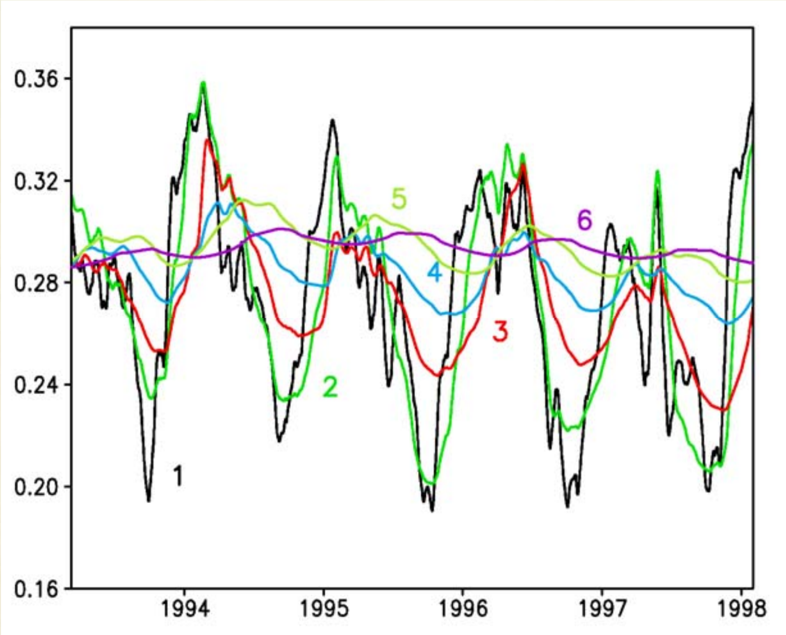




Since lower soil layers are slow to respond, dry anomalies in lower soil layers can play a large role in the perpetuation of a surface drought.

When a very dry anomaly is imposed in the upper layers, but the deep layers are initialized with climatological values, the response is muted.

CCM3 SOIL MOISTURE EVOLUTION AT DEPTH THROUGH A 5 YEAR PERIOD

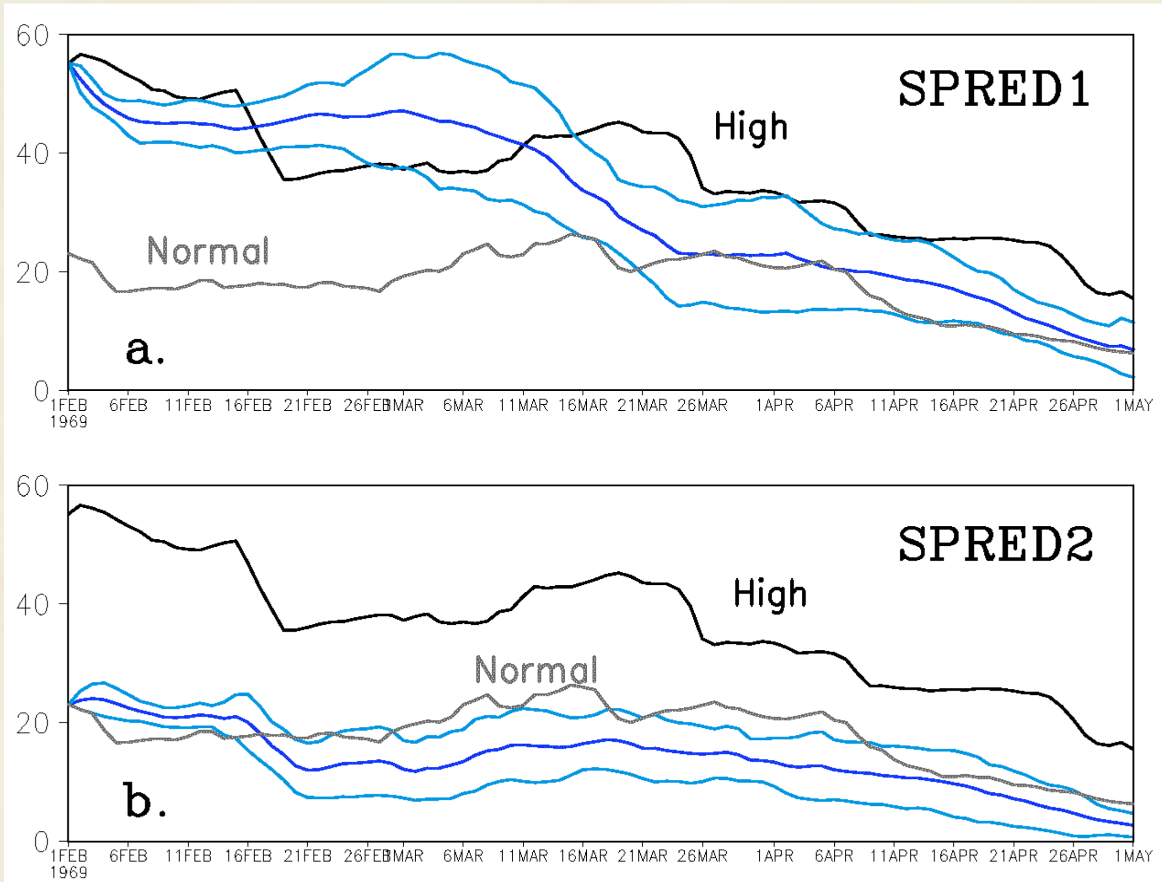


Evolution of soil moisture (volumetric fraction) in all six layers during 5 years from CCM3/SST. Layers are numbered 1-6 (top to bottom soil layers).

Deep layers show little year-to-year fluctuation in the model control, further demonstrating how slow they are to change.

Large changes in deep layer moisture are more likely to impact historic and prehistoric extended periods of drought rather than year-to-year variability.

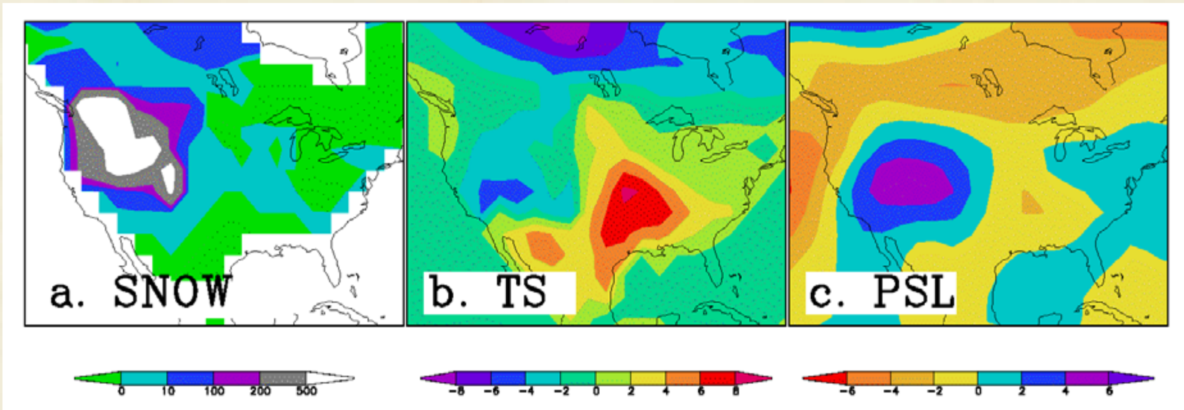
What about winter snowcover?



February – in this case, the initial prescription of snow cover is clearly
more important than the initial atmospheric state in determining the subsequent evolution of snow cover

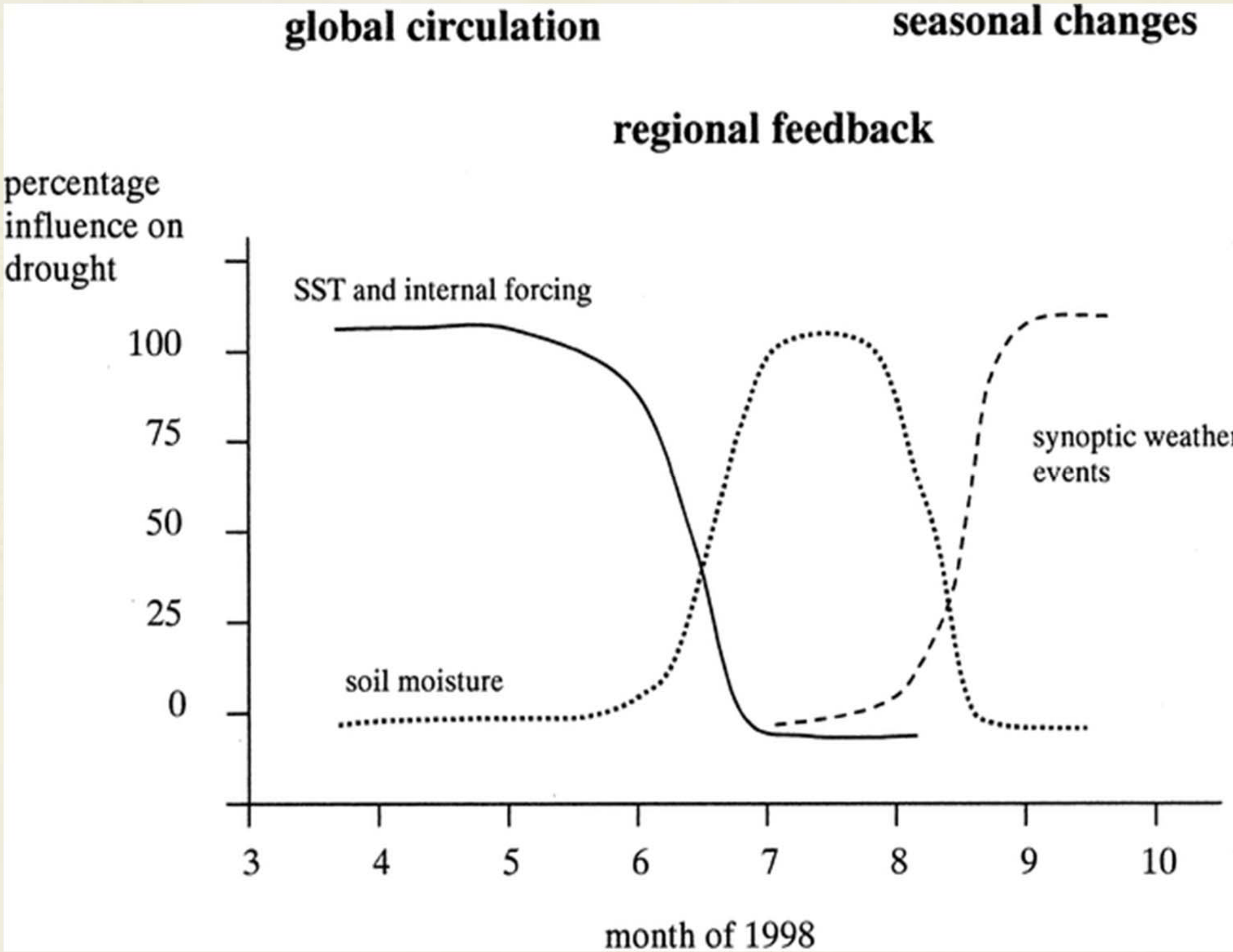
Do western snow cover anomalies have a robust effect on the central US?

The runs with an exaggerated 1 m initial snow anomaly show downstream changes in surface temperature and surface pressure over the Great Plains



These robust changes reflect changes in atmospheric circulation, with a more southerly flow bringing warm air into the central U.S.

Effects of remote and local land surface processes likely vary during droughts



(From Hong and Kalnay, 2002, for 1998 drought)

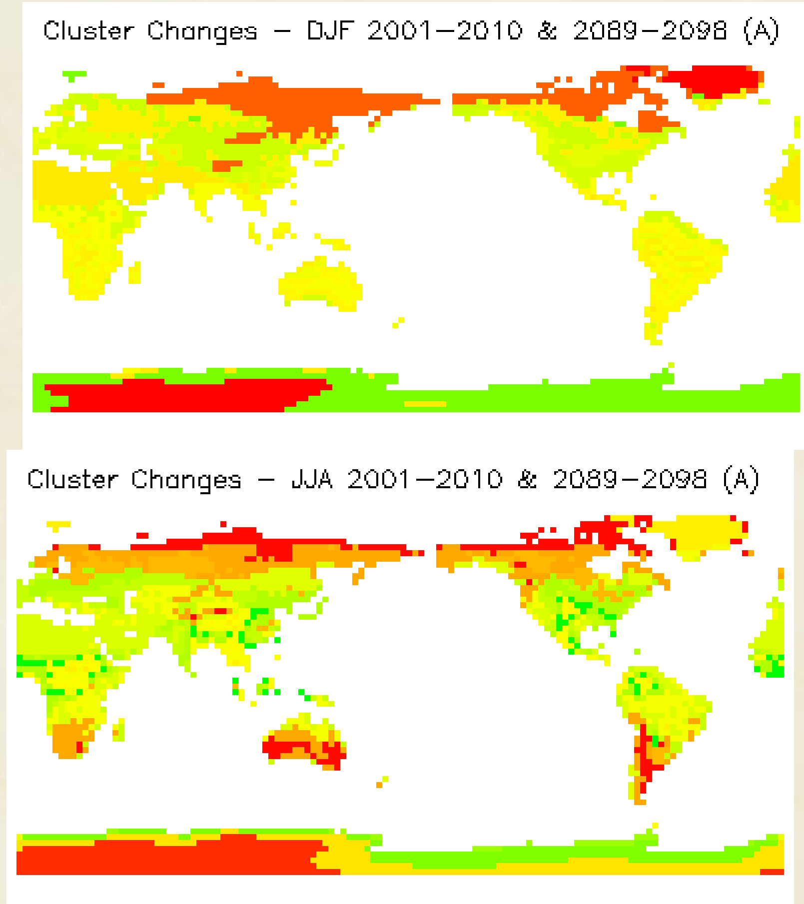
Future Great Plains Drought

What will happen with predicted greenhouse-gas global warming?

Indications from IPCC climate models are that precipitation may decrease over the Great Plains regions, though the models disagree on the magnitude of the decrease

Even if precipitation remains unchanged, warmer temperatures will increase the likelihood of drought, by enhancing potential evapotranspiration

The combined effects of temperature, precipitation, and soil moisture



Cluster changes (as stoplight colors) for DJF (top) and JJA (bottom) between 2001-2010 and 2089-2098. Yellow denotes no change; red/orange denotes warmer and wetter and green denotes warmer and drier. The intensity
of the color reflects the amount of clusters that changed

Human-induced drought: Growing corn versus switchgrass in the Great Plains

Switchgrass may utilize water resources more efficiently than corn

But this also means less water cycled through the vegetation and into the atmosphere

Broadly similar to what happens with reduced soil moisture

Implications

- The reduction in water input to the atmosphere means less water available for local and regional precipitation, and also affects the surface energy balance, resulting in more sensible and longwave heating of the atmosphere.

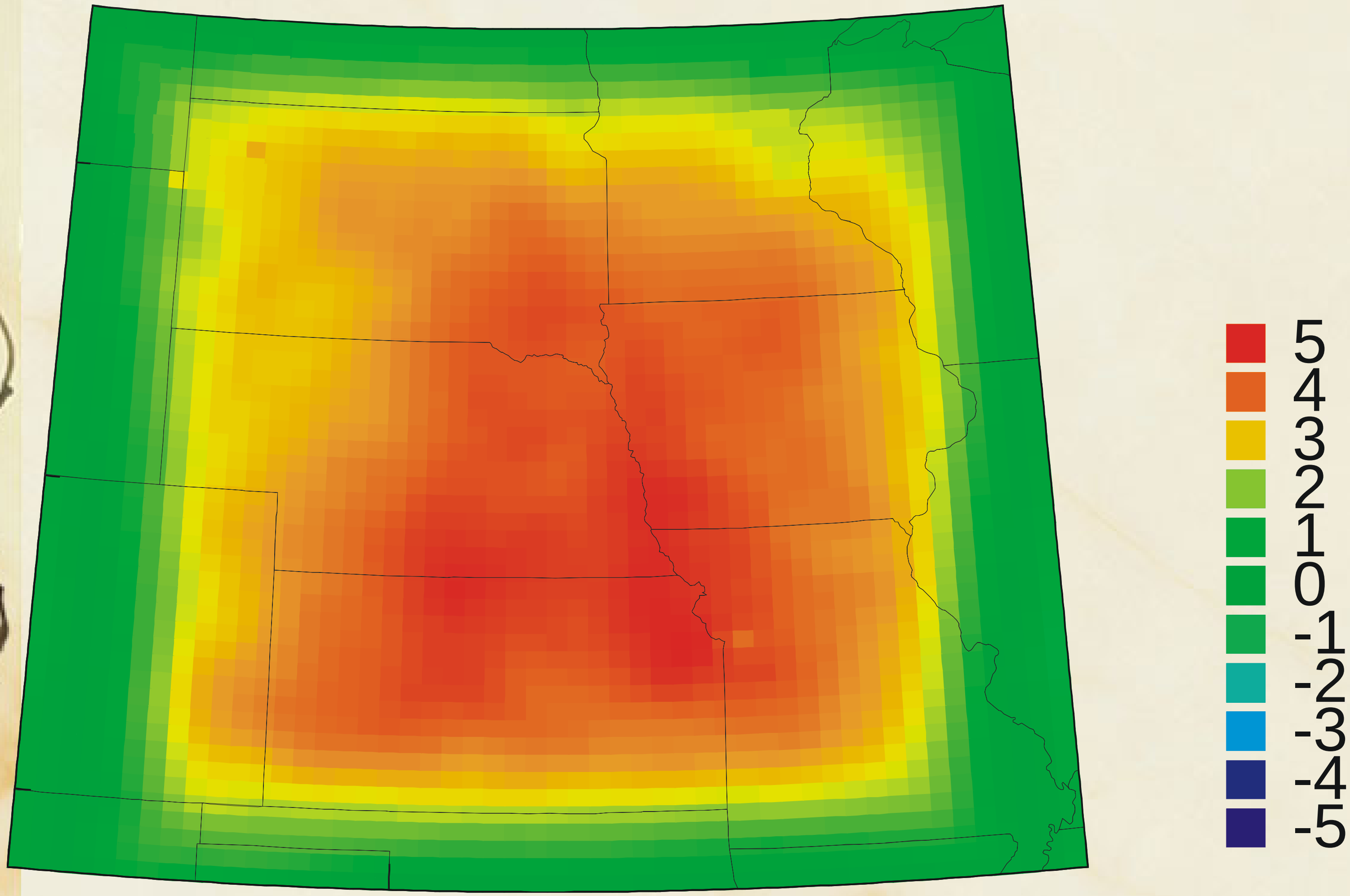
- These effects may cause a significant increase in surface air temperature and stabilization of the atmosphere, leading to a reduction in precipitation as well as increased evaporative potential

- ***Both would help negate any increased water efficiency of switchgrass***

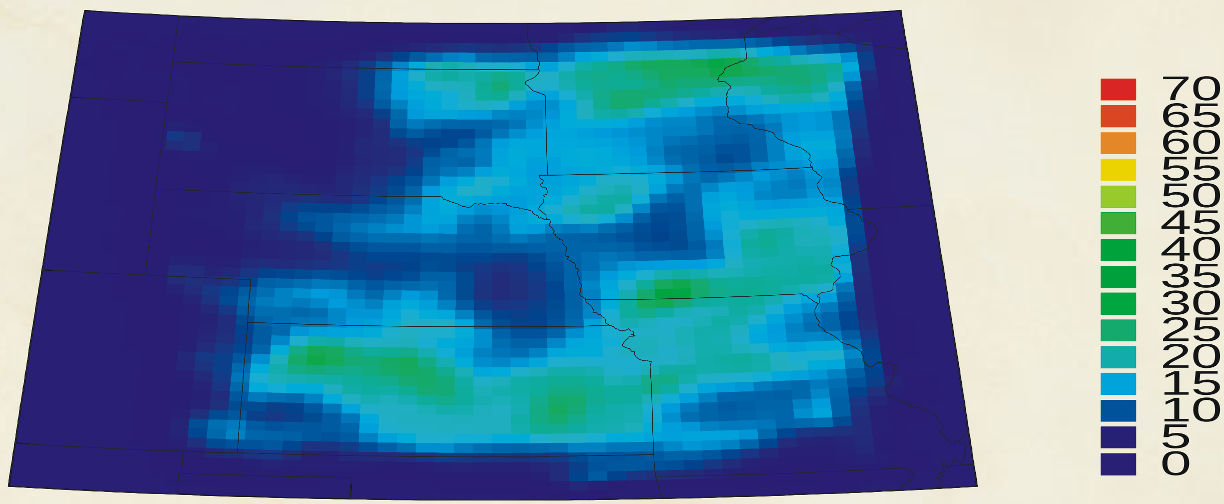
Temperature and precipitation for Control, all corn and all switchgrass for a year with ‘normal’ precipitation

2003				
		May	**June**	**July**
Precip (cm)	**Control**	9.85	11.12	5.37
	Crop	10.85	13.00	6.15
	Grass	9.10	10.02	4.44
T_{max} (°C)	**Control**	24.4	28.0	33.5
	Crop	22.5	26.0	30.9
	Grass	25.3	28.9	34.7
T_{min} (°C)	**Control**	12.9	17.1	21.6
	Crop	12.3	16.4	20.7
	Grass	12.9	17.2	22.0
T_{ave} (°C)	**Control**	18.1	22.0	27.2
	Crop	16.8	20.7	25.4
	Grass	18.5	22.6	27.9

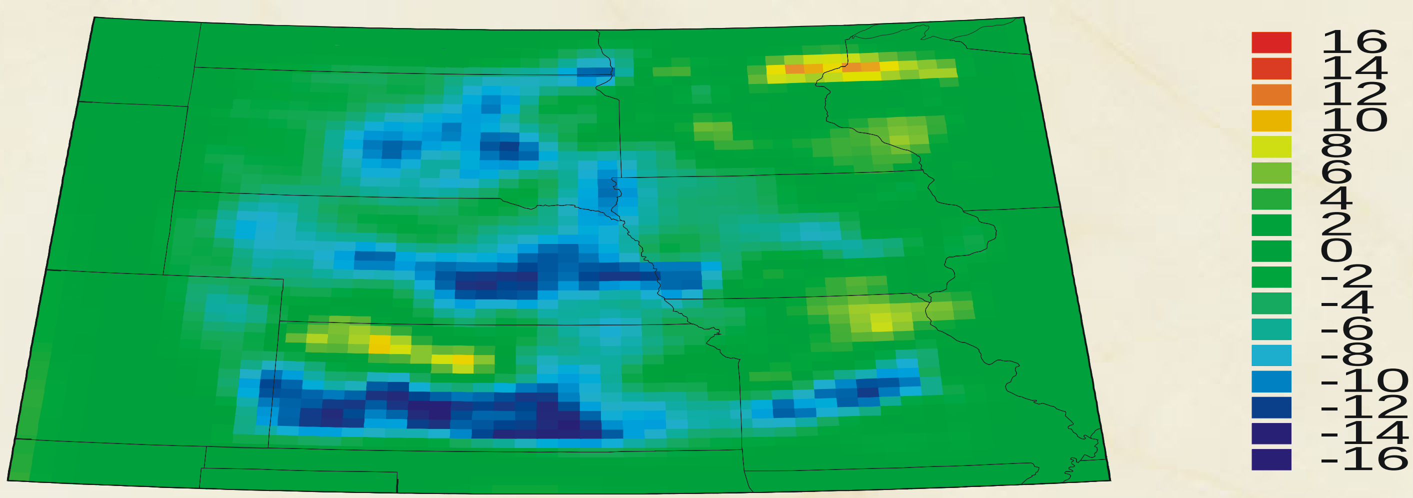
June 2003 Grass-Crop Tmax



June 2003 Control Prec



June 2003 Grass-Crop Precip



SUMMARY

Drought is an ubiquitous feature of the Great Plains

The historic period has been relatively ‘wet’

Sea surface temperature patterns likely initiate most droughts

Local feedbacks involving soil moisture and snow cover can enhance and prolong drought

Drought is likely to become even more common in the future, both because of greenhouse gas-induced global warming, and because of local land use practices

We’d best be prepared!!!