Climate Change and Agricultural Sustainability – A Global Assessment

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How will climate change change the world?

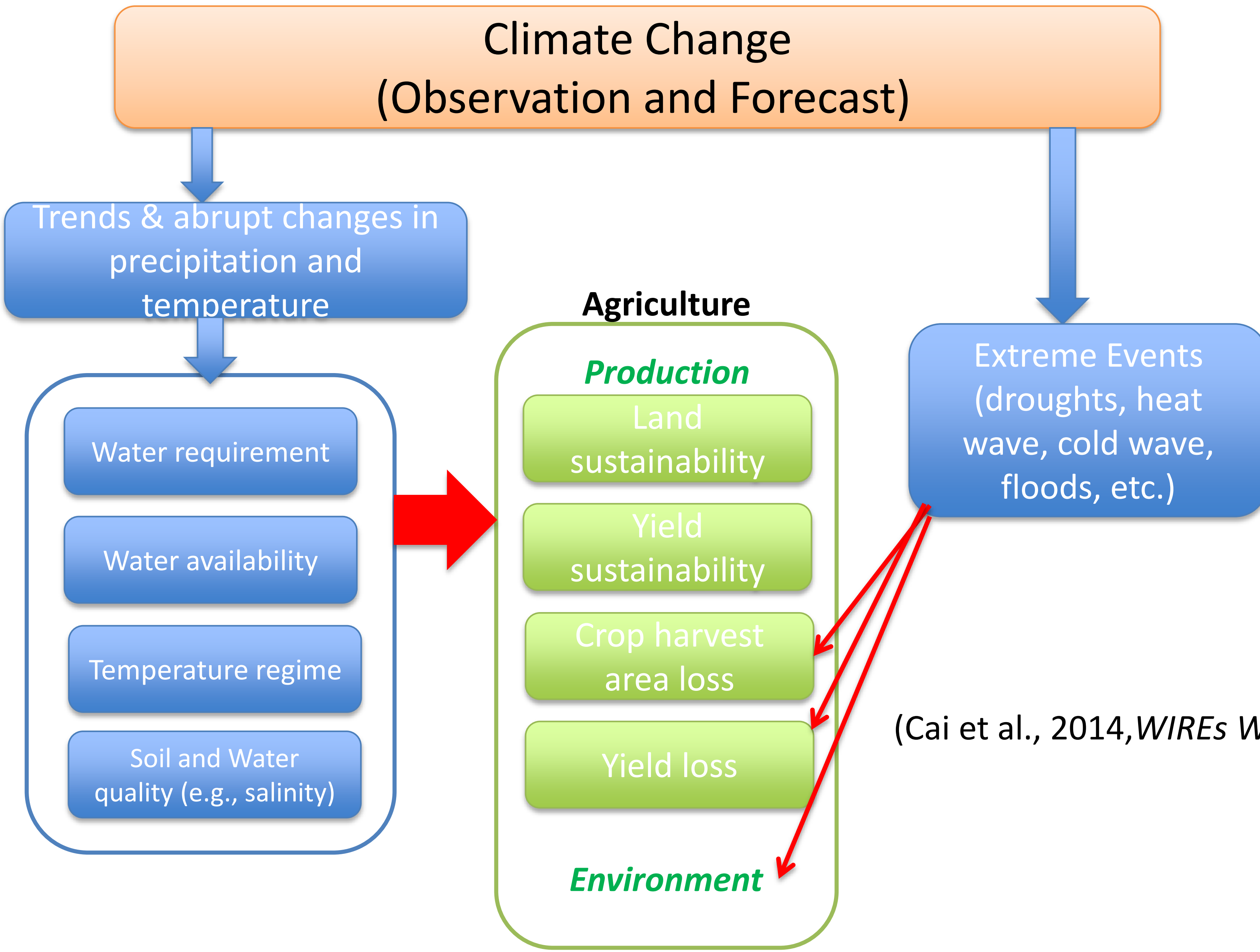
Bring the whole world down, or

Bring some areas down and some up but the world can still be a normal world

"The sea became mulberry fields, while mulberry fields became sea." A Chinese idiom

苍海桑田

Climate change and agricultural sustainability



(Cai et al., 2014, *WIREs Water*)

Findings from existing assessments

- **Food and Agriculture Organization (FAO)**: "The anticipated impacts of climate change pose an additional stress on food production systems under pressure to satisfy the food needs of a rapidly growing and progressively wealthier world." *FAO Water Report 36: Climate Change, water and food security*
- **Int'l Food Policy Res. Inst. (IFPRI):** "Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security." *"Climate Change: Impact on Agriculture and Costs of Adaptation"*
- **IPCC: t**he assessed studies suggested a number of fairly robust findings. The first was that climate change would likely increase the number of people at risk of hunger compared with reference scenarios with no climate change (*IPCC Fourth Assessment Report*)

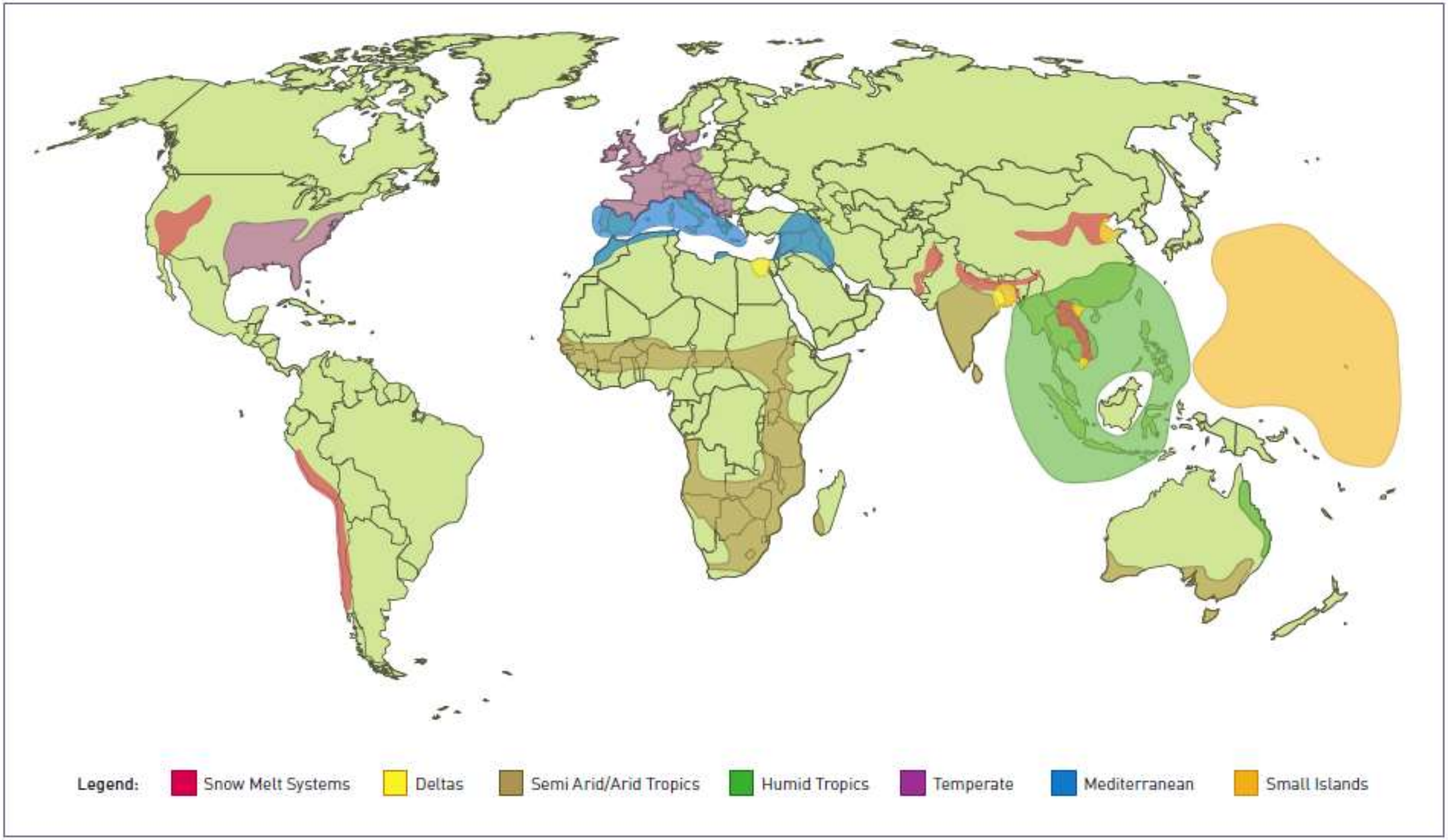
What do those assessments tell us?

- Pessimism?

- Uncertainties
  - Models such as GCMs, RCMs,
  - Future social and economic development
  - Technologies and policies

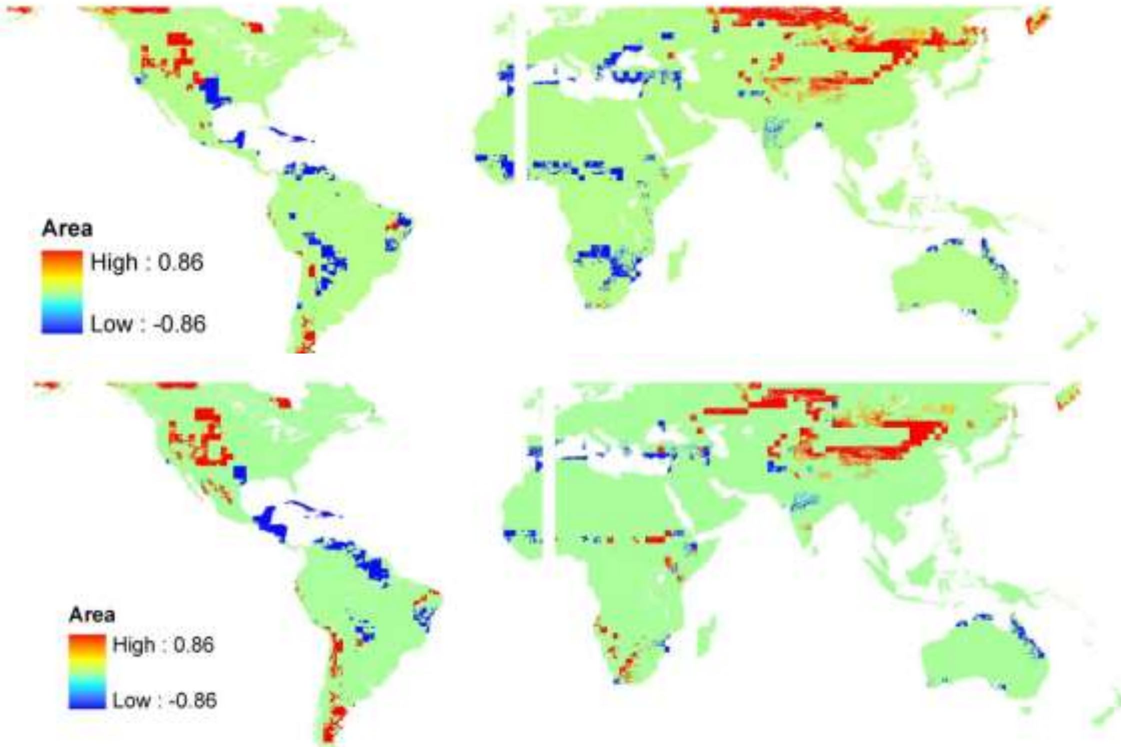
- Regional impacts
  - Typology (such as regional large irrigation systems, deltas, groundwater, etc.)
  - Local changes and adaptation

Main agricultural water management systems that climate change is expected to impact



FAO (2010), *Clim,. Ch., water and food security*

Arable land availability under climate change



Gross potential arable land changes (km^2) under A1B-RMSEMM scenario (upper) and B1-SAM scenario (lower) due to the changes in soil temperature regime and air humidity (Zhang and Cai , 2011, *Environ. Res. Let.*)

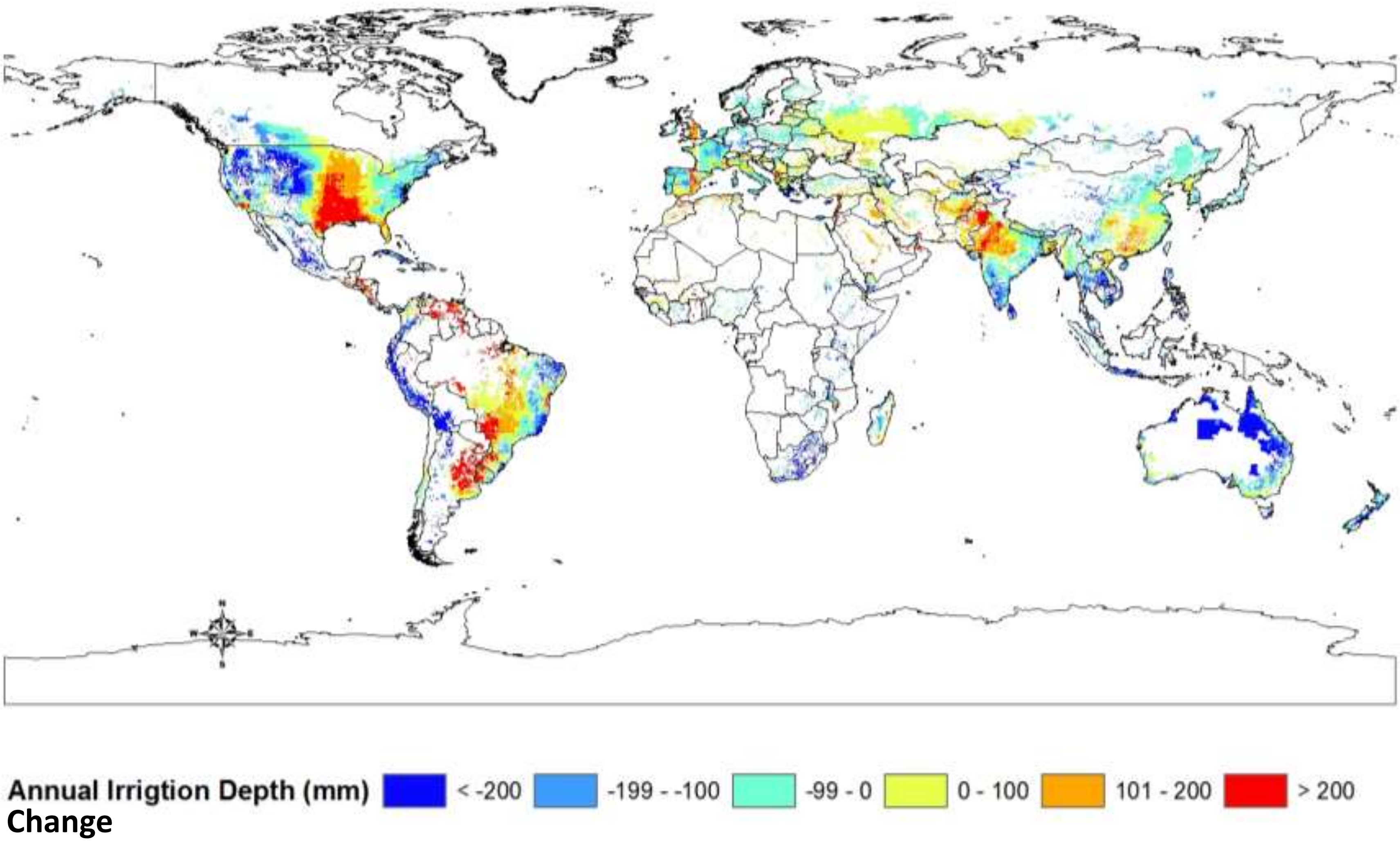
Net potential arable land areas and change percentages under historic and projected scenarios

	Africa		China		India		Europe		Russia		South America		US		Global	
	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)	Mkm^2	(%)
Baseline	10.33		3.79		2.33		3.11		1.96		8.82		3.24		41.32	
A1b-SAM	8.47	−18	5.28	39	2.00	−14	2.45	−21	2.71	38	5.65	−36	3.46	7	38.05	−8
A1b-RMSEMM	7.14	−31	4.77	26	2.02	−13	2.43	−22	3.05	56	6.76	−23	3.20	−1	37.62	−9
B1-SAM	9.26	−10	5.09	34	2.05	−12	2.65	−15	2.35	20	7.16	−19	3.78	17	40.62	−2
B1-RMSEMM	7.99	−23	4.68	24	2.05	−12	2.65	−15	2.66	36	7.48	−15	3.57	10	39.46	−5

(Zhang and Cai, 2011, *Environ. Res. Letter*)

Irrigation water requirement change

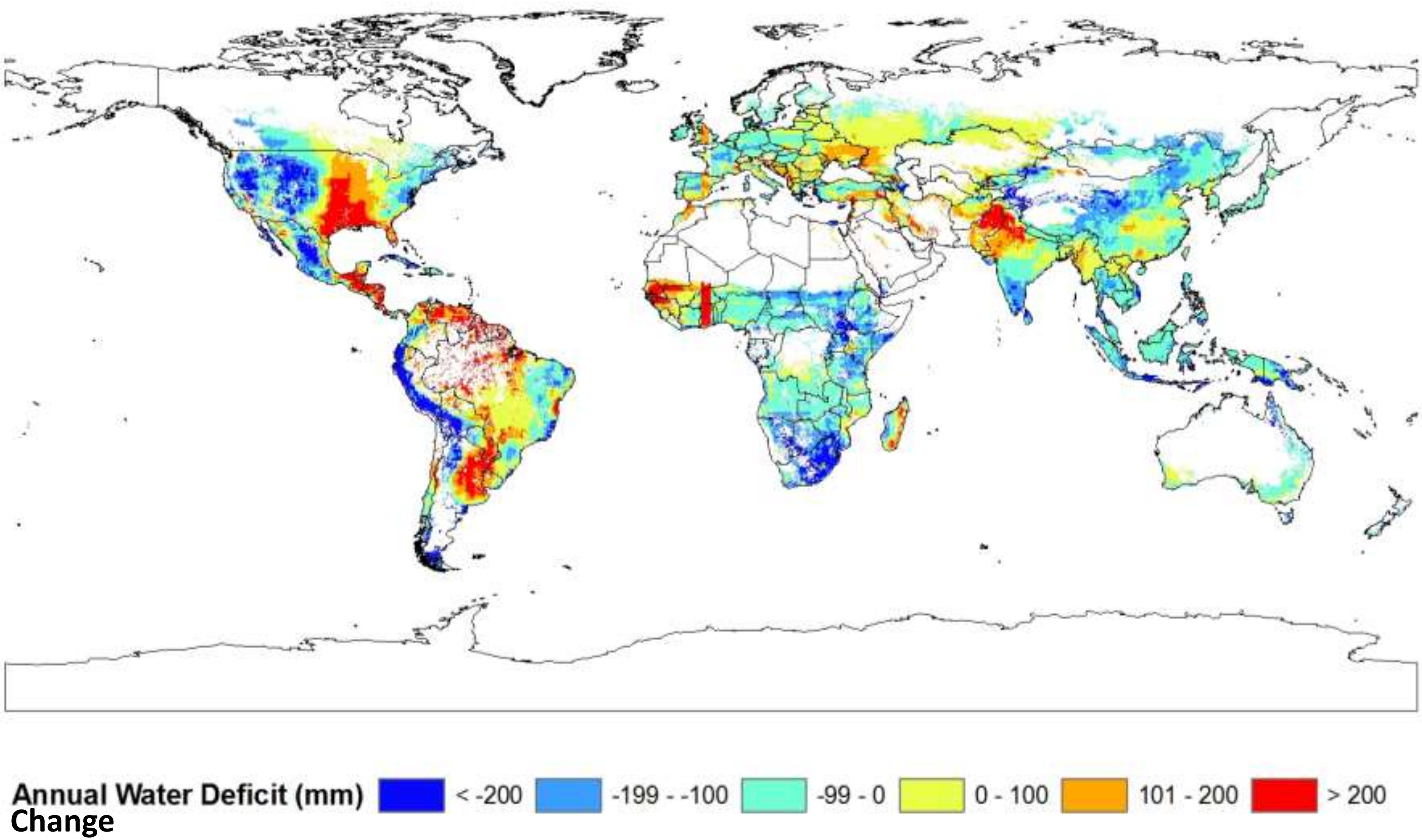
(Compared to the scenario with the climate of 1961-1990)



(Zhang and Cai, 2013, *GRL*)

Rainfed crop water deficit change

(compared to the scenario with the climate of 1961-1990)



(Zhang and Cai, 2013, *GRL*)

Table 1. Regional and Global Changes of Water Deficit for (a) Irrigation Crops and (b) Rainfed Crops under Reference Scenario (1961–1990) and Four Projected Scenarios (2070–2099)

	Africa		China		Europe		India		South America		United States		Global	
	km^3	%	km^3	%	km^3	%	km^3	%	km^3	%	km^3	%	km^3	%
(a) Irrigation crops														
Reference	86		173		48		341		44		121		1289	
A1B-RMS	−6	−7	−27	−16	2	5	−4	−1	−14	−32	3	2	−71	−6
A1B-SAM	−10	−11	−13	−8	−3	−7	20	6	−8	−18	−3	−3	−29	−2
B1-RMS	−7	−9	−30	−18	−1	−3	−4	−1	−14	−32	−10	−8	−103	−8
B1-SAM	−11	−13	−14	−8	−6	−12	18	5	−9	−20	−11	−9	−56	−4
(b) Rainfed crops														
Reference	492		139		385		305		265		422		2871	
A1B-RMS	−136	−28	−38	−28	59	15	−42	−14	−20	−8	122	29	−109	−4
A1B-SAM	−39	−8	−16	−12	12	3	16	5	57	22	94	22	95	3
B1-RMS	−143	−29	−40	−29	30	8	−31	−10	−24	−9	57	13	−245	−9
B1-SAM	−40	−8	−17	−12	6	1	8	3	46	17	51	12	−7	0

Zhang and Cai (2013, *GRL*)

Causes of declining crop evapotranspiration (ET)

- The key role of declining diurnal temperature range (DTR) (the variation in temperature that occurs from the highs of the day to the cool of nights). Observations demonstrate decrease of ET in many areas as a result of declining DTR (caused by increased cloud coverage and/or aerosol concentration)
- A strong correlation between the declining pan evaporation and decreased DTR (Peterson *et al*., 2010, *Nature*; Shen et al., 2010, *Hydrol. Processes*) (increasing humidity, decreasing radiation, constant ave. vapor pressure)
- The future warmer climate is likely to cause decrease in DTR (*IPCC, 2013,* AR5)

The impact of extreme weather events

More than 70% of the so called billion-dollar events in the second half of the past century related to extreme climatic events (Beniston 2007, *Gl. & Planetary Ch.*).

Excess precipitation

- Excess moisture has been the most common cause for both insurance indemnity and disaster payments in California (Lobell et al. 2011, *Cl. Change*)
- US maize production losses due to excess soil moisture could be doubled by 2030 under climate change (Rosenzweig et al. 2002, *Gl. Ch. human health*)
- Excess precipitation triggers losses due to pests and plant diseases (Schaap et al. 2011, *Reg. Environ. Ch.*)

Flooding

- Flood loss in the agricultural sector has not gained much attention yet
- The use of agricultural lands as part of an integrated management of flood risk is gaining increasing consideration and practice (Pivot et al. 2002, *J. Hydro*; Kenyon et al. 2008, *Land Use Pol.*).
- More frequent flooding causes more nutrient and sediment load and soil loss

The impact of extreme weather events

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Hurricanes

- Increase of costs due to increase of intensity and frequency of hurricanes (Chen and McCarl, 2009, *JAAE*)
- The deterioration of agricultural land due to landslides (Philpott et al. 2008, *Ag. Eco. Environ*)

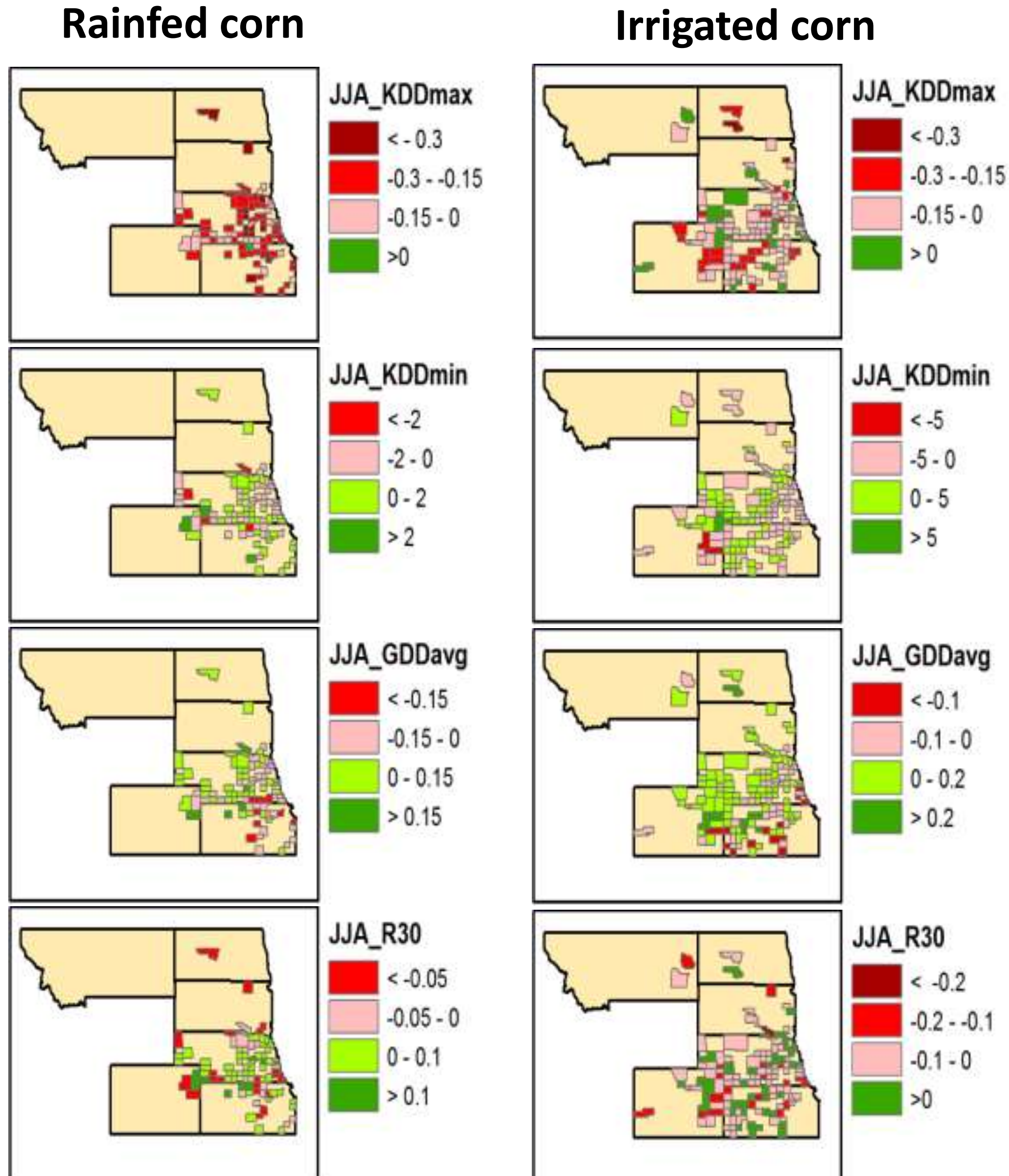
Droughts and heat waves

- Recently most places in the world faced more frequent and severe droughts leading to huge damages
- Nonlinear impact propagation from meteorological droughts to agricultural and hydrological droughts
- High temperature and prolonged warm season provides a more favorable condition for some insects to grow that eventually decreases the crop productivity
- Glacier retreat

Two examples of the impact of extreme weather

- **Midwest, US**
- **Northern India**

Impact of extreme weather on corn yield (case study with Nebraska, Yan and Cai, 2014)



Notation:

JJA: June-July-August

KDD: Killing degree days, accumulating the extreme high daily maximum temperature (**KDD_{max}**) or minimum temperature (**KDD_{min}**)

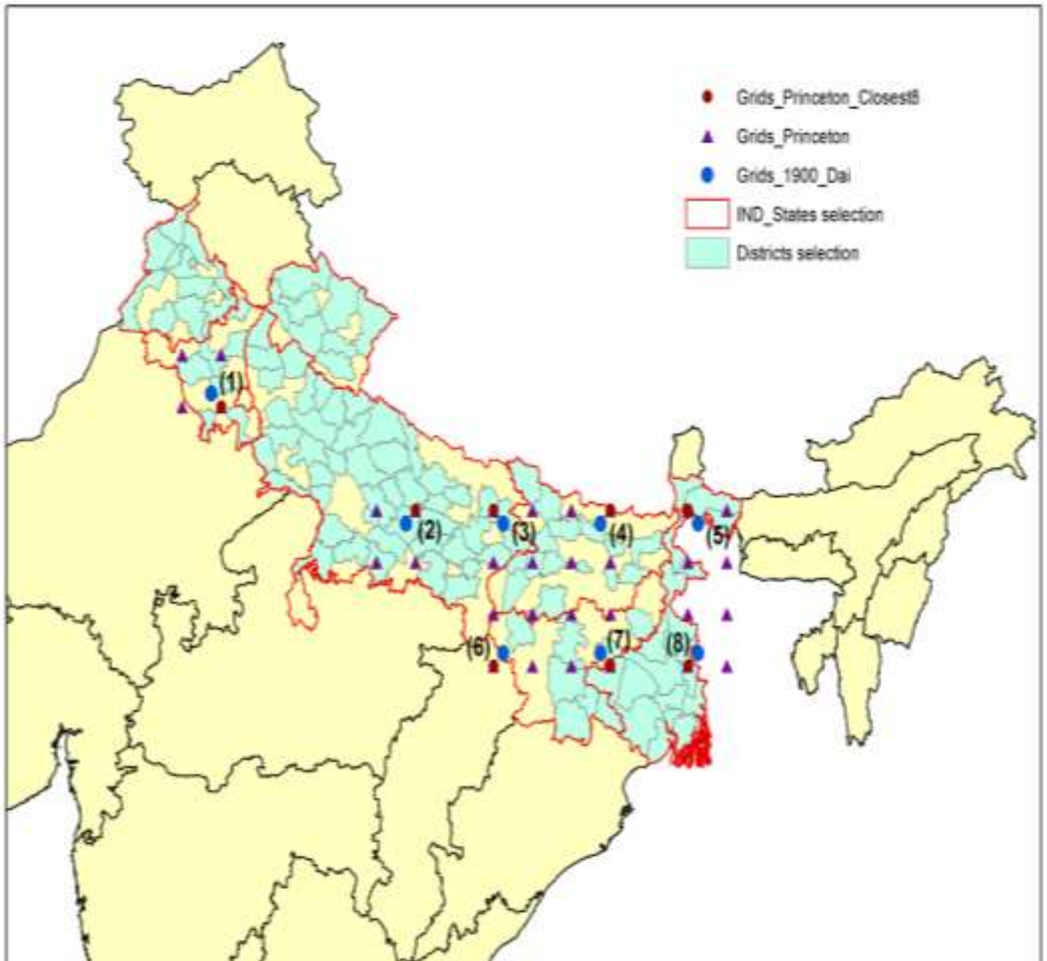
GDDavg: growing degree days

R30: Cumulative rainfall over threshold 30mm/day

Drought assessment in Northern India

8 study sites in Northern India

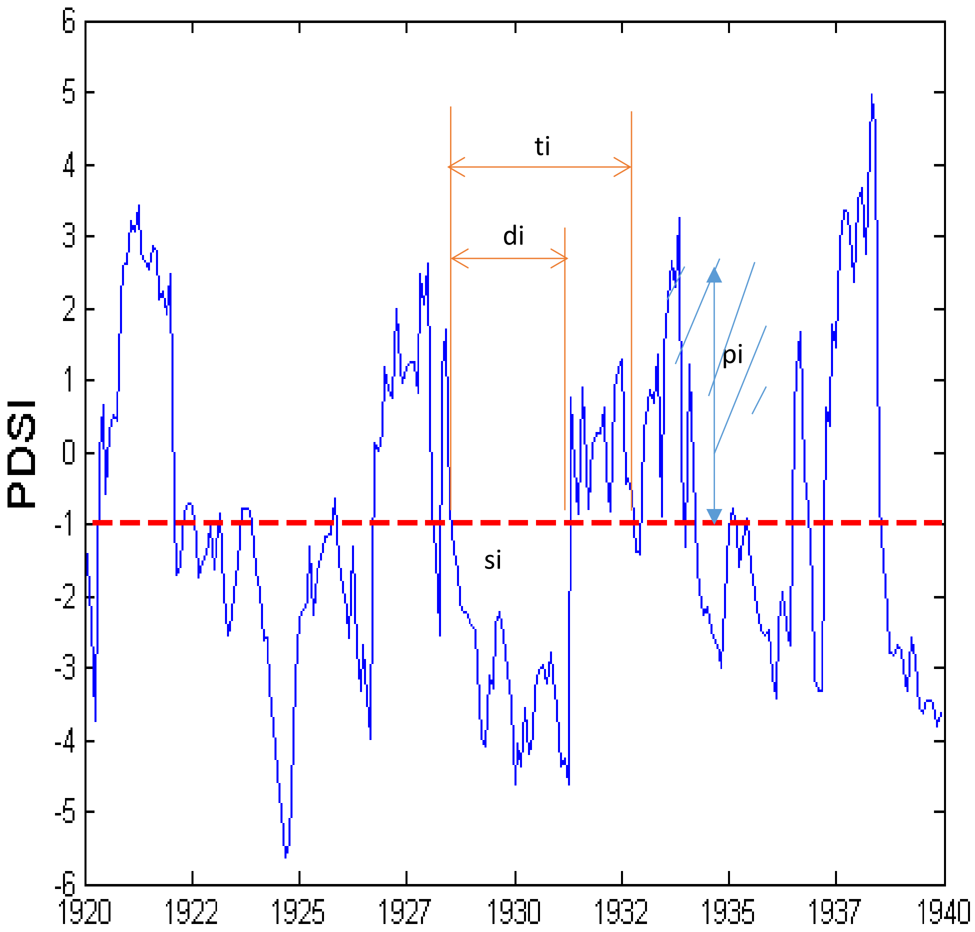
- Dai's PDSI dataset, 1900-2012 (Dai 2014)
- 32 sites of Princeton PDSI dataset, 1948-2008 in the same region



Drought Characteristics

1) Duration 2) Severity

3) Inter-arrival Time 4) average Intensity 5) Peak Intensity



di: Duration

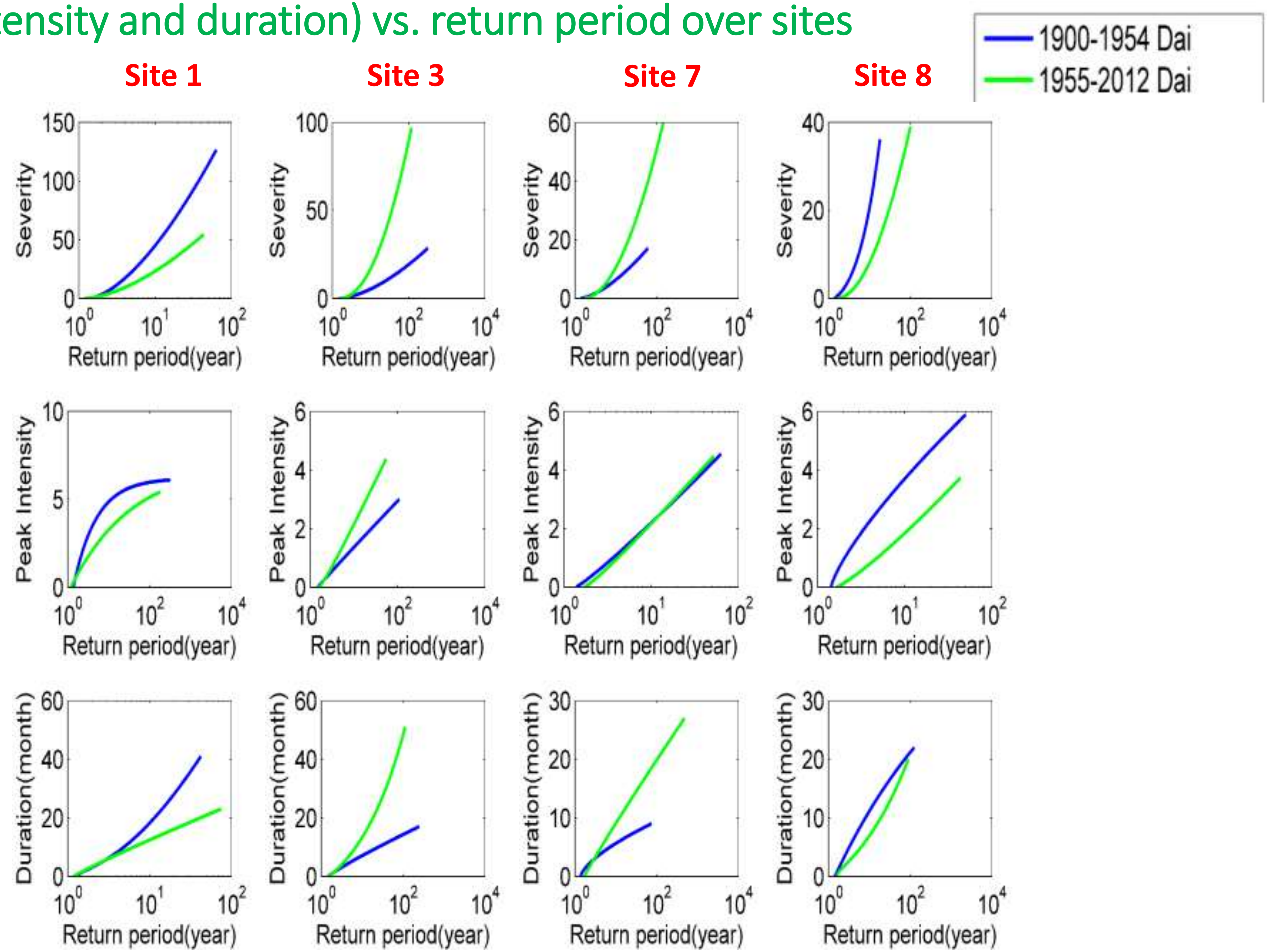
si: Severity (cumulative intensity)

ti: Inter-arrival time

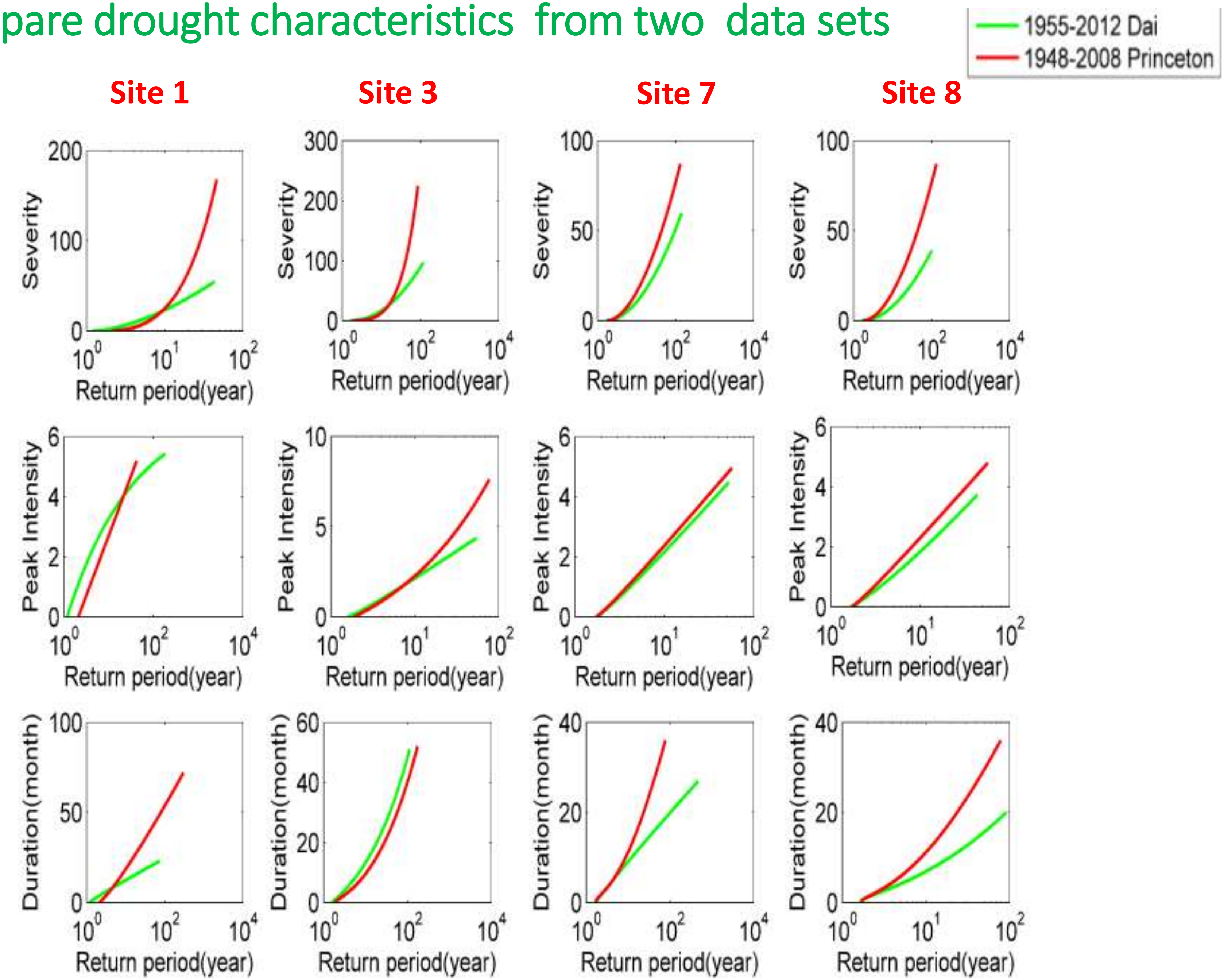
pi: Peak intensity

Average Intensity= severity/duration

Compare drought characteristics (severity, peak intensity and duration) vs. return period over sites



Compare drought characteristics from two data sets



Conclusions

Global warming but regional/local challenges (?)

- Climate change may have mixed effects on agriculture
- Climate change may cause significant changes in regional agriculture
- Uncertainty remains as a major concern