# Defining Climate Extremes From the Viewpoint of Impacts: Examples from Agriculture

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# The Importance of Extremes

TABLE 4. Comparison of simulated event probabilities for current climate and for 3°F (1.7°C) increase in mean at Washington, DC and Dallas.

| Case | Day event | Total event | Run event |
|---|---|---|---|
| | Washington, DC [Threshold = 95°F (35°C)] | | |
| Current | 0.137 | 0.353 | 0.177 |
| Base* | 0.294 | 0.764 | 0.471 |
| | Dallas [Threshold = 100°F (37.8°C)] | | |
| Current | 0.257 | 0.578 | 0.378 |
| Base* | 0.481 | 0.778 | 0.667 |

5 consecutive days or more above threshold

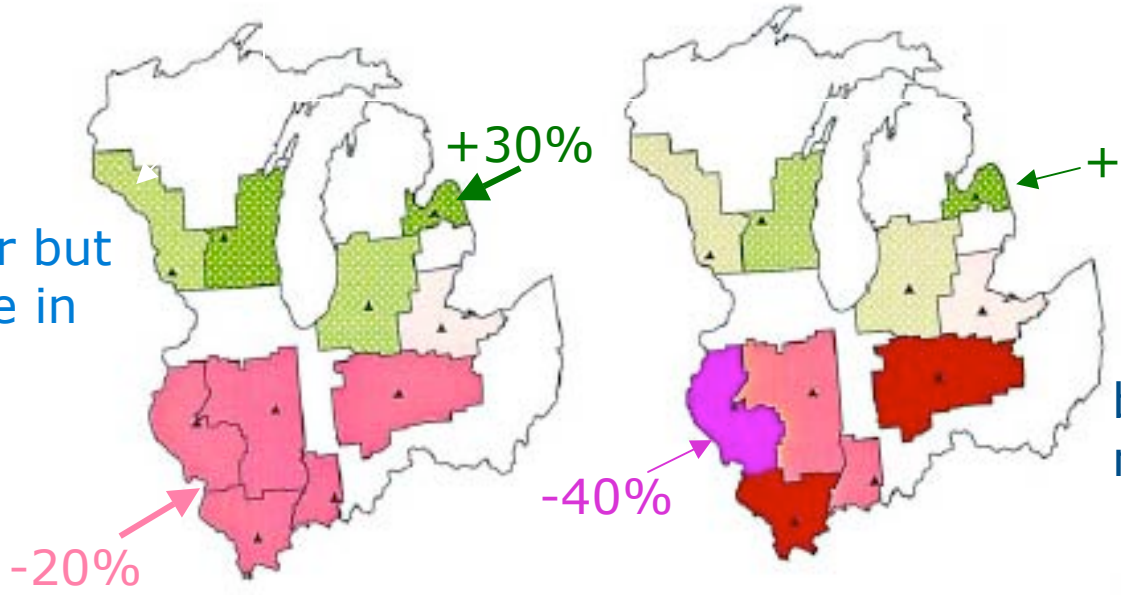
* 3°F increase in mean with variance and autocorrelation held constant.

Source: Mearns, Katz, Schneider, 1984

# Percent change in mean decadal yield for long-season corn: Climate Change with $2xCO_2$: (a) unchanged variability, and (b) two times current variability

Growing season mean:
+2.8°C

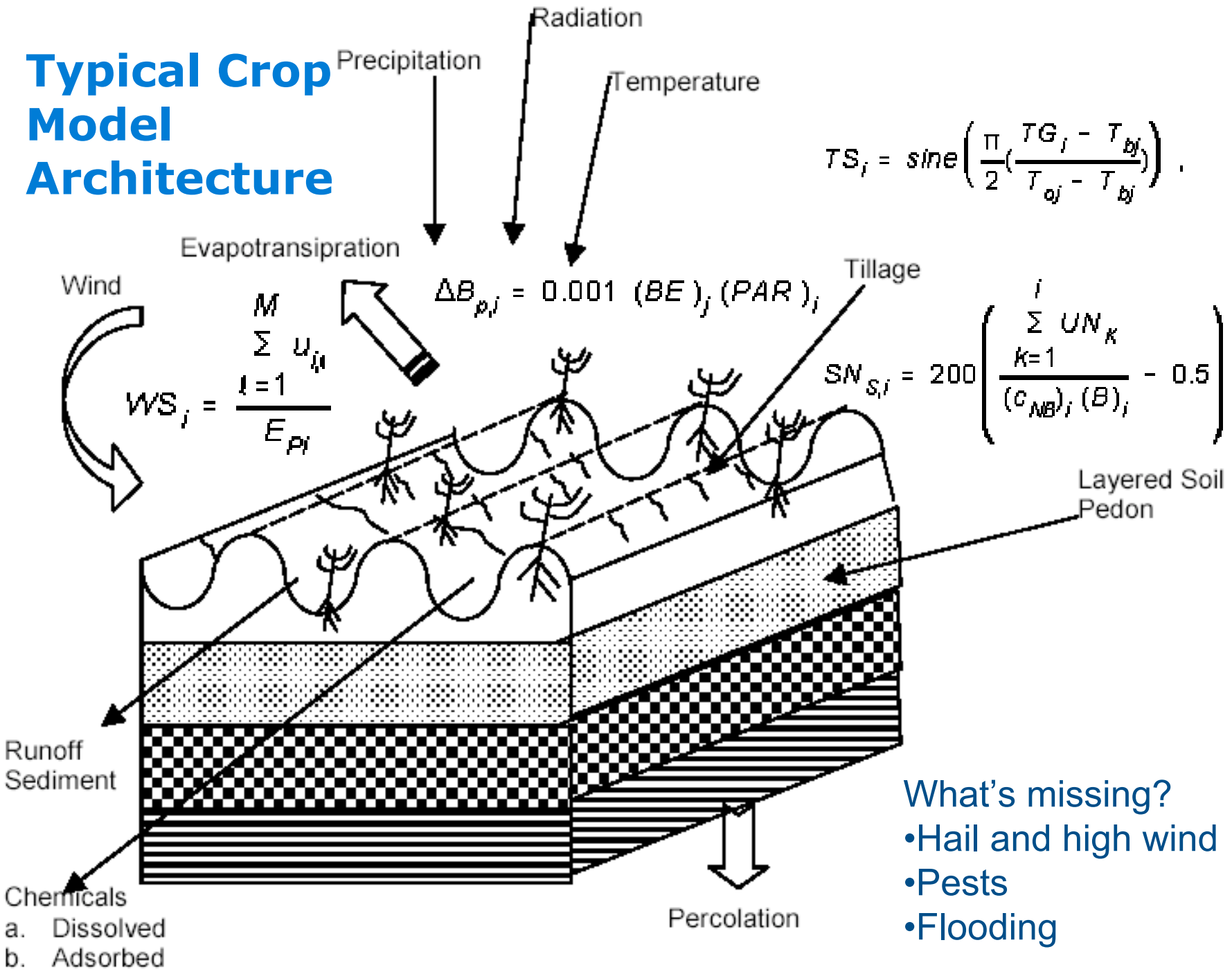
a. warmer but no change in extremes




b. warmer and more extremes


Southworth et al

# Typical Crop Model Architecture




$$TS_i = sine\left(\frac{\pi}{2}\left(\frac{TG_i - T_{bj}}{T_{oj} - T_{bj}}\right)\right)$$

$$\Delta B_{p,i} = 0.001\ (BE)_j\ (PAR)_i$$

$$WS_i = \frac{\sum_{l=1}^{M} u_{i,l}}{E_{pi}}$$

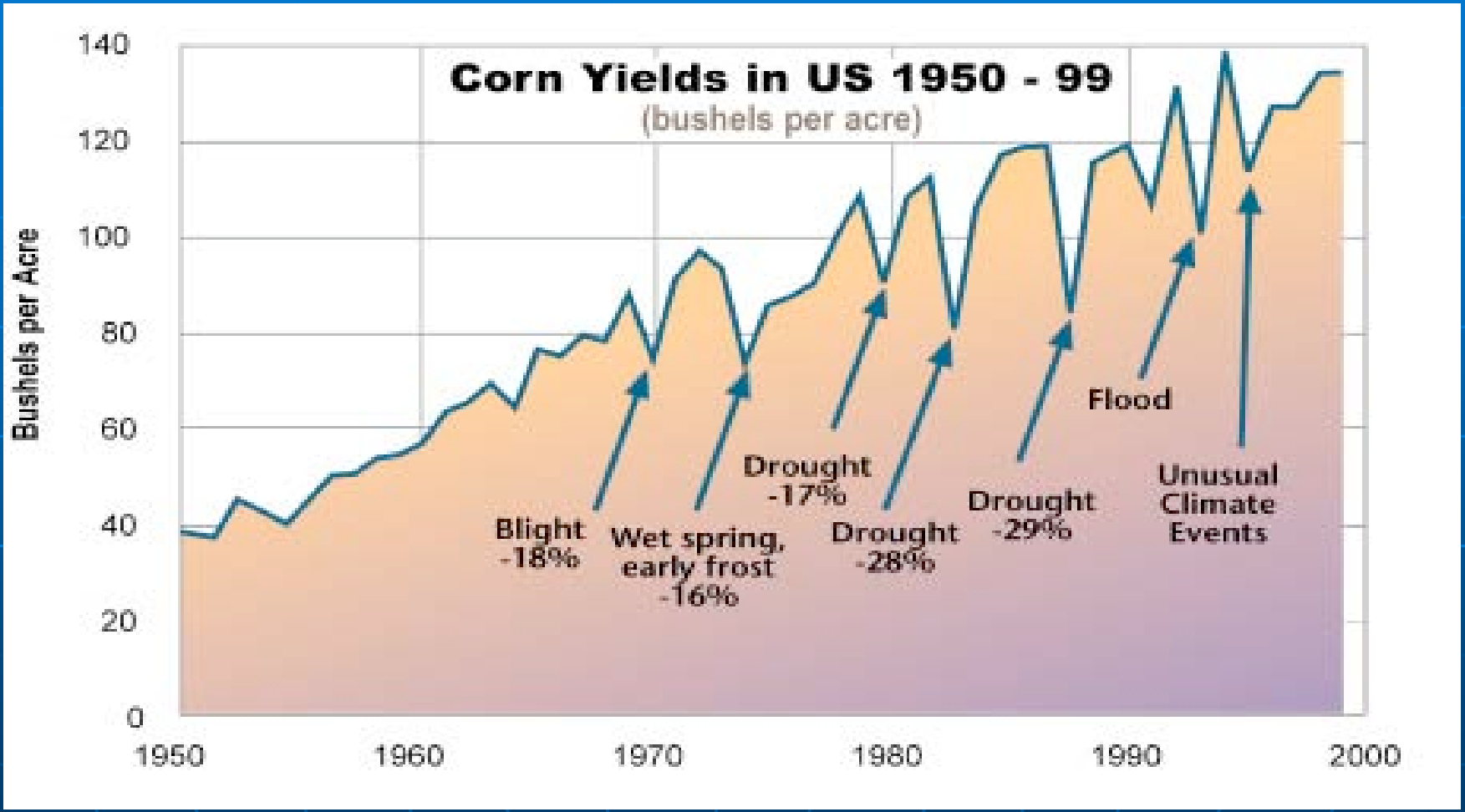
$$SN_{S,i} = 200\left(\frac{\sum_{k=1}^{i} UN_k}{(c_{NB})_i\ (B)_i} - 0.5\right)$$

What's missing?

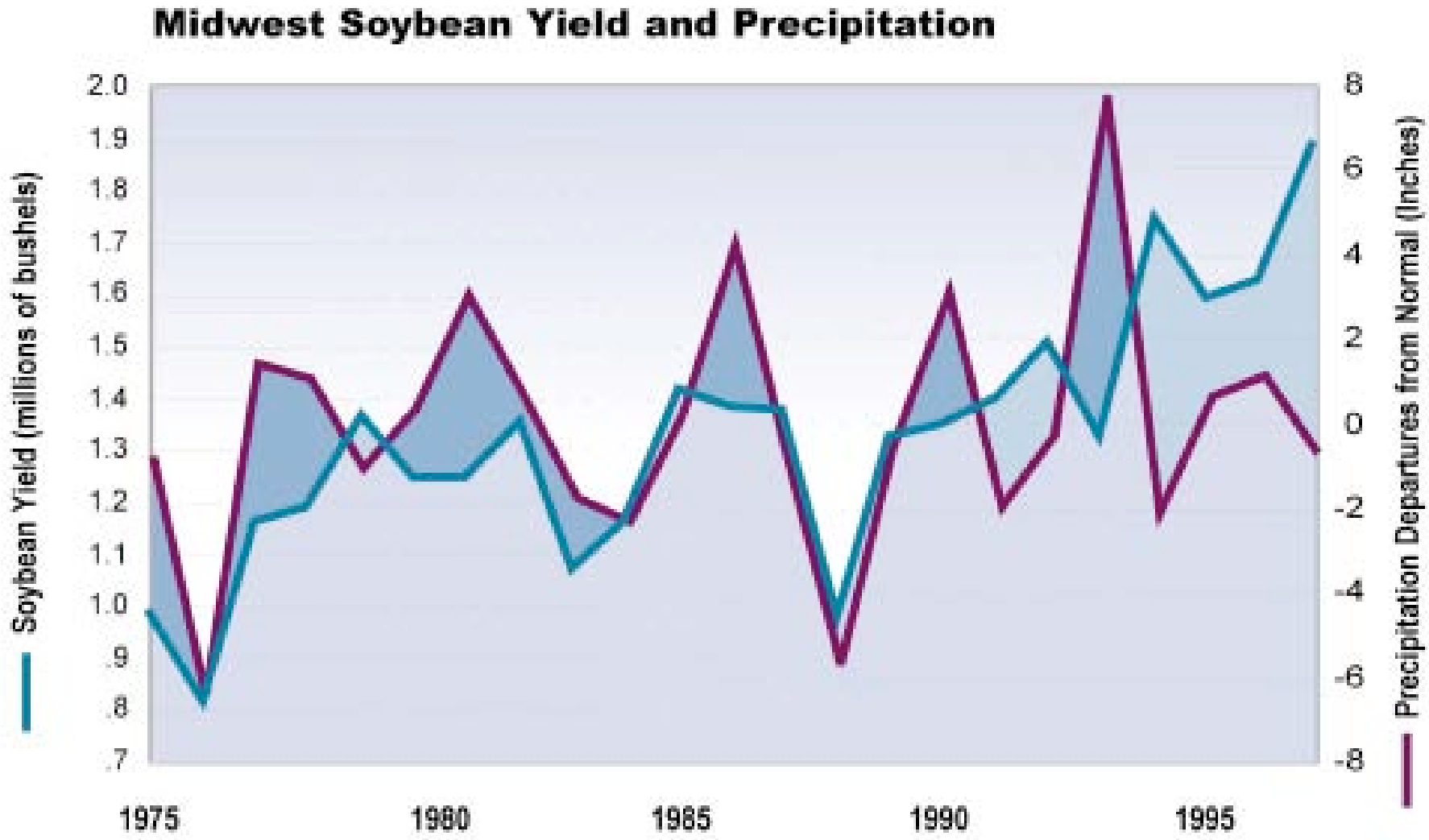
- Hail and high wind
- Pests
- Flooding

Long-term observation of impact trends in highly managed sectors is maybe even trickier than projecting forward with impact models

# Effects of extreme climate and climate-related disease events on U.S. corn yields, 1950-1999

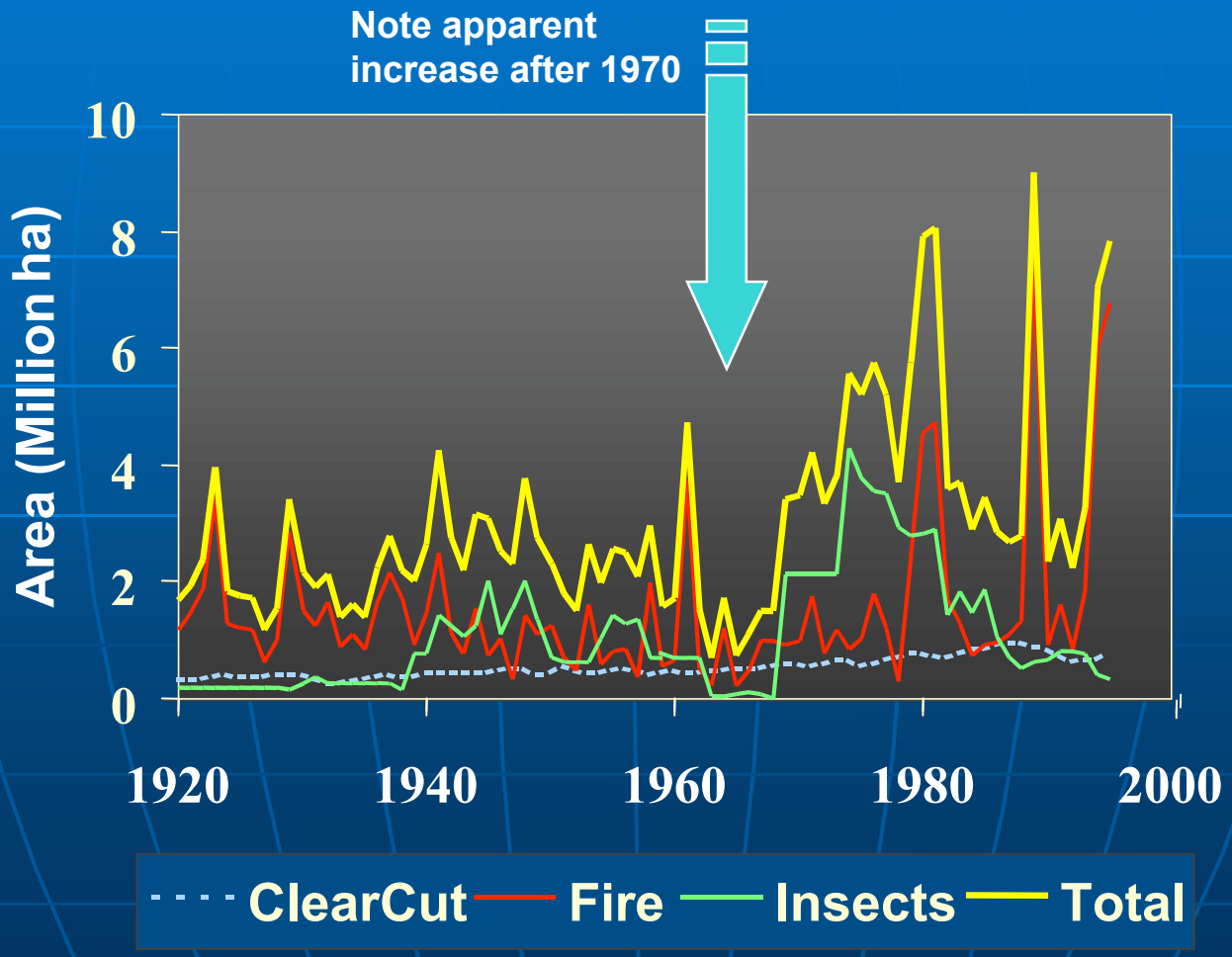



Source:http://www.usgcrp.gov/usgcrp/Library/nationalassessment/

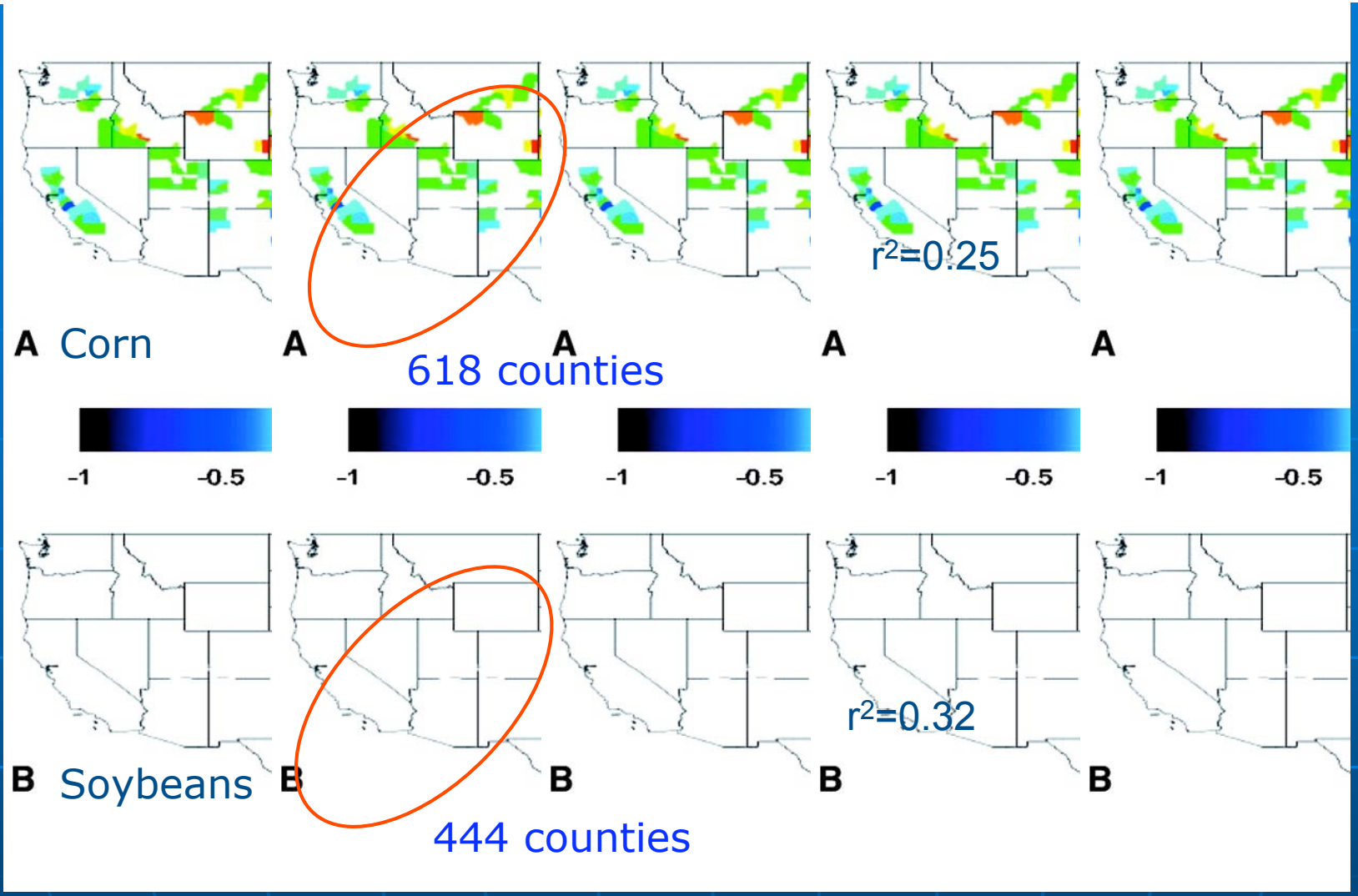



Source:http://www.usgcrp.gov/usgcrp/Library/nationalassessment/06C.pdf

# Disturbances in Canada's forests (1920 - 1995)




Courtesy of M. Apps




Correlation between June to August average temperature anomalies and (**A**) corn and (**B**) soybean yield anomalies for 1982-98.

# Toward the monitoring of climate extremes with sector-specific measures

Time series of agro-climatic (thermal time) indices for global maize production zones

# Thermal Time: Annual Maize Growing Degree Days

$GDD_{annual} = \Sigma[(TMAX_{daily} + TMIN_{daily})/2] - TBASE,$

TBASE = 10EC for maize

when TMAX < TBASE, TMAX = TBASE
when TMIN < TBASE, then TMIN = TBASE

# Thermal Time: Maize Heat Stress Days Growing Degree Days During Anthesis

$HSD_{annual} = \Sigma[(TMAX_{daily} - TBASE]$

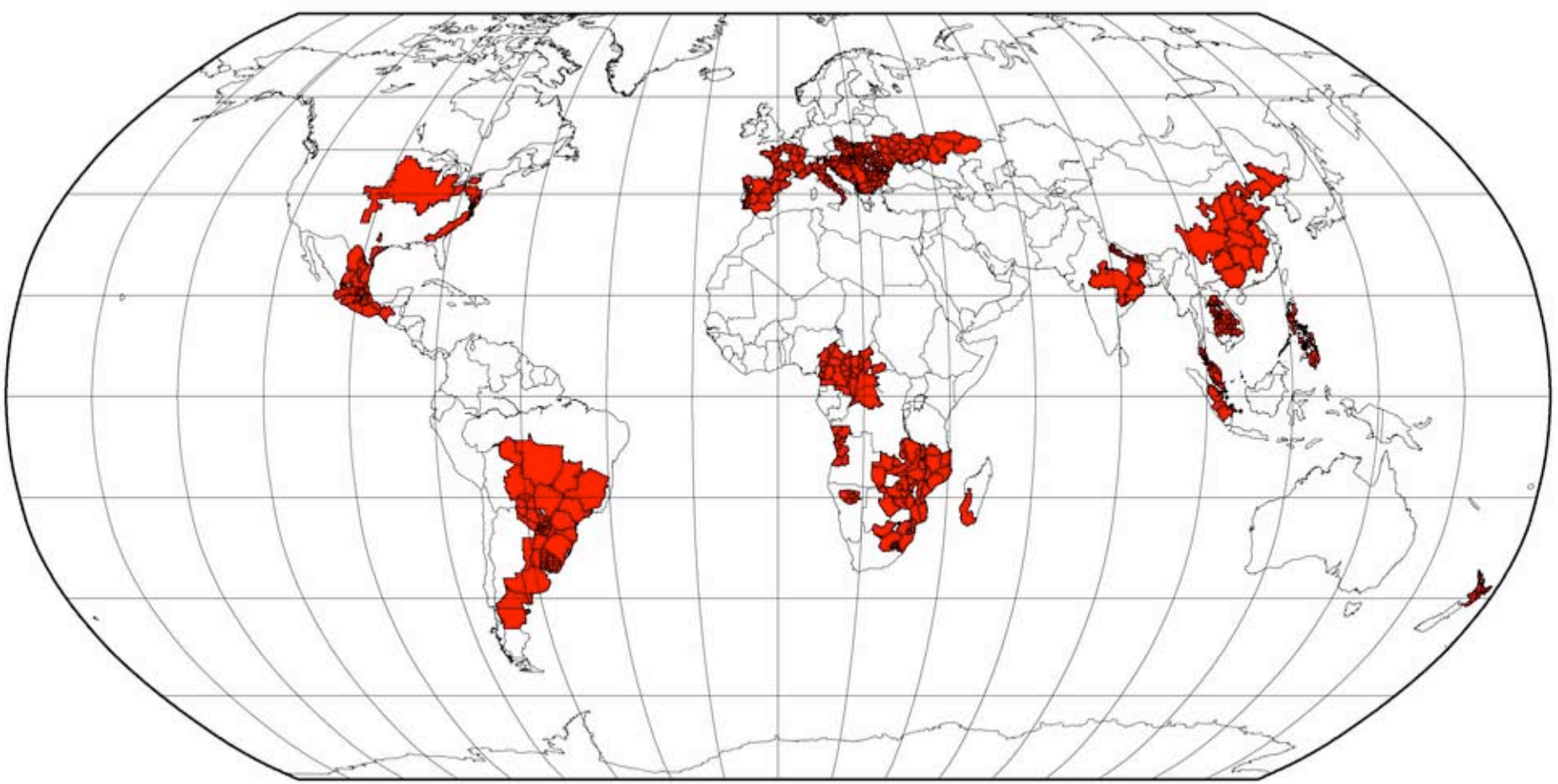
TBASE = 30EC for maize

when TMAX < TBASE, TMAX = TBASE

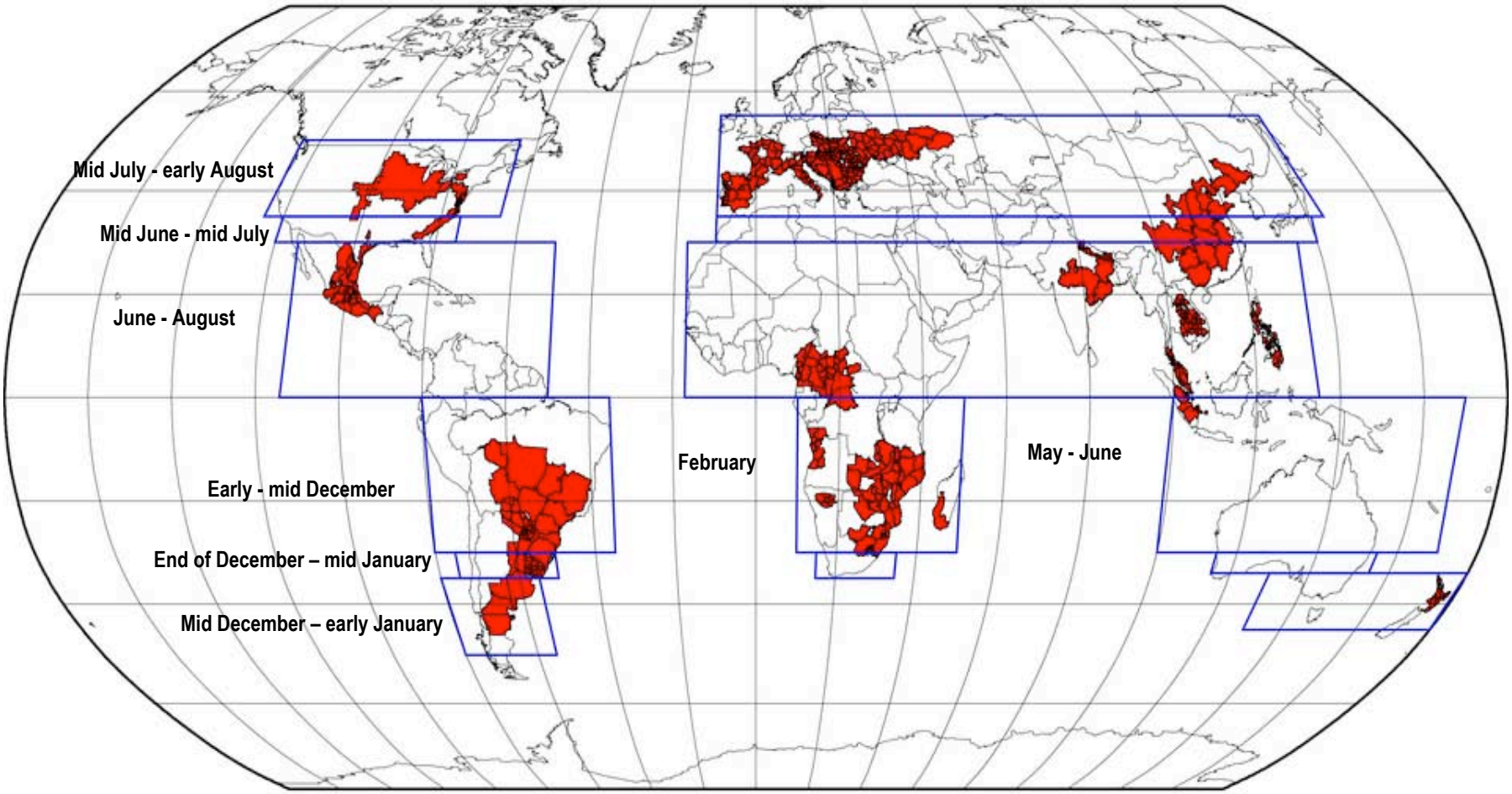
# Advantages to monitoring extremes with thermal time indices

- Phenology (rate of growth) directly regulated by accumulated heat
- Excessive accumulated heat at critical times disrupts translocation of photosynthate to grainfill
- Climate influence is not affected by technological development (at least not thus far)

# Major Maize Production Regions

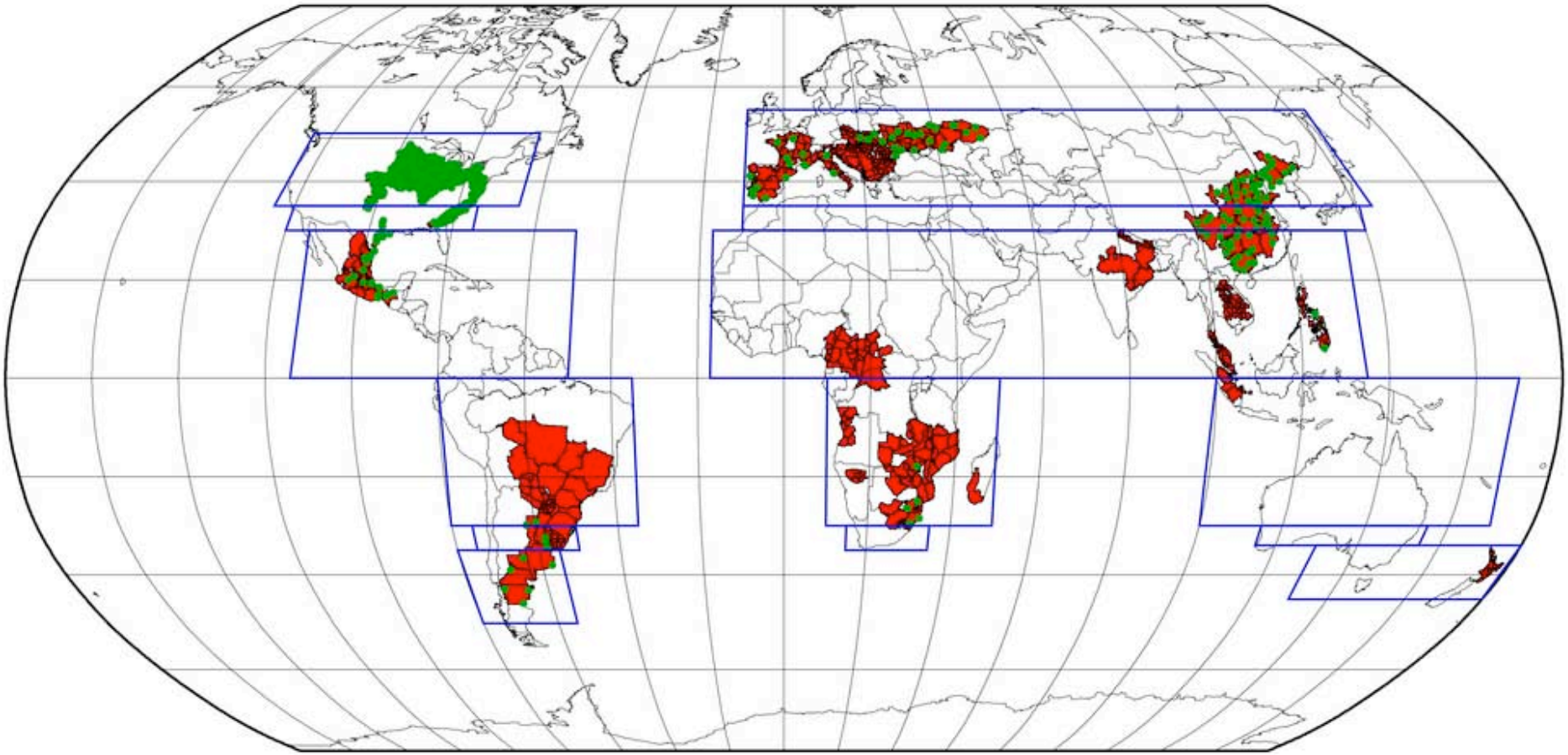


# Average period of anthesis in maize across the major crop growing regions of the world



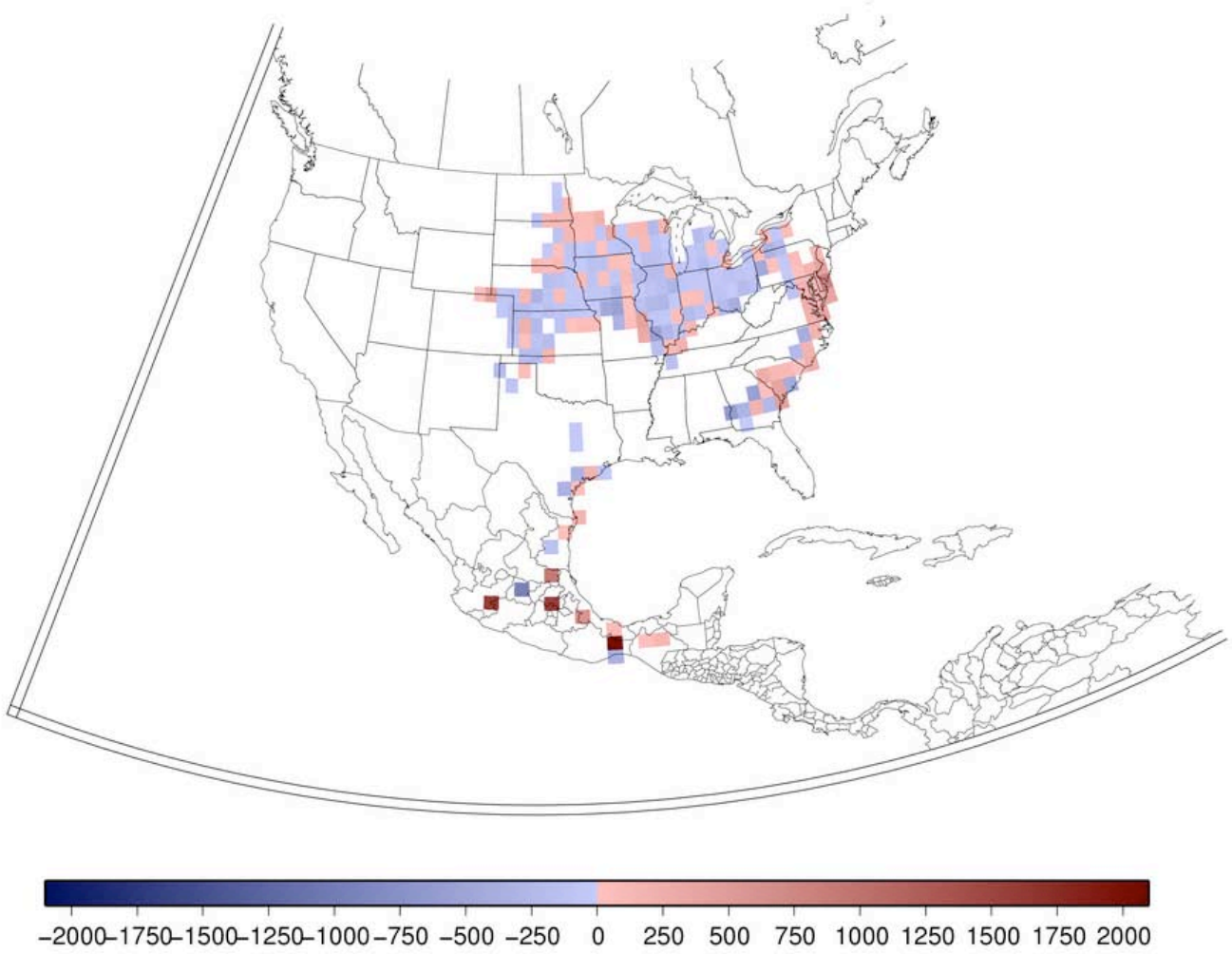
# GHCN-Daily Stations (784), with polygonal “anthesis” regions

- Long-term (at least 40 years (from 1950 through 2004) with each year at least 99% non-missing for Northern Hemisphere and at least 30 years with each year at least 80% non-missing, for Southern Hemisphere.
- TMAX and TMIN
- Station data spatially averaged to 1E grids for mapping
- Exclude days that were “flagged” by GHCN-Daily QC



# Maize Growing Degree Days (GDD) Index—North America 1950-2004

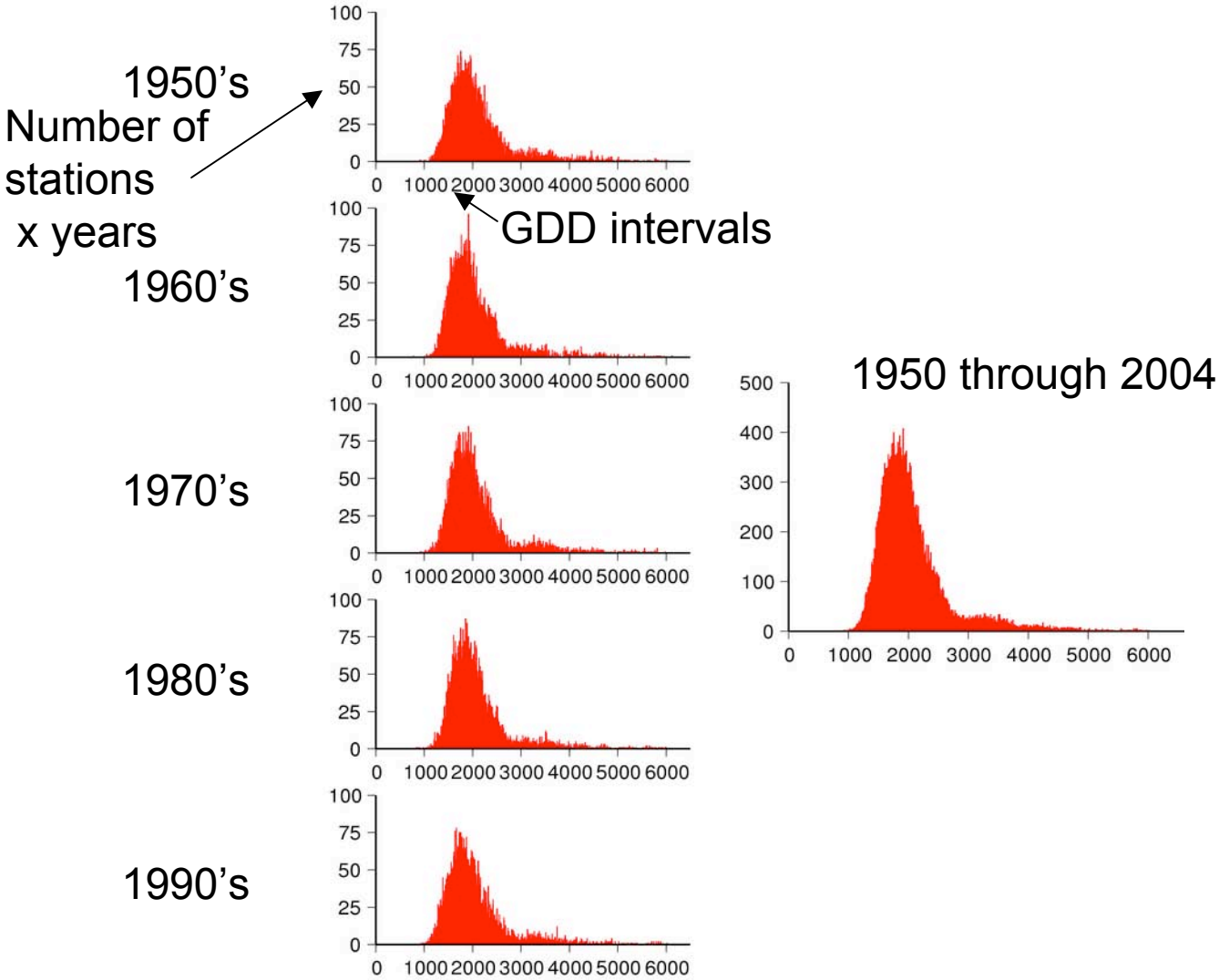
Linear Fit (trends) of annual growing degree days

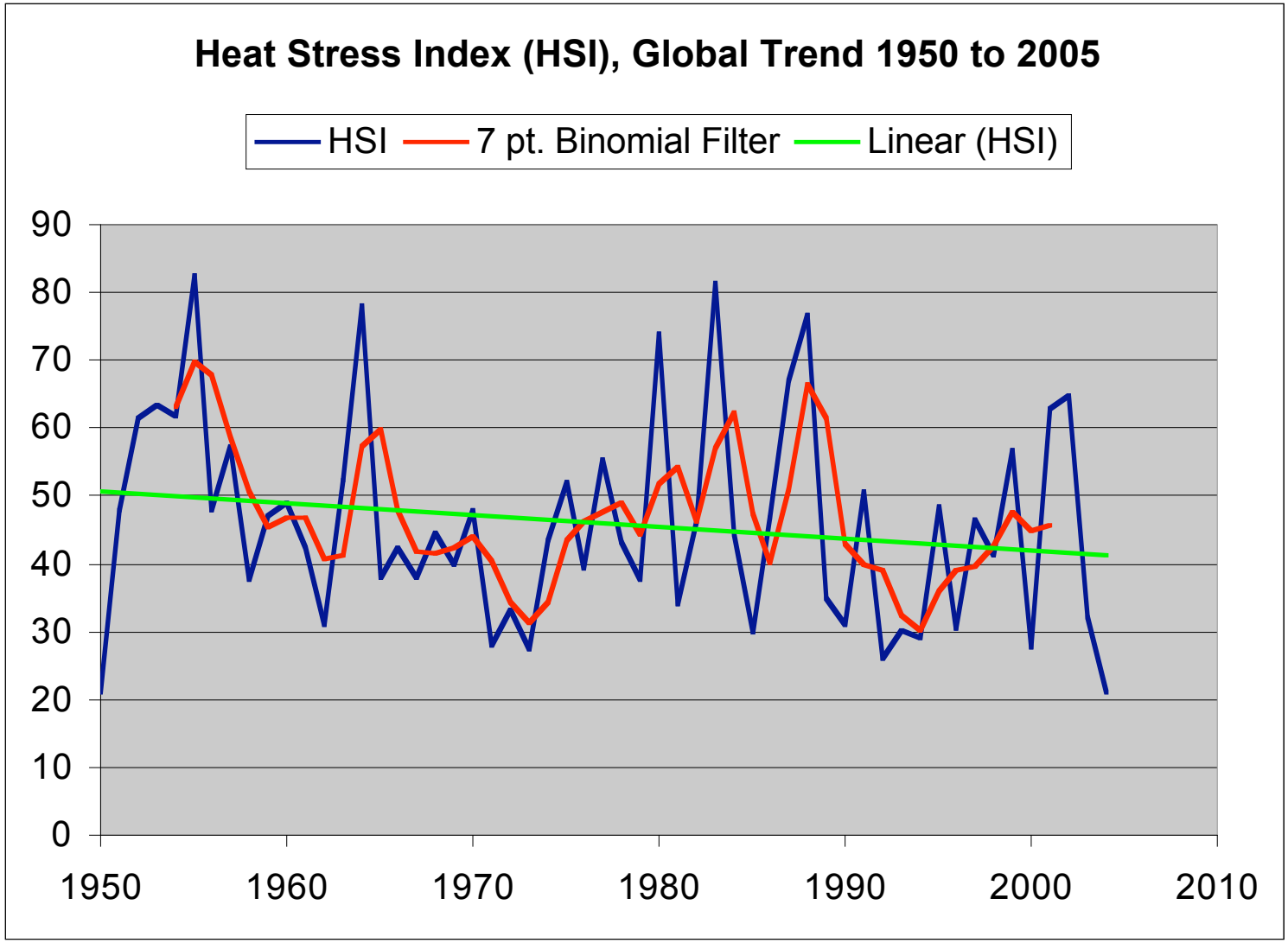



Trends (Days per Century)

# Maize Growing Degree Days (GDD) Index—North America

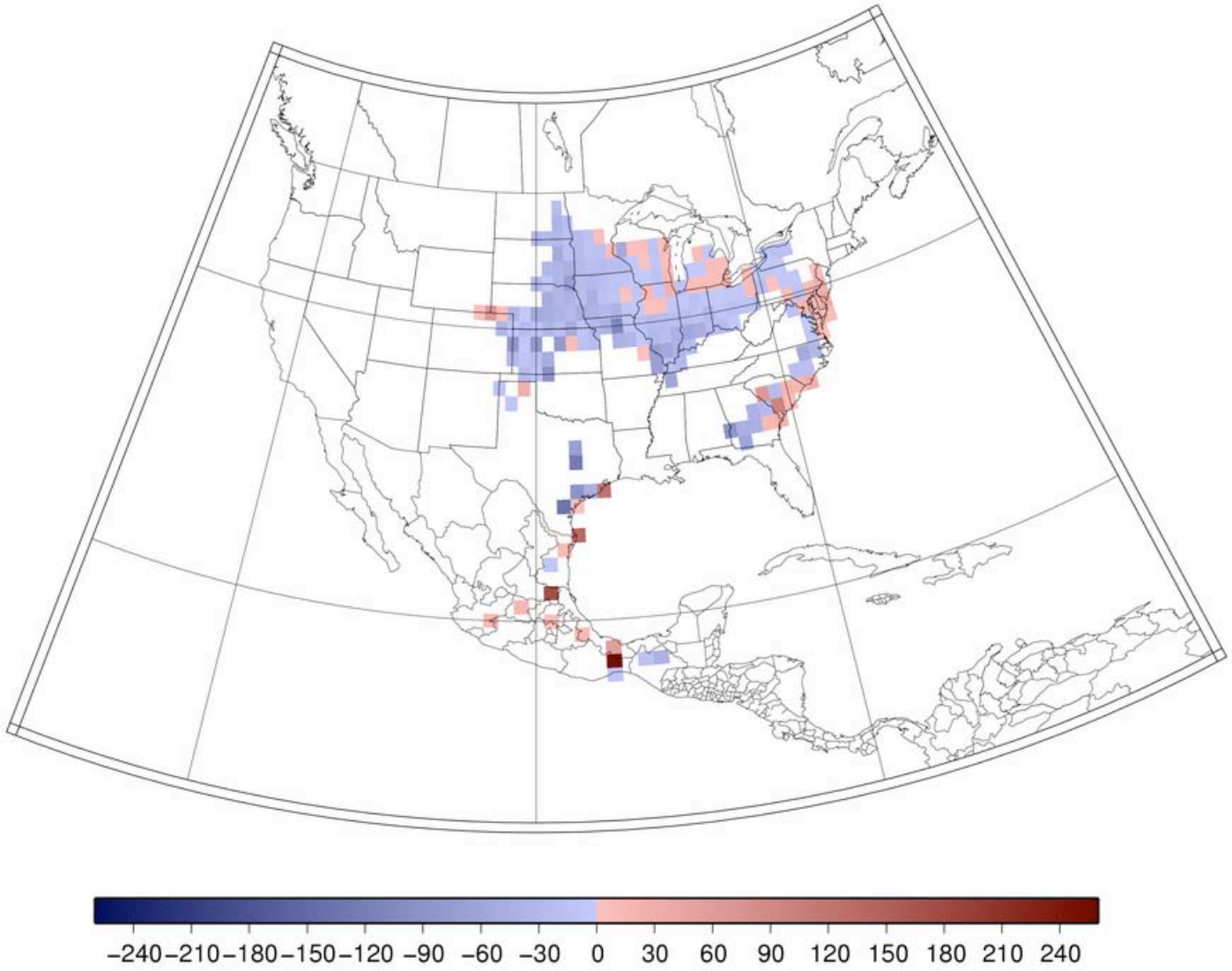
## Frequency of Annual Growing Degree Day Totals




Heat Stress Index (HSI), Global Trend 1950 to 2005
HSI
7 pt. Binomial Filter
Linear (HSI)
90
80
70
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
2010

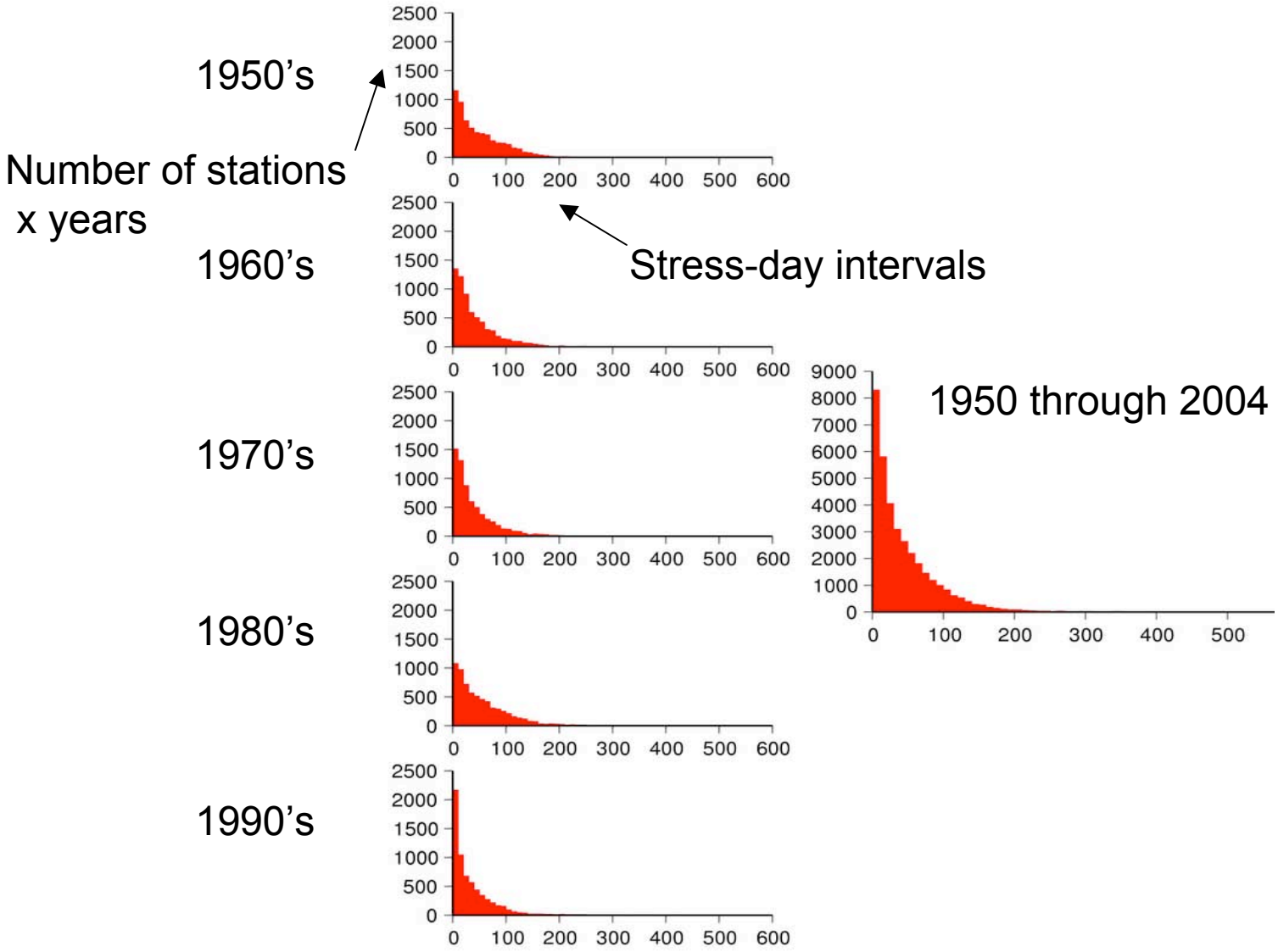
# Maize Heat Stress-Day Index—North America 1950-2004

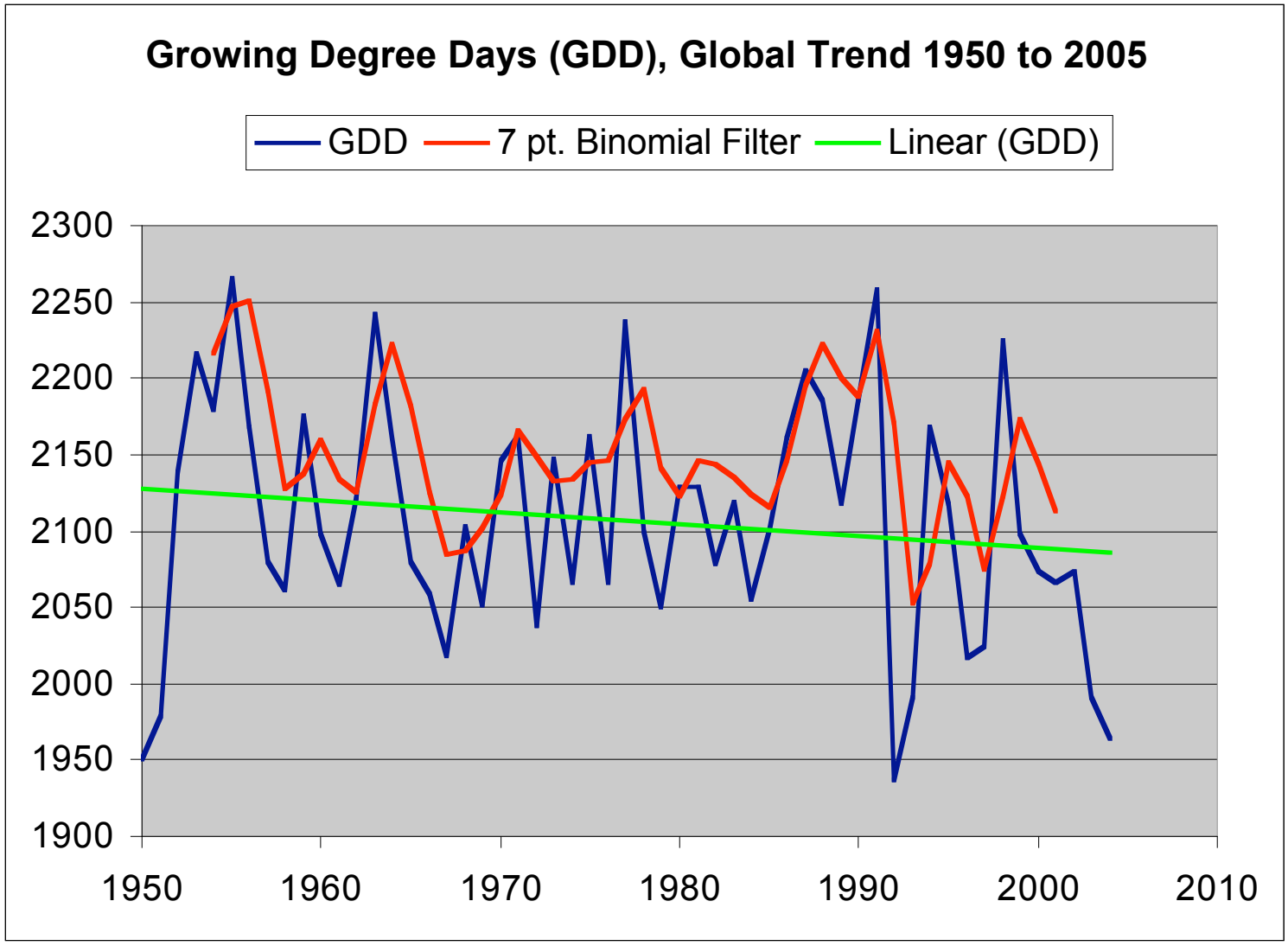
## Linear Fit (trends) of annual heat stress days for anthesis



# Maize Heat Stress-Day Index—North America 1950-2004

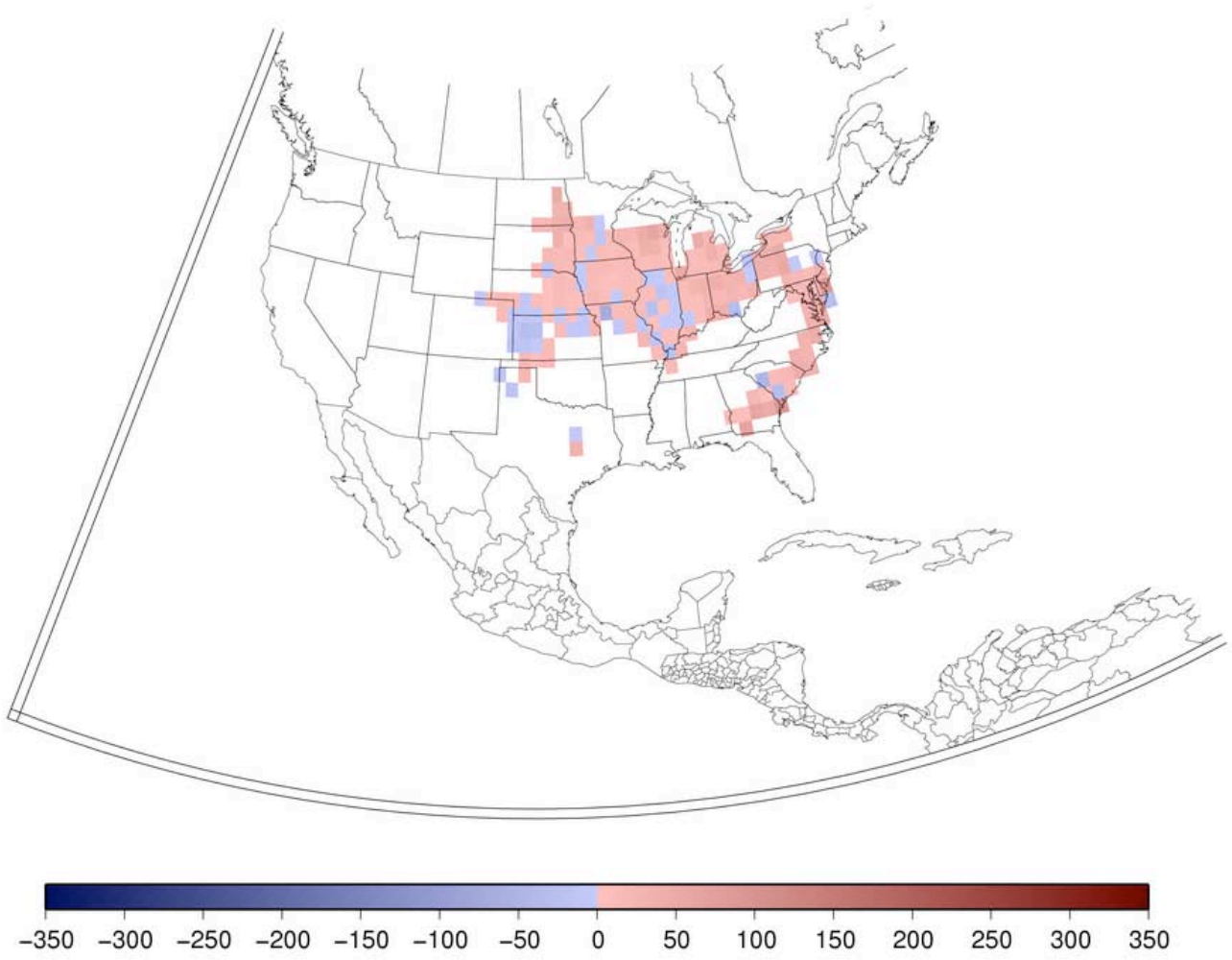
## Frequency of Annual Heat Stress Days for Anthesis



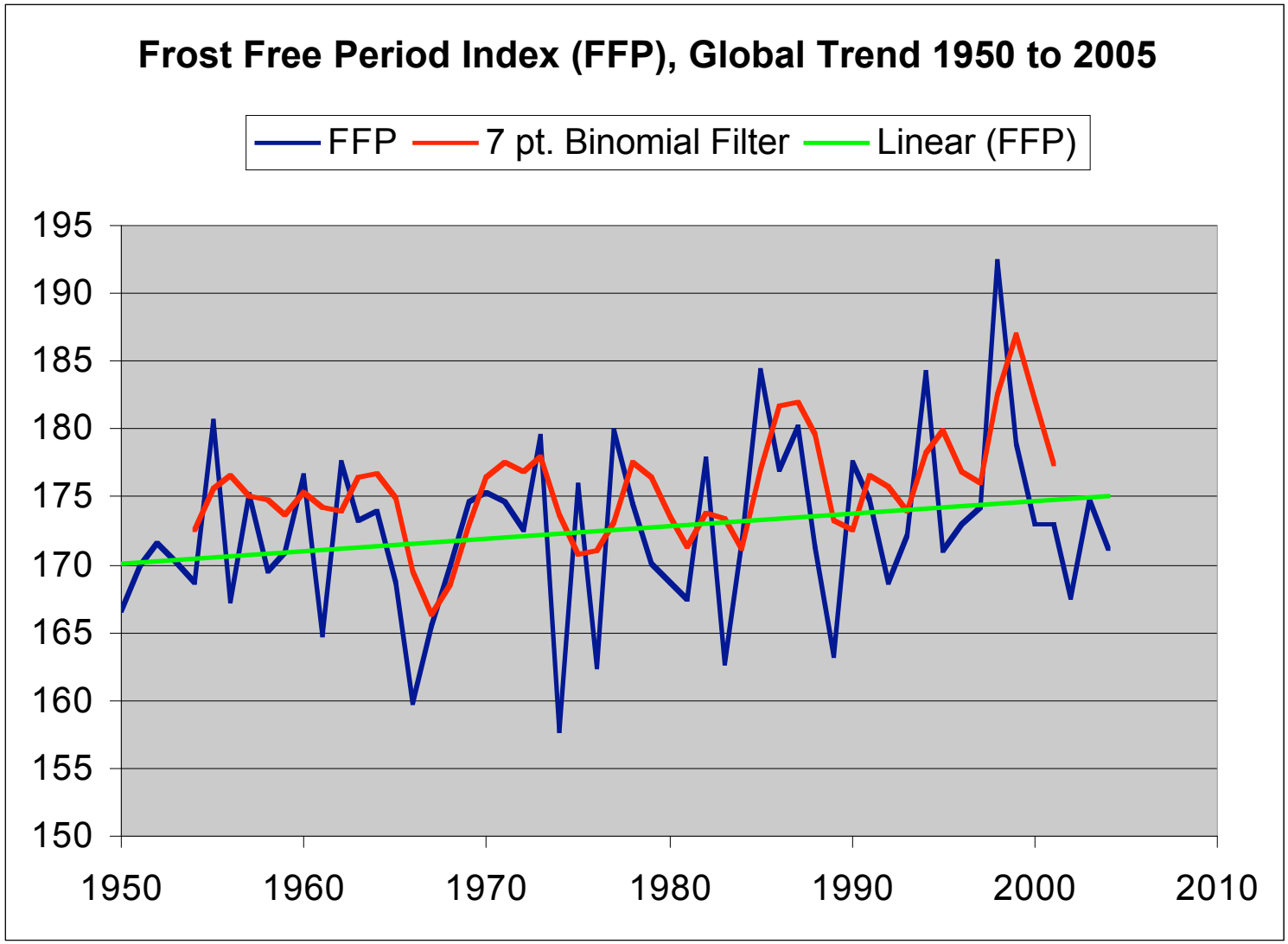

Growing Degree Days (GDD), Global Trend 1950 to 2005
GDD
7 pt. Binomial Filter
Linear (GDD)
2300
2250
2200
2150
2100
2050
2000
1950
1900
1950
1960
1970
1980
1990
2000
2010

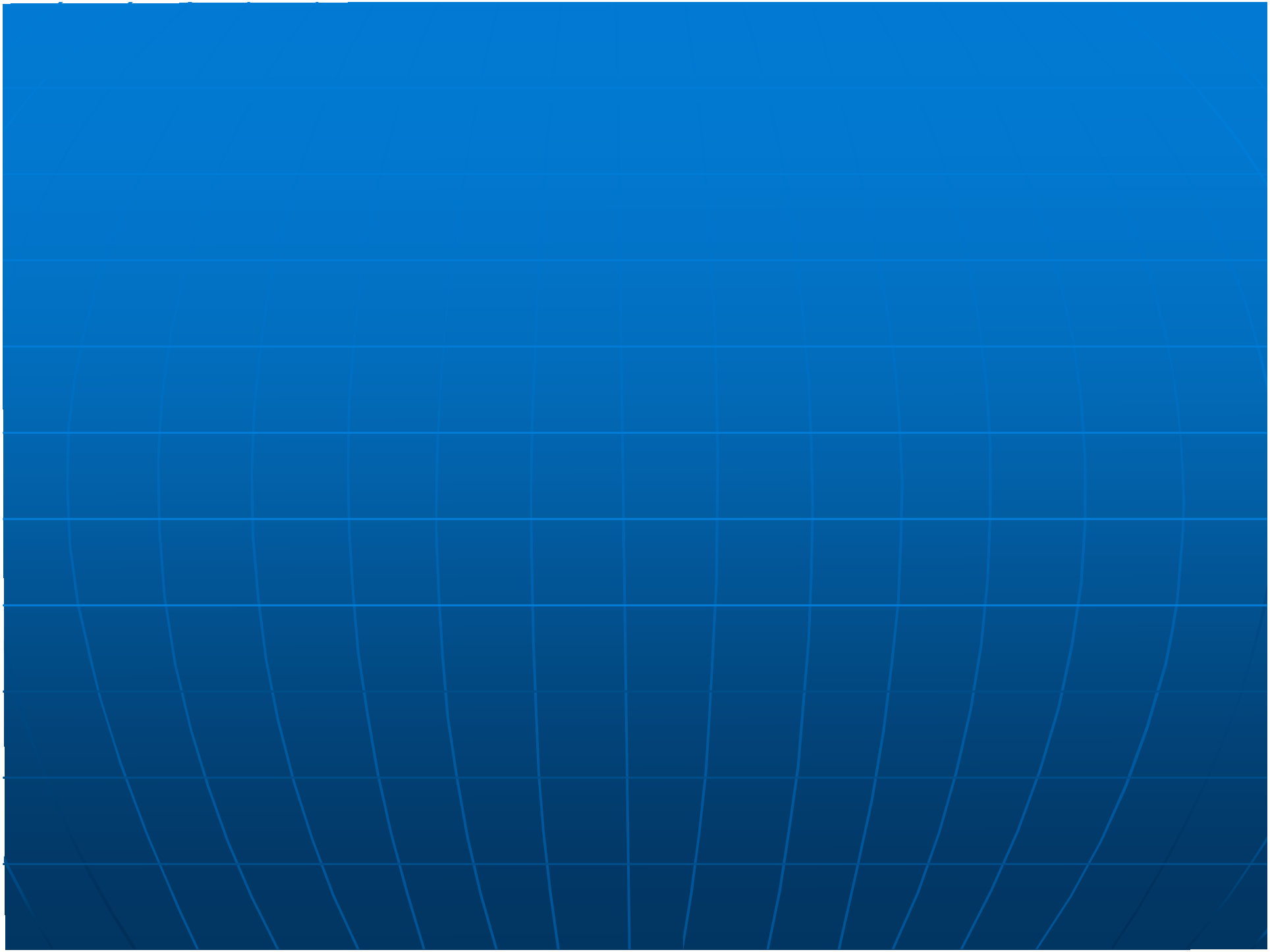
# Frost Free Period (FFP) Index (North America)

Linear Fit (trends) of the FFP annually accumulated days, 1950-2004



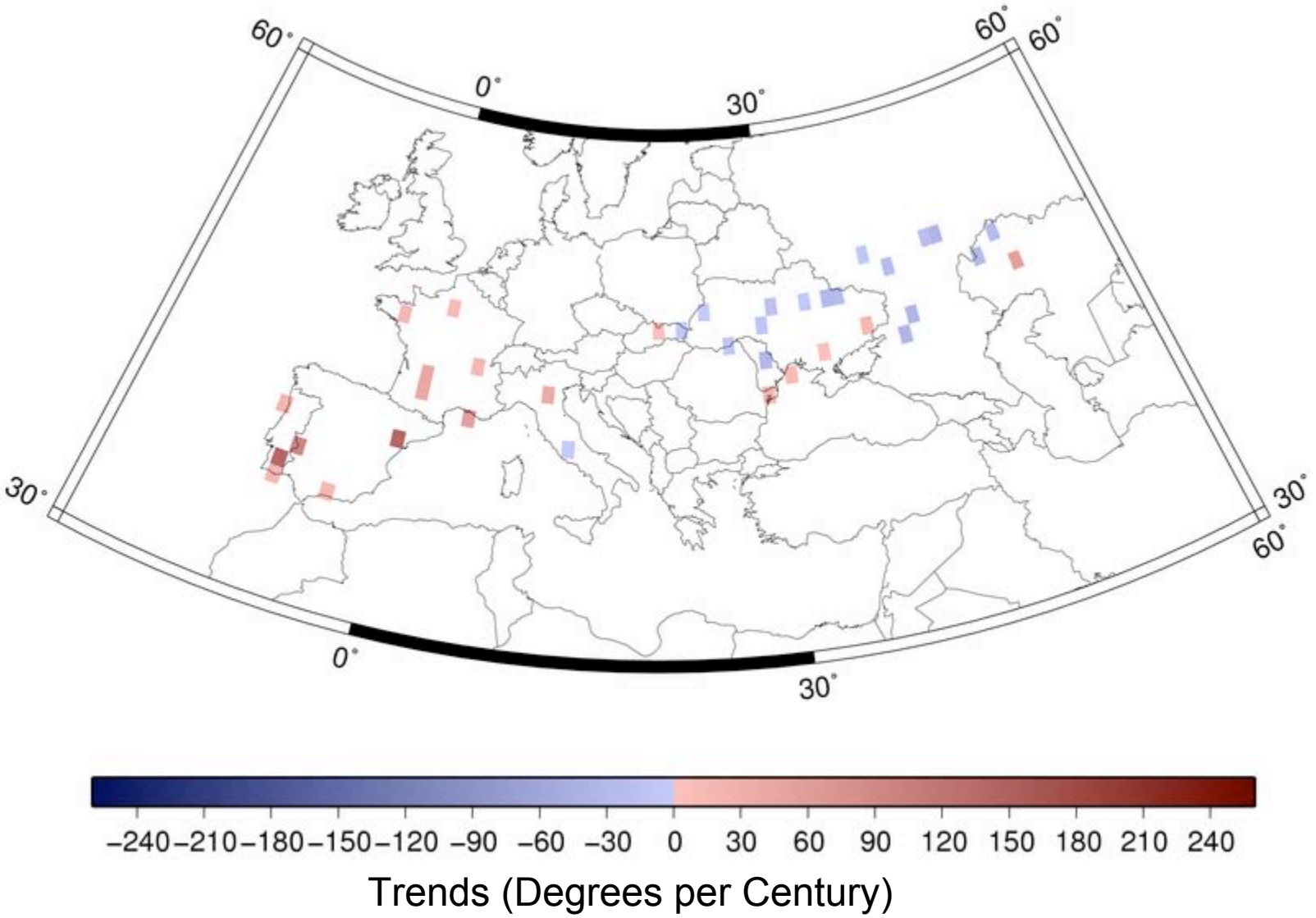

Trends (Days per Century)


Frost Free Period Index (FFP), Global Trend 1950 to 2005
FFP
7 pt. Binomial Filter
Linear (FFP)
195
190
185
180
175
170
165
160
155
150
1950
1960
1970
1980
1990
2000
2010



# Maize Heat Stress-Day Index—Eurasia

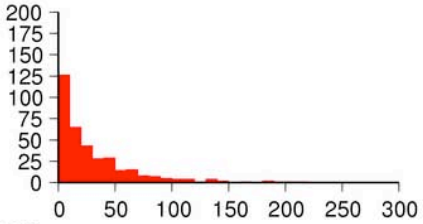
Linear Fit (trends) of the heat stress annually accumulated degrees



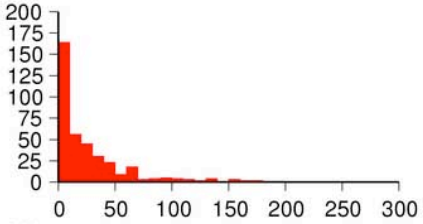
# Maize Heat Stress-Day Index—Eurasia

**Frequency of Heat Stress Index Annual Accumulated Degrees for period of anthesis**

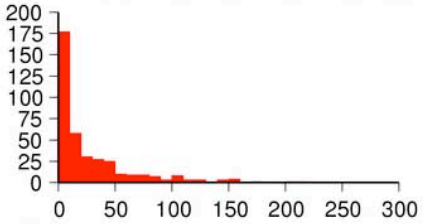
1950's



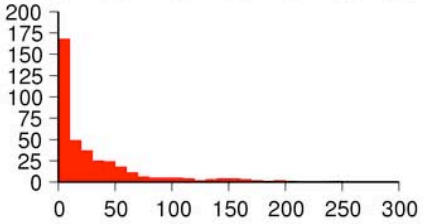

1960's



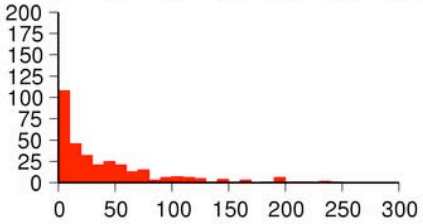

1970's



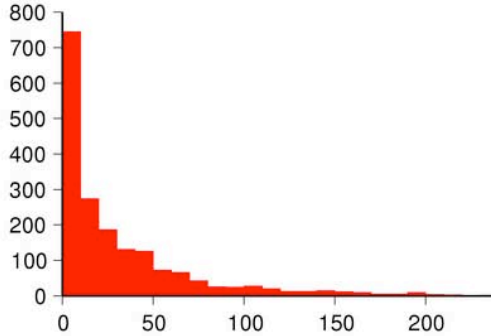

1980's




1990's

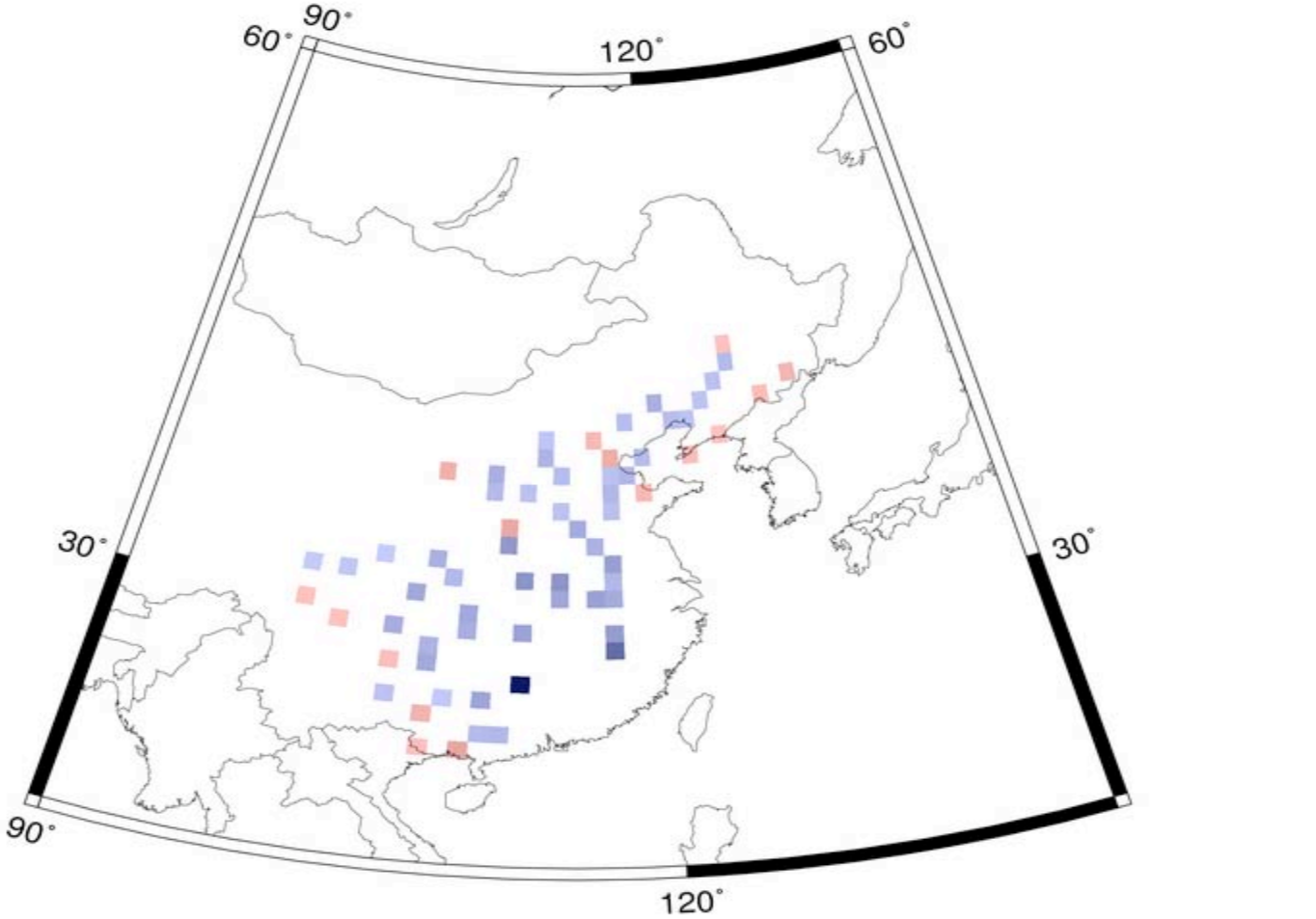



1950 through 2005



# Maize Heat Stress-Day Index—Asia

Linear Fit (trends) of the heat stress annually accumulated degrees



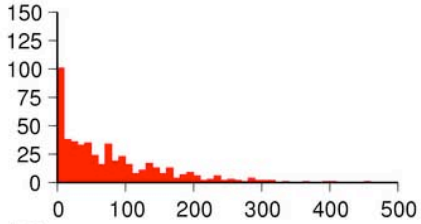


Trends (Degrees per Century)

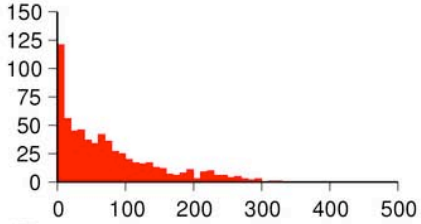
# Maize Heat Stress-Day Index—Asia

**Frequency of Heat Stress Index Annual Accumulated Degrees for period of anthesis**

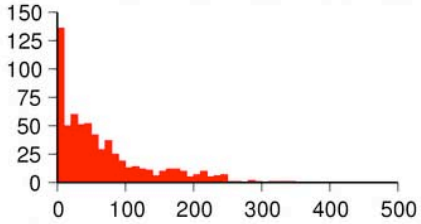
1950's



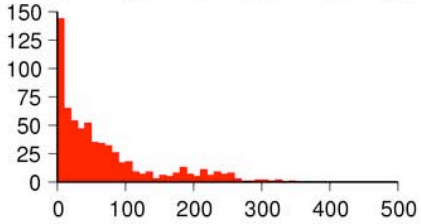

1960's



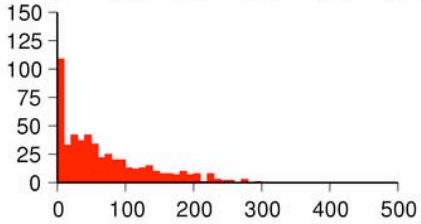

1970's



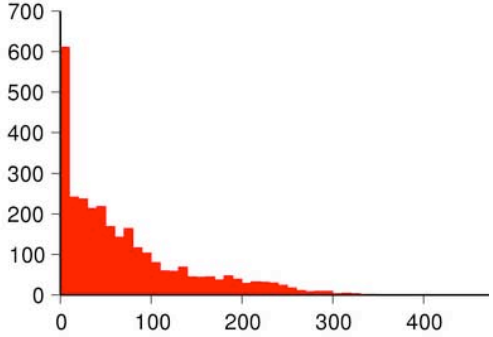

1980's




1990's

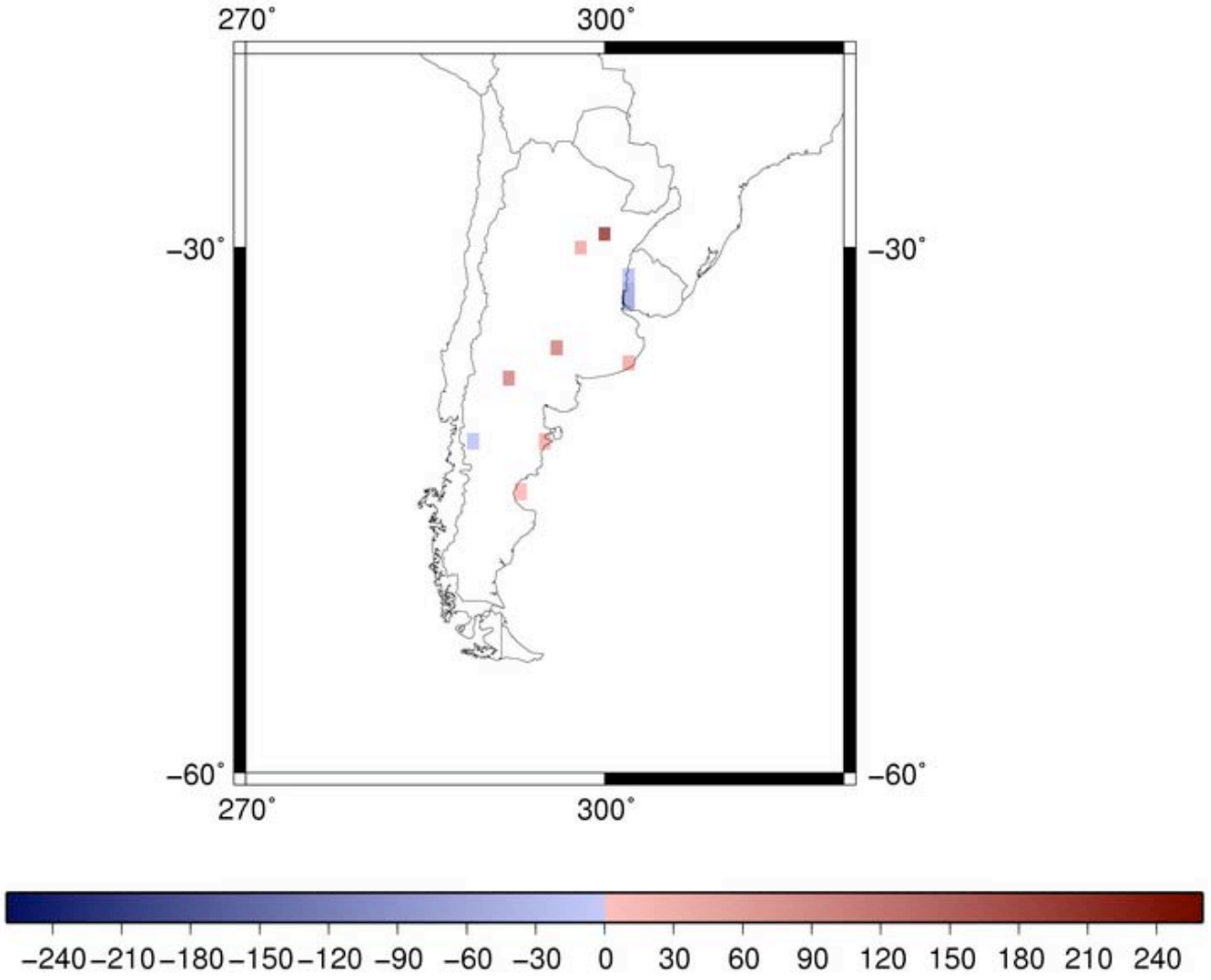



1950 through 2005



# Maize Heat Stress-Day Index—South America

Linear Fit (trends) of the heat stress annually accumulated degrees



# Maize Heat Stress-Day Index—South America

**Frequency of Heat Stress Index Annual Accumulated Degrees for period of anthesis**

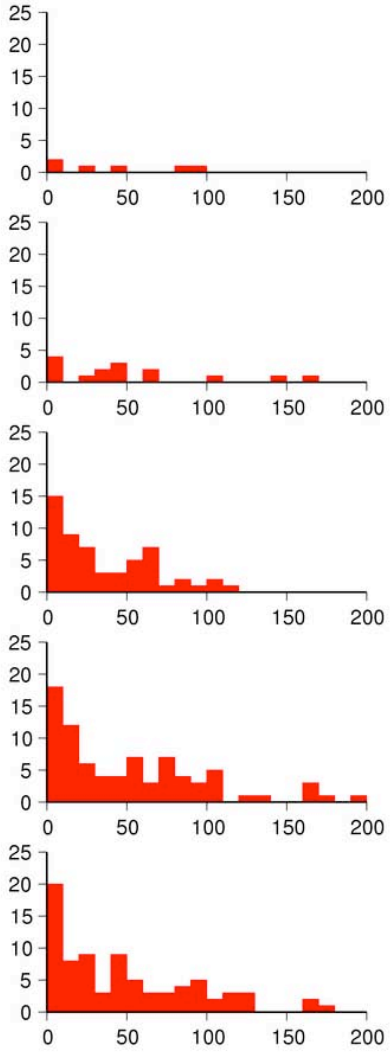
1950's

1960's

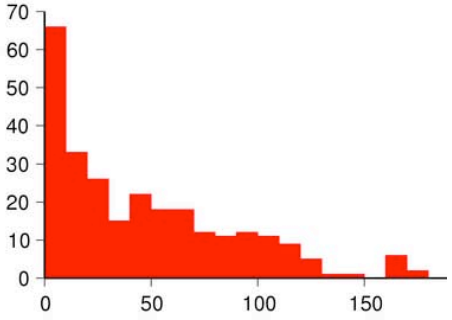
1970's

1980's

1990's

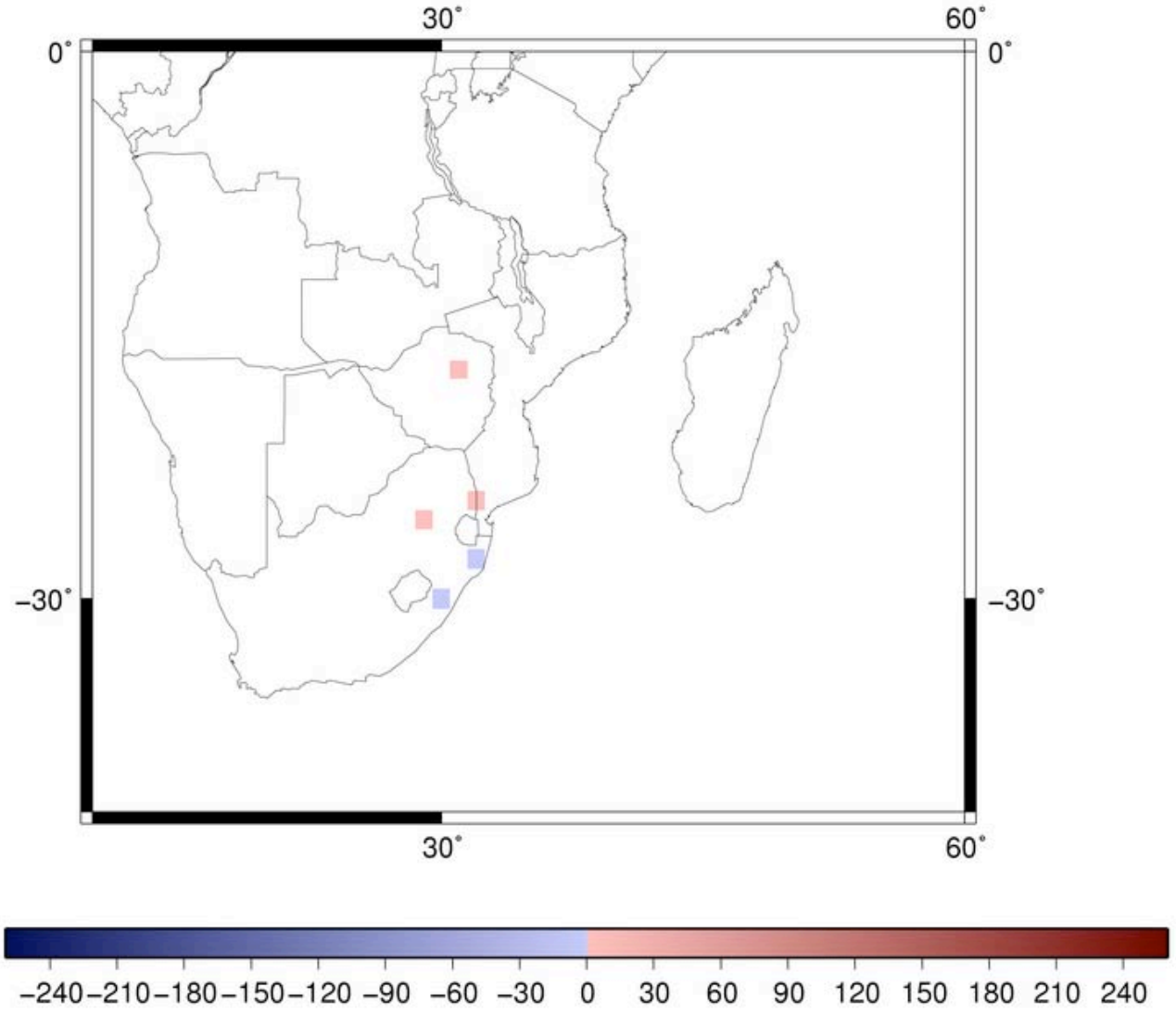



1950 through 2005



# Maize Heat Stress-Day Index—Africa

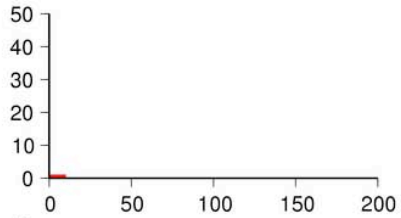
Linear Fit (trends) of the heat stress annually accumulated degrees



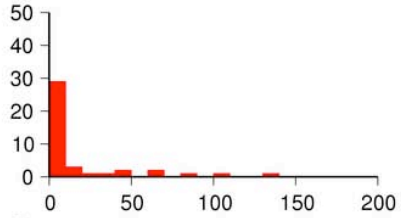
# Maize Heat Stress-Day Index—Africa

**Frequency of Heat Stress Index Annual Accumulated Degrees for period of anthesis**

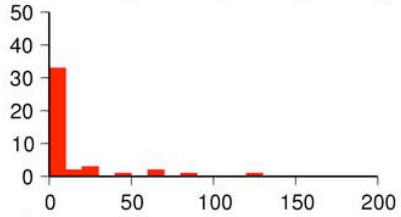
1950's



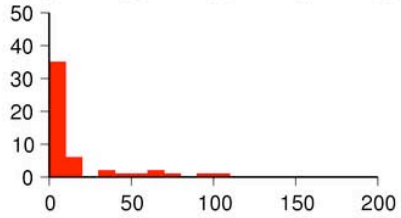

1960's



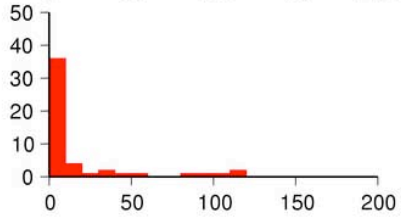

1970's



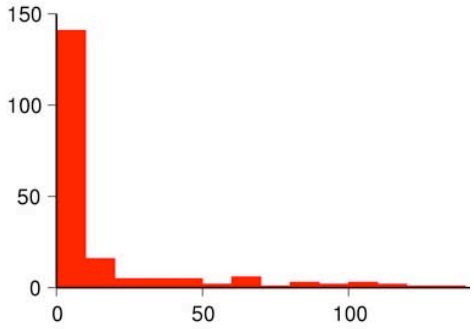

1980's




1990's

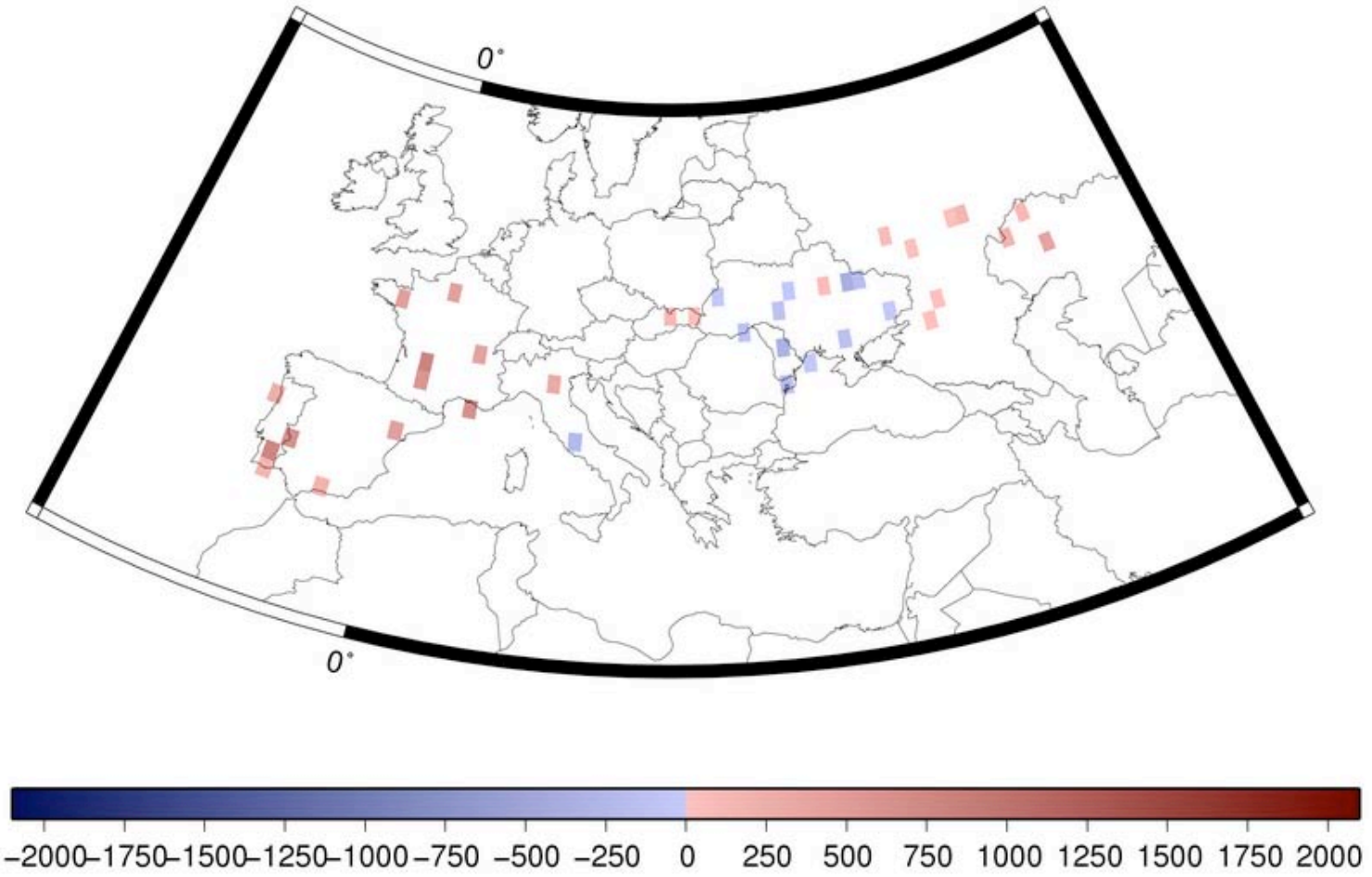



1950 through 2005



# Maize Growing Degree Days (GDD) Index—Eurasia

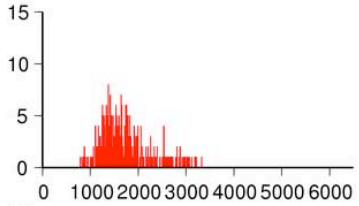
Linear Fit (trends) of the GDD annually accumulated degrees



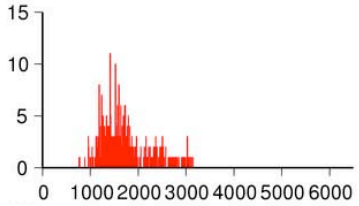
# Maize Growing Degree Days (GDD) Index—Eurasia

## Frequency of GDD Index Annual Accumulated Days

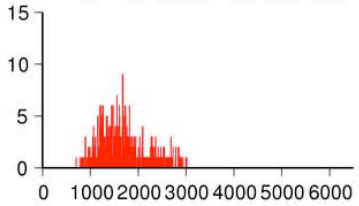
1950's



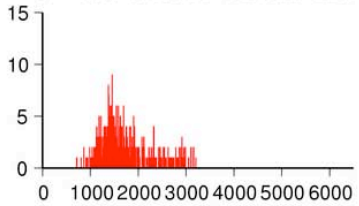

1960's



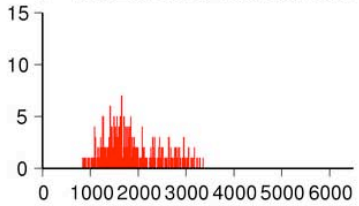

1970's



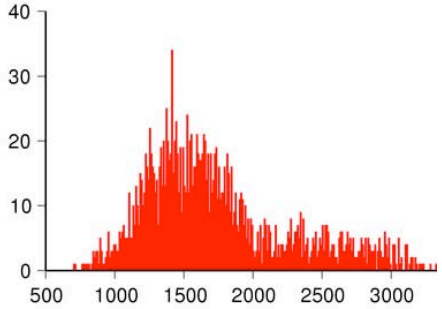

1980's




1990's

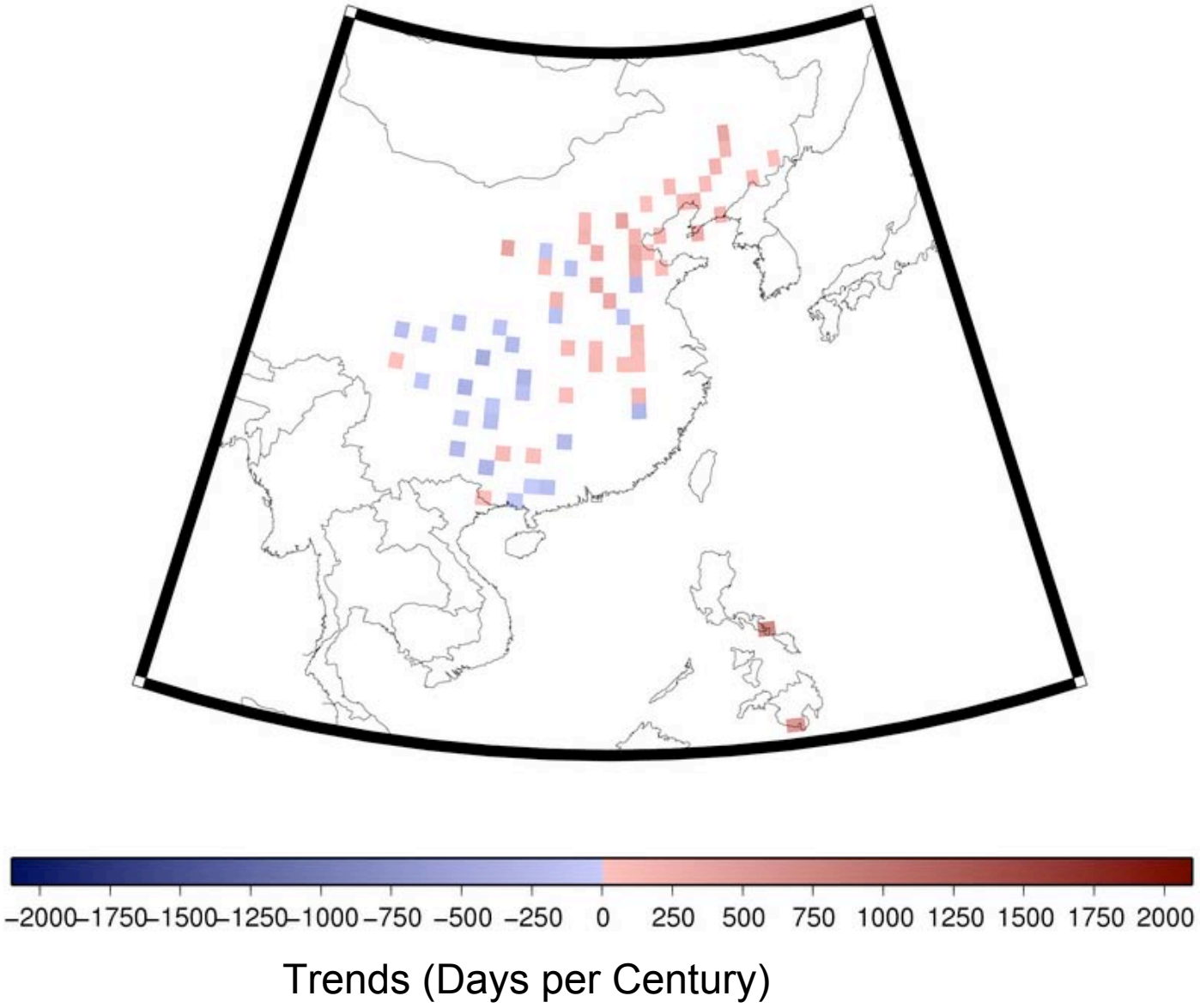



1950 through 2005



# Maize Growing Degree Days (GDD) Index—Asia

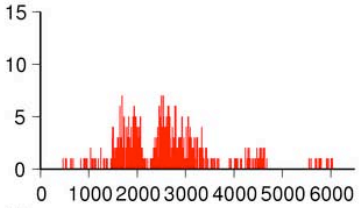
Linear Fit (trends) of the GDD annually accumulated degrees



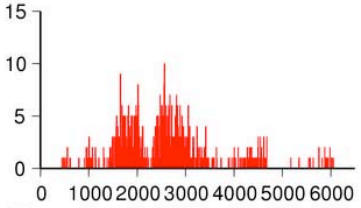
# Maize Growing Degree Days (GDD) Index—Asia

## Frequency of GDD Index Annual Accumulated Days

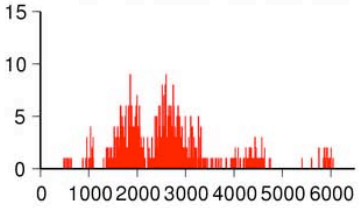
1950's



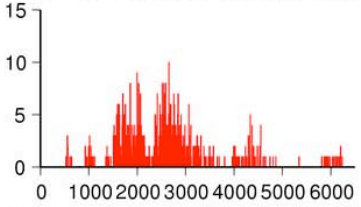

1960's



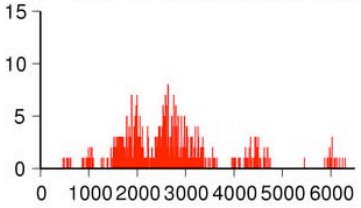

1970's



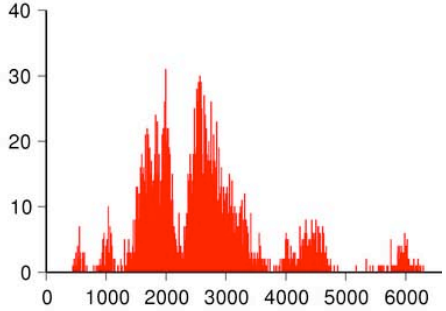

1980's




1990's

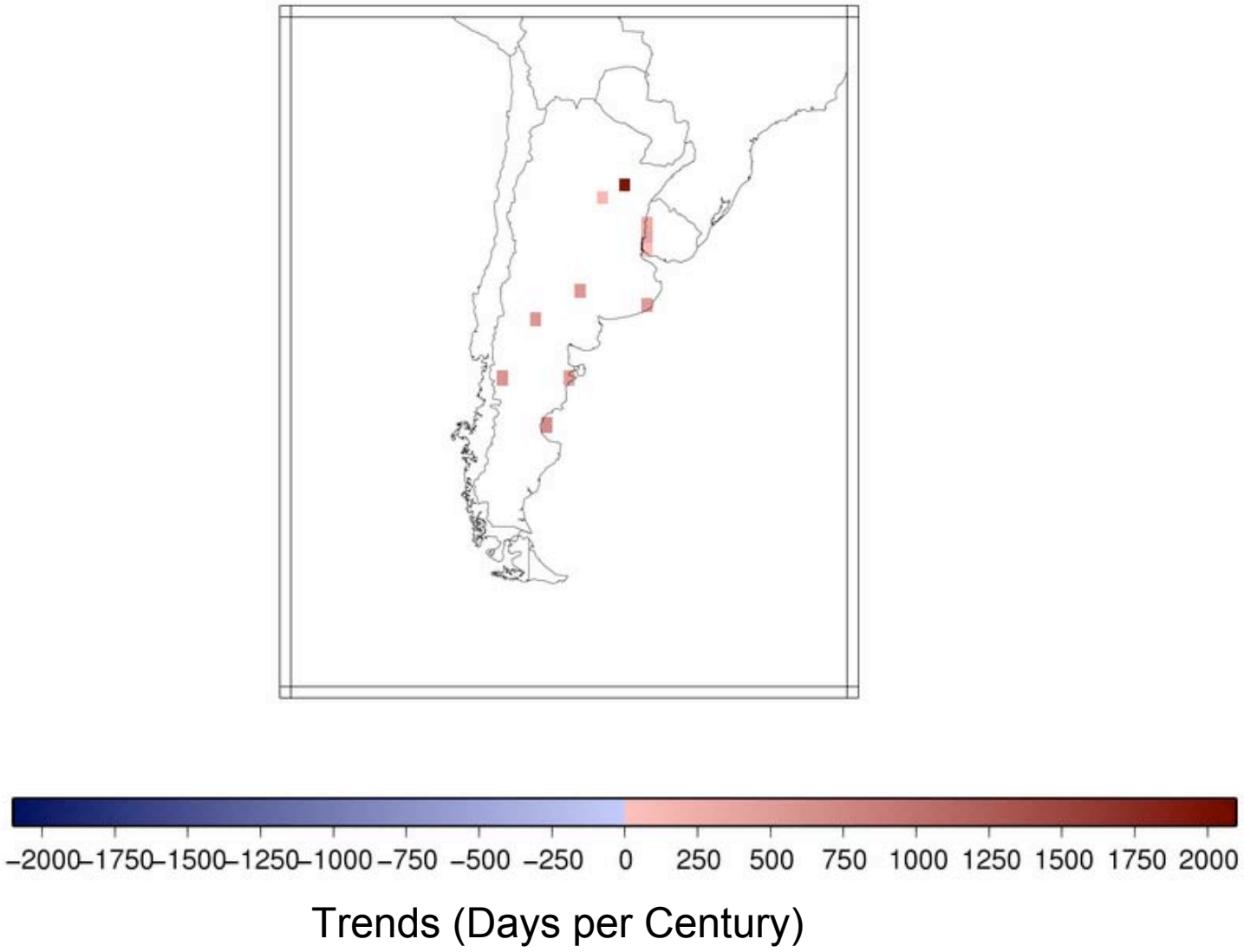



1950 through 2005



# Maize Growing Degree Days (GDD) Index—South America

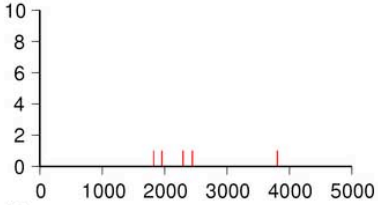
Linear Fit (trends) of the GDD annually accumulated degrees



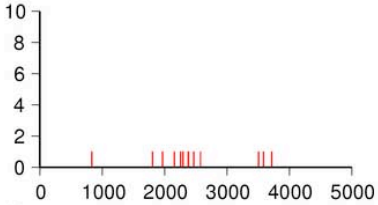
# Maize Growing Degree Days (GDD) Index—South America

## Frequency of GDD Index Annual Accumulated Days

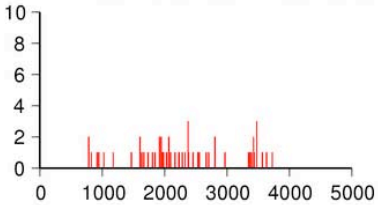
1950's



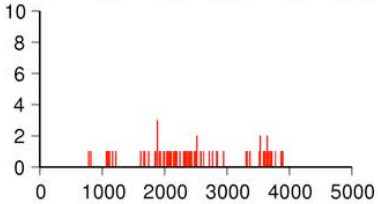

1960's



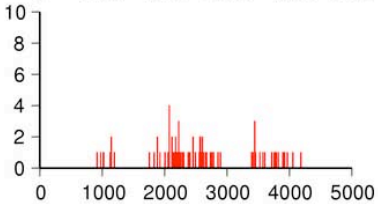

1970's



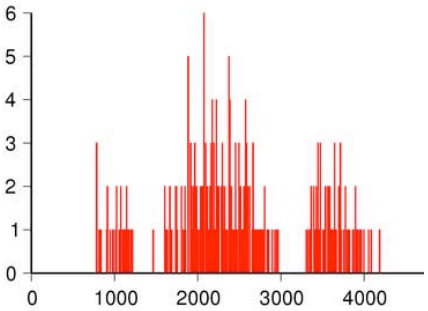

1980's




1990's

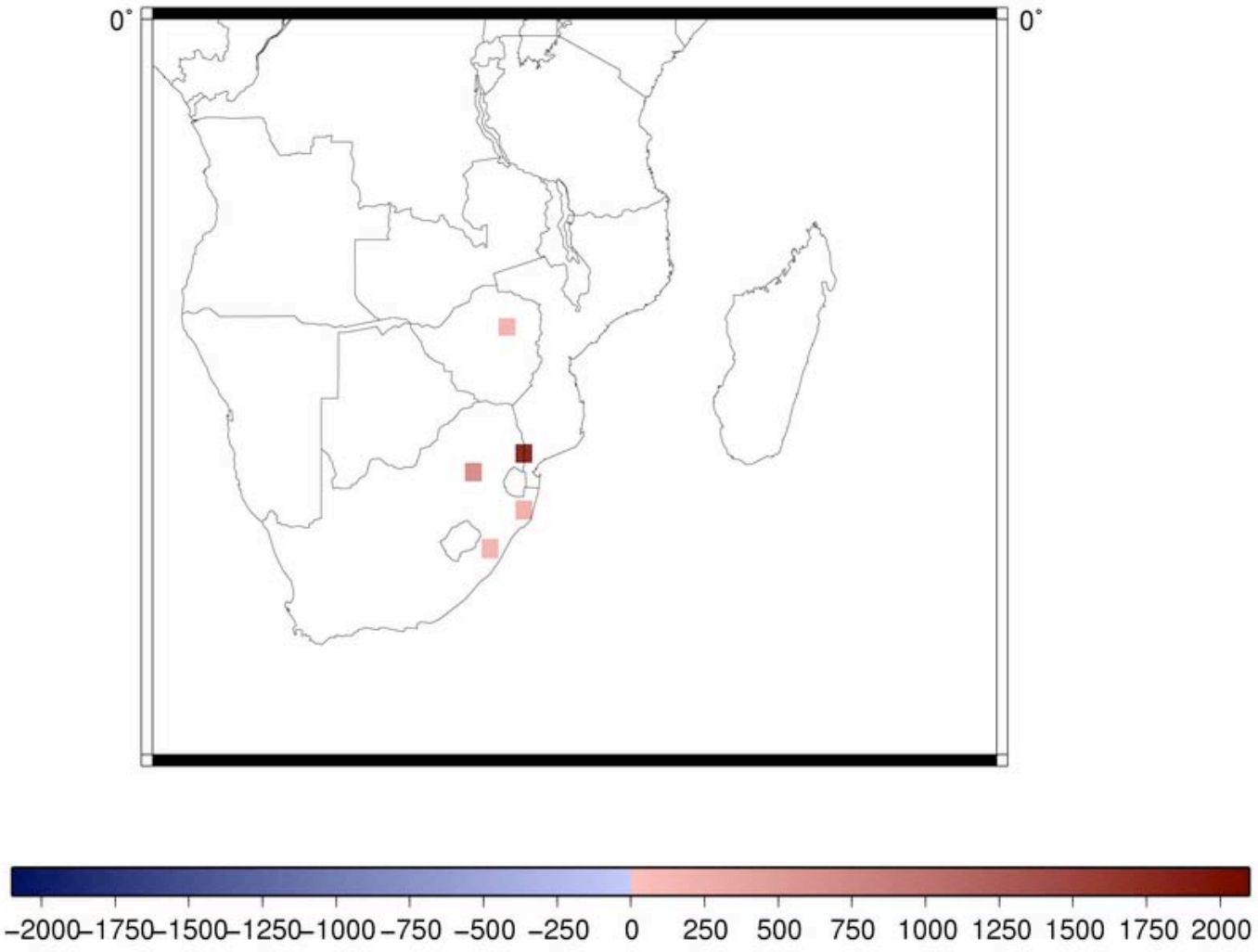



1950 through 2005



# Maize Growing Degree Days (GDD) Index—Africa

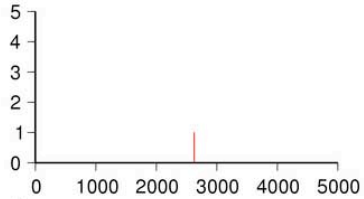
Linear Fit (trends) of the GDD annually accumulated degrees



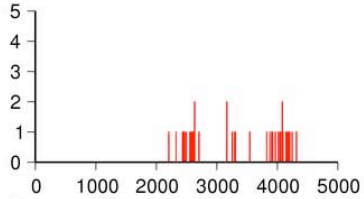
# Maize Growing Degree Days (GDD) Index—Africa

## Frequency of GDD Index Annual Accumulated Days

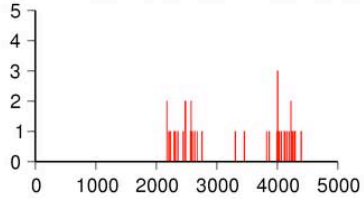
1950's



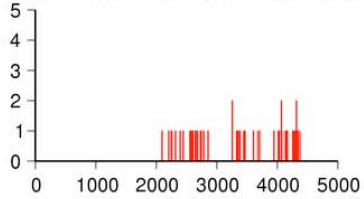

1960's



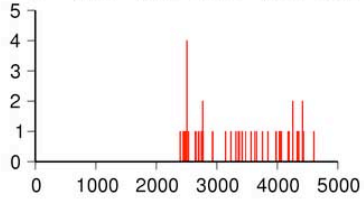

1970's



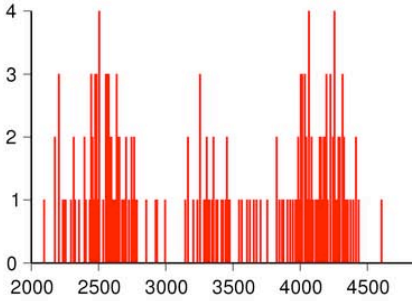

1980's




1990's

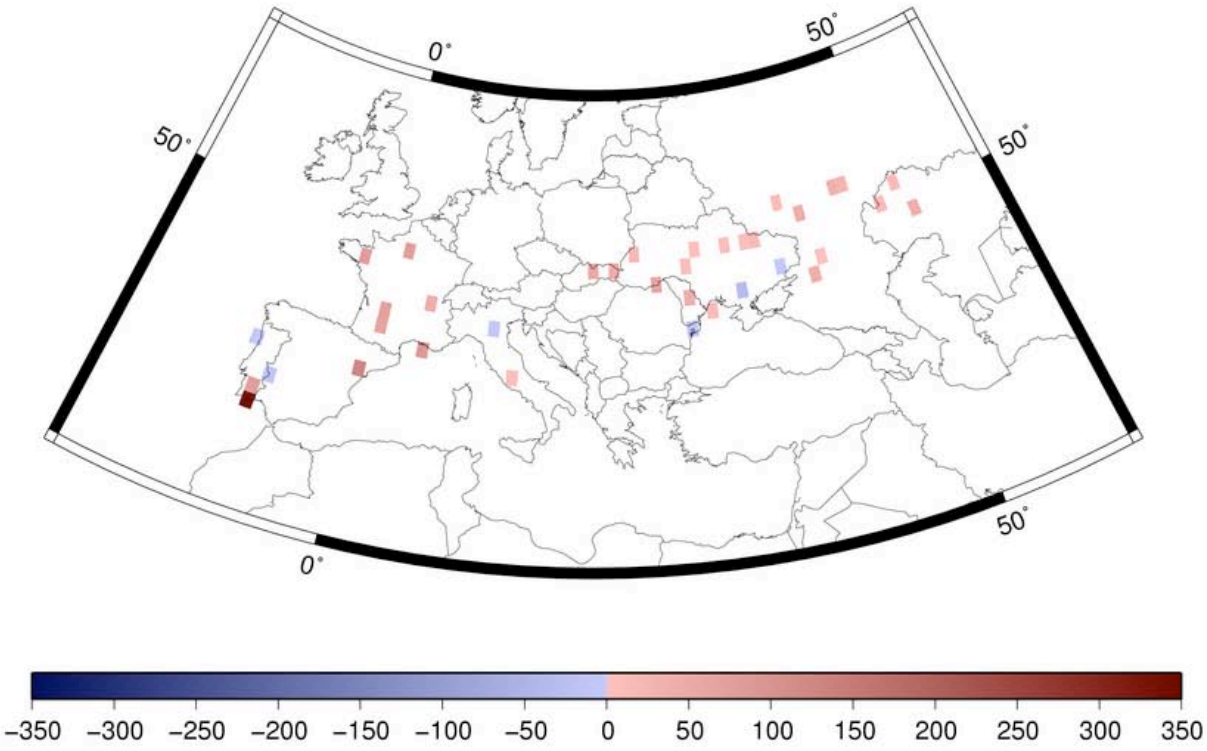



1950 through 2005



# Frost Free Period (FFP) Index (Eurasia)

Linear Fit (trends) of the FFP annually accumulated days

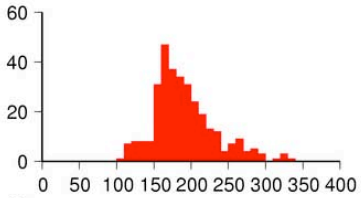



Trends (Days per Century)

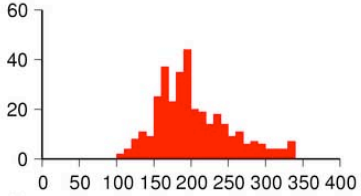
# Frost Free Period Index (Eurasia)

**Frequency of FFP Index Annual Accumulated Days**

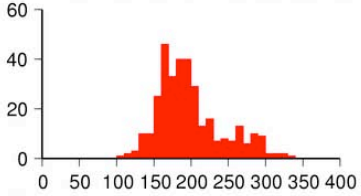
1950's



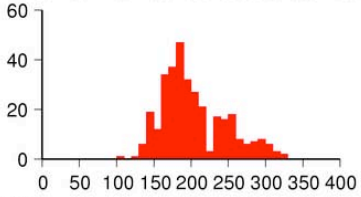

1960's



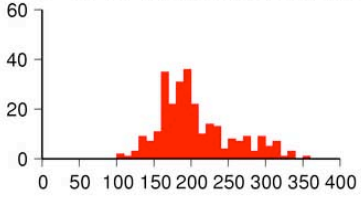

1970's



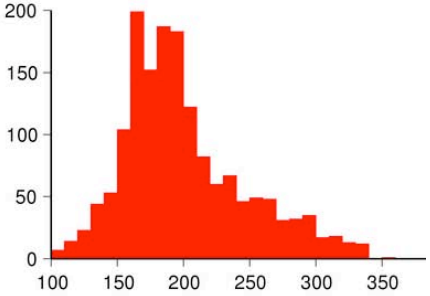

1980's




1990's

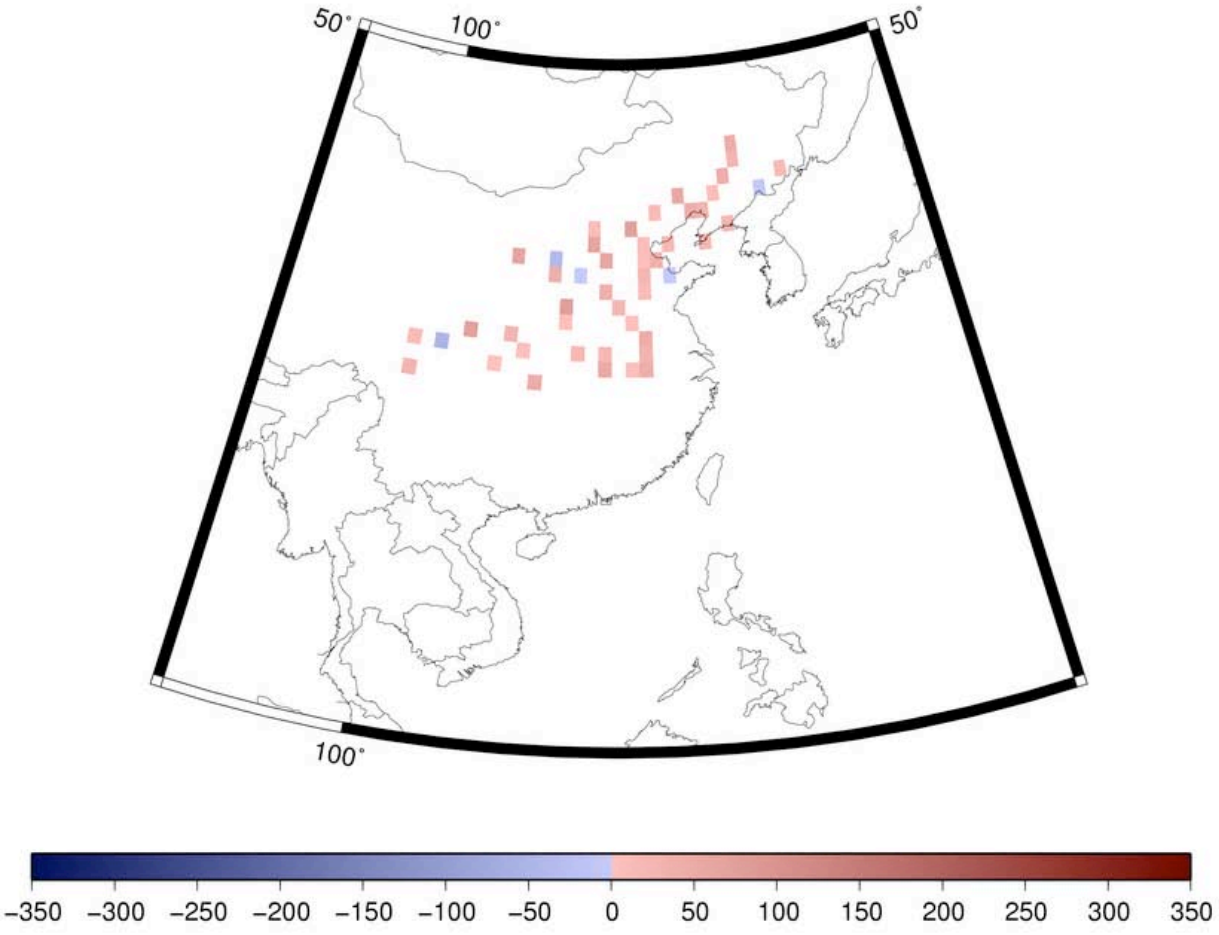



1950 through 2005



# Frost Free Period (FFP) Index (Asia)

Linear Fit (trends) of the FFP annually accumulated days

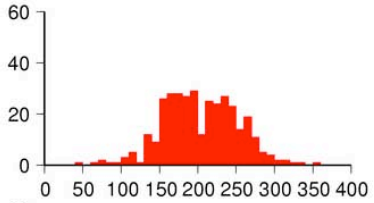



Trends (Days per Century)

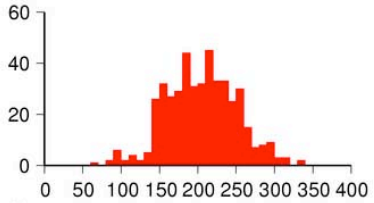
# Frost Free Period Index (Asia)

**Frequency of FFP Index Annual Accumulated Days**

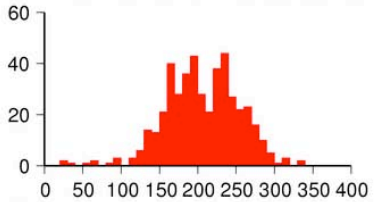
1950's



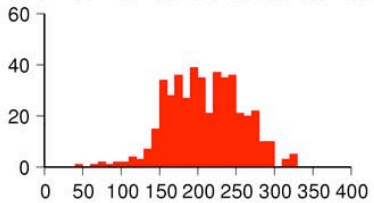

1960's



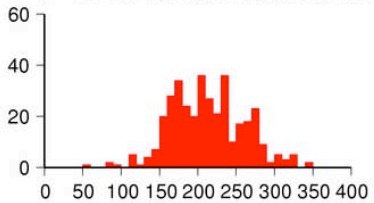

1970's



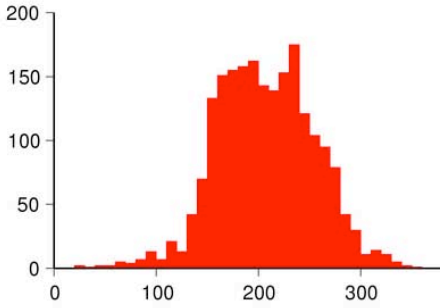

1980's




1990's




1950 through 2005



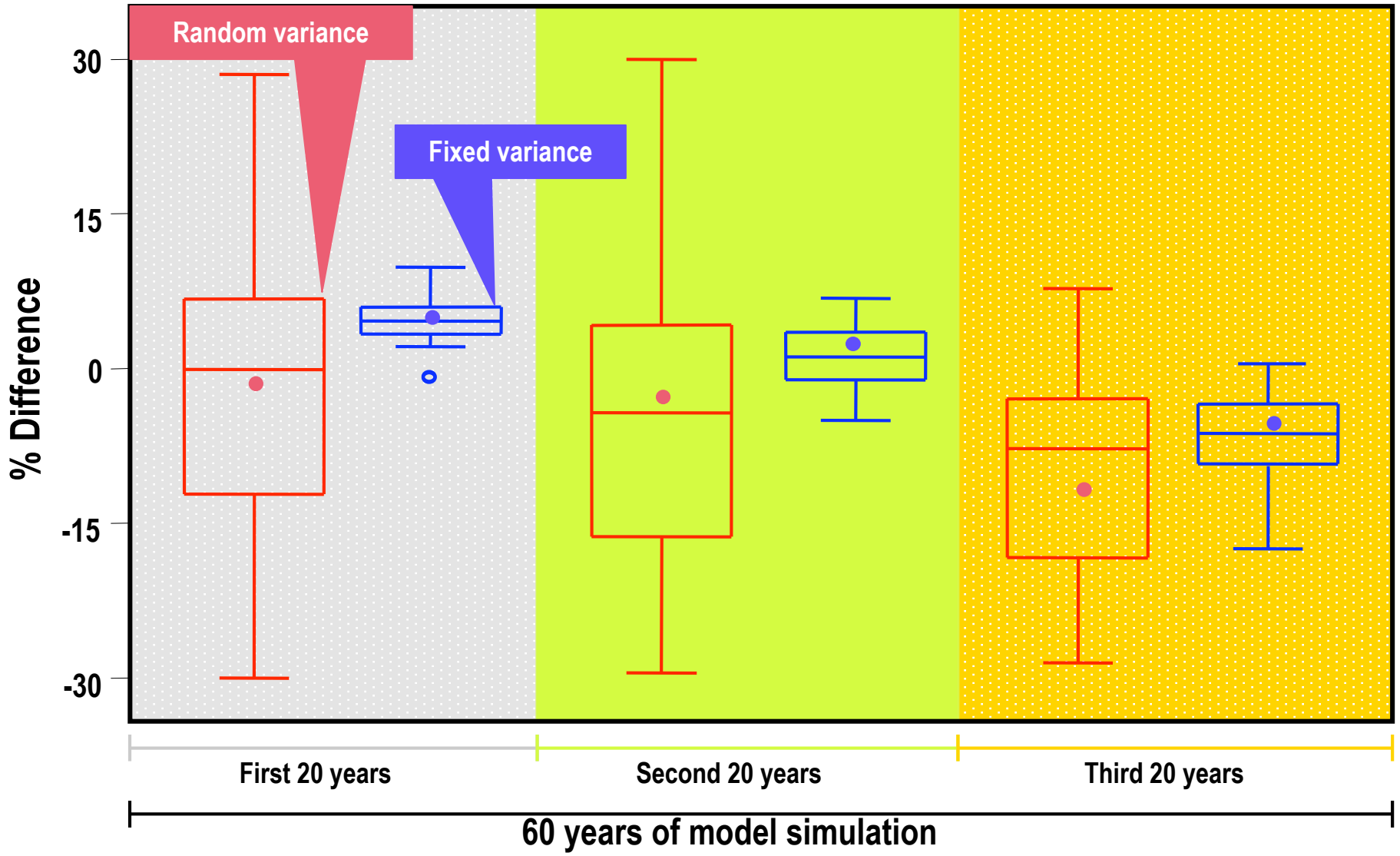
# Using Monte Carlo simulation

- Not widely practiced in impact analysis
- Simple first step is use in representing uncertainty of future climate variability in impact modeling
  - What happens when a range of artificially modified variances are sampled at different stages of transient climate change for input to a crop model?

    Vs.

    Use of one variance all the way through?

# Difference in Mean Corn Yields (% of 1960-1995 Baseline) to RegCM Climate with Random and Fixed Variance

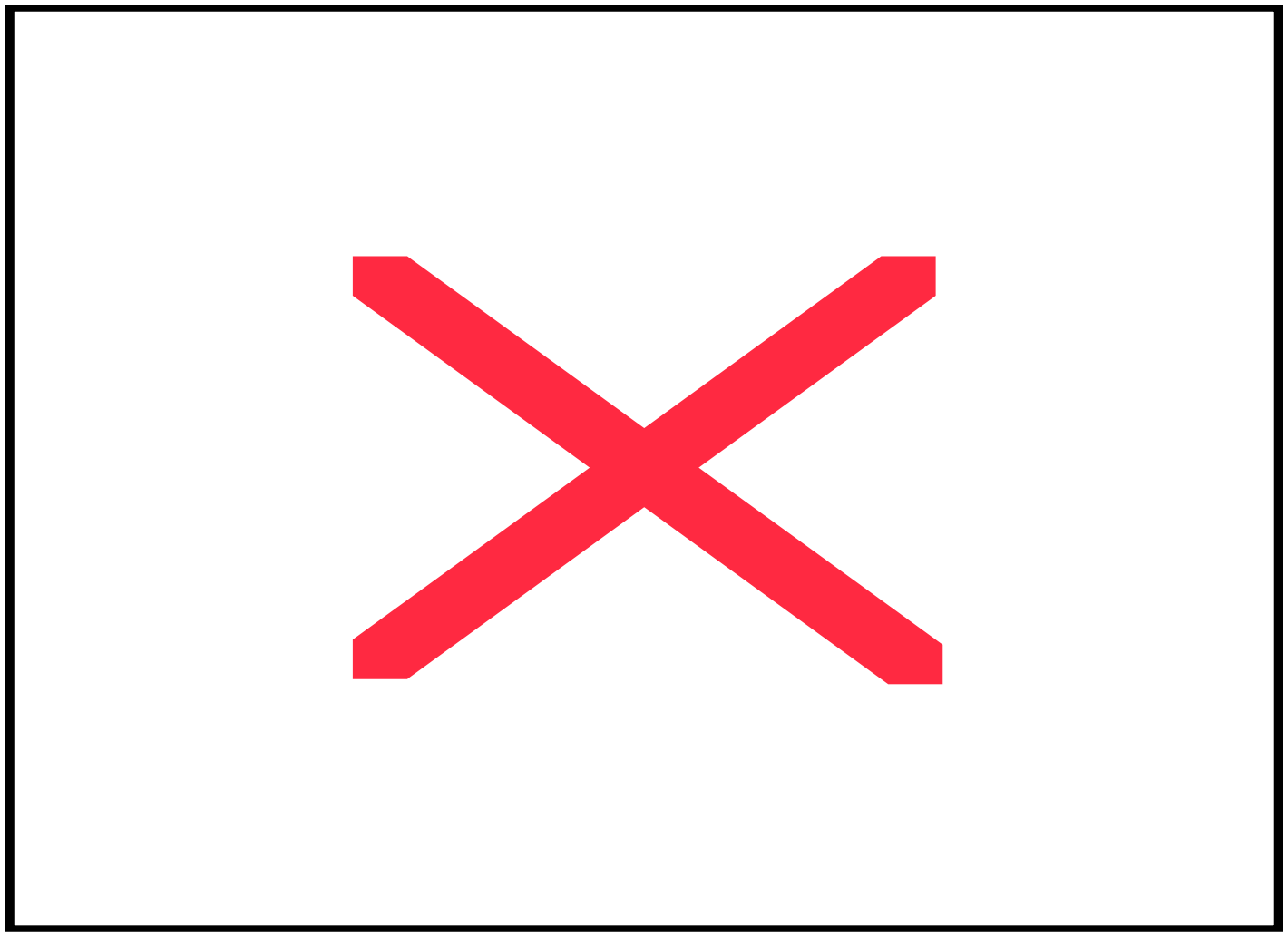


# Damage from the flood of 1993 in U.S. Dollars

| State | Agricultural Damages | Total Damages |
|---|---|---|
| Illinois | 166,501,898 | 752,341,452 |
| Iowa | 1,030,029,938 | 1,422,693,996 |
| Kansas | 855,849,448 | 1,067,841,569 |
| Minnesota | 698,041,346 | 997,582,279 |
| Missouri | 540,666,103 | 2,201,033,455 |
| Nebraska | 120,521,073 | 207,005,433 |
| North Dakota | 35,038,604 | 70,983,015 |
| South Dakota | 276,217,794 | 493,545,229 |
| Wisconsin | 133,835,068 | 287,499,684 |
| Total of Affected States | 3,852,701,272 | 7,500,536,112 |

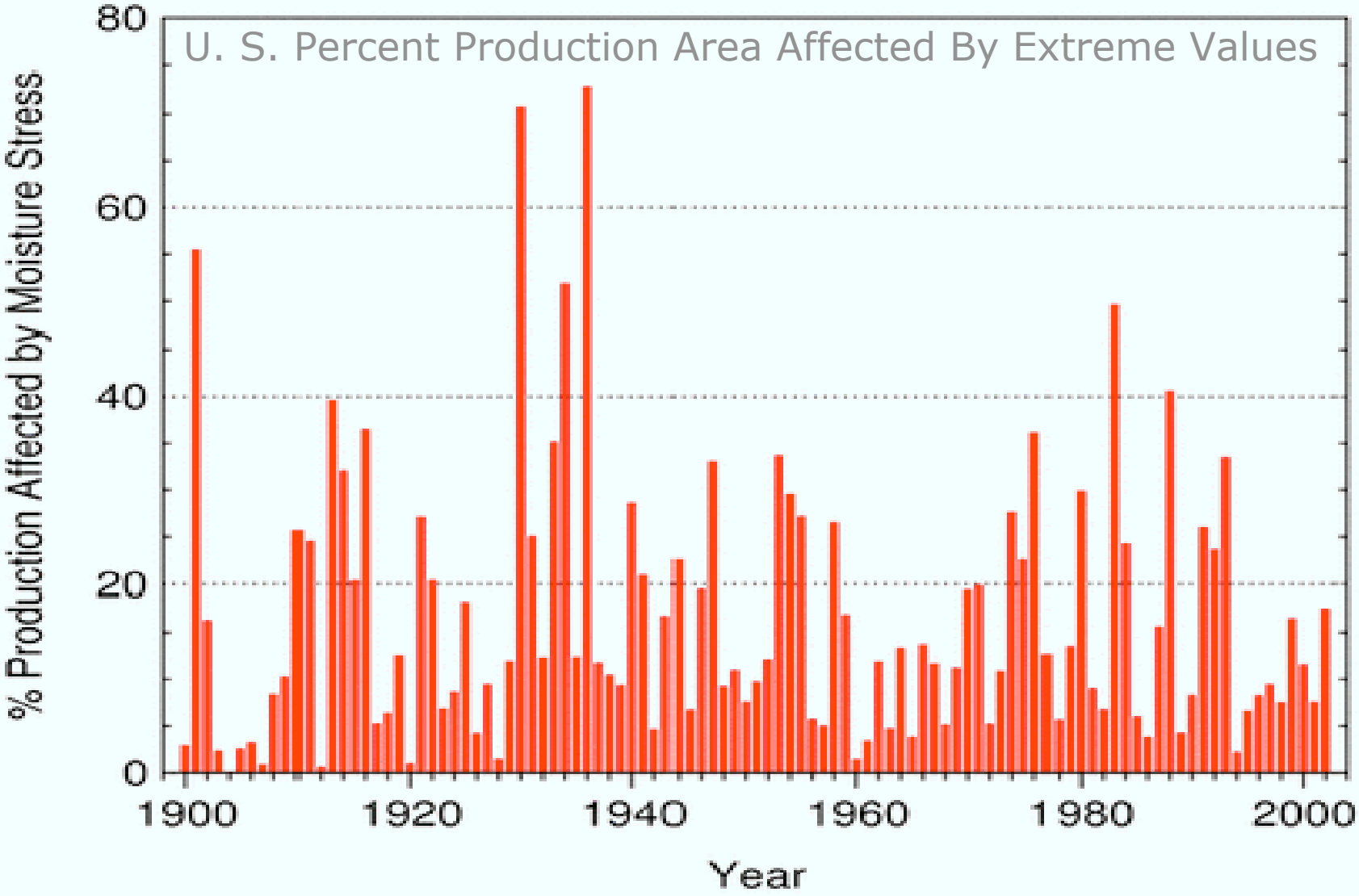
Source: http://www.wes.army.mil/el/flood/tabgifs.html

Region affected by the flood of 1993



# Soybean Moisture Stress Index

## 1900 - 2002

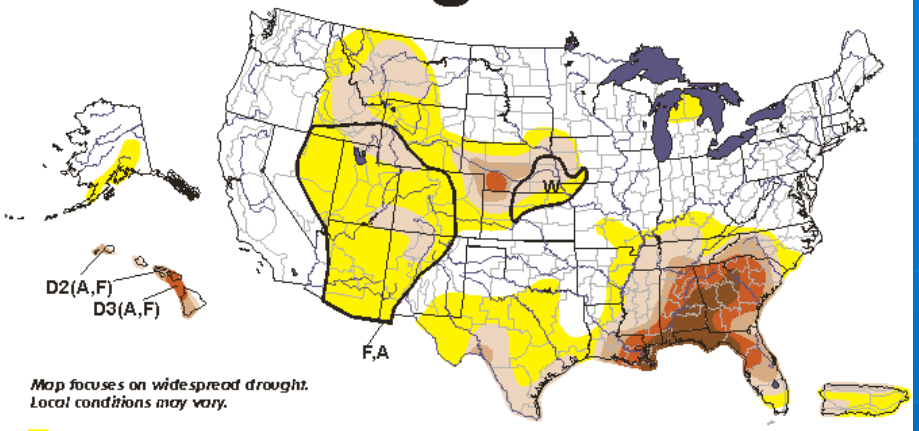



Based on Palmer Z-Index >= 5.0 and <= -2.0

National Climatic Data Center / NESDIS / NOAA

July 18, 2000 Valid 8 a.m. EDT

# U.S. Drought Monitor




*Map focuses on widespread drought.*
*Local conditions may vary.*

D0 Abnormally Dry
D1 Drought–First Stage
D2 Drought–Severe
D3 Drought–Extreme
D4 Drought–Exceptional
Delineates Overlapping Areas

Drought type: used only when impacts differ

A = Agriculture
W = Water
F = Wildfire danger

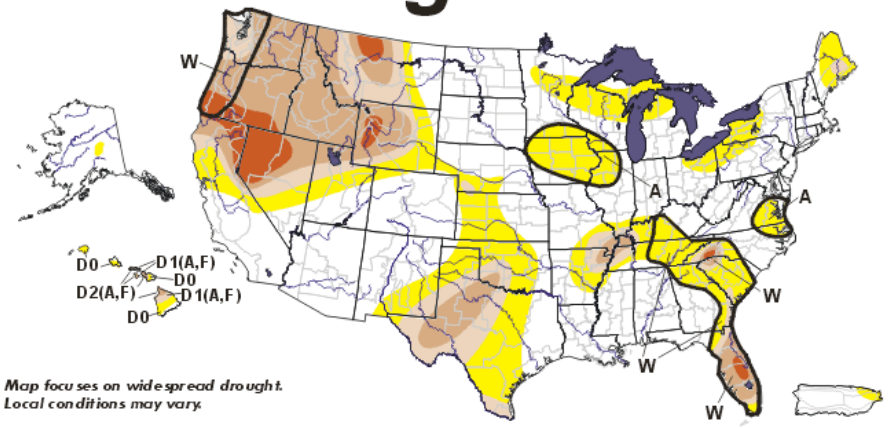
See accompanying text summary for forecast statements

USDA

*Released Thursday, July 20, 2000*

July 17, 2001 Valid 8 a.m. EDT

# U.S. Drought Monitor




*Map focuses on widespread drought.*
*Local conditions may vary.*

D0 Abnormally Dry
D1 Drought–Moderate
D2 Drought–Severe
D3 Drought–Extreme
D4 Drought–Exceptional
Delineates Overlapping Areas

Drought Impact Types:
A = Agriculture
W = Water (Hydrological)
F = Fire danger (Wildfires)
(No type = All 3 impacts)

See accompanying text summary for forecast statements
http://enso.unl.edu/monitor/monitor.html

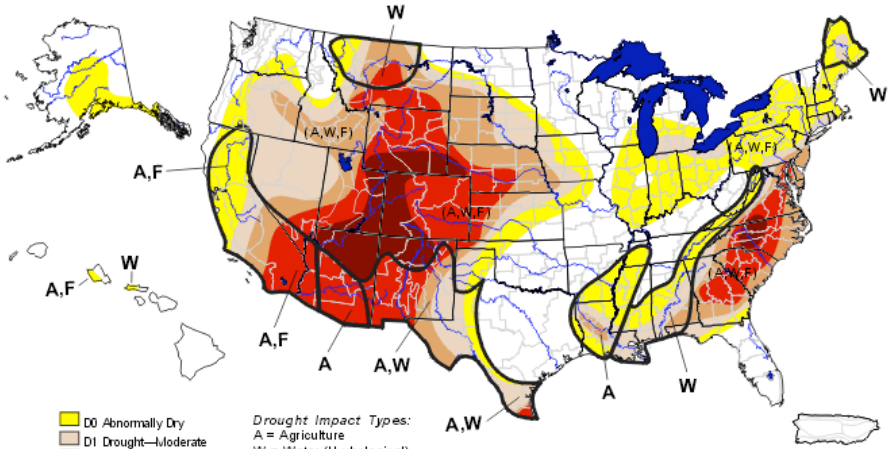
USDA

*Released Thursday, July 19, 2001*

**Author:** Brad Rippey

# U.S. Drought Monitor

July 23, 2002
Valid 8 a.m. EDT




D0 Abnormally Dry
D1 Drought—Moderate
D2 Drought—Severe
D3 Drought—Extreme
D4 Drought—Exceptional

*Drought Impact Types:*
A = Agriculture
W = Water (Hydrological)
F = Fire danger (Wildfires)
Delineates dominant impacts
(No type = All 3 impacts)

*The Drought Monitor focuses on broad-scale conditions. Local conditions may vary.* See accompanying text summary for forecast statements.

**http://drought.unl.edu/dm**

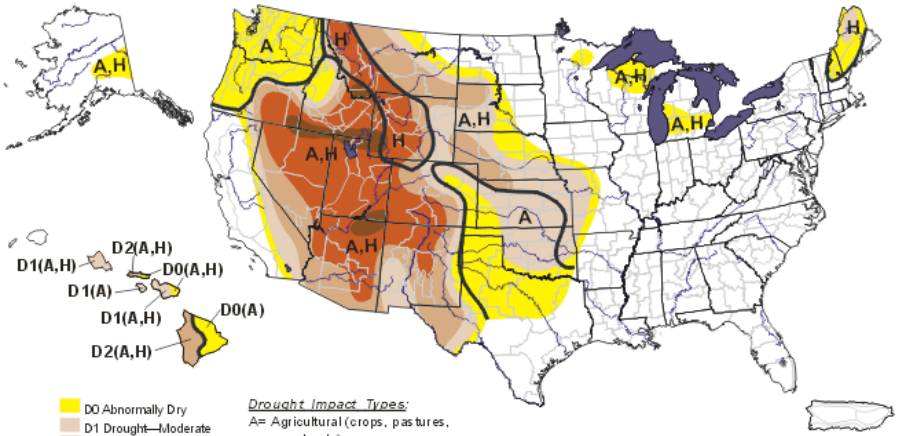
USDA

*Released Thursday, July 25, 2002*

**Author:** Brad Rippey, USDA

# U.S. Drought Monitor

July 22, 2003
Valid 8 a.m. EDT




D0 Abnormally Dry
D1 Drought—Moderate
D2 Drought—Severe
D3 Drought—Extreme
D4 Drought—Exceptional

*Drought Impact Types:*
A= Agricultural (crops, pastures, grasslands)
H= Hydrological (water)
No type = both impacts
Delineates dominant impacts

*The Drought Monitor focuses on broad-scale conditions. Local conditions may vary.* See accompanying text summary for forecast statements.

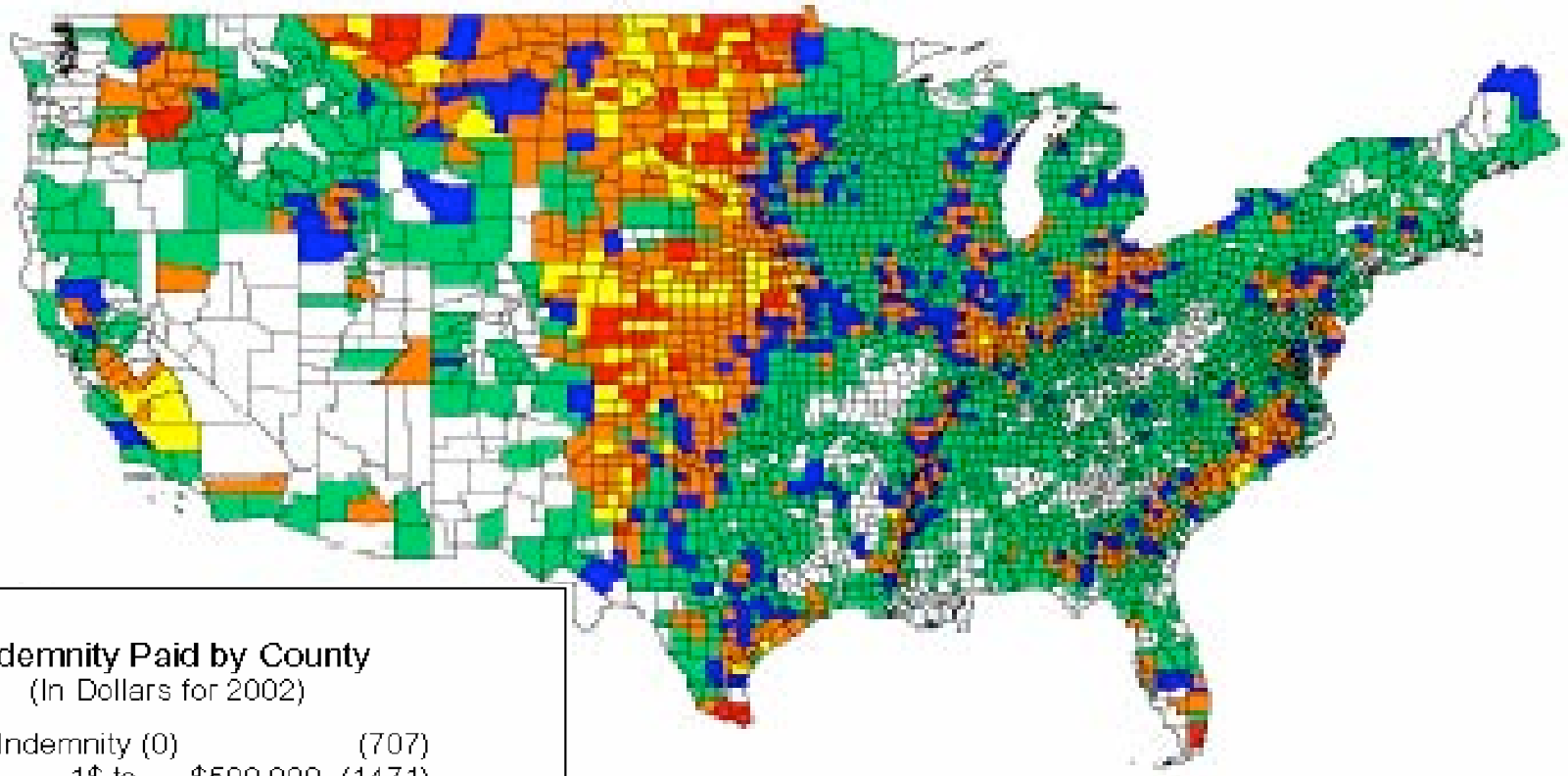
**http://drought.unl.edu/dm**

USDA

*Released Thursday, July 24, 2003*

**Author:** Brad Rippey, USDA

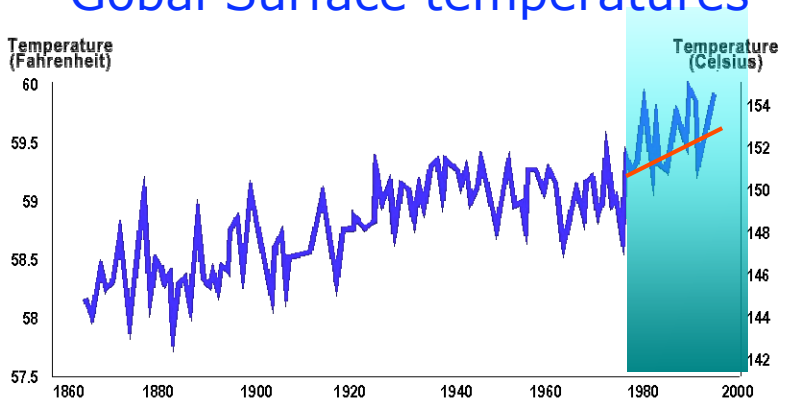
# 2002 RMA Crop Indemnities
# (As of 01/13/2003)

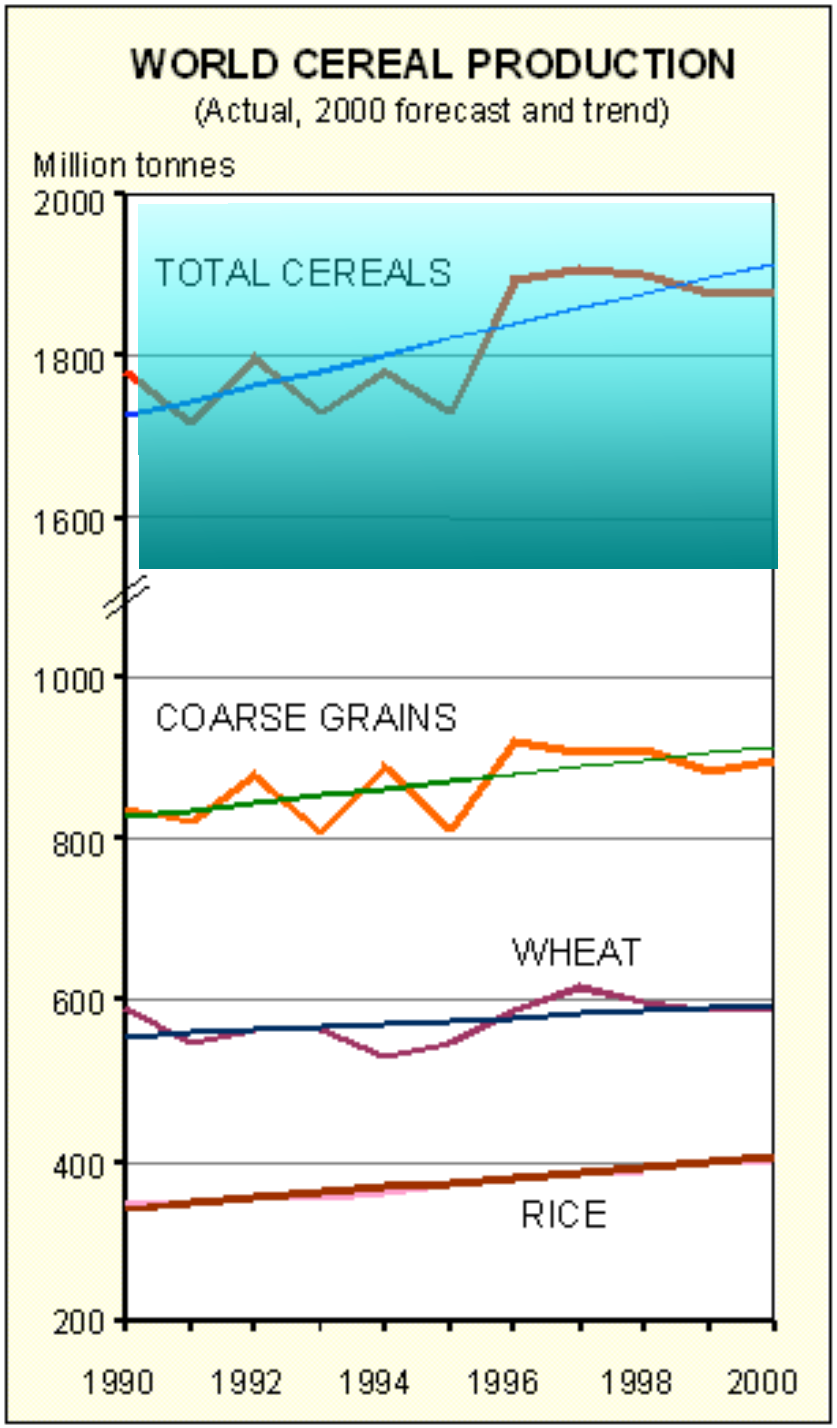


Indemnity Paid by County
(In Dollars for 2002)

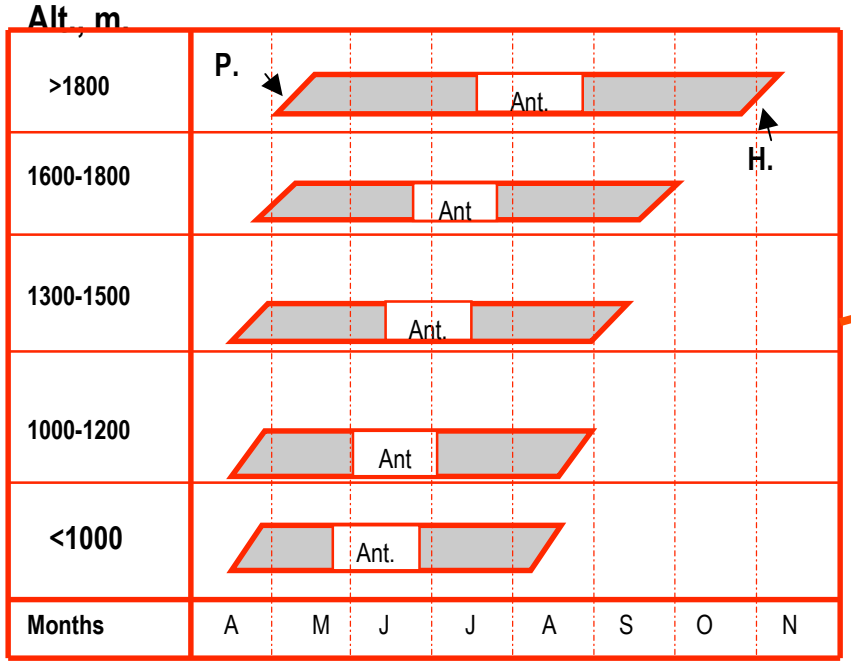
| | |
|---|---|
| No Indemnity (0) | (707) |
| 1$ to $500,000 | (1471) |
| $500,000 to $1,000,000 | (333) |
| $1,000,000 to $5,000,000 | (543) |
| $5,000,000 to $10,000,000 | (114) |
| over $10,000,000 | (51) |

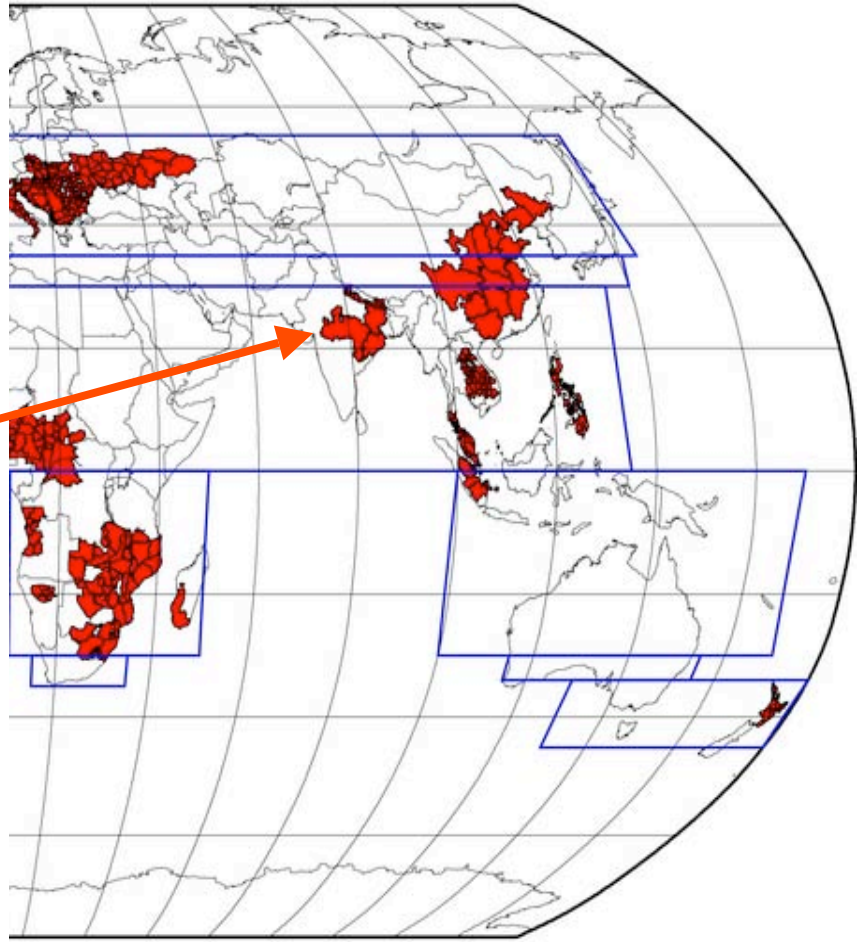
## Gobal Surface temperatures



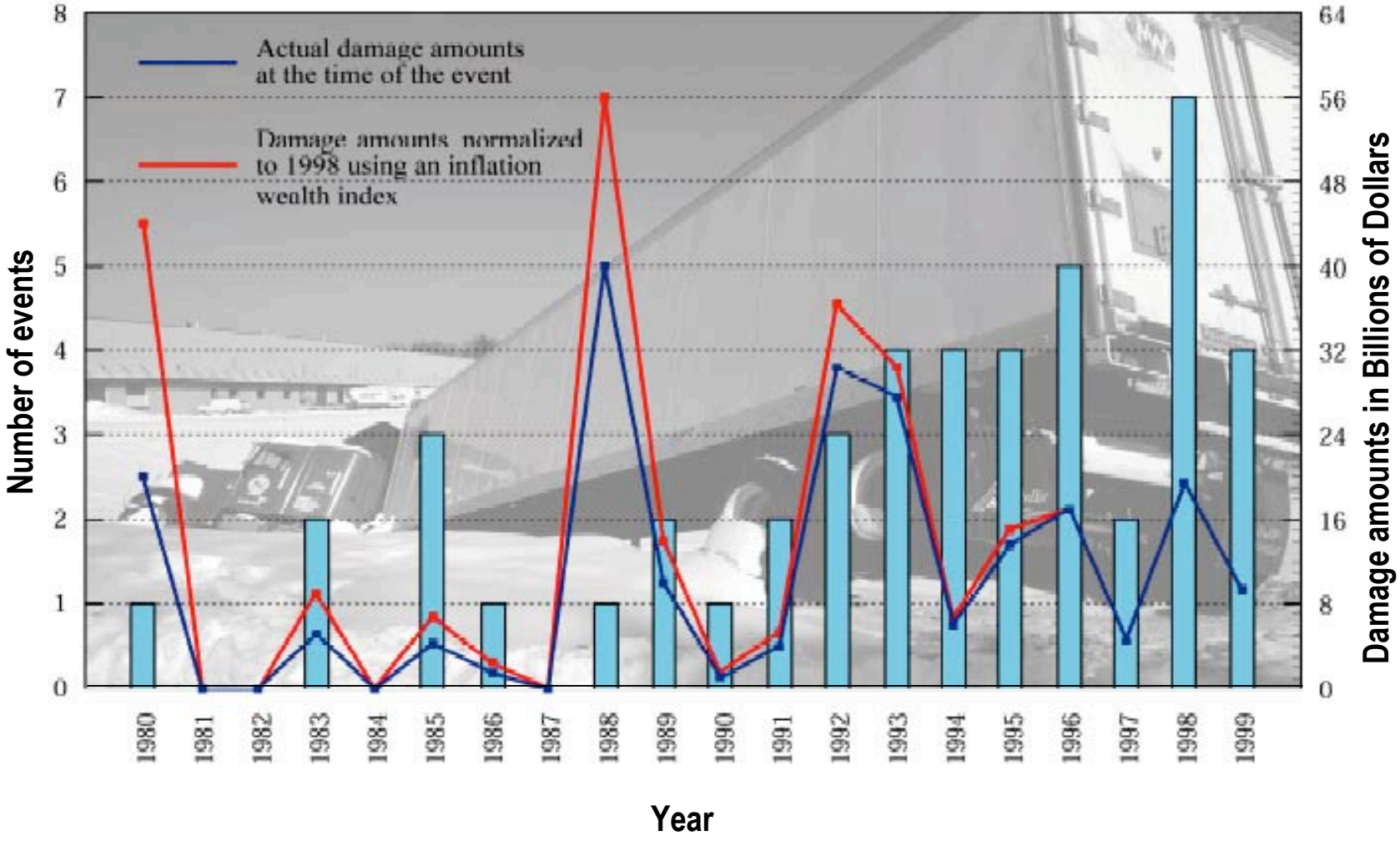



# Average anthesis period by altitude in the Hindu-Kush Himalayan Region of South Asia



# $ Damage estimates disaster due to extreme events:




Source: http://lwf.ncdc.noaa.gov/oa/reports/billion/new-paper2x.PDF