

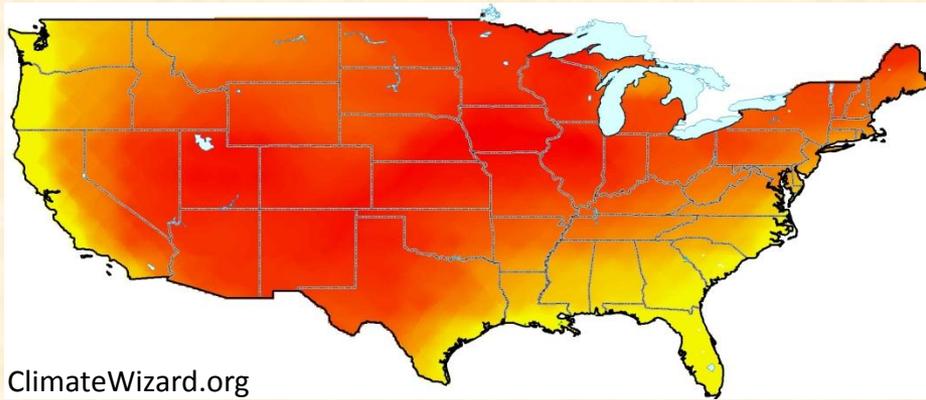


Predicting the effects of climate change on agricultural pest incidence: How secure is our food supply?

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Climate Change!



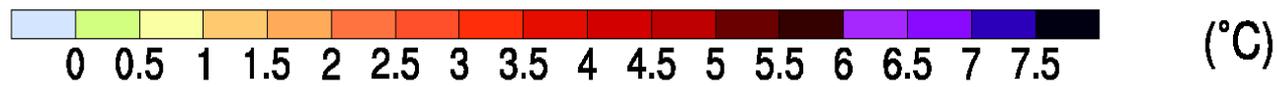
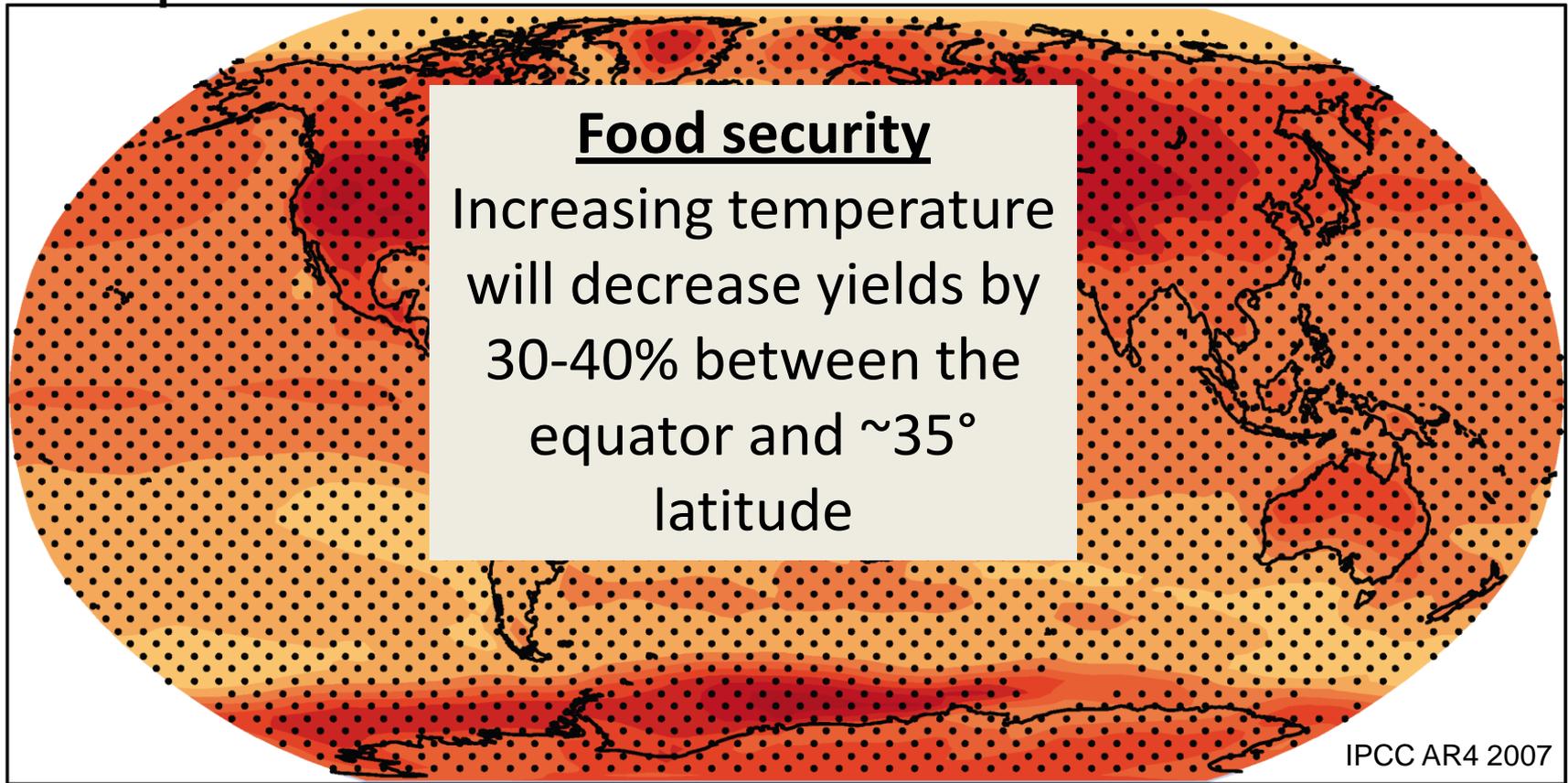
- Global warming
- Rising sea levels
- Changing precipitation patterns: droughts and floods
- Increased intensity of storms



- Shrinking glaciers
- Loss of biodiversity
- Decreased food security



Projected June, July, August average surface temperature change:
“2080-2099” minus “1980-1999”



Average of 21 climate models forced by Scenario A1B. Multiply by ~1.2 for A2 and ~0.66 for B1



... but what about pests?



The global impact of pests

- Currently
 - 3.7 billion acres of cropland
 - In 2008, ~2.5 billion tons of maize, rice and wheat were produced
 - Yield loss caused by animal pests ranges from 8 – 15%
- 2050? 2100?

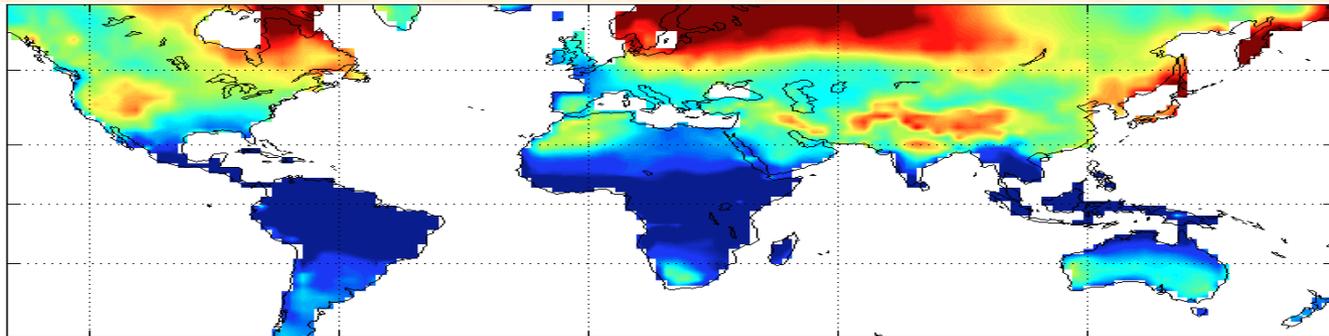


Today's Story



From simple to complex systems

- Simple system: Sunflower stem weevil phenology
- Complex system: Russian wheat aphid incidence
- Global pest pressure models



Sunflower stem weevil

Cylindrocopturus adspersus (LeConte)
(Coleoptera: Curculionidae)



Sunflower stem weevil lifecycle

- Females deposit eggs on the sunflower stalk
- Larvae move into the stalks
- Mature larvae overwinter in the stalk residue
- Pupate in the stalk residue
- Emerge from the stalk residue in the spring or summer
- Adults mate and oviposit

Sunflower stem weevil control

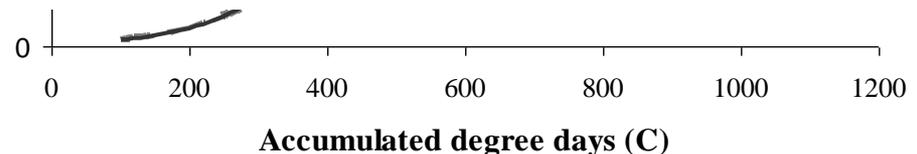
- Pesticide applications timed to occur after emergence
- Alter planting date – poor oviposition sites



Defining and calculating degree days:

- Degree days are units of heat used to measure development or growth
- Accumulated degree days are calculated as:

$$\sum (\text{Daily Max Temp} + \text{Daily Min Temp}) / 2 - \text{Temp threshold}$$



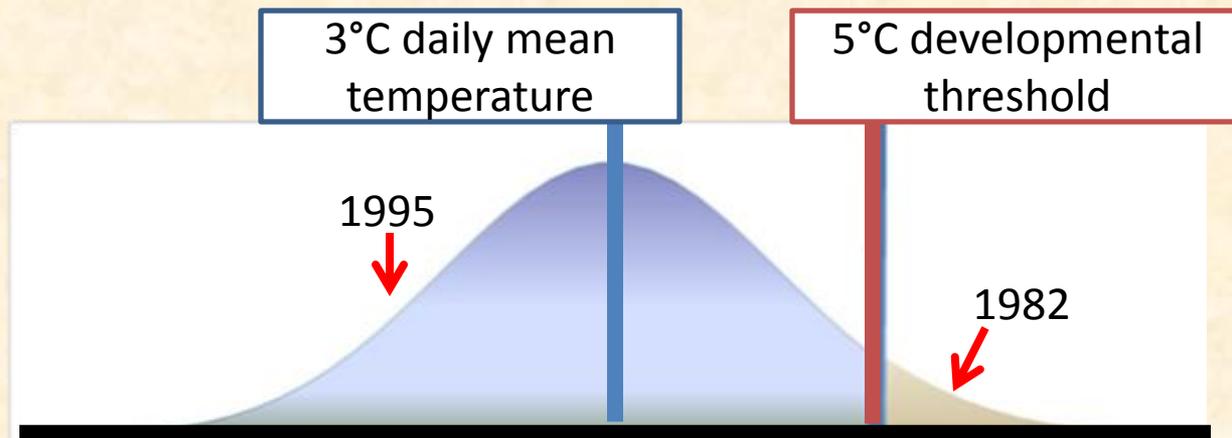
Accumulated degree days (C)

Building a spatially-explicit emergence model

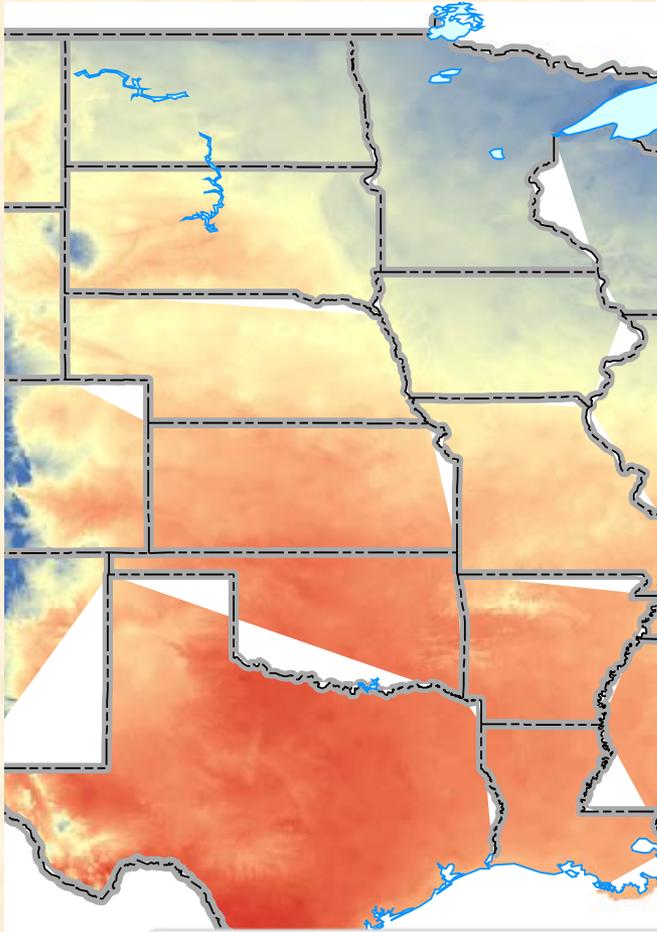
- Use climatic averages and climate simulation averages to obtain measurements for mean daily temperature
- Mean daily temperature – Developmental threshold = Degree days

Learning moment! (this would have resulted in substantial errors)

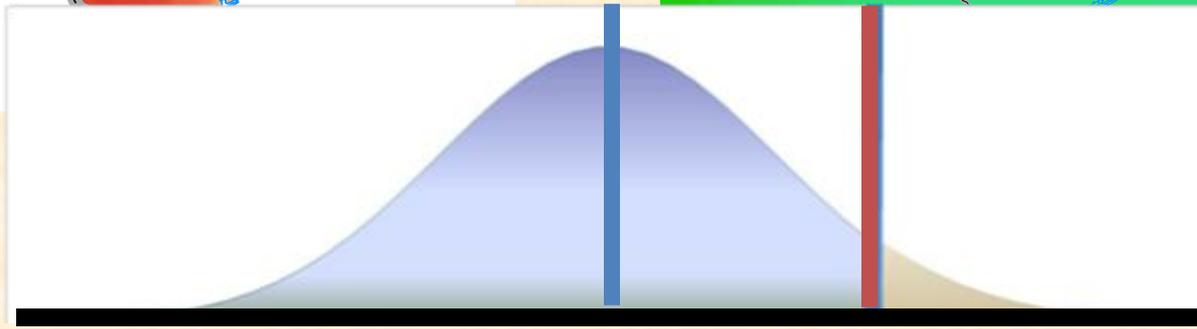
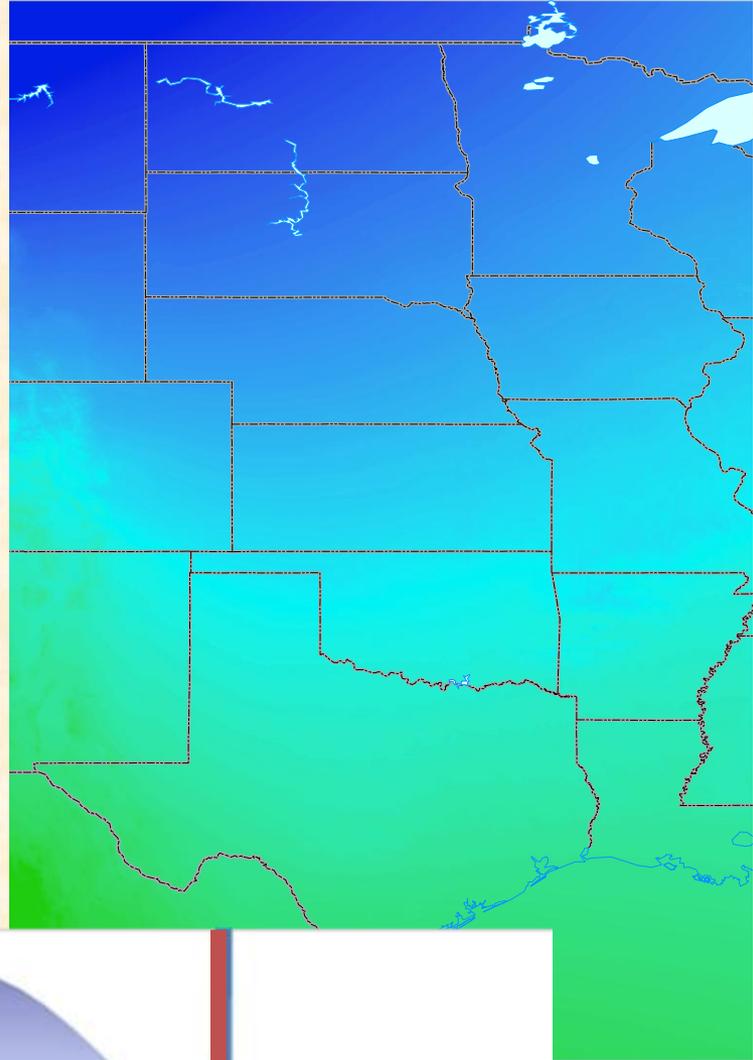
Why?



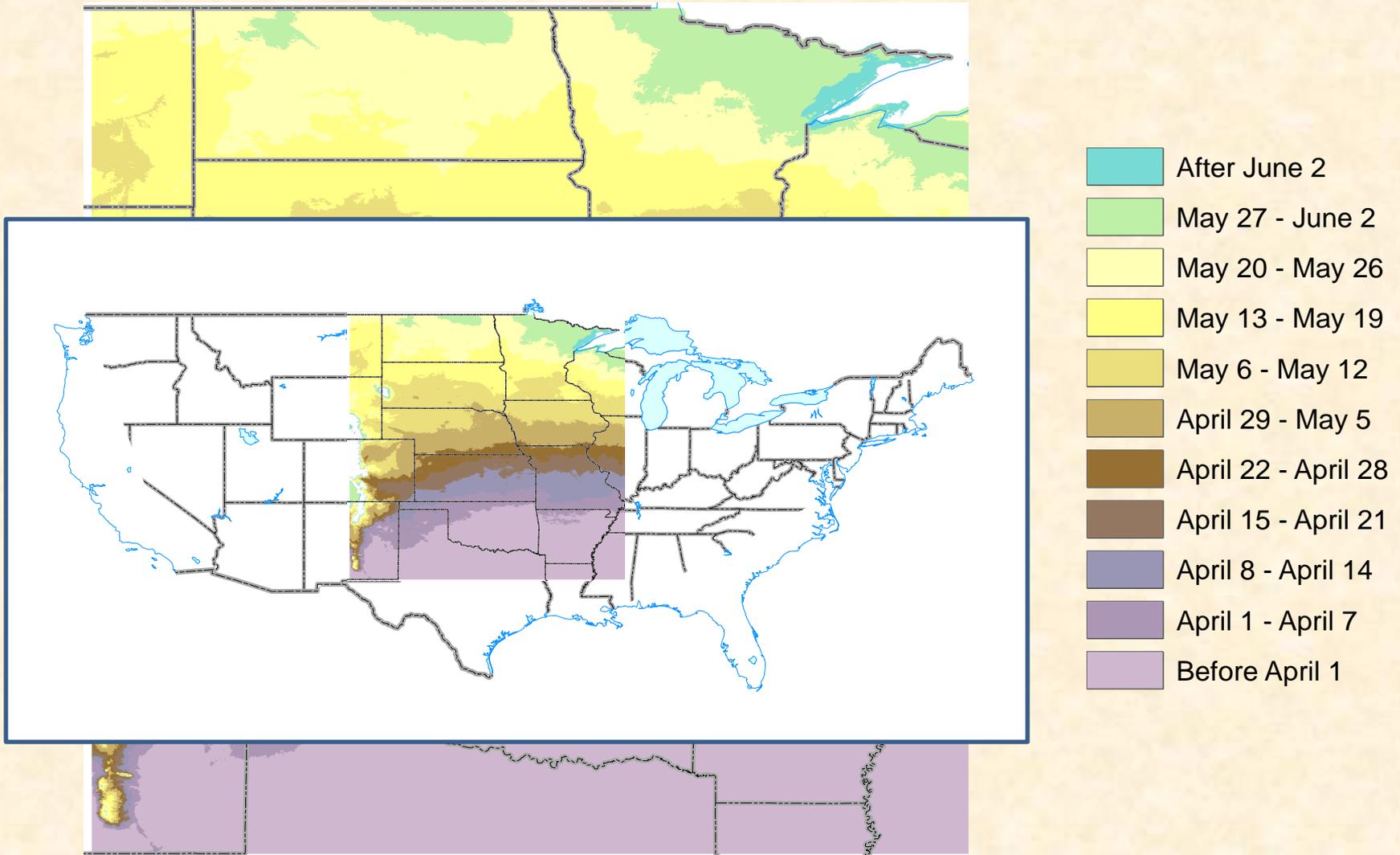
Mean temperature



Temperature variation

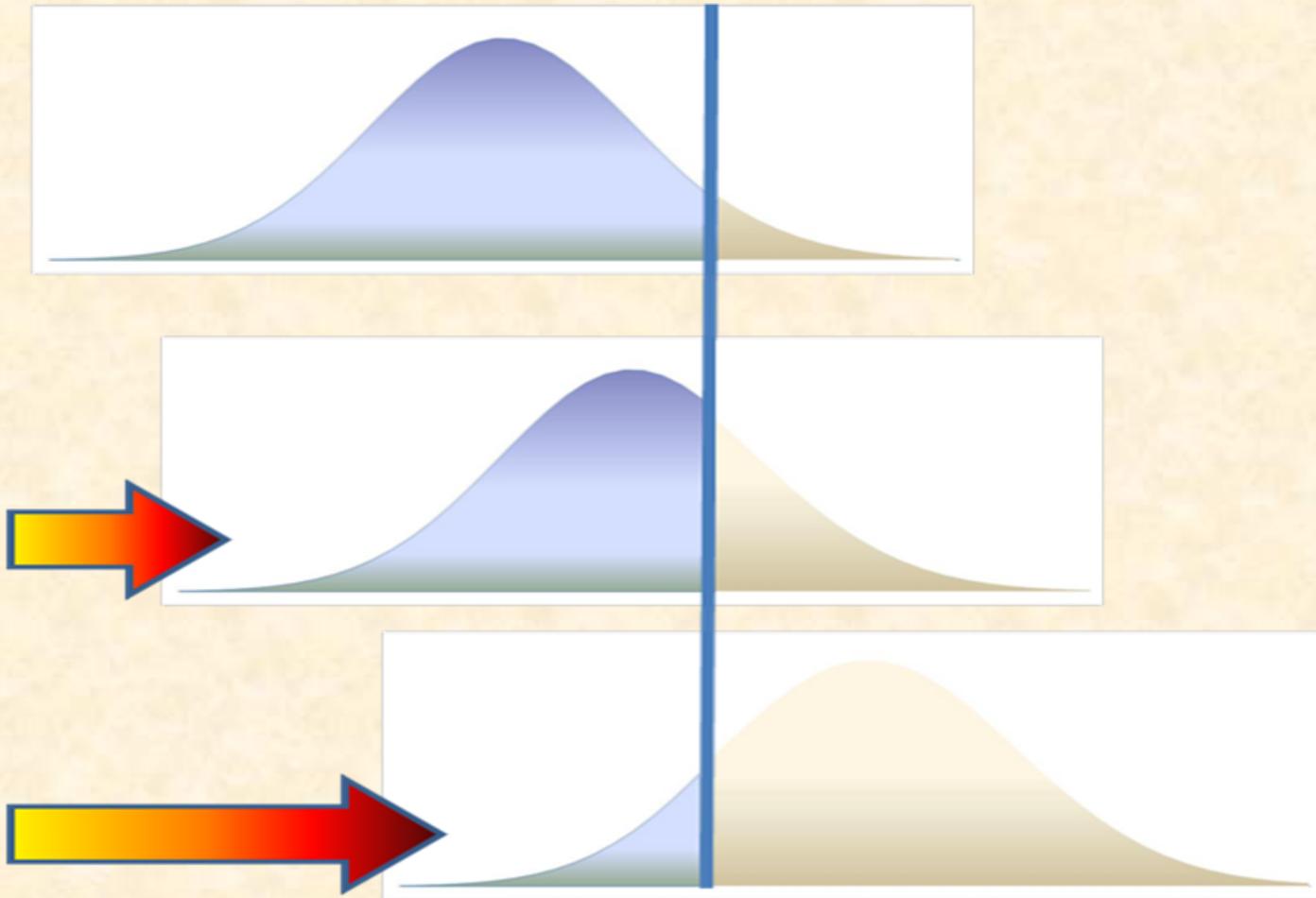


Modeling the effective start date of the Sunflower stem weevil's emergence using weather data from 1971-2000

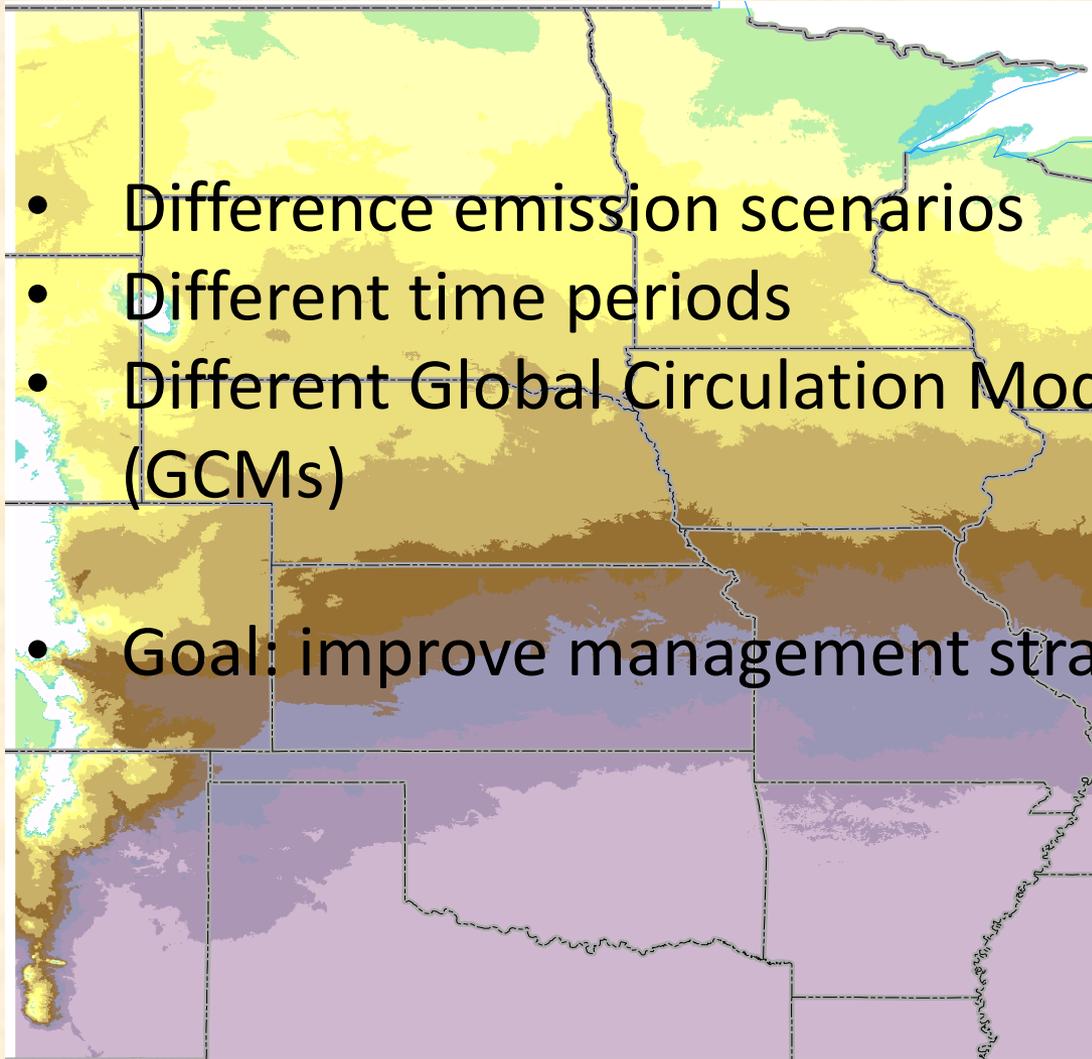


Climate Change

Linear increase temperature = Non-linear increase # degree days

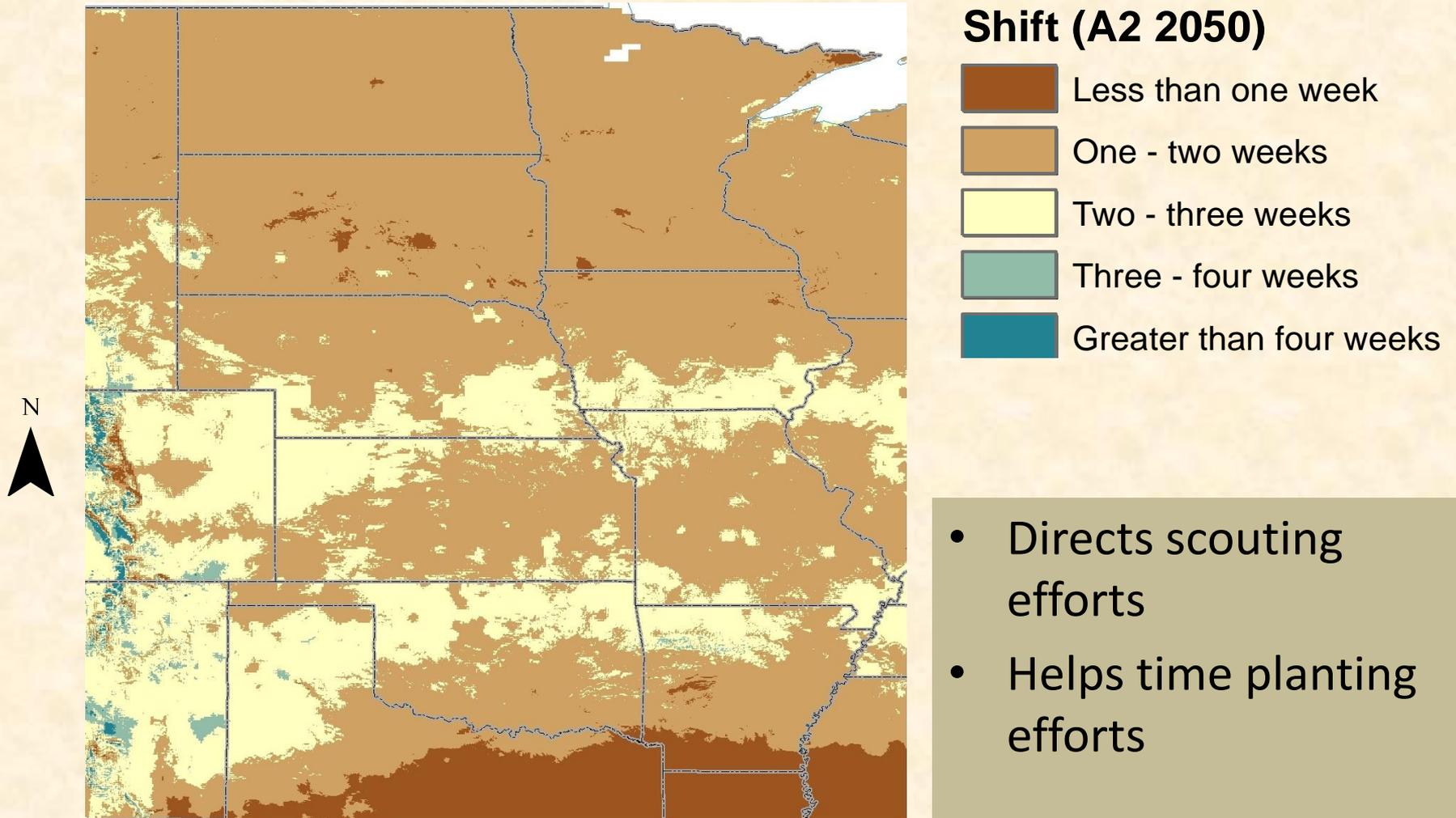


Emergence with conditions change



- Difference emission scenarios
- Different time periods
- Different Global Circulation Models (GCMs)
- Goal: improve management strategy

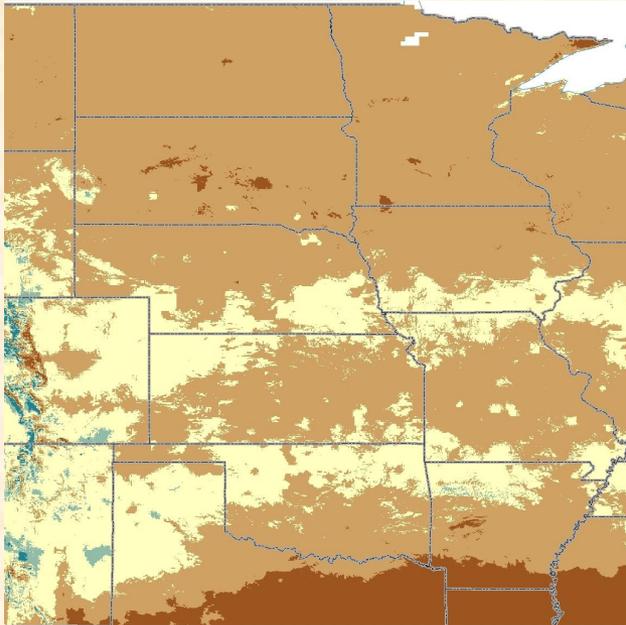
Earlier Sunflower stem weevil emergence by 2041-2060



Data obtained from www.climatewizard.org for A2 scenario 2041-2060 ensemble average of 16 global circulation models

The effect of climate change on the Sunflower stem weevil

- Shift in phenology
- Implications for integrated pest management
 - Reducing pesticide application errors
 - Improve crop management
- Models might suggest novel tactics



Shift (A2 2050)



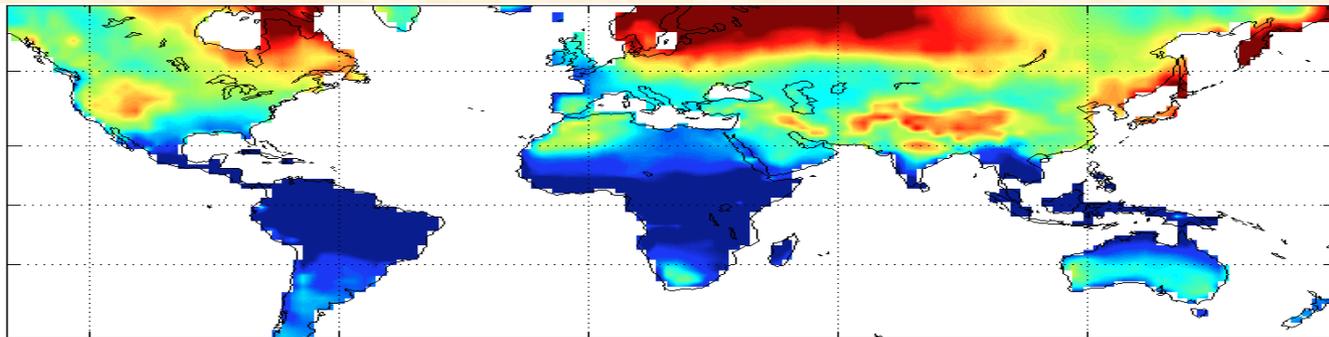


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- Complex system: Russian wheat aphid incidence
- Global pest pressure models



The Russian wheat aphid
Diuraphis noxia (Kurdjumov)
(Homoptera: Aphididae)



- First documentation in the US was in 1986
- Damage estimates in the first ten years were estimated at ca. billion \$
- Management tools are limited
 - Resistant cultivars
 - Biological control
- Pesticide applications are the primary control method



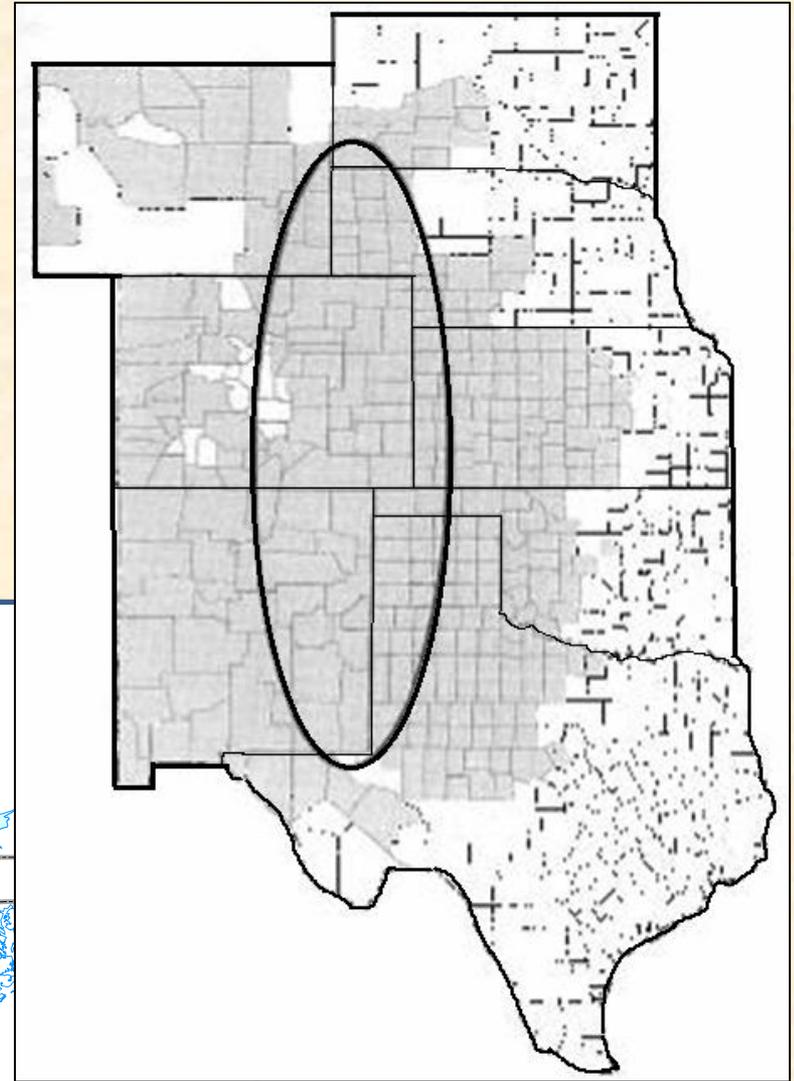
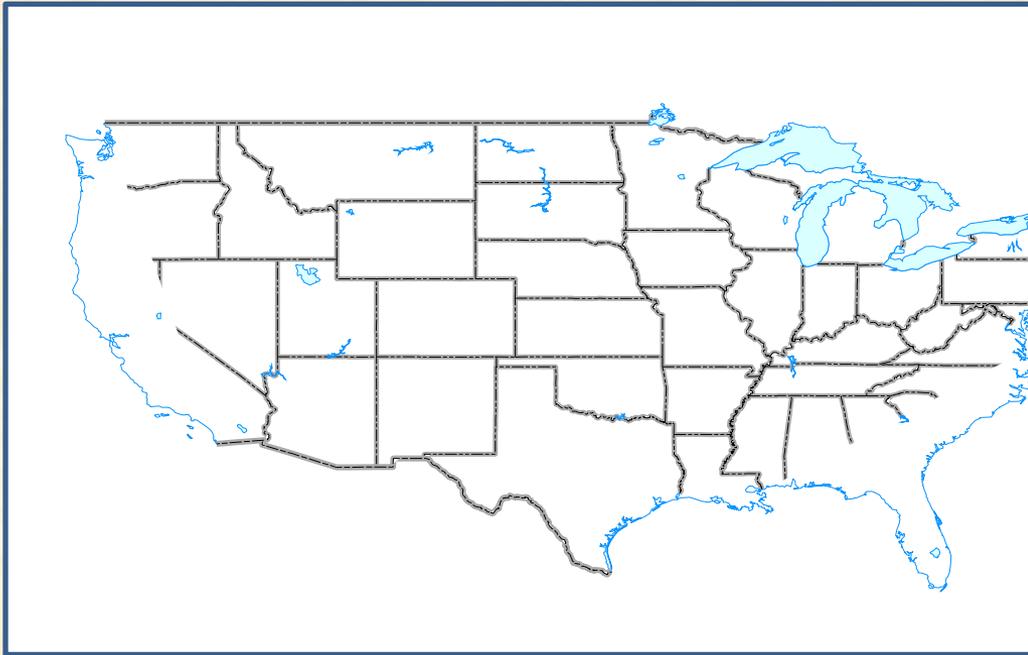
- Primarily parthenogenetic
- Telescoping generation strategy
- High intrinsic rate of increase

Substantial costs → Research effort

Numerous spatially-implicit models exist for describing the population dynamics of small-grain aphids

- Mechanistic models
- Correlative models
- Anecdotal models

Which models are successful for predicting aphid pressure?

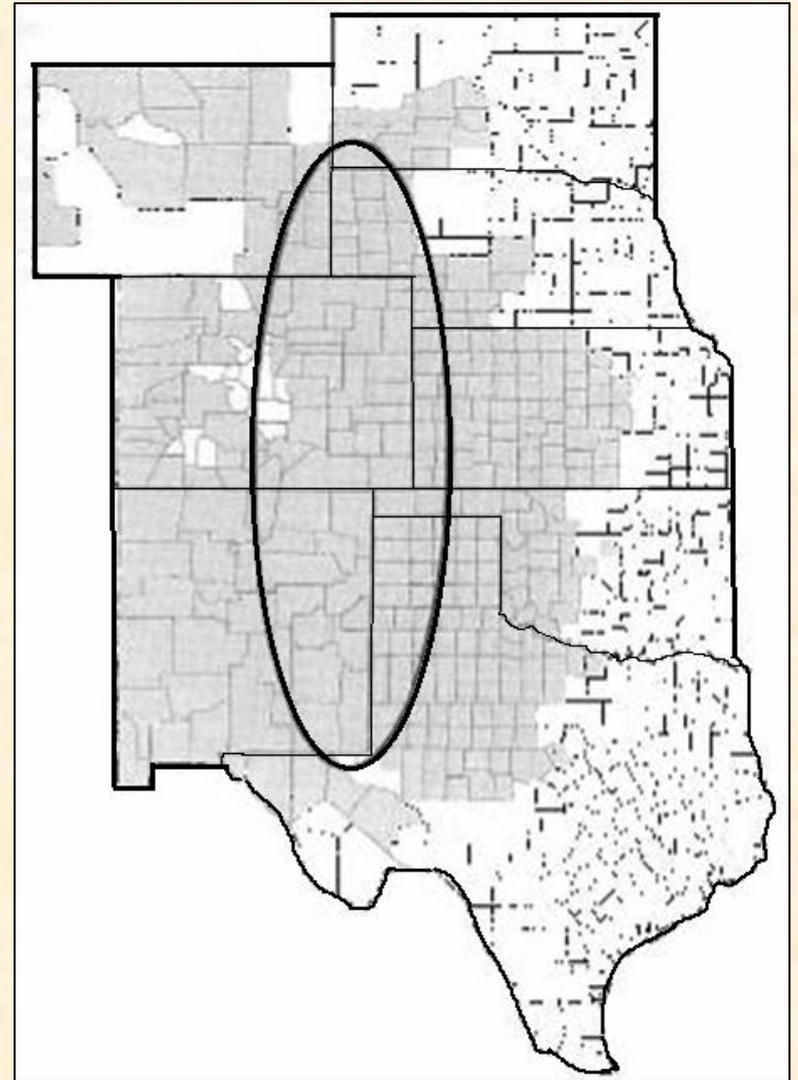


Population dynamic models

18 spatially-implicit weather or climate-driven models

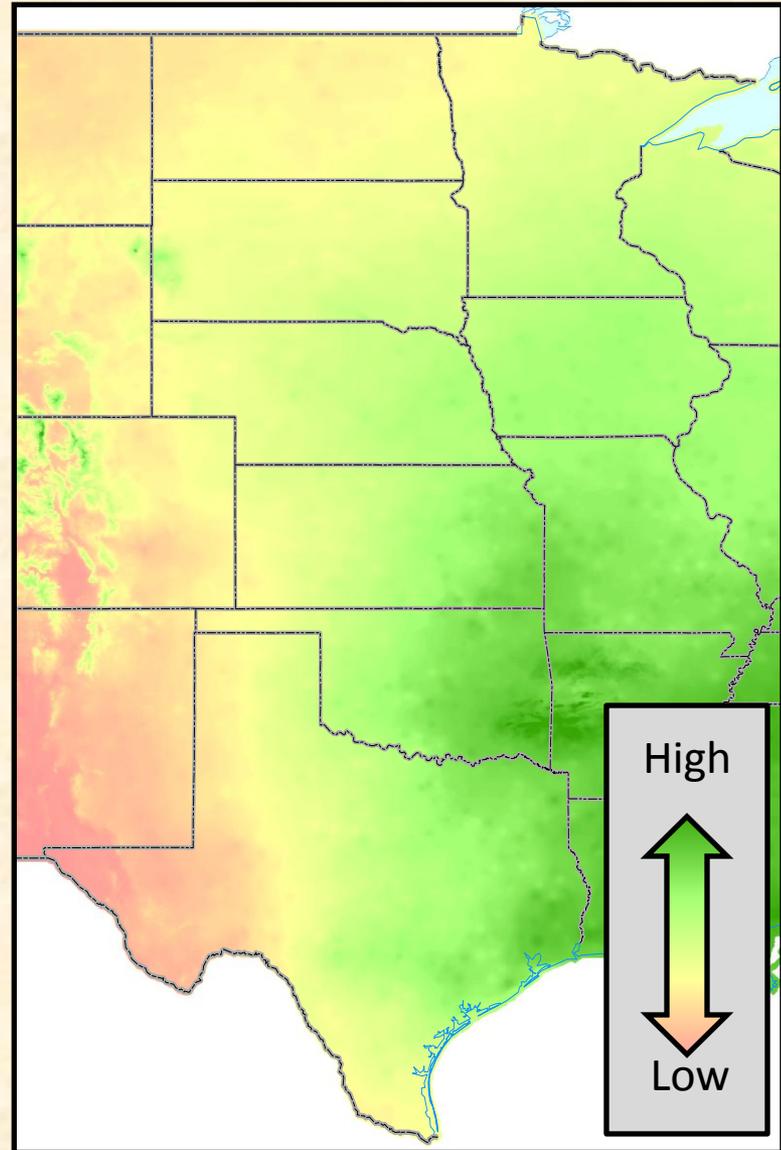
- Literature
- My own work
- Farmer and extension agent experience

Models were transformed into spatially-explicit models

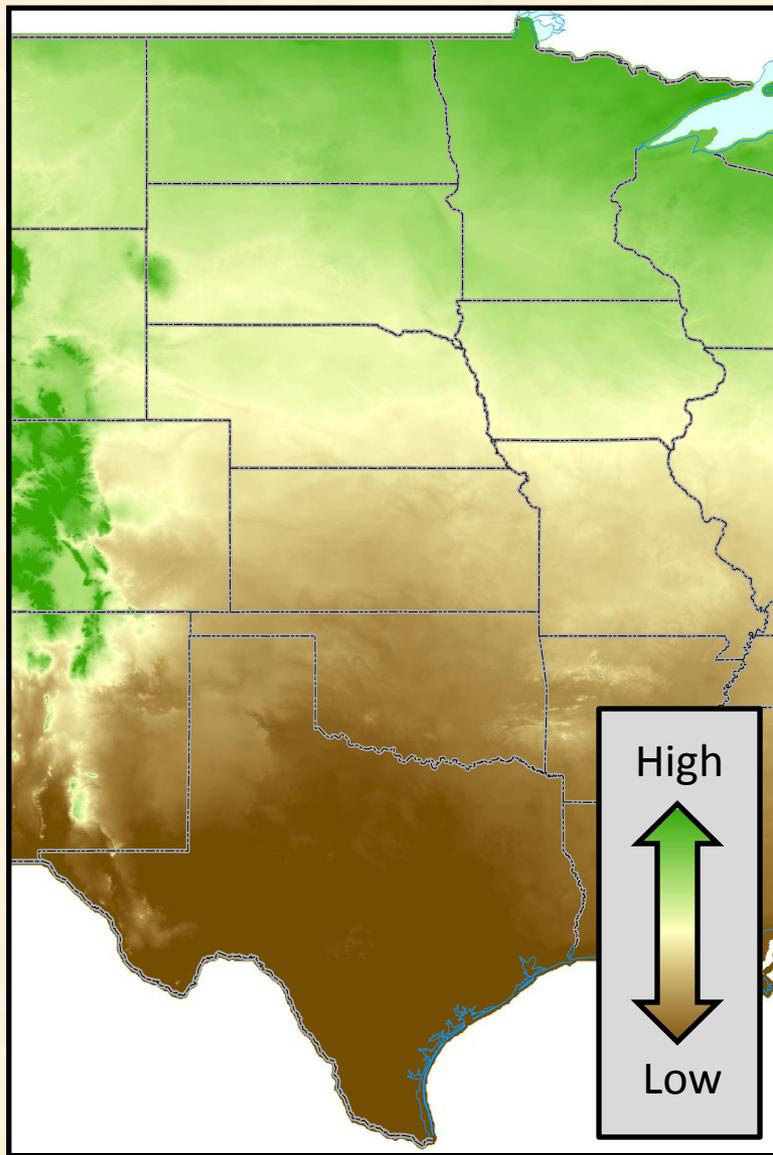


Spring Precipitation

Precipitation in the spring has a negative effect on Russian wheat aphid density*



*Legg, D. E., and M. J. Brewer. 1995. Relating within-season Russian wheat aphid (Homoptera, Aphididae) population-growth in dryland winter-wheat to heat units and rainfall. *Journal of the Kansas Entomological Society* 68: 149-158.



Oversummering food availability: C3 plant productivity

Russian wheat aphids are limited to feeding on grasses using the C3 photosynthetic pathway

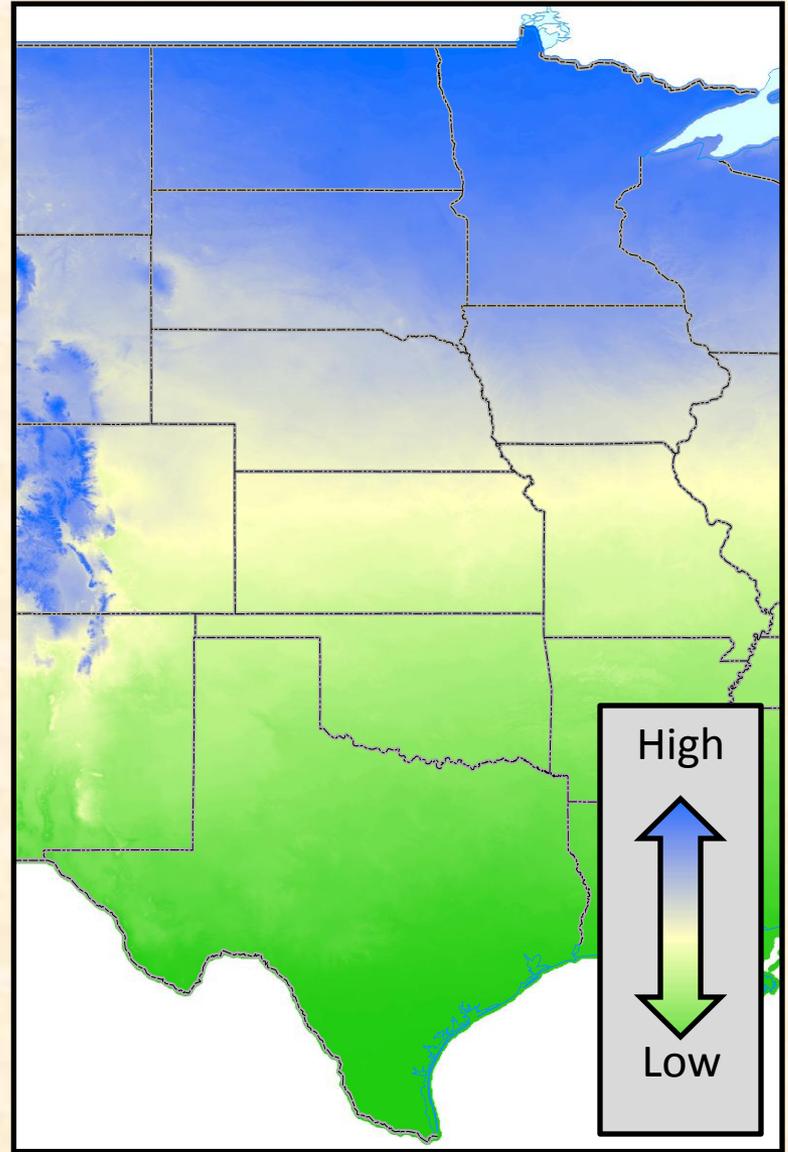
C3 production in the Great Plains region was modeled using mean annual temperature and mean annual precipitation

Epstein, H. E., W. K. Lauenroth, I. C. Burke, and D. P. Coffin. 1997. Productivity patterns of C-3 and C-4 functional types in the US Great Plains. Ecology 78: 722-731.

Winter Severity

Models quantifying different components of winter severity

Accumulated degree days below zero Celsius from October through April are expected to correlate with cereal aphid outbreaks*

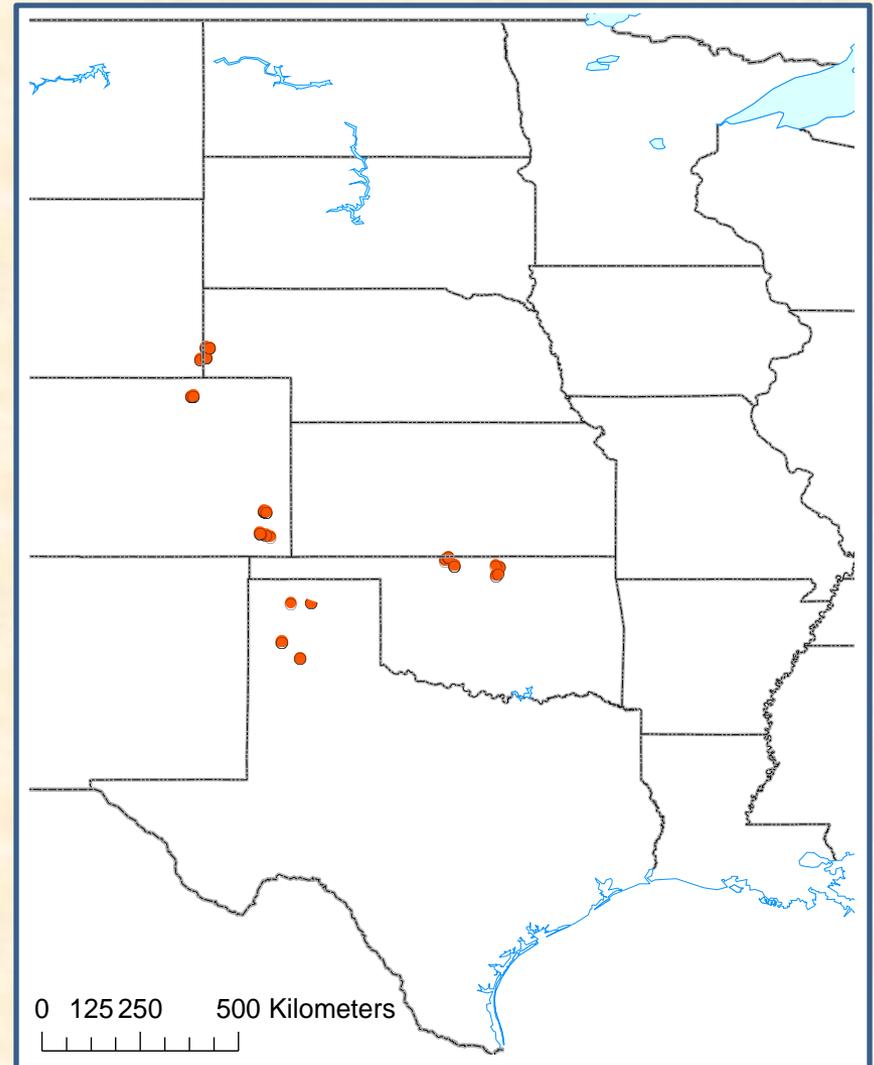


*Dewar, A. M., and N. Carter. 1984. Decision trees to assess the risk of cereal aphid (Hemiptera, Aphididae) outbreaks in summer in England. Bulletin of Entomological Research 74: 387-398.

Russian wheat aphid data

Large Integrated Pest Management database*

- 4 years
- 21 sites
- Russian wheat aphid density sampled throughout the growing season
- Aphid days** were calculated using aphid density measurements



* Elliott et al. 2002-2006 Area Wide Integrated Pest Management Project

** Archer, T. L., F. B. Peairs, K. S. Pike, G. D. Johnson, and M. Kroening. 1998. Economic injury levels for the Russian wheat aphid (Homoptera : Aphididae) on winter wheat in several climate zones. *Journal of Economic Entomology* 91: 741-747

Variables and models

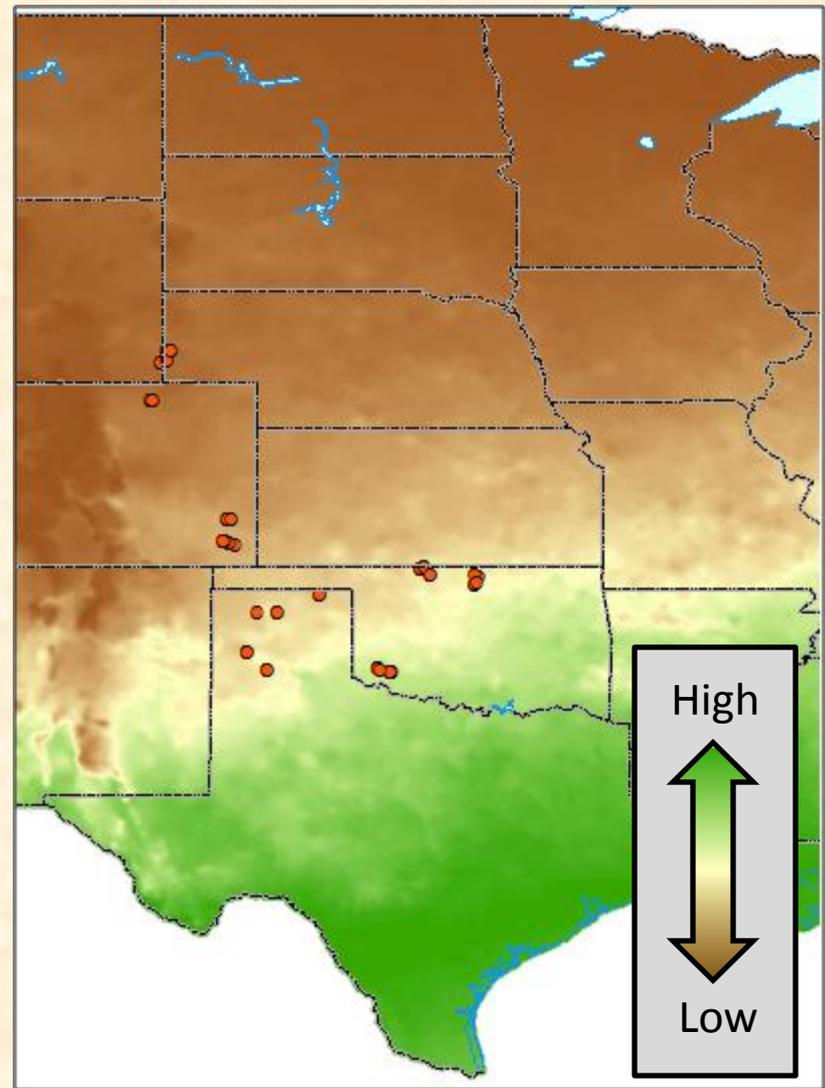
Aphid days – dependent variable

Population dynamic models -
independent variables
(A little confusing...)

More than one independent
variable?

Ran all subsets of the independent
variables regressed against $\ln(\text{aphid days})$.
For example:

$$\ln(\text{aphid days} + 0.1) = \alpha + \beta_1 * (\text{Fall Fecundity}) + \beta_2 * (\text{Spring Precipitation})$$



Fall Fecundity: Fecundity is modeled to have a non-linear relationship with temperature with optimal temperature occurring around 18.5 C*

*Merrill, S. C., T. O. Holtzer, and F. B. Peairs. 2009. *Diuraphis noxia* reproduction and development with a comparison of intrinsic rates of increase to other important small grain aphids: a meta-analysis. *Environmental Entomology* 38: 1061-1068.

Multimodel inference and model averaging

- Akaike's Information Criterion adjusted for small sample sizes (AICc) was used to select good candidate models
- 24 candidate models were selected
- Selected candidate models were averaged based on their AICc weight
- Model-averaged result:

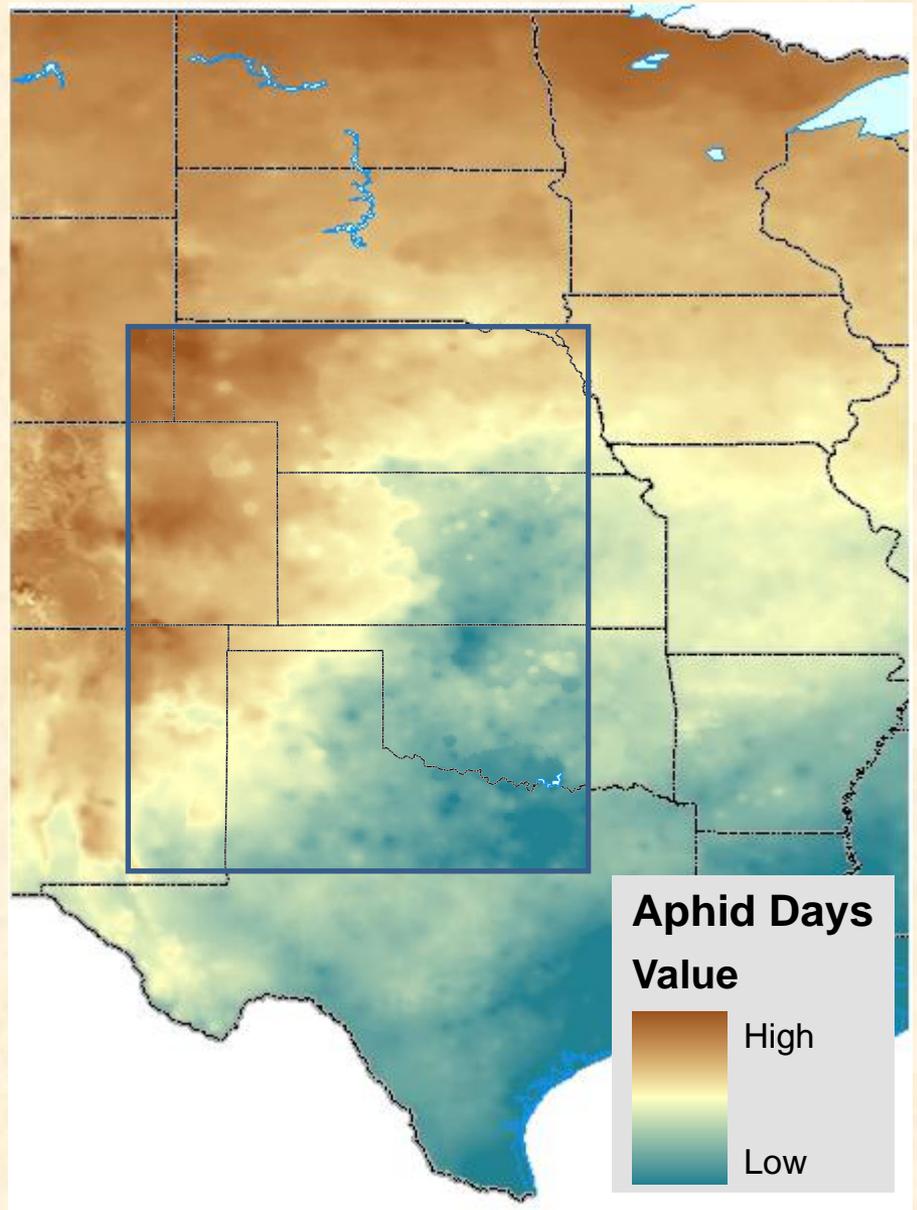
$$\ln(\text{aphid days} + 0.1) = - 1.683 + 0.000836 * [\text{Fall Temperature}] - 0.267 * [\text{Fall Precipitation}] - 0.000148 * [\text{Dewar \& Carter}] - 0.0257 * [\text{Spring Precipitation}] + 0.0183 * [\text{Spring Fecundity}] + 0.0954 * [\text{C3 Production}] - 0.0669 * [\text{Oversummering Temperature}] + 4.169 * [\text{July Intrinsic rate of increase}] + 0.00808 * [\text{July Fecundity}] + 0.0574 * [\text{Legg \& Brewer}]$$

Variable rank	Predictor variable (Model)	Variable relative importance weight	Effect direction
1	Fall precipitation	1.000	-
1	C3 production	1.000	+
3	Spring precipitation	0.956	-
4	Legg and Brewer (1995)	0.840	+
5	Spring fecundity	0.259	+
6	July fecundity	0.249	+
7	July intrinsic rate of increase	0.206	+
8	July degree days > 28°C	0.188	-
9	Dewar and Carter (1984)	0.087	-
10	Fall temperature	0.062	+

Results

Russian Wheat Aphid incidence

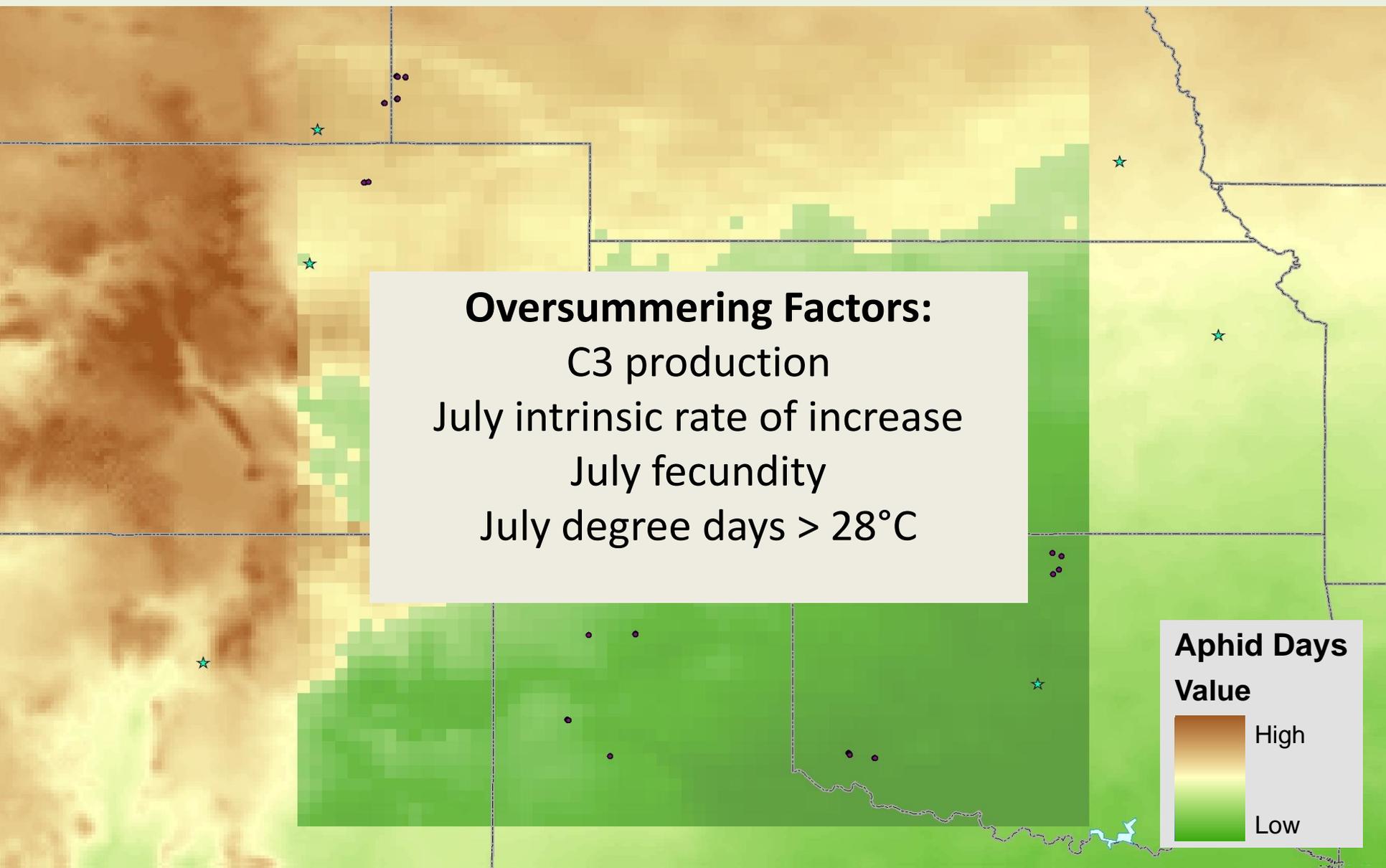
Using weather conditions observed from the 2002-2003 season as model inputs results in the spatiotemporal Russian wheat aphid day map depicted.



Simulating climate change

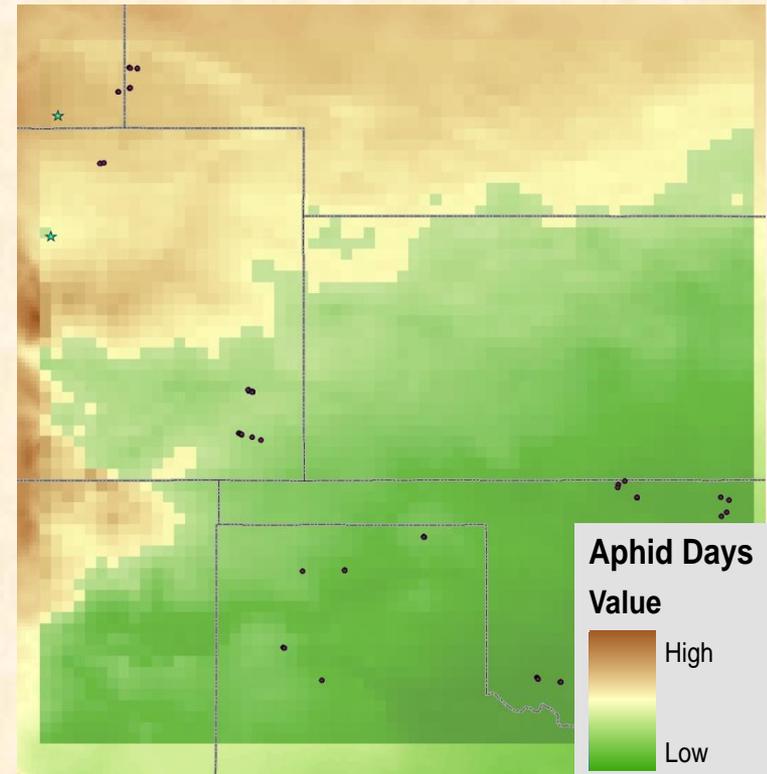
- Numerous climate change simulation options
 - Emission scenarios
 - Global Circulation Models (GCMs)
 - Different time periods
- This work uses an ensemble average of 16 GCMs for the 2041-2060 time period* look at the three primary emissions scenarios
 - A2: high emissions
 - A1B: medium emissions
 - B1: low emissions

Aphid days modeled using an ensemble average of 16 GCMs using the A2 scenario (2041-2060)



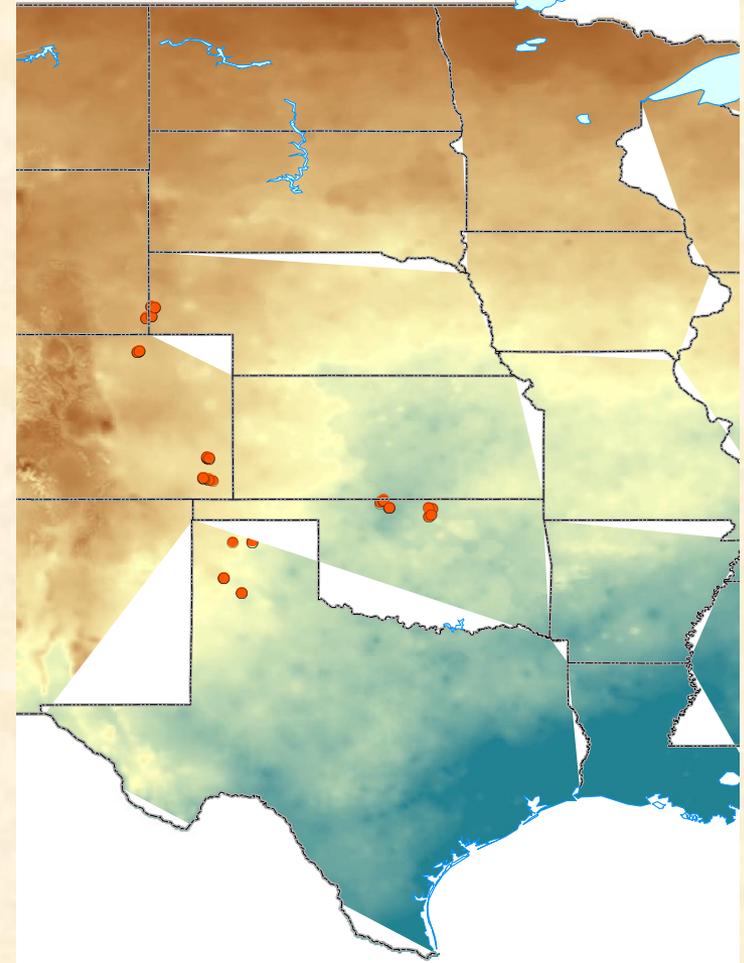
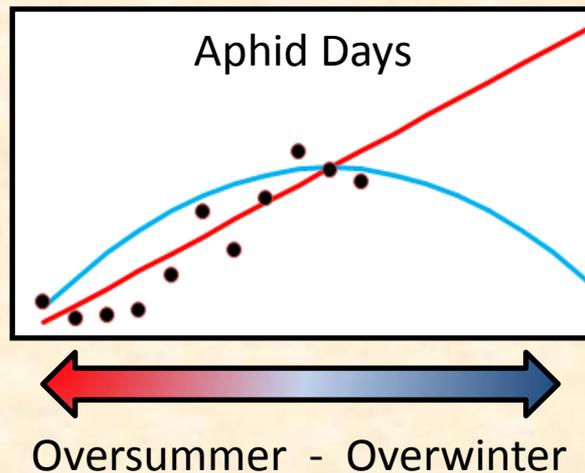
Russian wheat aphid day model conclusions

- Predictions are driven by harsh oversummering conditions
- Improve strategy
 - Reduce application errors
 - Placement of resistant cultivars
- Provide solace to stakeholders across much of the Great Plains region



Challenges to building species-specific prediction models

- Massive data for each species
- Observations are (relatively) easy but experiments are difficult
 - Correlation verses causation
- Need to capture boundary conditions



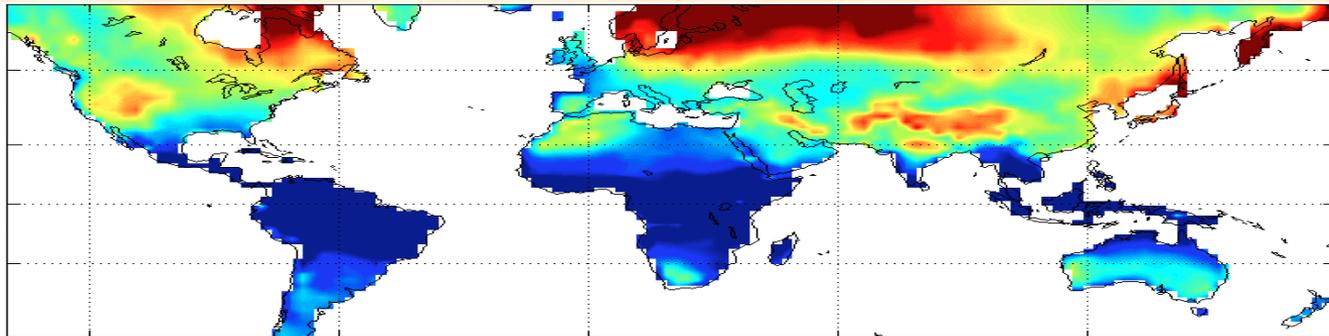


Today's Story

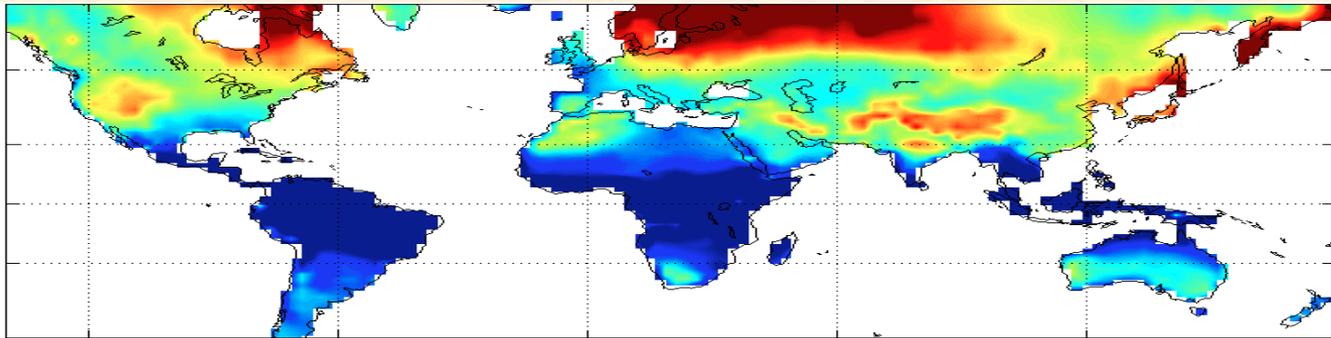


From simple to complex systems

- Simple system: Sunflower stem weevil phenology
- Complex system: Russian wheat aphid incidence
- Global pest pressure models



Global warming, pest pressure, and global food security



Josh J. Tewksbury, David S. Battisti

(University of Washington)

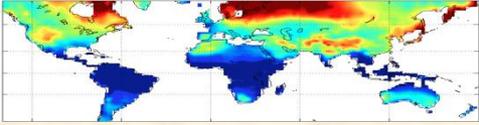
Curtis. A. Deutsch

(UCLA)

and

Rosamond L. Naylor

(Stanford)



Building a global pest pressure model

- Climate component
 - Use projected climate change from numerous emission scenarios and GCMs (temperature only)
- The pest population dynamic model
 - population growth
 - population metabolism
- Crop dynamics
- Goal: simulate change in crop yield and production due to pests

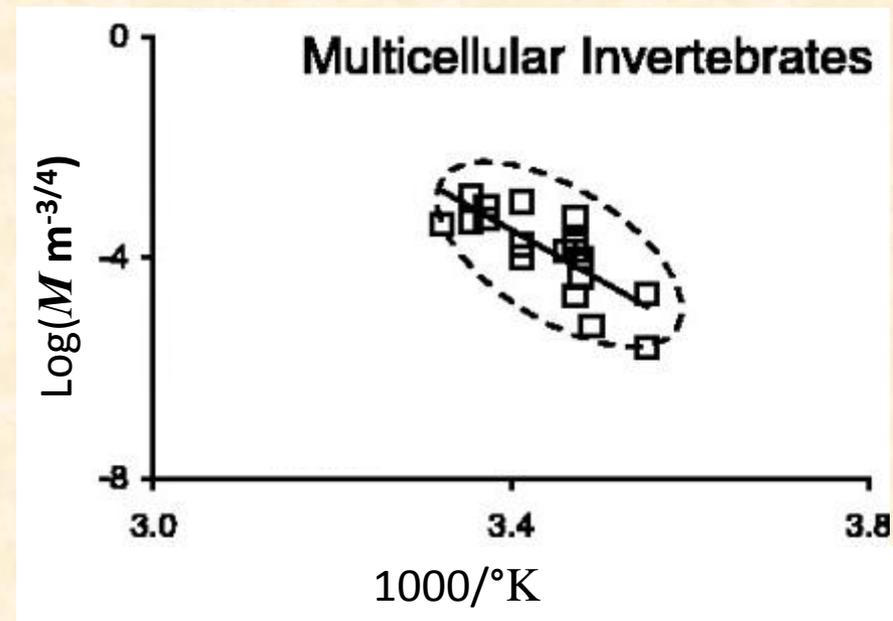
Temperature -> Metabolism ->

$$\text{metabolic rate } M = b_0 m^{3/4} e^{-E/kT}$$

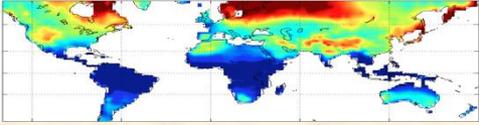
b_0 = taxon-specific normalization constant; m = mass

E = activation energy; k = Boltzmann's constant; **T = temperature**

- Metabolic rate is closely related to temperature across a wide range of organisms
- Consumption scales with metabolic rate over a wide range of temperatures

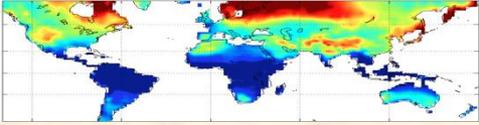


Gillooly et al 2001 Effect of size and temperature on metabolic rate. *Science* (293) 2248-2251



Δ Temperature \rightarrow Δ Metabolism \rightarrow Δ Consumption

- Calculate current mass normalized metabolic rate (M):
 - current climate data
 - integrate metabolic function
- Project climate in ~ 75 years (2070 – 2100) and calculate new metabolic rate (M_{75})
- $(M_{75} - M_{\text{current}}) / M_{\text{current}} =$ proportional change in metabolic rate

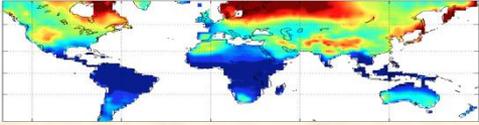


Population metabolism P can be calculated as the product of the organism's metabolic rate M and the population density n over the course of the growing season

$$P = \int_{t_p}^{t_h} n \cdot M dt$$

$$Losses = \beta P = \beta \int_{t_p}^{t_h} n \cdot M dt$$

Where β represents the amount of yield loss per unit of pest metabolism



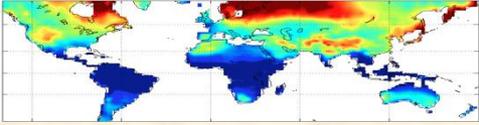
Methods:

Informing β and pest population dynamics

- Use estimates of insect pest damage to crop yields $L = \lambda Y$, where Y is crop yield and λ is the fraction lost to insect pests in recent decades*

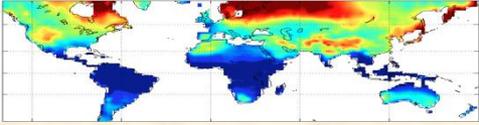
Crop	Losses due to Pests Today
Rice	15.1% (7-18%)
Maize	9.6% (6-19%)
Wheat	7.9% (5-10%)

- *These values constrain integrated population metabolism and pest population dynamics during the growing season*



Methods: Global pest pressure

- Given estimates of crop losses and estimates of temperature, we can estimate pest unit metabolism, consumption, and losses
- Select values of the remaining parameters:
 - α (adjusted growth rate) informs n
 - ϕ (population survival) informs n_o



Methods: Global pest pressure

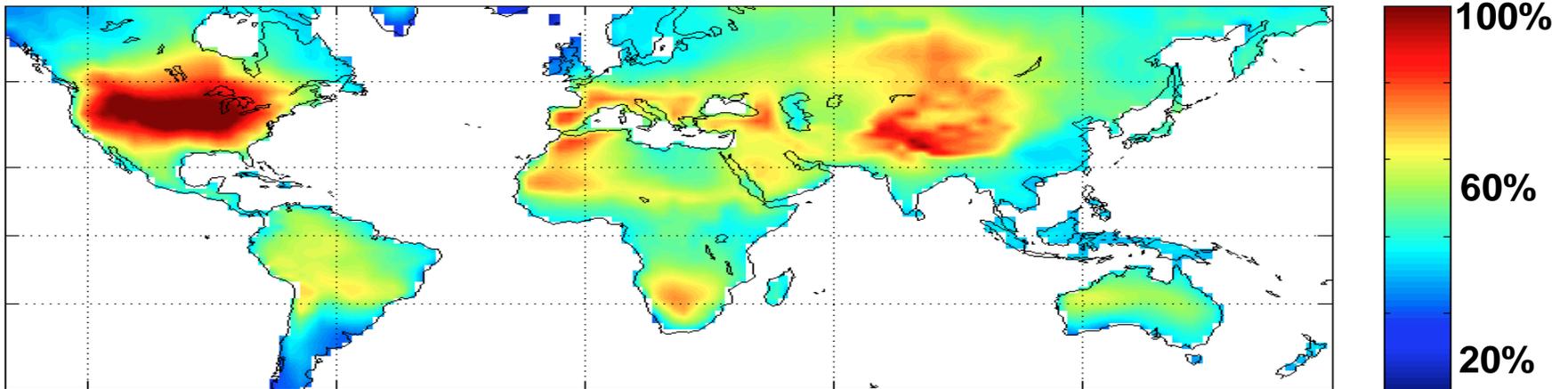
- For each set of α and ϕ , calculate
 - temperature-dependent pest population density, n
 - integrated metabolic rate over time, M

$$Losses = \beta P = \beta \int_{t_p}^{t_h} n \cdot M dt$$

- Change in n , M and $Losses$

Impact of climate change on metabolism

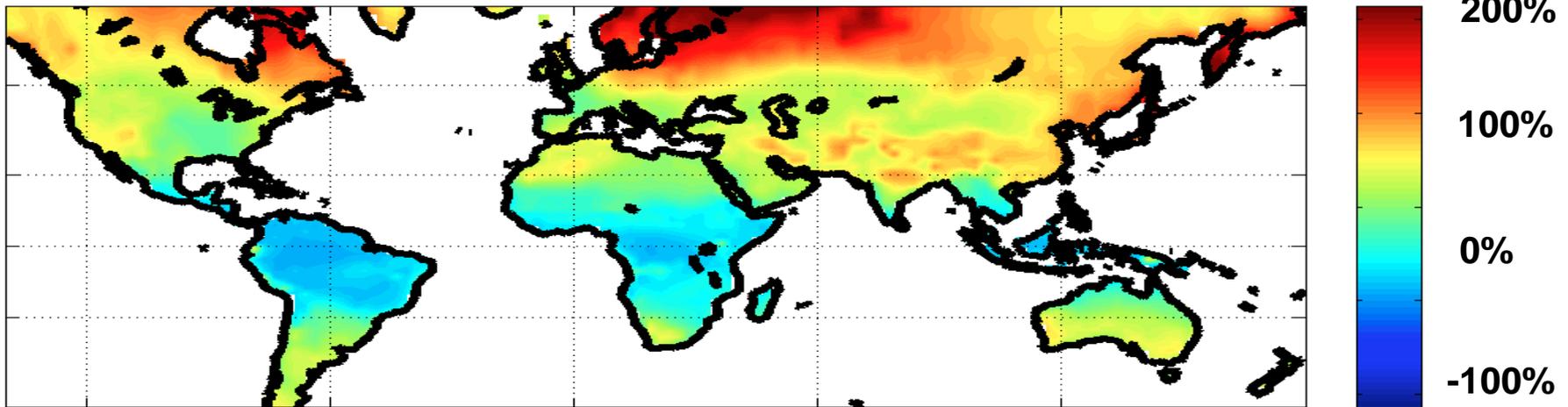
Percent increase in insect metabolic rate*



*Using response from GFDL model w/ A2 emission scenario for 2100, $\alpha = 0.3r$, $\phi = 0.1$
Tewksbury et al, in preparation

Impact of climate change on population size

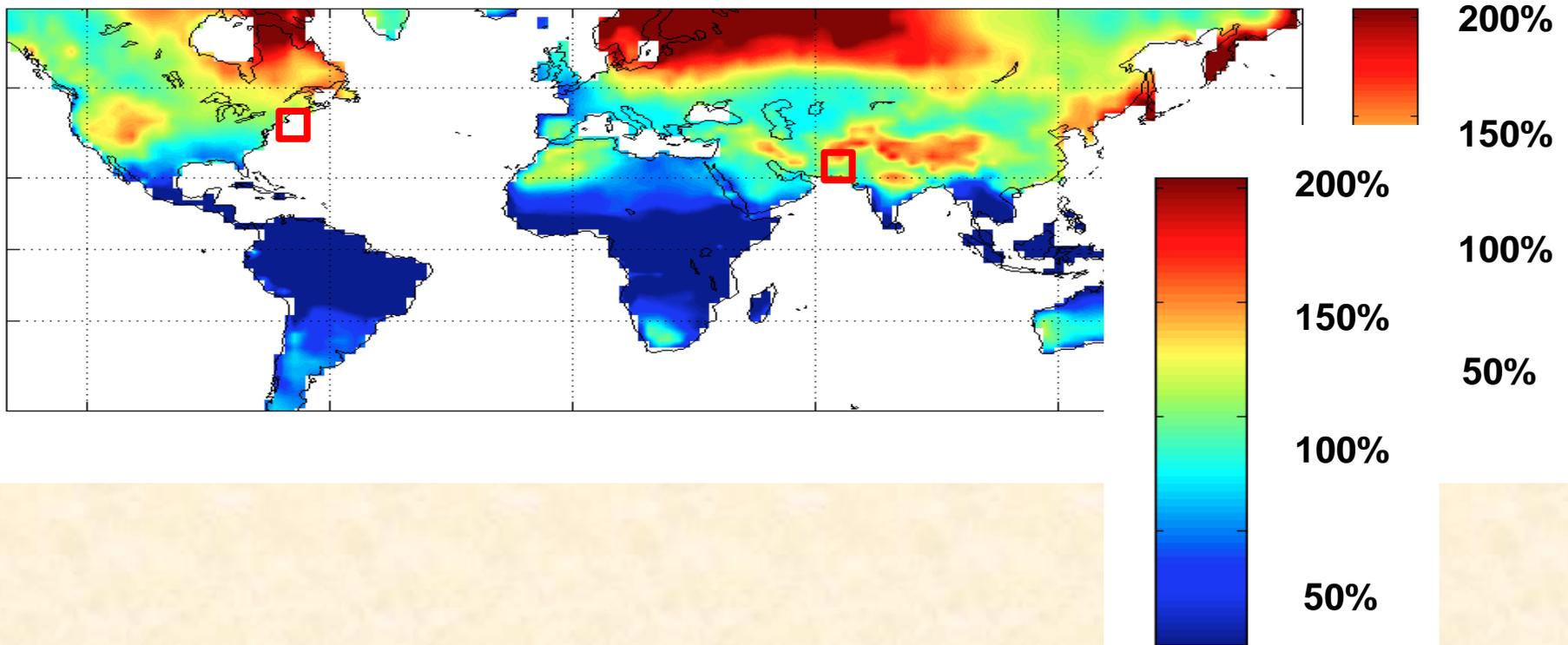
Percent change in insect population growth*



*Using response from GFDL model w/ A2 emission scenario for 2100, $\alpha = 0.3r$, $\phi = 0.1$
Tewksbury et al, in preparation

Impact of climate change on crop losses

Percent increase in insect crop losses*

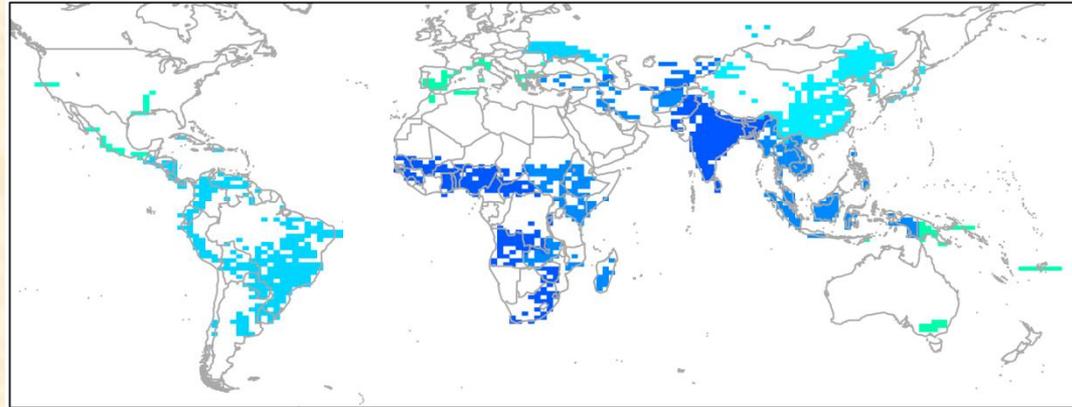


*Using response from GFDL model w/ A2 emission scenario for 2100, $\alpha = 0.3r$, $\phi = 0.1$
Tewksbury et al, in preparation

Yield Lost to Pests: *Rice*

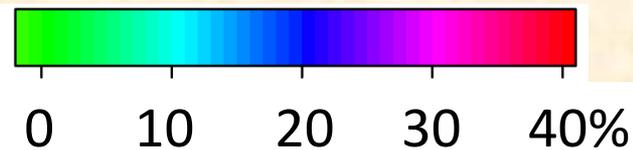
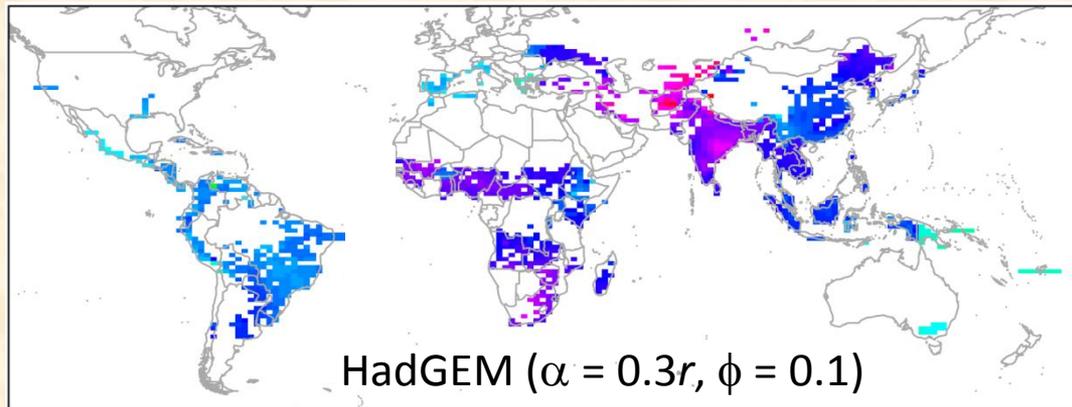
“Today”

- Total yield loss in China, India and Bangladesh increases by 10% to ~20-30%
 - Rank 1, 2 and 4 in world production



“2070-2100”

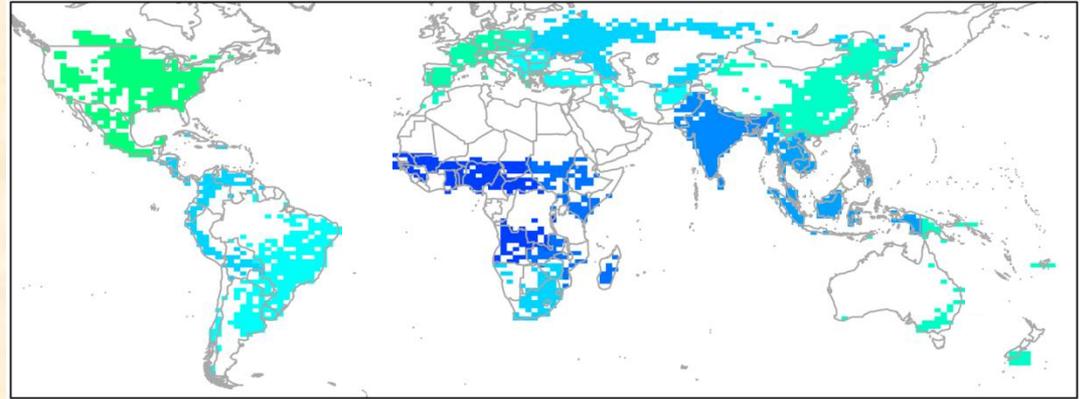
- Damage is even greater if a higher fraction of pests make it through diapause in a warmer world



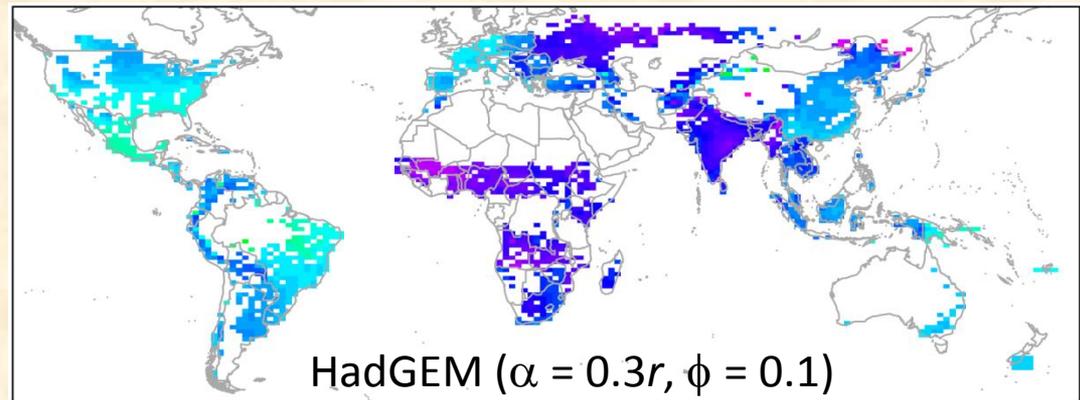
Yield Lost to Pests: *Maize*

“Today”

- Increase in yield loss is greatest in midlatitudes (metabolism and fitness increase)
- Yield loss doubles to ~12% in the US and China, the two largest producing countries
- Yield loss increases to 25% in much of Africa (an increase of ~5%)



“2070-2100”

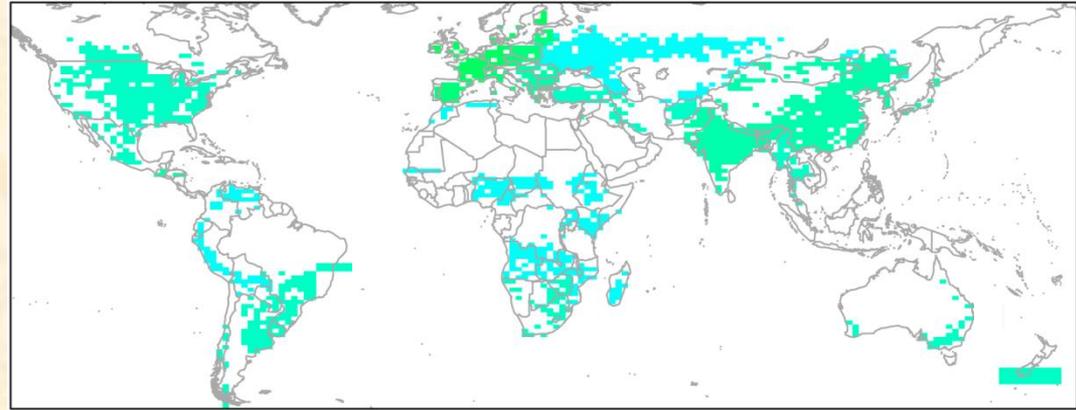


0 10 20 30 40%

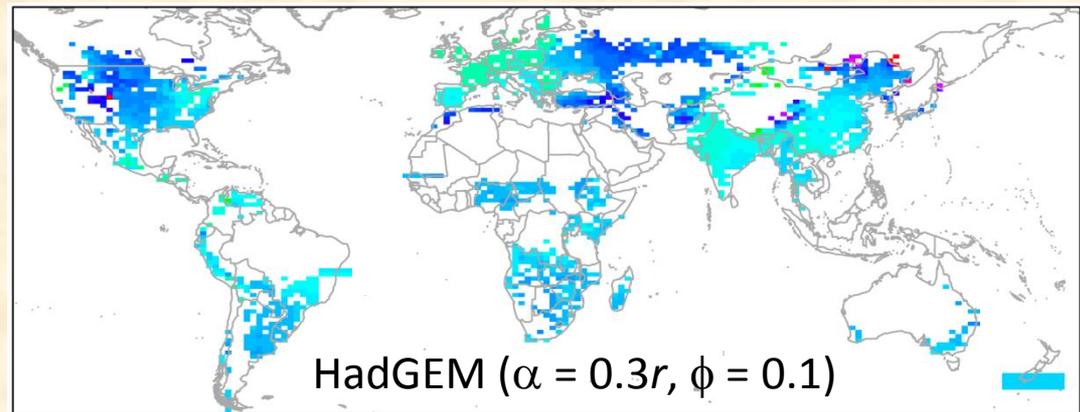
Yield Lost to Pests: *Wheat*

- Increase in yield loss is greatest in midlatitudes (metabolism and fitness increase)
- The yield loss doubles to 15 to 20% in the two largest producing countries, the US and Russia

“Today”



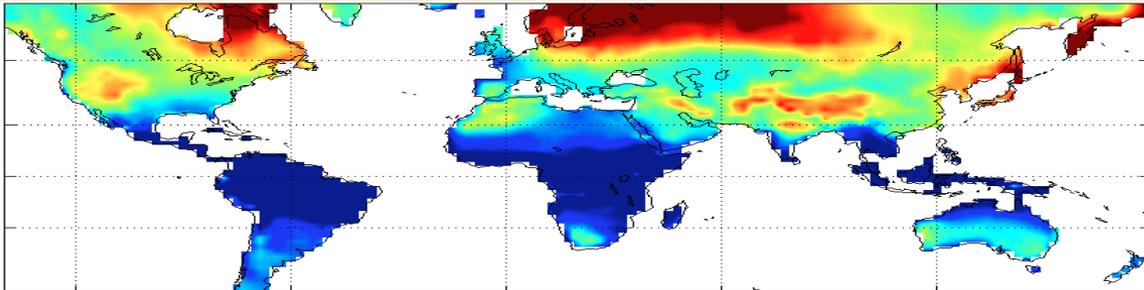
“2070-2100”

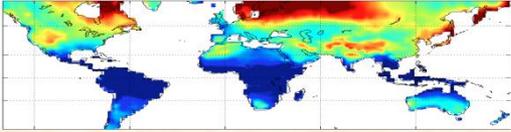


0 10 20 30 40%

Caveats

- No evolution
- No change in pesticide use, cropping timing, and crop varietal choice
- Generic insect model - population dynamics of individual insect species may not follow model predictions
- Ontogeny matters but changes in crop condition and insect response are not included
- Impacts of changing precipitation are not in the model





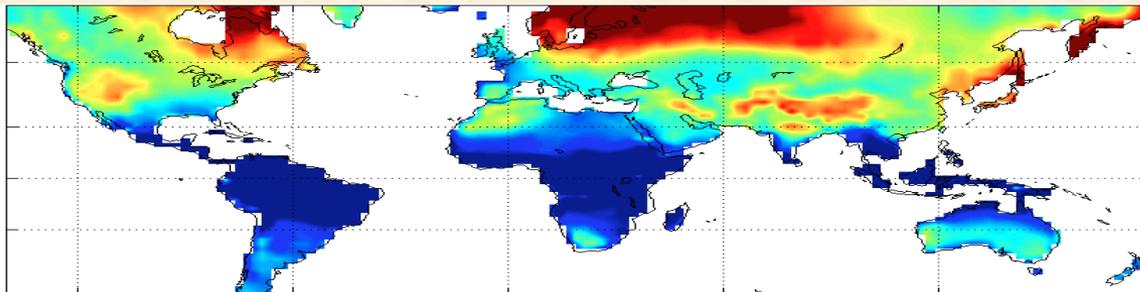
Global Pest Pressure Model Conclusions

- Significant yield losses to our staple grains
- Losses tend to be highest where production is highest (e.g., rice in China & India; wheat and maize in US, China and Russia)
 - Losses sum to tens of billions of dollars per year
 - Implications for global food security
- Pest damage will be additive to decreased yields caused by temperature change (even with sufficient water and nutrients)
- The global pest pressure model:
 - A tool for prioritizing regions for further study
 - An indicator to start adaptation and mitigation efforts

General Conclusions



- Modeling efforts can provide information to aid in mitigation and adaptation efforts
- Models have value for informing integrated pest management strategy and may suggest novel tactics
- At the species level, modeling efforts should inform and improve strategy to help reduce the impact of climate change on crop losses
- On the global pest complex level, climate change is likely to cause dramatic reductions in food availability and food security



Acknowledgements

- Thomas Holtzer, Frank Peairs, Josh Tewksbury, Curtis Deutsch, David Battisti, and Ros Naylor
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