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Incorporating agricultural responses to flexible scenarios for carbon, temperature, and water into GCAM

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Outline

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- Role of emulators for GCAM
- Our crop yield emulator
- Results
- Future work
- Acknowledgements - Alex and Meridel!
- Questions

Role of emulators for GCAM

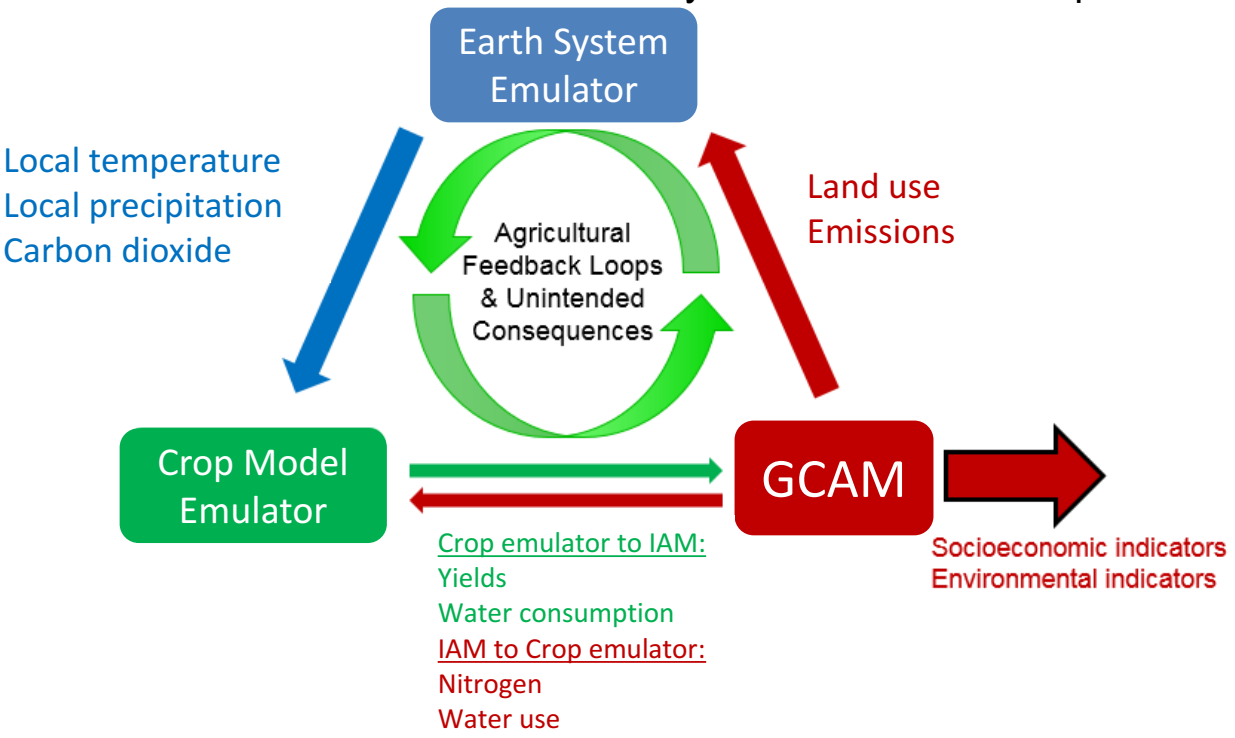
Emulators and GCAM

Results today are from the first step in the process: an emulator that takes any **earth system model temperature, precip, CO2 data** and produces **crop yield changes** for use in GCAM (blue and green arrows)

With our approach, the emulator captures both agricultural response to long term average earth system state changes AND the spread of all crop model results.

It can be used in the short term for more time-efficient uncertainty studies while development of other arrows continues.

Ruane et al:
An AgMIP framework for improved agricultural representation in IAMs, *ERL* 2017

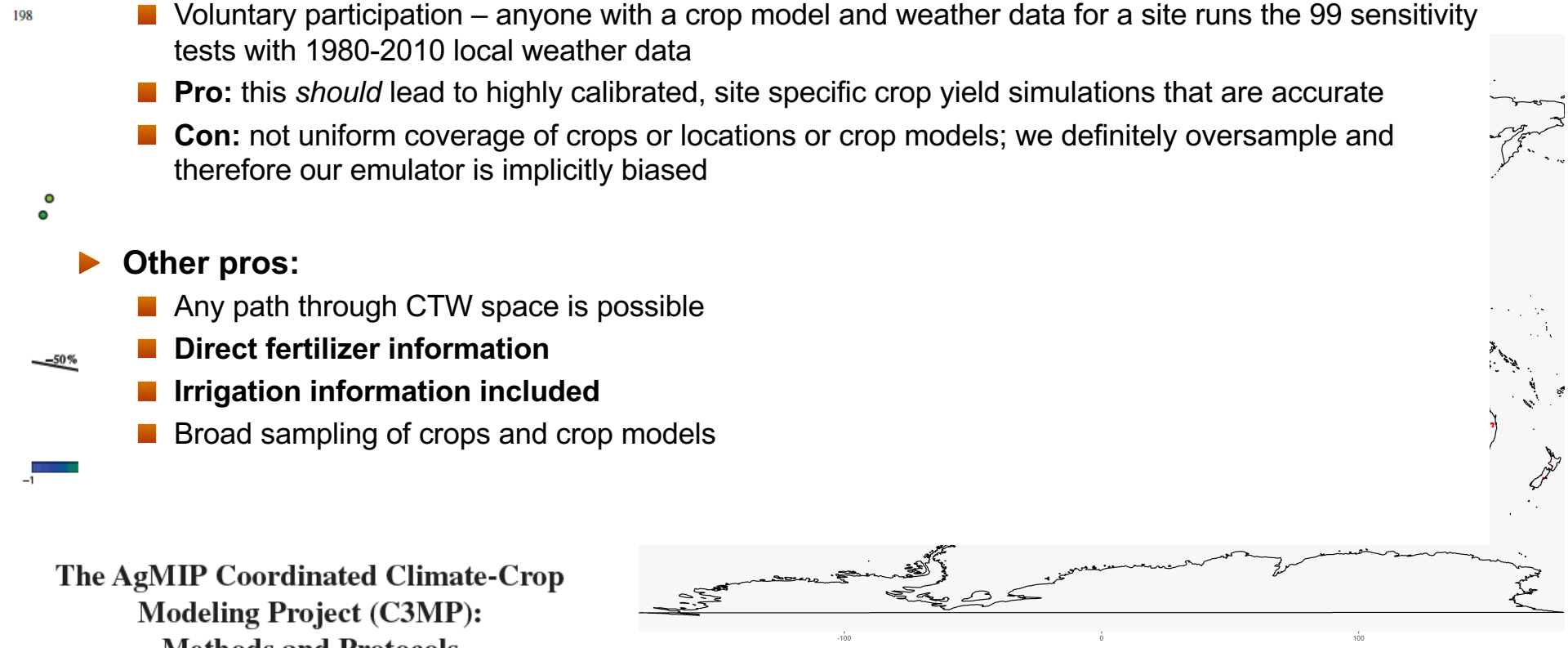


Our crop yield emulator

Our crop yield emulator

- Trained on the **AgMIP C3MP data** set:
  - Coordinated set of 99 sensitivity tests across different levels of **CO2** concentrations, **Temperature** changes, and **Precipitation** changes (CTW space) for specific crops at ~670 **specific sites**
  - Voluntary participation – anyone with a crop model and weather data for a site runs the 99 sensitivity tests with 1980-2010 local weather data
  - **Pro:** this *should* lead to highly calibrated, site specific crop yield simulations that are accurate
  - **Con:** not uniform coverage of crops or locations or crop models; we definitely oversample and therefore our emulator is implicitly biased

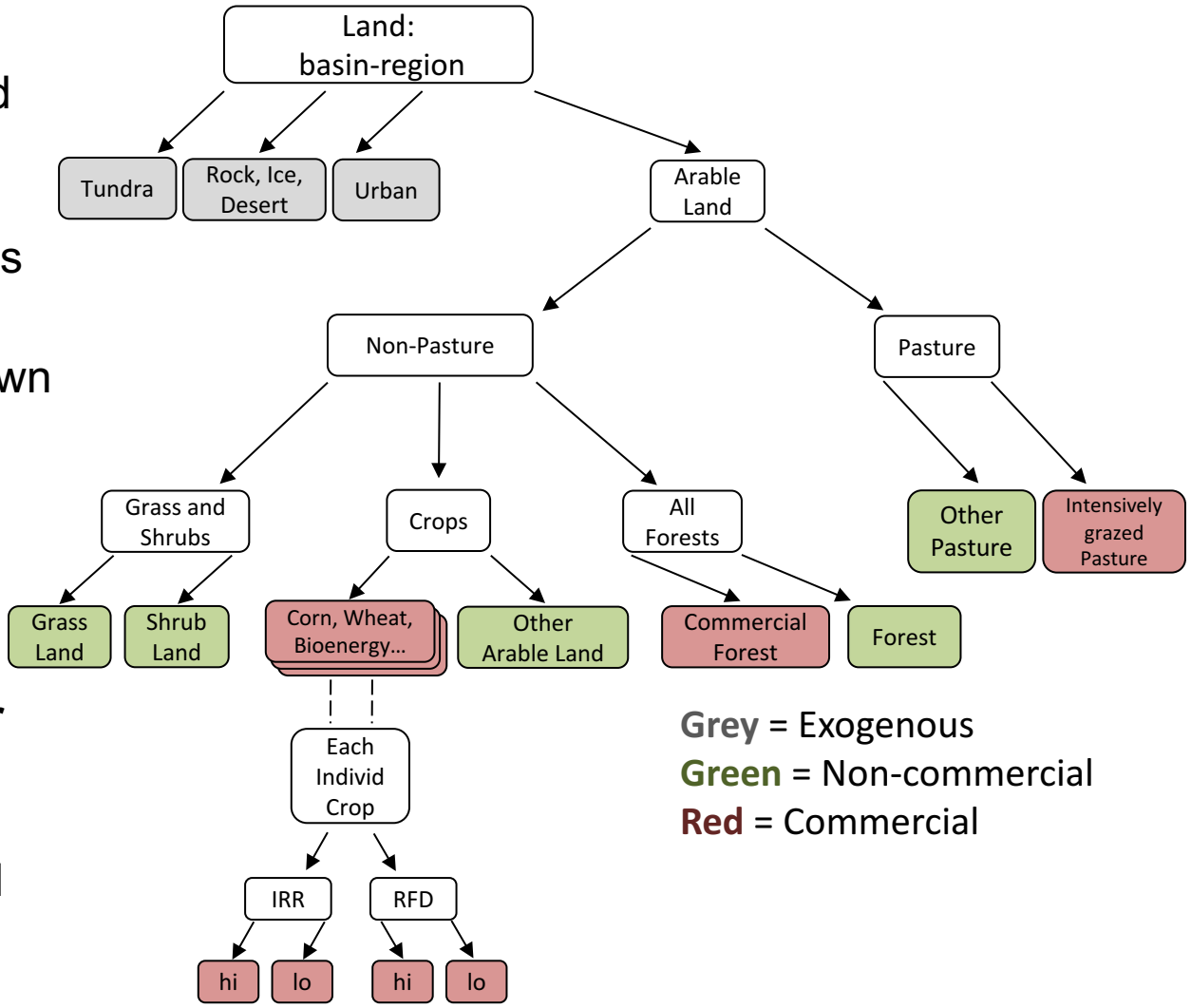
- **Other pros:**
  - Any path through CTW space is possible
  - **Direct fertilizer information**
  - **Irrigation information included**
  - Broad sampling of crops and crop models



The AgMIP Coordinated Climate-Crop Modeling Project (C3MP): Methods and Protocols

Up and coming version of GCAM

- Spatially divide the world by water basin and geopolitical region for a total of ~300 land regions (no more AEZs)
- Each crop also has its own competitive subnests: irrigated versus rainfed and low versus high N fertilizer application (N stress vs none).
- **Irrigation and Fertilizer information is HIGHLY desirable in data for GCAM moving forward**



Ensemble Forming and Quantities of interest

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Form ensembles of C3MP sites by GCAM commodity (or crop), irrigation, and Latitudinal band (or nitrogen application.)

For example, all irrigated corn in the tropics sites will form an ensemble.

1. We calculate the time-average yields for each of the 99 sensitivity tests for each ensemble member.
2. We fit the functional form to this ensemble of data to give **yield response to changes in long term average environmental state**.
3. We also calculate uncertainty bands to capture the spread of crop model behavior (not shown today).

2. is helpful for GCAM while it operates on 5 year time steps. We are also developing an approach to capture interannual variability.

Functional form

Ruane et al, *Global Change Biology,* 2014;

McDermid et al, C3MP protocol chapter, 2015

$$Y(CO_2,T,P) = a + bT + cT^2 + dP + eP^2 + f(CO_2) + g(CO_2)^2 + hTP + iT(CO_2) + jP(CO_2) + kTP(CO_2)$$

T = change from historic local temperature (plus/minus degrees C)

P = percent change from historic local precip (eg 150% increase)

CO2 = fixed CO2 concentration

Examine change in yield relative to the baseline response and CTW values; eg 10% increase in precipitation from baseline leads to X% change in yield from baseline.

This is the functional form that I use for the examples today, but the emulator we've built is flexible to allow other functional forms (which we are testing).

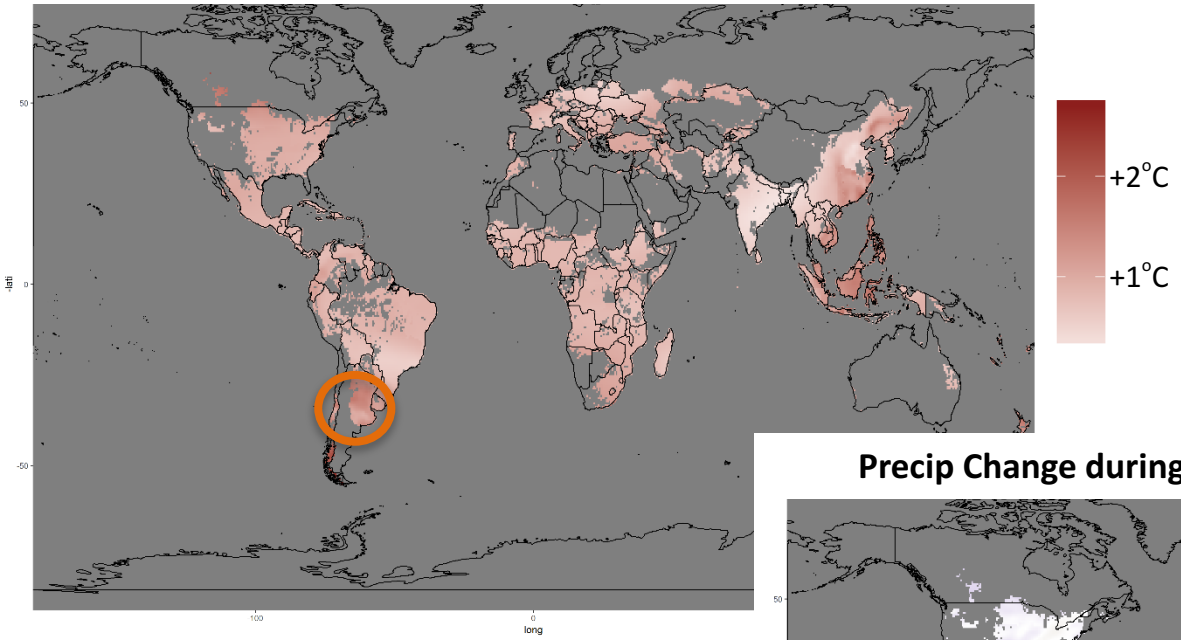
There is some wiggle room in precise functional form while still capturing same overall response.

Results

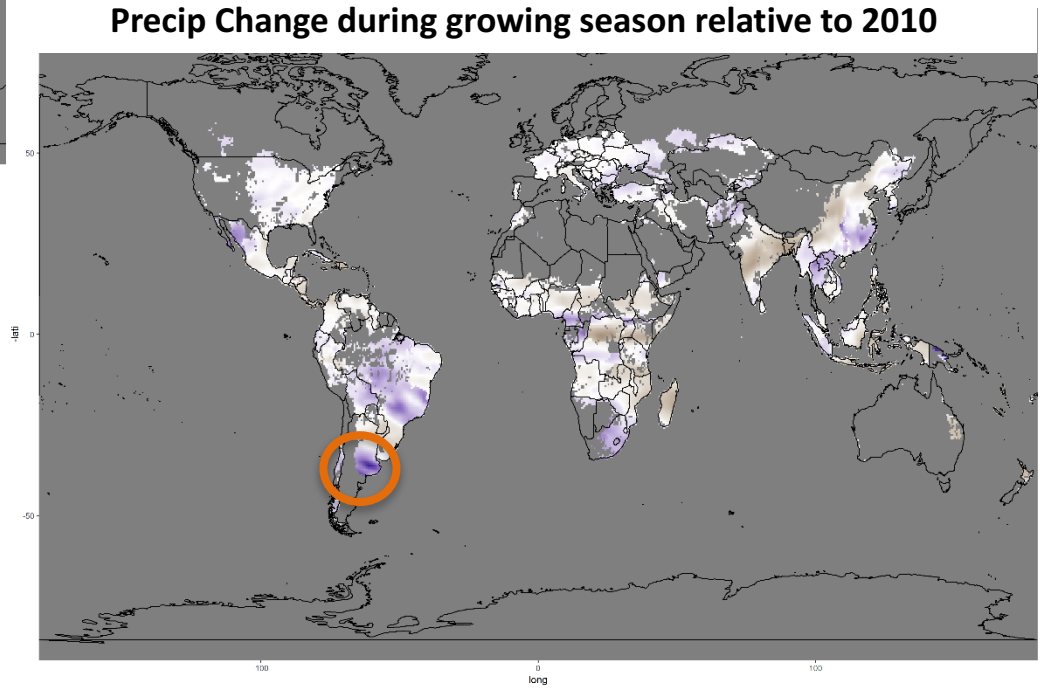
- Regridded CCSM4 RCP 8.5
- Baseline = 2010
- Year of interest = 2050

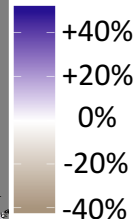
Rainfed Corn in 2050

Temperature Change during growing season relative to 2010



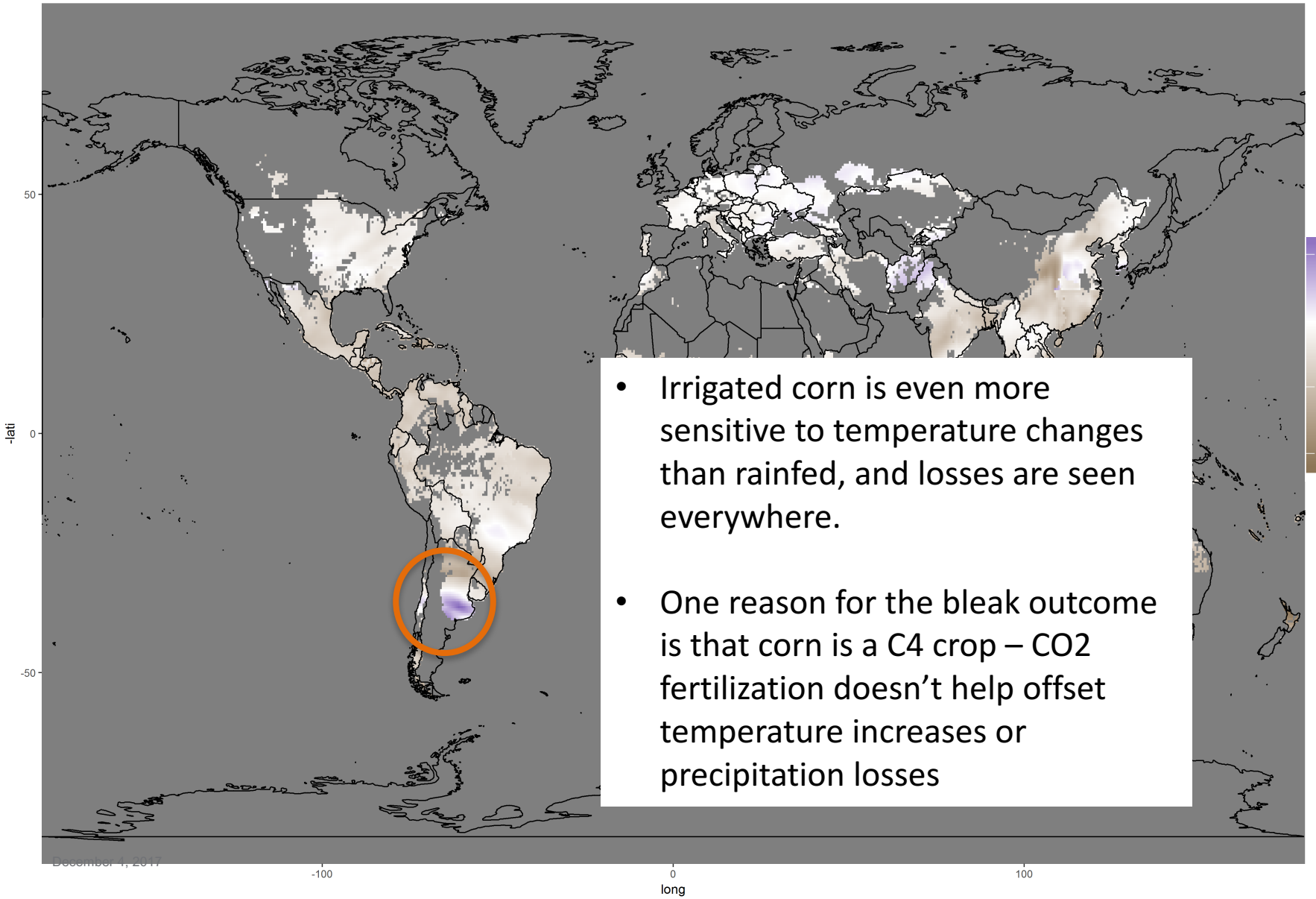
Precip Change during growing season relative to 2010





Areas based on SPAM 2005 harvested area

Rainfed Corn, Yield % Change in 2050



- Irrigated corn is even more sensitive to temperature changes than rainfed, and losses are seen everywhere.
- One reason for the bleak outcome is that corn is a C4 crop – CO2 fertilization doesn't help offset temperature increases or precipitation losses

Rainfed Corn, Yield % Change in 2050

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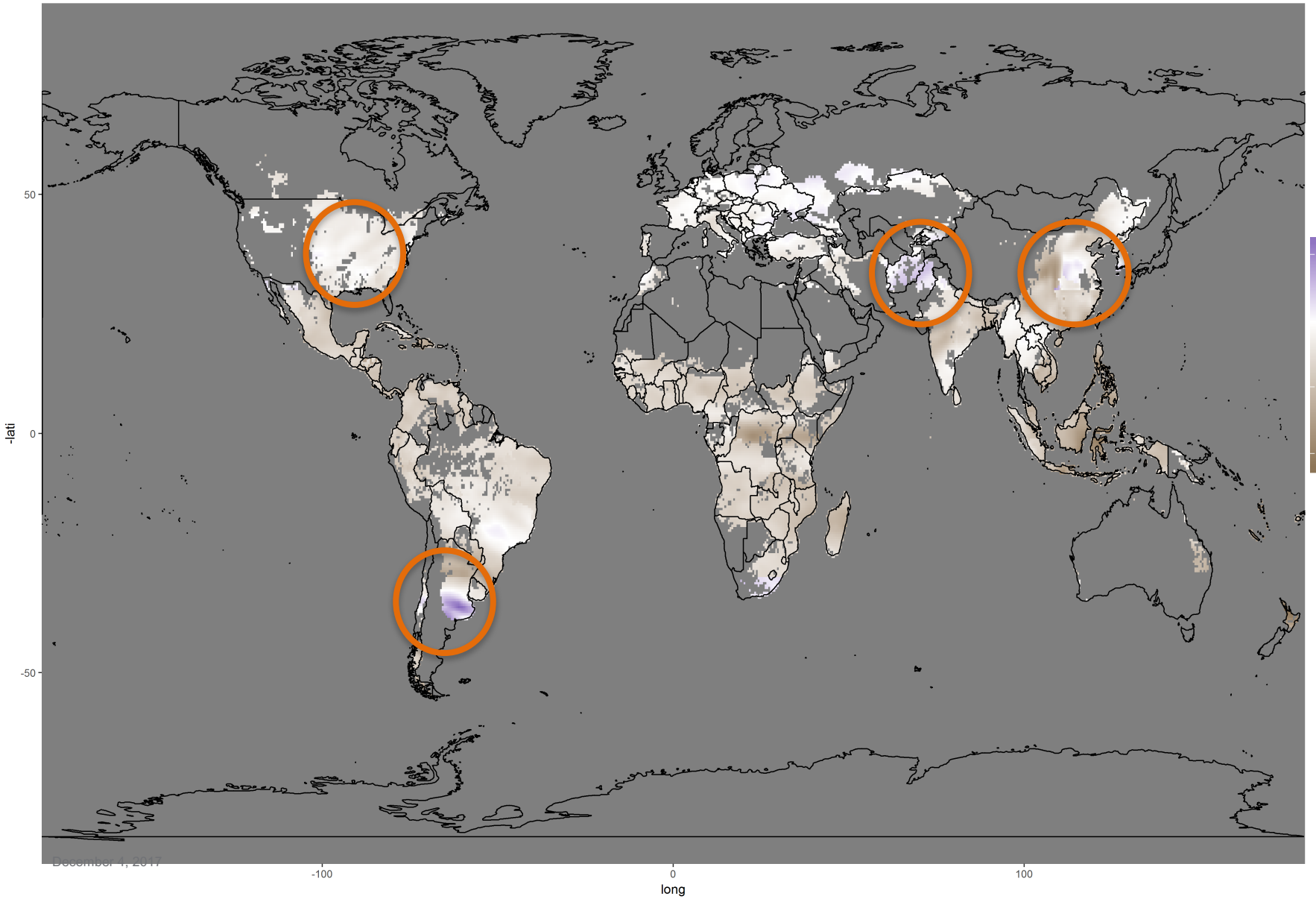
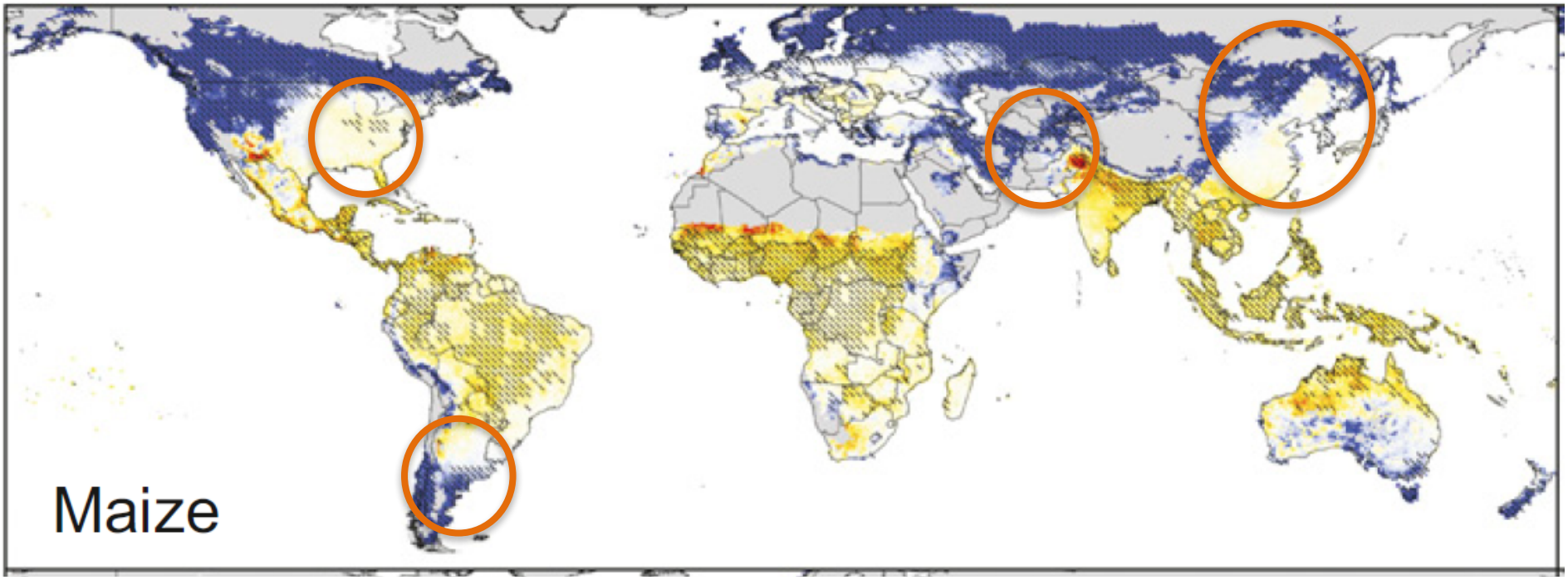


AgMIP Maize

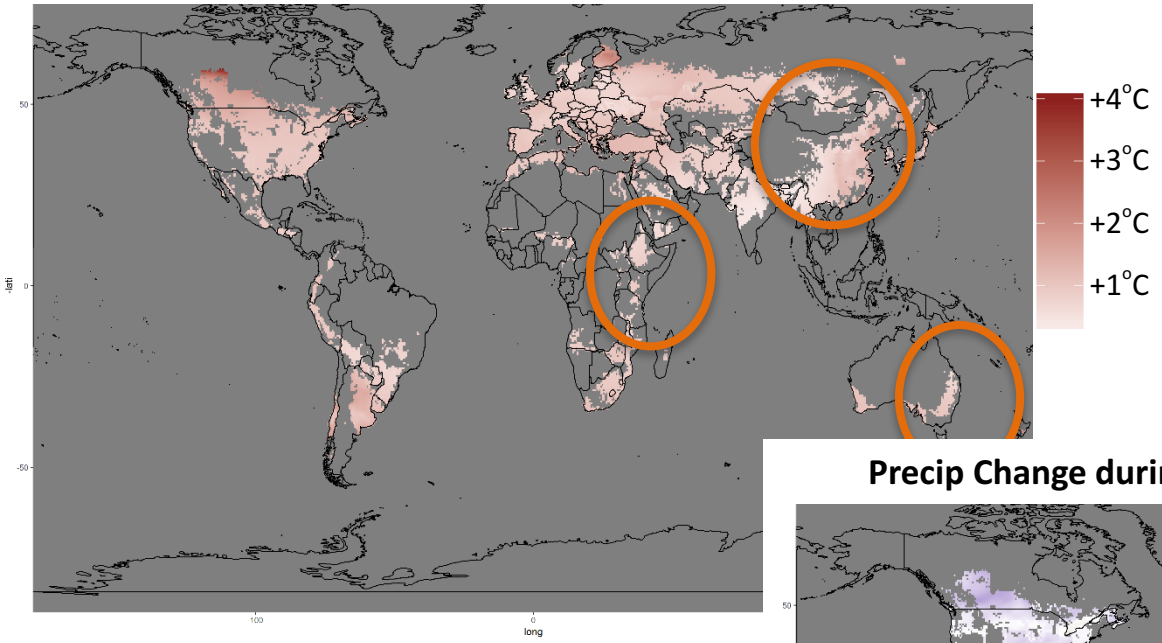
Rosenzweig et al: Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison, *PNAS* 2013

- Median yield changes measured in 2080 relative to a slightly different baseline than I showed (but that's flexible for ours) across all 35 AgMIP Fast track crop model – GCM combos
- CCSM4 is not one of the GCMs used in AgMIP Fast track. And they use a different harvested area mask.
- But even with our **VERY** simple approach (that we have a lot of planned improvements for), we are capturing **KEY** features of these more sophisticated **global gridded** crop models, with much less computation time.



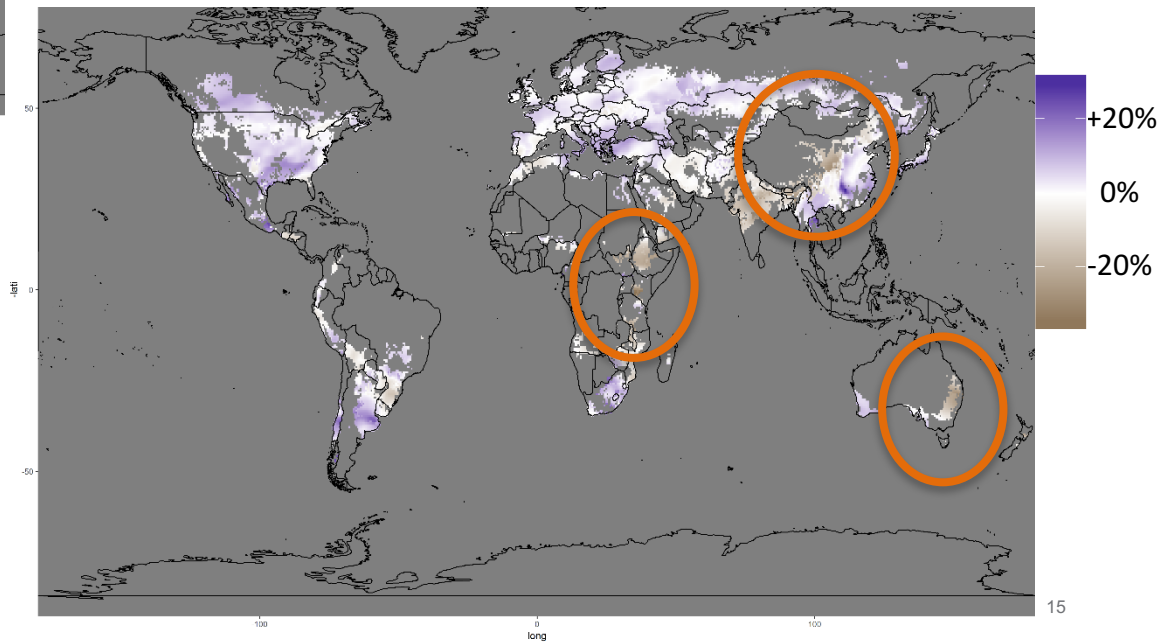
Rainfed Wheat in 2050

Temperature Change during growing season relative to 2010

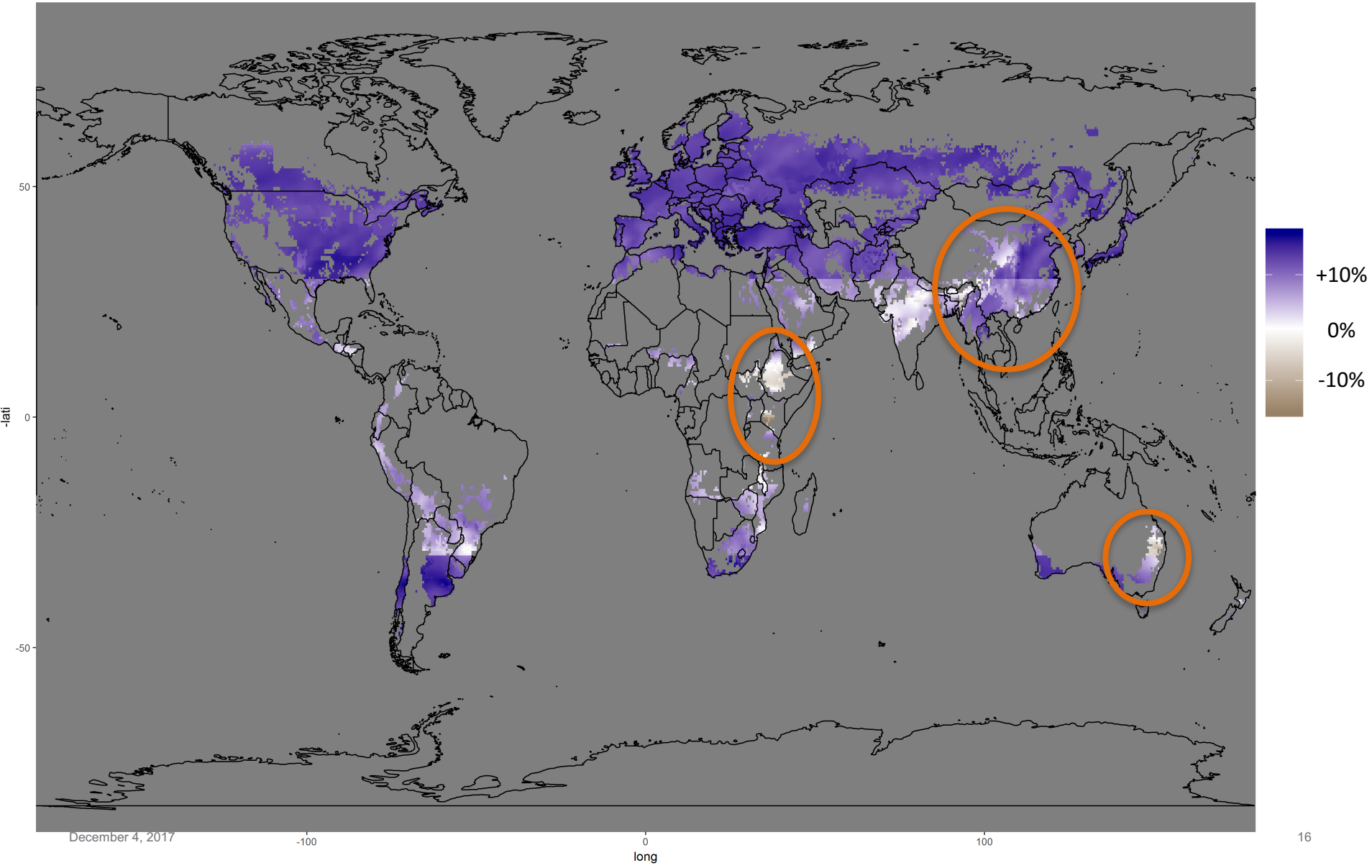


Note the 1-2 degree temperature change almost across the board. Because Wheat is sensitive to CO2 fertilization, and we haven't incorporated the saturation of CO2 fertilization yet, we expect to see some very large yield increases

Precip Change during growing season relative to 2010



Rainfed Wheat in 2050



Future directions

- With this new approach, we can join together with the Scaled Patterns with Variability Added Scenarios being generated and get agricultural responses for each, making for some really interesting GCAM runs **quantifying uncertainties.**

- Introduce more realistic latitude division (true tropics, true mid latitudes, maybe a buffer).
- Continually fine-tuning the functional form we use for the emulators – particularly exploring **saturating yield responses to CO2 increases.**
- Continue working with the **AgMIP global gridded crop modeling team on their emulators**, and eventually join together so that high fidelity, site specific data from C3MP can complement their global coverage (additional details in Ruane et al, An AgMIP framework for improved agricultural representation in IAMs, *ERL* 2017).
- Taking advantage of large amount of yearly C3MP and GGCMI data to train the emulator to emulate **interannual variability** in addition to the long term average earth system state currently modeled.

- Make all of this work available in an open-source, modular online repository that allows for flexible data sets, functional forms, ensemble criteria, growing seasons, etc.

Future directions with AgMIP

- Continue working with the **AgMIP global gridded crop modeling team on their emulators.**
- Support the Coordinated Global-Regional Assessment activities of AgMIP with the emulators.
- Continue collaborating with AgMIP at large.

- Crop yield emulators can only be well done if we understand the crop models and have the trust of the crop modeling community.

Acknowledgements/questions

- Alex Ruane and Meridel Phillips,
- AgMIP researchers
- Kate Calvin and Leon Clarke
- Cary Lynch

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