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What's New in GCAM v5

November 1, 2018

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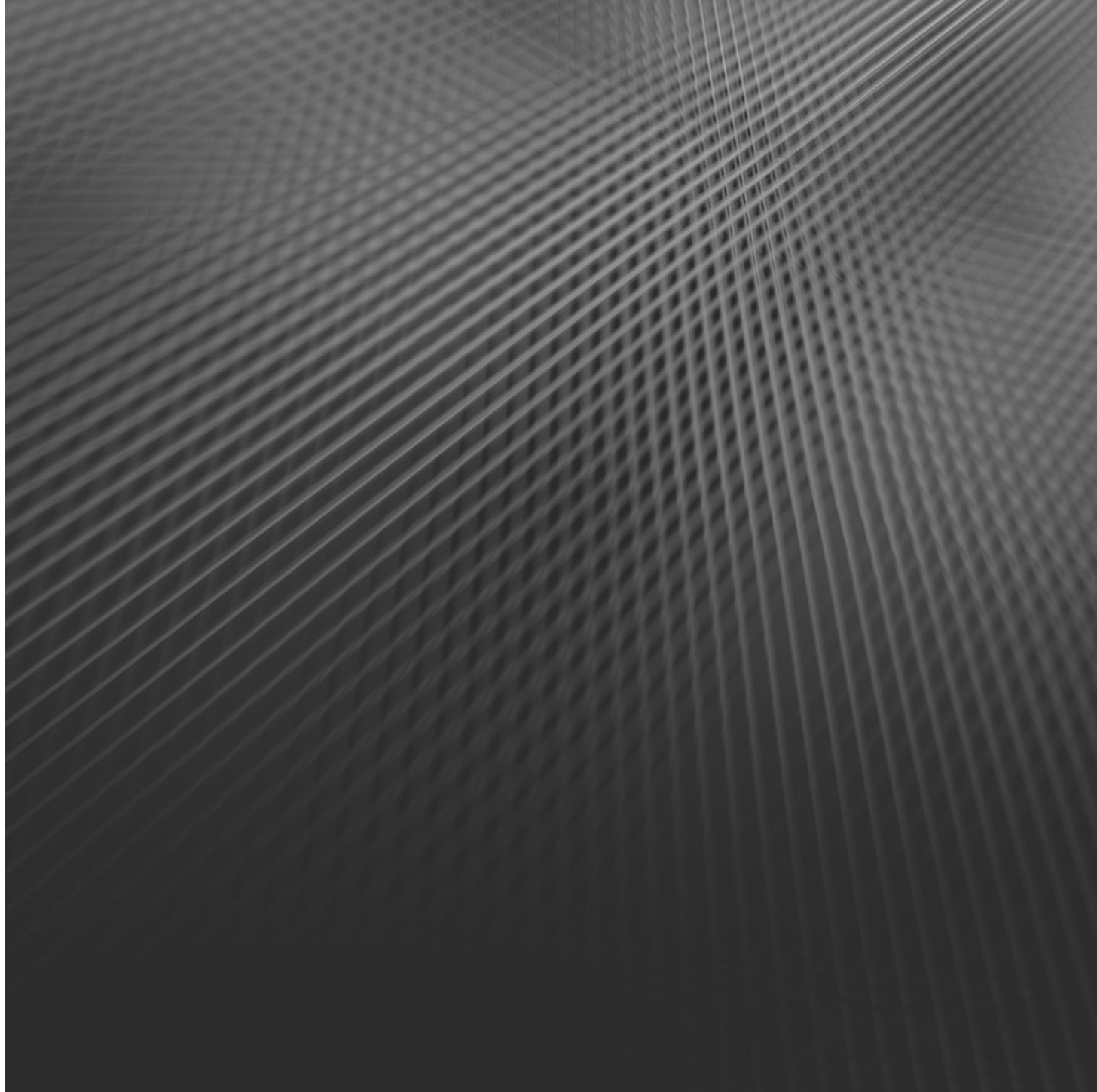

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Overview of GCAM v5

- Updated land use-land cover
- Water demand
- Endogenous Agricultural Management
- Hector updates
- Shared Socioeconomic Pathways
- GCAM data system
- Computational improvements

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Land use-land cover

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Water demand

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Water demands: definitions

- Water withdrawals: water withdrawn from a surface or groundwater source
- Water consumption: water used in a way that it is removed from its immediate water environment
- Biophysical water consumption: crop evapo-transpiration
- Seawater: water withdrawn from the ocean or brackish estuaries

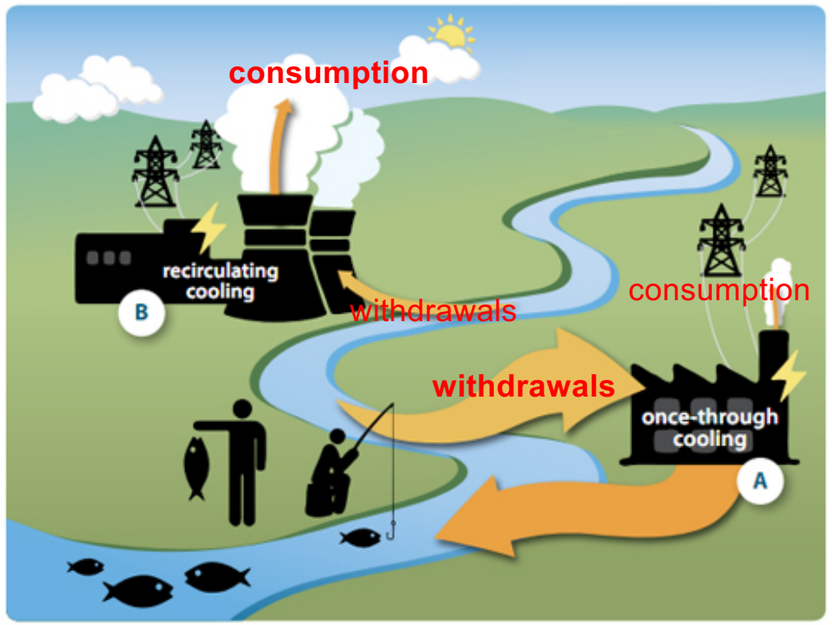
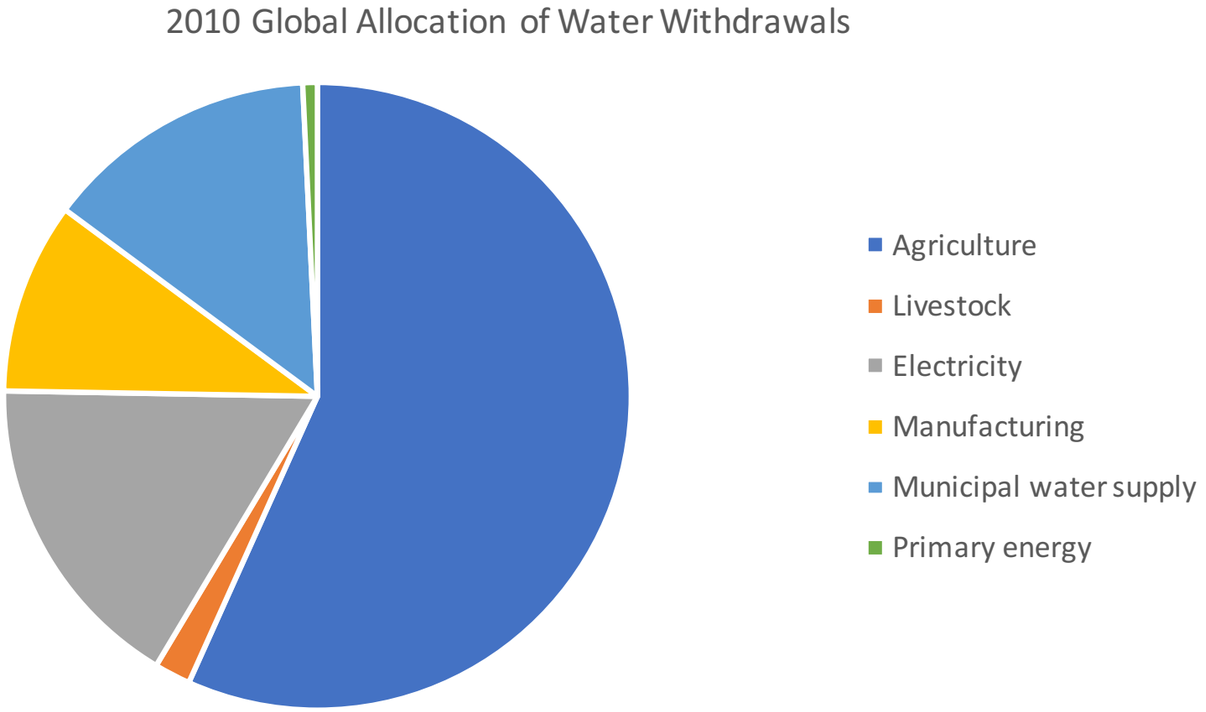


Image source: Union of Concerned Scientists

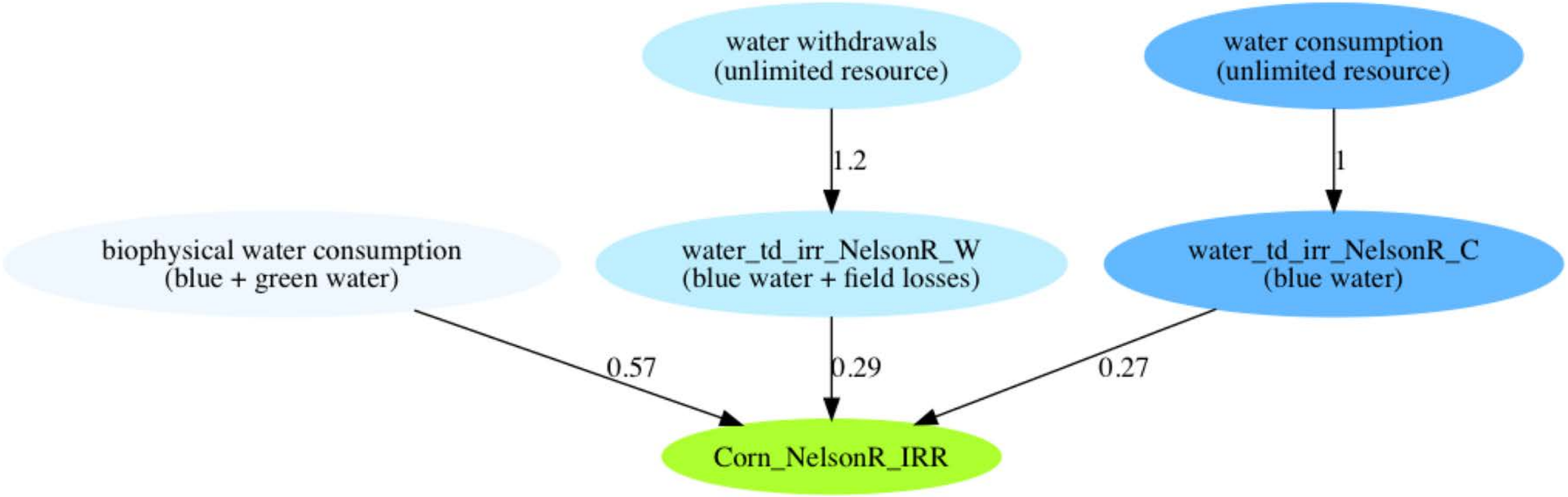
Water demands: sectors

- Agriculture (irrigated crop production)
- Livestock
- Electric power sector (mos thermo-electric cooling)
- Industrial manufacturing
- Municipal water (public wa supply)
- Primary energy production



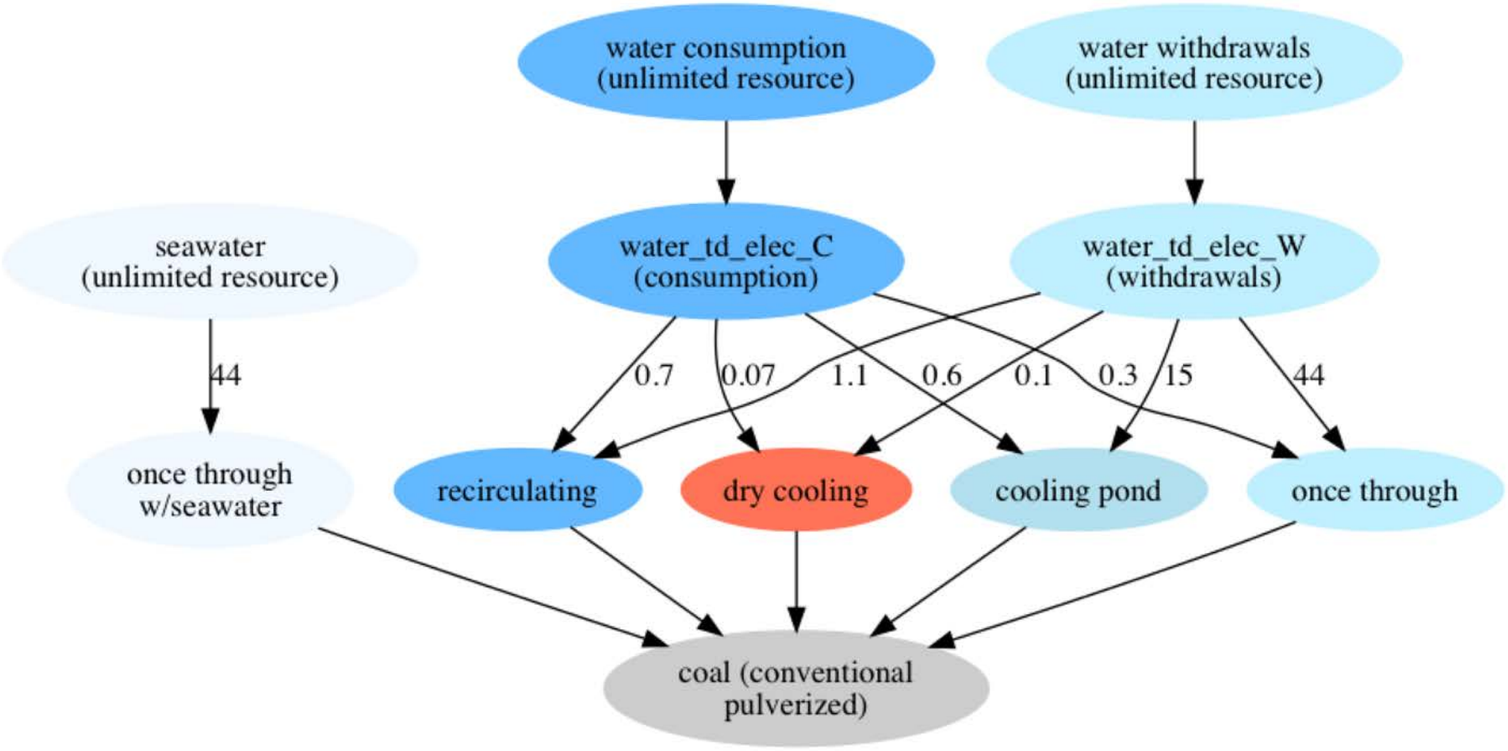
Agriculture

- Water input requirements of crop production
  - Unit: m^3 of water per kg of crop
  - Specific to each region, basin, and crop type
  - Withdrawals (irrigated techs only): blue water plus field losses
  - Consumption (irrigated tech only): blue water
  - biophysical water consumption (irrigated and rainfed techs): blue + green water



Electric sector

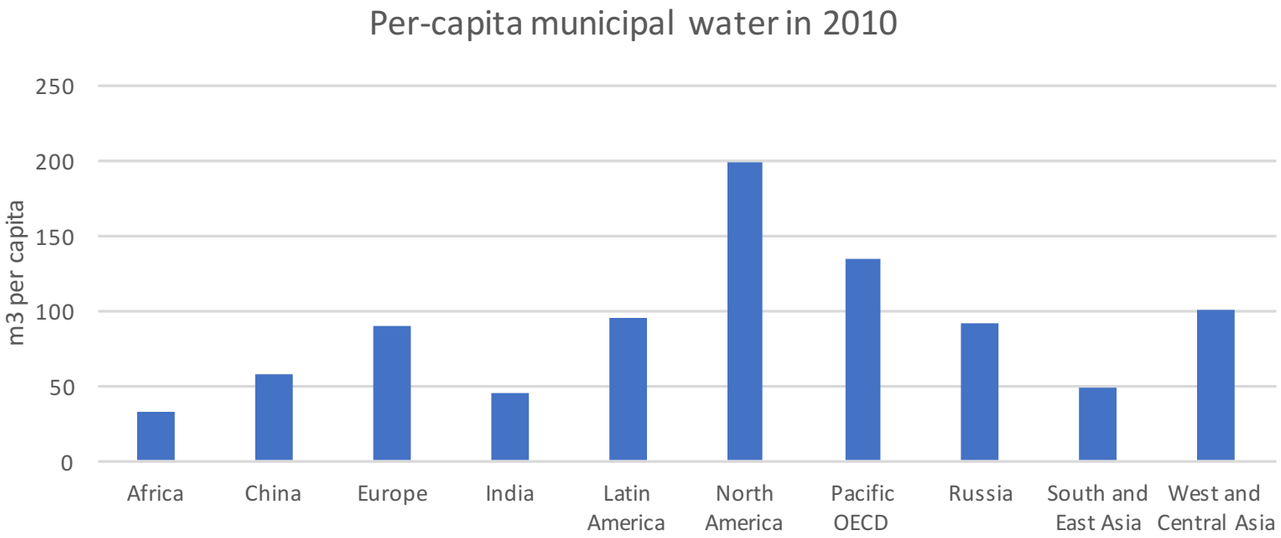
- Water input requirements of electric power generation
  - Unit: m^3 of water per GJ of electricity generation
  - Thermo-electric generation technologies are allowed up to 5 cooling system types
  - Future choice is generally exogenous as water prices are constant in GCAM 5.1



Municipal water

- Public water supply
  - Historical data from FAO Aquastat
  - Includes industrial sector use of municipal water
  - Excludes residential self-supply (i.e., wells)
- Future per-capita water demands (*pcW*) depend on per-capita GDP (*pcGDP*), water prices (*P*), and technological change (*Tech*)

$$pcW_t = pcW_{t-1} * \left(\frac{pcGDP_t}{pcGDP_{t-1}}\right)^{0.37} * \left(\frac{P_t}{P_{t-1}}\right)^{-0.33} * (1 - Tech_t)$$



Remaining sectors

- The remaining sectors' water demands are estimated bottom-up
- Industrial manufacturing
  - All industrial demands of water except for thermo-electric power plant cooling and primary energy production
- Livestock
  - Animal drinking water and operations
- Primary energy production
  - All water use from operations
  - Coal, oil (conventional and unconventional), natural gas, and uranium

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Endogenous Agricultural Management

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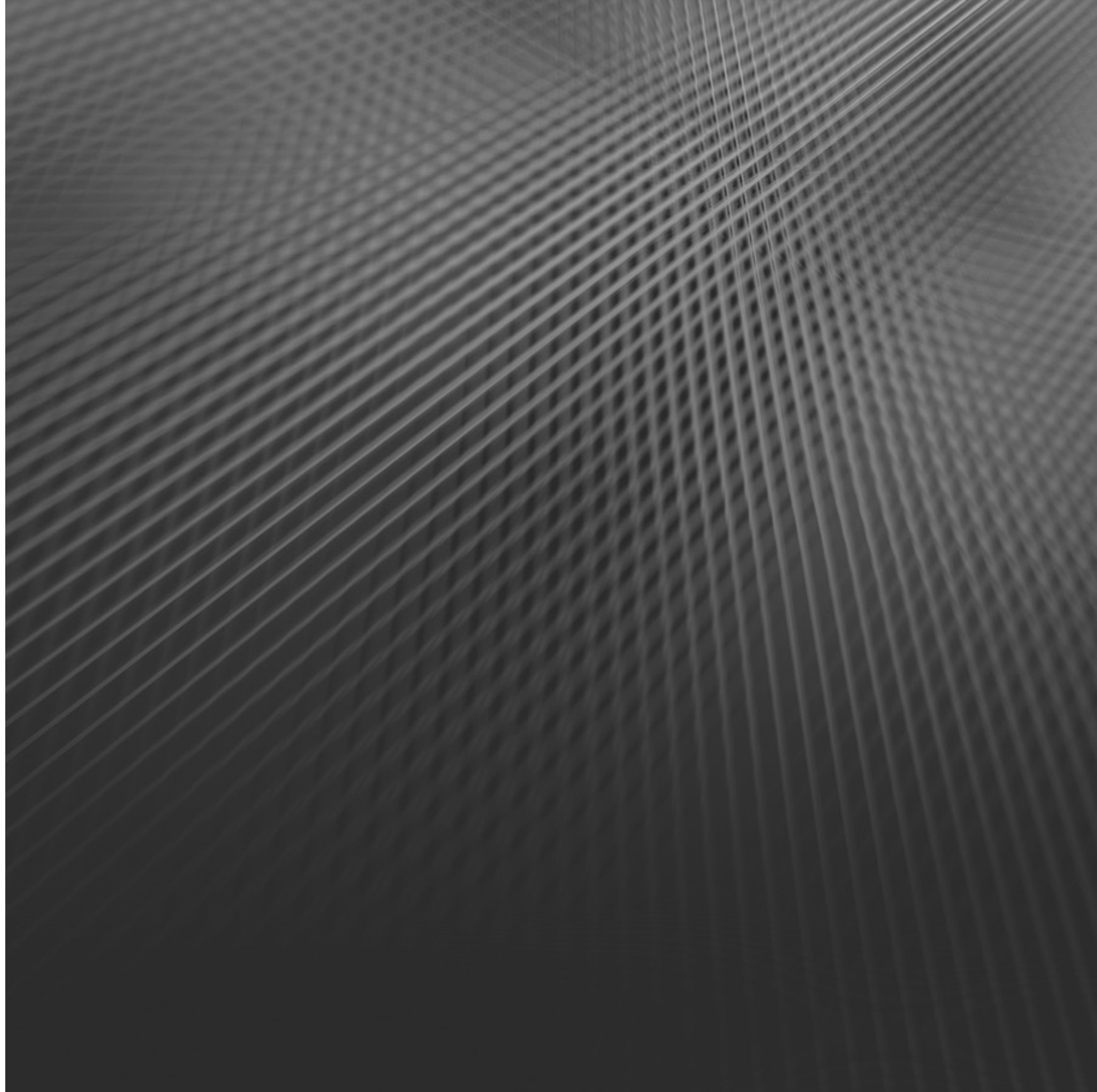
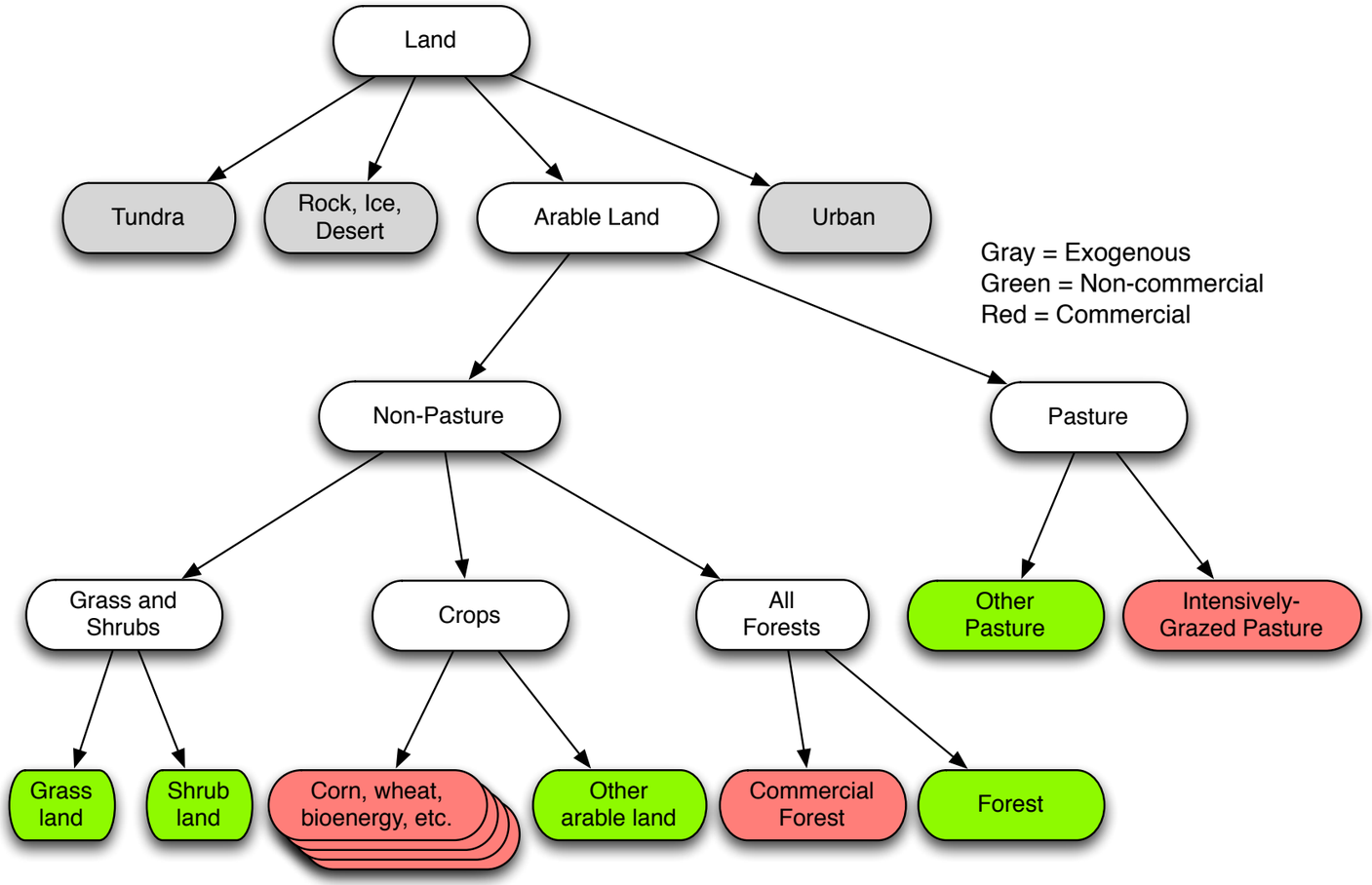
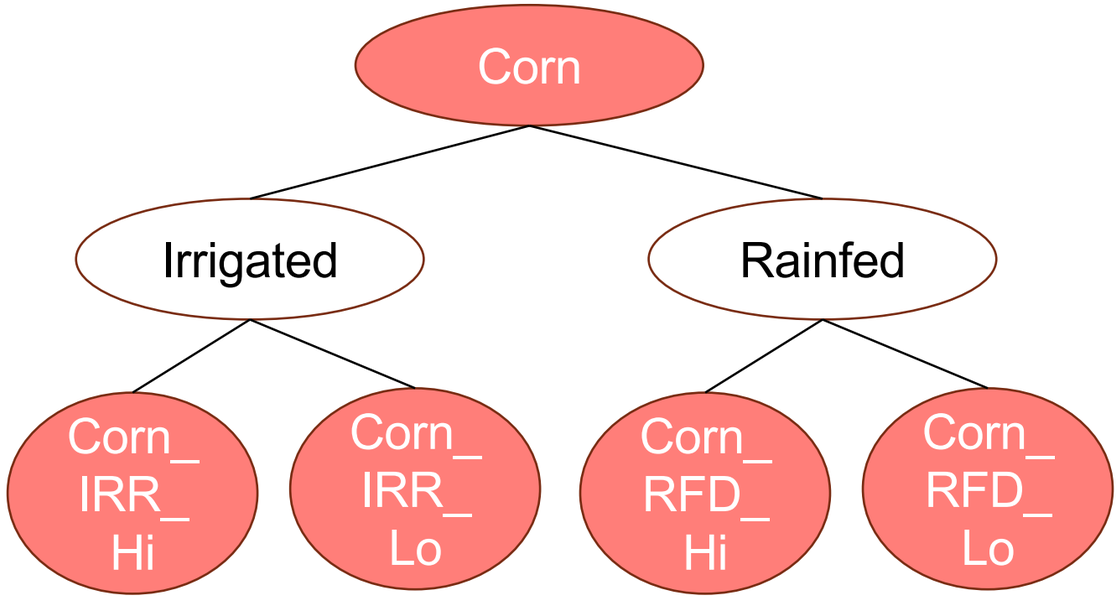


Prior versions of GCAM had a single crop, representing the average of all management practices.

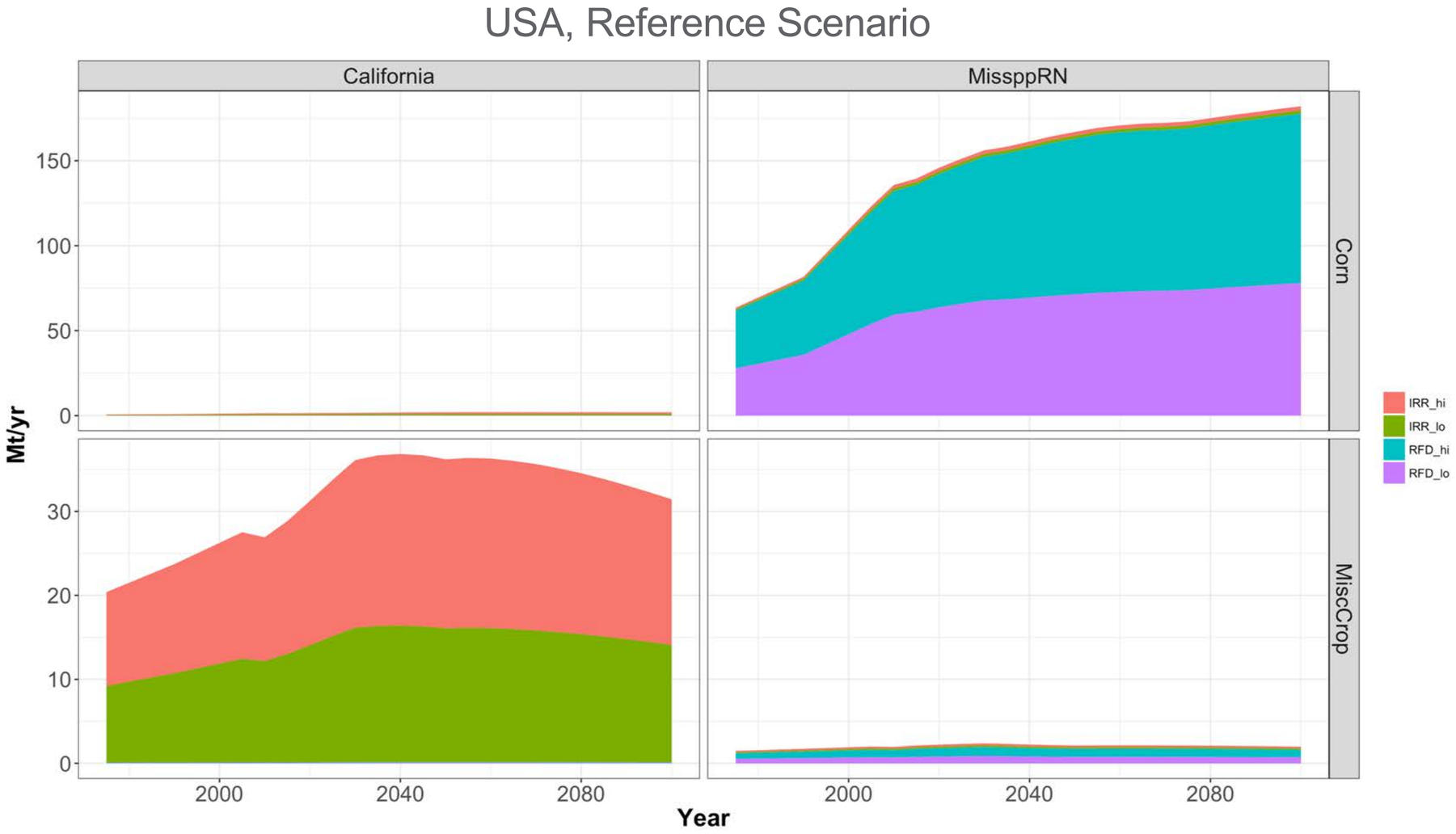


Starting in GCAM v5, we have separated crops into four management types.



- We use a combination of data sources (MIRCA, FAO) to separate irrigated versus rainfed land and production (and yield).
- For fertilizer, we are assuming the same fertilizer application in kgN/kg crop (but different per km^2). We are currently assuming 50% is high and 50% is low, with a yield difference of +/-10% from average observed.

Results


USA, Reference Scenario
California
MissppRN
Corn
MiscCrop
Mt/yr
150
100
50
0
30
20
10
0
2000
2040
2080
Year
IRR_hi
IRR_lo
RFD_hi
RFD_lo

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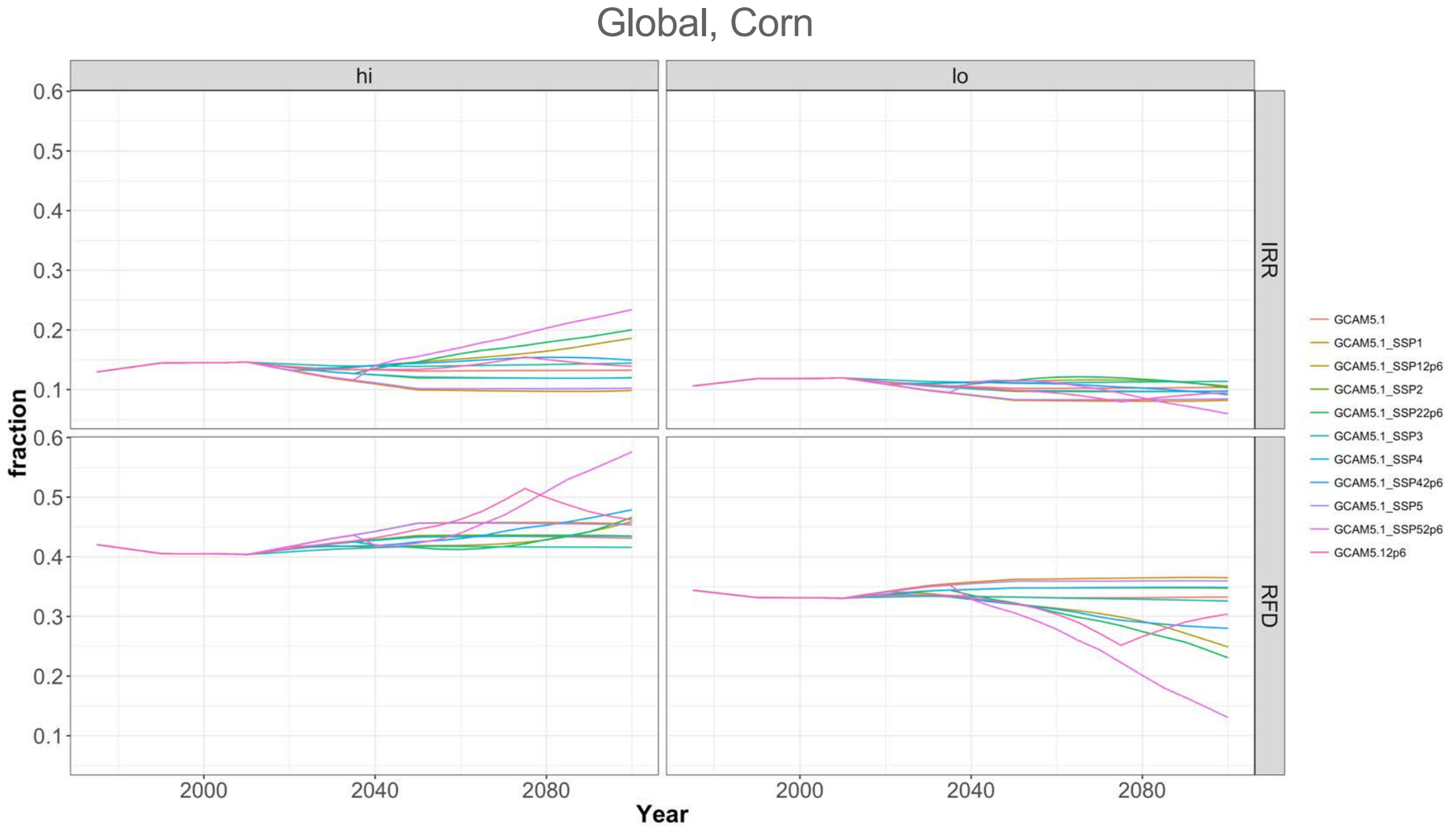
Results



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Hector Updates

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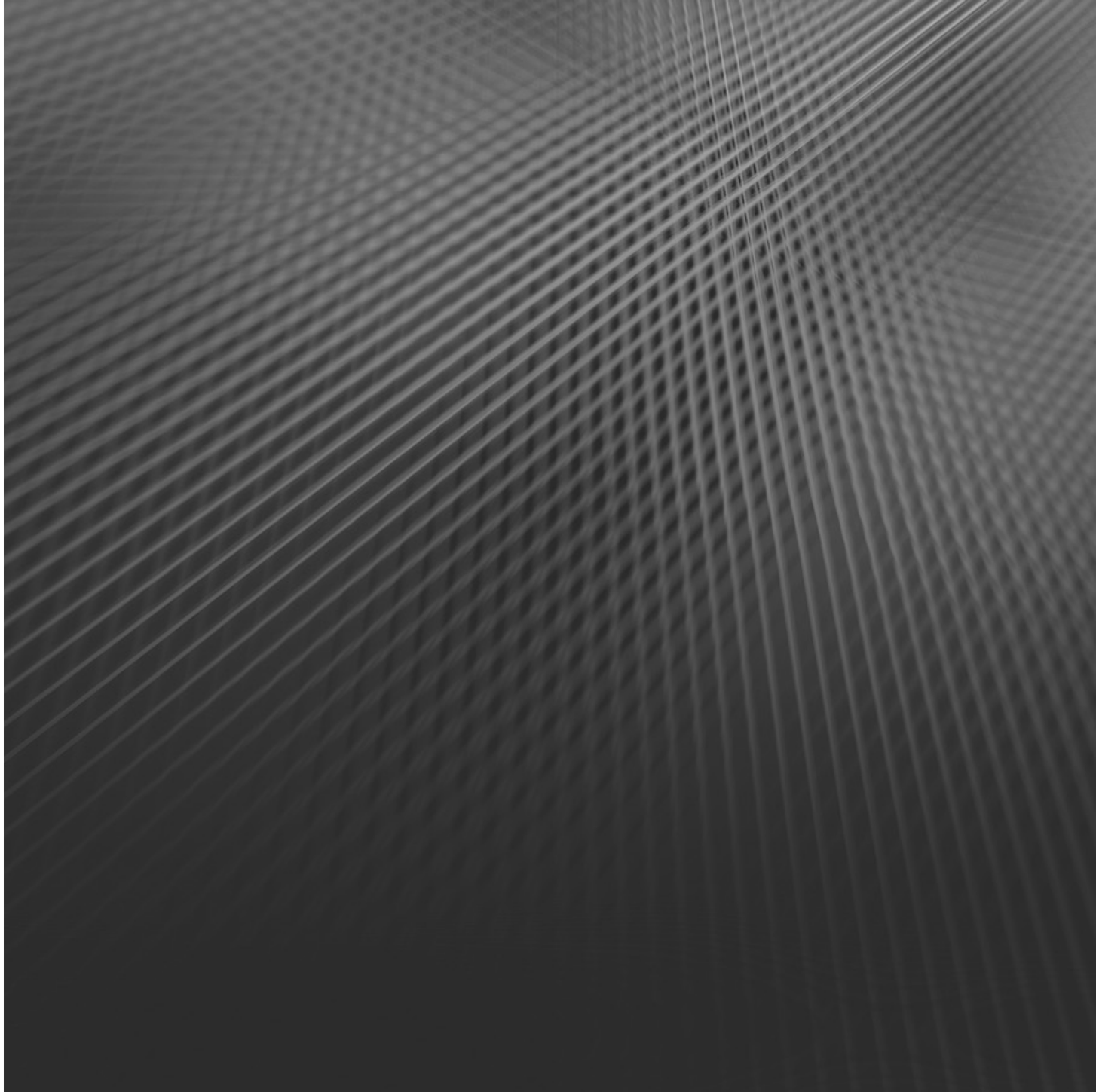
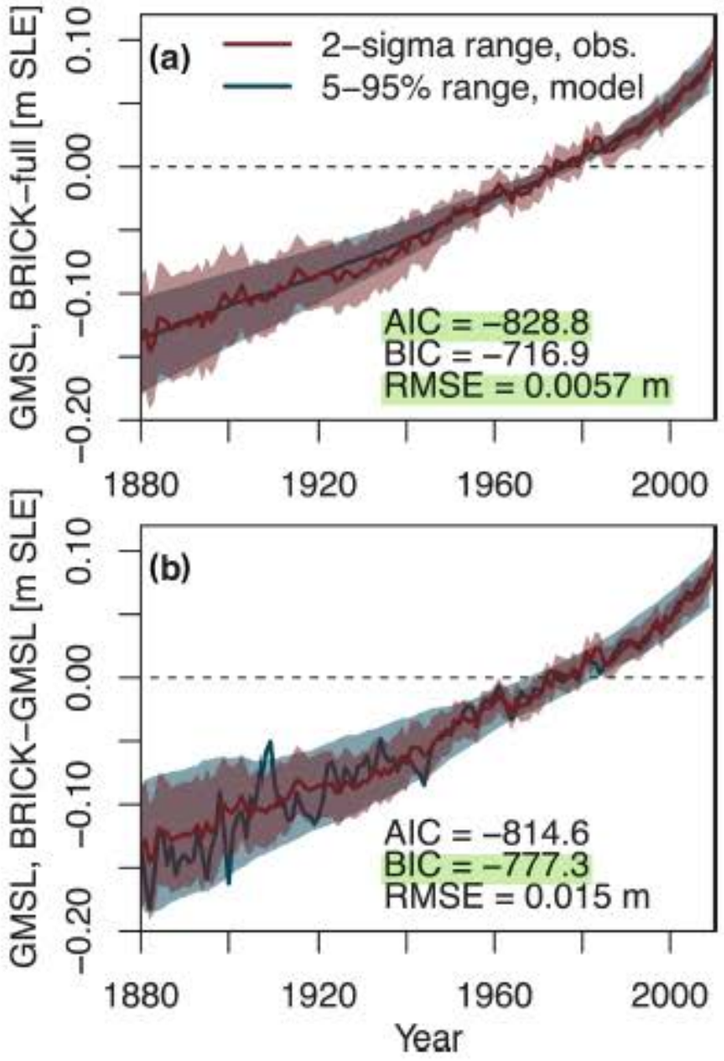


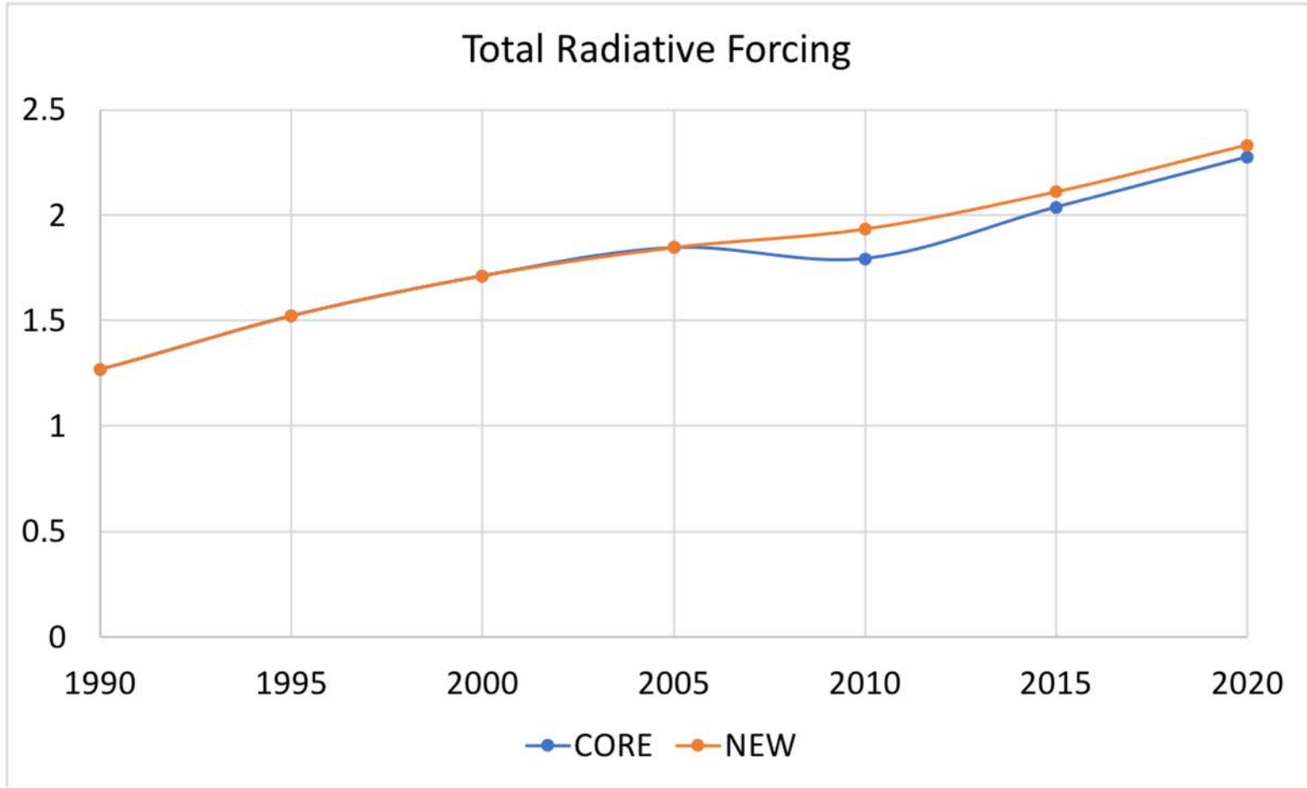
Recent Hector developments

- Ben Vega-Westhoff and Ryan Sriver – UIUC
  - DOECLIM – ocean heat diffusion
  - BRICK – sea-level rise model
    - ✓Contributions from Greenland, Antarctica, ice sheets and thermal expansion
- Adria Schwarber (UMD)
  - Fundamental impulse tests



Recent Hector developments

- We identified and fixed two minor bugs that were affecting radiative forcing in 2010 in coupled GCAM-Hector (these weren't issues in standalone Hector).
  - Unit conversion error for N_2O and NO_x
  - Missing emissions factors for protected lands



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SSPs

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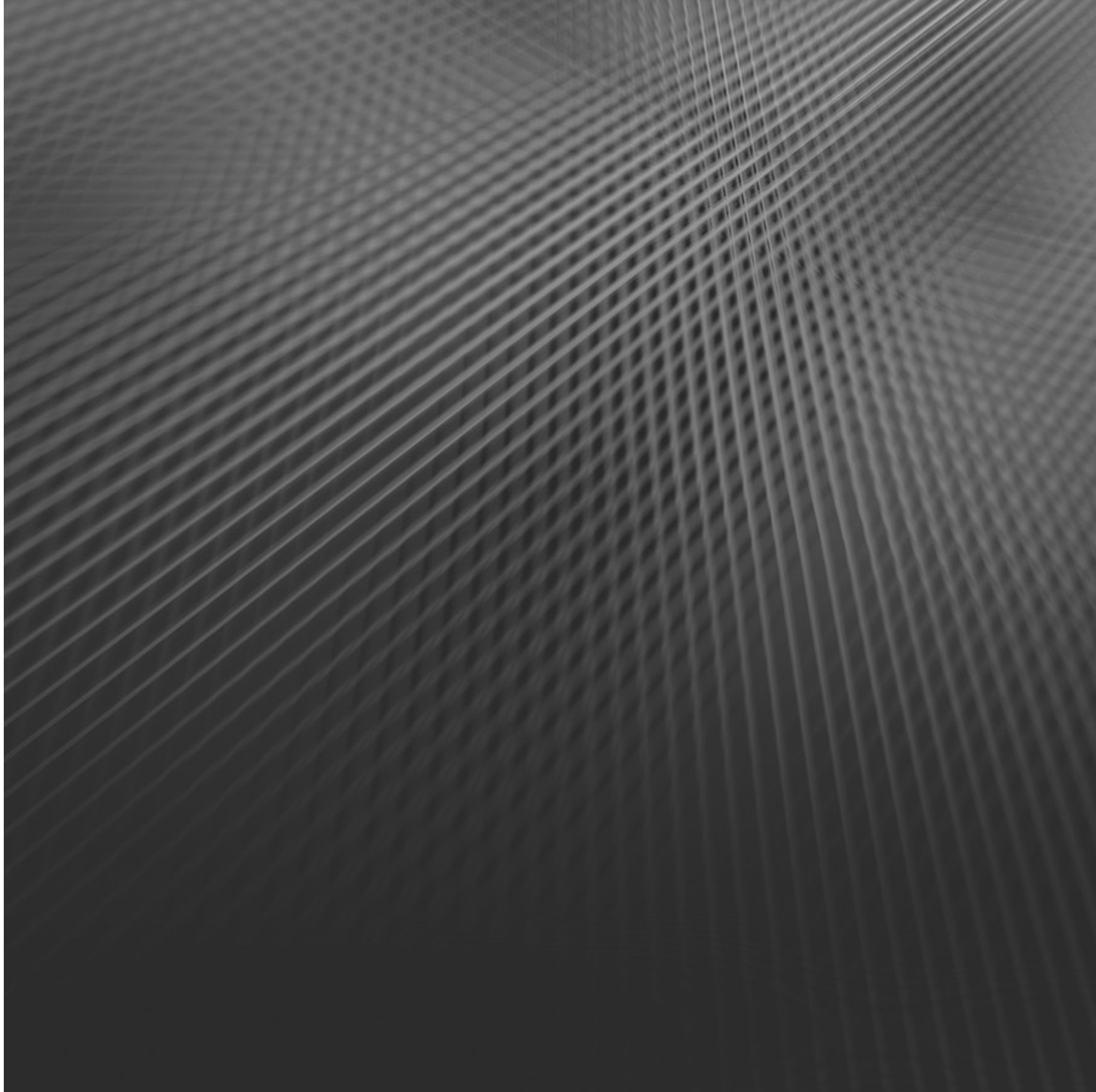
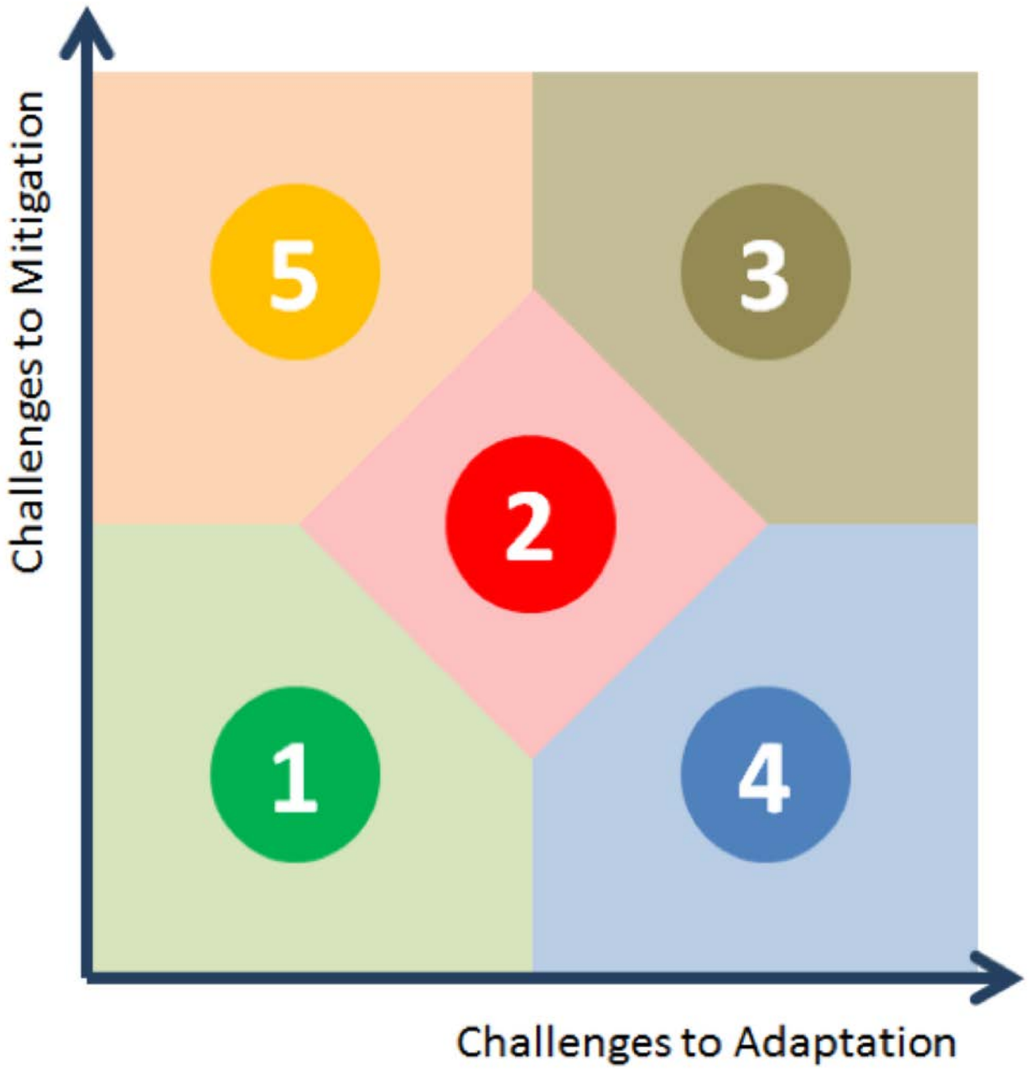


Overview of the SSPs

- The SSPs are new reference pathways for climate research.
- These five scenarios are defined along two axes: challenges to mitigation and challenges to adaptation.
- By themselves, the SSPs assume no climate mitigation, but these can be paired with different radiative forcing targets.



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GCAM Implementation of the SSPs

- To implement the SSPs within GCAM, we use the demographic and economic assumptions developed by Lutz et al. (2015) and Dellink et al. (2015) in combination with technology and policy assumptions derived from the SSP narratives (O'Neill et al. 2015).

Category	Variable	SSP1	SSP2	SSP3	SSP4 (High / Medium / Low Income)	SSP5
Socioeconomics	Population in 2100	6.9 billion	9 billion	12.7 billion	0.9 billion / 2.0 billion / 6.4 billion	7.4 billion
	GDP per capita in 2100	$46,306	$33,307	$12,092	$123,244 / $30,937 / $7,388	$83,496
Fossil Resources (Technological Change/Acceptance)	Coal	Med/Low	Med/Med	High/High	Med/Low / Med/Med / Med/High	High/High
	Conventional Gas & Oil	Med/Med	Med/Med	Med/Med	High/Low / High/Low / High/Low	High/High
	Unconventional Oil	Low/Med	Med/Med	Med/Med	Med/Low / Med/Low / Med/Low	High/High
Electricity (Technology Cost)	Nuclear	High	Med	High	Low /Low / Low	Med
	Renewables	Low	Med	High	Low / Low / Low	Med
	CCS	High	Med	Med	Low / Low / Low	Low
Fuel Preference	Renewables	High	Med	Med	High / High / High	Med
	Traditional Biomass	Low	Low	High	Low / Low / High	Low

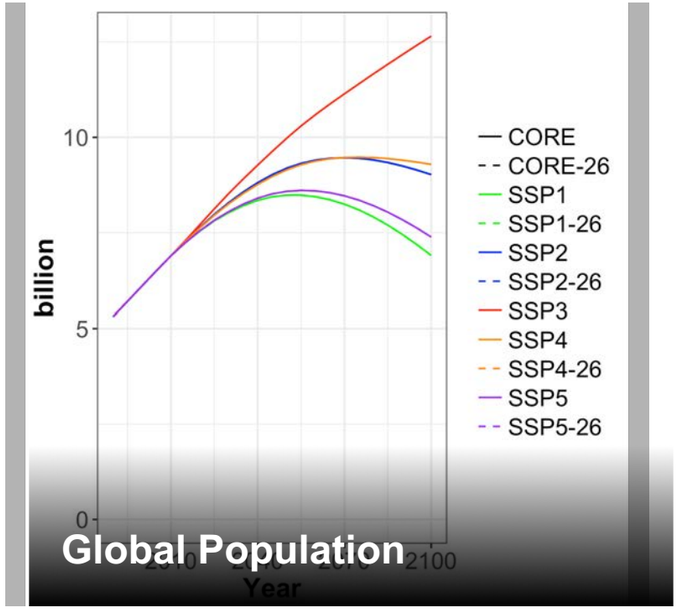
GCAM Implementation of the SSPs

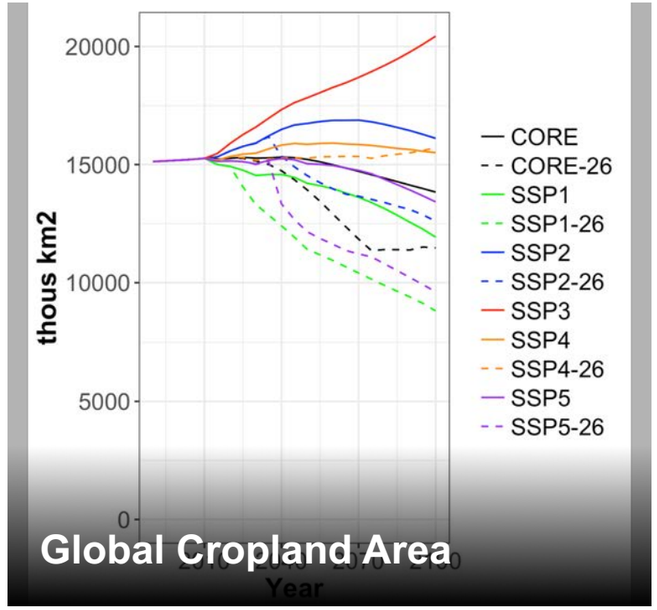
- To implement the SSP storylines within GCAM, we quantified “high”, “medium”, and “low” for each of the variables.

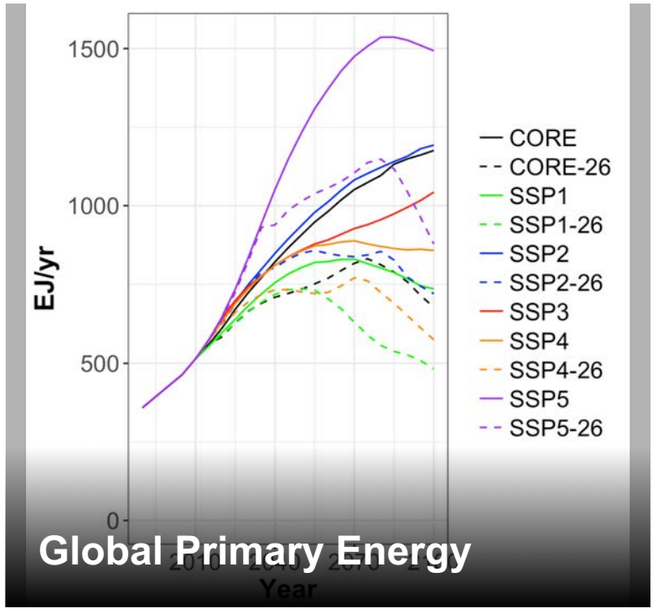
Variable	SSP1	SSP2	SSP3	SSP4 (High / Med / Low Income)	SSP5
Agricultural Productivity Growth	50% above GCAM default	GCAM default	50% below GCAM default	50% above GCAM default / GCAM default / 50% below GCAM default	50% above GCAM default
Meat Demand	Meat demand limited to 1000 kcal/per/day. Shift in preferences among meat products away from beef, sheep, and goats.	Meat demand limited to 1100 kcal/per/day.	Meat demand limited to 1400 kcal/per/day.	Meat demand limited to 1100kcal/per/day.	Meat demand limited to 1400 kcal/per/day.

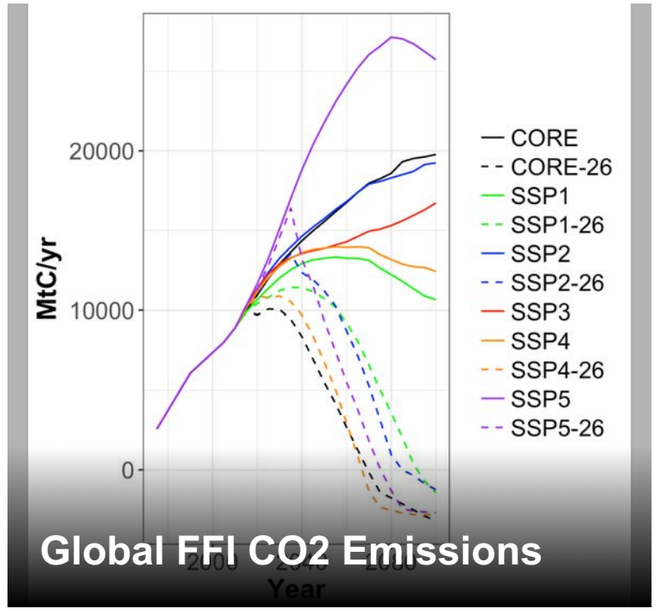
Results from the SSPs

- There are significant differences across SSPs and across radiative forcing levels.









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GCAM data system

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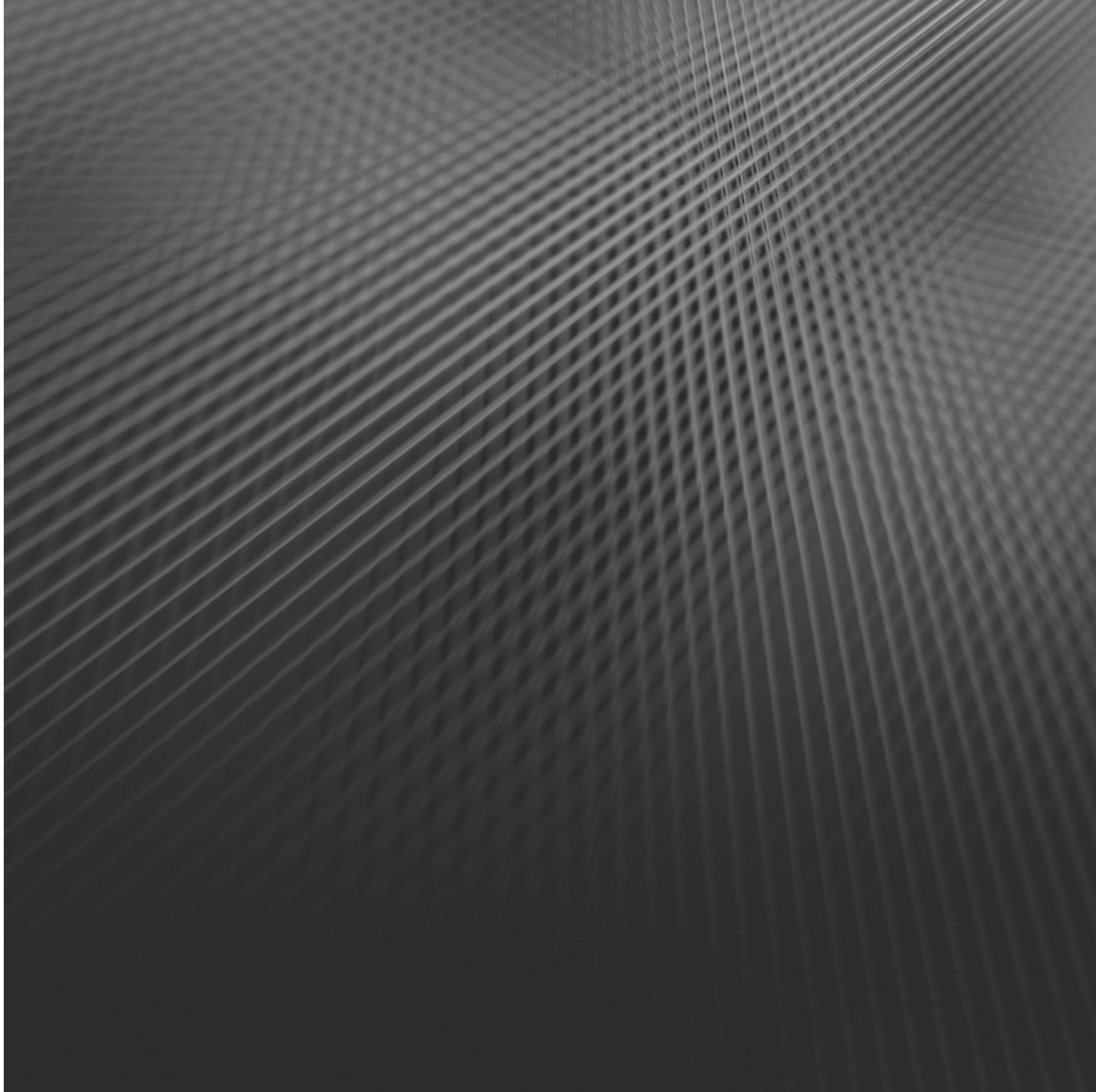

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The GCAM data system

- The new version of GCAM has a completely rewritten data system that assembles, checks, and calculates its inputs
- This sophistication is necessary because GCAM is a *computational engine*, not a static model
- The entire structure of the model can be defined and dynamically changed by its inputs

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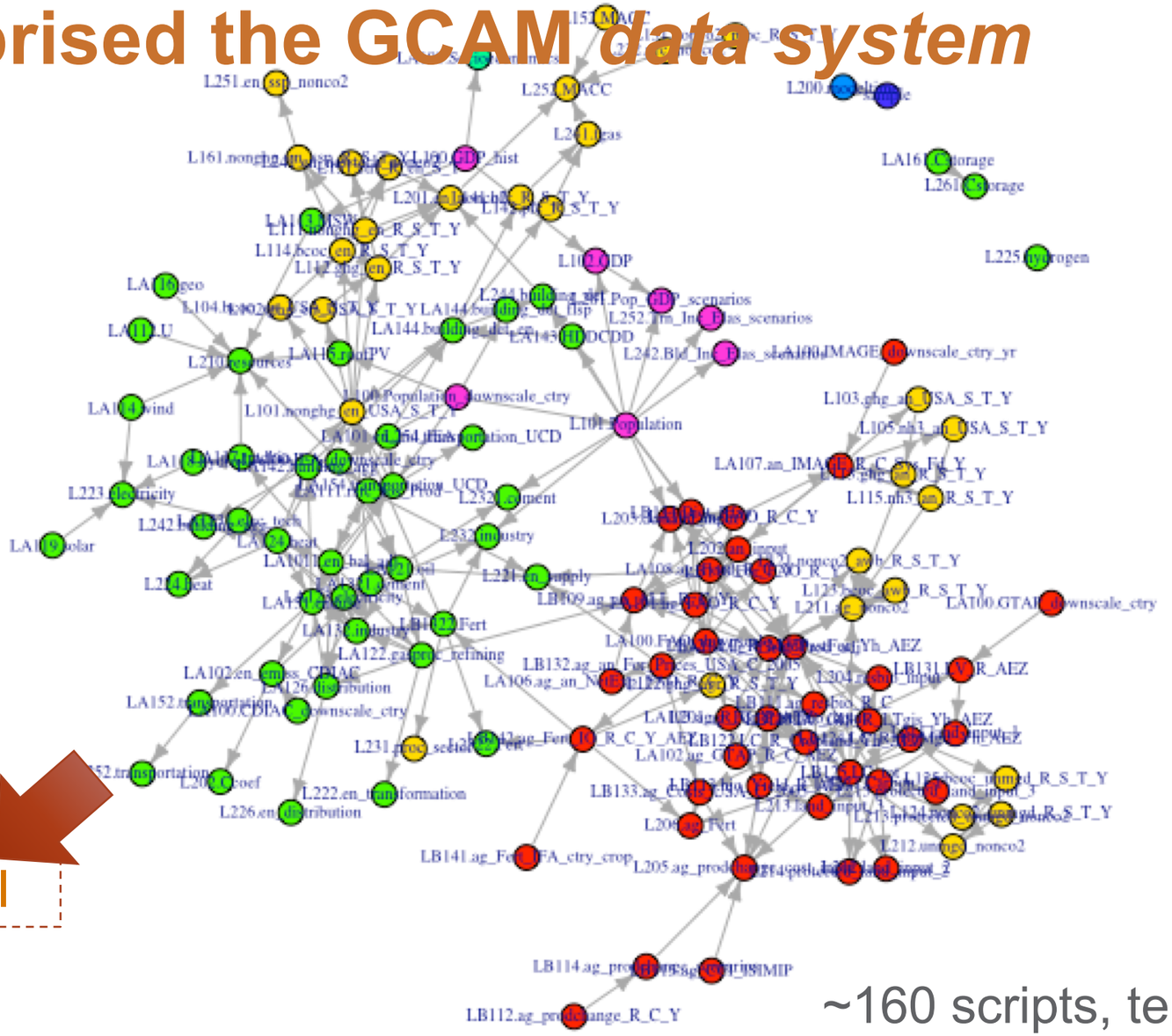
Before, a complex system of R scripts comprised the GCAM *data system*



xml

GCAM

~160 scripts, tens of thousands of lines of code

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Goals for the new data system

- Spread the knowledge and find problems
- Better documentation throughout
- Flexibility (change assumptions)
- Robustness
  - quickly know when things go wrong
- Code clarity
- Tools to diagnose, explore, modify, test
- Easy to use
- Speed

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Principles

- Clear and clean code, documentation, abstracted common code, discrete functions
- Lots and lots of “unit testing”
- R *package*: lots of good things for free, and very easy to install and run

```
> library(gcamdata)
> driver()
GCAM Data System v0.4
Found 190 chunks
Found 1345 chunk data requirement
Found 833 chunk data products
[1]"module_aglu_L2242.land_input”
[1]"- make_0.10”
[1]"module_aglu_LA100.0_LDS_prepr
”
[1]"- make 2.69”
[1]"module_aglu_LA100.FAO_downsca
[1]"- make_3.81"
```

(etc.)

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Testing and its benefits

- With what's called "continuous integration", i.e. continuous automated testing, we can enforce *lots* of good things
  - Correct outputs
  - Robust behavior
  - Code reviews
  - Documentation – system *will not build* with incomplete documentation

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Testing and its benefits

What inputs does it need? Does it use them all?

Is the code well behaved and well documented?

Chunk of code that does some particular data processing step

Does it produce promised outputs? Are they documented? Do they match old data system? What dependencies do they have?

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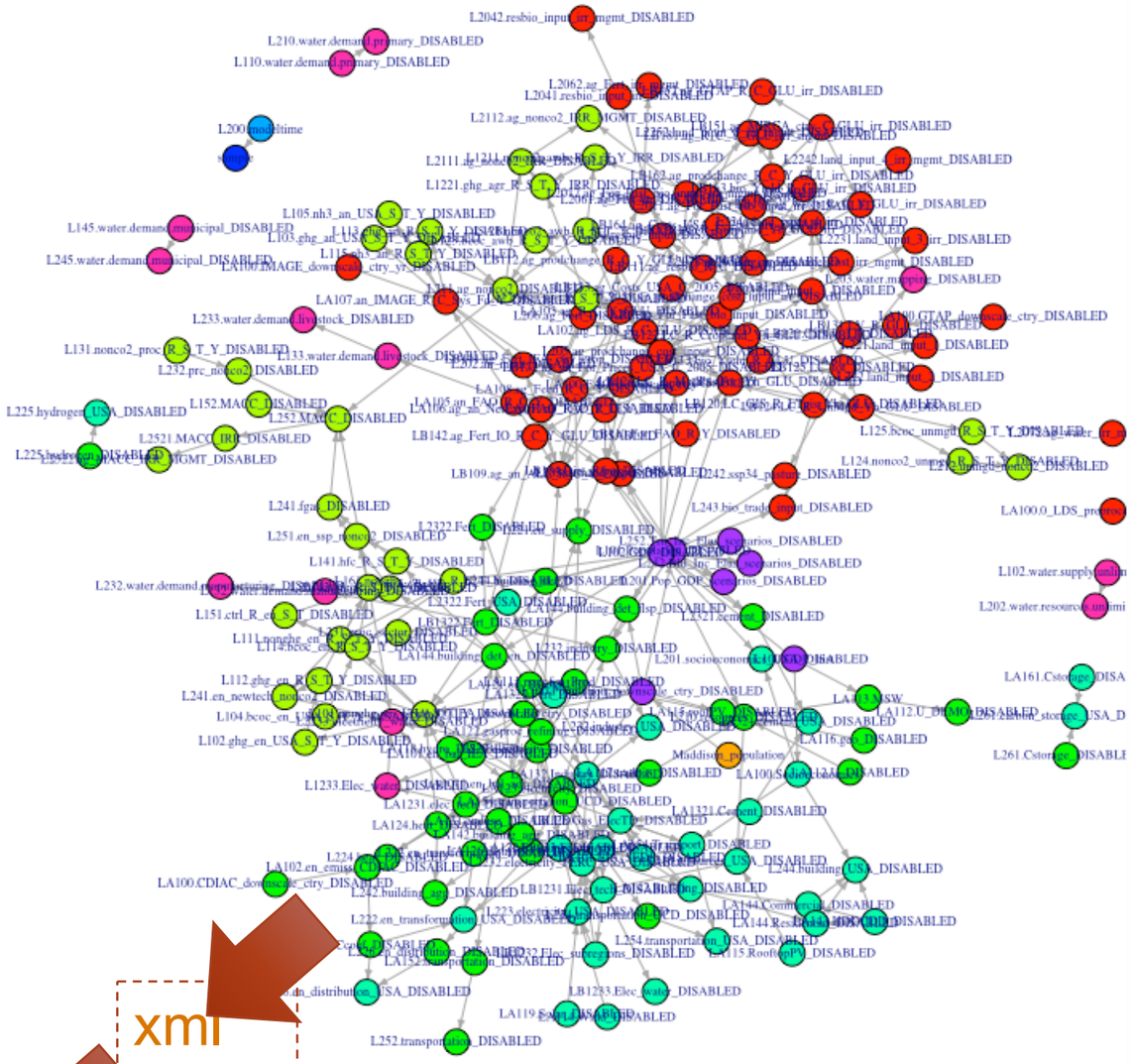
New capabilities enable better and faster research

- Because we define and enforce chunk behavior, we can do useful things:
  - Graph data flow
  - Get the provenance of any piece of data
  - Trace data and identify problems
  - 'Shim' into the data system to examine/change/test
- I.e., this can be a useful tool not just cumbersome scripts
- Data provenance: we can query the new data system for all steps and data sources that produced a particular GCAM input



xml

GCAM

```
> trace("bld_agg_gSSP1.xml")
1 - bld_agg_gSSP1.xml
        produced by module_socio_batch_bld_agg_
        Precursor: L242.IncomeElasticity_bld_gS
2 - L242.IncomeElasticity_bld_gSSP1
        produced by module_socioeconomics_L242.
        Building Income Elasticity: gSSP1 (Unit
        Uses previously calculated per-capita G
        Building income elasticity for each GCA
        Precursor: common/GCAM_region_names (#3
        Precursor: socioeconomics/A42.inc_elas
        Precursor: L102.pcgdp_thous90USD_Scen_R
3 - common/GCAM_region_names - read from file
        GCAM 32-region names (NA)
        Maps GCAM region IDs to region names
        Read from extdata/common/GCAM_region_na
        No precursors
4 - socioeconomics/A42.inc_elas - read from fi
        Building sector income elasticity, (pcg
inc_elas:unitless (% change in service demand
        aggregate buildings sector income elast
        Read from extdata/socioeconomics/A42.in
        No precursors
5 - L102.pcgdp_thous90USD_Scen_R_Y - produced
        Gross Domestic Product (GDP) per capita
of 1990 USD (MER))
        Computed as GDP/population.  Values pri
        historical; values subsequent are from
        Precursor: common/iso_GCAM_regID (#6 be
        Precursor: socioeconomics/SSP_database_
        Precursor: socioeconomics/IMF_GDP_growt
        Precursor: L100.gdp_mil90usd_ctry_Yh (#
        Precursor: L101.Pop_thous_R_Yh (#10 bel
        Precursor: L101.Pop_thous_Scen_R_Yfut (
6 - common/iso_GCAM_regID - read from file
        ISO to GCAM region mapping (NA)
        Maps iso codes to GCAM regions (includi
        ----------,,Former GCAM regions,
        Read from extdata/common/iso_GCAM_regID
        No precursors
```

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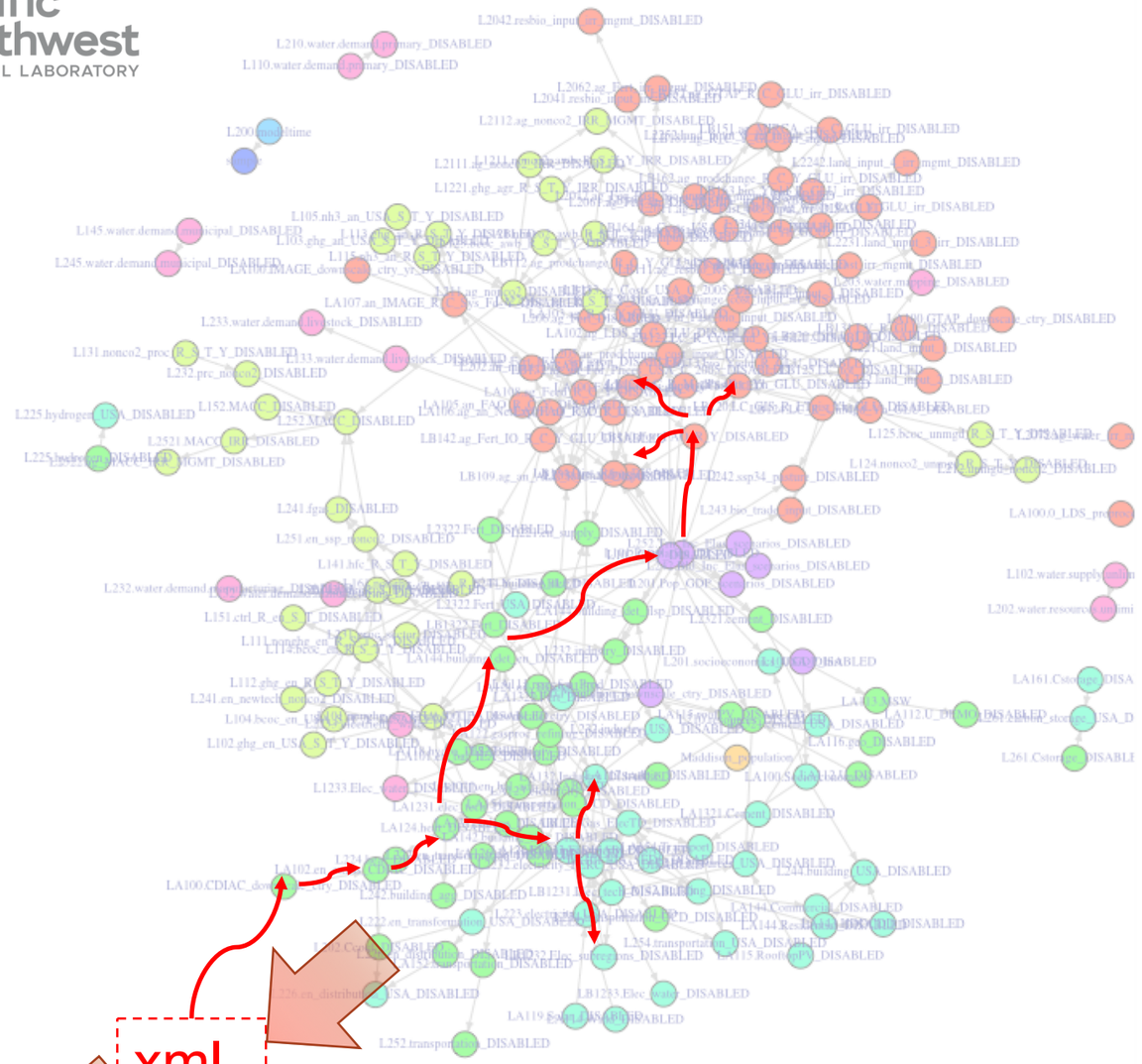

GCAM

```
> trace("bld_agg_gSSP1.xml")
1 - bld_agg_gSSP1.xml
        produced by module_socio_batch_bld_agg_
        Precursor: L242.IncomeElasticity_bld_gS
2 - L242.IncomeElasticity_bld_gSSP1
        produced by module_socioeconomics_L242.
        Building Income Elasticity: gSSP1 (Unit
        Uses previously calculated per-capita G
        Building income elasticity for each GCA
        Precursor: common/GCAM_region_names (#3
        Precursor: socioeconomics/A42.inc_elas
        Precursor: L102.pcgdp_thous90USD_Scen_R
3 - common/GCAM_region_names - read from file
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        Gross Domestic Product (GDP) per capita
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        Precursor: common/iso_GCAM_regID (#6 be
        Precursor: socioeconomics/SSP_database_
        Precursor: socioeconomics/IMF_GDP_growt
        Precursor: L100.gdp_mil90usd_ctry_Yh (#
        Precursor: L101.Pop_thous_R_Yh (#10 bel
        Precursor: L101.Pop_thous_Scen_R_Yfut (
6 - common/iso_GCAM_regID - read from file
        ISO to GCAM region mapping (NA)
        Maps iso codes to GCAM regions (includi
        ----------,,Former GCAM regions,
        Read from extdata/common/iso_GCAM_regID
        No precursors
```

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More capabilities

- Not tie ourselves specific data sources
  - E.g. scale to arbitrary input
- Easy to incorporate upgrade/different data assumptions
- Track units associated with data
- Produce smooth, arbitrary time series for backcasting experiments
- Easy-to-install and run R package

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Computational Improvements

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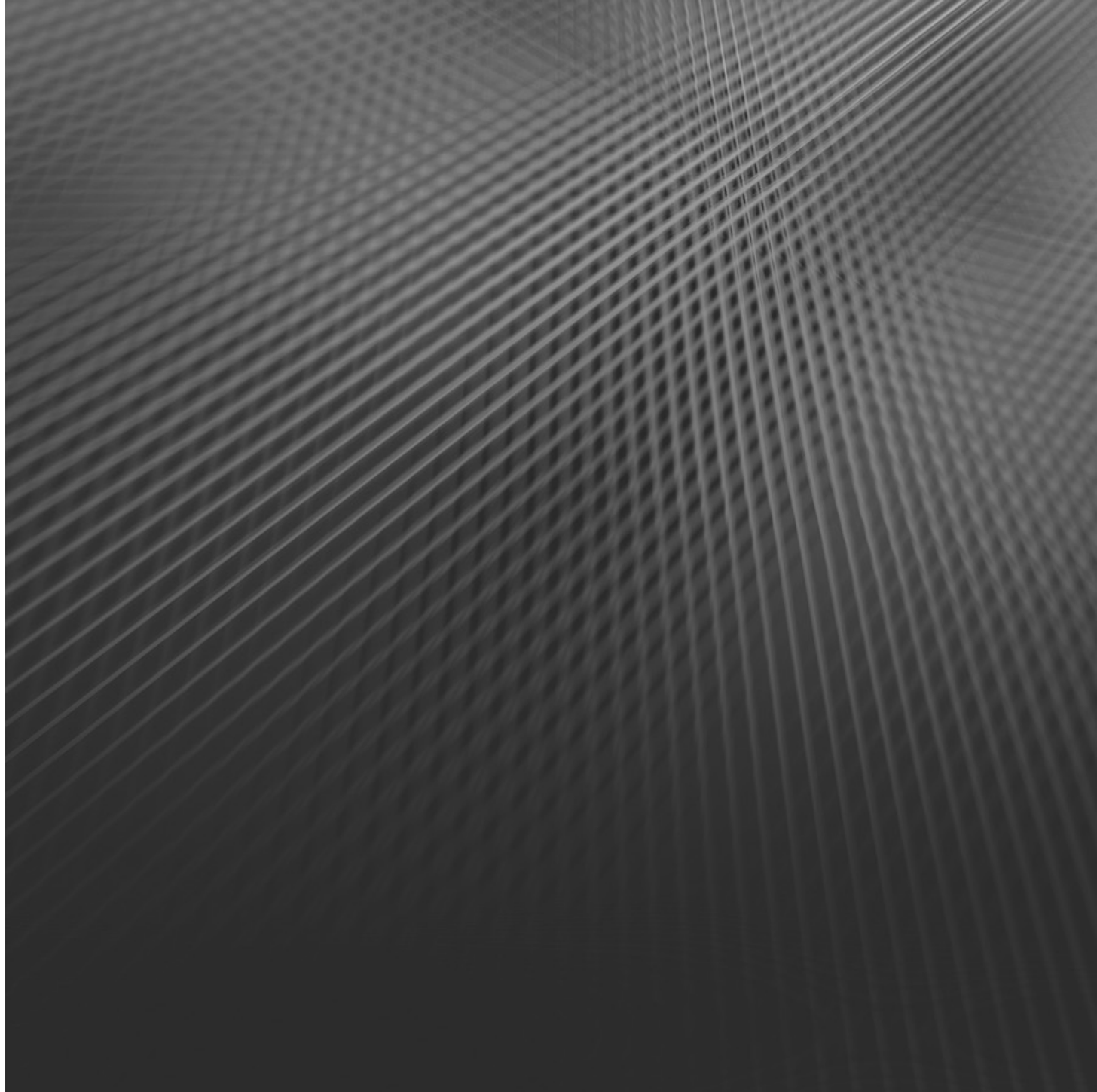

Improvement may not be the right word

- Agricultural modeling developments including switch to water basins and endogenous IRR/RFD and intensification really increased computational burden
  - Memory usage spiked to 16+GB
  - GCAM 5.1.2 slashes memory usage. Still recommend users have 8 GB

Remove non-maintained output formats

- The “output.xml” was a few GB large
  - Has been removed
- The XML Database output is about 2 GB of output per scenario
  - Users may consider ”filtering” which results to store to save space

Running GCAM in the cloud

- Amazon Web Services
  - We will make available free instances for the GCAM tutorials
  - We may maintain a GCAM image users can find on AWS and use
    - ✓ Still have to pay (~ $0.10 / hour) although could use “spot” pricing for considerably less

Checkpoint capability

- GCAM will now write “restart” files after each model period solves
- If your run crashes / gets terminated in the middle of a scenario you can quickly restart and get back to where it left off.

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Thank you