Discrepancies Between Offline and Fully Coupled CLM5 Crop Simulations

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Outline

- Fully Coupled vs. Offline CLM5 simulations
- Scenario overview
- Results
- Why are crop yields different?
- Conclusions

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Fully Coupled vs. Offline CLM5 simulations

Table 2.4: Atmospheric input to land model

Field	variable name	units
[1]Reference height	z'_{atm}	m
Atmosphere model's surface height	$z_{surf,atm}$	m
Zonal wind at z_{atm}	u_{atm}	m s^{-1}
Meridional wind at z_{atm}	v_{atm}	m s^{-1}
Potential temperature	$\overline{\theta_{atm}}$	K
Specific humidity at z_{atm}	q_{atm}	kg kg^{-1}
Pressure at z_{atm}	P_{atm}	Pa
Temperature at z_{atm}	T_{atm}	K
Incident longwave radiation	$L_{atm} \downarrow$	W m^{-2}
[2]Liquid precipitation	q_{rain}	mm s^{-1}
[2]Solid precipitation	q_{sno}	mm s^{-1}
Incident direct beam visible solar radiation	$S_{atm} \downarrow^{\mu}_{vis}$	W m^{-2}
Incident direct beam near-infrared solar radiation	$S_{atm} \downarrow^{\mu}_{nir}$	W m^{-2}
Incident diffuse visible solar radiation	$S_{atm} \downarrow_{vis}$	W m^{-2}
Incident diffuse near-infrared solar radiation	$S_{atm} \downarrow_{nir}$	W m^{-2}
Carbon dioxide (CO_2) concentration	c_a	ppmv
[3]Aerosol deposition rate	D_{sp}	kg m^{-2} s^{-1}
[4]Nitrogen deposition rate	NF_{ndep_sminn}	g (N) m^{-2} yr^{-1}
[5]Lightning frequency	I_l	flash km^{-2} hr^{-1}

From CLM5 Technotes (page 19)

- Atmospheric state variables (left) are passed to CLM5 every 30 minutes in fully coupled simulations
- These variables can be saved during fully coupled runs to force CLM with atmospheric data from different scenarios and climate models without the need to run CESM
- Due to data storage expenses, fully coupled atmospheric data are not always saved at the 30-minute time intervals needed to run CLM5
- Interpolation is needed to convert one or three hourly saved variables to force CLM5
- This can cause differences between offline and fully coupled CLM5 simulations, but it has been previously thought that this would not have a large impact on results

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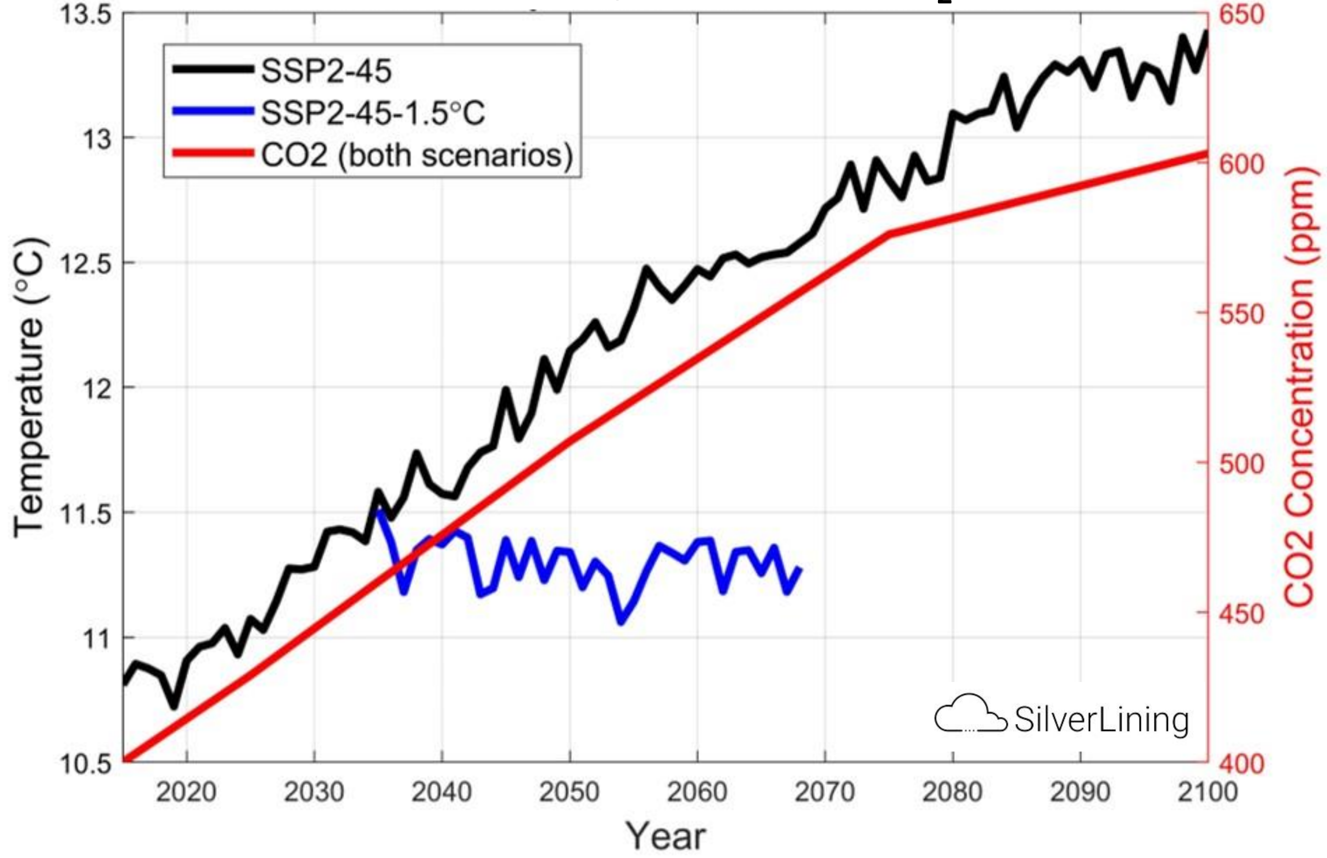
Scenario Overview

Global Mean Surface Temperature and CO_2 Concentration



NCAR ARISE simulations using stratospheric aerosol climate intervention to hold global average temperatures at 1.5°C above preindustrial levels relative to SSP2-4.5

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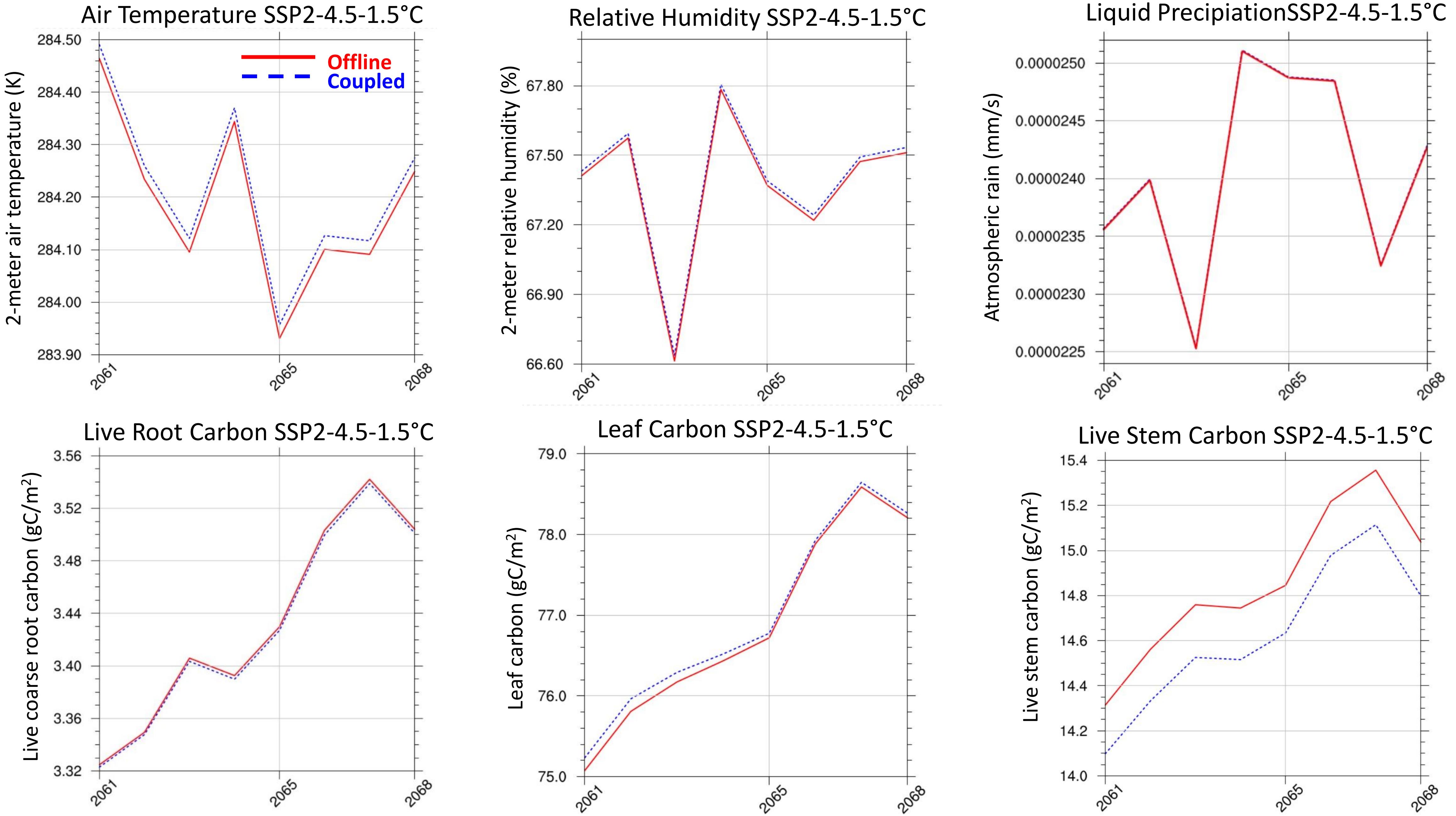
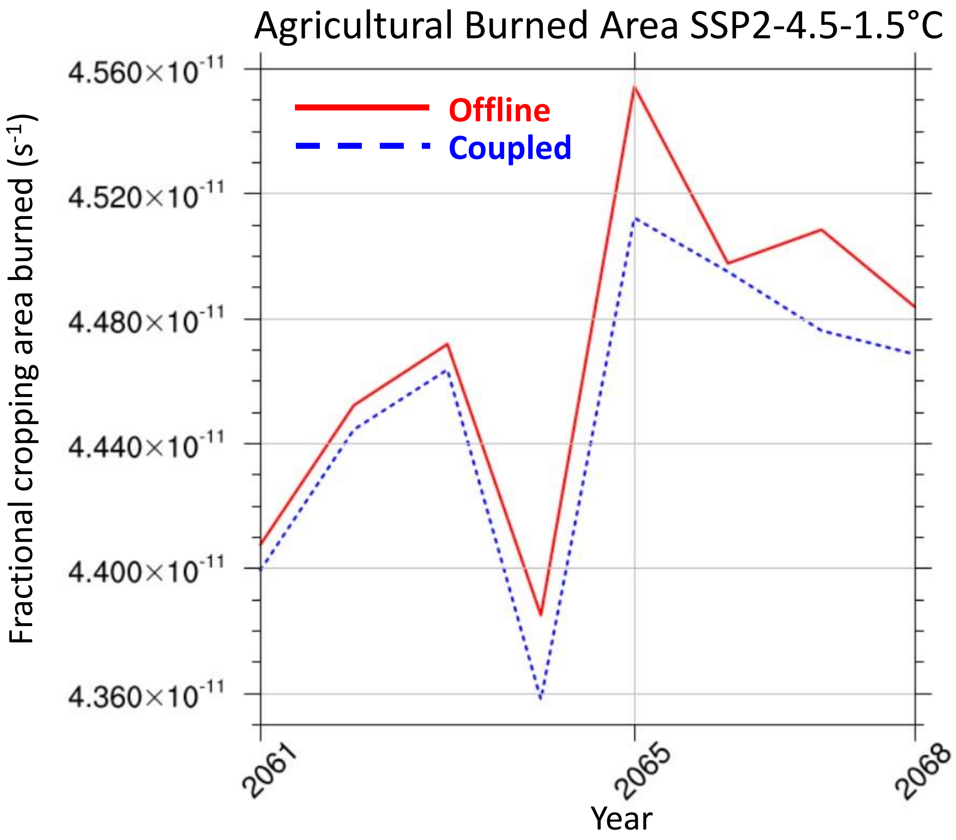
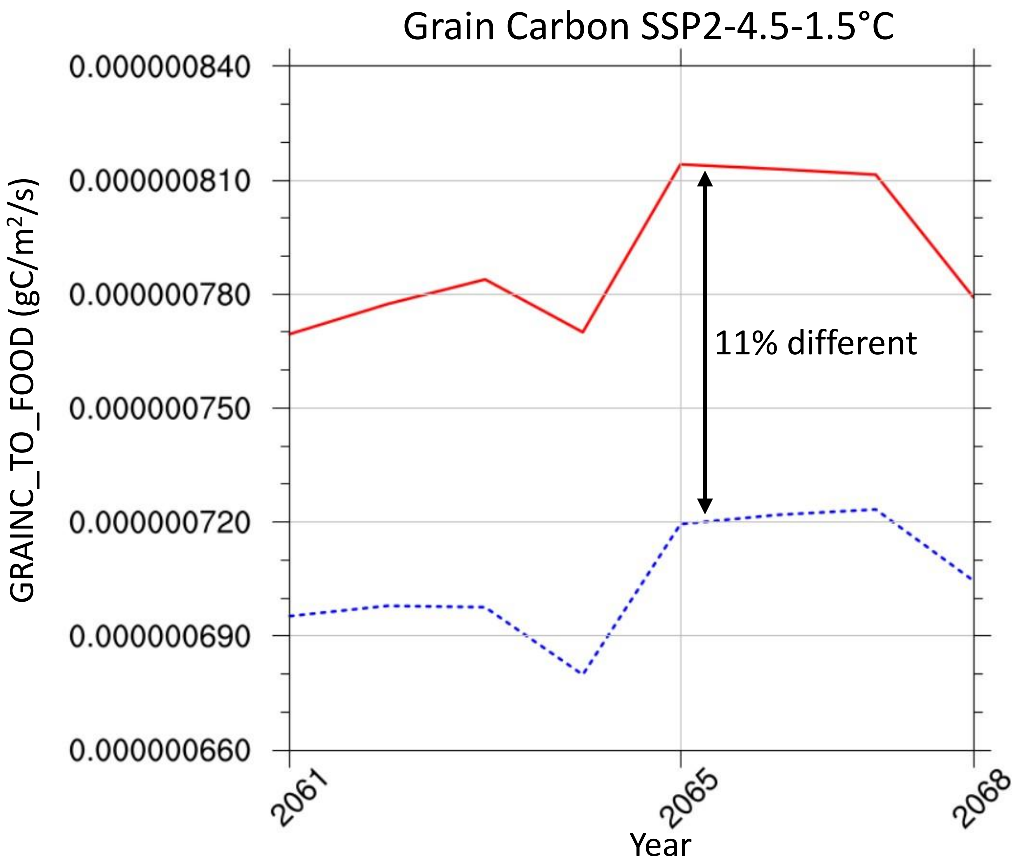
Results (one ensemble member)



Results





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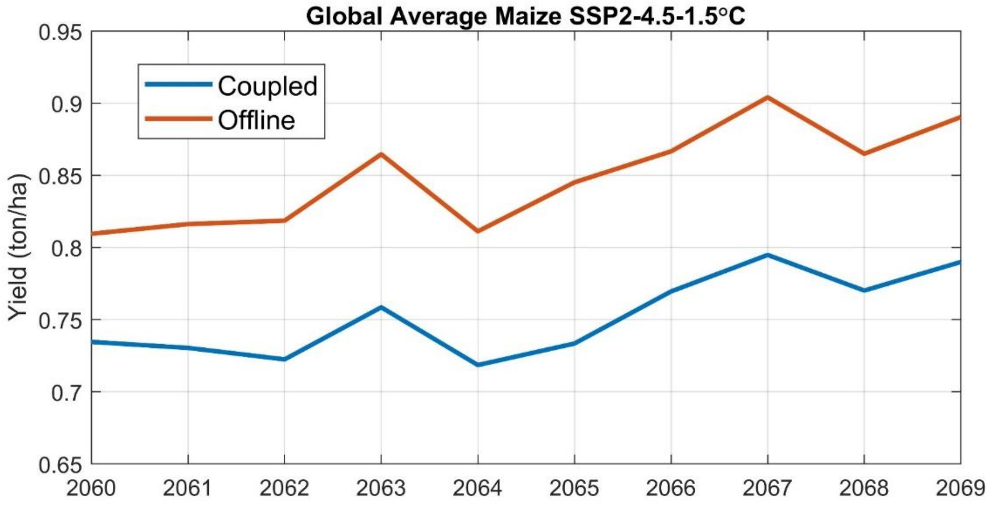
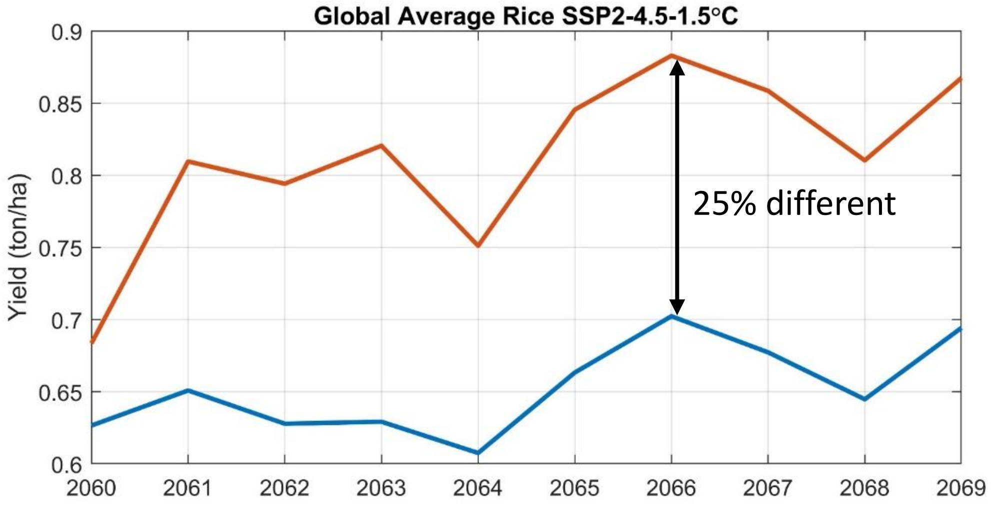
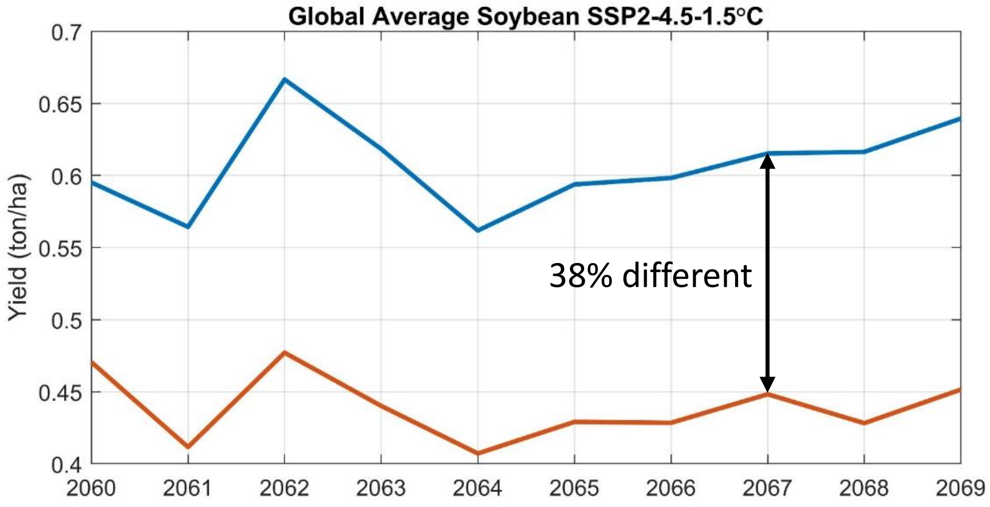
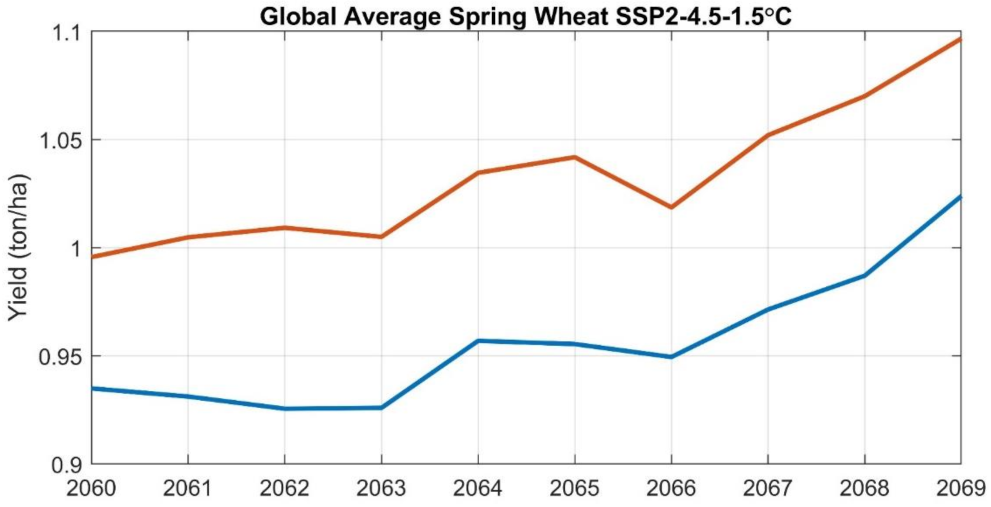
Results









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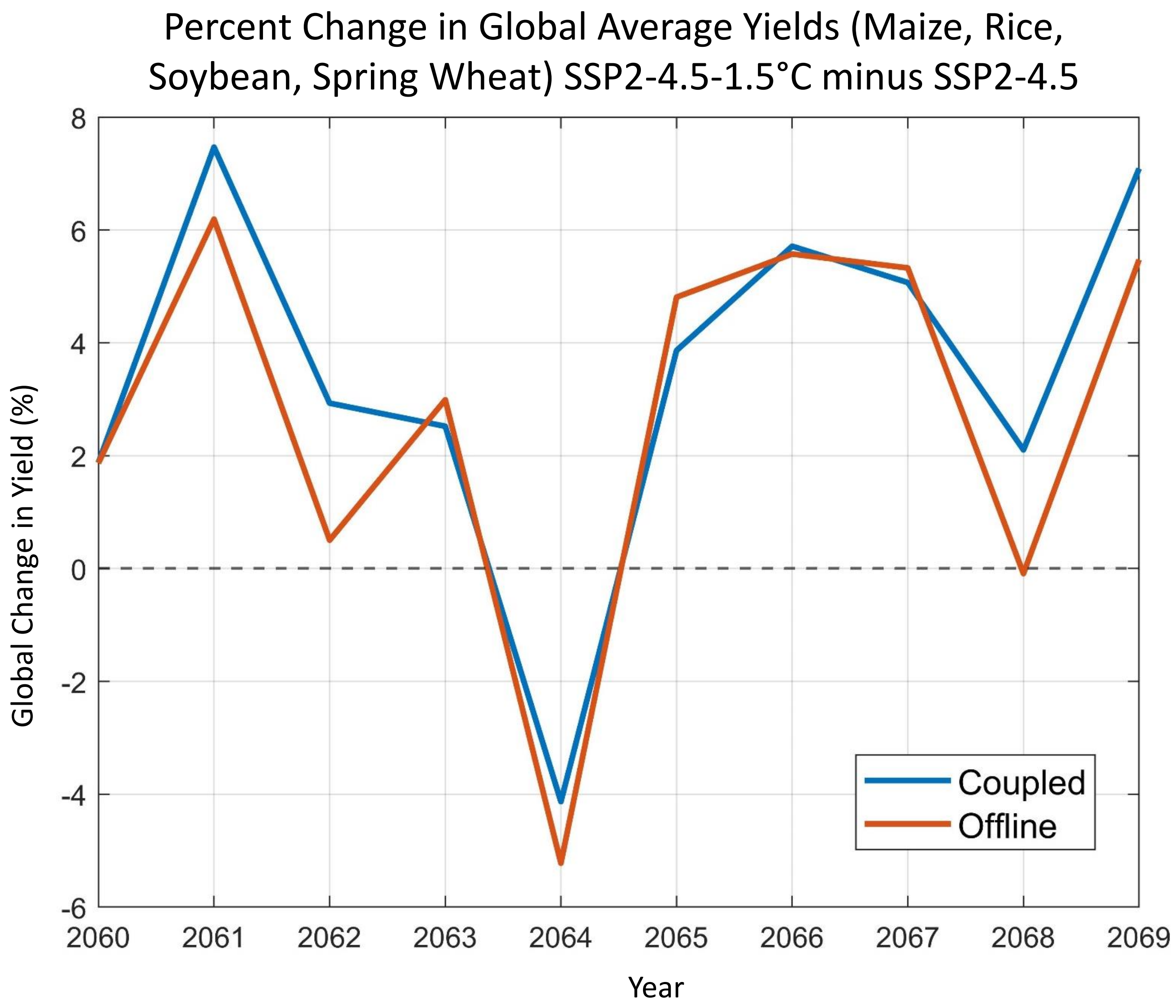
Results



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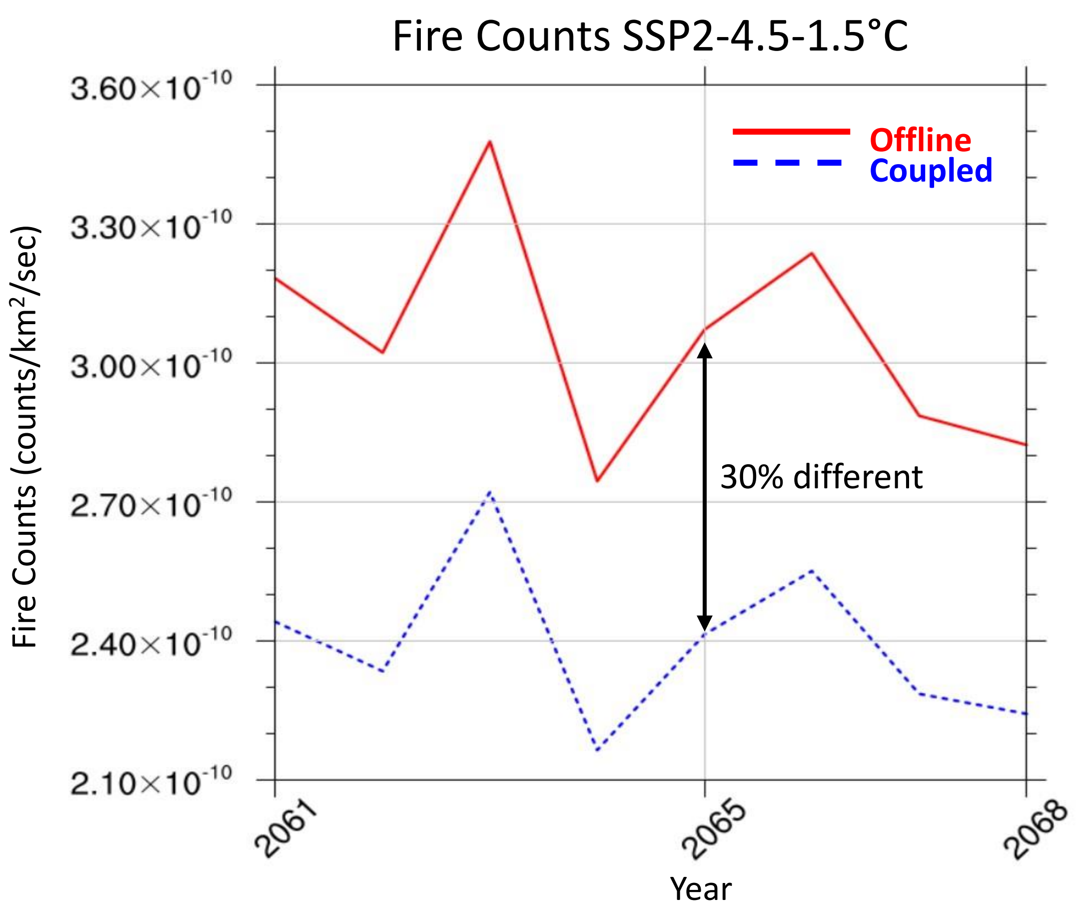
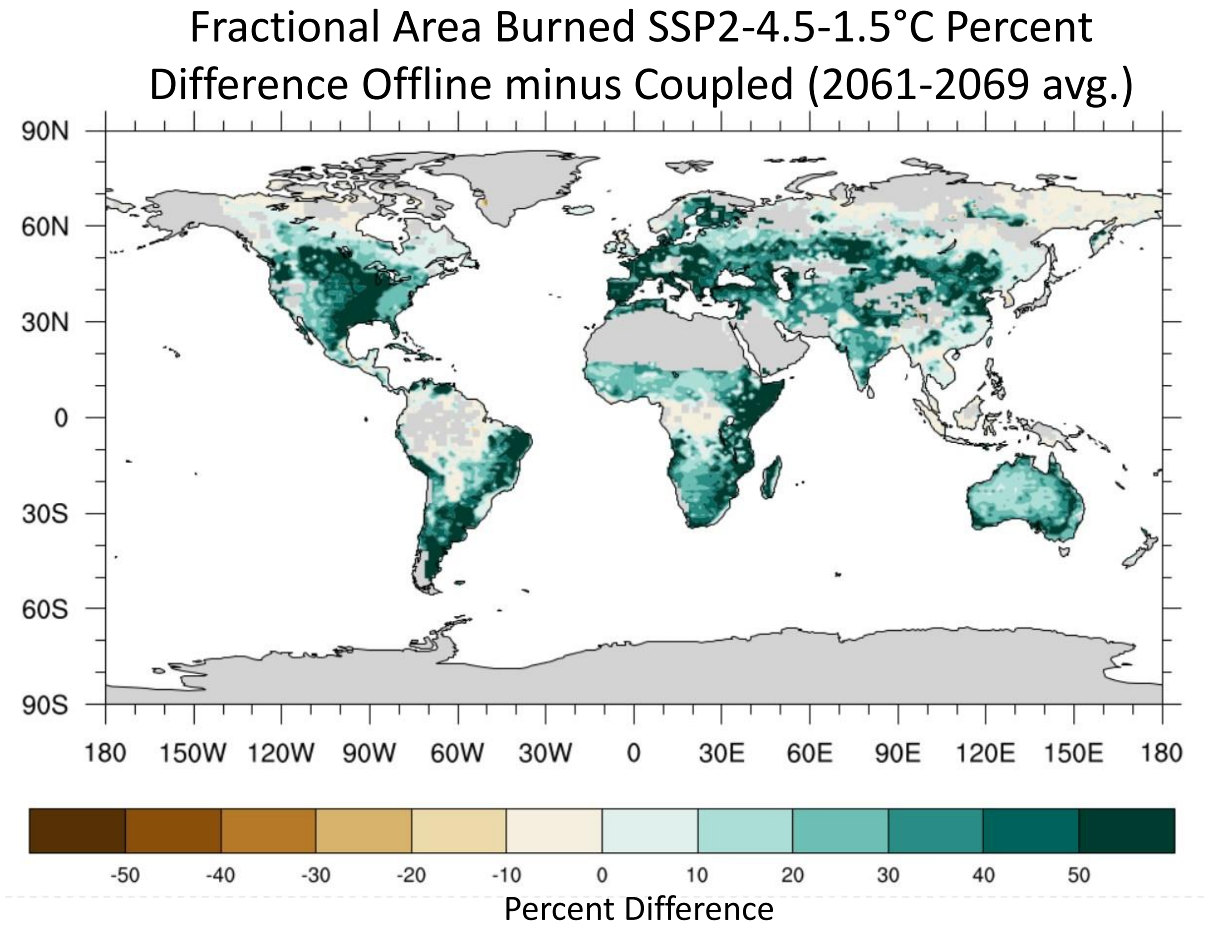
Results





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Fully Coupled vs. Offline CLM5 simulations

- CLM5’s default timestep is 30-minutes
- In a coupled simulation, CLM5 takes in 30-minute averaged variables from the atmosphere model, and outputs 30-minute averages back to the atmosphere model
- Coupled simulations will often save atmosphere data as 1-hourly and 3-hourly averages
- When offline, CLM5 will interpolate the 1-hourly and 3-hourly saved output from the coupled simulation back into the required 30-minute timesteps
- This interpolation process may be the reason for these variables being so different, and requires further attention

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Potential Cause of Differences

Output from coupled simulations (CMIP6)

	Timestep 1	Timestep 2	Timestep 3
ha2x1h	0:30:00	1:30:00	2:30:00
ha2x1hi	0:45:00	1:30:00	2:30:00
ha2x3h	1:30:00	4:30:00	7:30:00

CLM5 code automatic adjustment

ha2x1h	15 mins (900s)
ha2x1hi	45 mins (2700s)
ha2x3h	15 mins (900s)

```
<value stream="CPLHISTForcing.Solar">2700</value>
<value stream="CPLHISTForcing.nonSolarFlux">900</value>
<value stream="CPLHISTForcing.State3hr">900</value>
<value stream="CPLHISTForcing.State1hr">900</value>
```

New CPL timesteps after adjustment

ha2x1h	0:45:00	1:45:00	2:45:00
ha2x1hi	1:30:00	2:15:00	3:15:00
ha2x3h	1:45:00	4:45:00	7:45:00

- ha2x1h – hourly wind output
- ha2x1hi – hourly solar output
- ha2x3h – all other variables, three hourly (e.g., temp, precip)
- **Why does ha2x1hi have a 45-minute offset in timestep 1?**

- CLM5's code automatically adjusts CPL output, shifting the CPL start times
- **Why were these values chosen?**

- How does this impact results?

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New CPL timesteps after CLM5 adjustment

ha2x1h	0:45:00	1:45:00	2:45:00
ha2x1hi	1:30:00	2:15:00	3:15:00
ha2x3h	1:45:00	4:45:00	7:45:00

Added adjustments to make CPL data start in beginning or middle of timestep

	Beginning	Middle
ha2x1h	-45 mins (-2700s)	-15 mins (-900s)
ha2x1hi	-90 mins (-5400s)	-75 mins (-4500s)
ha2x3h	-105 mins (-6300s)	-15 mins (-900s)

Final CPL timesteps for two new scenarios

Beginning:

	Timestep 1	Timestep 2	Timestep 3
ha2x1h	0:00:00	1:00:00	2:00:00
ha2x1hi	0:00:00	0:45:00	1:45:00
ha2x3h	0:00:00	3:00:00	6:00:00

Middle:

	Timestep 1	Timestep 2	Timestep 3
ha2x1h	0:30:00	1:30:00	2:30:00
ha2x1hi	0:15:00	1:00:00	2:00:00
ha2x3h	1:30:00	4:30:00	7:30:00

- Three hourly and one hourly state variables (ha2x1h and ha2x3h) are averages of the period and should be adjusted to start at the middle of the period
- One hourly solar data (ha2x1hi) uses the cosine of the solar zenith angle (coszen), and should start at the beginning of averaging period
- Because of the 45-minute jump for ha2x1hi from timestep 1 to timestep 2, solar data was offset by -75 minutes in the “middle” scenario so that solar data will start at the beginning of the timestep from timestep 2 onward

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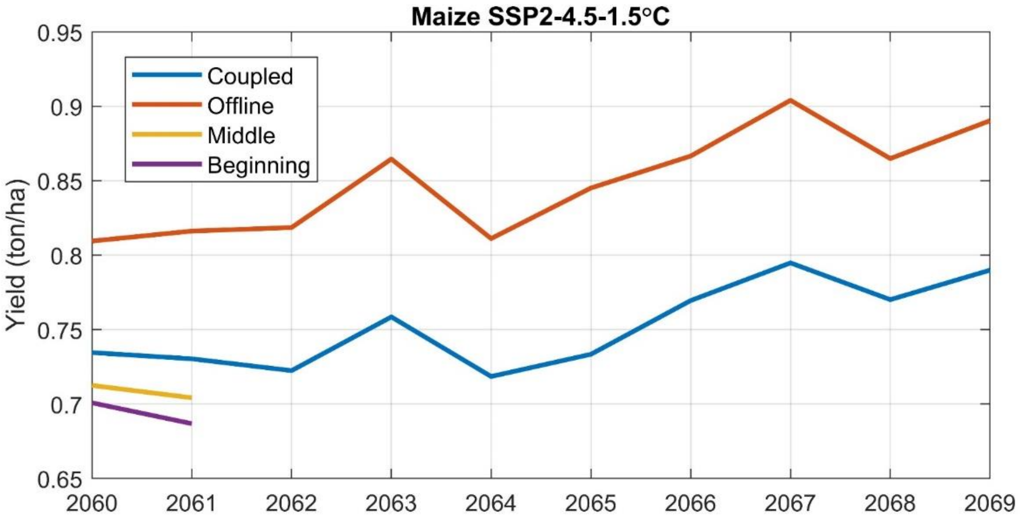

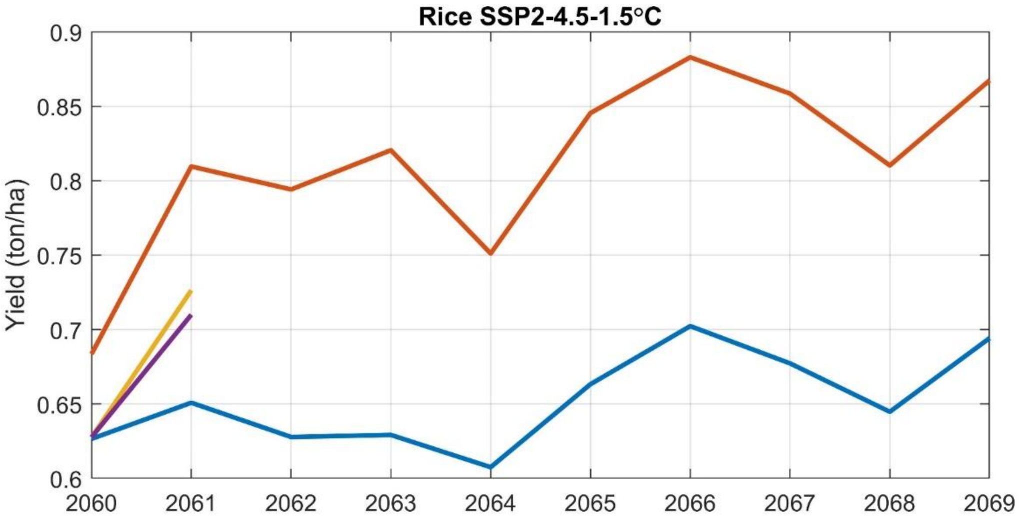

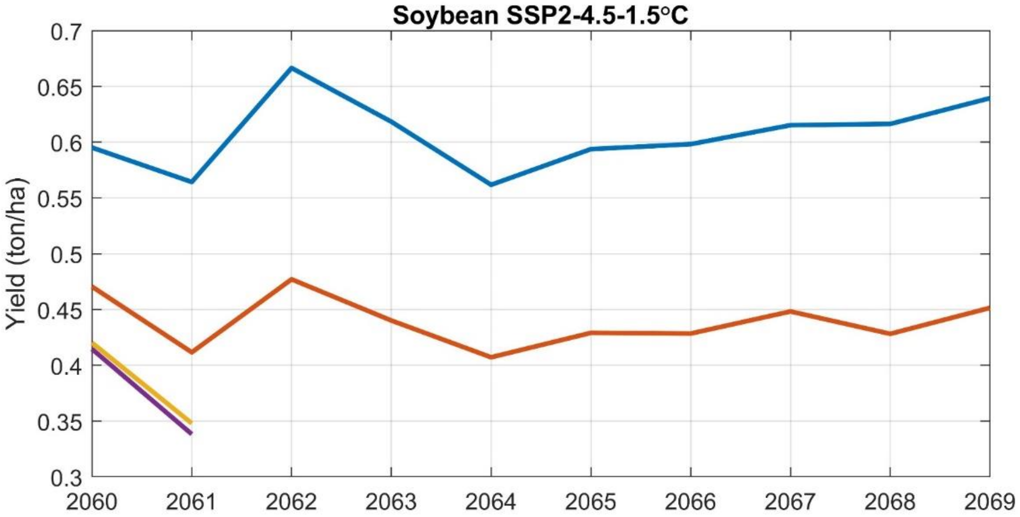

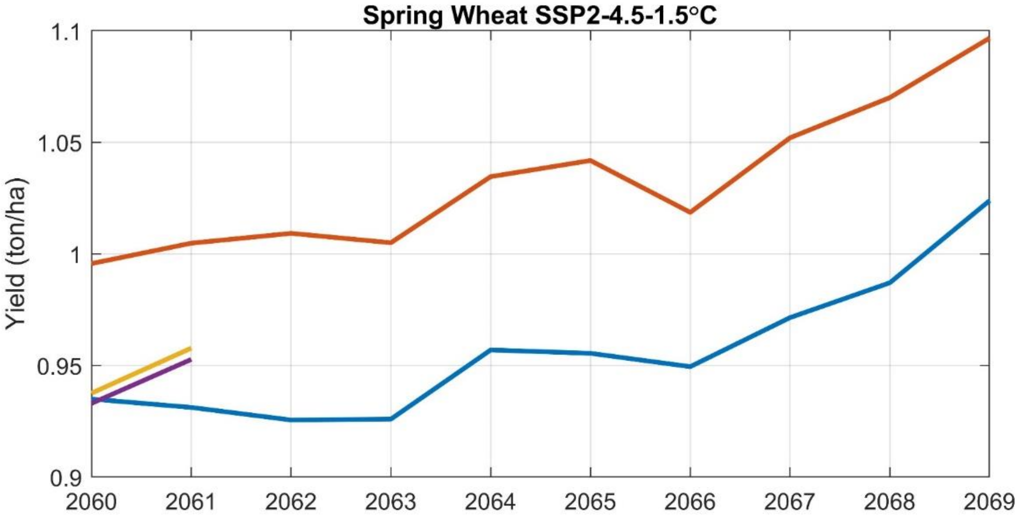

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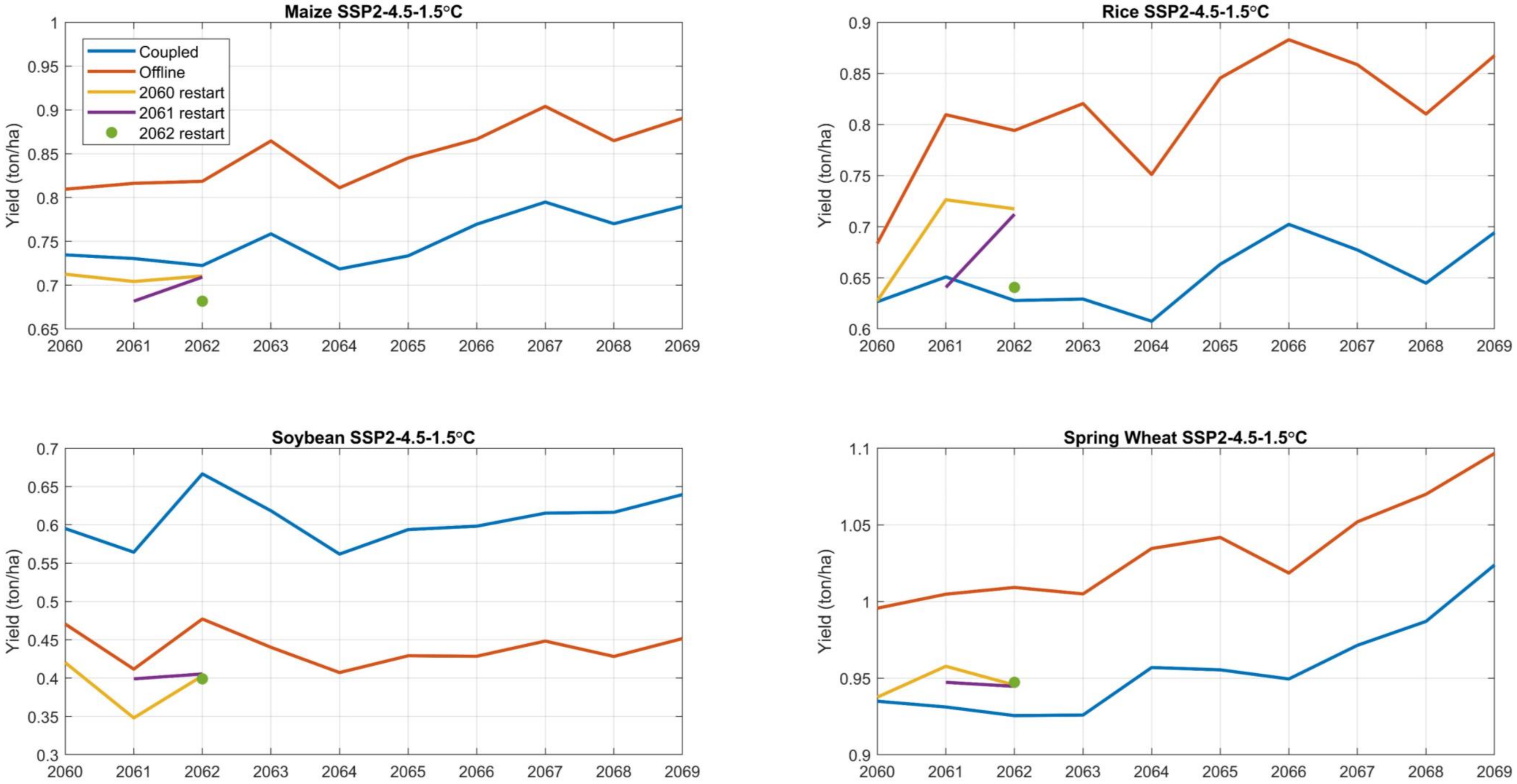
Initial land condition memory is only taken for the first timestep from the coupled run, and memory is supplied from the offline run for subsequent years. What if there is an initial condition restart file supplied for each year?



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Conclusions

- Offline CLM5 simulations forced with the same atmospheric data, show differences between fully coupled simulations under the same scenarios
  - Global average crop yields are 38% different for soybean, 25% different for rice, 10% different for maize, and 6% different for spring wheat
  - Global average fire counts and burned areas are about 30% different
- Reasons for CLM5 coded starting time adjustment values is unclear
- Changing these starting time offset values can have a large impact on crop yield results
- More work is needed to understand how different offset values can change offline results for crop yields in CLM5, as well as other variables
- Documentation for current offset values should be added if none exists
- Supplying restart memory files for each year from the coupled run helps to simulate rice offline, but does little to improve maize, soybean, or spring wheat

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