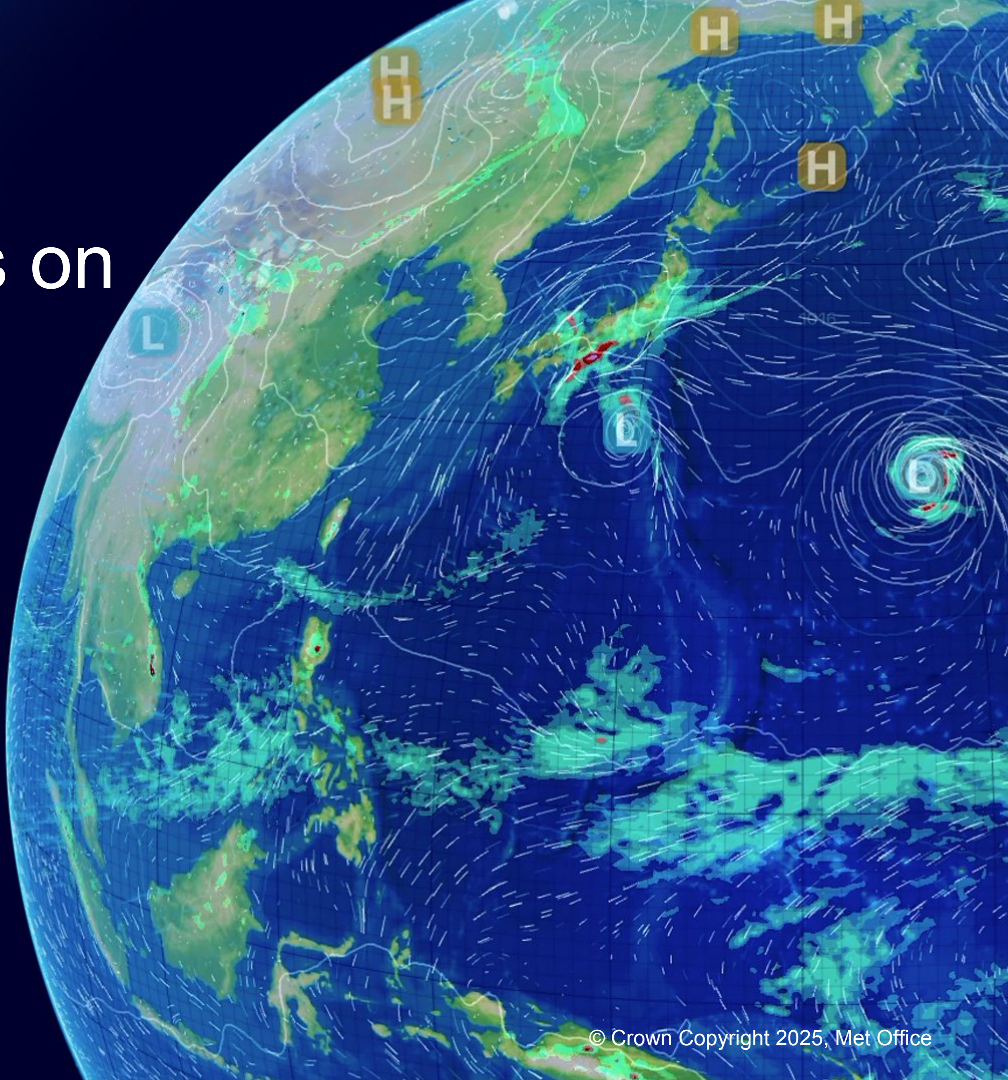
Simplified approach to assess climate's impacts on agriculture



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What can we say about climate's impacts on agriculture without using crop models?

- It may not always be practical to perform detailed crop model simulations
  - Insufficient driving data
  - Need to assess multi-sector impacts without an agriculture-specific setup
  - Want to get first order assessment for a wide range of climate/mitigation scenarios

- Working directly with ESM-type land surface model outputs, can we infer any agricultural impacts?
  - Spatial distribution
  - Year-to-year variation in response to environmental conditions
  - Not looking at climate's impacts on long-term trends for now

- ISIMIP3a simulations

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Models with C3-/C4-crop plant functional types (PFTs)

JULES-ES (UKESM):

- C3-/C4-crop PFTs duplicate C3-/C4-grass characteristics but with:
  - Unlimited nitrogen (fertiliser)
  - No competition with other PFTs (prescribed total cropland area)
- Competition between C3- and C4-crops
  - C3: most plants
  - C4: more efficient photosynthesis, adapted to hot and dry conditions

CLASSIC (CanESM)

ORCHIDEE-MICT (IPSL)

C3: most plants are C3
C4: more efficient photosynthesis, adapted to hot and dry conditions

Spatial distribution

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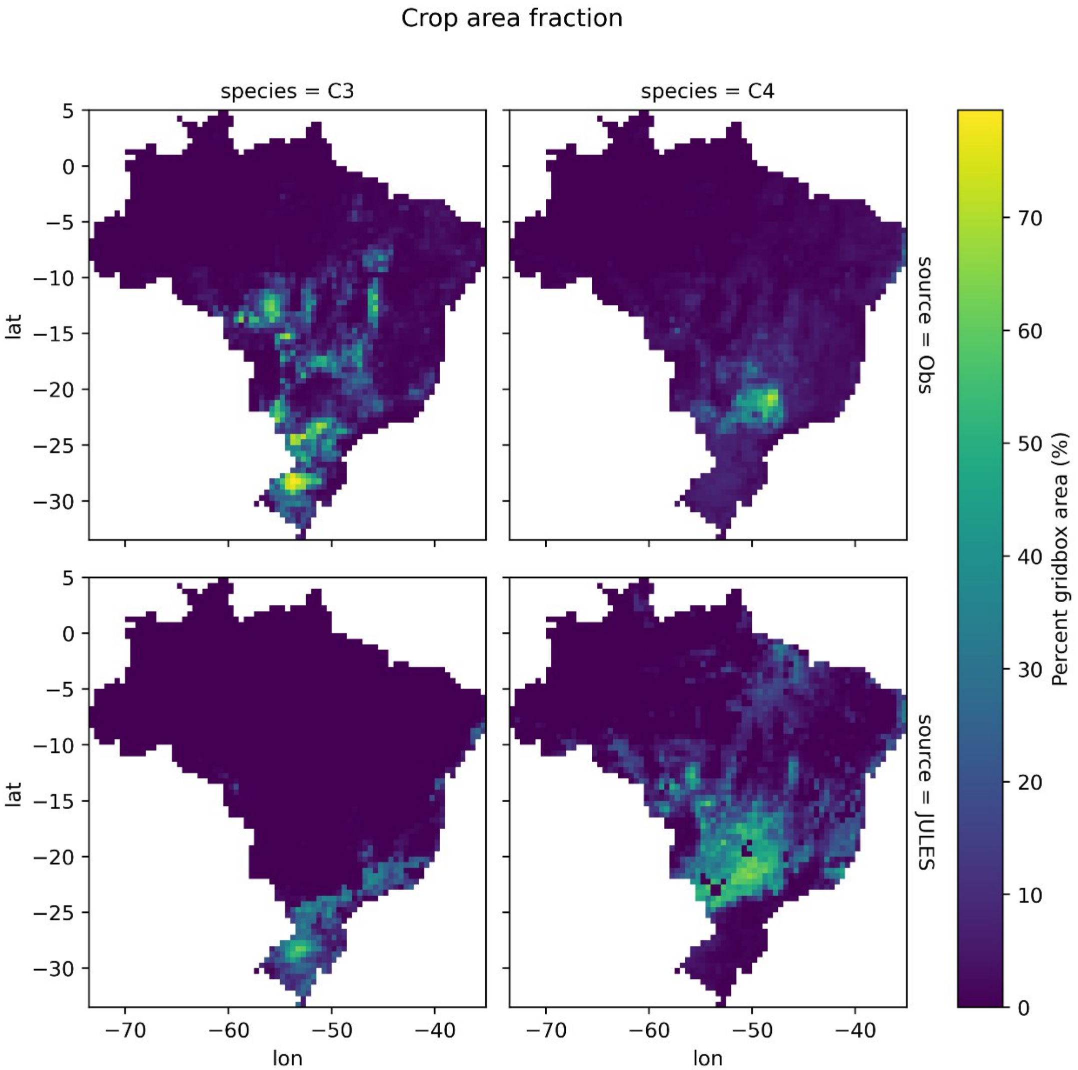
Spatial distribution

- Prescribed total cropland fractions, but with competition between C3 and C4 crop
- C4-crop outcompetes C3-crop in tropics in JULES
- Much more C3-crop in real life due to greater amount of C3 crops being planted (CROPGRIDS 2020 data)



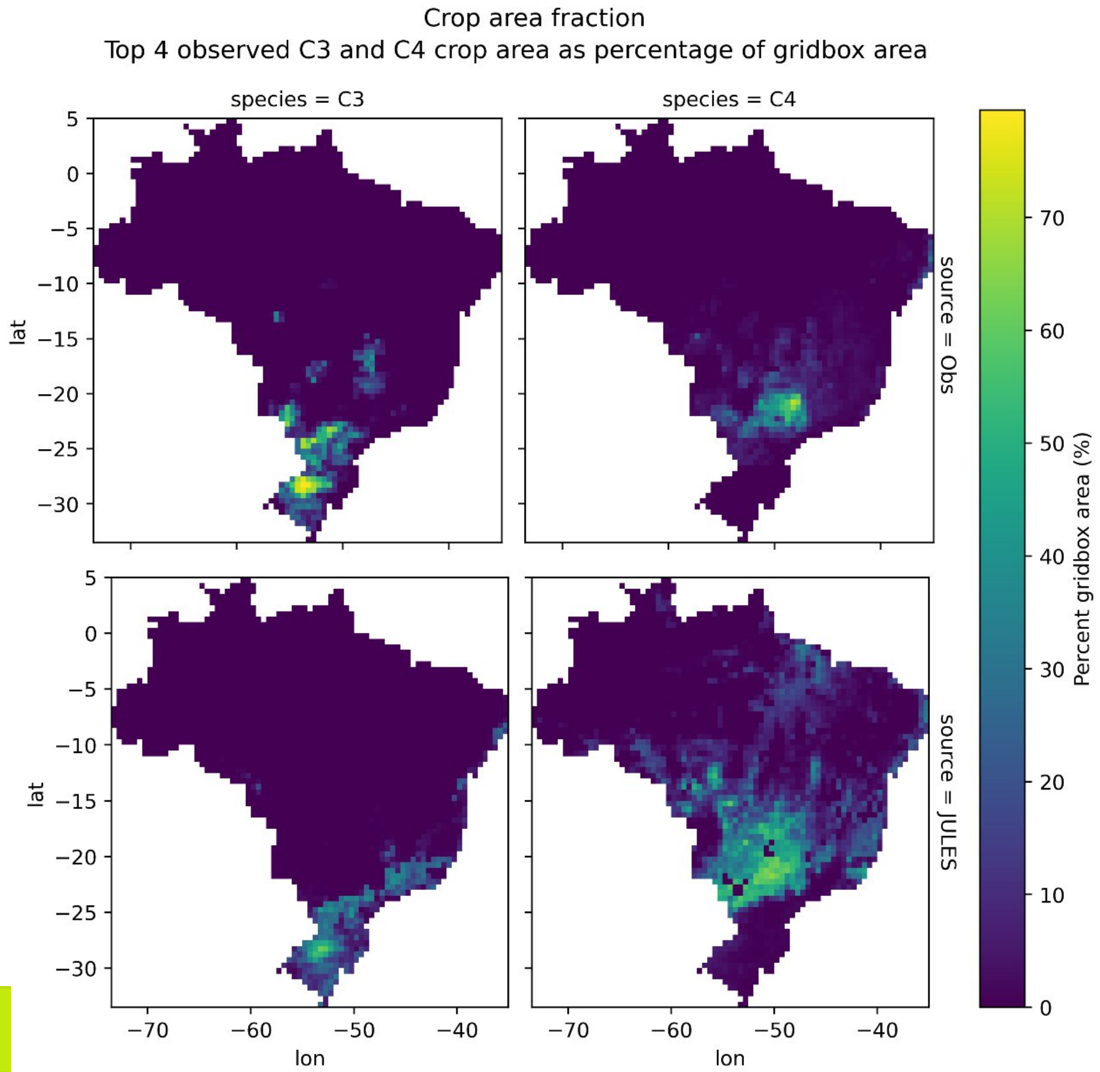
C3: most plants are C3
C4: more efficient photosynthesis, adapted to hot and dry conditions

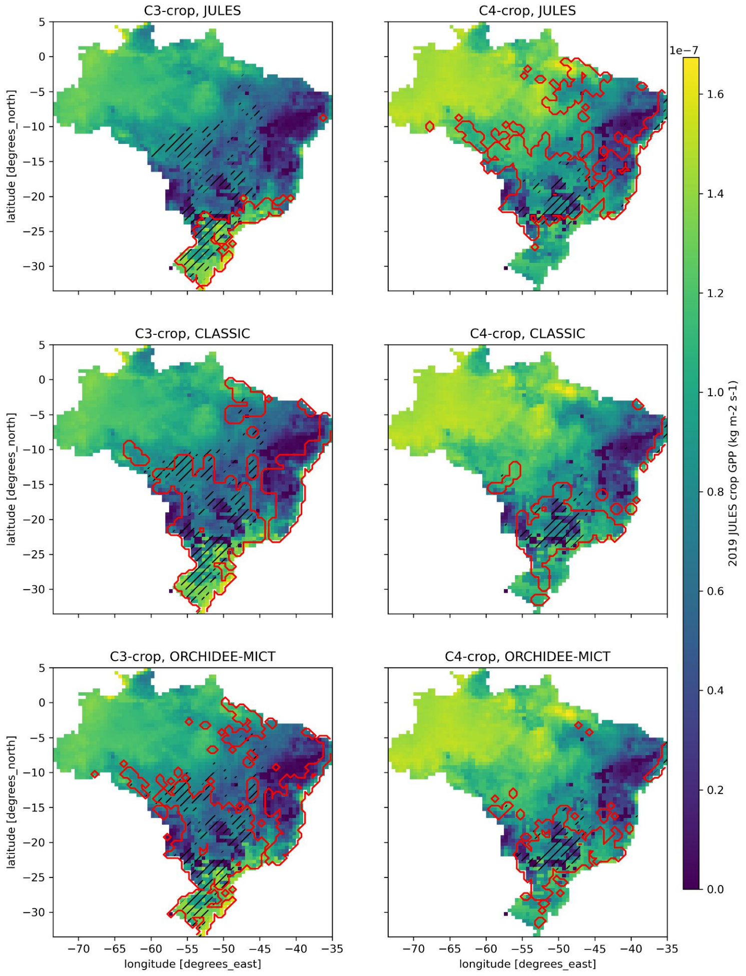
Spatial distribution

Focusing on the top 4 crops by area planted in Brazil:

- C3: soybean, wheat
- C4: maize, sugarcane

- C3-C4 divide at around 23°S latitude more consistent with model

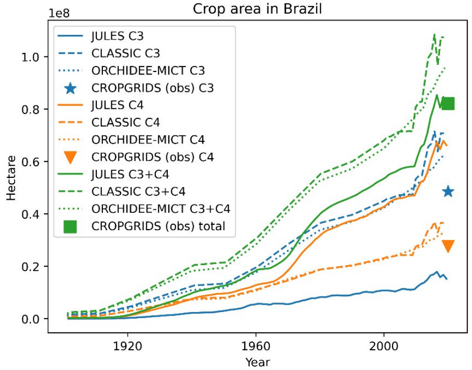




Spatial distribution
- comparison between models

- CLASSIC & ORCHIDEE-MICT have greater C3- than C4-crop coverage, consistent with observations and likely prescribed
- C3-C4 ratio flipped for JULES, mainly due to differences in tropical regions

- Where cropland > 10% of grid area
- Hatching: CROPGRIDS observed cropland area for soybean & wheat (C3), maize & sugarcane (C4)
- Red contours: model PFT cover



Temporal variation

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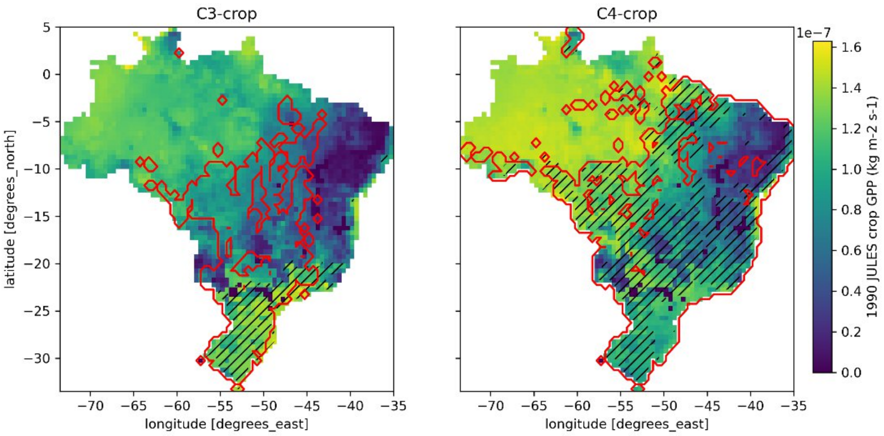
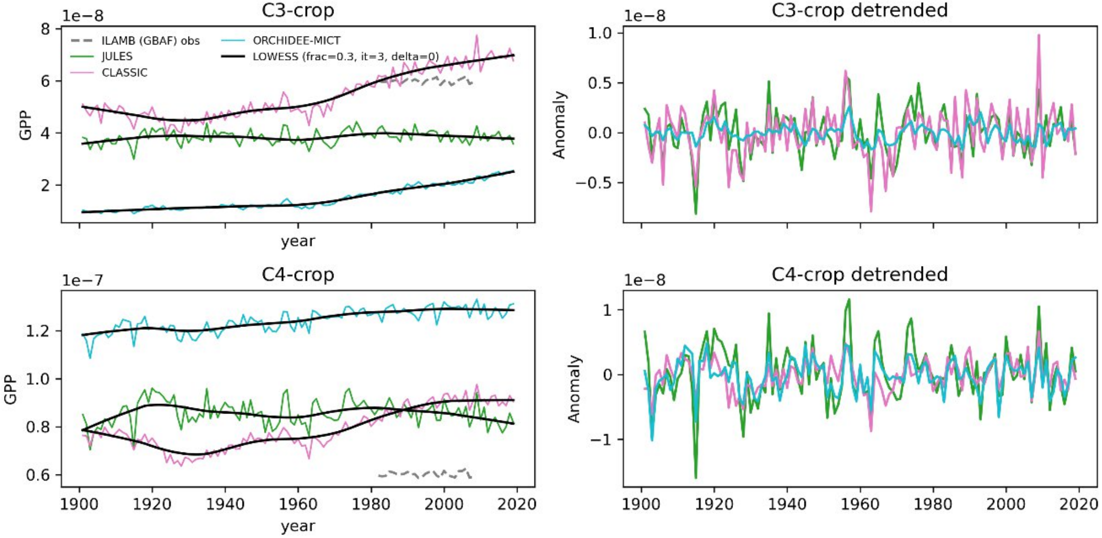
Temporal variation
- spatial aggregation & detrending

- Spatial average over regions where soybean or wheat (C3), and maize or sugarcane (C4) are planted in 2020 according to CROPGRIDS obs data
    - Red contours
- Remove long term trends and focus on year-to-year variability
    - Response to changes in meteorological conditions





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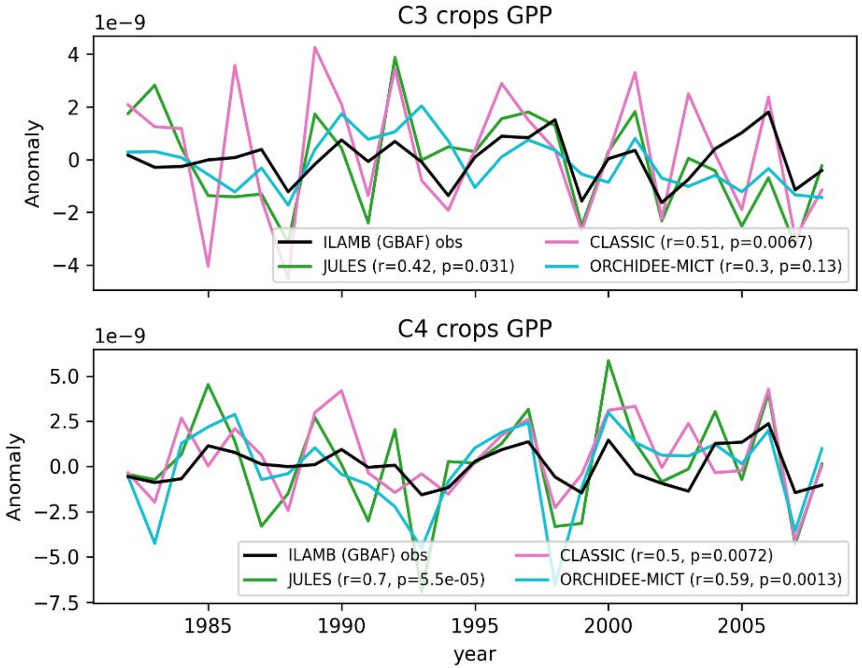
Year-to-year variability

- Models have some skill in capturing year-to-year variability in plant growth in response to variation in environmental conditions
    - GPP shown, similarly for C4-crop LAI but less so for C3-crop LAI



- Gross primary productivity (GPP): energy captured through photosynthesis, a way of measuring biomass growth
- Leaf area index (LAI): area of leaf per area of ground

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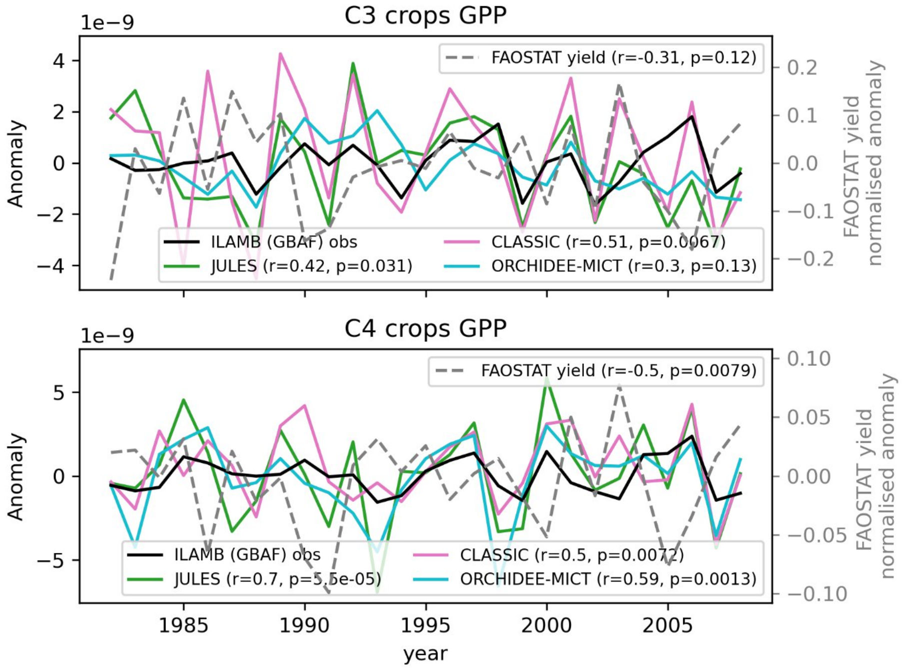
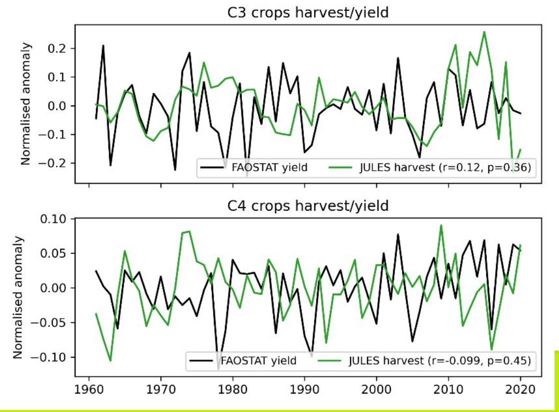
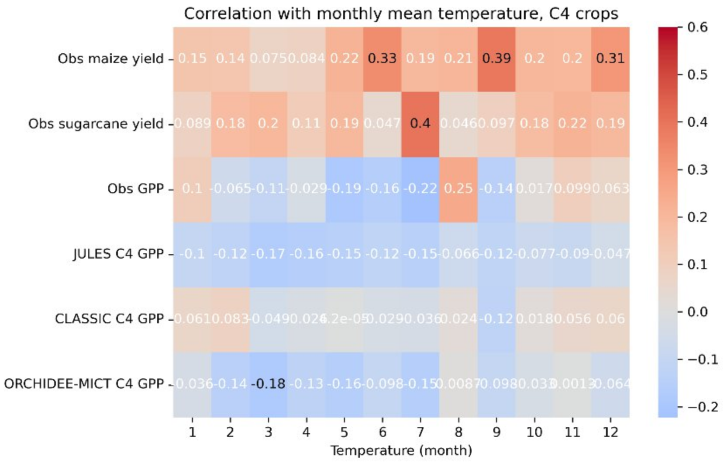
Year-to-year variability

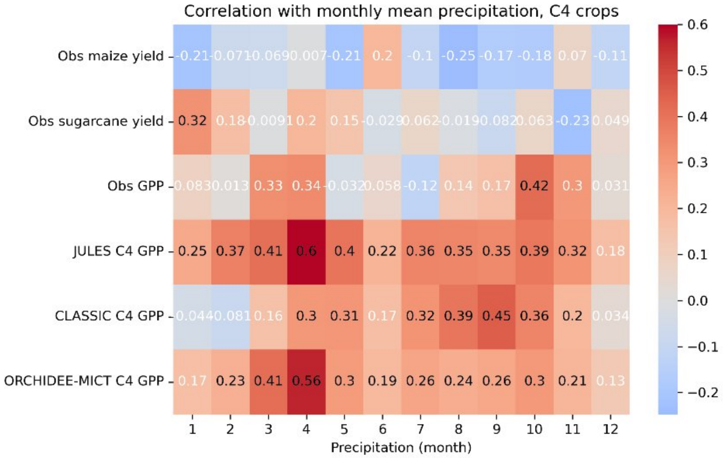
- Models have some skill in capturing year-to-year variability in plant growth in response to variation in environmental conditions
  - GPP shown, similarly for C4-crop LAI but less so for C3-crop LAI
- Correlation does not translate to yield





- Gross primary productivity (GPP): energy captured through photosynthesis, a way of measuring biomass growth
- Leaf area index (LAI): area of leaf per area of ground
- JULES harvest: accumulation of litter flux for crop PFTs

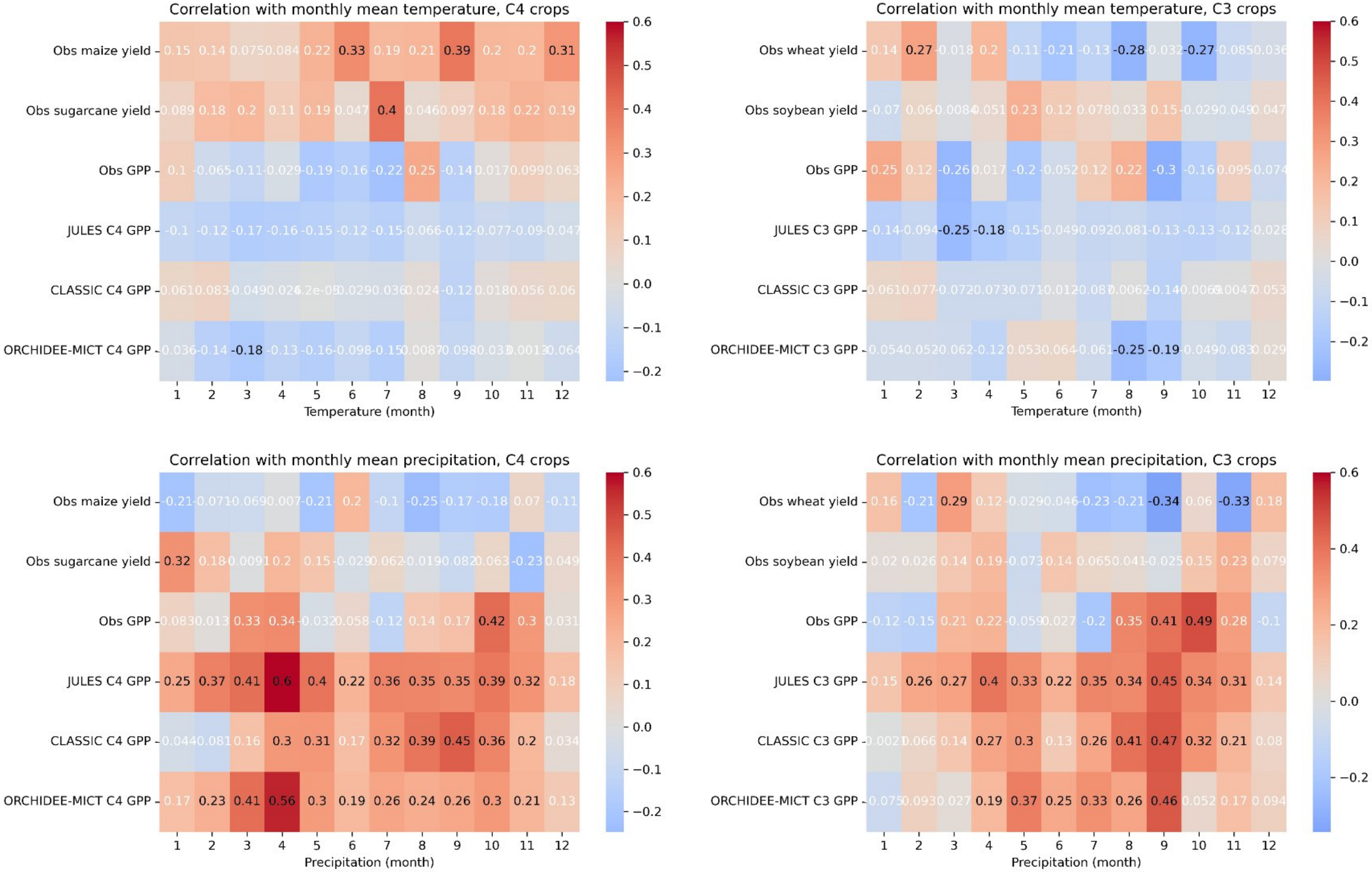




Correlation with meteorological variables

- GSWP3-W5E5 temperature & precipitation
- Yield and GPP do not have the same relationship with meteorological variables
  - Higher temperature preferred for yield, higher precipitation preferred for GPP
  - Similarly for LAI
  - Low statistical significance overall
- Response of GPP to precipitation more pronounced in models than in observations

- Pearson correlation
- Black: statistically significant (p-value < 0.05)


Correlation with monthly mean temperature, C4 crops
Correlation with monthly mean temperature, C3 crops
Correlation with monthly mean precipitation, C4 crops
Correlation with monthly mean precipitation, C3 crops
Obs maize yield
Obs sugarcane yield
Obs GPP
JULES C4 GPP
CLASSIC C4 GPP
ORCHIDEE-MICT C4 GPP
Obs wheat yield
Obs soybean yield
JULES C3 GPP
CLASSIC C3 GPP
ORCHIDEE-MICT C3 GPP
Temperature (month)
Precipitation (month)

Conclusions

à ESM land model outputs can be useful as first order indicators of changes in crop growth potential
- C3/C4 competition
- Response to interannual variability

à Cannot capture yield. Possible missing mechanisms:
- Crop specific characteristics/response
- Human influences affecting agricultural yield

à GPP has opposite correlation with meteorological conditions compared to yield
- GPP favours high precipitation, yield favours high temperature

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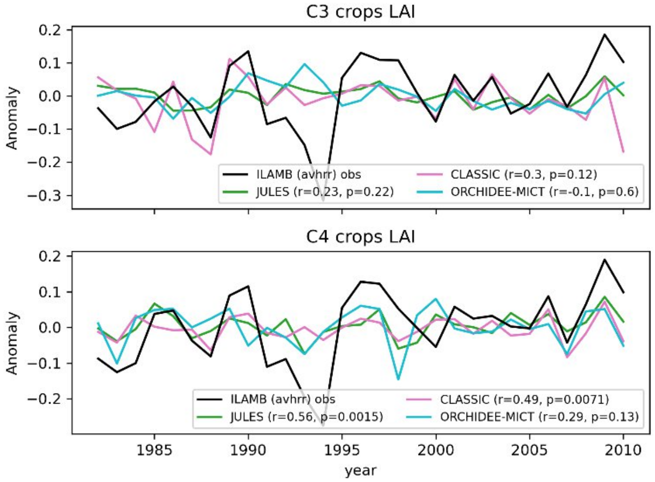
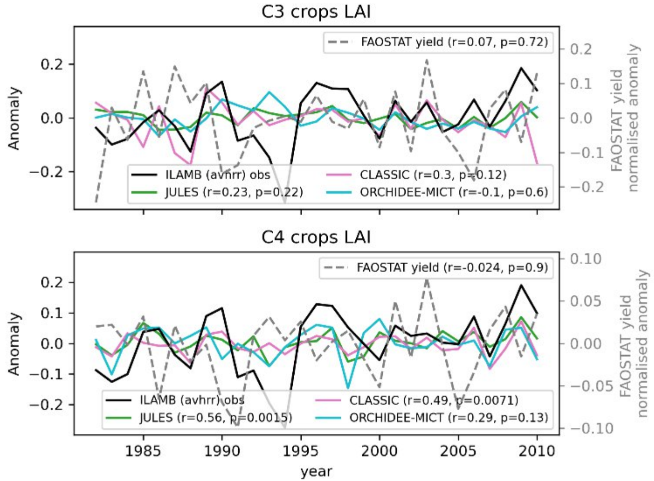
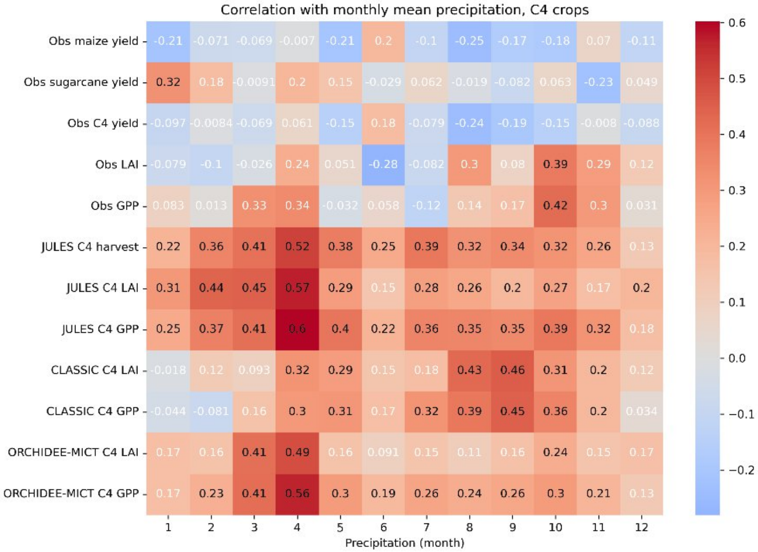
LAI



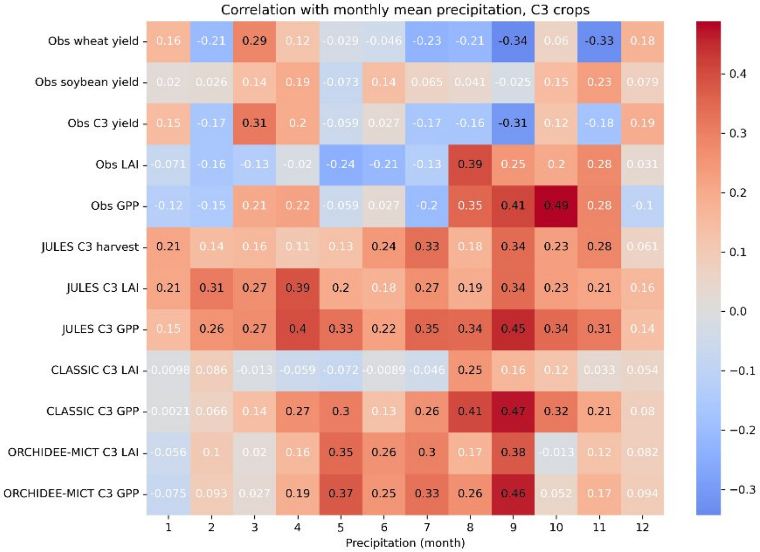
C3 crops LAI
Anomaly
ILAMB (avhrr) obs
JULES (r=0.23, p=0.22)
CLASSIC (r=0.3, p=0.12)
ORCHIDEE-MICT (r=-0.1, p=0.6)
C4 crops LAI
Anomaly
ILAMB (avhrr) obs
JULES (r=0.56, p=0.0015)
CLASSIC (r=0.49, p=0.0071)
ORCHIDEE-MICT (r=0.29, p=0.13)
year



C3 crops LAI
FAOSTAT yield (r=0.07, p=0.72)
Anomaly
FAOSTAT yield normalised anomaly
ILAMB (avhrr) obs
JULES (r=0.23, p=0.22)
CLASSIC (r=0.3, p=0.12)
ORCHIDEE-MICT (r=-0.1, p=0.6)
C4 crops LAI
FAOSTAT yield (r=-0.024, p=0.9)
Anomaly
FAOSTAT yield normalised anomaly
ILAMB (avhrr) obs
JULES (r=0.56, p=0.0015)
CLASSIC (r=0.49, p=0.0071)
ORCHIDEE-MICT (r=0.29, p=0.13)
year



Correlation with monthly mean precipitation, C4 crops
Obs maize yield -0.21 -0.071 -0.069 -0.007 -0.21 0.2 -0.1 -0.25 -0.17 -0.18 0.07 -0.11
Obs sugarcane yield 0.32 0.18 -0.0091 0.2 0.15 -0.029 0.062 -0.019 -0.082 0.063 -0.23 0.049
Obs C4 yield -0.097 -0.0084 -0.069 0.061 -0.15 0.18 -0.079 -0.24 -0.19 -0.15 -0.008 -0.088
Obs LAI -0.079 -0.1 -0.026 0.24 0.051 -0.28 -0.082 0.3 0.08 0.39 0.29 0.12
Obs GPP 0.083 0.013 0.33 0.34 -0.032 0.058 -0.12 0.14 0.17 0.42 0.3 0.031
JULES C4 harvest 0.22 0.36 0.41 0.52 0.38 0.25 0.39 0.32 0.34 0.32 0.26 0.13
JULES C4 LAI 0.31 0.44 0.45 0.57 0.29 0.15 0.28 0.26 0.2 0.27 0.17 0.2
JULES C4 GPP 0.25 0.37 0.41 0.6 0.4 0.22 0.36 0.35 0.35 0.39 0.32 0.18
CLASSIC C4 LAI -0.018 0.12 0.093 0.32 0.29 0.15 0.18 0.43 0.46 0.31 0.2 0.12
CLASSIC C4 GPP -0.044 -0.081 0.16 0.3 0.31 0.17 0.32 0.39 0.45 0.36 0.2 0.034
ORCHIDEE-MICT C4 LAI 0.17 0.16 0.41 0.49 0.16 0.091 0.15 0.11 0.16 0.24 0.15 0.17
ORCHIDEE-MICT C4 GPP 0.17 0.23 0.41 0.56 0.3 0.19 0.26 0.24 0.26 0.3 0.21 0.13
1 2 3 4 5 6 7 8 9 10 11 12
Precipitation (month)



Correlation with monthly mean precipitation, C3 crops
Obs wheat yield 0.16 -0.21 0.29 0.12 -0.029 -0.046 -0.23 -0.21 -0.34 0.06 -0.33 0.18
Obs soybean yield 0.02 0.026 0.14 0.19 -0.073 0.14 0.065 0.041 -0.025 0.15 0.23 0.079
Obs C3 yield 0.15 -0.17 0.31 0.2 -0.059 0.027 -0.17 -0.16 -0.31 0.12 -0.18 0.19
Obs LAI -0.071 -0.16 -0.13 -0.02 -0.24 -0.21 -0.13 0.39 0.25 0.2 0.28 0.031
Obs GPP -0.12 -0.15 0.21 0.22 -0.059 0.027 -0.2 0.35 0.41 0.49 0.28 -0.1
JULES C3 harvest 0.21 0.14 0.16 0.11 0.13 0.24 0.33 0.18 0.34 0.23 0.28 0.061
JULES C3 LAI 0.21 0.31 0.27 0.39 0.2 0.18 0.27 0.19 0.34 0.23 0.21 0.16
JULES C3 GPP 0.15 0.26 0.27 0.4 0.33 0.22 0.35 0.34 0.45 0.34 0.31 0.14
CLASSIC C3 LAI 0.0098 0.086 -0.013 -0.059 -0.072 -0.0089 -0.046 0.25 0.16 0.12 0.033 0.054
CLASSIC C3 GPP 0.0021 0.066 0.14 0.27 0.3 0.13 0.26 0.41 0.47 0.32 0.21 0.08
ORCHIDEE-MICT C3 LAI -0.056 0.1 0.02 0.16 0.35 0.26 0.3 0.17 0.38 -0.013 0.12 0.082
ORCHIDEE-MICT C3 GPP -0.075 0.093 0.027 0.19 0.37 0.25 0.33 0.26 0.46 0.052 0.17 0.094
1 2 3 4 5 6 7 8 9 10 11 12
Precipitation (month)