UKESM1: Land Use scheme and initial results from CMIP6 LUMIP simulations

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UKESM1: UK EARTH SYSTEM MODEL

LAND ICE SHEET MODEL NOT INCLUDED IN STANDARD UKESM1
Land cover in UKESM1

Gridboxes contain 4 distinct regions:

- Non-vegetated (urban, lakes)
- Vegetated
  - natural (5 tree / 2 shrub / C3, C4 grass PFTs)
  - crop (C3, C4 grass PFTs)
  - pasture (C3, C4 grass PFTs)

Competition between PFTs occurs separately in each region via TRIFFID DVGM

- relative abundance of PFTs in each region is therefore consistent with the climate.
Crop and Pasture in UKESM1

The fractions of the gridbox in which Crop + Pasture can grow are prescribed

- As crop + pasture areas grow, natural plants are cleared away
  - Aboveground biomass put into wood product pools
  - Wood product pools decay releasing CO₂
- Changes to crop / pasture area are net transitions not gross transitions

Crops:

- 30% of crop litter is intercepted as a ‘harvest flux’
- Prevents unrealistic accumulation of soil carbon in productive croplands
- Provides metric of crop productivity
- Crop PFTs are not nitrogen limited: perfect fertilizer application
  - Fertilizer flux exactly meets crop nitrogen demand – no accumulation in soil

Pasture:

- Not grazed
- Not fertilized or harvested

Description paper of UKESM1 land use scheme is being written by Eddy Robertson.
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Land use + land use change CO₂ emissions in UKESM1 are the sum of the decay of the wood product pools plus the crop harvest flux
Implementation of LUH2

Crop + pasture fraction ancillaries created from the following variables of LUH2:

**PASTURE** = \( \text{pastr} \): managed pasture

Rangeland was not included in pasture fraction to avoid excessive deforestation.

**CROP** = 
- \( \text{c3ann} \): C3 annual crops
- \( \text{c3per} \): C3 perennial crops
- \( \text{c4ann} \): C4 annual crops
- \( \text{c4per} \): C4 perennial crops
- \( \text{c3nfx} \): C3 nitrogen-fixing crops

Re-gridded to UKESM1 grid in Python + Iris
CMIP6: LUMIP experiments

Status as of 15\textsuperscript{th} September 2019:

- deforest-globe (x1 completed, awaiting processing)
- hist-noLu (x4: all completed, 3 submitted to ESGF)
- ‘mix and match’ land use scenarios:
  - ssp370-ssp126-lu (x5: 1 submitted to ESGF, 4 still running)
  - ssp126-ssp370-lu (x5: 1 submitted to ESGF, 4 still running)
  - esm-ssp585-ssp126-lu (x1 completed, awaiting processing)
  - esm-ssp585-ssp126-lu-ext (x1 not started)
  - land only simulations

- Next slides show (mostly):
  - timeseries of global mean Tas and Pr
  - maps of differences in Tas and Pr between experiment and control (final decadal mean)

- land only simulations
  - can only do a few and can’t upload to ESGF but could share results informally if any interest
PHASE 1  deforest-globe vs piControl

- Global mean temperature: almost 1K cooler by end (though cooling trend at start of piControl)
- Regional differences up to 3-3.5K though no analysis of statistical significance yet
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PHASE 1

deforest-globe vs piControl

- Tree fraction continues to reduce after forced deforestation
  - Climate induced loss of trees

![Graphs showing changes in vegetation and soil carbon over time, comparing deforestation and control scenarios.](image-url)
PHASE 1

deforest-globe vs piControl

- Tree fraction continues to reduce after forced deforestation
  - Climate induced loss of trees

![Graphs showing vegetation and soil carbon changes over time](image)
Evidence of land use contributing to cooling in 20th Century UKESM1 historical simulation.
...also a small impact on precipitation.
**PHASE 2**

ssp370-ssp126-lu vs ssp370

Red vs Yellow timeseries:

- Little signal in global mean temperature or precipitation but ensemble running
- Regional differences in final decadal mean temperature but statistical analysis not yet done
PHASE 2  ssp370-ssp126-lu vs ssp370

Red vs Yellow timeseries:

- little signal in global mean temperature or precipitation but ensemble running
- regional differences in final decadal mean temperature but statistical analysis not yet done
PHASE 2

ssp126-ssp370-lu vs ssp126

Blue vs Green timeseries:

• little signal in global mean temperature or precipitation but ensemble running
• stronger signal regionally than in red/yellow pair (statistical analysis not yet done)
PHASE 2

ssp126-ssp370-lu vs ssp126

Blue vs Green timeseries:

• little signal in global mean temperature or precipitation but ensemble running
• stronger signal regionally than in red/yellow pair (statistical analysis not yet done)
Thank you for your attention.
Future of land-use in JULES / UKESM1

• Representation of “gross landuse transitions” may be added
• Other potential developments
  • Improvement of crop and pasture PFT parameter sets
    • ...to make them more realistic, distinct from natural grasses
  • Addition of other sub-grid regions:
    • forestry, biofuels
  • Improvement of management:
    • irrigation,
    • grazing of pasture,
    • wood harvest in forested regions
    • wildfire suppression in crop regions [fire not yet in UKESM1]

LUH2 vs UKESM1 Crop and Pasture global area

Not identical due to differences in total land area.
hist vs hist-noLu

Hist-no-LandUse ensemble (blue)
Hist ensemble (red)
Hist-LandUse-only (green)
Vegetation carbon timeseries [BLUE vs GREEN CURVES]

- PHASE 2

- ssp370-ssp126-lu vs ssp370
ssp370-ssp126-lu vs ssp370

- Vegetation carbon timeseries from [RED and YELLOW CURVES]
Historical land carbon uptake is the net effect of two processes:

- Land-use change: deforestation, regrowth
- Climate and CO$_2$ impacts on undisturbed vegetation

UKESM is doing a good job of getting the historical land sink within observational estimates.

- Changes in UKESM veg / soil much less than HadGEM2ES:
  - 13PFTs vs 5PFTs
  - N limitation of vegetation growth

- In UKESM harvest C flux is removed
  - would have gone into soil C in HadGEM2ES.
Simulated historical land use emissions

Accurate simulation of historical LULCC emissions requires more than 1850 → 2015 experiment
• captures flux from harvest and deforestation...
• ...but neglects carbon taken up by regrowth of natural vegetation on abandoned agricultural land
• comparison of land carbon store historical vs hist-noLu captures all three

Land Use emissions from decay of cleared trees / shrubs

Harvest Flux
piControl ~ 0.9GtC/yr
Green: Observations

Blue: Difference in land carbon store: [Hist – Hist-noLu]

Red: Interactive LU emissions in esm-Hist (relative to esm-piControl)