Earth system modeling for gaining comprehensive understanding of global change

KAWAMIYA, Michio, Dr.

Director, CEMA/RIGC

Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

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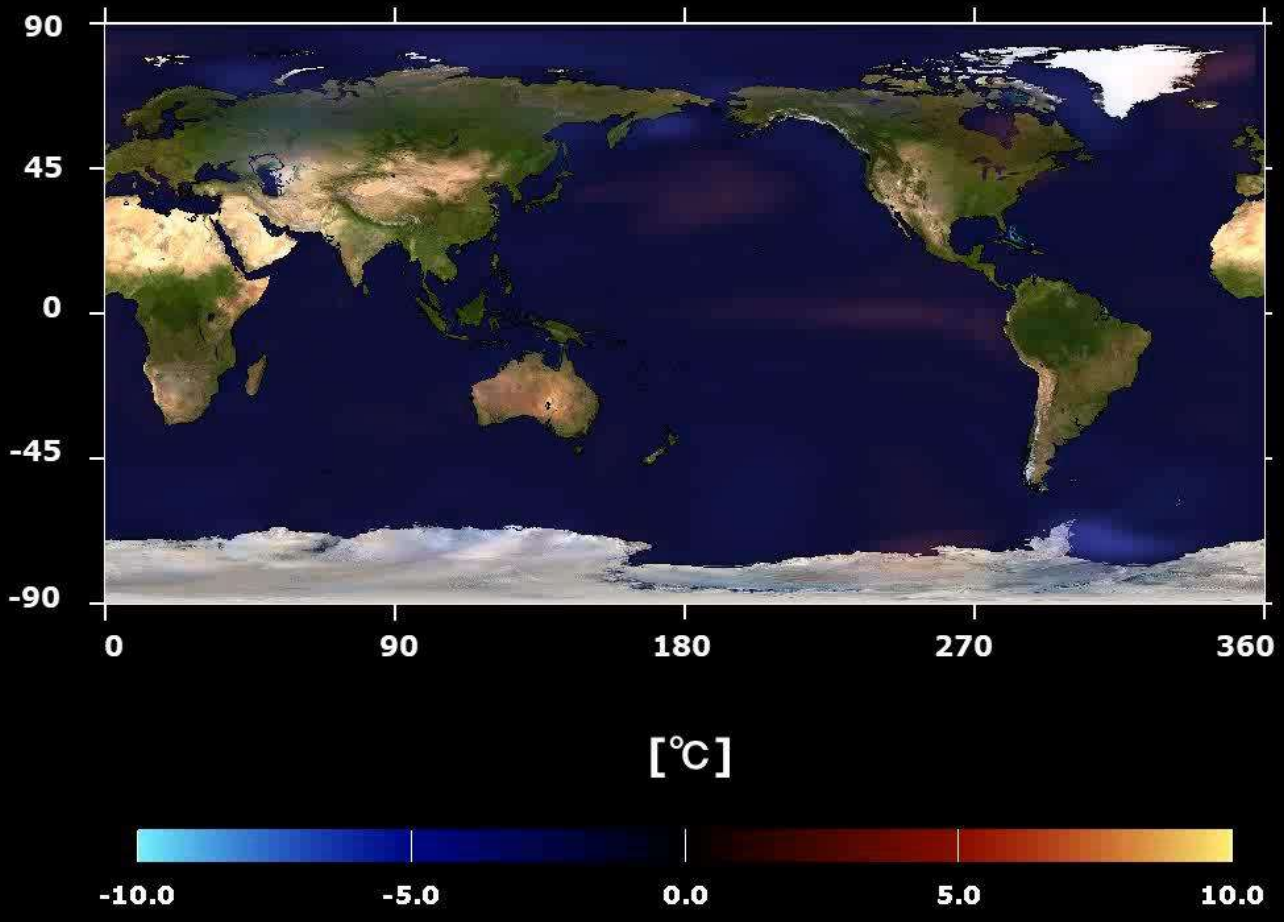
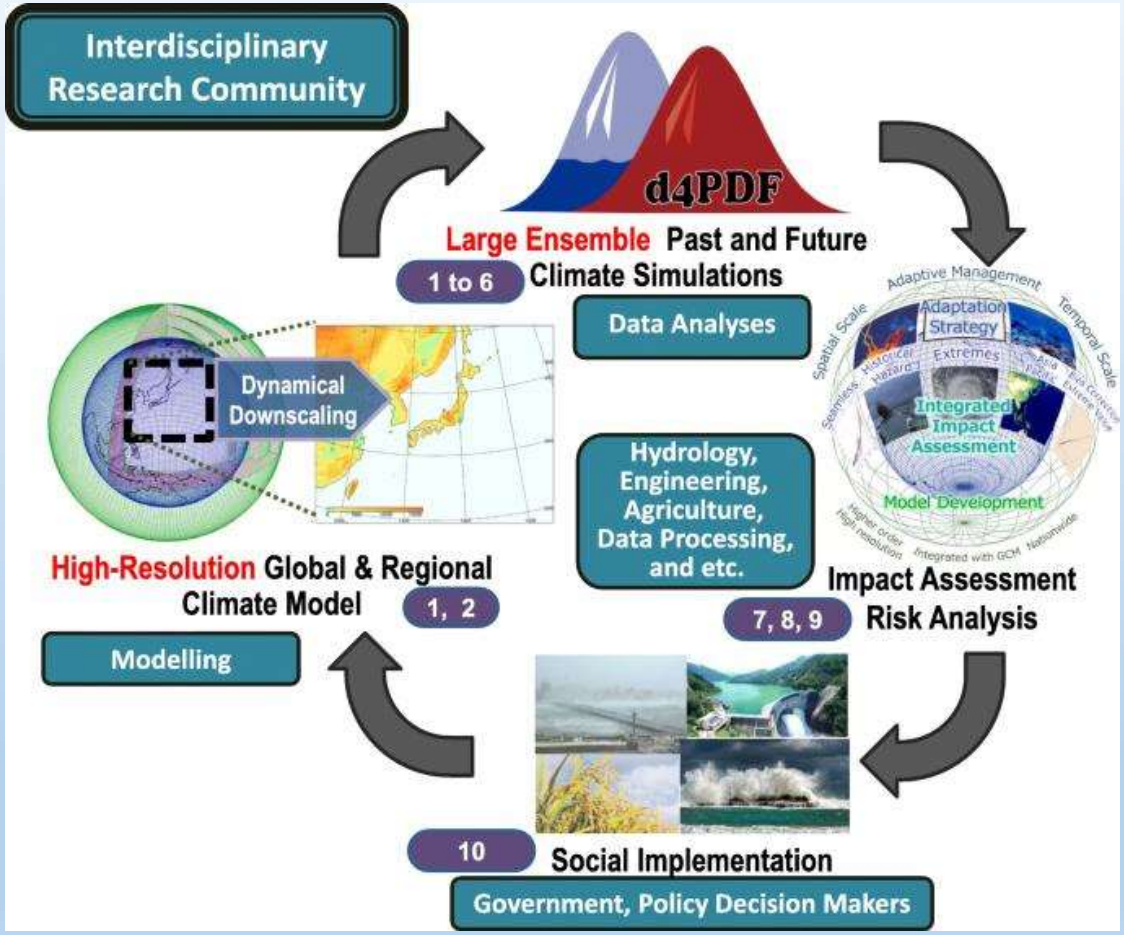
Surface air temperature

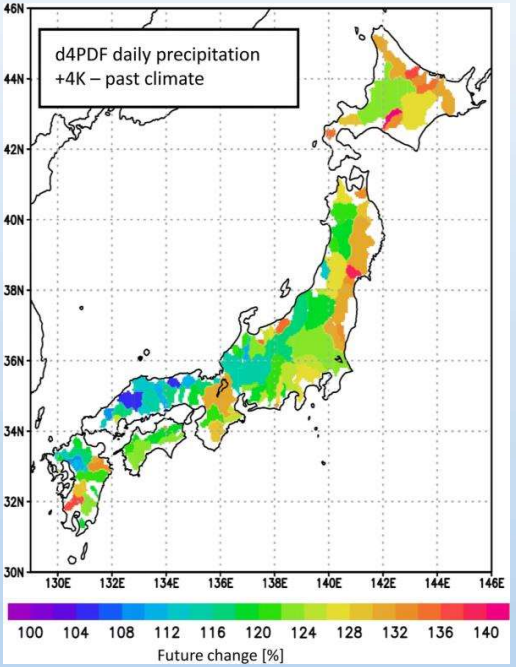


Computed on Earth Simulator

d4PDF: dataset for climate change adaptation

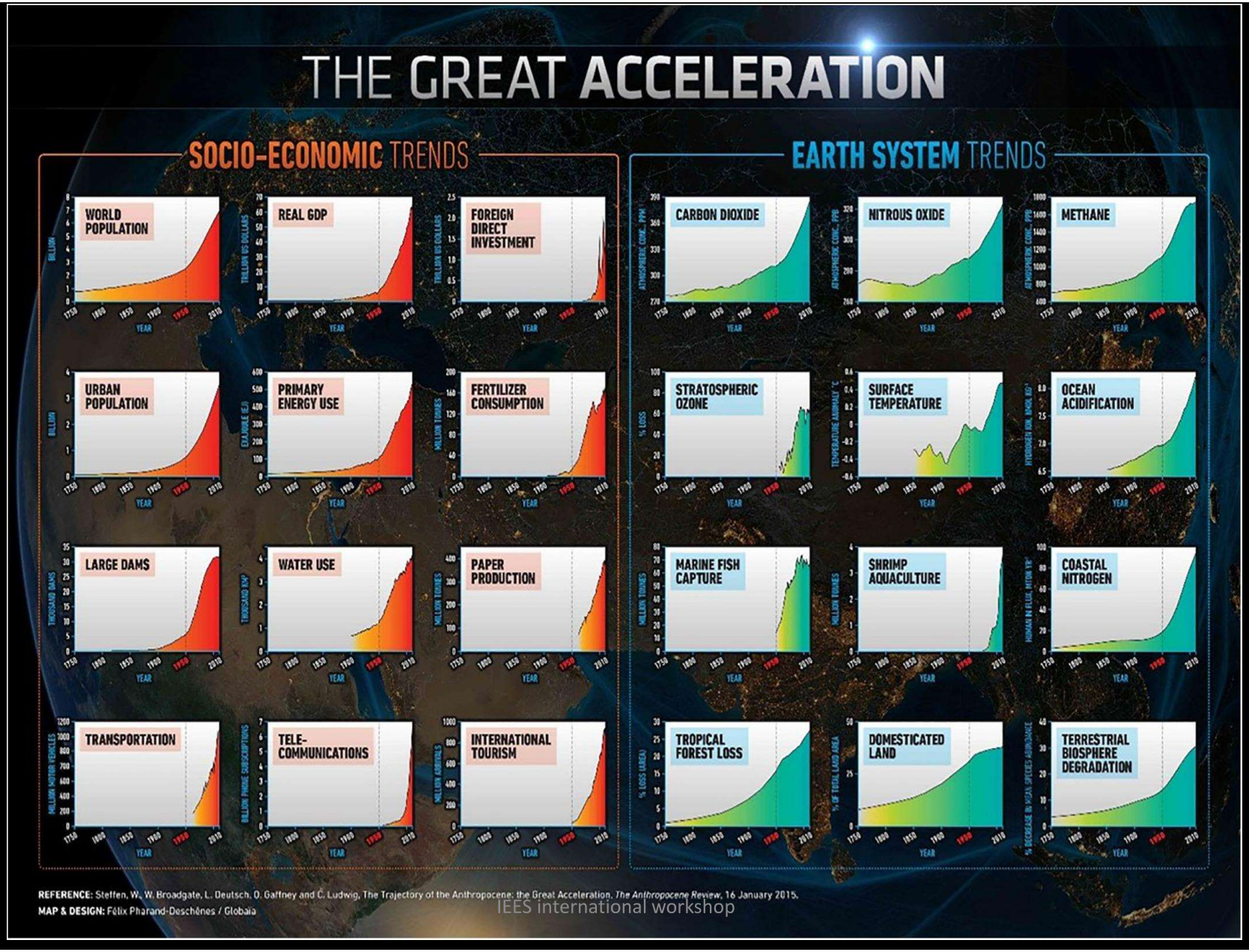


Mori and Ishii (2020)



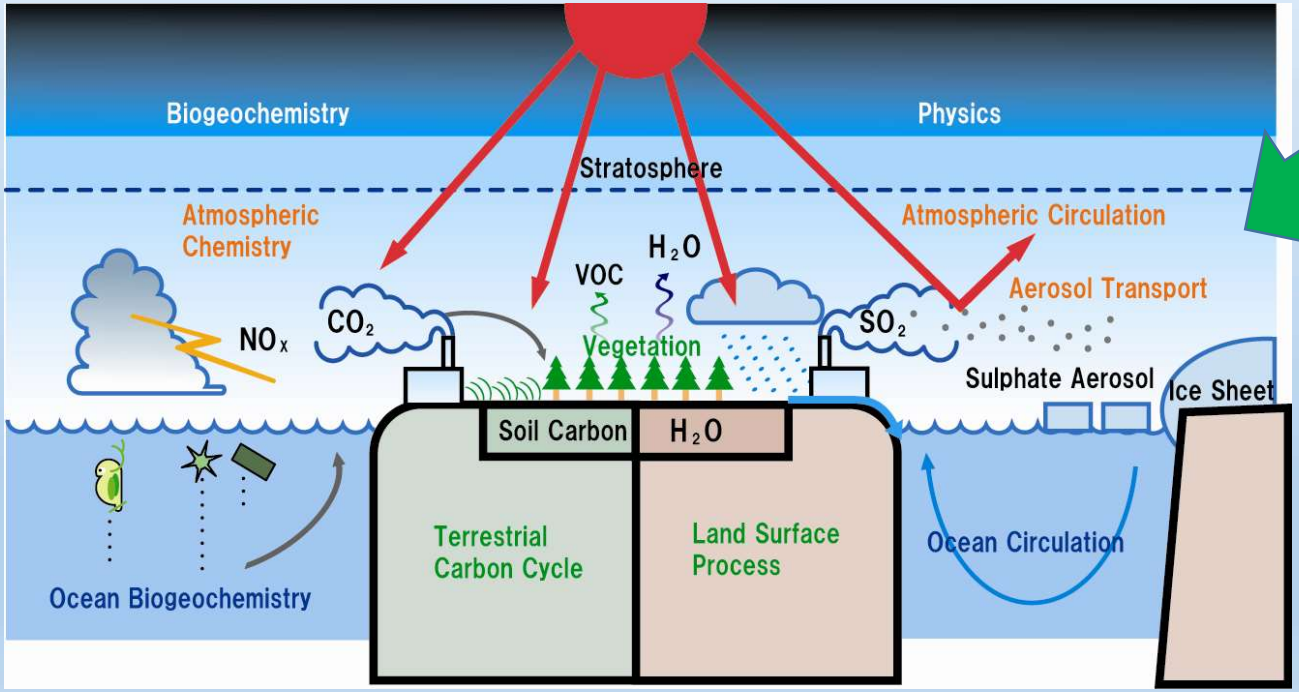
Hoshino and Yamada (2018)

Future changes in the maximum precipitation averaged over the first-class river basins (future minus past, unit: %), based on d4PDF.


THE GREAT ACCELERATION
SOCIO-ECONOMIC TRENDS
WORLD POPULATION
REAL GDP
FOREIGN DIRECT INVESTMENT
URBAN POPULATION
PRIMARY ENERGY USE
FERTILIZER CONSUMPTION
LARGE DAMS
WATER USE
PAPER PRODUCTION
TRANSPORTATION
TELE-COMMUNICATIONS
INTERNATIONAL TOURISM
EARTH SYSTEM TRENDS
CARBON DIOXIDE
NITROUS OXIDE
METHANE
STRATOSPHERIC OZONE
SURFACE TEMPERATURE
OCEAN ACIDIFICATION
MARINE FISH CAPTURE
SHRIMP AQUACULTURE
COASTAL NITROGEN
TROPICAL FOREST LOSS
DOMESTICATED LAND
TERRESTRIAL BIOSPHERE DEGRADATION
YEAR
REFERENCE: Steffen, W., W. Broadgate, L. Deutsch, O. Gaffney and C. Ludwig, The Trajectory of the Anthropocene: the Great Acceleration, The Anthropocene Review, 16 January 2015.
MAP & DESIGN: Félix Pharand-Deschênes / Globaia

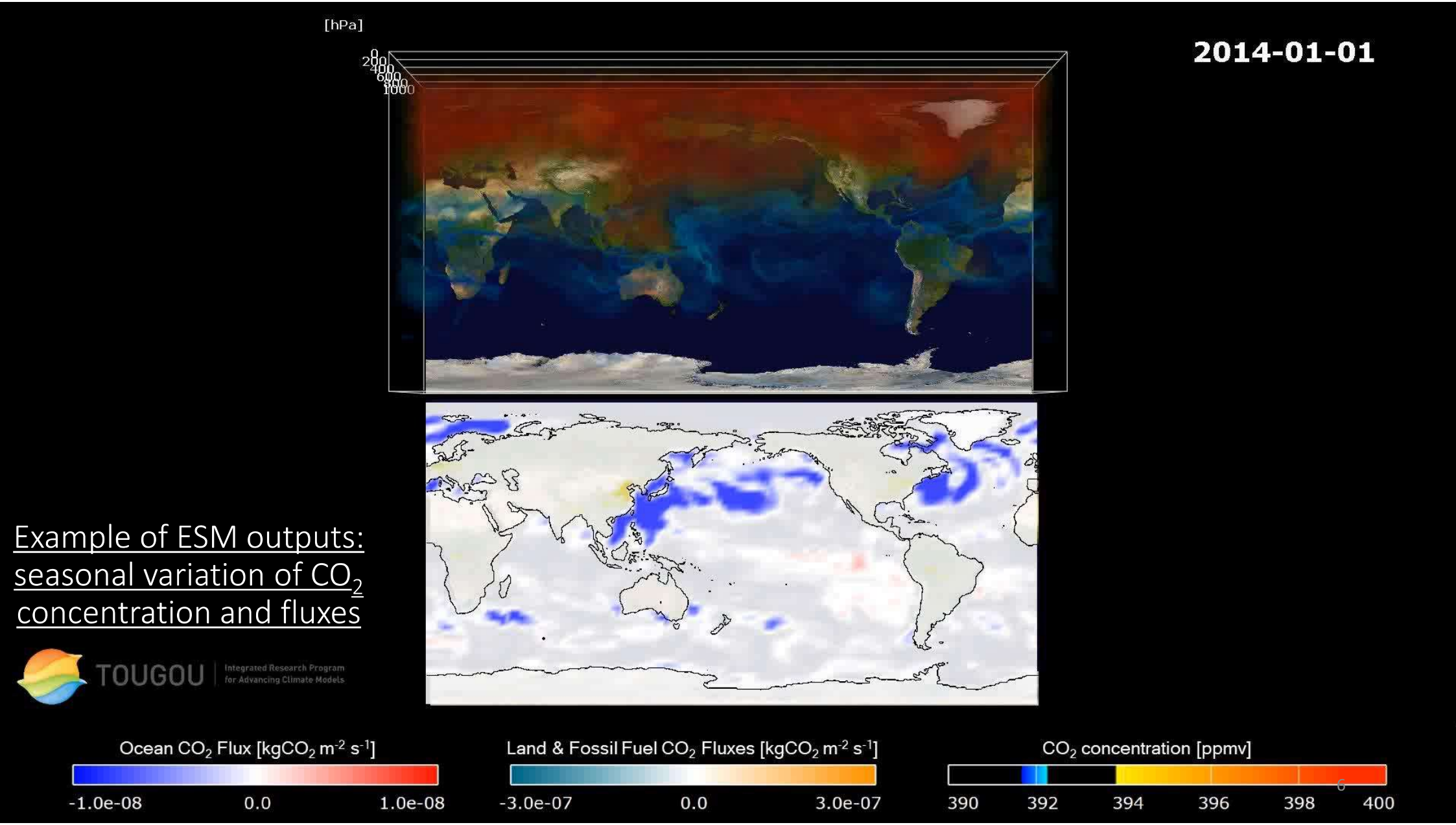
Earth system model

Earth system model

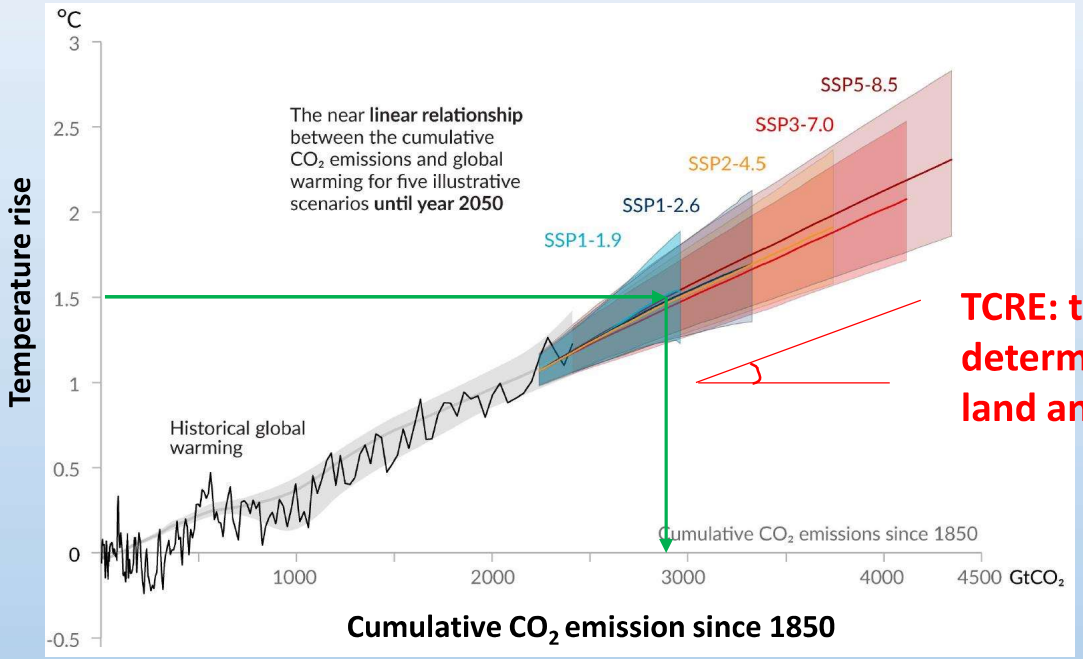


Socio-economic model

- **Earth system model:** Climate model with biogeochemical processes such as carbon cycle
- Incorporates processes like: **Land-use change (e.g., deforestation), non-CO_2 GHGs emissions, atmospheric chemistry etc.**
- **Coupling with a socio-economic model** is ongoing.


[hPa]
0
200
400
600
800
1000
2014-01-01
Example of ESM outputs: seasonal variation of CO_2 concentration and fluxes
TOUGOU
Integrated Research Program for Advancing Climate Models
Ocean CO_2 Flux [$kgCO_2\ m^{-2}\ s^{-1}$]
-1.0e-08
0.0
1.0e-08
Land & Fossil Fuel CO_2 Fluxes [$kgCO_2\ m^{-2}\ s^{-1}$]
-3.0e-07
0.0
3.0e-07
CO_2 concentration [ppmv]
390
392
394
396
398
400

Cumulative CO2 emission and temperature rise: the more you emit, the warmer it gets



TCRE: the slope of the graph determined by the response of land and ocean to the CO_2 increase

AR6, Fig.SPM10

Transient climate response to emission (TCRE): critical value to evaluate CO2 emission consistent with a given climate mitigation target .

The simple linear relationship has been identified by ESM studies.

Earth system models incorporate biogeochemistry, and more.

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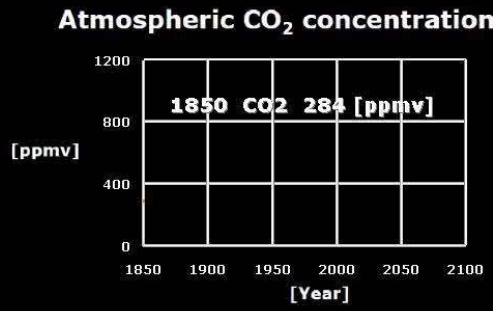
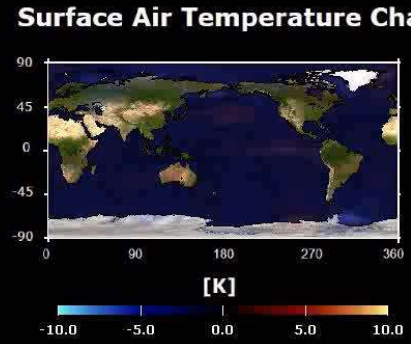
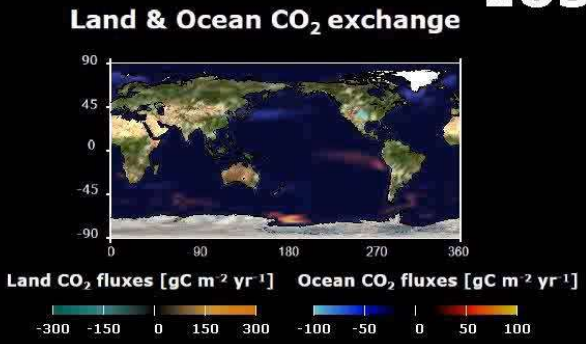
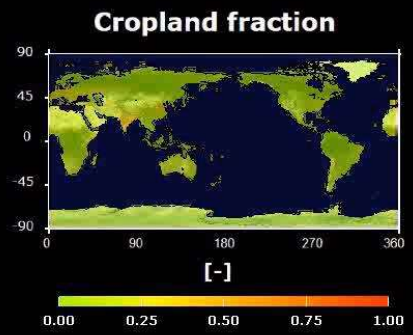
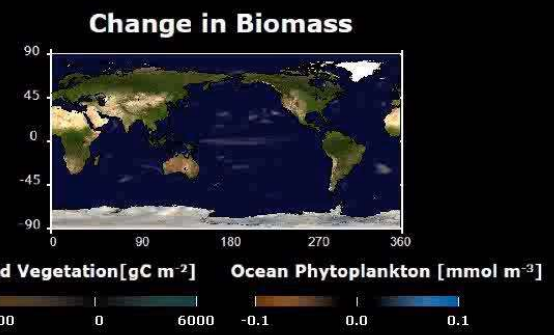
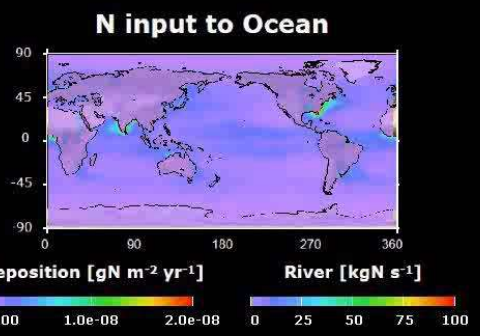


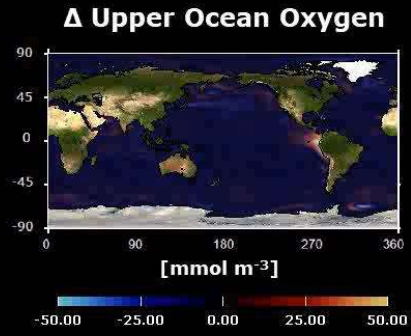


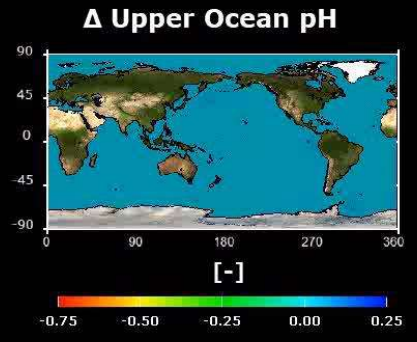






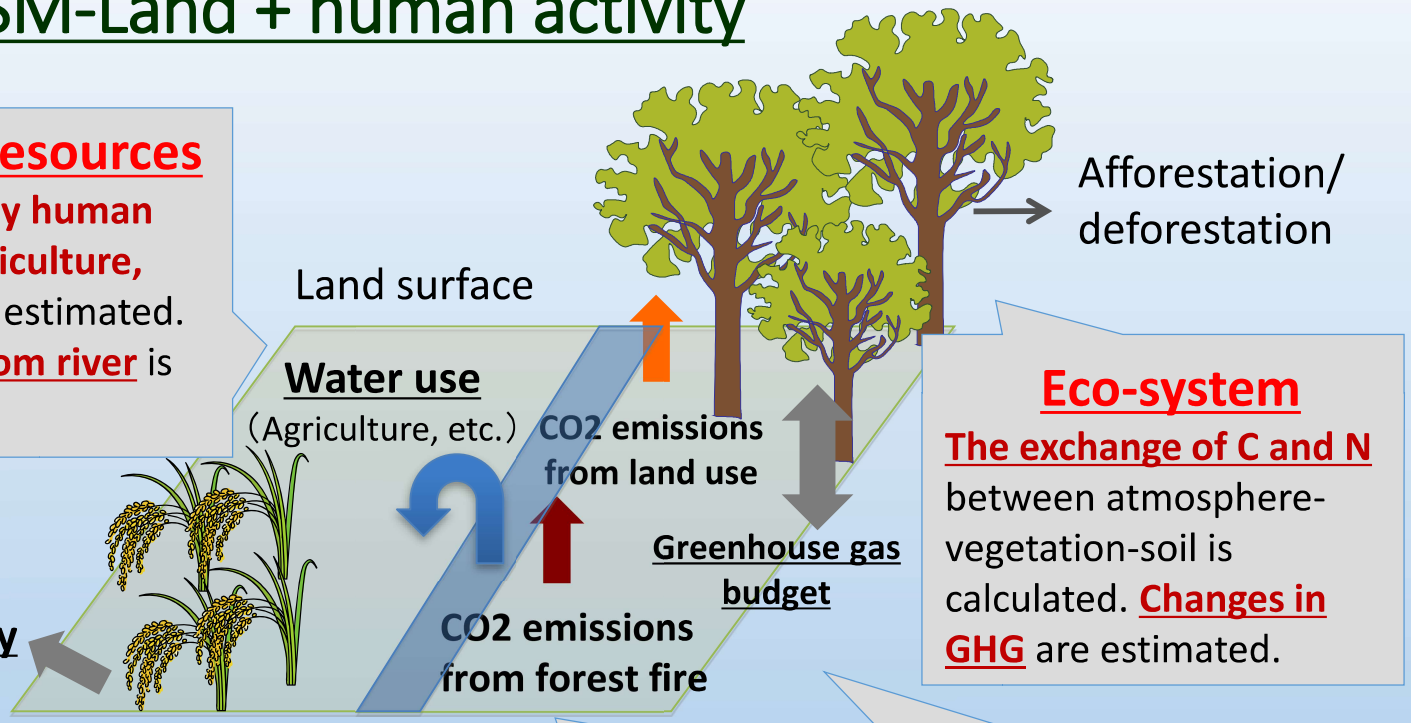






Integrated Terrestrial Model

ESM-Land + human activity



Water resources

Water use by human activity (agriculture, industry) is estimated. **Irrigation from river** is considered.

Eco-system

The exchange of C and N between atmosphere-vegetation-soil is calculated. **Changes in GHG** are estimated.

Crop growth

Crop yield is estimated . **The production of bio-energy crop** for mitigation option is considered.

Climate (Land surface)

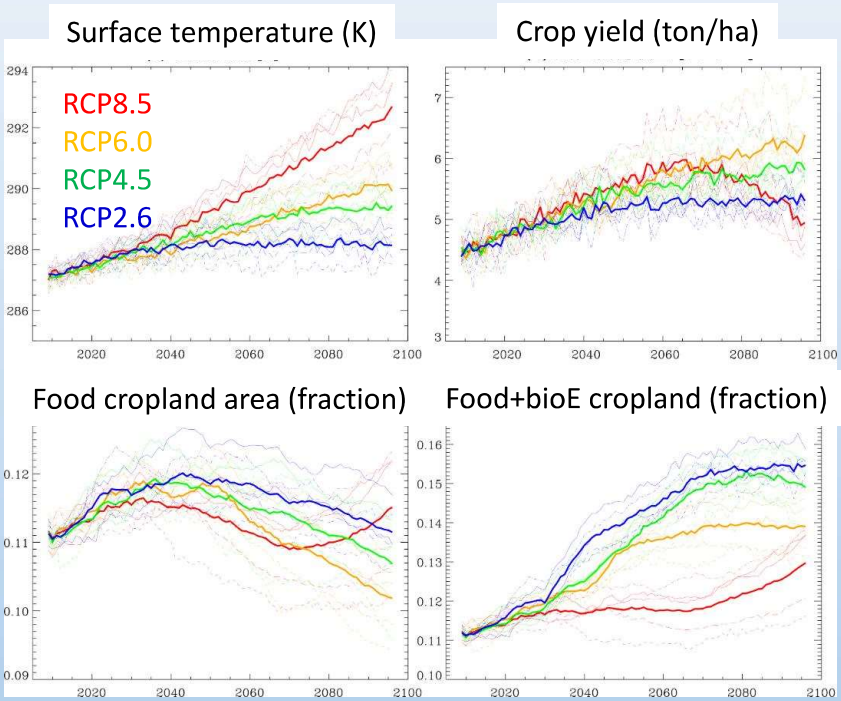
Soil water, temperature are calculated based on the water and energy budget. Atmospheric processes (precipitation etc) is option.

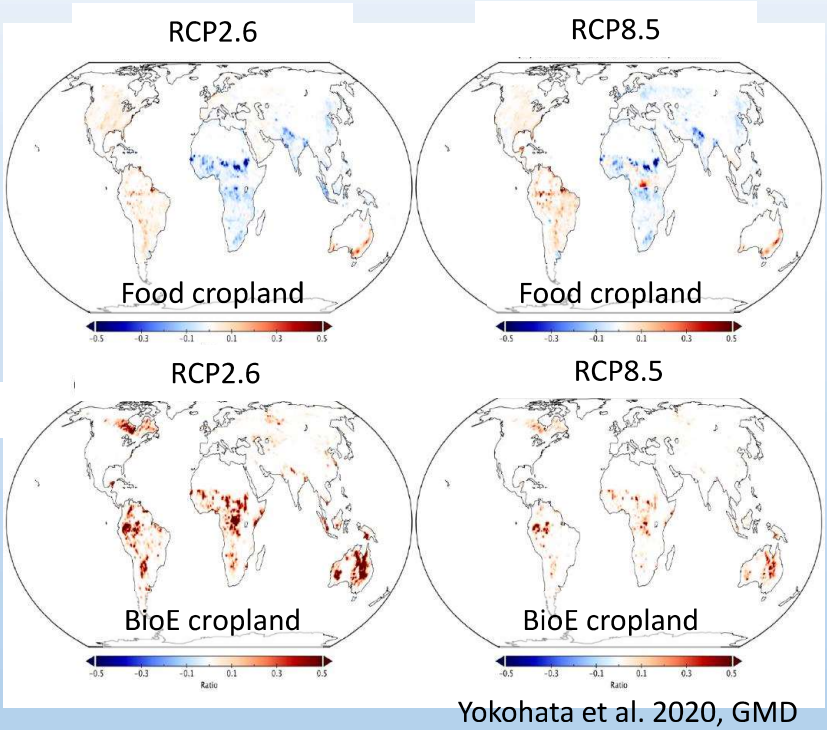
Land use

Land-use change (cropland-forest) is calculated based on future socio-economic scenarios. **Economic (e.g., trade) +natural (e.g. inclination) factors** are considered.

Yokohata et al. (2020)

ESM results projecting food, bio-energy, and land use



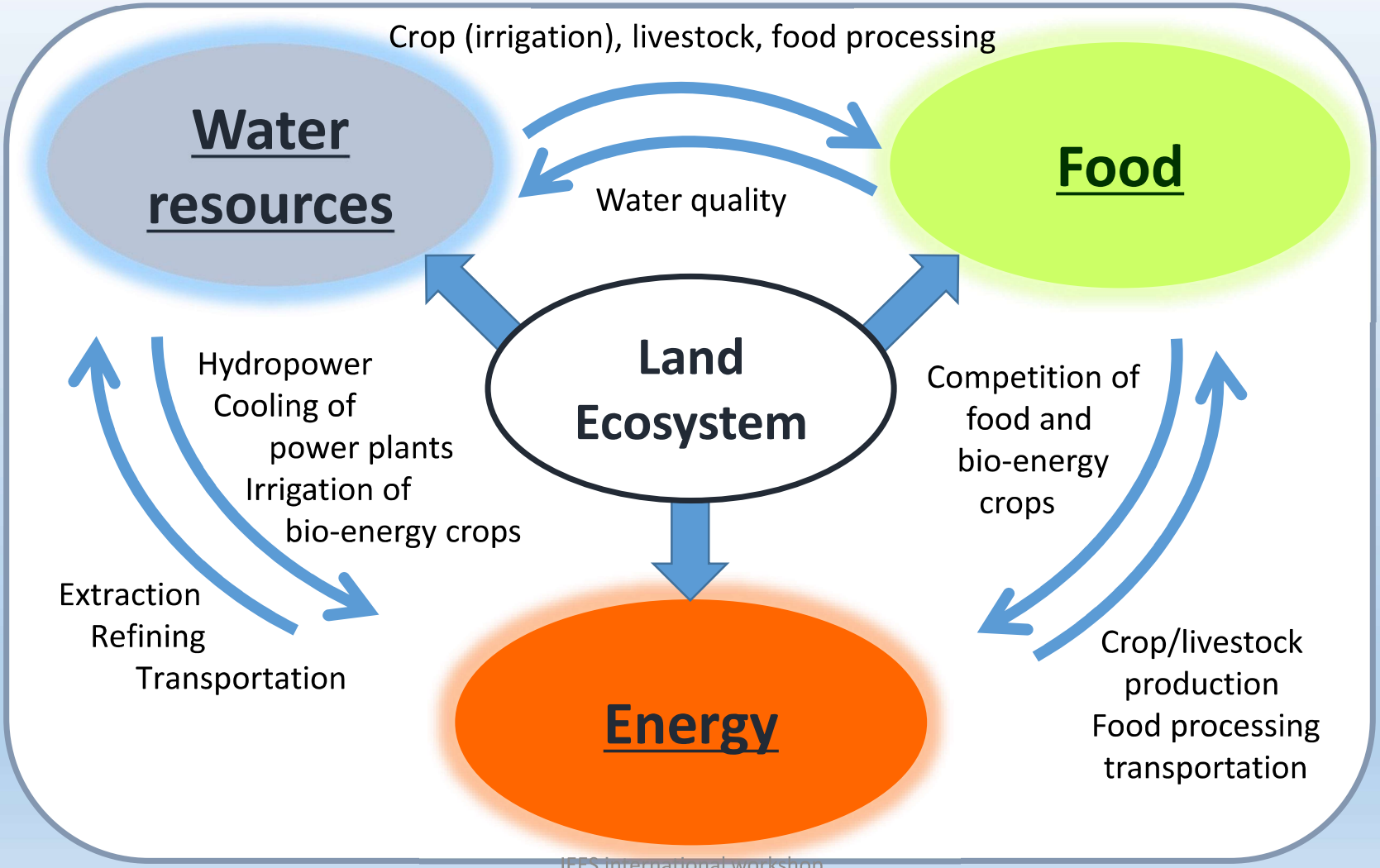


Yokohata et al. 2020, GMD

Demands for food and bioenergy projected by socio-economic models are utilized by the Earth system model to estimate future crop yields and land use.

-> Evaluation of Impacts of climate and socio-economic changes on water resources, crop yields, and ecosystem

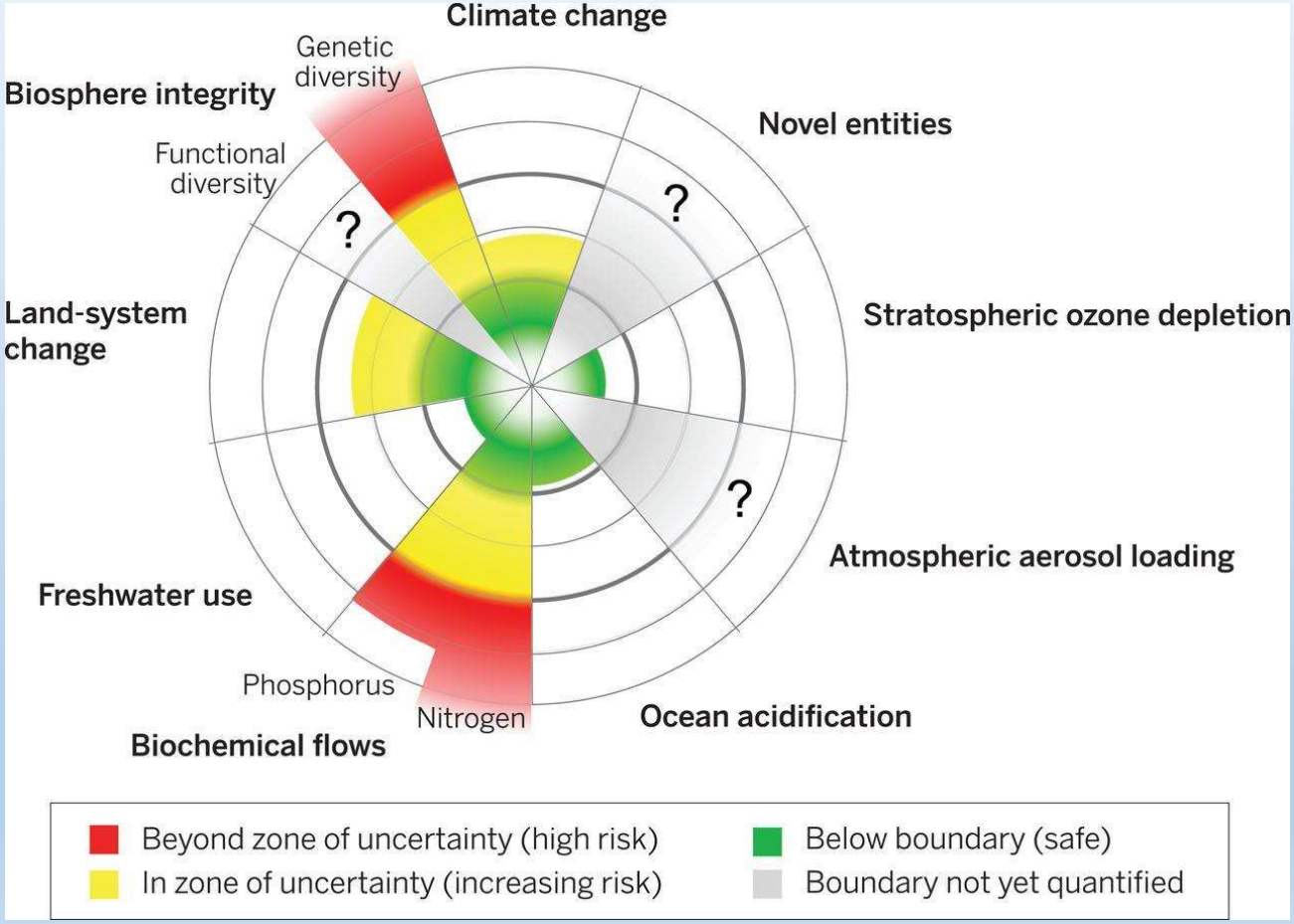
Water-Food-Energy nexus



Slide courtesy:
Dr. Yokohata

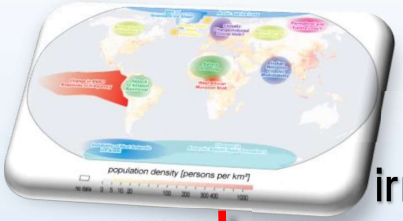
From IPCC WG2 AR5 Technical Summary

Global change is not just temperature rise

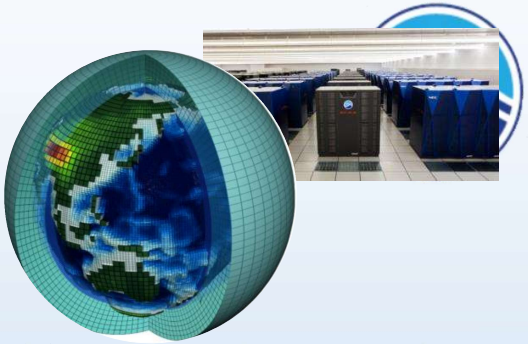


Steffen et al. (2015)

Unrepresented feedbacks (methane emission, wildfire etc.)



Tipping elements, irreversibility



Model development & application

- Decadal prediction
- Centennial scale projection

Feedbacks through socio-economics

Climate – biogeochemistry feedbacks

Emissions of GHGs & Aerosols

Uptake, release

Climate change Promotion, mitigation

Emission (perturbation)

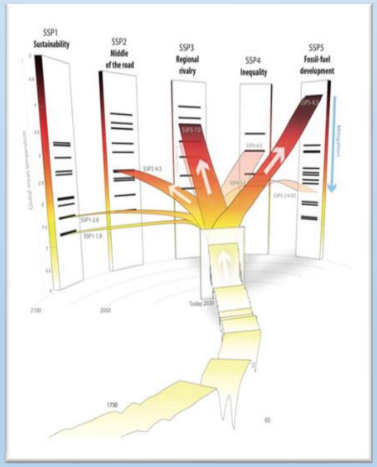
Land use

Biogeochemical cycles

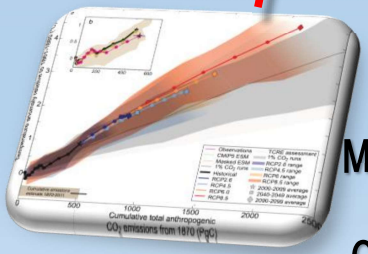
Climate

Impact (nature, society)

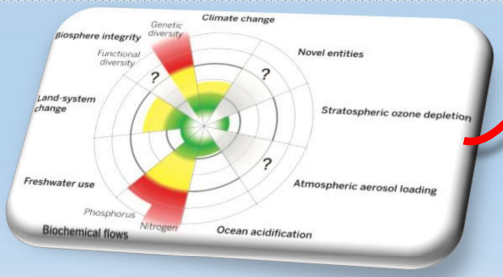
Direct impacts (air pollution, ocean acidification, nitrogen load, etc.)



Presenting the full picture and future options



Mitigation TCRE C budget



Planetary boundary

SDGs

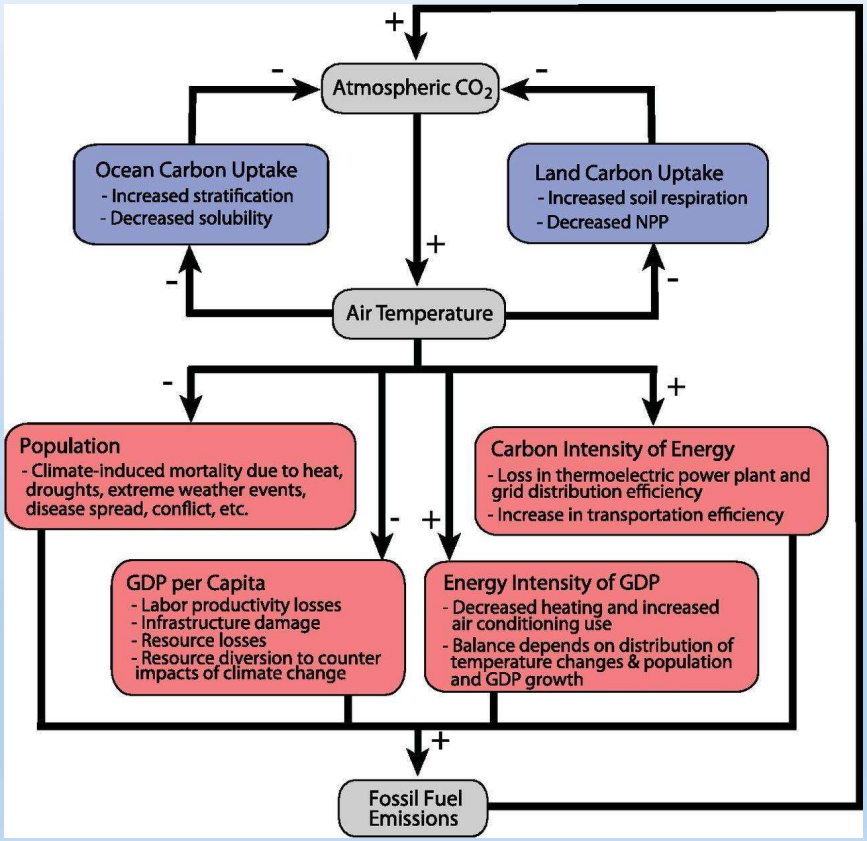
Slide courtesy: Dr. Hajima

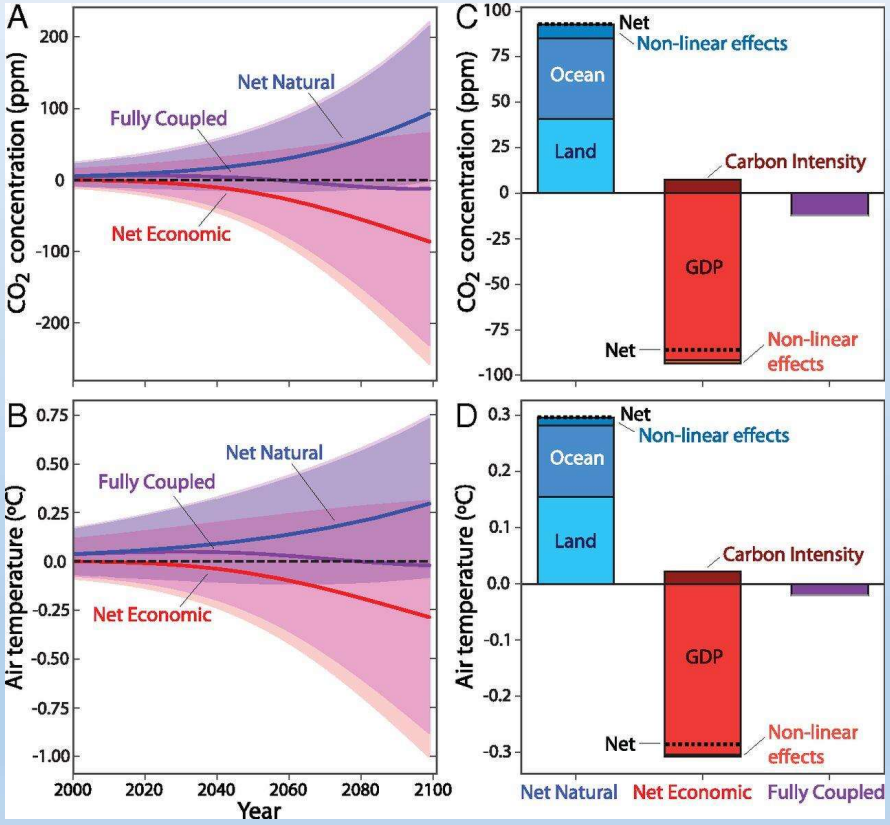
Summary

- ESMs have been contributing to mitigation/adaptation policies against climate change.
- Now expanding to accommodate many aspects of the Earth system, including human activities.
  - Capable of dealing with complex issues like water-energy-food nexus, tipping elements.
- Can server as a powerful tool for quantitively tackle planetary boundary issues.

Backup slides

Some studies indicate significant feedbacks b/w climate and society

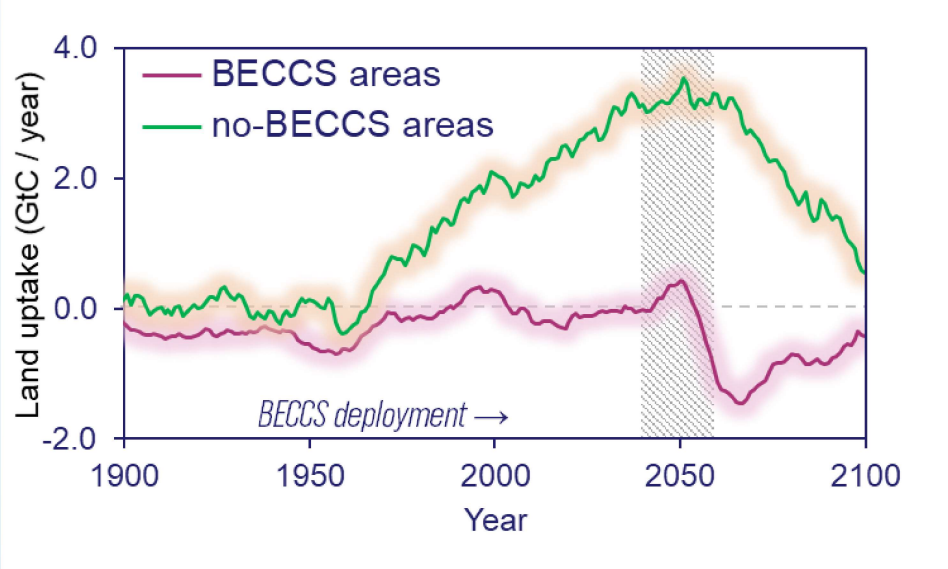


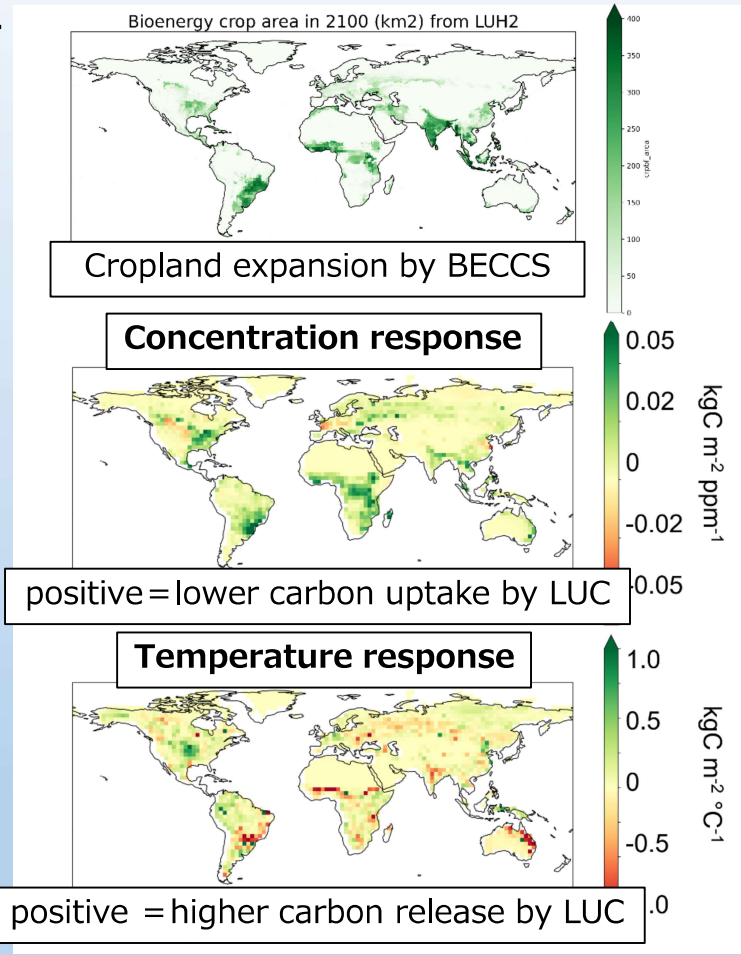


Woodard et al. (2018, PNAS)

Land-use change due to BECCS may lower terrestrial carbon uptake

Melnikova et al. 2021, Earth Sys. Dyn. Disc.





Expansion of cropland by BECCS decreases carbon sequestration per concentration change (concentration response) and increases carbon release per temperature change in temperature (temperature response): With these two combined, terrestrial carbon uptake decreases.