Global Nitrogen Loadings to Stream and Export to Oceans: History and Future

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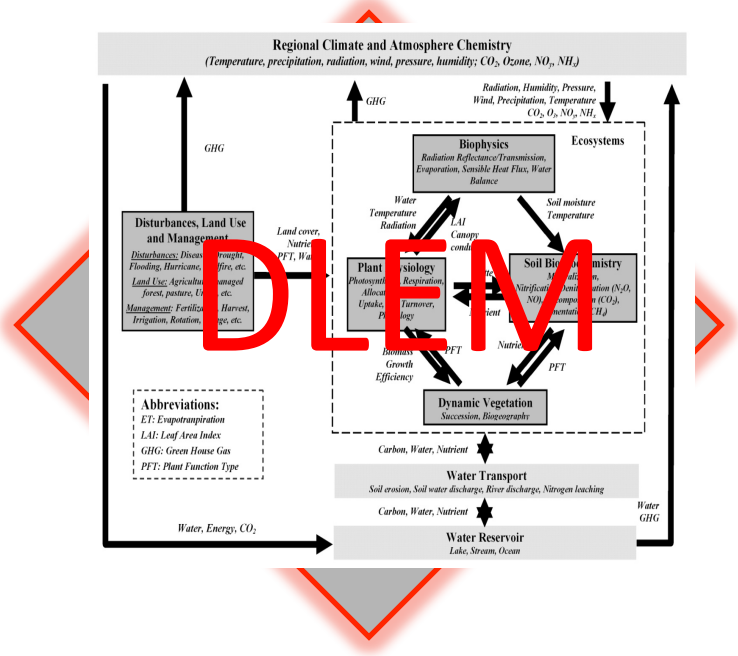
INMS-3, Edinburgh, 16th-19th April, 2018, Edinburgh

N-Dilemma

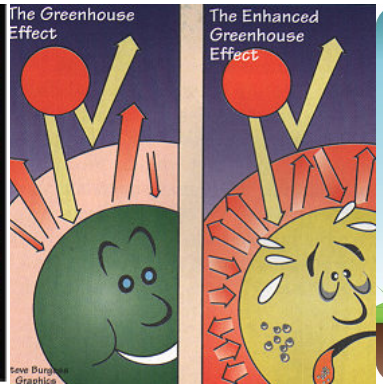
Greenhouse gas emission

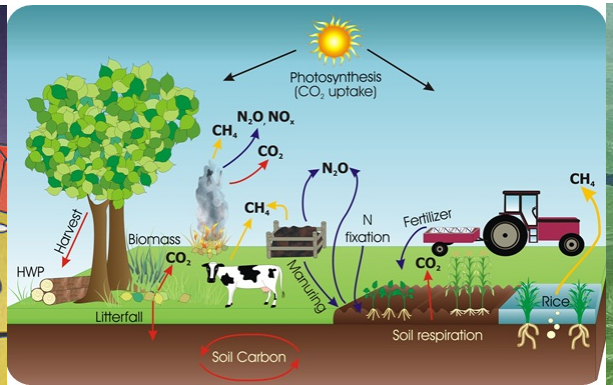
Carbon sequestration



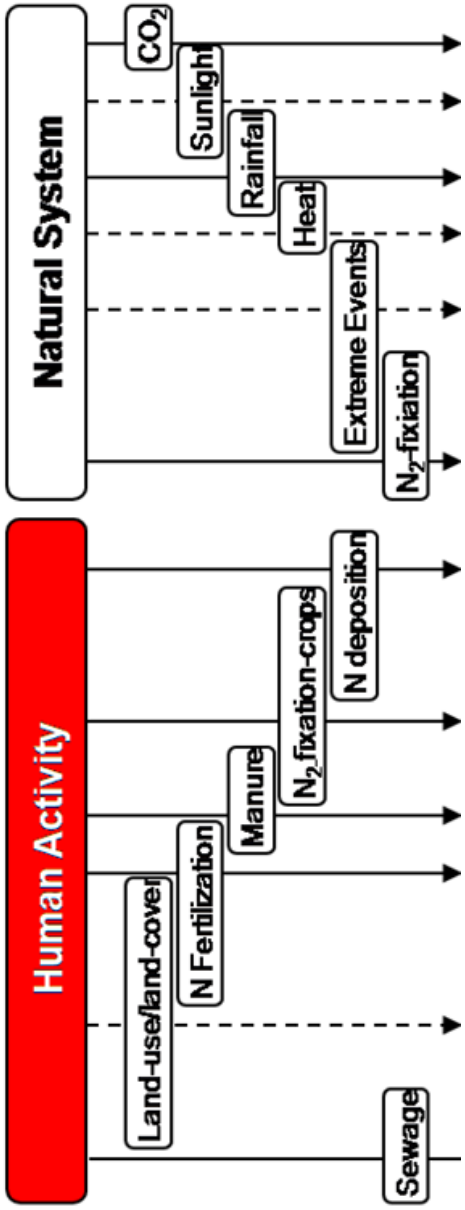
Crop yield Biomass

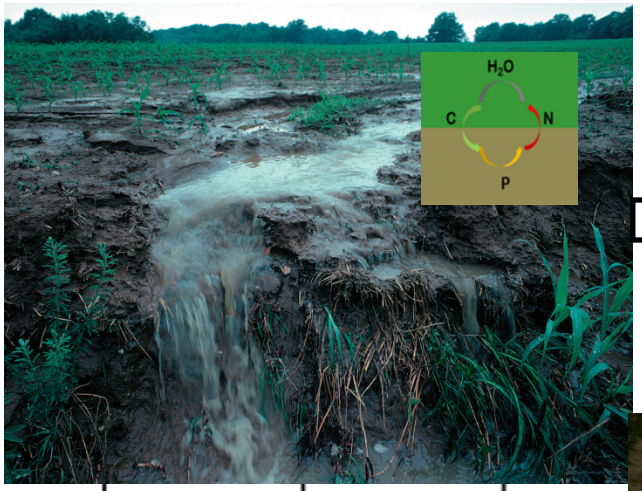
Water quantity and quality



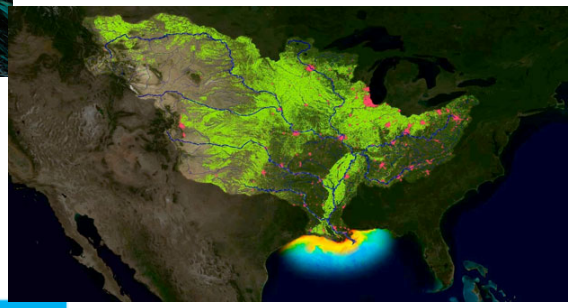


N yield and movement from land to aquatic system

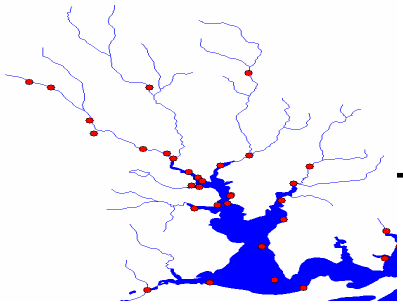




- Crop yield
- Biomass
- C sequestration
- N retention



Water | Nitrogen | Carbon



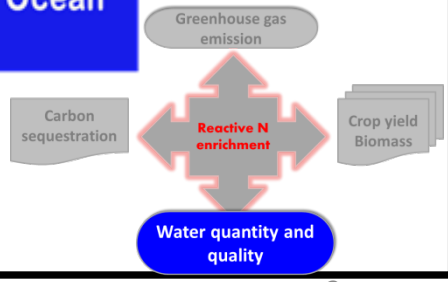
River Discharge

DOC, POC, DIC

DON, PON, DIN

DOP, POP, DIP

Ocean



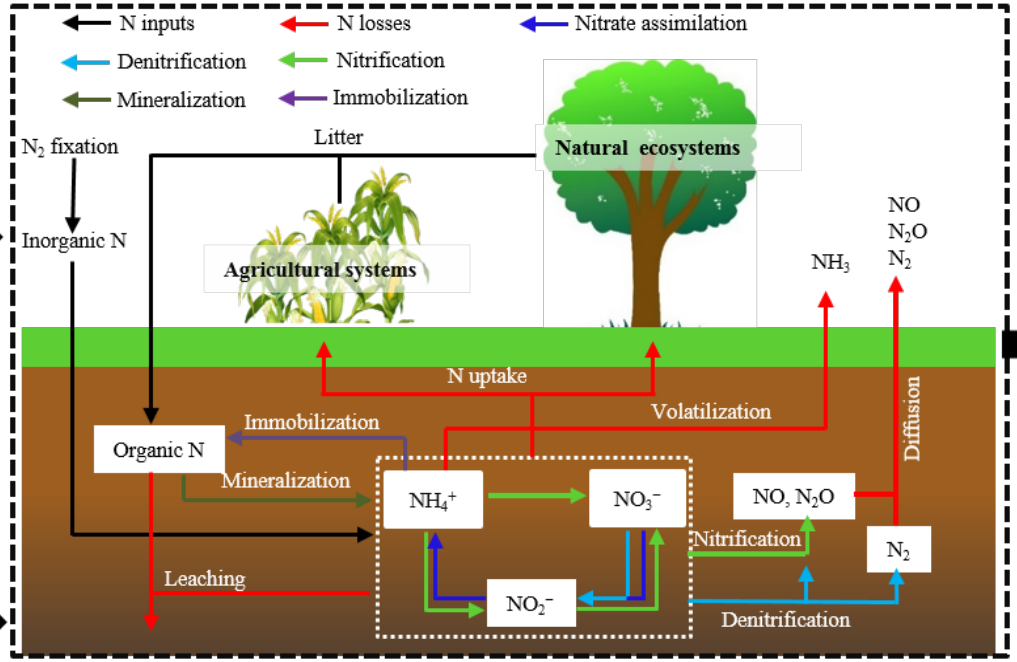
Framework of N2O Model intercomparison project

Model input data

- Climate (Temperature, precipitation, radiation, etc.)
- CO_2 concentration
- N deposition
- N fertilizer use
- Manure N use
- Irrigation
- Land cover and land use
- Soil texture
- topography (elevation, slope, aspect, etc.)

Model calibration & evaluation

- Field observations
- Statistical extrapolation
- Inversion models



Participating Models: CLM-CN, DLEM, LM3V-N, O-CN, LPJ-GUESS, ORCHIDEE, ORCHIDEE-CNP, TRIPLEX-GHG, VISIT

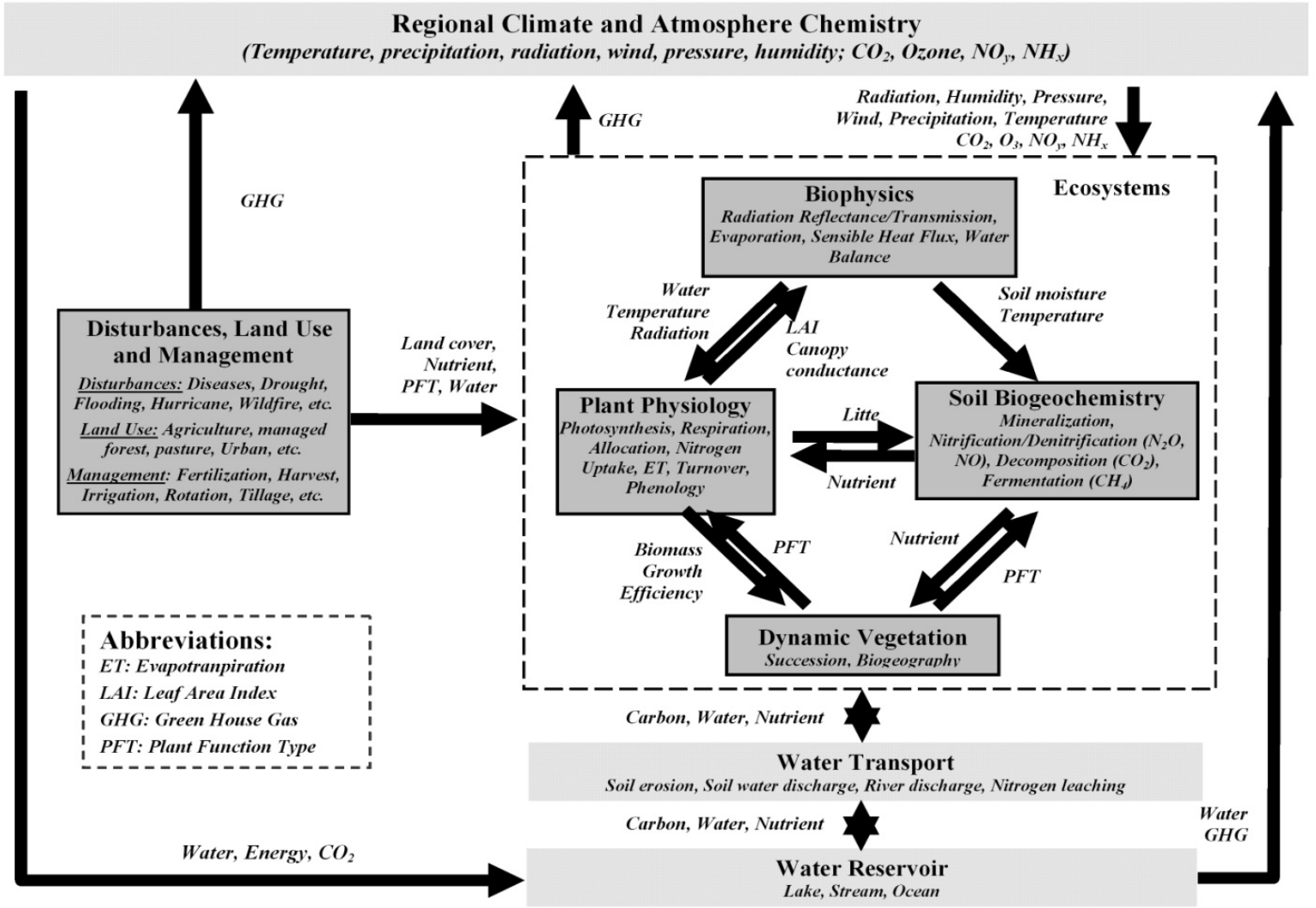
Objective 1
Unravel the major controlling processes of N_2O fluxes and the uncertainties from model structure and parameters

Objective 2
Quantify spatial and temporal patterns of global/regional N_2O fluxes, and attribute the relative contributions of multiple environmental factors

Objective 3
Provide a bench-marking estimate of global and regional N_2O budgets through synthesizing multi-source data

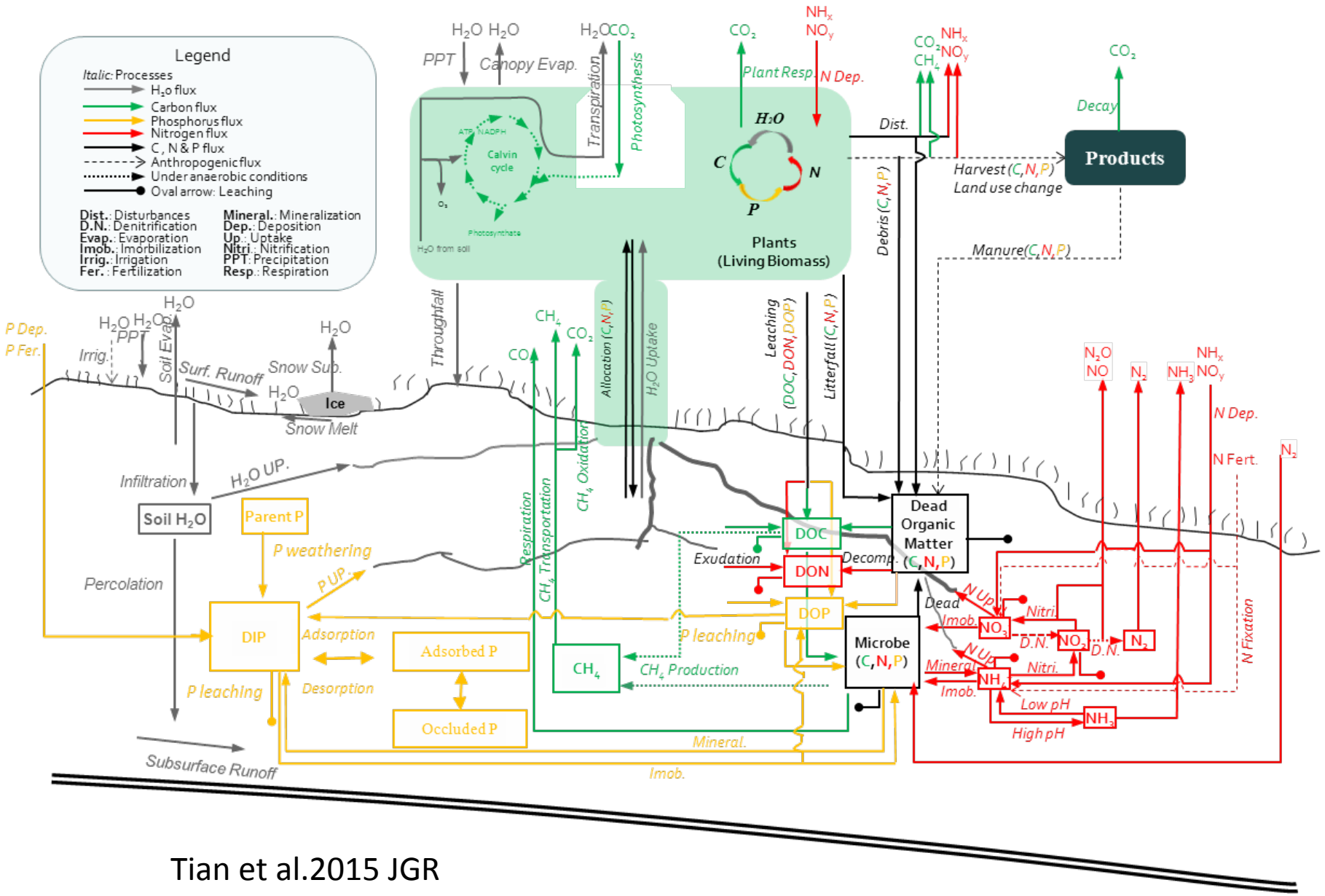
NMIP benchmarks for model performance and data evaluation

The Dynamic Land Ecosystem Model (DLEM)



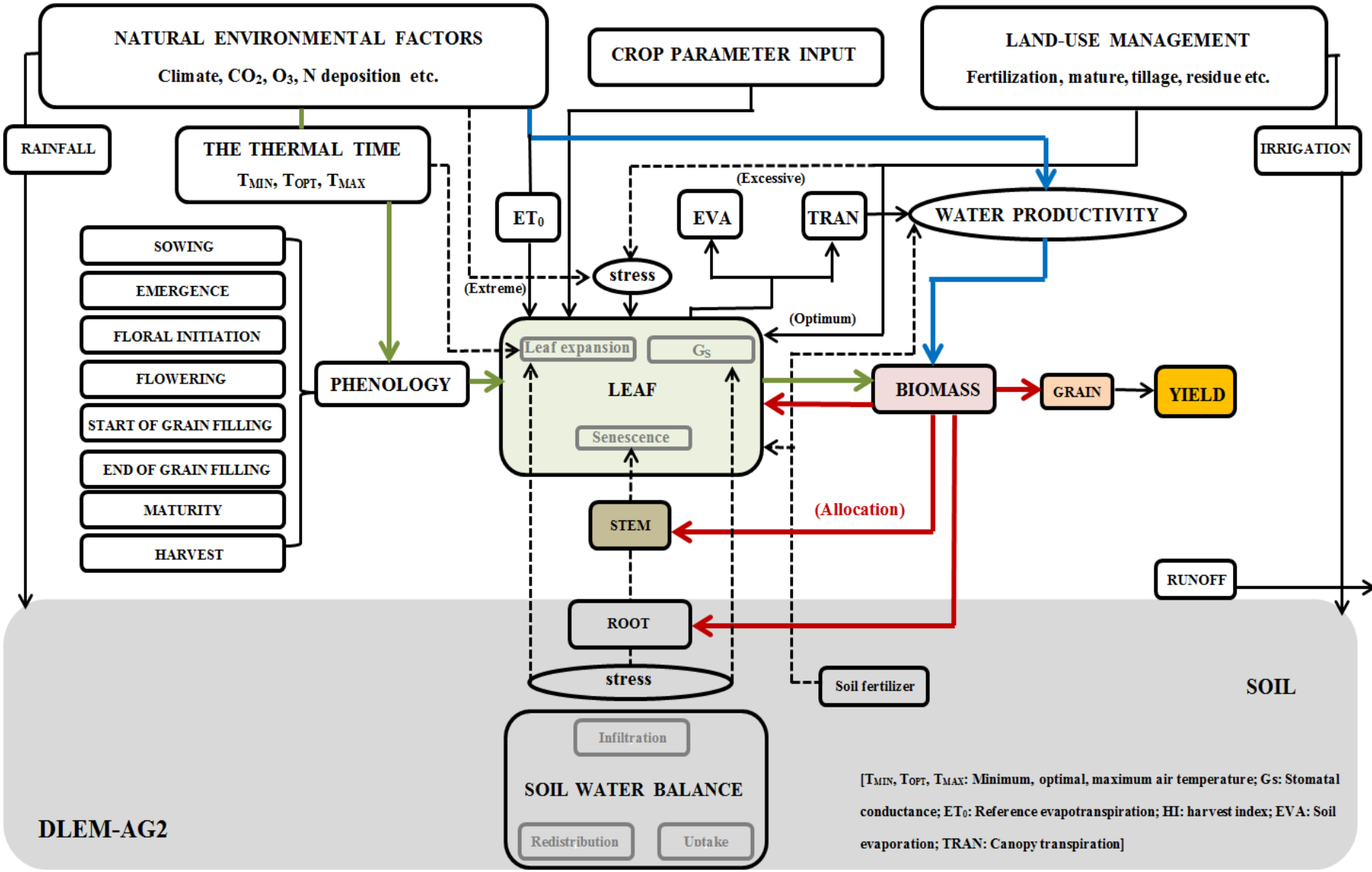
Tian et al., 2011 JGR

Key processes, pools, fluxes and their coupling in the DLEM



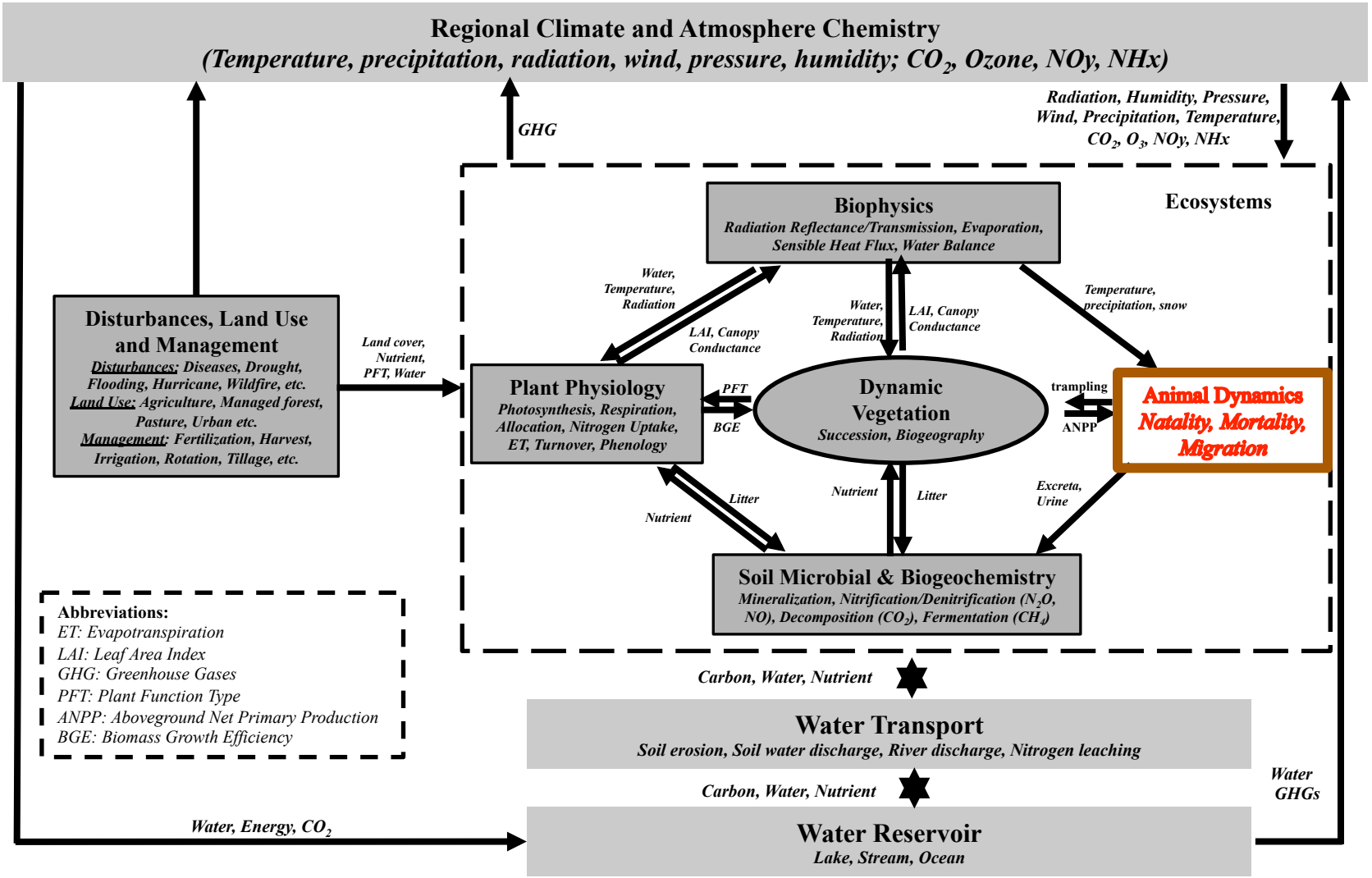
Tian et al.2015 JGR

The agricultural module of DLEM (DLEM-AG2)

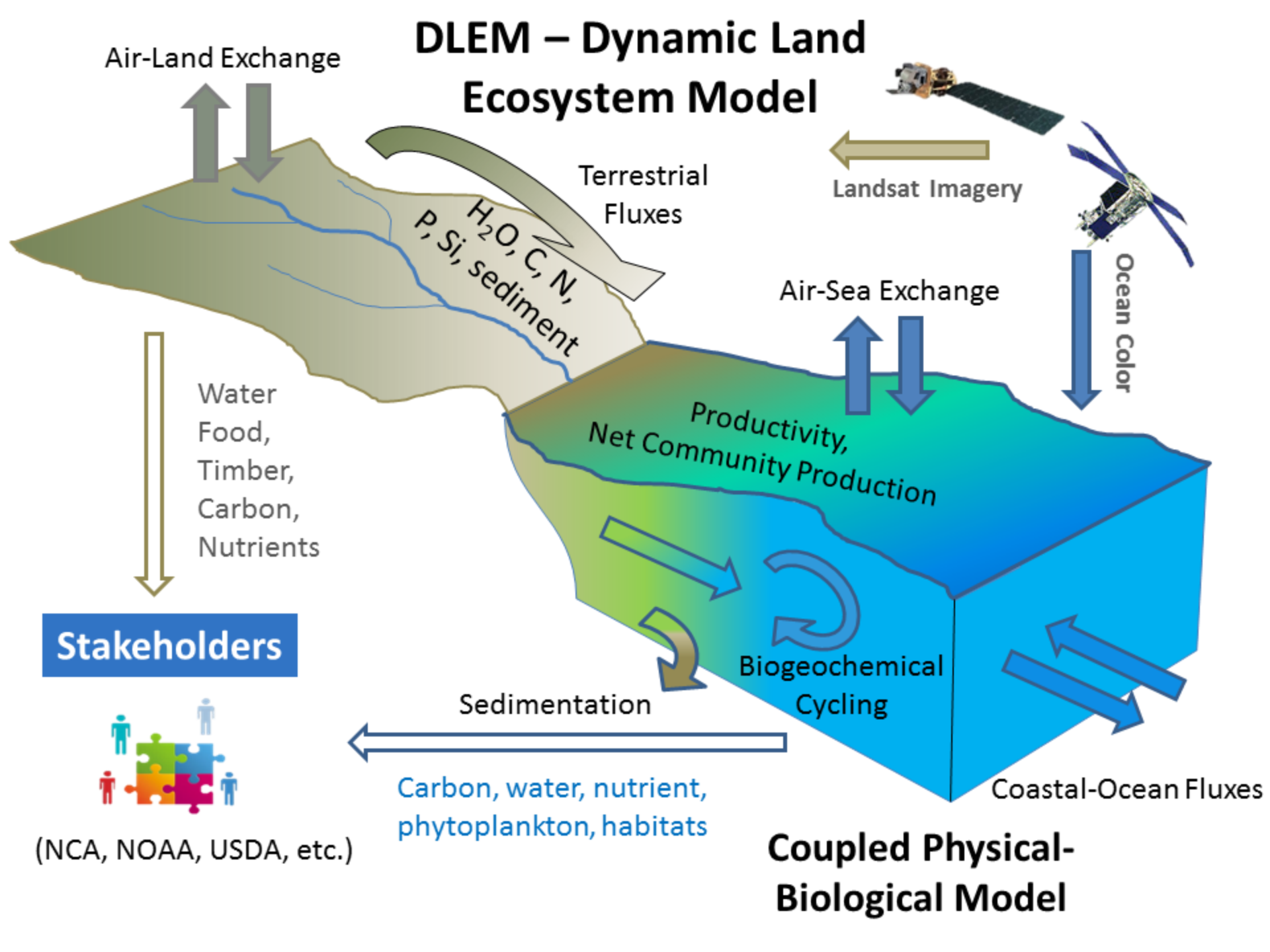


Zhang et al. 2018 JAMES

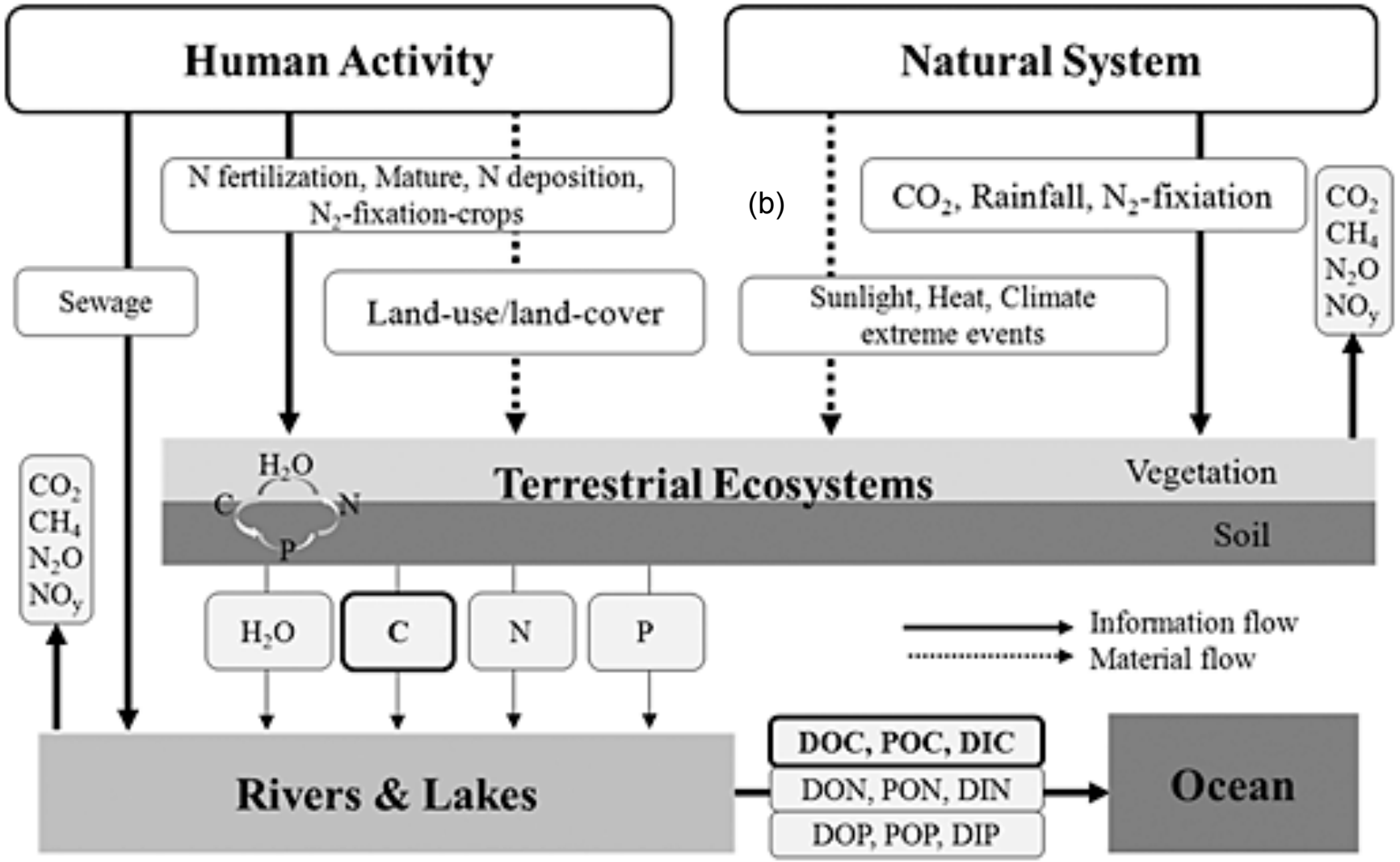
DLEM-Livestock Module



Integrating Herbivore Population Dynamics into DLEM (Dangal et al. 2018 *JAMES*)

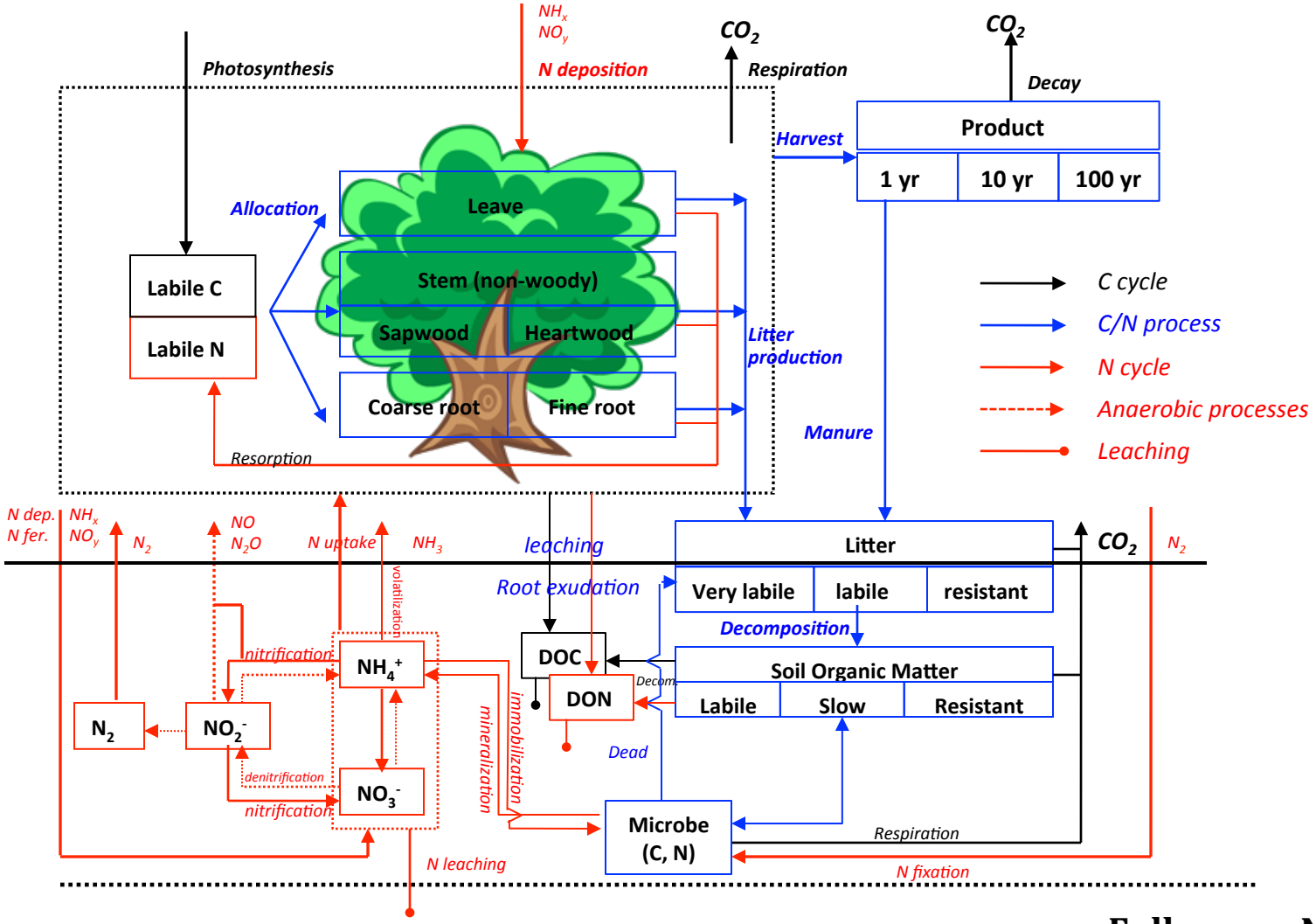

DLEM – Dynamic Land Ecosystem Model
Air-Land Exchange
Terrestrial Fluxes
H_2O, C, N, P, Si, sediment
Landsat Imagery
Ocean Color
Air-Sea Exchange
Water
Food,
Timber,
Carbon,
Nutrients
Productivity,
Net Community Production
Biogeochemical Cycling
Stakeholders
Sedimentation
Carbon, water, nutrient, phytoplankton, habitats
Coastal-Ocean Fluxes
(NCA, NOAA, USDA, etc.)
Coupled Physical-Biological Model

Methodology: Model Description



The framework of carbon and nutrient fluxes at the land-aquatic interface within the DLEM (Tian et al., 2015, GBC).

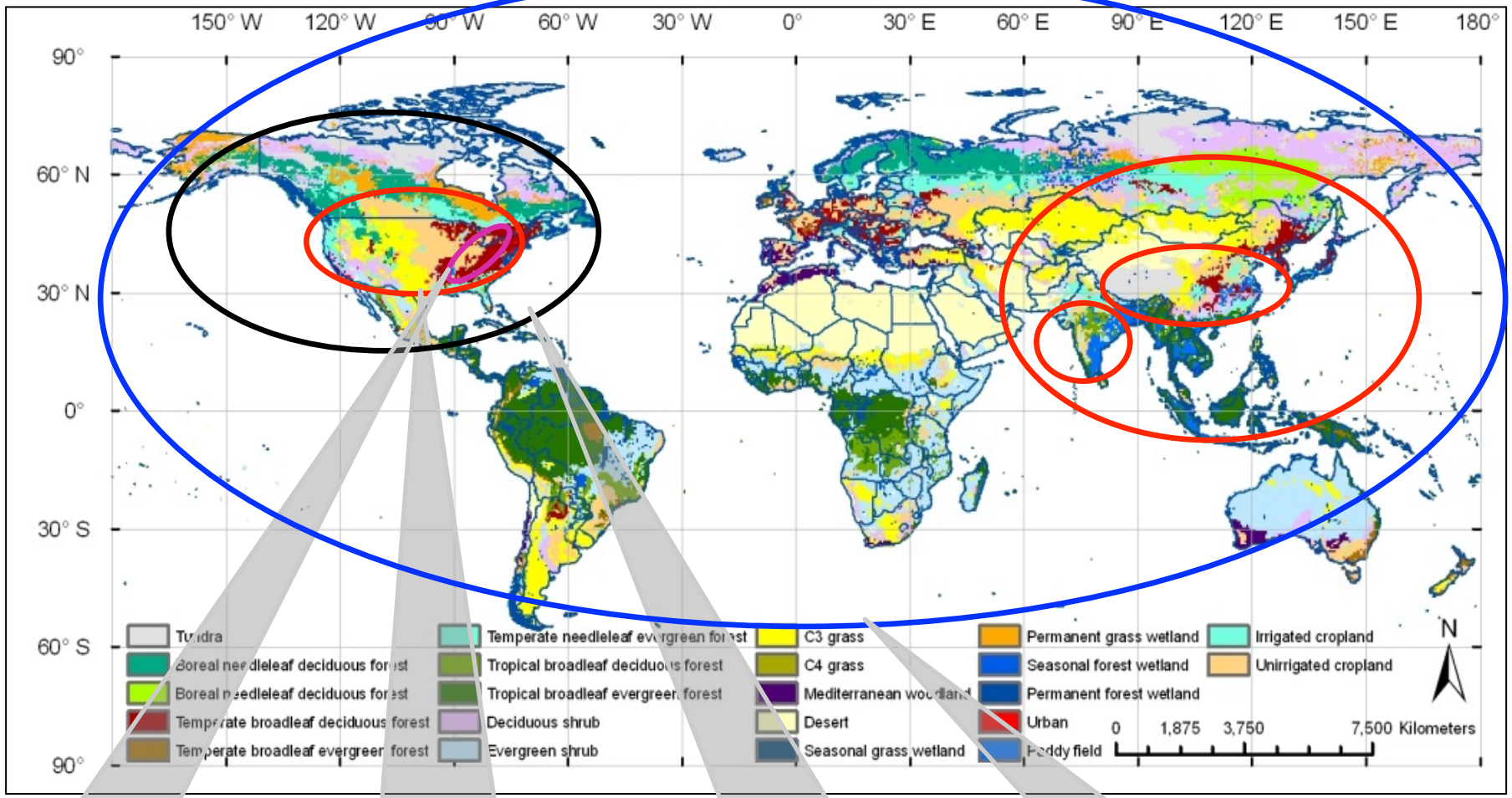
Nitrogen processes and C-N coupling in the DLEM



(Lu et al., 2012, *Ecological Applications*)

- **Fully-open N cycle**
- **N regulation to C cycling processes**

Days Months Years Decades Century Millennium



1km × 1km

5-arc min
(~9.2 km × 9.2 km at equator)

0.25 degree
(~25 km × 25 km at equator)

0.5 degree
(~50 km × 50 km at equator)

INPUT

Driving Factors

Climate
- *.Temperature*
- *.Precipitation*
- *.Radiation*
- *.Relative Humidity*

Atmospheric Compositions
- *.CO_2*
- *.O_3*
- *.Nitrogen Deposition*

Land Use
- *.Deforestation*
- *.Urbanization*
- *.Harvest*
- *.Fertilization*
- *.Irrigation*

Other Disturbances
- *.Wildfire*
- *.Disease*
- *.Climate Extremes*

Controlling Factors

Soil
- *.Physical Properties*
- *.Chemical Properties*
- *.Depth*

Geomorphology
- *.Elevation*
- *.Slope*
- *.Aspect*

River Network
- *.Flow Direction*
- *.Accumulative Area*
- *.River Slope*
- *.River Length*
- *.River Width*

Vegetation Functional Type

Cropping System

MODEL

Dynamic Land Ecosystem Model

OUTPUT

Biogeochem.-hydrolog. cycles

Carbon Fluxes and Storage:
.Carbon fluxes (GPP, NPP, Rh,NCE, NEP, CH_4, *VOC*, DOC, *DIC*)
.Carbon storages (LeafC, stemC, litterC, rootC, reproductionC, soilC)

Water Fluxes and Storage :
.ET, Runoff, Soil moisture

Nitrogen Fluxes and Storage :
.Nitrogen fluxes (N_2O, NO, N_2)
.Nitrogen storages (LeafN, stemN, litterN, rootN, reproductionN, soilN), TN

(Phosphorus Fluxes and Storage:
.LeafP, stemP, litterP, rootP, soilP, TP)

Ecosystem Goods and Services

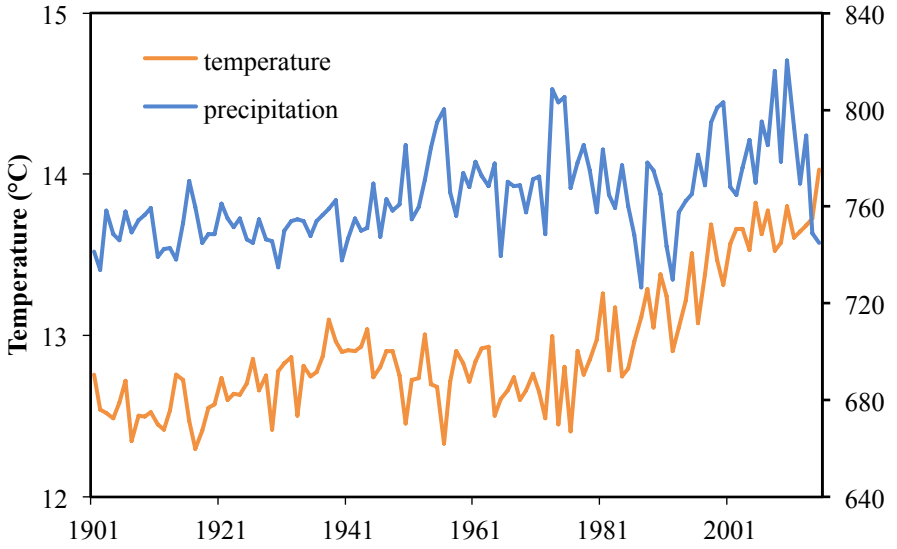
Climate related:
.GHG emissions (e.g. CO_2,CH_4 ,N_2O fluxes); VOC flux, Black carbon, …

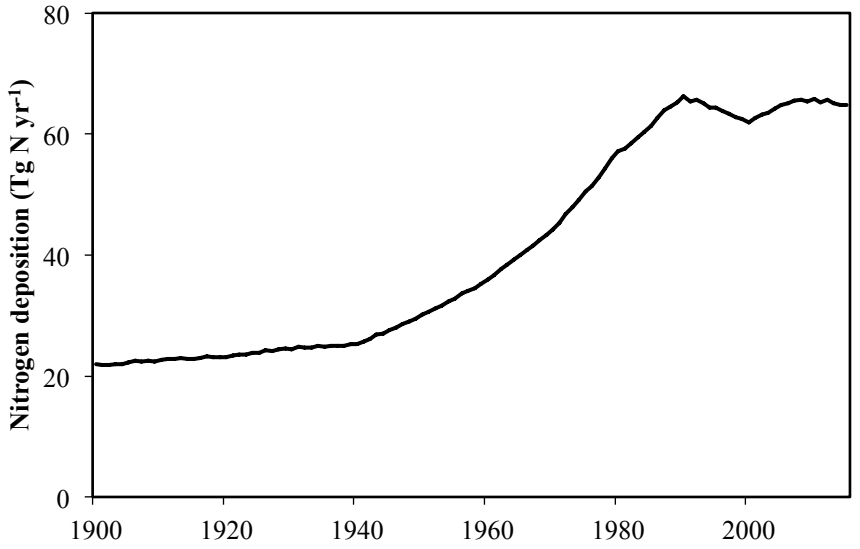
Ecosystem Goods
.Crop yield; Wood Products; Biofuel, …

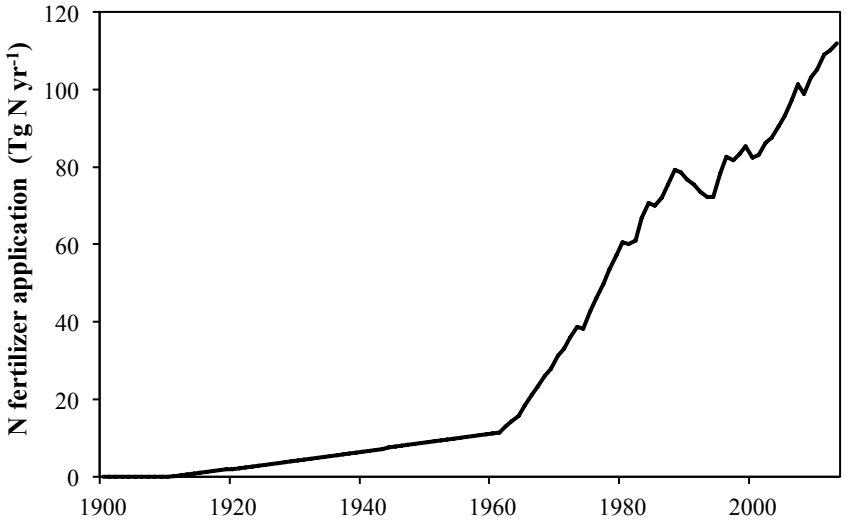
Water related
.Surface Runoff; Subsurface Flow;
.ET; Soil Moisture; water use efficiency
.River Discharge;

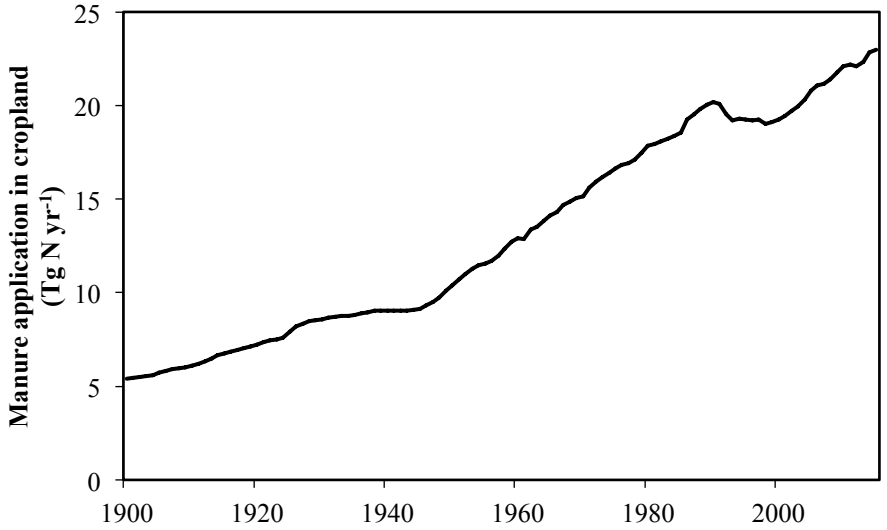
Nutrients related:
.N and *P* Storage and leaching;
.Export of TN and *TP*;
.Export of DOC and *POC*

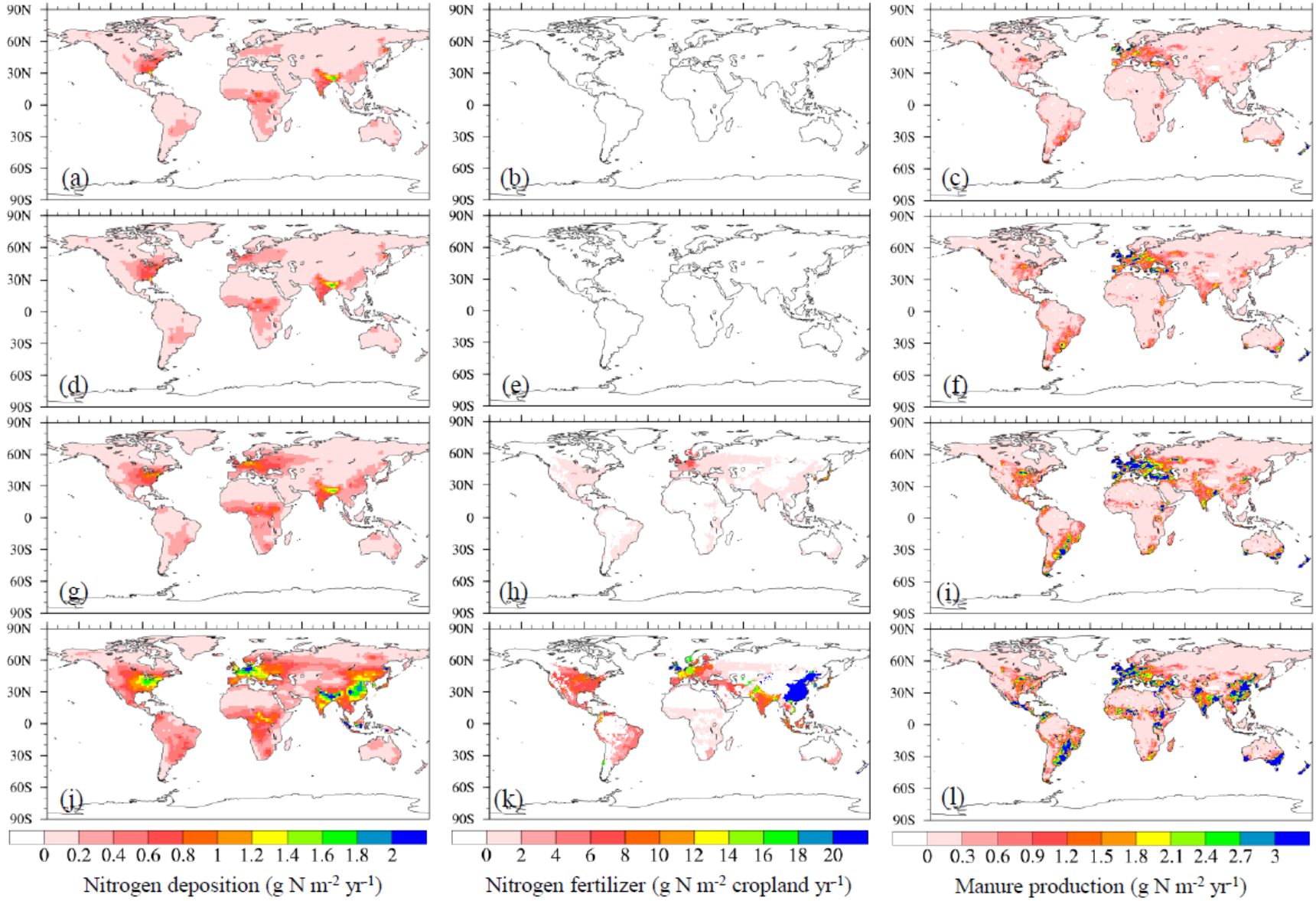
Input Data


temperature
precipitation
Temperature (°C)
Precipitation (m yr-1)
15
14
13
12
840
800
760
720
680
640
1901
1921
1941
1961
1981
2001


Nitrogen deposition (Tg N yr-1)
80
60
40
20
0
1900
1920
1940
1960
1980
2000

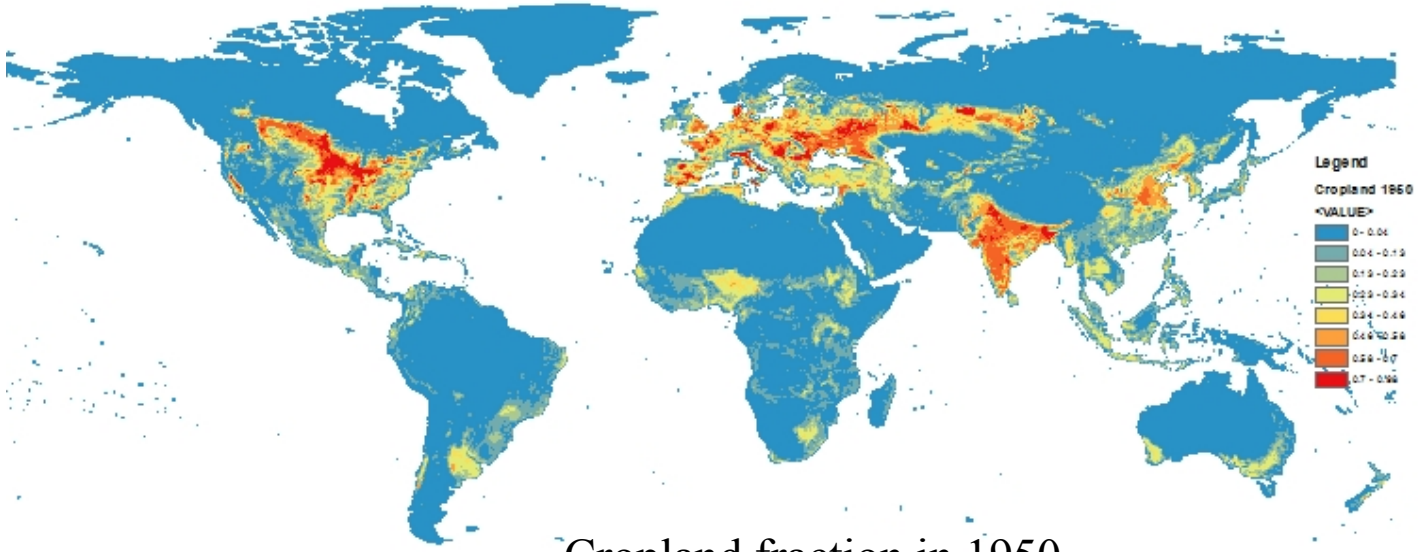

N fertilizer application (Tg N yr-1)
120
100
80
60
40
20
0
1900
1920
1940
1960
1980
2000


Manure application in cropland (Tg N yr-1)
25
20
15
10
5
0
1900
1920
1940
1960
1980
2000

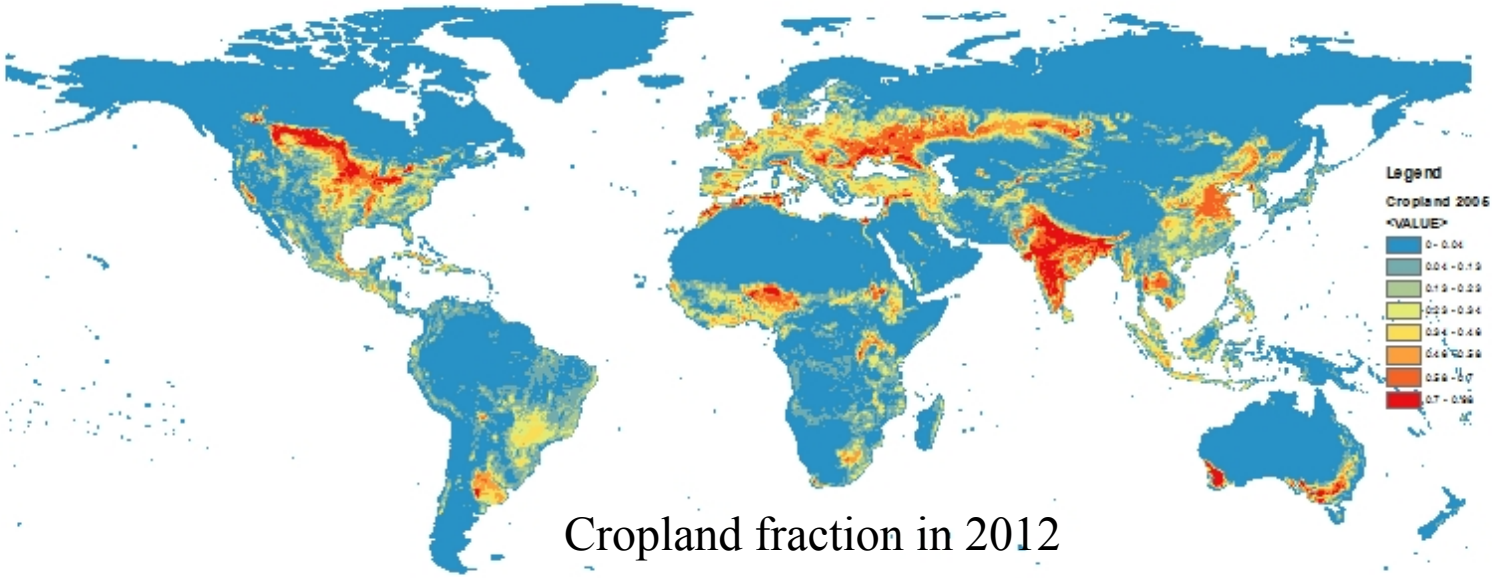


Spatial distribution of (a),(d),(g),(j) **N deposition** (g N m^{-2} yr^{-1}); (b),(e),(h),(k) **N fertilizer application** (g N m^{-2} cropland yr^{-1}); and (c),(f),(i),(l) **manure N production** (g N m^{-2} yr^{-1}) in (first row) 1860, (second row) 1900, (third row) 1950, and (fourth row) 2015.

Cropland Change



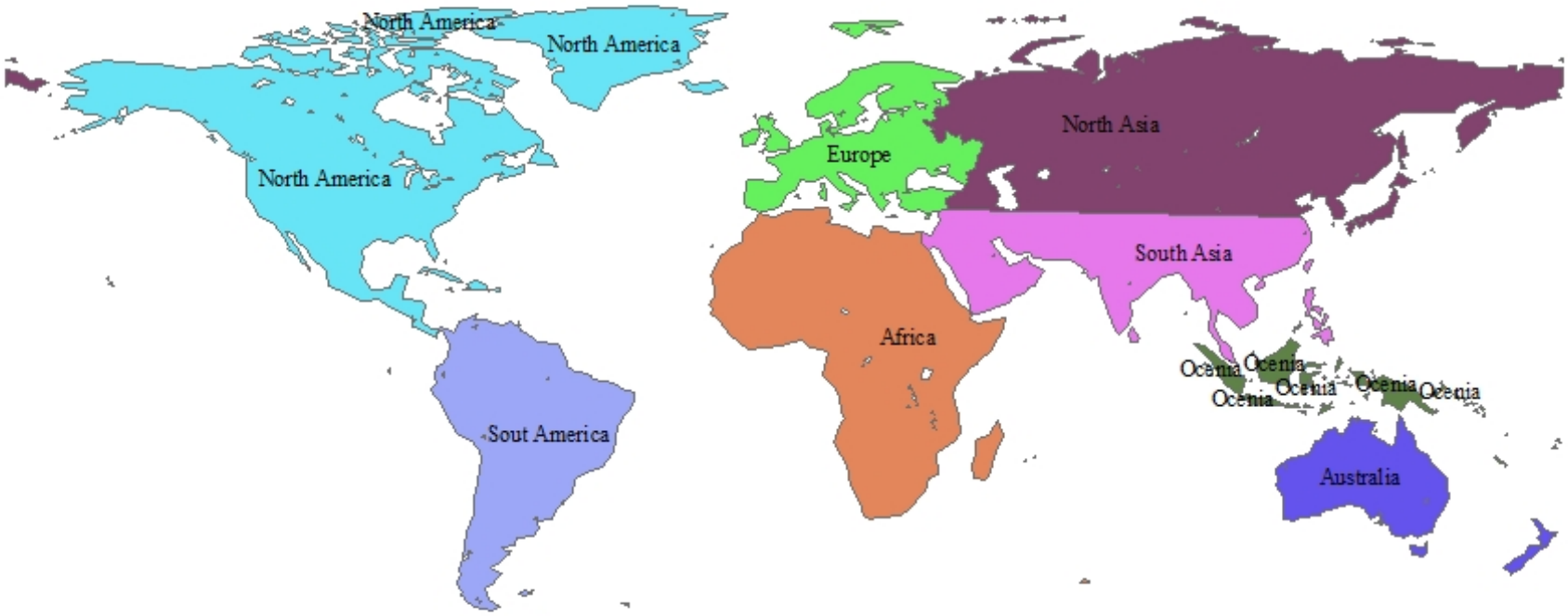
Cropland fraction in 1950



Cropland fraction in 2012

Study Region Category

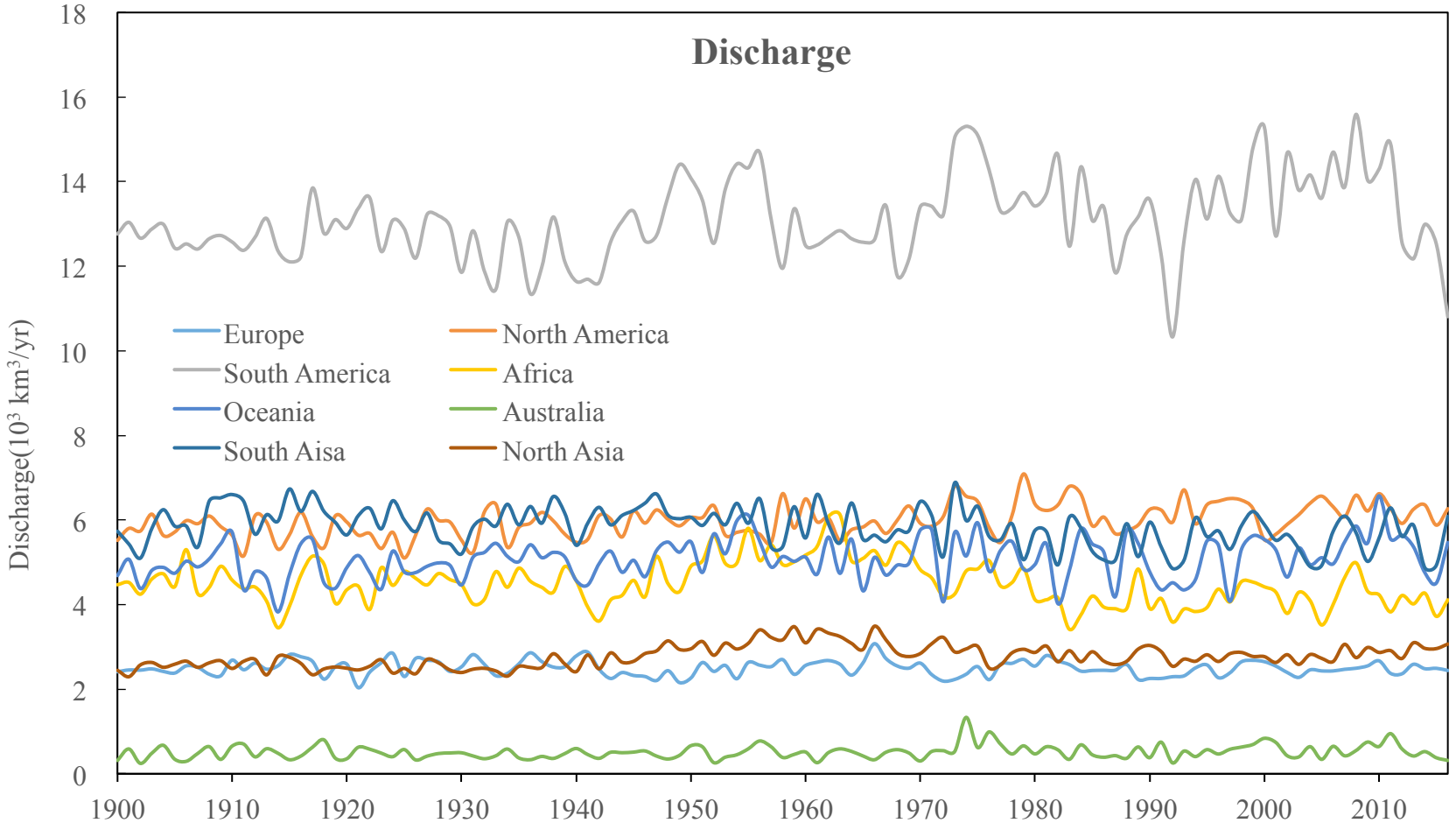
- According to Global News Model classifications for the Global land surface, we divided global into **eight** sub-regions: **Europe**, **North America**, **South America**, **North Asia**, **South Asia**, **Africa**,, **Oceania** and **Australia**.



The classification of sub-regions of the Global

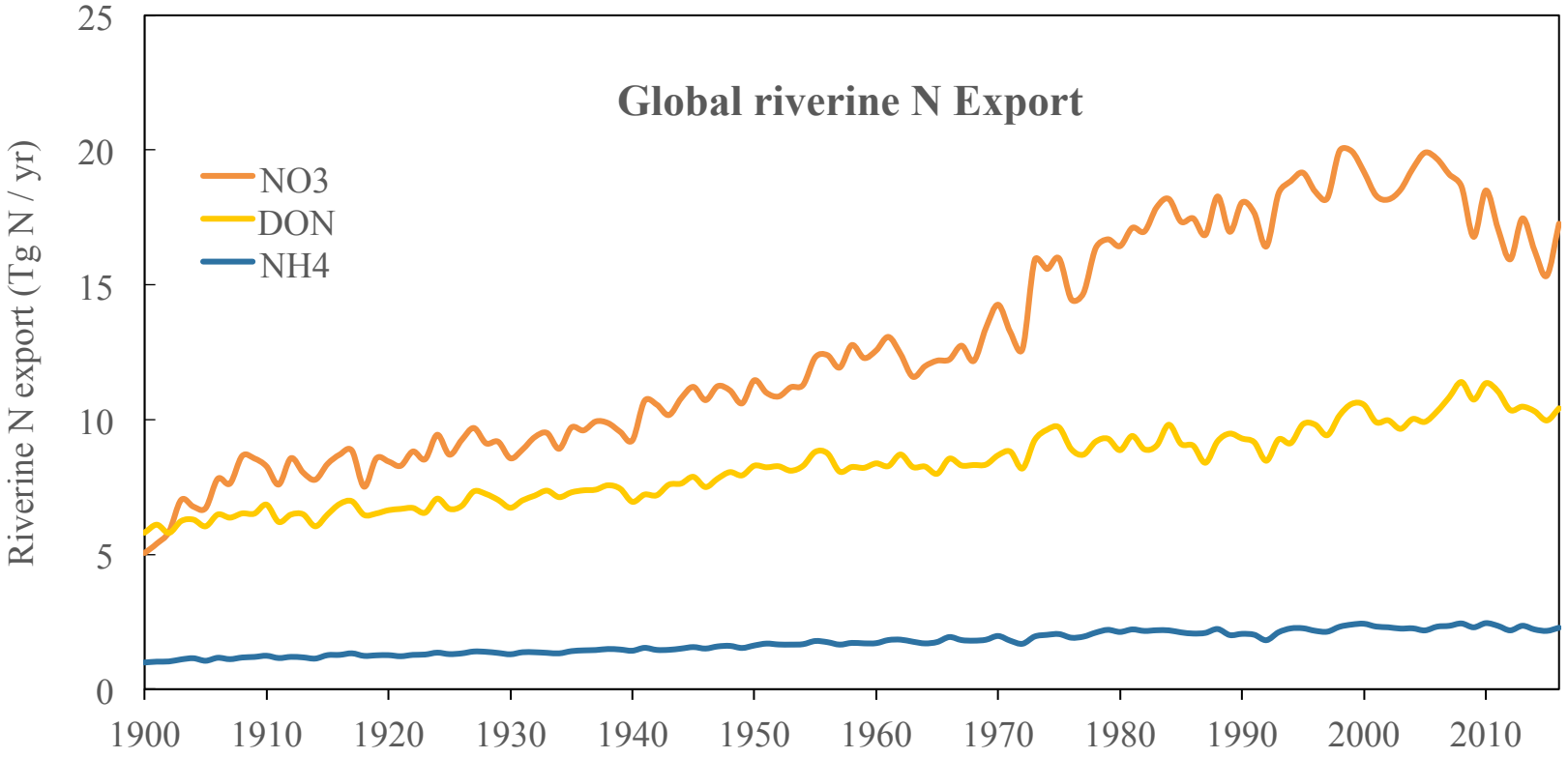
Preliminary Result

DLEM estimated discharge at continental scale

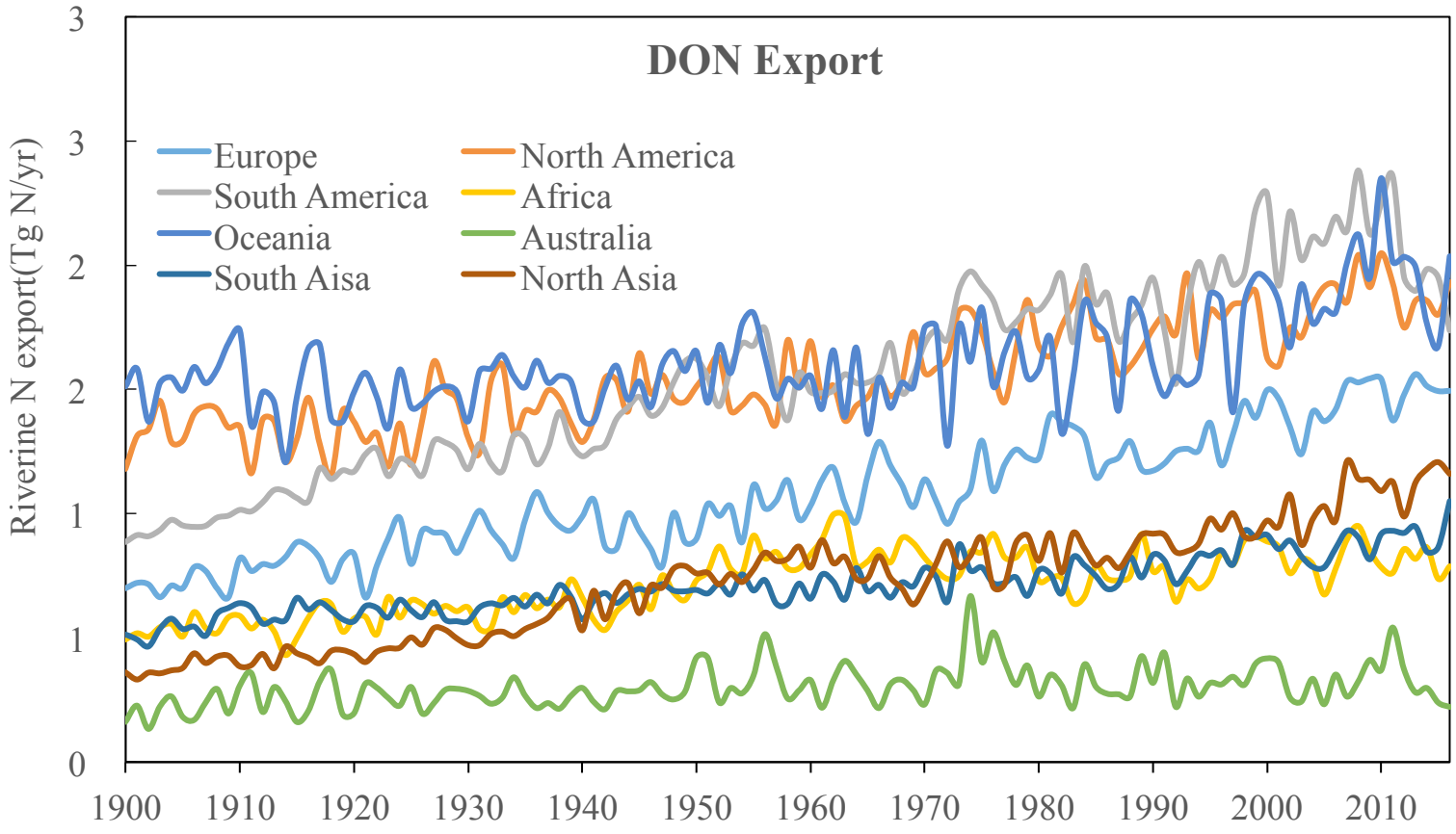


Preliminary Result

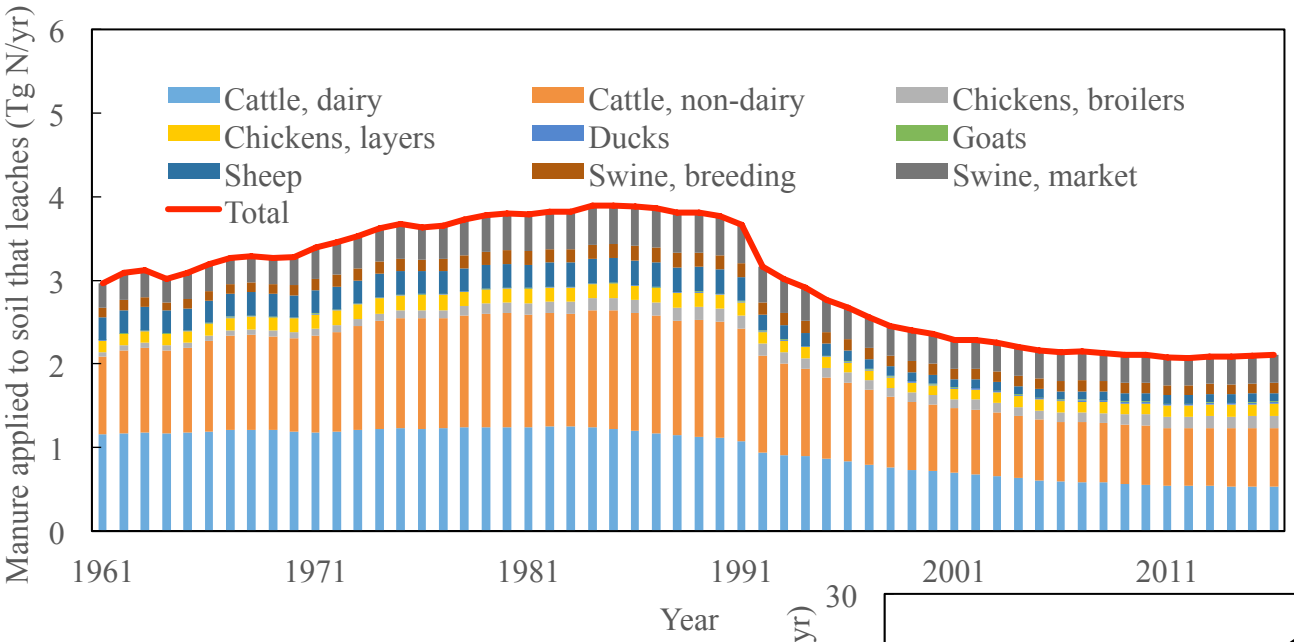
DLEM estimated riverine N export



DLEM estimated riverine DON export at continental scale

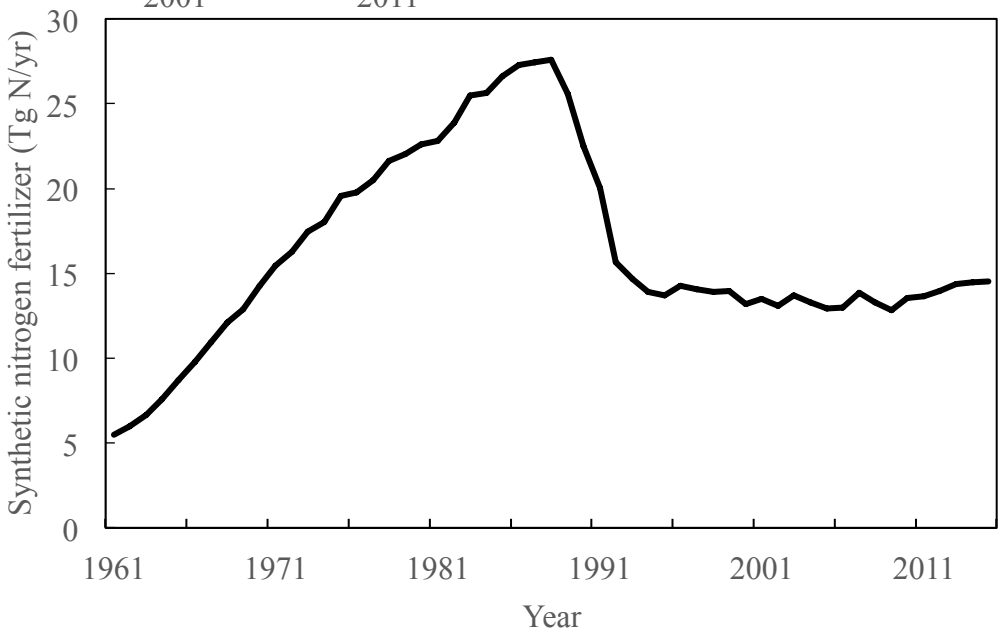


Manure N and N fertilizer data in Europe from FAO

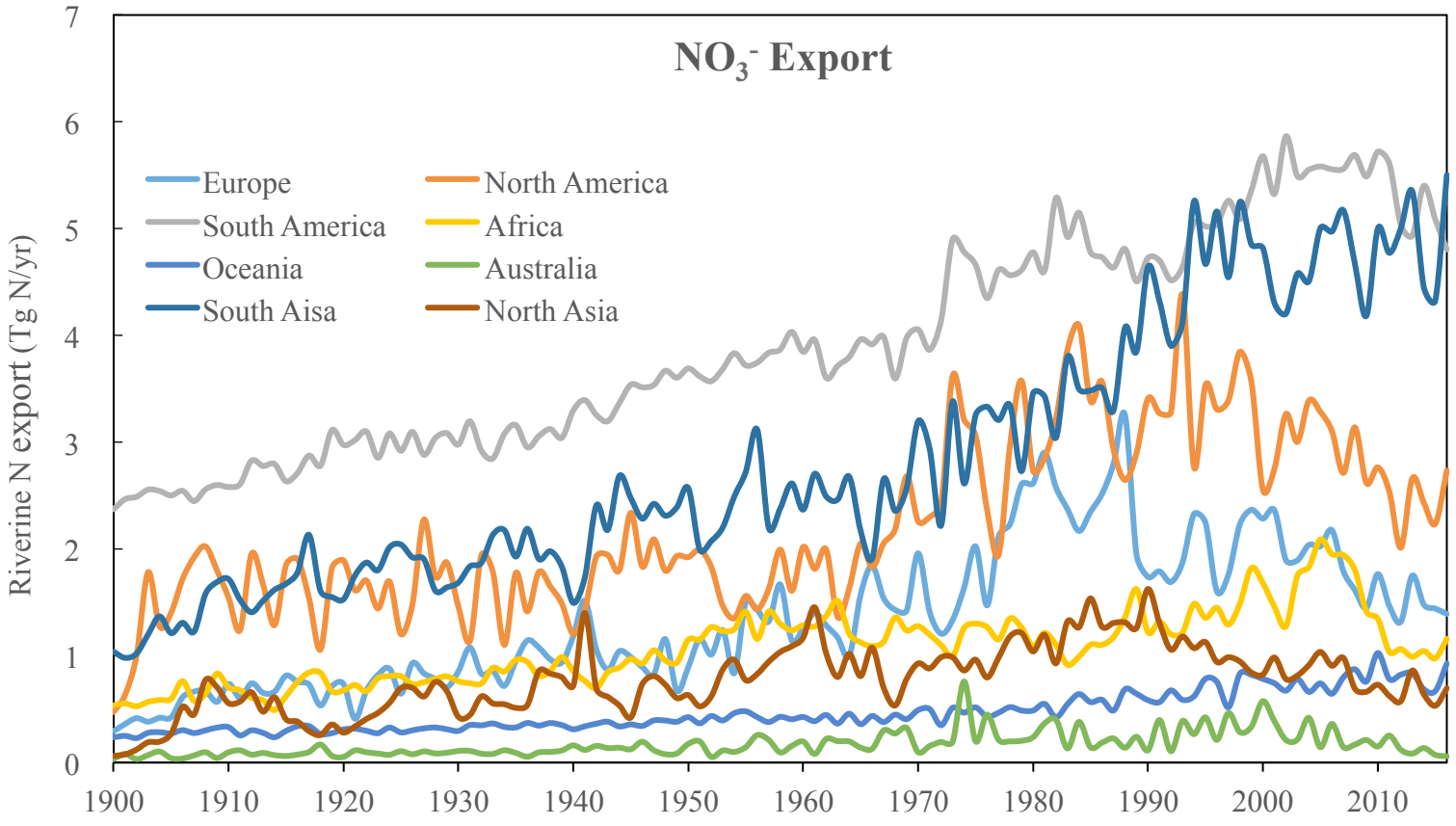


Manure applied to soil that leaches

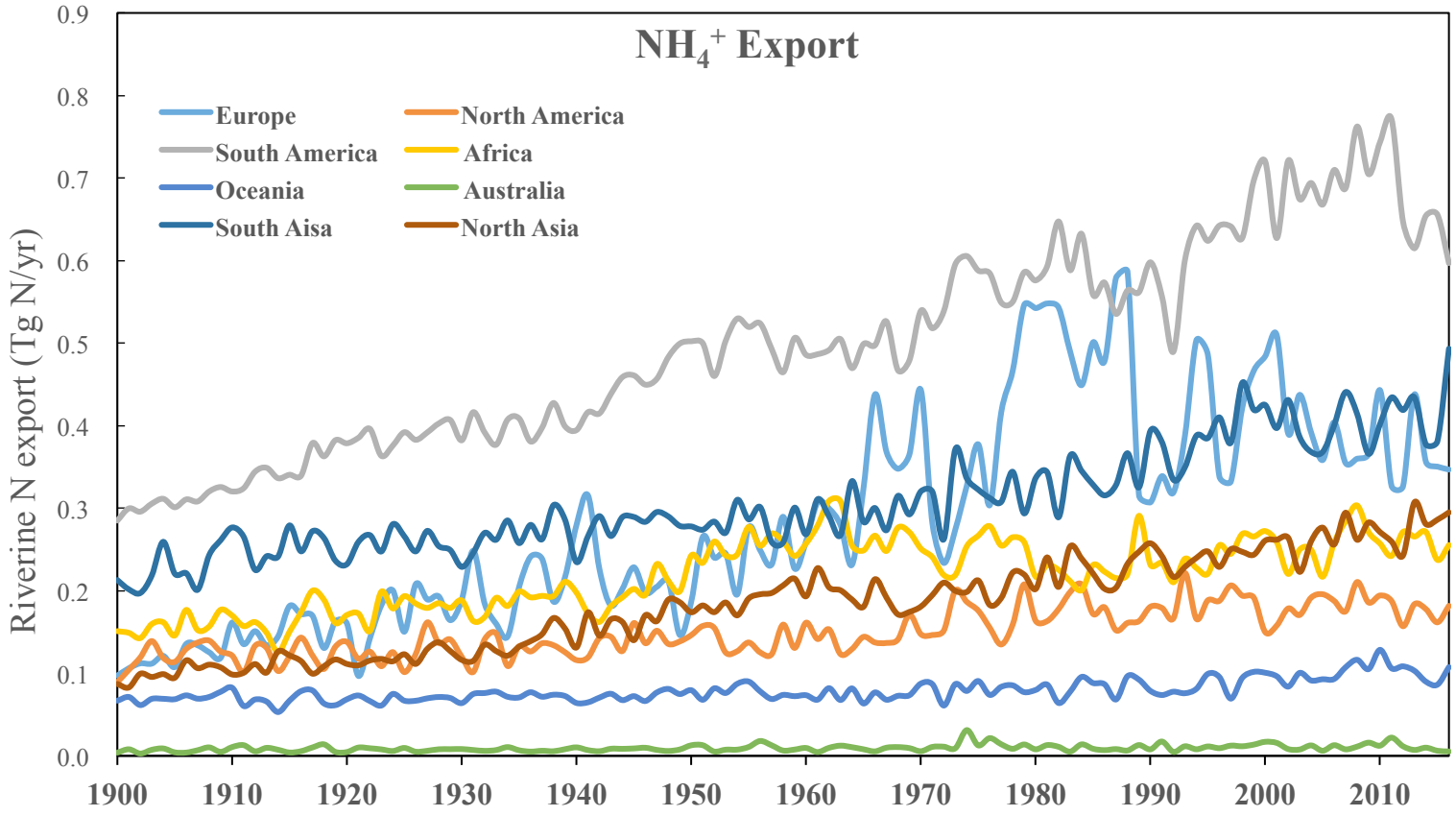
Synthetic nitrogen fertilizer



DLEM estimated riverine NO_3^- export at continental scale

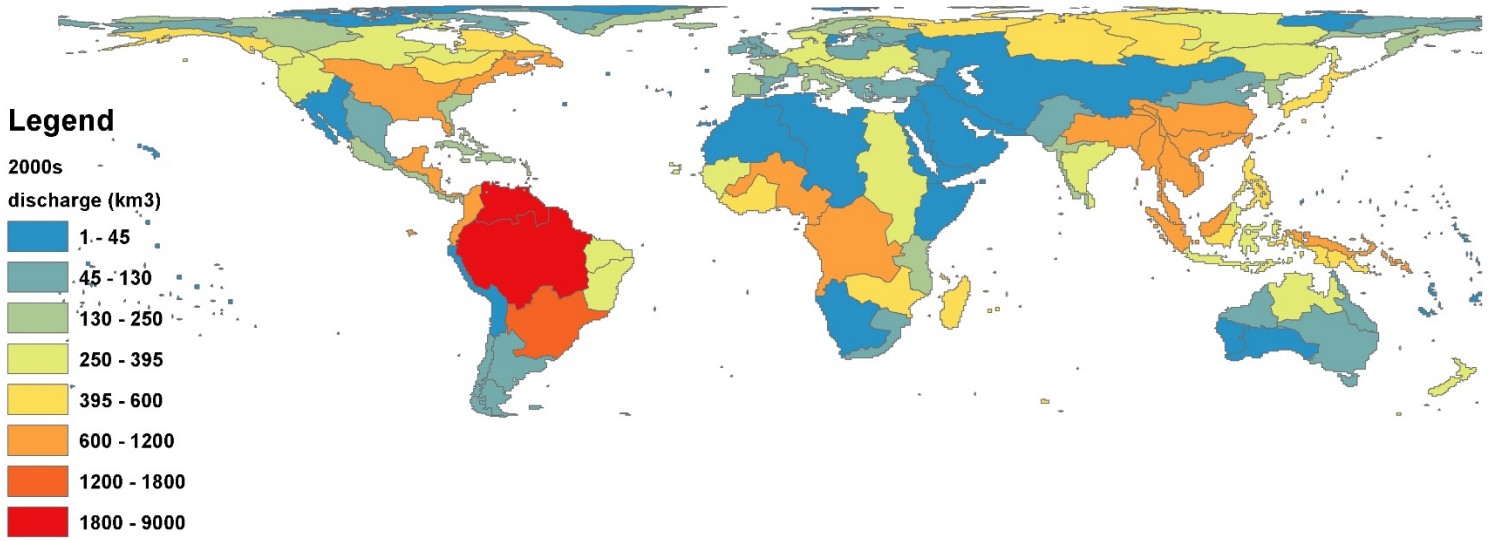


DLEM estimated riverine NH_4^+ export at continental scale

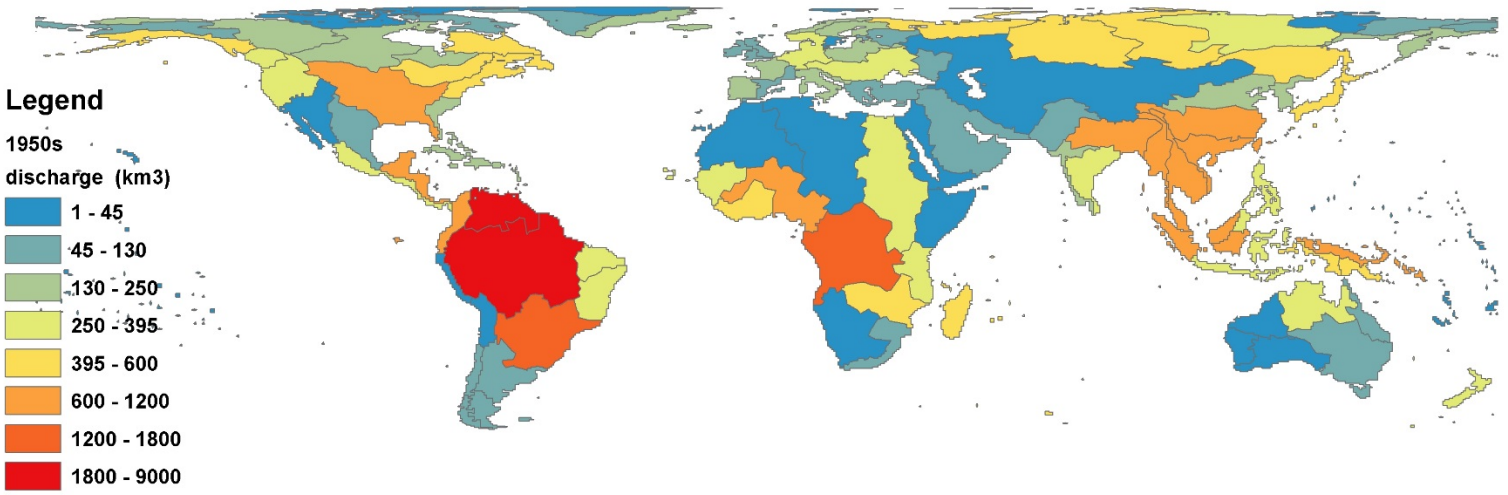


Comparison of river discharge between the 1950s and 2000s

Averaged Annual Discharge in the 2000s

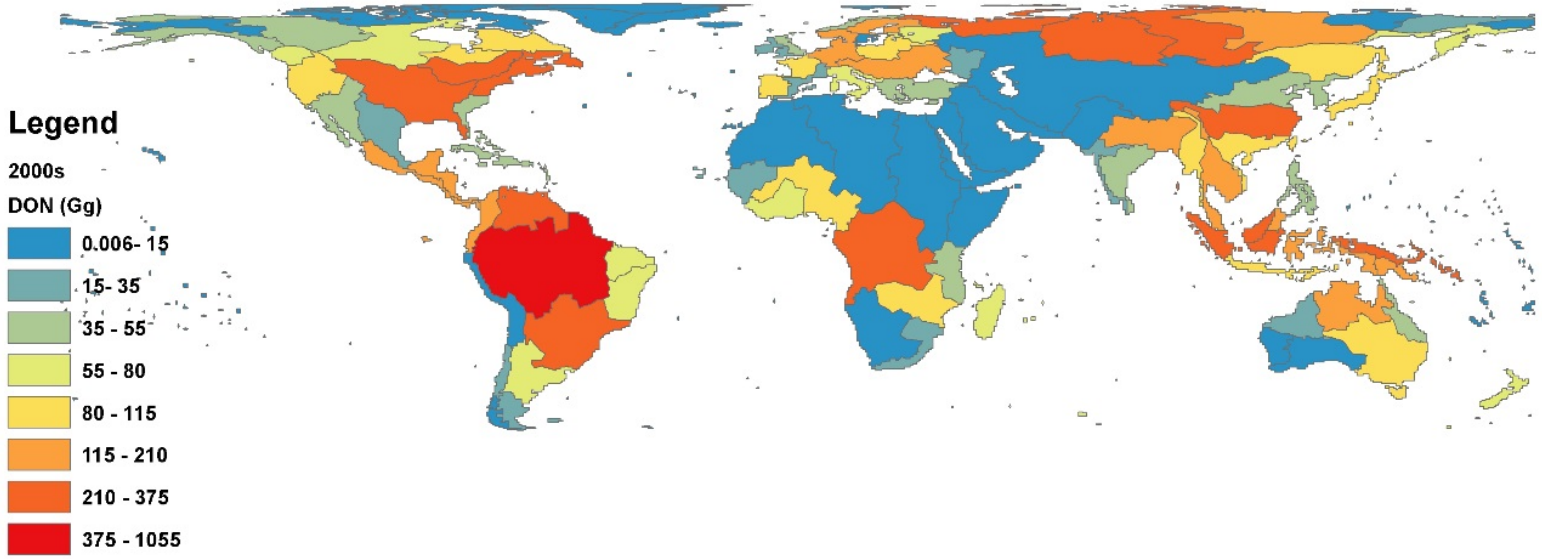


Averaged Annual Discharge in the 1950s

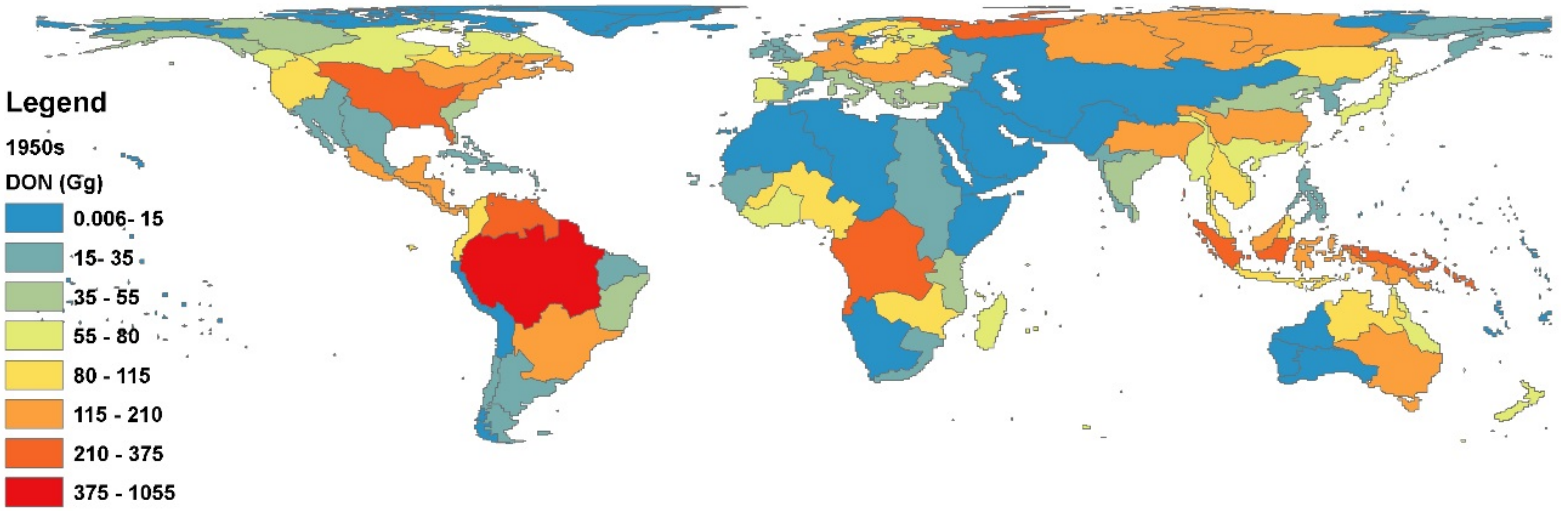


Comparison of riverine DON export between 1950s and 2000s

Averaged Annual riverine DON export in the 2000s

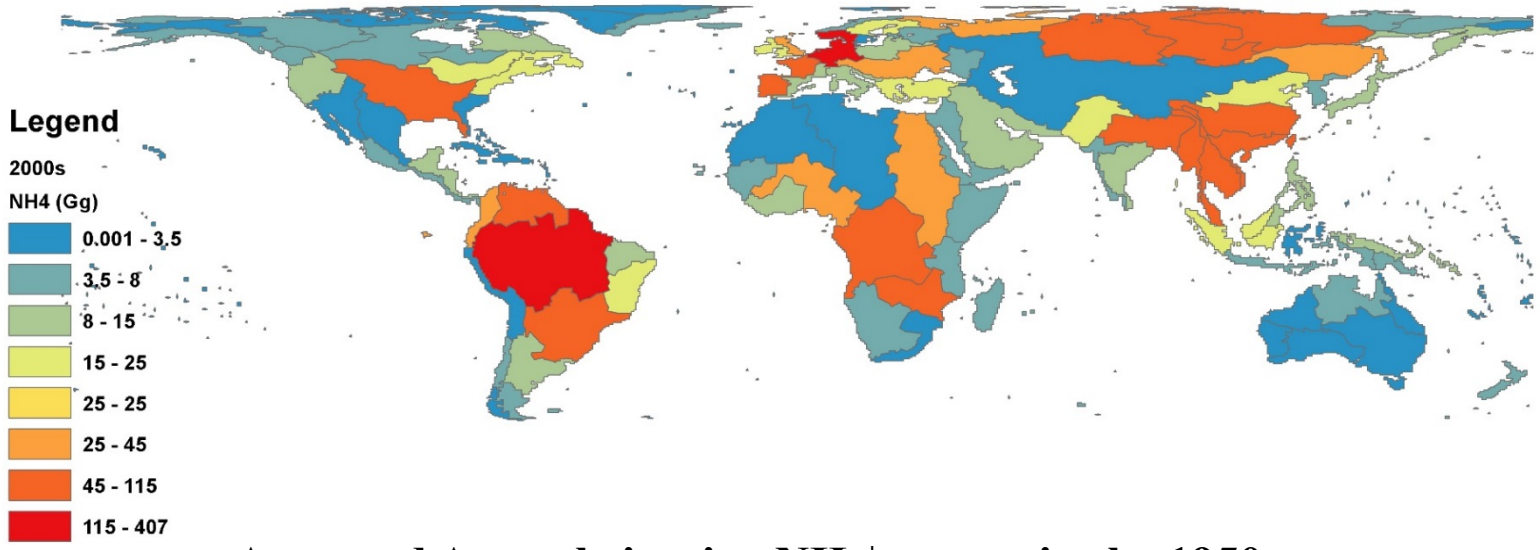


Averaged Annual riverine DON export in the 1950s

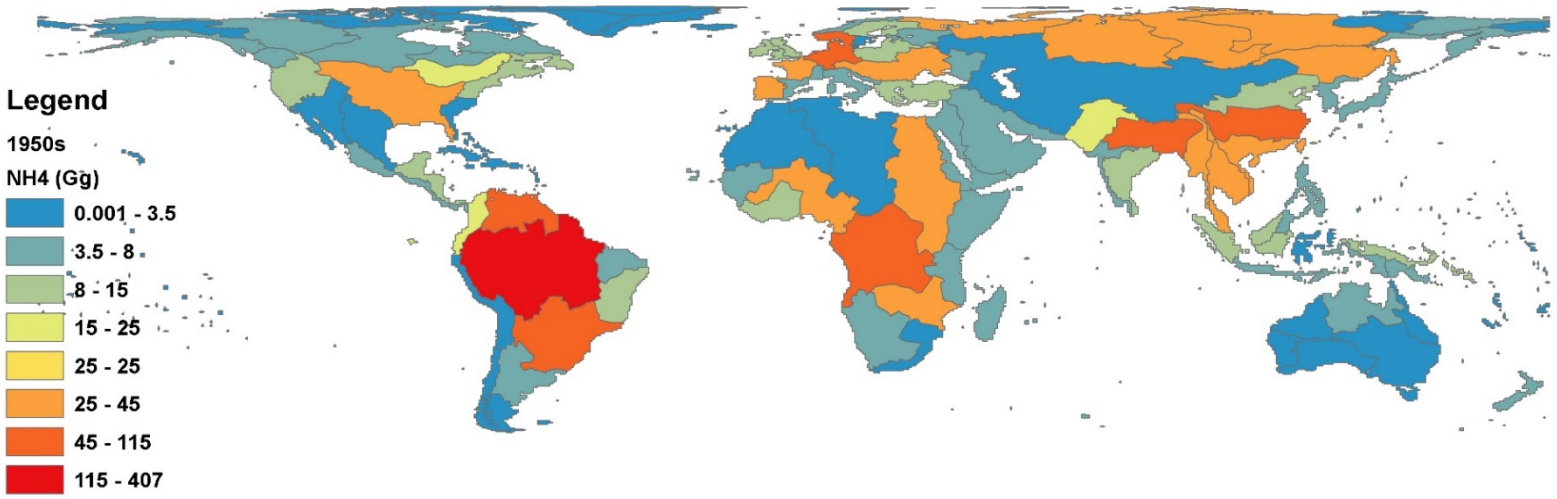


Comparison of riverine NH_4^+ export between 1950s and 2000s

Averaged Annual riverine NH_4^+ export in the 2000s

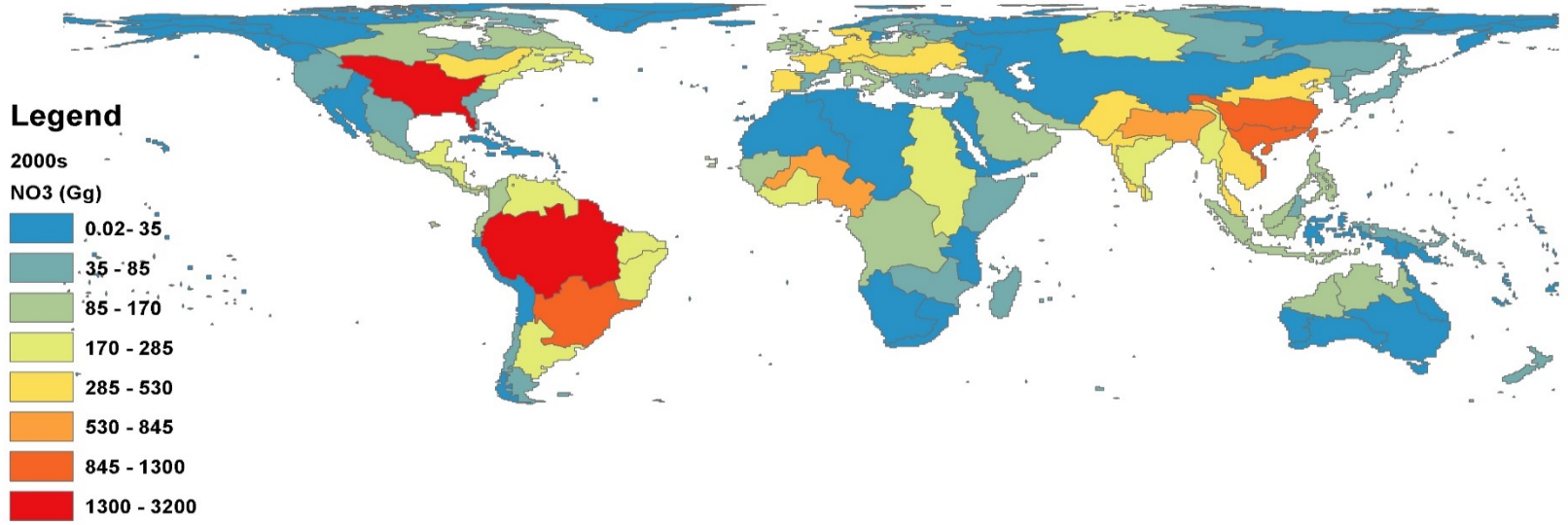


Averaged Annual riverine NH_4^+ export in the 1950s

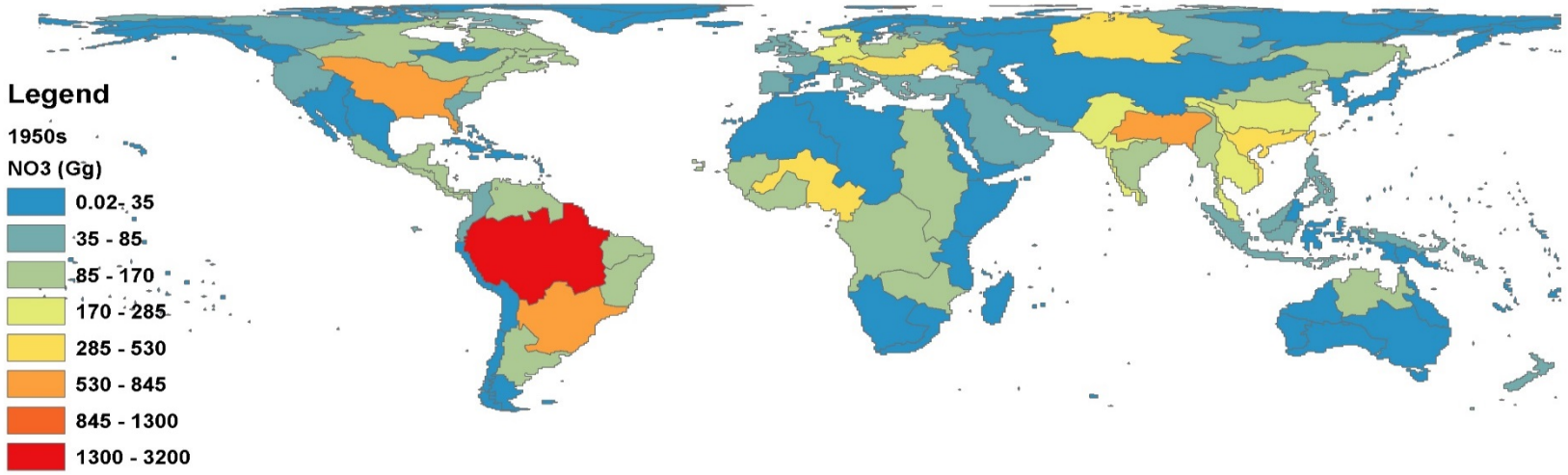


Comparison of riverine NO_3^- export between 1950s and 2000s

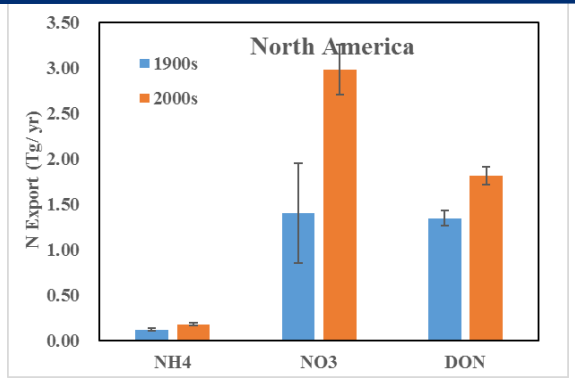
Averaged Annual riverine NO_3^- export in the 2000s

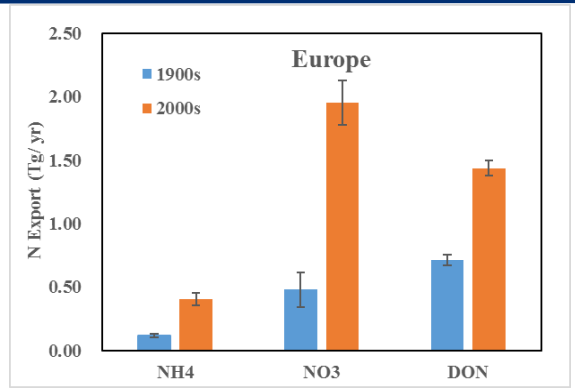


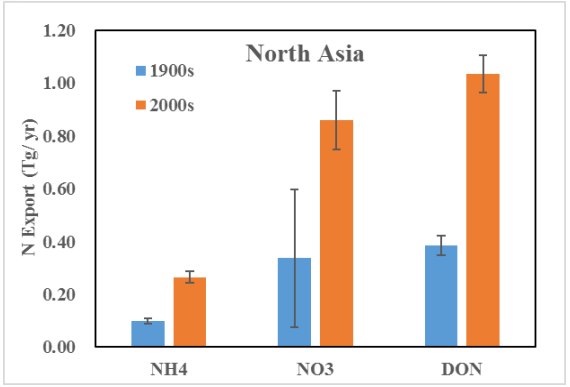
Averaged Annual riverine NO_3^- export in the 1950s

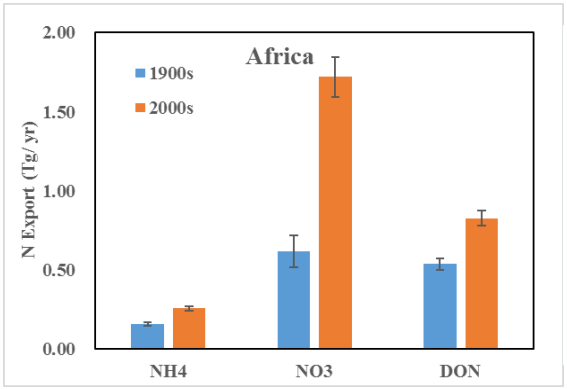


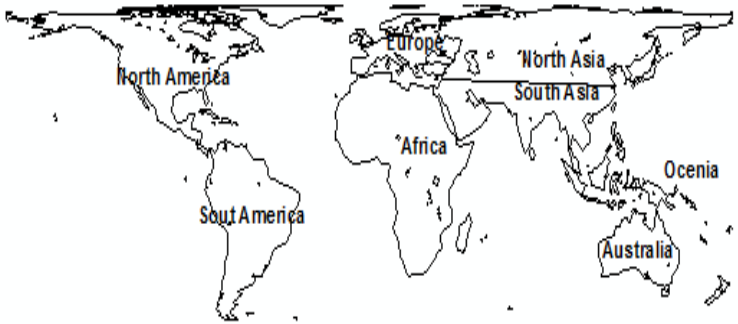
Continental N Export during the 1900s and 2000s

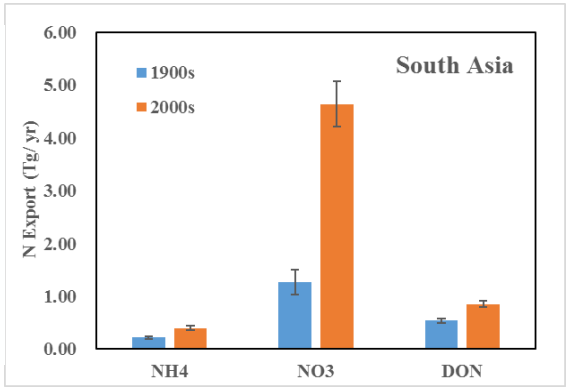


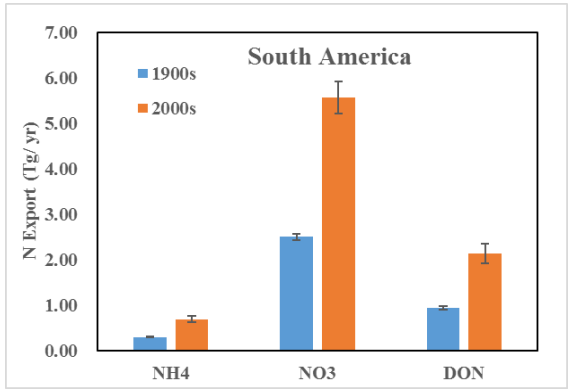


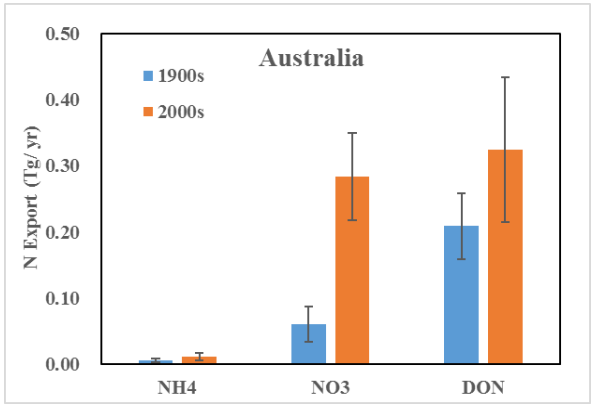


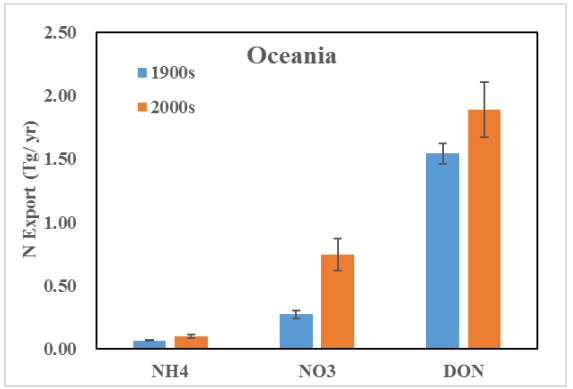




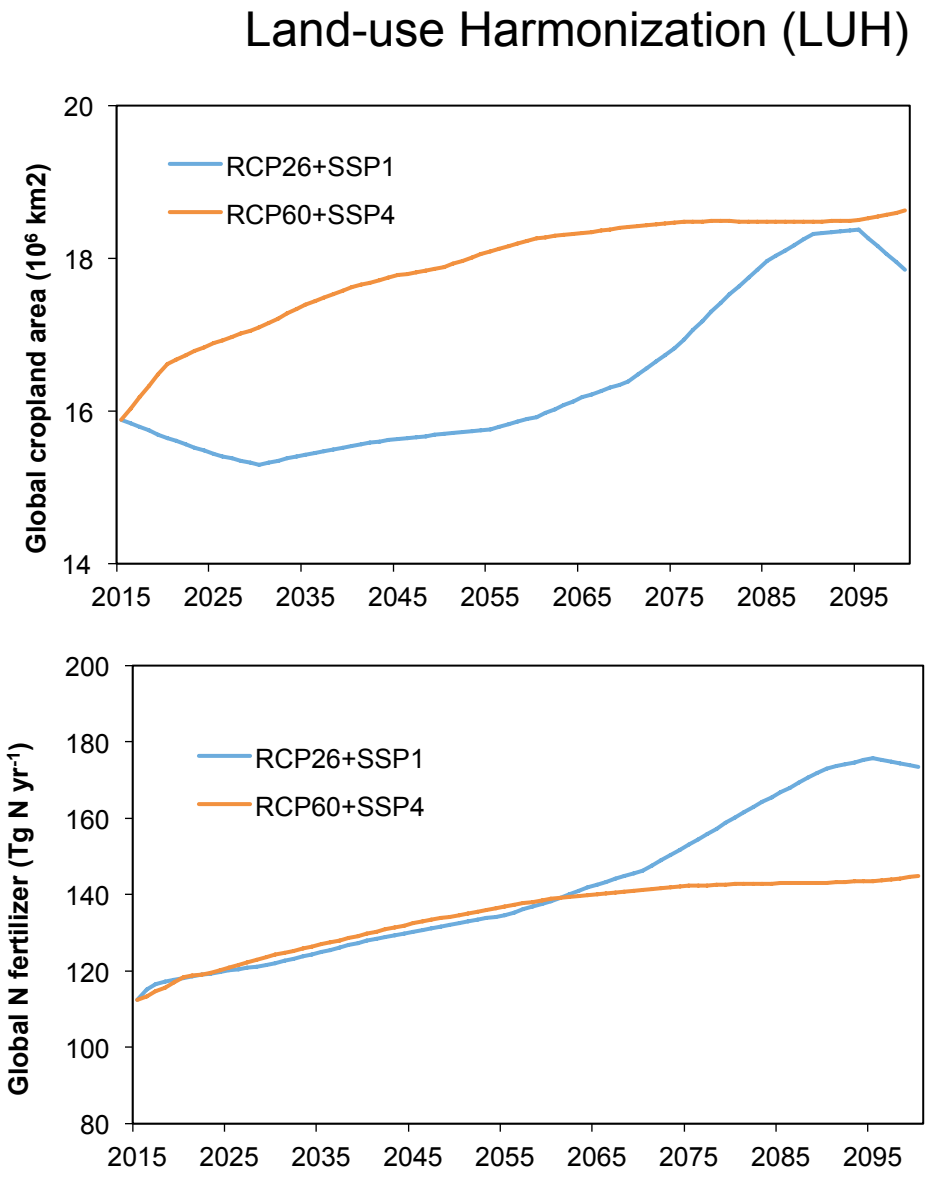






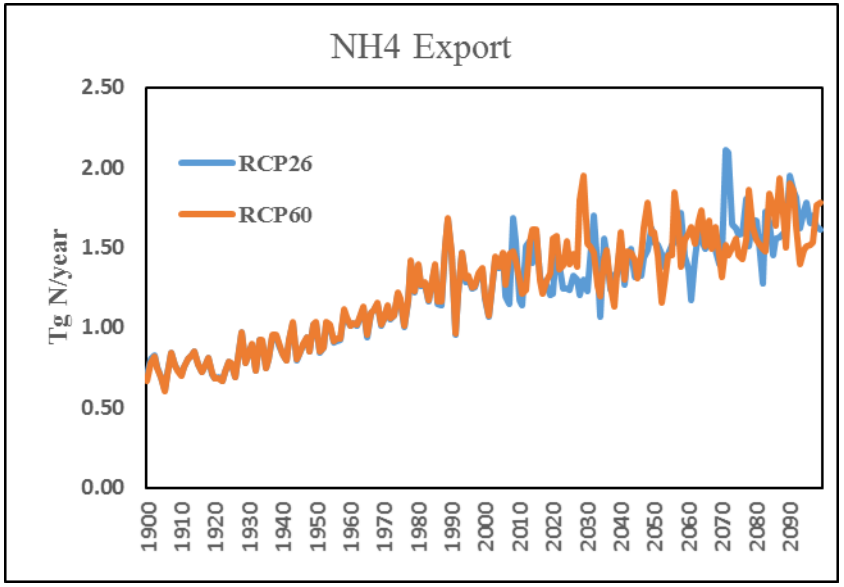


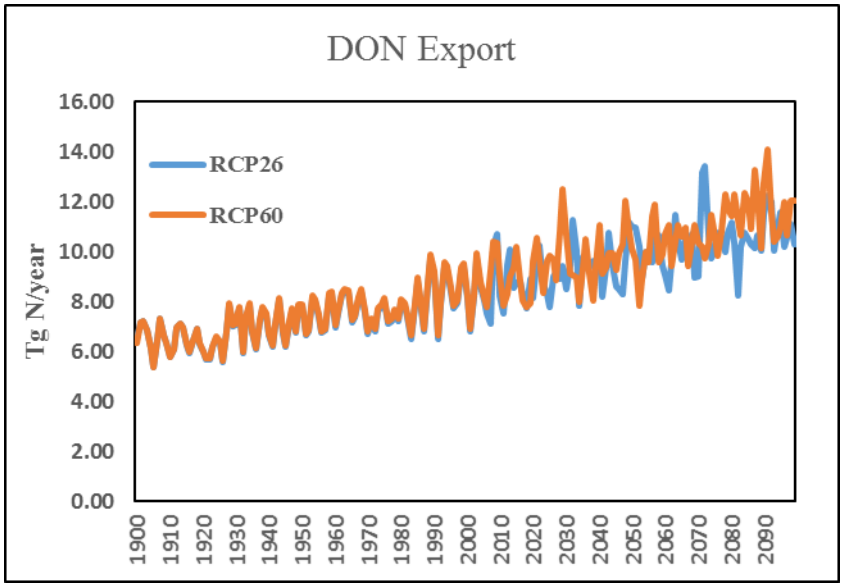
Changes in N fertilizer use and cropland area in the future

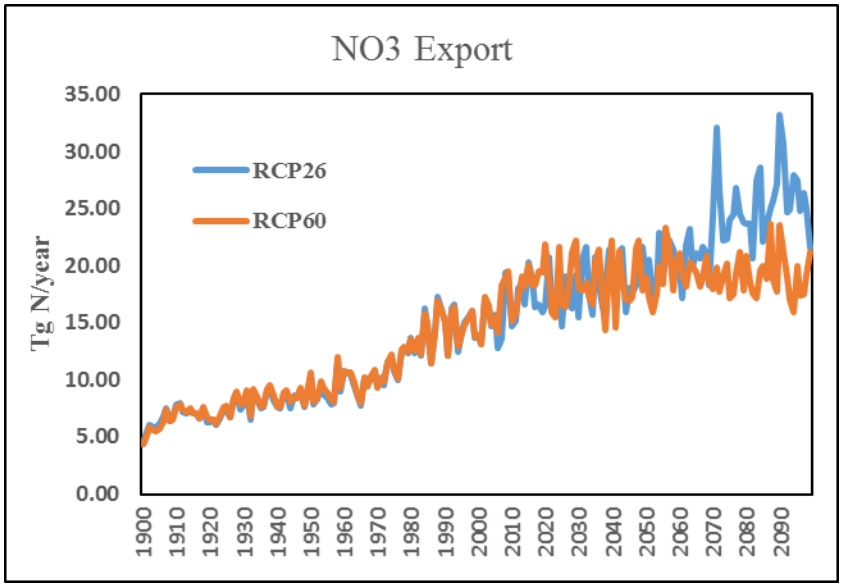


Future Projection:

Global Total N species







The Take-home Message

- The process-based model DLEM is an effective tool that could be applied to
  - estimate riverine inorganic and organic nitrogen fluxes from the terrestrial ecosystem to rivers and the oceans.
  - predict future N loading and export to rivers and oceans
  - attribute N loading and export to different driving factors such as N fertilizer use, N deposition, elevated CO_2, climate, etc.

- Future projections of N loadings to rivers and oceans are largely dependent on the scenarios of driving factors including: N fertilizer use, N deposition, Sewage, Manure, and climate.

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