Noah-MP Workshop, 2023.05.24, Online

Climate simulations with the nitrogen dynamics enhanced WRF model

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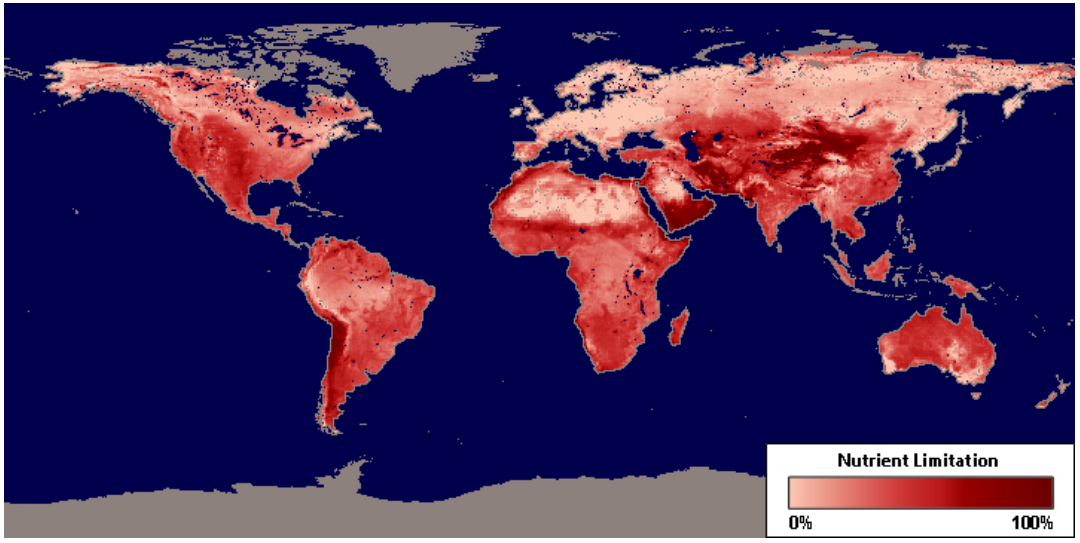
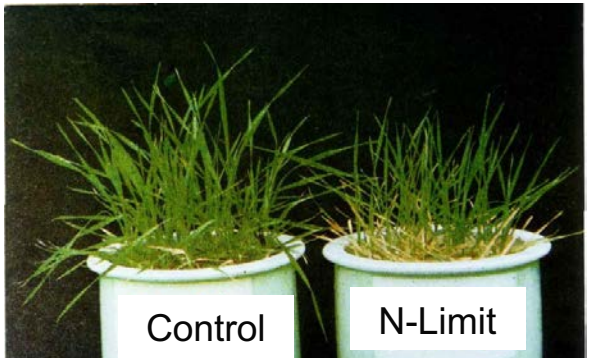
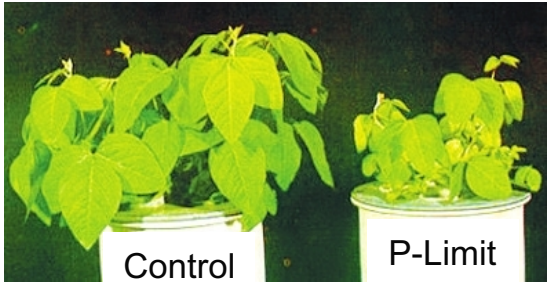
Nitrogen Limitation on Plant Growth

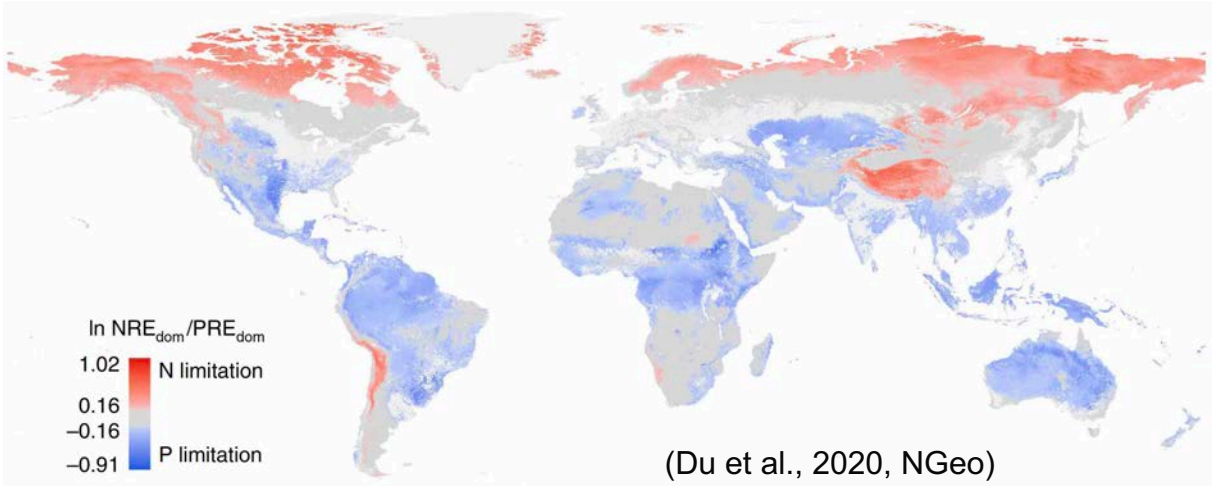


(Fisher et al., 2012, GBC)

Nutrient limitation is widely distributed globally.

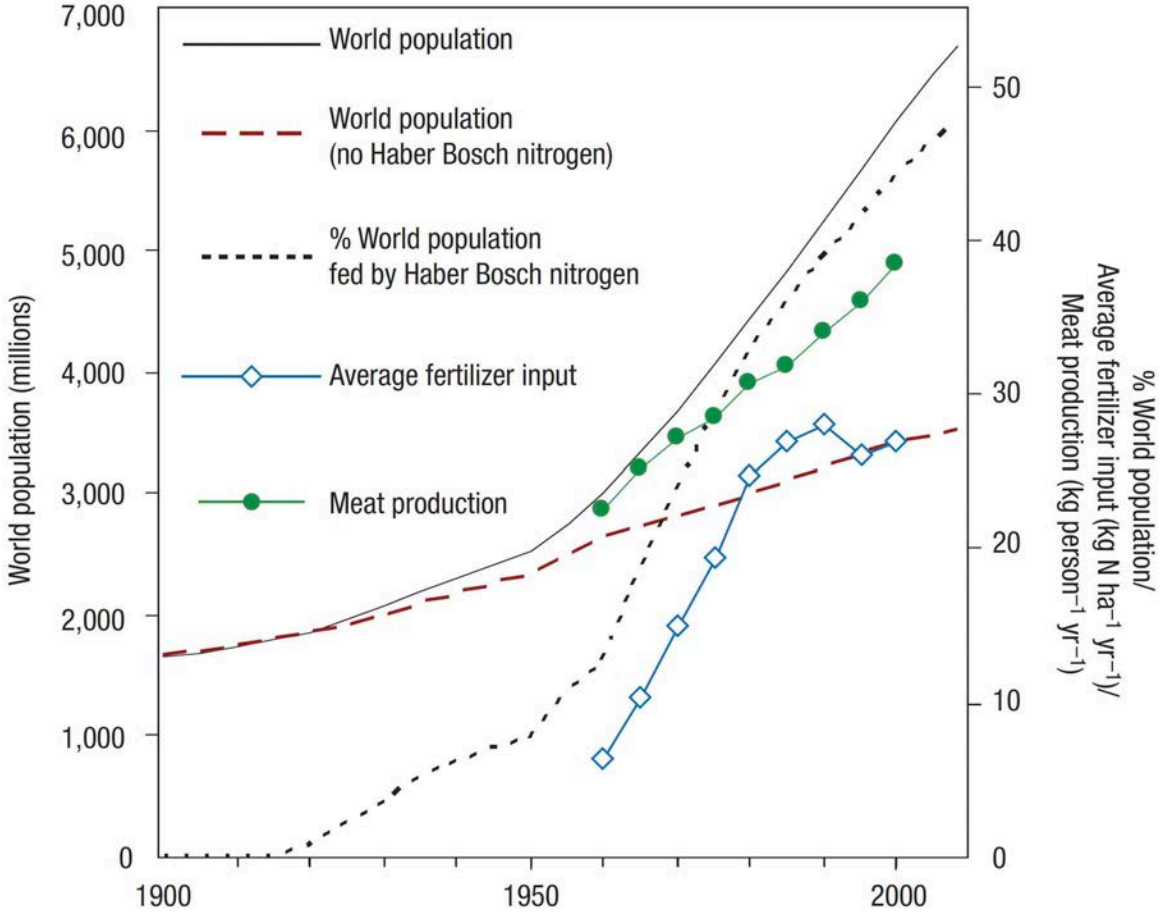






(Du et al., 2020, NGeo)

Fertilization

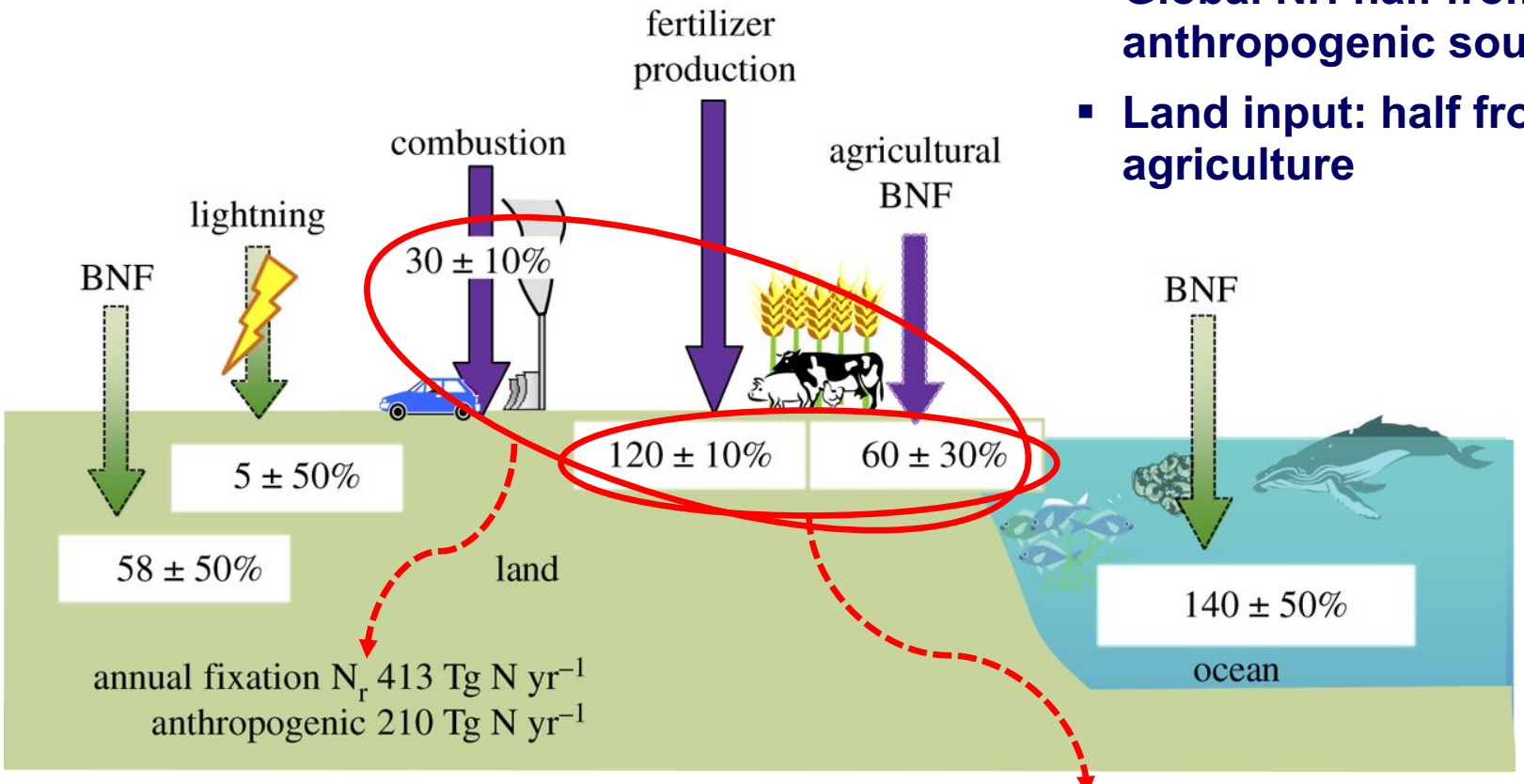


Half of the world's population relies on N fertilization.

(Erisman et al., 2008)

Global N Flux

- **Global Nr: half from anthropogenic sources**
- **Land input: half from agriculture**



(Fowler et al., 2013, Phil. Trans. R. Soc. B)

Agriculture N input / land input:
180 / 273

Eutrophication

China

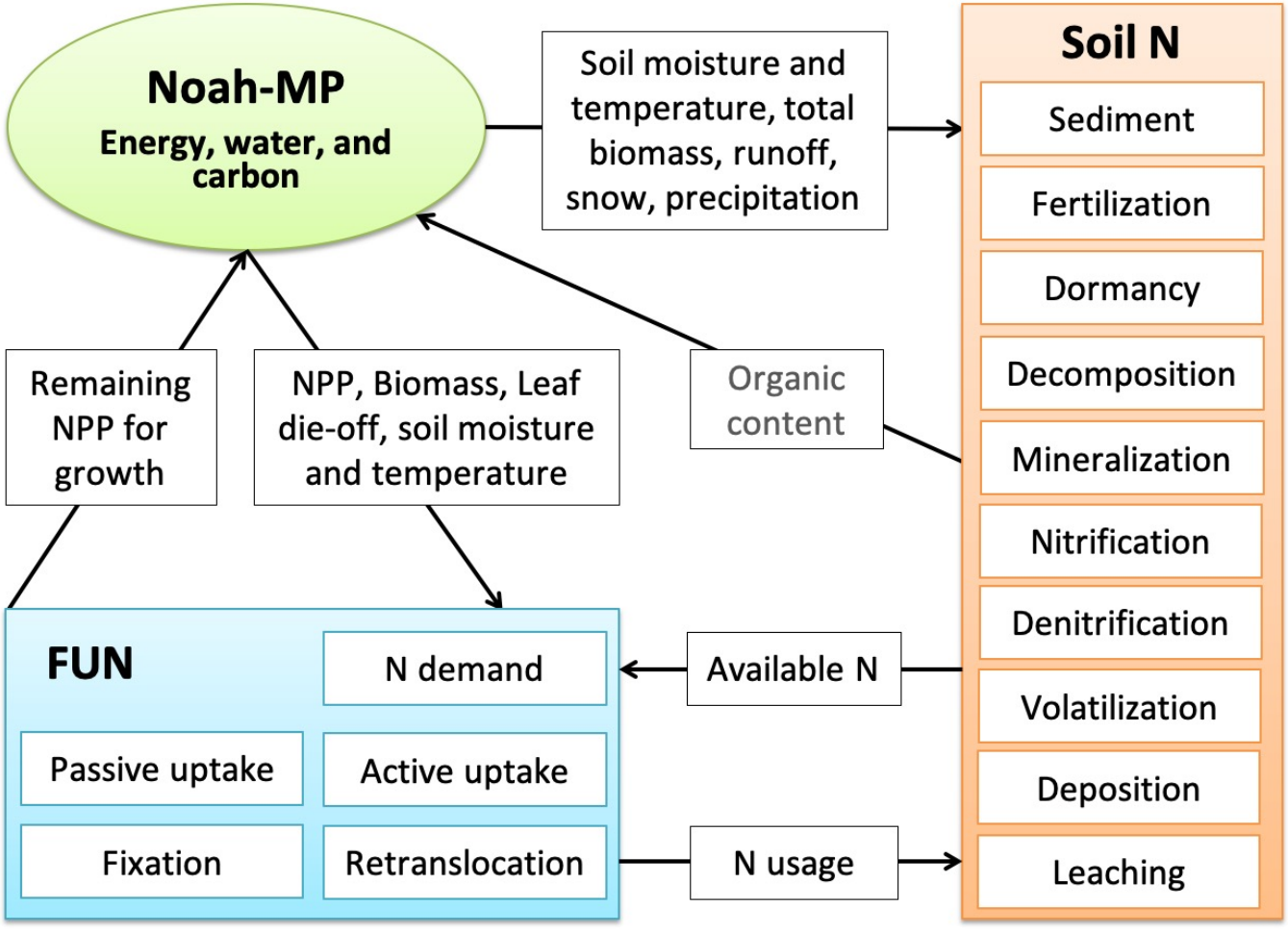
Denmark

U.S.

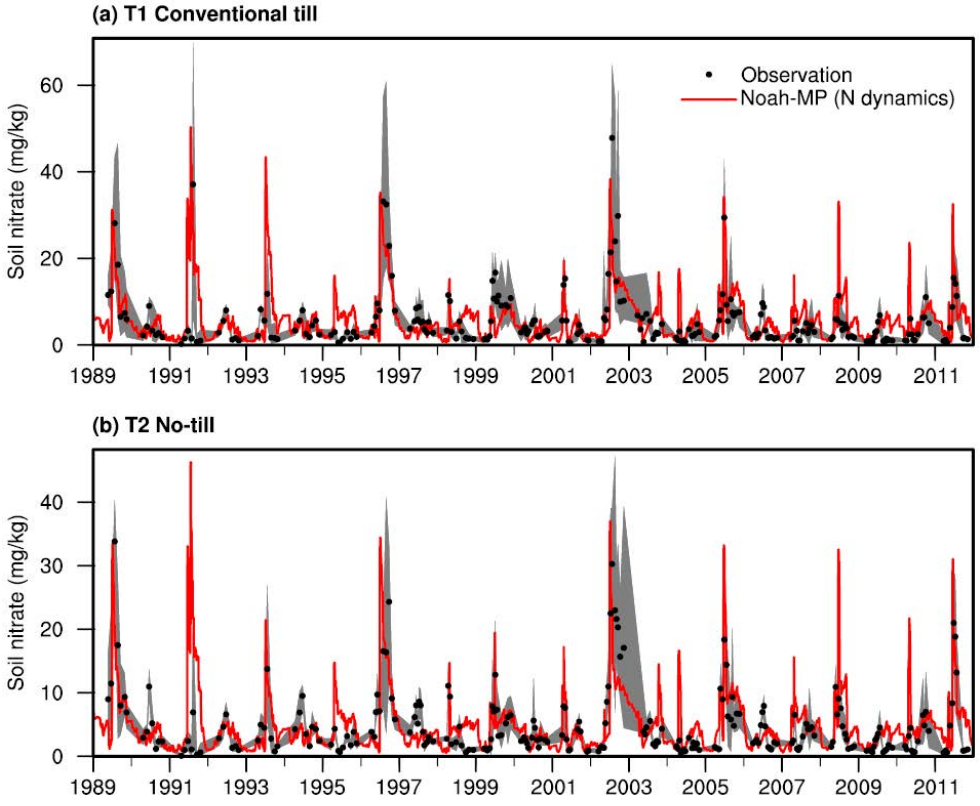
- A world wide problem
  - River, lake, & coastal waters
- Requires substantial costs to control them
- Nitrogen is the leading nutrient

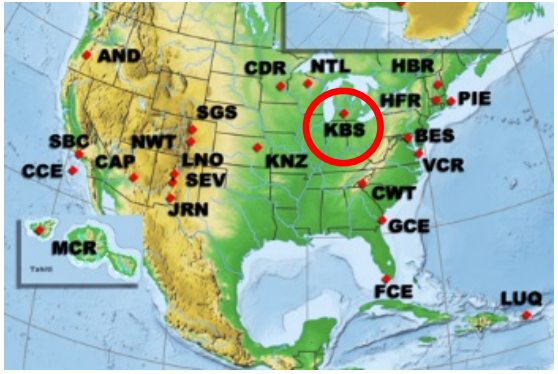
(Conley et al., 2009)

Noah-MP-CN


Noah-MP
Energy, water, and carbon
Soil moisture and temperature, total biomass, runoff, snow, precipitation
Soil N
Sediment
Fertilization
Dormancy
Decomposition
Mineralization
Nitrification
Denitrification
Volatilization
Deposition
Leaching
Remaining NPP for growth
NPP, Biomass, Leaf die-off, soil moisture and temperature
Organic content
FUN
N demand
Passive uptake
Active uptake
Fixation
Retranslocation
Available N
N usage

Soil Nitrate (NO_3)



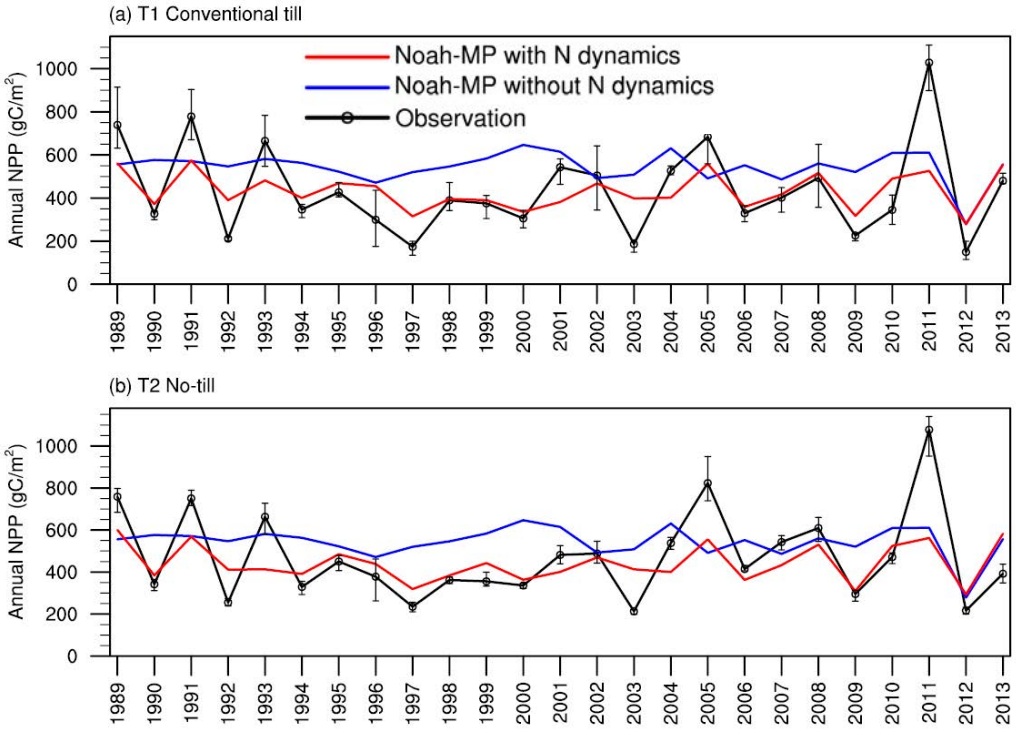


Treatment	Obs.	Model	R
T1: Tillage	5.61	5.77	0.58
T2: No-tillage	4.81	4.90	0.56

Model well represents the soil nitrate concentration fluctuations.

(Cai et al., 2016, GMD)

Annual NPP

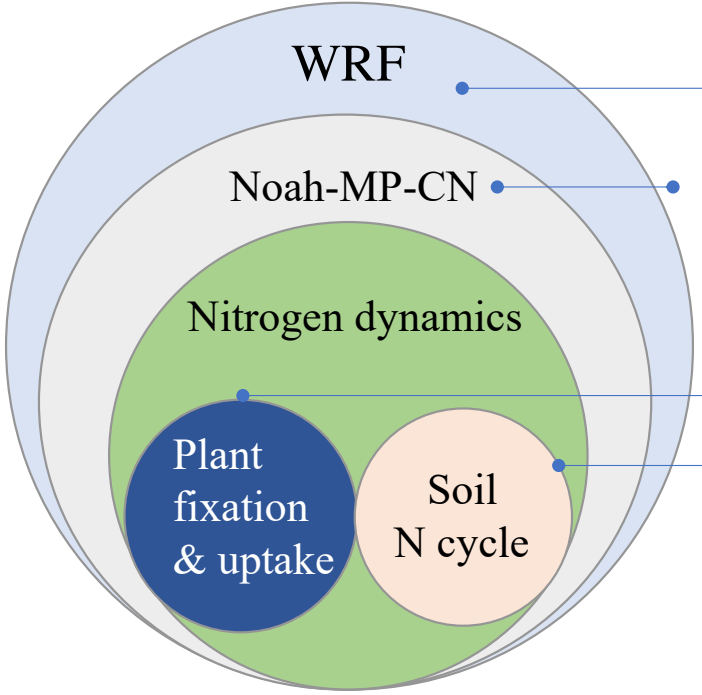


	Obs.	CTL	MPN
		Mean	
T1	437	544	432
T2	471	544	441
		Correlation	
T1		0.38	0.77
T2		0.30	0.72

Noah-MP with N dynamics: Annual NPP is closer to observation;
Correlation is significantly increased.

(Cai et al., 2016, GMD)

Noah-MP-CN and WRF Coupling



WRF → Atmosphere

Noah-MP-CN → Land

Nitrogen dynamics →
- N demand
- Passive uptake
- Active uptake
- Fixation
- Retranslocation
- Mineralization
- Immobilization
- Decomposition
- Denitrification
- Nitrification
- Volatilization
- N deposition
- N leaching

Nitrogen dynamics (module_sf_biogeochem.F)

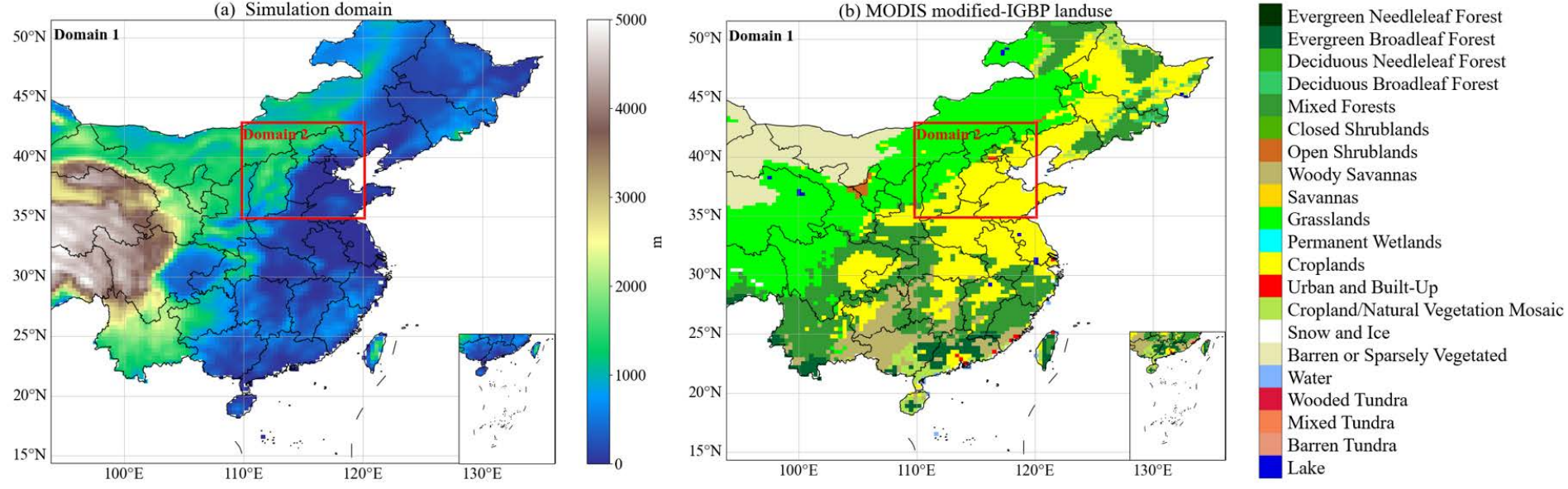
Physics —Add model→ module_sf_biogeochem.F —couple / modify→ module_sf_noahmplsm.F, module_sf_noahmpdrv.F, module_surface_driver.F → Noah-MP-CN

IO —modify→ registry.noahmp → Registry for new variables

Nitrogen Dynamics Improves WRF Simulations

with vs. without nitrogen dynamics

Study Domain and Model Setup

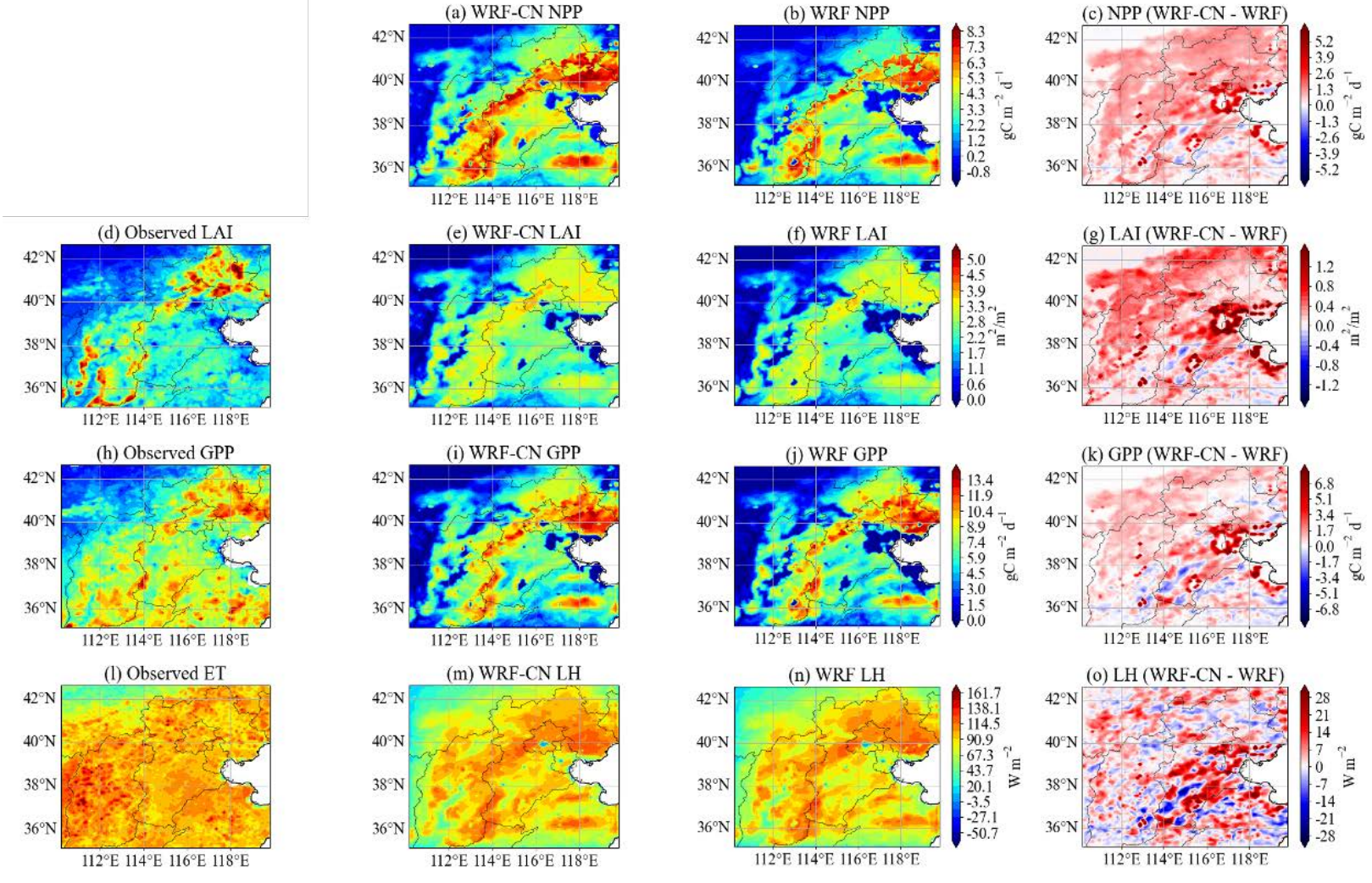


- **Summer 2018**
  - **May to August, May for spin-up**
- **Initialization: ERA5**
- **Spatial resolution**
  - **30 km for Domain 1； 10 km for Domain 2**

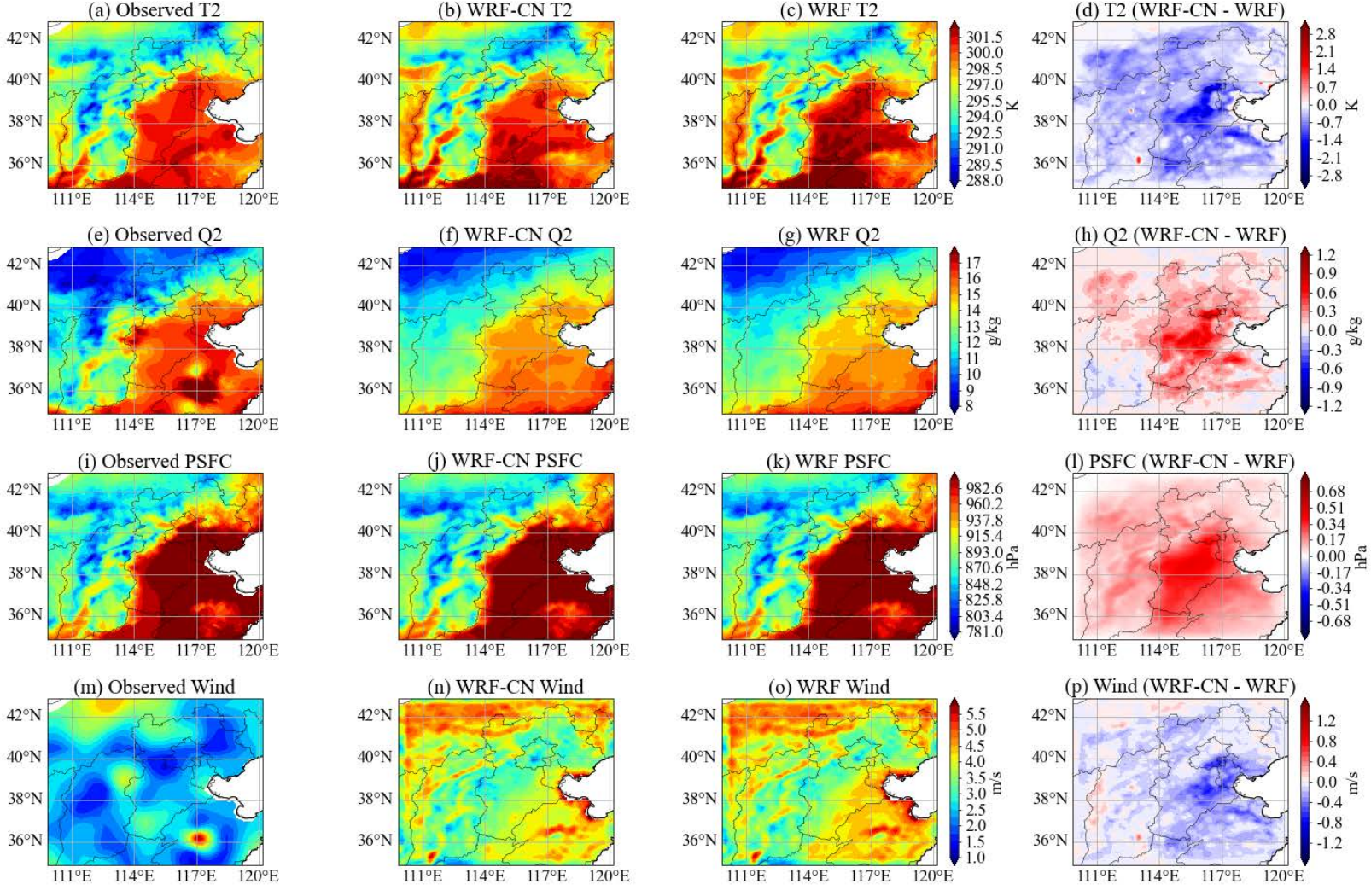
WRF Configuration

Physical process	Parameterization schemes
Microphysics	Single-Moment 6-class (Hong & Lim, 2006)
Cumulus physics	Tiedtke scheme (Tiedtke, 1989)
Longwave radiation physics	RRTM scheme (Mlawer et al., 1997)
Shortwave radiation physics	Dudhia scheme (Dudhia, 1989)
Boundary layer	Mellor-Yamada-Janjic scheme (Janjić, 1994)
Surface layer	Eta similarity (Janjić, 1994)
Land surface	Noah-MP (Niu et al., 2011); Noah-MP-CN (Cai et al., 2016)
Cloud fraction	Xu-Randall method (Xu & Randall, 1996)

NPP LAI GPP LH

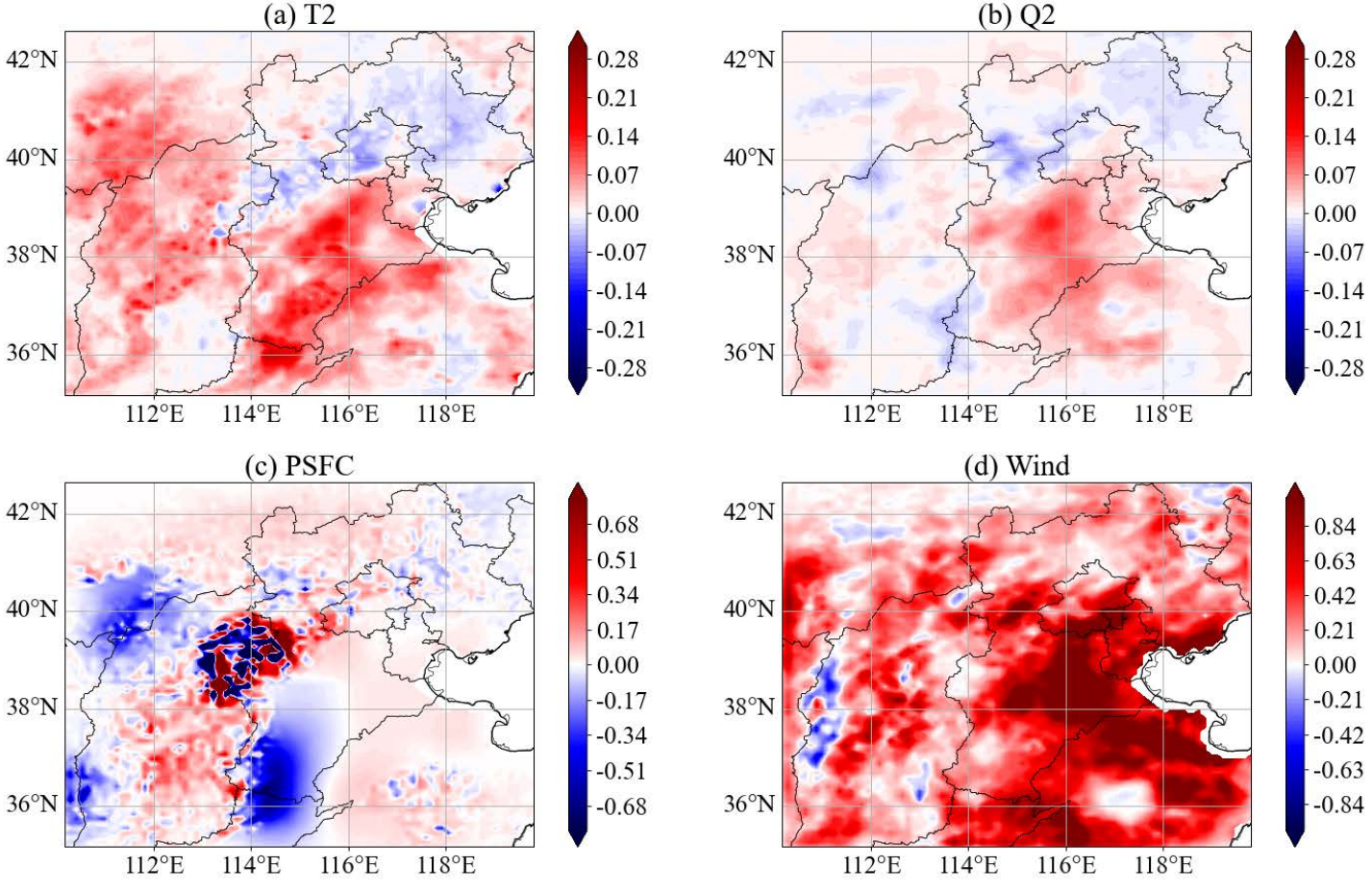


Temperature, Specific Humidity, Pressure, & Wind



NSE Difference (WRF-CN – WRF)

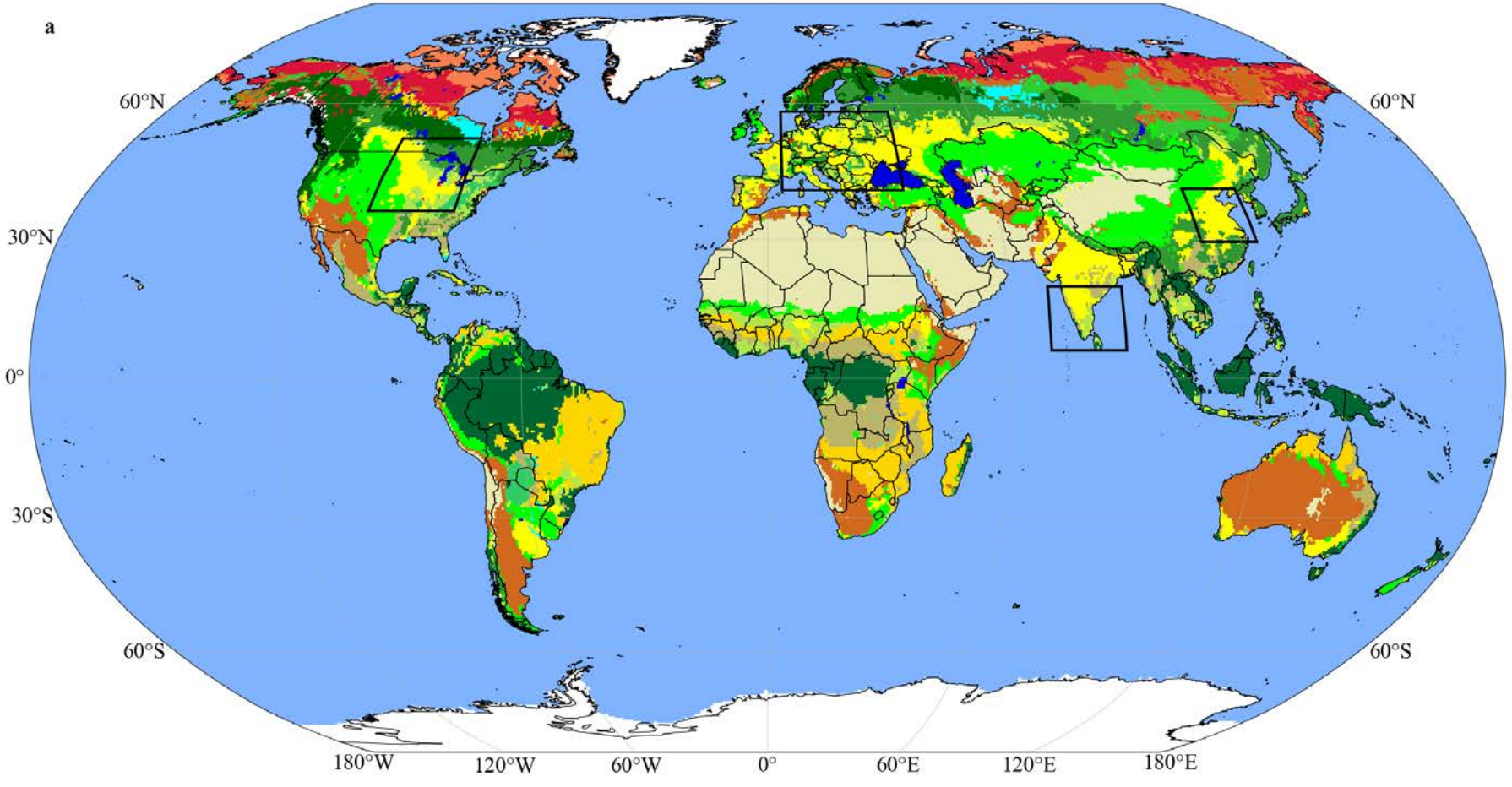
Mostly higher NSE: improved simulations for near-surface fields



Nitrogen fertilization impacts on WRF simulations

with vs. without nitrogen fertilization

Study Domain

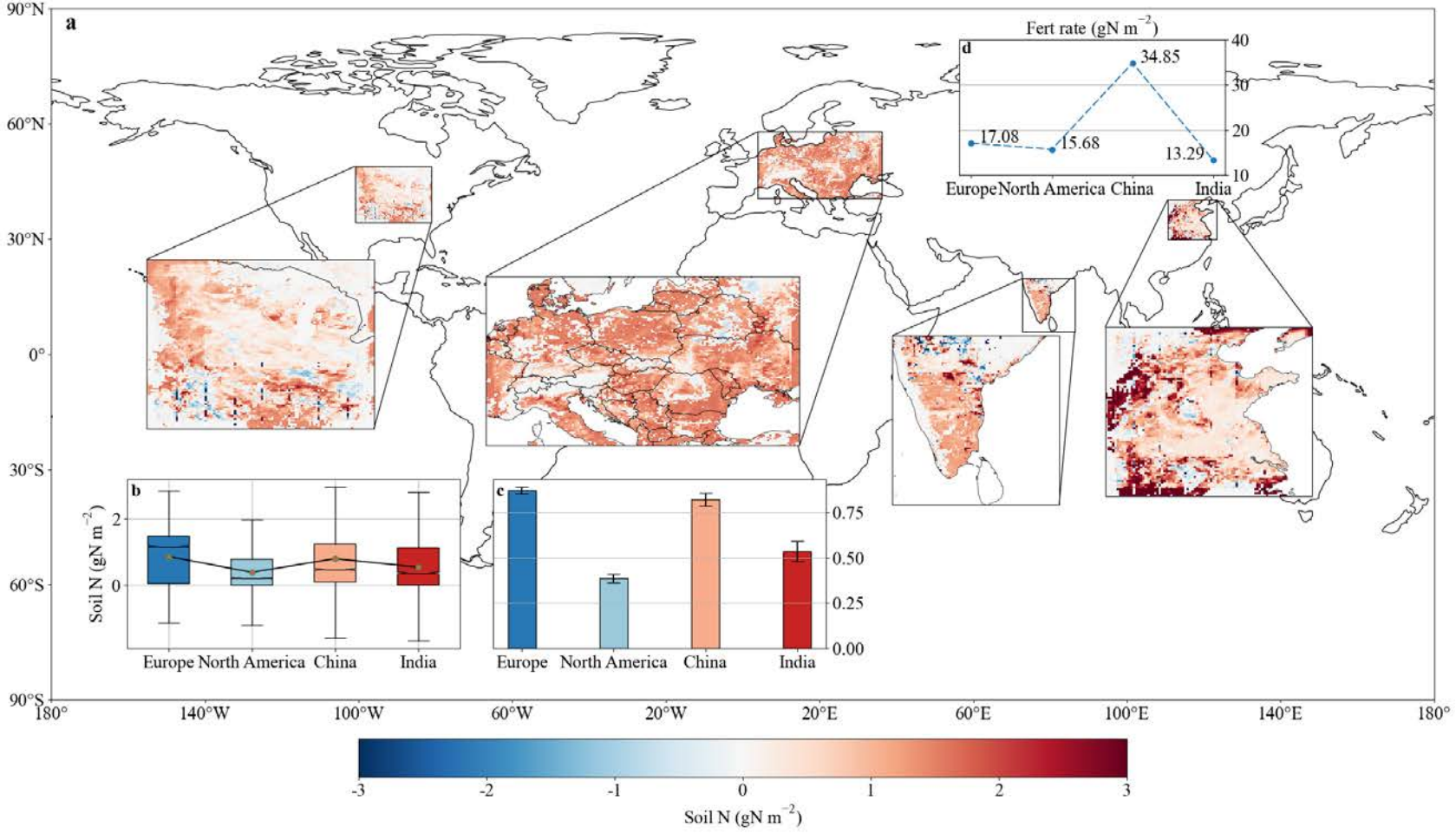


Land use map

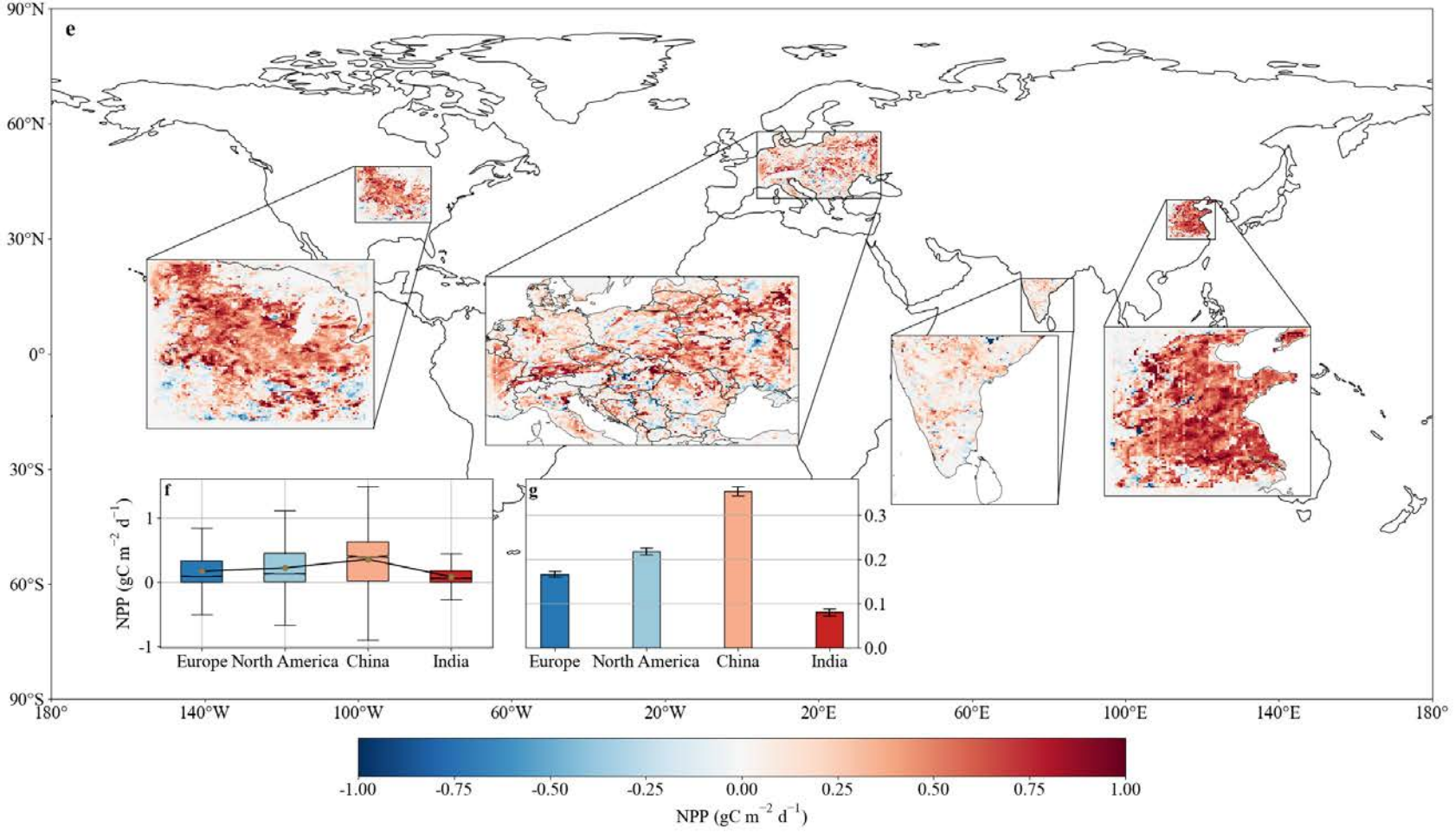
Cropland Percentage

Domain	Cropland Grid Count (%)
Europe	67.15%
North America	61.48%
India	76.83%
North China	76.30%

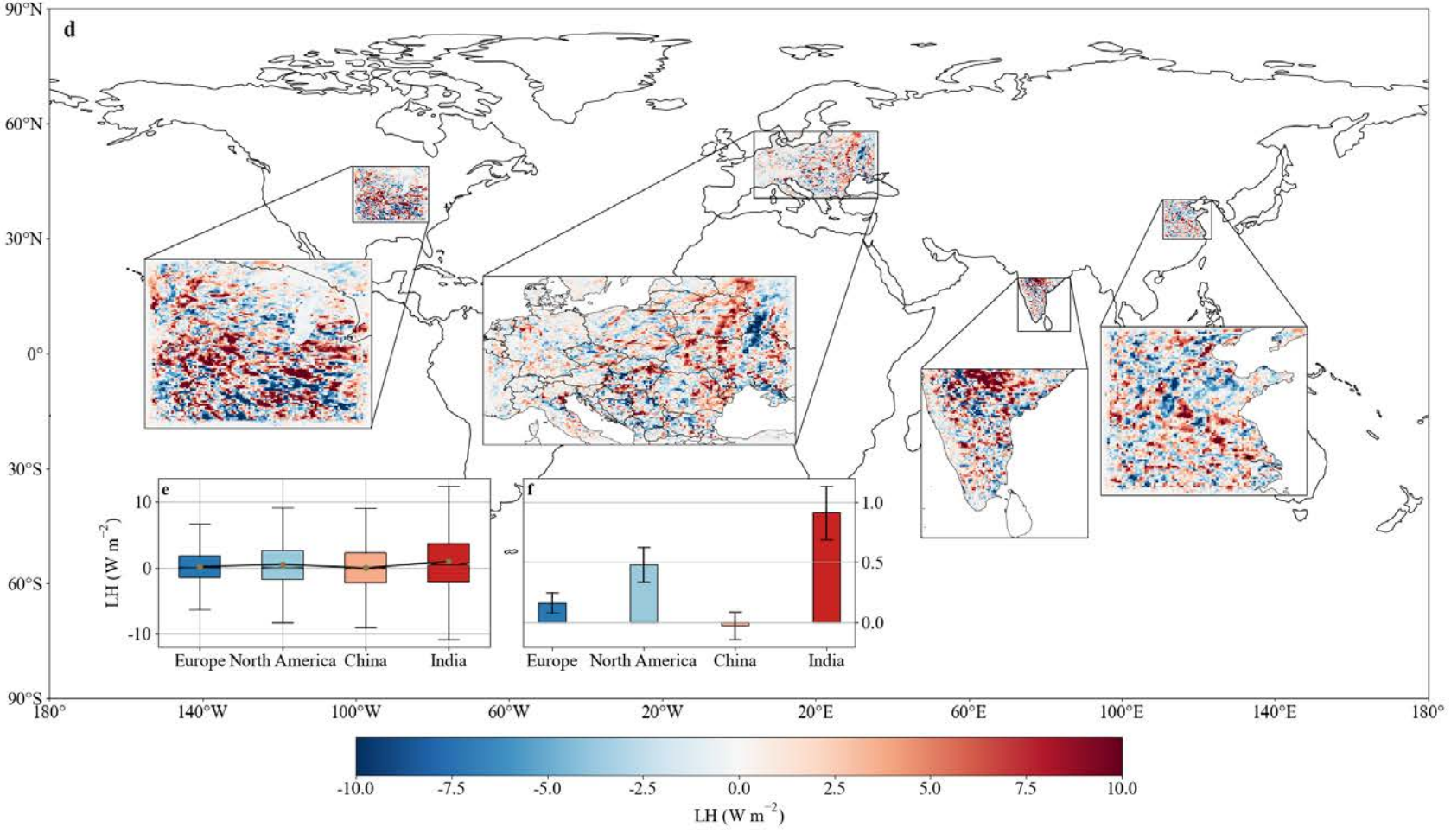
Soil NO_3


a
90°N
60°N
30°N
0°
30°S
60°S
90°S
180°
140°W
100°W
60°W
20°W
20°E
60°E
100°E
140°E
180°
b
Soil N (gN m^{-2})
2
0
Europe
North America
China
India
c
0.75
0.50
0.25
0.00
Europe
North America
China
India
d
Fert rate (gN m^{-2})
40
30
20
10
34.85
17.08
15.68
13.29
Europe
North America
China
India
-3
-2
-1
0
1
2
3
Soil N (gN m^{-2})

Net Primary Productivity



Latent Heat Flux



Conclusions

- Including nitrogen dynamics improved WRF simulated temperature, humidity, and wind.
- Nitrogen fertilization increase NPP and latent heat flux.
- Future work
  - Riverine nitrogen transport
  - Soil organic nitrogen
  - N_2O

Related References

- Cai, X., Z.L. Yang, J.B. Fisher, X. Zhang, M. Barlage and F. Chen, 2016. Integration of nitrogen dynamics into the Noah-MP land surface model v1.1 for climate and environmental predictions. *Geoscientific Model Development*, 9(1): 1-15.
- Liang, J., Yang, Z.-L., Cai, X., Lin, P., Zheng, H., & Bian, Q., 2020. Modeling the impacts of nitrogen dynamics on regional terrestrial carbon and water cycles over China with Noah-MP-CN. *Advances in Atmospheric Sciences*, 37(7), 679–695.
- Xitian Cai, Yeer Cao, Guo Zhang, Jingjing Liang, Hui Zheng, Kai Li, Zhenzhong Zeng, Yongjiu Dai, Zong-Liang Yang. Influence of terrestrial nitrogen dynamics on mesoscale near-surface meteorological fields. *Journal of Advances in Modeling Earth Systems*, 2023 (in revision)


Thank you for your attention!
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