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Quantifying and mapping China's crop yield gains from sustainable and unsustainable irrigation water use 1981-2000

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I. Research Questions

How much unsustainable water is used for irrigation in China (c.2000)?

How will crop yields change when the unsustainable water runs out?

II. Background

- Chinese agriculture depends greatly on irrigation water. ~40% of China's cropland is irrigated.
- It has been estimated that ~15% of China's irrigation water comes from unsustainable sources[1]
- Regions that rely on unsustainable irrigation water could face water shortages in the future, and may already be experiencing water stress today[1].
- Identifying crops, regions, and total crop yields that will be impacted by the eventual loss of unsustainable water can help plan for future water management.

III. Methods

1) Use 2 models: DNDC[2] for irrigated and rainfed crop yields per area, WBM for sustainable water availability and crop water requirements. Input 20 years of climate variability.

2) Model two scenarios:
   a) Only use sustainable water for irrigation
   b) Allow unsustainable water for irrigation

3) Scale the MIRCA2000 dataset of irrigated and rainfed cropland areas to reduce irrigation demand to sustainable water supply. Algorithm:

I = MIRCA2000 irrigated areas

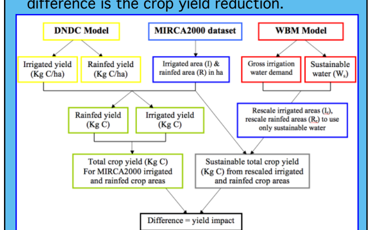
R = MIRCA2000 rainfed areas

W_s = sustainable water as a fraction of irrigation demand

I_r = rescaled irrigated areas = W_s * I

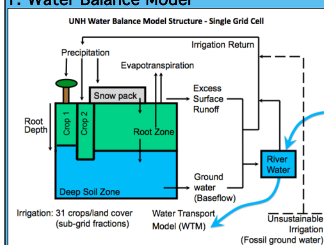
R_r = rescaled rainfed areas = R + (1 - W_s) * I

3) Calculate total crop yield for MIRCA2000 areas (I, R) and for rescaled areas (I_r, R_r). The difference is the crop yield reduction.

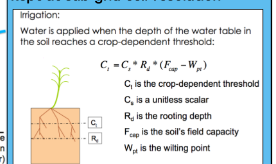


IV. Models

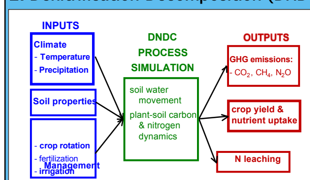
1. Water Balance Model

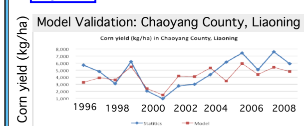


- A "bucket" model that keeps a water budget for each grid cell
- Cropland water budgets are kept at sub-grid cell resolution



2. Denitrification-Decomposition (DNDC) Agro-ecosystem model[2]





- A biogeochemistry model of crop growth based on nutrient cycling.
- Includes crop management parameters for fertilizer, manure, and multi-cropping rotations.
- Estimates crop yields (kg C/ha) for irrigated and rainfed crops based on soil conditions, management, and climate.
- Validated against statistical data at the county-level (China).

Model Inputs:

Model input type	Water Balance Model (WBM)	DNDC
Climate	MERRA[3]	MERRA[3]
Crop distribution	MIRCA2000[5]	CAAS
Irrigated areas	MIRCA2000[5]	all crop/soil/climate conditions simulated with and without irrigation
Cropping Intensity	AQUASTAT (2008)[8], MIRCA2000[5]	China statistical yearbook[4]
Crop categories	26 crops (31 including subcrops)	17 individual crops & 28 multi-cropping systems
Soil properties	UNESCO/FAO soil map of the world[6]	Third National Soil Survey
Spatial Resolution	30 arc minute grids	China counties (~30 arc min polygons)
		Resampled to 30 min grids
Temporal Resolution	Daily	Daily
	Aggregated to monthly & annual totals	Aggregated to annual total

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2) Li, C., Frolking, S., Frolking, T.A., 1992. A model of nitrous oxide evolution from soil driven by rainfall events, I. Model structure and sensitivity. *J. Geophys. Res.,* 97, 9759-9776.
3) Mitchell, T.D., Jones, P.D., 2005 An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology,* 25(6), 693-712.
4) State Statistical Bureau, *Statistical Yearbook of China 2000,* China Stat. Publ. House, Beijing, 2000.
5) Portmann, F.T., Siebert, S., D.P., 2010, MIRCA2000 - Global monthly irrigated and rainfed crop areas around the year 2000: A new high-resolution data set for agricultural and hydrological modeling, *Global Biogeochemical Cycles* 24, GB1011, doi:10.1029/2008GB003435.
6) FAO/UNESCO, 2003. Digital Soil Map of the World and Derived Soil Properties Version 3.6. CD ROM.
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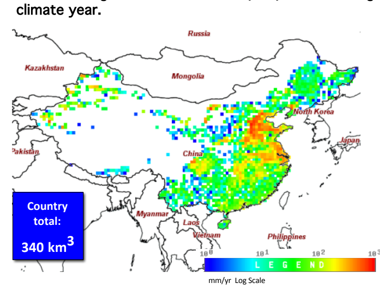
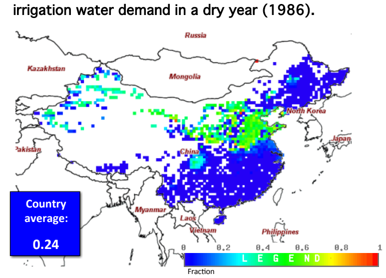
V. Results

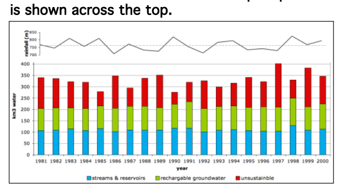
a. Annual irrigation water demand (mm) for an average climate year.



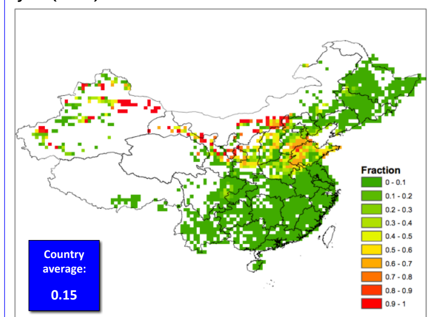
b. Unsustainable water as a fraction of total irrigation water demand in a dry year (1986).



c. Annual irrigation water withdrawals from streams & reservoirs, rechargeable groundwater, and unsustainable sources. Annual precipitation is shown across the top.

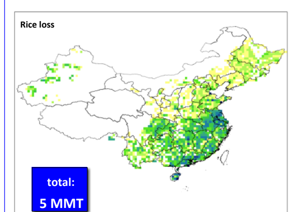


d. Annual reduction in irrigated crop yields due to loss of unsustainable water in a dry year (1986). Unit: fraction

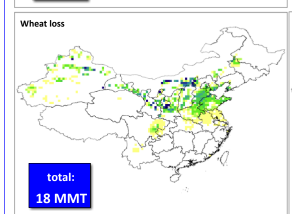


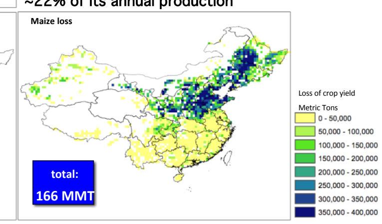
- The average loss for China in a dry year is 15% of total crop yields (~75 MMT C).
- The average loss for China in a wet year (not pictured) is 10% of total crop yields (~50 MMT C).
- There is a strong regional difference between crop yield losses southern China (0 - 20%) and in the north and north-eastern regions (40 - 100%).

e. Annual reduction in rice (top), wheat (bottom left) and maize (bottom right) crop yields due to loss of unsustainable water in a dry year (1986). Unit: metric tons



- Rice, wheat, and maize are the three dominant crops grown in China. Their reductions in yield due to loss of unsustainable water are significantly different.
- Rice loses 5 out of 150 MMT per year, ~3% of its annual production
- Wheat loses 18 out of 116 MMT per year, ~15% of its annual production
- Maize loses 166 out of 212 MMT per year, ~22% of its annual production





Sustainable crop yield from areas equipped for irrigation is 10% (wet year) to 15% (dry year) lower than fully irrigated crop yield.

<u>Impact on food: a quick calculation</u>

10% of irrigated yield = ~50 million metric ton C

1 metric ton Rice = ~1.3 x 10^6 Calories = one year of food for 2 people (assume 2000 Calories per year)

50 million metric tons x one year of food for 2 people = one year of food for 100 million people (7% China's pop.)