

Future changes in the trading of virtual water

Neal Graham

Mohamad Hejazi, Sonny Kim, Evan Davies, James Edmonds,
Fernando Miralles-Wilhelm

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Virtual Water Definitions and Historical Trends

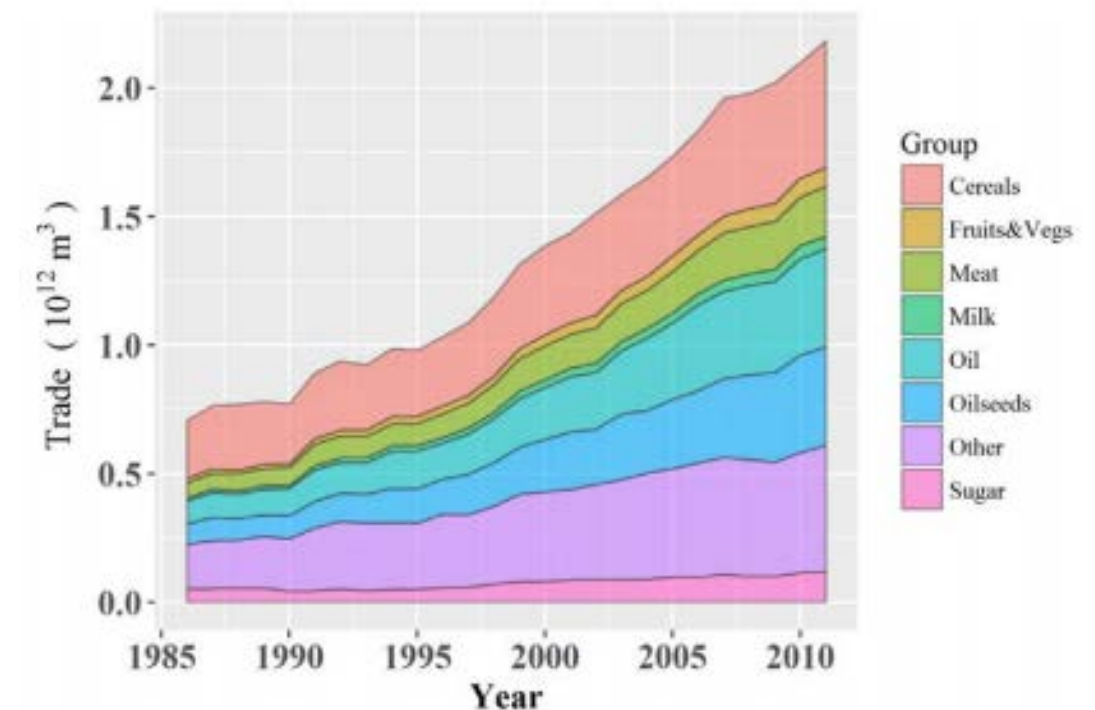
- Virtual water trade – Amount of water embedded in commodity production that is then traded in the global market (*Allen 1998*)
- Recent studies have found virtual water trading has at least doubled between 1987-2007.
- The nontrivial task of modeling trade in the future has largely hindered future analysis of virtual water trade.

Virtual Water



Adopted and modified from: watercalculator.org

- Soil moisture and transpiration consumed in crop growth
- Fresh surface runoff and groundwater consumed in crop growth

D'Odorico et al. (2019) *ERL*

Research Questions and Methodology

- *How will virtual water trading change throughout the century and what are the implications for green, blue, and nonrenewable groundwater?*
- *Are there significant spatial dependencies that arise in order to maintain the global agricultural market?*
- Using GCAM, we follow a SSP2-RCP6.0 business as usual future with temporally changing water supply, agricultural productivity, hydropower availability, building energy demands, and constraints placed on water resources to analyze virtual water trade throughout the century.

- Ag production is separated into Irrigated (IRR) or Rainfed (RFD) to calculate trade and virtual water trade at the basin level, b , for crop c .
 - As demand is calculated at regional scales, proportionate values of production and water are used to downscale to basin level.
- Groundwater contributions to virtual water trade are calculated based on the proportion of nonrenewable groundwater depletion, GWD to blue water withdrawals, BWW , within the specified basin.

Virtual Water Trade

$$Virtual\ Blue\ Water\ Exports_{b,c}(t) = \frac{BWC_{b,c}}{\left(\frac{P_{b,c,IRR}}{\sum_{i=1}^b P_{b,c,IRR}}\right)} * E_{b,c,IRR}$$

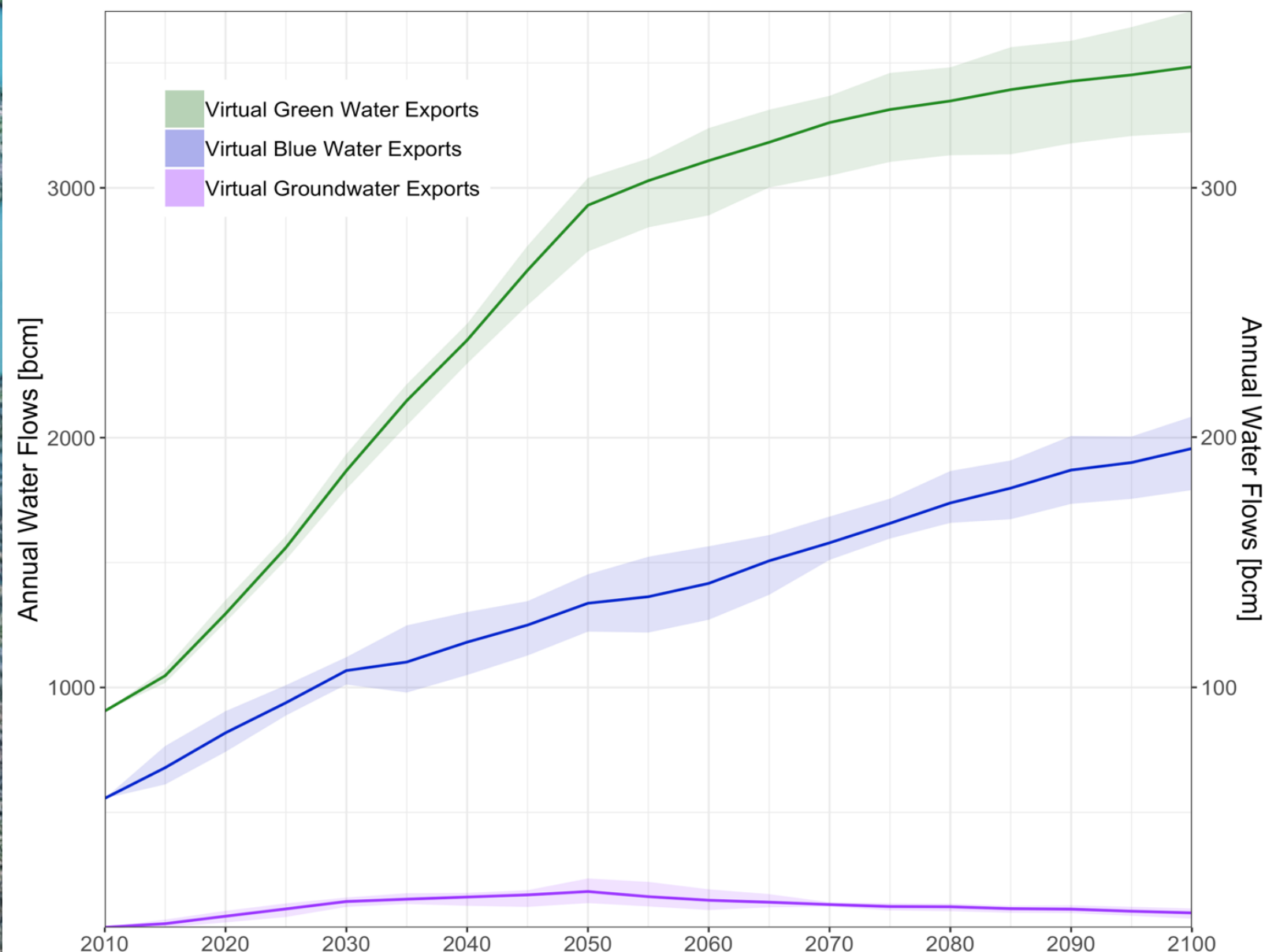
$$Virtual\ Blue\ Water\ Imports_{r,c}(t) = \left(\sum_{i=1}^{b_r} VBE_{b,c}\right) * \frac{I_{r,c,IRR}}{\sum_{i=1}^r I_{r,c,IRR}}$$

$$Virtual\ Blue\ Water\ Trade_{r,c}(t) = \left(\sum_{i=1}^{b_r} VBE_{b,c}\right) + VBI_{r,c}(t)$$

Virtual Groundwater Trade

$$Virtual\ Groundwater\ Exports_{b,c}(t) = VBE_{b,c}(t) * \frac{GWD_b}{BWW_b}$$

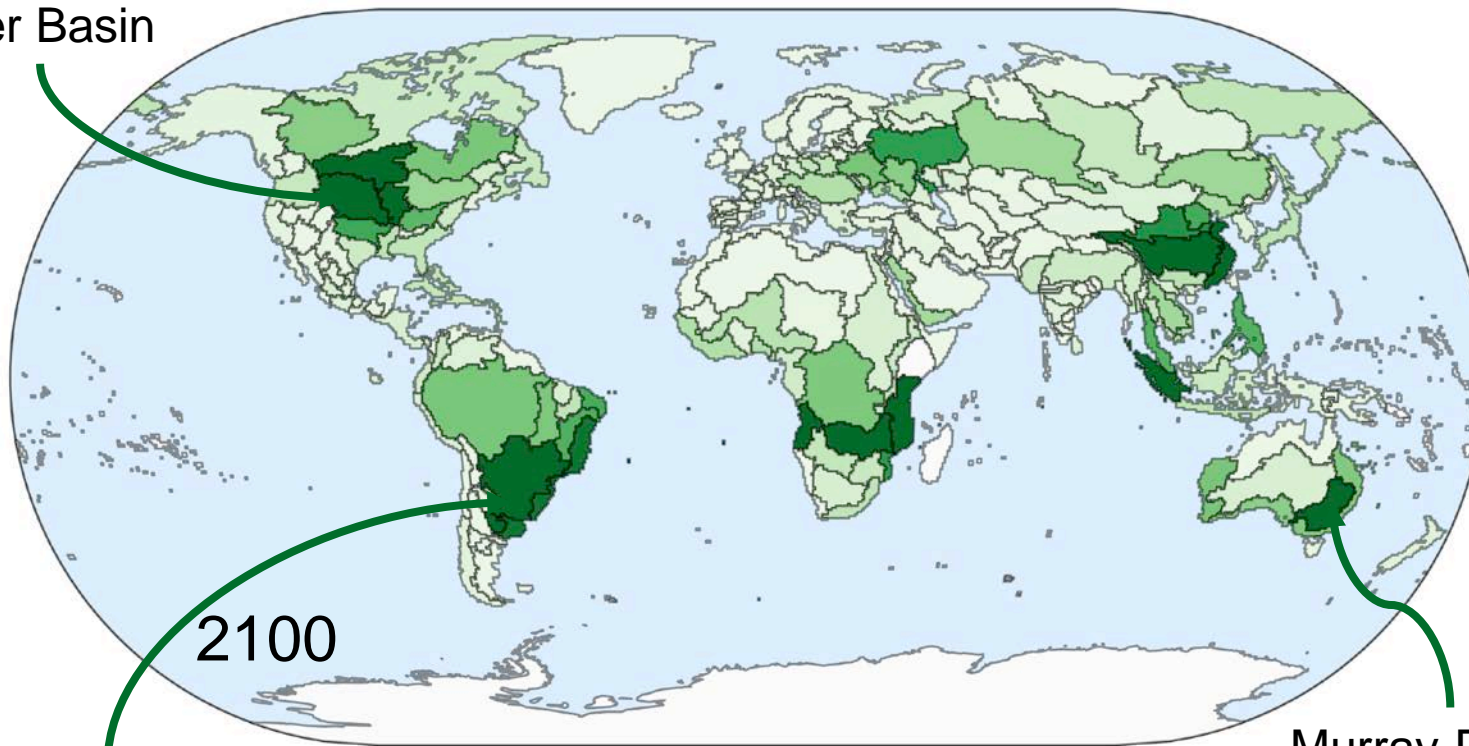
Virtual water trade in the future intensifies as a response to global food and biomass demands



- Global virtual water trade at least doubles by the end of the century.
- Green water trading growth slows after 2050 as population growth slows.
- Blue water trading experiences nearly linear increases throughout the century.
- Groundwater trading peaks mid-century with a final doubling by 2100.
- More virtual water trading = higher reliance on international trade.

Significant regional differences in green water trading arise by the end of the century

Missouri
River Basin



2100

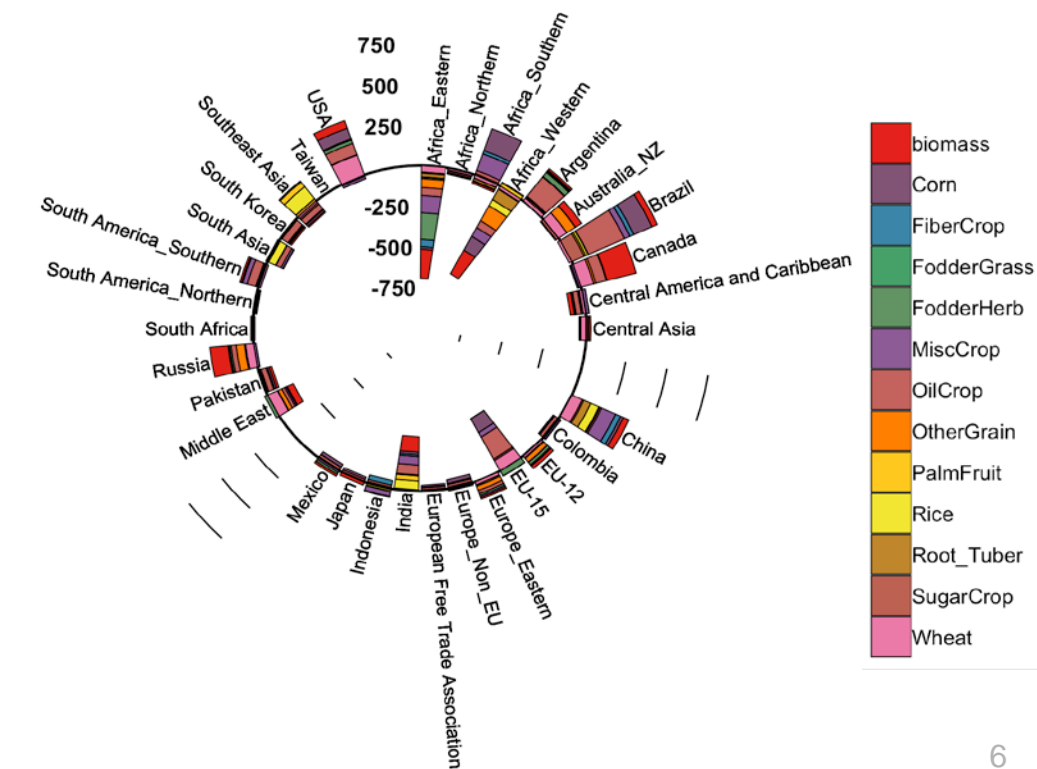
La Plata
River Basin

Virtual Green Water Exports [bcm]



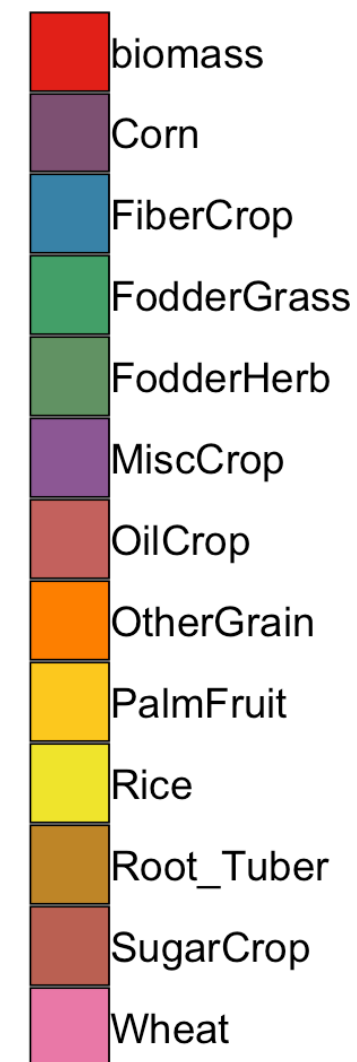
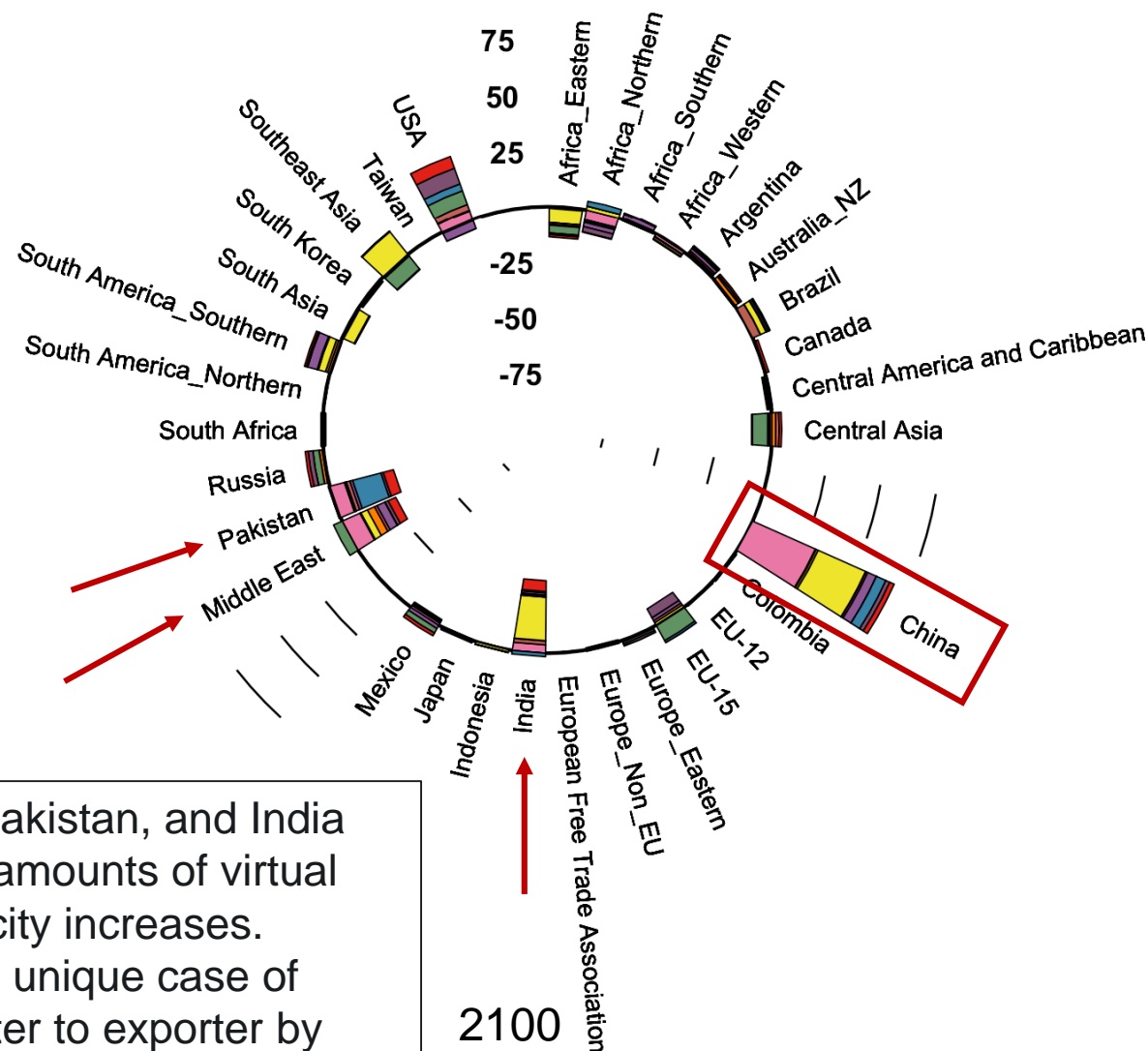
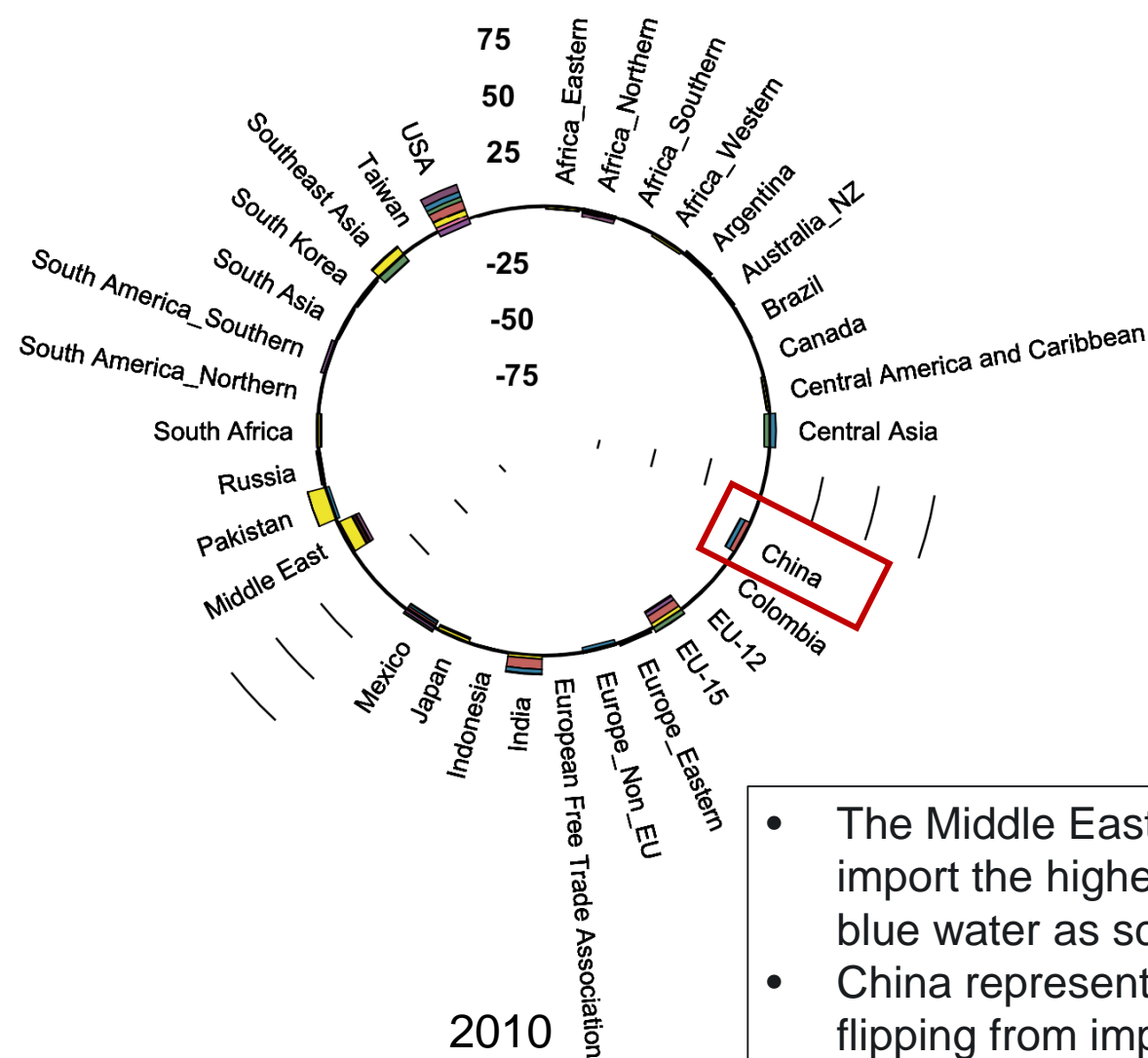
Murray-Darling
River Basins

- Brazil, China, Southern Africa, and the United States make up the largest exporters of green water.
- Exports of Corn, Wheat, and Oil Crops represent the largest proportion of green water being traded in the global market.



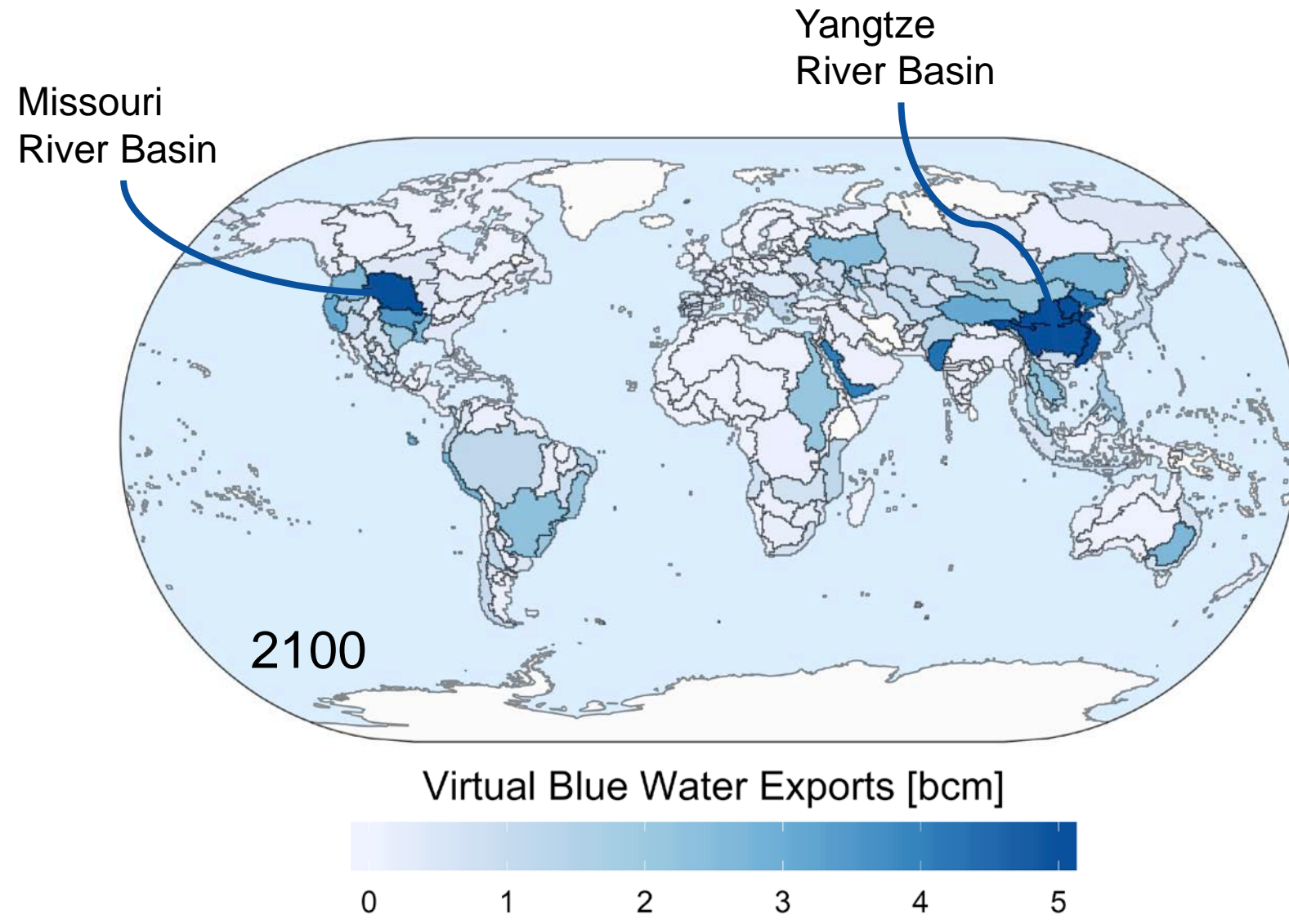
Population dynamics and water scarcity drive changes to blue water trading

Virtual Blue Water Trade [bcm]



- The Middle East, Pakistan, and India import the highest amounts of virtual blue water as scarcity increases.
- China represents a unique case of flipping from importer to exporter by 2100 due to population assumptions causing significant declines after 2030.

Large spatial differences remain with blue water trade by the end of the century

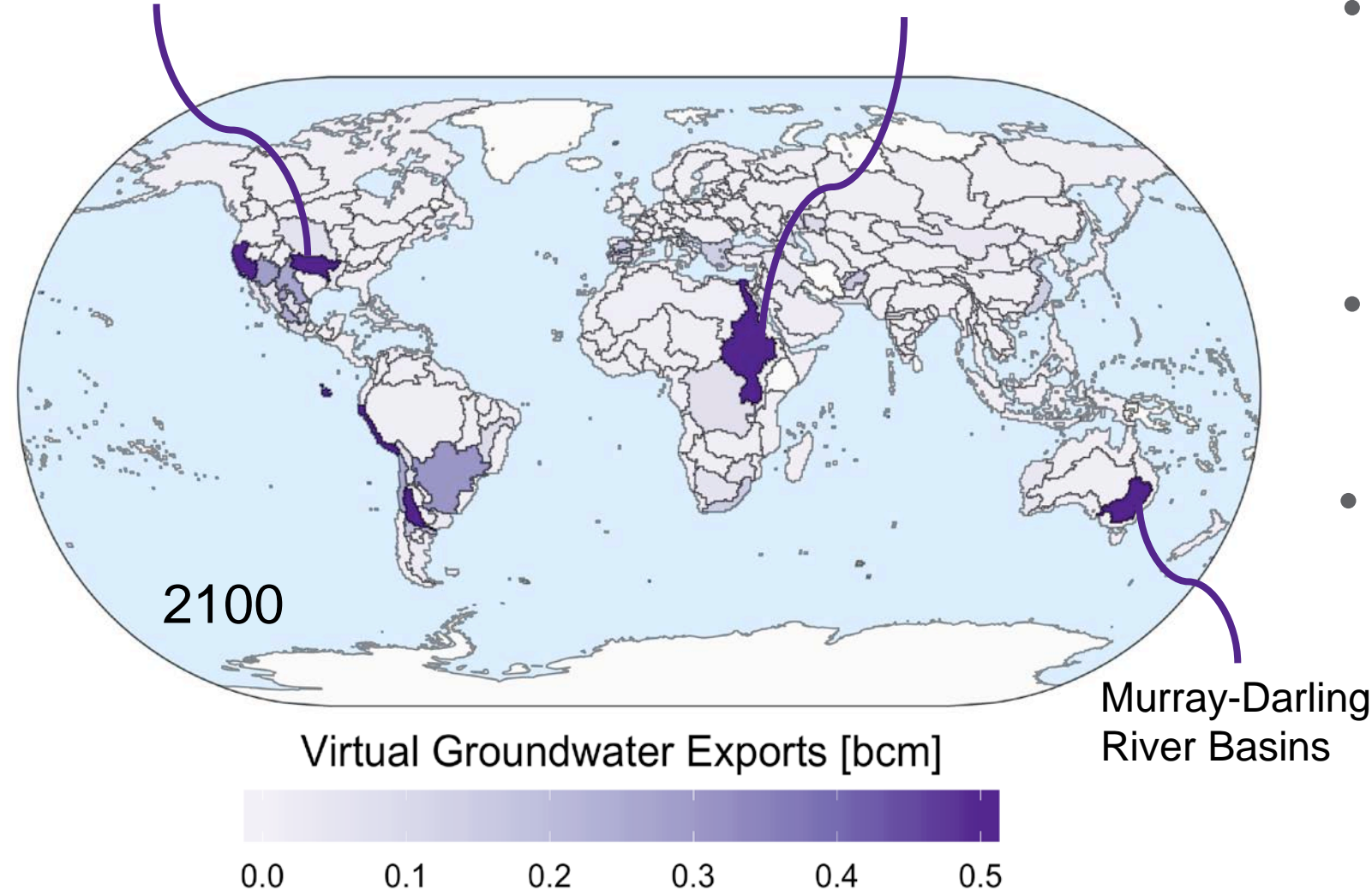


- Exports of virtual water are concentrated in areas of the midwestern United States, large portions of China, and much of South America.
- Additional exports of blue water continue from the Murray-Darling basin and the Nile River.
- These areas currently account for large proportions of the irrigated agricultural exports in the world.

Groundwater exports are concentrated in select basins which already experience large amounts of extraction

Ogallala Aquifer and
Arkansas River basin

Nile River basin



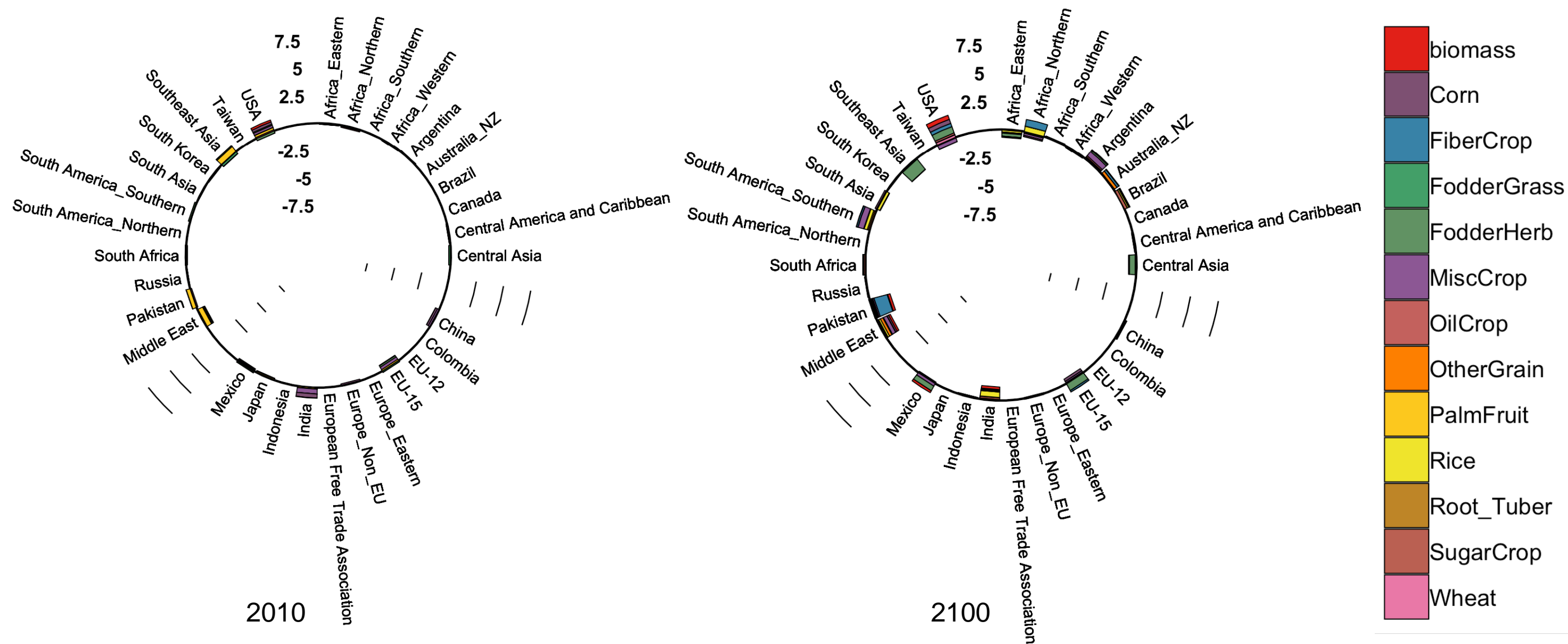
- Exports of nonrenewable groundwater originate from California (Central Valley aquifer), the Midwestern US (Ogallala aquifer), Murray-Darling basin in Australia, and the Nile River basin.
- Water use is split almost evenly among biomass, fibers, misc. crops, and rice.
- Areas in the United States expected to export nonrenewable groundwater in 2100 are historically some of the areas that observe the highest groundwater extraction presently.

- ***All sources of virtual water trade can be expected to at least double by the end of the century*** due to increases in population and increased biomass demands, with ***nearly every region seeing an intensification of VWT.***
- ***Population dynamics*** of certain regions ***result in increased exports into the future***, accounting for significant portions of virtual water trading.
- Areas of ***the United States, China, and South America*** will make up a large portion of future ***virtual water exports.***
- The amount of ***nonrenewable groundwater water embedded in agricultural trade*** at least ***doubles by 2100*** and originates from basins which already observe significant depletion.

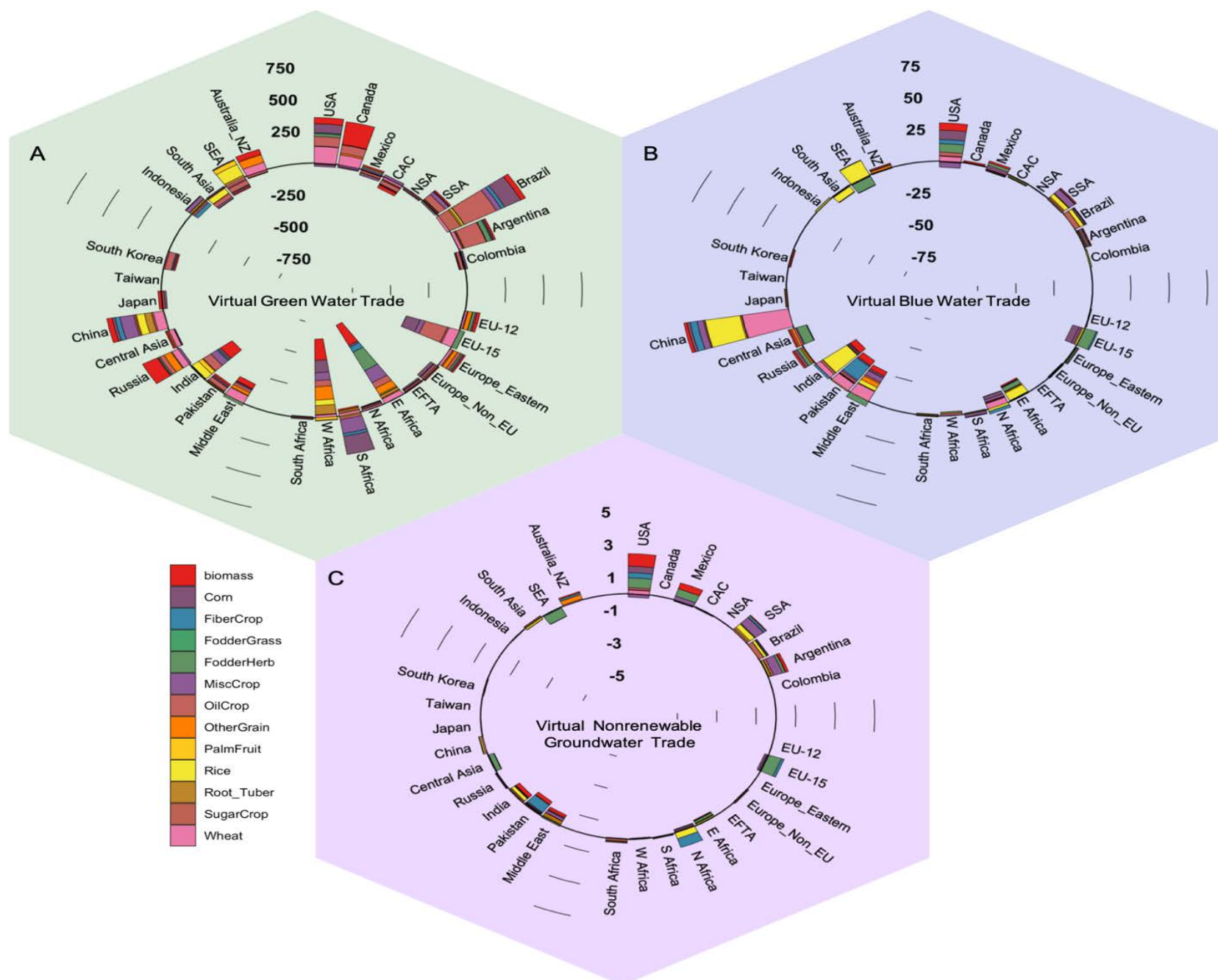
Thank you

Groundwater exports are concentrated in select basins which already experience large amounts of extraction

Virtual Groundwater Water Trade [bcm]

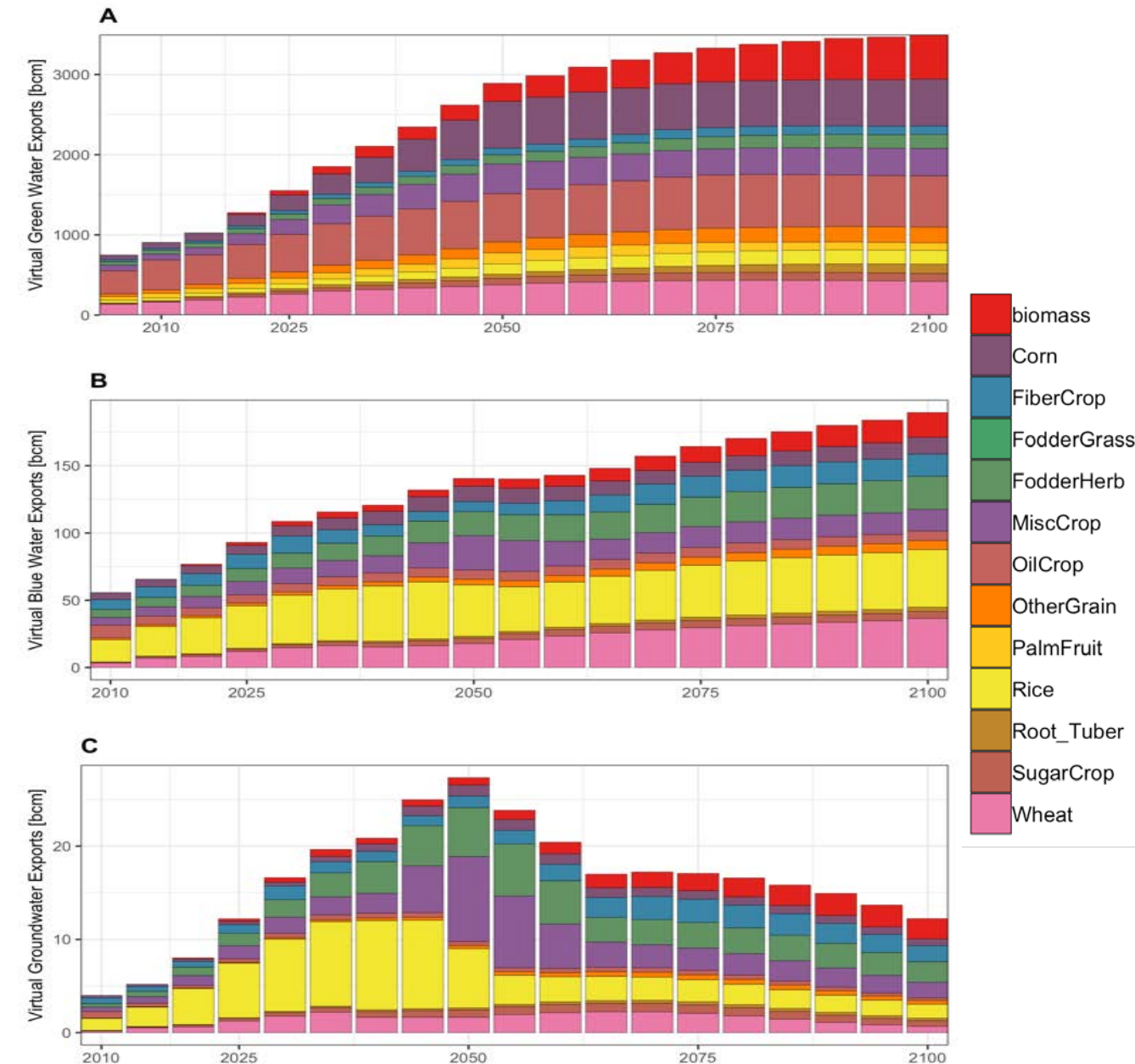


Total Virtual Water Trading in 2100

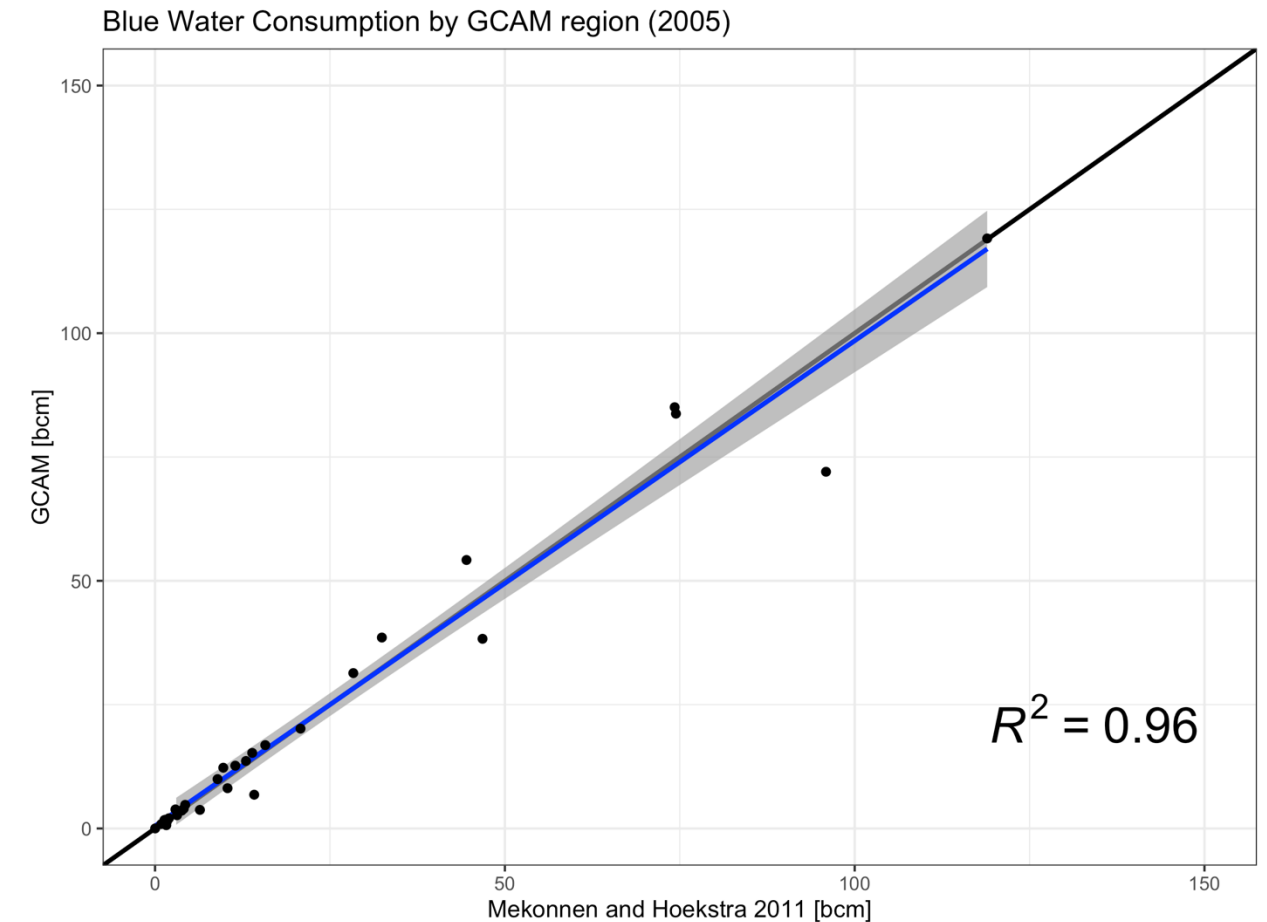
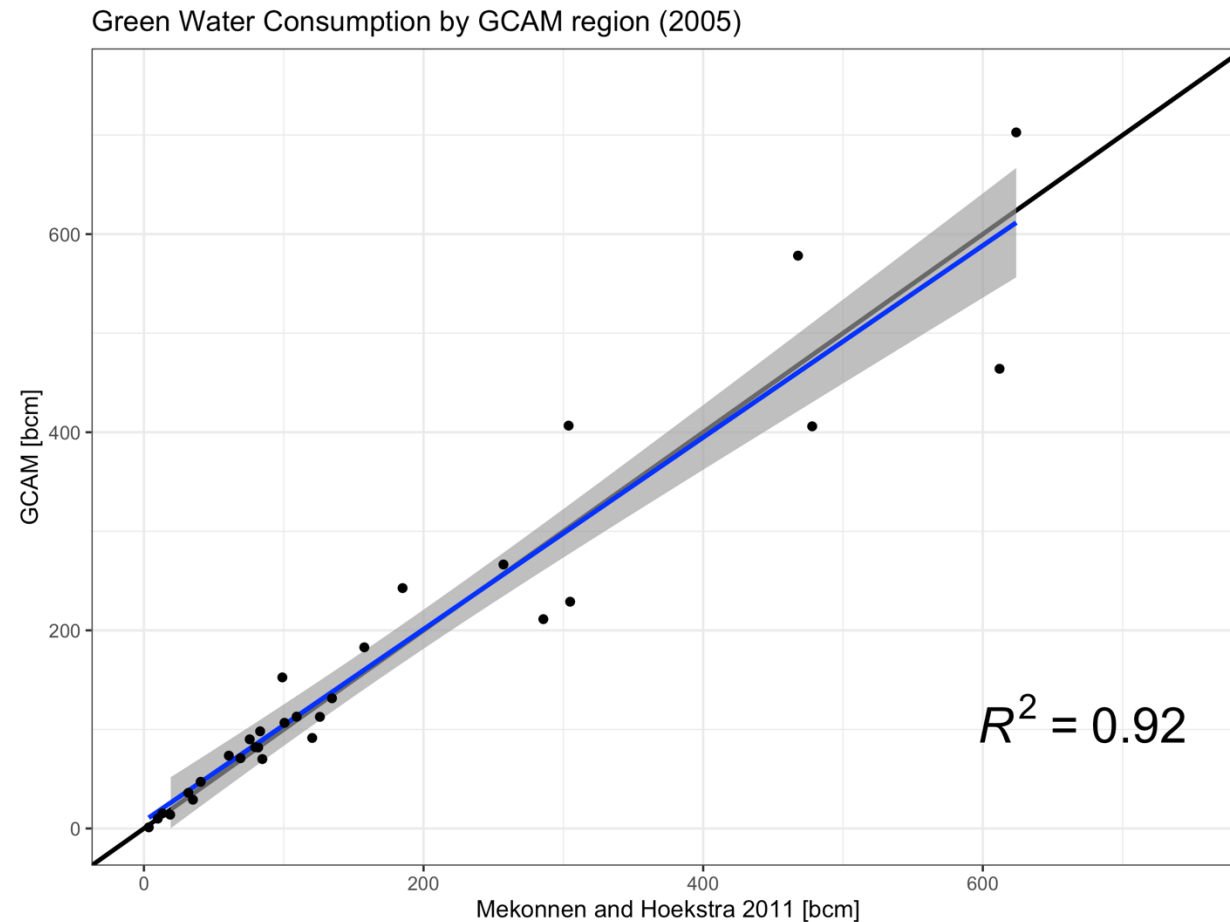


Disaggregation of Virtual Water Trading

- Oil Crops, Corn, and Wheat make up large portions of virtual green water trading.
- Rice and Wheat have the highest amount of blue virtual water contained in within traded goods
- Virtual nonrenewable groundwater is used to initially provide large amounts of rice before declining after 2040.



Comparison to previous studies



- Comparisons to Mekonnen and Hoekstra (2011) regional consumption values show high correlation. Thus any differences seen between studies arise from traded commodity classification.