Potential Climate Impact of Large-Scale Deployment of Renewable Energy Technologies

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1. A large-scale installation of windmills

- *Desired Energy Output:*

  supply 10% of the estimated world energy demand in 2100 (1400 EJ/yr; Reilly and Paltsev, 2007)

- *Installation Scale:*

  ~4.4 millions 1-MW devices (operating continuously! actual output varies with wind speed) that would occupy a very large area!

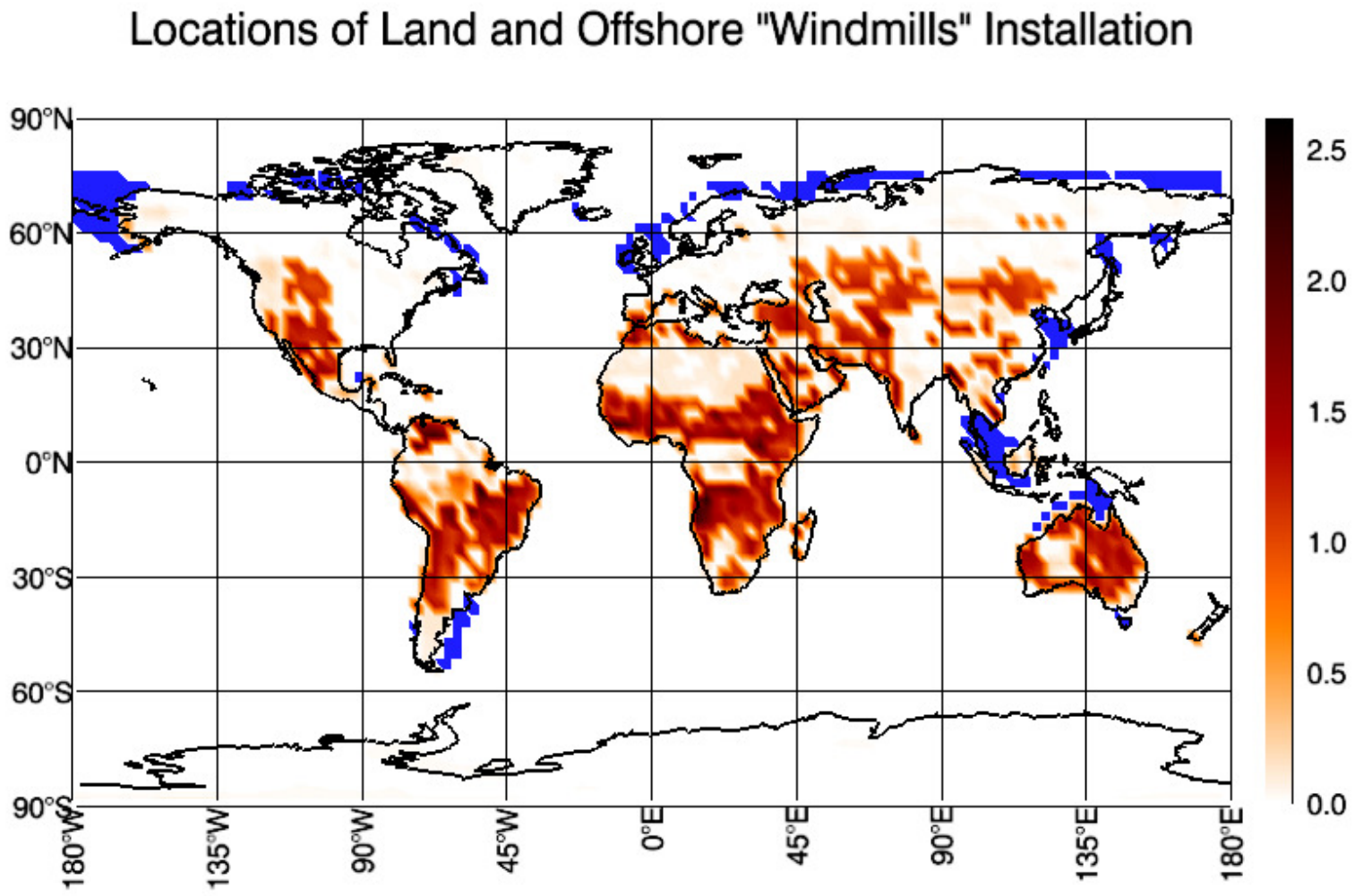
- *Interesting Science Issue:*

  What are the possible climatic impacts of such a large-scale installation of windmills?

Simulating the Climate Effects of Large-scale Installation of Windmills

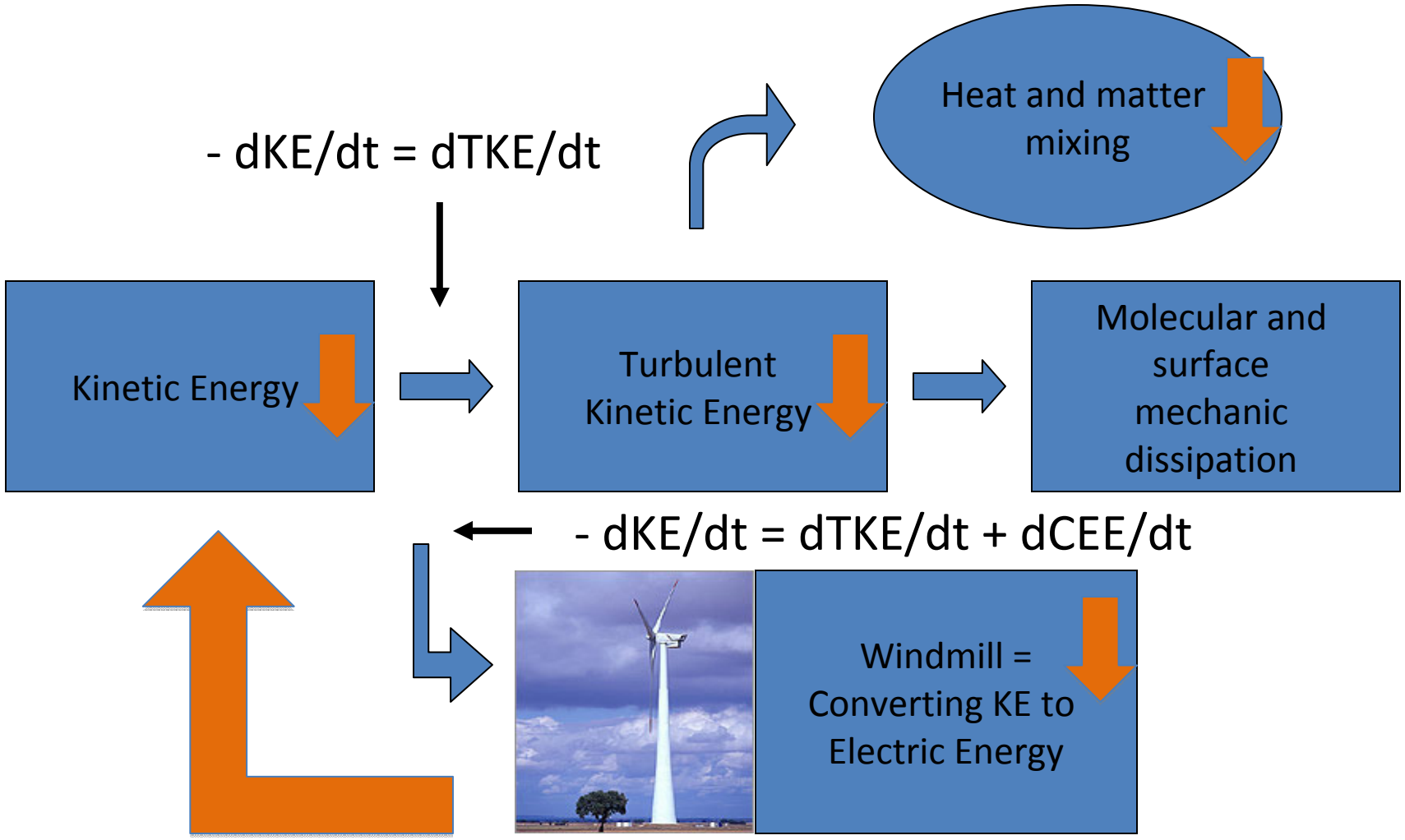
- NCAR CCM3 GCM+slab ocean, T42 (~2.8 degree, 18 layers) resolution
- Simulate windmills based on changes in surface roughness that convert kinetic energy to targeted power outputs
- Land Installation: all grass and shrub regions (~58 M km^2)
- Ocean Installation: ocean depth < 200 m (~10 M km^2)
- 60-year model runs with and without “windmills”
- Use the last 20-year mean of differences between the 2 runs to isolate the effects of windmills

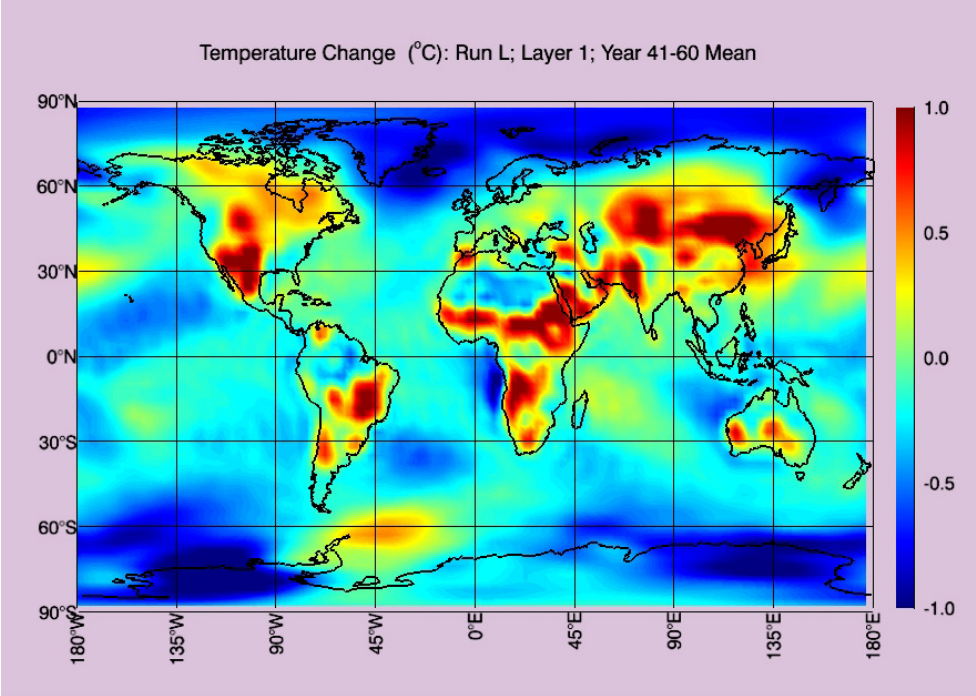
Red Color: *Change of surface momentum Drag (10^{-3});*
known ranges of real windfarms: 5 - 13
Blue Color: *Location of oceanic "installation sites"*

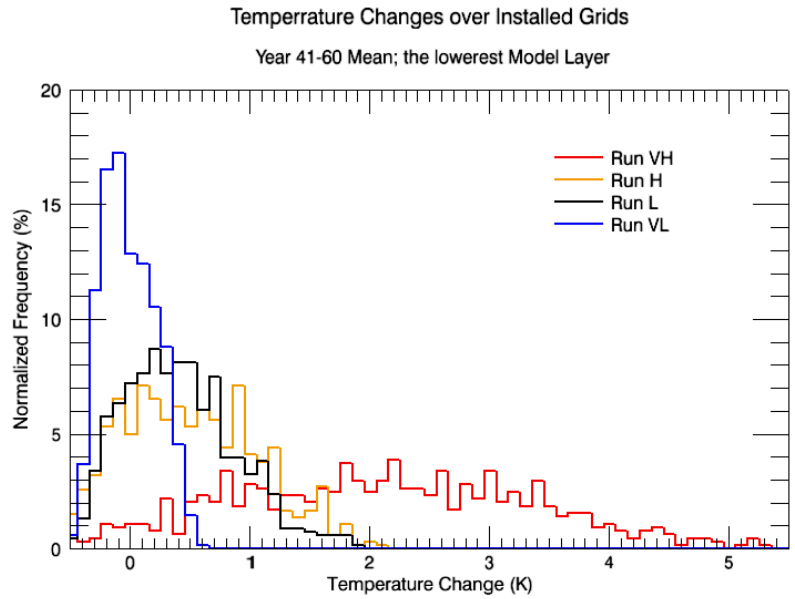


Wang and Prinn (2010)

What a windmill would do to the atmosphere: Energy cascade in the planetary boundary layer



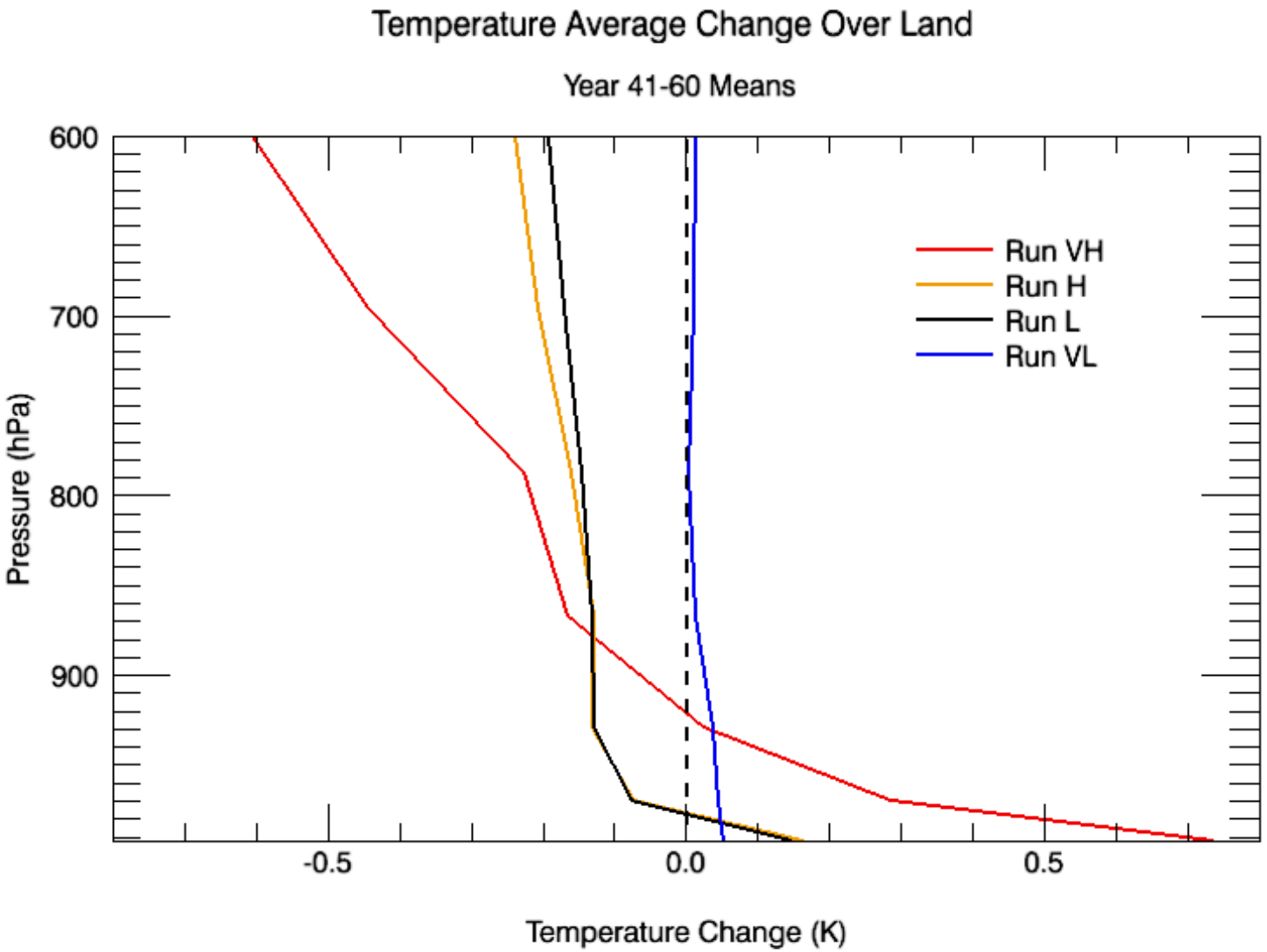




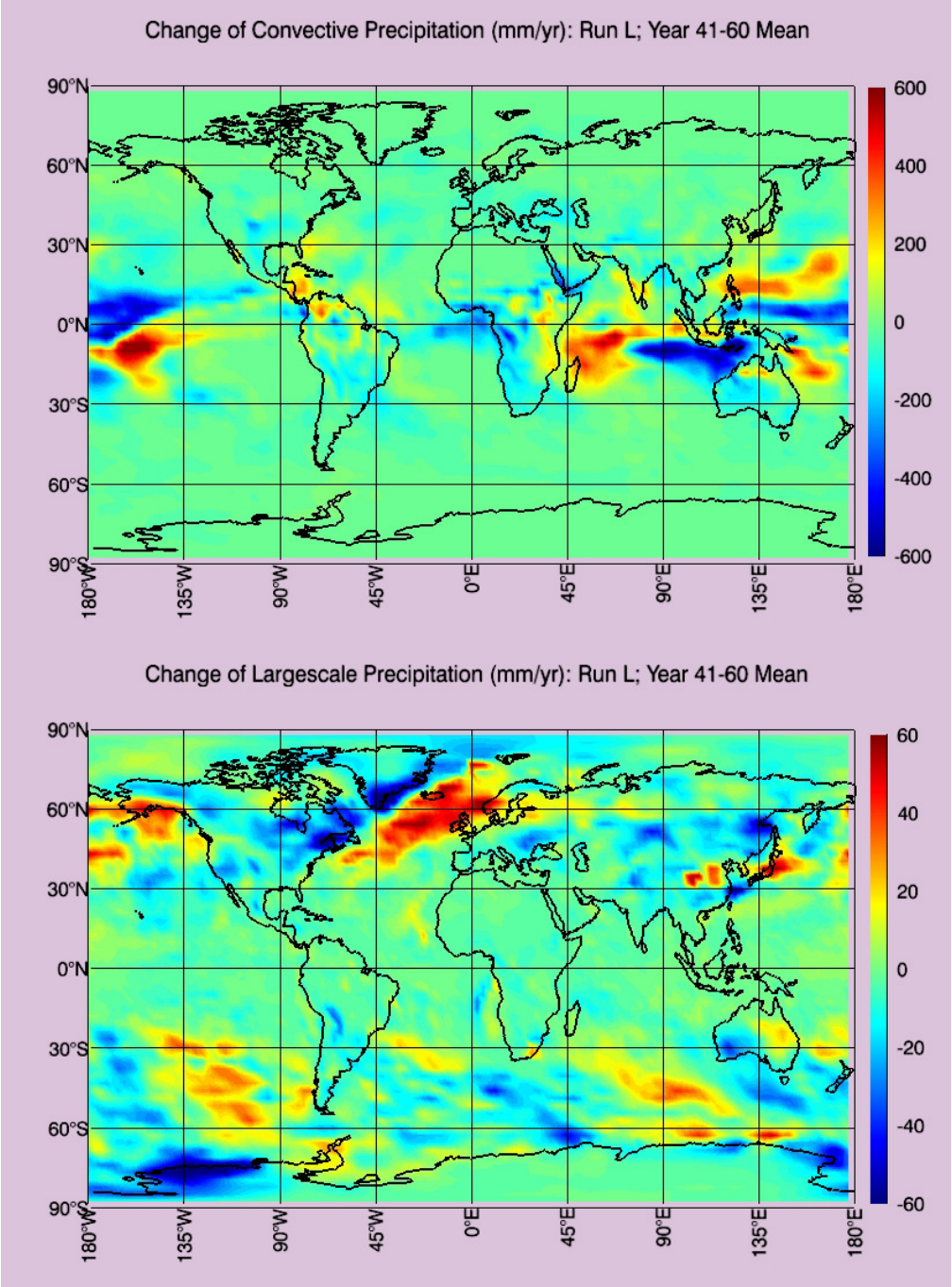
Temperature Change in the Lowest Model Layer

Wang and Prinn (2010)

Not the same story as GHG-caused warming

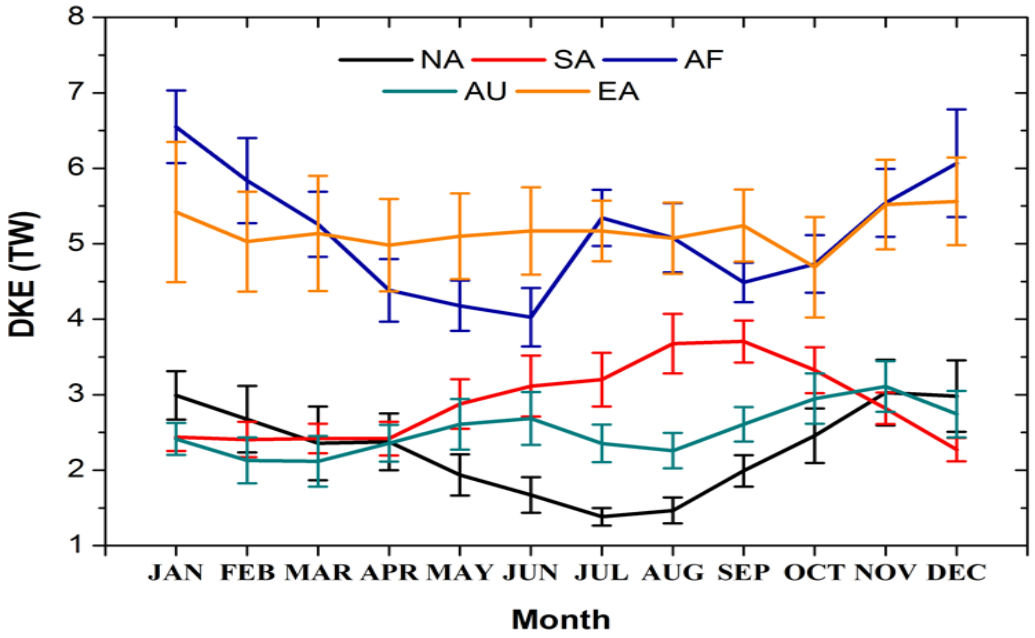


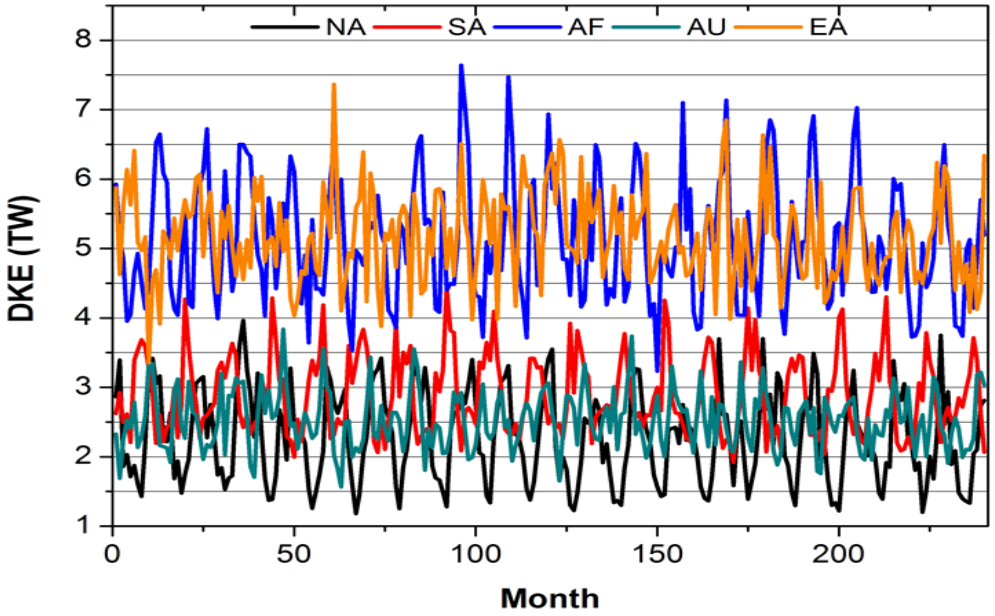
Wang and Prinn (2010)



Precipitation Changes

Wang and Prinn (2010)



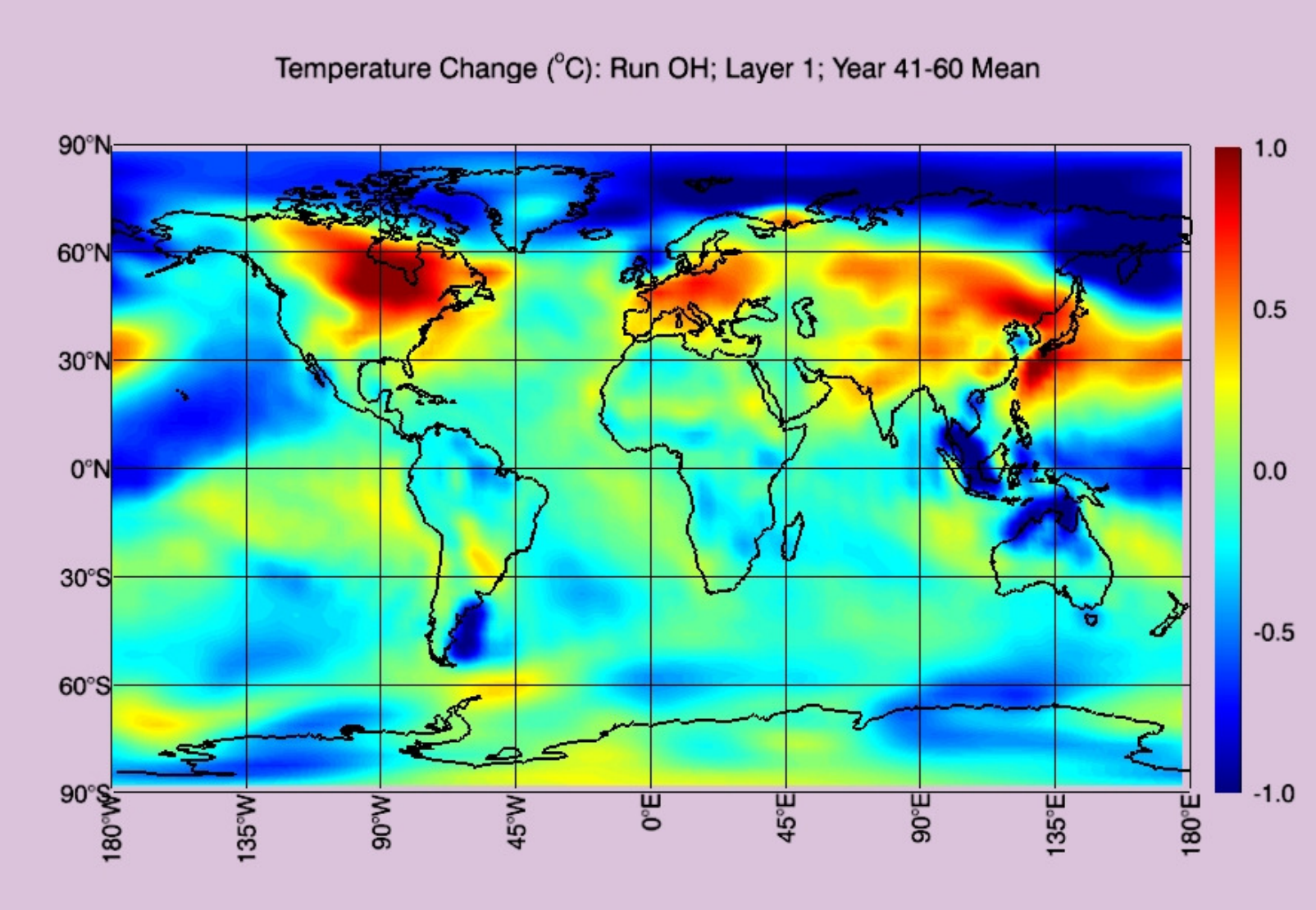


The Reliability Issue

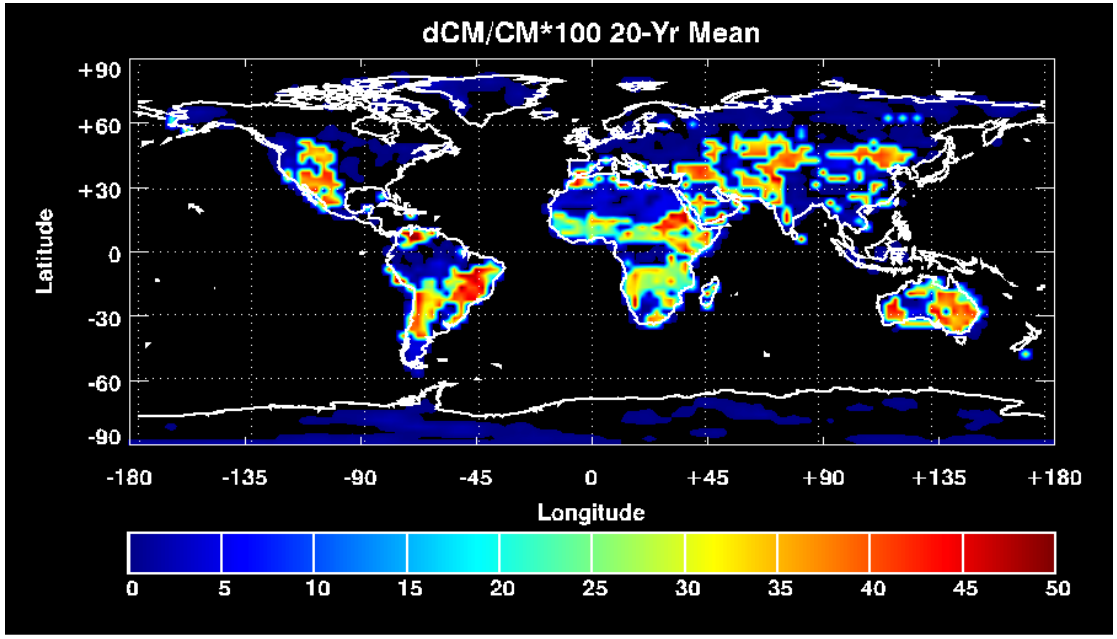
NA = North America
SA = South America
AF = Africa
AU = Australia
EA = East Asia

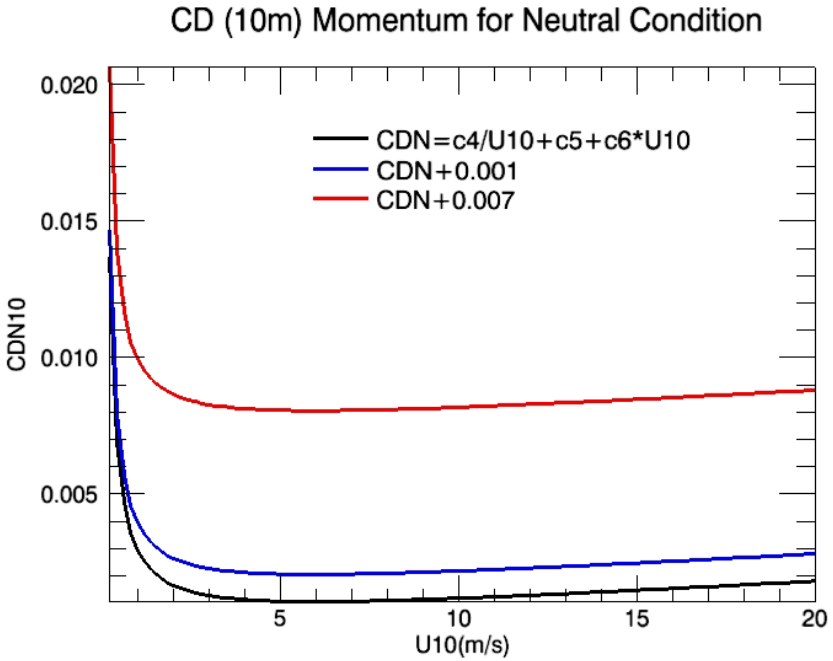
Wang and Prinn (2010)

Mysterious Ocean Deployment Story



Wang and Prinn (2010)





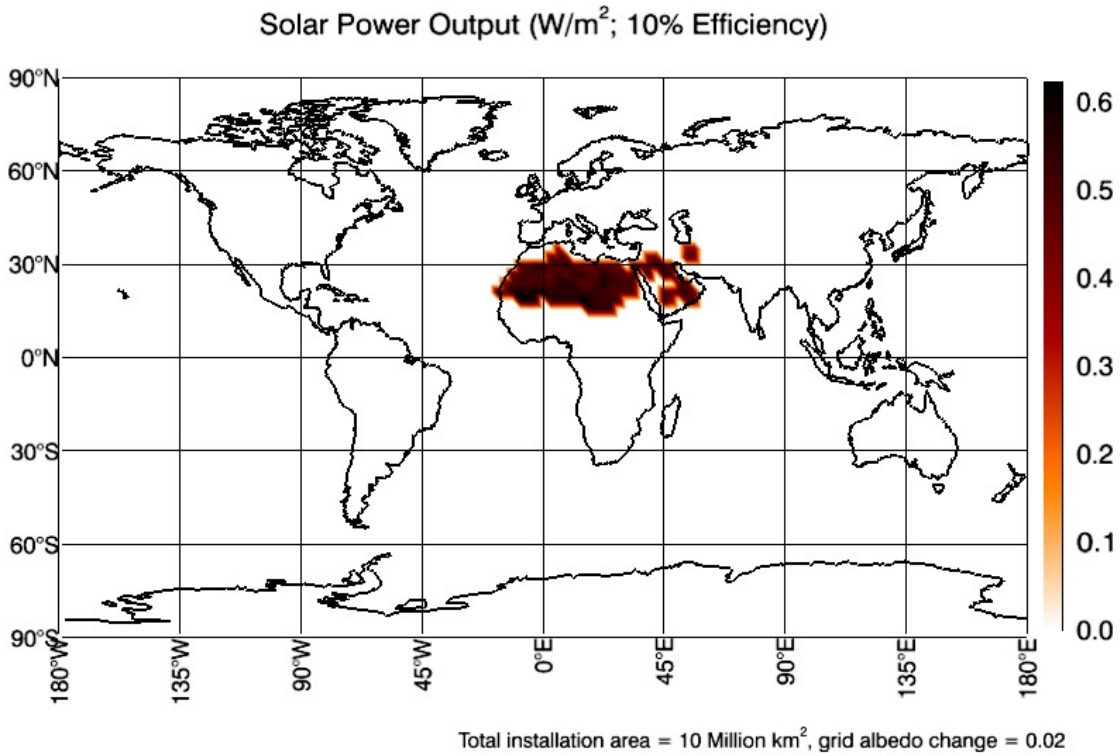
Ocean drag configured in the model might be too large?

Wang and Prinn (2010)

Major Climate Effects of Modeled Large-Scale Installation of Windmills

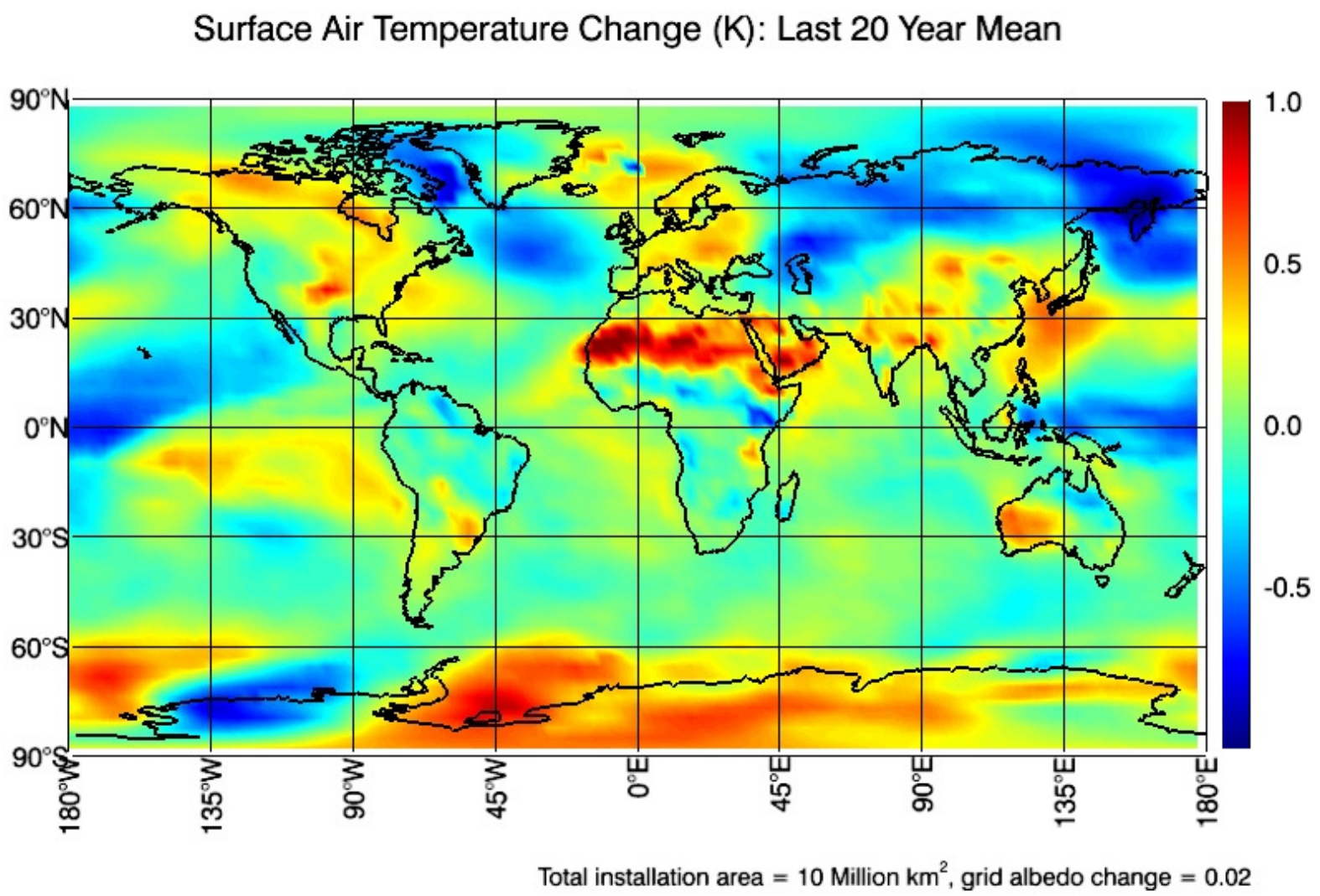
- Using land-based wind turbines to meet 10% or more of global energy demand in 2100 could cause surface warming exceeding 1^{o}C over land installations
- Surface cooling exceeding 1^{o}C is computed over ocean installations, but the validity of simulating the impacts of wind turbines by simply increasing the ocean surface drag needs further study
- Significant warming or cooling remote from both the land and ocean installations, and alterations of the global distributions of rainfall and clouds
- Intermittency of wind power on various time scales poses a demand for one or more options to ensure reliability
- High-resolution climate modeling, process modeling, and field observations are needed

2. Large-Scale Deployment of Solar Panel



- NCAR CCM3 +slab ocean, T42 (~2.8 degree, 18 layers) resolution
- Assume solar panels reduce grid albedo by 0.02, 10% conversion efficiency
- Solar panel arrays "installed" in Sahara and Mideast deserts (~10 M km^2)
- 60-year model runs with and without "solar panels"
- Use the last 20-year mean of differences between the 2 runs to isolate the effects of solar panels

Large-Scale Deployment of Solar Panel

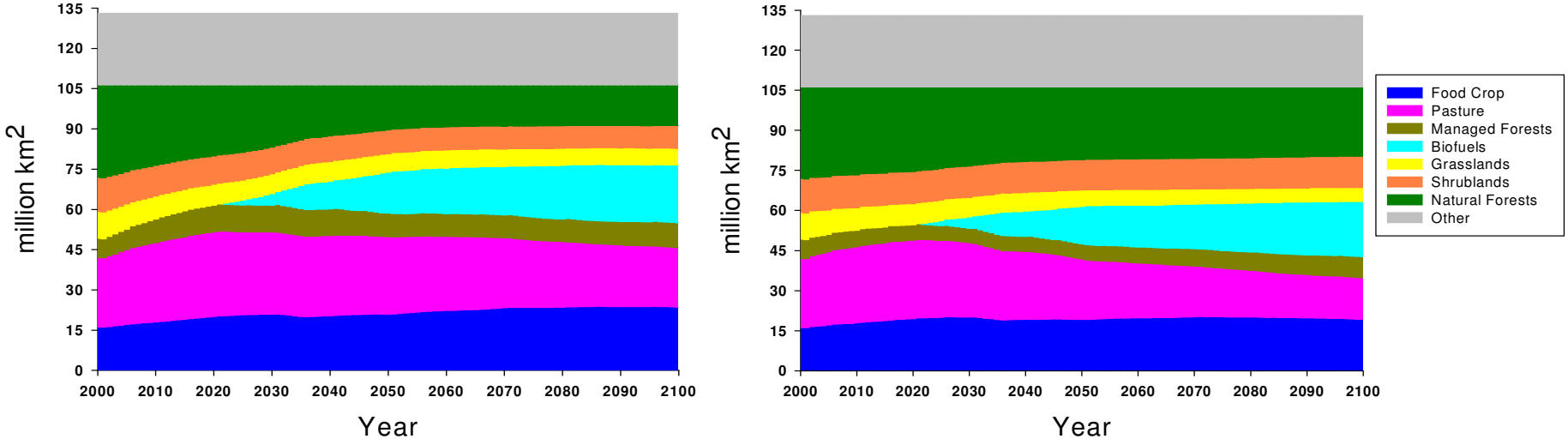


3. Two Stories about Indirect Effects of Biofuels: Ecosystem GHG implication

Land Use Evolutions

Deforestation Scenario:
convert nature areas to meet the demand as far as profitable

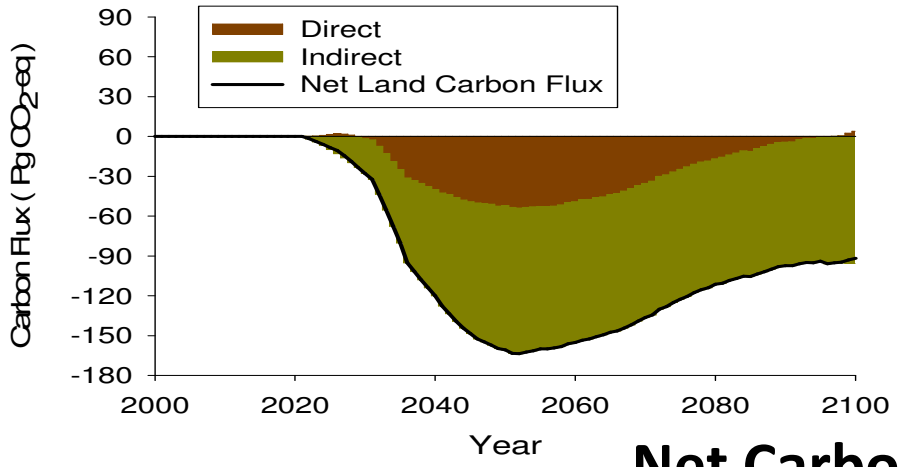
Intensification Scenario:
more intense use of existing managed land

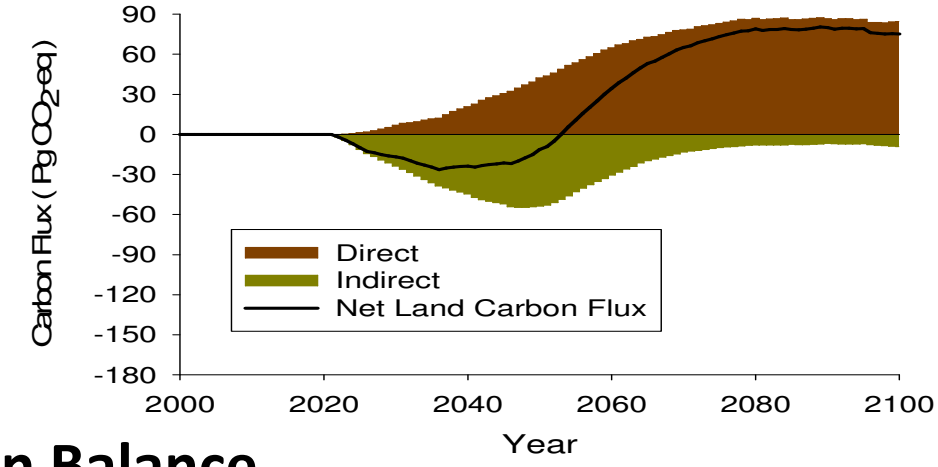


Melillo et al., (2009)

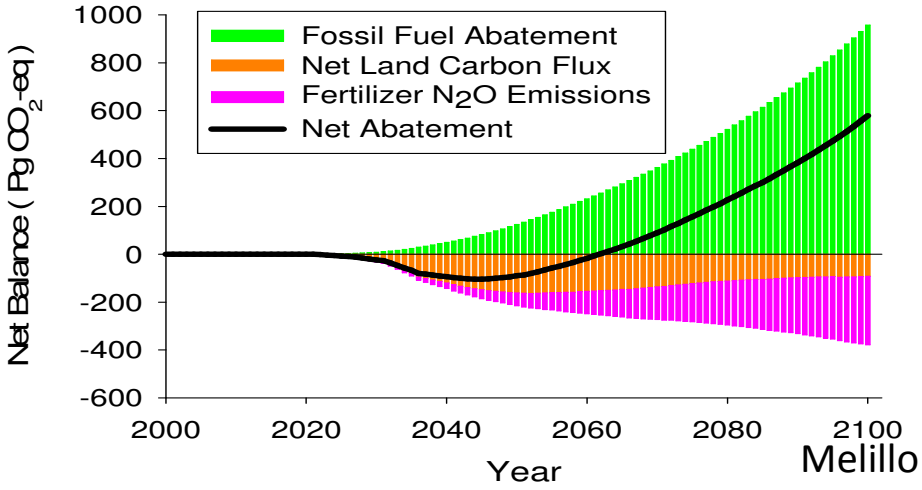
Two Stories about Indirect Effects of Biofuels: Ecosystem GHG implication

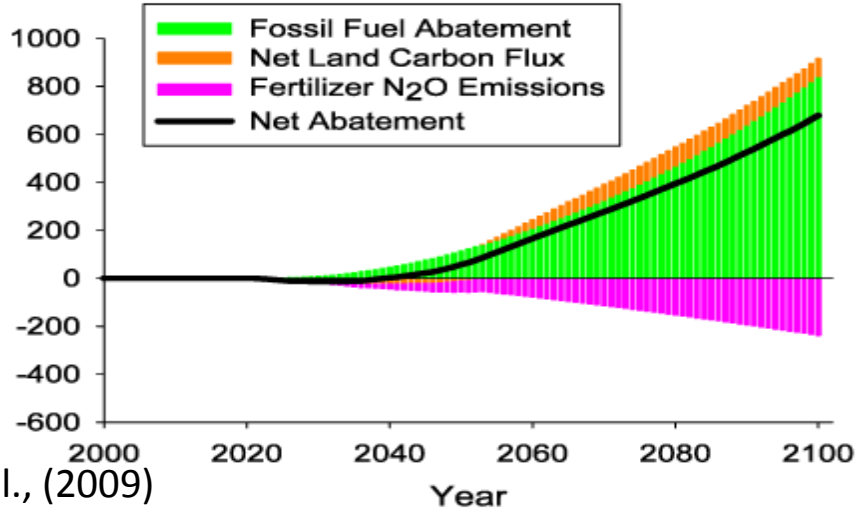
Net Land Carbon Flux (Negative = Emissions)





Net Carbon Balance





Melillo et al., (2009)

Ecosystem GHG implication of Biofuels
What have we learned and what type of research is need

- Vegetation and soil carbon effects on biofuels land use are mixed
- Indirect greenhouse gases implication associated with intensive biofuel scenario is very likely
- Extensive reliance on biomass for electricity would have ecosystem GHG implications
- In-depth research through modeling on the potential GHG implication of various scenarios associated with biofuel electricity production is needed

Needed Research

- High-resolution GCM for both wind and solar simulations
- More detailed energy (heat) partitioning, updated conversion rates
- Detailed process modeling (LES, mesoscale models) to support GCM parameterization
- In-depth economic analyses and modeling on the potential GHG implication of various scenarios associated with biofuel electricity production
- Large-scale deployment of renewable technologies in a changing climate