Energy Consumption and the Unexplained Winter Warming over Northern Asia and North America

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Motivation: The worldwide energy consumption in 2006 was close to 498 exajoules (498×10^{18} joules), corresponding to an energy consumption rate of 16 Terawatts (TW). Energy consumption takes place mainly in populated metropolitan areas, causing waste heat release to the surrounding atmosphere there. Such concentrated intense waste energy release is equivalent to a man-made energy transport into the atmosphere over populated metropolitan areas. Unlike the energy transport by atmospheric circulations which merely redistributes energy acquired from the Sun from one region to another, the man-made energy transport redistributes energy stored or sequestered by the Earth millions of years ago via pipelines and power lines to populated metropolitan areas. **Therefore, consumption of non-renewable energy represents a direct external energy source for the climate system.**

	Nature	Energy consumption
Energy	5000 TW over the area poleward of 45 degrees in each hemisphere	16 TW over the region where energy gets consumed.
Area used	$2\pi a^2(1-\sin\pi/4)$ $=74.7\times10^{12}m^2$	Assume that only 0.1% land surface occupied by people=> $0.15\times10^{12}m^2$
Average energy use per area	5000/74.7 W/m^2 = 66.9 W/m^2 in high latitudes.	16/0.15 W/m^2 = 106 W/m^2 in populated areas

Analysis Procedures

- Compilation of energy consumption data
  - Energy consumption rate per capita in 2006 for each country (http://www.eia.doe.gov/emeu/international/energyconsumption.html)
  - 2005 Gridded Population of the World (http://sedac.ciesin.columbia.edu/gpw).
- Input of heat from energy consumption into the NCAR CAM3 model
  - Total energy use in each region identified from the energy consumption data is divided by the total area of a GCM gridbox to obtain heat input in Wm^{-2}.
  - Consider the GCM grid points where energy consumption exceeds 0.4 W/m^2.
  - This energy is added to the lowest model layer (1000-985.112 mb) as sensible heat.
- GCM experiments
  - One control run for 100 years without additional heating.
  - Five perturbation runs, also for 100 years each, with different initial conditions spanning a year.
  - Prescribed climatological annual cycles of SST and aerosols.
  - Initial conditions are from restart files from previous model simulations.
  - First 5 years of data in each run are discarded.
- Model output analyses
  - Ensemble mean of the perturbation runs minus the control run gives the anomalies
  - Student t-test is applied to obtain statistically significant signals.
  - Sampling issues are addressed by comparing the ensemble average with a randomly Selected subset.
- Comparison with 20th Century CCSM4 simulations
  - Surface temperature trend over the second half of 20th century is obtained by taking the difference between 1981-2005 and 1956-1980.
  - Student t-test for significance of trend
  - Observed trend minus modeled trend measures model biases in trend simulation

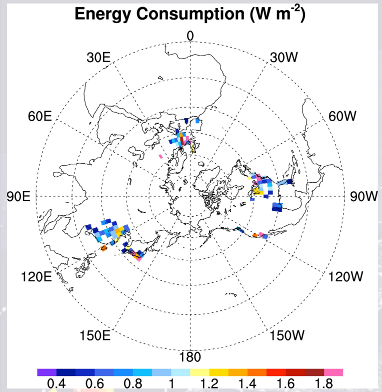


Figure 1. **Locations and area-averaged energy consumption of the 86 model grid points used in the perturbation runs.** Each value (in Wm^{-2}) is obtained by dividing the total estimated energy use by the area represented by the model grid point.

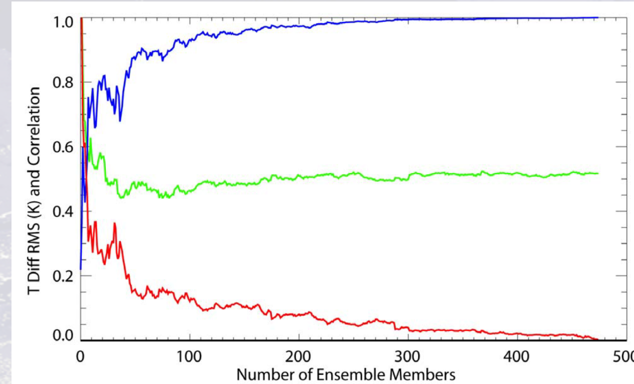


Figure S1: Sensitivity of the spatial pattern and its amplitude of the ensemble mean with respect to the ensemble member size. Blue curve is map correlation between the DJF mean of all 475 ensemble members and the DJF mean of the first m randomly selected ensemble members; Green curve is the spatial standard deviation of the DJF mean of first m randomly selected ensemble members; Red curve is the spatial standard deviation of the difference between the DJF mean of all 475 ensemble members and the DJF mean of the first m randomly selected ensemble members. The ordinate is m, the number of randomly selected independent ensemble members, and m runs from 1 to 475.

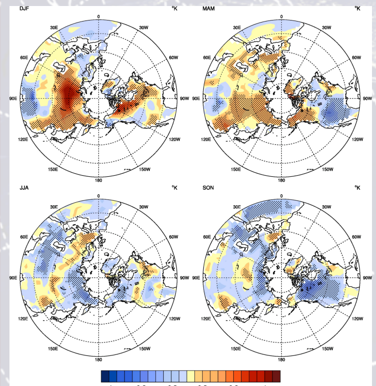


Figure 2. **Differences of seasonal mean surface air temperature differences between perturbation and control runs.** The areas exceeding 95% t-test confidence level are stippled.

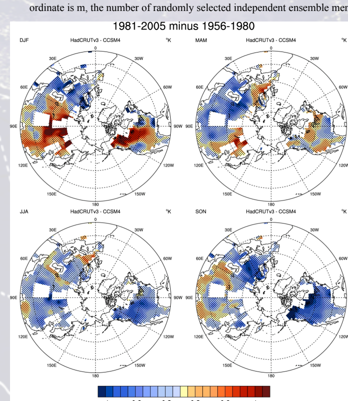


Figure 3. **Decadal land surface temperature trend differences between the HadCRUTv3 surface temperature observations and NCAR CCSM4 20th century ensemble simulations.** The trends in both observation dataset and NCAR climate simulation dataset are defined as the difference between the time mean of 1981-2005 and 1956-1980 as in (1). The blank areas over land are due to no observed data for part of the period from 1956 to 2005 and the ocean data are masked out. Stippling shows that the decadal trends are statistically significant at 95% confidence level in CCSM4 20th century simulations in comparison to the 1850 control run.

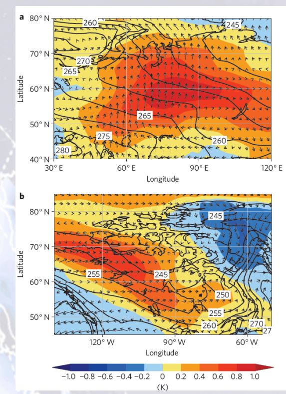
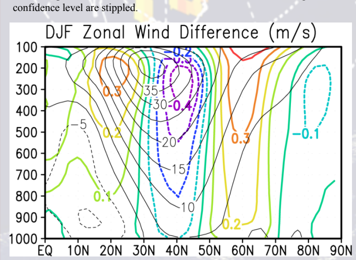


Figure 4: **Surface air temperature (contours, in units of Kelvin) for DJF from the perturbation run and differences of surface wind (vectors) and temperature (color shadings) between the perturbation and control runs.** It shows horizontal temperature advection in warm and cold anomaly regions for (a) central Asia and (b) Canada and northwestern Greenland.



Explanation: In response to the energy consumption forcing, upper atmosphere experiences a widening of the mid-latitude westerly jet stream and lower troposphere shows a strengthening of southwesterly flow in mid-latitudes. The enhanced warm air advection by the strengthened southwesterly flow in mid-latitudes causes the high latitude warming over the two continents in winter seasons.

Conclusions:

- The extra heat from energy consumption over the 86 major metropolitan areas alone can cause up to 1 degree of warming in winter seasons over northern latitudes of North America and Eurasian continents.
- The observed warming in the second half of the 20th Century cannot be explained by the warming caused by anthropogenic radiative and aerosol forcing alone.
- The warming pattern due to the energy consumption forcing can largely account for the unexplained winter warming over northern latitudes of Eurasia and North America continents.
- Inclusion of the energy consumption forcing, in addition to the anthropogenic greenhouse gases and aerosols, would improve the current global warming simulations.