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THE IMPACT OF REDUCED SEA-ICE EXTENT ON ARCTIC GREENHOUSE-GAS EXCHANGE

LPJ-GUESS WHyMe

LPJ-GUESS (Lund-Potsdam-Jena General Ecosystem Simulator)[1] is a process-based model of biogeochemistry and vegetation dynamics. It is designed for both regional and global applications. Biophysical and physiological processes are represented mechanistically, based on the same formulations as the Lund-Potsdam-Jena dynamic global vegetation model (LPJ-DGVM)[2,3], but plant resource competition is more detailed than LPJ-DGVM, being based on the interactions of plant individuals (each belonging to one of a set of prescribed plant functional types (PFTs)) at the neighbourhood scale. LPJ-GUESS has been evaluated in numerous studies[4].

LPJ-GUESS has now been developed to model upland and peatland ecosystems at high latitudes by incorporating recent developments to LPJ-DGVM (LPJ WHyMe v1.3.1)[5-7] that include soil freezing processes, peatland hydrology, peatland PFTs, and methane dynamics. This updated version of the LPJ-GUESS model has been used in this study and is referred to throughout as LPJ-Guess WHyMe. Also, we have introduced a numerical solution of the heat diffusion equation to LPJ-GUESS[5,6].

The model's soil column consists of four compartments: a snow layer of variable thickness, a litter layer of fixed thickness (5 cm), a soil column of depth 2 m (with sublayers of thickness 0.1 m), and finally a "padding" column of depth 48 m (with thicker sublayers) which is present to aid in the accurate simulation of temperatures in the overlying compartments. Soil temperatures in each sublayer are updated daily, in response to changing surface air temperature forcing and precipitation input, and taking into account both the insulating effects of snow and phase changes in the soil water. For peatland fractions of each gridcell, we use a hydrology scheme[5,8] in which the water table depth is updated daily in response to precipitation, snowmelt, evapotranspiration and surface runoff. Furthermore, the 2 m peatland soil column is subdivided into an upper 0.3 m acrotelm (within which the water table is allowed to fluctuate) above a 1.7 m permanently saturated catotelm layer. The water table is also allowed to extend above the soil surface to a maximum depth of 0.1 m.

Gridcell-averaged carbon methane fluxes are calculated by taking into account the peatland fraction of each gridcell. Using a similar procedure to TEM6 below, we derived carbon pools and vegetation in equilibrium with the conditions in the year 1901 by using a 500-year spin-up procedure for each 0.5º cell in the Arctic tundra region. Forcing for this spin-up period was taken from the CRU TS 3.0 dataset[9], and consisted of (de-trended) monthly temperature, precipitation and cloudiness for the period 1901-30, repeated throughout the 500 year period. CO_2 concentration data for the spin-up period were held constant at the year 1901 level (296 ppm, approx.). Thereafter transient CRU forcing for the period 1901-2006 was applied to force the model, along with observed CO_2 concentrations.

Terrestrial Ecosystem Model version 6 (TEM6)

TEM6 was modified from a model that simulated ozone pollution effects[10] to also include the influence of permafrost dynamics[11,12], atmospheric nitrogen deposition, biological nitrogen fixation, DOC leaching, wildfire[13], agricultural conversion and abandonment, and timber harvest on terrestrial C dynamics. C pools and associated fluxes are simulated at a monthly time-step for individual 'cohorts' of unique vegetation types and disturbance history organized within spatially explicit 0.5° latitude x 0.5° longitude grid cells. We used a methane dynamics module[14,15] to estimate biogenic emissions of methane from Arctic tundra. To initialize the C, N and water pools for the beginning of the analysis period (1997-2006), we simulated dynamics since the year 1000 for each cohort among the half-degree grid cells covering the Arctic tundra region.

The TEM simulations in this study were driven by temporally- and spatially-explicit data sets on atmospheric carbon dioxide concentration ([CO_2]), tropospheric ozone (O_3), N deposition, climate variability and change, and fire, forest harvest, and agricultural establishment and abandonment. Global annual atmospheric [CO_2] data are from the Mauna Loa station[16]. [CO_2] data for the time period of years 1000 to 1900 are held constant at the year 1901 level (296.3 ppm). Monthly air temperature (^{o}C), precipitation (mm), and incident short-wave solar radiation (Wm^{-2}) data derived from observations for the period 1901–2002, gridded at 0.5^{o} resolution, were obtained from the Climate Research Unit (CRU; University of East Anglia, UK)[9]. The CRU climate variables were extended to 2006 with NCEP/NCAR Reanalysis 1 data sets (NOAA-ESRL Physical Sciences Division, Boulder CO) using a regression procedure based on data anomalies from a ten-year (1993 – 2002) mean for each variable[17]. These data sets were hind-casted to year 1000 by a repeating 30-year cycle of the 1901 – 1930 monthly data to initialize the carbon pools with climate. The ozone (O_3) pollution data set used in this study, represented by the AOT40 index (a measure of the accumulated hourly ozone levels above a threshold of 40 ppbv)[18] and covers the time period from 1860 to 2006. Before 1860, the ozone level in each 0.5^{o} grid cell was assumed to equal the AOT40 of 1860 (which is equal to zero). The atmospheric N deposition data[19] were extended from 2000 to 2006 by adding the difference in annual N deposition rate from 1999 to 2000 to succeeding years, for each 0.5^{o} grid cell (e.g. 2001 N deposition rate = 2000 + (2000-1999), etc.). For years 1000 to 1859, annual N deposition was assumed to equal the per grid cell rates in 1860. More information on TEM6 can be found in previous publications by McGuire et al. and Hayes et al.[20,21].

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