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Supplement of

A new lightning scheme in the Canadian Atmospheric Model (CanAM5.1): implementation, evaluation, and projections of lightning and fire in future climates

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Theoretical formulation

The basic definition of CAPE is as follows:

$$CAPE = \int_{zb}^{zt} \frac{g(T_v^{(p)} - \bar{T_v})}{\bar{T_v}} dz \quad (1)$$

The integrand in this formula is the buoyancy ($B^{(p)}$)of a parcel of air which undergoes undiluted adiabatic ascent between the base level (z_b) and uppermost level (z_t) may be reached by moist convection. This level is typically the level of neutral buoyancy (LNB) for conditionally unstable atmospheric column.

The virtual temperature (T_v) is defined using a standard approximation as $T_v \simeq T[1 + (\frac{1}{\epsilon} - 1)r_v - r_c] \simeq T(1 + .61r_v - r_c)$, where $\epsilon \simeq .622$ is the ratio of the gas constants for dry air (R_d) and water vapour (R_v). (ref: {AMS Glossary of Meteorology; http://glossary.ametsoc.org/wiki/Virtual_temperature}). The remaining quantities in the above formulae are defined as follows:

$r_v, r_c = r_l + r_i$: respectively mixing ratios of water vapour and condensed [liquid (r_l) plus solid (r_i)] water.

$g(= 9.8m/s^2)$: acceleration due to gravity.

z_b, z_c : respectively the base and top levels of the convective layer.

$T_v^{(p)}$: the virtual temperature associated with a parcel of air lifted adiabatically from the base level (z_b) taking into accout the effects of condensation and latent heat release. The ascent is assumed to be reversible (i.e. all of the condensate generated in the ascent is carried upward with the parcel).

$\bar{T_v}$: the virtual temperature of the background (mean state) air (evuated from input values of the background temperature and water vapour mixing ratio).

Figure S1: CanAM's CAPE calculation from code documentation.

Text S1: Cumulus convection scheme in CanAM5.1

CanAM5.1 has separate parameterizations for deep and shallow convection. They are described in von Salzen et al (2013). Both parameterizations of convection use the same input profiles of temperature, moisture, and chemical tracer mixing ratios, which were output from the prognostic cloud scheme rendering them statically stable and at most fully saturated. Both schemes are permitted to be active in the same grid cells at any time within specific physical constraints for each scheme (von Salzen et al., 2005; Xie et al., 2002). The cumulus parameterization of Zhang and McFarlane (1995) is used to represent the effects of deep convection (hereafter denoted by ZM) in the model. The ZM-parameterization is a bulk mass flux scheme which includes a representation of convective scale motions. Effects of shallow convection are parameterized following von Salzen and McFarlane (2002) and von Salzen et al. (2005). In the parameterization, parcels of air are lifted from the planetary boundary layer (PBL) into the layer above the PBL. Shallow cumulus clouds are formed once the parcels reach the level of free convection (LFC), at which the parcels become positively buoyant. Above the LFC the parcels are modified by entrainment of environmental air into the ascending top of the cloud and also by organized entrainment at the lateral boundaries of the cloud. The cloud-top mixing produces horizontal inhomogeneities in cloud properties and vertical fluxes which are parameterized using joint probability density distributions of total water and moist static energy. The initial growth phase of the cumulus cloud is assumed to be terminated when its top reaches its maximum level. The growth phase is followed by instantaneous decay, with complete detrainment of cloudy air into the environment.

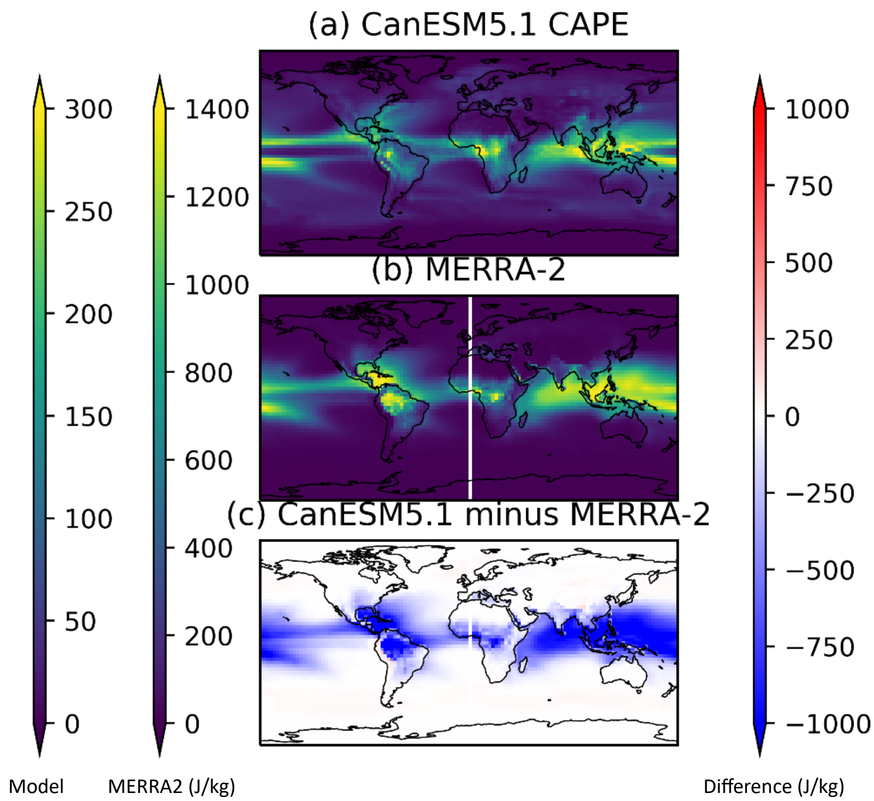

Figure S2: 2017-2019 annual mean of CAPE from (a) CanESM5.1 (left-most color bar), (b) derived by MERRA-2 reanalysis (middle color bar), and (c) their differences (right color bar) – all in J/kg. Note the different scales for the top two panels to highlight the range in values.

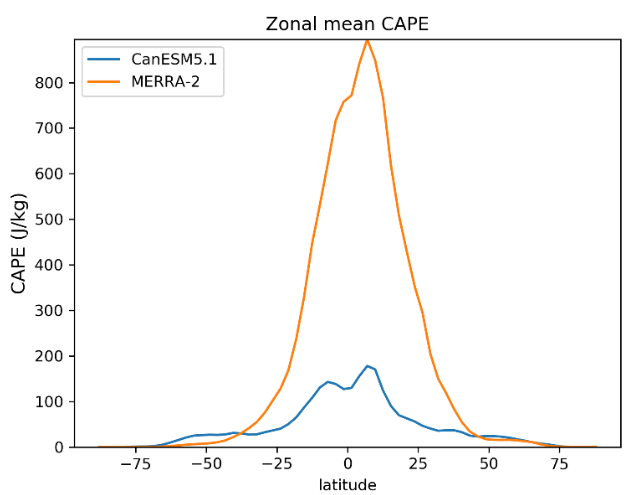

Figure S3: 2017-2019 annually averaged zonal mean CAPE from MERRA-2 (orange) and CanESM5.1 (blue).

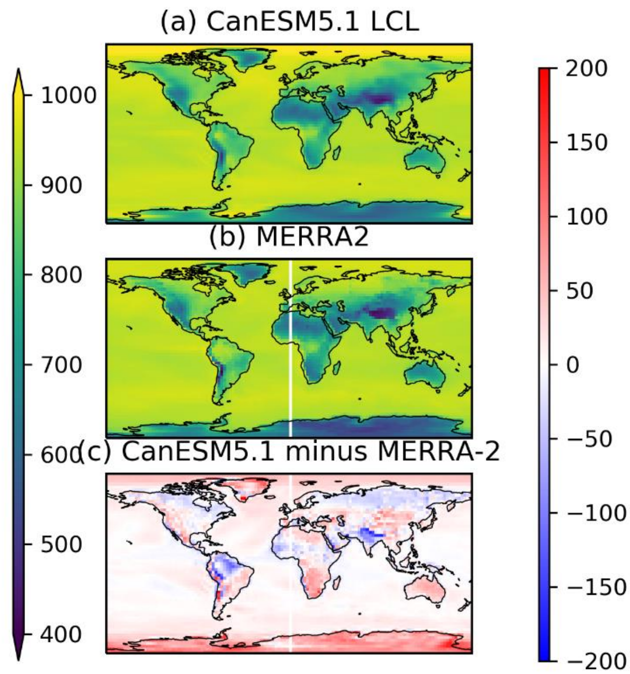

Figure S4: 2017-2019 annual mean of LCL from (a) CanESM5.1 and (b) derived by MERRA-2 reanalysis, and (c) their differences (all in hPa).

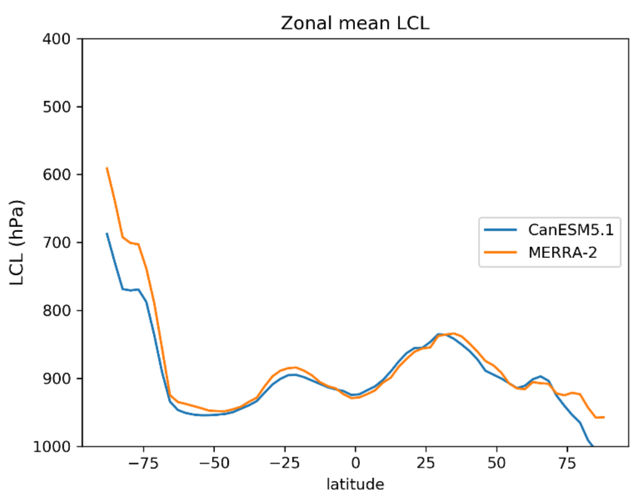

Figure S5: 2017-2019 annually averaged zonal mean LCL from MERRA-2 (orange) and CanESM5.1 (blue).

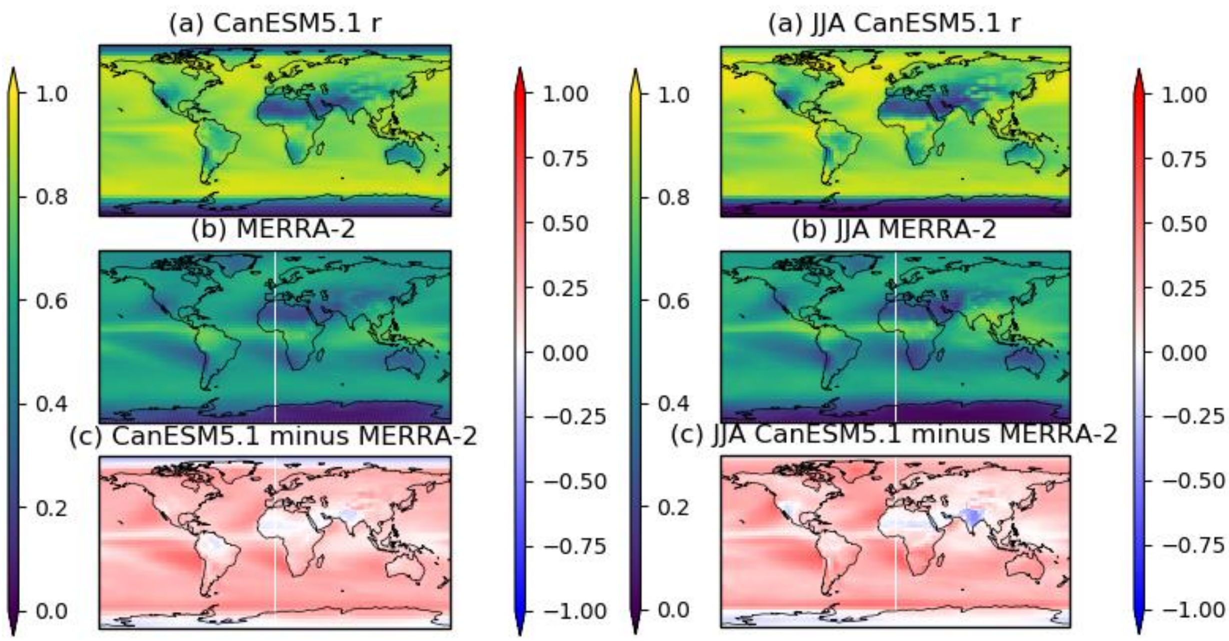

Figure S6: 2017-2019 (left) annual mean and (right) summertime (JJA) mean r from (a) CanESM5.1 and (b) derived by MERRA-2 reanalysis, and (c) their differences (unitless fractions).

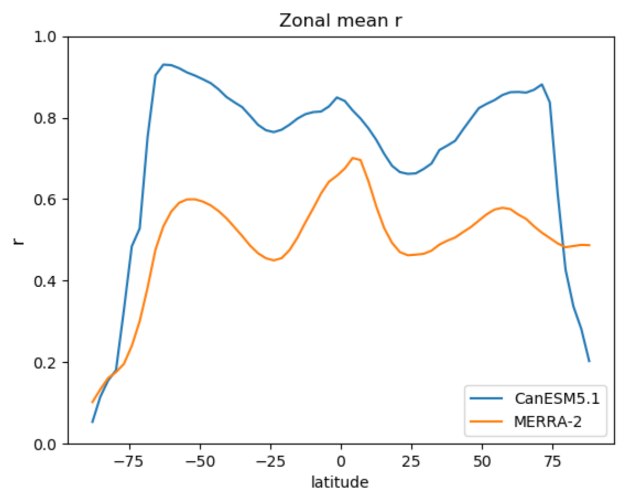

Figure S7: 2017-2019 annually averaged zonal mean r from MERRA-2 (orange) and CanESM5.1 (blue).

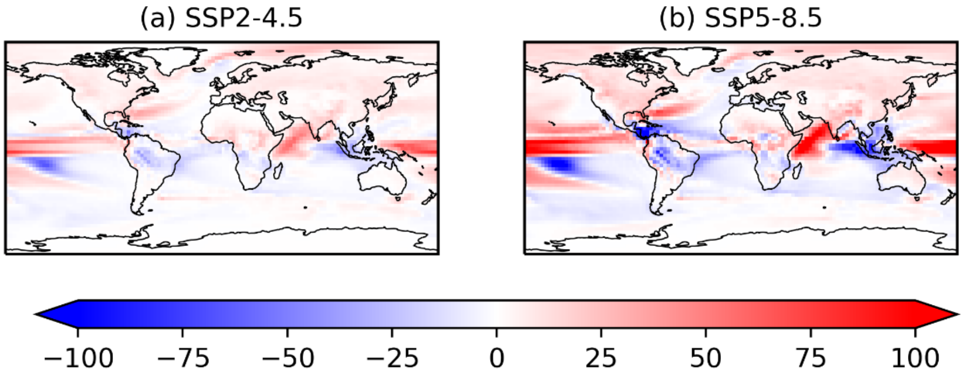

Figure S8: Future (2081-2100) minus present (2015-2035) average CAPE (J/kg) from CanESM5.1.

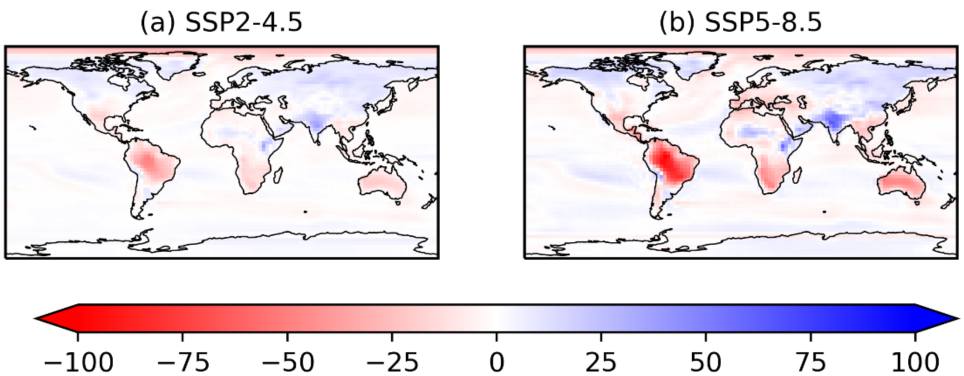

Figure S9: Future (2081-2100) minus present (2015-2035) average LCL (hPa) from CanESM5.1 (Note: colour bar reverse since a higher pressure indicates a lower altitude in the atmosphere).

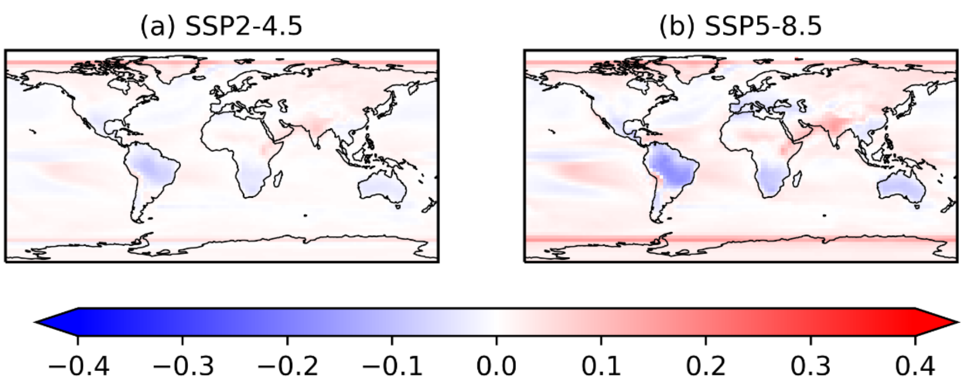

Figure S10: Future (2081-2100) minus present (2015-2035) average r (fraction) from CanESM5.1.

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