Documentation for the ClimEx CRCM5 Large Ensemble (v2.1)

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Contents

1 Important notes

1.1 Terms of use

- References, credits, and technical information to include for the ClimEx CRCM5 Large Ensemble (CRCM5-LE) are provided in the 'Terms of use' document.

1.2 Experimental framework and overview of the results

A general description of the ClimEx CRCM5 Large ensemble is provided in the following paper:

- Leduc, M., A. Mailhot, A. Frigon, J. Martel, R. Ludwig, G.B. Brietzke, M. Giguère, F. Brissette, R. Turcotte, M. Braun, and J. Scinocca, 2019: The ClimEx Project: A 50-Member Ensemble of Climate Change Projections at 12-km Resolution over Europe and Northeastern North America with the Canadian Regional Climate Model (CRCM5). J. Appl. Meteor. Climatol., 58, 663–693, `https://doi.org/10.1175/JAMC-D-18-0021.1`

1.3 Data use: removing the spin-up time

As described in Leduc et al. (2019), a spin-up period in the beginning of each simulation should be discarded from analysis, as the CRCM5 and CanESM2 models need some time to forget their initial conditions. More specifically, the analysis period should be:

- **1955-2099** for all simulations driven by CanESM2 (kb*, kc*, kd* and ke*). The first five years (1950-1954) should not be considered for analysis in order to obtain 50 independent members from the driving model CanESM2.

- **1980-2013** for all simulations driven by the ERA-Interim reanlysis. The first year (1979) should not be considered in order to account for the CRCM5 spin-up.

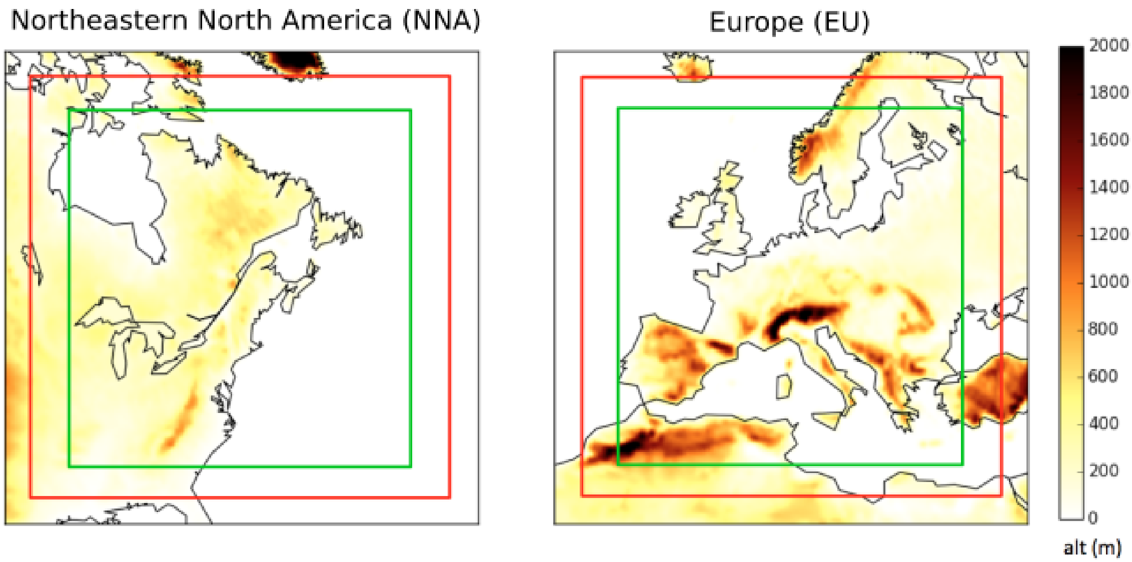

Figure 1: Integration domains (380x380 grid points) used by CRCM5 to produce the ClimEx large ensemble. Are also shown the "free domain" (340x340 grid points, in red) where the model is technically free from direct imposition of lateral boundary conditions. Finally, the "analysis domain" (280x280, in green) is the region where are archived all the output fields.

2 Simulations and terminology

Table 1: List of CRCM5 simulations produced within the ClimEx project.

N	Name	Domain	Pilot	Run period	Analysis period	Spectral nudging
1	kfa	EU	ERA-I	1979-2013	1980-2013	no
1	kfc	EU	ERA-I	1979-2013	1980-2013	yes
1	kfb	NNA	ERA-I	1979-2013	1980-2013	no
1	kfd	NNA	ERA-I	1979-2013	1980-2013	yes
50	kba-kcx	EU	CanESM2	1950-2099	1955-2099	yes
50	kda-kex	NNA	CanESM2	1950-2099	1955-2099	yes

Table 2: Table of correspondence between the CanESM2 and CRCM5 ensemble runs terminologies.

	GCM Family	**GCM Member**	**RCM Member**	**Domain**
1	historical-r1	r1i1p1	kba	EU
2	historical-r1	r2i1p1	kbb	EU
3	historical-r1	r3i1p1	kbc	EU
4	historical-r1	r4i1p1	kbd	EU
5	historical-r1	r5i1p1	kbe	EU
6	historical-r1	r6i1p1	kbf	EU
7	historical-r1	r7i1p1	kbg	EU
8	historical-r1	r8i1p1	kbh	EU
9	historical-r1	r9i1p1	kbi	EU
10	historical-r1	r10i1p1	kbj	EU
11	historical-r2	r1i1p1	kbk	EU
12	historical-r2	r2i1p1	kbl	EU
13	historical-r2	r3i1p1	kbm	EU
14	historical-r2	r4i1p1	kbn	EU
15	historical-r2	r5i1p1	kbo	EU
16	historical-r2	r6i1p1	kbp	EU
17	historical-r2	r7i1p1	kbq	EU
18	historical-r2	r8i1p1	kbr	EU
19	historical-r2	r9i1p1	kbs	EU
20	historical-r2	r10i1p1	kbt	EU
21	historical-r3	r1i1p1	kbu	EU
22	historical-r3	r2i1p1	kbv	EU
23	historical-r3	r3i1p1	kbw	EU
24	historical-r3	r4i1p1	kbx	EU
25	historical-r3	r5i1p1	kby	EU
26	historical-r3	r6i1p1	kbz	EU
27	historical-r3	r7i1p1	kca	EU
28	historical-r3	r8i1p1	kcb	EU
29	historical-r3	r9i1p1	kcc	EU

Table 2: (continued)

	GCM Family	GCM Member	RCM Member	Domain
30	historical-r3	r10i1p1	kcd	EU
31	historical-r4	r1i1p1	kce	EU
32	historical-r4	r2i1p1	kcf	EU
33	historical-r4	r3i1p1	kcg	EU
34	historical-r4	r4i1p1	kch	EU
35	historical-r4	r5i1p1	kci	EU
36	historical-r4	r6i1p1	kcj	EU
37	historical-r4	r7i1p1	kck	EU
38	historical-r4	r8i1p1	kcl	EU
39	historical-r4	r9i1p1	kcm	EU
40	historical-r4	r10i1p1	kcn	EU
41	historical-r5	r1i1p1	kco	EU
42	historical-r5	r2i1p1	kcp	EU
43	historical-r5	r3i1p1	kcq	EU
44	historical-r5	r4i1p1	kcr	EU
45	historical-r5	r5i1p1	kcs	EU
46	historical-r5	r6i1p1	kct	EU
47	historical-r5	r7i1p1	kcu	EU
48	historical-r5	r8i1p1	kcv	EU
49	historical-r5	r9i1p1	kcw	EU
50	historical-r5	r10i1p1	kcx	EU
1	historical-r1	r1i1p1	kda	NNA
2	historical-r1	r2i1p1	kdb	NNA
3	historical-r1	r3i1p1	kdc	NNA
4	historical-r1	r4i1p1	kdd	NNA
5	historical-r1	r5i1p1	kde	NNA
6	historical-r1	r6i1p1	kdf	NNA
7	historical-r1	r7i1p1	kdg	NNA
8	historical-r1	r8i1p1	kdh	NNA
9	historical-r1	r9i1p1	kdi	NNA
10	historical-r1	r10i1p1	kdj	NNA
11	historical-r2	r1i1p1	kdk	NNA
12	historical-r2	r2i1p1	kdl	NNA
13	historical-r2	r3i1p1	kdm	NNA
14	historical-r2	r4i1p1	kdn	NNA
15	historical-r2	r5i1p1	kdo	NNA

Table 2: (continued)

	GCM Family	GCM Member	RCM Member	Domain
16	historical-r2	r6i1p1	kdp	NNA
17	historical-r2	r7i1p1	kdq	NNA
18	historical-r2	r8i1p1	kdr	NNA
19	historical-r2	r9i1p1	kds	NNA
20	historical-r2	r10i1p1	kdt	NNA
21	historical-r3	r1i1p1	kdu	NNA
22	historical-r3	r2i1p1	kdv	NNA
23	historical-r3	r3i1p1	kdw	NNA
24	historical-r3	r4i1p1	kdx	NNA
25	historical-r3	r5i1p1	kdy	NNA
26	historical-r3	r6i1p1	kdz	NNA
27	historical-r3	r7i1p1	kea	NNA
28	historical-r3	r8i1p1	keb	NNA
29	historical-r3	r9i1p1	kec	NNA
30	historical-r3	r10i1p1	ked	NNA
31	historical-r4	r1i1p1	kee	NNA
32	historical-r4	r2i1p1	kef	NNA
33	historical-r4	r3i1p1	keg	NNA
34	historical-r4	r4i1p1	keh	NNA
35	historical-r4	r5i1p1	kei	NNA
36	historical-r4	r6i1p1	kej	NNA
37	historical-r4	r7i1p1	kek	NNA
38	historical-r4	r8i1p1	kel	NNA
39	historical-r4	r9i1p1	kem	NNA
40	historical-r4	r10i1p1	ken	NNA
41	historical-r5	r1i1p1	keo	NNA
42	historical-r5	r2i1p1	kep	NNA
43	historical-r5	r3i1p1	keq	NNA
44	historical-r5	r4i1p1	ker	NNA
45	historical-r5	r5i1p1	kes	NNA
46	historical-r5	r6i1p1	ket	NNA
47	historical-r5	r7i1p1	keu	NNA
48	historical-r5	r8i1p1	kev	NNA
49	historical-r5	r9i1p1	kew	NNA
50	historical-r5	r10i1p1	kex	NNA

3 List of archived variables

Table 3: List of archived variables for the ClimEx CRCM5 large ensemble, with Δt being the archiving frequencies for the Europe (EU) and northeastern North America (NNA) domains. The last column gives the type of data archive: (I) instantaneous value provided every archival time, (M) mean value during the archival period and (N) or (X) for miNimum or maXimum value between archival times. The choice of CRCM5 variables to be archived was made to comply with the needs of hydrological studies in the context of the ClimEx project. We archived additional variables that could be useful in other applications, but limitations on the total volume of data have restricted their number.

NetCDF Name	**Δt EU**	**Δt NNA**	**Description**	**Units**	**Type**
			2-D variables		
capei		3h	Convective Available Potential Energy	J kg-1	I
clt	day	day	Total Cloud Fraction	%	M
clwvi		day	Condensed Water Path	kg m-2	I
dds	3h	3h	Near-Surface Dewpoint Depression	K	I
evspsbl	day	day	Evaporation	kg m-2 s-1	M
evspsblland	day	day	Water Evaporation from Land	kg m-2 s-1	M
hfls	day		Surface Upward Latent Heat Flux	W m-2	M
hfss	day		Surface Upward Sensible Heat Flux	W m-2	M
hurs	3h	3h	Near-Surface Relative Humidity	%	I
huss	3h	3h	Near-Surface Specific Humidity	1	I
lflrt		day	Lake Floor Temperature	K	I
lif		day	Lake Ice Fraction	%	I
lit		day	Lake Ice Thickness	m	I
lmlthick		day	Lake Mixed-Layer Thickness	m	I
lmlt		day	Lake Mixed-Layer Temperature	K	I
mrfso	day	day	Soil Frozen Water Content	kg m-2	I
mrro	day	day	Total Runoff	kg m-2 s-1	M
mrros	day	day	Surface Runoff	kg m-2 s-1	M
mrso	day	day	Total Soil Moisture Content	kg m-2	I
mrsos	day	day	Moisture in Upper Portion of Soil Column	kg m-2	I
prc	3h	day	Convective Precipitation	kg m-2 s-1	M
prdc		day	Deep Convective Precipitation	kg m-2 s-1	M
prfr		day	Freezing Rain	kg m-2 s-1	M
pr	1h	1h	Precipitation	kg m-2 s-1	M
prlp	3h	day	Liquid Precipitation	kg m-2 s-1	M
prrp		day	Refrozen Rain	kg m-2 s-1	M
prsn		day	Snowfall Flux	kg m-2 s-1	M
prw		day	Water Vapor Path	kg m-2	I

Table 3: (continued)

NetCDF Name	**Δt EU**	**Δt NNA**	**Description**	**Units**	**Type**
ps	3h	3h	Surface Air Pressure	Pa	I
psl	3h		Sea Level Pressure	Pa	I
rlds	3h		Surface Downwelling Longwave Radiation	W m-2	M
rlus	3h		Surface Upwelling Longwave Radiation	W m-2	M
rlut	3h		TOA Outgoing Longwave Radiation	W m-2	M
rsaa	3h		Shortwave Radiation Absorbed by Atmosphere	W m-2	M
rsds	3h	3h	Surface Downwelling Shortwave Radiation	W m-2	M
rsdt	3h		TOA Incident Shortwave Radiation	W m-2	M
rsus	3h		Surface Upwelling Shortwave Radiation	W m-2	M
rsut	3h		TOA Outgoing Shortwave Radiation	W m-2	M
sfcWindmax	day	day	Daily Maximum Near-Surface Wind Speed	m s-1	X
snc	day	day	Snow Area Fraction	%	I
snd	day		Snow Depth	m	I
snw	day	day	Surface Snow Amount	kg m-2	I
tas	3h	3h	Near-Surface Air Temperature	K	I
tasmax	day	day	Daily Maximum Near-Surface Temperature	K	X
tasmin	day	day	Daily Minimum Near-Surface Temperature	K	N
ts	day	day	Surface Temperature	K	I
uas	3h	3h	Eastward Near-Surface Wind	m s-1	I
vas	3h	3h	Northward Near-Surface Wind	m s-1	I
			3-D Atmospheric variables (at 1000, 925, 850, 700, 500 and 200 hPa)		
hus	3h	3h	Specific Humidity	1	I
ta	3h	3h	Air Temperature	K	I
ua	3h	3h	Eastward Wind	m s-1	I
va	3h	3h	Northward Wind	m s-1	I
zg	3h	3h	Geopotential Height	m	I
			3-D Soil variables (9 layers from surface to bedrock[1])		
mrfsl	day	day	Soil Layer Frozen Water Content	kg m-2	I
mrlsl	day	day	Water Content of Soil Layer	kg m-2	I

[1] The 9 layers are taken from the 17 soil layers reaching a depth of 15 meters. Starting from the surface, the thickness of each layer in meters is: 0.1, 0.2, 0.3, 0.4, 0.5, 0.5, 0.5, 0.5, 0.5 meters, giving a corresponding depth for each layer in meters of: 0.1, 0.3, 0.6, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 meters.

Table 4: List of invariant fields for the ClimEx CRCM5 large ensemble. These fields are enclosed into invariant simulations labeled as kax and kay for the EU and NNA domains respectively.

NetCDF Name	**Description**	**Units**
areacella	Atmosphere Grid-Cell Area	m^2
bedrock	Bedrock Depth	m
clayfrac	Clay Fraction	%
cropFrac	Crop Fraction	%
grassFrac	Grass Fraction	%
lakeFrac	Lake Area Fraction	%
ldpth	Lake Depth	m
orogf	Filtred Orography	m
sandfrac	Sand Fraction	%
sftgrf	Grounded Ice Area Fraction	%
sftlf	Land Area Fraction	%
sftof	Sea Area Fraction	%
treeFracPrimDec	Total Primary Deciduous Tree Fraction	%
treeFracPrimEver	Total Primary Evergreen Tree Fraction	%
urbanFrac	Urban Fraction	%
wetlandFrac	Wetland Fraction	%

4 Suggested reading for a first contact with a regional climate model

- Laprise, R. 2008: Regional climate modelling. J. Comput. Physics. 227(7), 3641-3666. doi:10.1016/j.jcp.2006.10.024.
- Laprise, R, R de Elia, D Caya, S Biner, E Diaconescu, P Lucas-Picher, M Leduc, A Alexandru, L Separovic. 2008. Challenging some tenets of Regional Climate Modelling. Meteorology and Atmospheric Physics, 100(1-4), 3–22. `http://doi.org/10.1007/s00703-008-0292-9`.

5 Templates for the description of CRCM5-LE simulations (and driving data)

In reports/publications, a description of CRCM5-LE simulations should include the following information to describe the configuration of the run:

- CRCM5 version (CRCM5 v3.3.3.1) and
- the run's name(s) following either Ouranos' operational 3-letter name of simulation (ex. kda) or the CORDEX naming convention;
- prescribed reference(s) and acknowledgements,

- regional domain and horizontal resolution,
- time window of simulation,
- driving data (e.g. reanalyses or GCM –version, member, and RCP if future projection–).
- The lake model (implemented at the sub-grid scale and the resolved grid scale) should also be cited with reference(s) if relevant for the analysis (see note on the lakes below).

Suggestion of text on regional domain and resolution:
The ClimEx simulations were performed using the same configuration over the European and Northeastern North America domains:

- ... over a domain covering Europe (EU) or Northeastern North America (NNA) with a horizontal grid-size mesh of 0.11 degrees (on a rotated latitude-longitude grid), corresponding to a12-km resolution, using 5-minute time steps.

The CRCM5 was run on larger grids than those kept for validation. The real size of the computational domain was 380x380 and a 50-point depth security zone was removed surrounding the domain to avoid artefacts from coarse resolution boundary conditions. This gives a free zone for analysis of 280X280 grid points.

Suggestion of text on spectral nudging (when applicable for the CRCM5 simulation used):

- ... a spectral nudging technique was applied to large-scale winds (Riette and Caya 2002) within the interior of the regional domain to keep CRCM's large-scale flow close to its driving data.

Suggestion of text on the driving data:
... for historical simulations, the run was driven by atmospheric and oceanic fields taken from...

- 6-hourly ECMWF ERA-Interim global reanalyses (European Center for Medium-Range Weather Forecasts ReAnalyses; Dee et al. 2011), publicly available on a grid of approximately 80 km spatial resolution.

... for climate change projections, the run was driven by atmospheric and oceanic fields taken from...

- 6-hourly atmospheric simulation and daily ocean outputs of each of the 50 members of the Canadian Earth System Model version 2 Large Ensemble (CanESM2-LE; Fyfe et al. 2017; Sigmondet al. 2018; T63 approximately corresponding to 2.8oX2.8o on a latitude-longitude grid). Regional simulations were performed using the IPCC RCP 8.5 future greenhouse gas projected evolution from 2006 (Meinshausenet al. 2011), as was the global driving model.

More information on the CanESM2-LE:
For the historical period (1850–1950), each of the five CMIP5 members takes its initial 1850 year at 50-year intervals from a preindustrial CMIP5 'piControl' simulation that has reached equilibrium. With a constant 284.7 ppm atmospheric CO2 concentration, this equilibrated control simulation has a stationary climate. Then, employing a small random perturbation, 10 new simulations are launched from each of the original 5 historical CMIP5 simulations on 1 January 1950 up till 2100."The random perturbation to the initial atmospheric state is introduced via a parameterization of one aspect of model cloud properties. This parameterization employs a random number generator with a pre-set seed; the 50 individual simulationswere based on different seeds. In this way, different climate change realizations were produced without any change to the model dynamics, physics or structure." (Fyfe et a. 2017). Observed emissions (in CO2 and non-CO2 GHGs, aerosols and land cover) are used during the historical period up to 2005 with observed explosive volcanoes and solar cycle forcings. For the 2006-2100 period, each member is a continuation of each of the five historical simulations employing the future RCP 8.5 scenario of forcings. These future simulations employ a solar cycle forcing comprised of a repetition of roughly the last observed solar cycle prior to 2006 but no explosive volcanic forcing. This generates 50 equally likely runs of 150 years (1950-2100), resulting in an artificial timeline of $50 \times 150 = 7500$ years of modelled climate over the domains. This enables to catch rare events in the data - and by this toinvestigate extreme events and natural variability with probabilistic approaches. Note that the basic reference for CanESM2 is: Arora et al. (2011).

Information on the lakes in CRCM5:
CRCM5 is coupled to sub-grid scale lakes (when the lake covers less than 100% of a model tile, the ground part being taken over by the CLASS land surface scheme) and to resolved lakes (when the lake covers 100% of a tile such as is the case for the Great Lakes and Lake Winnipeg for example). Unless otherwise specified, the lake model used is FLake, the Freshwater Lake model (Mironov et al. 2010). Martynov et al. (2010) describe the resolved lake model, namely over the American Great Lakes, while Martynov et al. (2012) look at the regional climate effect of sub-grid scale lakes. The data defining the percent coverage of lakes over each grid tile of a specified regional domain and resolution is available as an output from the CRCM5.

Note on possible analyses of CRCM5 simulations:
RCMs driven by reanalyses can be evaluated against observations for specific simulated periods, not only on a long-term statistical basis but also on an event basis, because the reanalyses represent actual climate periods (with assimilation of observed meteorological data). Consequently, temporal correlation of the simulation with the observations is meaningful and generally positive at all temporal scales. Correlations of large-scale dominated variables such as temperature or geopotential height can reach values near unity for small domains or for strong spectral nudging. For variables where small scales play a more important role such as precipitation, correlations are generally lower than those for temperature, and even lower in the case of the summer seasons. In GCMs, there is no assimilation of observed meteorological data, only the concentration/emissions of greenhouse gases and

aerosols (and land-use change, etc.) evolve following observed and possible future values. Hence, in the GCM-driven simulations, no temporal correlation can be expected, and no link to specific years can be made, the analysis needs to occur in terms of climatological statistics, which requires runs of sufficient length (typically a minimum of 20–30 years).

6 List of references

Specific to ClimEx

- Leduc, M., A. Mailhot, A. Frigon, J. Martel, R. Ludwig, G.B. Brietzke, M. Giguère, F. Brissette, R. Turcotte, M. Braun, and J. Scinocca (2019) The ClimEx Project: A 50-Member Ensemble of Climate Change Projections at 12-km Resolution over Europe and Northeastern North America with the Canadian Regional Climate Model (CRCM5). J. Appl. Meteor. Climatol., 58, 663–693, `https://doi.org/10.1175/JAMC-D-18-0021.1`.

- von Trentini, F., M. Leduc and R. Ludwig (2019) Assessing natural variability in RCM signals: comparison of a multi model EURO-CORDEX ensemble with a 50-member single model large ensemble. Clim. Dyn. `https://doi.org/10.1007/s00382-019-04755-8`.

Specific to CRCM5:

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- Martynov A, L Sushama, R Laprise. 2010. Simulation of temperate freezing lakes by one-dimensional lake models: performance assessment for interactive coupling with regional climate models. Boreal Env Res 15:143-164.

- Mironov D, E Heise, E Kourzeneva, B Ritter, N Schneider, A Terzhevik. 2010. Implementation of the lake parameterisation scheme FLake into the numerical weather prediction model COSMO. Boreal Env Res 15:218-230.

- Riette S, D Caya. 2002. Sensitivity of short simulations to the various parameters in the new CRCM spectral nudging. – In: RITCHIE, H. (Ed.): Research activities in Atmospheric and Oceanic Modeling, WMO/TD No. 1105, Report No. 32: 7.39–7.40.

Others:

- Arora, V.K., J.F. Scinocca, G.J. Boer J.R. Christian, K.L. Denman, G.M. Flato, V.V. Kharin, W.G. Lee, and W.J. Merryfield, 2011: Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases. Geophysical Research Letters, 38, L05805, doi:10.1029/2010GL046270, 2011.

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- Fyfe, J.C., C. Derksen, L. Mudryk, G.M. Flato, B.D. Sante, N.C. Swart, N.P. Molotch, X. Zhang, H. Wan, V.K. Arora, J. Scinocca, Y. Jiao, 2017: Large near-term projected snowpack loss over the western United States. Nature Communications, 8:14996. DOI: 10.1038/ncomms14996.

- Meinshausen, M, S. J. Smith, K. Calvin, J. S. Daniel, M. L. T. Kainuma, J-F. Lamarque, K. Matsumoto, S. A. Montzka, S. C. B. Raper, K. Riahi, A. Thomson, G. J. M. Velders, D.P. P. van Vuuren, 2011: The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change, 109:213–241. DOI 10.1007/s10584-011-0156-z.

- Sigmond, M., J.C. Fyfe, N.C. Swart, 2018: Ice-free Arctic projections under theParis Agreement. Nature climate change. DOI 10.1038/s41558-018-0124-y.