Evaluating the impact of aerosols on Numerical Weather and Subseasonal Prediction

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1 Introduction

The first phase of the WGNE Aerosol project (WGNE-AerI) entitled Evaluating aerosol impacts on Numerical Weather Prediction (NWP, Freitas (2015)), considered case studies selected in order to understand how NWP models perform forecasts with interactive aerosols in comparison with no interactive aerosols. Different cases of pollution events were selected, as follows:

- Dust storm over Egypt on April 18, 2012;
- Pollution in China on January 12-16, 2013;
- Smoke in Brazil on September 5-15, 2012.

Different model characteristics (domain, grid-spacing, aerosol species, emissions, aerosol and cloud physics, and assimilation techniques) were considered in the case studies experiments, taking into account the complexity of the operational systems used by WGNE's participating centers.

The results of the case studies showed strong differences across the forecasts, which was expected due to the range of different model configurations. The impact of aerosols were observed in most meteorological variables analyzed, but did not show clearly if the effects are statistically significant for NWP due the nature of the study. The most prominent effect of including aerosols in the forecast systems was observed for the radiative shortwave flux at surface and 2 meter air temperature, in association with aerosol direct effects and especially at local scales. Another important result is that when climatological aerosol fields are used within the forecast systems instead of interactive aerosols, the transient and strong pollution events were not realistically represented in the forecasts. However, the questions raised prior to the first phase of the project were not sufficiently answered due to the limitation of the study.

The Subseasonal to Seasonal (S2S) WWRP–WCRP joint research project (WWRP/WCRP, 2018) recognizes the importance of aerosols on subseasonal to seasonal timescales that was not explored in WGNE-AerI and understands that the incorporation of interactive aerosols on S2S models can be an opportunity to improve the skill of models as well as contribute strongly to support policy makers and end-users providing skillful air quality forecasts. However, currently few operational meteorological centres are able to run a fully integrated weather/aerosol/chemistry NWP system with interactive aerosols and even less are able to run fully coupled modelling systems for longer timescales, like S2S. All the operational S2S models contributing to the S2S WWRP–WCRP joint research project database use climatological aerosols (WWRP/WCRP, 2018), which may represent a limitation in S2S forecasts (for more information about S2S project visit http://s2sprediction.net). Such models do not represent the direct and indirect effects of aerosols, impacting the skill of the atmospheric circulation and do not represent persistent and intense events especially considering biomass burning and synoptic dust events. Sub-seasonal experiments performed using the ECMWF coupled model with interactive aerosols (direct effects only) suggest significant skill in predicting the weekly variability of aerosols and also significant improvements in the tropical and extratropical skill scores (Benedetti and Vitart, 2018).

To further explore the importance of interactive aerosols in short to medium-range and subseasonal predictability, it is necessary to coordinate a systematic and statistically robust study and associated database to support the analysis. This project proposes the development of the second phase of the WGNE Aerosols project but now including a joint collaboration between WWRP/S2S Steering Group and the WMO Global Atmosphere Watch (GAW) Scientific Advisory Group (SAG) on Modelling Applications (SAG–APP).

The WGNE-S2S-GAW Aerosols project (WGNE-S2S-GAW-Aer) should consider a longer period of evaluation and will consider two main components: one is built on WGNE-AerI by running higher resolution regional models in order to address the importance of interactive aerosols on weather predictability; the second component considers sub-seasonal reforecasts experiments based on ensemble approach in a global scale in order to address the importance of interactive aerosol on sub-seasonal predictability. The WGNE-S2S-GAW-Aer will benefit from the expertise of the Joint Working Group on Forecast Verification Research (JWGFVR) regarding the best metrics to be used to assess both NWP deterministic and ensemble forecasts, taking advices on what metrics to evaluate meteorological and air quality variables.

We propose to build the WGNE-S2S-GAW-Aer on the experimental design of the WGNE-AerI, by largely relying on the existing configurations of the models used in different modelling groups, to set-up a range of experiments that explore the effects of interactive aerosols on predictive skill. The goal of the project is to better understand the impact of aerosols on NWP and S2S prediction under current model capabilities available in participating institutions. Therefore, for the WGNE-S2S-GAW-Aer, a systematic study should consider the diversity and complexity of participating modelling groups. We understand the scientific importance of standardized experiments considering the same initial and boundary conditions, physical and dynamical consistencies as much as possible and pre-defined emission database. However, it would be too expensive and not feasible specially for meteorological centres to adopt such practices due to human and computational resources. It is also not realistic to provide a feedback for centres based on such kind of experiments and suggest the adoption of practices other than those currently adopted by centres. This is why our proposal is based on the current model, computational and human resources available in each participating institution.

The proposed protocol is a collaborative effort of many expert scientists on modeling, observational and forecast verification research under the WMO WCRP, WWRP and GAW programs. We expect the participation from modelling groups contributing with either global and/or limited-area models.

2 Experiment setup

We propose two different sets of experiments, focusing on the short timescale and the subseasonal timescale.

The general model configuration to be adopted by modelling groups (grid-spacing, vertical resolution, data assimilation, cloud and aerosol complexity, spin-up for atmospheric composition, emission sources) should be compatible with the configuration of the operational system or the latest version currently used for short-range and S2S prediction.

The experiments will consist of a set of runs that include: interactive aerosols with focus on the direct effect (the whey aerosols absorb and scatter shortwave and longwave radiation) and experiments considering no-aerosol loading or climatological aerosols. Experiments that include the effect of aerosols on the cloud microphysics (called indirect effect) will be optional.

Due to storage limitations, a priority list of model output variables is required and can be find in Appendix A. It includes the main meteorological and air quality variables as well as optical properties of aerosols. The complete list of model output variables is presented in B. We strongly recommend modelling groups archive the complete list of variables in case we need a specific variable to be analysed that is not included in the list of priority variables.

2.1 Limited-area domain (focus on short timescale)

Modelling groups can contribute with limited-area models in one or more experiments for regional domains listed on Table 1. The experiments configuration should consider:

- Forecast length: 72h (3-days forecasts) from 00:00 UTC;
- Time resolution: 3 hours;
- Period: see Table 1;

- Model data: Variables listed in Appendix A;
- Suggested deadline to deliver model outputs: **Preferably 21 September 2020 (if necessary, timeline can be extended according to modelling groups needs)**.

Table 1: Experiments description. Aerosols events to be analysed, period of simulation, domain with initial and final latitude/longitude (lat/lon), lat/lon of the center of the domain, total number of experiments to be performed per year (required and optional), effects to be analysed and total hours of forecasts to be performed per year. BBS means biomass burning smoke. NA means no-aerosol loading.

Aerosol events	Period	Domain	Center of the domain	Total number of experiments per year	Effects to be analyzed	Total hours of forecasts per year
Dust in Egypt	Mar–Apr–May (2016–2018)	0^o to 60^oE 0^o to 50^oN	30^oE, 25^oN	2 (3 optional)	Direct Indirect (optional) Climatological/NA	92 days * 72h 1 exp = 6,624h 2 exp = 13,248h
BBS in South America	Aug–Sep–Oct (2017–2019)	32^oW to 76^oW 33^oS to 6^oN	60^oW, 10^oS			
BBS in South Africa	Aug–Sep–Oct (2016–2018)	0^o to 60^oE 40^oS to 10^oN	30^oE, 15^oS			
BBS in North America	TBD	TBD	TBD			
Dust in East Asia	Mar–April–May (2016–2018)	80^oE to 120^oE 20^oN to 50^oN	100^oE, 35^oN			
Anthropogenic pollution in East Asia	Jan–Feb–Mar (2016–2018)	80^oE to 120^oE 20^oN to 50^oN	100^oE, 35^oN			

2.2 Global domain (focus on subseasonal timescale)

Modelling groups can contribute with global models in one or more experiments for the global domain (see Table 2). The experiments configuration should consider:

- Aerosol events to be analyzed:
  - Focus on dust and biomass burning smoke; pollution in Asia is included as an additional and optional experiment.
- Re-forecast period: 2003–2019
  - Dust – Minimum requirement: 1st May start date. Recommended additional start dates: 1st April and 1st June;
  - Biomass burning smoke – Minimum requirement: 1st September start date. Recommended additional start dates: 1st August and 1st October;
  - Pollution in Asia – Minimum requirement: 1st January start date. Recommended additional start dates: 1st December and 1st February;

- Forecast length: 768 h (32-days) from 00:00 UTC;
- Time resolution: 6 hours;
- Minimum number of ensemble members: 5;
- Effects to be analyzed:
  - Direct
  - Indirect (optional)
  - Climatological aerosols;
- Model data: Variables listed in Appendix A;
- Timeline to deliver model outputs: **2–years (2020–2021)**.

Table 2: List of experiments to be conducted in the global domain, for subseasonal prediction purposes, considering the period of simulations, the total number of experiments, the total hours of forecasts, the minimum number of ensemble members and simulation length.

Aerosol events	Re-forecast Period (2016-2019)	Total number of experiments	Effects to be analyzed	Minimum Number of ensemble members	Simulation length (in days)
Dust	May Optional: April and June	2 (3 optional)	Direct Indirect (optional) Climatological	5	32
Smoke	September Optional: August and October		Direct Indirect (optional) Climatological		
Pollution	January Optional: December and February		Direct Indirect (optional) Climatological		

3 Model validation

The availability of short-range and subseasonal predictions that will be produced within the experiments requires investigating the quality of the forecasts produced by the participating modeling groups.

In order to assess the quality of the forecasts produced, it should be considered which observation dataset will be used and define basic statistical scores. The following should be considered:

- The use of a reference database:

  - Aerosol properties: CAMS and/or MERRAero; AERONET
  - Weather variables: SYNOP data and ERA5 reanalysis.

- Adopt already existing statistical scores (e.g. Continuous ranked probability skill score, CRPSS) and possibly new ones proposed by JWGFVR – mostly deterministic for the limited-area predictions at short-range time-scales and mostly probabilistic for the global forecasts at sub-seasonal time-scales.

- Evaluate aerosol optical depth and possibly aerosol concentrations (important for local applications) among models.

4 Data delivery

In this section we describe the proposed technical details to modelling centres deliver produced data.

Grid

All fields should be provided on a regular lat/lon grid at a grid space of 1.0°/1.0° of lat/lon for global experiments and 0.2°/0.2° of lat/lon for regional experiments. Climate and Forecast Metadata convention (CF) NetCDF format (http://cfconventions.org/) is required.

File names

The following naming convention for the files containing the data is proposed:

- Interactive aerosol: <CENT>_<EVENT>_INT_<YYYYMMDD>00_<hh>
- No interactive aerosol: <CENT>_<EVENT>_NOINT_<YYYYMMDD>00_<hh>

where:

- CENT: is the center identifier, e.g. CPTEC;
- EVENT: is the considered aerosol event. It must be DUST or BBS;

- YYYY: year of the experiment, e.g., 2018;
- MM: month of the experiment, e.g., 03 (March);
- DD: day of the experiment, e.g., 01;
- 00: is the start time of the simulation, that must be 00 (UTC);
- hh: forecast range in hours.

Ex:
CPTEC_BBS_INT_2018090100_06.nc
CPTEC_BBS_NOINT_2018090100_06.nc.
Both outputs refer to the 6 hour forecast range.

Metadata

A document describing additional information about model data should be provided. This document must include the general configuration of the modelling system as: dynamical core, initialization (soil moisture, sea surface temperature, snow etc), data assimilation, vertical coordinate system, grid–spacing, vertical resolution, model top, physical parameterizations (speciall attention should be given to aerosol complexity) for regional and/or global experiments. It is also required information about the model spin-up (speciall attention should be given to atmospheric composition spin-up). Detailed information about emission sources also should be provided.

The description about the algorithm used to interpolate data from the model native grid to the regular lat/lon grid should be provided.

The metadata should be uploaded along with the model data.

Data delivery

The data will be collected and archived at CPTEC. The procedure adopted to upload model data and metadata will be provided personally. Please contact Ariane Frassoni (ariane.frassoni@inpe.br with a copy to afrassoni@gmail.com) to receive more information about data delivery.

A Priority list of model output variables and storage estimation

In this appendix it is considered a more concise and priority list of variables proposed as model outputs and the respective storage estimation. Compared with the complete list presented in the Appendix B, this list also present a reduction of the number of levels for multi-level variables in addition to the reduction of the number of variables.

For the regional experiments (NWP aerosol experiments), the total estimation is computed considering CPTEC regional model in a 20km horizontal resolution and 7 vertical levels (1000, 925, 850, 700, 500, 200, 50) for 3D variables, with limited-area domain over South America in a binary format (ieee-32 bits), with forecast length of 72h with time resolution of 3h. The total computed cost considers a set of 2D and 3D variables for a period of 3 days of forecast (integration of 72h), 92 days of consecutive simulations for 3 different years.

For the subseasonal experiments (S2S aerosol experiments) the total estimation is computed considering ECMWF IFS model archived on a 1x1 degree horizontal resolution and 10 vertical levels (1000, 925, 850, 700, 500, 300, 200, 100, 50 and 10 hPa) for 3D variables, with daily time resolution. It is considered 5-member ensemble and at least 32-day long simulations for three different starting dates. The total computed cost considers a set of 2D and 3D variables, 5 ensemble members running for 32 days of simulation for 3 different integration days for 2 different experiments (interactive aerosols and climatological aerosols) for 16 years (2003-2019).

A.1 NWP aerosol experiments

The more concise list of variables that can be considered as outputs in the NWP experiment are listed below. The meteorological single-layer and multi-level instantaneous variables are listed in Tables 3 and 4, respectively. Air quality and aerosol optical properties single-layer and multi-level instantaneous variables are listed in Tables 5 and 19, respectively. Accumulated single-layer and multi-level meteorological variables are listed in Table 7. Table 8 summarizes the cost of the output variables based in Tables 3–7.

Table 3: Meteorological variables: instantaneous single fields.

Meteorological single-layer fields

Variable name	Units
2m temperature	K
2m dew point temperature	K
10m zonal wind component	m/s
10m meridional wind component	m/s
Mean sea-level pressure	Pa
Skin temperature (at the interface atmosphere – surface)	K
Column water vapor (precipitable water)	kg/m^2
PBL height	m

Table 4: Meteorological variables: instantaneous multi-level fields.

Meteorological multi-level fields

Variable name	Units
Temperature	K
Geopotential height	gpm
Zonal wind component	m/s
Meridional wind component	m/s
Vertical wind component	Pa/s
Specific humidity	kg/kg

Table 5: Air quality/aerosol properties variables: instantaneous single-layer fields.

Air quality/aerosols single-layer fields

Variable name	Units
PM 2.5 vertical integration	mg/m^2
PM 2.5 concentration at the first level of the model	$\mu g/m^3$
PM 1 micrometer at the first level of the model	$\mu g/m^3$
PM 10 micrometers at the first level of the model	$\mu g/m^3$
Total optical depth at 550 nm	
Light scattering coefficient	
Aerosol absorption coefficient	
Aerosol* mass column integrated	kg/m^2

*Dust for Egypt domain and total for other analysis

A.2 S2S aerosol experiments

The more concise list of variables that can be considered as outputs in the S2S experiment are listed below. The meteorological variables for instantaneous single-layer and multi-layer

Table 6: Air quality/aerosol properties variables: instantaneous multi-layer fields.

Air quality/aerosols multi-layer fields

Variable name	Units
CO concentrations	ppbv
SO2 concentrations	ppb
Non methane VOCs mixing ratio	ppbm
Nitrogen oxide concentrations	ppbv
Nitrogen dioxide concentrations	ppbv
Ozone concentrations	ppbv

Table 7: Meteorological variables: accumulated single-layer fields.

Meteorological fields

Variable name	Units
Single-layer fields	
Large-scale precipitation	mm
Convective precipitation	mm
Shortwave downwelling radiative flux at the surface	W/m^2
Longwave downwelling radiative flux at the surface	W/m^2
Surface sensible heat flux	W/m^2
Surface latent heat flux	W/m^2
Evaporation	mm

Table 8: Cost estimated based in the variables listed in the previous tables.

Cost
Number of 2D variables: 23
Number of 3D variables: 12
0.00059 Gb (per day of integration) * 3 days of forecast (72h integration) * 92 days * 3 years= 0.48 Tb
Considering a compression of about 25% with netCDF conversion, the total is about:
Total = 0.36 Tb per model per experiment

fields are listed in Tables 9 and 10. The daily averages meteorological variables for single-layer fields are listed in Table 11. Accumulated variables for single-layer fields are listed in Table 12. Aerosol optical properties and air quality variables are listed in Table 13. Table 14 summarizes the cost of the output variables based on Tables 9 and 13.

Table 9: Meteorological variables: instantaneous single-layer fields.

Meteorological variables: instantaneous single-layer fields

Variable name	Units
10m zonal wind component	m/s
10m meridional wind component	m/s
Mean sea-level pressure	Pa
Stream Function at 200hPa	m^2/s
Velocity Potential at 200 hPa	m^2/s

Table 10: Meteorological variables: instantaneous multi-level fields.

Meteorological variables: instantaneous multi-level fields

Variable name	Units
Geopotential height	gpm
Temperature	K
Zonal wind component	m/s
Meridional wind component	m/s

Table 11: Meteorological variables: single-layer daily average (4 x per day).

Meteorological variables: single-layer daily average

Variable name	Units
Skin temperature	K
Surf. Air. Temp.	K
Surf. Air Dewpoint Temp.	K
Sea surface temperature	K
Sea ice cover	Proportion of sea ice
Total cloud cover	%
Total column water	kg/m^2

Table 12: Meteorological variables: accumulated single-layer fields.

Meteorological variables: accumulated single-layer fields

Variable name	Units
Outgoing long-wave radiation	$W/m^2/s$
Surface latent heat flux	$W/m^2/s$
Surface sensible heat flux	$W/m^2/s$
Surface solar radiation downwards	$W/m^2/s$
Total precipitation	kg/m^2
Runoff	m
Surface runoff	m

Table 13: Air quality/aerosols variables

Air quality/aerosols fields

Variable name	Units
Daily average (4 x per day) variables: single-layer fields	
Dust optical depth at 550 nm	
Sea salt optical depth at 550 nm	
Sulfate optical depth at 550nm	
Organic Matter optical depth at 550 nm	
Total optical depth at 550 nm	
Light scattering coefficient	
Aerosol absorption coefficient	

Table 14: Cost estimated based in the variables listed in the previous tables.

Cost
40 2D fields (132 kb /day/variable/ensemble member) – 15360 days of integrations (5 member ensemble) * 2 experiments
Total = 0.08 Tb per model

B Complete list of model output variables and storage estimation

The list of variables proposed as model outputs and the respective storage estimation for the WGNE-S2S-GAW-Aer are presented here. A desirable list is presented for both NWP and S2S experiments. A more concise list of variables, those considered priority, are presented in Appendix A.

For the regional experiments (NWP aerosol experiments), the total estimation is computed considering CPTEC regional model in a 20km horizontal resolution and 19 vertical levels for 3D variables, with limited-area domain over South America in a binary format (ieee-32 bits), with forecast length of 72h with time resolution of 3h. The total computed cost considers a set of 2D and 3D variables for a period of 3 days of forecast (integration of 72h), 92 days of consecutive simulations for 3 different years.

For the subseasonal experiments (S2S aerosol experiments) the total estimation is computed considering ECMWF IFS model archived on a 1x1 degree horizontal resolution and 10 vertical levels (1000, 925, 850, 700, 500, 300, 200, 100, 50 and 10 hPa) for 3D variables, with daily time resolution. It is considered 5-member ensemble and at least 32-day long simulations for three different starting dates. The total computed cost considers a set of 2D and 3D variables, 5 ensemble members running for 32 days of simulation for 3 different integration days for 2 different experiments (interactive aerosols and climatological aerosols) for 16 years (2003-2019).

B.1 NWP aerosol experiments

The list of variables that can be considered as outputs in the NWP experiment are listed below. The meteorological single-layer and multi-level instantaneous variables are listed in Tables 15 and 16, respectively. Air quality and aerosol optical properties single-layer and multi-level instantaneous variables are listed in Tables 18 and 19, respectively. Accumulated single-layer and multi-level meteorological variables are listed in Table 17. Table 20 summarizes the cost of the output variables based in Tables 15–17.

B.2 S2S aerosol experiments

The list of variables that can be considered as outputs in the S2S experiment are listed below. The meteorological variables for instantaneous single-layer and multi-layer fields

Table 15: Meteorological variables: instantaneous single fields.

Meteorological single-layer fields	
Variable name	Units
2m temperature	K
2m dew point temperature	K
10m zonal wind component	m/s
10m meridional wind component	m/s
Surface pressure	Pa
Mean sea-level pressure	Pa
Surface albedo	%
Skin temperature (at the interface atmosphere – surface)	K
Water equivalent of accumulated snow depth	kg/m^2
High cloud cover (between 0 and 400 hPa)	%
Medium cloud cover (between 440 and 680 hPa)	%
Low cloud cover (between 800 hPa and surface)	%
Column water vapor (precipitable water)	kg/m^2
Column cloud water (liquid)	kg/m^2
Column cloud ice (frozen)	kg/m^2
Soil moisture (absolute water content) in the first layer of the surface model (closest to the land-surface)	mm
Shortwave downwelling radiative flux at the surface	W/m^2
Longwave downwelling radiative flux at the surface	W/m^2
PBL height	m

are listed in Tables 21 and 22. The daily averages meteorological variables for single-layer fields are listed in Table 23. Accumulated variables for single-layer fields are listed in Table 24. Aerosol optical properties and air quality variables are listed in Table 25. Table 26

Table 16: Meteorological variables: instantaneous multi-level fields.

Meteorological multi-level fields

Variable name	Units
Temperature tendency associated to the total radiative flux divergence	K/s
Temperature	K
Relative humidity	
Geopotential height	gpm
Zonal wind component	m/s
Meridional wind component	m/s
Vertical wind component	Pa/s
Specific humidity	kg/kg

Table 17: Meteorological variables: accumulated single-layer and multi-layer fields.

Meteorological fields

Variable name	Units
Single-layer fields	
Large-scale precipitation	mm
Convective precipitation	mm
Large-scale snow	mm
Convective snow	mm
Shortwave downwelling radiative flux at the surface	W/m^2
Net shortwave radiation flux at the surface	W/m^2
Longwave downwelling radiative flux at the surface	W/m^2
Net longwave radiation at the surface	W/m^2
Momentum flux, u component	Ns/m2
Momentum flux, v component	Ns/m2
Surface sensible heat flux	W/m^2
Surface latent heat flux	W/m^2
Evaporation	mm
Multi-layer fields	
Temperature tendency associated to the total radiative flux divergence	K/s

summarizes the cost of the output variables based on Tables 21 and 25.

Table 18: Air quality/aerosol properties variables: instantaneous single-layer fields.

Air quality/aerosols single-layer fields

Variable name	Units
PM 1 micrometer	$\mu g/m^3$
PM 2.5** individual components – concentration at the first level of the model	$\mu g/m^3$
PM 10 micrometers	$\mu g/m^3$
Dust optical depth at 550 nm	
Sea salt optical depth at 550 nm	
Sulfate optical depth at 550nm	
Organic Matter optical depth at 550 nm	
Total optical depth at 469 nm	
Total optical depth at 550 nm	
Total optical depth at 670 nm	
Total optical depth at 865nm	
Total optical depth at 1240 nm	
Light scattering coefficient	
Aerosol absorption coefficient	
Aerosol$^+$ mass column integrated	kg/m^2

**The number of new optional variables will depend on the methodology used to compute PM2.5 and should consider all the components used to compute PM2.5

$^+$Dust for Egypt domain and total for other analysis

Table 19: Air quality/aerosol properties variables: instantaneous multi-layer fields.

Air quality/aerosols multi-layer fields

Variable name	Units
CO concentrations	ppbv
SO2 concentrations	ppb
PM 2.5 micrometers	$\mu g/m^3$
Non methane VOCs mixing ratio	ppbm
Nitrogen oxide concentrations	ppbv
Nitrogen dioxide concentrations	ppbv
Ozone concentrations	ppbv

Table 20: Cost estimated based in the variables listed in the previous tables.

Cost
Number of 2D variables: 46
Number of 3D variables: 16
1.9 Gb (per day of integration) * 3 days of forecast (72h integration) * 92 days * 3 years= 1.58 Tb
Considering a compression of about 25% with netCDF conversion, the total is about:
Total = 1.19 Tb per model per experiment

Table 21: Meteorological variables: instantaneous single-layer fields.

Meteorological variables: instantaneous single-layer fields

Variable name	Units
Potential vorticity at 320K	$Km^2kg^{-1}s^{-1}$
10m zonal wind component	m/s
10m meridional wind component	m/s
Mean sea-level pressure	Pa
Surface pressure	Pa
Stream Function at 200hPa	m^2/s
Velocity Potential at 200 hPa	m^2/s

Table 22: Meteorological variables: instantaneous multi-level fields.

Meteorological variables: instantaneous multi-level fields

Variable name	Units
Geopotential height	gpm
Specific humidity	Kg/kg
Temperature	K
Zonal wind component	m/s
Meridional wind component	m/s
Vertical wind component	Pa/s

Table 23: Meteorological variables: single-layer daily average (4 x per day).

Meteorological variables: single-layer daily average

Variable name	Units
CAPE	J kg-1
Skin temperature	K
Snow depth water equivalent	m
Snow density	kg/m^3
Snow albedo	Proportion
Soil wetness top level	kg/m^3
Soil wetness top 1m	kg/m^3
Soil temperature top level	K
Soil temperature top 1m	K
Surf. Air Max. Temp.	K
Surf. Air. Min. Temp.	K
Surf. Air. Temp.	K
Surf. Air Dewpoint Temp.	K
Sea surface temperature	K
Sea ice cover	Proportion of sea ice
Total cloud cover	%
Total column water	kg/m^2

Table 24: Meteorological variables: accumulated single-layer fields.

Meteorological variables: accumulated single-layer fields

Variable name	Units
Snow fall water equivalent	kg/m^2
Outgoing long-wave radiation	W/m^2/s
Surface latent heat flux	W/m^2/s
Surface net solar radiation	W/m^2/s
Surface net thermal radiation	W/m^2/s
Surface sensible heat flux	W/m^2/s
Surface solar radiation downwards	W/m^2/s
Total precipitation	kg/m^2
Convective precipitation	kg/m^2
North-South surface stress	N/m^2/s
East-west surface stress	N/m^2/s
Runoff	m
Surface runoff	m

Table 25: Air quality/aerosols variables

Air quality/aerosols fields

Variable name	Units
Instantaneous variables: multi-level fields	
Ozone	
Daily average (4 x per day) variables: single-layer fields	
Dust optical depth at 550 nm	
Sea salt optical depth at 550 nm	
Sulfate optical depth at 550nm	
Organic Matter optical depth at 550 nm	
Total optical depth at 469 nm	
Total optical depth at 550 nm	
Total optical depth at 670 nm	
Total optical depth at 865nm	
Total optical depth at 1240 nm	
Light scattering coefficient	
Aerosol absorption coefficient	
Daily average (4 x per day) variables: multi-level fields	
CO concentrations	ppbv
SO2	ppb

Table 26: Cost estimated based in the variables listed on Tables

Cost
171 2D fields (132 kb /day/variable/ensemble member) – 15360 days of integrations (5 member ensemble) * 2 experiments
Total = 0.34 Tb per model

References

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