A common set of model output for YOPP

Introduction – Core Model Output

This document sets out a common set of model fields that should be output, where feasible, from all model simulations carried out in conjunction with the Year of Polar Prediction (YOPP). It should be read in conjunction with the YOPP modelling plan (YOPP, 2017), which describes plans for producing a set of YOPP reference datasets and running a variety of modelling experiments to address key scientific issues. This specification for YOPP common model output has been developed by the YOPP model task team, whilst taking into account the primary verification goals, as set out by the YOPP verification task team (Casati et al, 2017).

Outputting a consistent set of core fields, with common units and conventions, will facilitate the use of YOPP data for a wide range of research, projects, including:

- comparisons between different model runs; and
- verification of model data against observations.

Section A of this document defines a core set of fields that should be output at all model grid points. In addition, modelling teams are requested to more detailed output at key observation locations, see section B on *Site-specific Output*. For detailed local process modelling, using single-column models (SCM) or large eddy simulation (LES), output should follow the guidelines set out in section B.

It is recognised that not all variables will be relevant to all models: for example, atmosphere-only models will not include ocean and sea ice variables. Modelling teams are strongly recommended to output as many of these core output fields as possible, in order to maximise the utility of YOPP model datasets.

This set of core model fields is intended to include the most important output fields, which can be readily produced from most models without being an undue burden on model data providers. The list is based on a subset of the variables included in the TIGGE and S2S datasets, and also taking into account the requested model output for CMIP6. Sea Ice and ocean output is based on agreed output for SIMIP and the APPLICATE project, respectively.

Additional model output

While all modelling teams are requested to output the set of core fields defined in this document, we expect that they would want to include additional model output. These more comprehensive datasets can include ensembles and site-specific model output, e.g. to permit an enhanced analysis of specific physical processes Most experiments would include a wider range of diagnostics, higher frequency output, and/or more output levels, etc. Table 1 shows the hierarchy of core and additional model output that are suggested to increase the value of the YOPP model datasets.

Table 1: Examples of additional model output

Basic model output	Additional model output options	
Core model fields at all grid points (section A)		Site-specific output at key observation locations (section B)
Output on 8 standard pressure levels	Output on additional pressure levels.	Output on model levels
Initial and forecast output from a single model realization	Ensemble model output, to indicate uncertainty in both initial conditions and forecast	
Output every 3-6 hours	Output every hour	Output at sub-hourly frequency

A. Common model output at all model grid points

The common set of atmospheric fields that are requested on the full model grid includes:

- Wind, temperature, geopotential height and humidity in the free atmosphere;
- Wind and temperature near the surface;
- Precipitation;
- Parameterized energy and momentum fluxes near the surface;
- Single level fields characterizing the atmospheric model surface, e.g., orography, land/sea points, snow & ice cover/depth, etc.

The requested list of atmospheric model output fields is shown in Table A1.

For simulations that include a dynamic ocean and sea-ice additional variables should be included: Sea-ice concentration, thickness, and drift, plus (near-) surface ocean T, S, and velocities. These are listed in Table A2 and A3.

Some key issues:

- **Output frequency for atmospheric data**. It is recommended that atmospheric model output data be written every 3 hours, to resolve the diurnal cycle and be consistent with CMIP6. If that is not feasible, output should be produced every six hours, for shorter-range forecasts (up to at least 5 days), as TIGGE. For longer-range forecasts, output should be at least every 24 hours, as S2S. More frequent data are requested for site-specific output, see below.
- **Output frequency for ocean and sea ice data**. Daily averages are often used for ocean and sea-ice modelling, so that convention should continue to be followed. However, model output at the surface should match the frequency of the atmospheric model, where possible, to support coupling studies. For extended runs, it is recognized that it may be impractical to store daily 3D fields, due to high data volumes – in such cases, monthly resolution is acceptable.

- **Output levels for atmospheric data.** Atmospheric data should be output on a minimum of eight pressure levels, as listed in Table A1. The levels have been chosen to sample near surface levels as well as the free troposphere and stratosphere. Output on additional levels, including model levels as well as pressure levels is encouraged.
- **Output levels for ocean and sea ice data.** Output should be on model levels. There are no commonly accepted physical standards for output levels from ocean or sea ice models. There is no recommendation from OMIP, and GODAE request model level output.
- **Precipitation and fluxes**. Precipitation should be accumulations over each output time interval (e.g., 3 hours). Fluxes should be the average over each time interval – this is consistent with CMIP6, although not with TIGGE and S2S, which used accumulations from the beginning of the model run. Although instantaneous fluxes could be more useful for process studies, they may fluctuate strongly, so are not included in the core output on the full model grid.
- **Budget terms**. For atmospheric models, output should include terms in the energy budget at the surface and top of the atmosphere (radiation, sensible and latent heat). The surface momentum budget should include turbulent momentum flux, plus other terms including gravity wave drag and orographic drag where available. For sea ice models, terms in the momentum and ice mass balance may also be supplied, following SIMIP practice, as listed in Notz et al (2016).
- **Extremes**. The maximum wind speed, and maximum and minimum temperatures should be output every 6 hours (or at the chosen output frequency) to enable extremes to be calculated (e.g., local day-time maximum and night-time minimum temperatures).
- **Horizontal resolution.** Fields should be output on the original model grid, since the range of experiments will cover a wide range of resolutions and domains.
- **Sea ice output.** For multi-thickness category sea ice models, we adopt the approach described in Notz et al. (2016): “To report grid-cell averages for multi-category models, the properties of the individual categories should be averaged to a single value for each time step by calculating the area weighted average across all categories.”
- **Site-specific output.** In addition to the core output, model teams are requested to consider outputting a more comprehensive set of physical variables at high frequency, for key observation locations (at super-sites, for selected locations in the Arctic and Antarctic), see section B, on *Site-specific Output*.

Table A1. Proposed core atmospheric model output for YOPP

Multi-level

Name	*Unit*	*Notes*
Geopotential height	gpm	Minimum set of pressure levels: 1000, 925, 850, 700, 500, 250,

		100, 10 hPa
U-velocity	m s^{-1}	Minimum set of pressure levels: 1000, 925, 850, 700, 500, 250, 100, 10 hPa
V-velocity	m s^{-1}	Minimum set of pressure levels: 1000, 925, 850, 700, 500, 250, 100, 10 hPa
W-velocity	Pa s^{-1}	Minimum set of pressure levels: 1000, 925, 850, 700, 500, 250, 100, 10 hPa; positive downwards (increasing pressure)
Temperature	K	Minimum set of pressure levels: 1000, 925, 850, 700, 500, 250, 100, 10 hPa
Specific humidity	kg kg^{-1}	Minimum set of pressure levels: 1000, 925, 850, 700, 500, 250, 100, 10 hPa

Single Levels

Name	***Unit***	***Notes***
Land-sea mask	Proportion	Only from Control Member in ensemble forecasts.
Orography	gpm	Only from Control Member in ensemble forecasts.
Mean sea level pressure	Pa	
Surface pressure	Pa	
10 metre u-velocity	m s^{-1}	Instantaneous
10 metre v-velocity	m s^{-1}	Instantaneous
Average 10m u-velocity	m s^{-1}	Averaged since previous output time
Average 10m v-velocity	m s^{-1}	Averaged since previous output time
Maximum 10m wind speed	m s^{-1}	Maximum grid-box value, since previous output time
Wind gust speed at 10m	m s^{-1}	Diagnosed wind gust speed
10 metre air temperature	K	Instantaneous
Surface air temperature	K	At nominal height of 2m (instantaneous)
Maximum surface air temperature	K	Since previous output time
Minimum surface air temperature	K	Since previous output time

Surface air dew point temperature	K	At nominal height of 2m
2m relative humidity	%	
2m specific humidity	kg kg^{-1}	
Skin temperature	K	
Total precipitation	kg m^{-2}	The sum of convective precipitation and large scale precipitation accumulated over each output time interval.
Snow depth water equivalent	kg m^{-2}	
Snow fall water equivalent	kg m^{-2}	Frozen precipitation, accumulated over each output interval.
Surface albedo	%	Not in TIGGE. S2S uses daily average snow albedo
Total cloud cover	%	
Cloud base height	m	User-oriented (aviation)
Horizontal visibility	m	At nominal height of 2m. User-oriented (aviation & navigation).

Atmospheric budget terms

Name	***Unit***	***Notes***
Time-average outgoing long wave radiation	W m^{-2}	At top of atmosphere
Time-average incoming short-wave radiation	W m^{-2}	At top of atmosphere
Time-average outgoing short-wave radiation	W m^{-2}	At top of atmosphere
Time-average surface latent heat flux	W m^{-2}	The flux sign convention is positive downwards.
Time-average downward surface short-wave radiation	W m^{-2}	TIGGE has net surface solar radiation
Time-average upward surface short-wave radiation	W m^{-2}	
Time-average surface downward long-wave radiation	W m^{-2}	TIGGE has net surface thermal radiation
Time-average surface	W m^{-2}	TIGGE has net surface thermal

upward long-wave radiation		radiation
Time-average surface sensible heat flux	Wm^{-2}	The flux sign convention is positive downwards.
Time-average northward turbulent surface stress	N m^{-2}	Not in TIGGE. Other terms in the momentum budget should also be included where available.
Time-average eastward turbulent surface stress	N m^{-2}	Not in TIGGE. Other terms in the momentum budget should also be included where available.
Time-average magnitude of turbulent surface stress	N m^{-2}	Not in TIGGE. Other terms in the momentum budget should also be included where available.
Time-average total column water vapour	kg m^{-2}	For validation of radiation budget
Time-average total column liquid water	kg m^{-2}	For validation of radiation budget
Time-average total column ice water	kg m^{-2}	For validation of radiation budget

Table A3. Proposed core ocean output for YOPP

Ocean

Name	***Unit***	***Notes***
Ocean temperature	K	Model levels
Ocean salinity	g kg^{-1}	Model levels. Proportion as parts per 1000, equivalent to “practical salinity unit”.
Sea surface height	m	
Ocean u-velocity	m s^{-1}	Model levels
Ocean v-velocity	m s^{-1}	Model levels
Ocean w-velocity	m s^{-1}	Model levels
Ocean mixed-layer depth	m	Levitus (1982) definition
Sea Surface Height Above Geoid	m	
Sea Floor Depth	m	Ocean bathymetry. Sea floor depth for present day. Reported as missing for land grid cells.
Ocean Grid-Cell Area	m^2	

Ocean budget terms

Name	***Unit***	***Notes***
Ocean surface heat flux	W m^{-2}	Positive downwards

Ice-ocean heat flux	W m^{-2}	Positive downwards
Water flux into sea water	m s^{-1}	Positive downwards
Water flux into sea water due to sea ice thermodynamics	m s^{-1}	Positive downwards
River runoff	m s^{-1}	Positive downwards
Virtual salt flux into sea water	psu m s^{-1}	Positive downwards
Ocean surface x stress	N m^{-2}	
Ocean surface y stress	N m^{-2}	

Sea State

Name	***Unit***	***Notes***
Significant wave height	m	
Peak period	s	From the 1D spectrum (comparison with buoys)
Mean period	s	From the second moment (TM02)
Wave direction	degrees	

Table A2. Proposed core sea-ice output for YOPP

Sea Ice

Name	***Unit***	***Notes (SIMIP names in italics)***
Sea ice area fraction	1	*siconc*
Sea ice thickness	m	*sithick* Thickness in ice-covered fraction only
Snow thickness on sea-ice	m	*sisnthick*
Surface temperature	K	*sitemptop* Surface temperature of snow or non-snow covered ice
Sea ice u-velocity	m s^{-1}	*siu*
Sea ice v-velocity	m s^{-1}	*siv*
Sea ice salinity	g kg^{-1}	*sisali*
Temperature at snow–ice interface	K	*sitempsnic*
Temperature at ice–ocean interface	K	*sitempbot*
Sea-ice or snow albedo	1	*sialb*
Compressive sea ice strength	Pa m	*sicompstren* In EVP models can be diagnosed from thickness and concentration
Normal stress (pressure)*	Pa	*sistresave*

Ridged ice area fraction*	1	*sirdgconc*
Ridged ice thickness*	m	*sirdgthick*
Sea-ice area fractions in thickness categories*	1	*siitdconc*
Sea-ice thickness in thickness categories	m	*siitdthick*
Age of sea ice*	s	*siage*
Fast ice area fraction*	proportion	Not a SIMIP variable, but represented in some models e.g., RIOPS
Fast ice thickness	m	Not a SIMIP variable, but represented in some models e.g., RIOPS

Sea ice budget terms

Name	***Unit***	***Notes (SIMIP names in italics)***
Time-average surface energy flux	W m^{-2}	Positive downwards, not a SIMIP variable; flux at surface of snow or non-snow covered ice
Time-average ice-ocean energy flux	W m^{-2}	Positive downwards

*Sea ice properties of particular relevance to marine navigation

B. Site-Specific Output

In addition to the common set of output fields, modelling teams are requested to output additional data to permit process-based evaluation with observations from key locations. The proposed set of locations comprises IASOA super-sites (https://www.esrl.noaa.gov/psd/iasoa), ECCC super-sites (ecpass.ca) selected Antarctic stations, and at key locations covering the so–called “third pole” (Tibetan plateau). In order to facilitate the study of ocean-cryosphere-atmosphere coupling processes, data should also be extracted at the (changing) locations of the research ship Oden (INTAROS) and the MOSAIC drifting observatory (http://www.mosaicobservatory.org/) and a few fixed locations (to be defined) over the Arctic and Southern Oceans. Table B1 shows the locations of the super-sites, including IASOA, ECCC and Antarctic sites.

Table B1: Locations for site-specific model output, corresponding to supersites

Supersite	**Latitude Longitude**	**Elevation**
	Arctic	
Barrow (Alaska)	71.325°N, 156.625°W	8-20 m
Oliktok Point (Alaska)	70.49525°N 149.88688°W	2-6 m

White Horse (Canada)	60.71°N, 135.07°W	682 m
Eureka (Canada)	80.083°N 86.417°W	0-610 m
Iqaluit (Canada)	63.74°N, 68.51°W	5-11 m
Alert (Canada)	82.492°N, 62.508°W	8-210 m
Summit (Greenland)	72.58°N, 38.48°W	3210-3250 m
Ny-Ålesund (Svalbard)	78.923°N, 11.53°E	0-30 m
Sodankyla (Finland)	67.368°N, 26.633°E	198 m
Pallas (Finland)	67.967°N, 24.117°E	305 m
Tiksi (Russia)	71.596°N, 128.889°E	1-30 m
Cherskii (Russia)	68.733°N, 161.383°E	8 m
	Antarctic	
Ice Base Cape Baranova (Russia)	79.3°N, 101.7°E	24m
Alexander Tall Tower	79.012°S, 170.723°E	
Casey	66.281°S, 110.528°E	
Davis	68.577°S, 77.967°E	
Dome-C	75.08°S, 123.34°E	3233 m
Dumont d'Urville	66.66°S, 140.01°E	0-50 m
Halley IV	75.58°S, 26.66° W	130 m
King George Island	62.5°S, 59.0°W	
Georg von Neumayer	70.65°S, 8.25°W	42 m
Mawson	67.603°S, 62.874°E	
Syowa	69.005°S, 39.589°E	18 m
Terra Nova Bay	75°S, 164°E	
Amundsen-Scott South Pole	90°S, 0°E	2835 m
	Third Pole	
Mera (Nepal)	27.7°N, 86.9°E	4570-4520 m
Tanggula (China)	32.58°N, 91.86°E	5100 m
Xidatan (China)	35.719°N, 94.12517°E	4940-6420 m
Iaohugou (China)	37.5°N, 96.5°E	4180 m

The motivation is to support detailed evaluation of the model representation of a range of physical processes, as described in the YOPP modelling plan (YOPP, 2017). The processes to be evaluated include: the radiation budget, turbulence and energy balance; clouds and vertical profiles of water vapour, liquid and ice water content; aerosols and hydrometeors microphysics; and any other physical processes which are supported by the observations at the super-sites.

Some key issues:

- **Output levels.** In order to permit detailed process studies, vertical profiles will be needed on the native model vertical levels.
- **Output frequency**. High frequency output will be needed to support process studies. Depending on the model, output is requested at least hourly. If possible, data should be output every 5 to 15 minutes, or for every model time-step. Output at every time-step is likely to be noisy, but even that could be interesting to model developers. Since the output data is high frequency, averages and extremes during each output period are not required.
- **Output locations**. Output is requested at least for the four model grid-points nearest (surrounding) the super-site location. Ideally, model output should be provided for the set of model grid points sampling the area within 20km of the observation site. The precise locations will be left to model teams to decide, since the choice will be dependent on the model grid.

Output variables

The site-specific output should include the core variables that were listed in Table A1. There are some modifications to that list: output should be at all model levels to allow detailed process studies; some time-averaging and extreme fields are not included, because of the high frequency output. Table B2 shows the core site-specific output taking into account those modifications.

Modelling groups are also encouraged to produce additional output, to enable more focused process studies and allow detailed comparisons with observations of microphysics data, where available from the super-sites, for example:

- Model parameters for the direct calculation of Mixing Layer Height.
- Water vapour and cloud liquid & ice profiles (kg m^{-3}), or column-integrated liquid and ice water paths (kg m^{-2})
- Cloud fraction for each model level. Cloud optical properties: cloud opacity and thickness, vertical profiles (and column integrated) liquid and ice optical depth. Effective cloud cover (total cloud cover with optical depth).
- Prognostic microphysics variables (to obtain hydrometeors particles class and phase, size and shape, mass and concentration/density, number and average size per unit volume). For both liquid and solid phase: mixing ratio (kg kg^{-1}), concentration (# m^{-3}), effective radius (m).
- Surface precipitation type (drizzle, rain, snow, graupel, hail, freezing rain, ice pellets) and rate (kg m^{-2} s^{-1}).
- Snow depth (m); snow surface temperature; snow-layer profile temperature (K). Surface roughness for heat and momentum (m); type of soil and vegetation (if applicable); soil surface temperature (K), soil moisture (kg m^{-2}); soil temperature profile (K) and soil moisture profile (kg m^{-3}).

- Vertical profiles of moisture, heat and momentum fluxes; Gravity wave drag, orographic and turbulence surface stress ($m^2 s^{-2}$); friction surface velocity ($m s^{-1}$)
- Tendency of air temperature, specific humidity and wind components due to advection.

While the requested site-specific data are primarily focused on atmospheric process studies at the observation supersites, additional sea-ice and ocean output, at the standard ocean locations and the drifting sites (MOSAiC and Oden) based on tables A2 and A3, would also be invaluable for studying coupling processes.

Table B2. Core atmospheric model site-specific output

Multi-level

Name	***Unit***	***Notes***
Geopotential height	gpm	Model levels
U-velocity	$m s^{-1}$	Model levels
V-velocity	$m s^{-1}$	Model levels
W-velocity	$m s^{-1}$	Model levels
Temperature	K	Model levels
Dew-point temperature	K	Model Levels
Specific humidity	$kg kg^{-1}$	Model levels

Single Levels

Name	***Unit***	***Notes***
Land-sea mask	Proportion	Only from Control Member in ensemble forecasts.
Orography	gpm	Only from Control Member in ensemble forecasts.
Mean sea level pressure	Pa	
Surface pressure	Pa	
10 metre u-velocity	$m s^{-1}$	
10 metre v-velocity	$m s^{-1}$	
Wind gust speed at 10m	$m s^{-1}$	Diagnosed wind gust speed
10m air temperature	K	
Surface air temperature	K	At nominal height of 2m
10m dew point temperature	K	Additional site-specific output
Surface air dew point temperature	K	At nominal height of 2m
Skin temperature	K	
Total precipitation	$kg m^{-2}$	The sum of convective

		precipitation and large scale precipitation accumulated over each output time interval.
Snow depth water equivalent	kg m^{-2}	
Snow fall water equivalent	kg m^{-2}	Frozen precipitation, accumulated over each output interval.
Surface albedo	%	Not in TIGGE. S2S uses daily average snow albedo
2m specific humidity	kg kg^{-1}	
10m specific humidity	kg kg^{-1}	Additional site-specific output
Total cloud cover	%	
Cloud base height	m	
Cloud top height	m	
Horizontal visibility	m	At nominal height of 2m

Atmospheric budget terms

Name	***Unit***	***Notes***
Time-average outgoing long wave radiation	W m^{-2}	At top of atmosphere
Time-average incoming short-wave radiation	W m^{-2}	At top of atmosphere
Time-average outgoing short-wave radiation	W m^{-2}	At top of atmosphere
Time-average surface latent heat flux	W m^{-2}	The flux sign convention is positive downwards.
Time-average downward surface short-wave radiation	W m^{-2}	TIGGE has net surface solar radiation
Time-average upward surface short-wave radiation	W m^{-2}	
Time-average surface upward long-wave radiation	W m^{-2}	TIGGE has net surface thermal radiation
Time-average surface downward long-wave radiation	W m^{-2}	TIGGE has net surface thermal radiation
Time-average surface sensible heat flux	Wm^{-2}	The flux sign convention is positive downwards.
Time-average northward turbulent surface stress	N m^{-2}	Not in TIGGE.
Time-average eastward	N m^{-2}	Not in TIGGE.

turbulent surface stress		
Time-average total column water vapour	kg m^{-2}	For validation of radiation budget
Time-average total column liquid water	kg m^{-2}	For validation of radiation budget
Time-average total column liquid water	kg m^{-2}	For validation of radiation budget

References

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