

M23 Delivery of documentation for individual model data, as described in the protocol

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* **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

** **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

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Executive Summary

ASPECT (Adaptation-oriented Seamless Predictions of European ClimaTe) project produces a step change in the information provided for European decision-makers, planners and practitioners tailored to support improved resilience to future climate and weather. The project is delivered by a consortium of European climate specialists with a balance of physical science (prediction, projection and impacts) and social science (user engagement, climate services, communication).

ASPECT will design and generate an enhanced global ensemble prediction system spanning the seasonal to decadal timescales, tailored to user needs for climate adaptation. The project will also produce a range of derived information, such as metrics for evaluating predictive skill of means and extremes (WP2), end-user-oriented outputs (WP4 and WP5), temporally merged prediction–projection datasets (WP3), a catalogue of extreme events (WP3), statistically downscaled data (WP3), and specific impact-relevant indicators (WP4). In addition, selected outputs from impact models and social science data (WP5) may be included.

As part of the protocol outlined in Work Package 6 (WP6), comprehensive documentation for new prediction simulations and 30-year initialised climate outlooks will be generated and produced to the users. These simulations will be stored on ESGF (Earth System Grid Federation) data nodes or ECMWF/CDS, and the aim of the document is to provide a structured collection of documentation to ensure data transparency, usability, and discoverability.

About ASPECT

ASPECT aims to establish and demonstrate a **seamless climate information system** providing predictions with a time horizon of up to 30 years. This project is supported by cutting-edge research and by the practical application of climate information to various socio-economic sectors.

The project's goal is to enhance existing prediction systems and to integrate their outputs across different timescales, combining them with climate projections to create a unified and seamless source of climate information. This integrated framework will serve as a standard for sectoral decision-making and climate adaptation. While the main focus is on European climate information, ASPECT also extends its scope globally wherever there is strong policy relevance, such as in disaster preparedness.

Coordinated by the **Barcelona Supercomputing Center (BSC)**, ASPECT brings together a consortium of eight partners and three UK-associated partners, combining world-leading expertise across the physical and social sciences as well as IT. The partnership covers areas such as climate prediction and projection, impact assessment and applications, user engagement and co-development, communication, climate-service design and delivery, and data management.

The consortium includes **BSC**, **CMCC**, **ECMWF**, **MPI**, **RHMZ**, **SMHI**, **UKMO**, **University of Leeds**, **University of Oxford**, **University of Zagreb**, and **Raventós Codorníu**.

1 Introduction

1.1 Purpose and Scope

In ASPECT, new predictions and projection model simulations are used to produce gridded output data. In particular, the simulations for the following timescales have been run:

- seasonal predictions (up to 7 months);
- multi-annual predictions (up to 36 months);
- decadal predictions (up to 10 years);
- extended decadal predictions (up to 20 years);
- 30-year initialised outlooks (up to 30 years);
- centennial climate projections (1850 - 2100).

Simulations using protocols similar to seasonal predictions but extending over several years are referred to as 'multi-annual predictions'. The decadal predictions are part of the DCPP experiment family, following the CMIP6/CMIP7 protocols. Also, protocols for the 30-year initialised outlooks have been defined as part of the ASPECT project, and they are documented in this document.

This document, therefore, provides the primary documentation for the new ASPECT experiments. Specifically, it includes:

- detailed descriptions of the model simulations, including configurations and experimental setups;
- guidance on how to locate, access, and download the data.

For the new simulations, ASPECT made an effort to enrich the datasets with structured, standardised, and informative metadata, in line with the FAIR data principles. This documentation plays a key role in ensuring that users can effectively discover, access, understand, and correctly interpret the data.

The ASPECT documentation provides:

- an overview of the available datasets;
- descriptions of the models and experimental designs;
- lists of available variables and their temporal frequencies;
- information on where the data are stored and how they can be accessed or downloaded;

To ensure consistency across forecast systems and institutions, WP6 has defined standard documentation templates for model descriptions and distributed them to project partners. These templates are completed by the institutions responsible for each forecast system.

1.2 Acronyms and Abbreviations

Acronyms and abbreviations used in this document are defined in the following tables.

Institutions and organisations

Acronym	Definition
ASPECT	Adaptation-oriented Seamless Predictions of European ClimaTe
BSC	Barcelona Supercomputing Center
CMCC	Euro-Mediterranean Center on Climate Change
C3S	Copernicus Climate Change Service
ECMWF	European Centre for Medium-Range Weather Forecasts
MPI	Max-Planck Institute for Meteorology
RHMZ	Republic Hydrometeorological Service of Serbia
SMHI	Swedish Meteorological and Hydrological Institute
UKMO	UK Met Office
WMO	World Meteorological Organization

Acronym	Definition
CDS	(Copernicus) Climate Data Store
CF conventions	Climate and Forecast Conventions
CMIP	Coupled Model Intercomparison Project
CMOR	Climate Model Output Rewriter
CORDEX	Coordinated Regional Climate Downscaling Experiment
DMP	Data Management Plan
ESGF	Earth System Grid Federation
FAIR	Findable, Accessible, Interoperable & Reusable
GRIB	GRIdded Binary or General Regularly-distributed Information in Binary form
MARS	(ECMWF) Meteorological Archive and Retrieval System
NetCDF	Network Common Data Form

PID	Persistent IDentifiers
S2D	Seasonal to Decadal
SCI	Seamless Climate Information
WP	Work Package

2 Description of the ASPECT experimental design

This section describes the experimental design adopted within the ASPECT project, with a particular focus on its alignment with established C3S, CMIP and DCPP (Decadal Climate Prediction Project) frameworks. It outlines experiment protocols and model configurations used to generate the ASPECT prediction across different timescales. Where applicable, the ASPECT experiments follow C3S and DCPP conventions to ensure consistency, interoperability, and comparability with existing datasets, while also documenting project-specific extensions, such as the experimental design for the 30-year initialised outlooks.

2.1 Seasonal prediction

This table shows the centres that provide data to this project, together with the configuration of their systems.

Table 1a: ASPECT Experimental Design (seasonal predictions)

Centre	Time range(forecast and hindcast	Hindcast Period	Real-time forecast ensemble size	Hindcast ensemble size	Initial conditions	Hindcast production schedule	Model
ECMWF	215 days	1993 - 2016	51 members	25 members	1st of the month	fixed	SEAS5
CMCC	184 days	1993 - 2016	50 members	30 members	1st of the month	fixed	CMCC-CM3
UKMO	215 days	1993 - 2016	2 members/ day	7 members /start time	Forecast: each day of the month Hindcast: 1st, 9th, 17th, 25th of month	on-the-fly	HadGEM3-GC3.2

A description of each data provider's specific model is available in the next section.

2.2 Multi-annual predictions

Multi-annual predictions use the same protocol as seasonal predictions, but are extended in time. A description of the system configuration by the individual centres is provided in Table 2.

Table 1b: ASPECT Experimental Design (multi-annual predictions)

Centre	Length of forecast and Hindcast	Initialization	Period	Real-time forecast ensemble size	Hindcast ensemble size	Model Version
ECMWF	27 months	May/Nov 1st of the month	1993 - 2025	May 2026 ongoing	22 members	SEAS6-Prototype (expver=ivdg)
ECMWF	24 months	May/Nov 1st of the month	1991 - 2025	May 2026 ongoing	25 members	SEAS5 (expver=i12h)
BSC	36 months	May/Nov 1st of the month	Nov init: 1960-2023 May init: 1980-2021	Nov init 2025 (decadal) HR not available	20 members	EC-Earth3
					15 members	EC-Earth-3-HR
CMCC	28 months	May/Nov 1st of the month	1980 - 2023	Nov init 2025 (decadal) May 2026 TBD	15 members	CMCC-CM2-SR5
UKMO	Depends on initial date	May 11 months /Nov 17 months 1st of the month	1980 - 2023	Not possible to provide a real-time update	40 members	DePresys3 DePresys5: integrations ongoing. Expected by end of project
MPI	24 months	May/Nov 1st of the month	1980 - 2023	May/Nov 2024, 2025 Initialization completed. (Data needs to be uploaded)	30 members	MPI-ESM-LR

2.3 Decadal predictions

The following table shows the centres that provide decadal data to the project, together with the configuration of their systems.

Table 1c: ASPECT Experimental Design (decadal predictions)

Centre	Period	Real-time forecast ensemble size	Hindcast ensemble size	Model Version
BSC	1960 - 2025	50 members Last available Nov 2025	10 members	EC-Earth3
BSC	1960 - 2025	30 members In development	10 members	Prototype EC-Earth4
CMCC	1960 - 2025	40 members	40 members	CMCC-CM2-SR5
MPI	1960 - 2019	Nov 2020, …, 2025 Initialization completed. (Data needs to be uploaded)	80 members	MPI-ESM-Low res
UKMO	1960 - 2025		40 members	GC5[1]

The length of the forecast is 10 years, and the models are initialised on the 1st of November of each year.

2.4 Extended decadal predictions

The following table shows the centres that provide extended decadal data to the project, together with the configuration of their systems.

Table 1d: ASPECT Experimental Design (extended decadal predictions)

Centre	Period	Real-time forecast ensemble size	Hindcast ensemble size	Model Version	Forecast lengh
BSC	1960 - 2025 every 5 years	Nov 2025 initialization completed. (Data needs to be uploaded)	10 members	EC-Earth3[6]	30 years
CMCC	1960 - 2025 every 4/5 years	20-member Nov 2025 initialization completed. (Data needs to be uploaded)	15 members	CMCC-CM2-SR5	20 years
MPI	1960 - 2019 every year	Nov 2020, …, 2025 Initialization	16 members	MPI-ESM-Low res	20 years

[1] https://centaur.reading.ac.uk/112173/,

		completed. (Data needs to be uploaded)			

The length of the forecast is 20 years, and the models are initialised on the 1st of November every 4-5 years.

2.5 30-year outlooks

Finally, the following table shows the centres that provide 30-year data to the project, together with the configuration of their systems.

Table 1e: ASPECT Experimental Design (30-year initialised outlooks)

Centre	Length of forecast and Hindcast	Initialization	Period	Real-time forecast ensemble size	Hindcast ensemble size	Model Version
ECMWF	30-year initialized	Jan 1st of the month	1990,1995, 2020, and 2025	Jan 2025 available	11 members (1995 and 2020 with 5 ens) Single member forecasts every 2 years from 1992-2024	SEAS6 protopyte
BSC	30 years	Nov 1st of the month	1960 - 2025 every 5 years	Nov 2025 available (see above)	10 members	EC-Earth3

The length of the forecast is 30 years, and the models are initialised on the 1st of November. ECMWF will initialise the model for 3 start dates, while BSC every 5 years.

2.6 Projections

The following table shows the centres that provide projection data to the project, together with the configuration of their systems.

Table 1f: ASPECT Experimental Design (climate projections)

Centre	Length of forecast and Hindcast	Period	Real-time forecast ensemble size	Hindcast ensemble size	Model Version
BSC	Historical simulations	1850 - 2020		15 members	EC-Earth3

MPI	Historical simulations	1850 - 2014		50 members	MPI-ESM-Low res
MPI	Scenario Projections	2015 - 2100		50 members	MPI-ESM-Low res

The historical simulations (1850-2014) and climate projections (2015-2100) serve as an unperturbed control forecast.

3 Forecast system description

This section provides a detailed description of the ASPECT forecast systems, following conventions commonly used in C3S documentation. It describes the underlying climate models, their components and coupling strategies, and the configuration of the forecasting systems used to produce the ASPECT simulations. This information is essential for understanding the provenance of the simulations and for placing the ASPECT forecast systems in the broader context of climate modelling efforts.

In ASPECT, all the simulations were run through WP1. The description of the model can be found below:

3.1 BSC Systems

Documentation of the BSC prediction systems referenced in this ASPECT is available at:

- **BSC DCPP system of EC-Earth3**
- **BSC High-resolution forecast system**
- **BSC system based on EC-Earth4**

The multi-annual predictions (36-month), the decadal predictions, and the extended decadal predictions are all produced using the same forecast system, based on the standard-resolution EC-Earth3 model.

In addition, a dedicated multi-annual prediction experiment was performed using the high-resolution EC-Earth3 configuration. Further experiments were also conducted with the new BSC forecast system, which is based on EC-Earth4.

3.2 CMCC Systems

Documentation of the CMCC prediction systems referenced in this ASPECT is available at:

- **CMCC SPS4**
- **CMCC-CM2-SR5**

The multi-annual predictions (24-month), decadal predictions and, extended-decadal prediction all use the same model configuration and initial conditions (CMCC-CM2-SR5, Nicolì et al. 2023).

The seasonal predictions, instead, are produced with the new system, which is now operational in C3S.

3.3 ECMWF Systems

Documentation of the ECMWF prediction systems referenced in this ASPECT is available at:

- **SEAS5-v20171101 (seasonal and multi annual (expver=i12j))**
- **ECMWF SEAS6 prototype (for multi years)**

The seasonal prediction was run with the operational SEAS5 model, while the multi-annual predictions (36-month) and the 30-year outlooks were run with the new SEAS6-prototype.

3.4 MPI Systems

Documentation of the MPI prediction systems referenced in this ASPECT is available at:

- **MPI-ESM-Lowres**
- **MPI-ESM-Highres**

The multi-annual predictions (24-month) use the MPI-ESM-Highres system, while decadal predictions, extended decadal predictions, and climate projections all use the same model (MPI-ESM-Lowres)

3.5 UKMO Systems

Documentation of the UKMO prediction systems referenced in this ASPECT is available at:

- **HadGEM3-GC3.2**
- DePreSys5 prototype

4 Data access

ASPECT data are archived and made publicly available through multiple archival infrastructures, with access methods varying by system. In all cases, datasets can be searched using the available metadata and downloaded once they have been made publicly available.

Data archived within ESGF becomes fully accessible once it is published through the relevant ESGF data nodes. Predictions archived in MARS may experience a short delay before being released for open and public access, reflecting operational publication workflows.

Data archived in ESGF can be discovered and browsed via the ESGF portals (index nodes), which provide an interface for accessing datasets distributed across multiple ESGF data centres. ESGF also provides comprehensive guidance for users through its User Support documentation.

Data archived in MARS can be explored through the MARS catalogue via the web interface or accessed programmatically using the ECMWF Web API, enabling both interactive and automated data retrieval.

Further information on the access points for the ASPECT data can be found in the D6.1 deliverable and on the ASPECT Data Hub (https://www.aspect-project.eu/dataset/).

A summary of the data formats and conventions adopted for each ASPECT experiment type is provided in Table 2.

Table 2: Experiments, formats and archiving systems in ASPECT

Type of experiment	Institution	Format	Archive	Access
Seasonal Predictions	CMCC	GRIB	CDS	CDS request
	ECMWF	GRIB	CDS	CDS request
	UKMO	GRIB	CDS	CDS request
Multi-annual Predictions	BSC	NetCDF	ESGF	ESGF portals
	CMCC	NetCDF	ESGF	ESGF portals
	ECMWF	GRIB	MARS	MARS request
	UKMO	NetCDF	ESGF	ESGF portals
	MPI	NetCDF	Deutsches Klimarechenzentrum	Deutsches Klimarechenzentrum
Decadal Predictions	BSC	NetCDF	ESGF	ESGF portals
	CMCC	NetCDF	ESGF	ESGF portals
	UKMO	NetCDF	ESGF	ESGF portals
	MPI	NetCDF	Deutsches Klimarechenzentrum	Deutsches Klimarechenzentrum
Extended Decadal Predictions	BSC	NetCDF	ESGF	ESGF portals
	MPI	NetCDF	Deutsches Klimarechenzentrum	Deutsches Klimarechenzentrum
30-year initialized outlooks	BSC	NetCDF	ESGF	ESGF portals
	ECMWF	GRIB	MARS	MARS request
Climate Projections	MPI	NetCDF	ESGF	ESGF portals

In all cases, the data will strictly adhere to the archiving system's requirements. Detailed information on data access to these repositories is provided in the Data Access section of this document and in Appendix I.

Data Formats and Conventions

In ASPECT, model outputs are encoded in NetCDF and GRIB formats. NetCDF is a freely available and widely used format within the climate modelling community, while GRIB is the WMO-standard binary format for the international exchange of meteorological gridded data.

Most ASPECT data provided in NetCDF format follow the CF conventions and CMOR standards, and conform to the CMIP6 and CMIP7 controlled vocabularies. File naming and directory structures are consistent with the CMIP6 specifications, including the Global Attributes, Data Reference Syntax (DRS), filename conventions, directory structure, and controlled vocabularies.

NetCDF files are produced using the NetCDF Classic Model in the NETCDF4_CLASSIC format, which allows compression but does not support groups or compound data types. Each NetCDF file contains a single physical variable, along with the associated coordinate and grid variables, attributes, and metadata, from a single model simulation, corresponding to one ensemble member and one start date.

Model outputs encoded in GRIB format follow the established ECMWF rules and practices for long-range forecasts, ensuring consistency with operational dissemination and compatibility with existing ECMWF tools and workflows.

User Support
WP6 is the first point of contact for data-related issues. This DMP does not address the resolution of problems related to data content and should be tackled by the data producers.

5 Summary of available data

This section provides a summary of the currently available ASPECT data, outlining the central system and experiment.

5.1 Seasonal predictions

All ASPECT seasonal forecast data are served through the CDS and are currently stored at the ECMWF MARS archive, where data is kept in GRIB format. Because of this, the various forecasting systems of a given producing centre are labelled using the MARS-specific keyword "system" found in each GRIB header as an integer. For any data retrieval, the CDS (or MARS) requires that the "system" keyword be specified.

Using the "system" keyword to match real-time forecasts with their corresponding hindcasts is crucial for the correct use of the C3S seasonal forecast data. Details on how that label is assigned can be found in the following sections.

Systems producing their hindcasts as a fixed dataset

For these forecasting systems, a unique value of the keyword "system" is assigned in an attempt to closely match the version numbering used by the forecasting centres. Specifically:

Forecasting centre	System name	'System' value
CMCC	CMCC-CM3	4
ECMWF	SEAS5	51

Systems producing their hindcasts on-the-fly

Systems that follow this approach generate a new set of hindcasts close to the real-time forecast they relate to.

The following table lists the values of the 'system' keyword used in the CDS for on-the-fly hindcasts systems:

Forecasting centre	System name	'System' value
UKMO	GloSea6	600/601/602/603

Comprehensive and detailed documentation on seasonal forecasts available in the CDS can be found in the official C3S seasonal forecast documentation.

5.2 Multi-annual predictions

Multi-annual (extended seasonal) productions have been archived in a different archiving repository based on the model output format.

ECMWF data

Multi-decadal ECMWF data are stored in the MARS archive, where each dataset is identified using a set of specific MARS keywords.

The data can be accessed through the following MARS catalogue using the proper MARS keywords:

- Multi-annual predictions data (MARS)

These keywords are required to locate and retrieve the data correctly. The table below summarises the key values relevant to the ECMWF contribution:

Forecasting centre	System name	'expver' value	'class' value	'stream' value	'type' value	'levtype' value
ECMWF	SEAS6-prototype	ivdg	rd	mmsf (Multi-model seasonal forecast) msmm (Multi-model seasonal forecast atmospheric monthly means)	fc (forecast)	pl (pressure) sfc (surface)
ECMWF	SEAS5	i12j	rd	mmsf	fc	pl

				(Multi-model seasonal forecast) msmm (Multi-model seasonal forecast atmospheric monthly means)	(forecast)	(pressure) sfc (surface)

These keywords ensure that users retrieve the correct multi-decadal forecast data associated with the SEAS6-prototype system. In particular, the *expver* and *class* fields uniquely distinguish this dataset within MARS and differentiate it from other ECMWF forecast systems and data streams.

All available variables with their frequency are listed in the 'parameters' table, while data availability can be checked using a dedicated MARS tool available on the MARS catalogue web page.

Access to the data is open and available on demand; however, users are required to complete a simple registration process and submit a request to the project in order to obtain access.

BSC, CMCC and UMKO data

Multi-decadal data from BSC and CMCC are stored in ESGF.

The data can be accessed through the following ESGF search web interface using the proper keywords:

- Multi-annual predictions data (ESGF)

The relevant keywords that should be used are shown in the following table

Forecasting centre	System name	'Activity ID' value	'sourceID' value	'experimentID' value	'sub-experiment' value
BSC	EC-Earth3	DCPP	EC-Earth3	dcppA-hindcast	SYYYYMMDD 1980-2023
CMCC	CMCC-CM2	DCPP	CMCC-CM2-SR5	dcppA-hindcast	SYYYYMMDD 1980-2019
UKMO	DePreSys5 prototype	TBC	TBC	TBC	TBC

SYYYYMMDD stands for the start date of the forecast, where YYYY=year, MM=month and DD=day, where all available start dates are listed in the pop-up selection menu.

All available variables with their frequency are listed in the 'Classifications' facets. In ESGF terminology, a facet is the way to index the data, so each facet corresponds to a metadata attribute embedded in the dataset (mainly NetCDF global attributes and directory structure).

MPI Data

Multi-decadal data from MPI are stored at the World Data Center for Climate (WDCC), hosted and maintained by the German Climate Computing Center (DKRZ).

The data can be accessed through the dedicated entry for multi-annual prediction datasets at DKRZ, in the following link:

- Multi-annual predictions data (DKRZ)

Access to the data is free, but users must complete a simple registration process before downloading it.

Please also note that the output format is close to, but not fully compliant with, the CMOR standard, while the available variables are listed on the enter page together with the relevant documentation.

5.4 Extended decadal predictions

BSC and CMCC data
Similar to the multi-annual predictions, decadal and extended decadal data from BSC and CMCC are also stored in ESGF.

The data can be accessed through the following ESGF search web interface using the proper keywords:

- Decadal predictions data (ESGF)

The relevant keywords that should be used are shown in the following table

Forecasting centre	System name	'Activity ID' value	'sourceID' value	'experimentID' value	'sub-experiment' value
BSC	EC-Earth3	DCPP	EC-Earth3	dcppA-hindcast	SYYYY
CMCC	CMCC-CM2	DCPP	CMCC-CM2-SR5	dcppA-hindcast	SYYYY
UKMO	TBC	TBC	TBC	TBC	TBC

SYYYY stands for the start date of the forecast, where YYYY=year, where all available start dates are listed in the pop-up selection menu.

All available variables with their frequency are listed in the 'Classifications' facets.

MPI Data
Decadal and extended decadal data from MPI are also stored at the World Data Center for Climate (WDCC).

The data can be accessed through the dedicated entry for decadal prediction datasets at DKRZ, in the following link:

- Decadal - extended decadal predictions data (DKRZ)

From the entry for "MPI-ESM-LR 1.2.01 decadal prediction localEnKF monthly" (ensemble members 1-16) and "MPI-ESM-LR 1.2.01 decadal prediction localEnKF LE monthly" (ensemble members 17-80), a user can download tar files for monthly atmospheric, oceanic and ocean-biogeochemistry monthly-means products.

Also available are daily atmospheric, oceanic, and ocean-biogeochemistry data, as well as 3-hourly atmospheric data.

Access to the data is free, but users must complete a simple registration process before downloading it.

Please also note that the output format is close to, but not exactly matching, the CMOR standard, while the available variables are listed on the enter page.

5.5 30-year outlooks

ECMWF Data
30-year ECMWF data is stored in MARS.

The data can be accessed through the following MARS catalogue using the proper MARS keywords:

- 30-year outlook predictions data (MARS)

The relevant keywords that should be used are shown in the following table.

Forecasting centre	System name	'expver' value	'class' value	'stream' value	'type' value	'levtype' value
ECMWF	SEAS6-prototype	**TBC** (The experiment is expected to be completed by Q1/2026)	rd	mmsf (Multi-model seasonal forecast) msmm (Multi-model seasonal forecast atmospheric monthly means)	fc (forecast)	pl (pressure) sfc (surface)

Note: Please note that at the time of producing this document, the 30-year outlook run was still in progress, and some information was therefore not yet available. Once the run is complete, the ASPECT documentation will be updated to incorporate the complete set of details and better support user needs.

BSC Data
30-year outlook data from BSC are stored in ESGF.

So, the data can be accessed through the following ESGF search web interface using the proper keywords:

- 30-year outlook predictions data (ESGF)

The relevant keywords that should be used are shown in the following table

Forecasting centre	System name	'sourceID' value	'experimentID' value	'sub-experiment' value
BSC	EC-Earth4	EC-Earth4 (TBC) (The experiment is expected to be completed in the first half of 2026.)	dcppA-hindcast	SYYYY

SYYYYMMDD stands for the start date of the forecast, where YYYY=year.

Note: As with ECMWF data, at the time this document was produced, the EC-Earth4 development was still in progress. Once the model is read and the run is completed, the ASPECT documentation will be updated accordingly to incorporate the complete set of details.

5.6 Other research outputs

Alongside the core simulations, the modelling centres and model-focused work packages (WP1-WP2-WP3) generate derived data products. These data include metrics for evaluating forecast skill for means, extremes, and user-relevant variables; temporally merged datasets combining information from forecasts, predictions, and projections; catalogues of extreme events; statistically downscaled datasets; and specialised indicators co-developed with super users.

This type of data has been stored in a central location where project partners and registered users can access additional ASPECT data that is not available through public repositories such as the CDS or ESGF.

The URL of the FTP portal is: https://aux.ecmwf.int/ecpds/home/aspect/

All research products are accompanied by their own documentation, which is typically included within the corresponding tar files. Therefore, no additional documentation is provided here.

Statistical downscaled data

For the moment, only data from Deliverable 3.2 (WP3) has been stored (output fields from statistical downscaling for user variables in full time series, for regions in Europe agreed with users in WP4 and WP5). That data has been created for the needs of ASPECT case studies and compressed into zip files for each case study, and each downscaling method applied. The internal data format is NetCDF, but not CMORised. It is important to note that within the

compressed file, detailed documentation is available describing data input, observations, scope and methodology, improvements achieved, etc.

Temporal Merging

The methodology developed and tested for temporal data merging is described in the D3.1 deliverable (internal ASPECT document). Several YAML files are used to provide unambiguous identifiers of the specific simulations chosen at each start date.

Such an identifier can typically be constructed from a combination of the model name and the identifiers of specific ensemble members (e.g. r1i1f1p1, r2i1f1p1, etc.) as used within the Coupled Model Intercomparison Project Phase 6 (CMIP6).

As part of D3.1 deliverable, the data associated with two recent publications: Cos et al. (2024) and Donat et al. (2024). These data are available at the following Zenodo repository links:

- Cos et al. (2024): https://doi.org/10.5281/zenodo.14393191
- Donat et al. (2024): https://doi.org/10.5281/zenodo.14393338

6 Detailed list of parameters

The list of variables that will be produced is available in Appendix III.

7 Recommendations for ASPECT data

Tools

GRIB and NetCDF are widely used formats for encoding gridded model outputs and in general environmental data. A broad ecosystem of open-source tools is available for reading and processing in both formats, enabling users to work with ASPECT data across a wide range of platforms and workflows.

For GRIB data, ecCodes provides a robust and comprehensive framework for decoding and inspecting GRIB messages, and is the reference software used within ECMWF operational workflows. For NetCDF data, the netCDF libraries are freely available and support the creation and handling of CF- and CMOR-compliant datasets, ensuring consistency with CMIP and ESGF standards.

Well-established community tools, such as Python xarray in combination with cfgrib, allow users to read and analyse GRIB and NetCDF data through a unified, high-level data model. These tools facilitate common analysis tasks, including subsetting, aggregation, and time-series extraction, while preserving the associated metadata.

In addition, higher-level libraries such as xarray and ECMWF EarthKit further enhance data interoperability and usability, enabling handling of large datasets, working across formats, and integrating ASPECT data into reproducible analysis workflows. Practical examples and usage demonstrations are available through the ASPECT Data Portal, helping users effectively access and exploit the data.

8 Existing Data used by the ASPECT project

Achieving ASPECT's objectives involves accessing a large number of different existing data sources. ASPECT will make use of data from existing weather and climate model datasets (e.g. C3S, CMIP5, CMIP6, CORDEX), and observational and reanalysis datasets (e.g. GPCP, E-OBS, HadCRUT, ERA-5, C3S regional reanalyses).

Data is available from their original repositories under the current access conditions (e.g. C3S's User Requirements Database[2]), while WP6 will provide documentation to explain where to find and how to access this data.

Below are the datasets that are used within the ASPECT project.

8.1 Seasonal predictions

C3S provides a multi-system seasonal forecast service, where data produced by state-of-the-art seasonal forecast systems developed, implemented and operated at forecast centres in several European countries. The data is available through CDS[3] and the catalogue entries defined by the type of variable (single-level or multi-level on pressure surfaces) and the level of post-processing applied (data at original time resolution, processing on temporal aggregation and post-processing related to bias adjustment). The available datasets are: Seasonal forecast daily and subdaily data, seasonal forecast monthly statistics, and seasonal forecast anomalies on pressure levels and single levels.

8.2 Climate projections

CMIP6 datasets are global climate model simulations from international research institutions as part of the Coupled Model Intercomparison Project (CMIP). These datasets provide projections for historical periods and future climate change under various greenhouse gas emission scenarios. CMIP6 data spans from 1850 to 2300. All data files are in NetCDF-4 format. Datasets can be found either in the main CMIP6 ESGF archive[4] or in CDS[5] . In CDS, it's only available a quality-controlled subset of CMIP6 available in ESGF. Also note that, the CDS subset of the CMIP6 dataset was first published in March 2021. This means that the data provided in the CDS reflects the status as of the end of 2020/early 2021.In practise it means that there might be some data in the CDS which were withdrawn from ESGF, or that newly published data in ESGF does not appear in the CDS. More details are available in the documentation of the CMIP6 CDS catalogue.

8.3 LESFMIP experiments

LESFMIP[6] (Large Ensemble Single Forcing Model Intercomparison Project) experiments are a number numerical model experiments that are designed to isolate the impacts of individual

[2] https://climate.copernicus.eu/user-requirements-gathering-and-analysis
[3] https://cds.climate.copernicus.eu/
[4] https://esgf-metagrid.cloud.dkrz.de/search
[5] https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cmip6?tab=overview
[6] https://www.frontiersin.org/journals/climate/articles/10.3389/fclim.2022.955414/full

external drivers. The requested diagnostics are the same for all LESFMIP experiments and the model output from LESFMIP is distributed through the Earth System Grid Federation (ESGF).

8.4 Reanalysis data available in CDS

ERA5 and ERA5-Land[7] are global atmospheric reanalysis datasets produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). These datasets combine model data with worldwide observations to create a comprehensive and consistent dataset using the laws of physics. ERA5 offers detailed atmospheric data from 1940 to the present with a resolution of 0.25 degrees, while ERA5-Land provides data from 1959 to the present at a higher resolution of 0.1 degrees. The datasets are available through CDS in GRIB2 format. Datasets are available in CDS.

8.5 Observations

Various gridded observations datasets from a selection of sources are available either in CDS or other sources like MetOffice.

The E-OBS[8] gridded observations dataset is an ensemble dataset available at 0.1 and 0.25-degree resolutions from 1950 to the present. It provides daily data for mean, minimum, and maximum temperatures, precipitation, sea level pressure, wind speed, relative humidity, and global shortwave radiation flux. Covering the European domain (25N - 71.5N, 25W - 45E), this dataset is calculated from station data acquired through the European Climate Assessment & Dataset (ECA&D) project. The data files are in NetCDF-4 format.

HadCRUT5[9] is a gridded dataset of global historical surface temperature anomalies relative to a 1961-1990 reference period. Data are available for each month from January 1850 onwards, on a 5 degree grid and as global and regional average time series.

Also, CDS offers a number satellite observations datasets, covering surface and upper-air radiation budgets, precipitation, cloud properties, and water vapour. It also includes ocean-related variables like daily and monthly gridded sea surface height and cryospheric variables such as glacier area, mass change, ice-sheet velocity, and elevation change. Additionally, CDS provides variables for lake water levels and temperatures, as well as soil moisture. All data files are available in NetCDF-4 format.

References

European Commission, Research & Innovation, Participant Portal H2020 Online Manual, http://ec.europa.eu/research/participants/docs/h2020-funding-guide/cross-cutting-issues/openaccess-data-management/data-management_en.htm

Horizon 2020 FAIR Data Management Plan (DMP) Template

[7] https://cds.climate.copernicus.eu/cdsapp#!/search?type=dataset&text=era5
[8] https://cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-gridded-observations-europe
[9] https://www.metoffice.gov.uk/hadobs/hadcrut5/

Appendix I Data Storage Infrastructures

CDS

The data published through CDS is stored on a common 1ºx1º degree grid prescribed by C3S and can be downloaded from the CDS catalogues.

Sub-daily/daily data on single or pressure levels catalogues

- Seasonal forecast daily and sub-daily data on single levels
- Seasonal forecast sub-daily data on pressure levels

This is the data at the original time resolution (once a day, or once every 6 hours for single levels, depending on the variable and once every 12 hours for pressure levels), and the data at this resolution is used to derive the monthly statistics.

Monthly Statistics catalogues

- Seasonal forecast monthly statistics on single-levels
- Seasonal forecast monthly statistics on pressure levels

Monthly statistics are made available, in addition to the sub-daily/daily original time resolution. These include

1. Ensemble: ensemble mean, hindcast climate mean
2. Individual members: monthly mean, monthly minimum, monthly maximum, monthly standard deviation *(note that this does not apply to all variables in all cases, e.g. no minimum for precipitation, or minimum, maximum and standard deviation for pressure level variables)*

These monthly aggregations are calculated from the original sub-daily/daily data provided, for each calendar month and lead-time in the hindcasts and real-time forecasts. In the case of wind, the speed is first calculated from the instantaneous u and v components of the wind at the original time resolution, then aggregated into monthly statistics.

CDS WebAPI

Data in CDS can be downloaded using CDS WebAPI. Detailed information on how to install and use CDS WebAPI (cdsapi) is available on the CDS webAPI training web page.

MARS

All the data that will be produced in GRIB format is stored in MARS (**M**eteorological **A**rchival and **R**etrieval **S**ystem).

MARS has detailed and very extensive documentation and a detailed web page on how to access archive datasets.

MARS data can be accessed through the ECMWF Web API (or MARS request). This Service will allow authorised users to **retrieve** and **list** MARS data from **outside the ECMWF facilities**. Detailed documentation is available on how to download and install ECMWF Web API as well as how to use this service.

Data available through MARS is stored in native model resolution and can be interpolated to a common 1ºx1º degree grid during their retrieval. Their access is restricted to a number of people in the ASPECT project.

Sub-daily/daily data on single or pressure levels catalogues

- Seasonal forecast daily and sub-daily data on single levels
- Seasonal forecast sub-daily data on pressure levels

This is the data at the original time resolution (once a day, or once every 6 hours for single levels, depending on the variable and once every 12 hours for pressure levels), and the data at this resolution is used to derive the monthly statistics.

Monthly Statistics catalogues

- Seasonal forecast monthly statistics on single-levels
- Seasonal forecast monthly statistics on pressure levels

Monthly statistics are made available, in addition to the sub-daily/daily original time resolution, including monthly mean, monthly minimum, monthly maximum, and monthly standard deviation for individual members.

The selection of a start date can be done by selecting the year and month at the bottom of the webpage.

ECMWF WebAPI

Data in MARS can be downloaded using ECMWF WebAPI. Detailed documentation on how to install and use ECMWF WebAPI is available on the access MARS and ECMWF WebAPI page.

It is important to understand how to get a bigger amount of data from the MARS archive. The link "Retrieve the selection in GRIB" link on the MARS catalogue page should be only used to get smaller data samples. The batch access via ECMWF's Web-API should be used for most common types of work and especially for big data sample retrievals. Please read here for more information.

Request Syntax

See brief request syntax

Interpolation

ECMWF WebAPI provides the functionality to interpolate the data to another grid, for example, to the common C3S 1ºx1º degree grid. In order to do so, the additional keys are needed in the MARS request

```
"interpolation": "--interpolation=grid-box-average"
"area": "89.5/0.5/-89.5/359.5"
"grid": "1/1",
```

Script example using WebAPI:

```
#!/usr/bin/env python
```

```
from ecmwfapi import ECMWFDataServer
server = ECMWFDataServer()
server.retrieve({
    "class": "od",
    "date": "2014-01-01",
    "expver": "1",
    "levtype": "sfc",
    "system" : "5",
    "method" : "1",
    "origin": "ecmf",
    "param": "2t/10u/10v",
    "step": "0/to/5160/by/6",
    "stream": "mmsf",
    "target": "CHANGEME",
    "time": "00",
    "type": "fc",
})
```

Finally, detailed instructions on how to download data from CDS and MARS can be found in the ASPECT repository relevant examples of MARS and CDS.

ESGF / CMIP6[10]

ESGF (**E**arth **S**ystem **G**rid **F**ederation) is an international collaboration for the software that powers most global climate change research, notably assessments by the Intergovernmental Panel on Climate Change (IPCC) and it is designed to handle large-scale data management for worldwide distribution.

The ESGF User Support web page can be found here.

ESGF has two main components, the data nodes (or data centres) and the index notes (or ESGF portals). ESGF data nodes are used to store data which is then published to the index node. In other words, the ESGF portal is an interface for users to access model data that are distributed in several data centres. Please note that the portal itself does not host any data but is only used to facilitate the search and download. The list of nodes with portals (index nodes) can be found in the link to the portals.

How to access data

[10]Coordinating an operational data distribution network for CMIP6 data (DOI: 10.5194/gmd-2020-153) https://gmd.copernicus.org/preprints/gmd-2020-153/gmd-2020-153.pdf

ASPECT data stored in ESGF can be downloaded in several ways, depending on the needs of the user, it can be a manual download for a small number of data or semi- automatically for larger number of data.

The first step is to search for data of interest through the ESGF portal (index nodes). Detailed instructions on how to make a data search and download are available on the ESGF User Support Page.

The first very basic way to download a single file, after the search for data, click on “list Files” and then “HTPPServer”, authenticate and download the file via the web browser.

An alternative more advance way to download files is to use the Wget script provided automatically by the index node, in order to download more than one file from one data node. After the search and selection of the files, download and run the Wget script.

Wget script has a number of very useful features:

- recognize if files have already been downloaded and skip them;
- interrupted download before having finished can simply restarted by running the script in the same directory
- recognize if a new version of the downloaded data is available in ESGF

Wget script can also be created using a special URL, with the help of the ESGF search RESTful API, so the search can be automatized e.g.

http://esgf-node.llnl.gov/search/cmip6/?source_id=EC-Earth3&experiment_id=dcppA-hindcast&sub_experiment=s1960&variable_id=tas&table_id=Amon

More information on the Wget script is available in the ESGF User Support Page.

There are additional very advanced ways to download data from ESGF, like the semi-manual procedure using sprocket or the ESGF PyClient.

Detailed instructions on how to use sprocket you can find in the ASPECT repository and the relevant examples.

Finally, there are suites like ESMValTool where someone can download data from ESGF and in addition can use it as a diagnostics and performance metrics tool for the evaluation of Earth System Models (ESMs) that allows for routine comparison of single or multiple models. More information about ESMValTool can be found on the ESMValTool documentation page and on tutorial page

Appendix II List of Variables

In the tables below, NetCDF DCPP and GRIB variables used in the project are provided.

Pressure Levels Fields

GRIB Name (C3S name)	GRIB short name	Units	GRIB Para mID	DCPP name	CF standard name	CMIP6 Short Name	CF canonical units
Geopotential	z	$m^2 s^{-2}$	129	geopotential	geopotential	zg, zg500	$m^2 s^{-2}$
Temperature	t	K	130	temp3d	air_temperature	ta	K
U-component of wind	u	$m s^{-1}$	131	ew wind	x_wind	ua	$m s^{-1}$
V-component of wind	v	$m s^{-1}$	132	ns wind	y_wind	va	$m s^{-1}$
Specific humidity	q	$kg kg^{-1}$	133	spec humidity	specific_humidity	hus	1

Single-level parameters

GRIB Name (C3S name)	GRIB short name	Units	GRIB Para mID	DCPP name	CF standard name	CMIP6 Short Name	CF canonical units
2 metre temperature	2t	K	167	sfc air T	air_temperature	tas	K
2 metre dewpoint temperature	2d	K	168	dew point temp	dew_point_temperature	tdps	K
10 metre U wind component	10u	$m s^{-1}$	165	ew wind	x_wind	uas	$m s^{-1}$
10 metre V wind component	10v	$m s^{-1}$	166	ns wind	x_wind	vas	$m s^{-1}$
-	-	-	-	day mean wind	wind_speed	sfcWind	$m s^{-1}$
-	-	-	-	specific humidity	specific_humidity	huss	1
	-	-	-	relative humidity (CMIP6 variable)	relative_humidity	hurs	%

	-	-	-	Daily minimum relative humidity (CMIP6 variable)	relative_humidity	hursmin	%
Mean sea level pressure	msl	Pa	151	mean sea level pressure	air_pressure_at_sea_level	psl	Pa
Surface pressure	sp	Pa	134	sfc pres	surface_air_pressure	ps	Pa
Total cloud cover	tcc	(0-1)	164	cld frac	cloud_area_fraction	clt	1
Soil temperature (level1)	stl1	K	139	-	soil_temperature		K
Skin temperature	skt	K	235	skin temp	surface_temperature	ts	K
Volumetric soil moisture	vsw	m^{-3} m^{3}	260199	soil moisture	mass_content_of_water_in_soil	mrso	kg m^{-2}
				frozen soil moisture	soil_frozen_water_content	mrfso	kg m^{-2}
Sea surface temperature	sst	K	34	sst	sea_surface_temperature	tso (C3S short name)	K
	-	-	-	sst	sea_surface_temperature	tos	K
Sea ice area fraction Sea-ice cover	ci	(0-1)	31	ice fraction	sea_ice_area_fraction	sic	1
	-	-	-	ice thinkmess	sea_ice_thickness	sit	m
Snow depth	sd	m of water equivalent	141	-	lwe_thickness_of_surface_snow_amount	-	m
Snow density	rsn	kg m^{-3}	33	snow density	snow_density	-	kg m^{-3}
Maximum temperature at 2 metres in the last 24 hours	mx2t24	51	K	day t max	air_temperature	tasmax	K
Minimum temperature at 2 metres in the last 24 hours	mn2t24	52	K	day t min	air_temperature	tasmin	K

10 metre wind gust since previous post-processing	10fg	49	m s^{-1}	day max wind	wind_speed_of_gust wind_speed	sfcWindmax	m s^{-1}
Total precipitation Large-scale precipitation Convective precipitation	tp (total) lsp (large scale) cp (convective)	228 (total) 142 (large scale) 143 (convective)	m	-	lwe_thickness_of_precipitation_amount lwe_thickness_of_stratiform_precipitation_amount lwe_thickness_of_convective_precipitation_amount	-	m m m
	-	-	-	net pcp	precipitation_flux	pr	kg m-2 s-1
	-	-	-	day max houtly pcp	precipitation_flux	pr	kg m-2 s-1
Snowfall	sf	144	m of water equivalent	-	lwe_thickness_of_snowfall_amount	-	m
	-	-	-	pcp as snow	snowfall_flux	prsn	kg m-2 s-1
Surface sensible heat flux	sshf	146	J m^{-2}	sensible up	surface_upward_sensible_heat_flux	hfss	W m^{-2}
Surface latent heat flux	slhf	147	J m-2	latent up	surface_upward_latent_heat_flux	hfls	W m^{-2}
Surface solar radiation downwards	ssrd	169	J m-2	solar down	surface_downwelling_shortwave_flux_in_air	rsds	W m^{-2}
Surface thermal radiation downwards	strd	175	J m-2	lw down	surface_downwelling_longwave_flux_in_air	rlds	W m^{-2}
Surface net solar radiation	ssr	176	J m-2	net solar	surface_net_downward_shortwave_flux	rss	W m^{-2}
Surface net thermal radiation	str	177	J m-2	net lw	surface_net_downward_longwave_flux	rls	W m^{-2}

Top net solar radiation	tsr	178	J m-2	-	toa_net_downward_shortwave_flux	-	W m^{-2}
TOA incident solar radiation Top incoming solar radiation	tisr	212	J m-2	toa solar incident	toa_incoming_shortwave_flux	rsdt	W m^{-2}
-	-	-	-	toa solar out	toa_outgoing_shortwave_flux	rsut	W m^{-2}
-	-	-	-	toa lw out	toa_outgoing_longwave_flux	rlut	W m^{-2}
Top net thermal radiation	ttr	179	J m-2	toa lw out	toa_net_downward_longwave_flux	rlut	W m^{-2}
	-	-	-		surface_upwelling_shortwave_flux_in_air	rsus	W m^{-2}
					surface_upwelling_longwave_flux_in_air	rlus	W m^{-2}
Eastward turbulent surface stress	ewss	180	N m^{-2} s	ew stress down	surface_downward_eastward_stress	tauu	Pa
Northward turbulent surface stress	nwss	181	N m^{-2} s	ns stress down	surface_downward_northward_stress	tauv	Pa
Evaporation	e	182	m of water equivalent	-	lwe_thickness_of_water_evaporation_amount	-	m
	-	-	-	net evap	water_evapotranspiration_flux	evspsbl	kg m-2 s
Runoff (or surface & sub-surface runoff)	ro (total) sro (Surface runoff) ssro (Sub-surface runoff)	205 (total) 8 (Surface runoff) 9 (Sub-surface runoff)	m	runoff	runoff_amount surface_runoff_amount subsurface_runoff_amount	mrro	kg m^{-2}

Runoff	ro	205	m	runoff	runoff_flux	mrro	kg m-2 s-1
Depth average potential temperature of upper 300m	thetao	151129	degC	depth avg pot temp (300, 700, 2000m)	sea_water_potential_temperature	thetao	K
Depth average salinity of upper 300m	so	262500	10^{-3}	mean salinity in upper 300m	sea_water_practical_salinity	so	psu
				ew speed	sea_water_x_velocity	uo	m s^{-1}
				ns speed	sea_water_x_velocity	vo	m s^{-1}
Depth of 14°C isotherm	t14d	262102	m	depth 14c	depth_of_isosurface_of_sea_water_potential_temperature	t14d	m
Depth of 17°C isotherm	t17d	262103	m	depth 17c	depth_of_isosurface_of_sea_water_potential_temperature	t17d	m
Depth of 20°C isotherm	t20d	262104	m	depth 20c	depth_of_isosurface_of_sea_water_potential_temperature	t20d	m
Depth of 26°C isotherm	t26d	262105	m	depth 26c	depth_of_isosurface_of_sea_water_potential_temperature	t26d	m
Depth of 28°C isotherm	t28d	262106	m	depth 28c	depth_of_isosurface_of_sea_water_potential_temperature	t28d	m
Mixed layer depth 0.01	mlotst010	151225	m	thickness mix layer	ocean_mixed_layer_thickness_defined_by_sigma_theta	mlotst	m
Mixed layer depth 0.03	mlotst0300	151226	m		ocean_mixed_layer_thickness_defined_by_sigma_theta		m

Sea ice thickness (sea ice volume)	sithick	174098	m		sea_ice_thickness	sivol	m
Sea surface height above geoid	zos	151145	m	sea sfc height	sea_surface_height_above_geoid	zos	m
Sea surface salinity	sos	151219		-	sea_water_practical_salinity	-	psu
	-	-	-	sss	sea_surface_salinity	sos	10-3
	-	-	-	thickness mix layer	ocean_mixed_layer_thickness_defined_by_sigma_t	mlotst	m
	-	-	-		ocean_meridional_overturning_mass_streamfunction	msftmyz	kg s^{-1}
Orography (geopotential height)	orog	156	gpm		surface_altitude		1
Land area fraction	sftlf	Categorical (0-1)	172		land_area_fraction		m