ECMWF: What does the future hold?

#UEF2023

Florian Pappenberger, Director of Forecasts & Deputy Director-General
(thanks to all my colleagues for input)

@FPappenberger

ECMWF

ECMWF

Established in 1975, Intergovernmental Organisation
- 23 Member States | 12 Co-operating States
- 400+ staff

24/7 operational service
- Operational NWP – 4x HRES+ENS forecasts / day
- Supporting NWS (coupled models) and businesses

Research institution
- Experiments to continuously improve our models
- Reforecasts and Climate Reanalysis

Operate Two EU Copernicus Services
- Climate Change Service (C3S)
- Atmosphere Monitoring Service (CAMS)
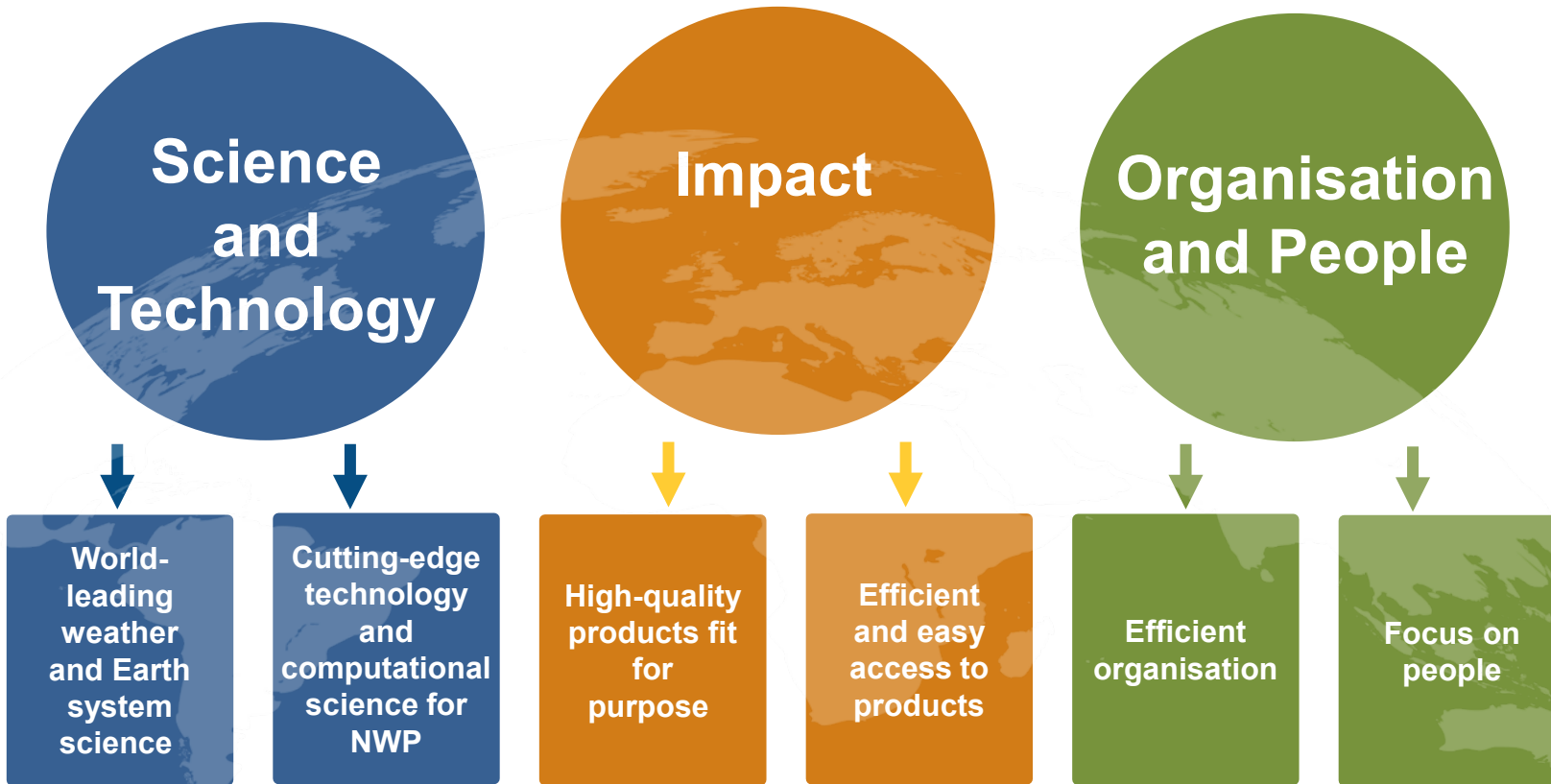- Support Copernicus Emergency Management Service (CEMS)

Destination Earth
- Operates the DestinE Digital Twin Engine (DTE)
- Operates two Digital Twins

Vision: ECMWF produces cutting-edge science and world-leading weather predictions and monitoring of the Earth system in close collaboration with the members of the European Meteorological Infrastructure, for a safe and prosperous society
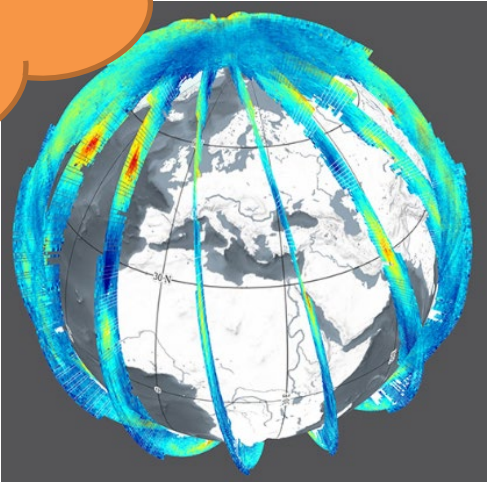
ECMWF Strategy 2021 - 2030

Science and Technology
- World-leading weather and Earth system science
- Cutting-edge technology and computational science for NWP

Impact
- High-quality products fit for purpose
- Efficient and easy access to products

Organisation and People
- Efficient organisation
- Focus on people

ECMWF STRATEGY 2021–2030

The strength of a common goal

ECMWF

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EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

Strategy Document

What we celebrated in the last year!

Migration to the Atos HPC

Copernicus — Europe's eyes on Earth

Copernicus second phase

Destination Earth first phase

Development of IFS Cycle 48r1

ECMWF

Integrated Forecasting System (IFS) Upgrades

Spring 2021
47r2

Autumn 2021
47r3

Autumn 2022
Atos

Spring 2023
48r1

2024
49r1

Single precision
(HRES, ENS, ENS-Ext)

Unified vertical resolution
(ENS, ENS-Ext to L137)

Moist physics upgrade
Observation use and data
assimilation (DA) changes

ENS resolution increase: 9 km
Daily ENS-Ext ensembles
(100 members daily)
Multi-layer snow scheme
Interactive Hybrid Linear Ozone
OOPS (multi-executable)

Improved COMPO suite

Improved surface
New ocean–sea ice
Updated land fields
Implementation of SPP
SEAS6: 100 ENS members
ERA6

Upcoming changes – Cycle 48R1

Watch this space!

- Planned for Q2 2023
- Test data currently available

HRES	ENS	ENS-Ext	Seasonal (ECMWF component)
9km (no change)	**18km → 9km**	36km (no change)	No change until SEAS6
10 days (step 240)	15 days (step 360)	46 days (step 1104)	
4x daily (no change)	4x daily (no change)	**Twice weekly → Once per day**	
137 model levels	137 model levels	137 model levels	
	50 members	**100 members**	
		Reforecast twice per week (one medium-range, one long-range)	

48r1 ENS scorecard

☑ rmsef ☑ ccaf ☑ crps ☐ spread ☐ diags

☑ n.hem ☑ s.hem ☑ tropics ☑ europe ☐ n.atl ☐ n.amer ☐ n.pac ☐ e.asia ☑ arctic ☐ antarctic (☑ all)

shaded boxes for confidence boundaries: ⦿ 95% ○ 50%/95% ○ 95%/99.7% || ○ significance triangles || ○ bars

What the Machine Learning Roadmap has achieved so far

M4 *in progress*
JupyterHub and machine learning libraries available

M8
IoT data used in operations

M13
2 use cases of machine learning accelerators for conventional modelling

M2
Machine learning network established and roadmap updated

M6
First machine learning training course

M11
5 machine learning applications integrated in operational workflow

2021   2022   2023   2024   2025   2026

M1
One machine learning conference per year

M5
Machine learning team established at ECMWF

M9
Copernicus ITTs involve machine learning

M12 *in progress*
Machine learning considered in HPC procurement

M3
Sufficient hardware for machine learning established

M7
4 machine learning benchmark datasets published

M10 *in progress*
Comprehensive and well-documented machine learning workflow in place

Vision 2031

- It is difficult to distinguish between machine learning and domain sciences
- Data handling fully capable to serve machine learning needs
- Fully supported diagnostic tools via trustworthy AI
- Physical constraints can be represented in deep learning
- Use of machine learning as easy and normal as data re-gridding
- Unsupervised learning and causal discovery used on a regular basis
- Machine learning solutions from end-users integrated in workflow

Since ECMWF launched its ML Strategy: **a busy and FAST evolving landscape**

Jan 2021
Machine Learning Roadmap

Feb 2022
Full medium-range NWP

Oct 2022
1km² global

Nov 2022
Tropical cyclones

Dec 2022
Extensive predictions

Apr 2023
7-day+ scores improve

Jan 2023
Global & Limited Area

ECMWF

Strategy to embed Machine Learning deeply into the ECMWF operational chain

Keisler - GraphNN 1°, competitive with GFS

NVIDIA – **FourCastNet** Fourier+ , 0.25°

O(10⁴) faster & more energy efficient than IFS

Jua.ai

1x1km global 48 hours lead time (deterministic)

5 minute timesteps

Huawei – PanguWeather 0.25° hourly product

"More accurate tracks" than the IFS.

Deepmind – GraphCast 0.25° 6-hour product

Predicts many variables and pressure levels with comparable skill to IFS.

Microsoft – ClimaX

Forecasting various lead-times at various resolutions, both globally and regionally

FengWu – China academia + Shanghai Meteorological Bureau 0.25° 6-hour product

Improves on GraphCast for longer leadtimes (still deterministic)

ECMWF's role in EU's DestinE initiative

Towards a Digital Twin Earth

ECMWF is responsible for the delivery of:

The DestinE **Digital Twin Engine** (DTE):
- common approach for a unified orchestration of Earth-system simulations and their fusion with observations, requiring **large-scale HPC** and data handling resources

Weather-induced and Geophysical* **Extremes Digital Twin**:
- capabilities and services for the assessment and prediction of **environmental extremes (a few days ahead)**

ECMWF + Météo-France and partners from 22 European countries

Climate Change Adaptation **Digital Twin**:
- capabilities and services in support of climate change **adaptation policies and mitigation scenario** testing **(multi-decadal)**

CSC and partners from 6 European countries

*not in phase 1

ECMWF · EUMETSAT · esa · EuroHPC Joint Undertaking · Funded by the European Union

Digital Twin engine & Digital Twins & Use cases
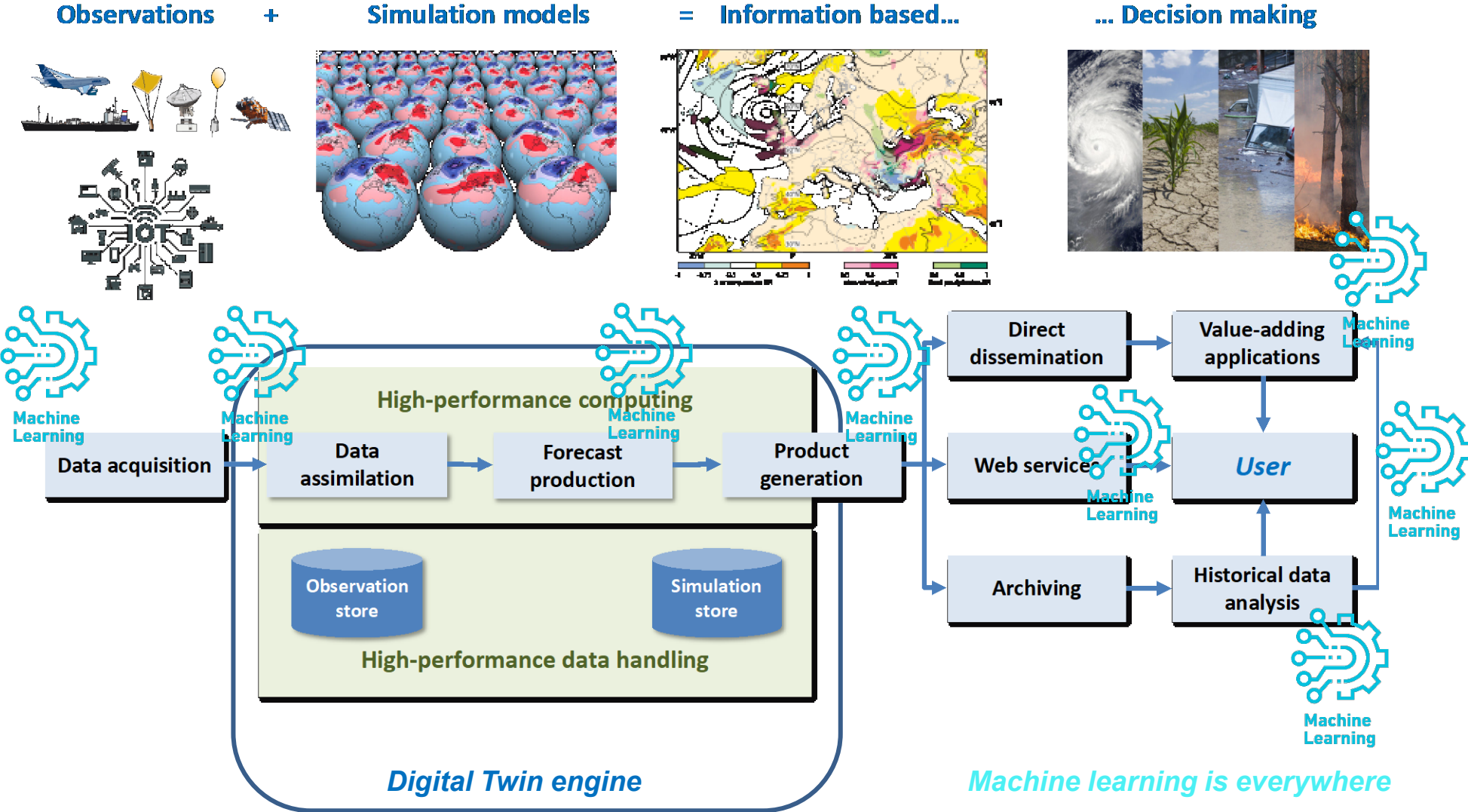
TC intensity better predicted as resolution increases from 9 to 1.4km
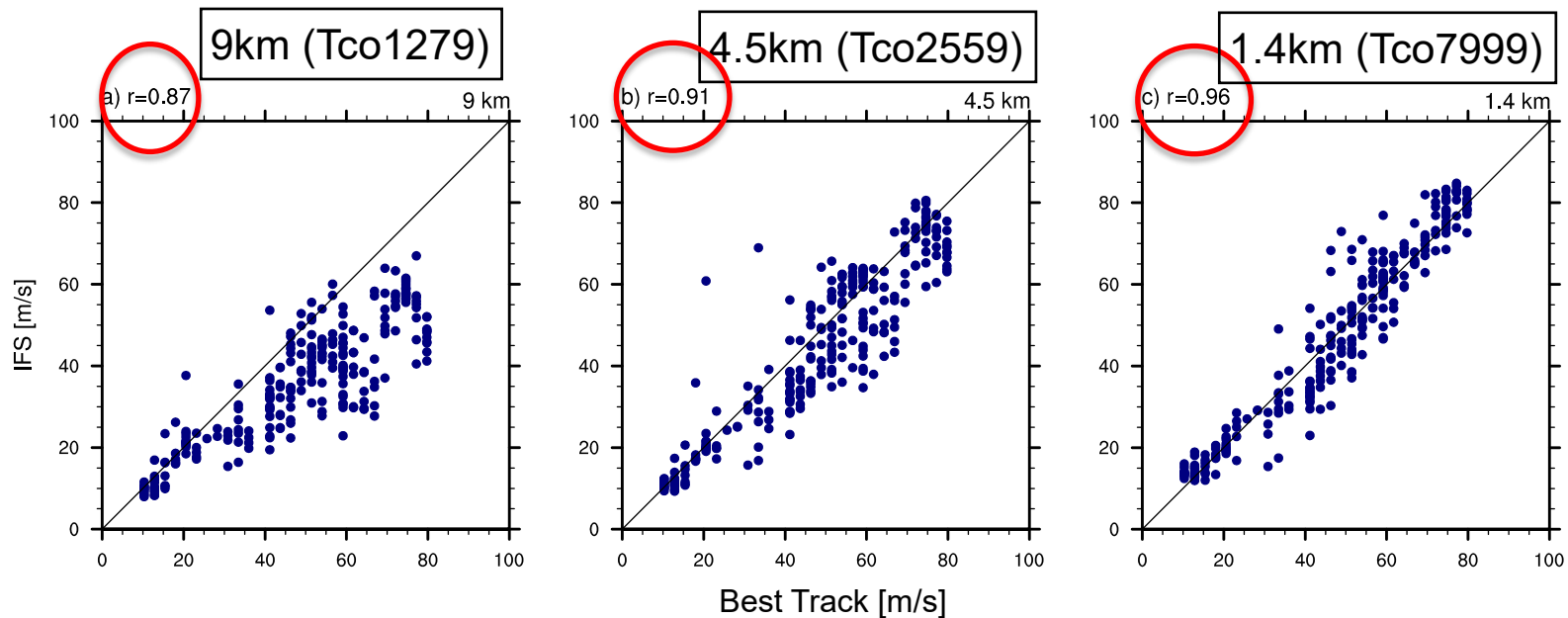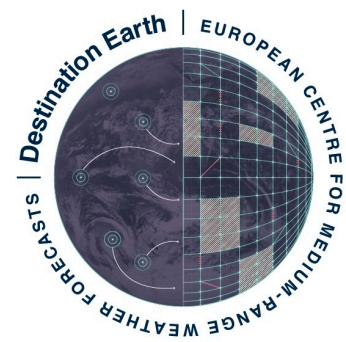
INCITE22 simulations

4 TCs (Irma, Ida, Florence, Teddy)
Improved max wind speed

Inna Polichtchouk
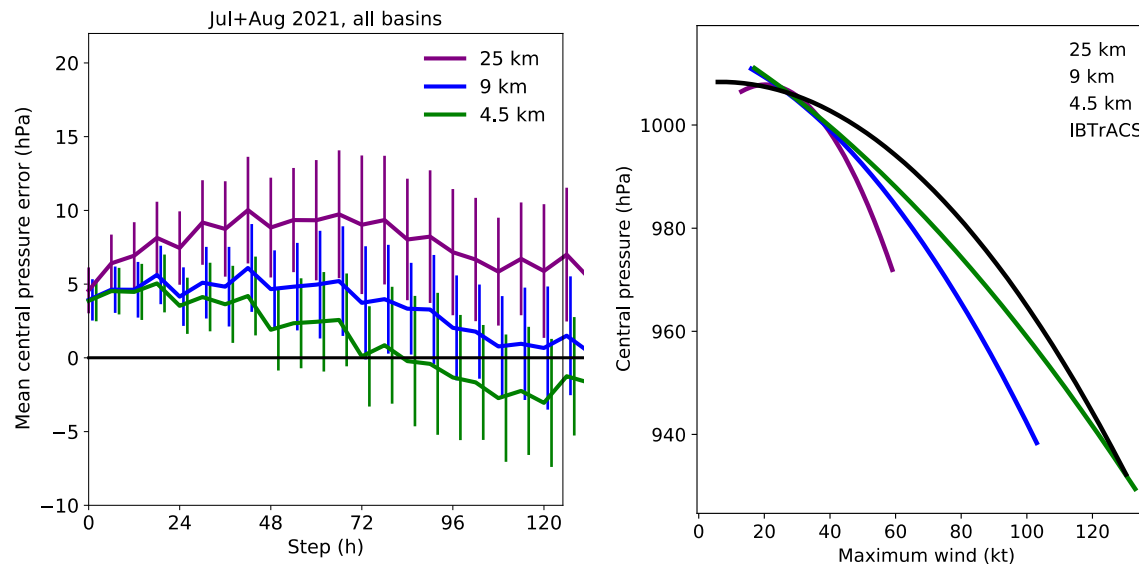
DestinE daily forecasts
Aug-Jul 21 and Jan-Feb 22

- Reduction of intensity RMSE at 4.5km
- Better MSLP/vmax relation

Michael Maier-Gerber

- **ECMWF: entrusted entity for C3S and CAMS**

  – Modernized Data Store platform under development and toolbox powered by ECMWF eartkit package

- **ECMWF: Contractor to Joint Research Centre (JRC) for operating:**

  – CEMS-EWS (Flood)

  – CEMS-EWS (Fire)

- ECMWF-EU Contribution Agreement 2021-2027
    - CAMS and C3S
    - <u>71% of the activities procured, with significant role for NMHSs in EU MSs, Norway and Iceland</u>
- On behalf of JRC:
    - CEMS Hydrological Forecast Computation
    - CEMS Fire Danger Forecast Computation

EUROPEAN STATE OF THE CLIMATE 2022

climate.copernicus.eu/esotc/2022

Anomaly in warmest daytime temperature in March 2022
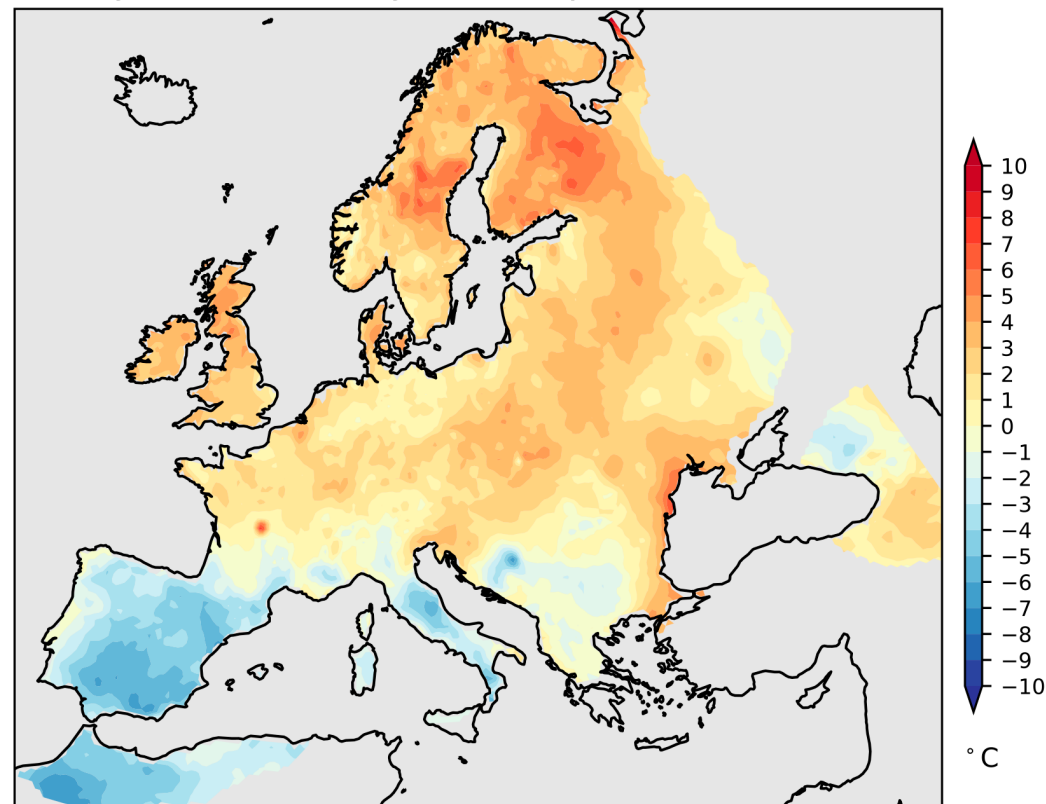
Data source: E-OBS Credit: C3S/KNMI Reference Period: 1991-2020

Copernicus Climate Change Service
European State of the Climate | 2022

PROGRAMME OF THE EUROPEAN UNION

Copernicus
Europe's eyes on Earth

IMPLEMENTED BY
ECMWF

Warmest daytime temperature anomaly (°C) in March 2022, relative to the average for the 1991–2020 reference period. Data source: E-OBS. Credit: KNMI/C3S/ECMWF.

Serving our users: moving towards a Climate and Atmosphere Data Store (CADS)

- Already in place: API; interoperability with MARS, ESGF; WPS, ftp, compliant with INSPIRE and WMO WIS

- CADS project will modernise the ADS and CDS: <u>operational by January 2024</u>

improved **interface** and **exploration** of ever-growing **catalogue** of data

Python development environment for data **access**, **analysis** and **visualisation** powered by **earthkit** tools
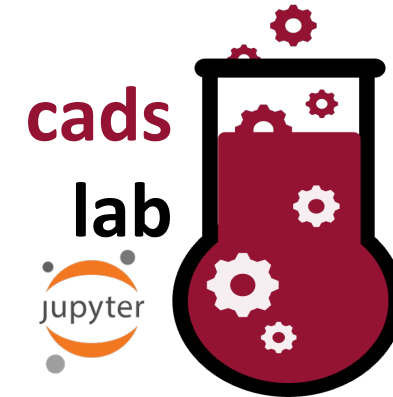
cloud resources and web interface underpinned by **Jupyter notebooks** and **cadstoolbox**

Contribution to **WEkEO**, a Copernicus cloud-based Data and Information Access Service (DIAS) in collaboration with EUMETSAT, Mercator-Ocean and EEA

Status of the European Weather Cloud

- ➤ Pilot project started 2019 by ECMWF and EUMETSAT

- ➤ Currently in operational ramp-up

- ➤ ECMWF on-going deployment of the new operational infrastructure in ECMWF Bologna Data Centre

- ➤ EUMETSAT running on public cloud infrastructure

Pilot project starts — 2019
Operational ramp-up — 2022
Planned start of operations — 2023
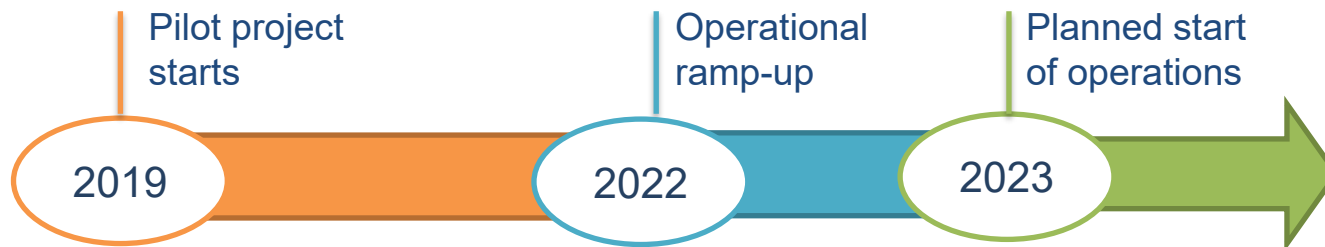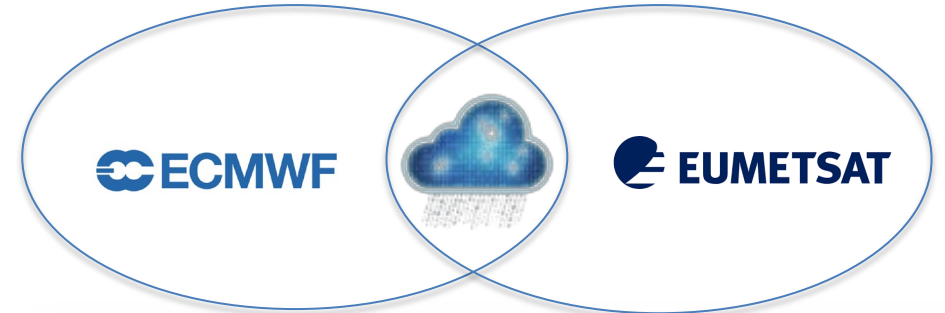
www.europeanweather.cloud

European Weather Cloud Use Cases Examples
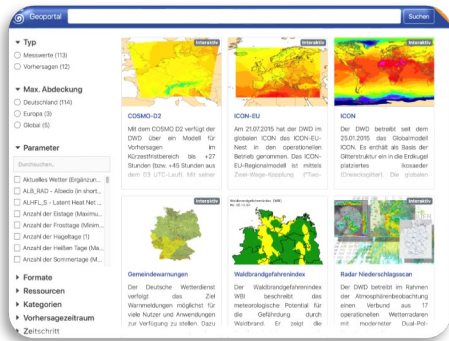
OGC web map services integrating maps in DWD's Geoportal

Forecast and climatology of cloud cover for Energy and Spatial sectors Météo-France Hosted on both ECMWF and EUMETSAT

Oxford University Jupyter notebook environments for ML on weather & climate data sets
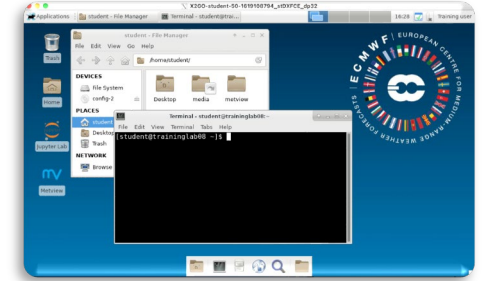
Virtual laboratories for training courses and workshops
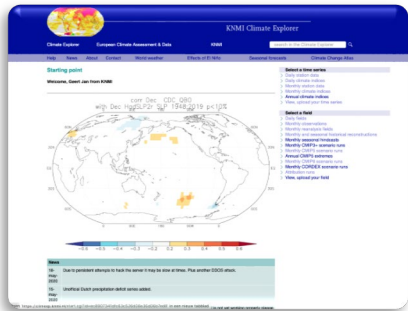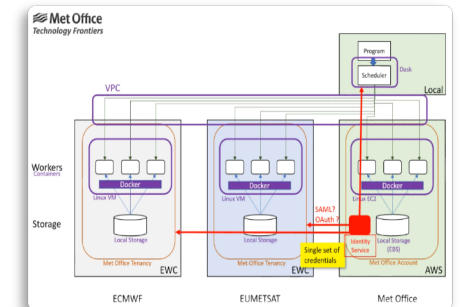

KNMI Climate Explorer setup on EWC
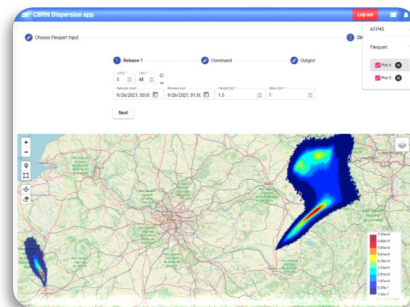
Atmospheric dispersion modelling from RMI
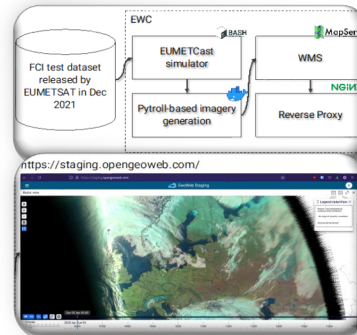
NordSat developing imagery generation tools for satellite products
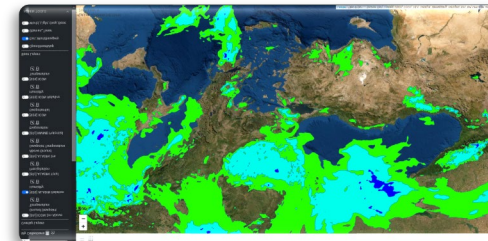
South-East European Multi-Hazard Early Warning Advisory System Common Interface Platform

UK Met Office demonstrates Data Proximate Compute use case
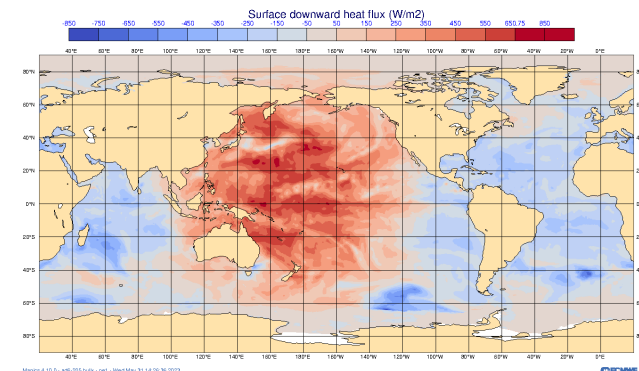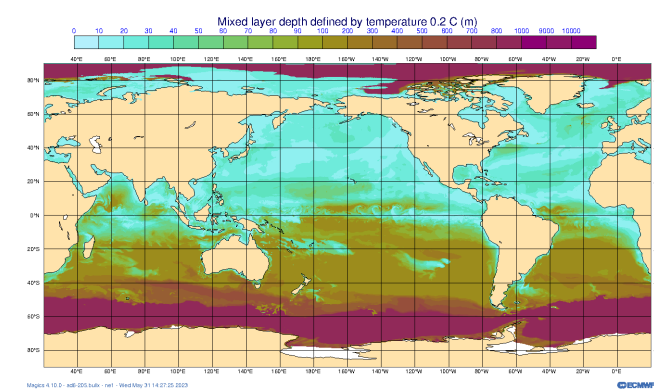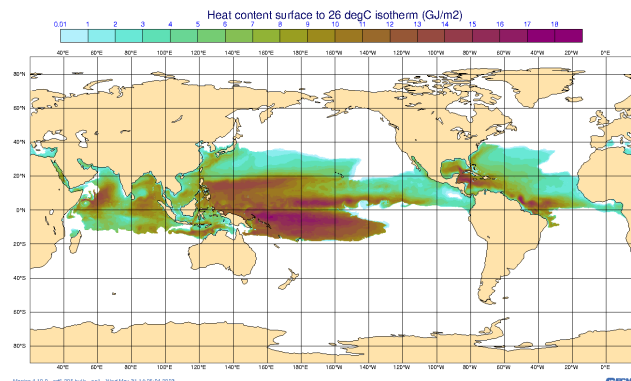
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Migration to GRIB2 Roadmap

- Expected to switch to full GRIB2 during 51r1 implementation
- Could be an earlier dedicated "technical" cycle (50r2?)
- More details in the article in ECMWF newsletter - Spring 2023
- Sign up to our mailing list: mtg2@lists.ecmwf.int
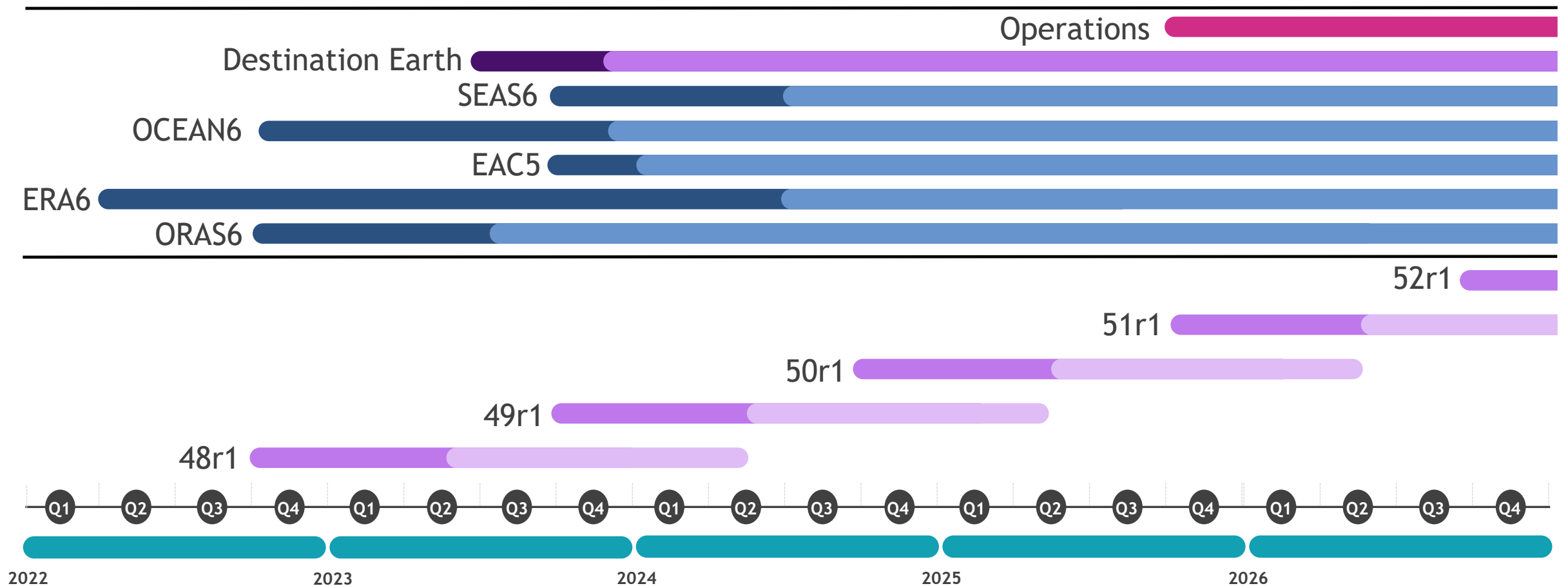
Ocean GRIB2 output with the NEMOV4 / SI3 upgrade (work in progress)

- With the upgrade of the ocean/sea-ice component of the coupled forecasting system to NEMOV4 / SI3 ocean fields in GRIB2 will become available for dissemination and archived in MARS

  o all forecasting systems

  o the ocean analysis system

- New IO-server based on MultIO

  + direct FDB output

- Data will be coded as an unstructured grid

- Interpolation to other grids such as regular or Gaussian grids will be supported via MIR

- Both 3D fields and 2D fields will be available

  - Examples of 3D fields:
    - Water temperature
    - Salinity
    - Currents
    - Water density
    - …

- Examples of 2D fields:
  - Sea surface temperature
  - Sea surface height
  - Mixed layer depth with multiple different definitions
  - Upper ocean heat content
  - Sea ice concentration
  - Sea ice thickness
  - Sea ice temperature
  - …

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Open Data at ECMWF

Free and open charts including meteograms (OpenCharts)
https://apps.ecmwf.int/webapps/opencharts

Free and open data available on public https service and in Microsoft Azure and Amazon AWS

Contents of the ECMWF archive catalogue provided with an open licence (CC-BY-4)
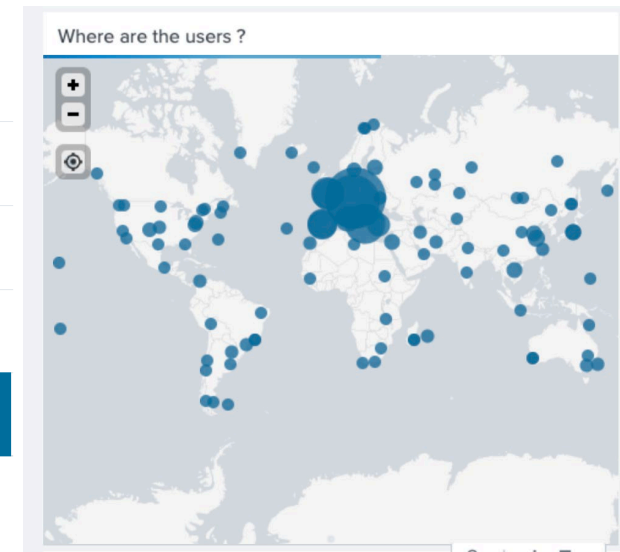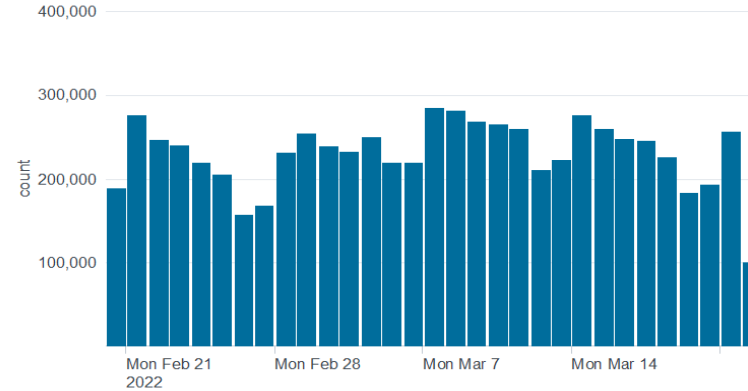
€ Reduced fees for some licence types

Access here:
https://data.ecmwf.int/forecasts
Supporting Documentation:
https://confluence.ecmwf.int/display/UDOC/ECMWF+Open+Data+-+Real+Time

Open Charts products served daily

Where are the users ?

ECMWF   Search site...   Help   Emma Pidduck

Home   About   Forecasts   Computing   Research   Learning   Publications

Charts   Datasets   Quality of our forecasts   About our forecasts   Access to forecasts

◀ View Datasets search

Open data

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For more information on using these products, please visit the ECMWF Support Portal and User Documentation.

Access the free version ›

Licence:
General

Important: higher resolution versions of the same products are available via the **Product Requirements Catalogue** and are subject to the ECMWF Standard Licence Agreement.

Product description

These products are a subset of the full Catalogue of ECMWF Real-time Products and are based on the medium-range (high-resolution and ensemble) and seasonal forecast models.

Products are produced at 0.4 degrees resolution in GRIB2 format unless stated otherwise.
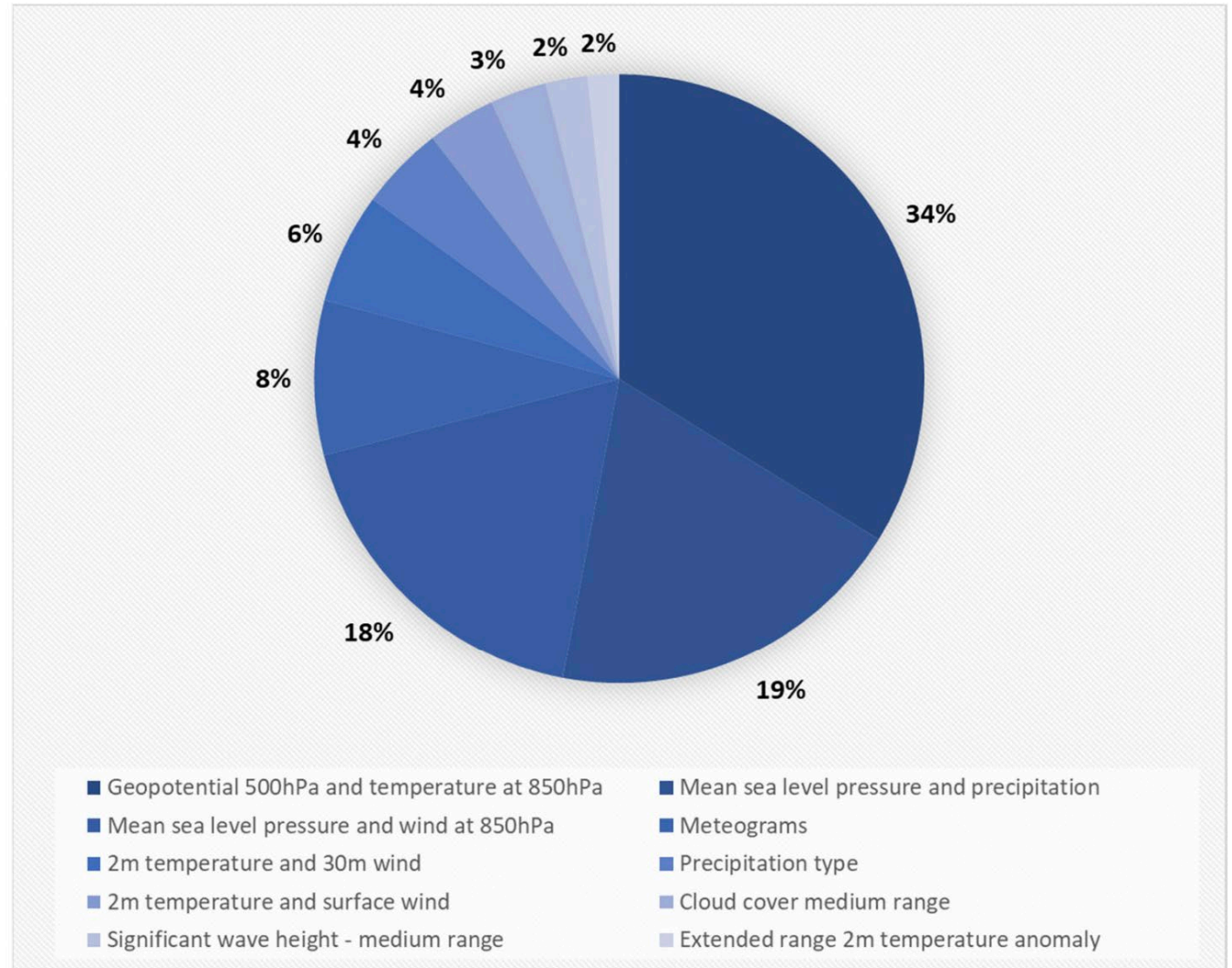
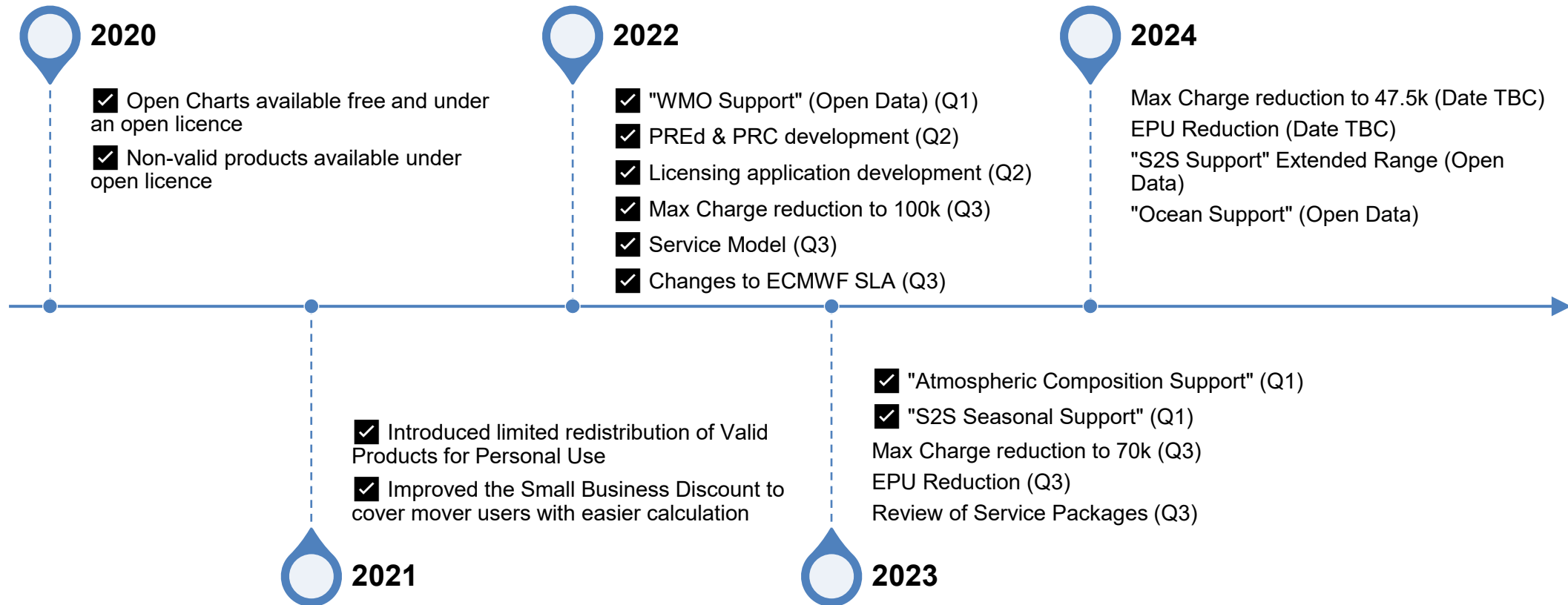# Open Data Usage Statistics - ECMWF Open Charts

- 200,000 products served per day with 20% of the users located within the Member and Co-operating States.

- 92% of products accessed are within the short- and medium-range.

- ECMWF Jupyter Notebook function is available for 20% of Open Charts.

- The Jupyter Notebook repository is the 4th most popular out of 60 ECMWF software repositories.

Access the charts here:
https://charts.ecmwf.int/

Pie chart values: 34%, 19%, 18%, 8%, 6%, 4%, 4%, 3%, 2%, 2%

Legend:
- Geopotential 500hPa and temperature at 850hPa
- Mean sea level pressure and precipitation
- Mean sea level pressure and wind at 850hPa
- Meteograms
- 2m temperature and 30m wind
- Precipitation type
- 2m temperature and surface wind
- Cloud cover medium range
- Significant wave height - medium range
- Extended range 2m temperature anomaly

Move to Open Data - Timeline

2020
- ☑ Open Charts available free and under an open licence
- ☑ Non-valid products available under open licence

2022
- ☑ "WMO Support" (Open Data) (Q1)
- ☑ PREd & PRC development (Q2)
- ☑ Licensing application development (Q2)
- ☑ Max Charge reduction to 100k (Q3)
- ☑ Service Model (Q3)
- ☑ Changes to ECMWF SLA (Q3)

2024
- Max Charge reduction to 47.5k (Date TBC)
- EPU Reduction (Date TBC)
- "S2S Support" Extended Range (Open Data)
- "Ocean Support" (Open Data)

2021
- ☑ Introduced limited redistribution of Valid Products for Personal Use
- ☑ Improved the Small Business Discount to cover mover users with easier calculation

2023
- ☑ "Atmospheric Composition Support" (Q1)
- ☑ "S2S Seasonal Support" (Q1)
- Max Charge reduction to 70k (Q3)
- EPU Reduction (Q3)
- Review of Service Packages (Q3)

Python and Jupyter and GitHub

A new Software Strategy

- Open development with interaction and feedback from the community

- Several packages already on GitHub

- Software componentisation

  - First components:

    - earthkit-data

    - earthkit-maps

JupyterHub

- Project restarted after move to Bologna by gathering and analysing requirements from 80+ Jupyter users

ECMWF | EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

THE STRENGTH OF A COMMON GOAL