Serving climate users: what lies ahead

Peter Bauer, Carlo Buontempo ECMWF

Thanks : Hans Hersbach, Chiara Cagnazzo, Anca Brookshaw, Irina Sandu, Bill Bell , and many others

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Operational service for users

- “The reply was fast, very friendly and the problem was solved.” (CUS-14159, joint support with the CDS team)
- “Great support! Fast and precise advices. Thanks.” (CUS-16563)
- “Really great to be connected with experts in the relevant field to get a detailed answer. Thank you very much for your assistance.” (CUS-17732, C3S312bLOT3 Sea Level Support)
- “The support was very helpful and covered all my questions even supplying me with additional information I had not thought of asking for at that time. Thank you very much!” (CUS-12405)
- User satisfaction:**4.2**

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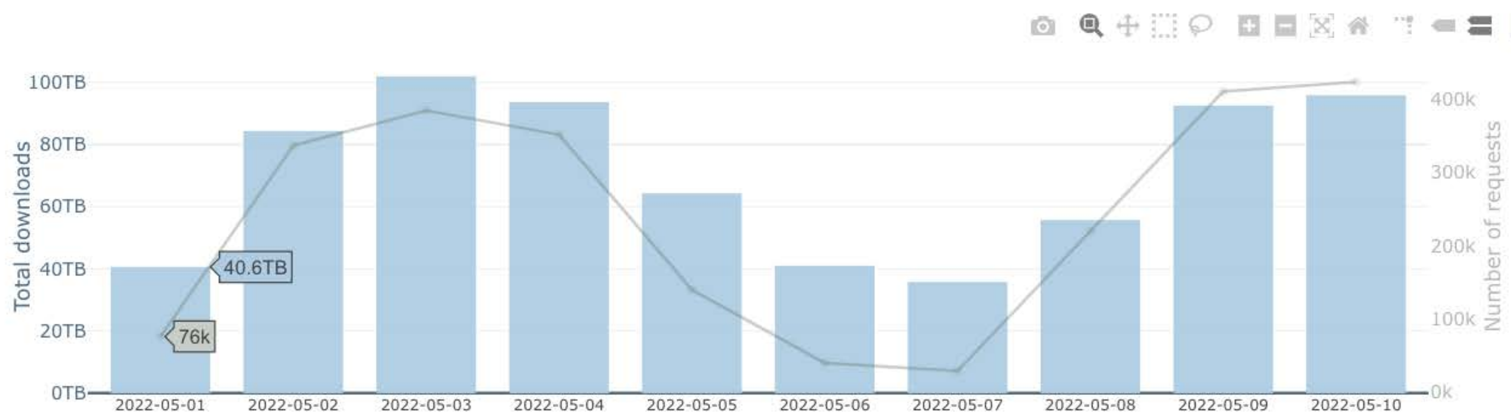
Reanalyses is at the core of C3S activities

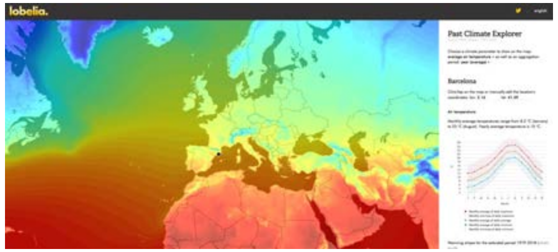
Registered users	Running users	Queued users	Running requests	Queued requests	At
131,839	182	306	379	3,353	11:57 UTC | 11/05/2022

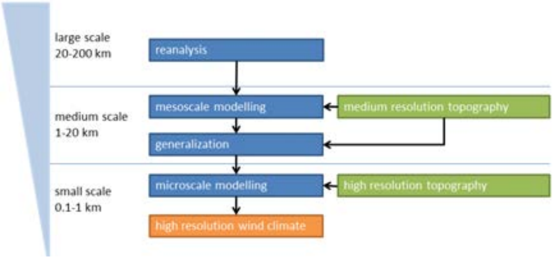
Daily downloads in Terabytes



Requests completed

Last 1h	18,621	4.3TB
Last 2h	41,129	9.0TB
Last 3h	61,904	13.3TB
Last 6h	123,920	27.2TB
Last 12h	243,794	52.5TB
Last 24h	434,029	96.8TB





https://globalwindatlas.info/about/method

Datasets Top 8 (Running or queued)

1. ERA5 hourly data on single levels from 1979 to present
2. ERA5 hourly data on pressure levels from 1979 to present
3. CMIP6 climate projections
4. ERA5 complete
5. ERA5-Land hourly data from 1950 to present
6. River discharge and related historical data from the Global Flo..
7. Arctic regional reanalysis on model levels from 1991 to present
8. Seasonal forecast daily and subdaily data on single levels

As shown in Chiara's talk on Monday reanalyses are at the crucial in most of the sectoral applications we developed. Also because of this 1 every 2 users registered on the CDS is a user of reanalyses,

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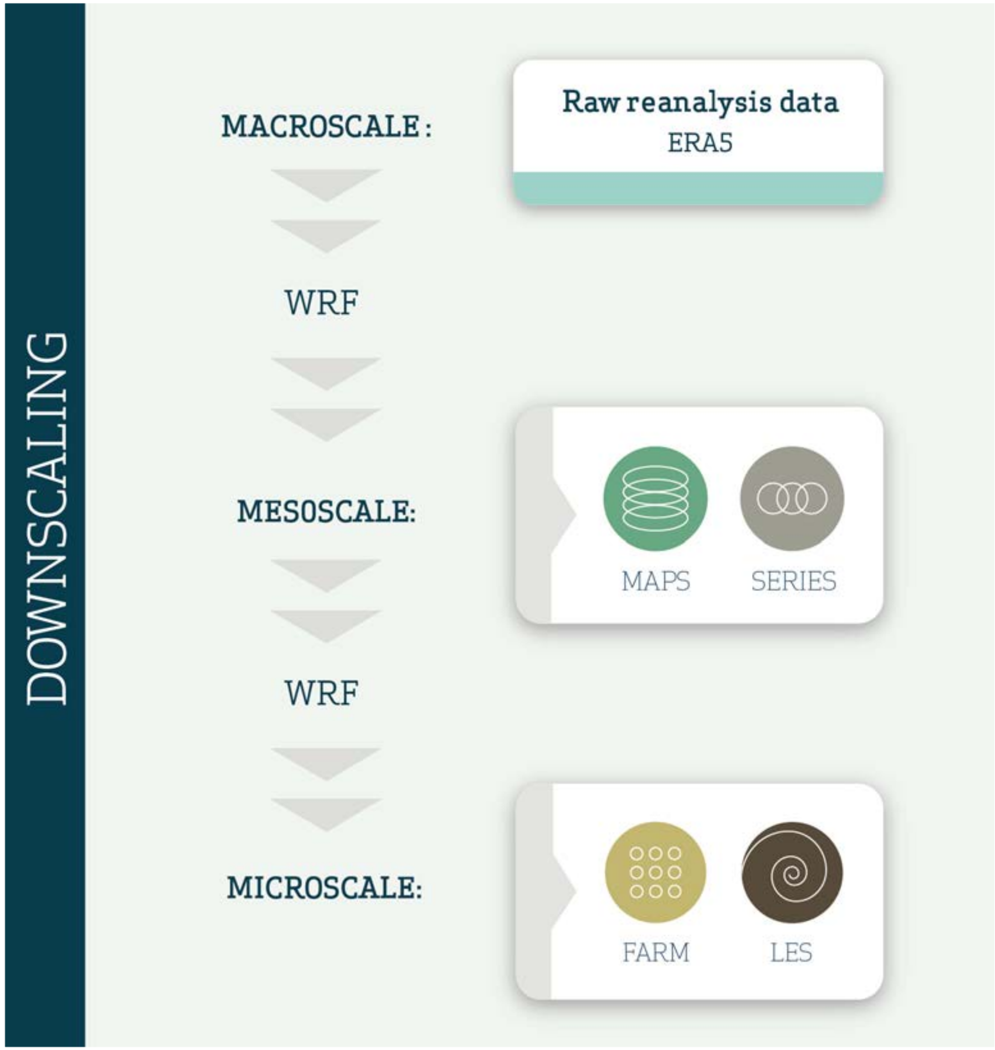
Vortex – added value ERA5 Wind Industry



Vortex products at different scales

Vortex products allows to reduce the bias and uncertainty in the estimations of long-term wind speed corrections and spatial and vertical interpolation across the windfarm area.

Accurate Wind Resource matters:

- Cost of Energy ~ 70US$/MW (IEA 2020)
- For a typical project of 100 MW with 35% capacity factor
- 1% AEP error reduction -> 230K US$/years
- 50 GW installed/year -> 100M US$/year

Injecting ERA5 in Vortex products had reduced on average the wind speed error by 3-4% compared to other Reanalysis products *.

* estimation based validations results from more than 250 sites across different location and markets. Results are strongly regional and site dependent.

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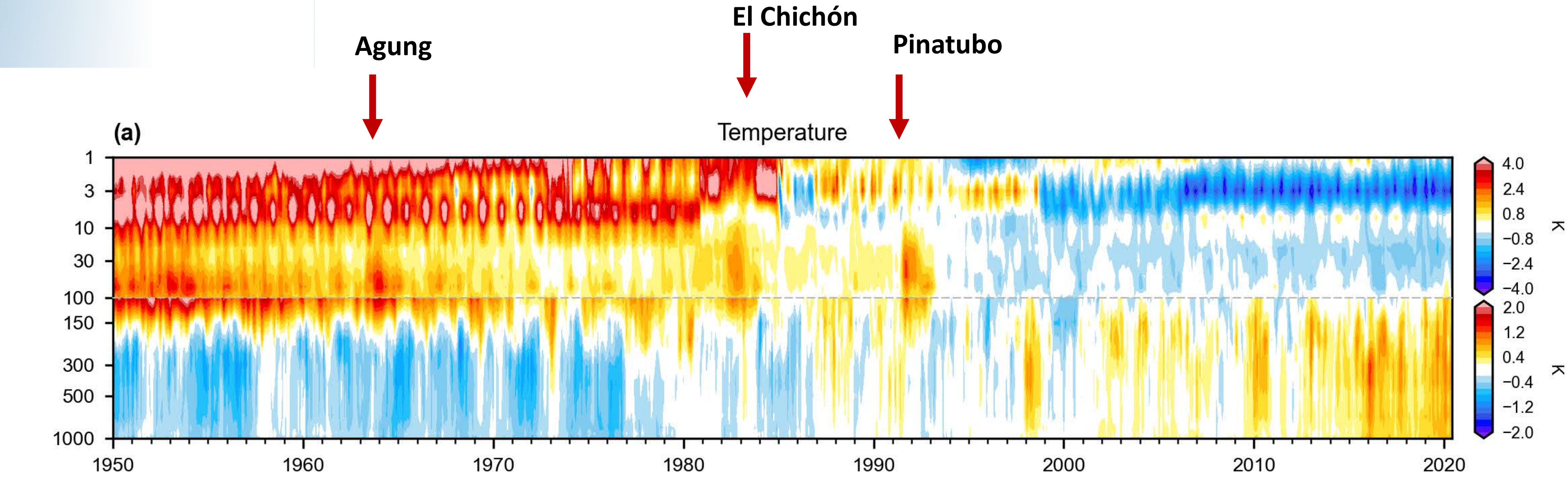
The evolution of upper-air mean temperature in ERA5 compared to 1981-2010



The temperature anomaly plot clearly shows, e.g.:

- the warming of the troposphere and cooling of the stratosphere
- the temporary effect of volcanic eruptions (Agung, El Chichon, Pinatubo)

Note: above 10 hPa anomalies are affected by difficulties in the assimilation →

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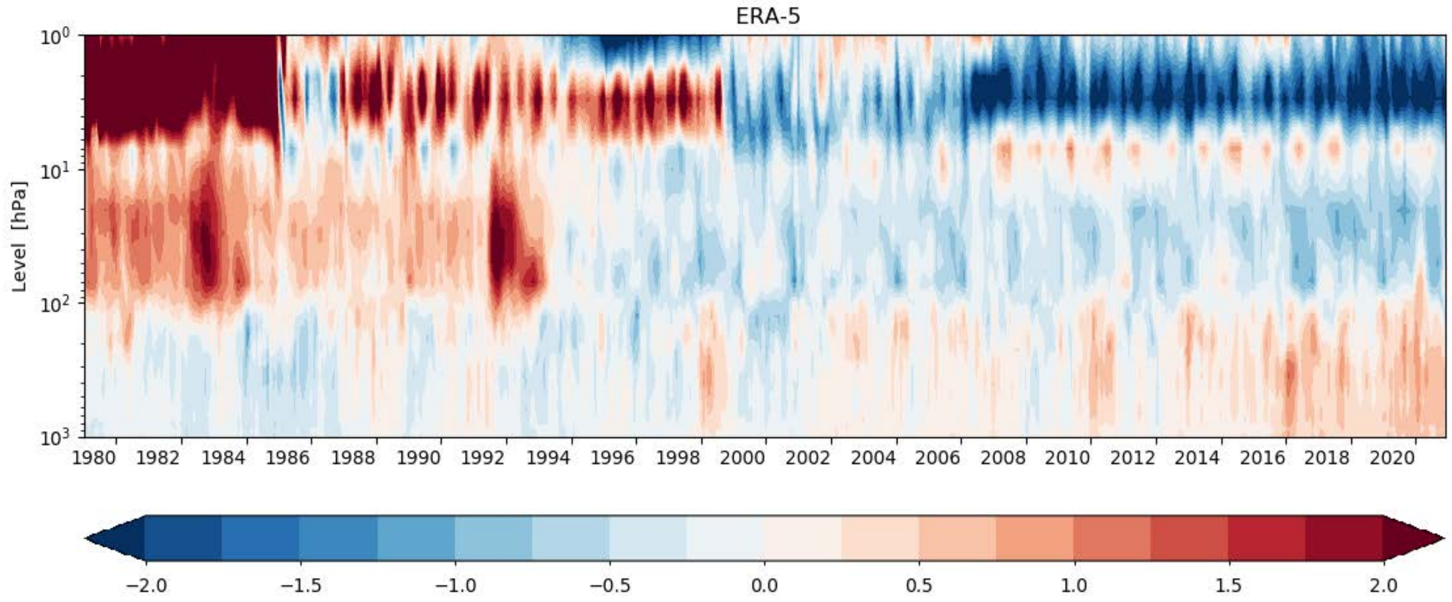
Means and variability example – ERA5 pressure levels

Assessed Dataset: ERA5 monthly averaged data on pressure levels from 1979 to present

- ERA5 global temperature anomaly (K) over the period (1979 - 2020) as a function in time vs pressure
- Upper stratosphere (above 10 hPa), unexpected jumps in values are observed with changes in assimilated observation instrument, e.g. 1985 (transition from NOAA-7 SSU to NOAA-9 SSU) and 1998 (transition from the TOVS to the ATOVS)
- A strong cold signal is apparent after 2006 at pressure level between 1-7 hPa, where a larger number of GPS radio-occultation (RO) observations are assimilated
- Global variability associated with major volcanic eruptions and El Nino signals



PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

implemented by ECMWF

EVALUATION AND QUALITY CONTROL (EQC): QUALITY CONTROLLED, RELIABLE DATA

INDEPENDENT **FULLY TRACEABLE**

TRANSPARENT TO THE USERS **REPLICABLE**

BASIC CHECK

- → Independent check on resolution
- → Dataset Completeness

DATASET MATURITY

- → Independent maturity assessment
- → Implement and adapt
- → Quality functions and methods

FITNESS-FOR-PURPOSE

- → Through state-of-the-art scientific use cases
- → Means and variability
- → Trend detection
- → Cross-comparison observations, models and reanalysis
- → Extreme events (selected)

SUMMARY

- → Summary for the User
- → User Guidance
- → (Application Matrix): Closeness of Datasets to User

OPEN SOURCE SOFTWARE FOR REPRODUCIBILITY & VERSIONING

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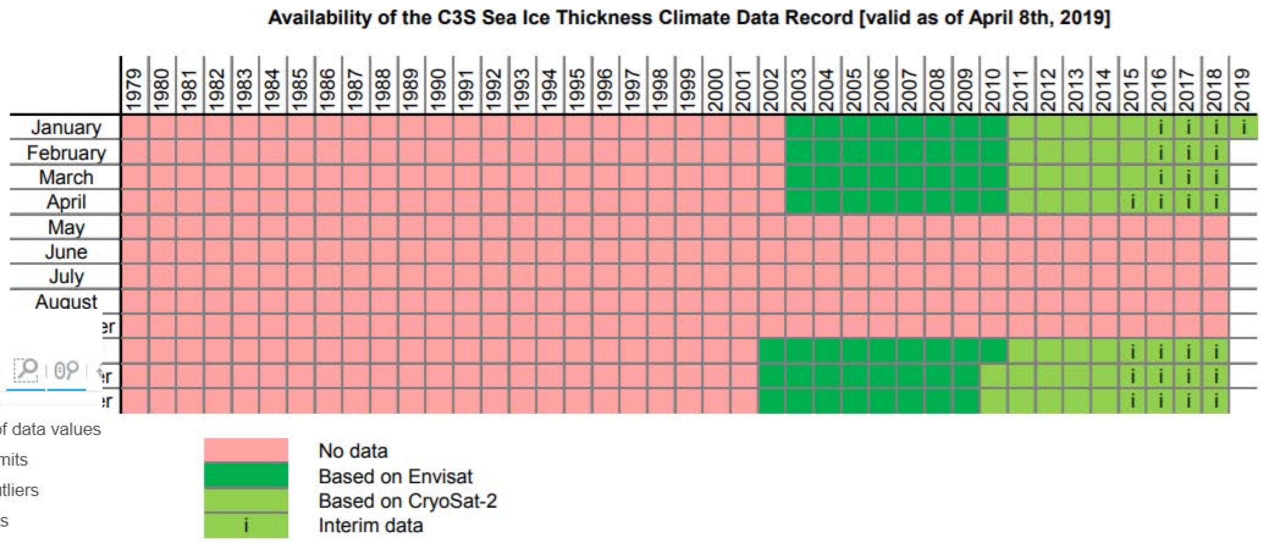
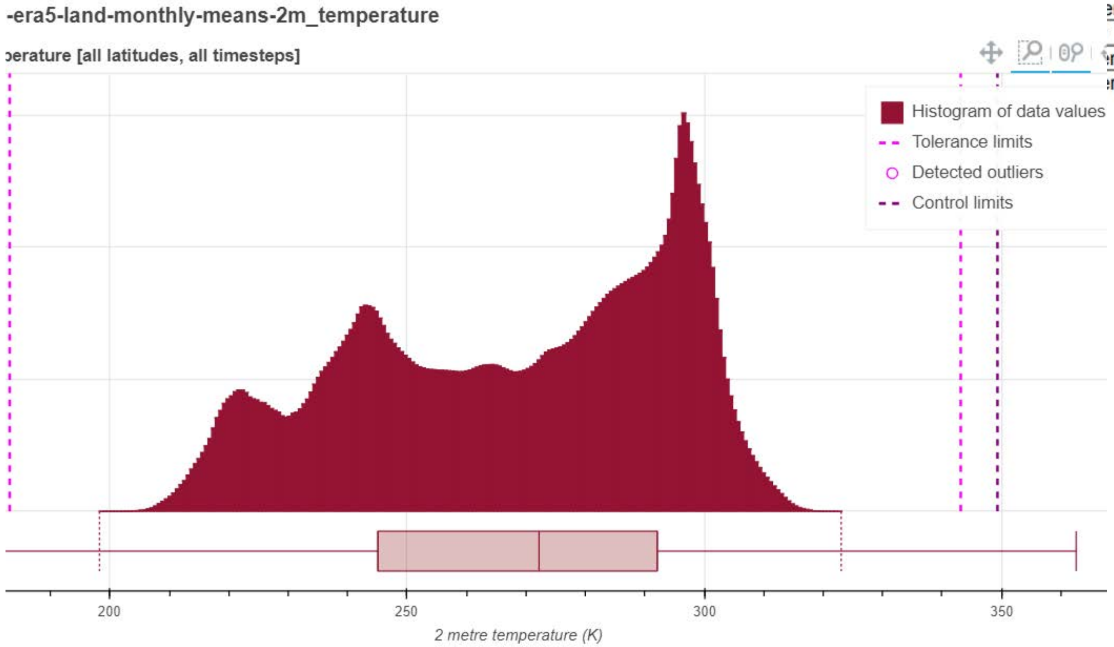
Basic Data Checks

Spatio-temporal coverage





Space and time completeness (monthly)	reanalysis_era5_land_monthly_means-era5_land-2m_temperature-spatial_temporal_completeness.pdf
Space and time completeness (daily/sub-daily)	reanalysis_era5_land-era5_land-2m_temperature-spatial_temporal_completeness.pdf
Is (are) the data file(s) temporally consistent with the metadata?	monthly: Yes - daily/sub-daily: Yes
Document (monthly)	reanalysis_era5_land_monthly_means-era5_land-2m_temperature-temporal_consistency.pdf
Document (daily/sub-daily)	reanalysis_era5_land-era5_land-2m_temperature-temporal_consistency.pdf
Is (are) the data file(s) spatially consistent with the metadata?	monthly: Yes - daily/sub-daily: Yes
Document (monthly)	reanalysis_era5_land_monthly_means-era5_land-2m_temperature-spatial_consistency.pdf
Document (daily/sub-daily)	reanalysis_era5_land-era5_land-2m_temperature-spatial_consistency.pdf
Physical plausibility ranges (monthly)	reanalysis_era5_land_monthly_means-era5_land-2m_temperature-valid_ranges.html
Physical plausibility ranges (daily/sub-daily)	reanalysis_era5_land-era5_land-2m_temperature-valid_ranges.html

Plausibility ranges

Maturity matrix for ERA5 winds on pressure levels (1979-2020)

Maturity Matrix

Metadata	User Documentation	Uncertainty Characterisation	Public access, feedback, and update	Usage
Standards	Formal description of scientific methodology	Standards	Public Access/Archive	Research
Collection level	Formal validation report	Validation	Version	Decision support system
File level	Formal product user guide	Uncertainty quantification	User feedback	
		Automated quality monitoring	Updates to record	

1	2	3	4	5	6

Lower scores denote less maturity

Summary assessment for ERA5 (1978-2022): Temperature ECV

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The temperature ECV of "ERA5 hourly data on pressure levels from 1979 to present" dataset is **global**, complete with a **high spatial and temporal resolution** with respect to previous generation of global reanalyses.
Data are available at 37 pressure levels ranging from 1000 hPa (surface) up to 1 hPa (top of stratosphere)
The high spatial (0.25°) and temporal (hourly) resolution of the ERA5 dataset along with **improved capability to reproduce the tropospheric processes** enable its use both for **climate monitoring and for impact assessment studies**.

Mean/climatology ☺

- ERA5 is a valid candidate for long-term climate studies, but also for retrospective weather and extreme event analysis
- Daily updates of ERA5 data are available five days behind real time (ERA5T).

Variability ☺

- Provides a complete set of atmospheric, ocean surface and land parameters, including > 250 different variables
- Data from a large set of instruments on current and recent satellite missions
- Mature dataset in terms of metadata, public access, user feedback, update and usage

Limitations 😐

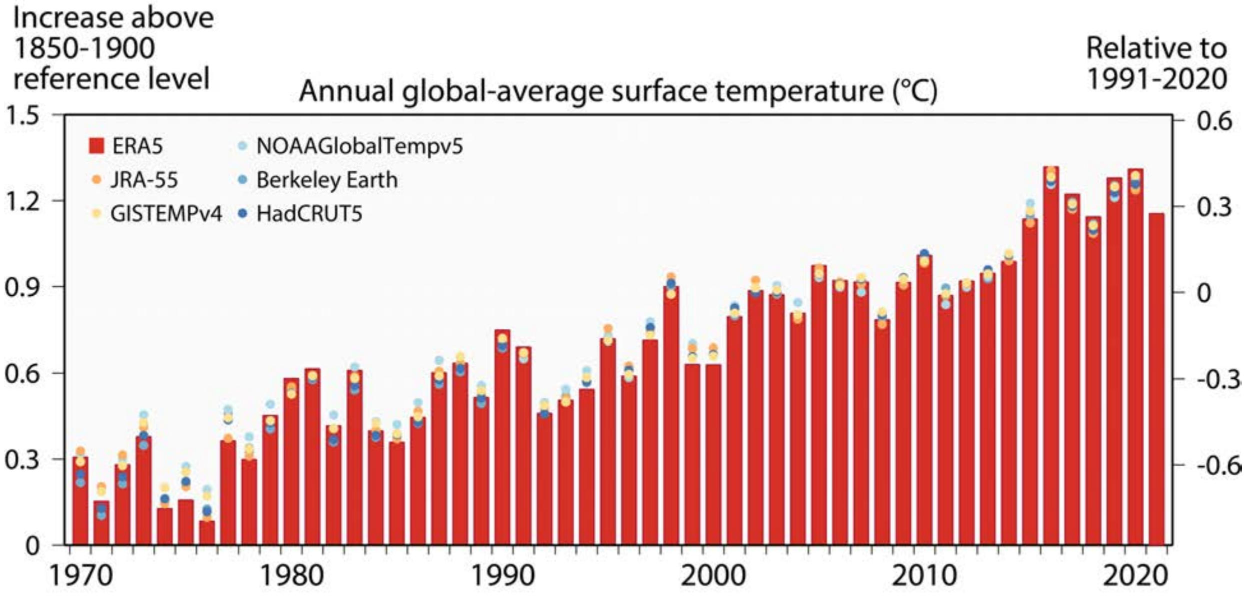
- Changes in the amounts and types of observational data that is assimilated may produce artificial trends.
- Variability at local scales can differ from the values provided by the reanalysis, which represent a statistical summary of the area surrounding a grid point.
- Even if higher than other global reanalysis datasets, the spatial resolution of ERA5 can be insufficient for some regional or local applications.

European State of the Climate & Climate Indicators

- 5th Edition, 2022 release end of April
- Structure similar to previous reports
- Thematic sections on:
    - Mediterranean heatwave
    - Flooding in central Europe
    - And more
- Preparation for pilot joint report WMO Climate Change Service

Key climate indicators

- ✓ Responding to monitoring and reporting for UNFCCC
- ✓ Capture long-term trends, but also year-to-year variability



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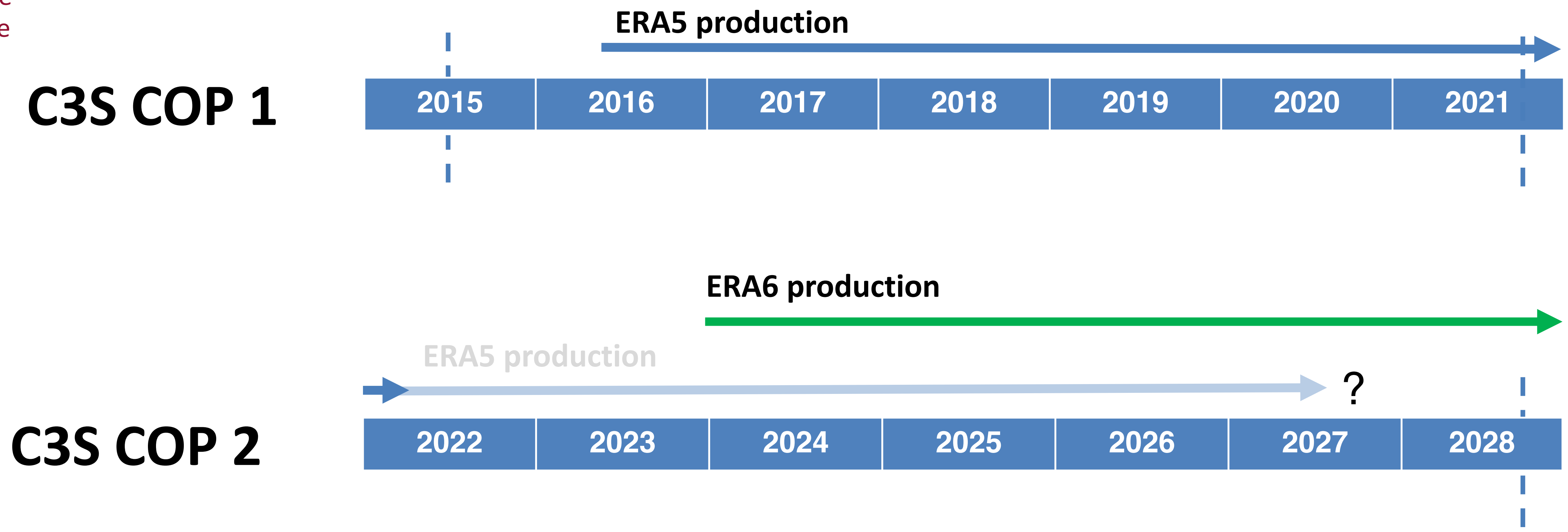
Copernicus Europe's eyes on Earth
implemented by ECMWF

Reanalysis: the transition from ERA5 to ERA6



- **ERA5** is based on the ECMWF model (CY41R2) from 2016
- **ERA6** will be based on the ECMWF model from mid-late 2023

→ 8 years of R&D driven improvements in forecast model, assimilation system & reprocessed observations

→ significant increase in compute power available → higher resolution reanalysis (31km → 18km)

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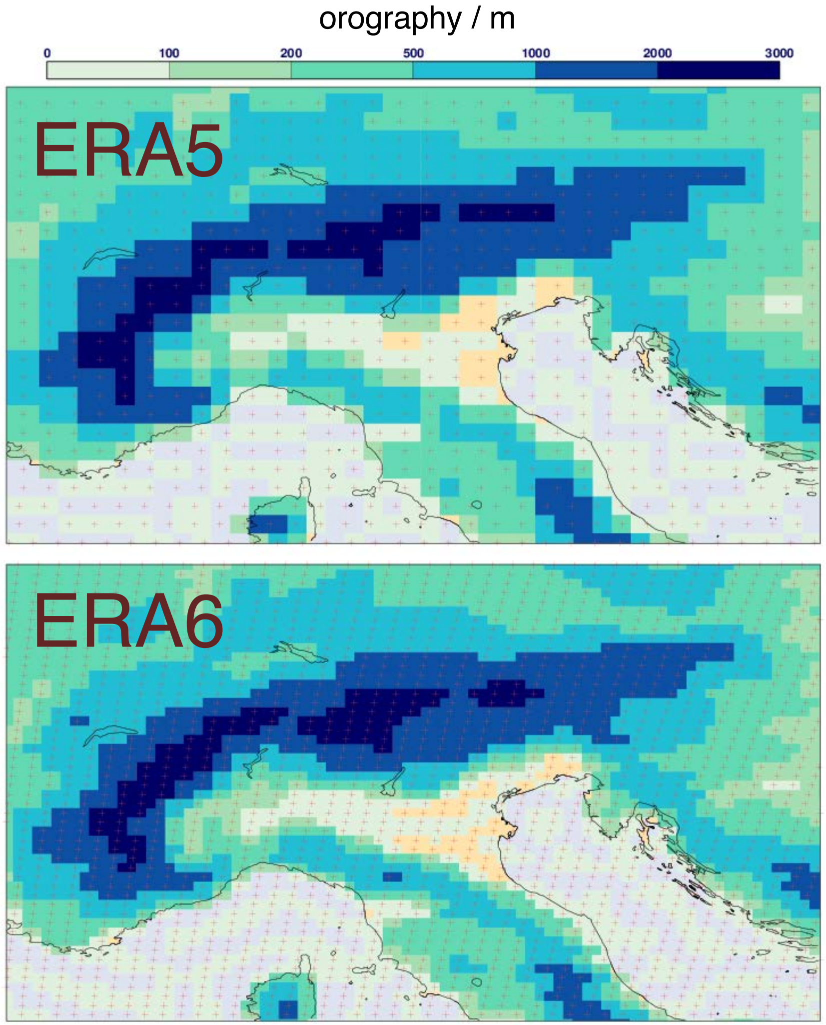
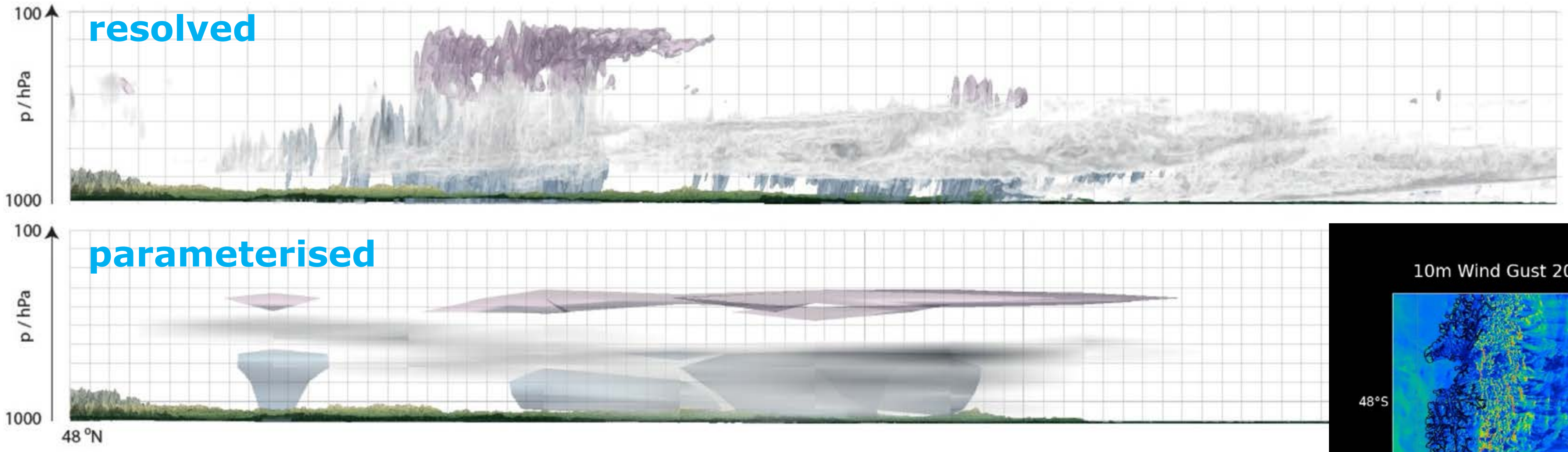
ERA6 in a nutshell

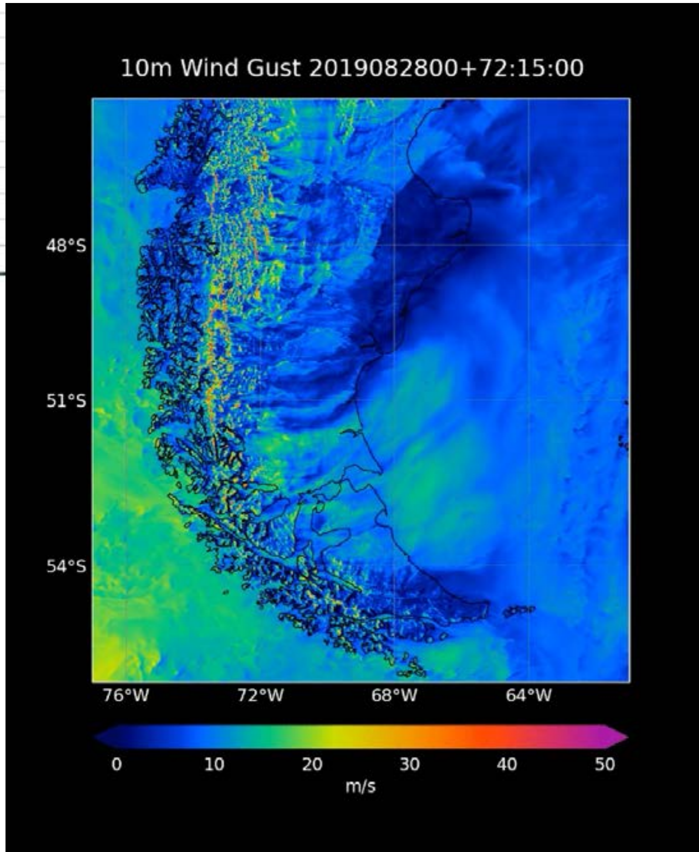
Better resolution (<18 km vs 31 km)



- **Higher resolution ensemble of assimilations** - improved representation of synoptic uncertainty
- **Enhanced coupling** between atmosphere, land and ocean
- **Improved treatment of biases** (from R&D on DA system l)
- **Extensive use of reprocessed conventional and satellite observations from COP1 investments**
- **Improved forcing datasets** (SST, sea ice, GHGs, aerosols) from latest R&D
- **More optimal data assimilation** (observation errors, background errors)
- **Estimation of mean-state uncertainties ('benchmarking')**
- Wider range of products, based on user feedback

What we really need: storm resolving in the atmosphere



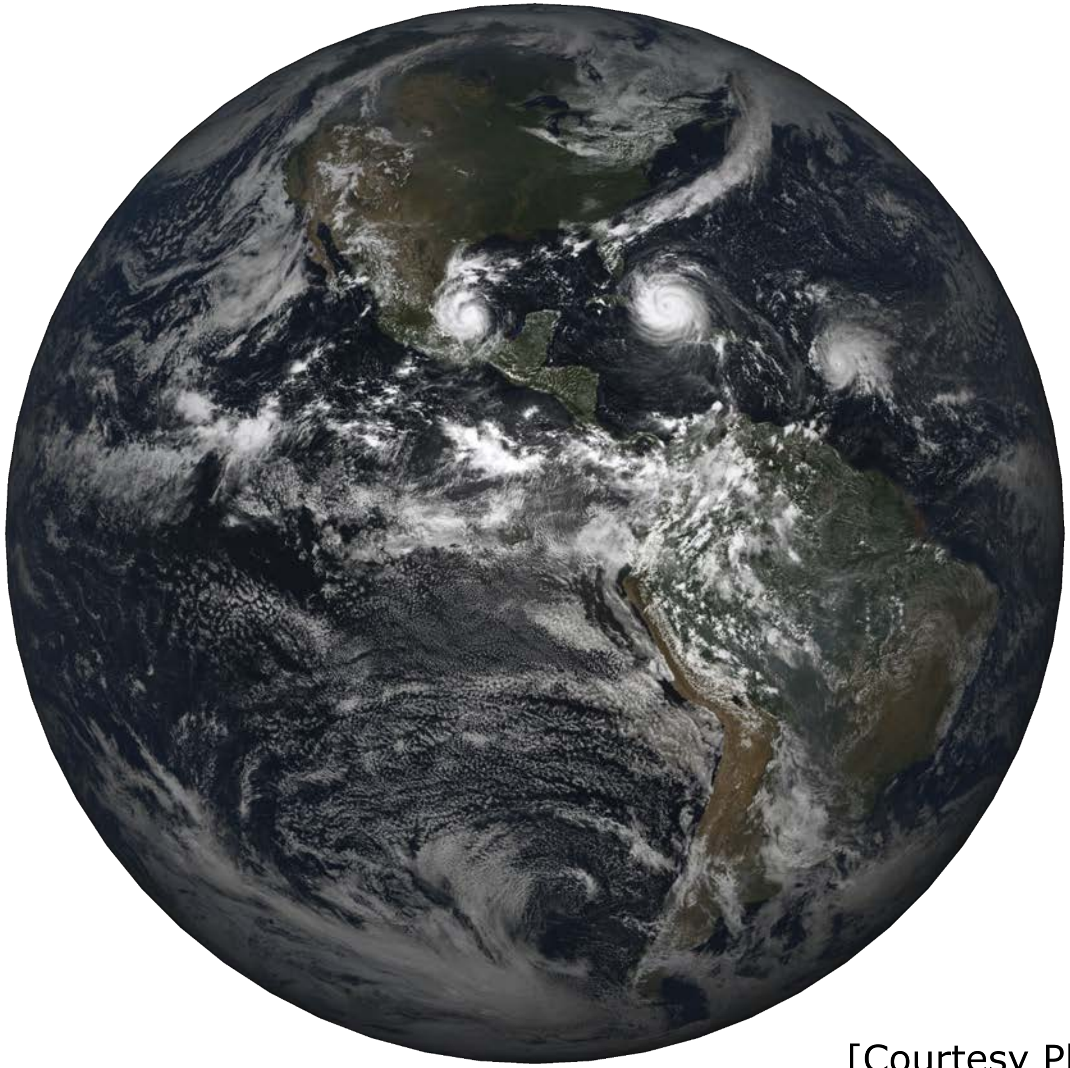


… and how dynamical and moist process interact over complex surface

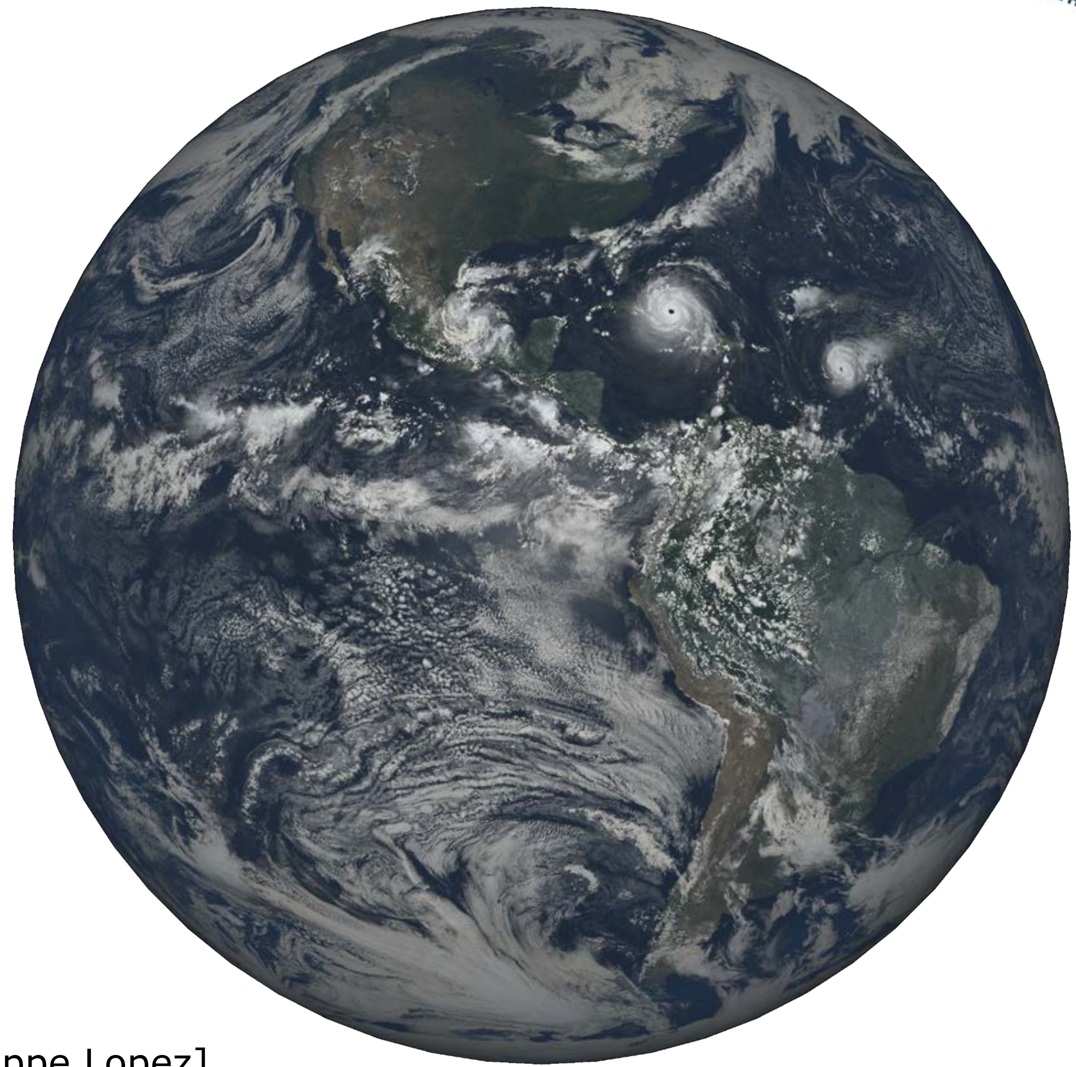
[Courtesy Bjorn Stevens and Philippe Lopez]

Nearly there

GOES-16 satellite 08/09/2017 18 UTC



ECMWF 2.5km 18h forecast



[Courtesy Philippe Lopez]

Destination Earth (DestinE) - ECMWF's role

The DestinE **Digital Twin Engine** (DTE):

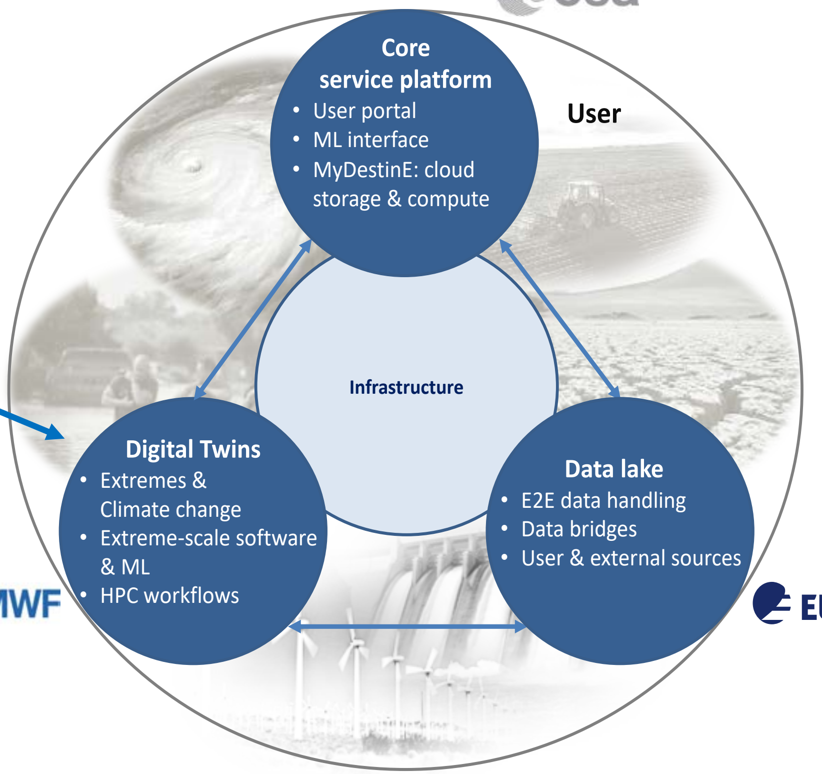
- common system approach to a unified orchestration of Earth-system simulations requiring large-scale HPC resources and the fusion of observations with models

Weather-induced and Geophysical **Extremes Digital Twin**:

- capabilities and services for the assessment and prediction of environmental extremes

Climate Change Adaptation **Digital Twin**:

- capabilities and services in support of climate change adaptation policies and mitigation scenario testing



Phase 1 (2021-2024): Delivery of 1st digital twin generation; demonstration of new capabilities at scale

Phase 2+ (2024-): Further develop the weather and climate DTs, fully integrate impact-sector elements; widen DTE scope, include other DTs

Turning requirements into practice

1. Much **better simulations** based on **more realistic models**
2. Better ways of **combining all observed and simulated information** from entire (physical + food/water/energy/health) Earth system
3. An information system that provides **convenient access to all data, models and workflows**

Digital Twin Engine and Digital Twins:

A. Create reference simulation system based on **much enhanced Earth system models**

B. Create reference **simulation-observation fusion system**

C. Extend (A) & (B) to **impact sectors** and select **use cases/applications** for unique capability demonstration

D. Implement underlying, **generic software infrastructures**:

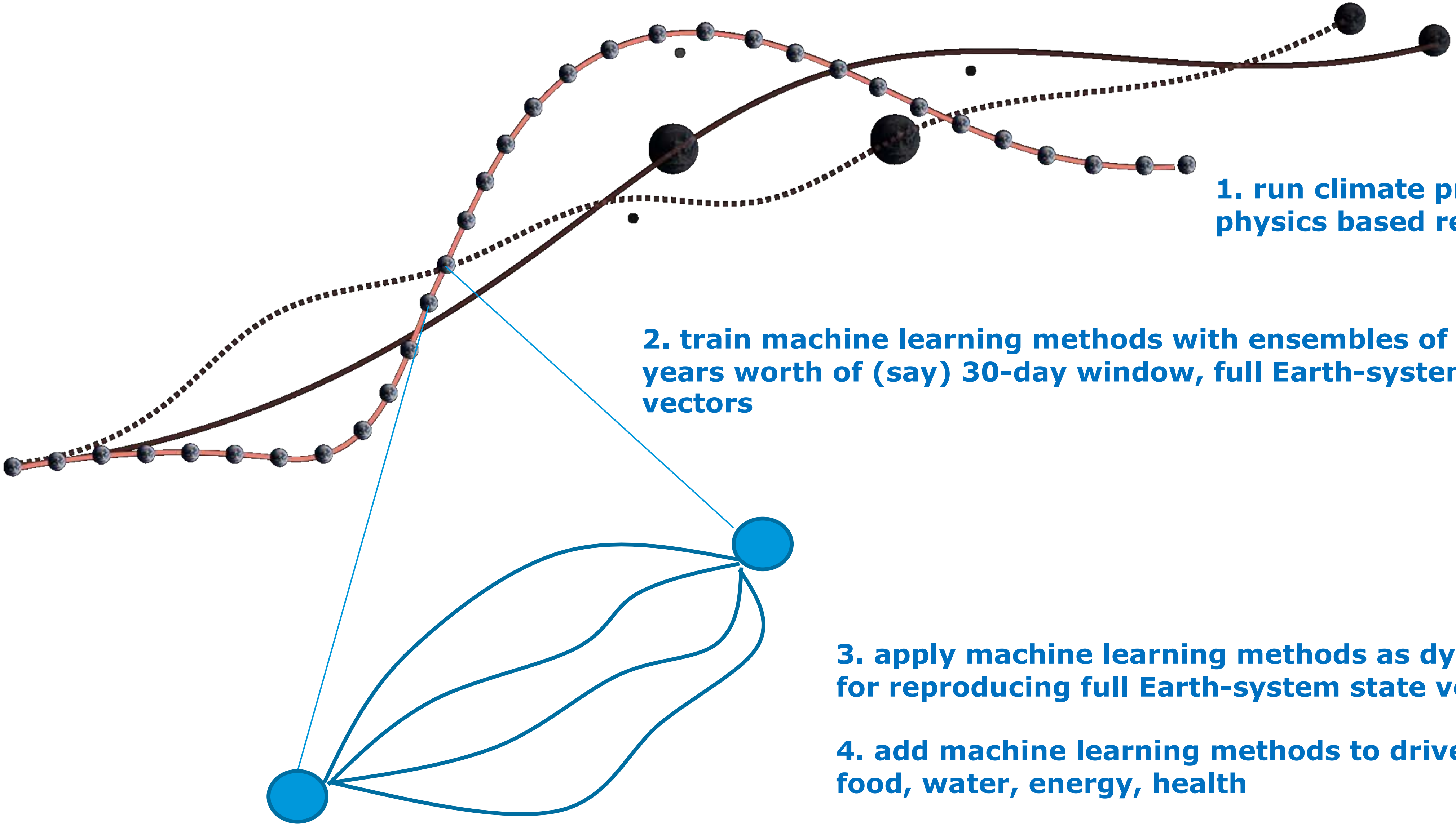
   a. demonstrate (A)-(C) at scale on wide range of **novel digital technology**

   b. connect with **DESP and DEDL** and demonstrate overall functionality

   c. prepare for **emerging digital twin applications and more users (in phase 2)**

The future is hybrid

B. Stevens
MPI director Hamburg



1. run climate projections with physics based reference models

2. train machine learning methods with ensembles of 100s years worth of (say) 30-day window, full Earth-system state vectors

3. apply machine learning methods as dynamic interpolators for reproducing full Earth-system state vectors in windows

4. add machine learning methods to drive applications for food, water, energy, health

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Take home messages

- Reanalyses are at the basis of the climate service provision. To keep serving our users well, it is essential to maintain an operational service including EQC, user support, knowledge base, etc.
- The systematic analysis of user requirements is one of the key drivers for the evolution of reanalysis products and it underpins the design of ERA6.
- A number of other factors are likely to affect the next generation of reanalyses: advancement in our models and data assimilation methodologies as well as the technological advancement in the way value can be efficiently extracted from these simulations.
- DestinE is represent a step change in some of these technologies and will provide the climate services arena with new tools and solution to address an ever-expanding set of societal users.

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Special Issue of Meteorological Applications

Special issue of the open-access journal [Meteorological Applications] to document recent innovative applications of reanalysis data in climate services

Meteorological Applications
Open Access
Science and Technology for Weather and Climate
RMetS

Chief Editors: Cristina Charlton-Perez and Dino Zardi
Impact factor: 2.119
2020 Journal Citation Reports (Clarivate Analytics): 64/94 (Meteorology & Atmospheric Sciences)
Online ISSN: 1469-8080

<u>Topics:</u>

- Reanalyses in climate and atmosphere monitoring
- Use of reanalyses for different sector applications (energy, insurance, agriculture, water…): current applications and limitations with suggestions for future developments
- Use of reanalyses for atmospheric and climate model evaluations
- The current use of reanalyses for climate impact modelling
- The role of reanalyses in the user engagement for SMEs
- Use of reanalyses to inform national adaptation plans
- Current applications of ocean reanalyses

Contacts:
Carlo Buontempo (carlo.buontempo@ecmwf.int)
Dick Dee (dee.mbox@gmail.com)
Chiara Cagnazzo (chiara.cagnazzo@ecnwf.int)

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