WGNE – evolution of systematic errors in Earth system modelling

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co-chair WGNE
European Centre for Medium Range Weather Forecasts (ECMWF)

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WCRP World Climate Research Programme

38 years of WGNE in WCRP & CAS !! Earlier structure since 1967 …

Working Group on Numerical Experimentation (WGNE)

WGNE co-chairs: *Nils Wedi (ECMWF), Ariane Frassoni (INPE)* ***WCRP Secretariat:*** *Nico Caltabiano*

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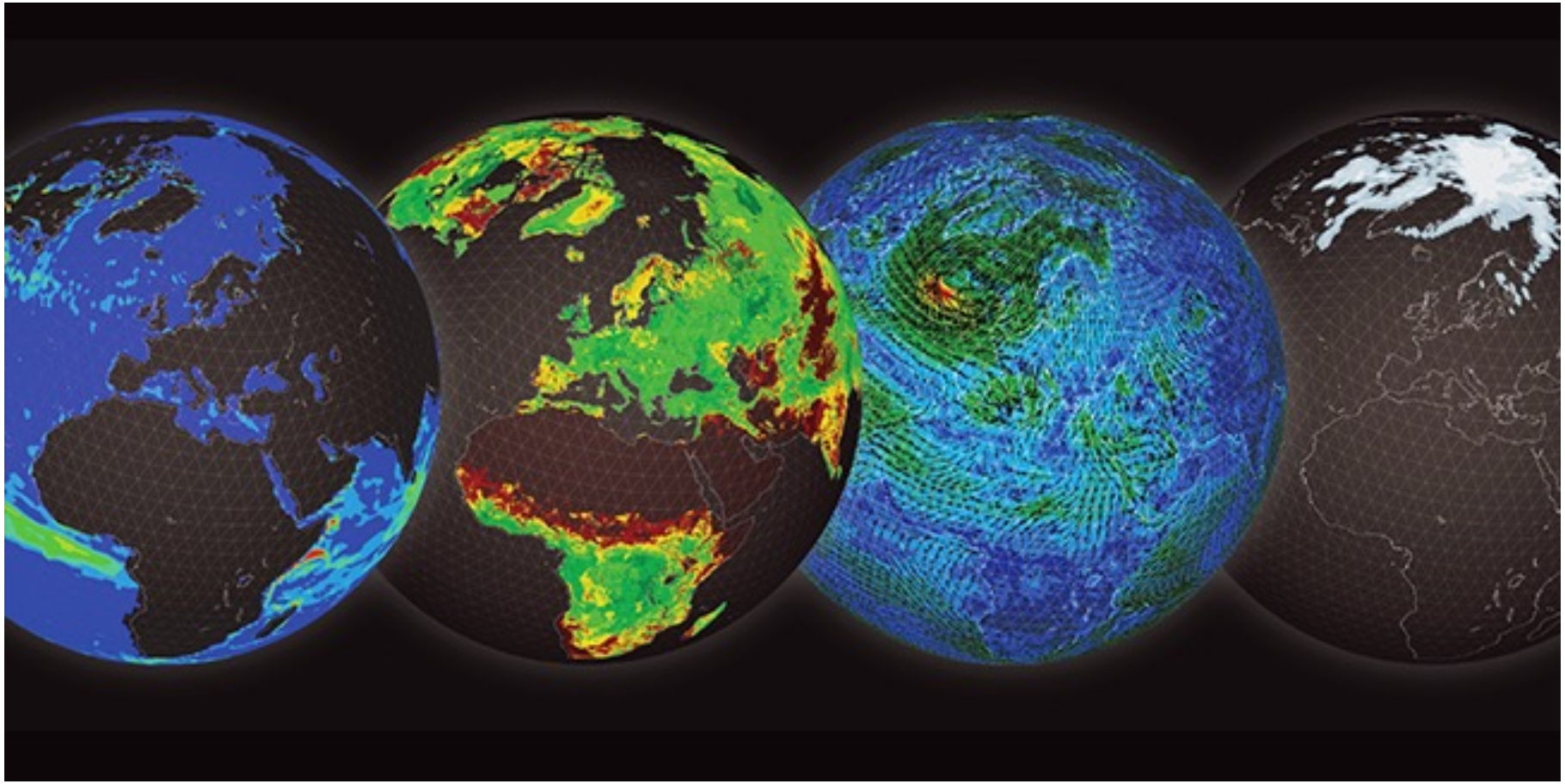
- *Ron McTaggart-Cowan-ECCC (Canada),*
- *Oscar Alves-BOM (Australia),*
- *Jian Sun-CMA (China),*
- *Elena Astakhova-Rushydromet (Russia) still supporting* ***wgne.net***

Contents

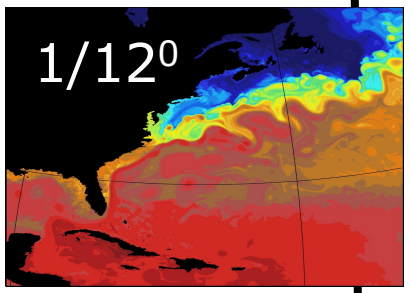
1. Earth system modelling
2. Review from 6th WGNE workshop
3. Weather parameters and high-impact weather indicators & EW4All
4. Rise of data driven forecasting
5. Interactivity & novel data delivery

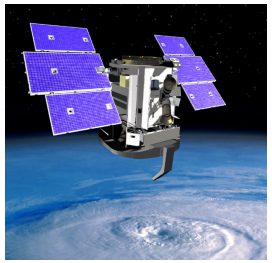
Multi-spheres concept in modelling & prediction



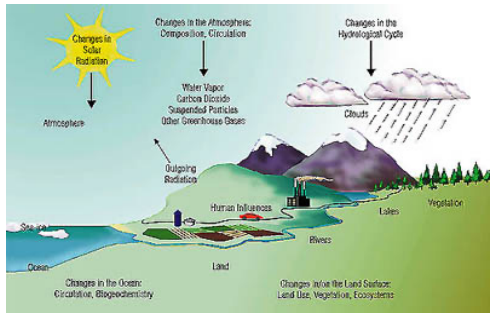
https://www.ecmwf.int/en/about/media-centre/news/2021/ecmwf-strategy-2021-30-and-machine-learning-roadmap-launched

A NEW AXIS CONSTRAINING SCALABILITY, BIG DATA HANDLING AND COMPUTING RESOURCES





EO, Data Assimilation



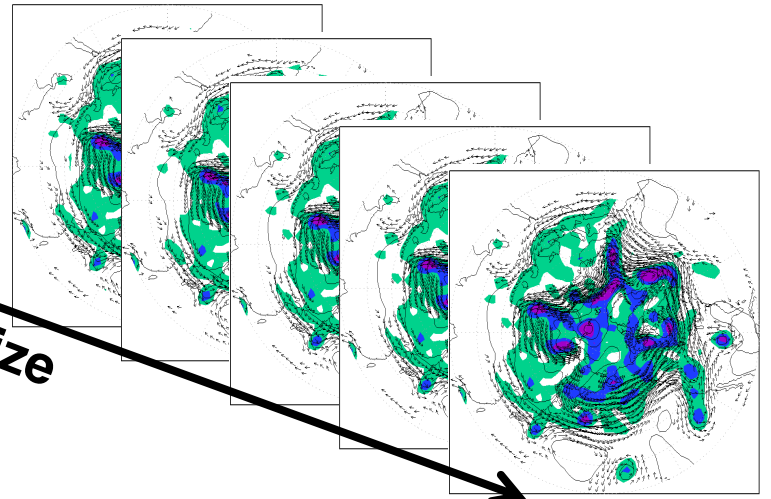
Resolution

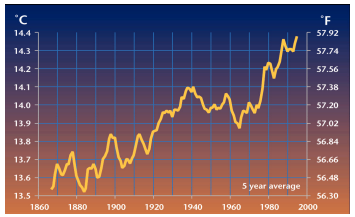
Computing Resources

Complexity

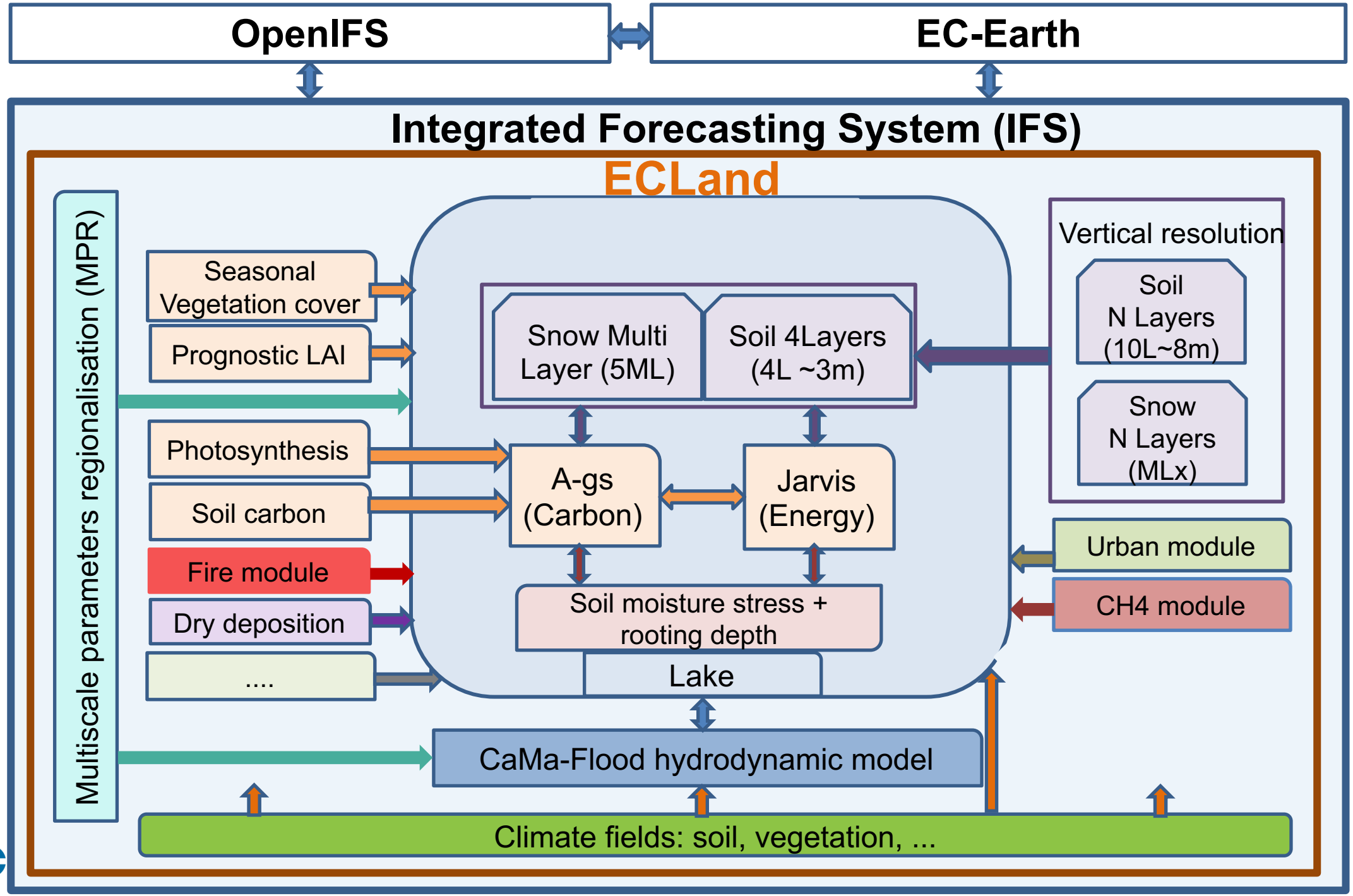
Impact Applications

Duration and/or Ensemble size





ECMWF


OpenIFS
EC-Earth
Integrated Forecasting System (IFS)
ECLand
Multiscale parameters regionalisation (MPR)
Seasonal Vegetation cover
Prognostic LAI
Photosynthesis
Soil carbon
Fire module
Dry deposition
....
Snow Multi Layer (5ML)
Soil 4Layers (4L ~3m)
A-gs (Carbon)
Jarvis (Energy)
Soil moisture stress + rooting depth
Lake
Vertical resolution
Soil N Layers (10L~8m)
Snow N Layers (MLx)
Urban module
CH4 module
CaMa-Flood hydrodynamic model
Climate fields: soil, vegetation, ...

Working Group on Numerical Experimentation (WGNE)

6th WGNE workshop on **systematic errors in weather and climate models** at ECMWF in 2022 (*https://events.ecmwf.int/event/241*)

Systematic Errors in Weather and Climate Models: Challenges and Opportunities in Complex Coupled Modeling Systems, *Frassoni, Reynolds, Wedi et al 2023*

https://doi.org/10.1175/BAMS-D-23-0102.1

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Systematic Errors in Weather and Climate Models

Selected qualitative conclusions for the 2024-2027 time-scale:

Constraining errors on troposphere-stratosphere coupling and improved predictability

Amplitude of diurnal cycle of precipitation over land remains a challenge

Reduction in systematic errors of upper ocean (SST, salinity, Gulf stream separation) and of some deep ocean properties

Substantial errors in high-latitudes remain

Substantial MJO simulation errors (and convective boundary layers in coupled models) remain

Substantially improved tropical cyclone track and intensity forecasts, in part through improved air-sea coupling

Improved hydrological and flood prediction and improved representation of vegetation and soil, and snow, in part based on more up-to-date mapping information

Increased complexity of very-high resolution simulations within coupled ocean-atmosphere-land systems give also rise to new systematic errors…

Bias correction of systematic errors through ML/AI advances

Recommendations to advance on systematic error reduction including data assimilation, machine learning, and a hierarchy of models supported by standardised and widely available observational data.

Forecast Errors in Weather and Climate Models 2013 → 2023

Met Office

Tim Graham & colleagues

Based on a range of global models

Area	Parameter	Forecast range								
		T+24 RMSE	T+24 10-year RMSE change	% difference	T+72	T+72 10-year RMSE change	% difference	T+120	T+120 10-year RMSE change	% difference
NH	pmsl	82,4417	67,0675	-22,9	211,6148	173,4242	-22,0	398,8079	354,9571	-12,4
	500 hPa GPH	6,5992	5,244	-25,8	20,7134	17,0331	-21,6	41,8865	37,211	-12,6
	250 hPa wind	3,3205	2,8675	-15,8	7,5864	6,7353	-12,6	12,5156	11,6188	-7,7
	250 hPa temp	0,6437	0,5743	-12,1	1,4889	1,3209	-12,7	2,3724	2,1715	-9,3
TR	850 hPa wind	1,6936	1,5059	-12,5	2,643	2,4518	-7,8	3,2955	3,1333	-5,2
	250 hPa wind	3,0121	3,1105	3,2	5,3702	5,5818	3,8	7,0235	7,3234	4,1
	250 hPa temp	0,3827	0,4454	14,1	0,6646	0,7205	7,8	0,8236	0,8538	3,5
SH	pmsl	96,6029	69,2929	-39,4	266,07	206,771	-28,7	507,1582	435,204	-16,5
	500 hPa GPH	8,343	6,1211	-36,3	26,2052	20,1679	-29,9	51,8982	44,0892	-17,7
	250 hPa wind	3,3525	2,952	-13,6	8,1274	6,9988	-16,1	13,6093	12,2837	-10,8
	250 hPa temp	0,665	0,5999	-10,9	1,5812	1,3605	-16,2	2,5117	2,2335	-12,5

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Forecast Errors in Weather and Climate Models 2013 → 2023

High Impact weather error reduction

Thomas Haiden

Feature	Current error or score (2023)	Error or score 10 years ago (2013)	Approximate improvement in 10 years	Comments
Tropical cyclone position	MAE (D+3) = 160 km MAE (D+5) = 250 km	MAE (D+3) = 180 km MAE (D+5) = 350 km	11% 29%	
Tropical cyclone intensity (central pressure)	MAE (D+3) = 11 hPa	MAE (D+3) = 15 hPa	27%	
Strong wind	ROCS (D+5) = 0.77	ROCS (D+5) = 0.72	6%	EFI (95th percentile) ROC skill in Europe
Significant wave height	SI (D+3) = 20% SI (D+5) = 30%	SI (D+3) = 23% SI (D+5) = 33%	13% 9%	SI = Scatter Index (error standard deviation divided by obs) in %
High temperatures	ROCS (D+5) = 0.92	ROCS (D+5) = 0.88	5%	EFI (95th percentile) ROC skill in Europe
Heavy rainfall	ROCS (D+5) = 0.68	ROCS (D+5) = 0.63	8%	EFI (95th percentile) ROC skill in Europe
Heavy rainfall	ETS (D+3) = 0.155 ETS (D+5) = 0.100	ETS (D+3) = 0.125 ETS (D+5) = 0.075	24% 30%	Equitable Threat Score (ETS) for >50mm/24h in N. Extratropics

EW4All Priority hazards:

- Flash-floods
- Drought/Dry spell
- Riverine Floods
- Tropical cyclone
- Thunderstorms/Squall lines
- Heat wave

The landscape …

https://community.wmo.int/en/news/exploring-possibilities-artificial-intelligence-areas-water-weather-and-climate

DeepMind & Google's ML-Based GraphCast Outperforms the World's Best Medium-Range Weather Forecasting System

https://www.science.org/doi/10.1126/science.adi2336

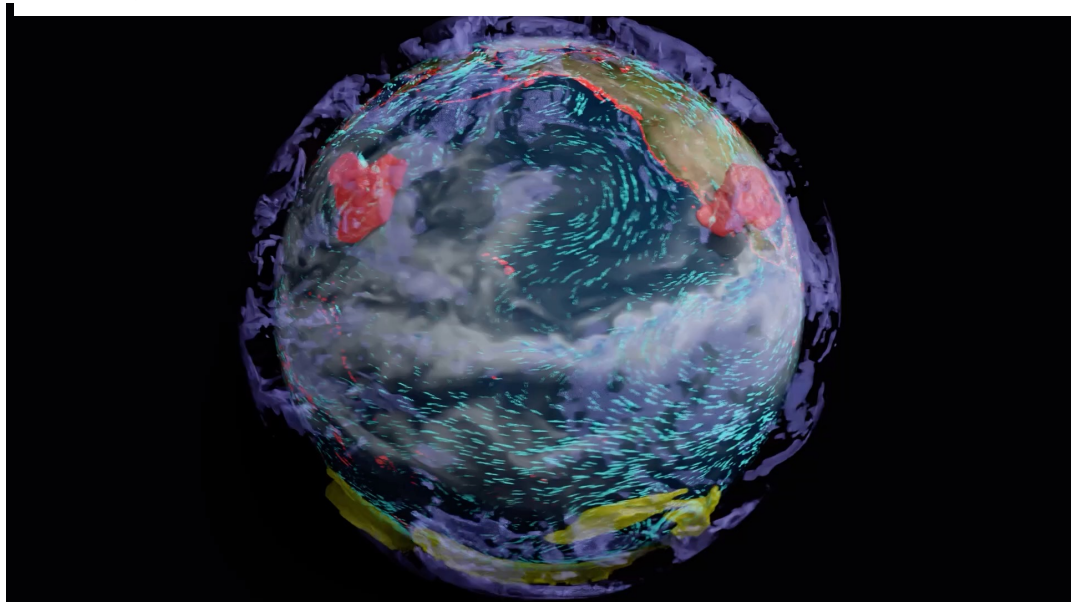
Natural language translation

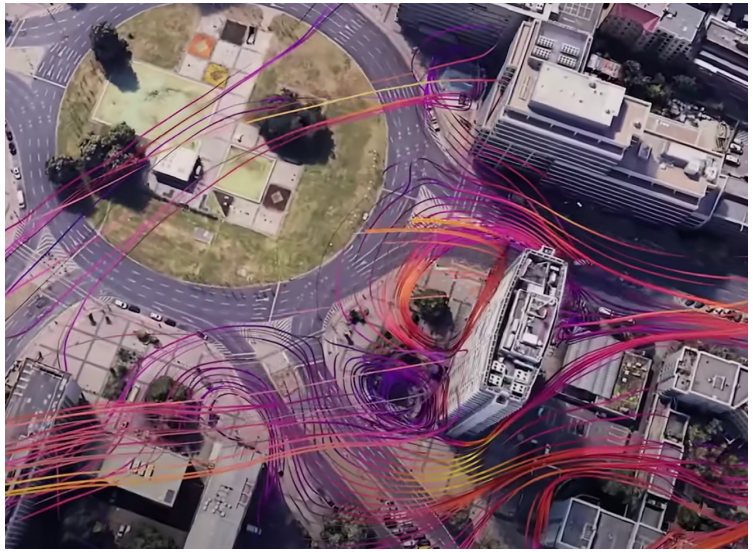
NVIDIA

HOME AI DATA CENTER DRIVING GAMING PRO GRAPHICS AUTONOMOUS MACHINES HEALTHCARE STARTUPS AI PODCAST

NVIDIA to Build Earth-2 Supercomputer to See Our Future

November 12, 2021 by JENSEN HUANG





ECMWF

The rise of data-driven forecasting …
… in 2023

THE RISE OF DATA-DRIVEN WEATHER FORECASTING
A FIRST STATISTICAL ASSESSMENT OF MACHINE LEARNING-BASED WEATHER FORECASTS IN AN OPERATIONAL-LIKE CONTEXT

A PREPRINT

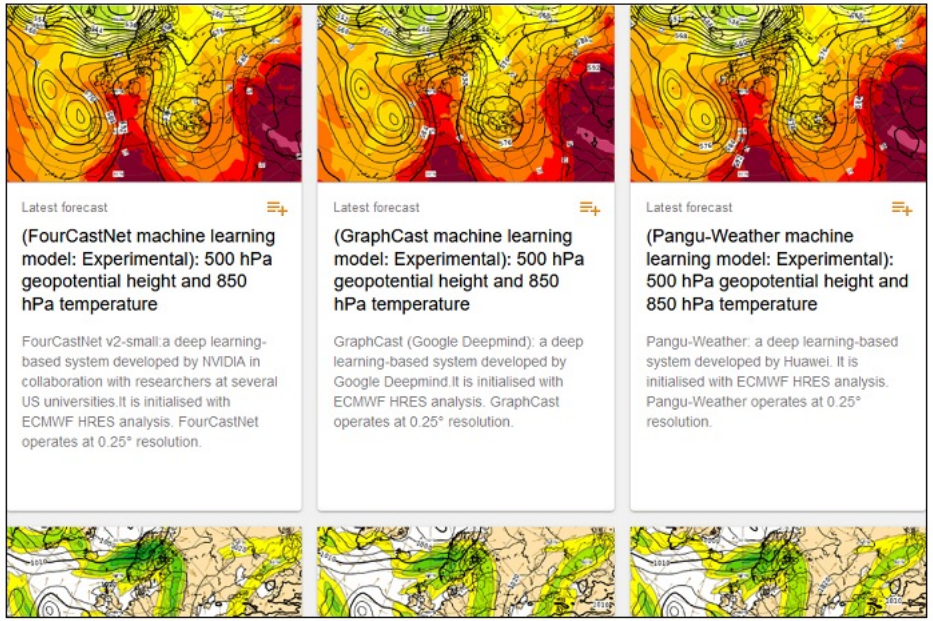
Zied Ben Bouallègue, Mariana C A Clare, Linus Magnusson, Estibaliz Gascón, Michael Maier-Gerber, Martin Janoušek, Mark Rodwell, Florian Pinault, Jesper S Dramsch, Baudouin Raoult, Florence Rabier, Matthieu Chevallier, Irina Sandu, Peter Dueben, Matthew Chantry, Florian Pappenberger

ECMWF

ABSTRACT

Data-driven modeling based on machine learning (ML) is showing enormous potential for weather forecasting. Rapid progress has been made with impressive results for some applications. The uptake of ML methods could be a game-changer for the incremental progress in traditional numerical weather

charts.ecmwf.int

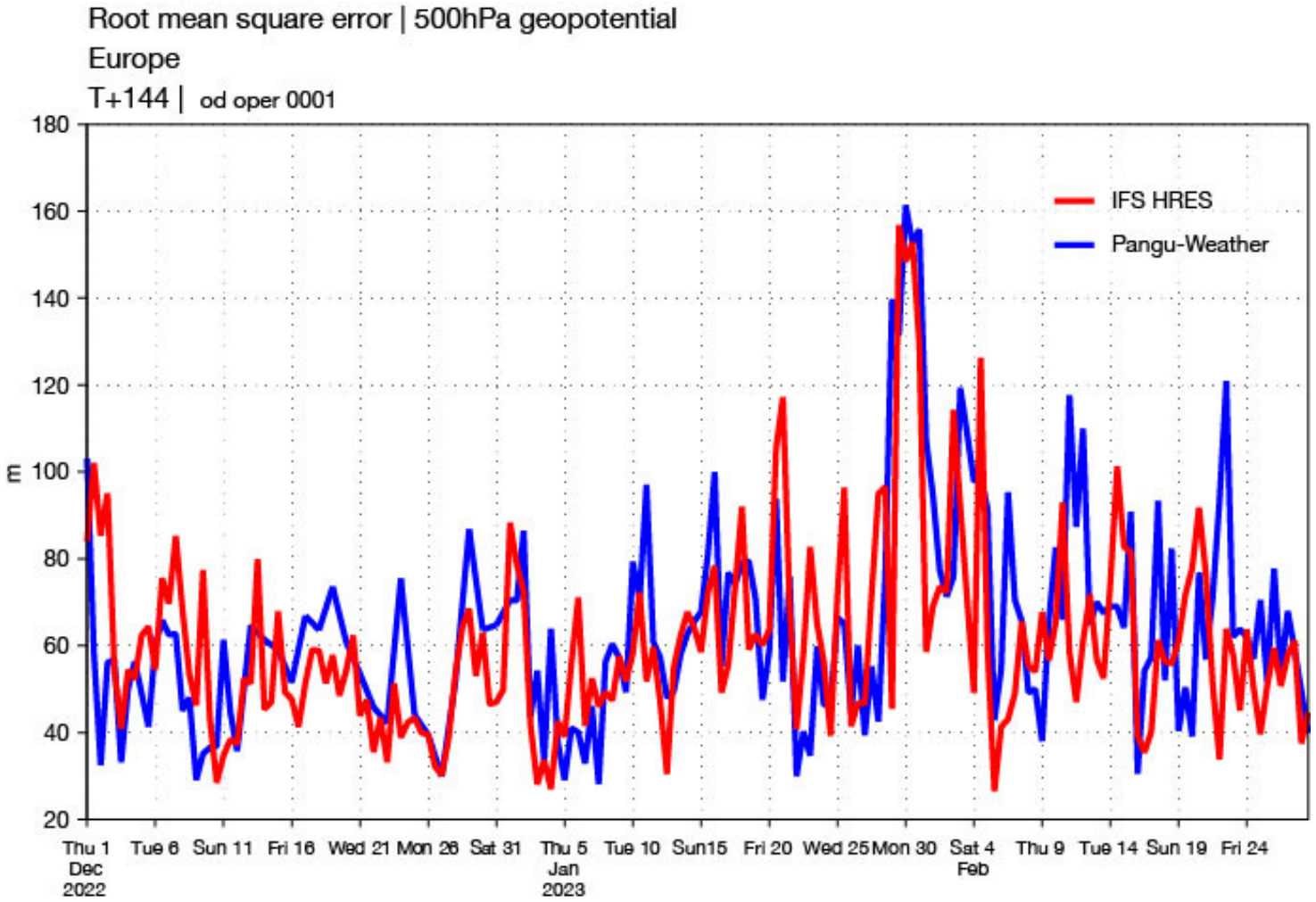


ECMWF unveils alpha version of new ML model

13 October 2023
The AIFS team

https://www.ecmwf.int/en/about/media-centre/aifs-blog

What results are showing
Time-series of RMSE over Europe, day 6



PanguWeather (initialised with ECMWF operational analysis) vs ECMWF HRES forecasts

- Results extremely close...
- ‘forecast busts’ at similar time
  – more ‘physical’ than one might think

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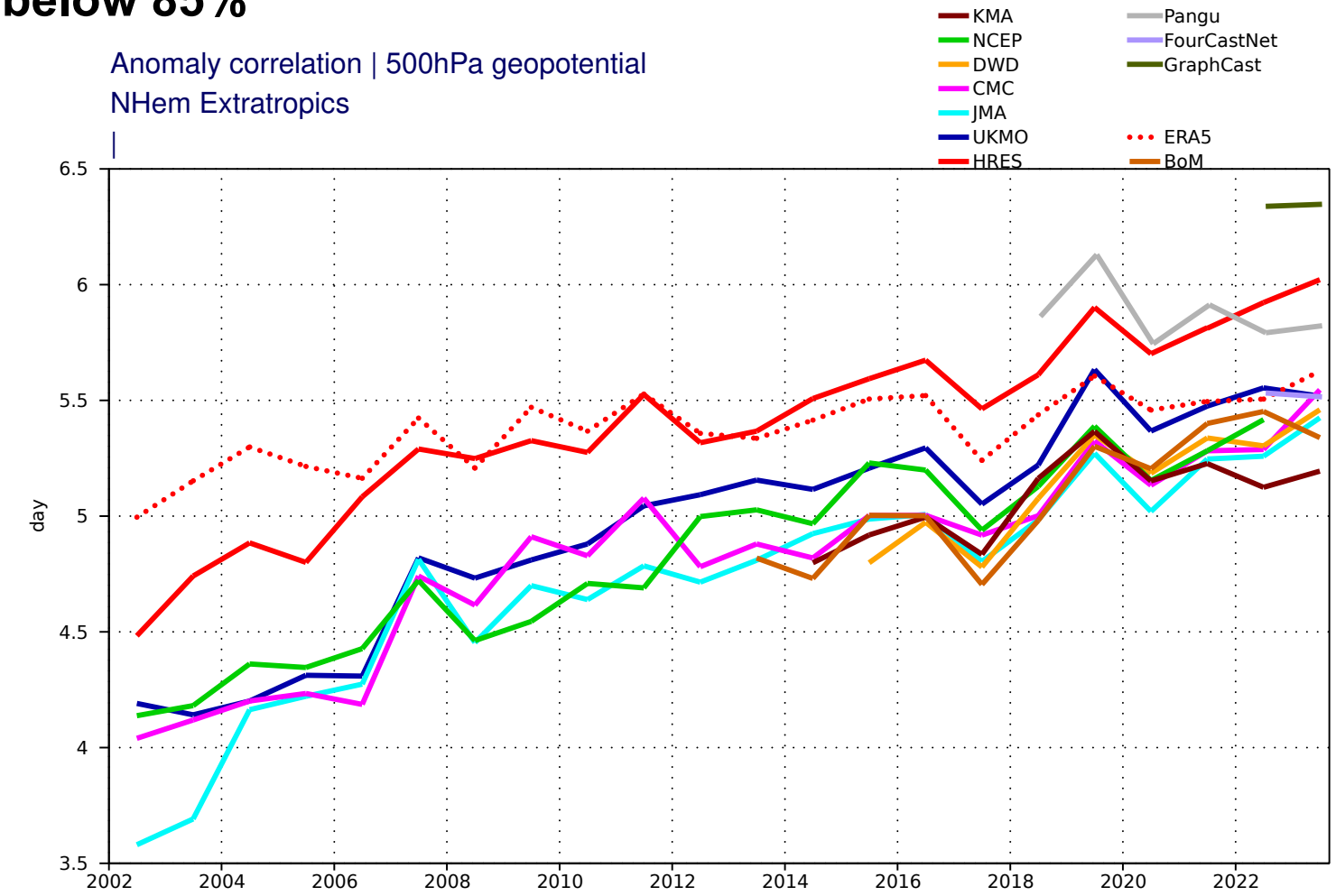
What results are showing
Headline score - 500hPa geopotential

Anomaly correlation of 500hPa geopotential over Northern Hemisphere Extratropics, falling below 85%

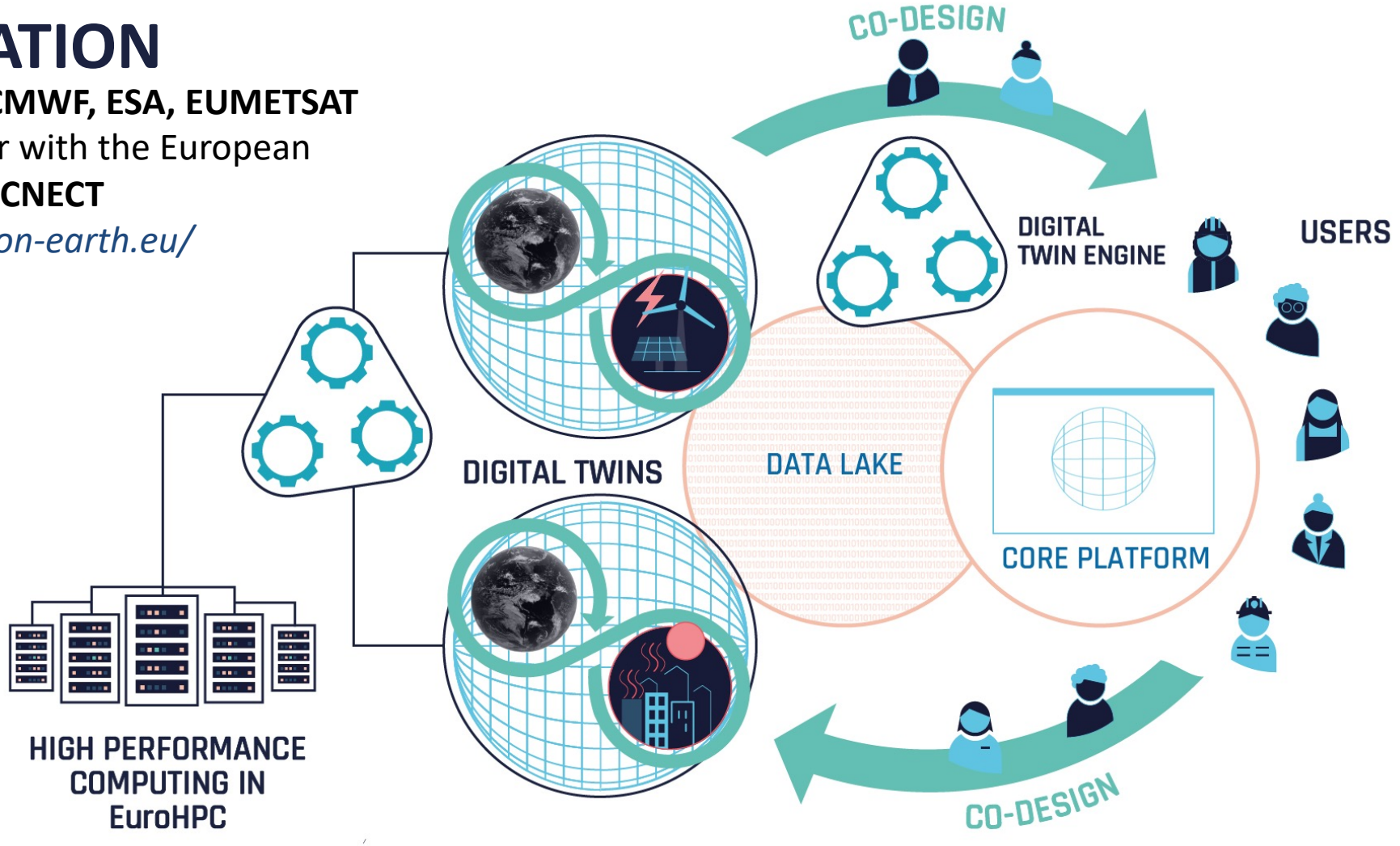


ML models (initialised with ECMWF HRES analysis)

INNOVATION

Three entities **ECMWF, ESA, EUMETSAT** working together with the European Commission **DG-CNECT**

https://destination-earth.eu/

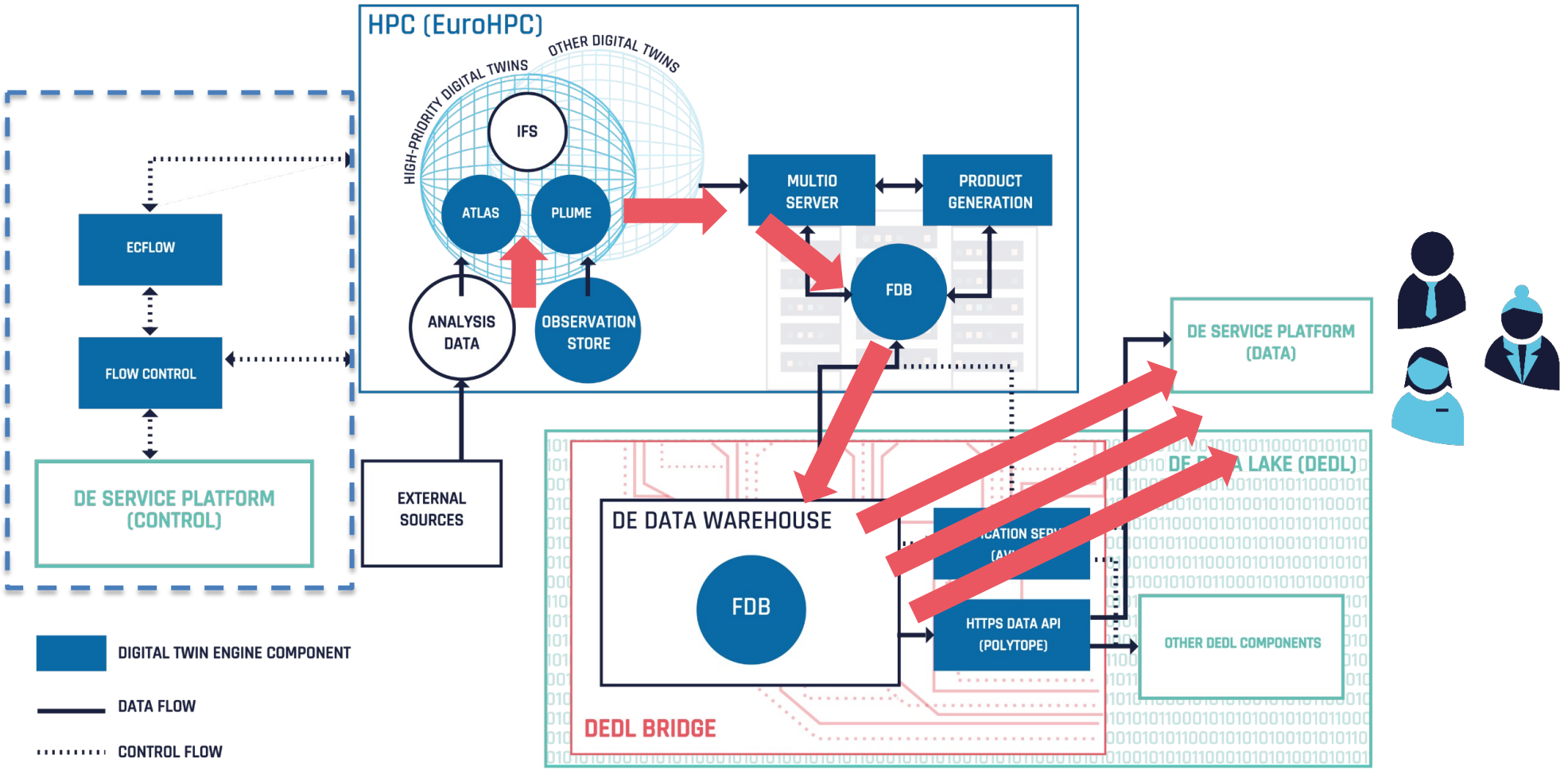


ECMWF

Funded by the European Union

ECMWF esa EUMETSAT

Digital Twins, managing Big Data & interacting with bespoke information resources



e.g. WIS2.0 compatible data access

https://pygeoapi.io/

https://polytope-client.readthedocs.io/en/latest/

Systematic Errors in Weather and Climate Models

Conclusions for 2024-2027 timeframe

1. **Significant improvements over last decade** on high-impact weather and multi-model hemispheric scores
2. Identified hazards **benefit from progress in land-surface modelling, higher horizontal resolution and integration with hydrological modelling** within land-surface schemes
3. **ML/AI can improve systematic errors**, **timeliness of delivery and uncertainty estimation**
4. Challenges WMCs readiness to make available **open Earth-system data and accelerate novel access patterns (including compute)**

EW4All Priority hazards:

- Flash-floods
- Drought/Dry spell
- Riverine Floods
- Tropical cyclone
- Thunderstorms/Squall lines
- Heat wave

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Thank you

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