

# **ECMWF** progress and plans

Andy Brown and Florian Pappenberger



ORGANISATION AND PEOPLE

**C**ECMWF







The strength of a common goal



5







## Integrated Forecast System (IFS) upgrades



## Integrated Forecast System (IFS) upgrades



## Medium range ensemble: 18 km to 9 km (same as HRES) Extended range ensemble: 50+1 members twice weekly to 100+1 members every day



## Evolution of ENS upper-air forecast skill

#### **News on ECMWF's forecast** performance Speaker: Thomas Haiden



## Integrated Forecast System (IFS) upgrades



## New ocean reanalysis performance

Mean SST biases (2015-2021)

Verf. CCIv2 SST

#### **Global-mean SST Diurnal Cycle**

ORAS5 ORAS6 0001 cci2 sosstsst tos 20152021 r1x1 bias 1.nc i5ou cci2 tos tos 20152021 r1x1 bias 1.nc 48°N 48°N 45°N 45°N 42°N 42°N 39°N 39°N 36°N 36°N Gulf Stream 33°N 33°N 30°N 30°N 81°W 78°W 75°W 72°W 69°W 66°W 63°W 81°W 78°W 75°W 72°W 69°W 66°W 63°W -4.75 -3.75 -2.75 -1.75 -0.75 0.25 1.25 2.25 3.25 4.25 -4.75 -3.75 -2.75 -1.75 -0.75 0.25 1.25 2.25 3.25 4.25





ORAS6 has a diurnal cycle close to observation

## Integrated Forecast System (IFS) upgrades



EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

# Summary of contributions to cycle 49R1 Model changes Data assimilation changes

- V1 Microwave and RTTOV assimilation package, including updates to RTTOV and all-sky all-surface assimilation of sea-ice areas for GMI/ASMR2 amongst other changes.
- V2 Wave model and convection package, including waves on Tco grid, new wind input parameterizations, sea-state dependent heat and moisture fluxes, hourly wave DA, improved CAT diagnostics, and updated non-orographic GWD.
- V3 Non-microwave observations package, including observation updates from IR and active sensing groups.
- V4 Land-surface model updates, including updated climate fields, modified vegetation properties, activation of urban tile, updated T2m interpolation, and shadowing of snow under high vegetation.
- V5 T2m assimilation package, activates assimilation of T2m observations.
- V6 VarQC and stratospheric balance assimilation package, including activation of VarQC in first trajectory, increased weight to GRAS/COSMIC-2 measurements, and activation of stratospheric balance in 4DVar.
- V7 Land-surface assimilation package, including changes to soil moisture background errors, updates to snow assimilation, and lapse rate correction for T2m assimilation.
- V8 Activation of the Stochastically Perturbed Parametrizations (SPP) scheme, which replaces the Stochastically Perturbed Parametrization Tendencies (SPPT) scheme in all IFS ensemble configurations.
- V9 Physics and numerics contributions, which includes ecRad optimizations, improved 10m wind diagnostics, improvements in TOA radiation budget, flexible aerosol treatment in radiation, time-dependent methane oxidation, and reordering sequence of physics chain in IFS.
- V10 Atmospheric composition package, including revisions to aerosol optical properties, chemistry updates, and many other changes.
- V11 Other technical/neutral changes, including bit-identical Ensemble control forecast and HRES.
- Updates to EDA, including Tco1279 FC+Traj, soft recentering, and new climatology for SES calculation.

## T2m verification against observations (NHEM, winter 2022/23)



CY49R1 improves NHEM T2m forecasts.

- Impact from several contributions.
- Largest impacts during NHEM winter.

#### **RD** esuite ensemble scores

Region (season)	CRPS (day 5)	RMSE (day 5)
N. Hem (DJF)	4.2 %	4.0 %
Tropics (DJF)	2.5 %	1.8 %
S. Hem (DJF)	0.3 %	0.6 %
N. Hem (JJA)	0.7 %	1.4 %
Tropics (JJA)	-0.7 %	-1.5 %
S. Hem (JJA)	-0.2 %	0.0 %

Bold values significant at 95% confidence level

## 10m wind verification against observations (NHEM, winter 2022/23)





#### CY49R1 improves 10m wind forecasts.

- Impact from several contributions.
- Increased spread from SPP is important.

#### **RD** esuite ensemble scores

Region (season)	CRPS (day 5)	RMSE (day 5)
N. Hem (DJF)	7.8 %	2.4 %
Tropics (DJF)	6.8 %	1.9 %
S. Hem (DJF)	3.8 %	1.4 %
N. Hem (JJA)	3.6 %	1.1 %
Tropics (JJA)	5.3 %	0.8 %
S. Hem (JJA)	5.1 %	1.1 %

Bold values significant at 95% confidence level

360

## 49R1 RD esuite: score cards (summer + winter combined)

### ENS Control (=HRES) (324 forecasts)

#### 50-member ENS (152 forecasts)

shaded boxes for confidence boundaries: 
95% 
50%/95% 
95%/99.7% 
Significance triangles

**Update on ECMWF Product Development** Speaker: Matthieu Chevallier

			n.hem	s.hem	tropics	europe		n.hem		s.hem		tropics			e v einn e i
		ccaf	seeps rmsef/sdef	ccaf/seeps rmsef/sdef	ccaf/seeps rmsef/sdef	ccaf/seeps rmsef/sdef		rmsef	crps	rmsef	crps	rmsef	crps	rmsef	crps
	an z	50					anz 5	0							
		100					1	00							
		250					2	50							
		500				· · · · · · · · · · · · · · · · · · ·		30 <b></b>							
		850					2	00							
	msl						8	50						Bennenseerees	
S	t	50					msl							Gaungaburganas	<b>THE CARDENESS</b>
		100					<u>t</u> 5	0		NUMBER OF STREET					
Ś		250					1	00				Concession Design			
$\leq$		230					2	50							
σ		500					5	00							CONTRACTOR DE LA CONTRACT
3		850					8	50		AND THE PARTY OF T					TTTT
A	21						# 5	0							
0	vw	50						0							
		100					1	00							
$\geq$		250					2	50							
$\geq$		500					5	00							
$\mathbf{O}$		850					8	50							
	10ff						<u>r</u> 2	00							
	<u>r</u>	250					7	00							
		700					<u>2t</u>					angeneneeneenee			
	10ff@se	a 💷					10ff@sea								
	swh						swh								
	mwp						mwp								
	OD Z	50					obz 5								
		100					1		(Bassas (Bas (B)))						Bellever and a second
		250					2	50							
		500						00							
		850				THE REAL PROPERTY.									-
	t	50					8	50	THE REPORT					Dessenanterest	<b>Necesconse</b>
		100					<u>t</u> 5	0							
$\mathbf{O}$		250					1	00			I THERE I DECENT			Research and the second s	III) CARACTERICATION CONTRACTOR
ž		500					2	50						1000000000000000000	
		850					5	00							
$\underline{\circ}$	21	0.50					8	50							
H	1000	50					ff 5	0		************	CARRENS CONTRACTOR				<b>HURSE</b> SSESSESSES
<sup>1</sup> U		100					1	00							TTD
~		100					2	50		******				TTTT: Base of the second	TTTTT - Bernstern
		250													- College and and a second second
Ψ.		500													
S		850					8	50	Contract Contract	TATISTICS CONTRACTOR					
	10ff						<u> </u>	00							The second second
$\bigcirc$	<u>r</u>	250				*****	2+								
		700					21								
	2d						20			******					
	tcc						tcc								
	<u>tp</u>						10ff								
	swh						<u>tp</u>			alle bit as a line () and		Censossanon and			
	10ff@se	a					swh								

## Integrated Forecast System (IFS) upgrades



## From ERA5 to ERA6; new climate dataset is being developed

ERA5 is the world-leading climate dataset for many applications.

Preparations of its follow-up, ERA6 are well underway:

- Taking onboard recorded user requirements from our huge ERA5 user base (over 160,000)
- Will capitalize on an additional 8 years of R&D at ECMWF plus increased compute power
- Double the atmospheric resolution: **14km globally** vs 31km; **ocean waves 14km** vs 40km.
- Has coupling with the ocean, providing additional information on the climate system.





ERA6 to start production in early 2025 Aim to make the first 20 years (2006-2026) available around Autumn 2026

## SEAS6 Real-time forecast enhancements at a glance:



### SEAS6 Reforecasts

#### Main set 1993-2022

7m fc: 33 members twice a month 13m fc: 22 members monthly 24m fc: 22 members twice a year

#### Supplementary set :

Back extension to 1961 for all Enhanced ensemble (up to 55 members ) for 7m fcs quarterly

## Integrated Forecast System (IFS) upgrades



# Higher-resolution 4D-Var data assimilation

0.04

0.02

of control

RMS error

ed by I

in RMS

ence

Differ

-0.02

-0.04

0.00

Change in RMS error in VW (TCo511 399-TL511 control) 1–Jun–2022 to 31–Aug–2022 from 164 to 183 samples. Verified against own–analysis. Cross–hatching indicates 95% confidence with Sidak correction for 20 independent tests. T+12 T+24 Pressure, hPa Pressure, hPa 100 100 400 400 700 700 100 1000 -90 30 60 -90 -30 0 30 60 90 -60 -30 0 90 -60 Latitude Latitude T+48 T+72 10 Pressure, hPa Pressure, hPa 100 100 400 400 700 700 1000 1000 -90 -60 -30 30 60 -90 -60 -30 30 60 90 0 90 0 Latitude Latitude T+96 T+120 10 Pressure, hPa Pressure, hPa 100 100 400 400 700 700 1000 1000 30 -30 30 -60 -30 0 60 -60 0 60 90 -90 90 -90 Latitude Latitude

		n.t	nem	s.h	em	tropics		
		ccaf/seeps	rmsef/sdef	ccaf/seeps	rmsef/ sdef	ccaf/ seeps	rmsef/sd	
an z	100							
	250							
	500							
	850							
msl								
ţ	100							
	250							
	500							
	850							
2t								
vw	100							
	250							
	500							
	850							
10ff								
<u>r</u>	250							
	700							
10ff@se	а							
swh								
mwp								
ob z	100							
	250							
	500							
	850							
t	100							
	250							
	500							
	850							
2t								
vw	100							
	250							
	500							
	850							
10ff								
<u>r</u>	250							
	700							
2d								
tcc			1					
<u>tp</u>								
swh								



## Products meeting users' needs







d 18 Oct 2023 00 UTC @ECMWF t+0-72h VT: Wed 18 Oct 2023 00 UTC - Sat 21 Oct 2023 00 UT

e forecast index and Shift of Tails (black contours 0,1,2,5,8) for total precipitation

### **Update on ECMWF Product Development** Speaker: Matthieu Chevallier

Latest developments on ECMWF's graphical products and apps Speaker: Cihan Sahin



Extended range meteogram - weekly mean anomalies srest - Brittany - France 48.48°N 4.74°W (ENS land point) 54 m Sunday 29 October 2023 00 UTC









EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS



Tropical cyclone strike probability (%) 5 30 25 30 48 50 40 70 80 90 31

## The open data goal





4 at 0.4 degrees and coarser.

## Machine Learning





#### Latest forecast Experimental: AIFS (ECMWF) ML model: Mean sea level pressure and 850 hPa wind speed

Experimental: FourCastNet ML model: Mean sea level pressure and 850 hPa wind speed

Latest forecast

AIFS (ECMWF): a deep learning-based system FourCastNet v2-small:a deep learning-based developed by ECMWF. It is initialised with system developed by NVIDIA in collaboration ECMWF HRES analysis. AIFS operates at 1° with researchers at several US universities. It is initialised with ECMWF HRES analysis. FourCastNet operates at 0.25° resolution.

=+



#### Latest forecast

resolution

Experimental: AIFS (ECMWF) ML model: 500 hPa geopotential height and 850 hPa temperature



#### Latest forecas Experimental: FourCastNet ML model: 500 hPa geopotential height and 850 hPa temperature

**MOOC Machine Learning in Weather** & Climate

#### ② Help **C**ECMWF Search site. - Log in Home About Forecasts Computing Research Learning Publications Who we are What we do lobs Media centre Suppliers Location

### ECMWF unveils alpha version of new ML model

13 October 2023 The AIFS team

#### View all AIFS blog posts

ECMWF is today launching a newborn companion to the IFS (Integrated Forecasting System), the AIFS, our Artificial Intelligence/Integrated Forecasting System (one "I" covering both Intelligence and Integrated)

Recent posts

ECMWF unveils alpha version of new ML model

The AIFS is barely a few months old and proudly entering its

Technical Memo



#### 878

Machine learning at ECMWF: A roadmap for the next 10 years

**Machine Learning Activities** at **ECMWF:** an overview Speaker: Mariana Clare (ECMWF)

**INVITED SPEAKER: Leveraging Large Language Models** for Weather and Climate Information Retrieval Speaker: Nikolay Koldunov (Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI))

## Enhanced ML efforts at ECMWF – project overview

#### The hybrid model

Enhanced and accelerated implementation of ECMWF ML Roadmap

#### **Delivering results**

# Development of a ML ensemble forecast

Data-driven model initialised with NWP analysis hence requiring conventional data assimilation.

**Embracing novelty** 

### Observations-driven ML system

A whole system reinventing the path from observations to predictions.

A scientific challenge

ECMWF collaborative project with Member States as one project of a EUMETNET programme

## Step 1: Evaluation in an operational setting

How to establish trust in a new type of forecasting system?

- Live daily forecasts provided openly
  - Only possible because of open-source contributions from NVIDIA, Huawei, Deepmind.

THE RISE OF DATA-DRIVEN WEATHER FORECASTING A FIRST STATISTICAL ASSESSMENT OF MACHINE LEARNING-BASED WEATHER FORECASTS IN AN OPERATIONAL-LIKE CONTEXT
A preprint V2
Zied Ben Bouallègue, Mariana C A Clare, Linus Magnusson, Estibaliz Gascón, Michael Maier-Gerber, Martin Janoušek, Mark Rodwell, Florian Pinault, Jesper S Dramsch, Simon T K Lang, Baudouin Raoult, Florence Rabier, Matthieu Chevallier, Irina Sandu, Peter Duchen, Matthew Chantry, Florian Pappenberger

ECMWF

- Enables real time evaluation of extreme events by operational analysts.
  - As a community we can better identify strengths and weaknesses.



# AIFS v0.2 – surface



4.5

 New AIFS version Previous AIFS version

Pangu-Weather

Funded by the <u>European Union</u> implemented by CECMWF COSA EUMETSAT

# DESTINE: A DIGITAL REPLICA OF OUR PLANET TO RESPOND AND ADAPT TO CLIMATE CHANGE AND EXTREME EVENTS

DestinE, in strategic partnership with EuroHPC Joint Undertaking:

- Establishes bespoke cutting-edge simulation capabilities
- Provides Earth-system information at scales where the impacts of extreme events and climate change are felt
- Fosters an innovative and thriving AI-enabled digital ecosystem



#### **ECMWF**



#### Globally, 4 days ahead, 2-4km







How will the approaching storm affect solar energy production?

# DestinE: How does km-scale benefit the representation of tropical cyclones?



9 km

4.5 km
IBTRACS

Maximum wind speed (kt)

... improved mesoscale features, intensity but lingering slow propagation bias



## CLIMATE DT: GLOBALLY CONSISTENT CLIMATE INFORMATION AT KM-SCALE

To enable policy actions in support of climate change adaptation

IPCC AR6 (2021), 100km







End-to-end climate DT workflow, including selected applications, deployed on LUMI

First ever projections (2020-2040) at ~ 5km across earth-system components running now on LUMI with 2 models (IFS-NEMO, ICON), streaming information to selected applications ; and historical runs at 10km since 1990



## **AI ACTIVITIES IN PHASE 2**

Towards a earth-system machine learning model leveraging DestinE data

Developing end-to-end workflows for ML model components like land, ocean, sea-ice, hydrology

Using data-driven methods for uncertainty quantification of Extremes and Climate DT

Climate emulator to rapidly explore 'what-if' scenarios

**ITT NOW OPEN** 

**Enhanced interactivity** Developing a forecast-in-a-box concept. ITT OPEN SOON Building ML demonstrators for impact-sectors (e.g., health, agriculture, urban) **ITT NOW OPEN** Develop of a weather and climate chatbot



#### FCMWF



ECMWF: entrusted entity for C3S and CAMS



Atmosphere Monitoring Service

- ECMWF: contractor to EC Joint Research Centre (JRC) for operating:
  - CEMS-EWS Flood
  - CEMS-EWS Fire



**Copernicus: a brief overview on the latest user-oriented advancements** Speaker: Stijn Vermoote

**The Copernicus Data Stores operated by ECMWF** Speaker: Edward Comyn-Platt

Forecasting atmospheric composition at ECMWF: introduction to the Copernicus Atmosphere monitoring Service (CAMS) Speaker: Laurence Rouil

**Copernicus National Collaboration Programmes at ECMWF** Speaker: Cristina Ananasso



Coper Europ















#### Temperature

Global air temperature +1.3°C Above pre-industrial level

European temperature (over land) +2.3°C Above pre-industrial level

Arctic temperature (over land) +3.3°C Above pre-industrial level

#### Ice and glaciers

Global glaciers -8200 km<sup>3</sup> Ice Ioss since 1976



European glaciers -850 km<sup>3</sup> Ice loss since 1976

Greenland Ice Sheet -5470 Gt Ice Ioss 1972-2022

Arctic sea ice extent -2.6 Mkm<sup>2</sup> September loss since the 1980s



#### Greenhouse gases

Carbon dioxide (CO<sub>2</sub>) concentration 419 ppm 2023 average

Carbon dioxide (CO<sub>2</sub>) increase +2.4 ppm per year Since 2010

Methane (CH4) concentration 1902 ppb 2023 average



Global sea level +10.3 cm Increase since 1993

**Global sea surface temperature** +0.6°C Increase since 1980 (60°S–60°N)

**Global ocean heat content +0.22°C** Increase since 1993 (upper 2000 m)





pulse.climate.copernicus.eu

climate.copernicus.eu/climate-indicators

# Serving our users: moving towards a Climate and Atmosphere Data Store



We have taken the feedback of CDS and ADS toolbox users onboard, and this has informed the design of the online development environment we will offer in the new system

- Jupyter Notebook online development environment
  - Synergy with training material to improve accessibility
- earthkit will be the supported user software
  - ECMWF wide software packages
  - Completely open-source and exportable (anyone anywhere)

earthkit is the namespace for ECMWF open-source python code

- It can be installed and used by anyone, anywhere
- It provides quality assured and supported software that ECMWF and C3S will use operationally
- Made up of sub-packages which address specific areas
  - Only need to install those which are relevant



The Copernicus Data Stores operated by ECMWF Speaker: Edward Comyn-Platt

## **European Weather Cloud**

- Pilot project started 2019 by ECMWF and EUMETSAT
- Went operational October 2023
- ECMWF part deployed of the new operational infrastructure in ECMWF Bologna Data Centre
- EUMETSAT part running on public cloud infrastructure



- Online access to the cloud computing resources
- Flexibility in provisioning, managing and deleting resources on-demand
- Rich and fast data availability, with data locality for processing
- Community: knowledge, applications, synergies, collaborations
- Ongoing training webinars for users



www.europeanweather.cloud

# CODE FOREARTH Innovation - Collaboration - Open Source Coding

## Encouraging innovation, Strengthening relationships and Fostering collaboration

## 2024 edition has 13 teams Coding phase 2 May – 31 August!

- Stream 1 <u>Data visualization and visual narratives</u>
- Stream 2 <u>Machine Learning for Earth Sciences</u>
   <u>applications</u>
- Stream 3 <u>Software development for Earth</u>
   <u>Sciences applications</u>

ECMWF with contributions by:

Since 2018, the programme (previous ESoWC) produced 35+ open-source software developments highly beneficial to the activities at ECMWF and to users

Website: https://codeforearth.ecmwf.int/

## User engagement



The 'Green' Book

Use and Verification of ECMWF Products in the Member and Co-operating States: Survey Results Speaker: Tim Hewson (ECMWF)

#### Thank you for your feedback!

Technical<br/>MemoExcessionUse and Verification of<br/>ECMWF products<br/>in Member and<br/>Co-operating StatesEmo Technical Memo Technical Memo<br/>Technical Memo<br/>Technica

## ECMWF's new user-focused LinkedIn channel

- Focused on current users of all ECMWF data & products
- Providing user-centric, in-depth information and added value with a high degree of technical information
- Community of 803 and growing!

ECMWF Users

Environmental Services · 791 followers

Advancing global NWP through international collaboration



![](_page_42_Picture_5.jpeg)

![](_page_42_Picture_6.jpeg)

Topics: open data, cycle updates, data formats & naming, user events

-> We want to engage with our community: get in touch if you have a particularly interesting use-case to share or milestone to celebrate

## **C**ECMWF

#### https://www.linkedin.com/showcase/ecmwf-user-engagement/

![](_page_43_Figure_0.jpeg)