

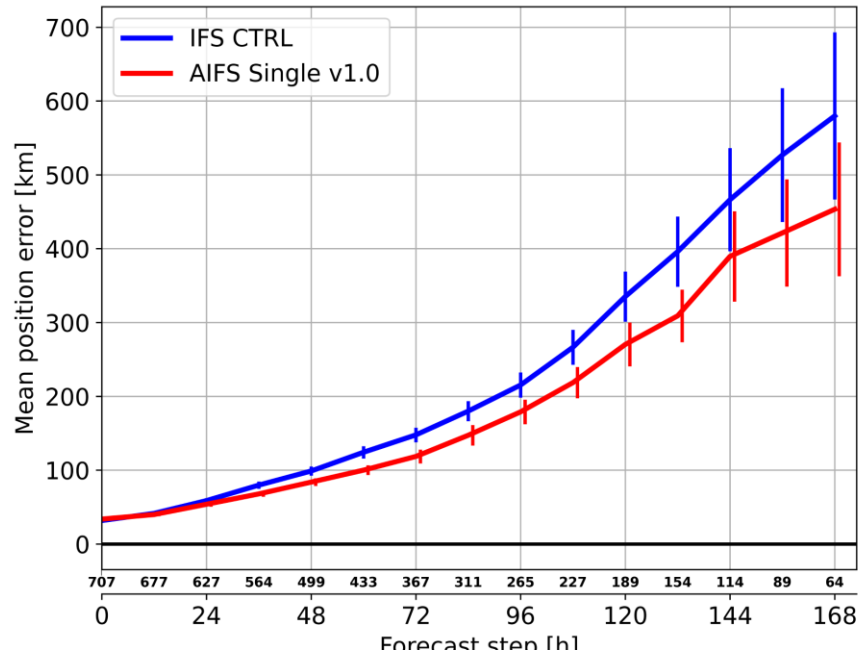
The Impact of AI on NHMS activities (Empowering WMO Members to leverage AI)

*Veronique Bouchet, Science and Innovation Department
Nir Stav, Yuki Honda, Infrastructure Department, WMO*

December 3, 2025

Why ML forecasting

Tropical Cyclone tracks (2024)

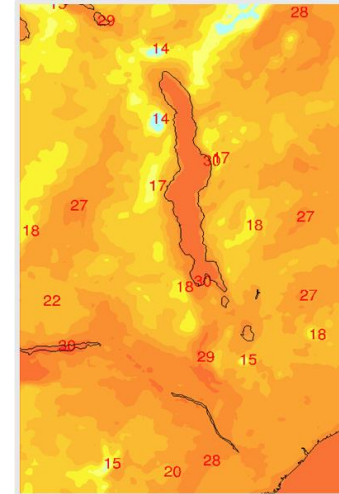


Courtesy of Florian Papenberger, ECMWF

EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS



Bris-Malawi



COSMO

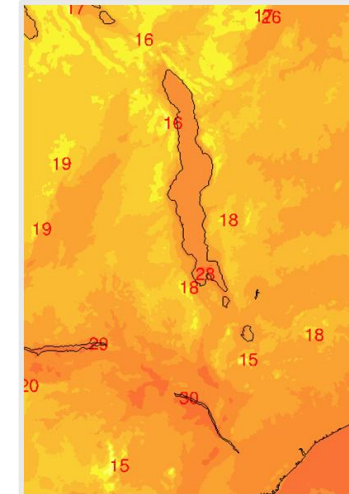
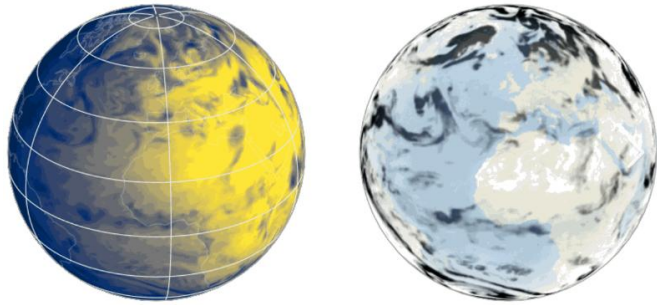


Fig: 2m temperature field (courtesy of Amos Mtanya, Lene Østvand and Roar Skålin) from AI-WP and COSMO

Results from
early
September
2025

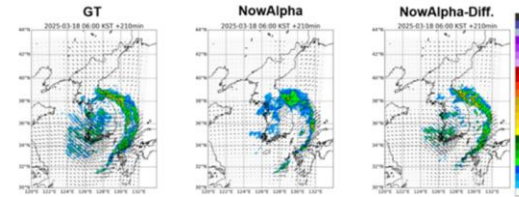
- Run of an AI-WP model over Malawi by Malawi staff
- Using Anemoi framework Forecast-in-a-Box to run Bris (MetNo) at DCCMS (Malawi) on affordable hardware.
- Downscale global data as input data to Bris.
- Runs model on: Mac Studio M4 with 128G memory, 40 GPU cores, 16 CPU cores, cost about \$5000.

AI Innovations of relevance to NMHSs value chain



Numerical Weather Prediction Emulators - ex:

- **NMHSs:** AIFS – ECMWF, AICON – DWD, Bris – MetNorway (regional)
- **Private sector:** GraphCast, GenCAST – Google; FourCastNet – NVIDIA; Aurora – Microsoft, PanguWeather - Huawei
- **Academia:** FuXi - Fudan University; Ar - Cambridge



210-min lead time (2025-03-18 06:00 KST) : KMA's improved 2025 diffusion-based model (right) captures the cyclonic pattern more realistically than the 2024 model (middle), consistent with GT (ground truth)

Courtesy of Hyun-Kyoung Lee, KMA

Satellites and Radar analyses and Nowcasting:

- Images analyses and computer vision
- Transformer and Diffusion models

Downscaling:

- Similar methods as emulators
- Particularly for connecting to downstream applications (Agriculture, ...)



Courtesy of Zhang Wei, CMA

AI Agents:

- Based on combination of Predictive models and Large language Models (LLMs)

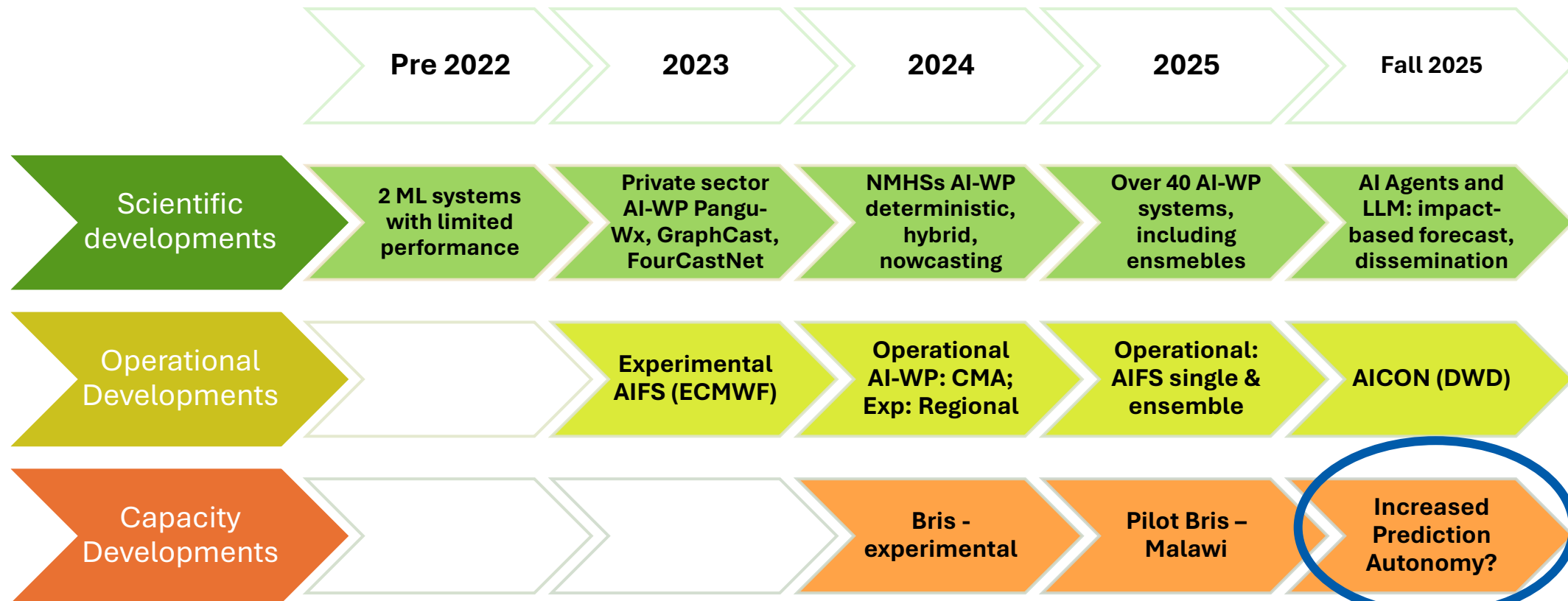
Data analyses, QA/QC, Data fusion:

- Treatment of Observations

The different areas are at different levels of maturity and uptake. All are progressing rapidly.

The importance and availability of data is crucial to their development and use, however sometimes needs to think differently.

Unprecedented pace of transformation of meteorology and hydrology



What does it mean to ensure no one is left behind ?

- The cost of running an AI system is computationally inexpensive
- The quality of the forecasts for a growing number of weather variables is matching those from physic-based NWP systems, with some caveats.
- If validated, opening the potential for larger level of autonomy in weather prediction and early warning for a number of national centres

WMO sponsored AI Activities and events since 2023

Initiation of WIPPS pilots (AINPP, ..)

[WIPPS Pilot Project | World Meteorological Organization](#)

Task team on AI4WX under Research Board

[FileCloud » TT-AI4Wx-Interim-Report-ENDORSED.pdf](#)

OCP @ EC-79

[Sixth High-Level Session of the Open Consultative Platform on Artificial Intelligence \(AI\) \(OCP-HL-6\)](#)

WMO AI Conference in UAE - Sept 2025

[WMO AI Conference: AI for Weather Prediction, Advances, Challenges & Future Outlook](#)

Call to Stakeholders at Cg-Ext

WIPPS AI Roadmap (reviewed), Call to Stakeholders to collaborate on AI (draft) and JAG-AI (approved) at (EC-79)

[EC-79-d04-1-AI-ROADMAP-TO-EVOLVE-WIPPS-AND-PPE-approved_en.docx](#)

WAIC Meteorological Forum in China - July 2025

<http://www.wmc-bj.net/publish/cms/view/4c6df5c0a5d14617b71c21e63013bd00.html>

Task team final report

https://filecloud.wmo.int/share/s/0B0tfA_TTDKKRI8NL_fzxQ

First results of Bris-DDWF4all

In addition to Task Team on AI4Wx and WIPPS pilots, WMO co-organized three forums over the summer to better understand Member needs, and consult with the community at large, including the private sector.

Developing understanding and setting directions



Coordinating actions to ensure no one is left behind

Research Board Task Team on AI4Wx

Objective: identify emerging AI activities across WMO with potential to address scientific gaps, regional disparities, and capacity needs, and provide recommendations to guide future AI-related work.

Membership: Research Board Management Committee, Chairs of relevant WMO bodies (SAP, WGNE, WWRP, WIPPS and SG-FIT), SERCOM Management Committee, GAW and PPE office

Key Messages

- Given the level of maturity in AI development, the TT-AI4Wx has concluded that increased adoption of AI technologies by NMHSs is beneficial.
- Therefore, the TT-AI4Wx recommends that the RB encourage NMHSs to consider the integration of AI into their production cycle.
- https://filecloud.wmo.int/share/s/0B0tfA_TTDKKRI8NL_fzxQ

Recommendations

Coordination and Agility: Strengthen cross-body engagement and a more agile and efficient approach to working across WMO bodies

Equity and Capacity Building: Empower underrepresented regions; provide training, infrastructure and access to AI tools

Research and Innovation: Prioritize evaluation, verification and benchmarking of AI models; high impact events and data-sparse regions

Workforce Development: Build skills in AI implementation, interpretation, and ethics; include societal data expertise.

Infrastructure and Standards: Ensure robust observation/reanalysis networks; establish shared platforms, data standards, open AI tools and trustworthy evaluation.

WIPPS* Roadmap for inclusion of AI systems

by NMHSs and WIPPS-DCs, particularly in the context of EW4All

1. Data Availability and Quality

1. Provision of long-term observation/analysis dataset for AI training and verification
2. Observation requirements for high-impact forecasting
3. Quality control of observations

2. Prediction and post-processing

1. Benefit and applicability of AI-ESP for nowcasting and forecasting
2. High-resolution AI-based forecasts for local area
3. Compatibility between initial fields and training dataset
4. High-resolution data-driven models
5. Benefit and necessity of post-processing

3. Verification

1. WIPPS standard verification of AI-ESP model outputs
2. Verification of AI-ESP model outputs for local weather elements and extremes
3. Verification of meteorological consistency between variables of AI-ESP model outputs
4. Verification of forecast scenarios

4. NMHS infrastructure and capacity requirements

1. Use of AI-ESP model outputs in operational forecasting and warning
2. Implementation and maintenance of AI-based systems

5. Model Explainability and Transparency

1. Guidelines on the use and interpretation of AI-ESP model outputs
2. Guidelines on developing explainable AI-ESP

6. WIPPS Framework and Technical Regulations

1. Expansion of WIPPS activities to accommodate AI-ESP model outputs
2. Impact of AI on the WIPPS cascading process

6 categories

18 sub-categories and

52 questions

WIPPS Pilot Projects



**Coordinating actions to ensure
no one is left behind**

Informing the roadmap through pilot projects

Testing through WIPPS Pilot Projects <https://community.wmo.int/en/wipps-pilot-project>

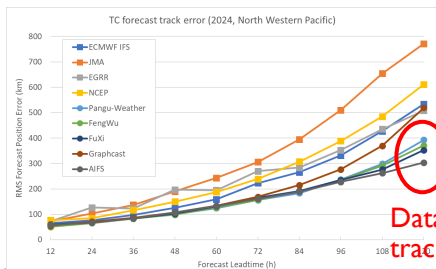
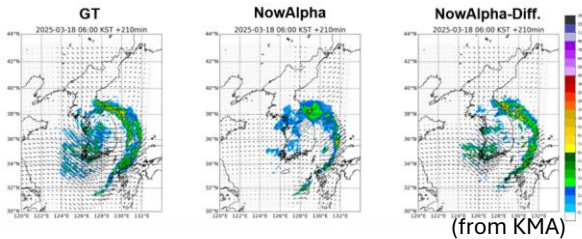
Key issues and challenges identified will be addressed through pilot projects. Each of these pilot projects will serve as a proof of concept for broader AI integration into WIPPS and will be designed to test the scalability and effectiveness of AI solutions in operational settings.

Nowcast

Short to Medium

Sub- to Seasonal

AI for Nowcasting Pilot Project



Data-driven models
tracks generally
outperformed
traditional NWP.

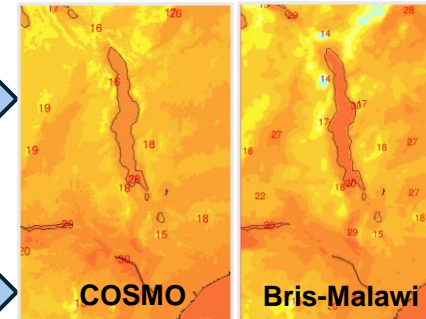


Data-Driven Weather Forecasting for All

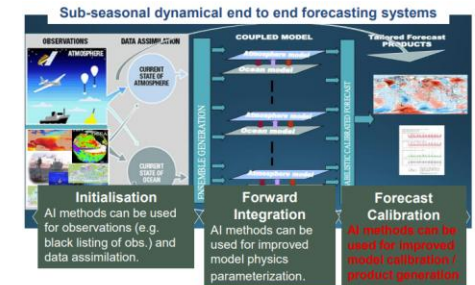
AI in TC Analysis and Prediction

Weather Prediction Model Intercomparison Project

Global Riverine Flood Prediction Pilot



AI Weather Quest



AI methods as alternatives to dynamical models
(from AI Weather Quest website)

a. AI for Nowcasting Pilot Project (AINPP)

Summary/Purpose

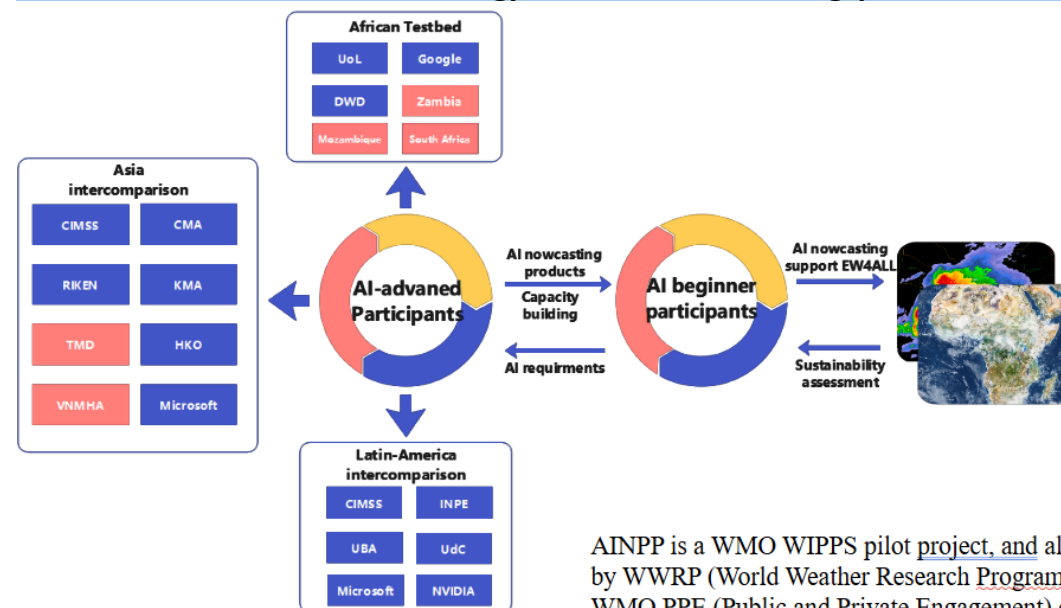
- **Support EW4All**
- **Boost WIPPS with AI:** Post-project, AI-driven nowcasting tools for operational use to enhance seamless WIPPS.
- **Bridge Nowcasting Gaps:** AI with satellite data offers a cost-effective solution.
- **Share AI Successes:** Their simplicity and lower costs make them ideal for developing nations.
- **Build Capacity and Self-Reliance:** Promotes AI
- **Foster Public-Private Partnerships:** Collaboration between national services and private companies

Expected Outcomes

- Assess the efficacy of AI-driven nowcasting and identify 1-2 prospective WIPPS-DCs/RSMCs for nowcasting
- Report on cons and pros of AI for nowcasting and propose any changes to the role of a WIPPS-DC for nowcasting.
- AI-based weather nowcasting products in developing countries, aiming for operational status.
- Guidelines or Good Practices for AI Use in Nowcasting
- Recommended practices for public-private engagement
- Software and data repositories/procedures for running trained nowcasting models for benchmarking.
- Verification methodology for AI-nowcasting products.

Participants

- AINPP Steering Group by David John Gagne and Kan Dai:



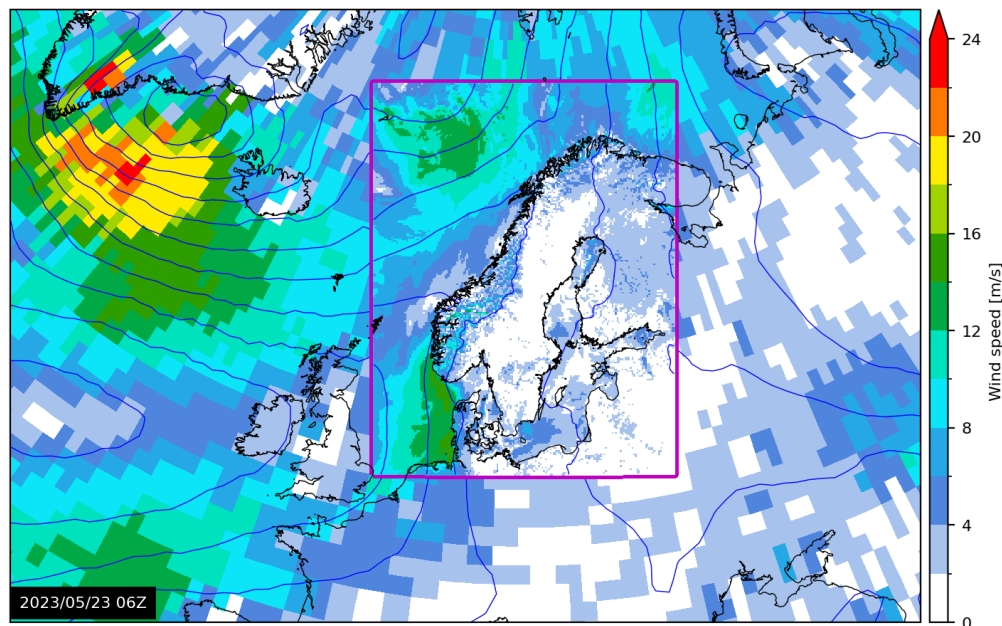
AINPP is a WMO WIPPS pilot project, and also supported by WWRP (World Weather Research Programme) and WMO PPE (Public and Private Engagement) office.

From David John Gagne (NCAR) at WMC Beijing Workshop

b. Data-Driven Weather Forecasting for All

Summary/Purpose

- Approximately one-third of the global population lacks adequate multi-hazard early warning systems, with the greatest gaps in LDCs and SIDS. The proposed pilot project addresses this need by leveraging cutting-edge AI-based data-driven models, such as Bris and AIFS, to enhance forecasting capabilities.
- The project aligns with the EV4All initiative and aims to ensure that forecasting advancements benefit vulnerable communities. By tailoring models to local conditions and building capacity, the project strives for inclusivity and long-term impact.



Expected Outcomes

- Deployment of the “Forecast-in-a-Box” system for a selected region.
- Refined Bris model adapted to local geographical and climatological conditions.
- Training workshops for NMHS staff on using DDM-based forecasting systems as part of Sarepta.

Expected Benefits to NMHSs

- Improved capacity to provide accurate and reliable localized weather forecasts.
- Use of DDM-based forecasting systems and comparison with available global and limited area physical NWP models.
- Enhanced ability to support MHEWS.
- Increased resilience against climate risks
- Empowerment through training and knowledge sharing.
- Narrowing the gaps among NMHSs, LDC/SIDS in adopting advanced techniques using AI/ML in earth system prediction.

Participants

- WMO Members:
 - MET Norway
 - ECMWF
 - Department of Climate Change and Meteorological Services (DCCMS; Malawi)

From Jørn Kristiansen (MET Norway) at WMC Beijing Workshop

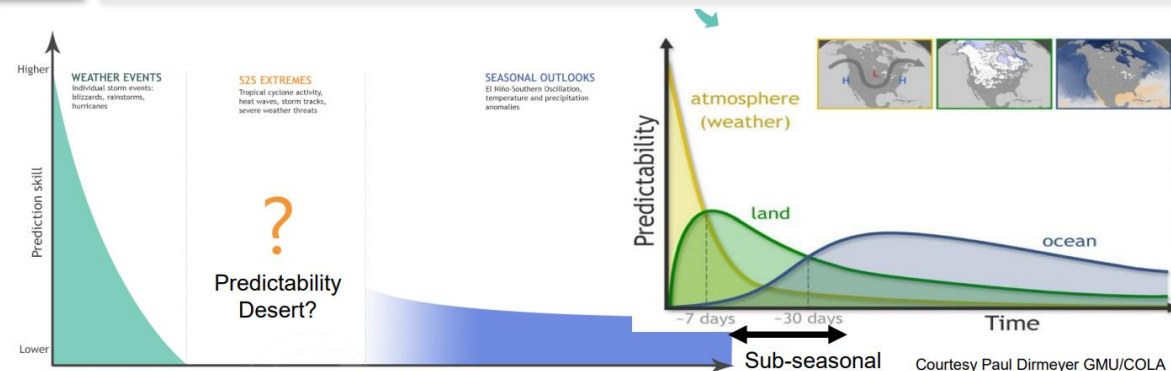
c. AI Weather Quest – Competition for AI model for S2S forecasts

Summary/Purpose

- Provide a forum to exchange experiences and best practices to compare AI-based S2S forecasts. The overall aim is to motivate active research in AI-based S2S forecasts to build awareness and trust and a healthy competition to improve forecast performance.
 1. Advance AI/ML for S2S Forecasting
 2. Provide an open, standardized framework to evaluate AI-based S2S models.
 3. Build a global community to exchange knowledge and best practices

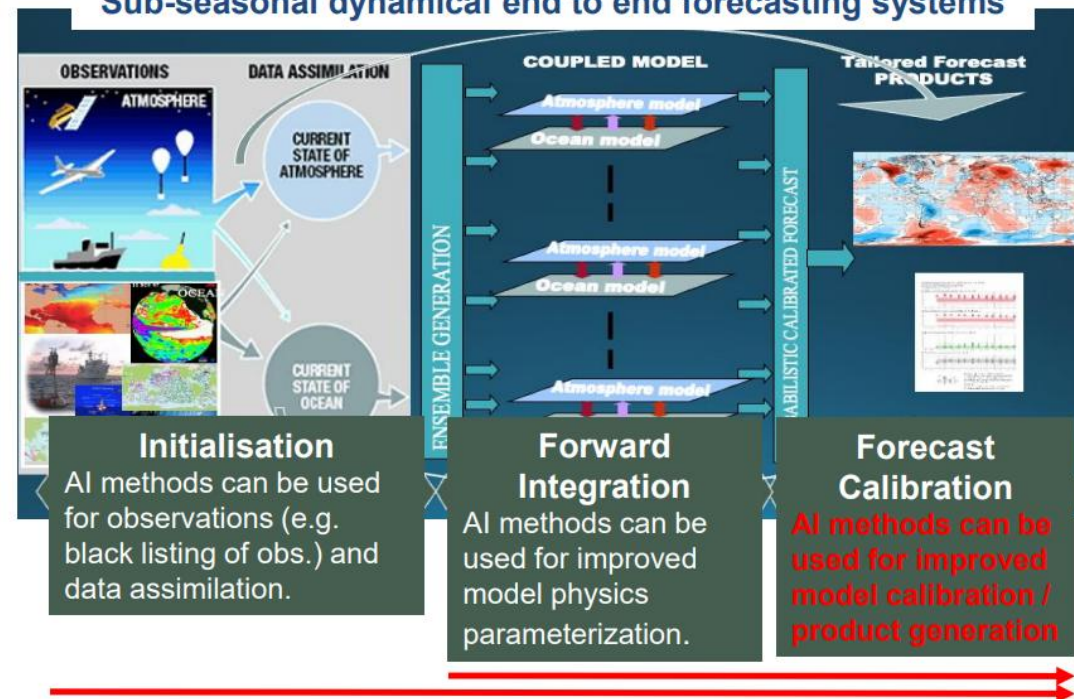
Expected Outcomes

- Establish criteria to compare S2S forecasts from both dynamical models and AI-based systems.
- Documentation of AI-based S2S forecast models methodologies
- A series of webinars and events to share progress and build community of AI S2S model developers and foster exchange of experiences
- Summary report/article in the WIPPS Newsletter
- Forecasts data submissions to compare and tune AI-based forecasts



Use of Artificial Intelligence for improved Sub-seasonal prediction

Sub-seasonal dynamical end to end forecasting systems



AI methods as alternatives to dynamical models

e. UNESCAP/WMO Typhoon Committee initiative on AI Applications in TC Analysis and Prediction

Summary/Purpose

A Research-to-Operation project to assess and review the applications of AI in tropical cyclone analysis and forecasting

- Primarily focusing on TC track forecasting in 2024-2025
- Coordinate data exchange
- Verification and inter-comparison
- Sharing experiences and good practices
- Explore the future operational use of AI-based tropical cyclone analysis and forecasting

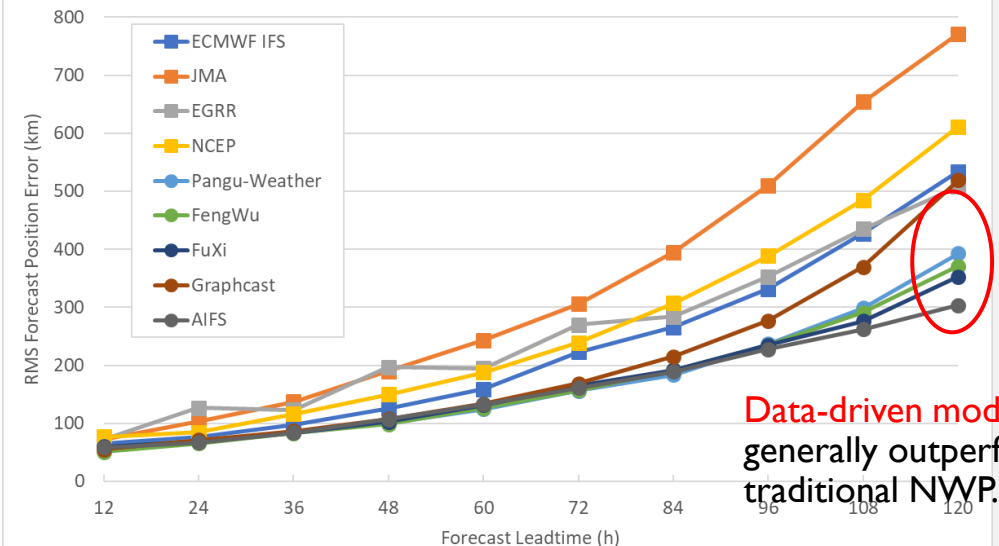
Expected Outcomes

- Promote development and application of AI/data-driven models in TC forecasting
- Data exchange (real-time or non-real-time) among Typhoon Committee Members of TC forecast tracks from 18+ data-driven models
- Annual summary report on verification results, latest development and applications, sharing of pros and cons
- Articulate user requirements, bridging among operational users, research community and AI developers
- Series of events for exchange and capacity building

Participants

- UNESCAP/WMO Typhoon Committee Members
- Initiative led collaboratively by an Expert Team under Typhoon Committee Working Group on Meteorology
- contributed by China; Hong Kong, China; Japan; Macao, China; Malaysia; the Philippines; Republic of Korea; Socialist Republic of Viet Nam and the United States of America

TC forecast track error (2024, North Western Pacific)



Data-driven models tracks generally outperformed traditional NWP.

f. WMO pilot study of global riverine flood prediction products

Summary/Purpose

- Floods are recognized as priority hazards under the Early Warnings for All (EW4All) initiative in many regions
- WMO aims to support Members' flood forecasting and warning services by providing them with global flood prediction products through WIPPS
- facilitate the contributions of non-traditional sources to the WIPPS
(non-traditional sources are entities other than national governmental organizations such as private sectors or non-partner international/ intergovernmental organizations)

Expected Outcomes

- Suggestions for common forecast products and formats, operational practice, and verification approaches for operational global flood forecasting;
- Suggestions regarding the possibility, the pathway, the product specification and the requirements to include operational global flood forecasting into WIPPS; and
- Collection of Members' feedback regarding the usefulness of operational global flood prediction products.

Participants

- WMO Members:
Australia, Belize, Bulgaria, Denmark, Hungary, India, Iran, Israel, Kazakhstan, Mauritius, Norway, Pakistan, South Africa, Thailand
- Global modelling centres:
CEMS (ECMWF, JRC), Deltares, DHI, GEO, Google, NASA, SMHI, Univ. Tokyo/JAXA,



d.WGNE Weather Prediction Model Intercomparison Project (WP-MIP)

Purpose

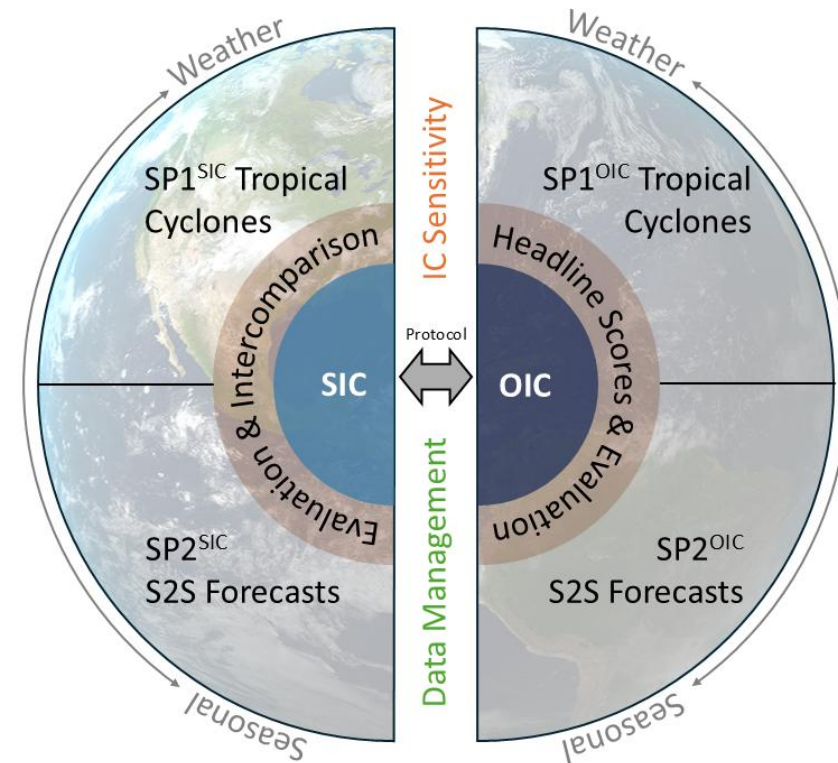
- The Weather Prediction Model Intercomparison Project (WP-MIP) aims to accelerate the development and integration of the next-generation of operational weather prediction systems.
- The project will create a public database of predictions from the full spectrum of artificial intelligence-based (AIWP), physically based (NWP) and hybrid systems using standard production pipelines. This centralized archive will be used for distributed diagnostics and model evaluation, with the goals of:
 - Identifying the strengths and weaknesses of the different prediction paradigms in an operational context;
 - Providing guidance to operational centres on metrics to use for fair evaluation and comparison of AIWP, NWP and hybrid systems; and,
 - Accelerating the development of the full spectrum of operational models.

Participants

- Project Co-Leads: Linus Mangusson and Ron McTaggart-cowan
- Subproject Leads:
 - SP1: Masashi Ujiie and Jan-Huey Chen
 - SP2: Debbie Hudson
- Participating WMO Groups: WIPPS, JWGFVR, PDEF, WGSIP
- Participating GPCs: BoM, CMC, DWD, ECMWF, JMA, NOAA, UKMO

Key Features

- Centralized Forecast Database (AIWP, NWP, Hybrid)
- Two Forecast Streams:
 - Same Initial Conditions (SIC) and
 - Own Initial Conditions (OIC)
- Optional Subprojects for deeper diagnostics
- Open Collaboration for submissions and diagnostics



Learn more: <https://www.wcrp-esmo.org/activities/wp-mip>

Developing relevant verification methods for AI models – prediction and nowcasting



Environment and
Climate Change Canada
Environnement et
Changement climatique Canada

VerAI 2025 – Montreal October 22-23, 2025
([Verification of AI-models in Operational Centers](#))

- 200 international participants
- Led by the WWRP Joint Working Group on Forecast Verification Research ([JWGFVR](#)) with the Research Board-WCRP Working Group on Numerical Experiment ([WGNE](#))

Two main aspects examined:

1. Adapting established **verification practices** to the specific features of **AI-based forecasts**, and
2. Testing spatial metrics and developing new diagnostics for meaningful comparisons, to ensure that **WMO Members** and forecast users can trust and interpret outputs from both paradigms with confidence.

Coordinated WP-MIP verification exercise will include:

- Summary statistics and diagnostics against observation and IFS analysis.
- Spatial and consistency-based verification methods.
- Application of extreme dependence indices and scoring functions.
- Regional studies (Africa, South America) leveraging local expertise.

Planned outputs:

- Publication in an AMS special collection (submission from June 2026).
- Contribution of developed methods to a centralized verification tool.
- Display of verification results on a dedicated online platform.

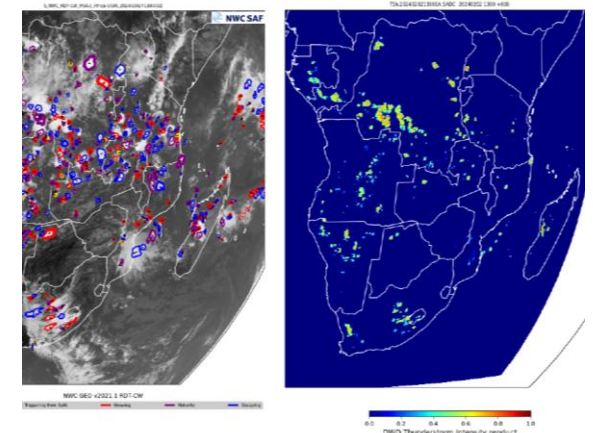
ASNIP

The African Satellite Nowcasting Intercomparison Project (ASNIP) compares two storm nowcasting products:

EUMETSAT NWC SAF – Rapidly Developing Thunderstorms (RDT) and the DWD Thunderstorms Product (DWD-TS)

Both use Meteosat Second Generation (MSG) satellite data to detect active convective storms.

Objective: Understand differences between products and improve their operational use across Africa.



Engaging an entire community to support



Coordinating actions to ensure no one is left behind

WMO AI Conference



Hosted by UAE National Center of Meteorology - September 2025



- Followed the sixth High-Level Session of the Open Consortium Platform at EC-79 on Public-Private Engagement on AI.
- WMO AI Conference brought together more than **50 international experts** across NMHSs, public and international organizations, private industry and academic institutions to **deepen the discussions on opportunities to build an AI ecosystem for global good in weather, climate and hydrology and related environmental research to operations.**
- **Frank and open conversations on:**
 - Collaborations between actors
 - Service Implications
 - Data requirements and Infrastructure
 - Establishing trust
 - Capacity development
 - Governance frameworks
- for **responsible and equitable adoption of AI**, good practices and system needs to accelerate **innovation, interoperability, and capacity development**—particularly for developing countries and small island states.

- [Conference minisite](#) and [WMO News](#)

Private Sector

- Microsoft
- Synoptic Data
- NVIDIA
- Space42
- Google
- Tomorrow.io
- Brightband
- IBM Research

Academic Institutions

- Khalifa University
- University of Singapore
- University of Chicago
- Brown University
- The Alan Turing Institute
- NCAR – United States of America

NMHSs

- ANAM – Burkina Faso
- CMA - China
- CMO - Caribbean
- ECCC – Canada
- KMA – Republic of Korea
- Malawi DCCMS
- Met Éireann - Ireland
- MET Norway
- Meteo France
- MeteoSwiss
- NiMet - Nigeria
- NOAA/NWS –United States of America
- NCM – Saudi Arabia
- NCM – United Arab Emirates

Regional and International

- ACMAD
- ECMWF
- EUMETSAT
- HMEI
- INPE-Brazil
- WMO

WMO AI Conference Statement

Outcomes and affirmed intentions:



AI plays a complimentary role to existing efforts in weather, climate and hydrological prediction, and there is opportunity to advance this together.



Respect for authoritative role of NMHSs in producing official warnings based on public trust and scientific rigor.



On-going dialogue on public and private datasets to fully realize opportunities afforded by AI, with greater openness at the national level in terms of additional observational and auxiliary data that will be needed. On-going



Investment in capacity and training, and expansion of AI-based pilot projects, focusing on regionally-based implementation and narrowing the digital divide.



Common principles to guide responsible and effective integration of AI into meteorological, climate, hydrological and environmental services that are grounded in transparency, collaboration, sustainability, innovation and ethics.



Continued dialogue at multiple levels and increased representation of the private sector and academia in relevant WMO working structures.



Moving from intentions to realizations: breakout sessions laid out initial directions to continue the dialogue and collaboration

WMO Call to All Stakeholders and WMO Governance

Engaging the broad community

- To announce that WMO will work collaboratively with stakeholders to meet a wide variety of global needs by applying AI/ML technologies to strengthen the entire weather, climate, water and environment-related services value chain.
- Resolution 2.3(2)/1 – WMO Call to All Stakeholders to Collaborate on the Development of Artificial Intelligence (AI) and Machine Learning (ML) Environmental Monitoring and Prediction Technologies, Tools and Applications

Oversight of WMO activities through JAG-AI: Joint Advisory Group on Artificial Intelligence

- Reporting to INFCOM and RB, JAG-AI to provide advice, oversight, coordination and monitoring of WMO activities in relation to the development and implementation of artificial intelligence (AI) technologies to the meteorological and hydrological value cycle.
- To focus on promotion and acceleration of the integration of AI into the WMO infrastructure and research activities, supporting the development of weather, climate, hydrological, marine and related environmental services.

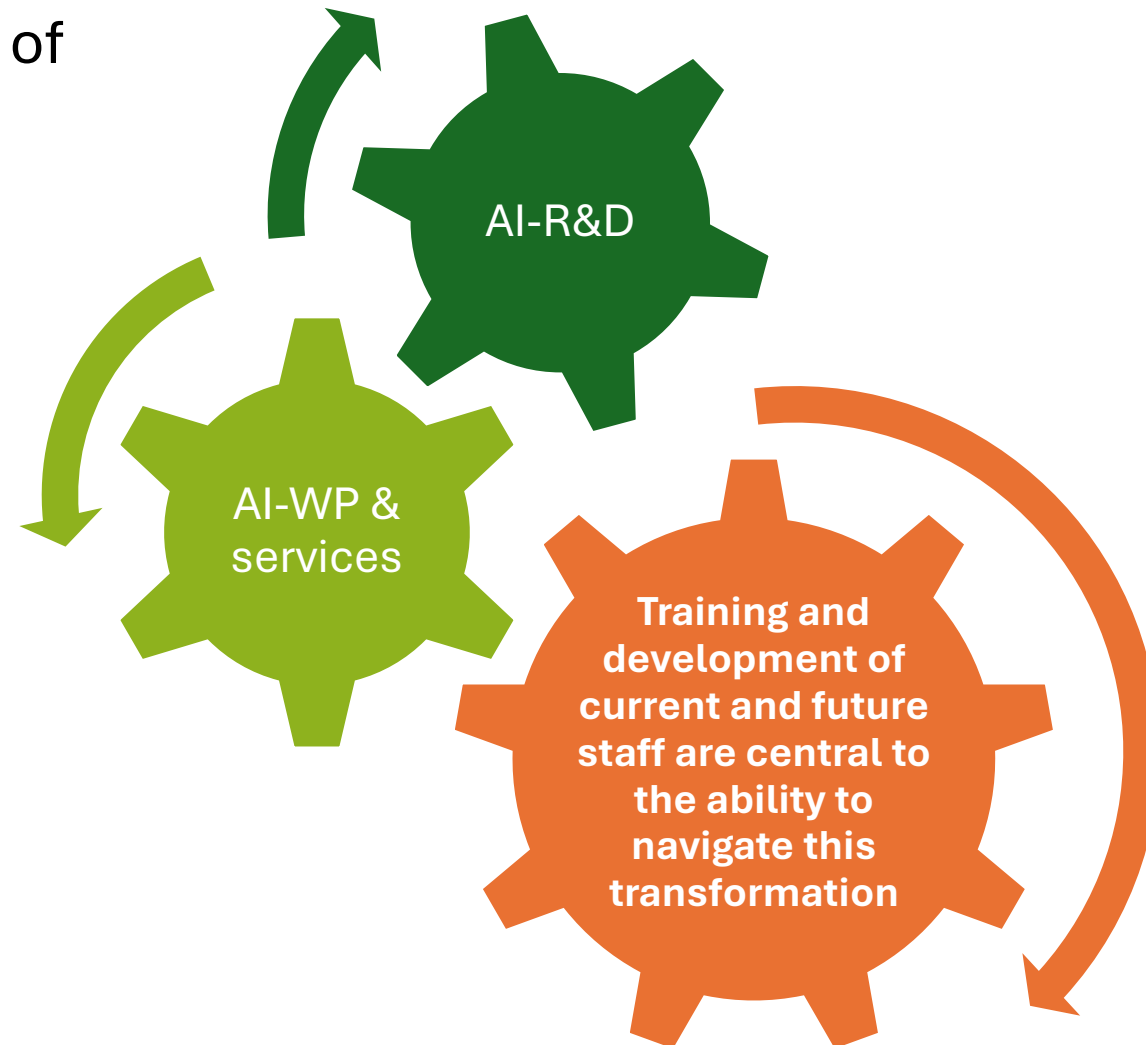
Workforce transformation : a pillar of change



**Coordinating actions to ensure
no one is left behind**

Workforce transformation : a pillar of change

Constant regardless of the size
and level of resources of
NMHSs:



TT- AI4WX recommendations for the workforce

The rapid advent of the era of competitive AIWP models and the ongoing pace of development in the field have left many research and government institutions falling behind in terms of workforce skills and capability with the required technologies and underpinning knowledge.

Training programs for new staff and new curricula for students

Online tutorials on AI tools and infrastructure for varied levels of experience and use

Training developed with private companies and weather/climate prediction centers

Flexibility to enroll in courses at other institutions in subjects which fill gaps in existing curricula

Training on communication techniques that use AI, such as language translation and situational awareness

Ethics training regarding the potential biases and inequities introduced by AI

Enabling an existing workforce: Training program +

Technical skills in pre-developed AI model implementation and running

Interpretation of AI-based model outputs, value-add services, user requirements, etc

Experience in the collection of societal data that feeds AI-based decision models

Legal and ethical aspects of AI (biases, quality, transparency, etc.)

Mentorship programs pairing AI experts with domain scientists

For organizations who are running or developing AI models fully “in-house”

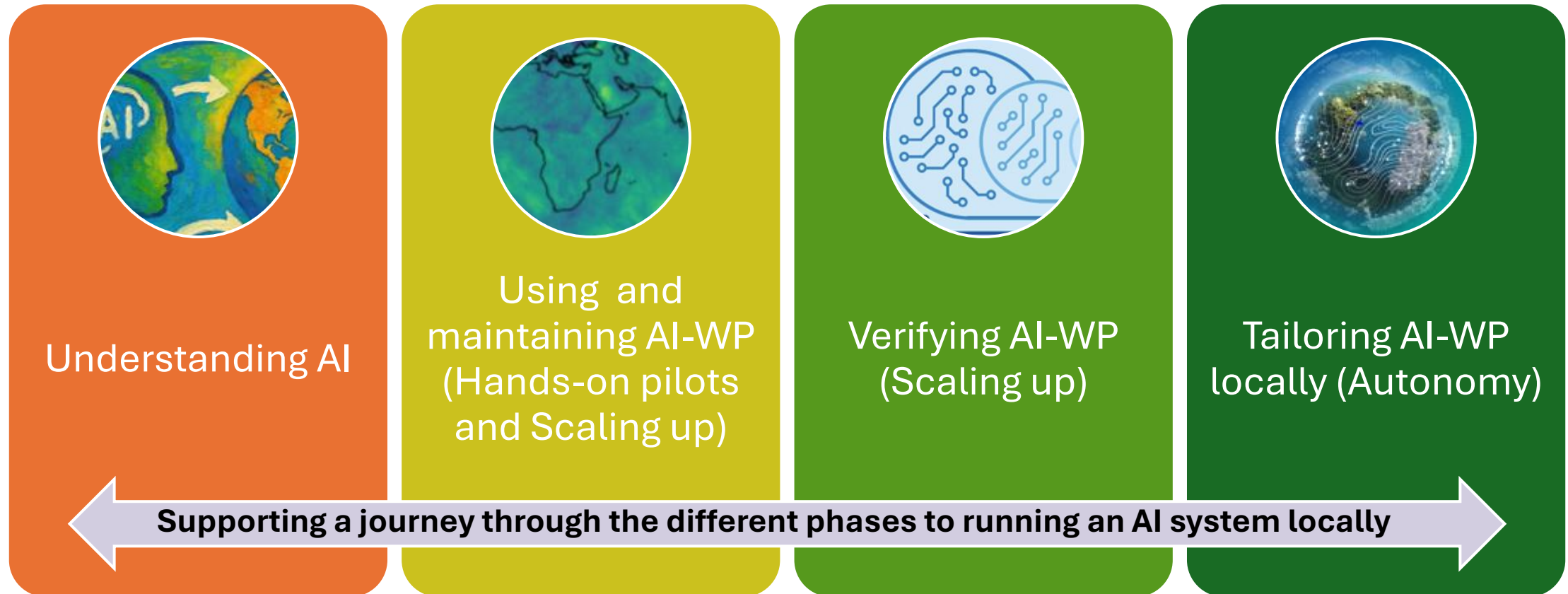
Expertise in computer science, AI development, software architecture and development

Expertise in IT architecture and operations (HPCs, GPU clusters, data storage and access maximizing data mobility, cloud computing)

Data curation to ensure that AI and ML applications are built on high-quality, well-documented, and reproducible data

Building the workforce support to AI-WP capacity building

Possible framework to articulate training and capacity development, based on pilot to ops and heterogeneity in LMCIs, with coordination of regional and national structures for further design and delivery.



WMO AI conference in UAE – Steps to AI capacity building



Break-out session on democratising benefits for LMIC:

- Sub-group on capacity development and skills

Multiple expressions of interest from regional and national centres in Africa to contribute actively to effort.



Opportunities

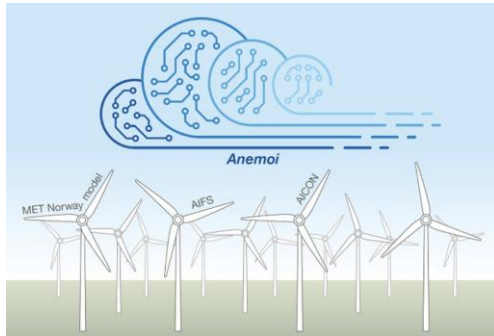
- There is a plethora of existing training material: Existing training material should be aggregated, curated and publicized
- WMO should develop AI training in partnership with partners, regional centres and local universities
- Successes should be developed into use cases
- WMO-certified courses should be provided in cooperation with the private sector and academia
- WMO should direct some of its scholarships towards AI
- Existing peer-support arrangements can be built upon to include AI projects



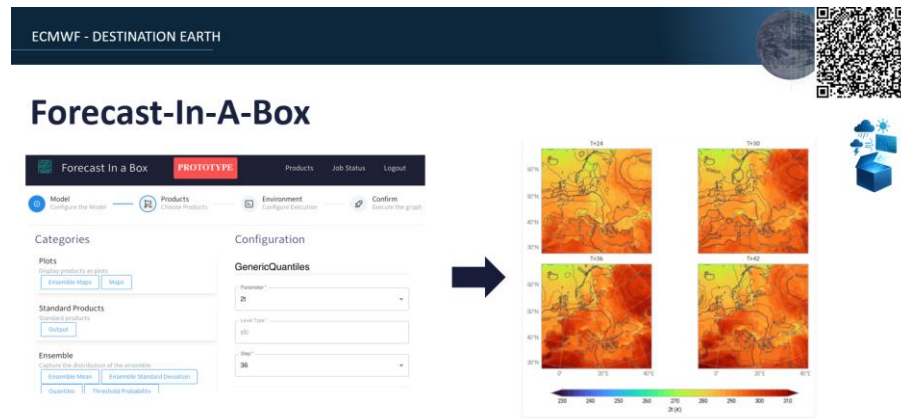
Challenges

- Small services find it difficult to free resources for training courses
- There is a lack of local data available to be incorporated into local pilots or training
- Difficult to put training into practice after completion, risking losing their skills
- Partners (private, academia, development) lack understanding of local challenges

Examples of Existing Tools and Training



- **Anemol:** *Open-source framework* that provides a complete toolkit to develop data-driven weather models – from data preparation through to inference
- Empowering *real-time running* and operationalization of data-driven models at meteorological centres
- A *highly modular framework*



Produce on demand forecasts including the visualization.

Courtesy of Florian Papenberger, ECMWF

MOOC MLWC - 2. Concepts of Machine Learning



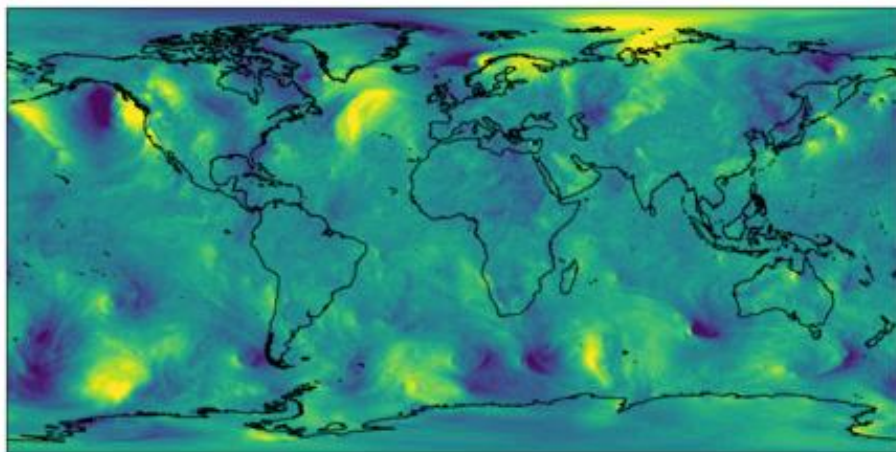
ECMWF – Massive Open Online Course



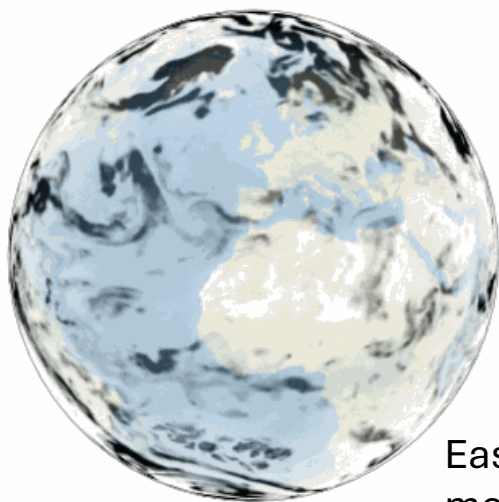
EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS



Tools: What Anemoi enables?



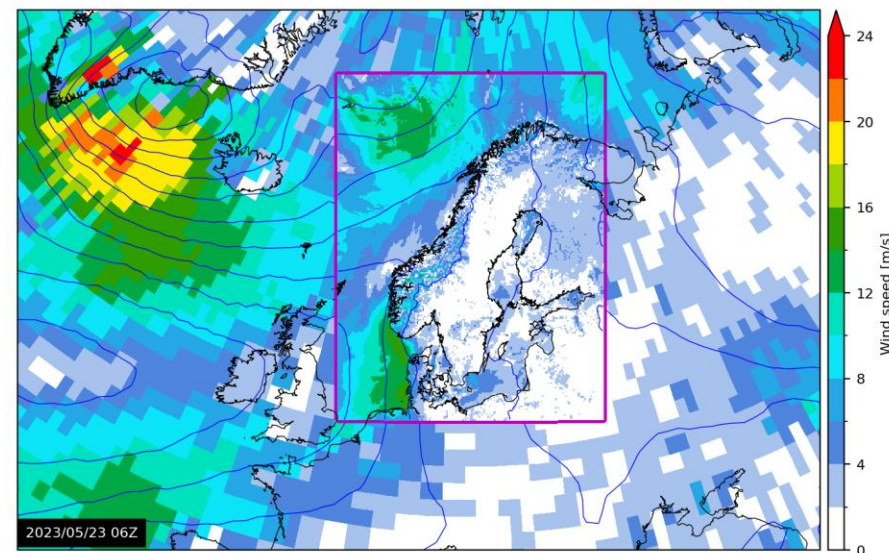
Training deterministic & ensemble models



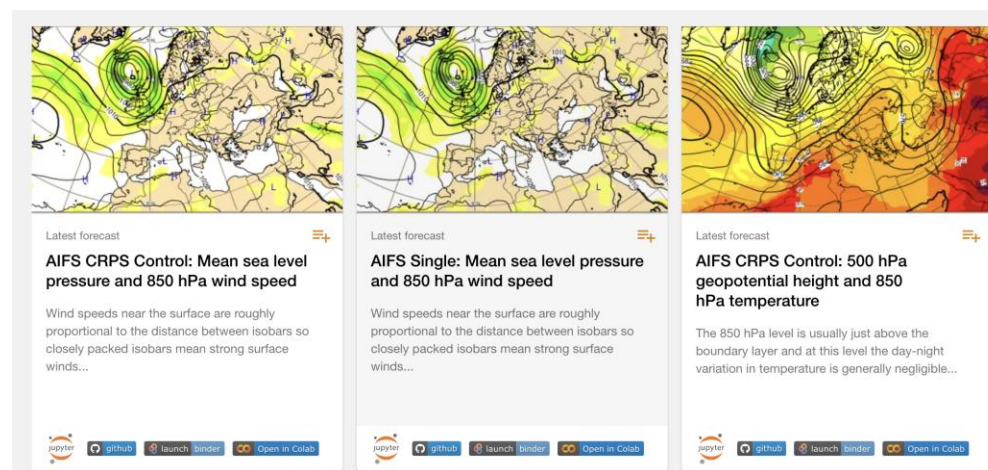
Easy exploration of more atmospheric fields

Regional high-resolution modelling:

Nipen et al. 2024

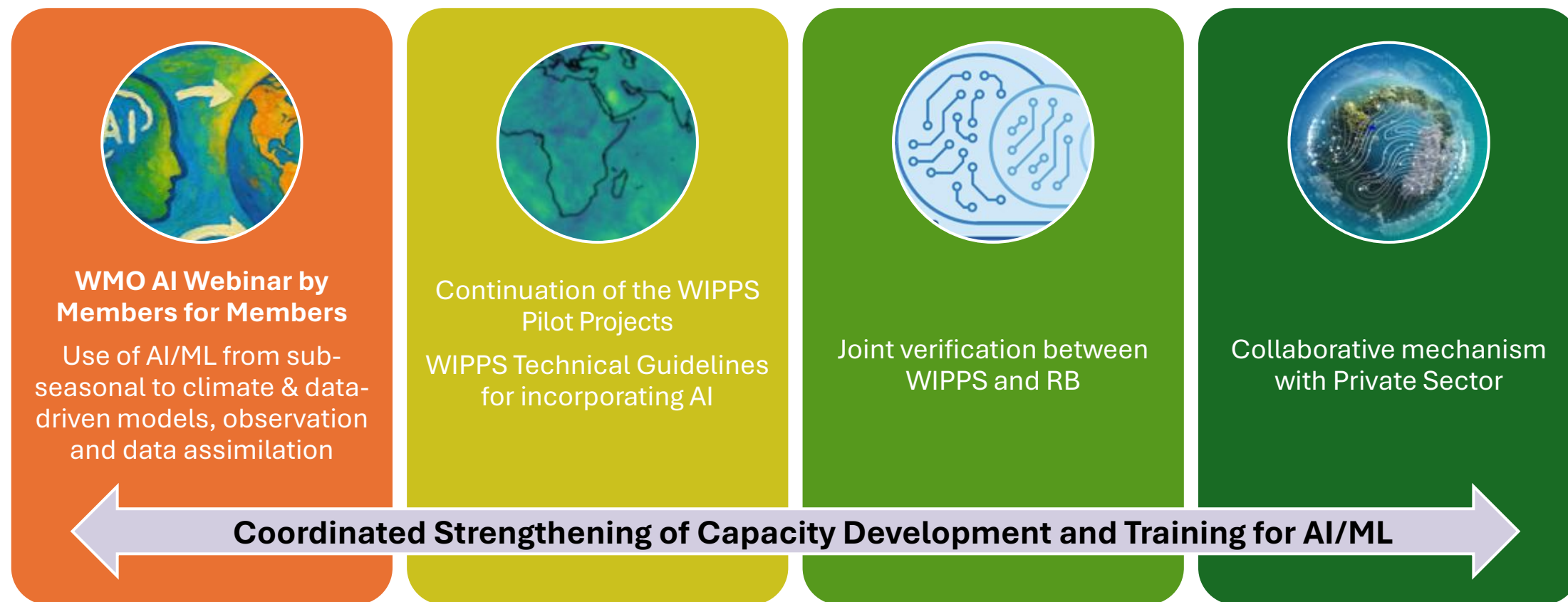


Real-time running at operation centres
Anemoi is powering ECMWF's operationalisation of AIFS in 2025.



Looking forward to the next few months

Under the oversight of the Joint Advisory Group on AI and with a view to scaling up the Data-Driven Weather Forecasting for All:



Thank you



WORLD
METEOROLOGICAL
ORGANIZATION

