Operational global (weather) EPS

Black: current, Red: recent upgrade, Green: planned or research, Purple-not updated

Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
ECMWF (Europe)	TCo1279L137 TCo319L137 9/36km	15d 46d daily	50+1 100+1	SV(Total energy norm) + EnDA	SPPT SPP STOCHDP	coupling to ocean model, EDA-based land-surface pert. in ENS Ics	Hindcasts on fixed days of month; every 2d (36km) and 4d (9km)
Met Office (UK)	20kmL70 10km	8d 80d	17+1 44 for DA	En-4DEnVar	SKEB2 + SPPT Additive Inflation	Soil moisture and deep soil temperature Coupling to ocean/ice (NEMO/CICE) (with SST pert.)	Ensemble forecasts use archived analysis increments for bias correction and perturbation
Meteo France (France)	T1798(C2.2) L105	4d	34+1	SV (Total Energy Norm)+ EnDA (randomly chosen)	RPP + 2 convection schemes (Tiedtke-Betchtold & PCMT) SPP	N (SURFEX) Surface perturbations (incl. SST)	
HMC (Russia)	SLAV 0,9°x0,72°L96 0.225°x(0.16-0.24°)L51	10d	40+1	LETKF with centering to oper analysis	SPP + SPPT(T & vort only) STOCHDP	N	Abandon SPPT at least for temperature
NCEP (USA)	C384L64 (~25km) C384L127	16d 35d (00Z)	30+1	EnKF f06 EnKF anl	SPPT, SKEB SPP, CA	2-Tier SST Coupling to WW3, MOM, CICE6, GOCART	Offline 31-year hindcast Offline 30-year hindcast

Operational global (weather) EPS

Black: current, Red: recent upgrade, Green: planned or research, Purple-not updated

Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
DWD (Germany)	26km,L120: two-way nest with 13 km over Europe 20/10 km in Q4/25 or Q1/26	180h	40 + 10	LETKF with recentering to DET analysis	Perturbed physics parameters Stochastic representation	SST random pert.	ICON 10 members include prognostic mineral dust using ICON-ART (since Q4 2023)
NRL/FNMOC (USA)	T359L60 S2S: T681L134	16d S2S: 45-d	21 S2S: 16	local Ensemble Transform and SST pert. S2S: Ensemble of DAs	SKEB-mc Analysis Correction-based Additive Inflation (ACAI) S2S: ACAI	SST variation (diurnal model + SST initial pert.) S2S coupled	Part of the U.S. multi-model ensemble
CMC (Canada)	0.35° L84 0.225° L84	16d 32d once weekly	20+1	Local ensemble transform KF with randomized cross-validation + reduced random additive inflation	SKEB + minor rebalancing of stochastic parameter peturbations	coupled ocean (NEMO) and sea ice (CICE)	GEM (part of NAEFS)
CPTEC/INPE (Brazil)	TQ126L28 (~100km; 28 sigma levels) Upgrade to the BAM 1.2.1	15d	15	EOF-based perturbation Combination between EOF and EnKF (using a hybrid 3DEnVar data assimilation framework)	N	N	Currently working to integrate medium-range (15 days) with extended forecast (~30 days)
JMA (Japan)	Tq479L100 128 Tq479L100 128 Tq319L100 128	11d 18d 34d	51 51 25	SV(Total energy norm) +LETKF (pert. Inflation)	Stochastic perturbation of physics tendency Perturbing humidity input into the convective parameterization as a model ensemble method	Two-tiered SST approach to the global domain after day 6 SST pert.	

Operational global (weather) EPS

Black: current, Red: recent upgrade, Green: planned or research, Purple-not updated

Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
Bureau (Australia)	~60kmL70 33km	10d	18				UM8.2->10.6
CEMC (China)	~50kmL87 25km S2S: 45km	15d 60d	31 (twice per day) 4	ETKF	SSPT		S2S system is coupled atm-ocean-ice-land
KMA (Korea)	~32kmL70	12d	25	ETKF Hybrid Ensemble 4D-Var	Random Parameters (RP2) and SKEB2.	coupled ocean (NEMO) and sea ice (SI3)	UM
	~32kmL91 ~24kmL91	12d 15.5d	26 26	LETKF Hybrid Ensemble 4D-Var	SPPT, SPDT, SSST	N	KIM
IMD (IITM India)	T1534 L60 ~12.5 km	10d runs at 00 and 12 UTC	20+1	EnKF	STTP	N	

Black: current, Red: recent upgrade, green: planned or research

Operational regional (weather) EPS

Black: current, Red: recent upgrade, Green: planned or research, Purple-not updated

Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
Met Office (UK)	2.2kmL70 1.5kmL70	120h	3 per hour	High Resolution Analysis + global EPS	Stochastic physics using random parameter	Global EPS SST, soil moisture and deep soil temperature perturbations, SST from 1.5km NEMO UK shelf-seas forecast (with SST pert)	18 member time-lagged ensemble created using 6 x 1-hourly cycles
Meteo France (France)	1.3km L90 750m	51h	24+1	Deterministic Analysis (3DEnVar) + Pert. From 3.2km ensemble assimilation	SPPT Random Perturbed Parameters	Pert. of surface LBC selection with clustering Coupling to 1D-OML	AROME
DWD (Germany)	2.1km L65	48h (8x/day) + RUC: 14h (24x/day)	20 20	Ensemble DA based on LETKF with 40 members	Randomized choice of parameter perturbations from a fixed set of possible values	European nest of global ICON EPS (13km grid), soil moist pert.	ICON in limited area mode
HMC (Russia)	2.2km	48h	10	Multi model	SPP, Additive model-error pert.	Multi model	
JMA (Japan)	5kmL96	39h	20+1	SV(Total energy norm) from JMA global and regional models Hybrid DA	N SPPT	SV(Total energy norm) from JMA global model Perturbed SST	Incorporation of SPPT is planned in 2023

Operational regional (weather) EPS

Black: current, Red: recent upgrade, Green: planned or research, Purple-not updated

Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
NCEP/SREF (US)	16kmL41		1+12 NMMB 1+12 WRF_ARW	Multi analysis	Variety of physics scheme	Stochastic soil moisture	Frozen
NRL/FNMOC (US)	36/12/4km	120h	10+1 20+1	Perturbed synoptic scales Perturbed Rankine Vortex	Perturbed drag coefficients Multi-microphysics (NRL, Thompson, Morrison)	GEFS/NAVGEM with synoptic perturbations, SST cooling param when uncoupled	COAMPS-TC In all basins
NRL/FNMOC (US)	45/15/5km	72h	20+1	Downscaling from global ensemble	Parameter variations	NAVGEM ensembles	COAMPS (non-TC ensembles used for research only)
CMC/REPS (Canada)	0.09°L84	72h	1+20	Global analysis departures from ensemble mean, recentered on the 0.135° global deterministic analysis	SKEB + minor rebalancing of stochastically perturbed parameterizations	Global pilot EPS with REPS-consistent random additive inflation	Part of the North American Ensemble Forecast System
CEMC (China)	~10km 3km	84h	1+15	ETKF	SPPT	Global EPS	
KMA (Korea)	2.2kmL70	72h	13	Downscale from Global EPS	RP	Global EPS	UM
	3kmL40	120h	13	Downscale from Global EPS	-	Global EPS	KIM

NCEP

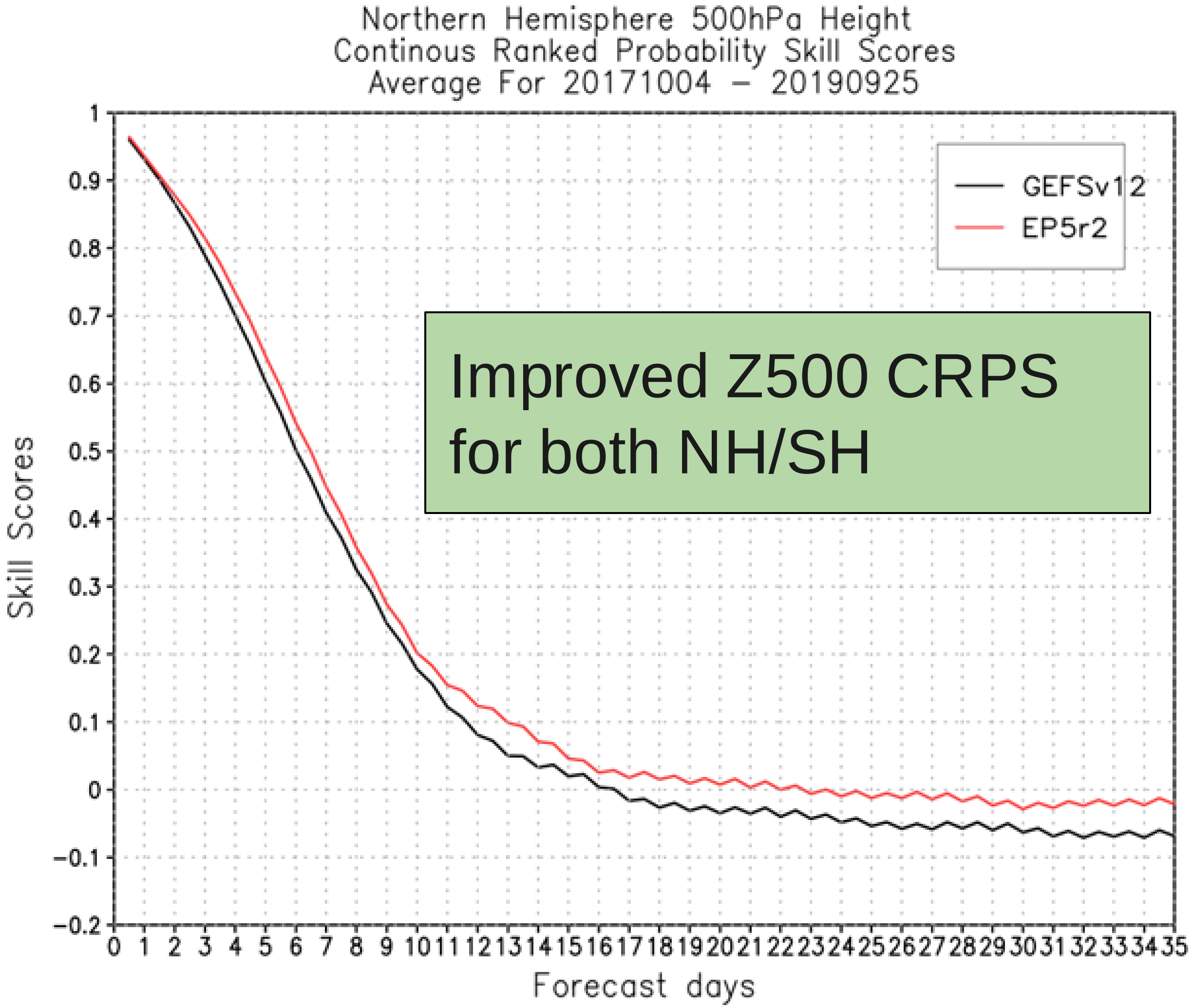
Model Configurations (GEFSv12 vs GEFSv13)

Components		V12 (Sep 23. 2020)	V13 (targeting FY26)
Atmos	Dynamics	**FV3 (Finite-Vol Cubed-Sphere) GFSv15**	FV3 (Finite-Vol Cubed-Sphere) GFSv17
	Physics	**saSAS, GFDL-MP, K-EDMF, oroGWD**	**saSAS, Thompson-MP, sa-TKE-EDMF, uGWD**
	Initial perturbation	**EnKF f06 (previous cycle)**	EnKF f00 (early cycle)
	Model uncertainty	**5-scale SPPT and SKEB**	5-scale SPPT, SKEB, **SPP, CA**
	Boundary (ocean surface)	**NSST + 2-tiered SST**	NSST
	Resolutions	**C384L64 (25km)**	**C384L127 (25km)**
Land	Model	**NOAH-LSM**	**NOAH-MP**
	Initial perturbation	**N/A**	Soil moisture
Ocean	Model	**N/A**	**MOM6 (0.25^{o}L75)**
	Initial perturbation		**SOCA-Ens**
	Model uncertainty		**5-scale oSPPT and ePBL**
Ice	Model		**CICE6 (0.25^o)**
	Initial perturbation		**SOCA-Ens**
Wave	Model	**WW3 (1-way) (0.5^o)**	**WW3 (2-way) (0.25^o lat/lon grid)**
Aerosol	Model	**GOCART (1-way)**	**GOCART (TBD)**

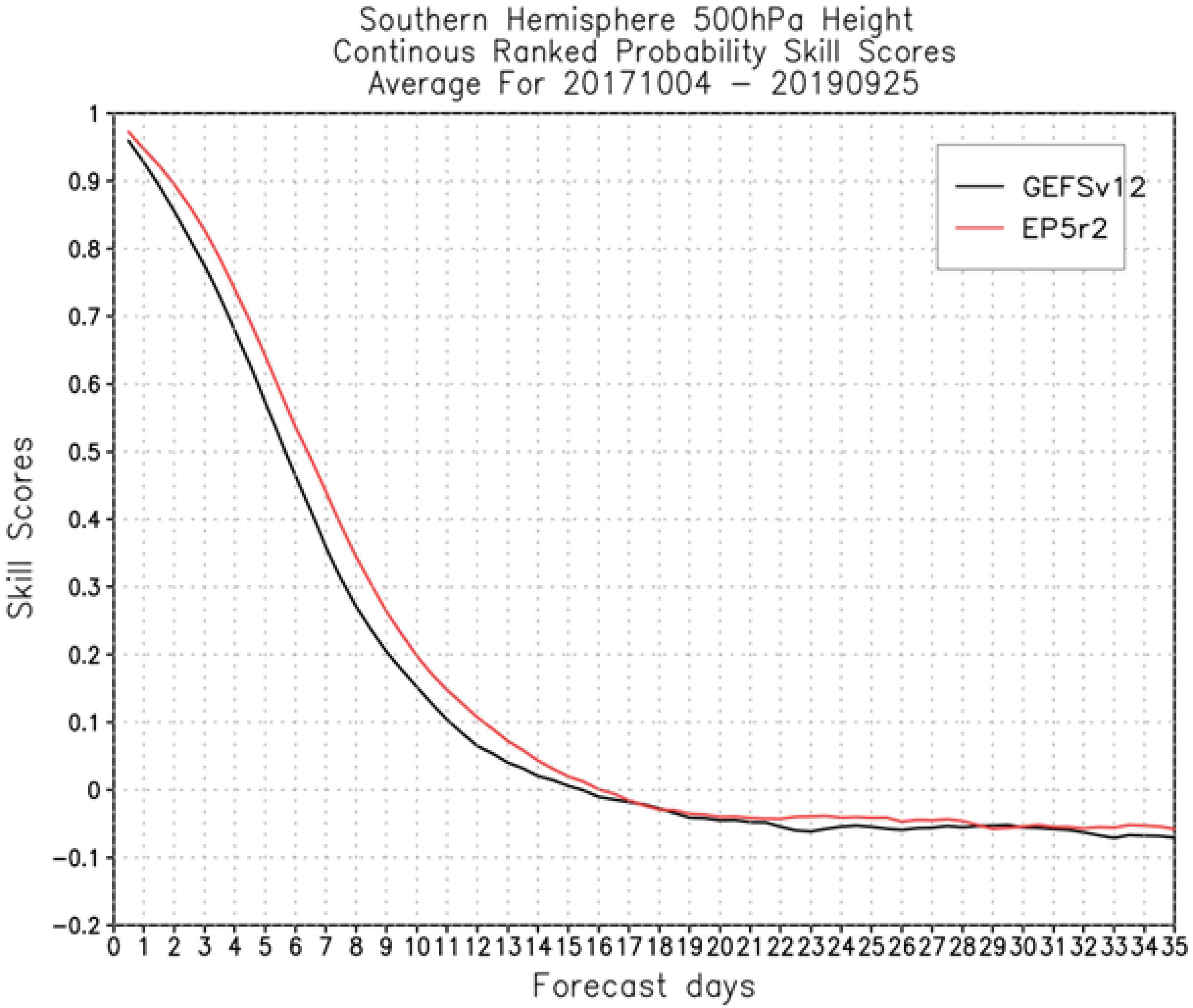
Credit: Bingfu, NOAA/NWS/NCEP/EMC

Z500 CRPS

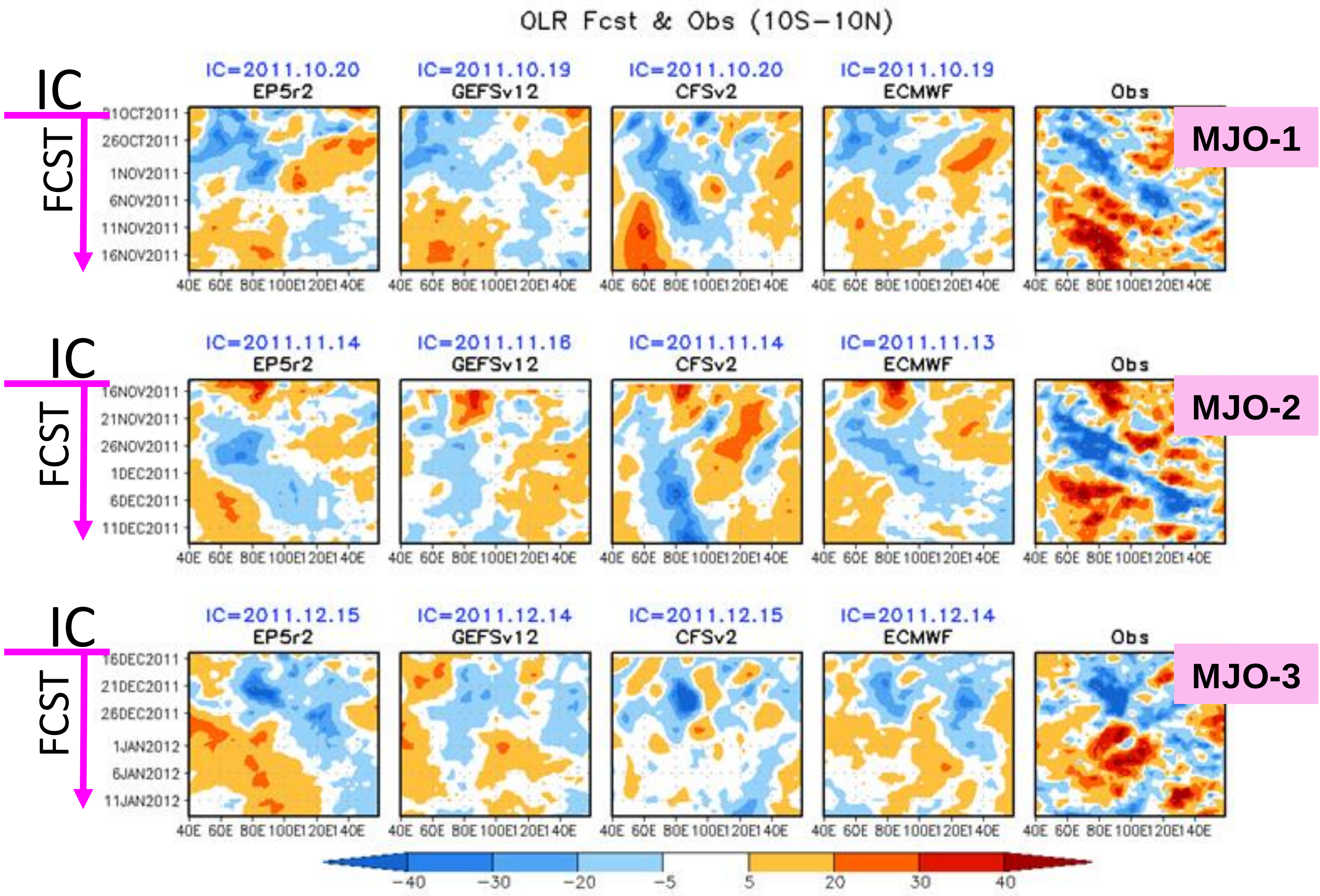
EP5r2 --> GEFSv13 Prototype



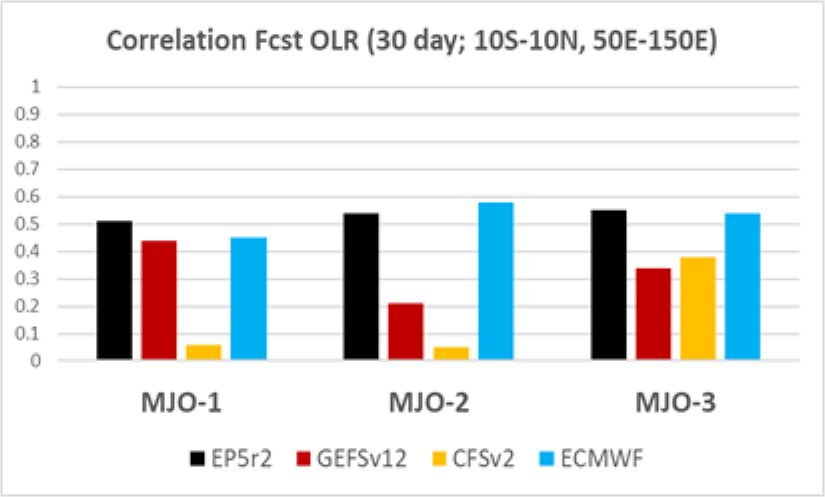
Improved Z500 CRPS for both NH/SH



OLR (10S-10N) Fcst & Obs



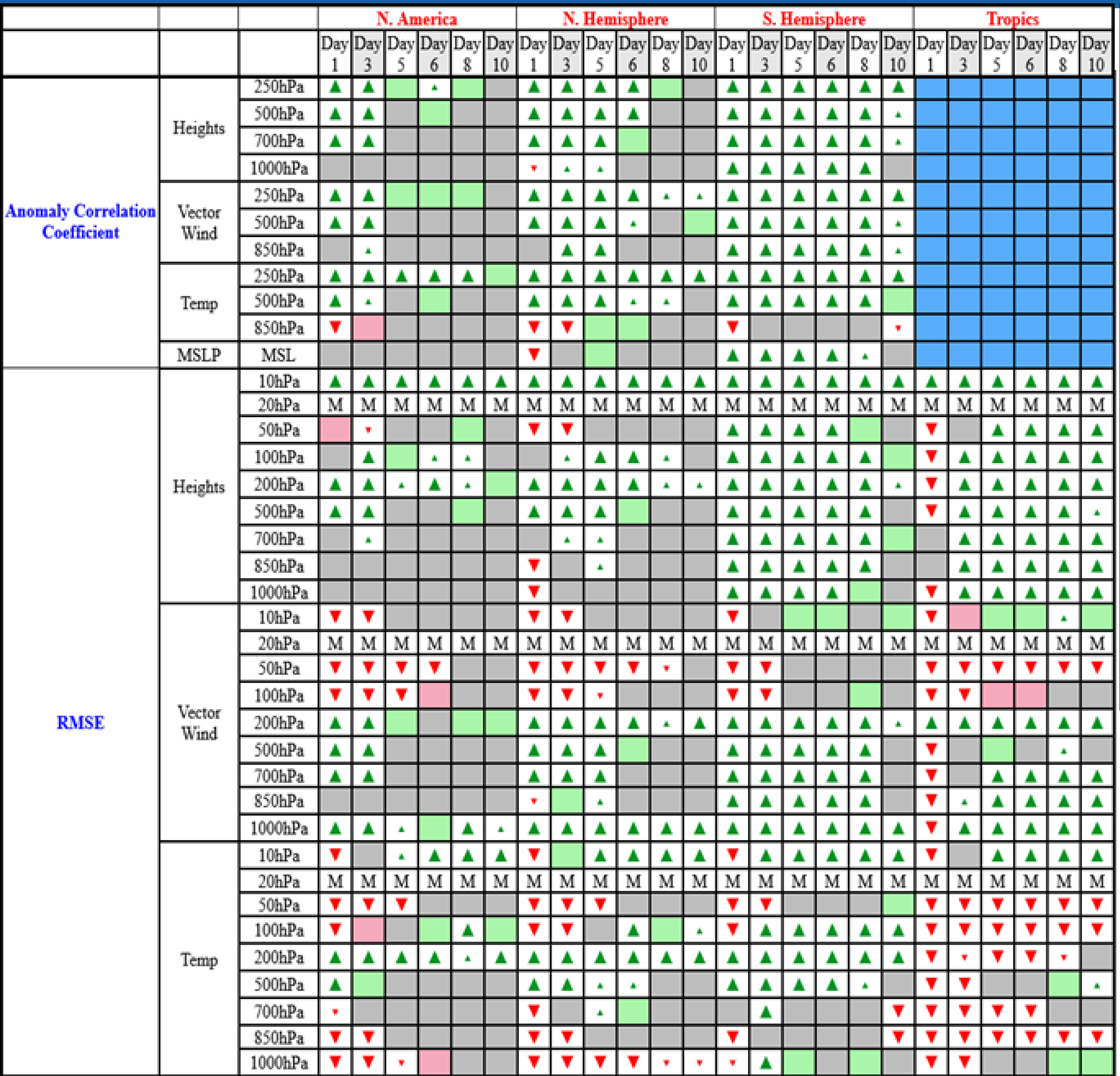
EP5r2 --> GEFSv13 Prototype

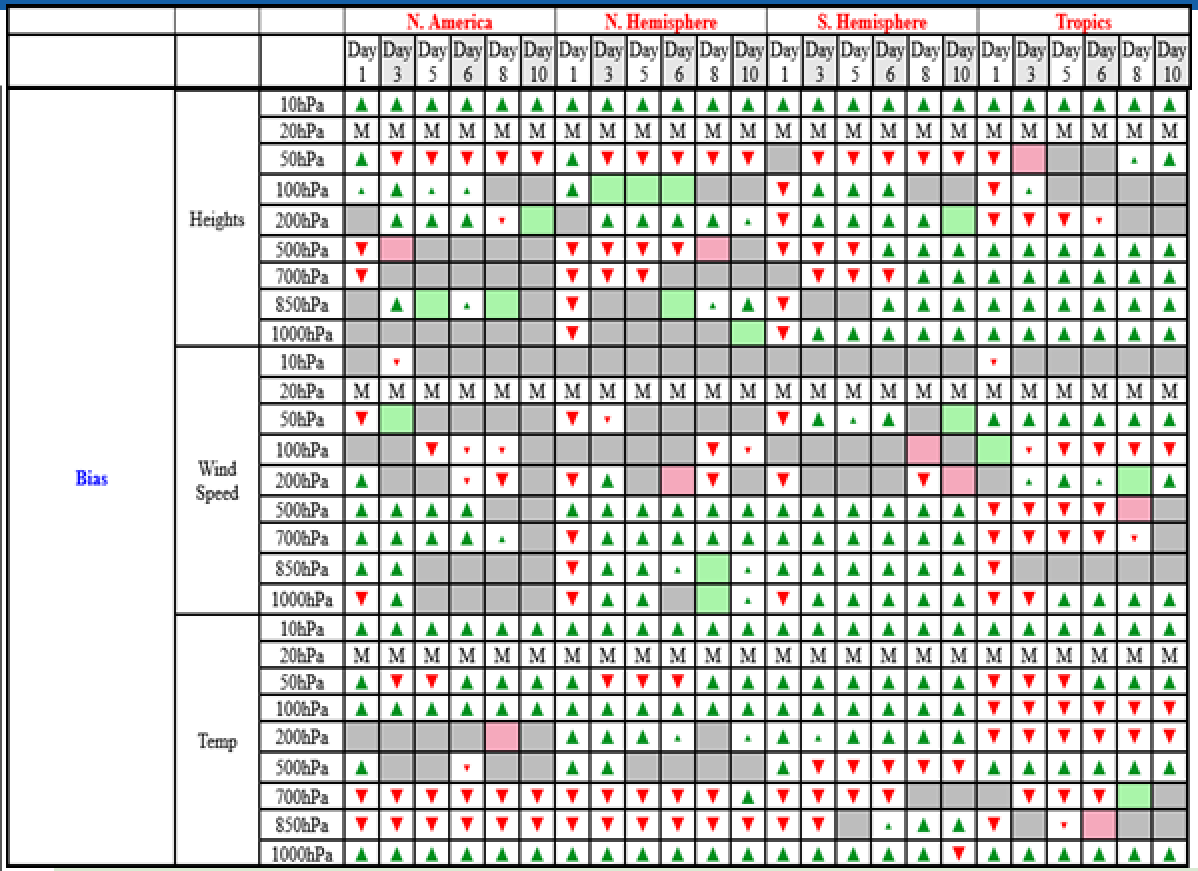


- GEFSv13 prototype is overall better than GEFSv12 and CFSv2
- GEFSv13 prototype is comparable to ECMWF

Credit: Minyue Chen, NOAA/NWS/NCEP/CPC

GEFSV13 Prototype vs GEFSv12 Scorecard: (Oct 2017 - Sep 2019)





- **ACC:** significantly improved
- **RMSE:** overall improved, except temperature in the tropics
- **Bias:** mixed results, degradation at lower level

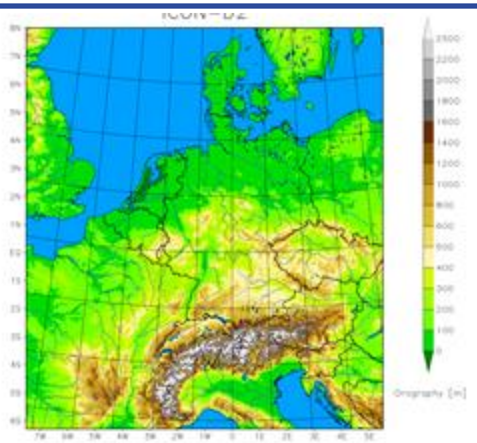
Credit: Bing Fu, NOAA/NWS/NCEP/EMC

DWD

Updates and plans for regional EPS

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

ICON-D2-EPS / ICON-RUC-EPS



- ~ 2.1 km icosahedral grid , 65 vertical levels
- 20 members
- boundary conditions ICON-EU-EPS (~13km grid)
- initial conditions 4D-LETKF (based on 40 members)
- perturbation of physics parameters, fixed over forecast run (random value with or without temporal corr. between runs)

ICON-D2-EPS

- 00, 03, 06, 09, 12, 15, 18, 21 UTC
- 48 hours forecast

ICON-RUC-EPS operational since July 2024

- hourly forecast start
- 14 hours forecast
- two-moment microphysics incl. hail

research & development

- stochastically perturbed parameterizations (SPP)
- combination of ICON-RUC-EPS with nowcasting ensembles for seamless prediction and warnings (grid and object-based)

Updates and plans for global EPS

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- Operational configuration: 26 km L120 global with two-way nesting over Europe to 13 km L74 (top of nested domain at about 23 km; global 75 km)
- April 2024: reduced SST perturbations, accompanied by larger EPS perturbations in convection scheme (combined perturbation of entrainment parameter and convective adjustment time scale; initial downdraft mass flux)
- Large beneficial impact on precipitation and cloud cover in tropical regions with active convection, moderate beneficial impact throughout the troposphere (T, RH, wind) due to increased spread and reduced RMSE (plus reduced drizzle bias for precip)
- May 2024: introduction of multiplicative amplification of soil moisture spread, combined with revised adaptive parameter tuning (APT) for soil moisture
- Moderate improvement of T2M and RH2M (primarily due to the APT change)

Plans for 2025

- Next resolution upgrade for global EPS to 20 km (10 km over Europe)
- Date not yet decided due to dependency on storage system upgrade; currently planned for Q4/25 or Q1/26

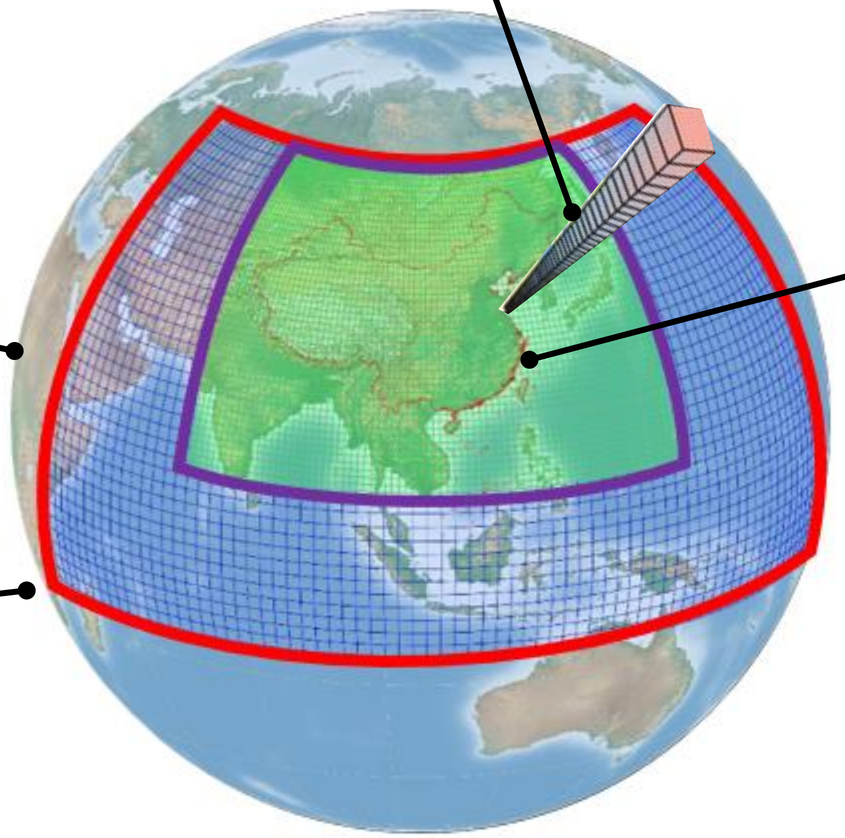
CEMC

CEMC's Operational Ensemble System

87 layers， 63km

GEPS：50km/25km

CMA-GEPS：
- 87 layers， top to 0.1hPa
- 50km operation, 25km on test
- 1 control + 30 members
- 15day forecast（00,12UTC）



REPS：10km/3km

CMA-REPS：
- China domain, 10km operation, 3km on testing
- 1 control +15 member
- 3.5day forecast（00,12UTC）

CPS：45km

CMA-CPS：
- Sea-land-ice-atm coupled， 56 layers, top to 0.1hPa
- Global 45km
- S2S sub-system：1-60day forecast， 4 member per day
- Seasonal forecast：1-13month， every month， 21 members

GEPS: Global Ensemble Prediction System
REPS: Regional Ensemble Prediction System
CPS: Climate Prediction System

Ensemble development Strategy (2024-2035)

1. Improving CMA operational ensemble forecasting systems

- Operational implementation of 25km-GEPS, the number of ensemble members will be increased to 41
- Operational implementation of 3km-REPS for improving forecasting skills of heavy precipitation and severe convective weather.
- Based on CMA-CPSv3, a high-resolution climate system model will be developed at T382L70

2. Future Plans for MCV-based ensemble

- Weather-climate integrated ensemble forecasting technology
- Sub-kilometer-scale ensemble forecasting technology
- Ensemble forecasting techniques for ocean and ice model components
- Research of ensemble forecasting techniques for land model
- AI ensemble forecasting

Meteo-France

Recent evolution of ARPEGE-EPS

- ***Next e-suite (49t1 under construction)***
  - Possible removal of singular vectors (i.e. EDA only): improved scores except reliability
  - Surface perturbations, coupling to a 1D ocean mixed-layer model
  - Mixed precision
- ***Future work***
  - Stochastic parameter perturbation

SV+EDA

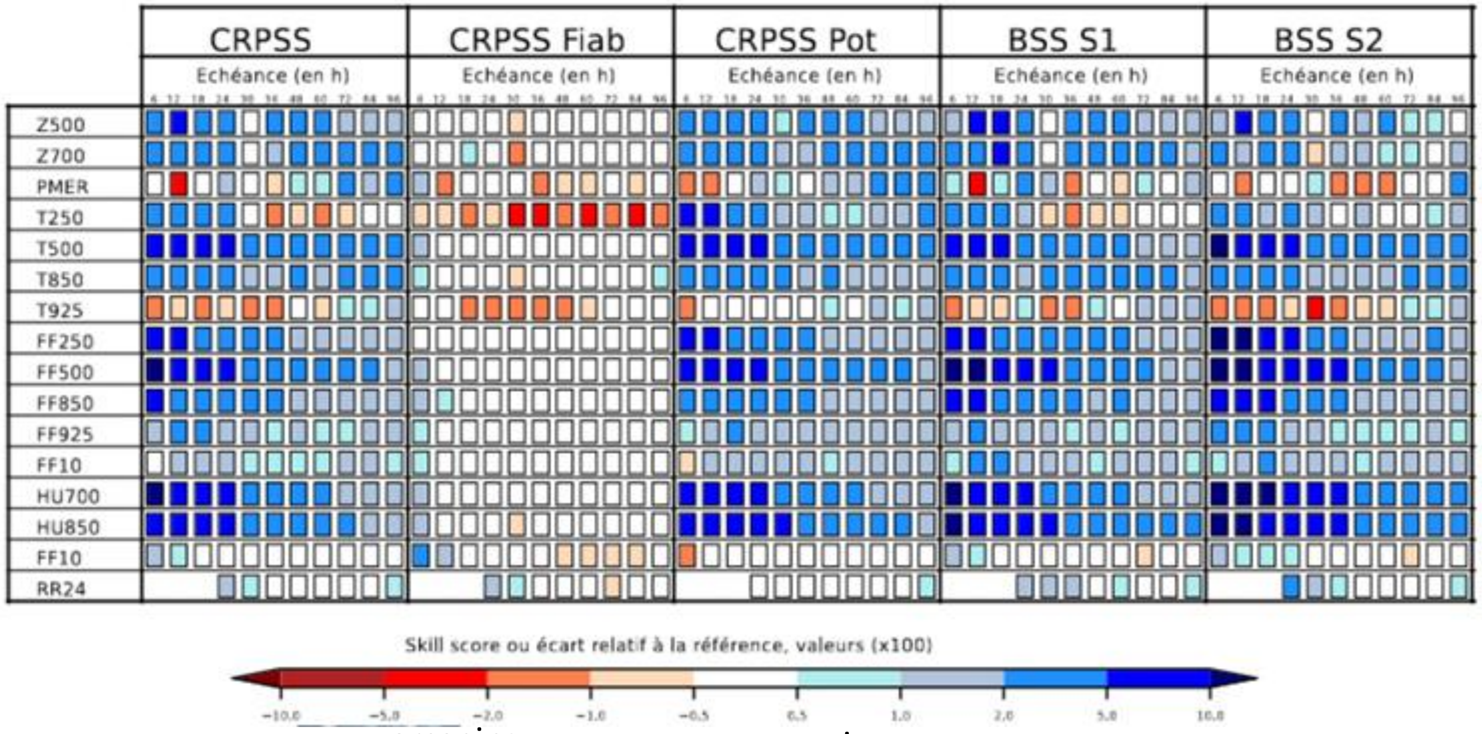
Geopotential
Mean sea-level pressure

Temperature

Windspeed

Specific Humidity

Wind gusts
Precipitation



worsening improvement

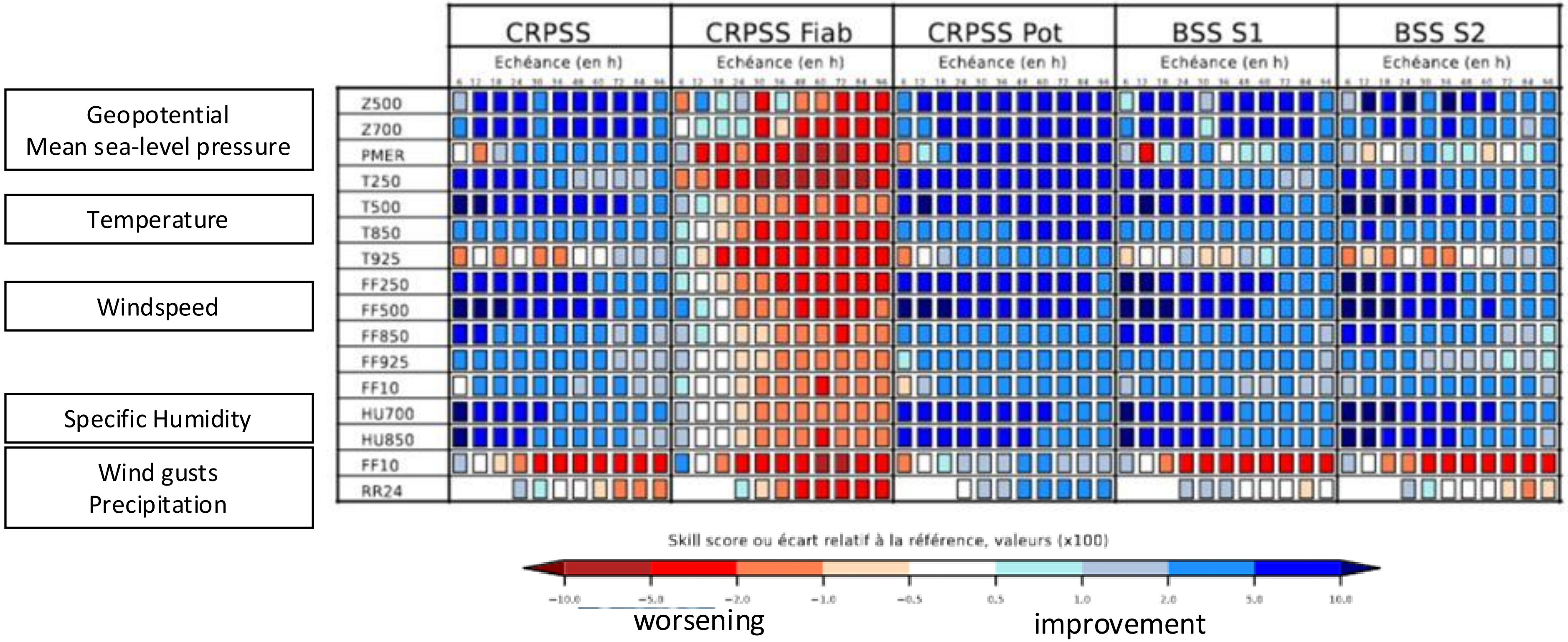
Change in scores from cy48t1_op1 to new ARPEGE-EPS ***SV+EDA*** *vs ECMWF analyses and SYNOP observations as a function of lead time (Northern Hemisphere)*

Courtesy C. Labadie, L. Raynaud

Recent evolution of ARPEGE-EPS

- ***Next e-suite (49t1 under construction)***
  - Possible removal of singular vectors (i.e. EDA only): improved scores except reliability
  - Surface perturbations, coupling to a 1D ocean mixed-layer model
  - Mixed precision
- ***Future work***
  - Stochastic parameter perturbation

EDA-only

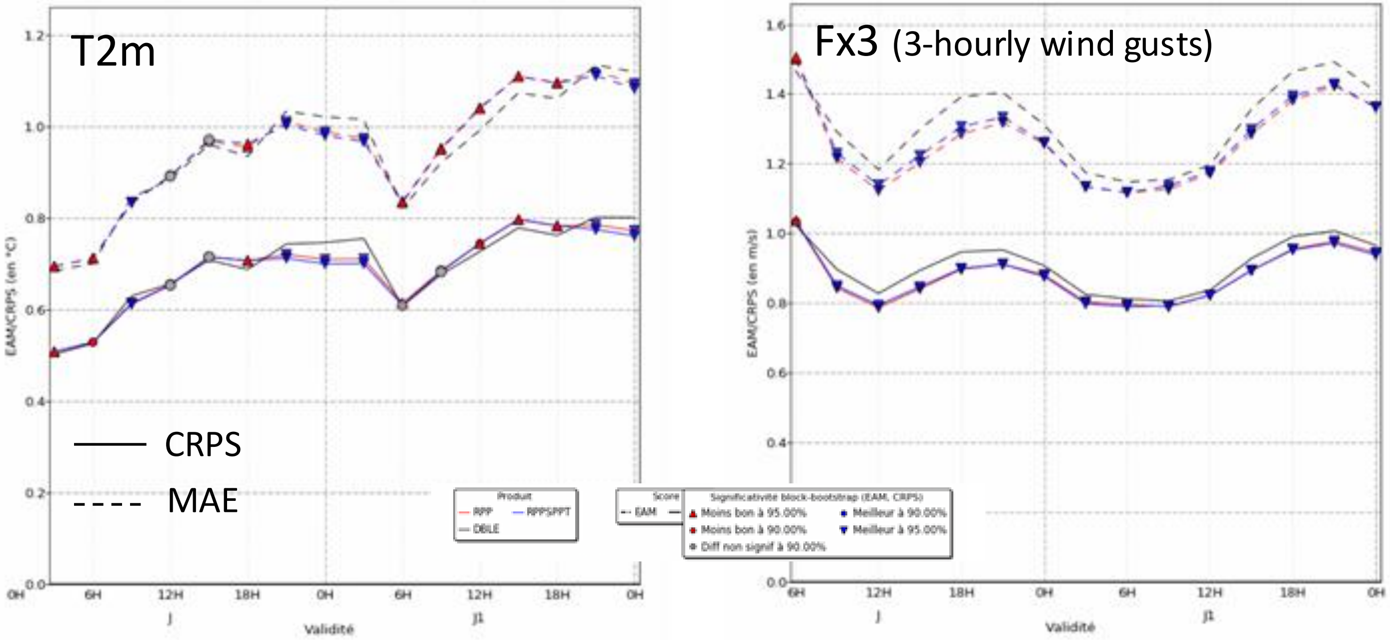


*Change in scores from 48t1_op1 to new ARPEGE-EPS **EDA-only** vs ECMWF analyses and SYNOP observations as a function of lead time (Northern Hemisphere)*

Courtesy C. Labadie, L. Raynaud

Recent evolution of AROME-EPS

- ***Next e-suite (49t1)***
  - Random perturbed parameters (RPP) will complement SPPT: 19 parameters from the different physics schemes are randomly perturbed at the beginning of the forecast (then fixed during time integration)
- ***Future work***
  - Coupling to a 1D ocean mixed layer model
  - Prototype at 750 m



Impact of randomly perturbed parameters alone (red) and combined with SPPT (blue), compared to current operational configuration (SPPT alone, black), as a fonction of lead time

Courtesy G. Roux, L. Raynaud

KMA/KIAPS

Upcoming Operational Ensemble System Upgrade at KMA

- A horizontal resolution increase from 32 km to 24 km in Global KIM EPS at KMA with the version upgrade (KIMv4.0)
- Forecast length of global-medium 12d → 15d

Ongoing research at KIAPS (~ 2026)

- Development of a new extended-range prediction system (targeting ~4 weeks, 32-km resolution)
  - Using the KIM model
  - Coupled model system (NEMO/Si3, WW3, Noah-MP) & data assimilation

  → Two global ensemble predictions with KIM (medium-range & extended-range)

- Model uncertainty using Stochastically Perturbed Parameterizations
  - Starting from last year, intensive testing with applicable physics modules has started
  - Searching the optimal perturbation
  - Performance comparison with the current methodology (SPPT, SPDT, SSST)

Met Office

Model development for ensembles

- Development of a glossary of terms for ensembles – would WGNE be interested in pushing this as a WMO reference?
- Plan to retire deterministic models in 2026
- A lot of thought around how to develop for the best ensemble vs the best deterministic model.
- Also work around verification and visualisation. How to provide useful information from ensembles to operational meteorologists?

Package Testing Discussion Outcomes
What will we do differently?

Activity	Notes	Timeframe	Team / Lead
Including ensembles in package testing	Plan to have early meeting with key people along the chain to decide what kind of tests are relevant, depending on the proposed change. Expect that some form of ensemble case study / very short trial will have already been run by science developers as part of the research cycle. For package testing, consider using small ensembles and applying fair scores. For regional ensembles: use operational domain size in early tests.	GC6/RAL4	Mike Bush / Martin Willett / Tim Graham Link with physics developers, verification experts and R2O
Use of climate ensembles	(GC) Could a 5 member AMIP/coupled ensemble be useful to understand significance of changes to model introduced by (e.g.) bias correction, additive inflation, SST perturbations. (RAL) Discuss climate strategy with Chris Short to discuss computational costs of running, say, a 3-year ensemble as well as or instead of a 5-year deterministic	GC6/RAL4	Mike Bush / Martin Willett / Tim Graham Link with climate
Interaction between new science and existing stochastic physics schemes	Plan to hold early meeting with key people where a physics change might impact existing stochastic physics settings.. For example: • Removal or addition of any parameters to the RP scheme (regional only – discuss with Mike Bush / Anne McCabe) • Change to science that may impact SKEB (e.g. changes to the semi-lagrangian advection scheme) • SPPT should be model physics agnostic, but replacement / tuning should be considered if adding new stochastic physics schemes	GC6/RAL4	Mike Bush / Martin Willett/ Cyril Morcrette / Warren Tennant Links with research cycle and pre-PS trialling

Package Testing Discussion Outcomes
What will we do differently (ctd)?

Activity	Notes	Timeframe	Team / Lead
Tuning	Need to understand how much benefit we get from tuning a deterministic simulation • Are there any simple tests to understand this? • Test this by running GC5 without some of the tuning changes. o What about bias corrections/additive inflation? • Dependency on how we assess the ensemble (e.g. CRPS improved by reduced biases)	GC6 or later	Martin Willett Link with physics developers
Accounting for some aspects of the ensemble (e.g. additive inflation) being tuned to the control configuration	There is usually a big improvement in the ensemble statistics once trials are run with new additive inflation / bias increments, consistent with the new science This needs to be communicated clearly when presenting results before the new additive inflation / bias increments are present - possible ways to do this are to give some info about the percentage improvement typically seen on previous GC updates A better alternative would be to devise and test a trialling approach in which early ensemble trials are not affected by this (e.g. test the impact of trialling using the random contribution but not include the bias correction contribution in the current increment-based approach) (David Walters)	GC6 or later	Martin Willett / Tim Graham Link with DA and Pre-PS Trialling

Package Testing Discussion Outcomes
Research questions and practicalities

We will need to take pragmatic approaches with the activities below, use trial and error, and update our plans according to changes in resources

Activity	Notes	Timeframe	Team / Lead
What is the optimal size of ensemble, trial length and resolution for use in package testing?	Simple experiments (possibly using data we already have) to inform ensemble size and trial length for use in package testing. Even if we know the optimal size we may not have the time or resources to run it, so we will need to make pragmatic decisions. We need to understand whether results from low resolution ensemble trials give useful information. This should feed into what we ask developers to run (e.g. full resolution case studies vs low res ensemble trial).	Medium	Martin Willett, Mike Bush Link with verification experts and DA & pre-PS trialling in R2O
How much do case study ensembles tell us about final ensemble trials?	Case studies can focus on a range of different weather types. Over time we could develop a list of case studies that are particularly useful for evaluating ensemble characteristics. Case studies won't give us sufficient information to understand reliability. May give early warnings about the stability of a change. How does this fit in with testing with and without DA?	Medium	Martin Willett, Mike Bush, APP, R2O Link with research cycle, verification and DA & pre-PS trialling
How do the different components of the ensemble system contribute to the ensemble performance?	Use an understanding of how the different perturbation types contribute to the ensemble spread and error characteristics to inform the focus of future research For MOGREPS-UK, the spread PEG have looked at this in terms of isolating the different perturbation types. For MOGREPS-G, work has been done by Warren Tennant to isolate the impact of the different stochastic physics schemes. It may be useful to revisit these approaches with new model configurations.	Ongoing	Warren Tennant, members of the ensemble spread PEG (e.g. Aurore Porson, Anne McCabe, David Flack)

Summary/Discussion

- Thanks to everyone who has provided slides
- Would a glossary of terms so that all groups use the same terms be useful?
- Challenges of developing models for ensembles:
  - Cost of running at high resolution
  - Dependence of DA/additive inflaction etc on control model.