Ensembles Overview 2023

Tim Graham (with input from WGNE representatives)

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/20km	8d 8d/14d	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 & PCMT) SPP	N (SURFEX) Once a 1D ocean mixed layer model implemented in the e-suite, testing initial SST pert.	
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

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Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
DWD (German)	26km,L120: two-way nest with 13 km over Europe	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 (Q4 2023 or Q1/2024)
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.	

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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
CMA (China)	～ 50kmL60	15d	31	SVs	SPPT	N	GRAPES
KMA (Korea)	~40kmL70 32km (p)	12d	24 44	ETKF Hybrid Ensemble 4D-Var	Random Parameters (RP2) and SKEB2.	N	

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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 1.5kmL90	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	51h	16+1 24+1	Deterministic Analysis (3DEnVar) + Pert. From 3.2km ensemble assimilation	SPPT Random Perturbed Parameters	Pert. of surface LBC selection with clustering	AROME
DWD (Germany)	2.1km	48h (8x/day)	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
CMA (China)	~ 10km	84h	15	ETKF	SPPT	Global EPS	GRAPES
KMA (Korea)	3kmL70	45h	23+1	Downscale from Global EPS LETKF	RP	Global EPS	UM

Summary of tables

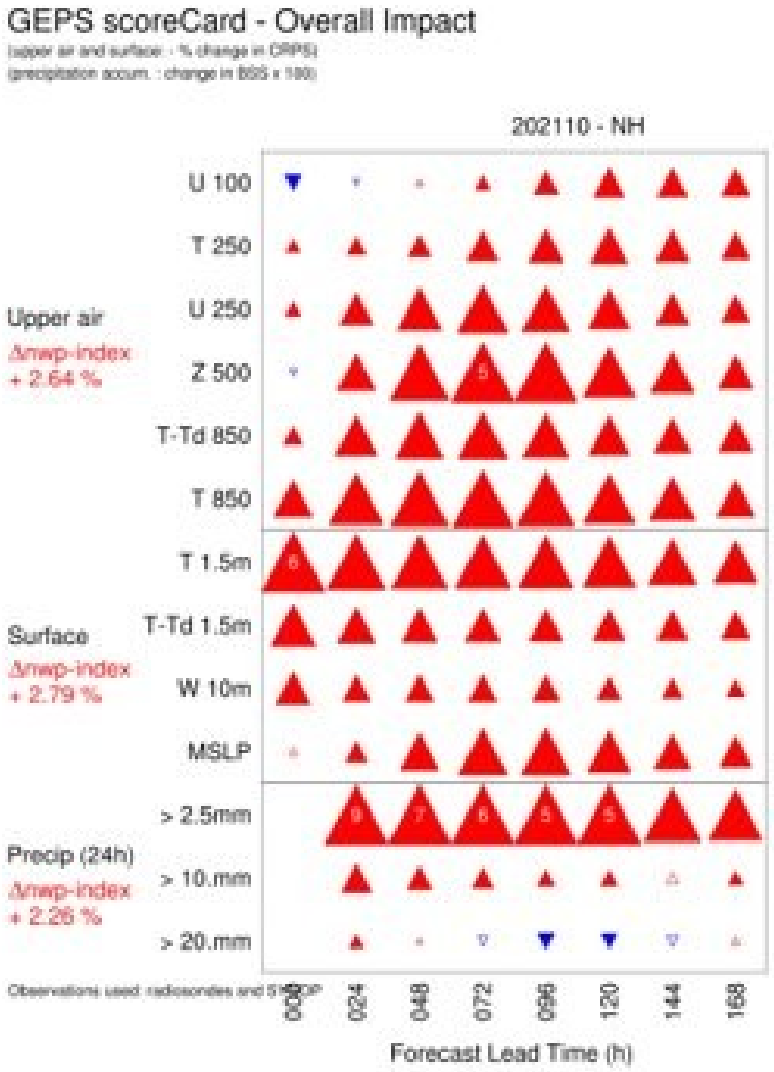
	Operational	Research
SPP/RPP	Met Office (R),HMC, NCEP, JMA, CMA, DWD	ECMWF, Meteo France, NCEP
SPPT	ECMWF, Met Office (G), HMC, NCEP,	
STOCHDP	HMC	ECMWF
SKEB(2)	Met Office, NCEP, CMC	
Additive Inflation	NRL, Met Office	
Cellular Automata		NCEP
Humidity perturbations		JMA
Multi-physics	Meteo France (convection), NCEP/SREF	
2 tiered SST	NCEP, JMA	
SST perturbations	Met Office, DWD, NRL, JMA	Meteo France
Coupling	ECMWF, Met Office, CMC, NRL	Meteo France (1D ocean ML model), NCEP, Bureau,
SV	ECMWF, Meteo France	

CMC updates

Ron McTaggart-Cowan and Leo Separovic

Upcoming CMC Ensemble Upgrade

- A major upgrade to the CMC Global Ensemble is in final pre-parallel testing, with implementation planned for mid-2024:
  - Grid spacing reduced from ~39 km to ~25 km in both the LETKF (256 members) and forecasts (20+1 members)
- Large improvements are found for most probabilistic scores, but a transient bias in the tropics leads to deteriorations of 200 hPa temperatures (not shown)



Summary of relative CRPS changes over the Northern Hemisphere fall/winter 2022 test period in the proposed GEPS upgrade.

Research Plans for CMC Ensembles

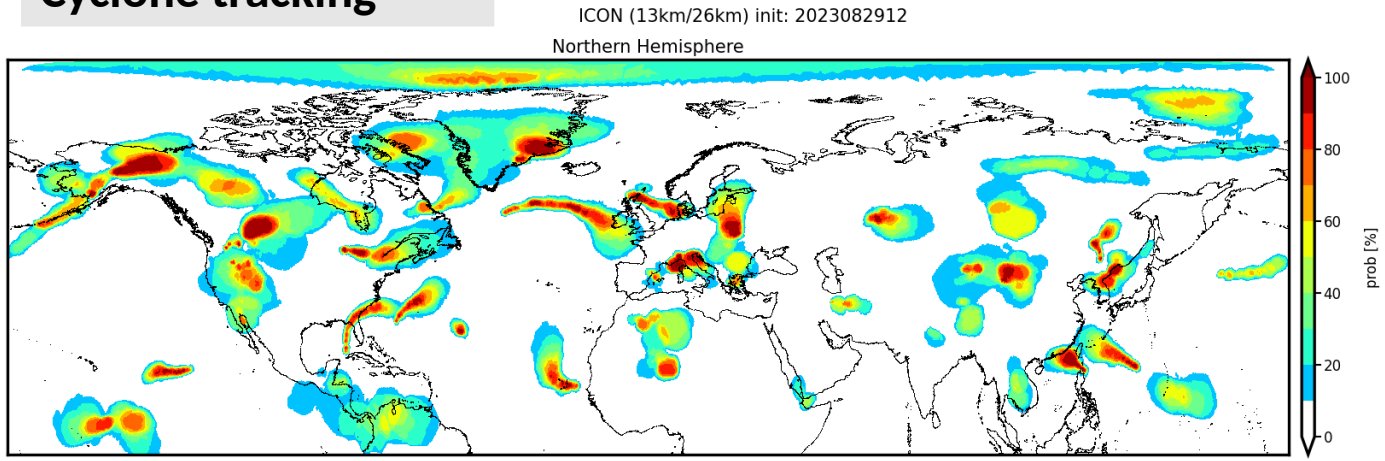
- There are ongoing discussions about the relative benefits of increasing the number of perturbed forecast members (currently 20) versus another increase in resolution (grid spacing to ~15 km as in the global deterministic system)
- A 4-km cycling regional LETKF-based system is under development to replace the 10-km downscaling ensemble
- Introduction of new fair scoring rules (e.g. ignorance score) to better assess changes in forecast skill
- Investigation of AI/ML techniques for creating ensemble members

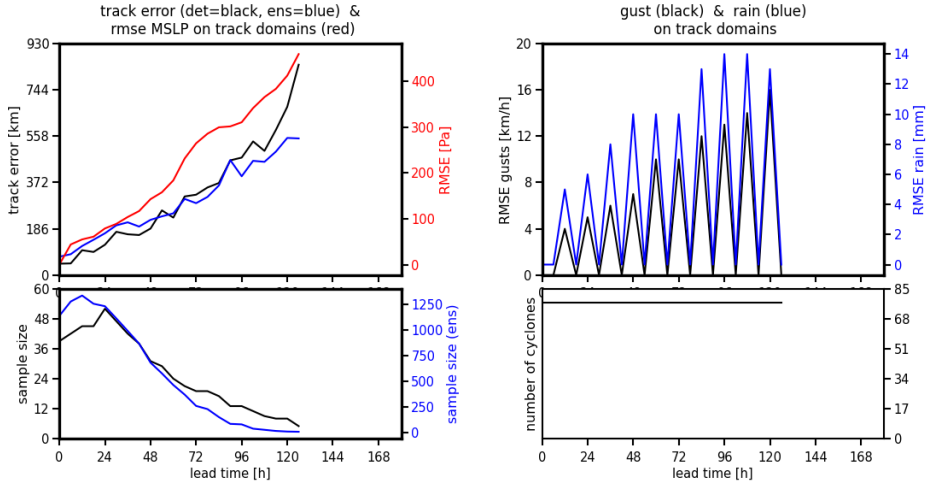
DWD updates

ICON-EPS global

Cyclone tracking

M. Denhard, 2023;"Neighborhood based probabilistic Cyclone forecast products“, in preparation.





Singular vectors without tangent linear code

Krylov Methods for Adjoint-free Singular Vector based perturbations *J. Winkler, M. Denhard, B. Schmitt, 2020: Q J R Meteorol Soc. 2020;146:225–239.*

➡ include machine learning (AI)

Lanczos Algorithm

linear / adjoint

$$\left[\mathbf{A^* A}\right]\left[\mathbf{Q}_{n,m}\right] \sim \left[\mathbf{Q}_{n,m}\right]\left[\mathbf{H^* H}_{m,m}\right]$$

$\mathbf{A^*A}$ – symmetric matrix

tridiagonal

$$\begin{pmatrix} \diagdown & 0 \\ 0 & \diagdown \end{pmatrix}_{m \times m}$$

$\sim O(m \times n)$

Arnoldi Method

New!

non-linear

$$\left[\mathbf{A}\right]\left[\mathbf{Q}_{n,m}\right] \sim \left[\mathbf{Q}_{n,m}\right]\left[\mathbf{H}_{m,m}\right]$$

$\mathbf{A}$ – non-symmetric matrix

hessenberg

$$\begin{pmatrix} \diagdown & \diagdown \\ 0 & \diagdown \end{pmatrix}_{m \times m}$$

$\sim O(m^2 \times n)$

ICON-D2-EPS

Physically based Stochastic Perturbations for boundary layer turbulence (PSP2)

$$\left(\frac{\partial \phi}{\partial t}\right)_{all} = \frac{\partial \phi}{\partial t} + \underbrace{\alpha \cdot \eta \cdot \sqrt{\overline{\phi'^2}}}_{\text{Stochastic perturbations}}$$

ϕ ={T, q, w}

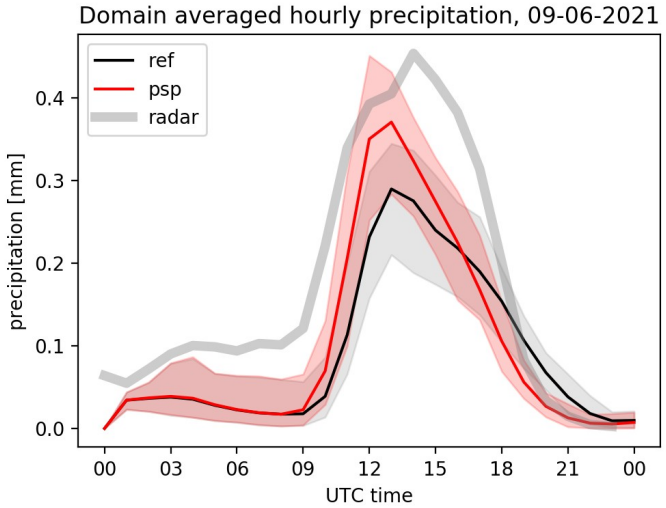
$\eta(t, \sigma)$: Random field , regenerated every 10 min with spatial correlation σ

α: perturbation ampl., scaling factors

ϕ': physical scaling/subgrid-scale variance of variable ϕ

Kober and Craig, 2016 Hirt et al., 2019

Collaboration between DWD and Ludwig Maximilians University (LMU): PSP2 in ICON

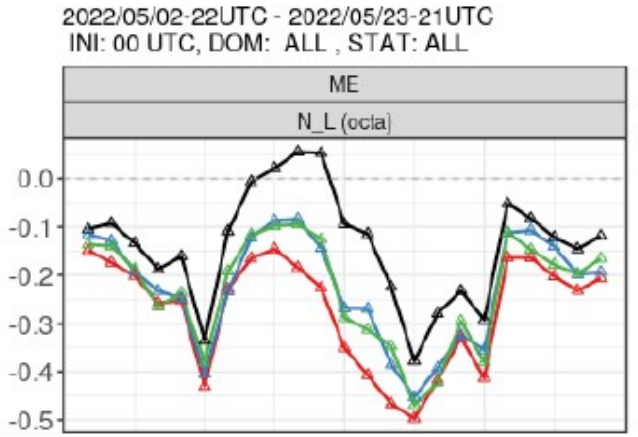


Effect on the convection initiation in days with weak synoptic forcing

Puh et al., 2023

On-going: test of different vertical profiles of the BL perturbation

ref_dry_days
PSP-S Standard
PSP-T Tangent-hyperbolic
PSP-G Gaussian



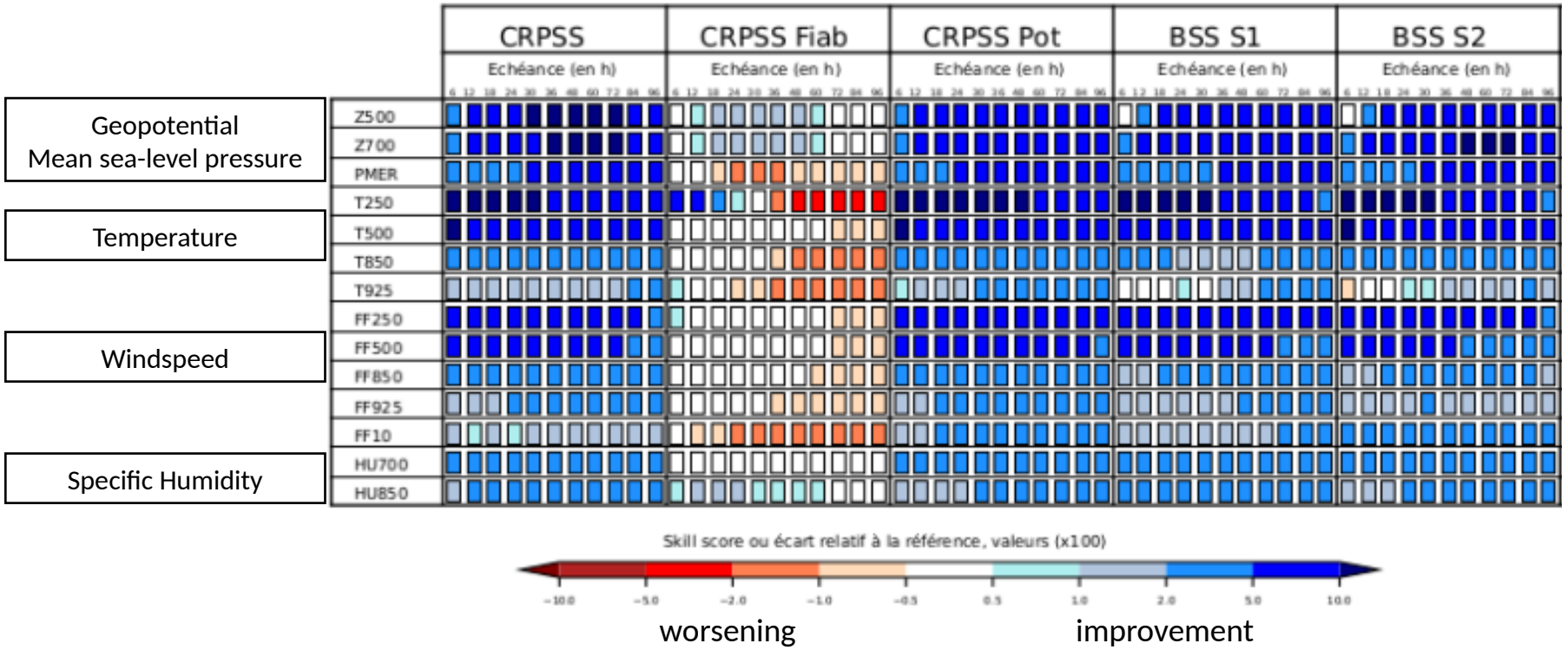
Plans for 2024: continue the research on PSP2; implement and test SPP in ICON

M. Puh, C. Keil (LMU), C. Gebhardt, C. Marsigli, S. Löber, A. de Lozar (DWD)

Meteo France updates

Recent evolution of ARPEGE-EPS

- ***New version to be released early 2024***
- ***ARPEGE evolutions:***
  - physics updates: including ECRad and convection closure
  - assimilation updates: new observations, implementation of a 4D-Var hybrid scheme with 3D anisotropic covariances issued from the ensemble assimilation system
- ***Reduced contribution from singular vectors to compute perturbed initial conditions***

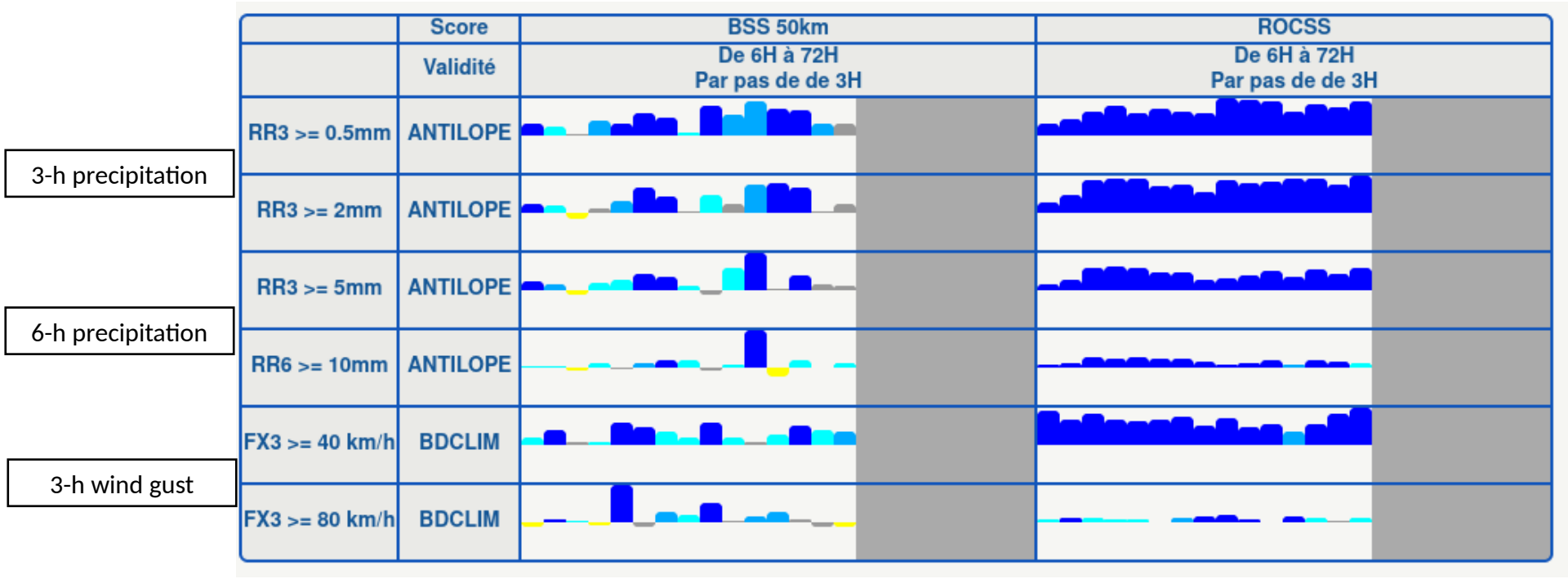


Change in scores from old to new ARPEGE-EPS vs ECMWF analyses and SYNOP observations as a function of lead time (Northern Hemisphere, from 04/08/2022 to 15/04/2023)

Courtesy L. Raynaud

Recent evolution of AROME-EPS

- ***New version to be released early 2024***
- ***AROME evolutions:***
  - Physics update, including ECRad, and assimilation updates including new observation and implementation of a 3DEnVar assimilation scheme



Change in BSS and ROCSS of precipitation and wind gust as a function of lead time, from the 17-member AROME-EPS (current operational setup) to a 25-member AROME-EPS (2024)*

Courtesy L. Raynaud

Met Office updates

Met Office Ensemble Research/Development

- **Strategic Action to use ensembles by default and retirement of deterministic models around end of 2025**
- Review of model development process for ensembles. How to test whether model developments improve ensembles
  - Cost
  - Dependence of DA/ensemble on existing model (e.g. covariance statistics).
- Development of an ocean ensemble DA system – how to bring this into coupled forecasts.
- Assessment of use cases for ensembles and how we communicate with users of the forecasts

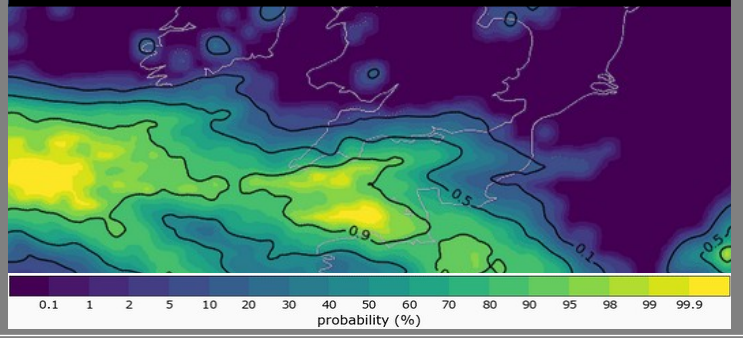
Classes of use cases for ensembles

1) Use cases for ensemble stats

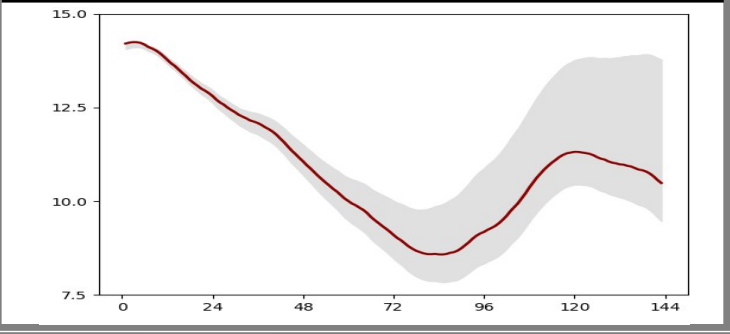
1a. Best estimated values

09:00	10:00	11:00	12:00	13:00
10%	10%	10%	40%	40%

1b. Probability distributions

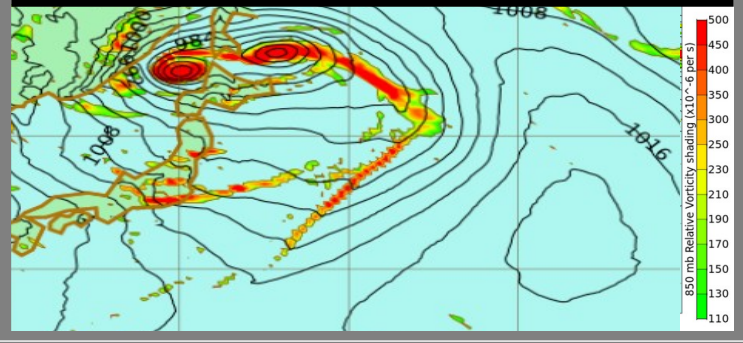


1c. Ranges of uncertainty

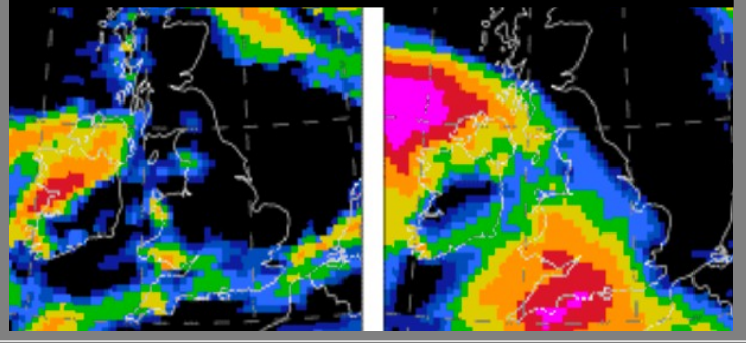


2) Use cases for 1 or more members

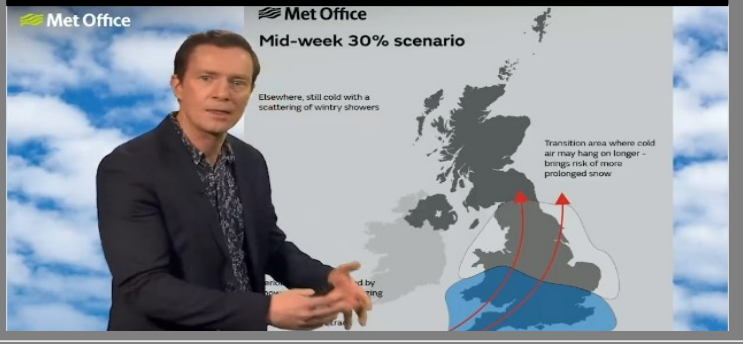
2a. Representative member



2b. Realistic low-prob. extremes

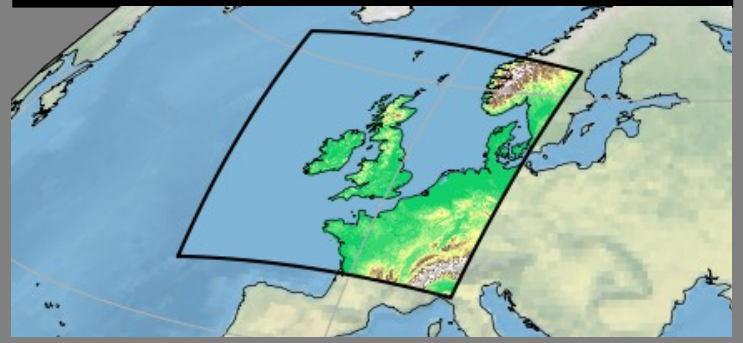


2c. Probable “storylines”



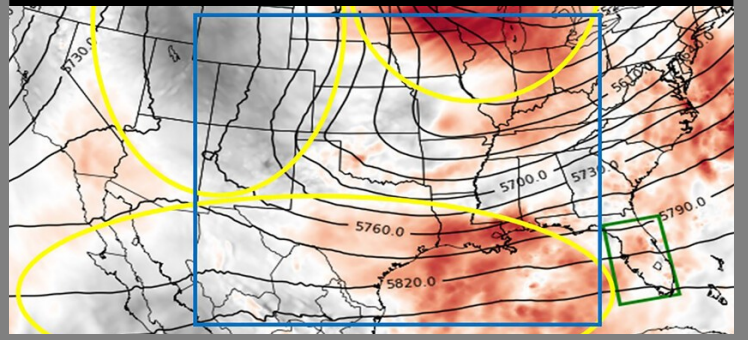
3) Use cases for all members

3a. Driving downstream models



3b. Correlated prob. distribution

3c. Extra ensemble processing



ECMWF updates

Ensemble research and development at ECMWF

- developments to improve ensemble skill with SPP for longer lead times, i.e. improved MJO skill in extended-range and reduced SST biases in long-range
- coupled processes SPP perturbations
- research towards an ensemble configuration for km-scale (4.4km; funded by DestinE) including suitable configuration of unperturbed model and representation of model uncertainties
- changed configuration of reforecasts (planned for 2024/5)
- mesoscale ocean-atmosphere interactions
- configuration of NEMO4/SI3 for future operational implementation
- offline land-sfc DA for initialisation of reforecasts and extended-range
- research on how to build an ensemble with ML models (e.g. AIFS)

Results for TC Ida

Initialization 27-08-2021 at 0000 UTC

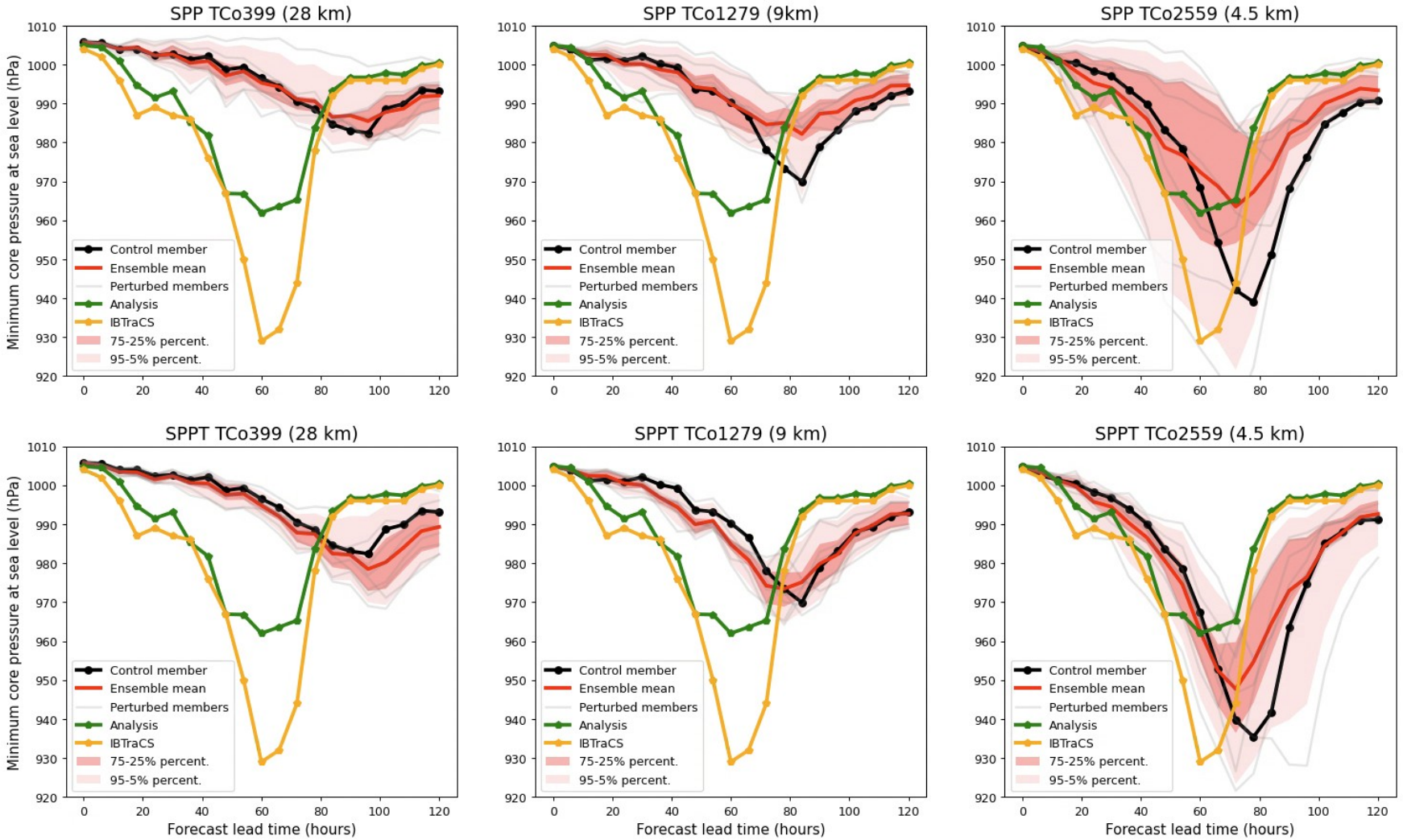
DestinE Phase I 2022-2024

TCo399 and TCo1279 struggle to capture the intensity of Ida

TCo2559 does a much better job at capturing the intensity

TCo2559 provides reasonable predictability of the TC intensity 1-day earlier than TCo1279 with members reaching up to 920 hPa in the run initialized at 26-08-2021

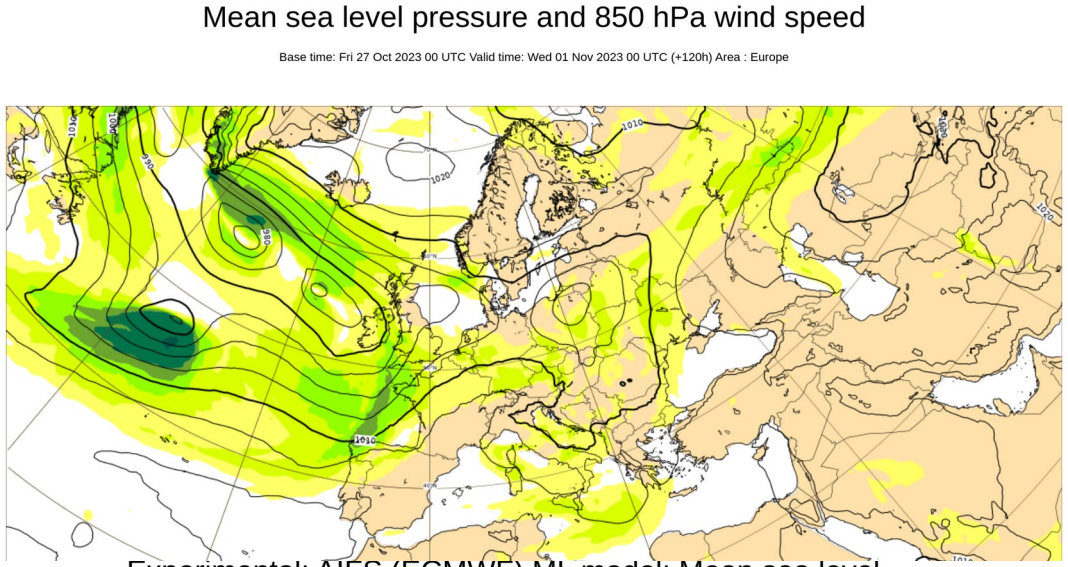
SPP generates more spread than SPPT and has members that exhibit more rapid intensification phase



Towards an AIFS ensemble

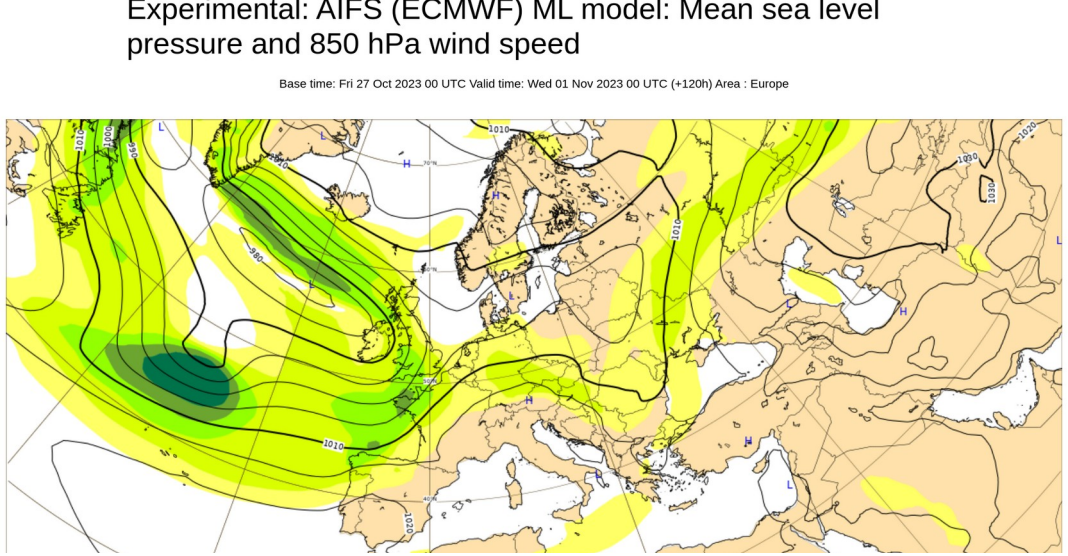
NWP model

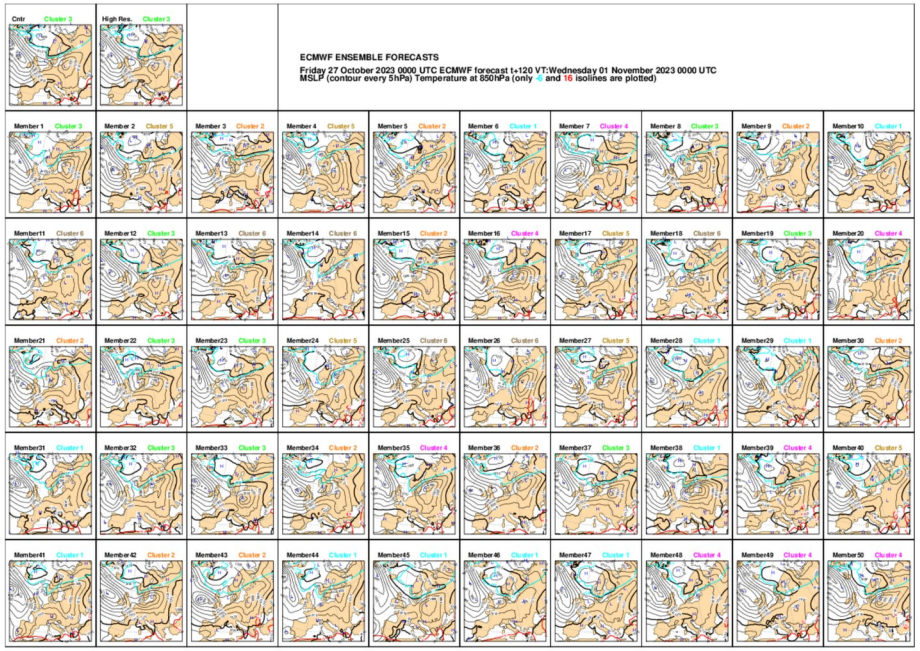
IFS



ML model
(GNN based)

AIFS





?

ECMWF

NCEP updates

GEFSv13 Configurations (planned)

Components		V12 (Oct. 2020)	V13 (Q1FY26)
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°L75)
	Initial perturbation	N/A	SOCA-Ens
	Model uncertainty	N/A	5-scale oSPPT and ePBL
Ice	Model	N/A	CICE6 (0.25°)
	Initial perturbation	N/A	SOCA-Ens
Wave	Model	WW3 (1-way) (0.5°)	WW3 (2-way) (0.25° lat/lon grid)

new

GEFSv13 Prototype Experiments - EOS highlights

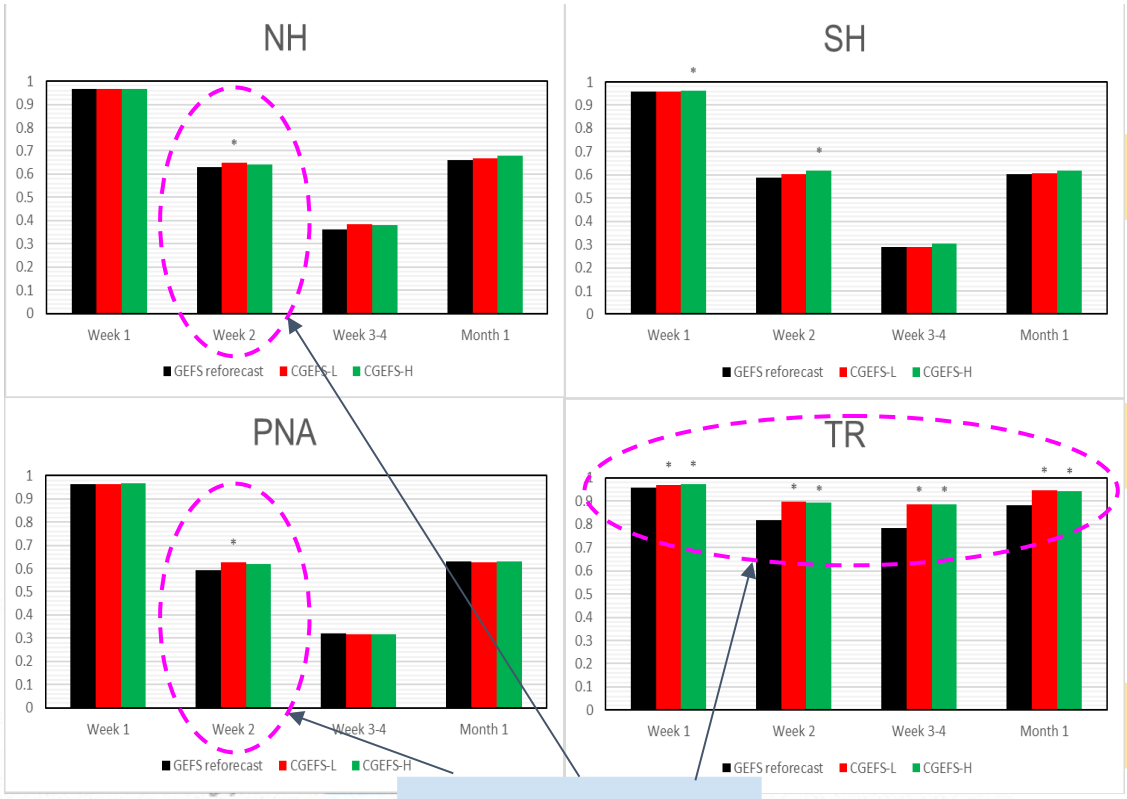
Editor's highlights - JGR Atmosphere (2023) --- Zhu, Y., B. Fu, B. Yang, H. Guan, E. Sinsky, W. Li, J. Peng, X. Xue, D. Hou, X.-Z. Liang and S. Shin, 2023: Quantify the Coupled GEFS Forecast Uncertainty for the Weather and Subseasonal Prediction.

Eos

A New Coupled Modeling System Improves Forecast Skills

Building on older versions, the new Global Ensemble Forecast System with coupled atm

By Minghua Zhang
21 February 2023



Significantly improve the skills

Built on top of the current operational Global Ensem ... system is developed by fully coupl
skills are assessed by using anomalies of 500 hectop ... ds at different heights, tracks and
Oscillation (MJO) among others. The new system is s ... d times than the uncoupled syster

Citation: Zhu, Y., Fu, B., Yang, B., Guan, H., Sinsky, E., Li, W., et al. (2023). Quantify the coupled GEFS forecast uncertainty for the weather and sub
Atmospheres, 128, e2022JD037757. https://doi.org/10.1029/2022JD037757

—Minghua Zhang, outgoing Editor in Chief, *JGR: Atmospheres*

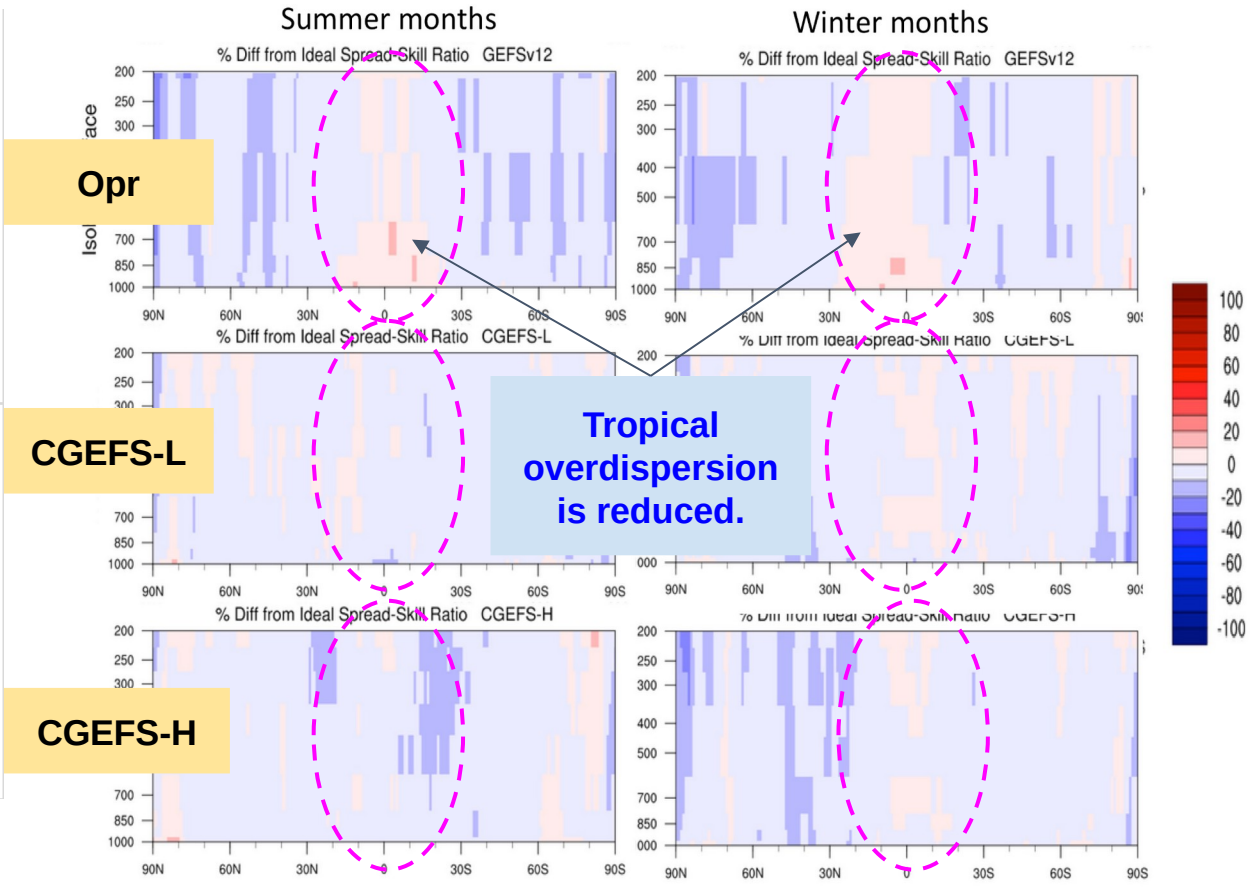


Figure 9: The vertical cross section of the ratio for boreal summer six months (left column) and boreal winter six months (right column) of zonal wind from surface (1000hPa) to 200hPa in vertical, for 144 hours (6 days) forecasts, and for the GEFSv12 reforecast (top), CGEFS-L (middle) and CGEFS-H (bottom).

GEFSv13 ensemble prototype performances

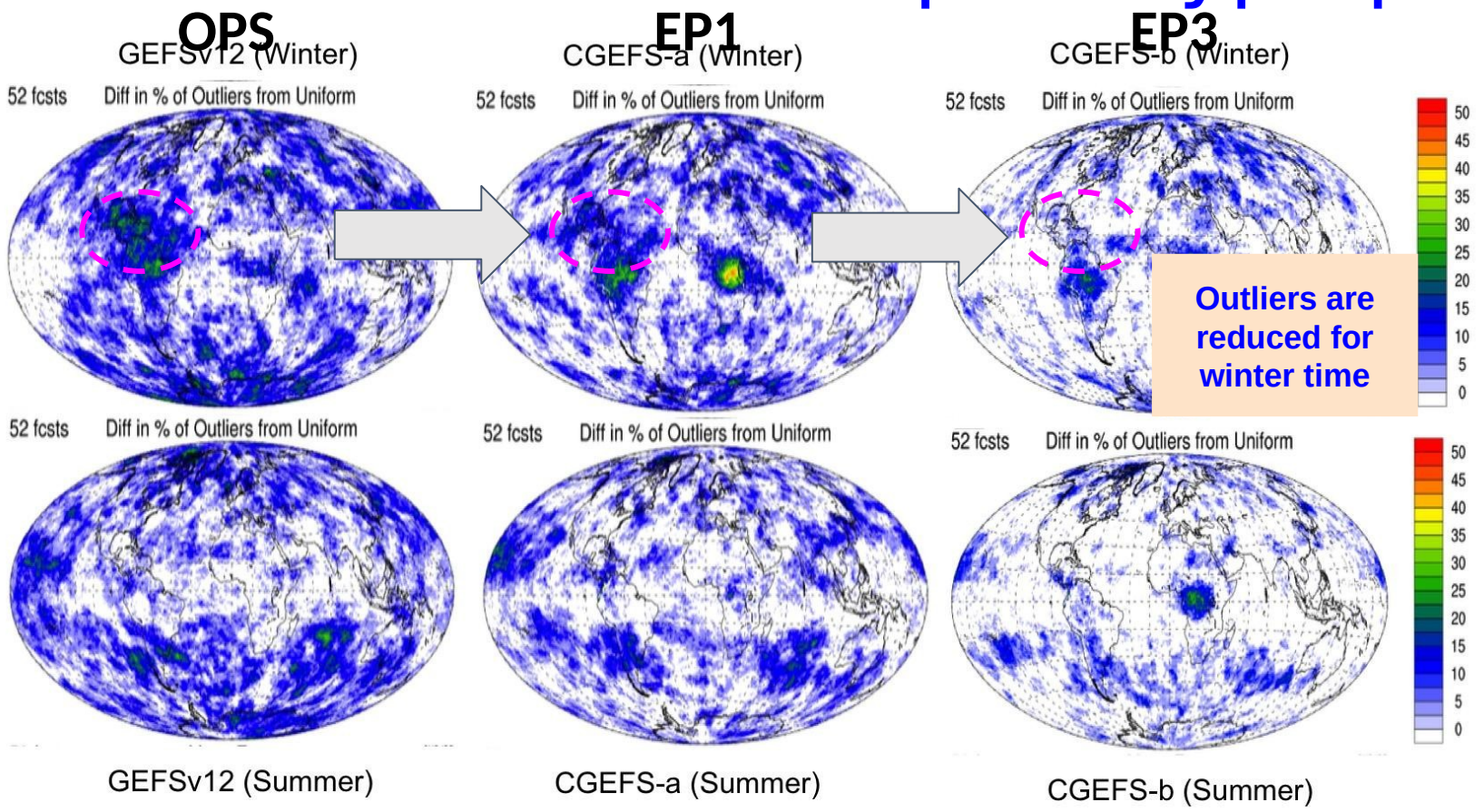


Figure 3. Distribution of the ratio of 500 hPa height 120h forecast outliers from uniform (in percentage) in GEFSv12 (left), CGEFS-a (middle) and CGEFS-b (right) for summer (bottom) and winter (top).

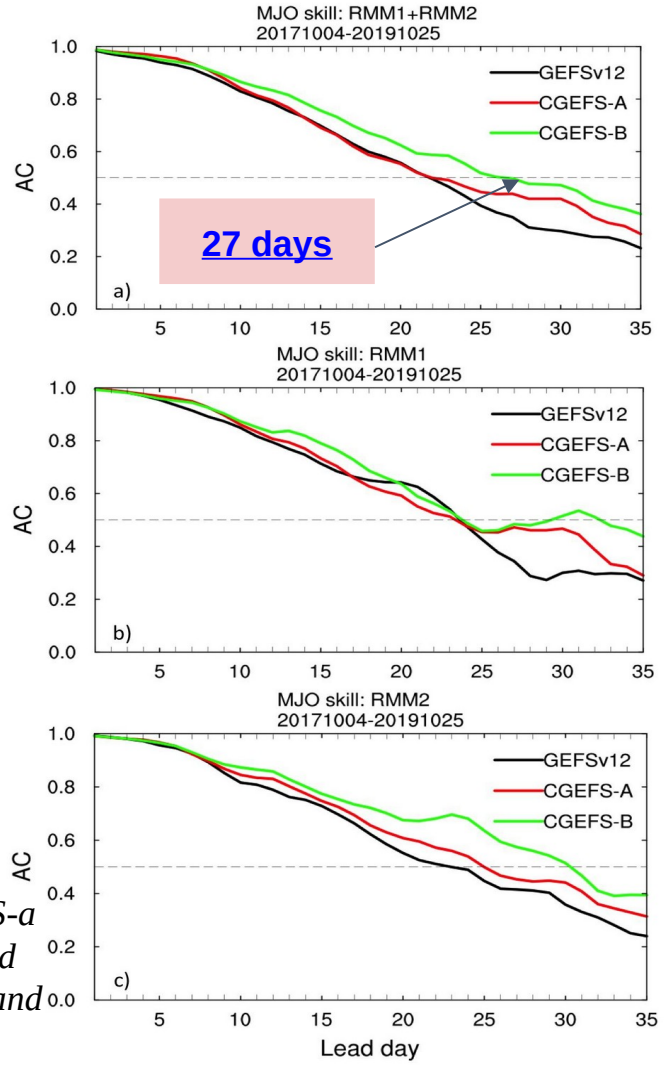


Figure 11. The MJO index for the GEFSv12 (black), CGEFS-a (red) and CGEFS-b (green).The MJO forecast skill is defined as the bi-variate anomaly correlation between the analysis and forecast real-time multivariate MJO index 1 and 2

Bing Fu et al. 2023: Weather to subseasonal prediction from the UFS coupled Global Ensemble Forecast System Submitted to "weather and forecasting"

Summary

- GEFSv12
  - Configurations: (1-way coupled)
    - ATM (C384L64) - WAV - CHM
  - Implementation: (September 23, 2020)
- GEFSv13
  - Configurations: (fully-coupled)
    - ATM (C384L127) - OCN - ICE - WAV - CHM
  - Planned implementation time:
    - Q1FY26 - GEFSv13 implementation

HMC updates

Developments in global ensemble prediction at Hydrometcentre of Russia

- Current version: SLAV 0,9°x0,72°L96, SPP + SPPT (T and vorticity only)
- Changes since autumn 2022: update of the model, some tuning of perturbations in SPP
- Research on STOCHDP: Implemented. Tuning 3D shape and magnitude of the perturbation. So far, small positive impact on spread
- Plans to experiment further with SKEB2
- Plans to abandon SPPT at least for temperature
- The version under development: SLAV 0.225°x(0.16-0.24°)L51
- Current work: code optimization to fit operation requirements