WGNE35 Ensemble Overview

1) Overview of Recent Operational Upgrades and Plans with Ensemble Tables
2) Current Ensemble Research: Center Highlights
3) Extra Slides include all Center Contributions

Recent Upgrades and Plans: Global

- Resolution and Member Number: ECMWF, Meteo France, HMC, CMC, CPTEC, JMA
- Initial Condition Methodology: Met Office (En-4DEnVar), HMC (LETKF), CMC (LETKF, reduced random additive inflation), CPTEC (EnKF, Hybrid 3DVar), JMA (pert. Inflation in LETKF)
- Model Uncertainty Methodology: ECMWF (SPP, STOCHDP), Met Office (SPT, analysis increments), Meteo France (new model pert)., HMC (SPP), NCEP (process-based params), DWD (convection scheme, stochastic representation), NRL (multi-physics, analysis-based increments), CMC (SKEB + Stochastic parameter perts.)
- Boundary Condition Perturbations: Met Office (ocean coupling, SST perts.), NCEP (land and ocean stoch perts, coupled ocean and sea-ice), NRL (atmo-ocean-sea ice coupling), JMA (two-tiered SST approach after day 12)

Recent Upgrades and Plans: Regional

- Resolution and Member Number: Met Office, Meteo France, DWD, HMC, JMA,
- Initial Condition Methodology: HMC (ICON-EPS), JMA (Hybrid DA), Met Office (hourly-cycling time-lagged)
- Model Uncertainty Methodology: HMC (SPP, additive model-error perts), JMA (pert. tendencies), CMC (stochastic parameter perts.), NRL (perturbed drag coefficients)
- Boundary Condition Perturbations: Met Office (SSt from 1.5km NEMO UK Shelf-seas forecast, with SST perts.), HMC (ICON-EPS), JMA (perturbed SST), NRL (SST cooling parameterization when uncoupled)

Operational global (weather) EPS

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

Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
ECMWF (Europe)	TCo639L91 TCo319L91 18/32km 11 and 9 km	15d 46d	51 100	SV(Total energy norm) + EnDA	SPPT SPP STOCHDP	coupling to ocean model, EDA-based land-surface pert. in ENS Ics	Hindcast dataset increased
Met Office (UK)	20kmL70	8d	17+1 44 for DA	En-4DEnVar	SKEB2 + SPT	SST, Soil moisture and deep soil temperature Coupling to ocean (with SST pert.)	Ensemble forecasts use archived analysis increments for bias correction and perturbation
Meteo France (France)	T1198(C2.2) L90	4d	35->50	SV (Total Energy Norm)+ EnDA (randomly chosen)	A new set of 10 physical packages, new model pert.	N SURFEX and pert.	
HMC (Russia)	T169L31 SLAV 0,9°x0,72°L96	10d	12+2->40	Breeding LETKF	N SPP	N	Control is produced by 2 models.
NCEP (USA)	C384L64 (~25km)	16d 35d (00Z)	30+1	EnKF	Stochastic pert. to account for random model errors SKEB, SPPT, Process based param.	2-Tier SST Stochastic pert. of land and ocean, couple with ocean and sea-ice	Dynamical core: FV3 31-year hindcast
DWD (German)	40km	180h	40	LETKF	Change convection scheme Stochastic representation	SST random pert.	ICON

Operational global (weather) EPS

Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
NRL/FNMOC (USA)	T359L60	16d 45-d coupled	21 16 for coupled	local ET SST pert.	SKEB-mc Multi physics ensemble, Analysis-based increments	SST initial pert. S2S atmo-ocean-ice	Part of the U.S. multi-model ensemble
CMC (Canada)	0.35° L45 0.35º L84	16d	20	Ensemble KF + random additive inflation, Local ensemble transform KF + reduced random additive inflation	stochastic pert. of physical tendencies and SKEB, further pert. to the physics SKEB + sotchastic parameter peturbations	coupled ocean (NEMO) and sea ice (CICE)	GEM (part of NAEFS)
CPTEC/INPE (Brazil)	T126L28	15d	15	EOF-based perturbation	N	N	Couple with earth system model
BoM (Australia)	~60kmL70 33km	10d	18				UM8.2->10.6
JMA (Japan)	TL479L100 128 TL479L100 128 TL319L100 128	11d 18d 34d	27 51 13 51 13 25	SV(Total energy norm) +LETKF (pert. Inflation)	Stochastic perturbation of physics tendency	Two-tiered SST approach after day 12 SST pert.	Update model Enhancement of horizontal resolution is planned in 2022
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	

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

Operational regional (weather) EPS

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)	2.5km 1.3km	45-51h	16	Deterministic Analysis + Pert. From 3.2km ensemble assimilation	SPPT	Pert. of surface LBC selection with clustring	AROME
DWD (Germany)	2.2km (2.1km)	27h 45h (03 UTC run) 48h (all runs)	20	Ensemble DA based on LETKF	Randomized choice of parameter perturbations from a fixed set of possible values	European nest of global ICON EPS (20km grid), soil moist pert.	COSMO ICON in limited area mode (Q1/21)
HMC (Russia)	2.2km	48h	10	ICON-EPS	N SPP, Additive model-error pert.	ICON-EPS	Test-operation ICON
JMA (Japan)	5kmL76 5kmL96	39h	20+1	SV(Total energy norm) from JMA global model Hybrid DA	N Pert. tendency	JMA global EPS Perturbed SST	
NCEP/SREF (US)	16kmL41		1+12, 1+12	Multi analysis	Variety of physics scheme	Stochastic soil moisture	Frozen

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

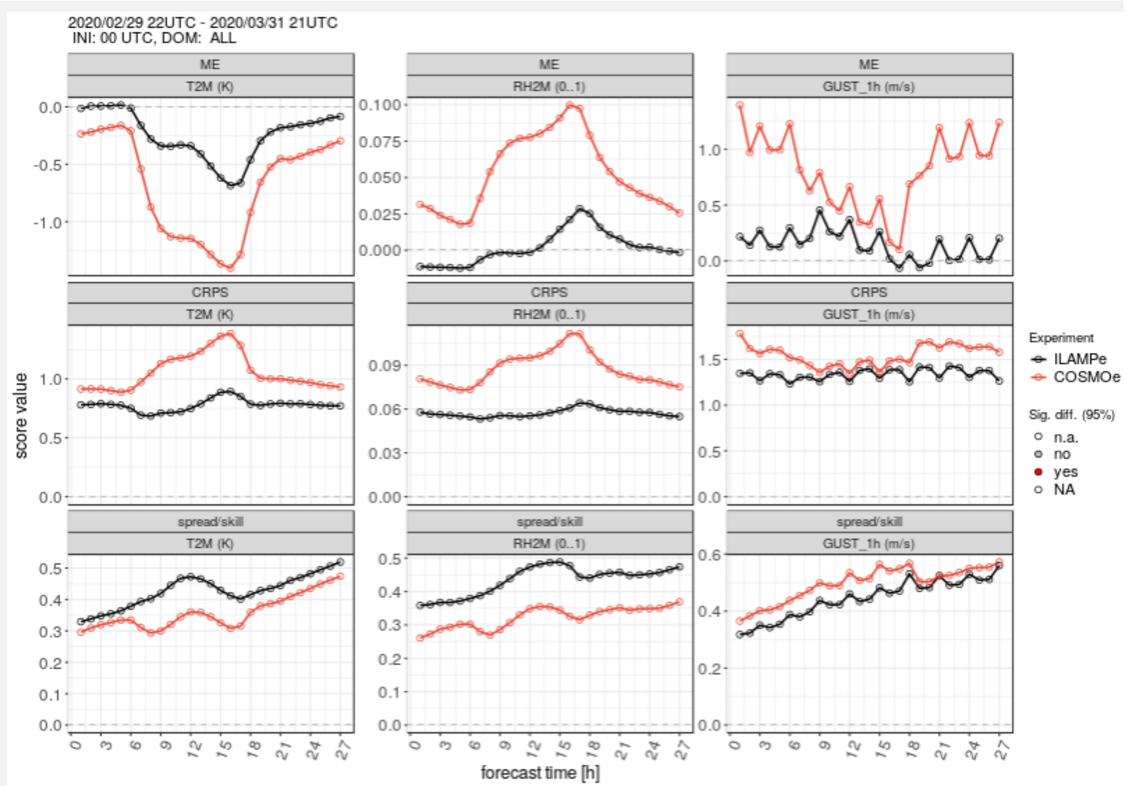
Operational regional (weather) EPS

Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
NRL/FNMOC (US)	36/12/4km	120h	10+1	Perturbed synoptic scales Perturbed Rankine Vortex	Perturbed drag coefficients	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
CMC (Canada)	15kmL84	72h	20+1	Interpolated from global EPS	Stochastic pert. of physics, Stoch. Parameter Pert.	Global EPS	GEM
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

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

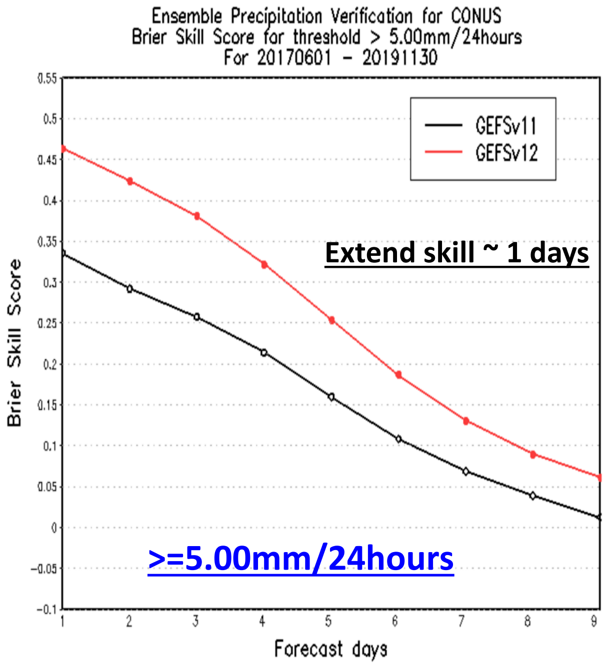
Center Highlights: New Models

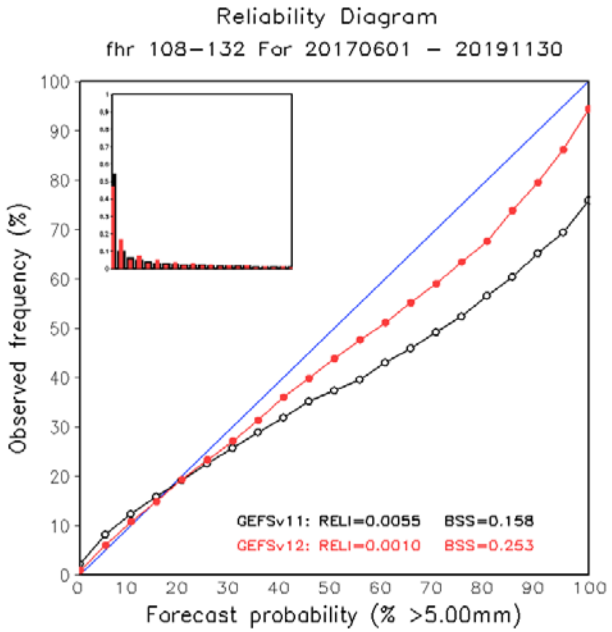
DWD: ICON-D2-EPS vs. COSMO-D2-EPS, March 2020



- Reduction of CRPS exceeds 20% in most months for 2m-temperature, 2m-humidity and 10m-gusts,
- Large improvements are also obtained for surface pressure, 10m winds, cloud cover and radiation
- Moderate improvements for precipitation (for which COSMO-D2 was already well optimized)

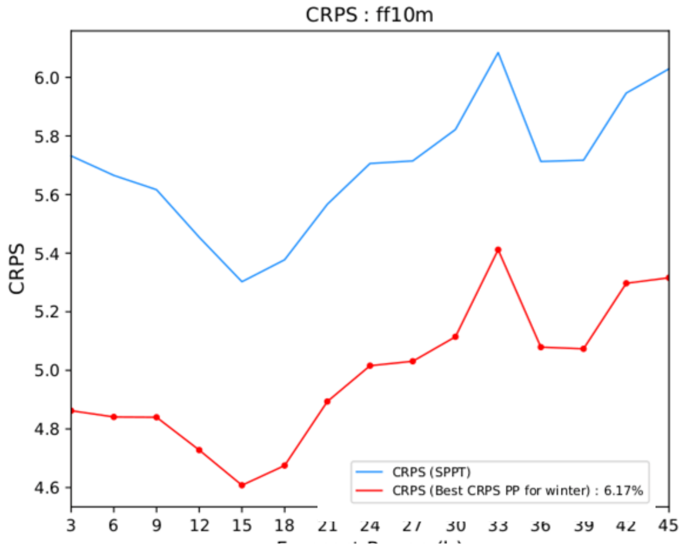
NCEP: GEFSv12 (FV3) vs. GEFS V11 (GFS)

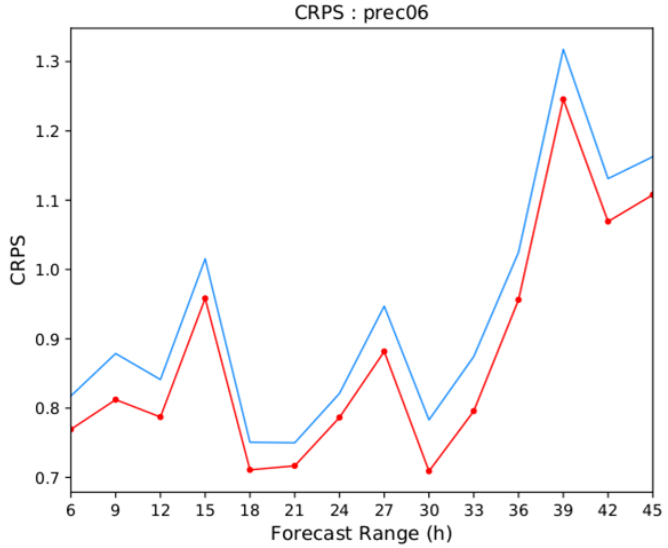




- Higher 500-hPa AC and CRPS scores to extend skillful forecast more than 12 hours.
- Increased ensemble spread for better forecast uncertainty.
- Improved TC tracks, spread, and location of QPF maxima
- Better handling of deepening extratropical cyclones
- Extend PQPF skill by 1 day, more reliable precip forecasts
- Improved representation of weather events near topography

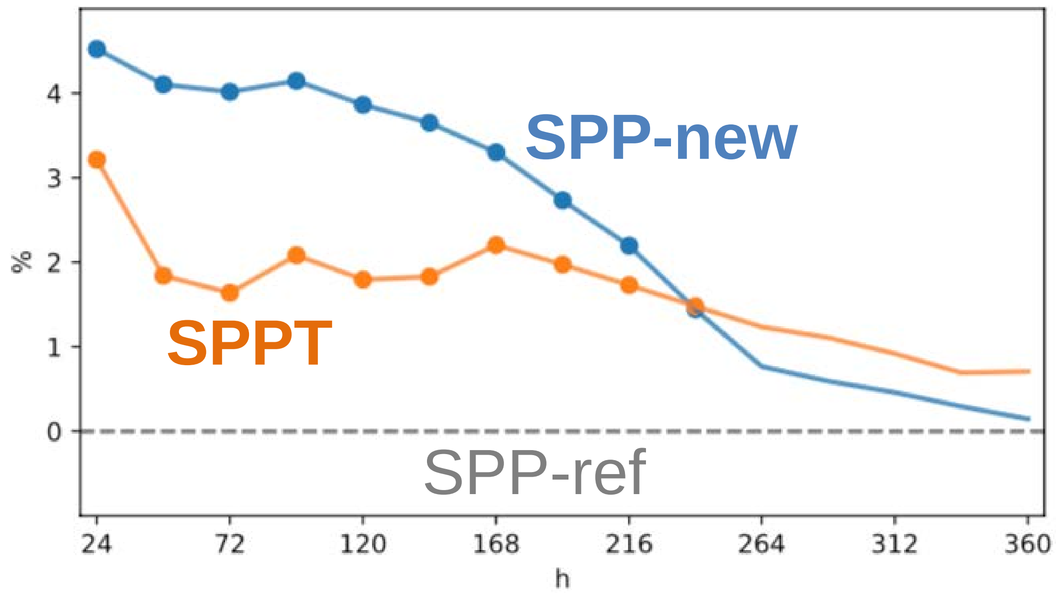
Center Highlights: Model Uncertainty – Parameter Perturbations





Meteo France: Big improvement from perturbed parameters in 10-m winds (top) and 6-h accumulated precipitation (bottom)

Relative Z500 ensemble spread increase wrt SPP-ref in N-Hem extra-tr.



ECMWF: Extended and revised SPP (Stochastically Perturbed Parametrizations):

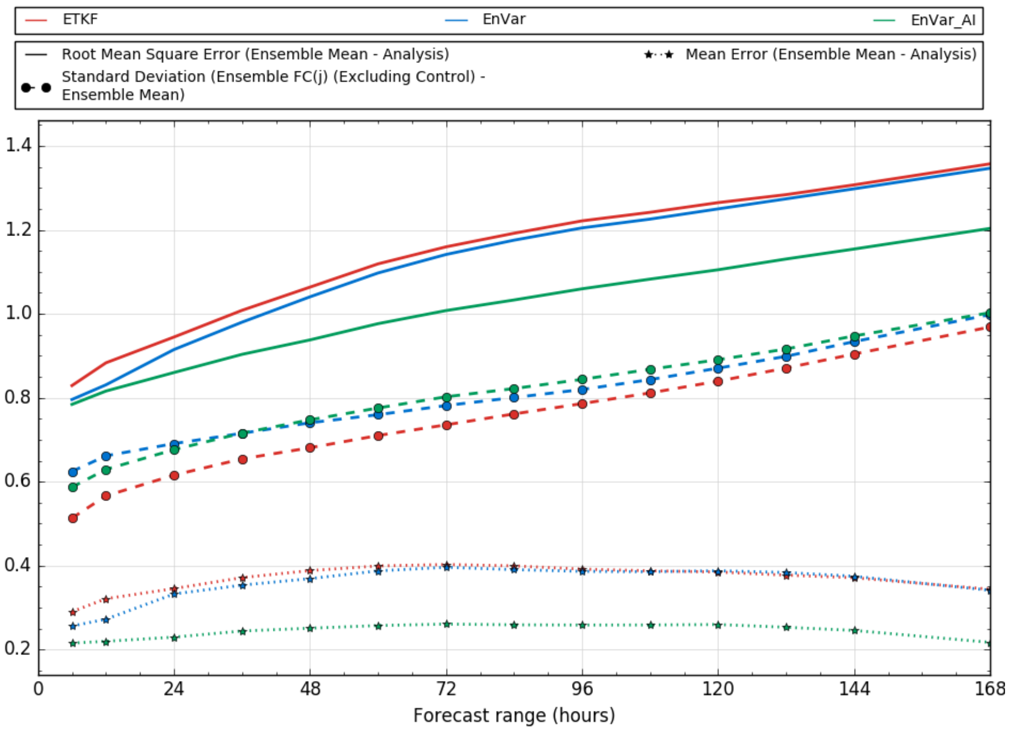
- ensemble skill now similar to SPPT
- candidate to replace SPPT in about 2023
- advantages: uncertainties are represented closer to sources of errors, local conservation better than in SPPT

STOCHDP (Stochastic Departure Points): Represents dynamical core uncertainties, likely to be of increased importance in the convection-permitting regime

Center Highlights: Model Uncertainty - Additive Inflation

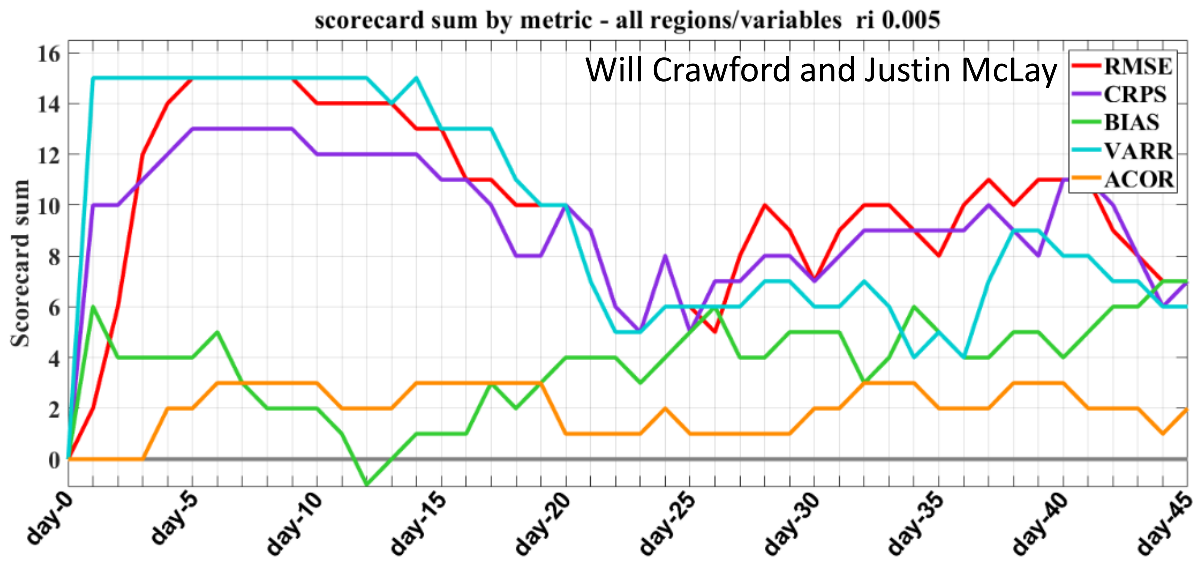
RMSE, spread, bias – T850 (tropics)

- *AI improves bias and RMSE*



Met Office: En-4dEnVar and Additive Inflation improves spread, bias and error in global ensemble.

Global score-card improvement for different metrics for ACAI in global coupled system



NRL: US Navy Global Coupled System ensemble forecasts

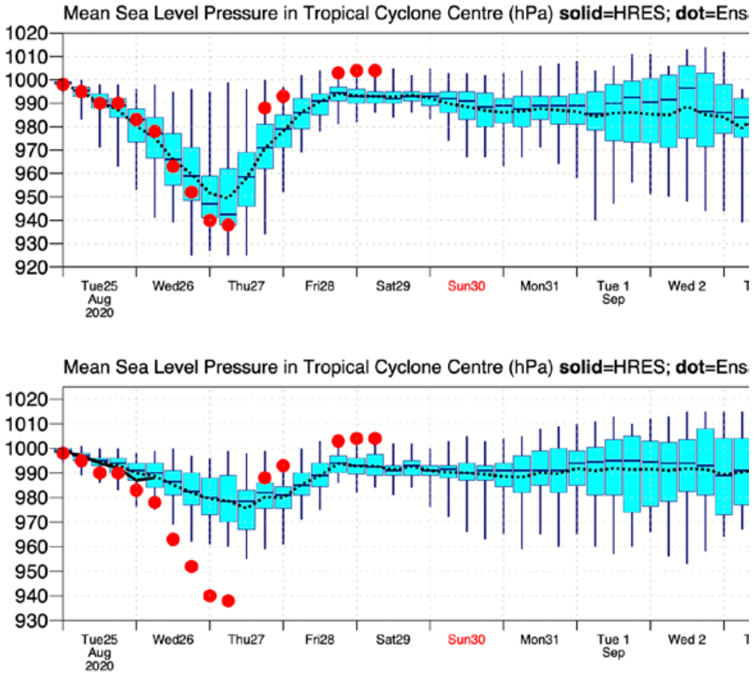
- Implemented Analysis Correction based Additive Inflation (ACAI) in atmospheric component.
- Substantial improvements over control coupled forecasts without model uncertainty over a wide range of metrics

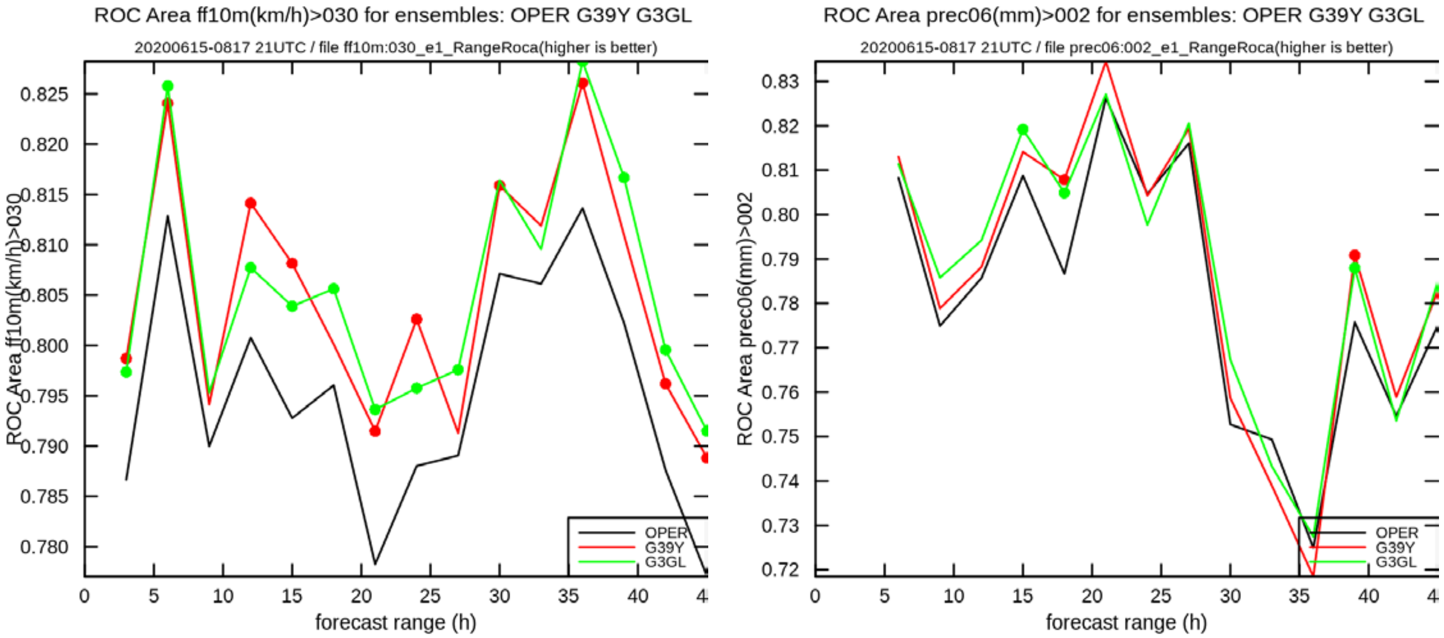
Center Highlights: Increased Resolution

TC Laura ensemble resolution tests

- Red dot: observed core pressure
- Solid black line: Oper High Res
- Box Plot: Ensemble distribution

From Arome-EPS 2.5 km to Arome-EPS 1.3 km



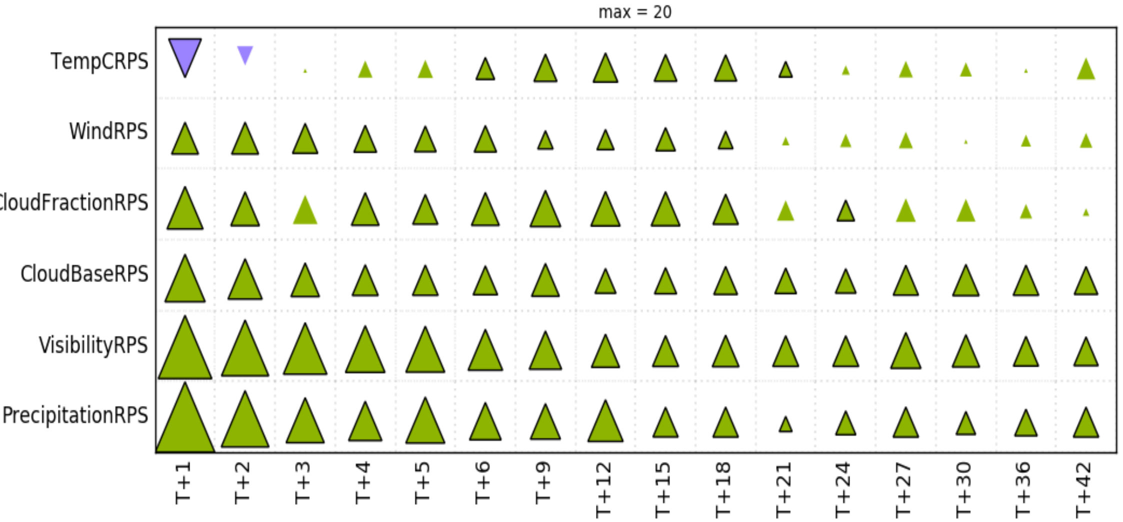


ECMWF: TCo1279L137(top) provides much improved intensity forecasts over current ensemble (bottom) as well as better landfall location forecasts for TC Laura

Meteo France: Two versions of Arome-EPS at 1.3 km resolution (in red and green) show improvement over the operational 2.5 km resolution ensemble (black) for area under the ROC curve for 10-m wind speed (left) and early 6-h accumulated precipitation (right)

Center Highlights: High-resolution Lagged Forecasts (Met Office) and Soil Perturbations (Russian Hydrometcentre)

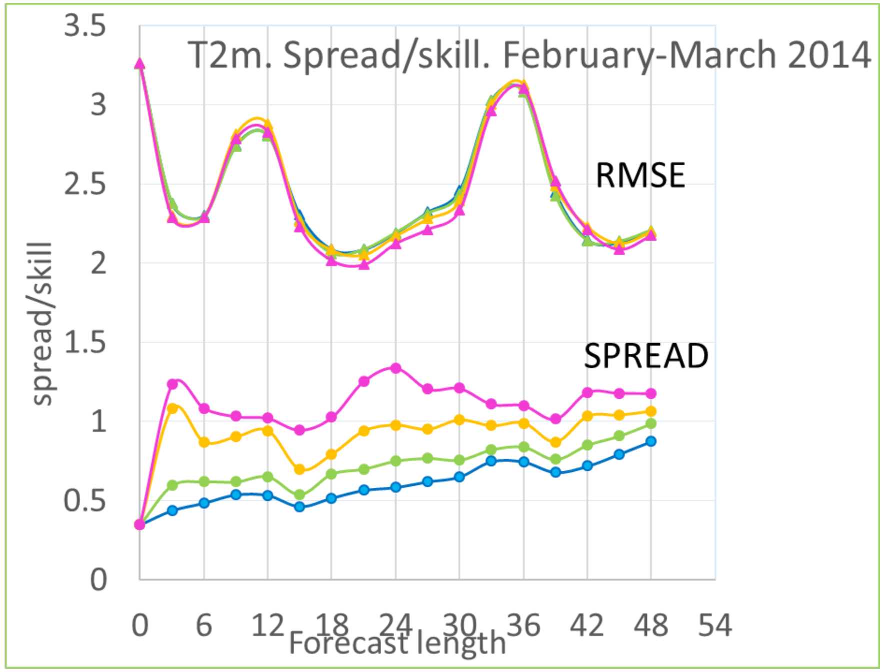
Ensemble scorecard: Summary of objective verification



Met Office: Hourly cycling in MOGREPS-UK provides improvements for almost all scorecard metrics. Case studies show better spatial structure of precipitation at short lead times and better probability products with more spread.

Testing AMPT Soil Perturbations in COSMO-Ru2-EPS

2.2km, 50 levels, 10-members over Soci region



No model perturbations AMPT only in the atmosphere
SPPT AMPT in the atmosphere and in the soil

Russian Hydrometcentre: Additive Model-error perturbations scaled by Physical Tendencies (AMPT):

- Applying AMPT to soil perturbation and soil moisture.
- With soil AMT pertubations, RMSE decreases and spread increases

Extra slides
Complete Center Contributions

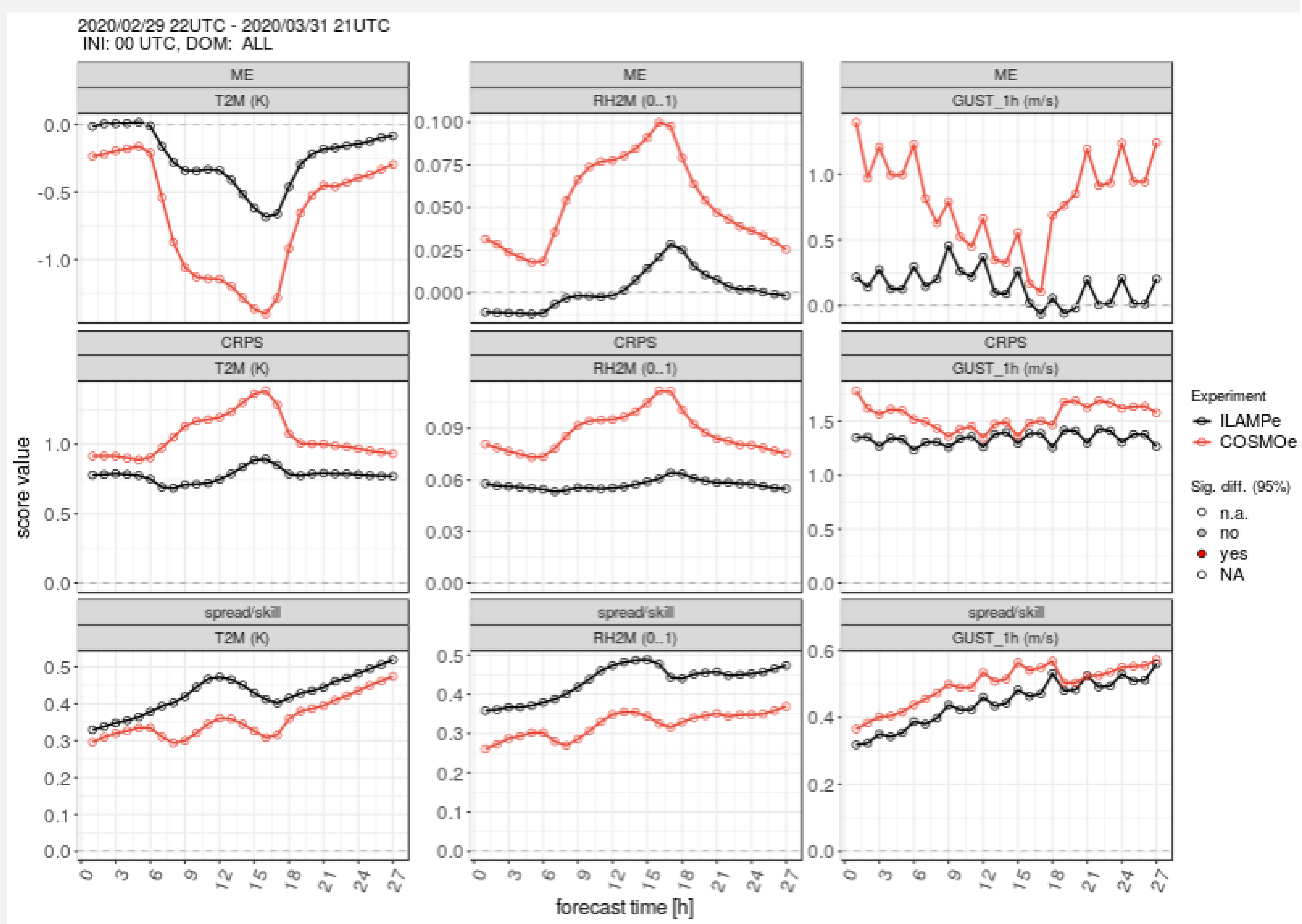
Extra slides
Complete Center Contributions

Slides from DWD

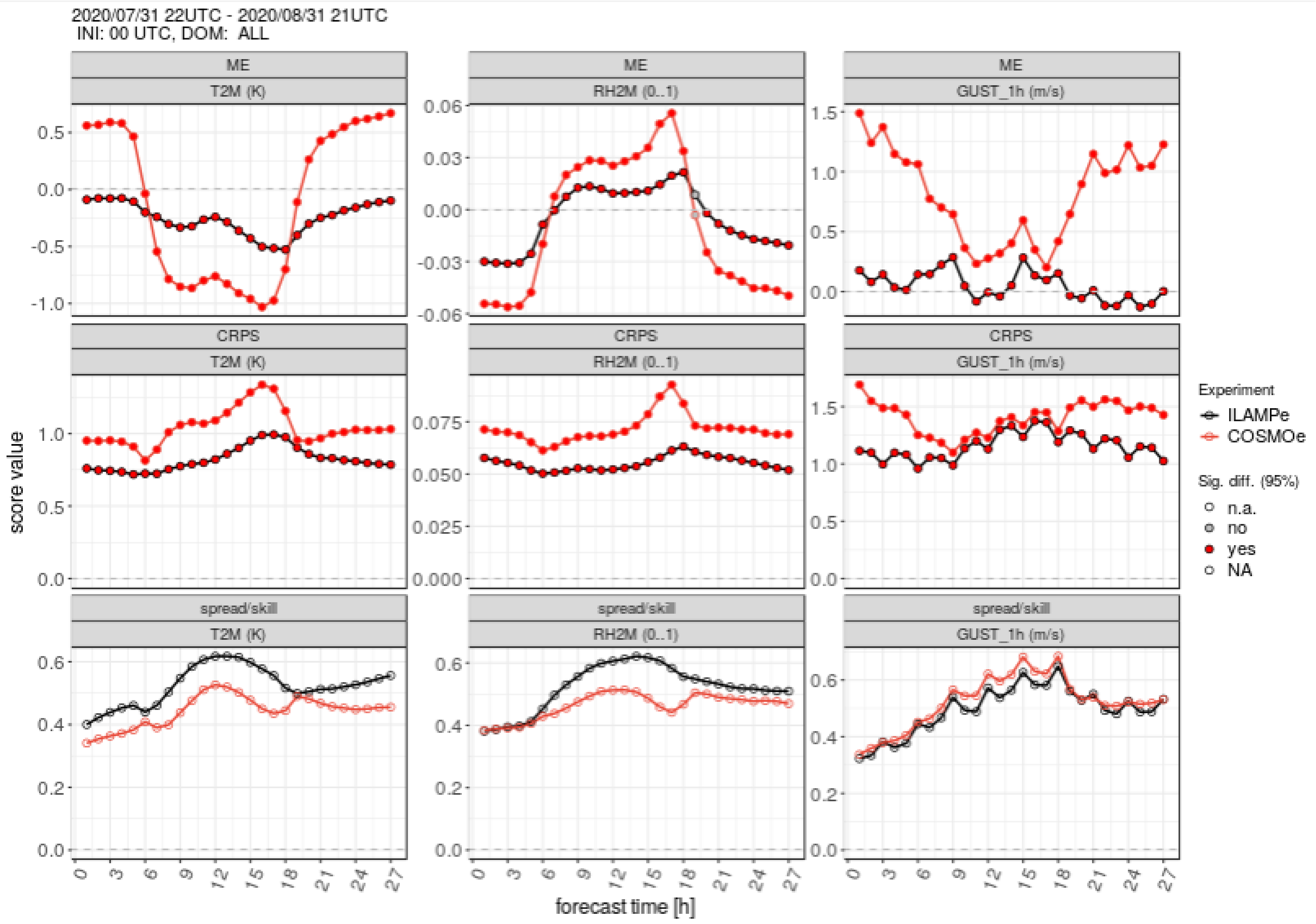
EPS updates at DWD

- ➔ Most important upcoming change: replacement of COSMO-D2(-EPS) by ICON-D2(-EPS)
- ➔ Minor resolution upgrade from 2.2 km to 2.1 km, but huge improvement in forecast quality (primarily) due to improvements in physics parameterizations and coupling with data assimilation (e.g. using the soil moisture analysis performed for the global system)
- ➔ Reduction of CRPS exceeds 20% in most months for 2m-temperature, 2m-humidity and 10m-gusts, large improvements are also obtained for surface pressure, 10m winds, cloud cover and radiation, and moderate improvements for precipitation (for which COSMO-D2 was already well optimized)
- ➔ Examples are shown on the subsequent slides

ICON-D2-EPS vs. COSMO-D2-EPS, March 2020



ICON-D2-EPS vs. COSMO-D2-EPS, August 2020



Global EPS: Ongoing work and plans

- Ongoing: recentering of mean of EPS analyses to deterministic analysis. This will improve the quality of the EPS analyses because the ensemble-variational deterministic assimilation is better able to correct model biases than the pure LETKF used for the EPS

- Plan for 2021/2022: Resolution upgrade from 40 to 26 km (and 20 to 13 km in the two-way nested domain over Europe); increase of ensemble size in the assimilation cycle
- Cost-benefit ratio still needs to be evaluated

- Further algorithmic work: see next slide

Approximation of Singular Vector Perturbations with the ICON model avoiding linear and adjoint model integrations

Winkler et al., 2019: Krylov methods for adjoint-free singular vector based perturbations in dynamical systems, *Q J R Meteorol Soc*. 2020;146:225–239.DOI: 10.1002/qj.3668

Prediction step

↓

Gram-Schmidt orthogonalisation

↓

Construction of subspace model

extend Krylov space (=> $K^{j+1}(\mathbf{A},\mathbf{q})$)

↓

final Perturbations **P**

$\mathbf{q}_{j=1}$ chose initial perturbation vector (=> $K^1(\mathbf{A},\mathbf{q})$)

for $j = 1 : m$ **do**

Lanczos

$\mathbf{w} \leftarrow \mathbf{L}^T \mathbf{L}\, \mathbf{q}_j$

$\alpha_j \leftarrow \mathbf{w}$

$\mathbf{w} \leftarrow \mathbf{w} - \mathbf{q}_j\, \alpha_j - \mathbf{q}_{j-1}\, \beta_{j-1}$

$\beta_j = |\mathbf{w}|$

$\mathbf{q}_{j+1} =$

$\sim O(m \times n)$

(new!) **Arnoldi**

$\mathbf{w} \leftarrow F(\mathbf{x} + \mathbf{q}_j(0)) - F(\mathbf{x})$

for $i = 1 : j$ do

$h_{i,j} \leftarrow \mathbf{w}$

$\mathbf{w} \leftarrow \mathbf{w} - \mathbf{q}_i\, h_{i,j}$

end for

$h_{j+1,j} = |\mathbf{w}|$

$\mathbf{q}_{j+1} =$

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

end for loop

$[\lambda, \mathbf{V}] = \mathrm{eig}(\mathbf{D})$ →

$\mathbf{P} = \mathbf{Q}_{n,m}\, \mathbf{V}_{m,m}$

← $[U; S; \mathbf{V}] \leftarrow \mathrm{svd}(\mathbf{H}_{m,m})$

NCEP Ensemble Systems

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September 2020

NCEP GEFS Status

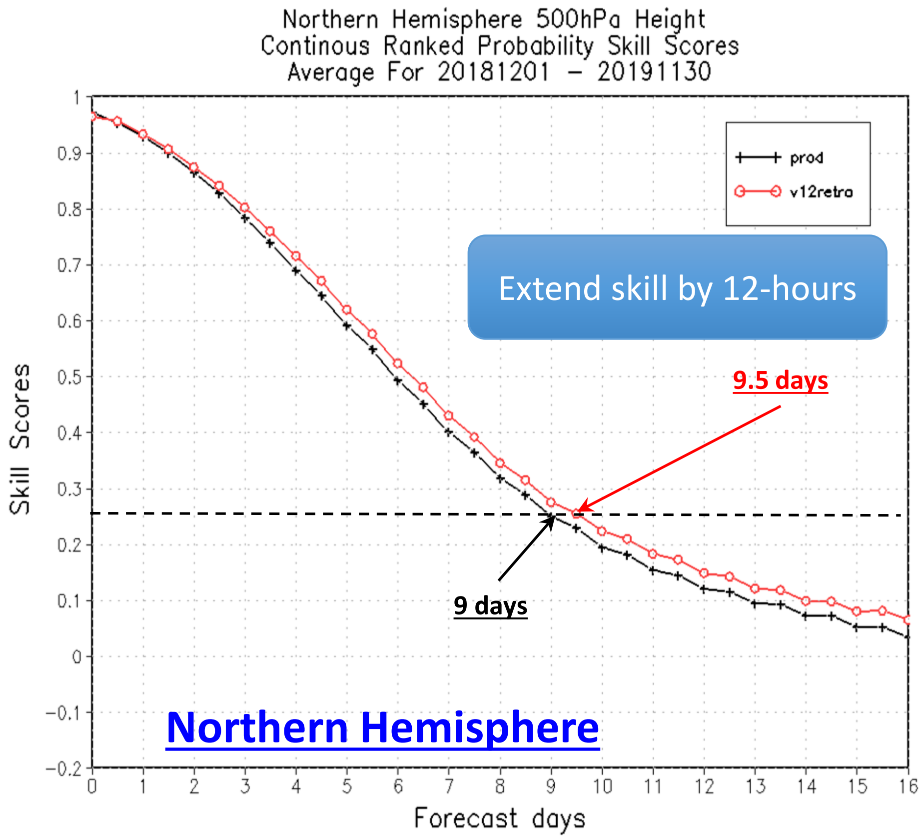
	V12 (current)	V13 (future)
GFS Model	FV3 (GFSv15)	FV3 (GFSv17)
Horizontal Resolution	C384 (25km)	C384 (25km)
Vertical resolution	L64 (hybrid)	L127 (hybrid)
Daily frequency	00, 06, 12 and 18UTC	00, 06, 12 and 18UTC
Forecast length	16days (35days for 00UTC)	16days (35 days for 00UTC)
Members	Control + 30 pert members	Control + 30 pert members
Computational Cost	460 nodes (in peak)	N/A
Execution time	~ 3 hours (16-d forecast)	~ 3 hours (16-d forecast)
Output resolution	0.25^{o} (selected) and 0.5^{o}	0.25^{o} (selected) and 0.5^{o}
Output frequency	3h first 10 days; 6h rest	3h first 10 days; 6h rest
Initial perturbations	EnKF f06	EnKF anl
Model uncertainty	SPPT and SKEB	SPPT, SKEB and others
Coupling	Wave Watch included in all 31 members	Wave Watch; Ocean (MOM6); Sea-ice (CICE6)
Reforecast	Offline – 31 years	Yes
Implementation	September 23rd 2020	2024

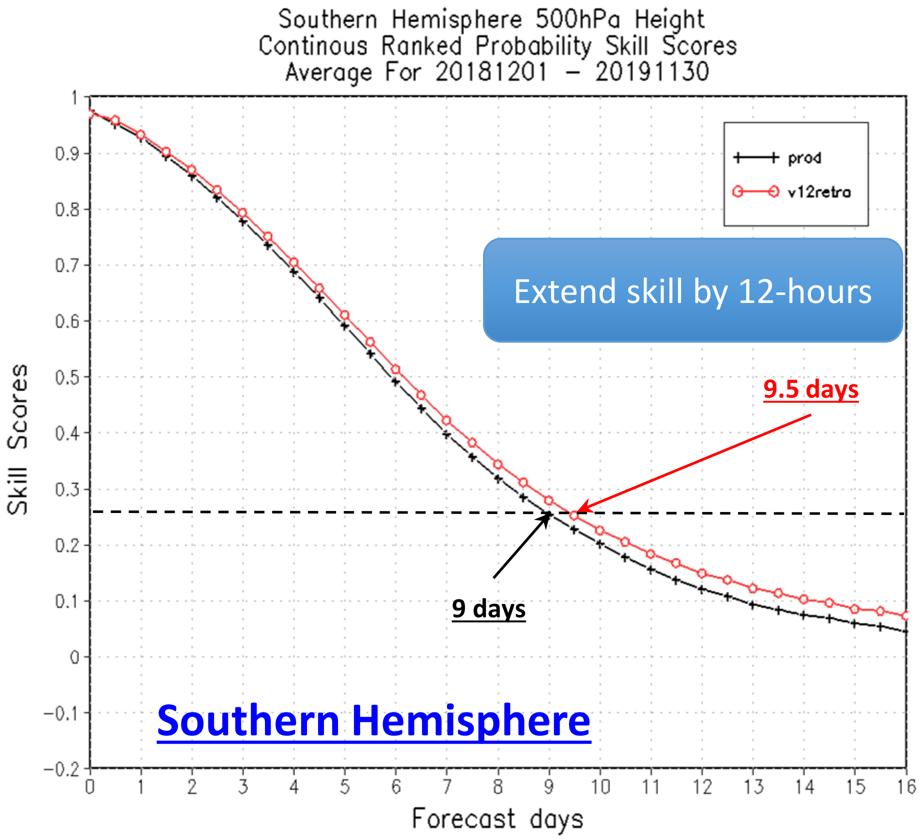
Benefits from GEFSv12 implementation (9/23/2020)

- GEFSv12 is much improved from GEFSv11:
  - Higher 500-hPa AC and CRPS scores to extend skillful forecast more than 12 hours.
  - Increased ensemble spread to better present forecast uncertainty.
  - Improved TC tracks, spread, and location of QPF maxima
  - Better handling of deepening extratropical cyclones
  - Extend about 1 day PQPF skill and more reliable precipitation forecasts
  - Improved representation of weather events near topography

- GEFSv12 is improved from SubX (GEFSv11+) and CFS of subseasonal forecast
  - GEFSv12 has demonstrated an extension of MJO skill by 2-3 days compared to GEFS SubX version.
  - GEFSv12 shows much better scores than GEFS SubX version and CFSv2 for 500hPa height PAC scores of NH and PNA.
  - GEFSv12 demonstrates excellent performance for stratosphere, mainly QBO and Sudden Warming's polar winds

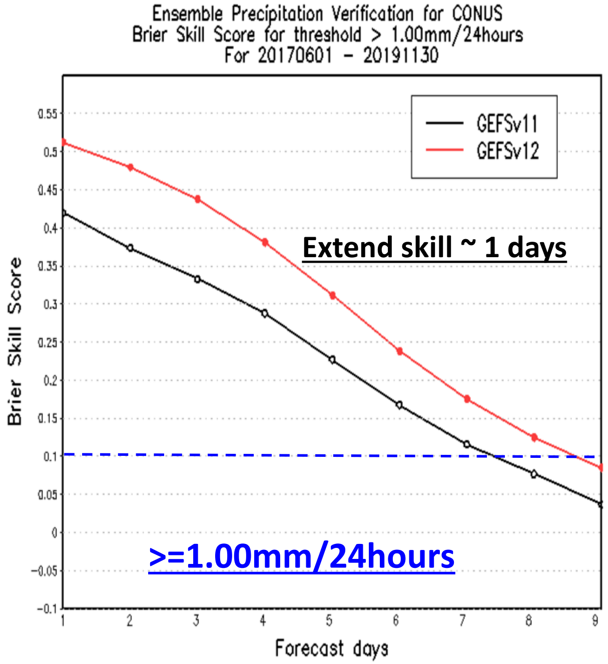
CRPS Skill of 500hPa geopotential height

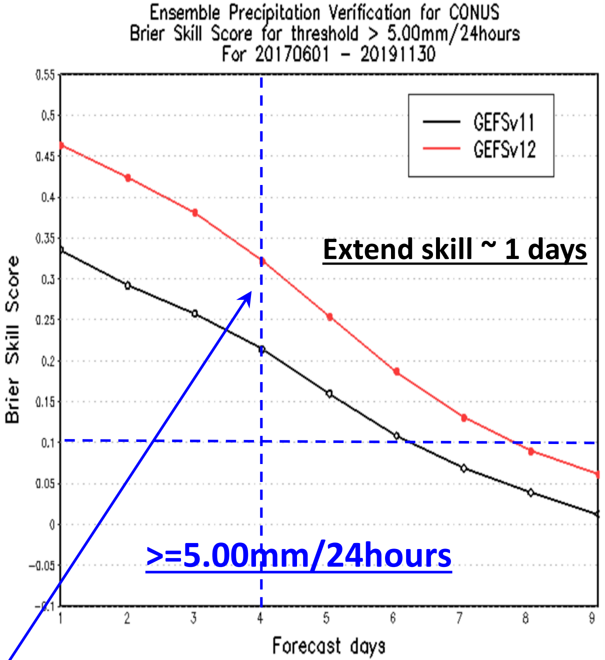


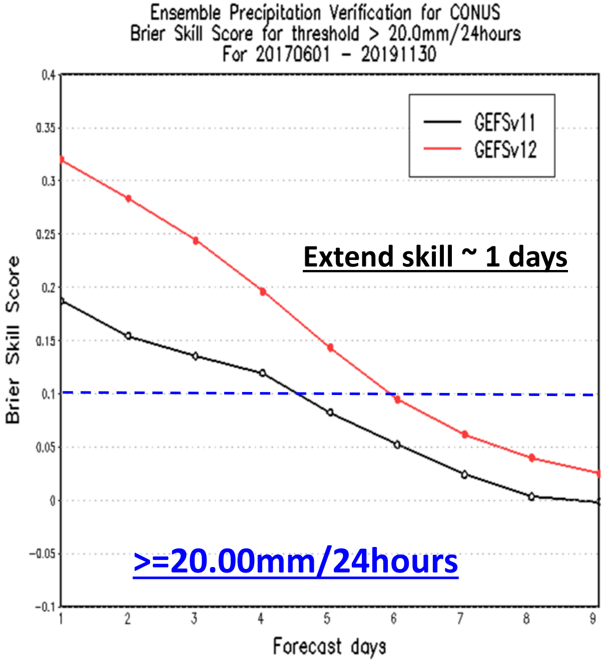


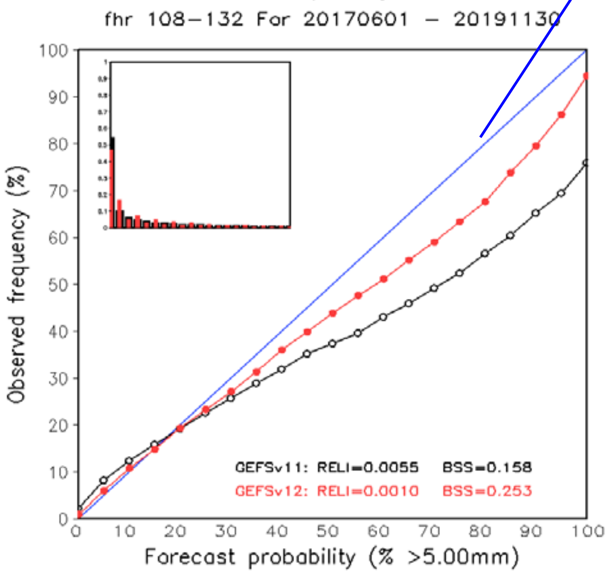
CRPSS – *Continuous Ranked Probabilistic Skill Score is one of evaluation tools to measure ensemble based probabilistic forecast. CRPSS=1 is for perfect forecast, CRPSS=0 is for no skill from reference (climatology), CRPSS=0.25 is similar to PAC=0.6 (pattern anomaly correlation of ensemble mean).* ***GEFS v12 has better CRPSS for both hemispheres of 500hPa heights***.

Brier Skill Scores of the CONUS PQPF









Brier Skill Score: *BSS=1 is for perfect forecast, BSS=0 is for no skill from reference climatology.*

Statistically, GEFSv12 has extended one additional day of useful probabilistic forecast skill over GEFSv11.

The forecast is more reliable (left plot) than GEFSv11.

GEFS (v13) Plan

- Unified Forecast System:
  - Full coupling system – atmo-land-ocean-ice-wave-aero
  - The same model for DA, GFS and GEFS
- Atmospheric model
  - GFS v17 with advanced physics
- Ensemble configuration
  - Initial perturbations – EnKF analysis from early cycle run
  - ~25km and 127 vertical levels for atmospheric model and 31 members.
  - ~25km horizontal resolution for ocean and sea-ice model
  - Forecast lead – 45 days to cover CPC monthly forecast (?)
  - Physical perturbations – process based perturbed parameterization (?)
- Support package
  - Reanalysis and reforecast
- Target implementation time
  - 2024

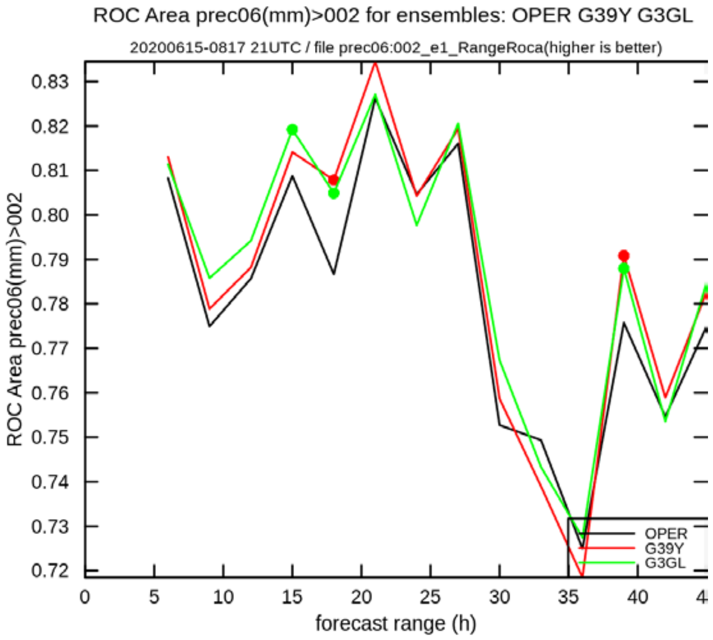
Short-Range Ensemble Forecast (SREF) System (no upgrade – frozen)

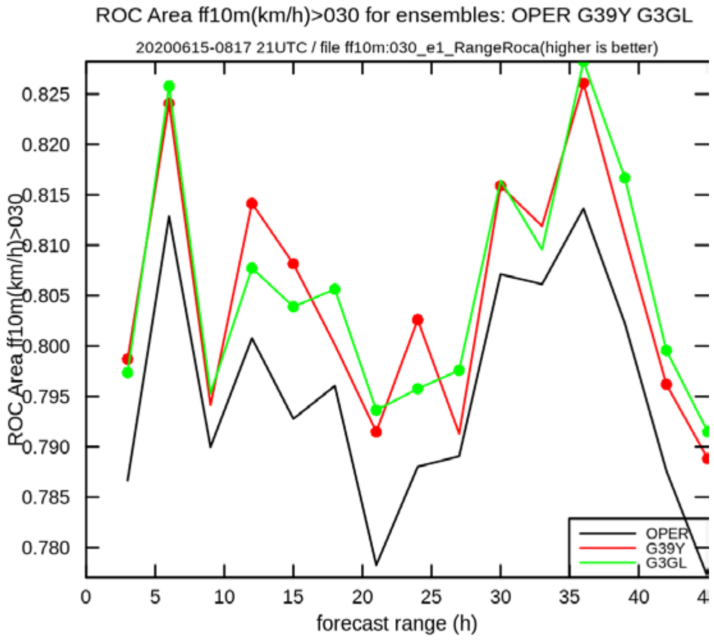
- Two model systems
  - NMMB, WRF_ARW
- Resolutions
  - Horizontal – 16 km
  - Vertical - 41 levels (model top?)
- Ensemble membership
  - NMMB – 1 control, 12 perturbed forecast
  - WRF_ARW – 1 control, 12 perturbed forecasts
- Enhanced IC diversity:
  - Mix use of multi analyses (NDAS, GFS and RAP) for each model core
  - Blending of GEFS and SREF IC perturbations for all members
- Enhanced physics diversity:
  - More variety of physics schemes
  - Stochastic flavor in physics parameters (GWD and soil moisture)
- Implement – Oct. 21 2015
- Current status
  - **System has been frozen, has no further development**

Slides from Meteo France

From Arome-EPS 2.5km to Arome-EPS 1.3km

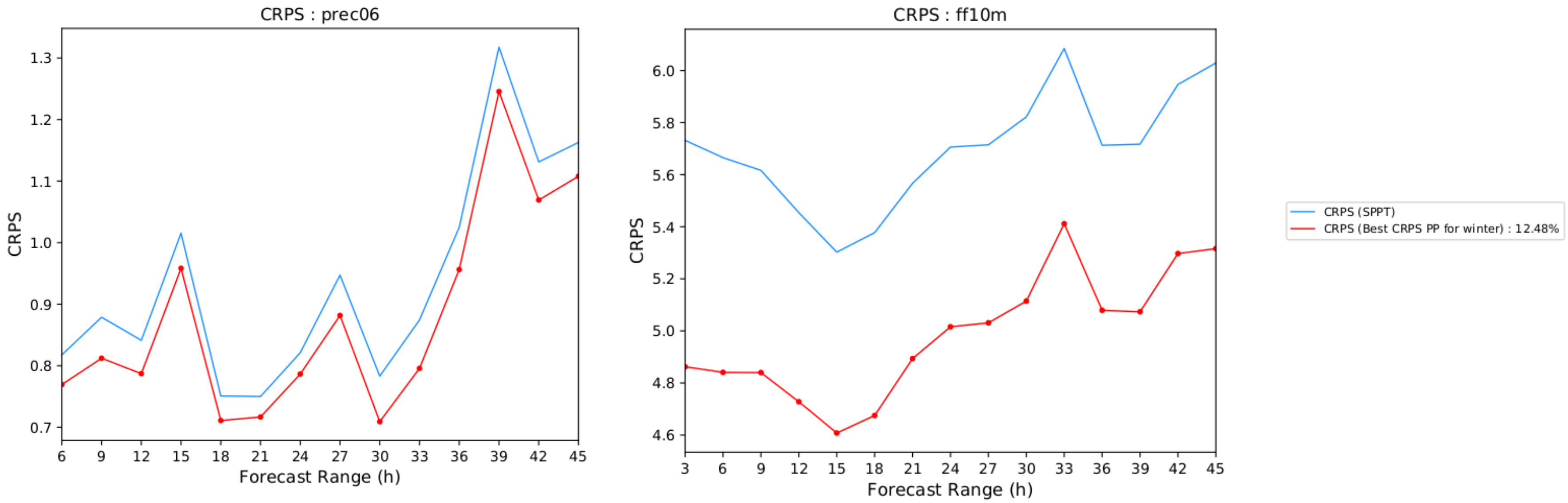
Area under the ROC curve - 2 months summer period :
- 6h-accumulated precipitation (left), 10-meter wind speed (right)
- Operational 2.5km (black) vs 1.3km (two versions, red and green)





Model error representation with perturbed parameters

- 21 parameters from different physics schemes are perturbed
- Each member uses a different combination of parameter values (which remain constant during the model integration)



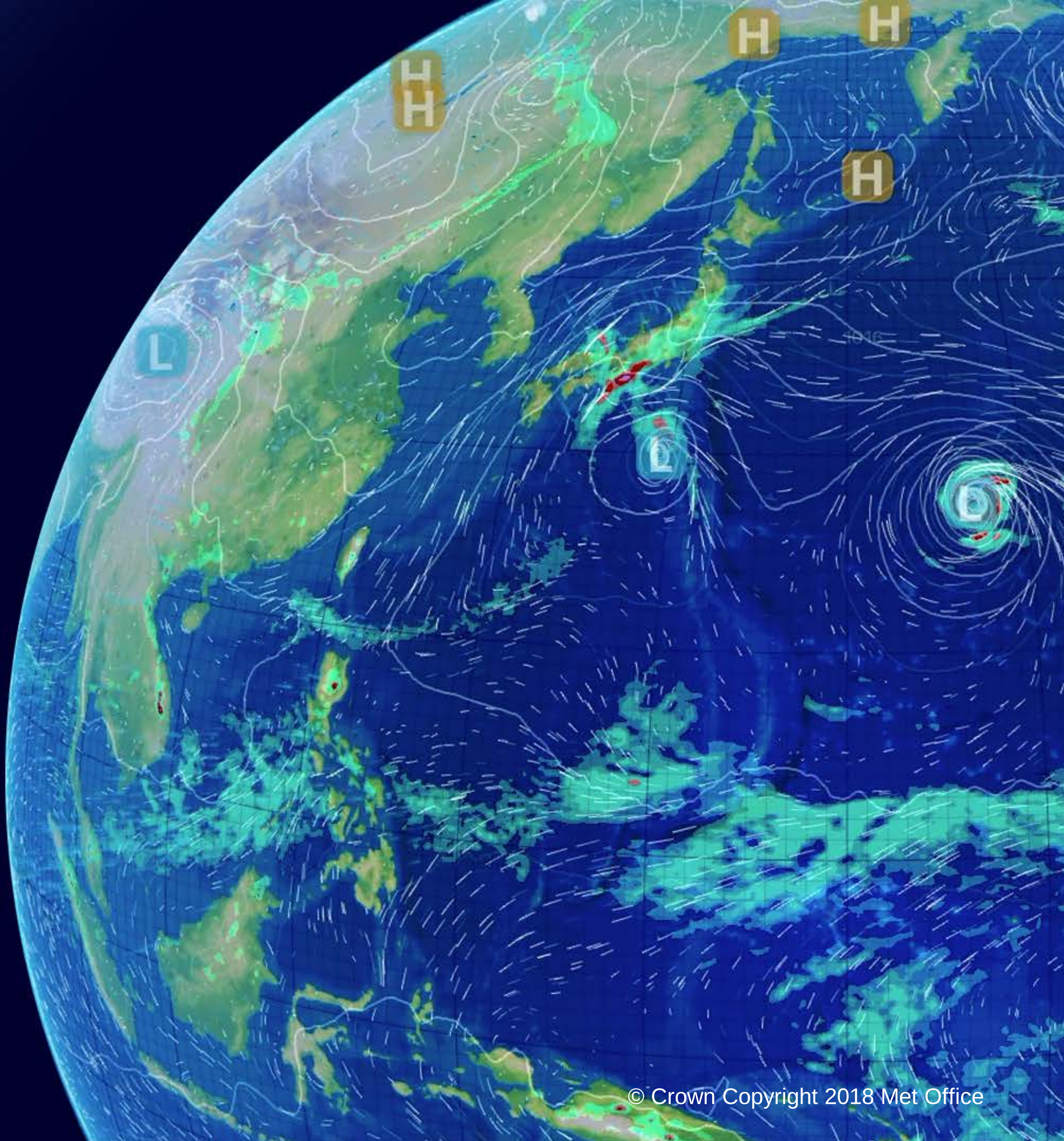
Slides from the Met Office

Met Office

MOGREPS: Met Office Global and Regional EPS

Warren Tennant, Aurore Porson, Anne McCabe, Jamie Kettleborough, Doug Smith

Update to WGNE

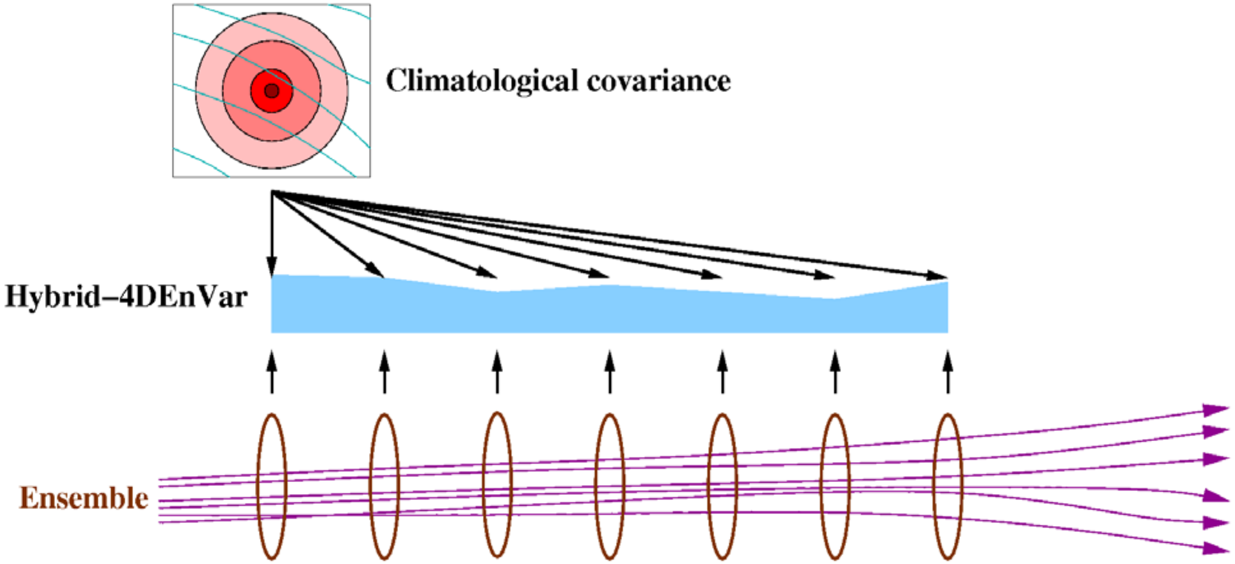


Met Office

Recent Global EPS update

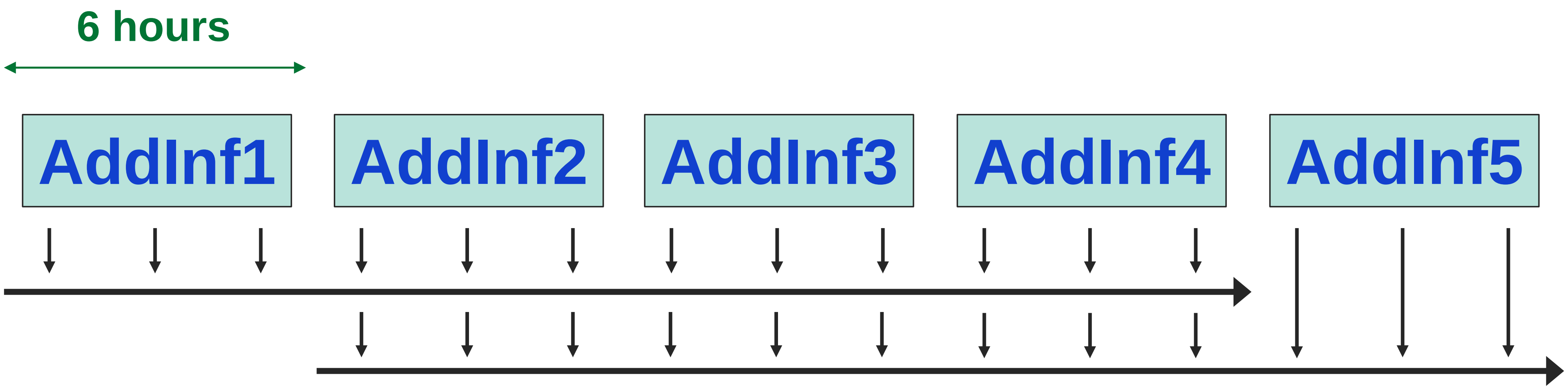
Ensemble upgrade (operational: Sep 2019)

Replace ETKF → (Hybrid-)En-4DEnVar



- 4DEnVar does not need a linear PF model because it uses ensemble information throughout assimilation window (still used in hybrid-4DVar deterministic model though).
- Still uses climatological background error covariances (hybrid scheme).
- The 4DEnVar executable can also do an ensemble of analyses: **En-4DEnVar**:
  - (For each member, create increments relative to its own background trajectory)
- Routines available to deal with inflation, perturbed observations, etc.

Additive inflation (operational: Sep 2019)



Create a year-long archive of data assimilation increments, then at each time-step during the model forecast add:

1. Randomly selected historical analysis increment (with 50% scaling) per six-hour period, retaining the selection for the same validity time in subsequent forecast cycles
   Adds spread in regions of large model error (as measured by DA scheme)
2. 3-month mean increment (with no scaling)
   Bias corrects forecasts in areas with large seasonal errors (as measured by DA)

En-4dEnVar & Additive inflation

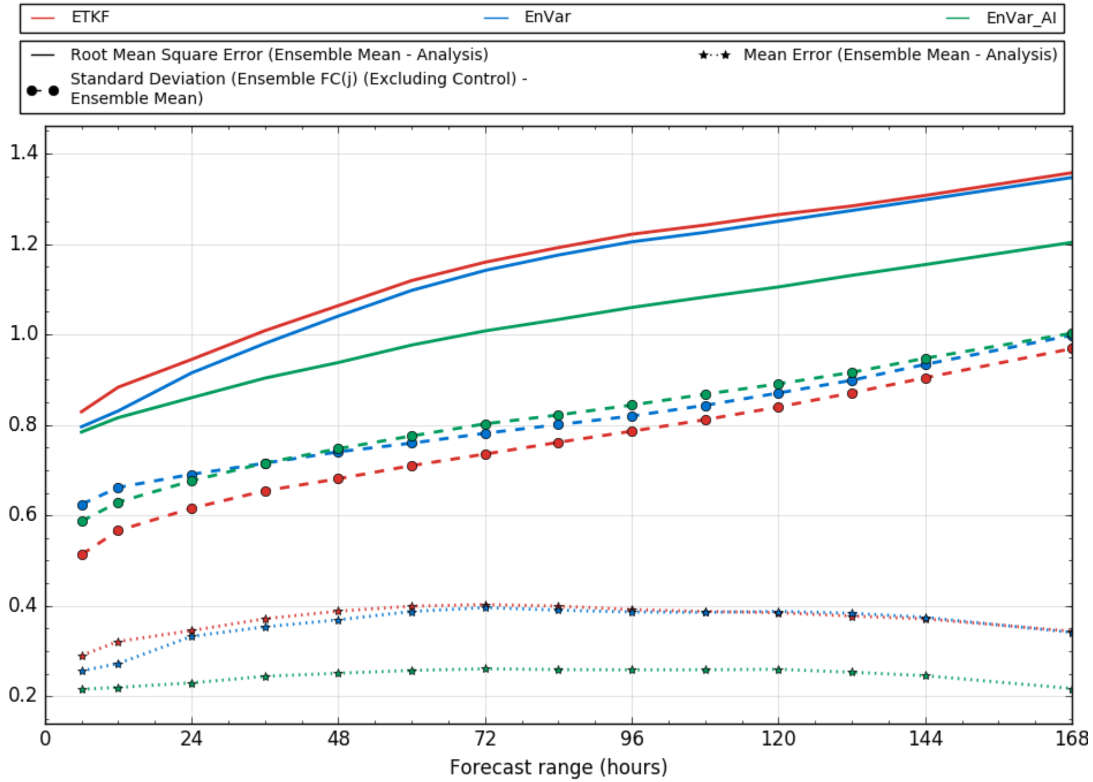
(early low-resolution results)

Improves spread, bias and error

Period: 1 Sep – 15 Oct 2018; Truth = ECMWF Analyses

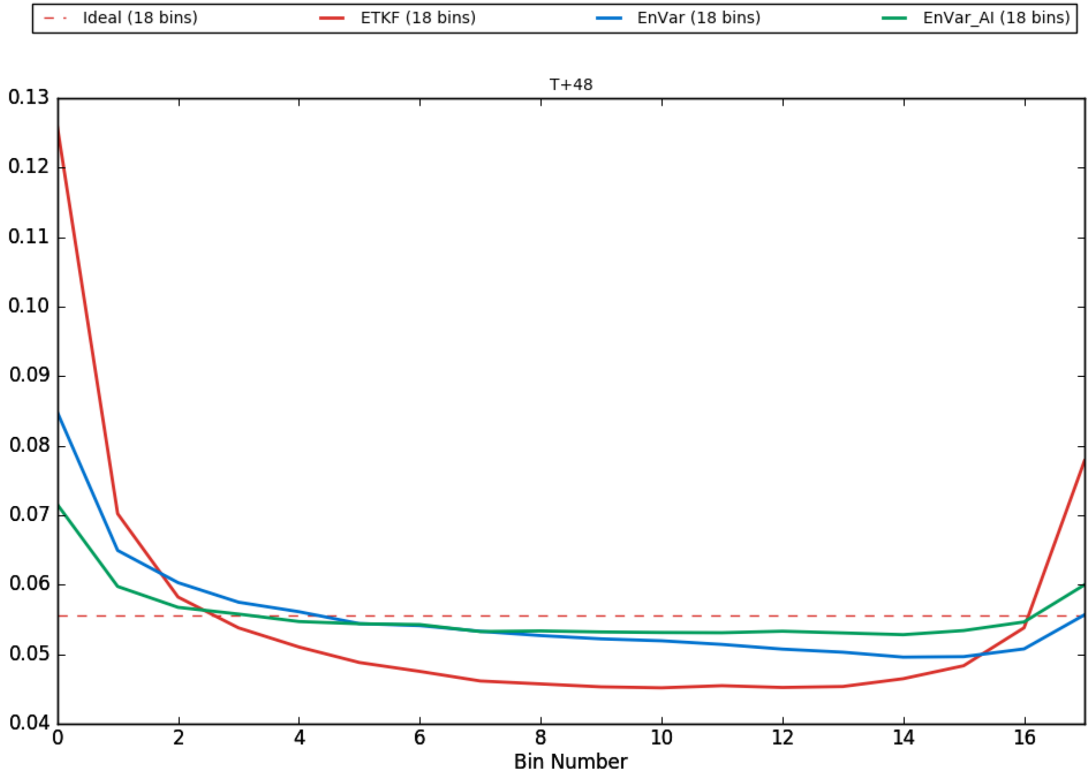
RMSE, spread, bias – T850 (tropics)

- *AI improves bias and RMSE*



Rank histogram (T+48h) – T500 (NH)

- *En-4DEnVar improves under-dispersion and AI improves bias*



Recent UK EPS update

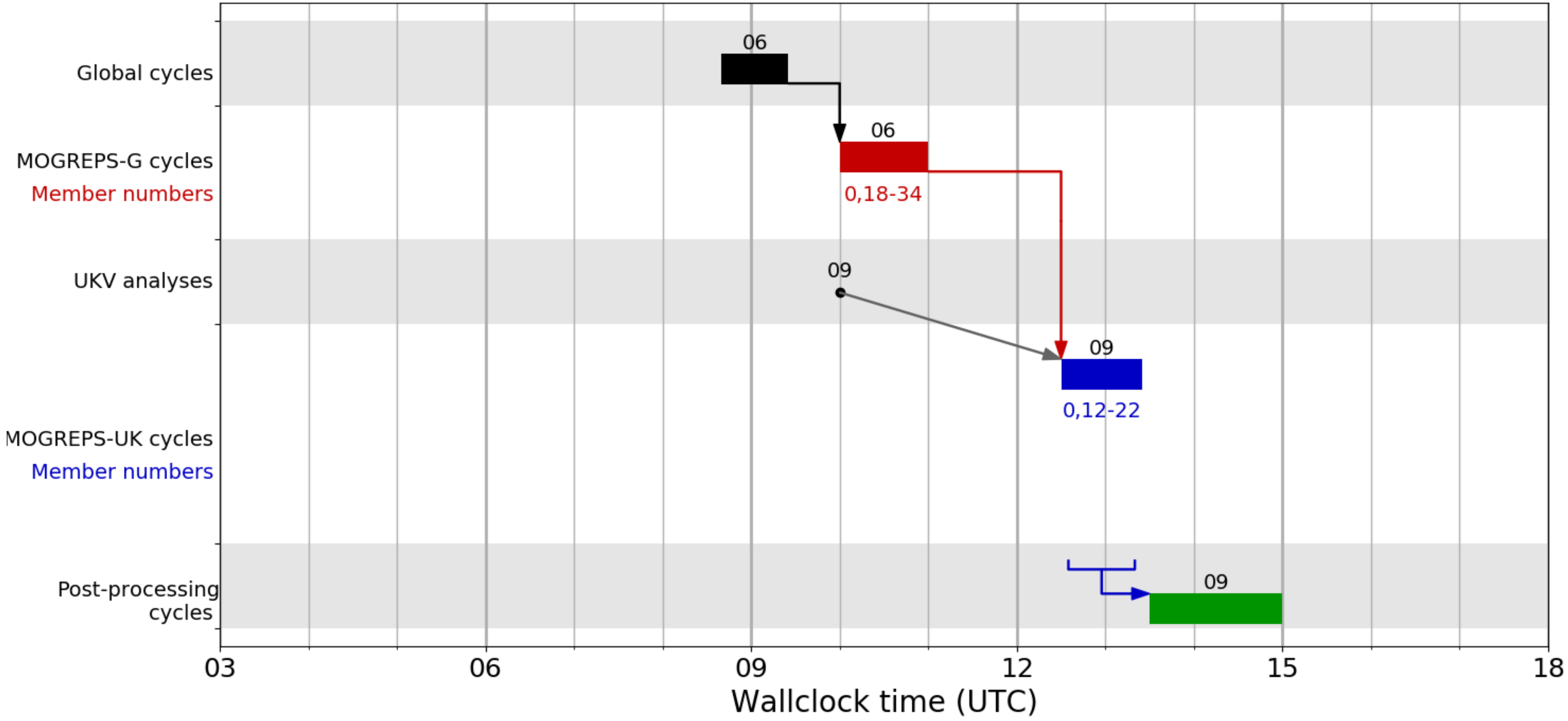
Hourly-cycling (operational: Jan 2019)

Hourly-cycling time-lagged T+120 MOGREPS-UK:

- 3 members per hour (out to T+125)
- Centred on latest UK hourly 4D-Var analysis
- LBCs and initial perturbations from global EPS
- 1 unperturbed control member every 6-hours
- Time-lagged over 6-hours → hourly-updating 18-member EPS

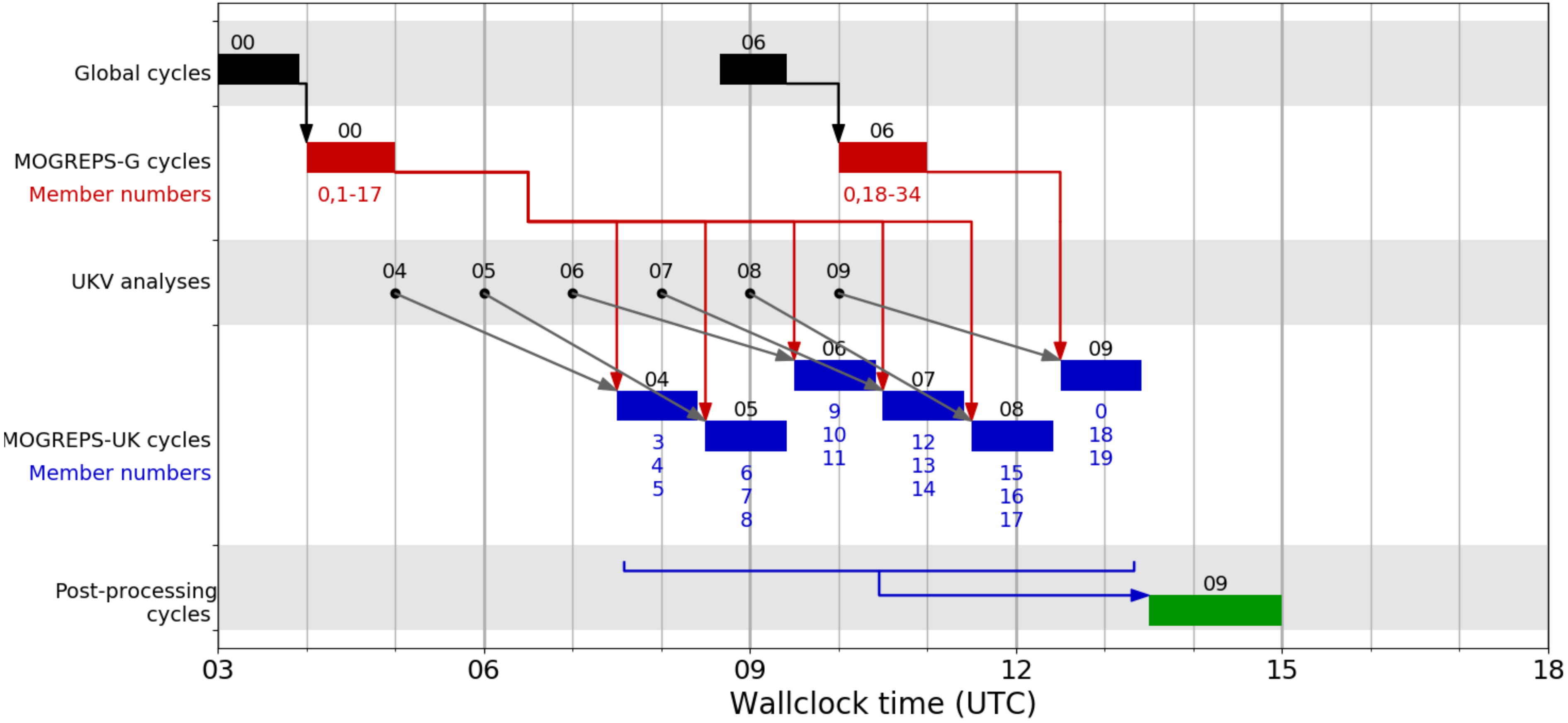
Previous 6-hourly MOGREPS-UK

09Z cycle



New hourly cycling MOGREPS-UK

09Z cycle



Ensemble scorecard: Summary of objective verification

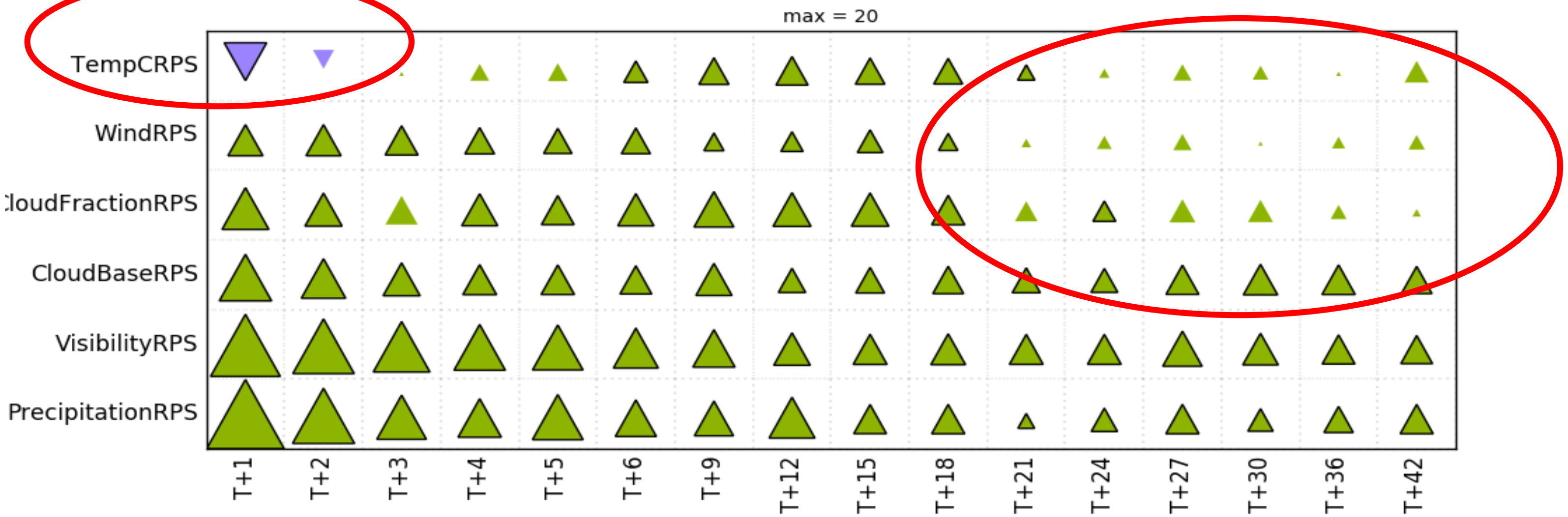
(Aurore Porson, Jo Carr, Susanna Hagelin, Rob Darvell, Rachel North, David Walters, Ken Mylne, Marion Mittermaier, Bruce Macpherson)

Porson et al. 2020, https://doi.org/10.1002/qj.3844

% Difference (MOGREPSH-UK 18-m 3x3 vs. MOGREPS-UK 12-m 3x3)

02 Dec 2017 – 01 Jan 2018

1) Temperature sensitive to differences in the times of the analyses between the 2 configurations.



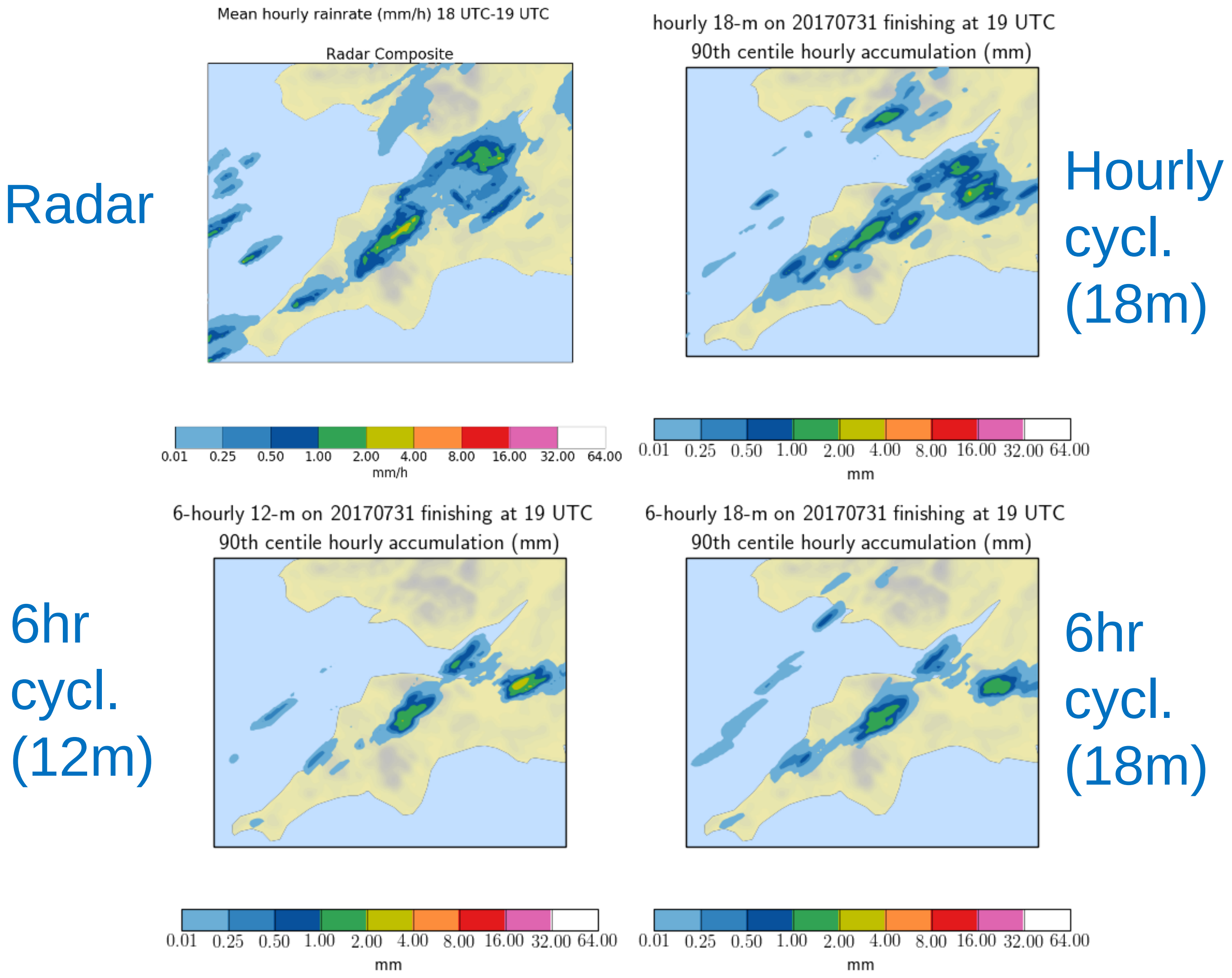
2) Smaller improvements at later forecast times

Application to case studies: Examples at short lead times

T+4 products now available for the hourly configuration

Better spatial structure at short lead times

Better probability products at short lead times with more spread between the members



Met Office

Seasonal and decadal ensemble systems

Seasonal ensemble (GloSea)

- Resolution:
  - Atmosphere: 60km L85
  - Ocean ¼ degree L75
- Hindcasts:
  - 1993 – 2016
  - 4 start dates per month, 7 members per start date, each run to 7 months
- Forecasts:
  - Each day run 2 members to 7 months + 2 members to 2 months
- Initialisation:
  - Nemovar for ocean
  - Met Office NWP analysis for atmosphere

- Routinely upgrade science in-line with Global Atmosphere process to maintain consistency with other Met Office global models.

Decadal ensemble (DePreSys)

- Resolution:
  - Atmosphere: 60km L85
  - Ocean ¼ degree L75
- Hindcasts:
  - 1960 – present day
  - Start date 1st November every 2 years
  - 10 members out to 5 years
- Forecasts:
  - Start 1st November each year
  - 10 members out to 5 years
- Initialisation:
  - Weakly coupled, nudging to Smith and Murphy (2007) ocean T & S; sea ice from HadISST

- Routinely upgrade science in-line with Global Atmosphere process to maintain consistency with other Met Office global models.

Slides from ECMWF

ECMWF ensemble news 2020

Martin Leutbecher, Zied Ben Bouallègue, Thomas Haiden,
Simon Lang, Sarah-Jane Lock and Frederic Vitart

ECMWF

Medium-range ensemble forecasts: Next resolution upgrades

Current medium-range resolution: TCo639L91 (18km), dt=720s

Candidates for medium range ensemble (15 days):

Resolution, timestep	Factor* (Single Precicion ~ x 0.7)
TCo1023L137 (11.3 km), dt=450s	6 (4.2)
TCo1279L137 (9 km), dt=450s	8.9 (6.2)

* Approximate cost increase (without operational output) and relative to TCo639L91 (18 km), dt=720s:

Planned in two stages (pending performance tests on XC40)

- 91 levels (Double Precision) → 137 levels (Single Precision), Cycle 47r2, Cray XC40 in Shinfield Park, Reading, Q2 2021
- TCo639 → TCo1000+, Cycle 48r1, BullSequana XH2000 in Bologna, Q3/Q4 2022

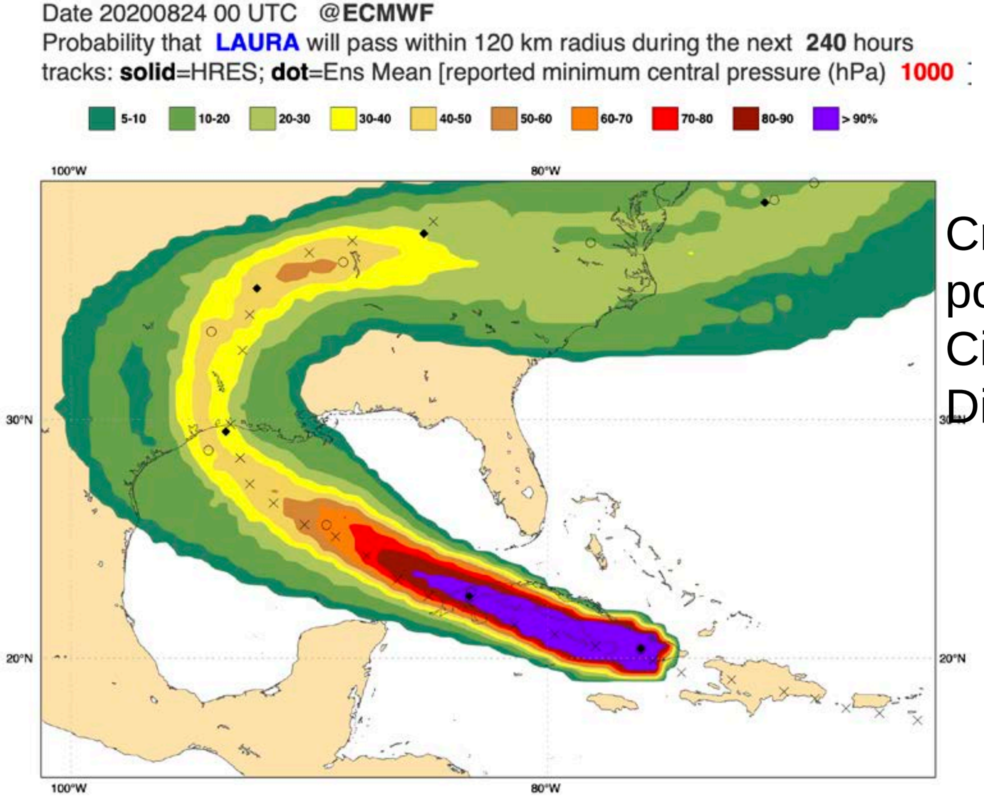
TC Laura 2020, resolution sensitivity
Oper ENS (TCo639L91) versus TCo1279L137 Experiment

Both started from same (oper) initial conditions, 50 perturbed members

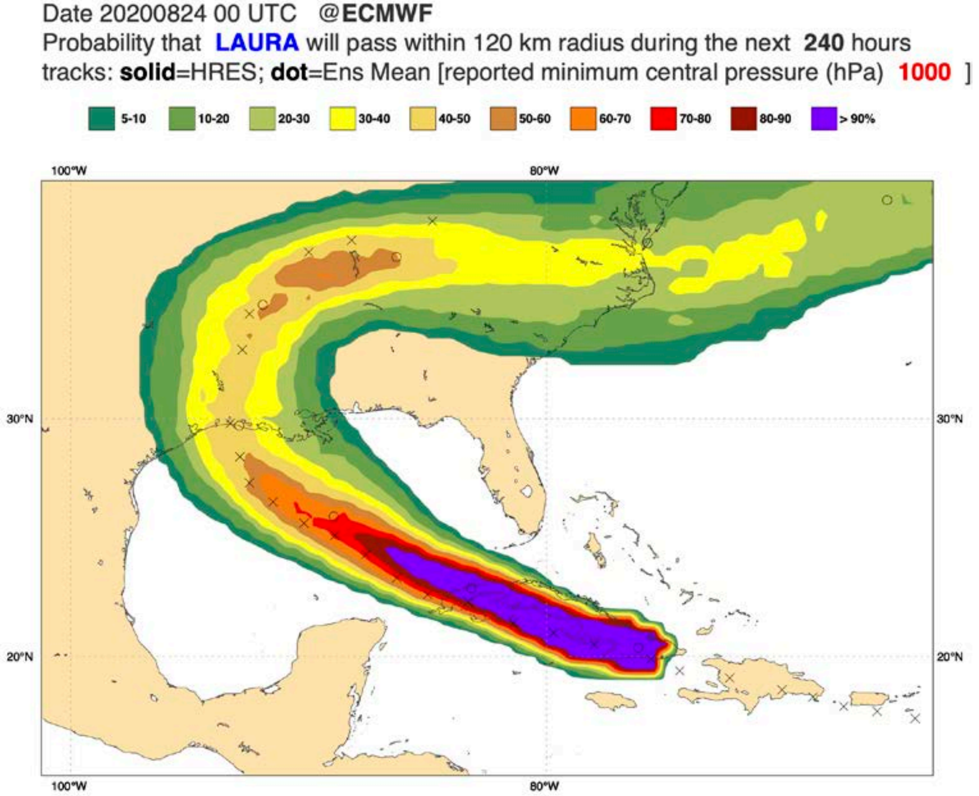
Subjective case assessment, TCo1279L137 vs TCo639L91:

Initial Date	Landfall location	Core Pressure at Landfall
2020082300	Significantly improved	Significantly improved
2020082312	≈ Neutral	Significantly improved
2020082400	Significantly improved	Significantly improved
2020082412	Significantly improved	Significantly improved
2020082500	Significantly improved	Significantly improved
2020082512	Improved	Significantly improved

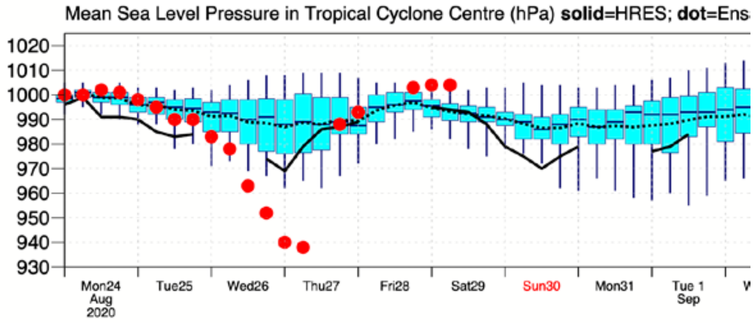
Oper, TCo639L91



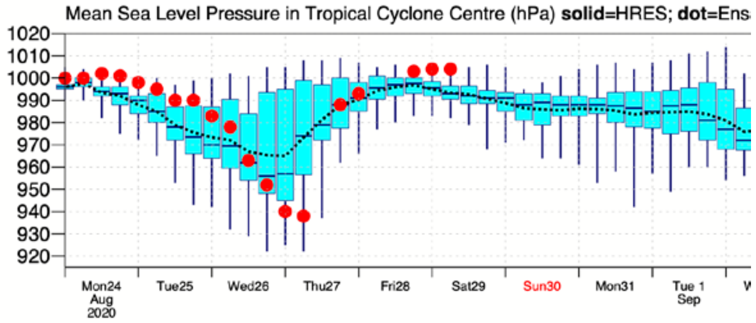
TCo1279L137



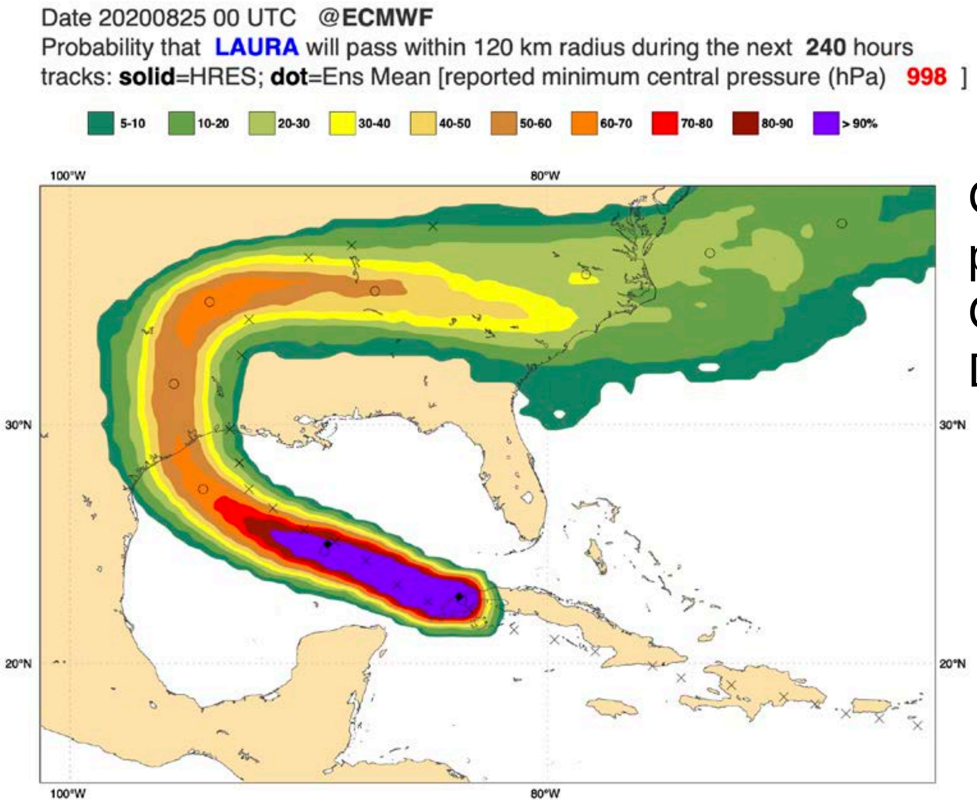
Crosses : observed position
Circle : ensemble mean
Diamonds : Oper HRES



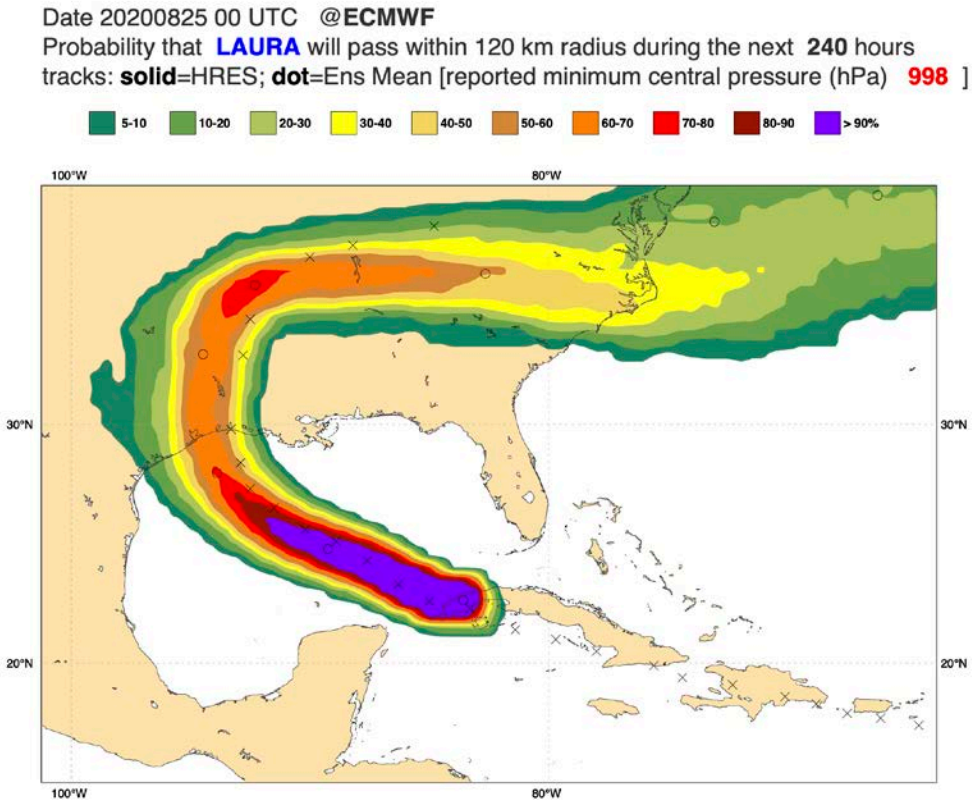
Red dot : observed core pressure
Solid black line : Oper HRES
Box plot : ensemble distribution



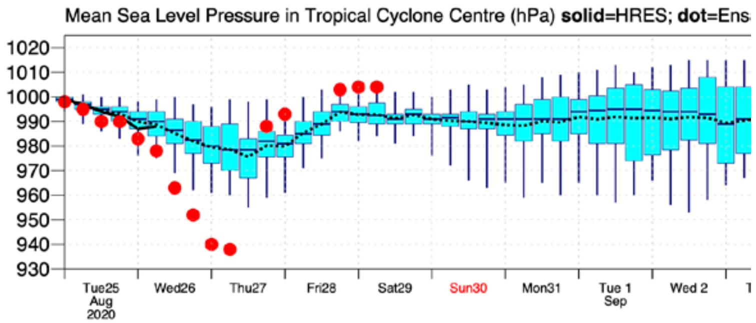
Oper, TCo639L91



TCo1279L137



Crosses : observed position
Circle : ensemble mean
Diamonds : Oper HRES



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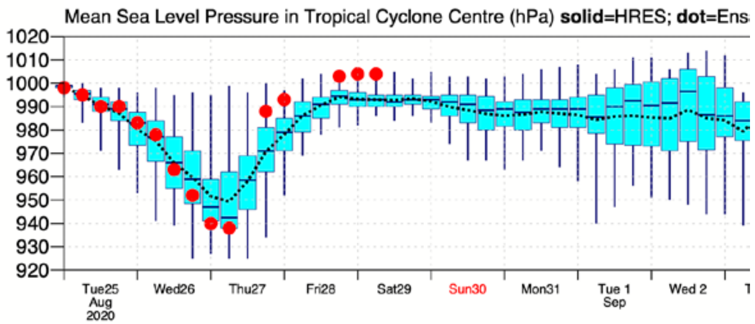


Extended-range ensemble forecasts

- Currently: **50 member twice weekly** (Mondays and Thursdays) at TCo319L91
- Single precision and **137 levels** planned in Cycle 47r2 on Cray XC40 in Shinfield Park, Reading, Q2 2021
- **100 member daily at TCo319L137** in Cycle 48r1 on BullSequana XH2000 in Bologna, Q3/Q4 2022
- Forecasts will start at TCo319 from initial time to enable increase in ensemble size
- Same configuration in terms of ensemble generation methodology, same model (i.e. model cycle), same initial conditions as medium-range ensemble except for horizontal resolution

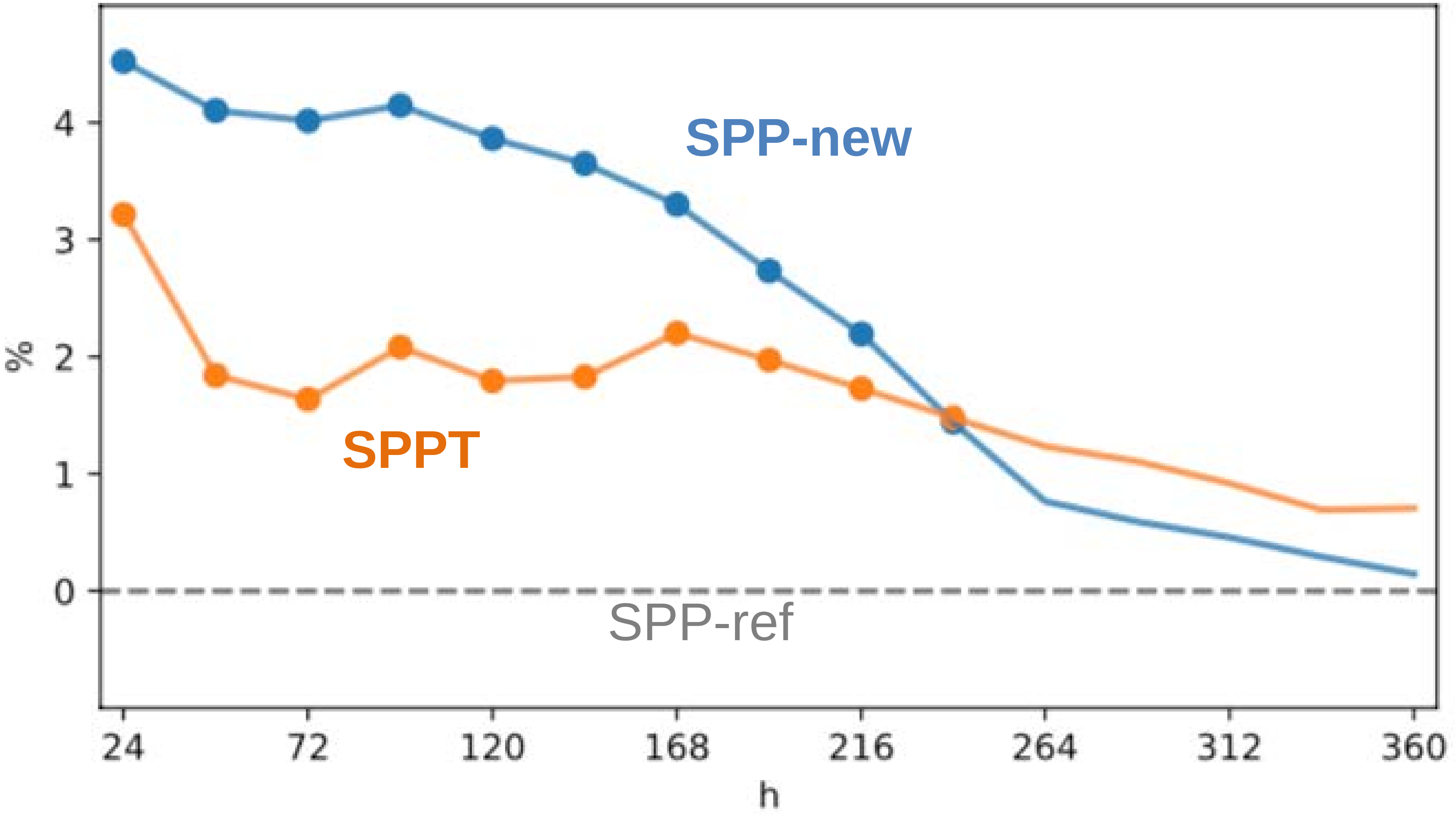
Representation of model uncertainties

- Operational scheme: SPPT using configuration described in Lock et al.
- SPP (Stochastically Perturbed Parametrizations): Original version has been extended and revised (manuscript submitted to QJ)
  - ensemble skill with SPP now similar to ensemble skill with SPPT
  - candidate to replace SPPT in about 2023
  - advantages: uncertainties are represented closer to the sources of the errors, local conservation better than in SPPT
- STOCHDP (Stochastic Departure Points): Represents dynamical core uncertainties, likely to be of increased importance in the convection-permitting regime

SPP revision: Summary

- **SPP** stands for **Stochastically Perturbed Parametrisations**; applied in the IFS physics parametrisations in radiation, vertical mixing, cloud and convection schemes
- Represents model uncertainties close to sources, improves physical consistency compared to SPPT, e.g. local conservation properties of energy and moisture
- Original version (**ref**) described by Ollinaho et al. 2017, https://doi.org/10.1002/qj.2931
  - 19 (20) quantities perturbed, 2000 km correlation scale for random fields
  - generates overall less spread than SPPT
- Revised version (**new**, consists of 7 stages) (Lang et al. 2020, submitted to QJ)
  - 27 quantities perturbed
  - 1000 km correlation scale for random fields
  - increased variance of random fields
  - generates slightly more spread than SPPT overall and is about as skilful as SPPT (Latest SPPT config., see Lock et al, 2019, https://doi.org/10.1002/qj.3570)

Relative Z500 ensemble spread increase wrt SPP-ref in N-Hem extra-tr.



Accounting for representativeness error in ensemble verification

- Many references state why there is a need to account for representativeness errors (REs) in ensemble verification
- However, in practice most ensemble verification does not account for it.
- Progress has been made at ECMWF to account for REs routinely: Ben Bouallègue et al (2020, https://doi.org/10.1175/mwr-d-19-0323.1) and Ben Bouallègue (2020, ECMWF Tech Memo 865, https://doi.org/10.21957/5z6esc7wr)
- Parametric models have been estimated using a normal distribution, a truncated normal distribution and a censored shifted gamma distribution for 2-metre temperature, 10-metre wind speed and 24-hour precipitation, respectively.
- The statistical models describe the distribution of values at station locations given area-average values of the respective variables
- The models are given as function of the horizontal averaging scale and can be applied to any NWP model output
- The distributions are estimated from high-density station observations over Europe by minimising the CRPS

Understanding changes of the Continuous Ranked Probabilty Score

- Can we explain quantitatively why the CRPS changes?
- Yes, with some simplifying assumptions: Assume homogeneous Gaussian model (hoG) of forecast-observation distribution
- This permits to compute the expected CRPS in closed form expression. The hoG approximation works remarkably well for actual NWP ensemble forecasts (within a couple of percent).
- Details are in an article (Leutbecher &Haiden, 2020, https://doi.org/10.1002/qj.3926)

$$\mathbb{E}\,\mathrm{CRPS} = \frac{\epsilon}{\sqrt{\pi}}\left[\sqrt{2+2\sigma_*^2}\exp\left(-\frac{b_*^2}{2+2\sigma_*^2}\right) + \sqrt{\pi}\,b_*\ \mathrm{erf}\left(\frac{b_*}{\sqrt{2+2\sigma_*^2}}\right) - \sigma_*\right]$$

with ϵ^2 denoting the variance of the error of the ensemble mean,
b_* denoting the bias of the ensemble mean normalised with ϵ, and
σ_* denoting the spread-error ratio

Slides from NRL

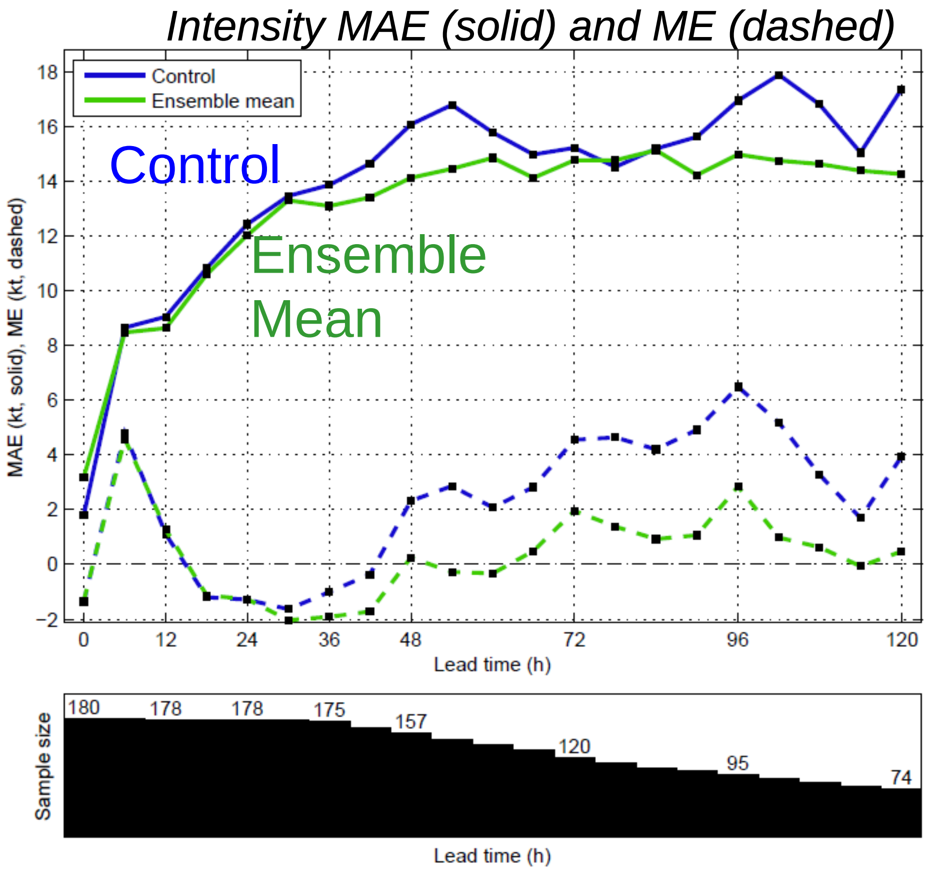
Probabilistic Prediction of Track and Intensity

COAMPS-TC Ensemble System

COAMPS-TC EPS Configuration

- 1 unperturbed control + 10 perturbed members
- Perturbations: Synoptic IC, vortex IC, lateral BC
- 36/12/4 km resolution (uncoupled; SST cooling)
- New: Refinements to initial vortex perturbations, Perturbed drag coefficient vs wind speed curve for each ensemble member
- Retrospective tests show the ensemble mean intensity errors are up to 12% lower than control
- Spread-skill relationship for track is very good, but under-dispersive for intensity

Intensity Error



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Probabilistic Prediction of Track and Intensity

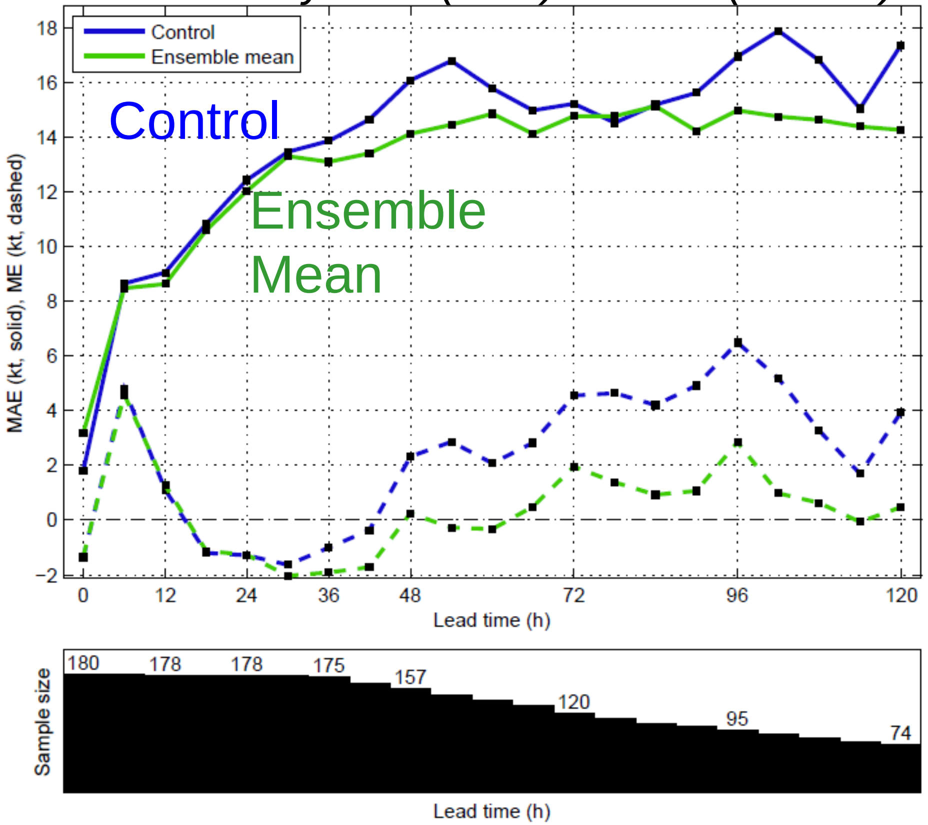
COAMPS-TC Ensemble System

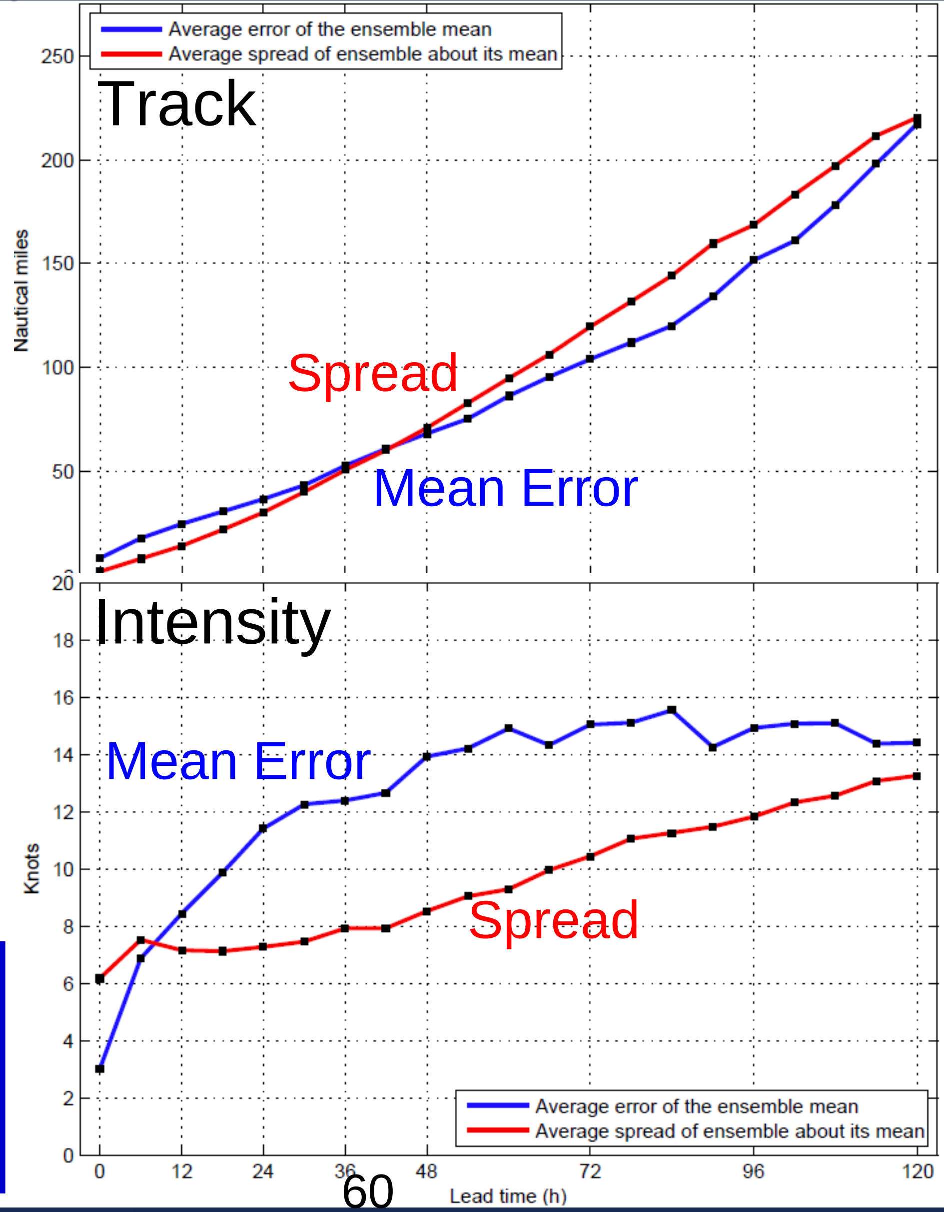
U.S. NAVAL RESEARCH LABORATORY

OFFICE OF NAVAL RESEARCH

Intensity Error

Intensity MAE (solid) and ME (dashed)





- Retrospective tests show the ensemble mean intensity errors are up to 12% lower than the control
- Spread-skill relationship for track is very good
- For intensity, the ensemble is under-dispersive

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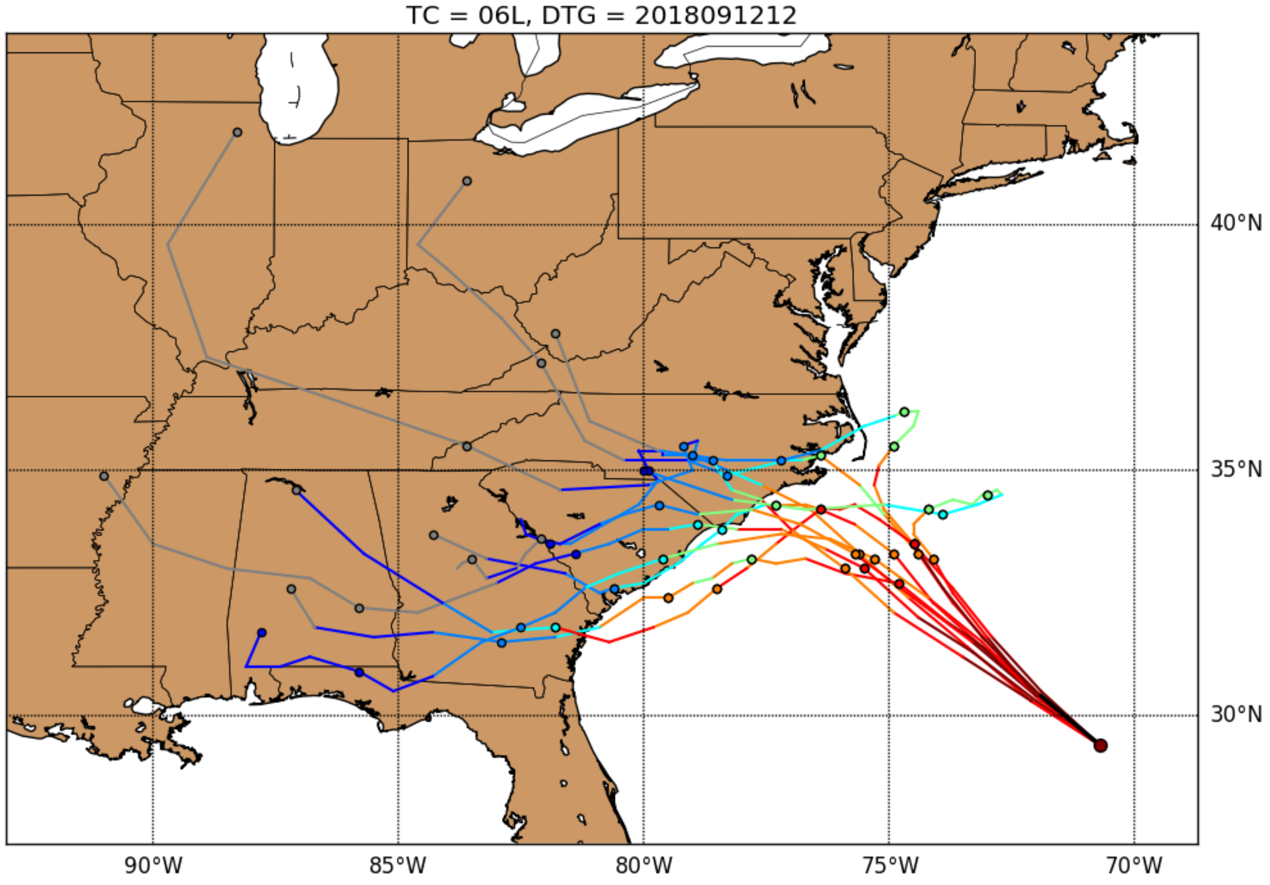
COAMPS-TC Ensemble System

COAMPS-TC EPS Configuration

- 1 unperturbed control + 10 perturbed members
- Synoptic-scale IC, vortex scale IC, and lateral BC perturbations
- Uncoupled with SST-cooling parameterization 36/12/4 km resolution, same as 2018 ops deterministic COAMPS-TC
- <u>New for 2018</u>: Refinements to initial vortex perturbations, Perturbed drag coefficient vs wind speed curve for each ensemble member
- **CTCX EPS in a demonstration mode at FNMOC in 2019 (2 storms at 00z and 12z)**

Florence (06L) (12Z 12 Sep 2018)



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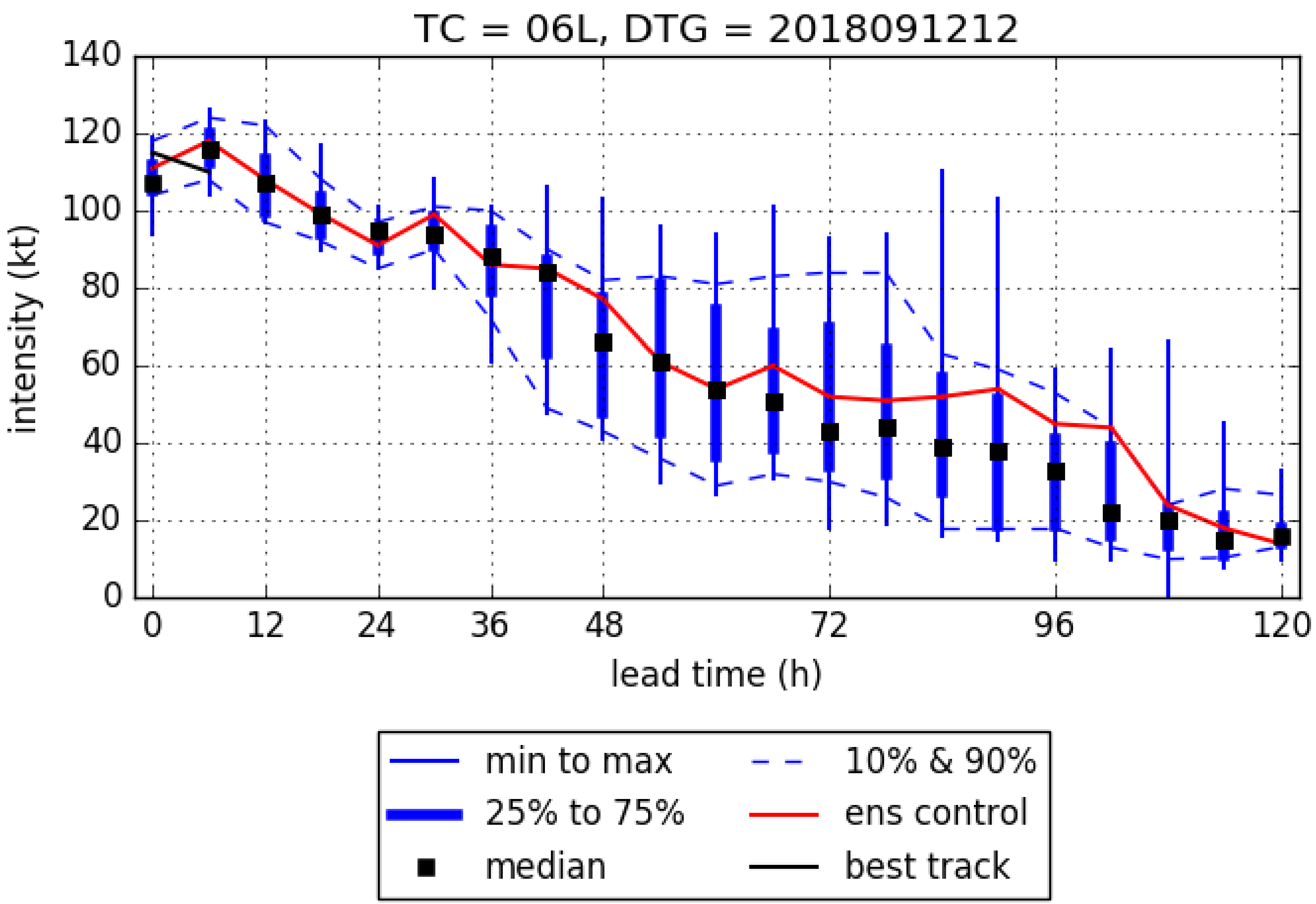

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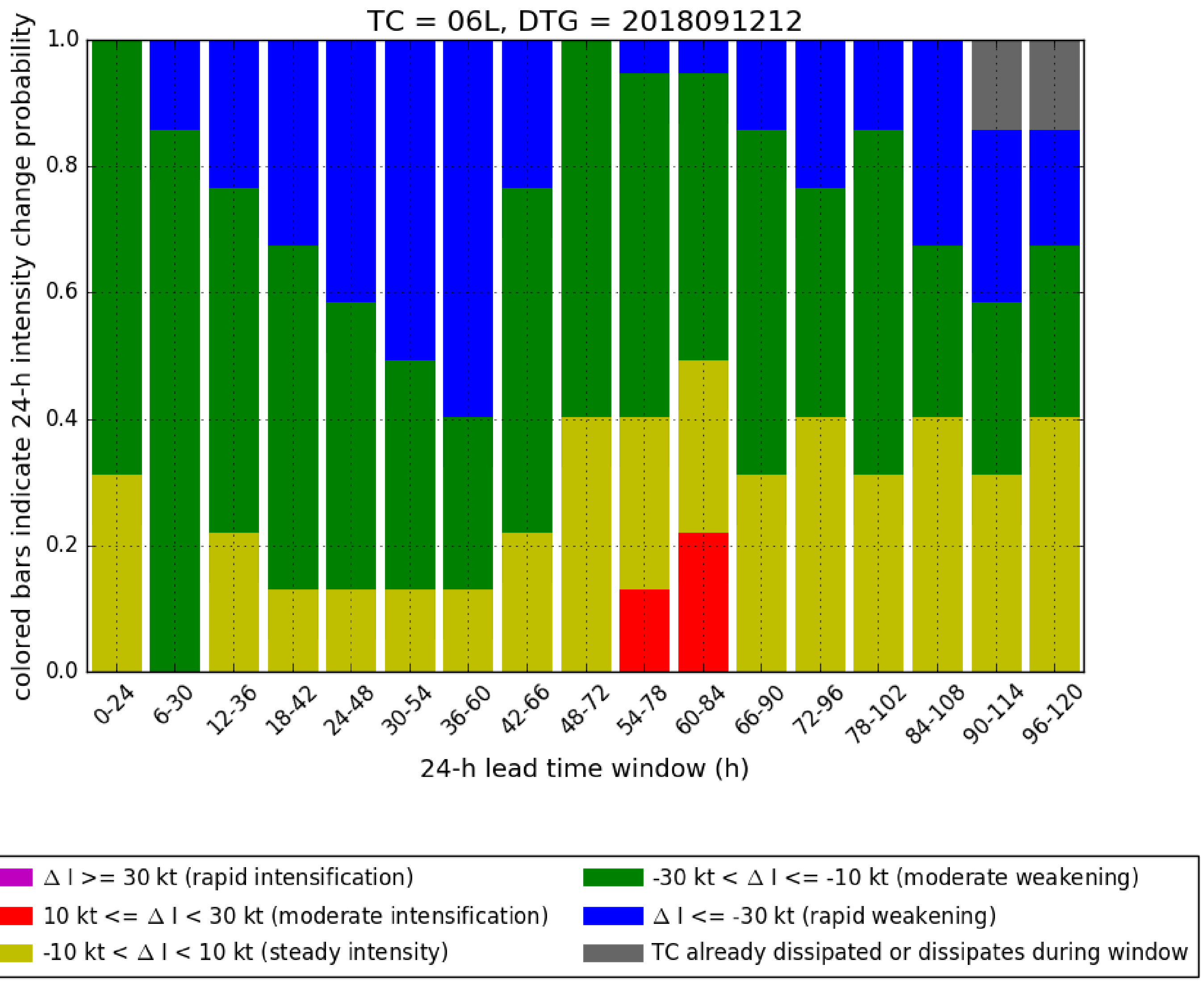
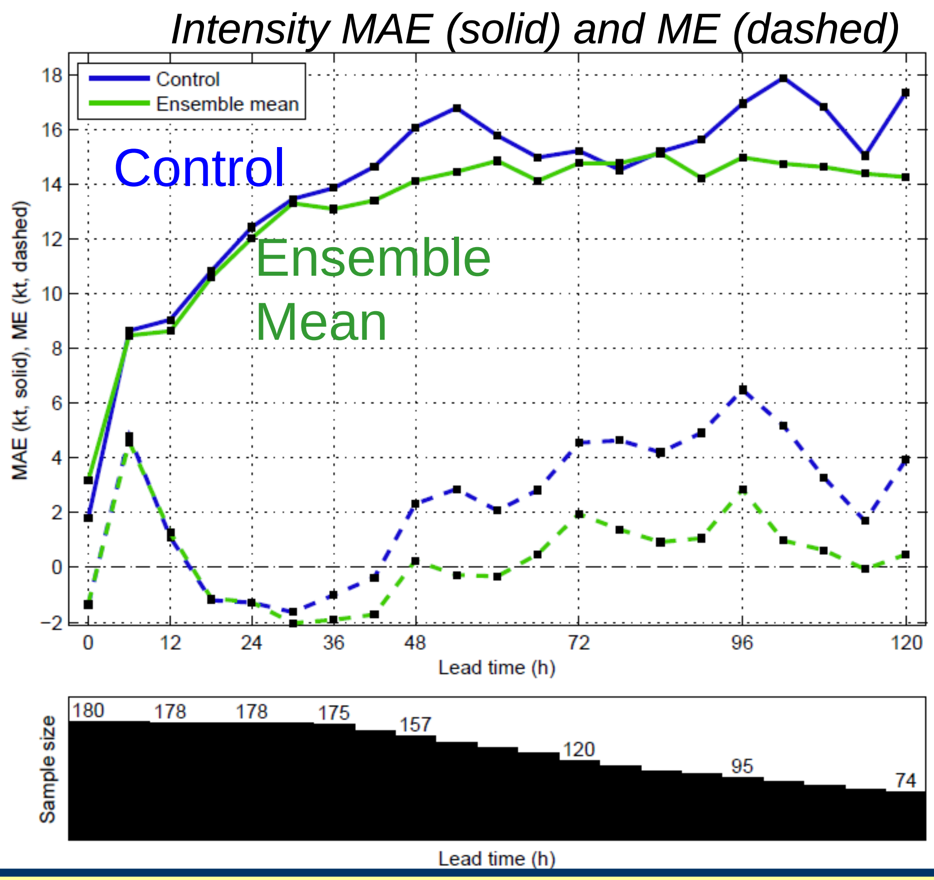
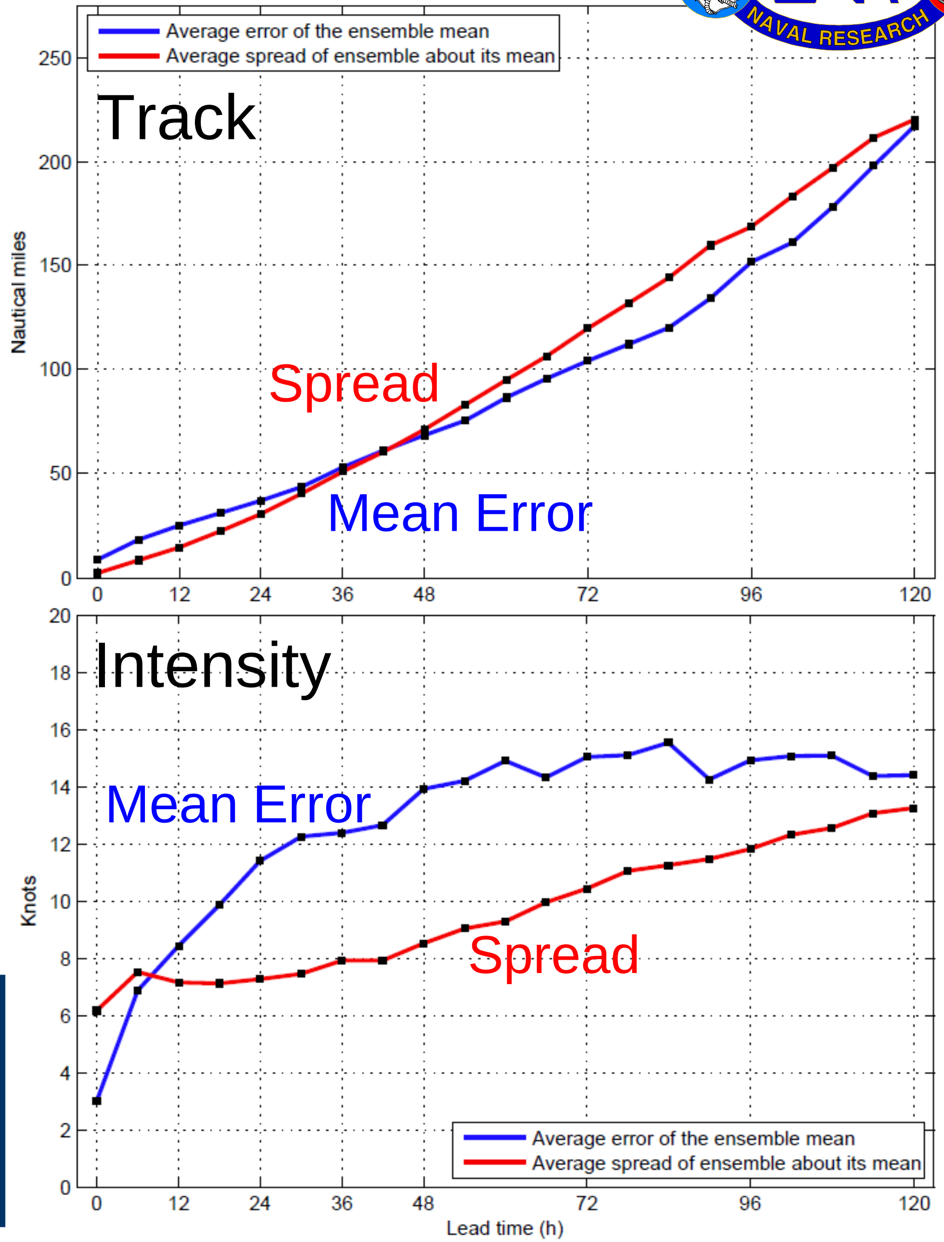


COAMPS-TC Ensemble System

Intensity Error





- Retrospective tests show the ensemble mean intensity errors are up to 12% lower than the control
- Spread-skill relationship for track is very good
- For intensity, the ensemble is under-dispersive

New US Navy Global Coupled 45-day Ensemble System

Initial Operational Capability (IOC): Operational on 31 AUG 2020

Forecast System	Time Range, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE
Deterministic short term	0-16 days Daily	T681L60 (19 km) 60 levels	1/25° (4.5 km) 41 layers Tides	1/25° (4.5 km)
Ensemble (probabilistic) long term	0-45 days 16 members 1x/week	T359L60 (37 km) 60 levels	1/12° (9 km) 41 layers No tides	1/12° (9 km)

- Atmospheric assimilation via NRL Atmospheric Variational Data Assimilation System - Accelerated Representer (NAVDAS-AR)
- Ocean/sea ice assimilation via Navy Coupled Ocean Data Assimilation (NCODA)
- Ensemble forecasts became operational on 31 August 2020.

US Navy Earth System Prediction Capability
ESPC V2

Coupled Model Configuration for ESPC V2
Scheduled to be delivered to FNMOC at the end of FY22

Forecast System	Time Scale, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Sea Ice CICE	Waves WW3	Land Surface LSM	Aerosol
Deterministic Short term	0-16 days daily	T681L136 (13 km) 136 levels	1/25° (4.5 km)[1] 41 layers Tides	1/25° (1.8 km)[2]	1/8° (14 km)	Module within NAVGEM	Module within NAVGEM
Ensemble (Probabilistic) Long term	0-45 days[3] twice weekly 30 members	T681L136 (13 km) 136 levels	1/12° (9 km)[1] 41 layers Tides	1/12° (3.5 km)[2]	1/4° (28 km)	Module within NAVGEM	Module within NAVGEM

[1] Horizontal resolution at the equator.

[2] Horizontal resolution at the North Pole.

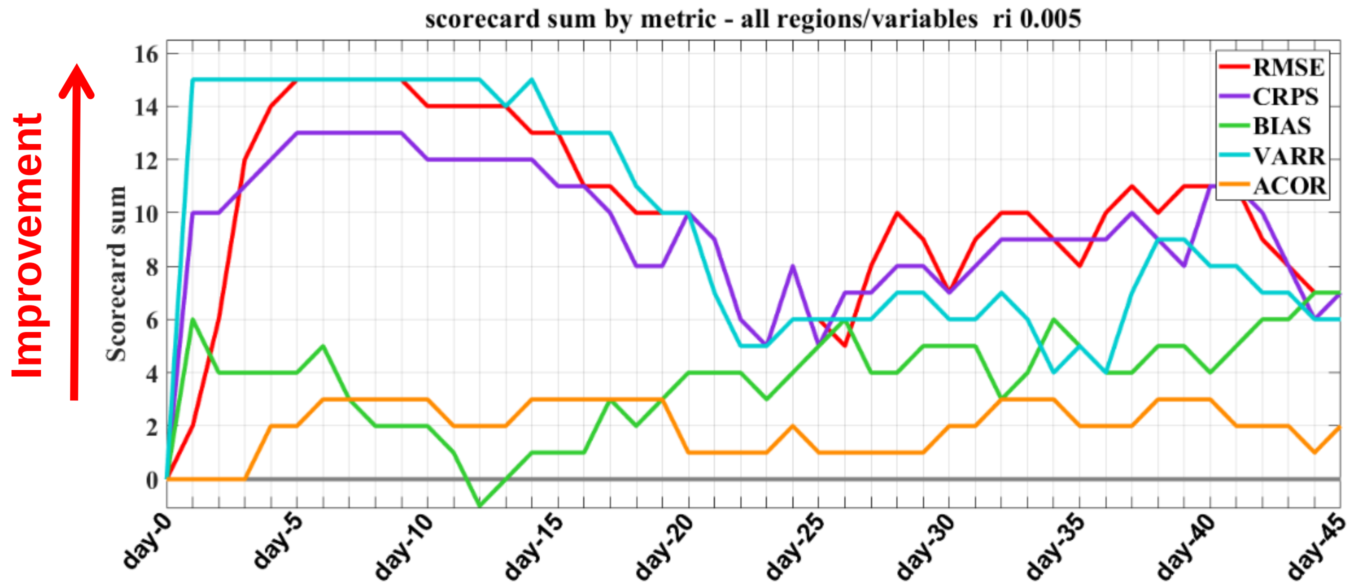
[3] The forecast length, frequency and number of members will be determined by the operational resources available.

Items in green are significant advancements beyond the ESPC IOC version

Improved Navy ESPC Model Uncertainty Methodologies

- Ensemble ESPC for IOC uses perturbed observations to create ensemble spread
  - Ensemble is under-dispersive, i.e. insufficient spread
- Implemented Analysis Correction based Additive Inflation (ACAI) in NAVGEM in Navy ESPC (Crawford et al., 2020 after Bowler et al. 2017)
  - These act on the ensemble ***during*** integration to improve spread/skill
  - ACAI improves forecast metrics, although some issues remain to be worked out, particularly at long leads.
- Stochastic Kinetic Energy Backscatter also improves performance (not shown).

Impact of ACAI on Navy ESPC ensemble performance metrics as a function of forecast lead-time



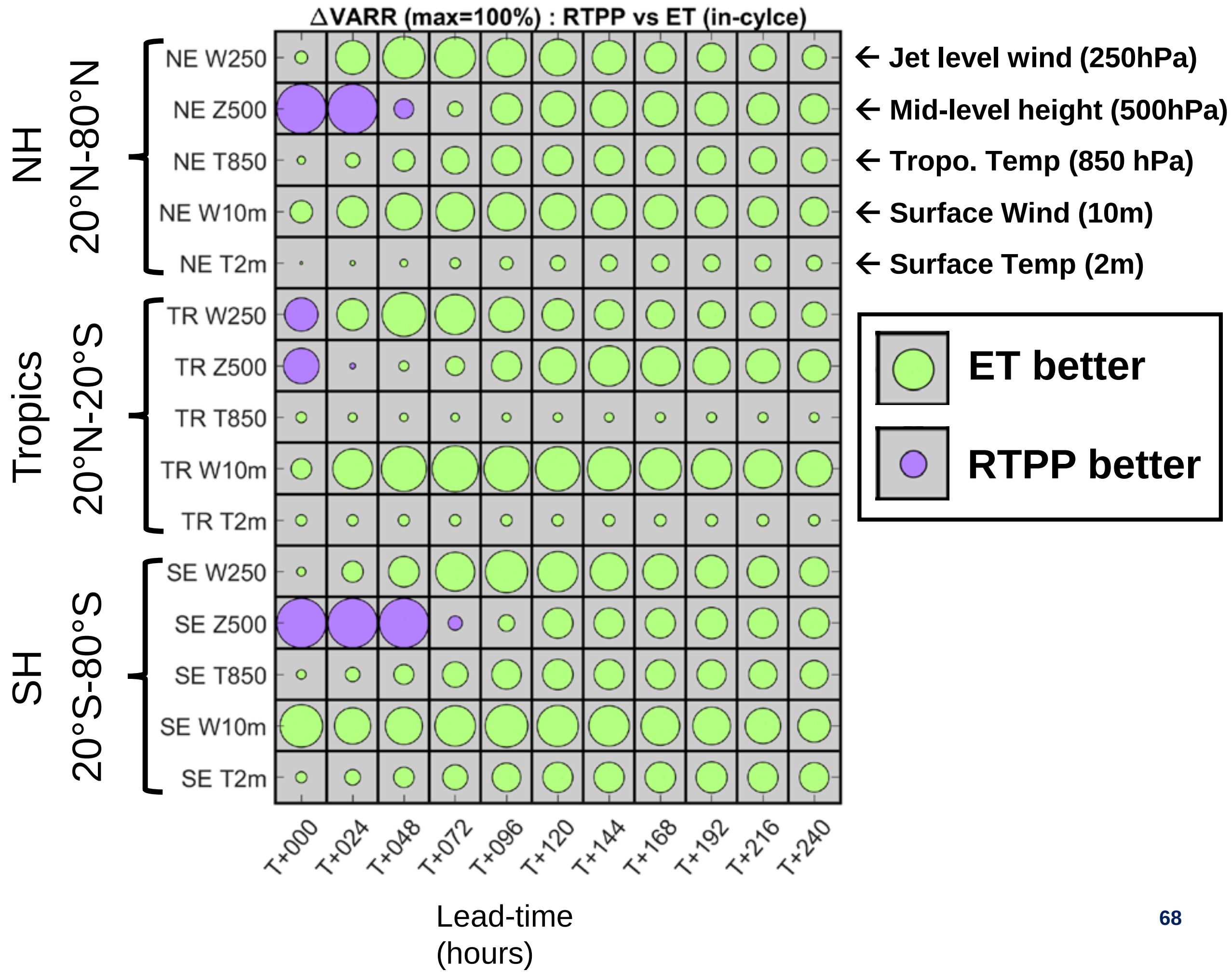
- Metrics computed relative to control and averaged across 52 45-day forecasts
- Each metric computed for 2m air temp, 10m wind speed, 850 hPa air temp, 500 hPa height and 250 hPa wind speed

Will Crawford and Justin McLay

Improved NAVGEM Ensemble Initialization Methodologies

- Test comparing NAVGEM ensemble ***initialization*** using Relaxation-To-Prior-Perturbations (RTPP) vs. the Ensemble Transform (ET)
- Scorecard indicates the ET-based initialization outperforms RTPP in nearly all region/variable/lead-time combinations for the spread-skill (VARR) metric
- Similar impacts are seen in other performance metrics
- Testing in the global coupled system is ongoing.

VARR: Ratio of ensemble spread to mean squared error



Will Crawford and Justin McLay

Slides from Russian Hydromet Center

New EPS at Hydrometcentre of Russia

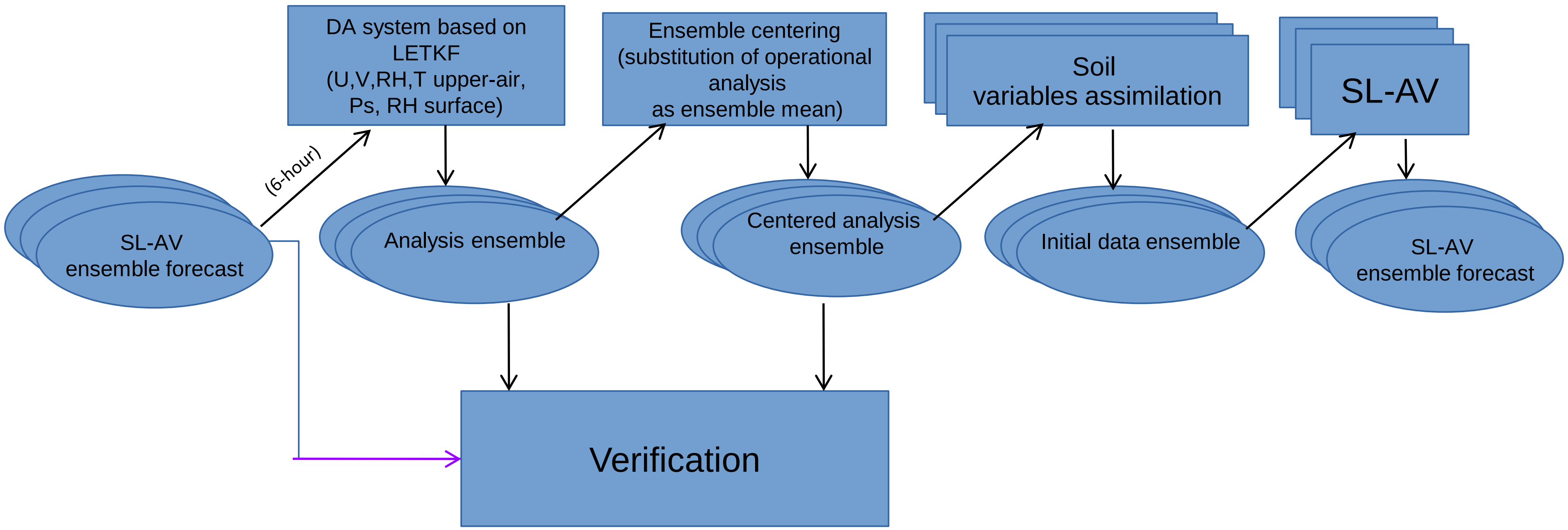
- ✓ SL-AV model[1], 0,9°x0,72°, 96 vertical levels, 10 days (14 in future)
- ✓ ensemble size – 40 or 60 members
- ✓ LETKF engine with multiplicative and additive inflation[2]
- ✓ Observations: SYNOP, SHIP,TEMP, AIREP,AMV, ASCAT
- ✓ Centering onto operational analysis of HMCR
- ✓ Model uncertainty: SPP under tuning, SKEB in future

[1]M. A. Tolstykh, R. Yu. Fadeev, V. V. Shashkin, G. S. Goyman, R. B. Zaripov, D. B. Kiktev, S. V. Makhnorylova, V. G. Mizyak, and V. S. Rogutov. Multiscale Global Atmosphere Model SL-AV: the Results of Medium-range Weather Forecasts. Russian Meteorology and hydrology, 2018 V 43 P 773-779. DOI: 10.3103/S1068373918110080

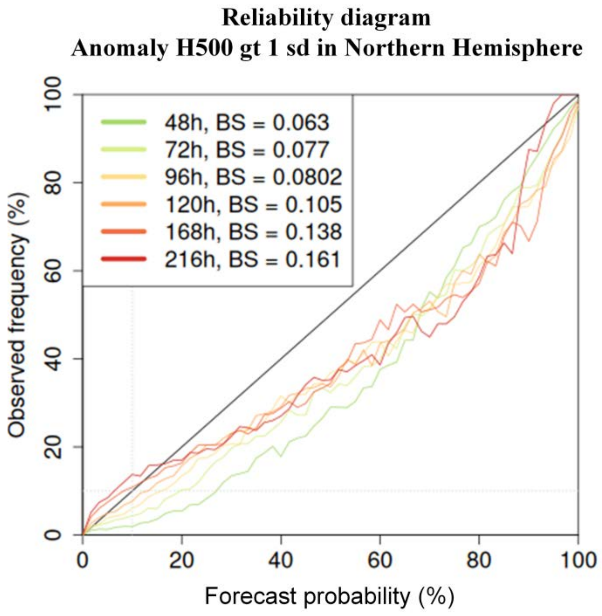
[2]A.V. Shlyaeva, M.A.Tolstykh, V.G.Mizyak, V.S.Rogutov. Local ensemble transform Kalman filter data assimilation system for the global semi-Lagrangian atmospheric model. Russ. J. Num. An. & Math. Mod. 2013 V 28 N 4 P 419-441

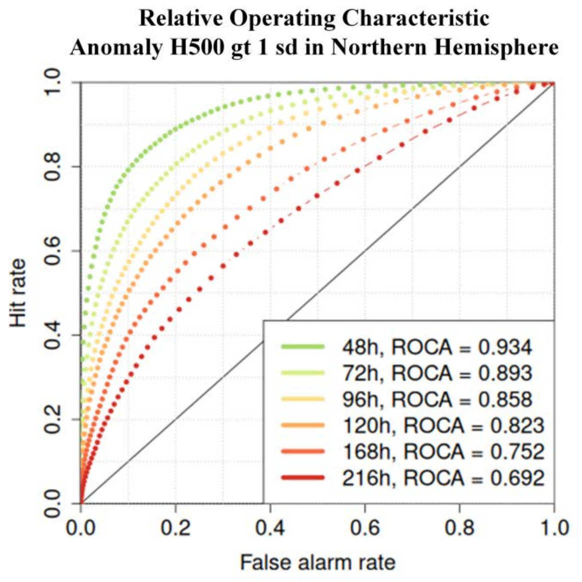
Ensemble prediction system

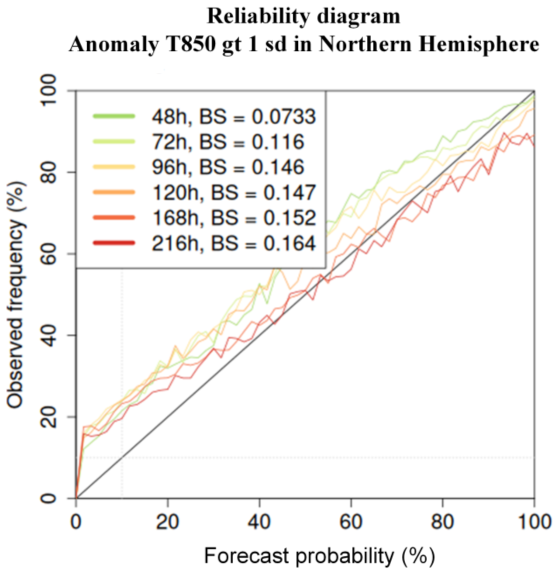
- The ensemble deviation from the ensemble mean analysis is calculated
- Each deviation is added to HMC operational analysis
- The modified ensemble is used to obtain an ensemble of forecasts by model simulation
- The mean analysis coincides with the operational one and the ensemble spread is generated in the ensemble assimilation system

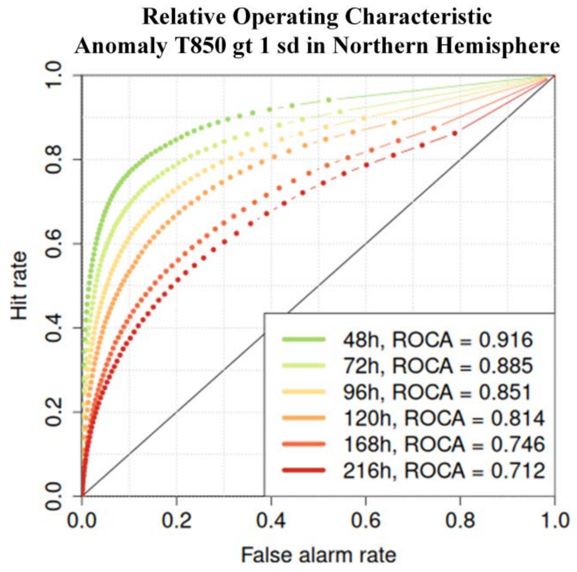


Tests before SPP implementation, Aug 2020.
Reliability diagrams and ROC









Details and outlook

- Runtime of whole program complex is about 1,5 hour for the 10 day forecast (60 members of ensemble) @992 processor cores
- Further steps: SPP tuning, stochastic perturbation of vorticity field

Research for mesoscale EPS

- Further development of the AMPT method aimed to take into account model uncertainty in mesoscale limited-area models in a new way

- Application of AMPT to soil perturbations. Both soil temperature and soil moisture are perturbed at the initial moment and during the model run. Perturbation magnitude decays with depth.

AMPT: Additive Model-error perturbations scaled by Physical Tendencies

The AMPT perturbations $\boldsymbol{\mathcal{P}(x, y, \mu, t)}$ are spatio-temporal random fields scaled by the area averaged (in the horizontal) modulus of the physical tendency ***P(x,y,*** $\boldsymbol{\mu, t}$***).***

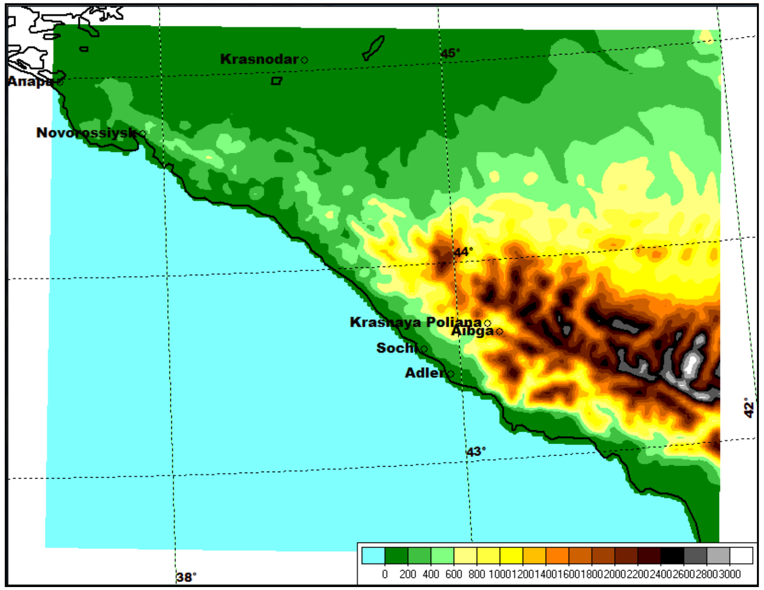
$$\mathcal{P}(x, y, \mu, t) = \sigma \cdot \overline{\{|P(x, y, \mu, t)|}\, \xi(x, y, \mu, t)$$

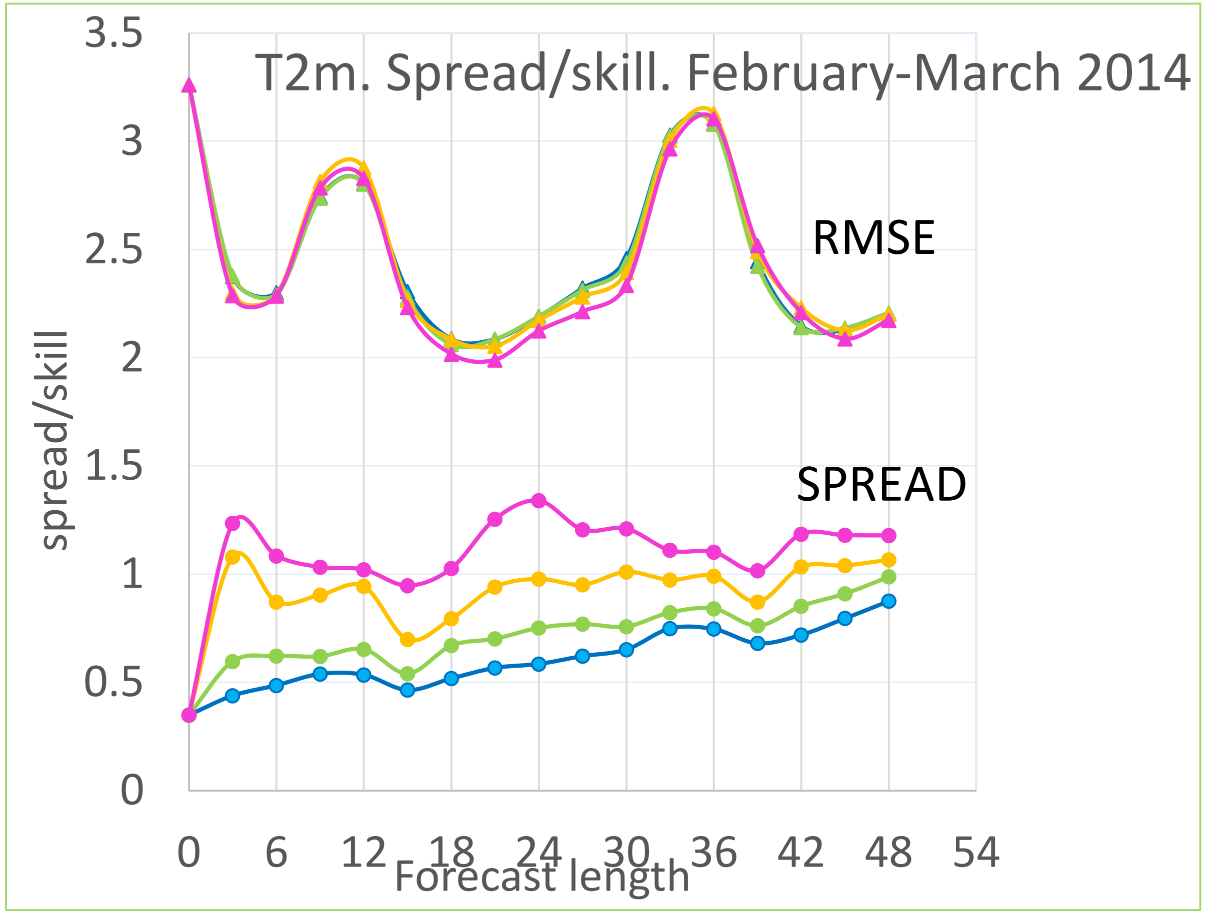
σ determines the perturbation magnitude,
the overbar denotes the horizontal averaging operator,
$\boldsymbol{\xi(x, y, \mu, t)}$ is the pseudo-random field generated by the Stochastic Pattern Generator SPG (Tsyrulnikov, Gayfulin, 2017),
$\boldsymbol{\mu}$ is the vertical coordinate.

New ! : now averaging can be over the **whole** domain (for Gaussian variables) or over a **sliding subdomain** (for non-Gaussian variables).

Testing AMPT soil perturbations in COSMO-Ru2-EPS (Febr-Mar 2014)

- ICs&BCs from COSMO-LEPS adapted by ARPA-SIMC for the Sochi region (resolution 7 km)
- 300*400 km area centered at Sochi
- 2.2 km, 50 levels
- 10 members



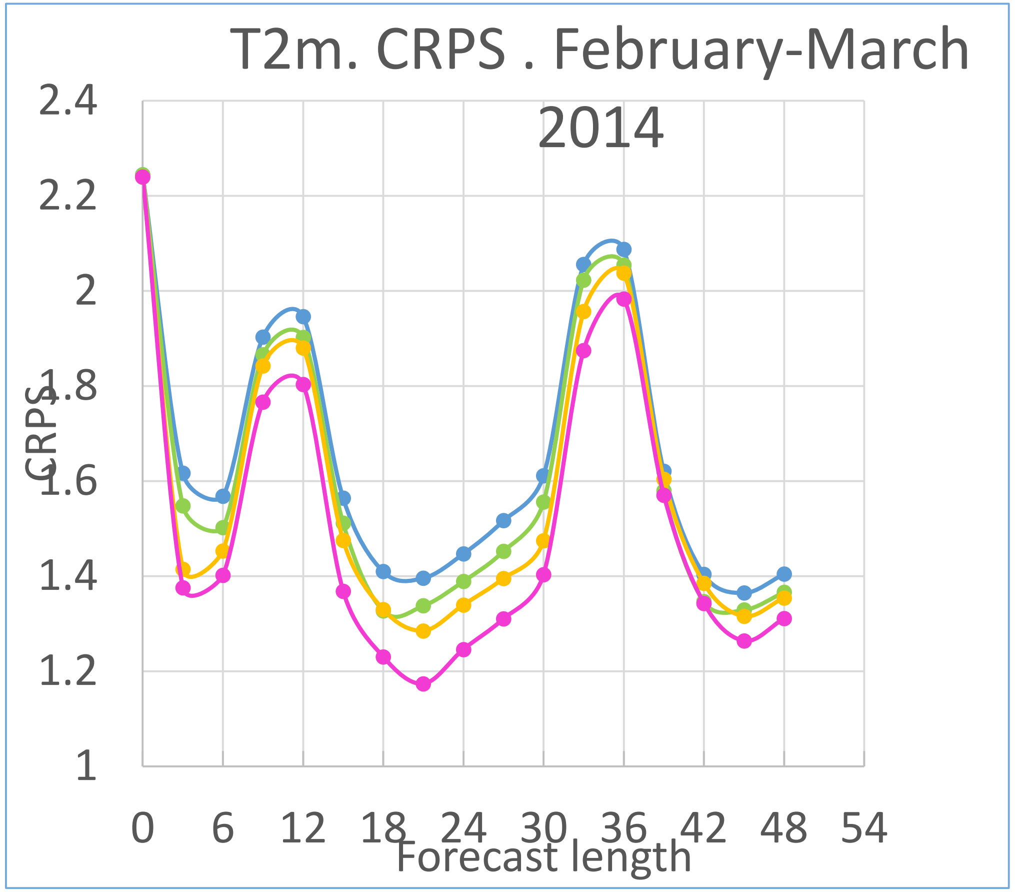


No model perturbations
SPPT
AMPT only in the atmosphere
AMPT in the atmosphere and in the soil

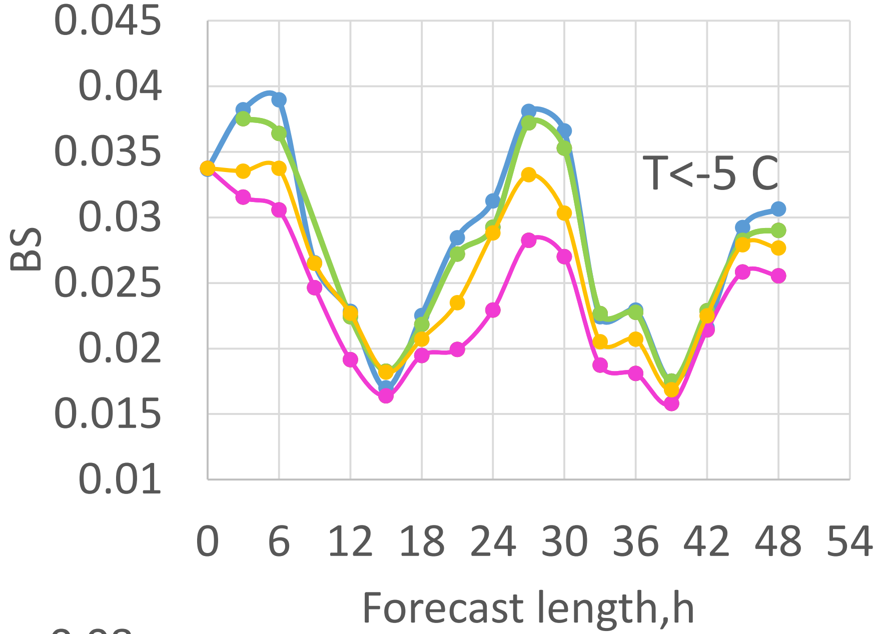
- Verification against ~40 stations

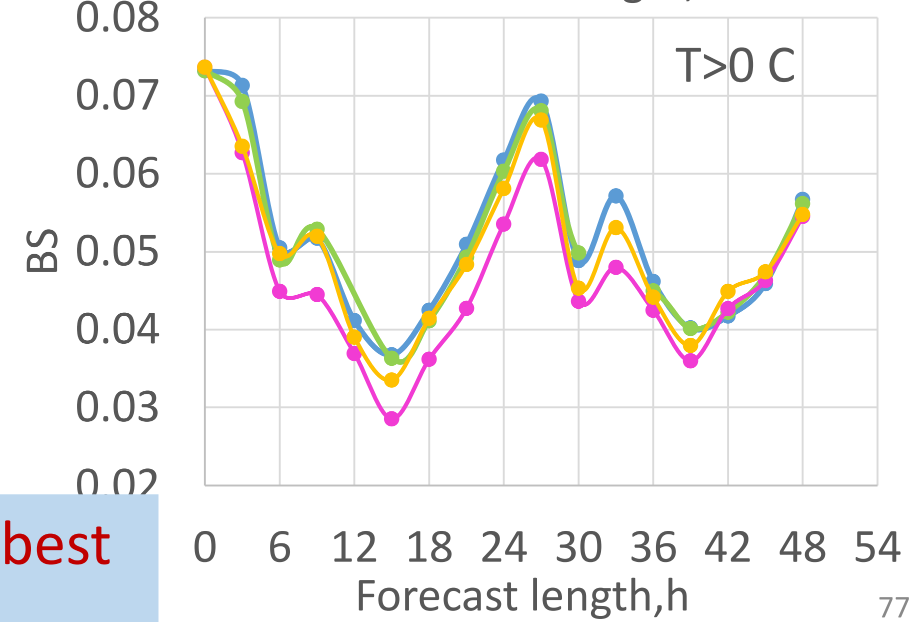
With soil AMPT perturbations RMSE decreases and SPREAD increases!

Continuous Ranked Probability Score (CRPS). The lower the better



Brier score. The smaller the better





No model perturbations

SPPT

AMPT only in the atmosphere

AMPT in the atmosphere and in the soil

Experiments with AMPT soil perturbations show the best results

Conclusions

- *Atmospheric* AMPT perturbations improve ensemble T2m forecast w.r.t. CRPS, Brier score, and ROCA.

- *Soil* AMPT perturbations add value w.r.t atmospheric AMPT perturbations in the lower troposphere.