WGNE37 Ensemble Overview

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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 (H or L) and Member Number: ECMWF, HMC, NCEP, DWD, CMC, CPTEC, JMA, Météo-France

- Initial Condition Methodology: CMC (LETKF), CPTEC(EnKF & EOF), HMC (LETKF), NCEP (EnKF Anl)

- Model Uncertainty Methodology: ECMWF (SPP, STOCDP), HMC (SPP, SPPT, STOCHDP), NCEP, DWD (stochastic representation), NRL(ACAI), CMC (SKEB+SPPT), Météo-France (Multi-physics > SPP + 2 convection schemes)

- Boundary Condition Perturbations and coupling: Met Office (coupled), NCEP (coupled), JMA (2-tiered SST approach in tropics), CPTEC (coupled)

Recent Upgrades and Plans: Regional

- Resolution and Member Number: Met Office, HMC, JMA, Météo-France
- Initial Condition Methodology: HMC (multi-model), JMA (Hybrid DA), CMC (reduced random additive inflation)
- Model Uncertainty Methodology: HMC (SPP, additive model error perturbations), JMA (SPPT), CMC (SKEB+SPP), Météo-France (SPPT but ongoing dev towards SPP)
- Boundary Condition Perturbations: Met Office (SST from 1.5km NEMO UK with SST pert.), DWD (higher-res BCs from global ICON), HMC (multi model), JMA (perturbed SST), CMC (Global pilot EPS with REPS-consistent random additive inflation)

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)	TCo639L137 TCo319L137 18/36km 9 km/36 km	15d 46d	51 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 14d	17+1 44 for DA	En-4DEnVar	SKEB2 + SPT	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)	SSPP + 2 convection schemes (Tiedtke & PCMT)	N SURFEX and 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	
NCEP (USA)	C384L64 (~25km) C384L127	16d 35d (00Z)	30+1	EnKF f06 EnKF anl	SPPT, SKEB Other methods being tested.	2-Tier SST Coupling to WW, MOM, CICE6, GOCART	Offline 31-year hindcast Offline 30-year hindcast
DWD (German)	40km 26 km (from Nov 2022 on)	180h	40	LETKF with recentering to DET analysis	Perturbed physics parameters Stochastic representation	SST random pert.	ICON

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
NRL/FNMOC (USA)	T359L60 T681L134 for coupled S2S	16d 45-d coupled	21 16 for coupled	local ET and SST pert. Ensemble of DAs for coupled.	SKEB-mc Analysis Correction-based Additive Inflation (ACAI)	SST initial pert. S2S coupled	Part of the U.S. multi-model ensemble Post-processing for aviation variables (e.g., icing, turbulence, cloud cover)
CMC (Canada)	0.35° L84 0.225° L84	16d	20	Local ensemble transform KF with randomized cross-validation + reduced random additive inflation	SKEB + 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 V2.1.0 (same used by Guimarães et al., 2020)	15d	15	EOF-based perturbation Combination between EOF and EnKF (using a hybrid 3DEnVar data assimilation framework)	N	N	Couple with earth system model
JMA (Japan)	Tq479L100 128 Tq479L100 128 Tq319L100 128 (linear grid to quadratic grid)	11d 18d 34d	51 51 25	SV(Total energy norm) +LETKF (pert. Inflation)	Stochastic perturbation of physics tendency	Two-tiered SST approach over the tropics after day 6 SST pert.	Update model and extension of the two-tiered SST approach to the global domain is planned in 2023

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
BoM (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	

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 1.5kmL90	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	Deterministic Analysis + Pert. From 3.2km ensemble assimilation	SPPT	Pert. of surface LBC selection with clustring	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 (20km grid; 13 km from Nov 22 on), 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

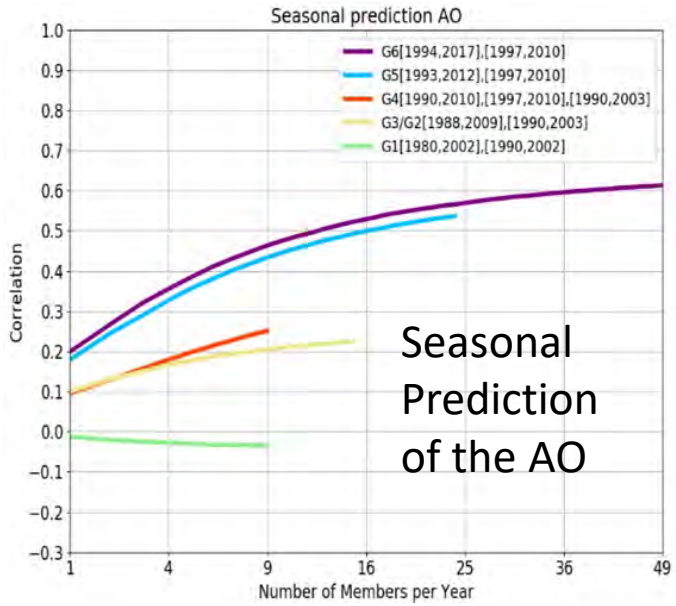
Operational regional (weather) EPS

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

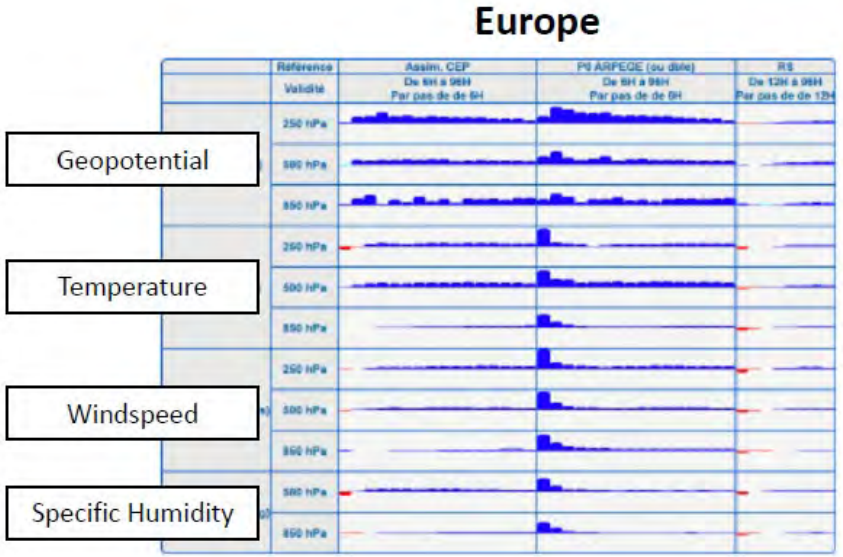
Center	Resolutions	FC Range	Members	Initial perturbation, DA	Model Uncertainty	B.C.	Note
NCEP/SREF (US)	16kmL41		1+12 NMMB 1+12 WRF_ARW	Multi analysis	Variety of physics scheme	Stochastic soil moisture	Frozen
NRL/FNMOC (US)	36/12/4km	120h	10+1 20+1	Perturbed synoptic scales Perturbed Rankine Vortex	Perturbed 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
CMC/REPS (Canada)	0.09°L84	72h	1+20	Global analysis departures from ensemble mean, recentered on regional deterministic analysis + reduced random additive inflation	SKEB + 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

General System Improvements

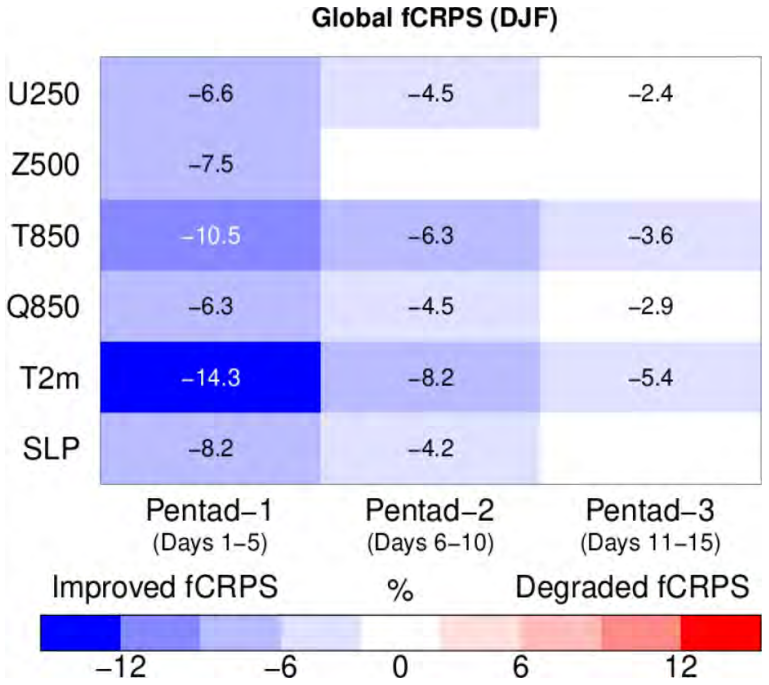
Met Office has had steady progress on seasonal prediction (now 6th generation). Large ensembles as important as model changes in extratropics.



Meteo France finds widespread improvement in ARPEGE-EPS with increased resolution new SPP scheme. Blue shows improvement in CRPS (similar over globe)



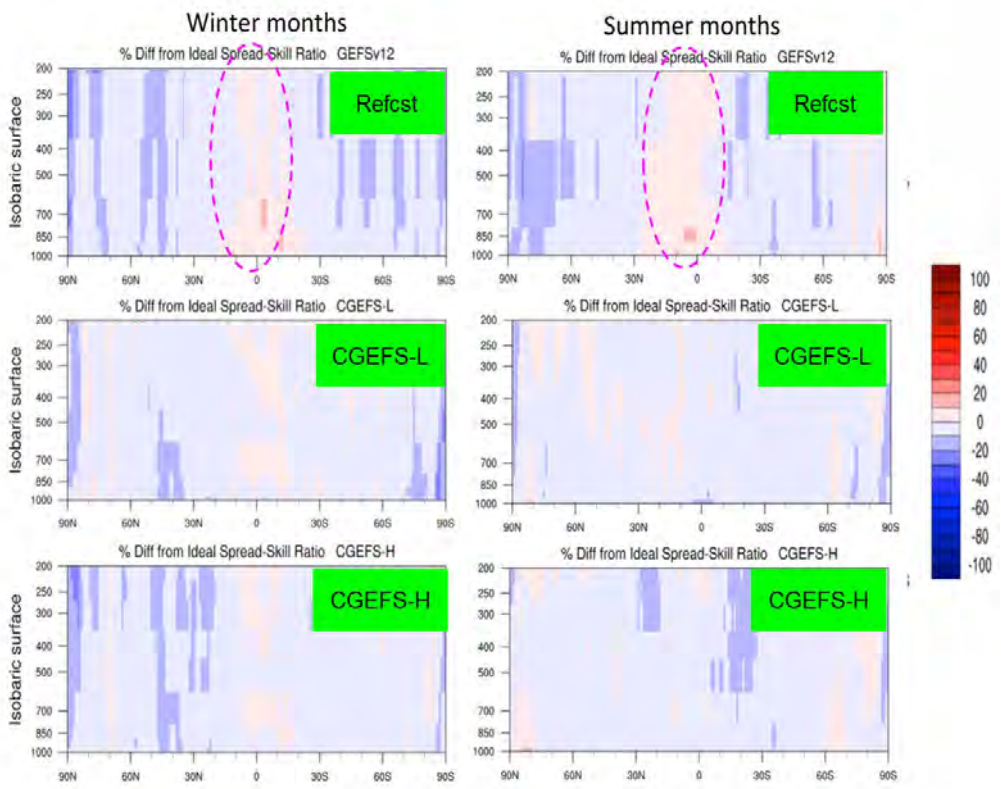
Canadian Global Ensemble Upgrade (SPP & SKEB, EnKF to LETKF DA, physic upgrades) have resulted in the largest improvement to the global ensemble prediction system in over a decade.



Relative change (%) in global fCRPS for Jan-Feb 2020 between the updated and operational GEPS. Changes that are statistically significant have values plotted in the appropriate cell.

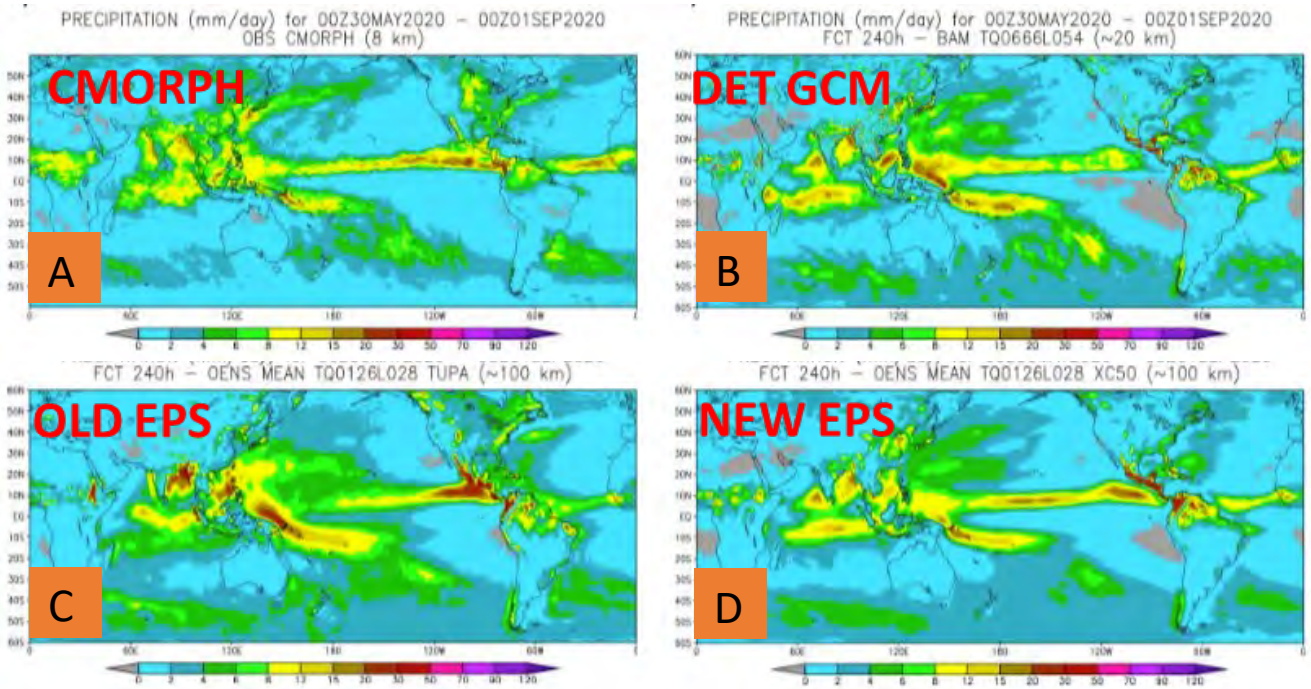
New Models

NCEP new fully coupled ensemble at both 0.5 deg (CGEFS-L) and 0.25 deg (CGEFS-H) substantially reduces over-dispersion in tropics (zonal wind below).



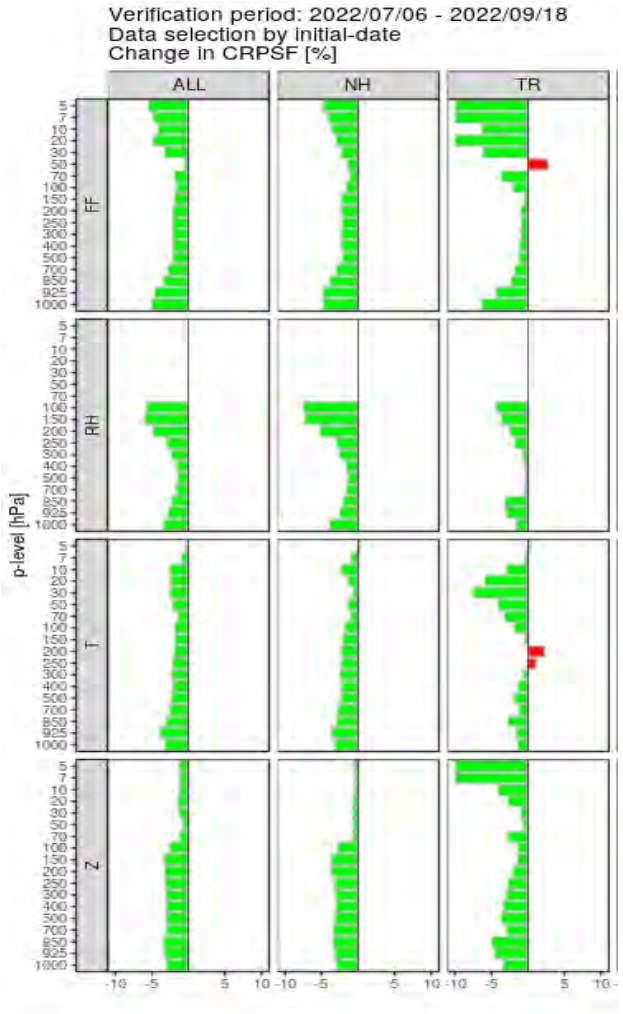
CPTEC GCM upgrade improves tropical precipitation forecasts (100-km res ensemble mean close to operational 20-km deterministic version for precip biases).

10-d Ensemble Mean Preciptation Forecasts

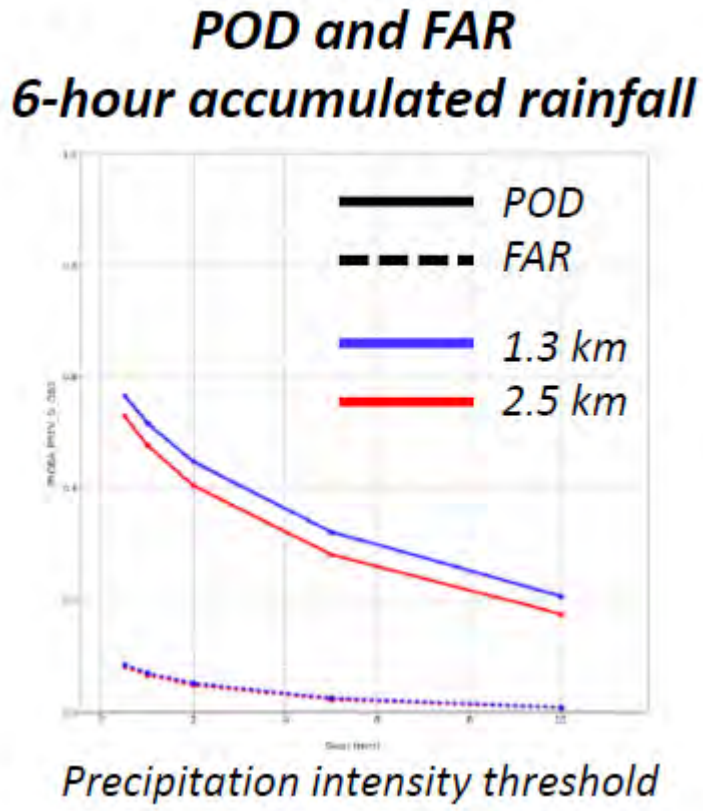


Increased Resolution

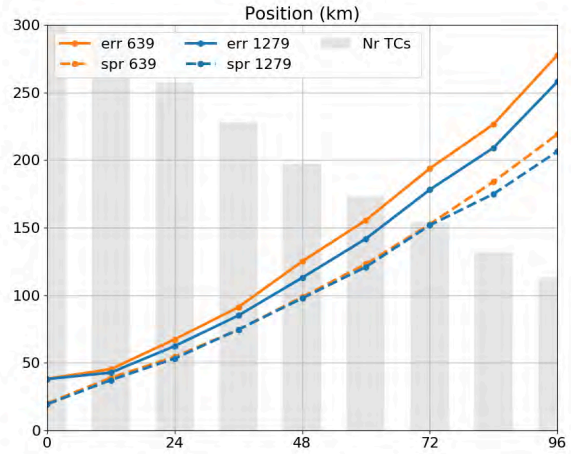
DWD ICON EPS sees widespread improvement from increasing resolution from 40/20km *to* 26/13 km, and L90 to L120, also using higher res orographic data.

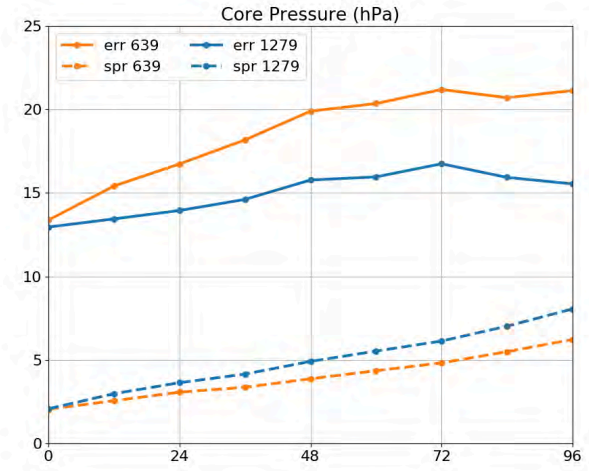


Meteo France finds increasing AROME-EPS resolution from 2.5 km to 1.3 km improved detection while keeping the number of false alarms small.



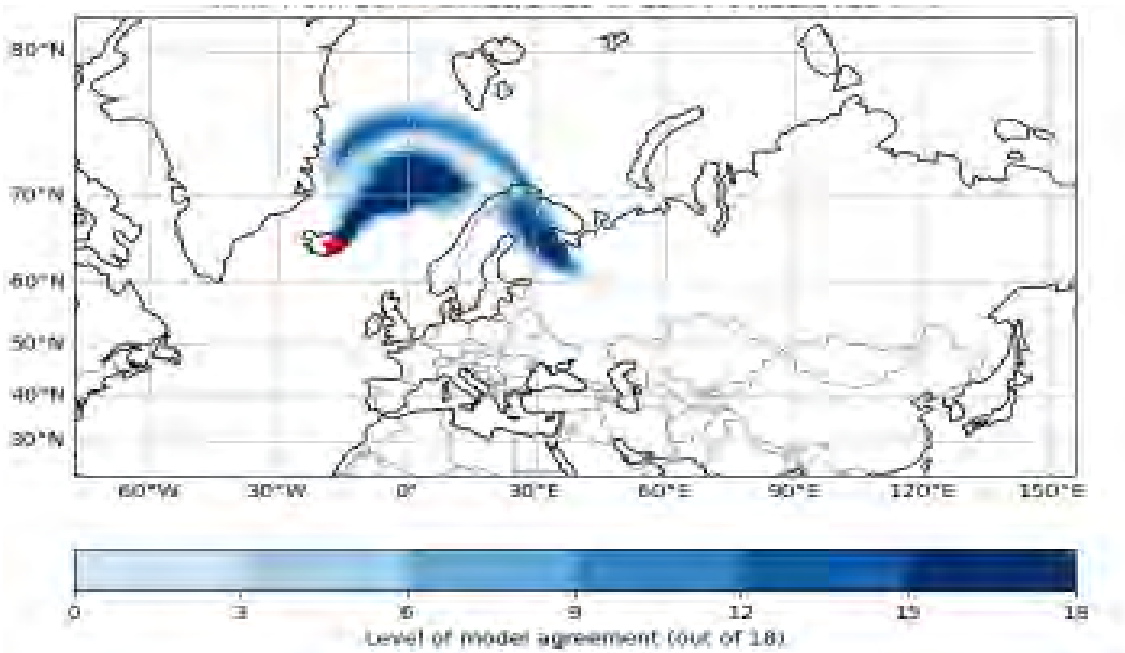
ECMWF sees widespread improvement from increasing resolution fro 18km to 9 km, including improvements in TC track and Intensity.



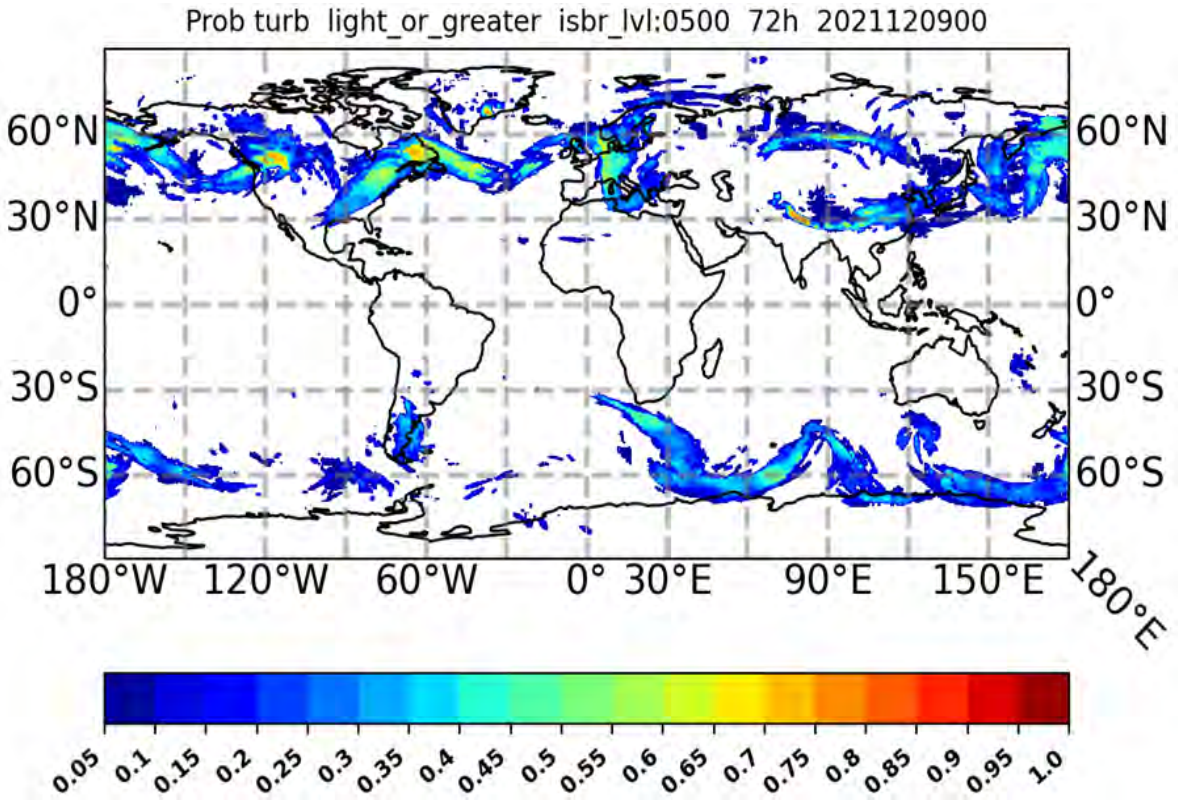


New Applications

New Applications from the Met Office include dispersion forecasts (below) and “wind droughts” for winter energy resilience.

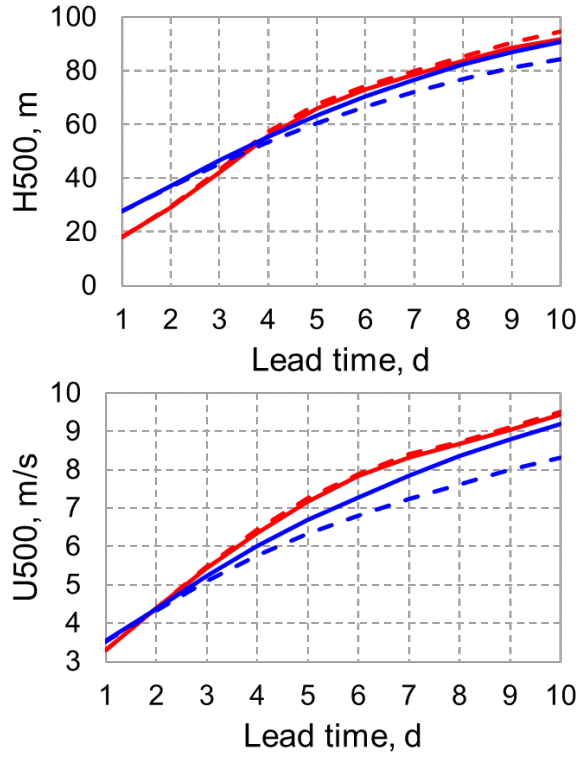


U. S. Naval Research Lab is producing turbulence probability products from calibrated fields.



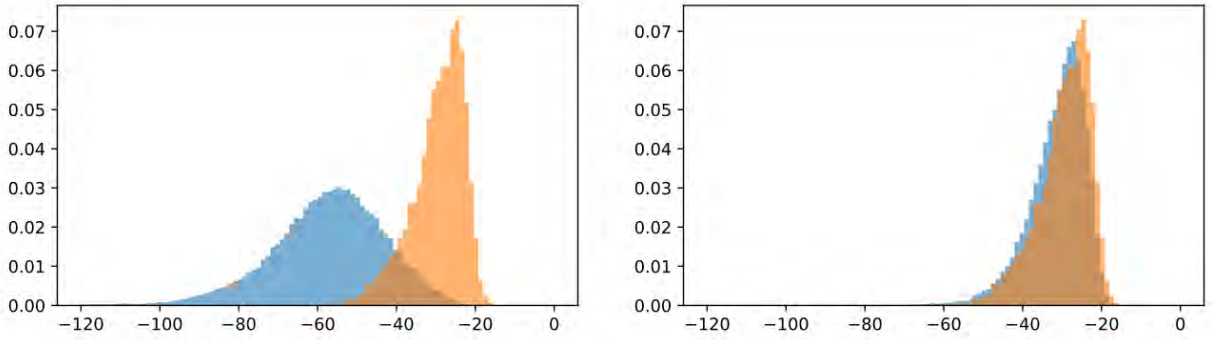
Model Uncertainty

Russian Hydromet Center shows improved ensemble performance using departure point perturbations.



RMSE SPP+SPPT
Sprd SPP+SPPT
RMSE SPP+SPPT+DP
Sprd SPP+SPPT+DP

ECMWF found Unexpected stability issues due to SPPT in the 9-kilometre ensemble (grid-point storms). Fixed with exclusion of saturation adjustment tendency.



Histograms of minimum omega values at each time step of 8 initial dates and all perturbed members / control forecast; Perturbed members in blue and unperturbed control forecast in orange. On the left: 47r3 with 48r1 cloud saturation changes and water conservation changes; On the right: after excluding the saturation adjustment tendency from SPPT. All forecasts with TCo1279 resolution.

Extra slides
Complete Center Contributions

Slides from DWD

ICON Resolution upgrade Nov. 2022

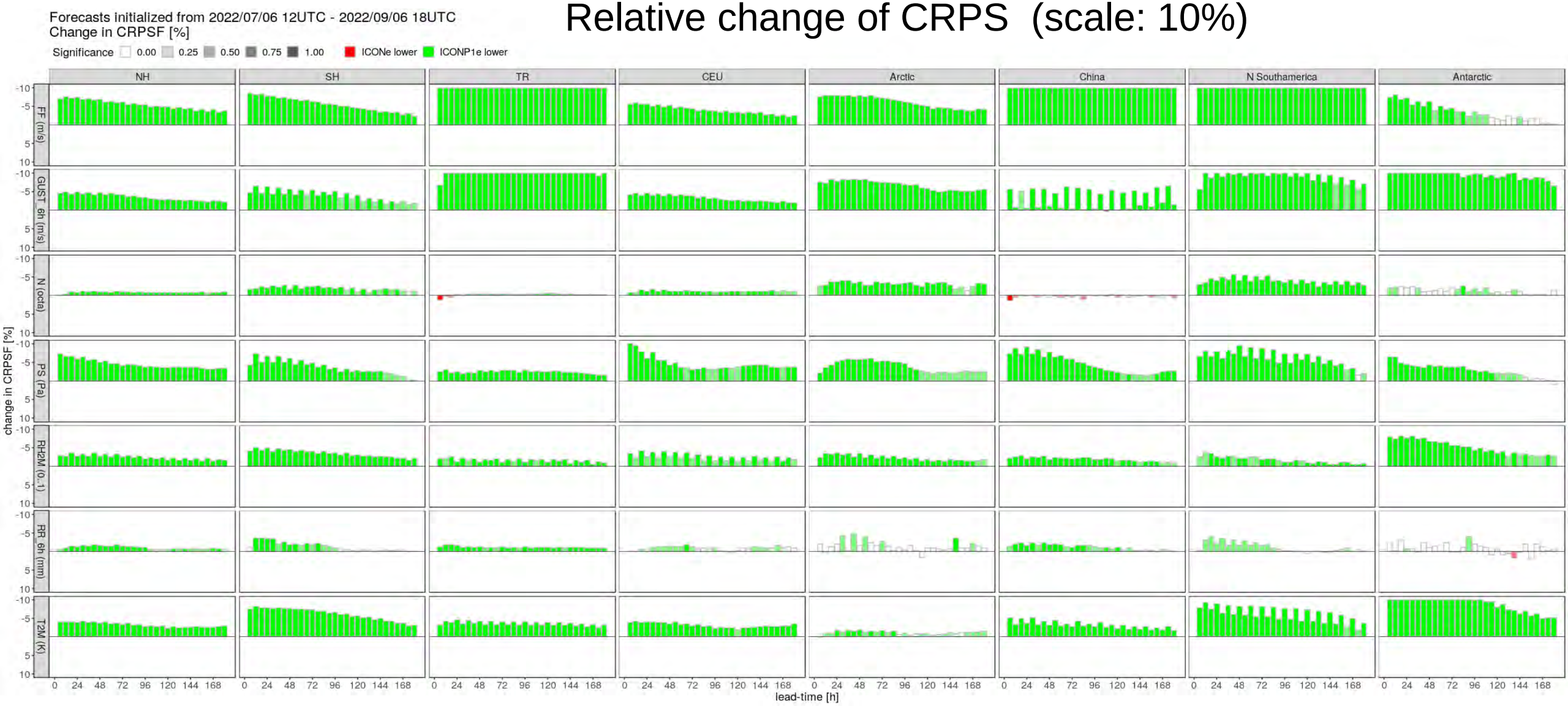
Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

- Enhance EPS resolution from 40/20 km to 26/13 km while keeping the deterministic configuration at 13/6.5 km
- Increase number of vertical levels from 90 to 120 (60 to 74 in EU-nest) in DET and EPS, placing the majority of the additional levels in the stratosphere
- This will be combined with using higher-resolved orography data (3´ instead of 30´´) and model-DA coupling for surface friction (see part 2 of this talk)
- The higher EPS resolution turns out to have a slight beneficial impact on the deterministic analyses due to the higher resolution of the ensemble B-matrix
- Subsequent slides: EPS verification results for current pre-operational phase; relative changes w.r.t. operational configuration

Scorecard EPS SYNOP verification

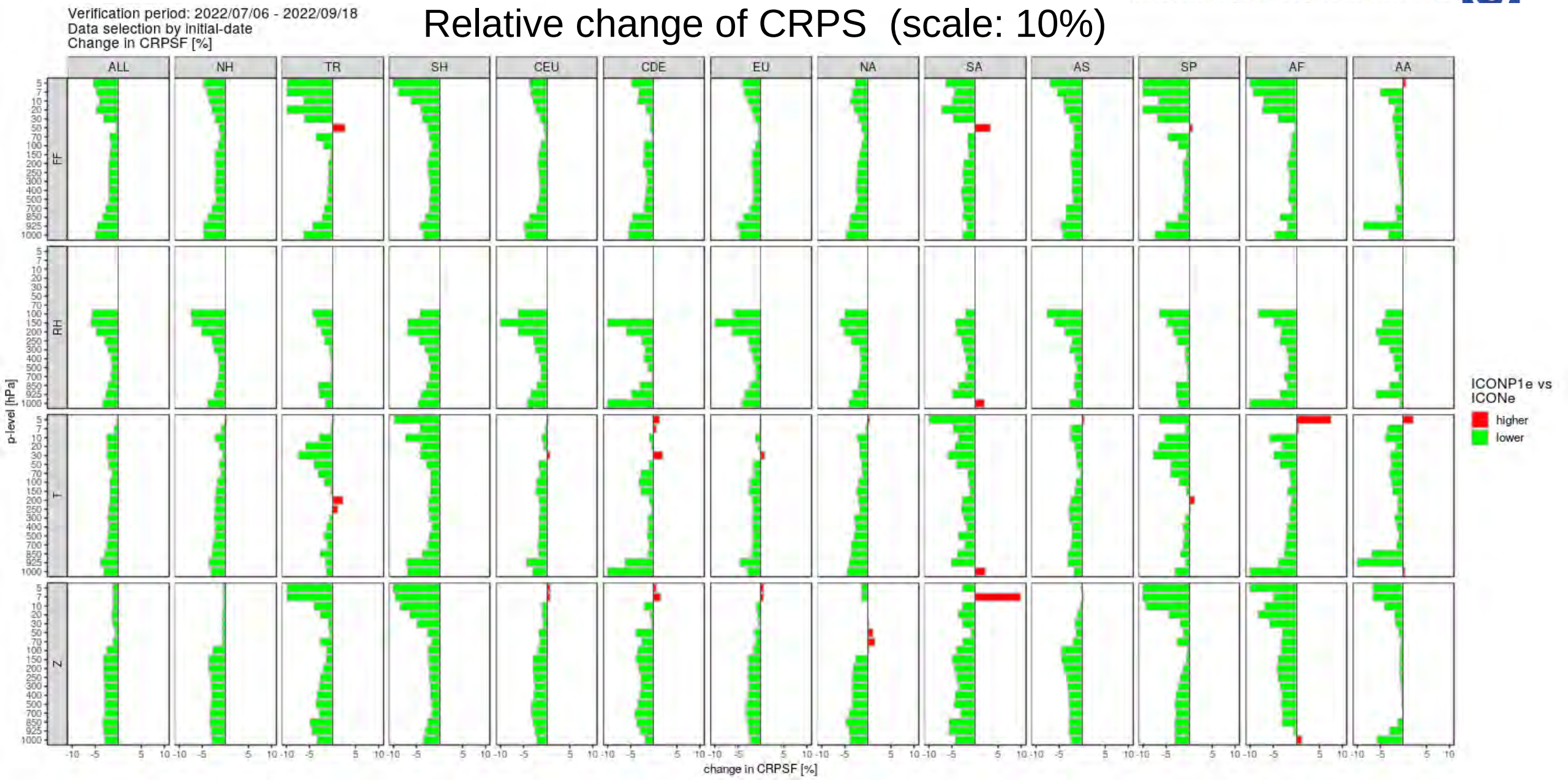
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Relative change of CRPS (scale: 10%)



Scorecard EPS radiosonde verification

Deutscher Wetterdienst



NCEP Ensemble Systems

Yuejian Zhu
Ensemble team leader
Environmental Modeling Center
NCEP/NWS/NOAA

September 2020

NCEP GEFS Status (No major upgrade since 2020)

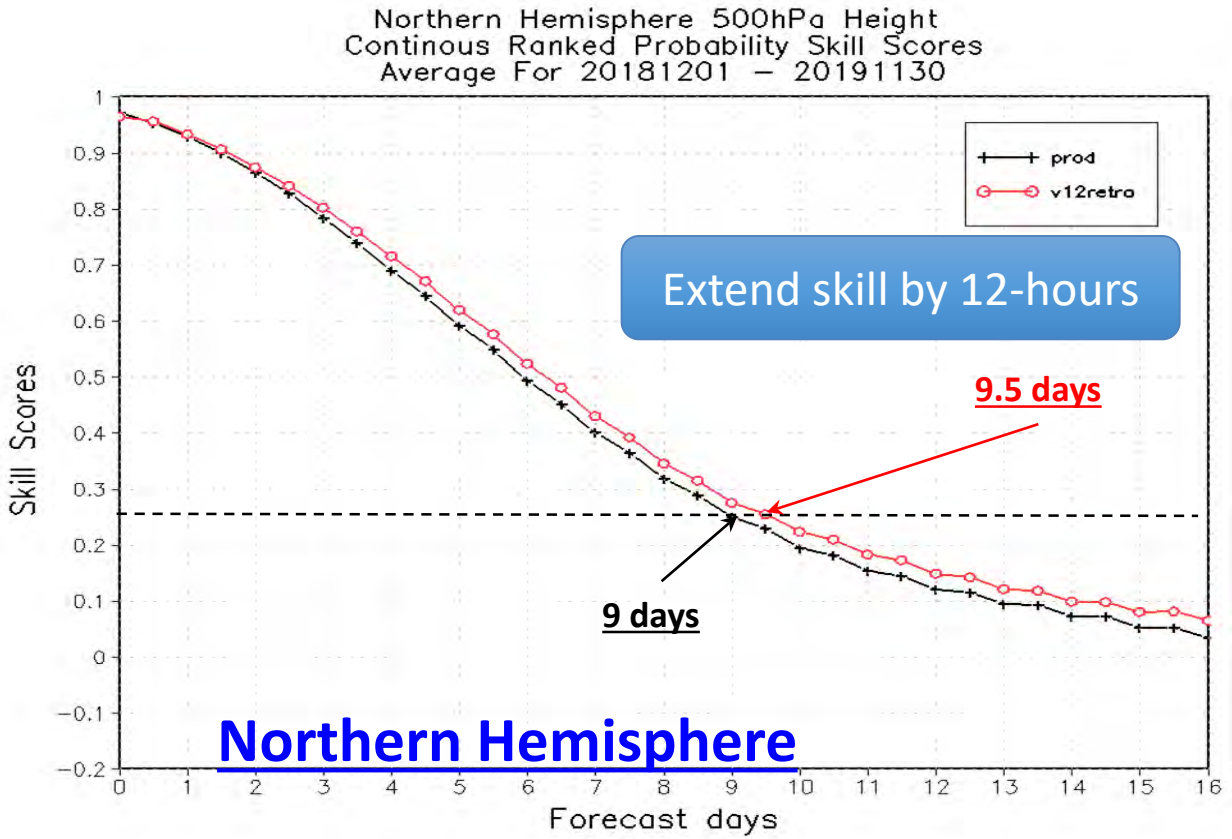
	V12 (current)	V13 (future)
GFS Model	FV3 (GFSv15)	FV3 (GFSv17)
Horizontal Resolution	C384 (25km)	C384 (25km)
Vertical resolution	L64 (hybrid)	L127 (hybrid)
Daily frequency	00, 06, 12 and 18UTC	00, 06, 12 and 18UTC
Forecast length	16days (35days for 00UTC)	16days (35 days for 00UTC)
Members	Control + 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° (selected) and 0.5°	0.25° (selected) and 0.5°
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 at 0.25dL75); Sea-ice (CICE6 at 0.25d); Aerosol (GOCART)
Reforecast	Offline – 31 years	Offline – 30 years (1993-2022)
Implementation	September 23rd 2020	2024

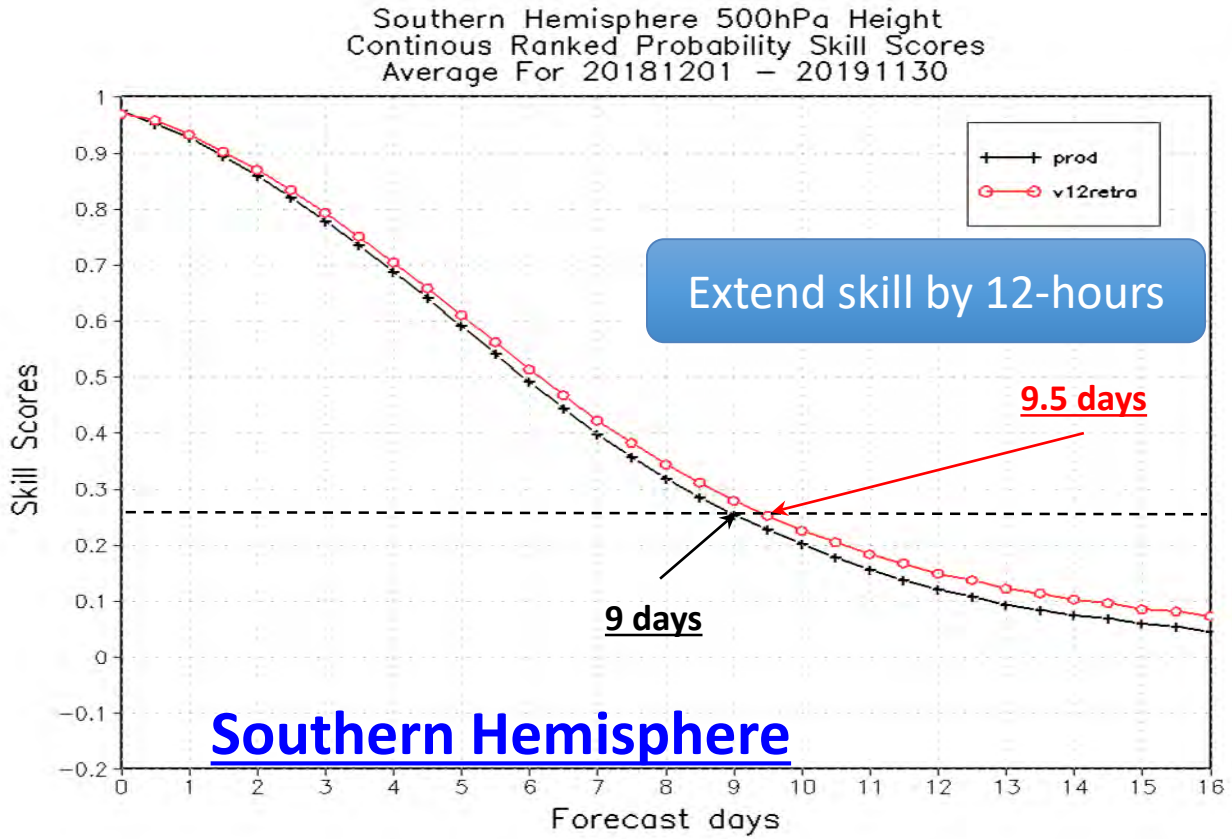
Benefits from GEFSv12 implementation (9/23/2020)

- 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

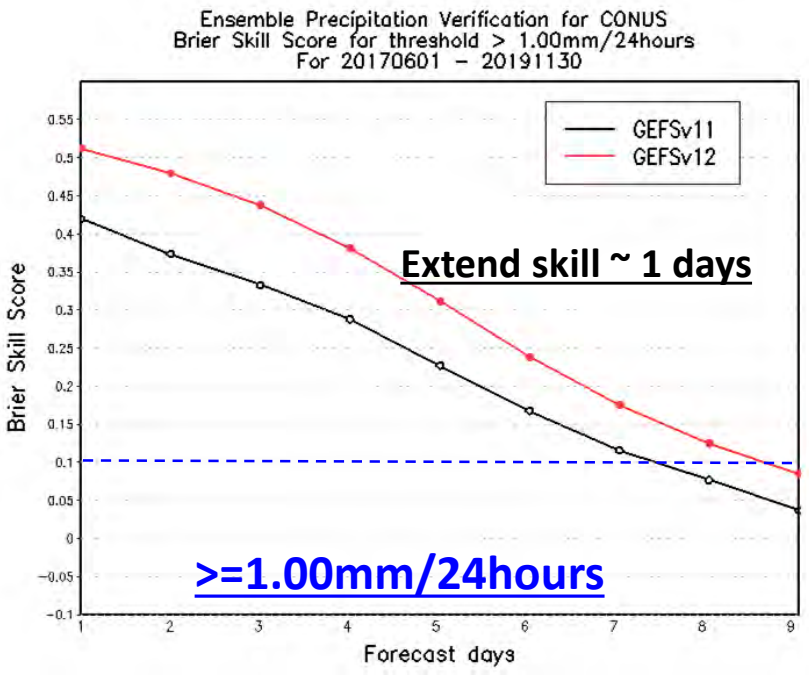
CRPS Skill of 500hPa geopotential height

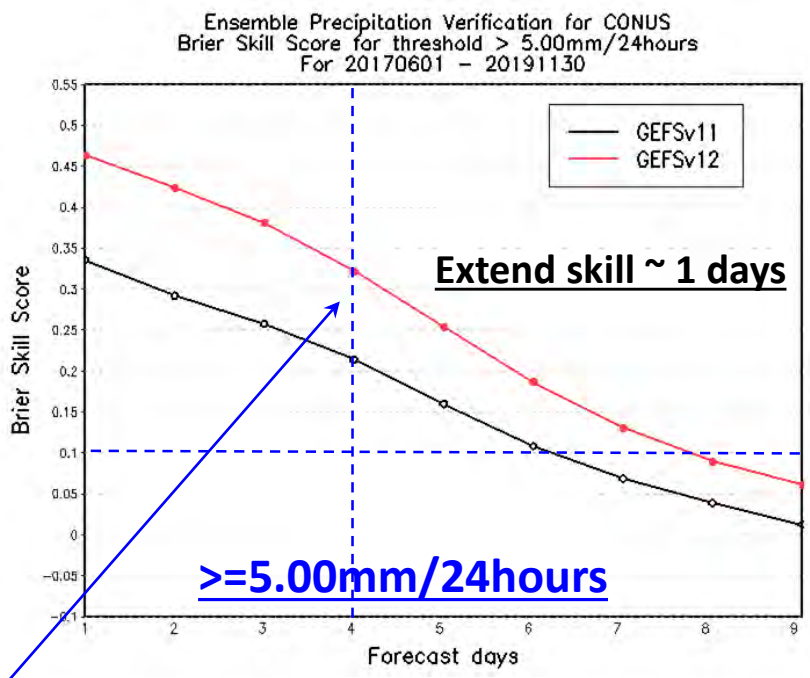


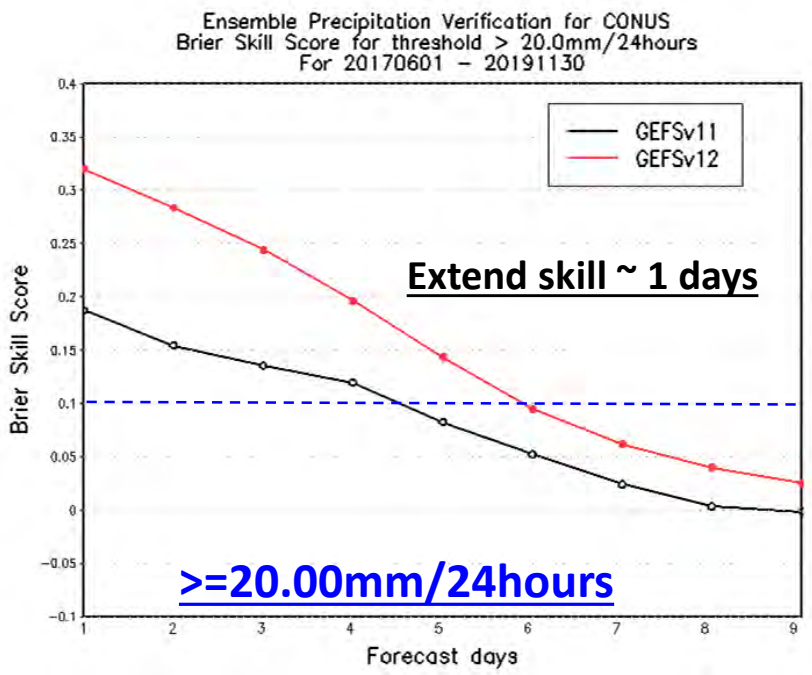


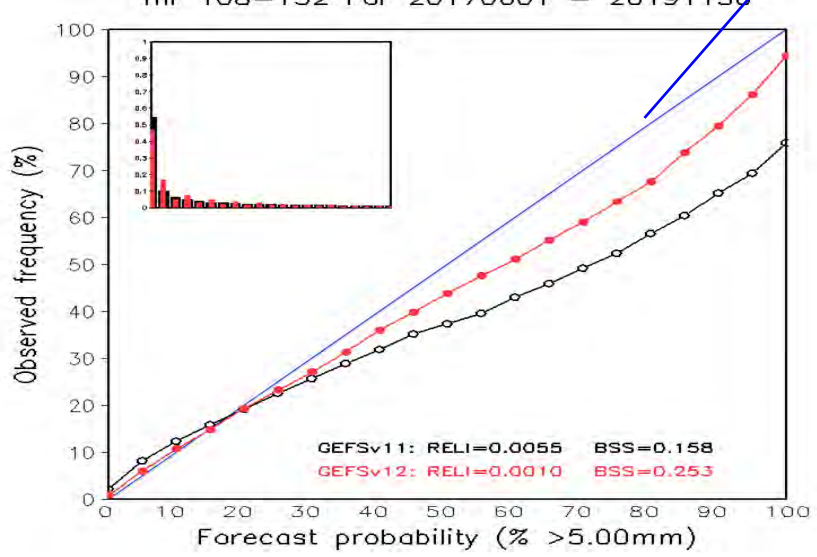
CRPSS – *Continuous Ranked Probabilistic Skill Score is one of evaluation tools to measure ensemble based probabilistic forecast. CRPSS=1 is for perfect forecast, CRPSS=0 is for no skill from reference (climatology), CRPSS=0.25 is similar to PAC=0.6 (pattern anomaly correlation of ensemble mean).* ***GEFS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

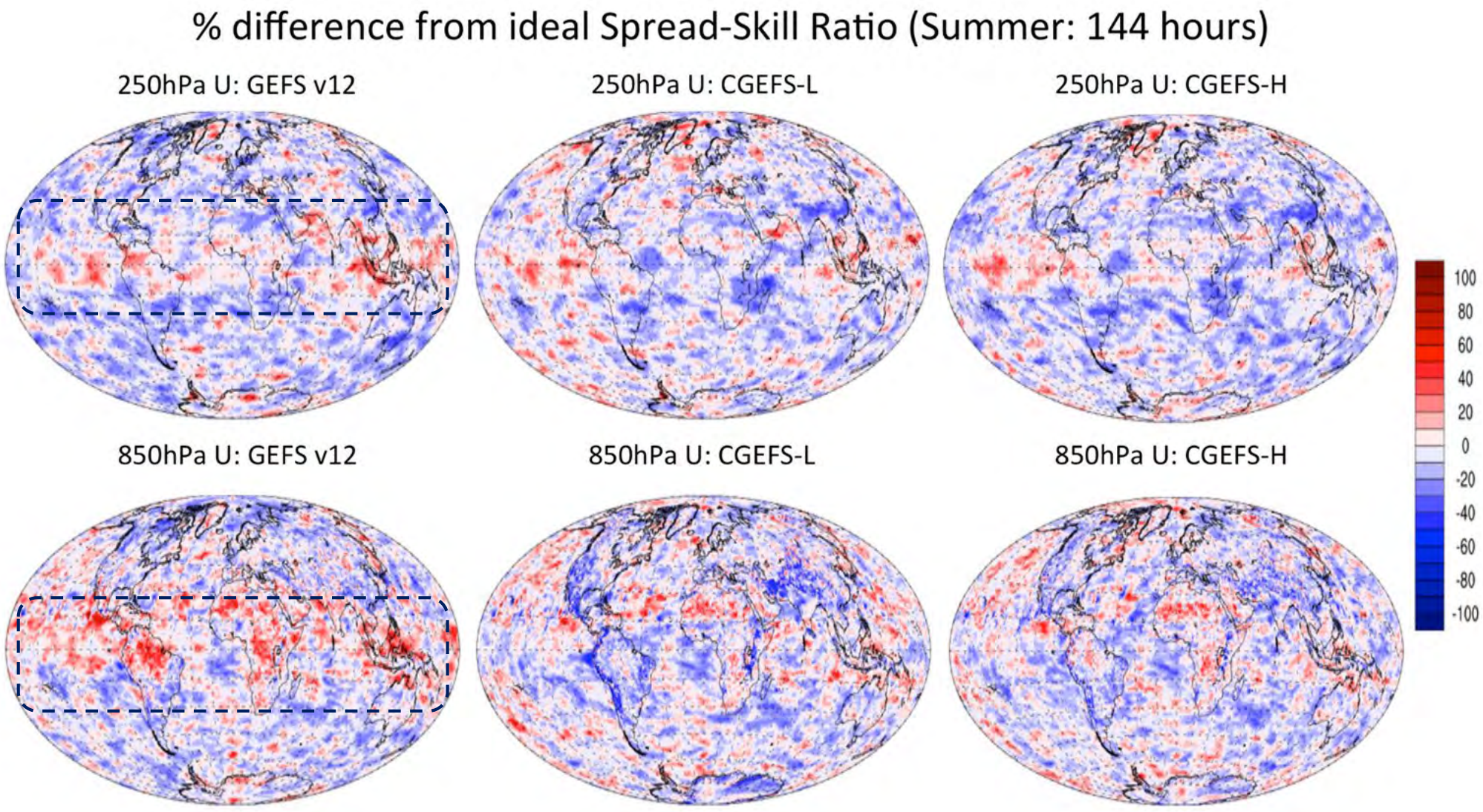
Statistically, GEFSv12 has extended one additional day of useful probabilistic forecast skill over GEFSv11.

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

GEFSv13 Expectations

- Unified Forecast System (UFS):
  - Full coupling system – atmo-land-ocean-ice-wave-aero
  - The same model for DA, GFS and GEFS
- Atmospheric model
  - GFS v17 with advanced physics included Thompson MP (replace GFDL MO), NOAH MP (replace NOAH LSM), sa-TKE-EDMF, and GWD to include non-station and turbulence
- 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 (75 vertical levels) and sea-ice model
  - Forecast lead – 35 days to cover sub-seasonal prediction
  - Model perturbations
    - Atmosphere (SKEB and SPPT 5-scale)
    - Ocean (oSPPT and ePBL; all 5-scale)
- Support package
  - Replay reanalysis and reforecast for 30 years (1993 – 2022; offline)
- Target implementation time
  - 2024
- Experiments of preliminary GEFSv13 – fully coupled system
  - See next 4 slides are based on 2-year experiments (once per week, initialized at 00UTC, 11 members).

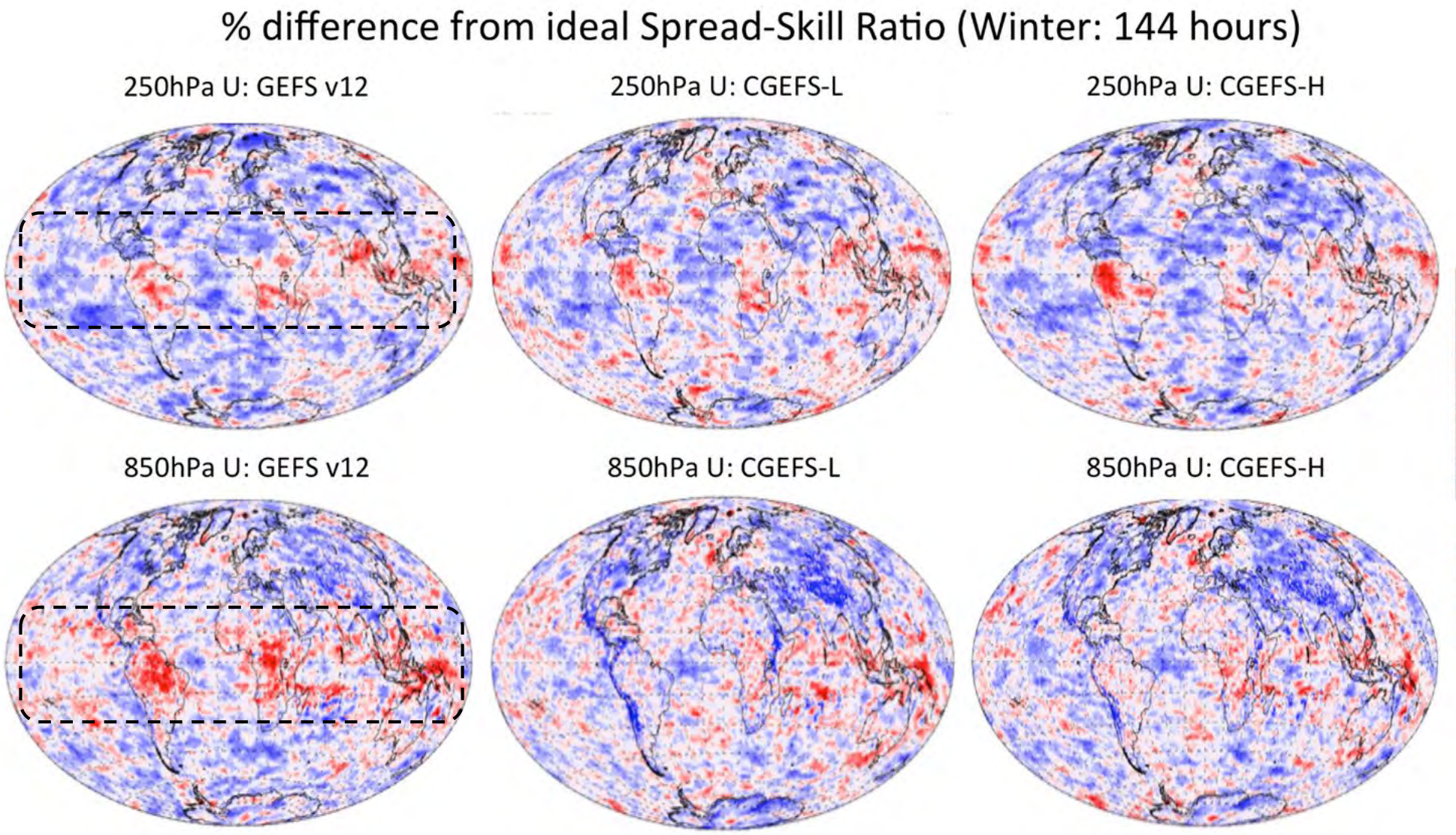
Spread-Error Ratio (April - September, 52 cases, 144-hr)



The boreal summer six months (April - September) error-spread ratio map of 850hPa zonal winds (upper row) and 250hPa zonal winds (lower row) at 144 hours (6 days) forecast for the GEFSv12 reforecast (left column), CGEFS-L (middle column) and CGEFS-H (right column).

GEFSv12 – current operation; CGEFS-L – Coupled GEFS at 0.5d; CGEFS-H – Coupled GEFS at 0.25d

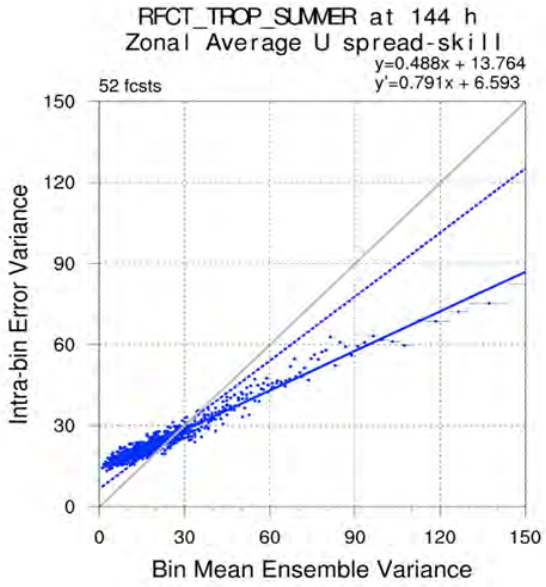
Spread-Error Ratio (October - March, 52 cases, 144-hr)

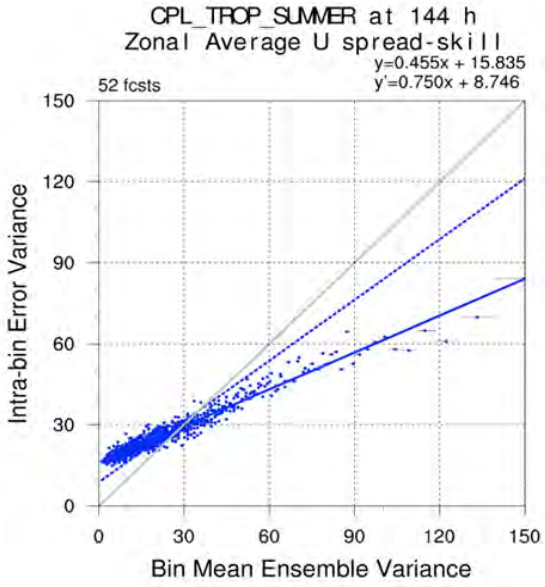


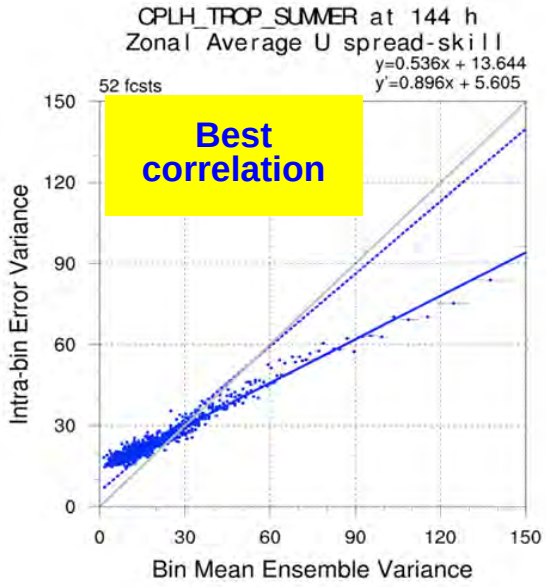
The boreal winter six months (October - March) error-spread ratio map of 850hPa zonal winds (upper row) and 250hPa zonal winds (lower row) at 144 hours (6 days) forecast for the GEFSv12 reforecast (left column), CGEFS-L (middle column) and CGEFS-H (right column).

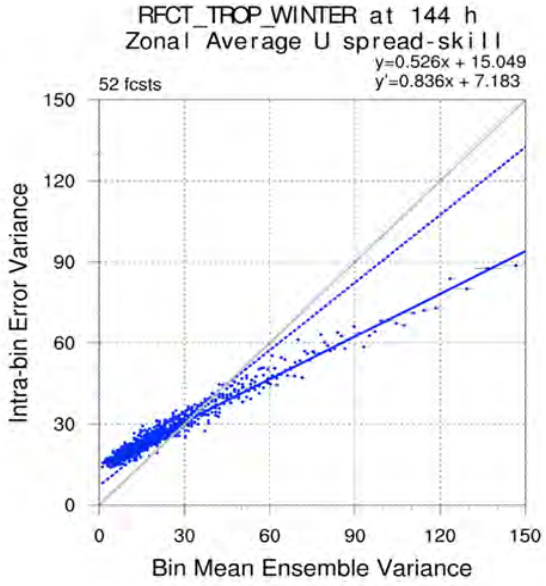
GEFSv12 – current operation; CGEFS-L – Coupled GEFS at 0.5d; CGEFS-H – Coupled GEFS at 0.25d

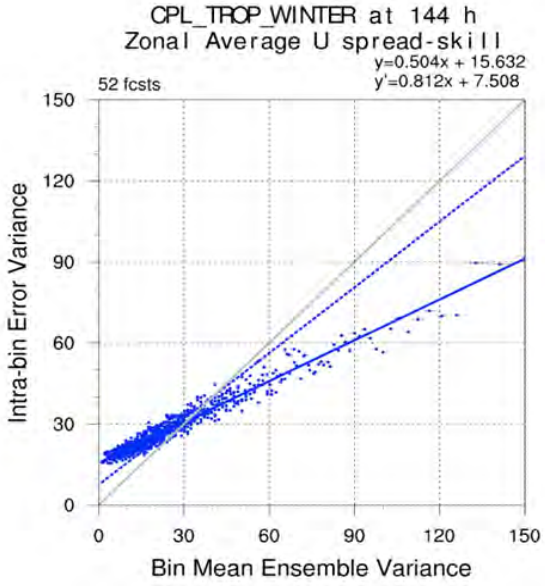
The Scatter Plot - Linear Variance Method for Diagnostics

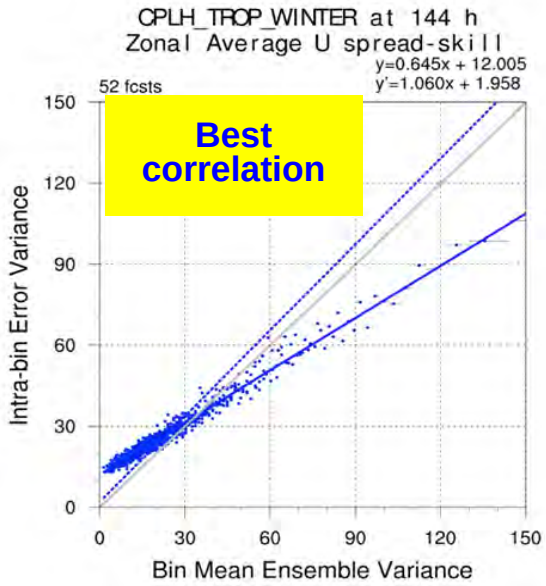








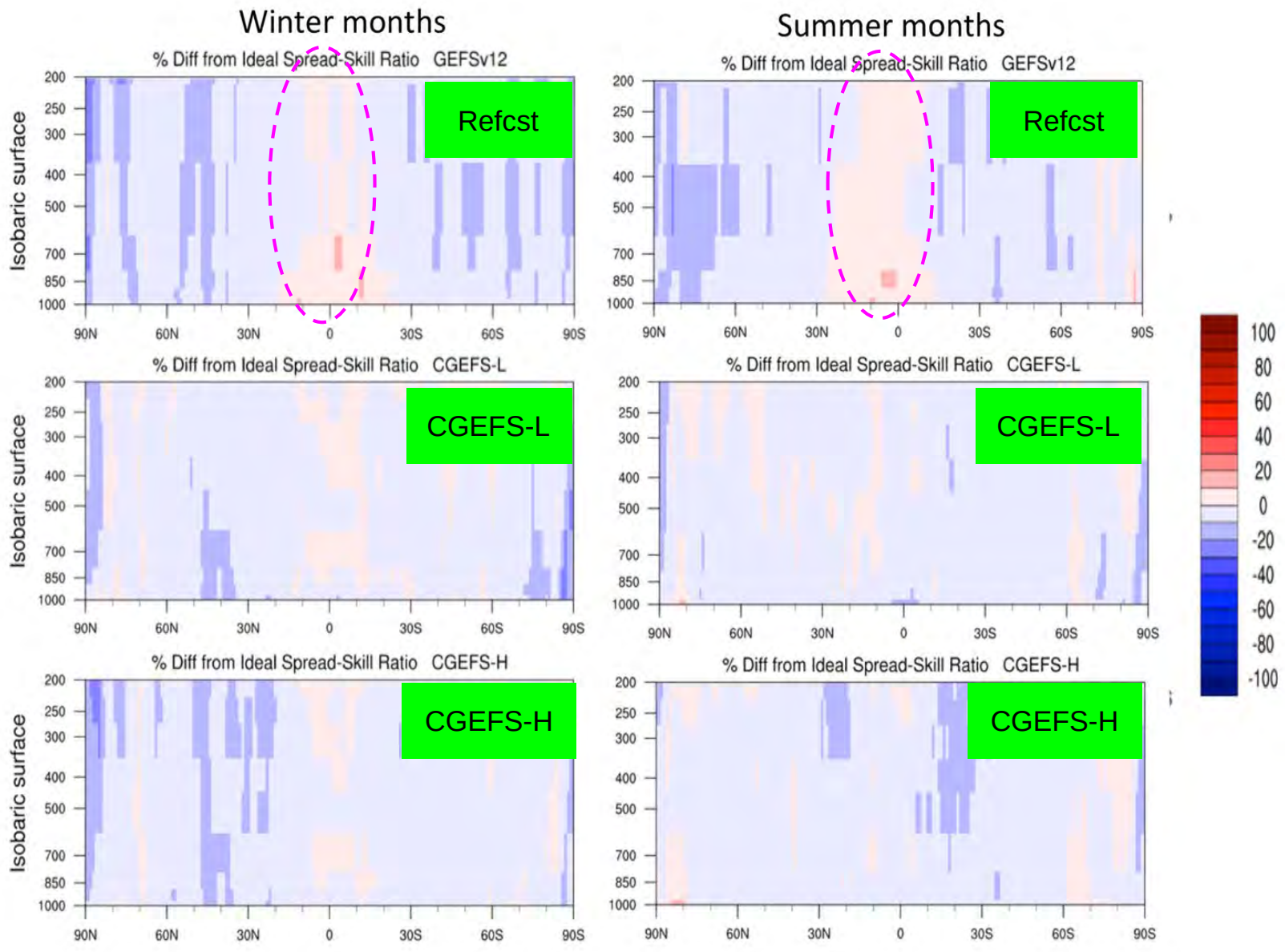




- *Linear Variance Method for Diagnostics (Kolczynski, 2011)*
- *The scatter plot of ensemble bin variance and mean error variance for boreal summer (6 months; upper row) and boreal winter (6 months; lower row) of tropical zonal winds on the 250hPa and forecast lead-time at 144 hours (6 days). The GEFSv12 reforecast is on the left column, CGEFS-L is on the middle column and CGEFS-H is on the right column.*
- *Solid blue line is for regression line; dot blue line is for assimilated regression line if there are sufficient ensemble*

GEFSv12 – current operation; CGEFS-L – Coupled GEFS at 0.5d; CGEFS-H – Coupled GEFS at 0.25d

Vertical cross section of the RMS error - spread ratio for zonal winds



- *The vertical cross section of the RMS error and ensemble spread ratio for boreal winter six months (left column) and boreal summer six months (right column) of zonal wind from surface (1000hPa) to 200hPa in vertical, and for the GEFSv12 reforecast (top), GGEFS-L (middle) and CGEFS-H (bottom)*
- *Forecast lead-time - 144 hours (6 days)*
- *Tropical over-dispersion for GEFSv12 reforecast is our major concern*
- *CGEFS-L reduces tropical over-dispersion*
- *CGEFS-H reduces tropical over-dispersion*

GEFSv12 – current operation; CGEFS-L – Coupled GEFS at 0.5d; CGEFS-H – Coupled GEFS at 0.25d

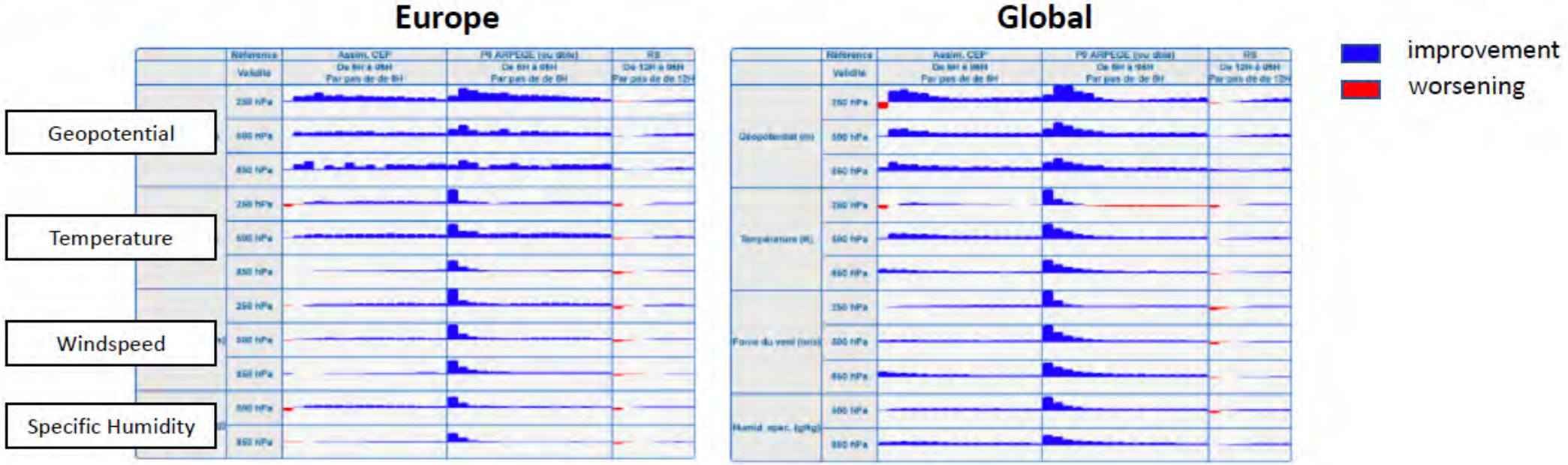
Short-Range Ensemble Forecast (SREF) System (no upgrade – frozen)

- 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

Recent evolution of ARPEGE-EPS

- ***New version released in June 2022***
- ***Increase of horizontal resolution*** from 7.5-36 km (France-antipodes) to 5-24 km (same as the deterministic forecast)
  > 34 + 1 members
- ***Model error scheme update***: from multi-physics to random perturbations of 50 parameterization parameters



Change in CRPS change from old to new ARPEGE-EPS*
vs. ECMWF analyses, ARPEGE analyses and Radiosoundings

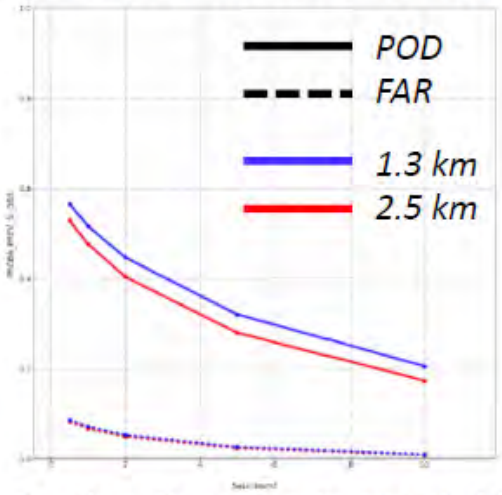
* Continuous Ranked Probability Score

Courtesy L. Raynaud

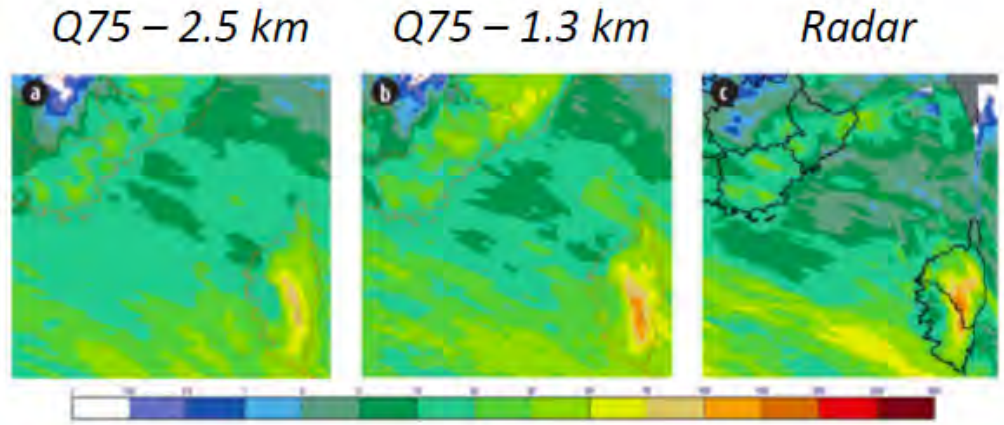
Recent evolution of AROME-EPS

- ***New version released in June 2022***
- ***Increase of horizontal resolution*** from 2.5 km to 1.3 km (same as the deterministic forecast) > 16+1 members
- ***Ongoing***: development of perturbed parameter approach to add to or replace the SPPT scheme

POD and FAR
6-hour accumulated rainfall



Precipitation intensity threshold



24-hour accumulated precipitation
valid on 08 November 2021, 2100 UTC

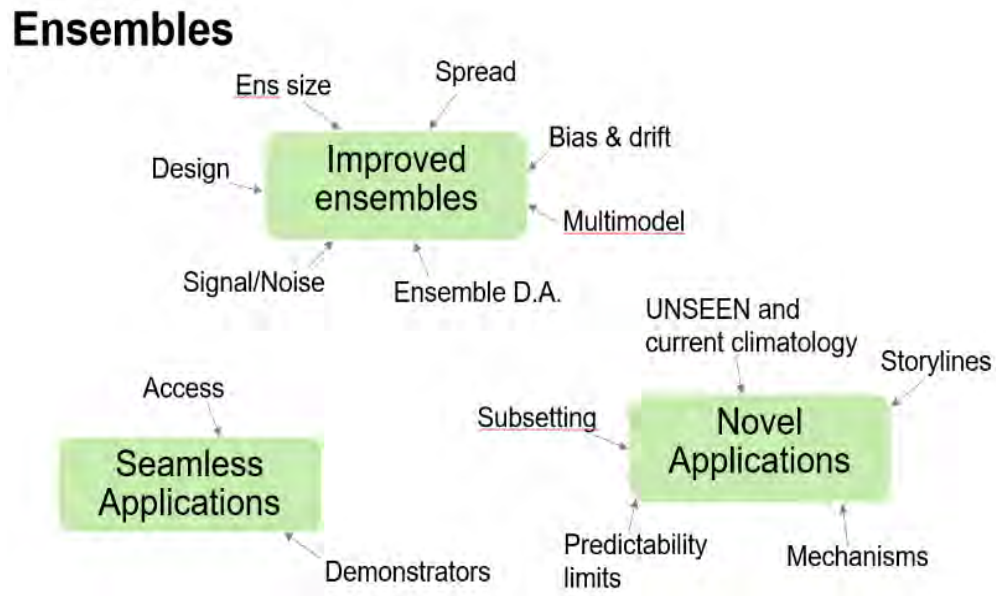
- Improved detection while keeping a reduced number of false alarms

Courtesy L. Raynaud

Slides from the Met Office

ENSEMBLES Research and Innovation activities

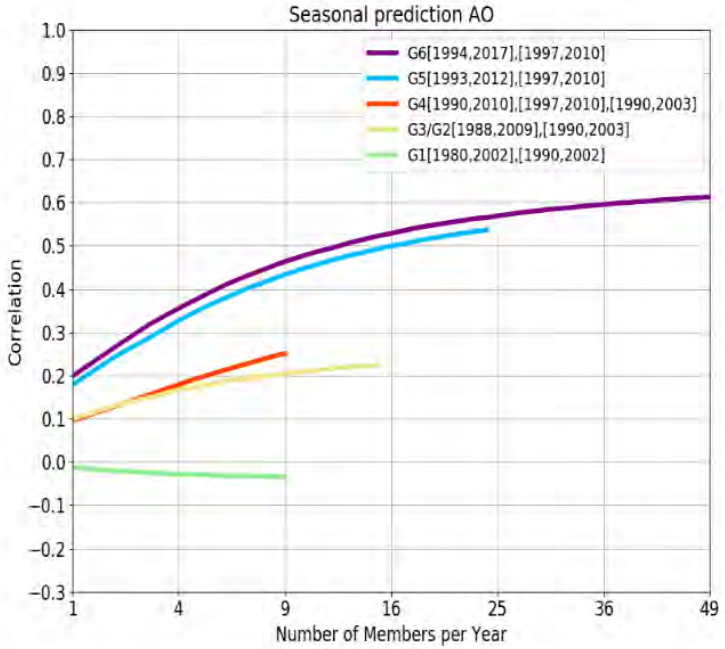
- **Cross office view of use of ensembles**
- **Ensembles for much more than just forecast uncertainty**
- **Key activities:**
  - **A. Ensemble weather reforecasts or equivalent data**
  - **B. Larger seasonal and decadal ensembles *(~4X)***
  - **C. Retire 10km deterministic model in favour of MOGREPS-G**
  - **D. Climate projection initial condition ensembles**
  - **E. New applications of ensembles**



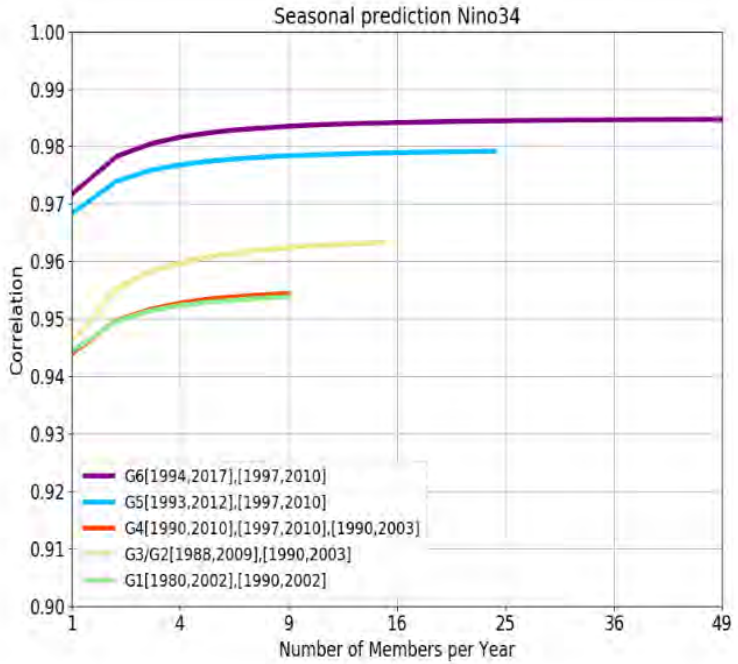
Adam Scaife

B) Large ensembles => improved prediction skill

Extratropical Skill – Arctic Oscillation



Tropical Skill – El Nino-Southern Oscillation



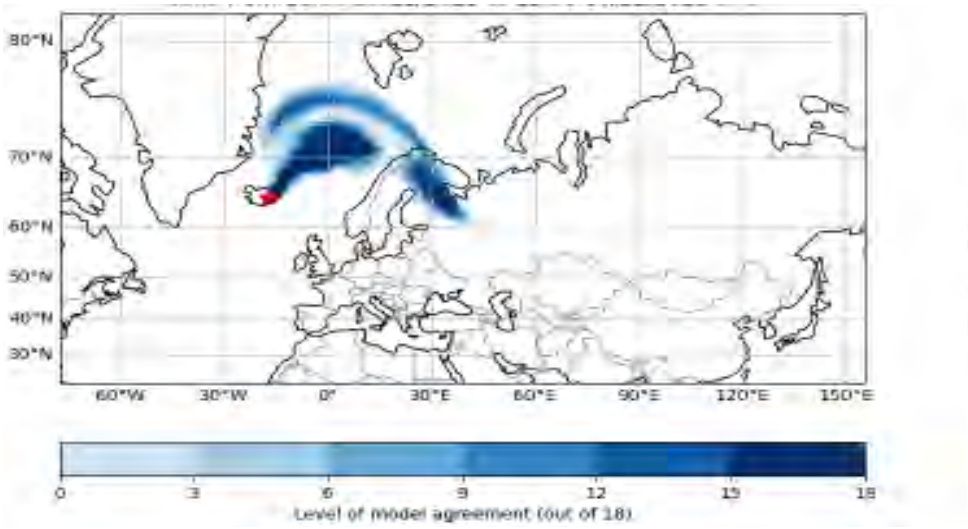
Met Office now on 6th generation seasonal prediction system

Reforecasts allow us to track progress and measure increasing skill

Large ensembles as important as model changes for extratropics

Adam Scaife

E) New applications of ensembles:

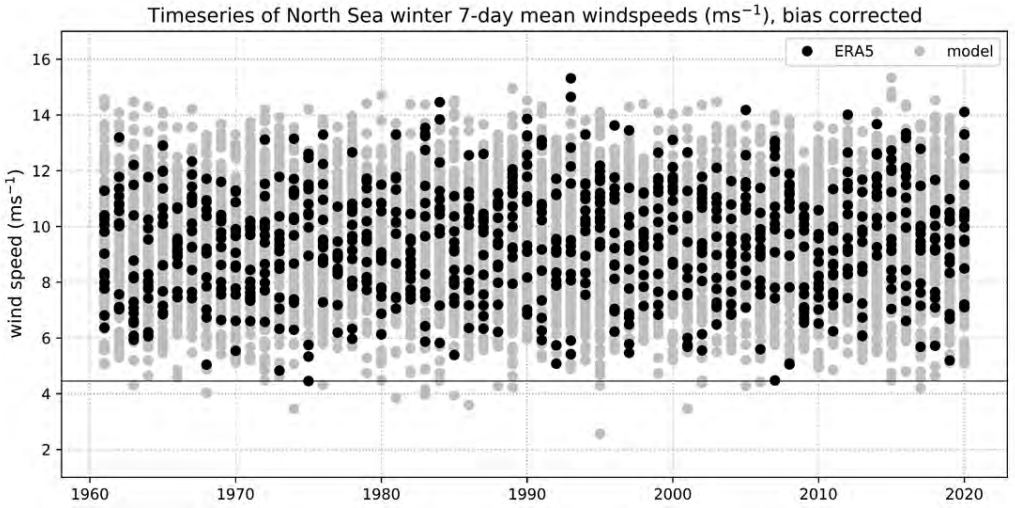


Source Term Uncertainty

Expert elicitation or perturbations or inversion

Timing, Height, Quantity, Composition

Leadbetter et al

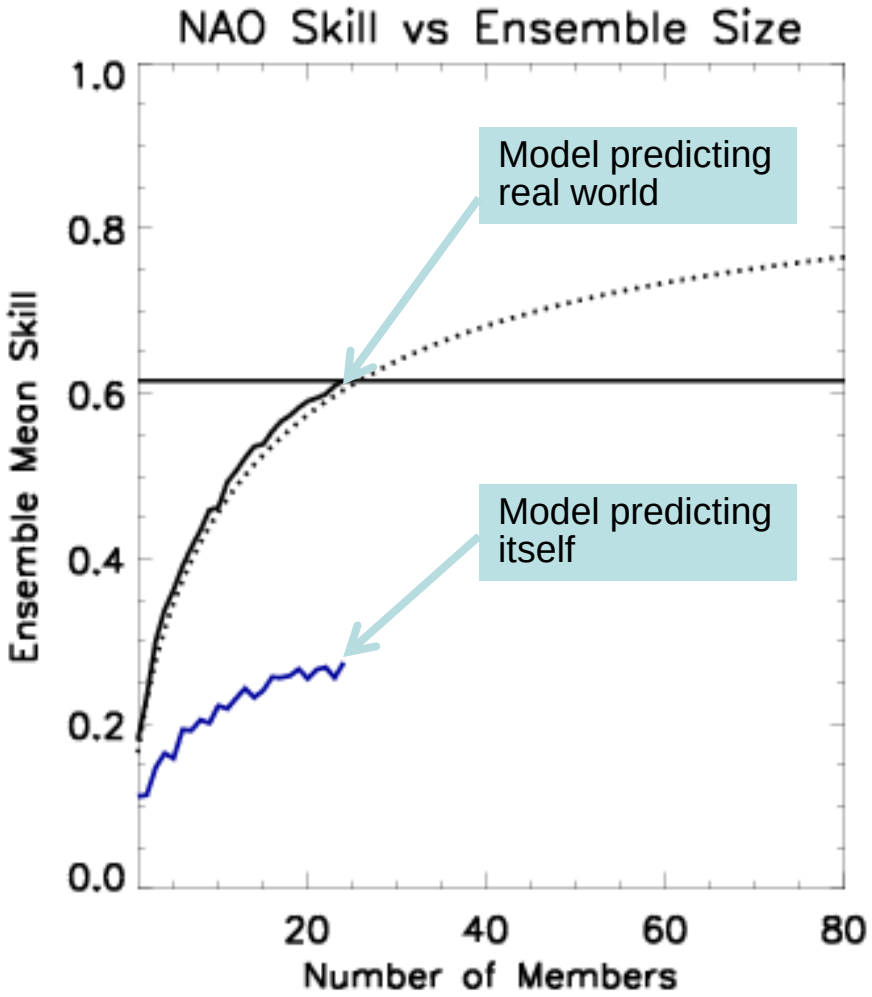


Kay et al

Dispersion forecasts using ensembles (left)

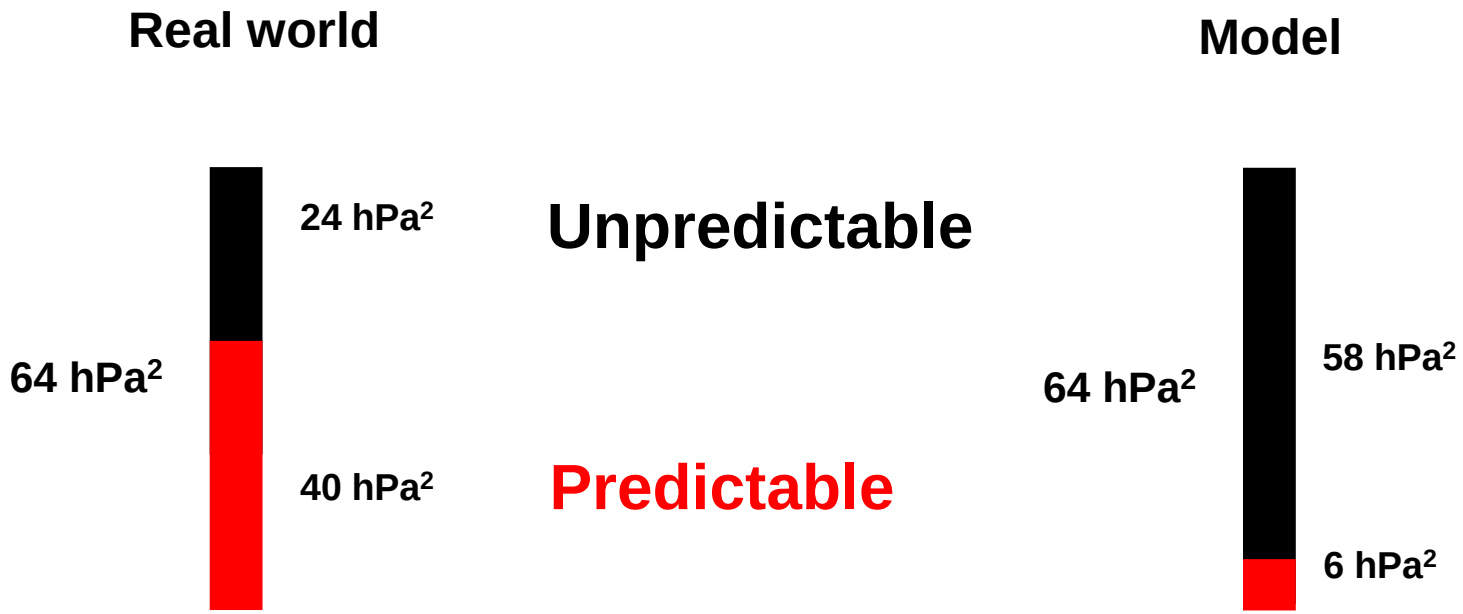
UNSEEN ‘wind droughts’ and winter energy resilience (above)

Last Point: an unresolved ‘Signal to Noise Paradox’



Model is better at predicting the real world than itself!

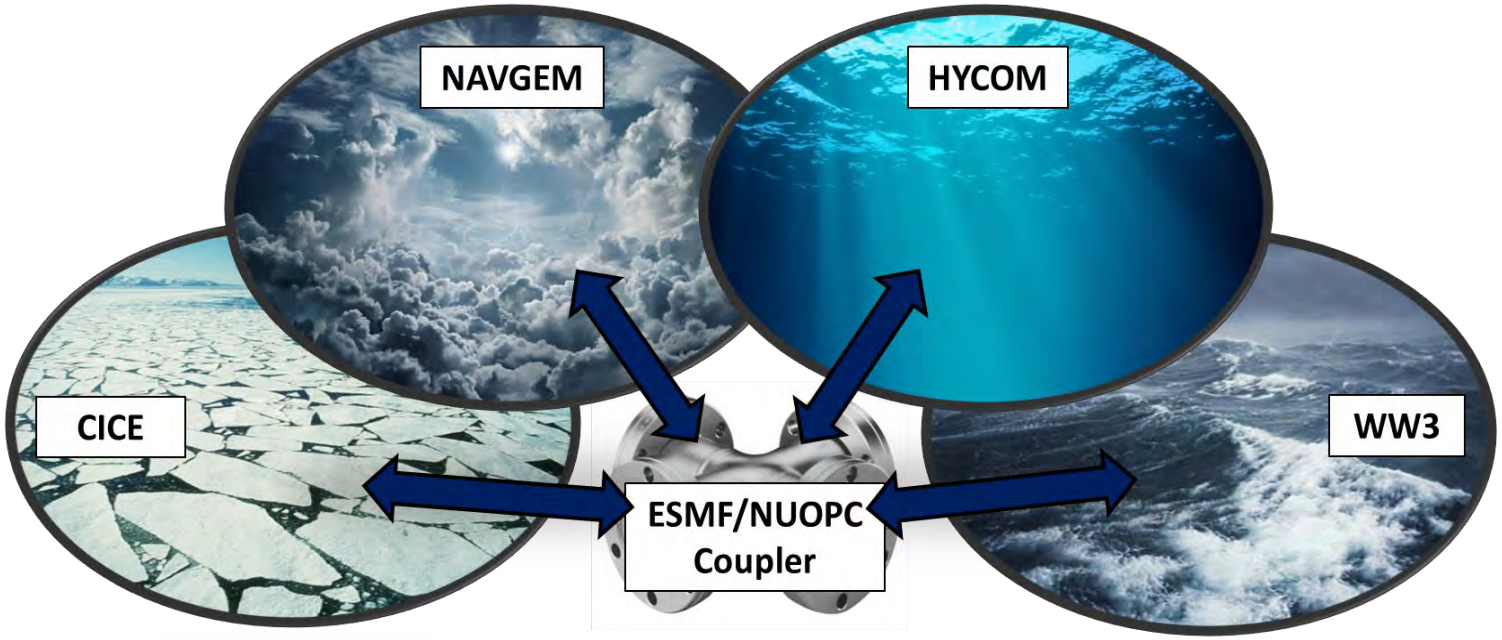
Occurs across monthly, seasonal, decadal timescales



Scaife and Smith, 2018

Slides from NRL

U. S. Navy ESPC Experiments

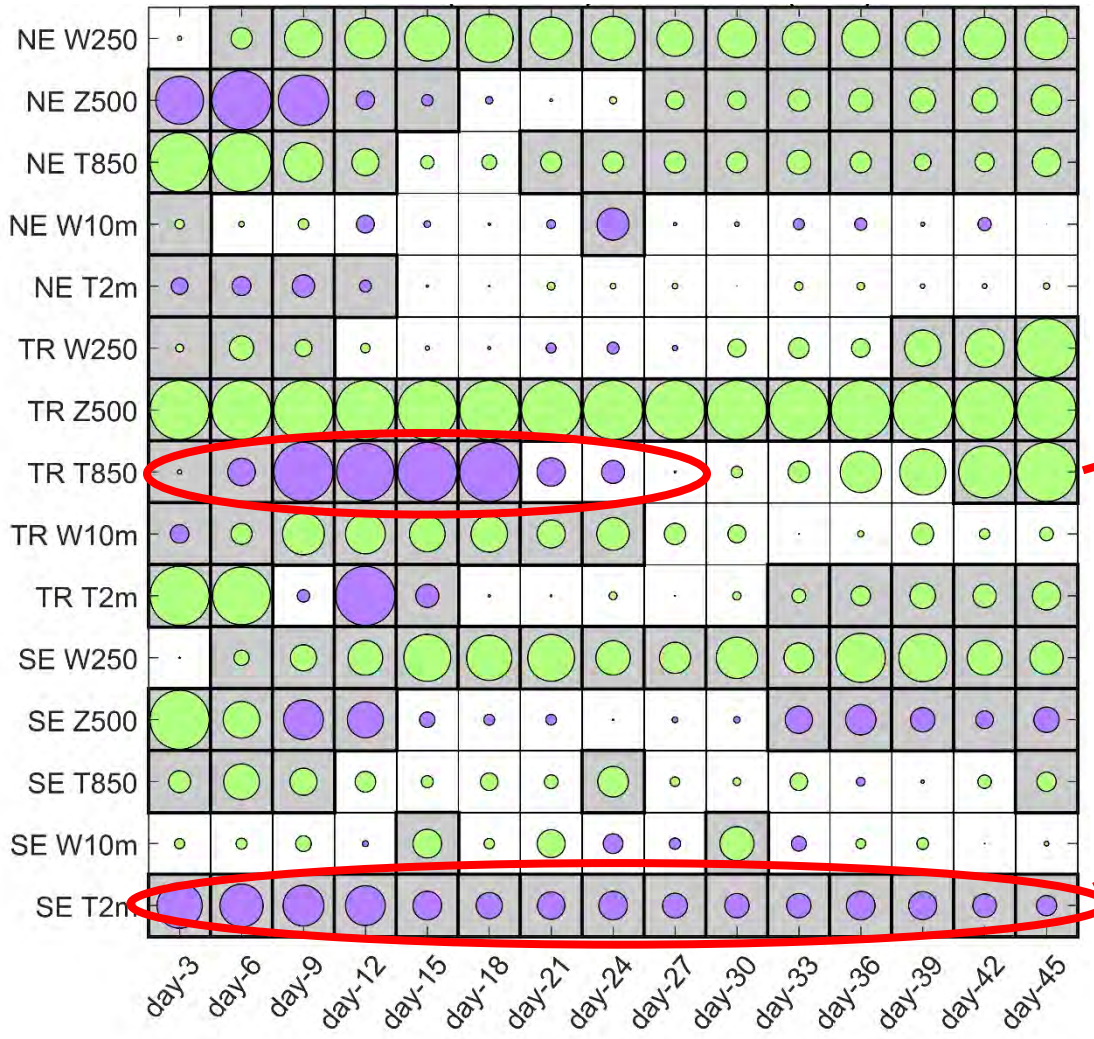


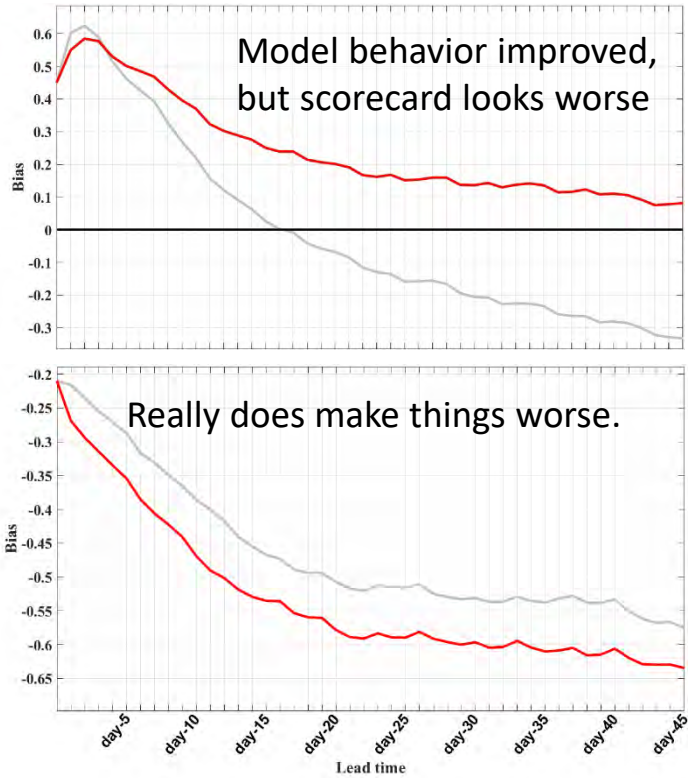
Navy Earth System Prediction Capability (Navy ESPC)

- 45-day 16-member ensemble forecasts became operational at Fleet Numerical Meteorology and Oceanography Center on 31 August 2020
- Operational ensemble configuration has 37 km atmosphere and 1/12 deg ocean and sea ice components
- See Barton et al. 2020 Earth and Space Science for detailed description
- Testing Analysis Correction-based Additive Inflation (ACAI, Crawford et al. 2020) for model uncertainty and bias correction.

ACAI in Navy ESPC Ensemble: Bias

Change in Bias : ACAI vs CTRL (max=30%)



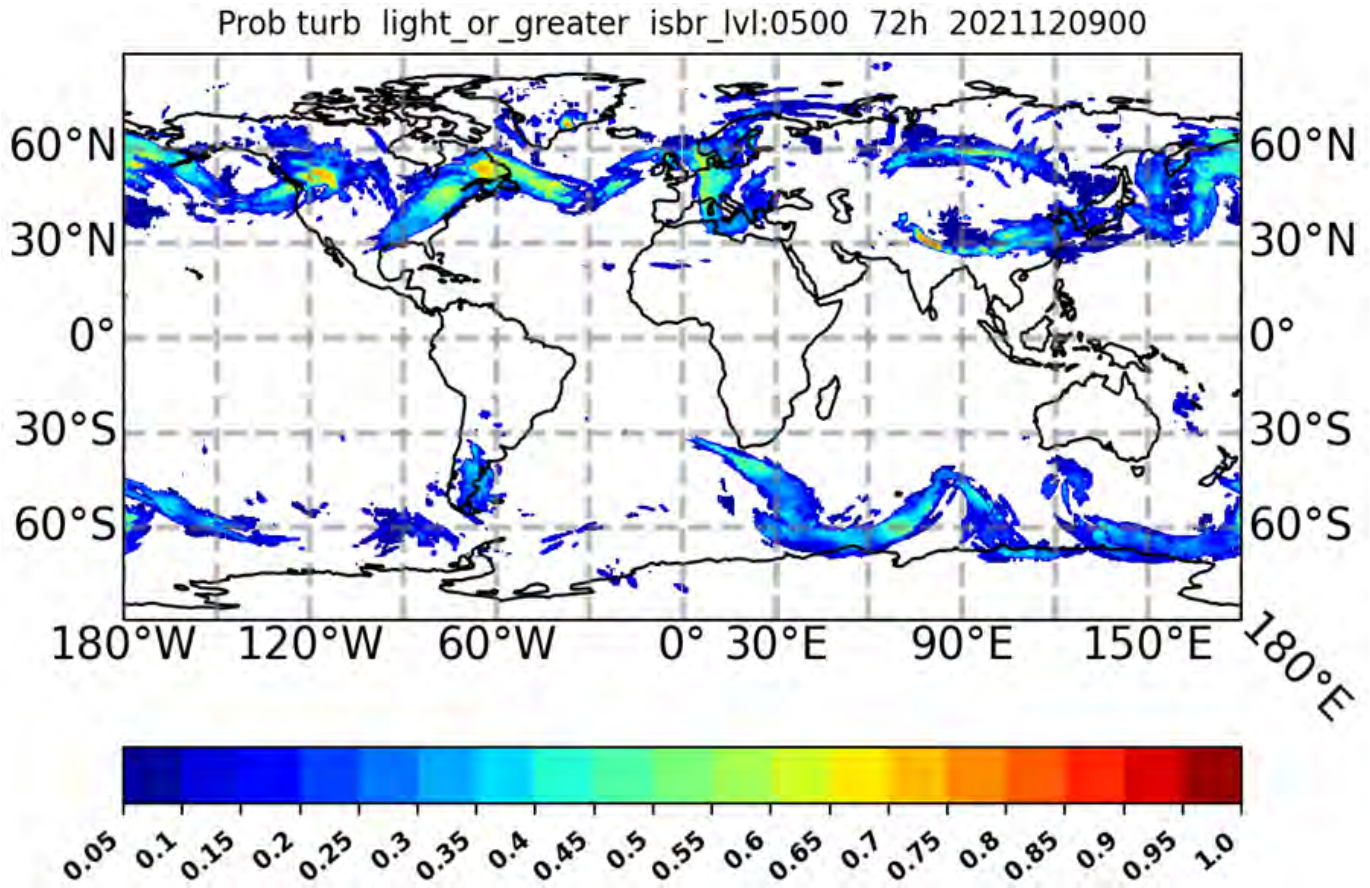


Control
ACAI

Crawford et al., In prep.

Post-Processing for New Products in the NAVGEM Ensemble

We developed and validated a calibration prototype for the probability of turbulence severity with good results (J. McLay).

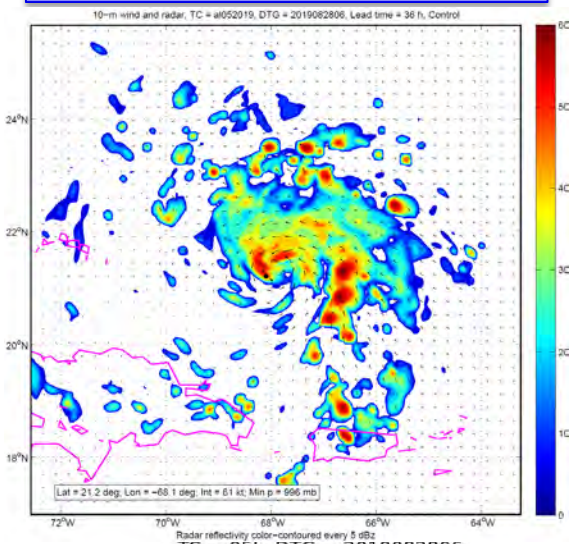


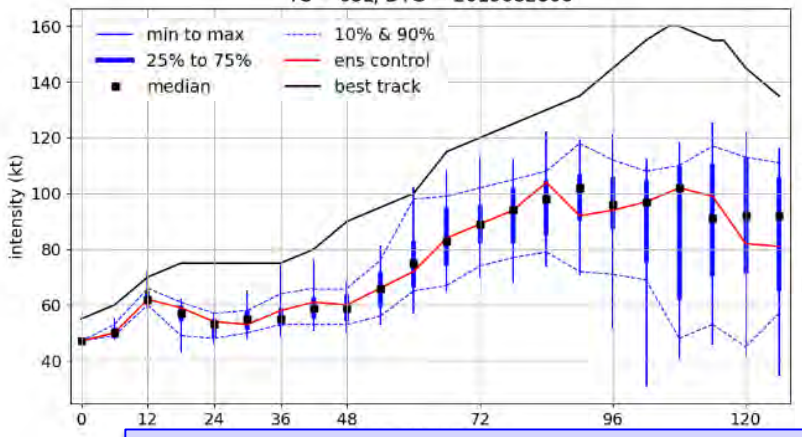
Calibrated (post-processed) NAVGEM ensemble T+72h forecast probability of 500hPa turbulence severity ≥ light category initialized 00UTC 09 Dec. 2021. The structure of the probability pattern reflects the underlying presence of vertical wind shear (associated with jet streaks and frontal zones) as well as zones of synoptic-scale deformation and convergence.

U.S. NAVAL RESEARCH LABORATORY

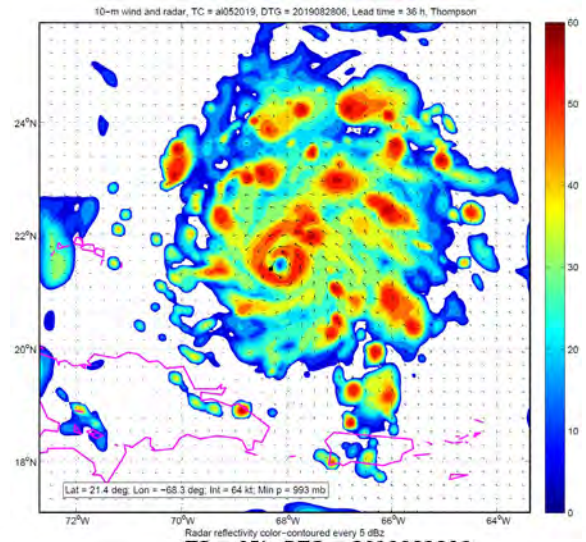
COAMPS-TC Ensemble: Exploring sensitivity to microphysics

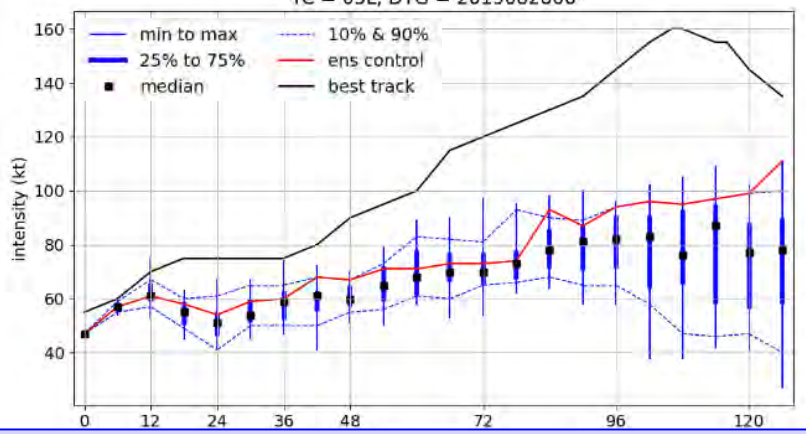
Control (NRL) Microphysics



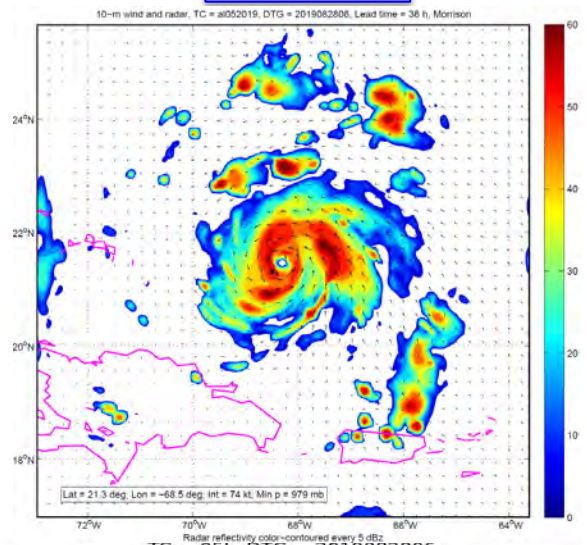


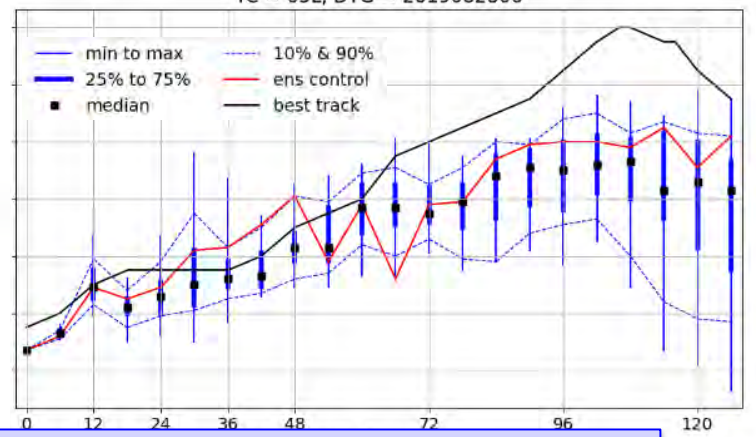
Thompson





Morrison





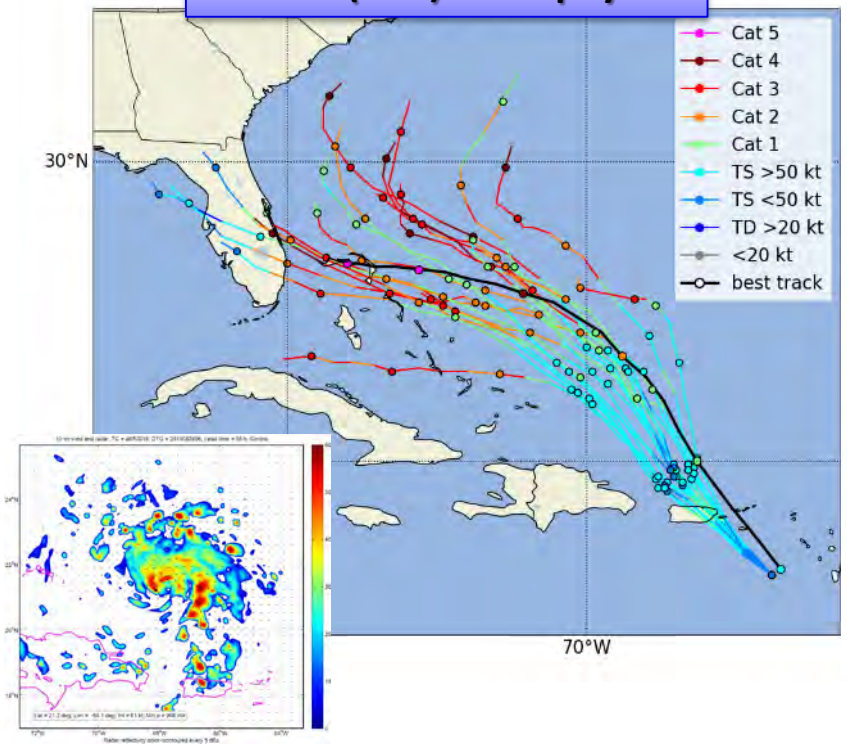
- TC size, intensity, and structure are all found to be quite sensitive to choice of microphysics scheme
- Track forecast is somewhat less sensitive
- A multi-microphysics ensemble (1/3rd of members use NRL, 1/3rd Thompson, 1/3rd Morrison) currently in-testing at NRL

U.S. NAVAL RESEARCH LABORATORY

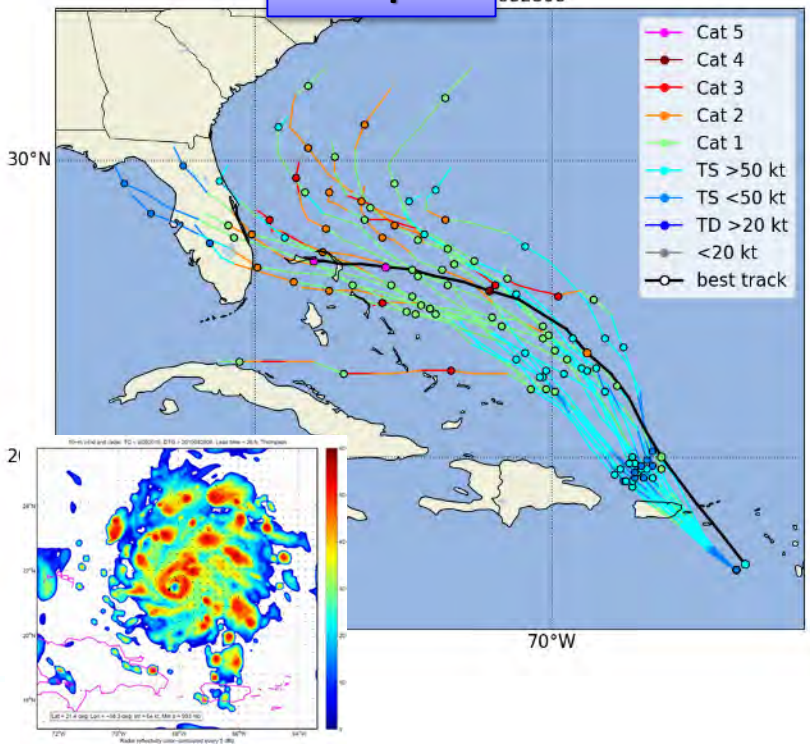
COAMPS-TC Ensemble: Exploring sensitivity to microphysics

Will Komaromi, Alex Reinecke, Jim Doyle, Jon Moskaitis

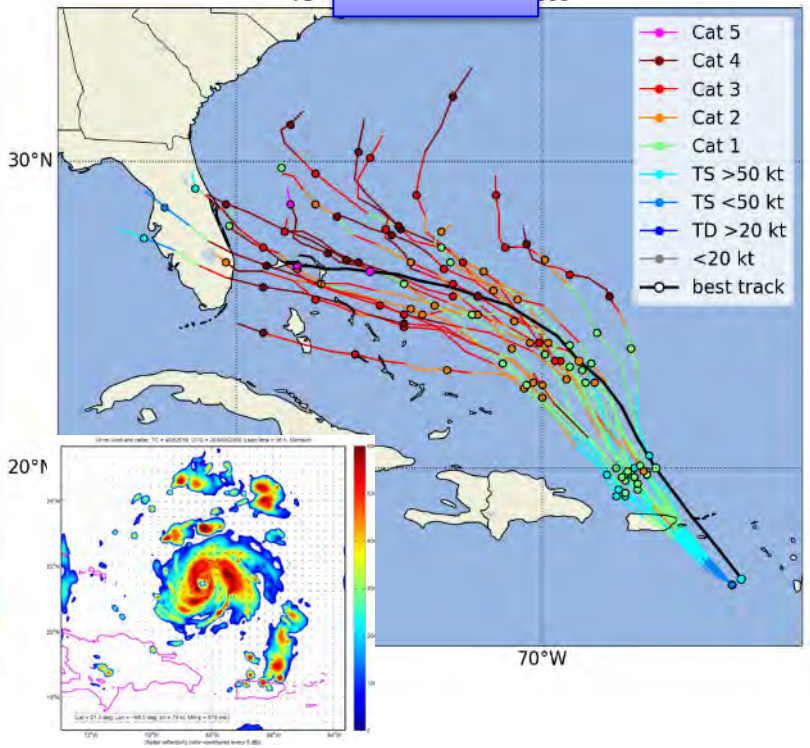
Control (NRL) Microphysics



Thompson



Morrison



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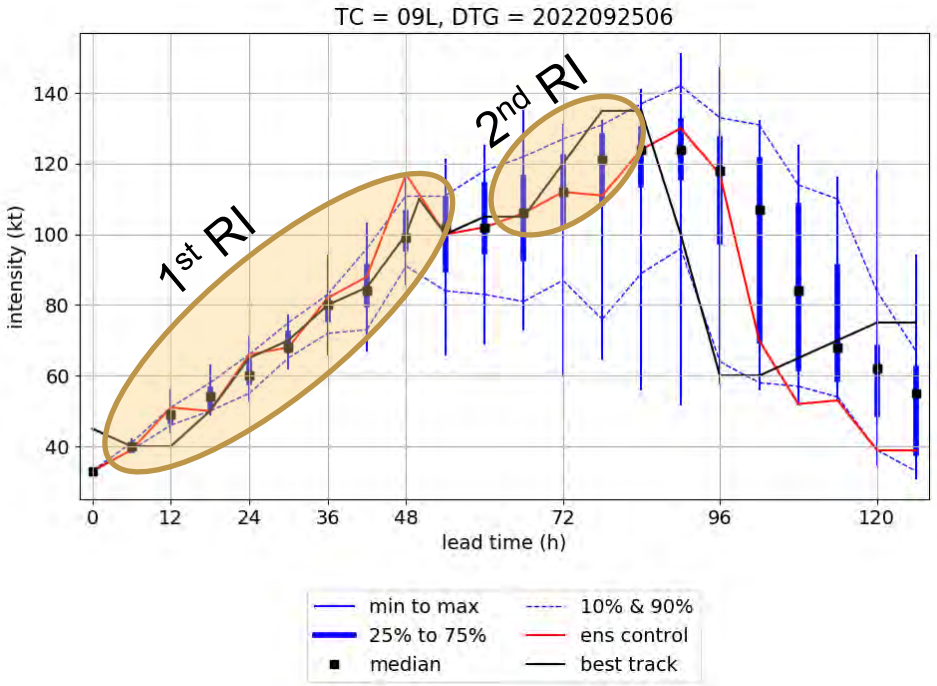
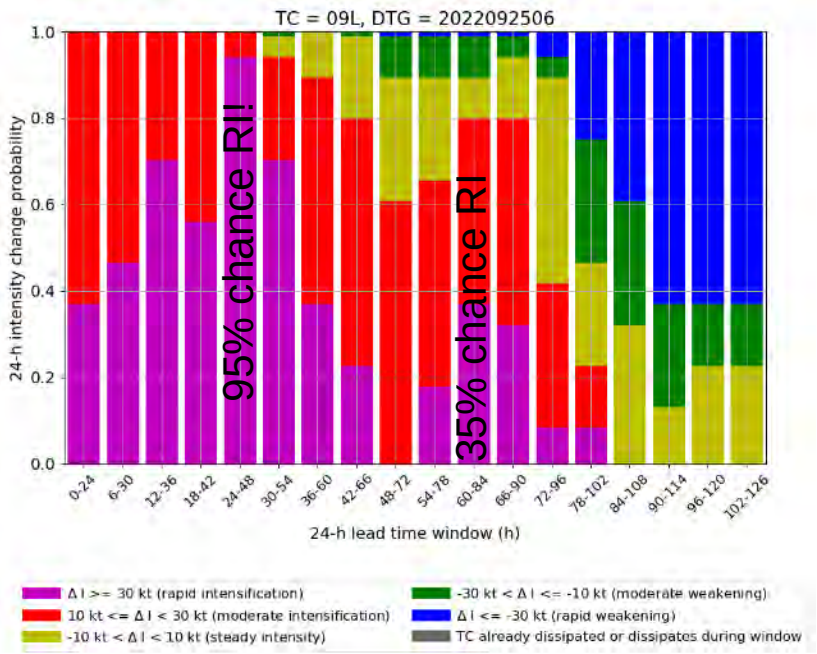
COAMPS-TC Ensemble: Hurricane Ian (2022)

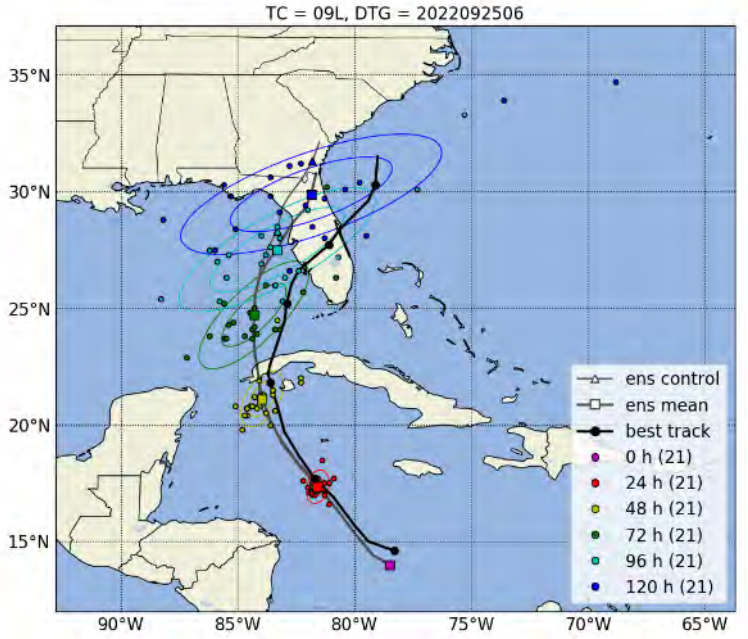
Probabilistic Intensity Candlestick Forecast



Probabilistic RI forecast



Track Forecast w/ 1/3rd and 2/3rd Probability Ellipses



- Hurricane Ian underwent rapid intensification (RI), from 40 kt at 1800 UTC 25 Sep 2022 to 110 kt at 0800 UTC 27 Sep 2022 (Cuba landfall), or +70 kt in 38 h.
  → 95% probability of RI per COAMPS-TC Ensemble
- A second RI period occurred prior to Florida landfall: +35 kt in 24 h, from 100 kt at 1200 UTC 27 Sep 2022 to 135 kt at 1200 UTC 28 Sep 2022.
  → 35% probability of RI per COAMPS-TC Ensemble, 80% probability of intensification

- While FL landfall was ultimately south of both the ensemble control and ensemble mean forecast, the best track falls within the 1/3rd probability ellipse at most lead times, and within the 2/3rd probability ellipse at all lead times

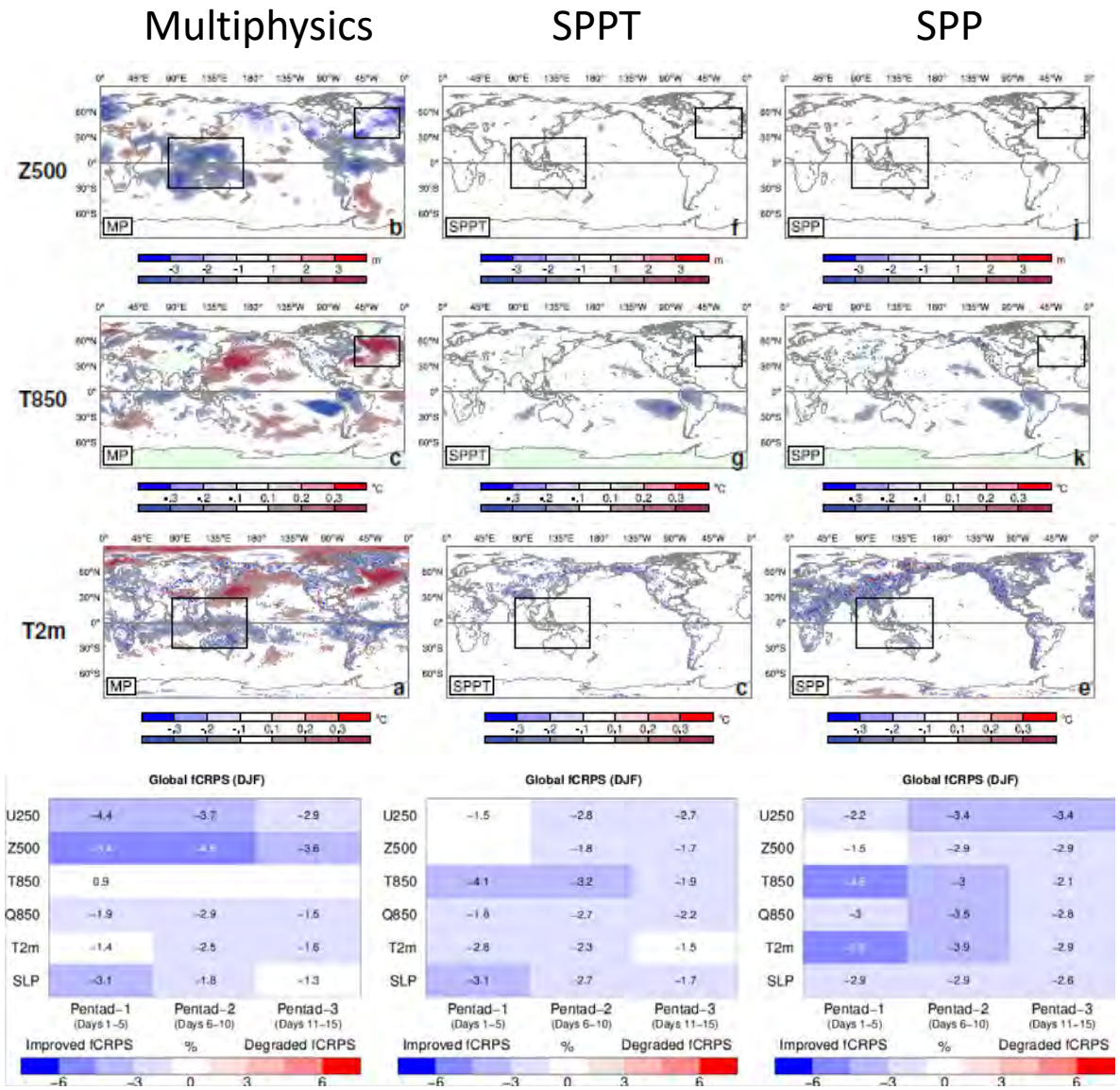
Slides from Environment and Climate Change Canada

Representing Model Uncertainty in Ensembles

- There are many sources of error within numerical models: uncertain physics, dynamics approximations, algorithmic choices …
- The growth of these errors with lead time needs to be represented in ensemble prediction systems to produce reliable guidance
- Current approaches are “multimodel” (different dycores or physics suites) or “stochastic” (perturbations to physics tendencies or inherently stochastic schemes)
- The model uncertainty community is actively working to move towards stochastically perturbed parameterizations (SPP) because of internal consistency and conservation properties
- Initial SPP implementations were unable to generate sufficient spread (Ollinaho et al. 2017)

Forecast Improvement

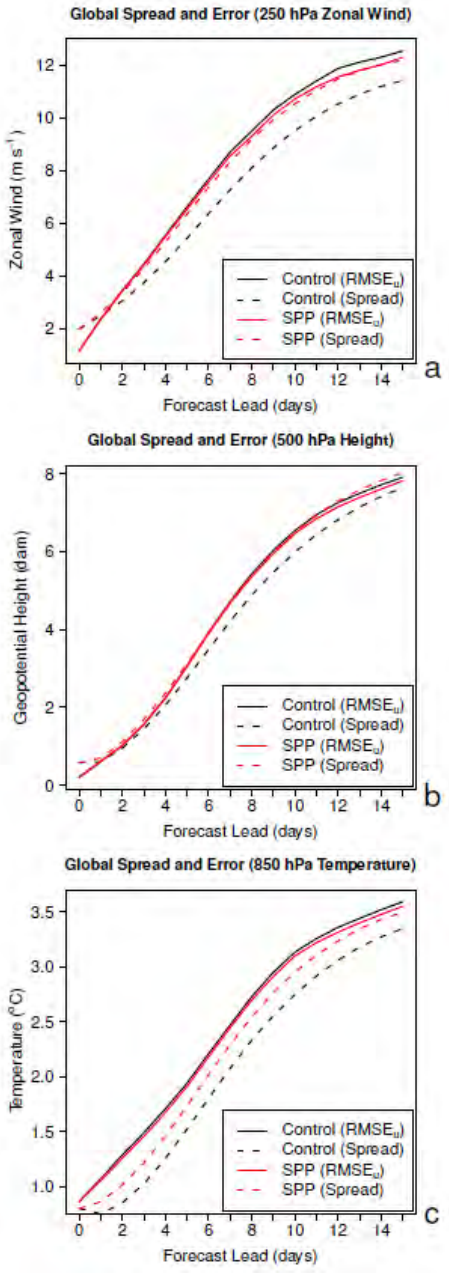
- Including a model uncertainty estimate improves the skill of the ensemble forecast (blue) at global scale
- Flow-independent spread generated by member-specific biases in multiphysics schemes degrades forecasts locally



Contribution of model uncertainty schemes to fCRPS over pentad 1 (top) and in global summary statistics for all lead times (bottom) for variables as indicated for each row.

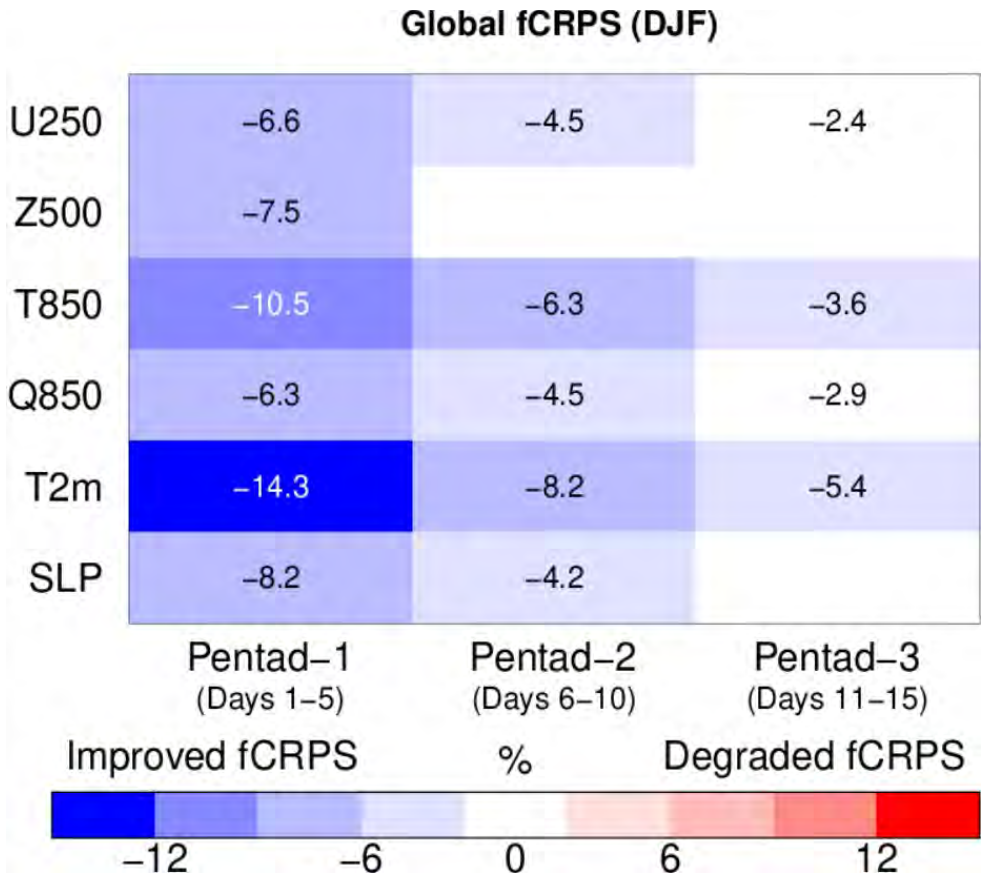
Ensemble Balance with Full SPP

- Individual SPP elements have differing impacts on ensemble behaviour, (hopefully) consistent with how the related uncertainties impact forecast skill
- The full SPP configuration is capable of generating sufficient spread to match RMSE throughout the forecast
- The SPP perturbations do not appear to degrade the ensemble mean – at least in terms of RMSE



Global RMSE (solid) and spread (dashed) in control ensembles (black; initial and SKEB perturbations) and with the full SPP scheme added (red) for the 250 hPa zonal wind (top), 500 hPa height (middle) and 850 hPa temperature (bottom).

Canadian Global Ensemble Upgrade



Relative change (%) in global fCRPS for Jan-Feb 2020 between the updated and operational GEPS. Changes that are statistically significant have values plotted in the appropriate cell.

- A Dec 2021 upgrade to the Canadian global ensemble (GEPS):
  - SPP model uncertainty (+SKEB)
  - EnKF- to LETKF-based assimilation
  - Major upgrade to model physics
- Large error reductions allowed us to scale down additive inflation
- The final result is the largest improvement to the GEPS in over a decade

Slides from ECMWF

ECMWF ensemble news 2022

Martin Leutbecher, Simon Lang, Sarah-Jane Lock and Frederic Vitart

ECMWF

Recent and upcoming ensemble resolution upgrades

- May 2021, cycle 47r2: Single precision and 137 levels (instead of 91), see ECMWF news and Lang et al (2021): More accuracy with less precision
- 2023, cycle 48r1: Horizontal resolution increases from 18 km to 9 km (TCo1279).

Extended-range ensemble forecasts

- Currently: **50 member twice weekly** (Mondays and Thursdays) at TCo319L91
- **100 member daily at TCo319L137** in Cycle 48r1 in 2023
- 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

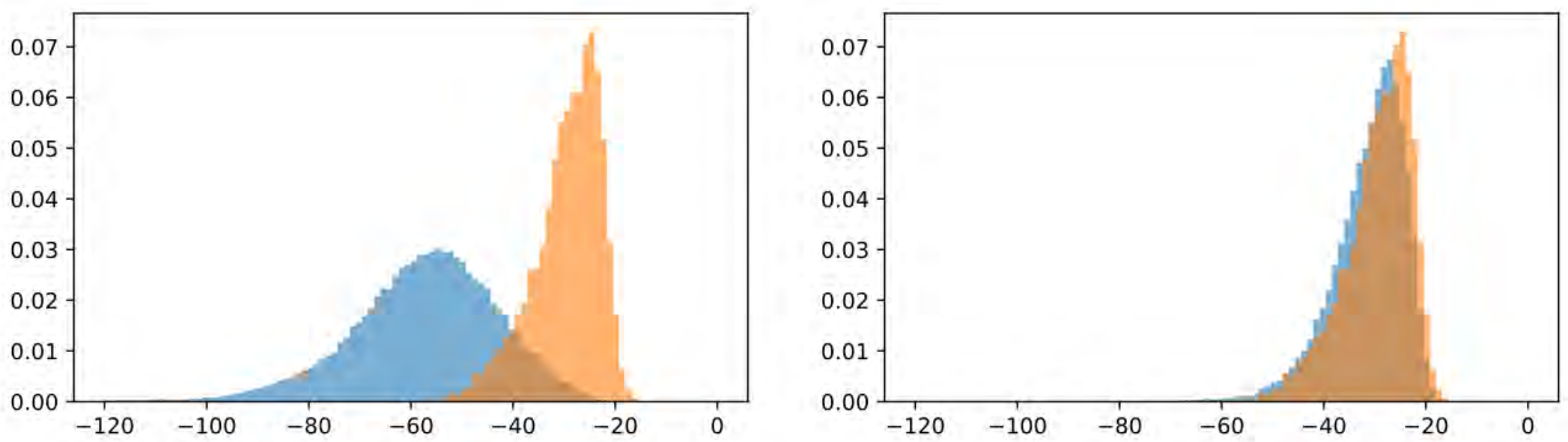
Representation of model uncertainties

- SPP (Stochastically Perturbed Parametrizations): Original version has been extended and revised (Lang et al 2021)
  - ensemble skill with SPP now similar to ensemble skill with SPPT
  - candidate to replace SPPT in cycle 49r1, to be implemented 2024
  - advantages: uncertainties are represented closer to the sources of the errors, local conservation better than in SPPT
- Extensive testing of SPP versus SPPT across all lead times from the EDA (hours in data assimilation) to seasonal forecasts
  - remaining issues (spread in MJO, changed SST biases in seasonal forecasts) are actively being worked on
  - for more details see poster at 6th WGNE workshop on Systematic Errors

Unexpected stability issues due to SPPT in the 9-kilometre ensemble

Crash frequency about 1 in 500 forecasts -> translates to approx. one crash every week with 50 ensemble members, 00 and 12 UTC starts → impossible to use operationally!

Crashes associated with grid point storms. Perturbed forecasts produce significantly higher maximum vertical velocities in 47r3 and especially in 47r3+revisions than in 47r1. Solution was found -> remove saturation adjustment tendency from SPPT (which was introduced in 47r1).



Histograms of minimum omega values at each time step of 8 initial dates and all perturbed members / control forecast; Perturbed members in blue and unperturbed control forecast in orange. On the left: 47r3 with 48r1 cloud saturation changes and water conservation changes; On the right: after excluding the saturation adjustment tendency from SPPT. All forecasts with TCo1279 resolution.

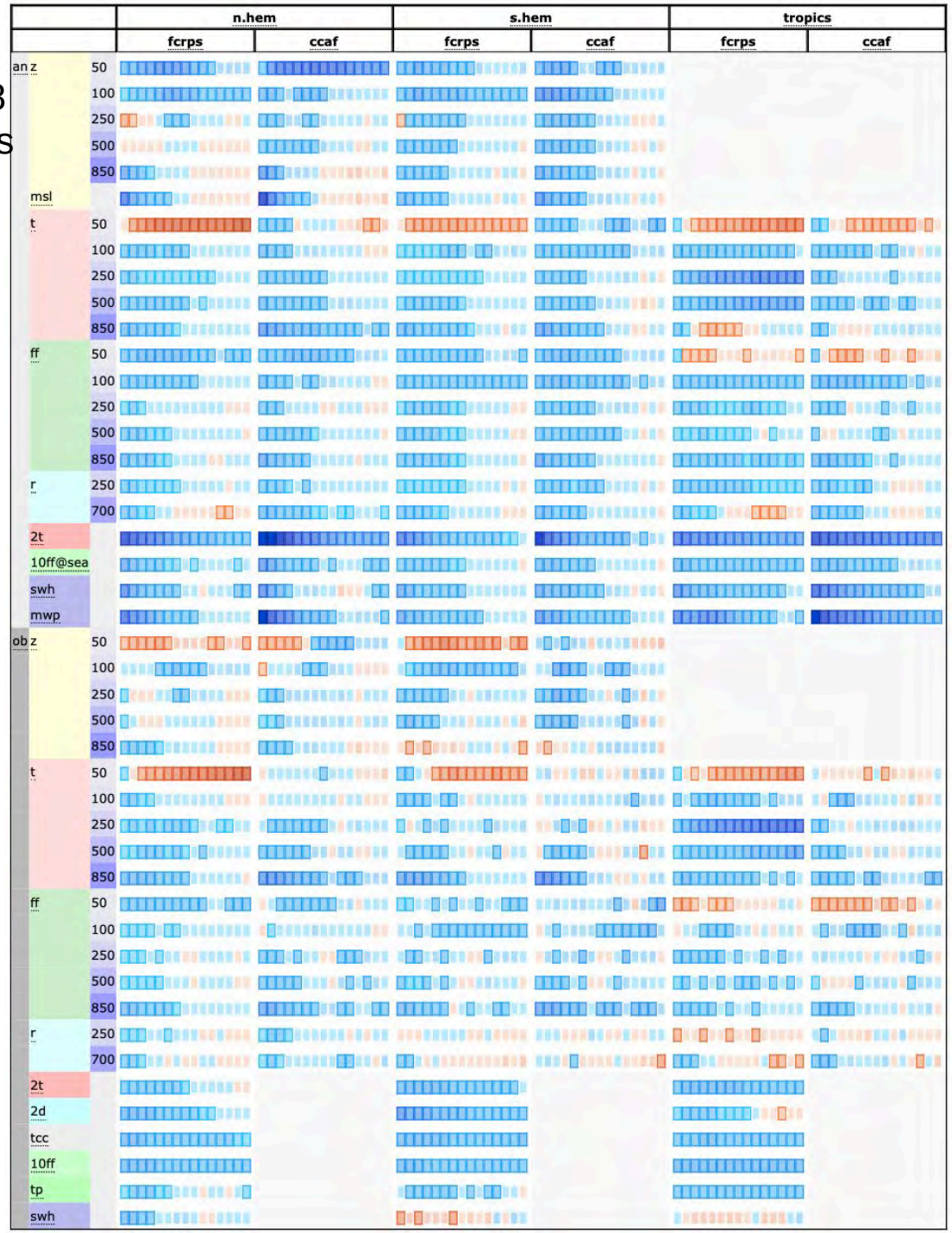
ENS impact from resolution upgrade 18 km → 9 km only; does not include all 48r1 model contributions and no DA contributions

8 pert members,
00, 12 UTC
20200602 - 20200812,
20210901 - 20211031,
20201202 – 20210201

9 km (TCo1279)
vs 18 km (TCo639)

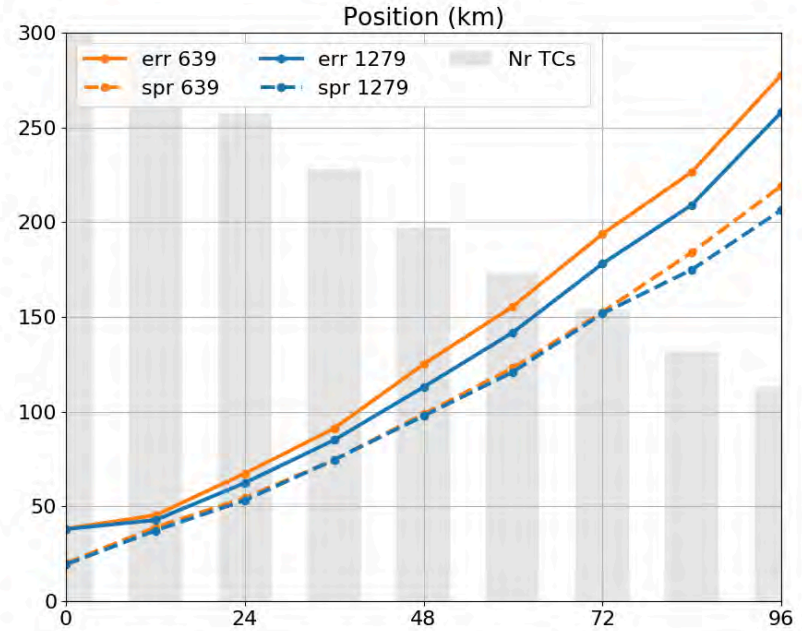
initialised from 47r3 analyses

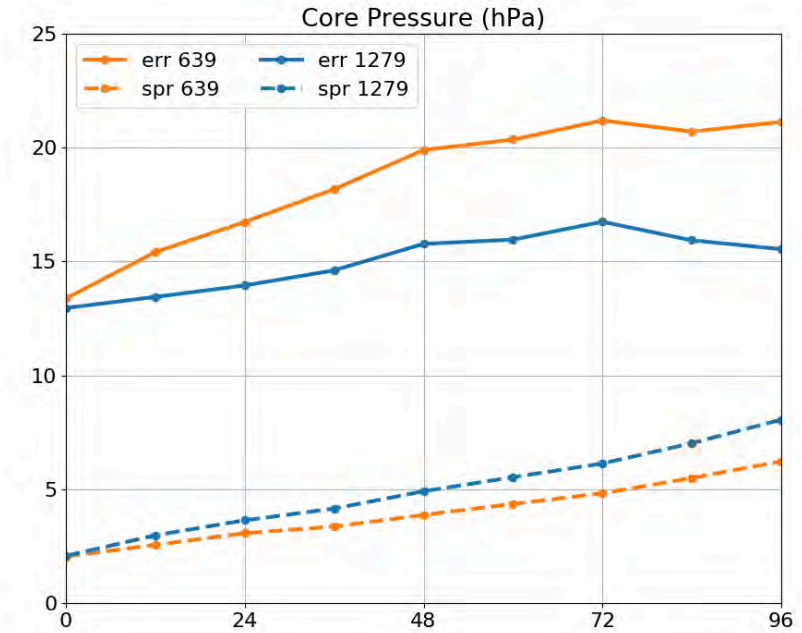
Blue colors show improvements
Degradations in stratosphere due to known resol. dependent bias



Impact on TC forecasts

-> better track and intensity forecasts



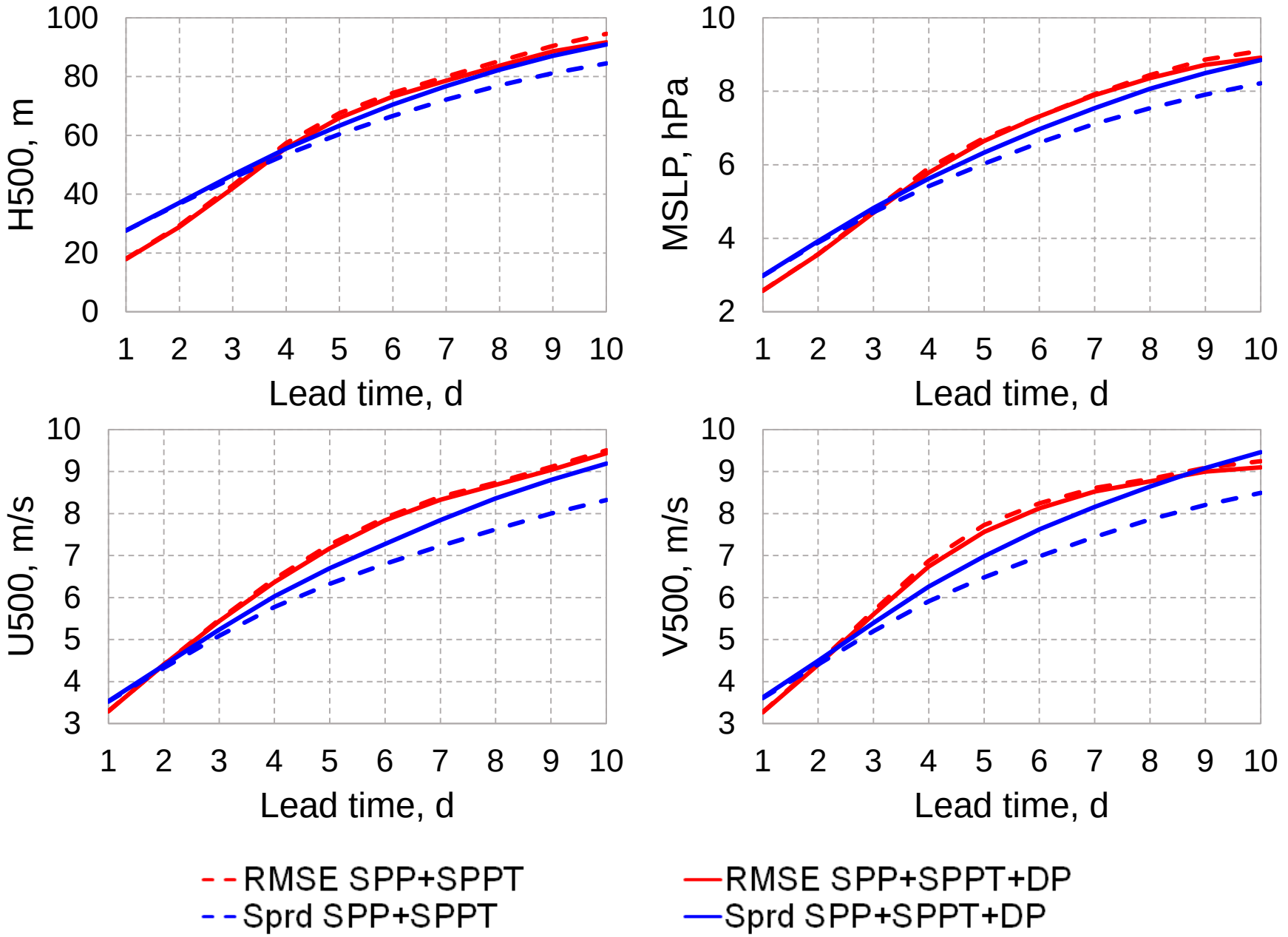


Slides from Russian Hydromet Center

Global Ensemble Prediction System

- Ensemble Prediction System is based on SL-AV model 0,9°x0,72°L96 *(Tolstykh etal, 2018, Russ. Meteorol. Hydrol., 43, 773–779, https://doi.org/10.3103/S1068373918110080)*
- Local Ensemble Transform Kalman Filter (LETKF) is used to generate perturbations in the ensemble of initial data
- Ensemble is centered to the HMC operational analysis
- The forecast length is 10 days
- The ensemble size is 40 members
- SL-AV model incorporates SPPT for temperature and vorticity and SPP for 27 parameters in physical parametrizations
- The system is operational since July 2022.
- Research: A new version of SL-AV model incorporates DP perturbations (Positive effect on spread, see next slide)

RMSE vs Spread, Southern Extratropics, Aug 2021



Slides from CPTEC

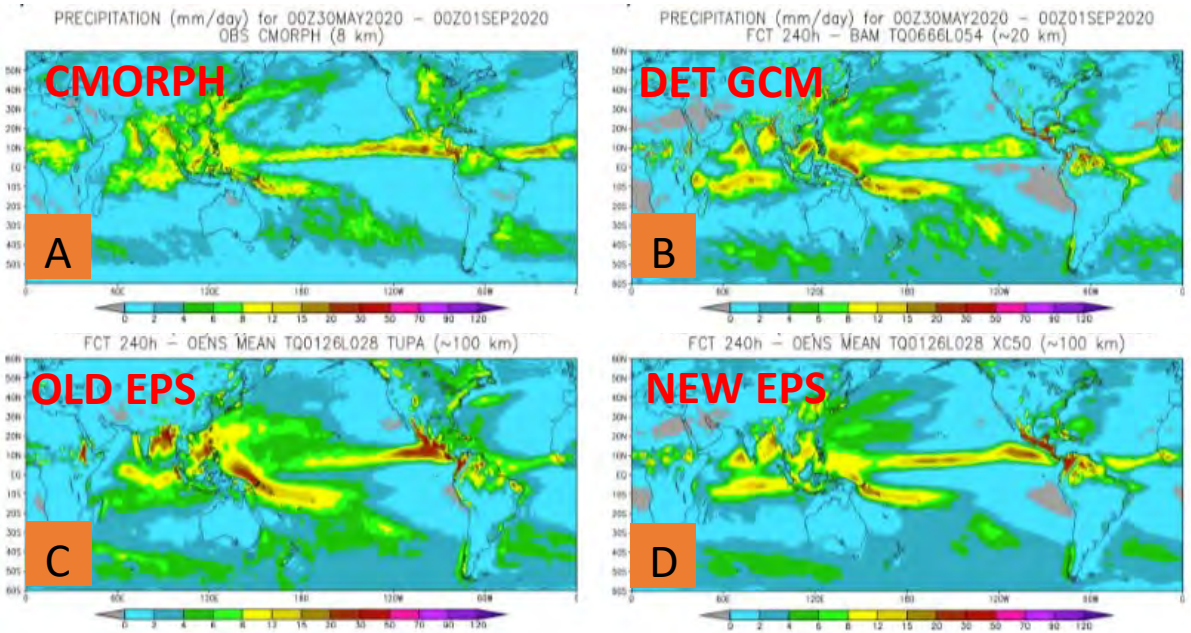
Ops Status: as of 2021, it was concluded the port of the CPTEC EPS suite to a Cray XC50 machine (used at ops at CPTEC):

- By the time, the GCM version of the EPS wasn't ported to the new machine, which motivated the upgrade of the atmospheric model to the current GCM version (still using the same sigma vertical coordinate);
- The resolution was kept the same as the previous version, i.e., TQ0126L028 with 15 members (IC EOF perturbation method using the NCEP analysis);
- With the port and upgrade, it was stabilished the CPTEC EPS version 2.2.0, **still not operational yet**.

Key Highlights:

Ensemble mean forecasts for the 240 hous lead time (10 says)

Valid for JJA/2020:

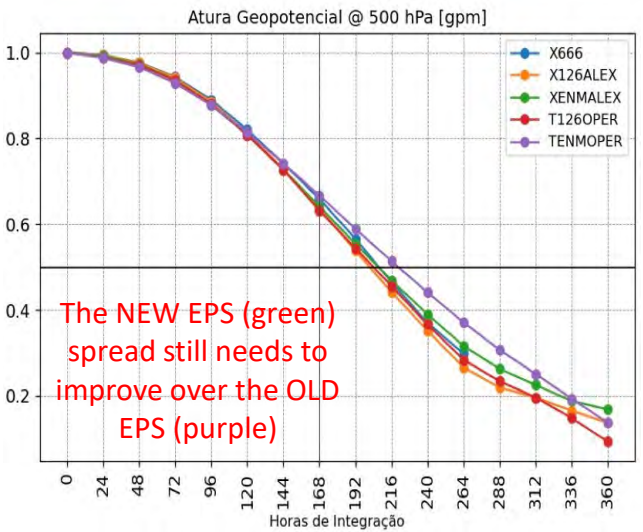


- Important improvements were found in the precip representation due to the GCM upgrade;
- The ensemble mean of the TQ0126L028 (~100km) EPS are very close to the operational TQ0666L064 (~20km) deterministic version of the model.

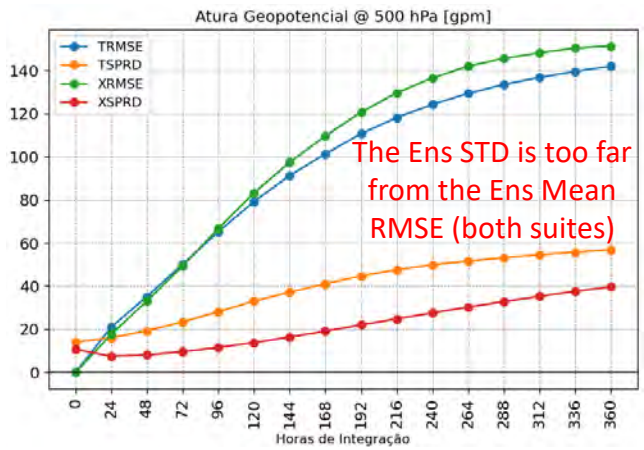
Challenge: to control the ensemble spread for the analysis and forecasts.

Despite the improvements found in the CPTEC EPS V2.0.0, the suite is still not operational due to the lack of computational resourses. Ongoing improvements are on the way in order to fix the ensemble underdispersion.

500 hPa Geop. Height Anomaly Correlation valid for JJA/2020

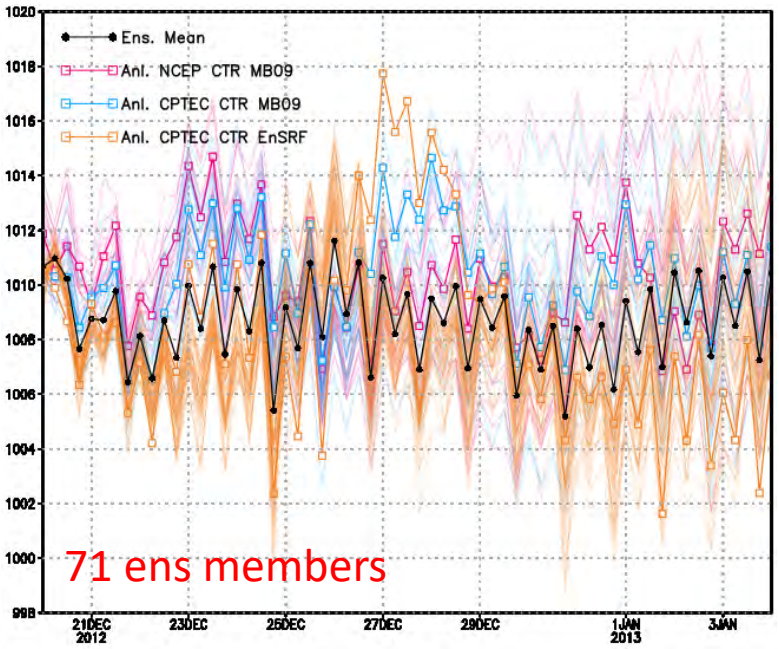


500 hPa Geop. Height Ens STD x Ens Mean RMSE Valid for JJA/2020



Research Status: ongoing research aiming the use of both EnKF and the EOF perturbation techiniques. The advantages is the possibility to use our own atmospheric analysis to produce the EPS under the same framework used by the data assimilation (i.e., the GSI hybrid 3DEnVar – **not operational yet**). This exercise will also serve to test the technique to be applied to the MONAN (Model for the Ocean-Land-Atmosphere predictioN-more info at https://github.com/monanadmin/monan).

Point over São Paulo state (46S;23W)
PSNM 15 dias (valid for 2012122000-2013010400)

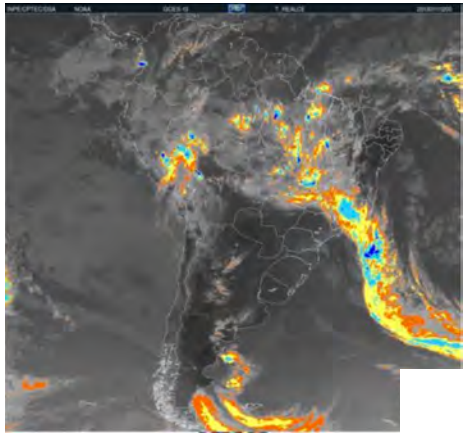


JBOM – "Just a Bunch of Members"

Gathering all the 15 ensemble members from the current EOF-based EPS suite (departing from the NCEP analysis) + 15 ensemble members from the EOF-based EPS suite (departing from the hybrid 3DEnVar deterministic analysis) + 41 ensemble members from the hybrid 3DEnVar analysis) looks like this.

The ensemble from the hybrid 3DEnVar (orange) looks different from the EOF-based ensemble (pink and blue). **Does the EnKF provide features that compliments the EOF-based method? Is the hybrid 3DEnVar deterministic analysis a good replacement for the NCEP analysis currently used with the EOF-based method?**

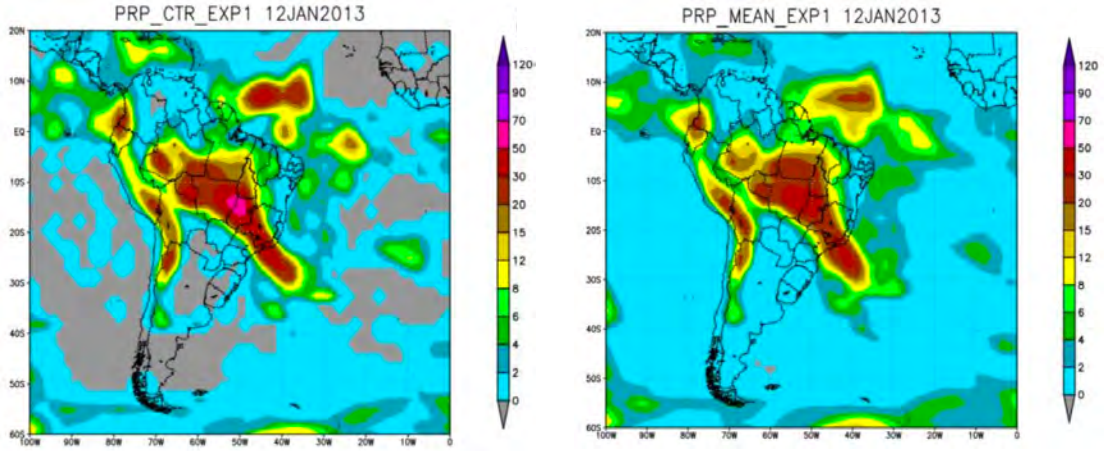
IR GOES-13 (valid for 12JAN2013)



At right: comparison between the CPTEC EPS generated from NCEP and CPTEC atm anl.

The plan (~3 years): CPTEC to produce its own atmospheric analysis (ideally from the 3DEnVar) and use it in the EPS.

CPTEC EPS using NCEP anl (precip 24h fct, valid for 12JAN2013)



CPTEC EPS using CPTEC anl (precip 24h fct, valid for 12JAN2013)