

Utilising the Uranie platform for optimisation of the stochastically perturbed parameterizations (SPP) scheme in HARMONIE-AROME

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With thanks to Michiel Van Ginderachter (Royal Meteorological Institute of Belgium)

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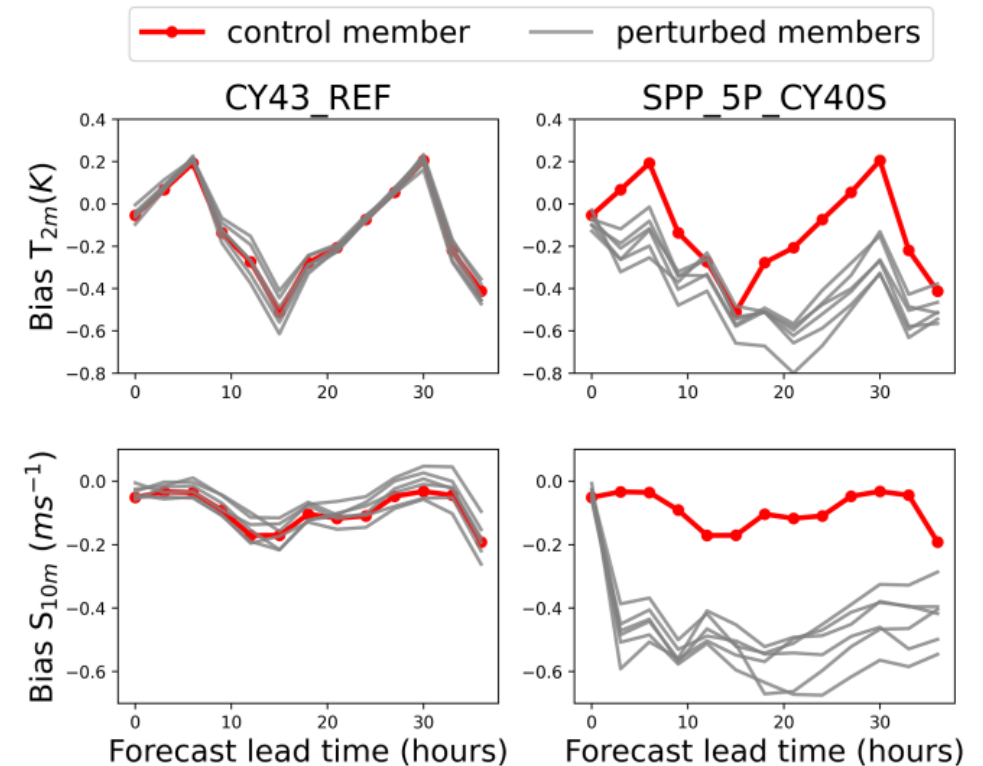
Background

- Uranie: a platform for uncertainty propagation, sensitivity analysis, and surrogate model generation.
 - Developed at CEA and based on the ROOT framework.
 - [Open-source](#).
- Previous work carried out by Michiel and Inger-Lise Frogner on using Uranie to study various problems in HARMONIE-AROME.
 - Part of the ESCAPE-2 project.
 - E.g. used to assess the impact of surface perturbations on RH2m member biases in cy40.
 - See [ASW 2022 presentation](#) and [ESCAPE-2 report](#).
- Further sensitivity and optimisation testing with cy46.
 - ACCORD scientific visit in Dec 2023.
 - ECMWF special project in 2024 to investigate how Uranie tools could be used for optimisation of the SPP scheme.



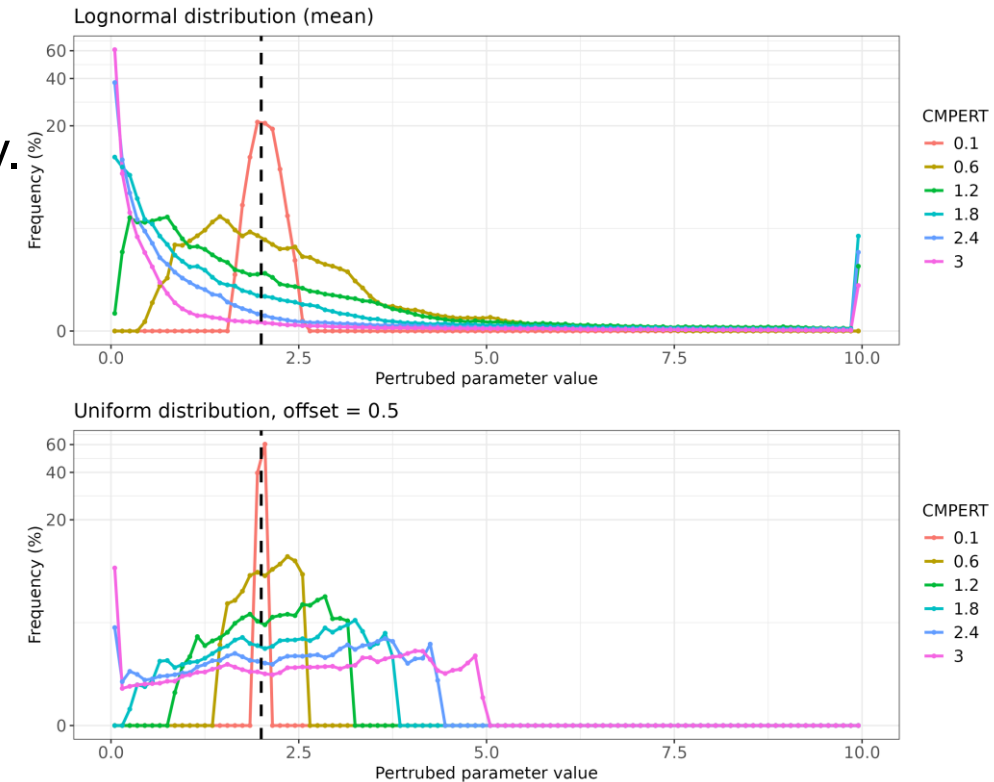
Background

- The SPP scheme introduces stochastic perturbations to closure parameters in the physical parameterizations (e.g. microphysics, radiation) and to model dynamics.
 - Operational in MetCoOp and UWC-W (5 parameter configurations).
- Perturbed parameter values drawn from some distribution.
 - Several configuration options to choose (e.g. lognormal/uniform, standard deviation, offset).
- Tuning of the SPP scheme for operational use can be a laborious process!
 - Typically seek to improve EPS performance without introducing systematic member biases.
 - [Frogner et al. \(2022\)](#) and [Tsiringakis et al. \(2024\)](#).
- Can we use Uranie to help this process?

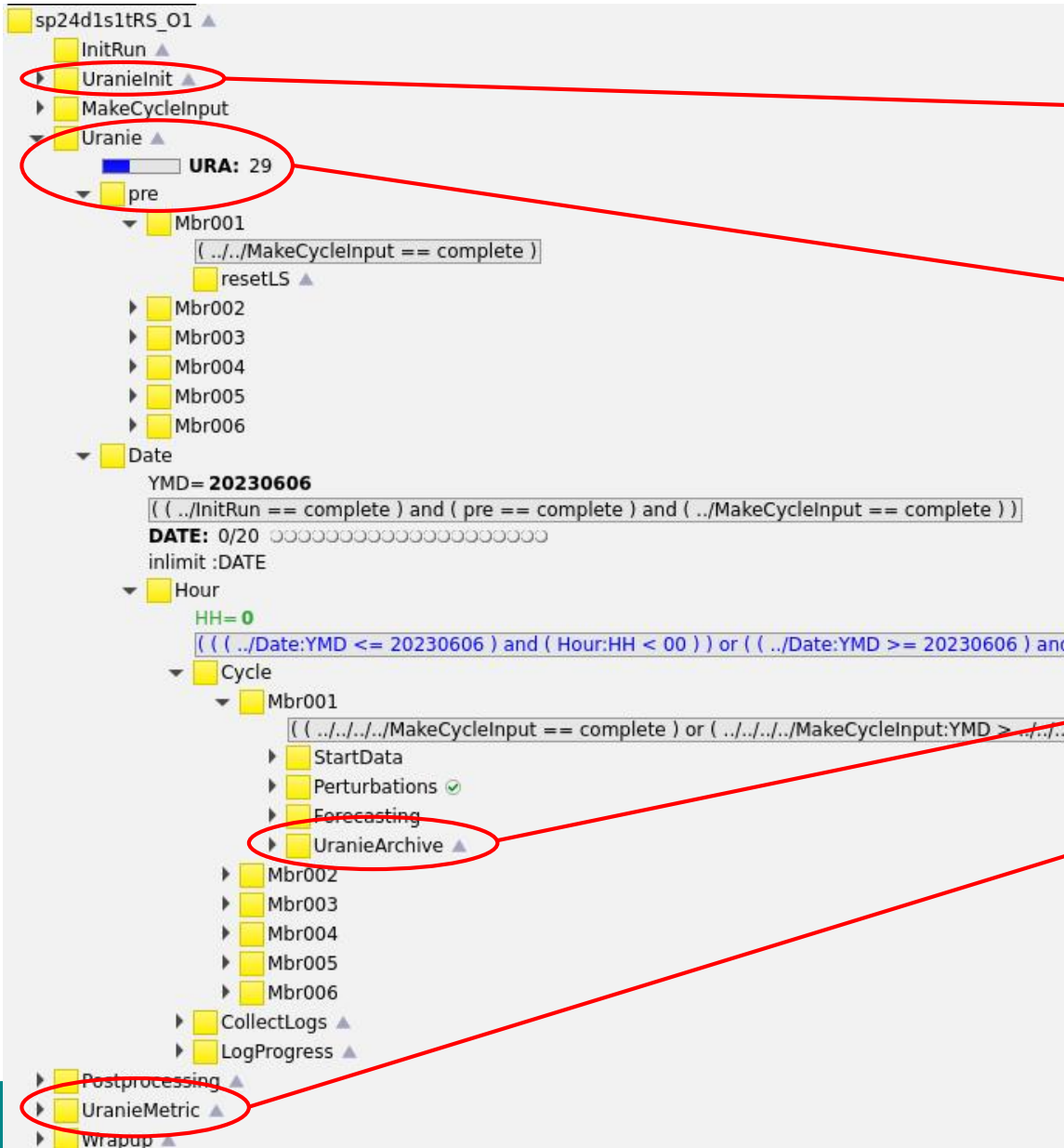


Optimisation workflow

- Optimise SPP parameter standard deviation (CMPERT) only.
 - All other distribution options are fixed.
 - CMPERT constrained to some “reasonable” range.
- Use the Efficient Global Optimisation (EGO) scheme:
 1. Generate N initial samples for CMPERT.
 2. Run the model for each sample and evaluate some cost function F .
 3. Train a Kriging surrogate using all samples available.
 4. Find the maximum “Expected Improvement” to predict a new value for CMPERT.
 5. Run model using this new value and repeat steps 3-5 until some stopping criteria are met.
- What is a suitable choice for the cost function F ?
 - Restricted here to constructing F using standard point verification metrics.
 - Significant limitations of course, but is a simple first attempt (and mimics manual tuning).



Optimisation workflow



Uranie tasks are largely shoe-horned into the HARMONIE-AROME workflow:

- Initialise Uranie and generate N samples for CMPERT (in `harmonie_namelists.pm`).
- Iterate over the N samples and run a full experiment for each CMPERT.
 - “URA” = current Uranie iteration.
 - Note that “Date” is nested in “Uranie”, such that a single iteration may have many forecast start dates.
- Archive data for each iteration if required.
- Generate a cost function for iteration URA:
 - If $URA < N$, move on to URA+1.
 - If $URA \geq N$, generate a new CMPERT. If the stopping criteria are not met, run another experiment with this value.

HARMONIE-AROME configuration

- Cycle 46 (dev-CY46h1_eps branch, old version).
- Irish domain, 1+6 members with 2.5km, 65 levels, single precision, 36h forecasts at 00 UTC.
- Parent-child setup where all ensemble members start from control member analysis files.
 - Significant speedup as DA cycles skipped for members.
- Only SPP perturbations are active:
 - As all members start from the same point, this allows for a direct assessment of the impact of individual SPP parameters.
- SPP parameters considered:
 - SLWIND (semi-lagrangian advection scheme): uniform dist., offset=0.5, clipping at [-0.4,0.4].
 - RFAC_TWOC (top entrainment term): uniform dist., offset=0.5, clipping at [0,10].

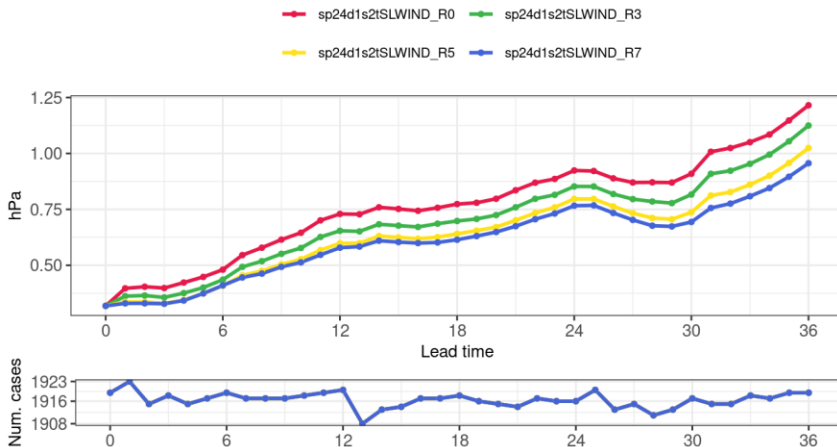


Reference experiments for SLWIND

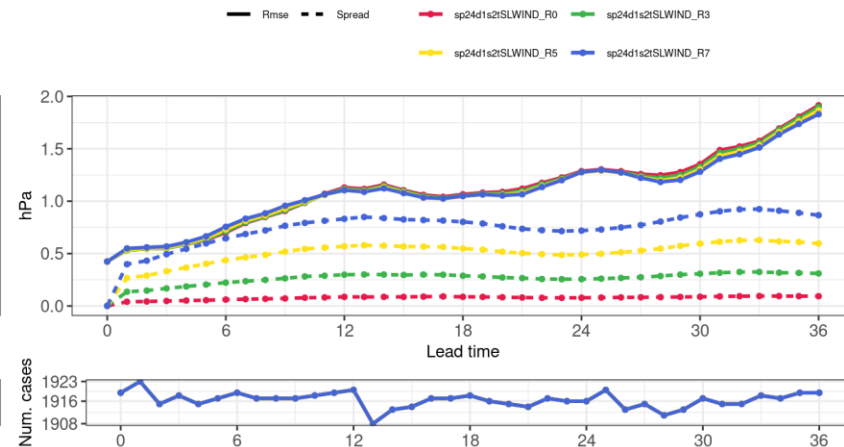
- First run a set of reference experiments for several SLWIND CMPERT in order to:
 - Gauge the impact of CMPERT on various possible choices for F .
 - Act as reference data to assess if EGO scheme is performing reasonably.
- 10-day winter period below (point verification using harp, all SYNOPs available).
 - PMSL scores indicate better spread and CRPS with increasing CMPERT.
 - Minimal impact on RMSE, but negative member biases emerge at larger CMPERT.

CMPERT = 0.05, 0.2, 0.4, 0.6

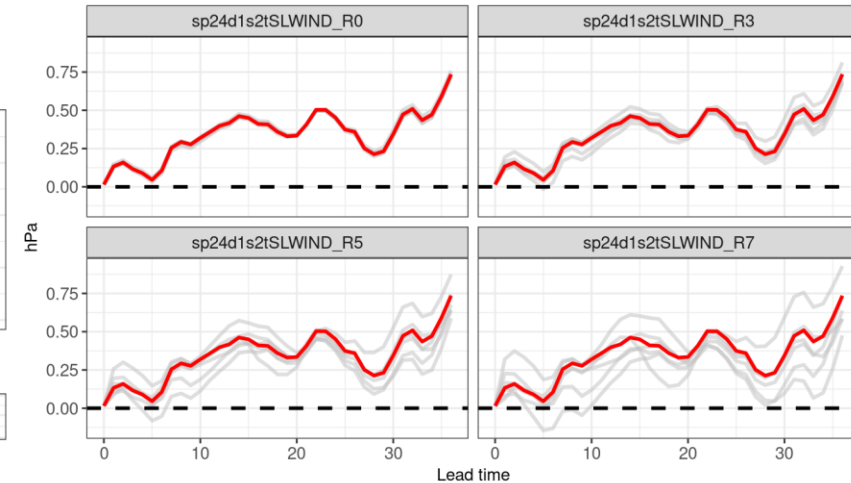
Crps : Pmsl : 2022-02-10-00 - 2022-02-20-00 (11 cycles)
All stations (176) : All cycles used



Rmse, Spread : Pmsl : 2022-02-10-00 - 2022-02-20-00 (11 cycles)
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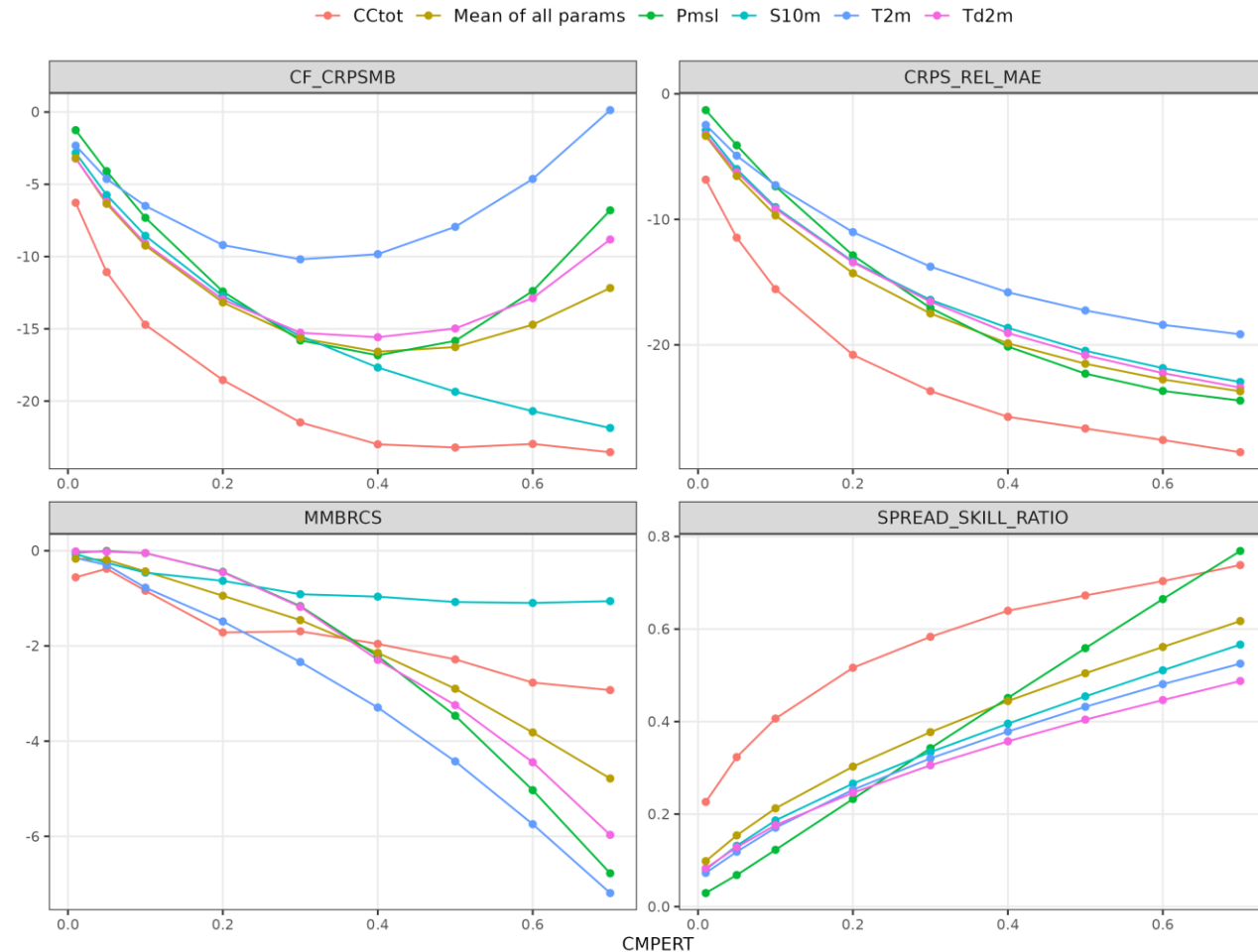
Bias : All Members : Pmsl : 2022-02-10-00 - 2022-02-20-00 (11 cycles)
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Reference experiments for SLWIND

- How to condense these standard point verification scores into a suitable cost function for optimisation?
- Many possible choices, but here we consider some simple ones:
 - Spread-skill ratio.
 - CRPS relative to MAE (CRPS_REL_MAE: how much does the ensemble improve?).
 - Mean Member Bias Relative to the Control Scaled by MAE (MMBRCS: is there a significant systematic member bias?).
 - $CF_CRPSMB = CRPS_REL_MAE + |MMBRCS|^q$ (balance CRPS and member biases changes).
- Cost function values vs CMPERT on right.

Variation in cost functions with CMPERT
SLWIND: 20220210-20220220 : Leadtime = last_24



Cost functions above averaged over lead times 12-36h with $q=1.5$.
Colours indicated different parameters/parameter mean.

Optimisation tests for SLWIND

- Consider CF_CPRSMB as a first guess for a “suitable” cost function.
 - This again aims to mimic manual tuning.
 - Use the mean value of this cost function over CCtot, T2m, Td2m, S10m, and Pmsl.
 - Based on reference experiments, one would expect an optimum CMPERT approx. 0.3-0.4.

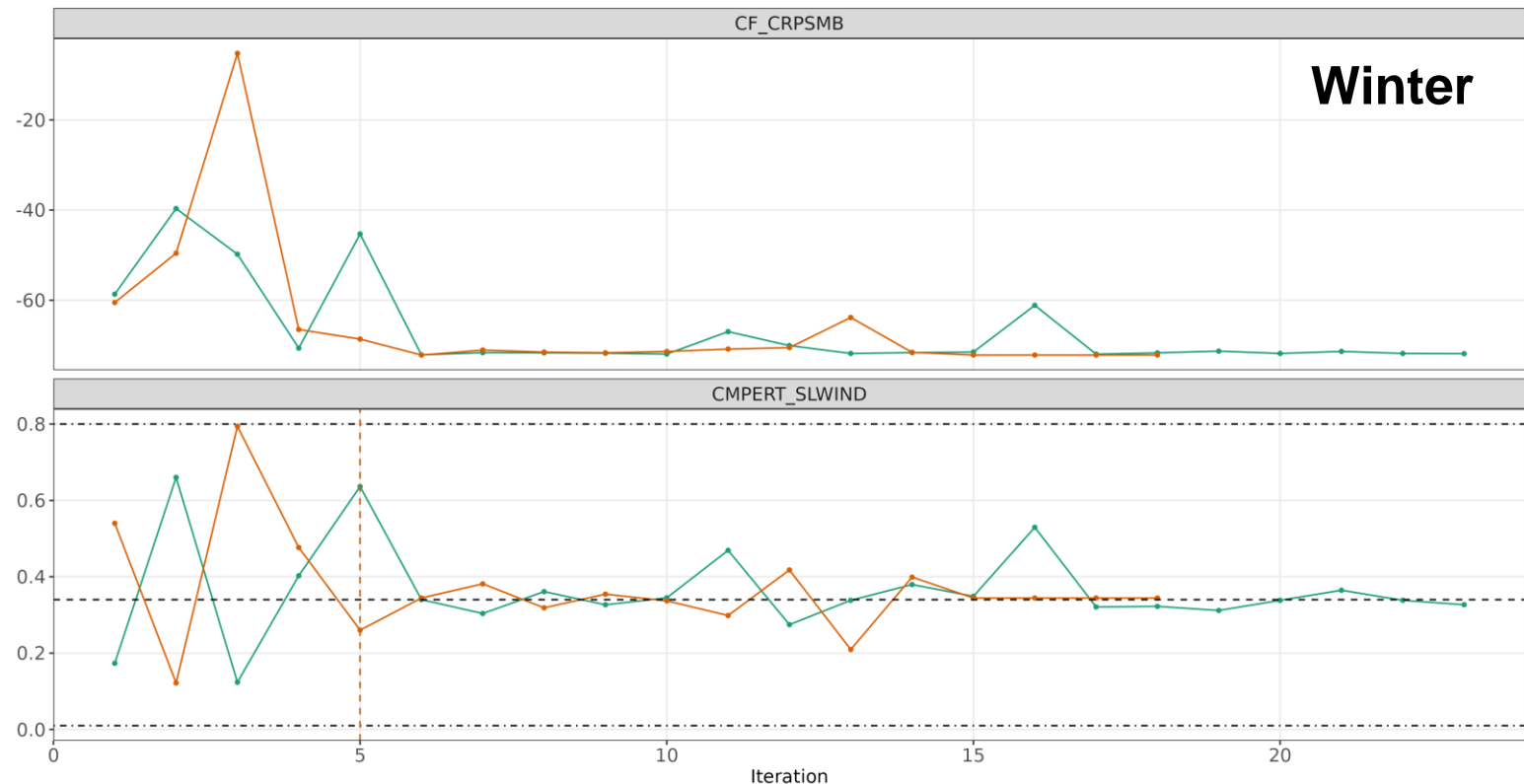
- Outcome of week-long optimisation tests on right:

- Initial sample size of 5.
- Two colours are the same experiment repeated twice.

- For winter, the predicted optimum CMPERT ~ 0.34 (reproducible).

Cost function = CF_CPRSMB: Variable = CCtot,Pmsl,S10m,T2m,Td2m: Period = 20220210 - 20220217

sp24d1s2tSLWIND_O1 sp24d1s2tSLWIND_O1R



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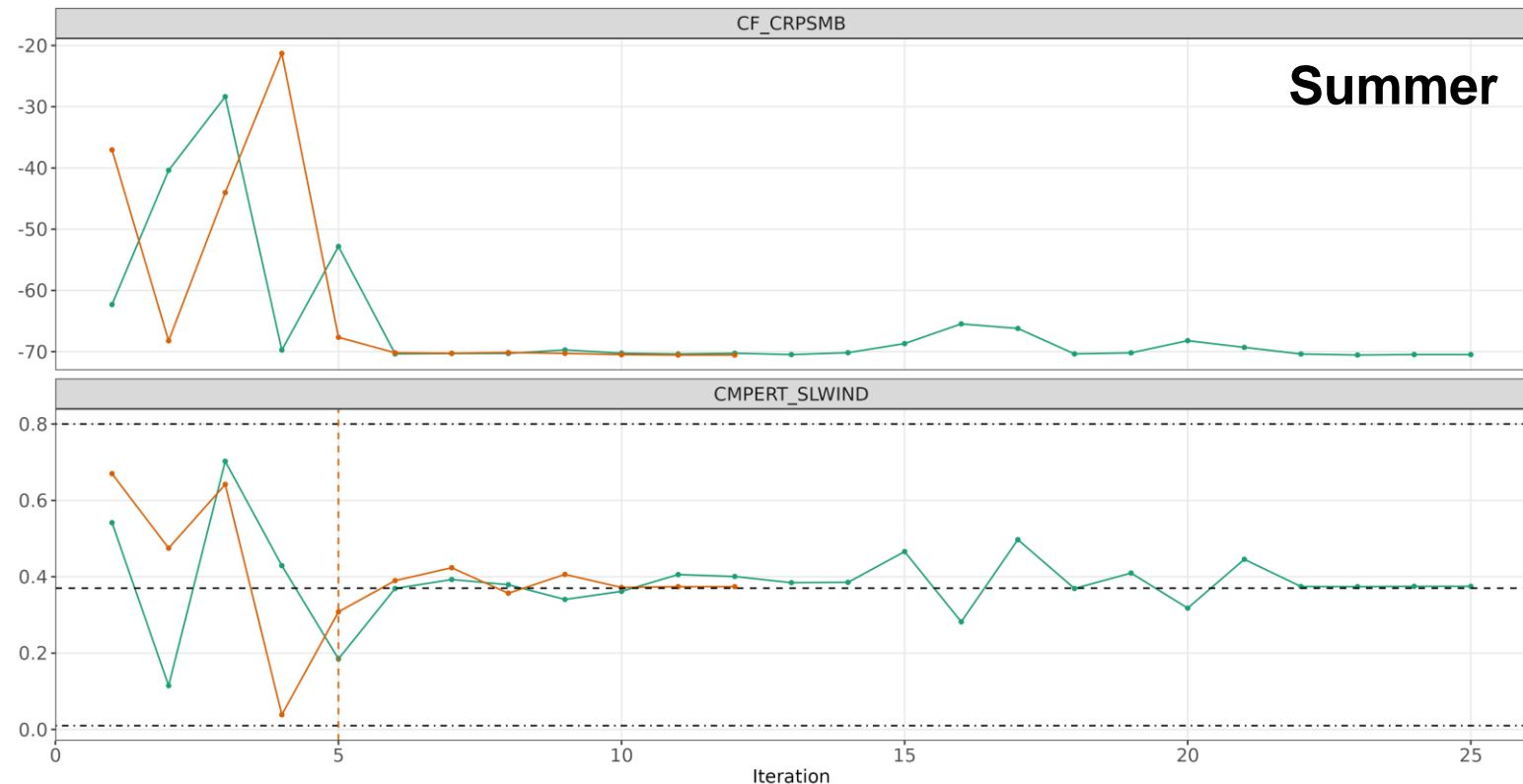
- For winter, the predicted optimum CMPERT ~ 0.34 (reproducible).

- For a summer, optimum ~ 0.37.

- Each experiment ~ 3M SBUs.

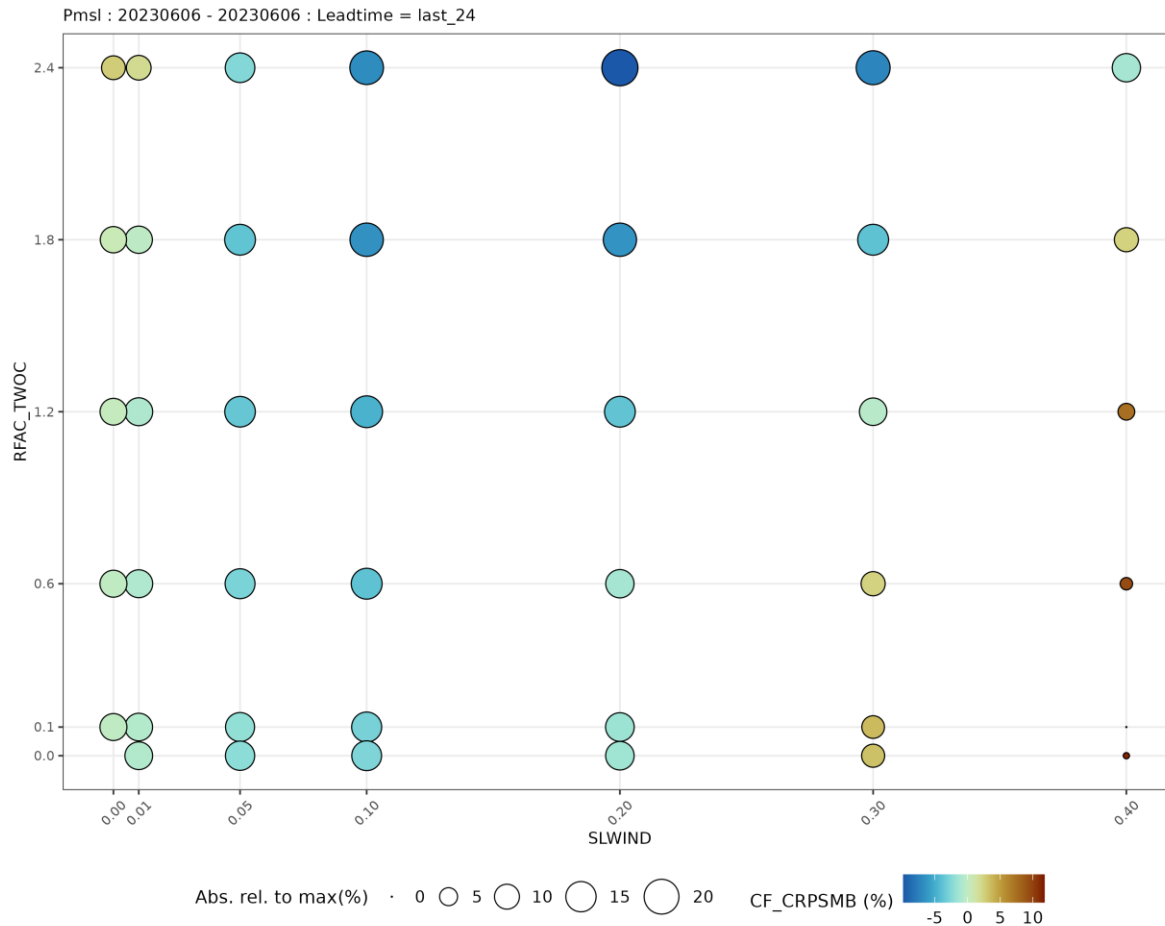
Cost function = CF_CRPSMB: Variable = CCtot,Pmsl,S10m,T2m,Td2m: Period = 20230606 - 20230613

sp24d1s1tSLWIND_O3 sp24d1s1tSLWIND_O3R



Reference experiments for SLWIND and RFAC_TWOC

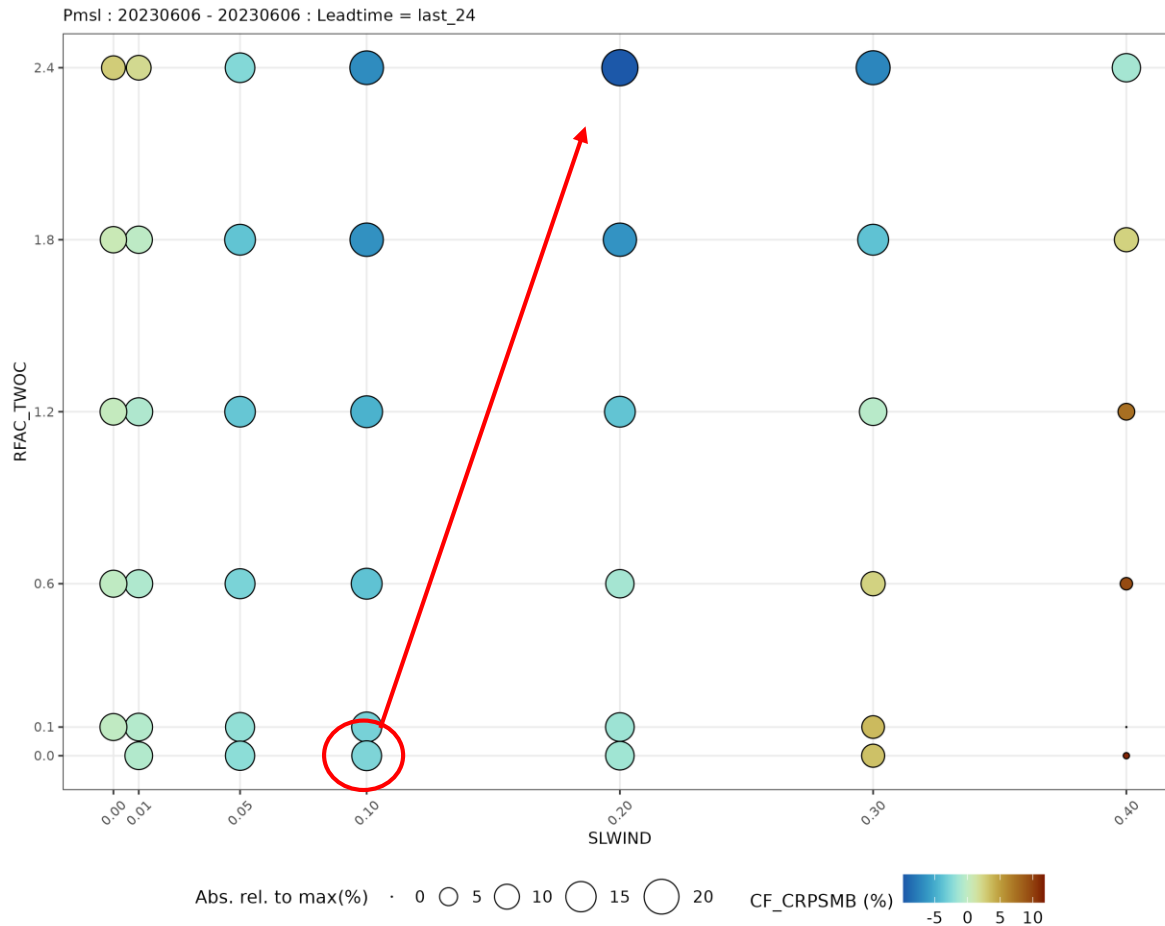
- Now consider optimising CMPERT for SLWIND and RFAC_TWOC simultaneously.
 - Run a series of reference tests to assess cost function behaviour in two-dimensions.



- Sample scatterplot of CF_CRPSMB for a single forecast start date and Pmsl.
 - CMPERT SLWIND on x.
 - CMPERT RFAC_TWOC on y.
- Large+blue indicate lower CF_CRPSMB.

Reference experiments for SLWIND and RFAC_TWOC

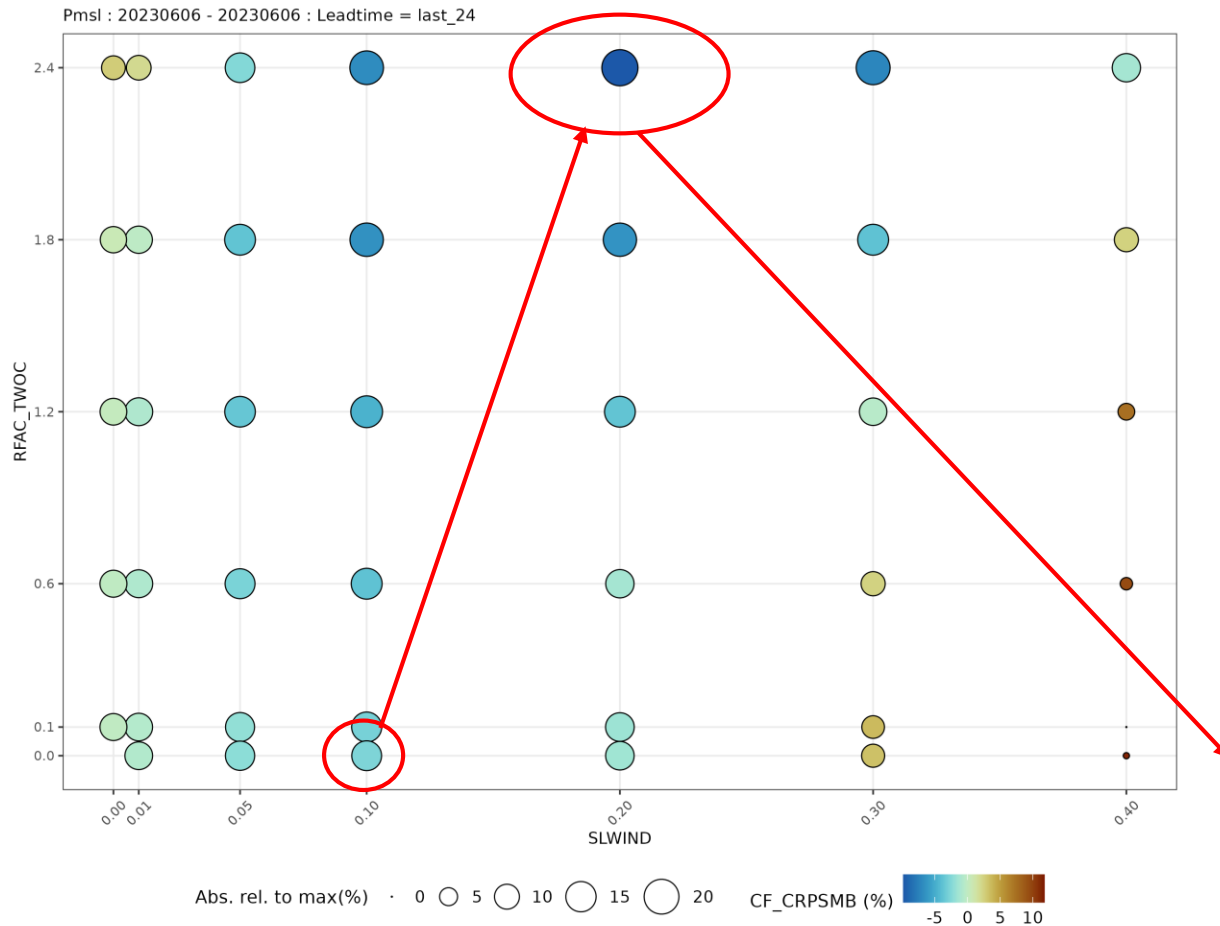
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- E.g. introducing RFAC_TWOC changes “optimal” SLWIND.

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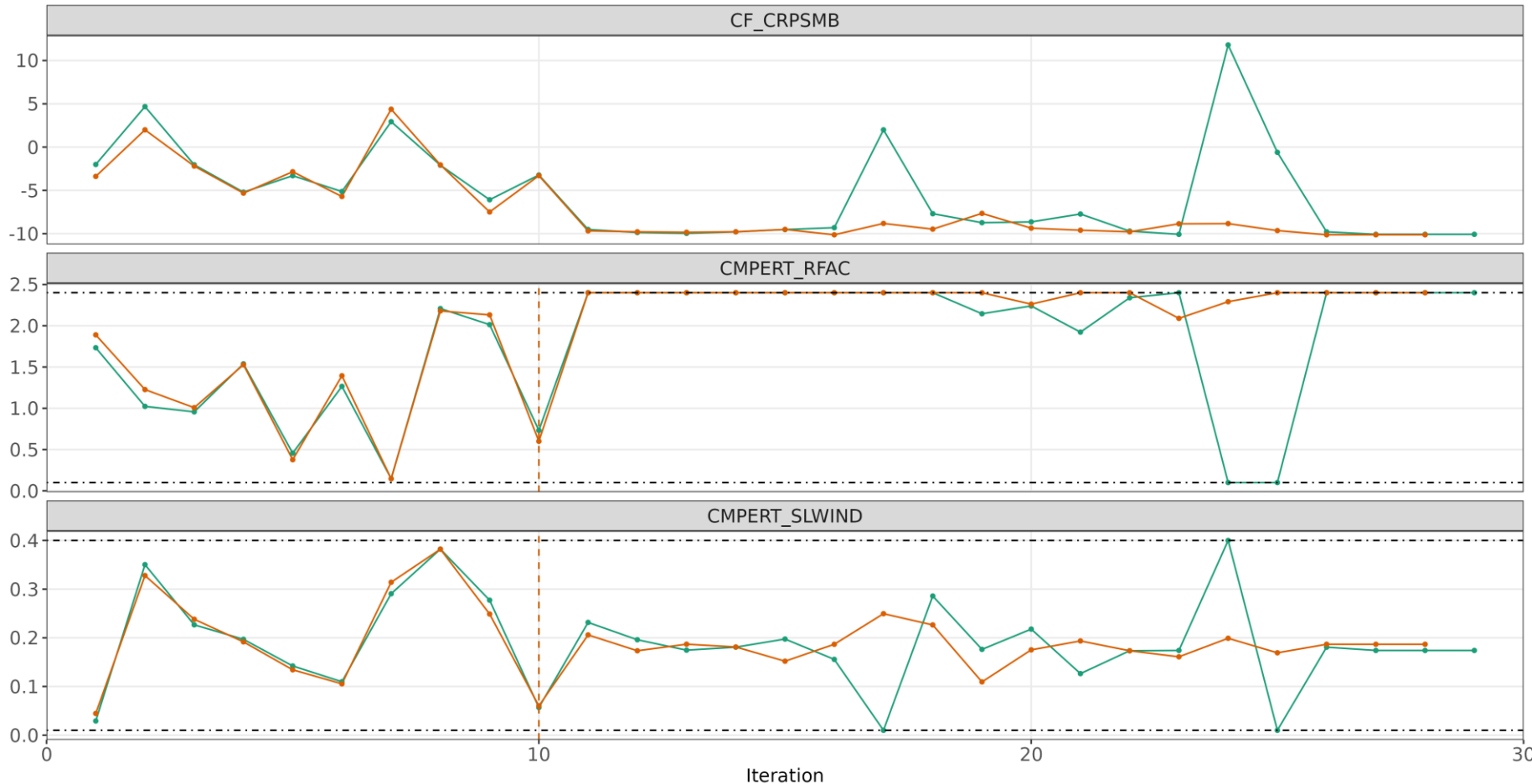
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 - CMPERT SLWIND on x.
 - CMPERT RFAC_TWOC on y.
- Large+blue indicate lower CF_CRPSMB.
- E.g. introducing RFAC_TWOC changes “optimal” SLWIND.
- Reference analysis would suggest optimum values of $\sim[0.2, 2.4]$.

Optimisation tests for SLWIND and RFAC_TWOC

- Results from single cycle optimisation runs are sensible (initial sample size of 10).
 - Two colours are the same experiment repeated twice.

Cost function = CF_CRPSMB: Variable = Pmsl: Period = 20230606 - 20230606

sp24d1s1tRS_O1 sp24d1s1tRS_O1R

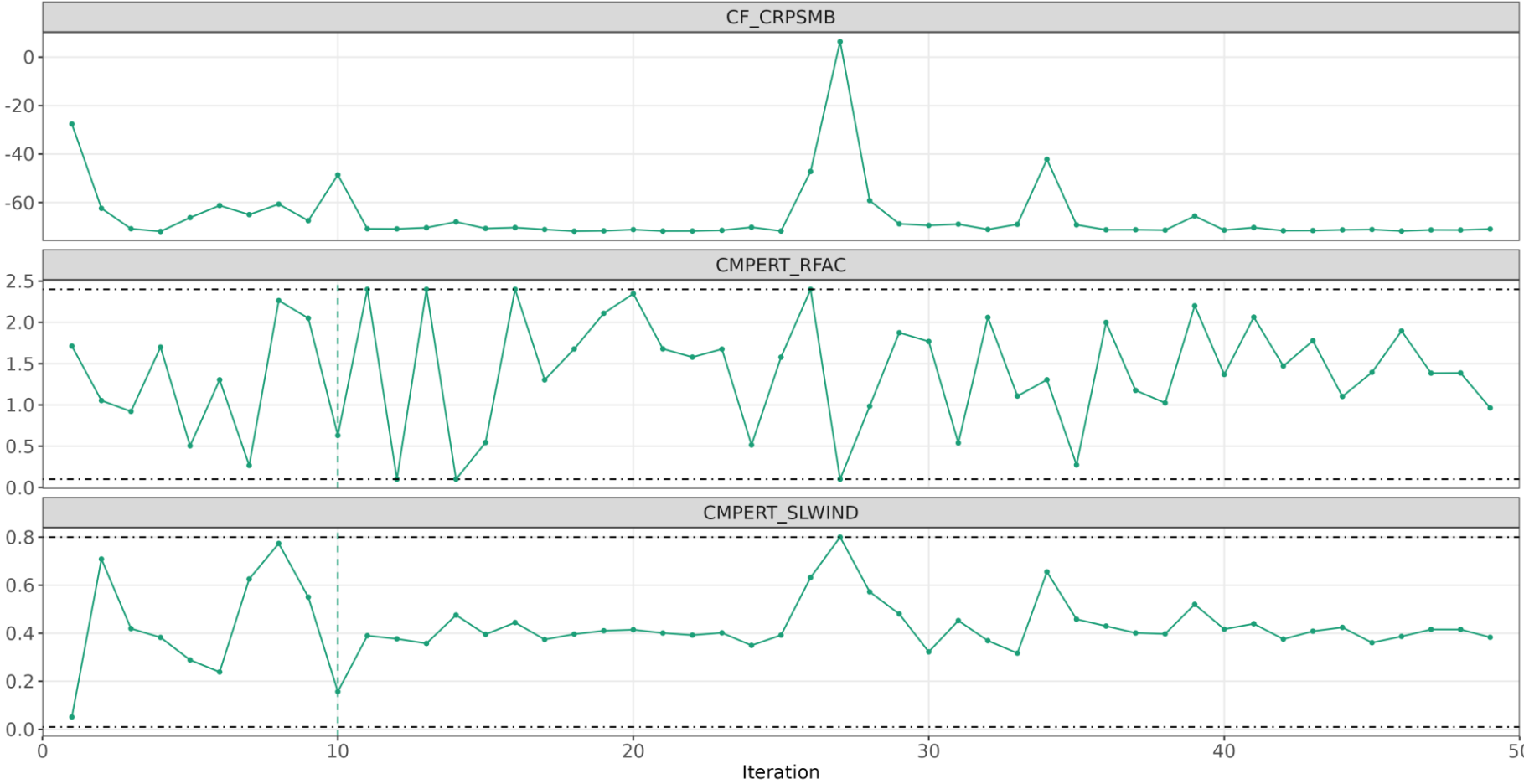


Optimisation tests for SLWIND and RFAC_TWOC

- Over a week-long period, CMPERT RFAC_TWOC does not converge (weak dependency).
 - CMPERT SLWIND converges to a similar value as single parameter optimisation runs.

Cost function = CF_CRPSMB: Variable = CCTot,Pmsl,S10m,T2m,Td2m: Period = 20230606 - 20230613

+ sp24d1s1tRS_O6

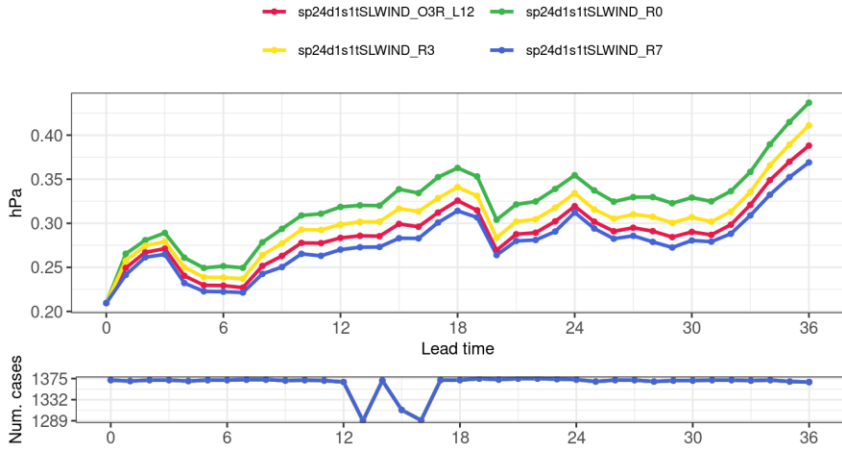


Summary

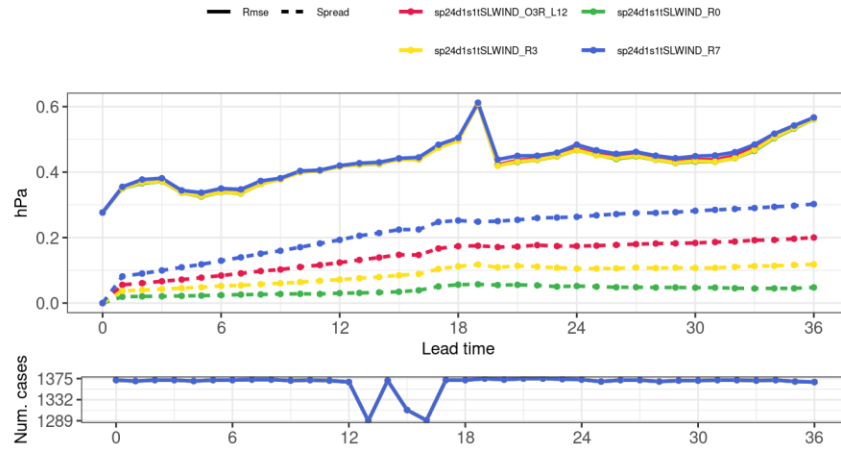
- Implementation of Uranie and the EGO scheme in HARMONIE-AROME seems to work okay.
- The choice of cost function used for SPP optimisation is crucial.
 - E.g. CRPS or spread-skill alone may lead to trivial results.
- Single parameter optimisation using CF_CPRSMB looks quite sensible.
 - Predicted optimal values agree with reference analysis, SBU costs are reasonable.
- Multi-parameter optimisation is more of a challenge, but results again seem okay.
- Future work:
 - Further cost function experimentation, more optimisation runs for multiple CMPERT.
 - Assess tuning of several distribution options (e.g. CMPERT and offset together).
 - Incorporate Uranie workflow into MUSC (subject of ACCORD scientific visit in May).
- Full set of results available in an [ECMWF special project report](#).
 - Note: You could of course do this with some software other than Uranie.

Optimisation tests for SLWIND

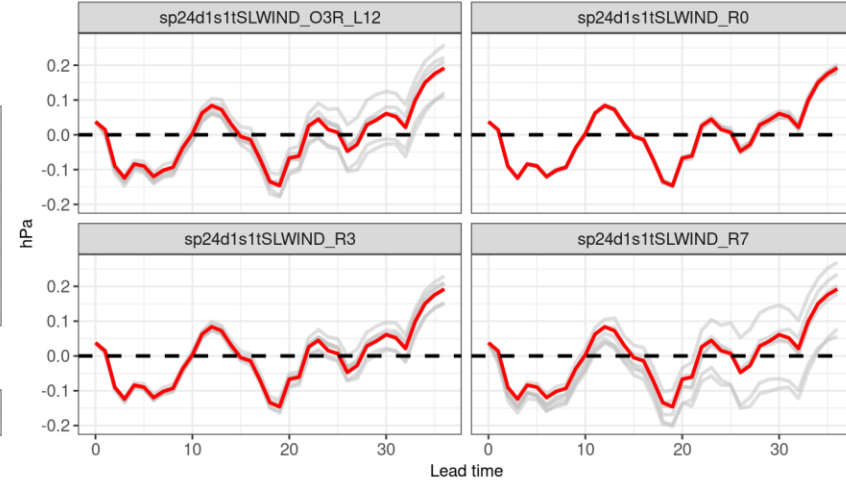
Crps : Pmsl : 2023-06-06-00 - 2023-06-13-00 (8 cycles)
All stations (172) : All cycles used



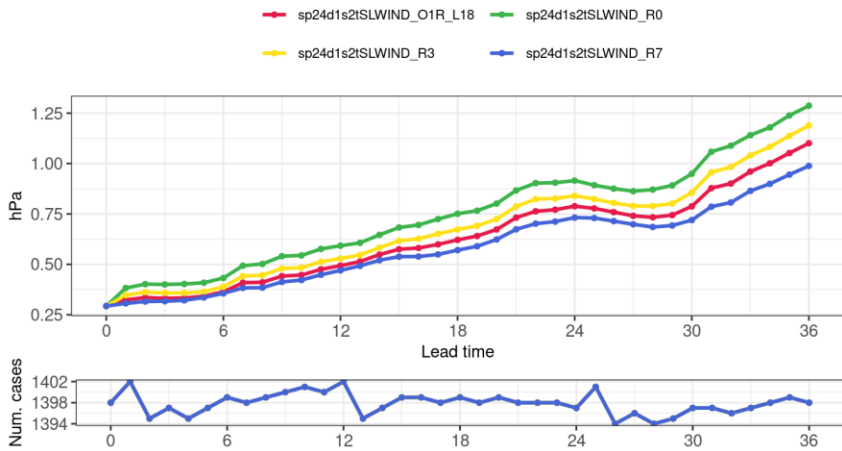
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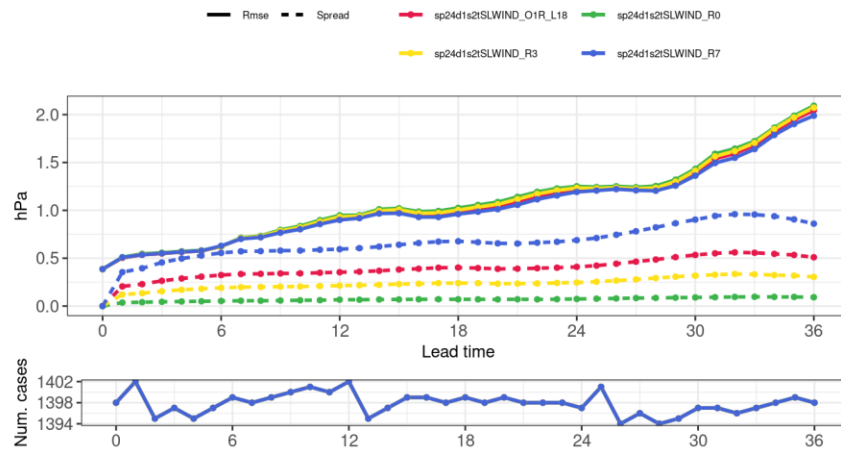
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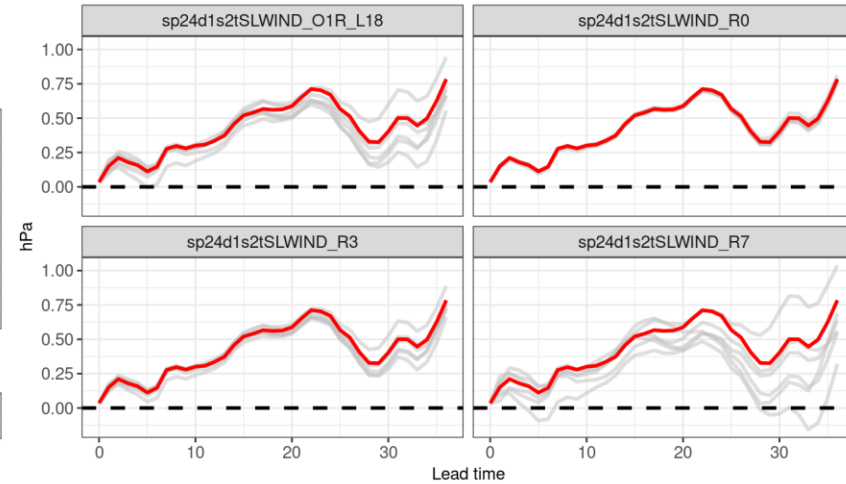
Crps : Pmsl : 2022-02-10-00 - 2022-02-17-00 (8 cycles)
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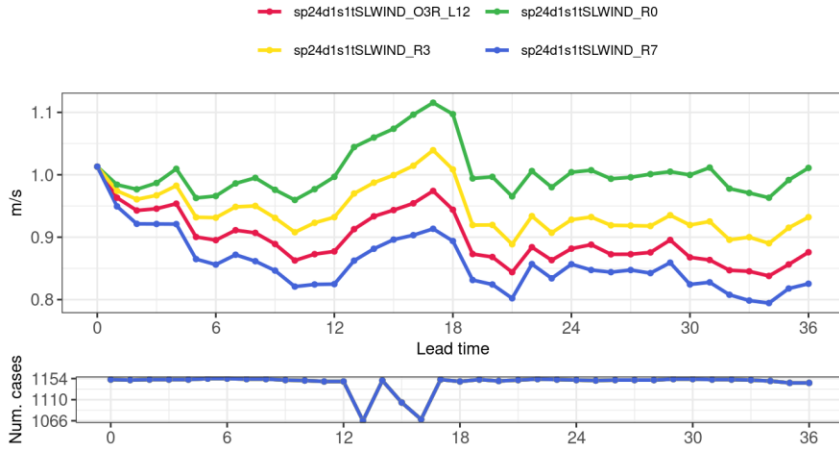


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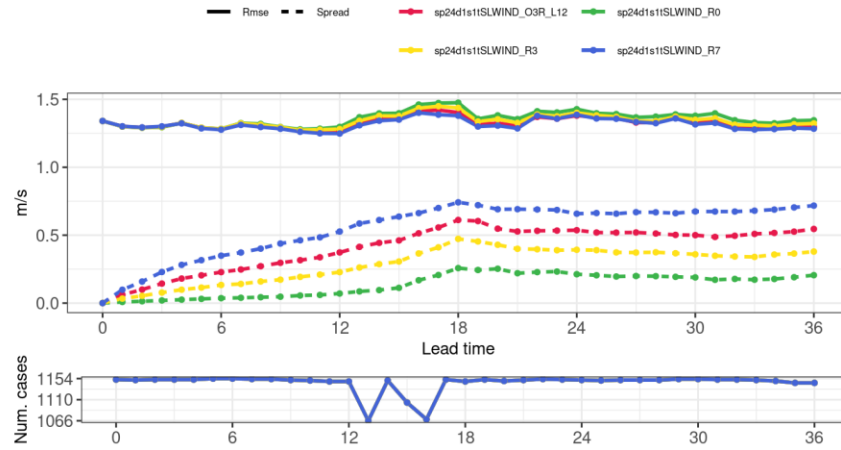


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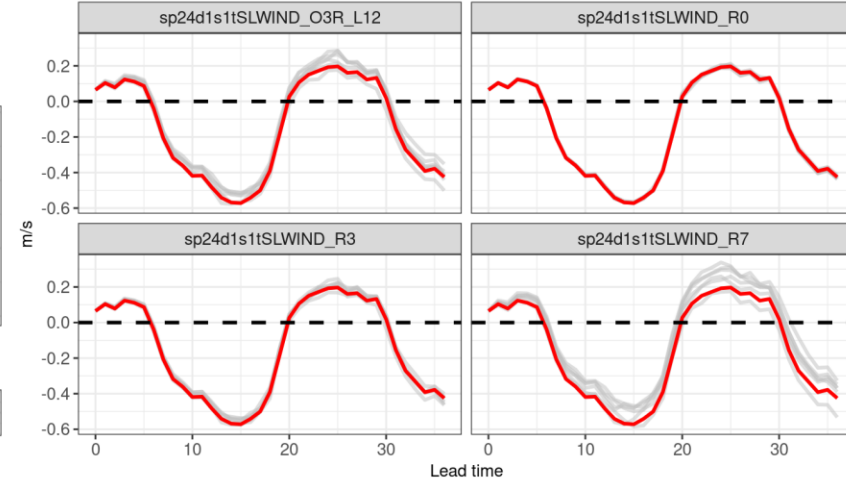
Crps : S10m : 2023-06-06-00 - 2023-06-13-00 (8 cycles)
All stations (145) : All cycles used



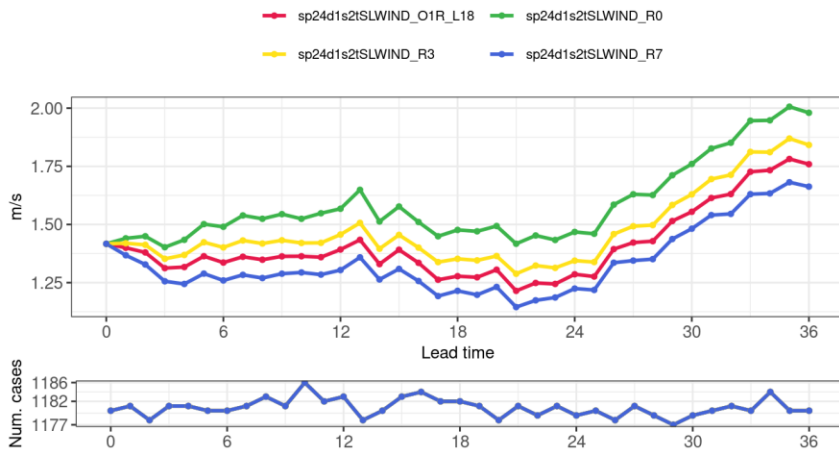
Rmse, Spread : S10m : 2023-06-06-00 - 2023-06-13-00 (8 cycles)
All stations (145) : All cycles used



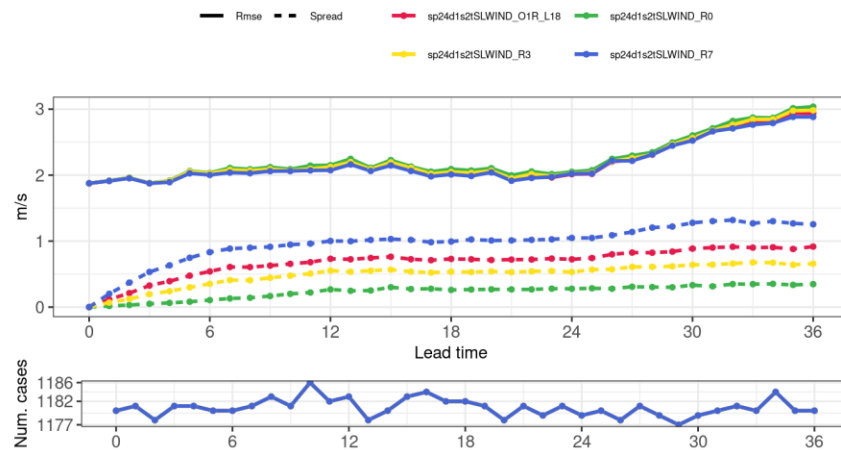
Bias : All Members : S10m : 2023-06-06-00 - 2023-06-13-00 (8 cycles)
All stations (145) : All cycles used



Crps : S10m : 2022-02-10-00 - 2022-02-17-00 (8 cycles)
All stations (149) : All cycles used



Rmse, Spread : S10m : 2022-02-10-00 - 2022-02-17-00 (8 cycles)
All stations (149) : All cycles used



Bias : All Members : S10m : 2022-02-10-00 - 2022-02-17-00 (8 cycles)
All stations (149) : All cycles used

