Strategies for generating physically consistent realizations from a multi-model blend

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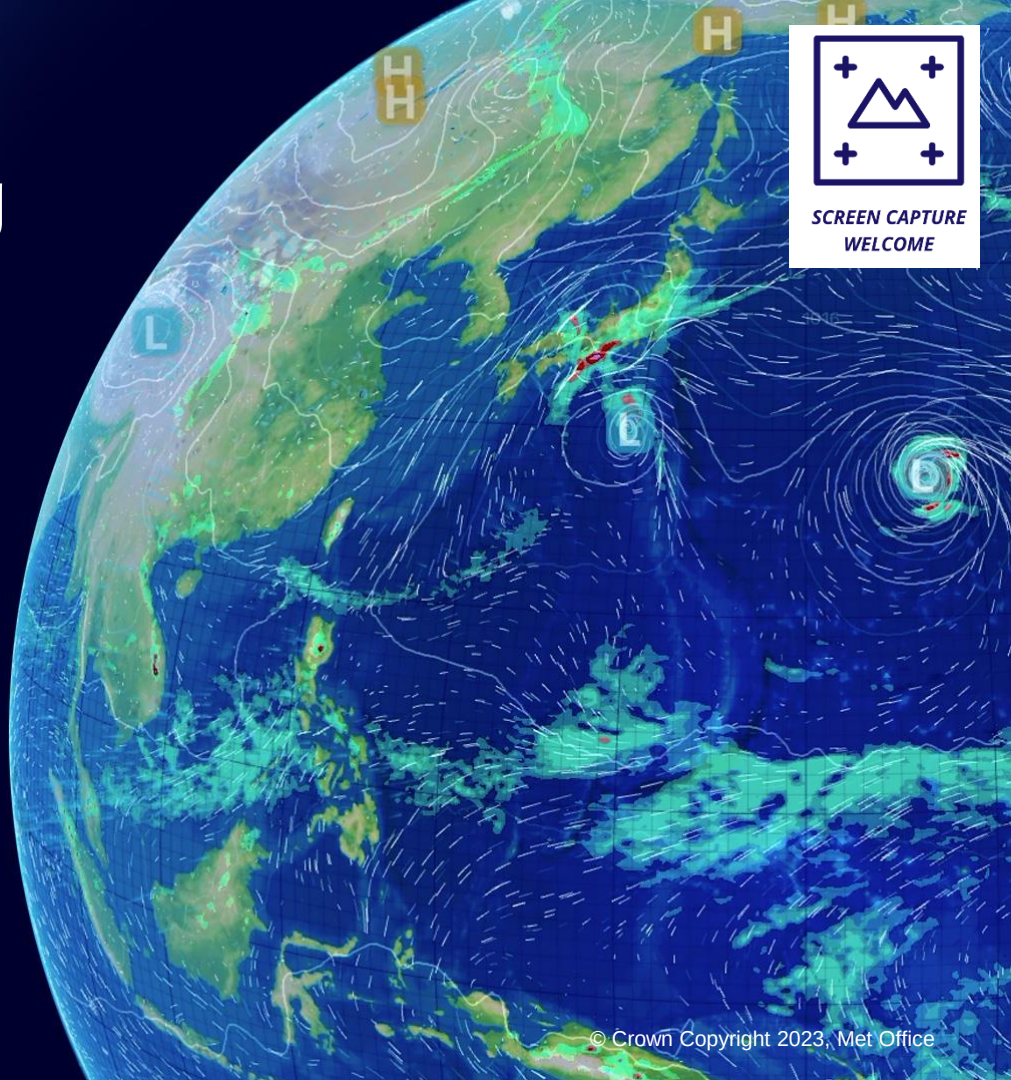

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Requirements for physically consistent realizations

- Physically consistent realizations are required for driving hydrological models.
- Other requirement for commercial applications.

Options

Description	Pros	Cons
Provide raw ensemble members	• Members are physically consistent.	• Won't benefit from further post-processing / calibration.
Post-process as members only	• Regeneration of realizations from probabilities not required.	• Potentially won't benefit from all post-processing steps.
Regenerate realizations after post-processing as probabilities	• Regenerated realizations benefit from all post-processing steps.	• Difficulty in generating realistic realizations from probabilities.

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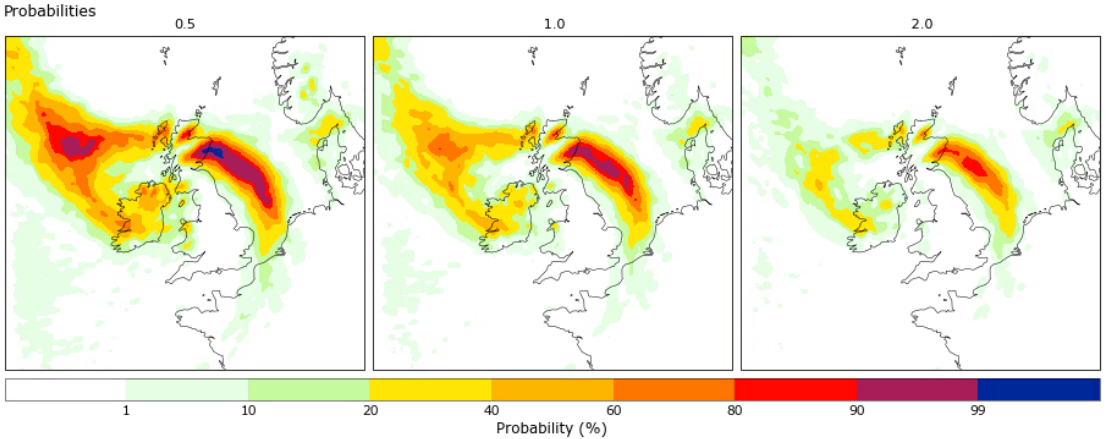
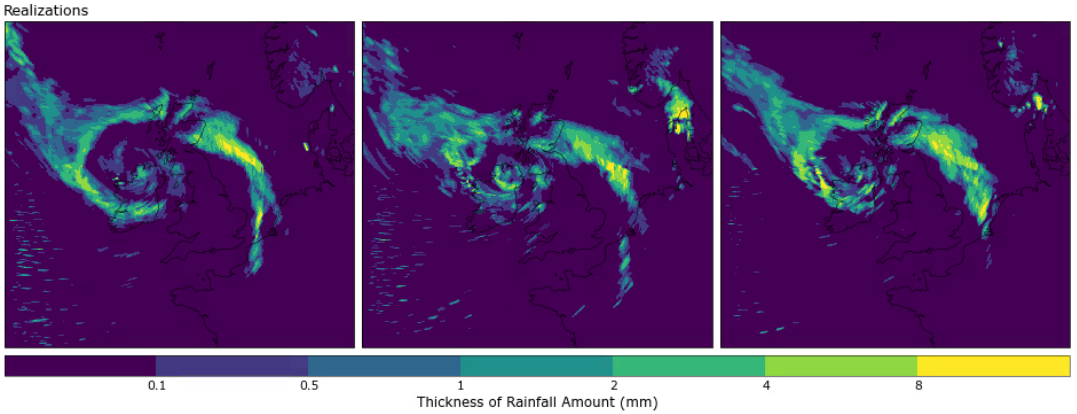


Aim to generate physically consistent realizations from probability forecasts created from a multi-model blend.



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Regenerating realizations after post-processing as probabilities

Use a Copula:

- A copula couples the distribution for a particular variable with the multivariate joint distribution.
- To use a copula-based approach, the multivariate dependence template needs to be defined somehow.

Approaches include:

- Using the raw ensemble forecast (Ensemble Copula Coupling).
- Use past observations (Schaake Shuffle).
- Assume a parametric Copula (e.g. Gaussian).

Recovering realizations – Using the raw ensemble forecast (Ensemble Copula Coupling, ECC)

Method	Univariate sampling	Involves randomness	Reference
ECC-R (Random)	Random	Yes (sampling)	Schefzik et al., 2013
ECC-Q (Quantile)	Equidistant	No	Schefzik et al., 2013
ECC-T (Transformation)	Percentiles from raw ensemble	No	Schefzik et al., 2013
ECC-S (Stratified)	Stratified	Yes (sampling)	Hu et al., 2016

ECC-T: Fit a CDF to the raw ensemble. Extract quantiles that correspond to percentiles from the raw ensemble.
ECC-S: Create equally-spaced probability bins. Randomly sample within each bin (Hu et al., 2016).

Table inspired by Table 1 in Lerch et al., 2020.

Recovering realizations – Using the raw ensemble forecast - Extensions

Method	Rationale	Reference
Dual ECC (dECC)	Forecasts aren't observations	Ben Bouallègue et al. (2016)
Modifications in Scheuerer & Hamill, 2018	Resolve ties	Scheuerer & Hamill (2018)
Bootstrapped ECC	Resolve ties	Taillardat and Mestre (2020)
Trajectory smoothing	Temporal smoothing	Bellier et al. (2018)
Distribution smoothing	Temporal smoothing	Bellier et al. (2018)
Template perturbation	Temporal smoothing	Bellier et al. (2018)

- Resolving ties randomly can lead to an unrealistic spatial pattern.
- The temporal trajectory can be noisy without additional processing.

Recovering realizations – Using historical information (Schaake Shuffle - SSh)

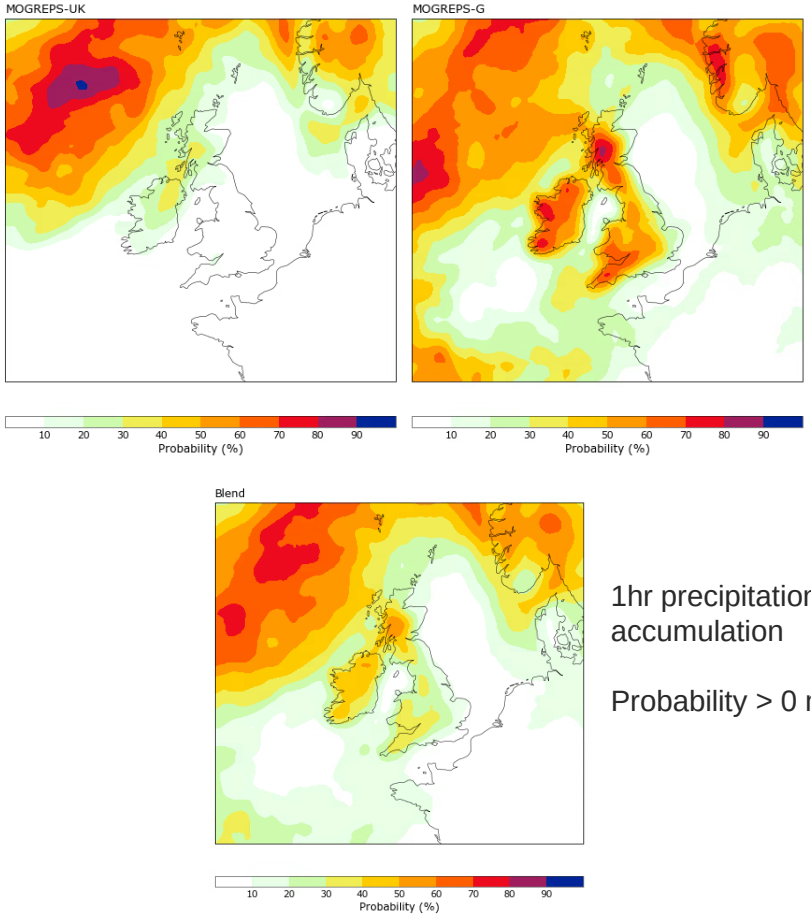
Method	Univariate sampling	Involves randomness	Reference
SSh-Q	Equidistant	Yes (selection of training cases)	Clark et al., 2004
SSh-R	Random		Lakatos et al., 2023
SSh-S	Stratified		Lakatos et al., 2023

Recovering realizations – Using historical information

Method	Dominant Rationale	Detailed Rationale	Reference
Similarity-based Schaake Shuffle	Find most appropriate past dates	Find similar forecast analogues	Schefzik, (2016)
Analogue Schaake Shuffle with Center of Gravity	Find most appropriate past dates	Find meteorologically similar observations	Bellier et al. (2017)
Analogue Schaake Shuffle and ECC	Find most appropriate past dates	Spatial ordering from SS, temporal ordering from ECC	Bellier et al. (2017)
Minimum Divergence Schaake Shuffle (mdSSh)	Find most appropriate past dates	Find statistically similar observations	Scheuerer et al., (2017)
mdSSh with spatial disaggregation	Plus spatial smoothness	Spatial smoothness	Scheuerer & Hamill (2018)

Creating a multi-model blend

- IMPROVER creates a multi-model blend by blending probability forecasts from different models.
- However, there is no single raw ensemble to use as a dependence template for ECC.



1hr precipitation accumulation

Probability > 0 mm

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Recovering realizations from a multi-model blend

- Use a Schaake Shuffle-type approach. Relies upon a multi-year dataset of historical observations (and possibly forecasts).
  - Having a multi-year dataset instantly available may be difficult to manage in an operational environment.
- Use ECC with options including:
  - Choose a single forecast source to use as the dependence template. In practice, this forecast source should be available at all lead times.
  - Group forecast sources and choose a representative member from each group. The temporal smoothness of the realizations may be an issue.
  - Create a multi-model blend in physical space as a dependence template.

Post-processing ensemble members directly

Avoiding the need to regenerate ensemble realizations is appealing.

However, there are still issues:

- Constructing a multi-model blend in physical space is challenging with potential for artefacts.
- Potential inconsistency between post-processed probability forecasts and post-processed ensemble realizations. Will this matter in practice?

Summary

- Multiple options exist for regenerating realizations from probability forecasts.
- Regenerating realizations from the multi-model blend of probability forecasts is challenging without a clear choice for dependence template.
- Generating post-processed ensemble members directly risks inconsistencies between the probability forecasts and the realization forecasts.

Future work

- Explore options for creating a dependence template that will regenerate realizations from probability forecasts using ECC.
- Consult with hydro-meteorologists and hydrologists to ensure that the regenerated realizations are physically consistent and suitable for driving hydrological models.

Thank you

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