How Well Can the NCEP Global Ensemble Forecast System Capture the Uncertainty in the Analysis and Forecast of Winter Storm Precipitation?

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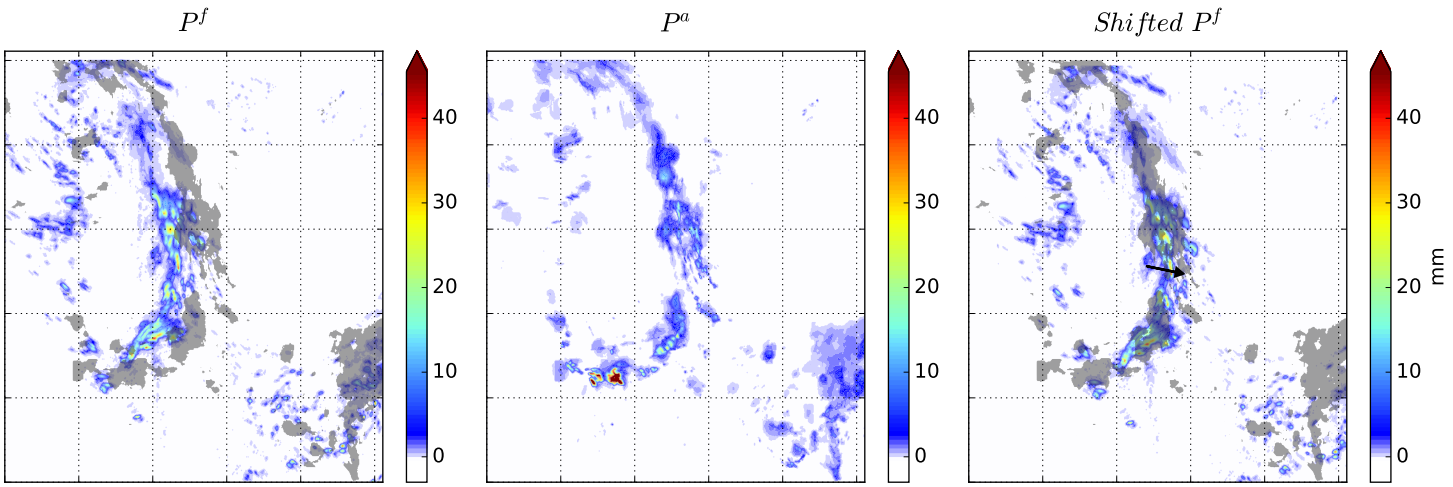
Introductory Remarks

The talk is about a **morphing-based** verification technique for **ensemble based prediction of coherent structures** (e.g., precipitation fields, radar images, PV-anomalies)



The central idea is to compute a shift vector that corrects the location error. This vector can be used

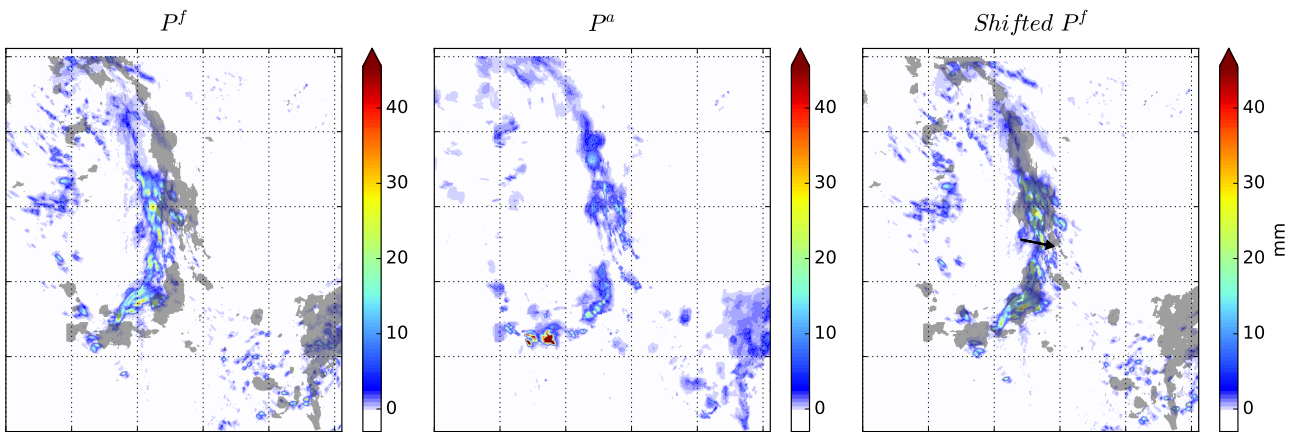
- to construct diagnostic relationships, or potentially,
- to estimate the innovation for the location "observation" in data assimilation

Brief History

- The papers that inspired our work: **Keil and Craig, 2007** (MWR, 135, 3248-3259), **2009** (WAF, 24, 1297-1308)
- First version of morphing-based algorithm: **Han and Szunyogh, 2016** (MWR, 144, 295-313)
- Latest version of morphing-based algorithm: **Han and Szunyogh, 2018** (MWR, 146, 1303-1318)
- Extension to ensemble forecasts **Han and Szunyogh, 2018** (Tellus A, 70, 1440870)

The Problem and Proposed Solution

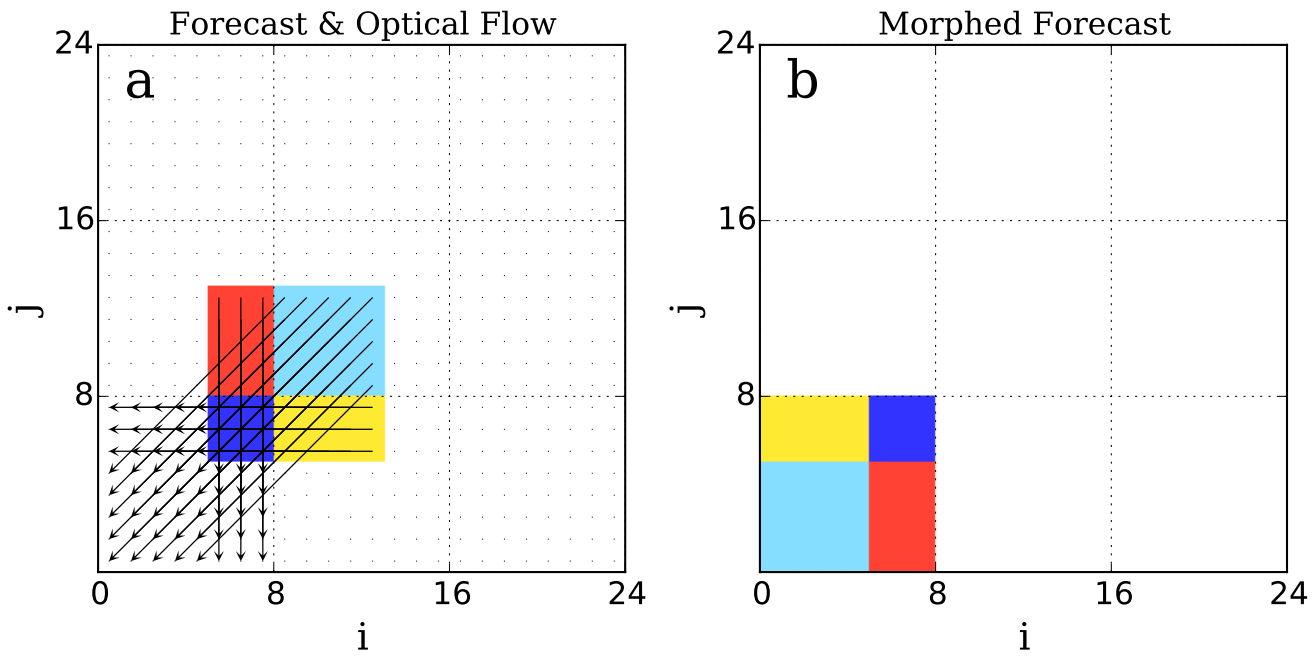
Measures based on measuring the loss of correlation between the spatial variations of the forecast and verification fields (e.g., root-mean-square error) indicate a rapid loss of predictive skill even for a small error of the location of the forecast structure, if the spatial variability within the coherent structure is high



Proposed Solution: (i) estimate the location error by a shift vector, then (ii) shift the forecast structure before computing the other diagnostics

Illustration of the Optical Flow

The **optical flow**, which is the collection of the **morphing vectors**, can be complicated, but its mean is the shift vector that can be applied to all elementary pixels of the forecast image



Data

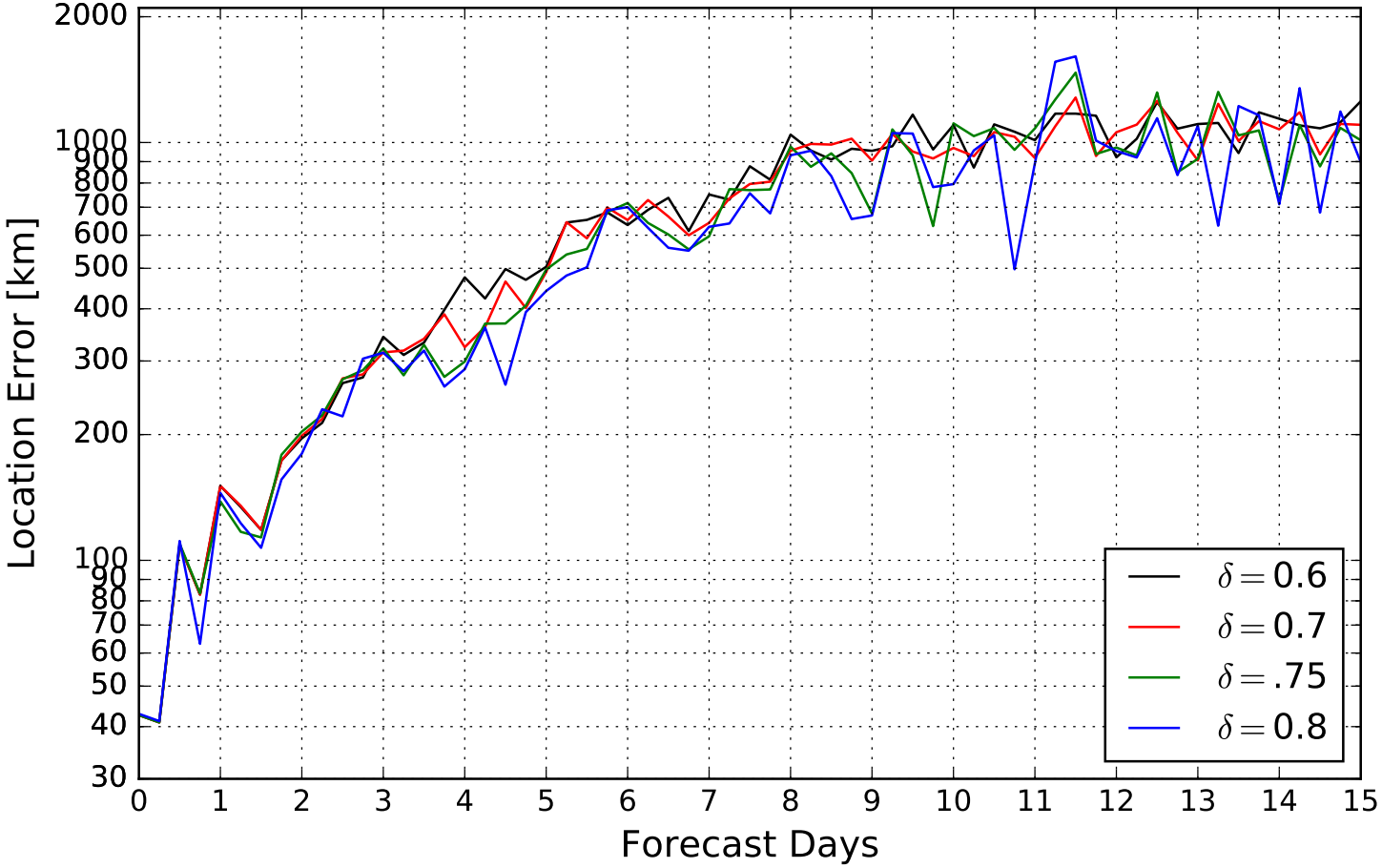
- **Forecasts:** Operational global deterministic and ensemble forecasts from NCEP
- **Verification Data:** Stage IV precipitation analyses
- **Forecasts Cases:** Different lead time forecasts of the 32 U.S. winter storms that were named by the Weather Channel in the winter of 2014/2015 and 2015/2016
- **Similarity Index:** The **Amplitude and Structural Similarity Index Measure (ASSIM)** (Han and Szunyogh 2018): the forecast structure is declared a prediction of the verification feature, if ASSIM is larger than a prescribed threshold value δ after the correction of the location error

A Few Notes on ASSIM

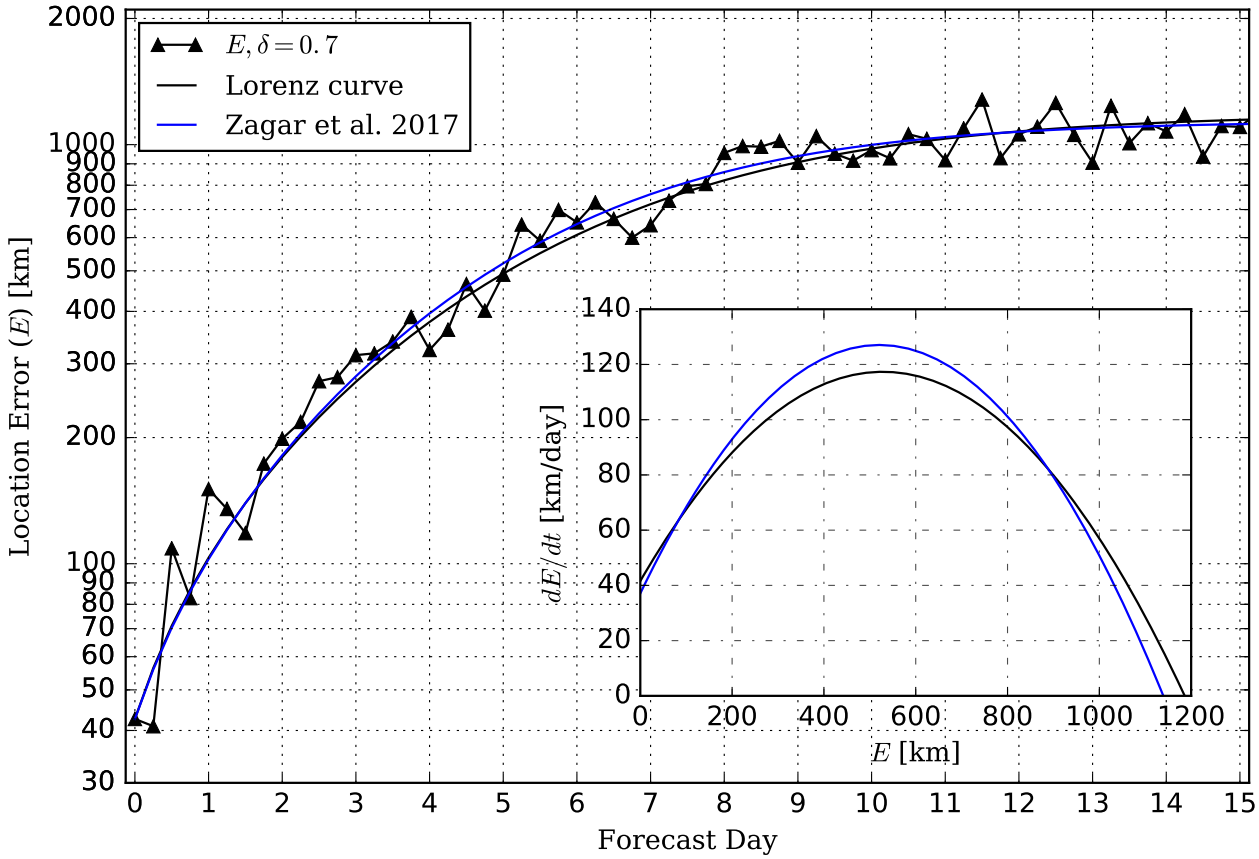
- ASSIM take a value between 1 and 0, with 1 indicating identical fields and 0 indicating fields of no similarity
- ASSIM is an adaptation of the **Wang-Bovik index** (Wang and Bovik 2002), also known as **SSIM**, of digital image processing
- Unlike the root-mean-square error, ASSIM (the Wang-Bovik index) treats the accuracy of the prediction of the **spatial variability** (variance) of the field and the **loss of correlation** between the forecast field and the verifying field as independent qualities of the forecast

The Error Growth Curve for the Deterministic Forecasts

The results are not sensitive to the choice of the threshold value δ of the similarity index



Lorenz-curve Analysis



The shape of the curve suggests that synoptic scale instabilities drive the uncertainty in the location.

Ensemble Diagnostics

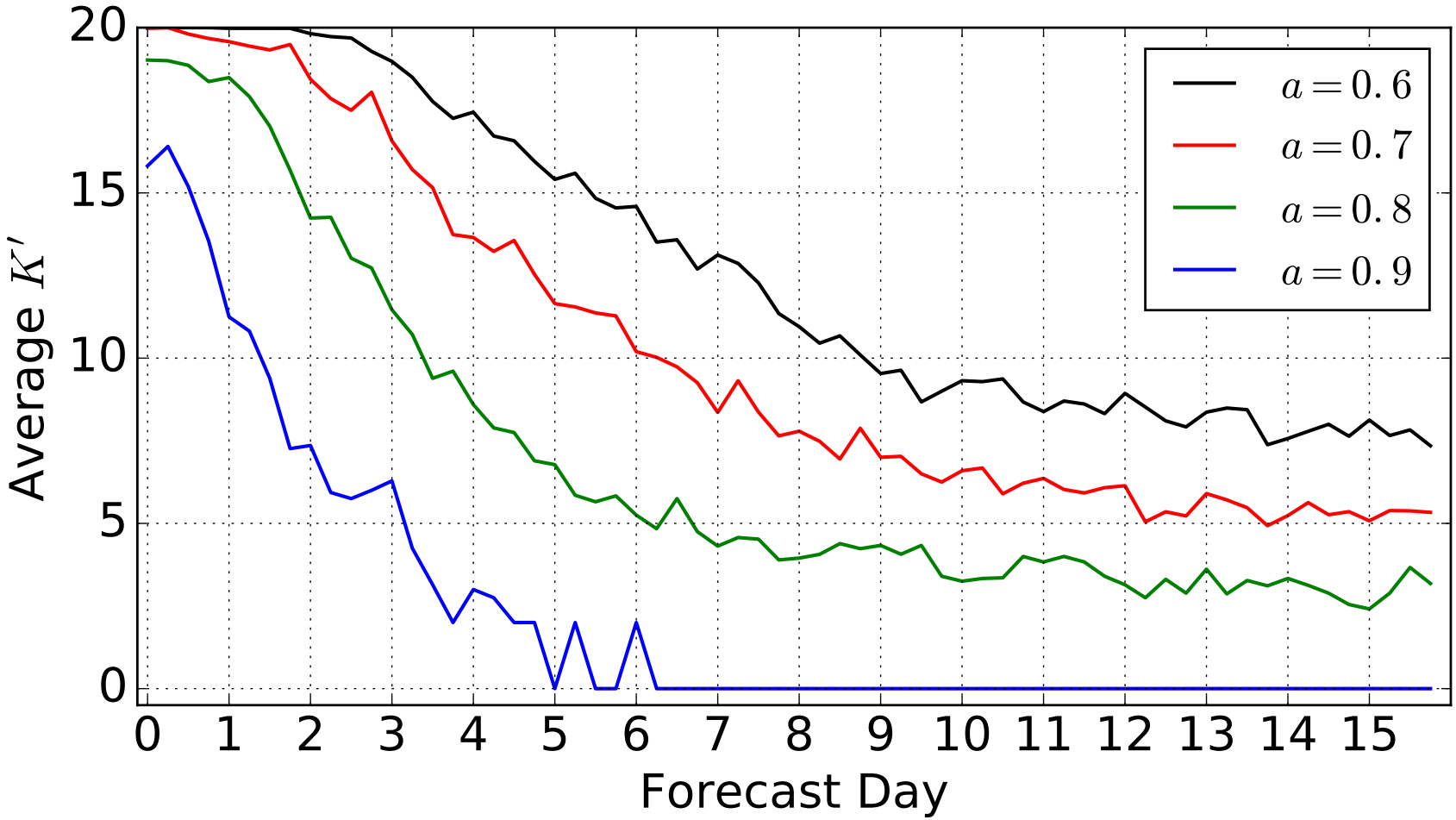
- Let K' be the number of ensemble members for which $ASSIM > \delta$ (K' depends on the storm and the forecast time)
- Let $d\mathbf{X}^k$ ($k = 1, \ldots, K'$) be the shift vector $d\mathbf{X}$ for ensemble member k, and $\overline{d\mathbf{X}}$ the ensemble mean of the K' shift vectors
- **Bias:**

$$E\left[\overline{d\mathbf{X}}\right]$$

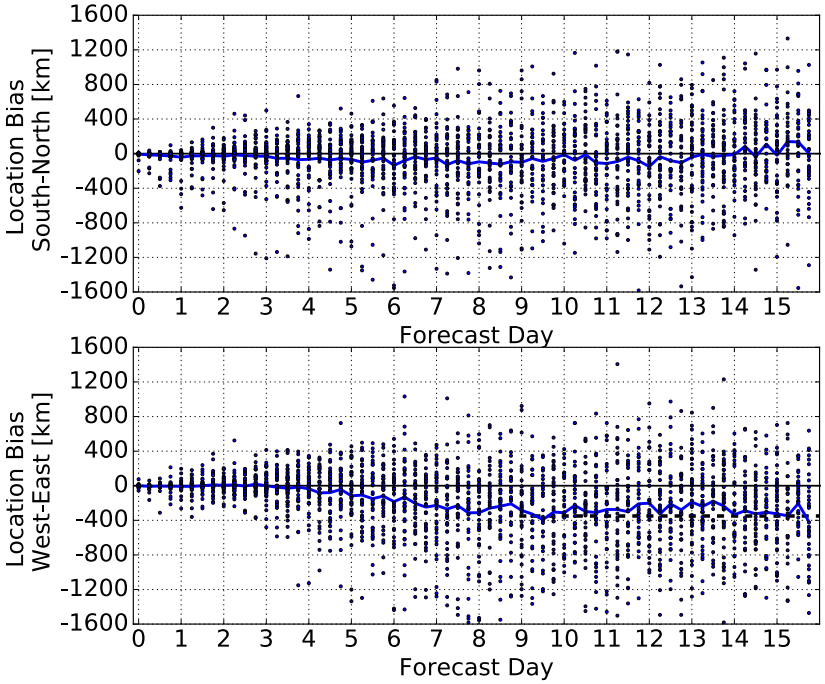
- **"Spread-skill relationship":**

$$E^{1/2}\left[\frac{1}{K'-1}\sum_{k=1}^{K'}\left(d\mathbf{X}^k - \overline{d\mathbf{X}}\right)^2\right] = E^{1/2}\left[\frac{K'}{K'+1}\overline{d\mathbf{X}}^2\right]$$

The Dependence of K' on δ



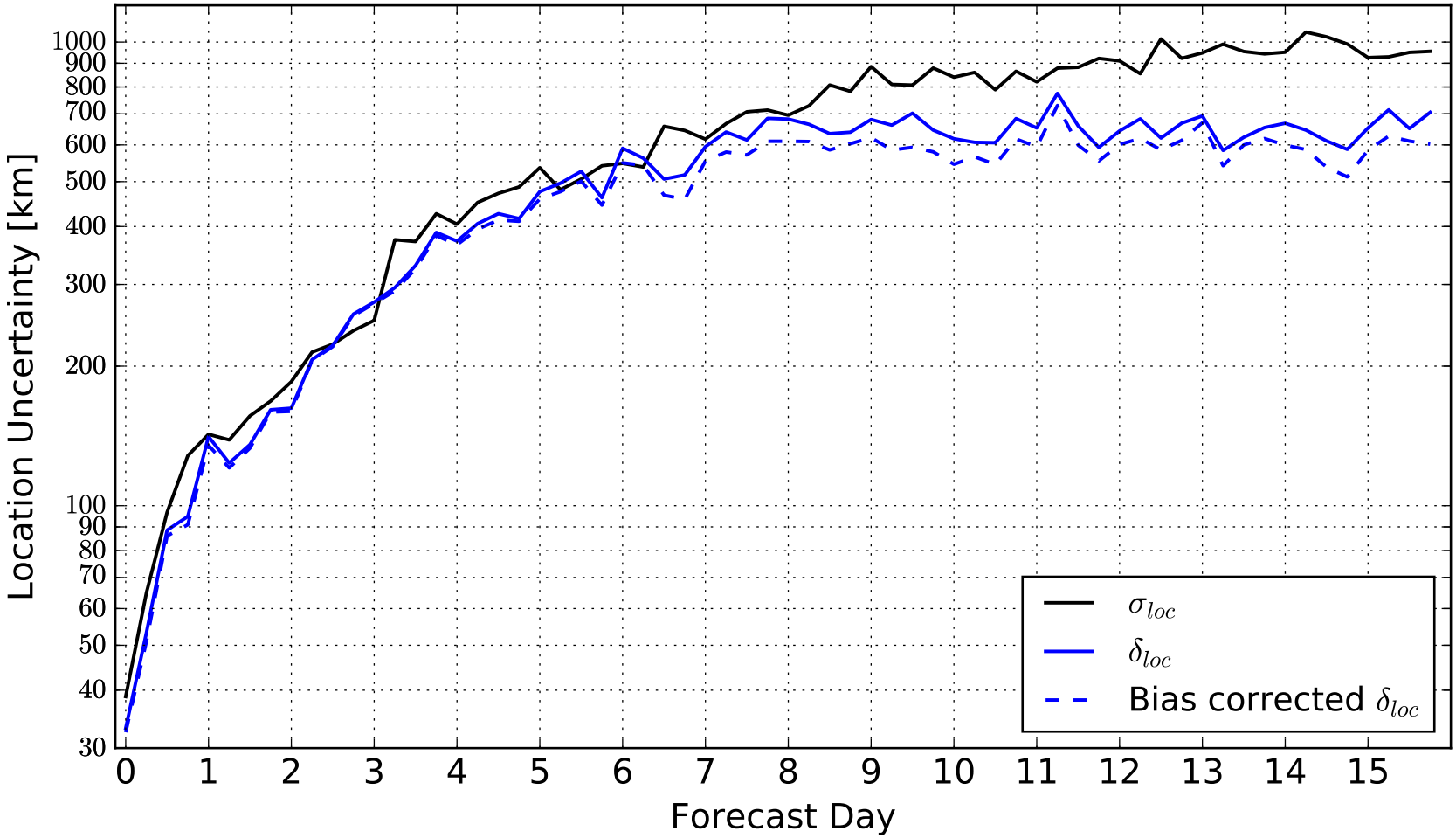
Location Bias in the Ensemble



The storms move too fast in the zonal direction after day 4. This suggests a slowly developing bias in the prediction of the zonal flow, which is consistent with Herrera et al. (2016) and Loeser et al. (2017)

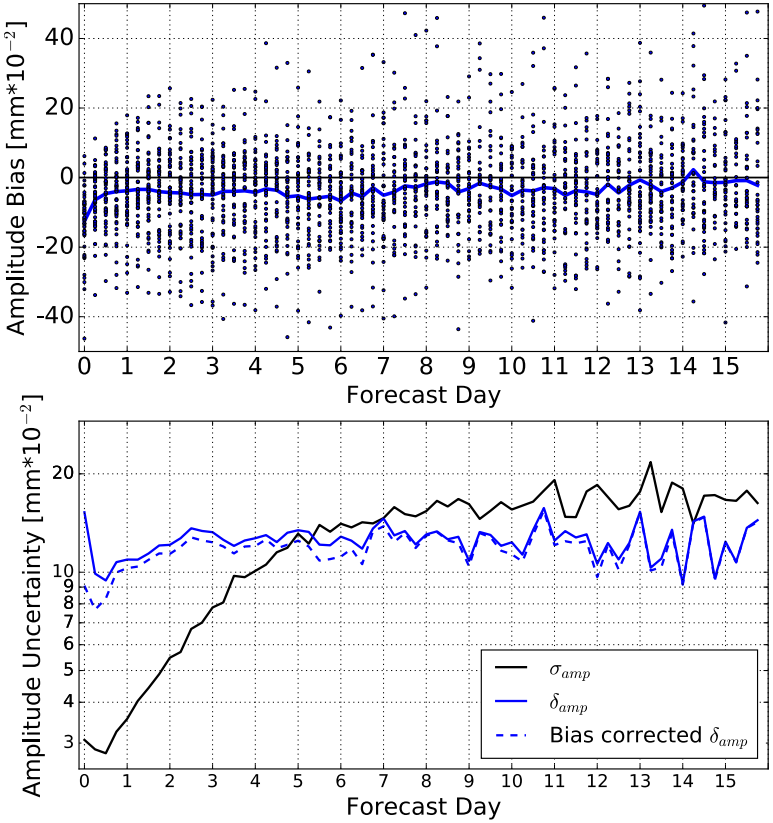
“Spread-skill” Relationship for the Location

black: spread, blue: “skill”



Bias and Uncertainty in the Precipitation Amount

black: spread, blue: “skill”



There is a lot of room for improvement of both the analysis and the representation of the analysis uncertainty of the precipitation amount!

Summary

- We introduced a morphing-based estimate of the location error of a coherent structure (e.g., precipitation)
- We derived the “spread-skill” relationship diagnostics for the location error
- The operational ensemble prediction system does a good job in predicting the uncertainty of the location for winter storms, but does a poor job in predicting the uncertainty of the precipitation amount for the same systems