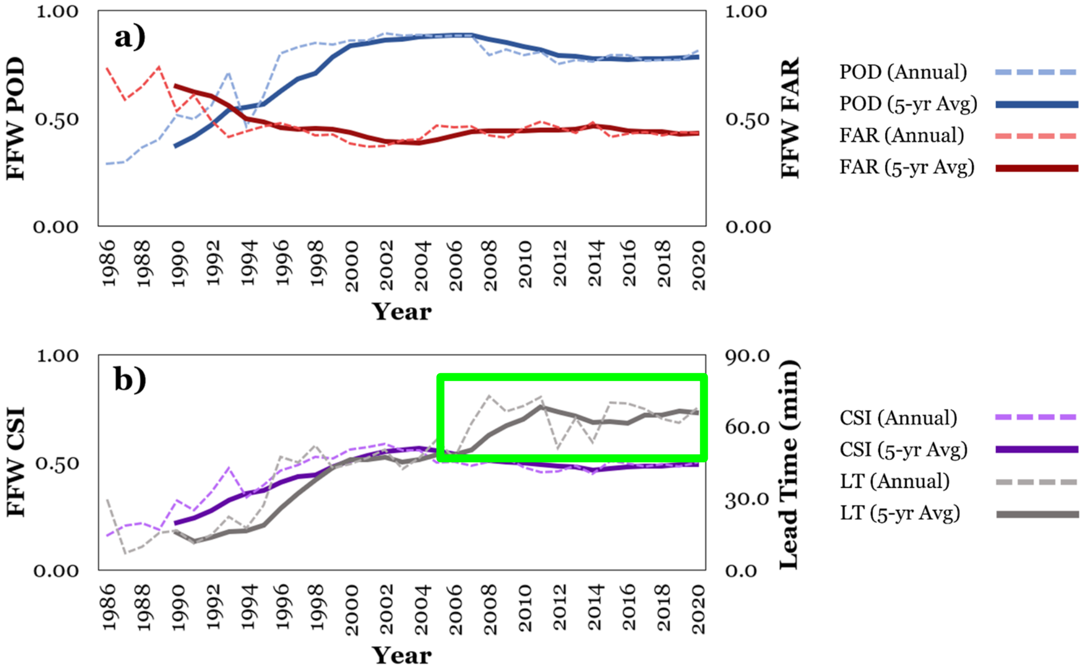
Initial Work on Precipitation Nowcasting within MRMS

Steven Martinaitis, Jackson Anthony, and Dean Meyer

Cooperative Institute for Severe and High-Impact Weather Research and Operations, Norman, OK
NOAA/National Severe Storms Laboratory, Norman, OK

FFWs and Lead Time

Flash Flood Warnings (FFWs) have seen improvements in statistical performance until the mid 2000s; however, performance has stagnated

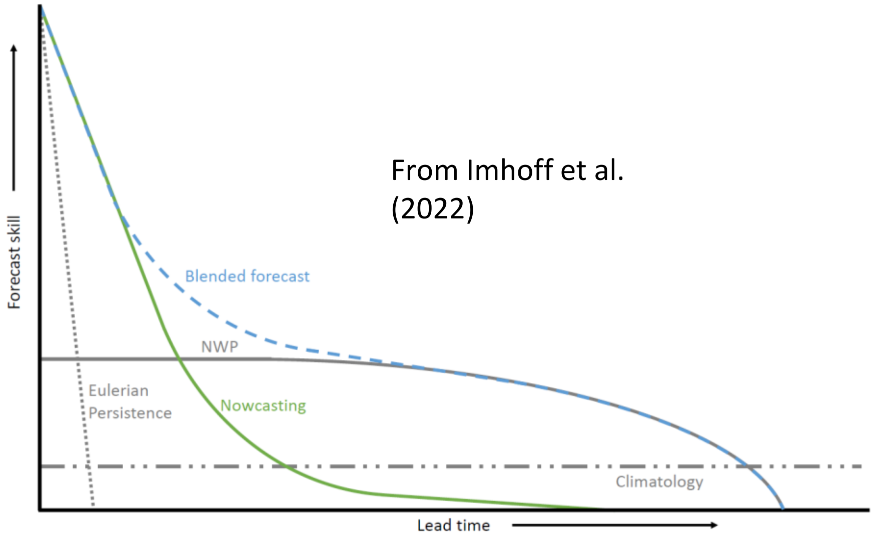


Introduction to Nowcasting

Nowcasting - Defined by the World Meteorological Organization as the ability to initialize the current weather situation and forecast by extrapolation for a period of typically 0-2 hours (some has talked about nowcasting out to 6 hours). It is possible to forecast small features such as individual storms with reasonable accuracy.

Shown to have greater skill in comparison to numerical weather prediction up to two hours from the initiation time

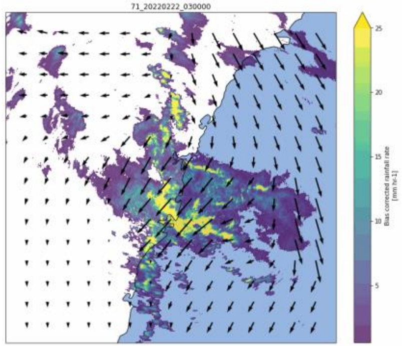
Shown to be quick in creating the nowcast output, which can be beneficial to warning operations

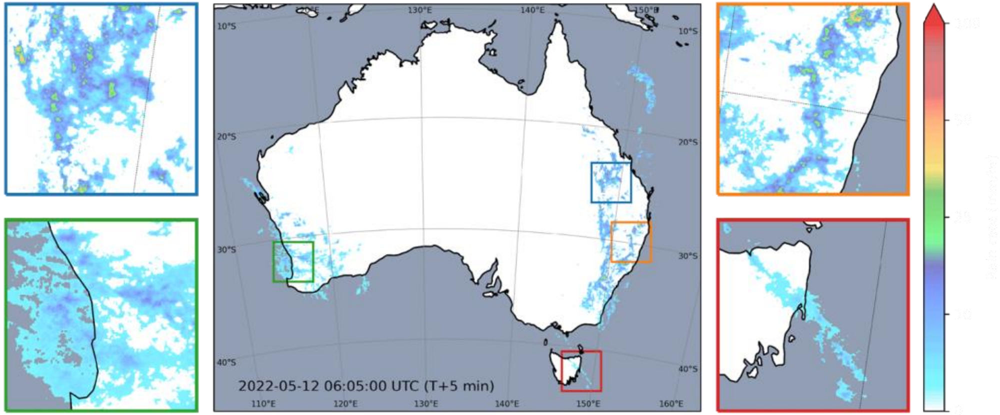


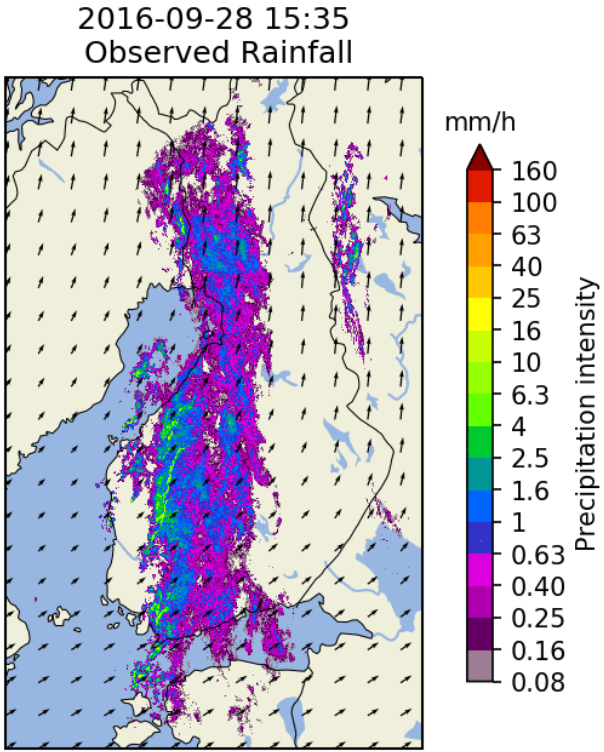
From Imhoff et al. (2022)

Examples of QPE Nowcast Applications

Nowcasting has been included in operational service (e.g., Belgium, Marshall Islands, Australia, Finland, Switzerland, Italy)

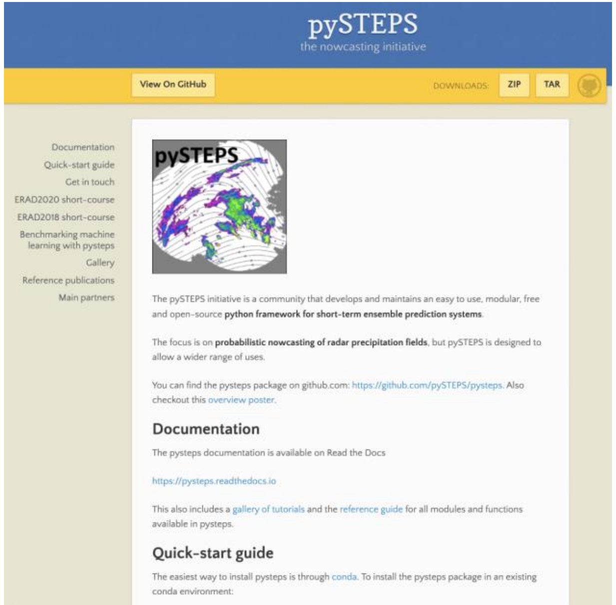






STEPS

A ensemble-based approach where the motion field is estimated using a local tracking approach based on LK optical flow and implements a scale filtering approach to progressively remove the unpredictable spatial scales during the forecast. Also includes a stochastic term which represents the variance associated to the unpredictable development of precipitation.



Available through the pySTEPS open-source and community-driven Python library

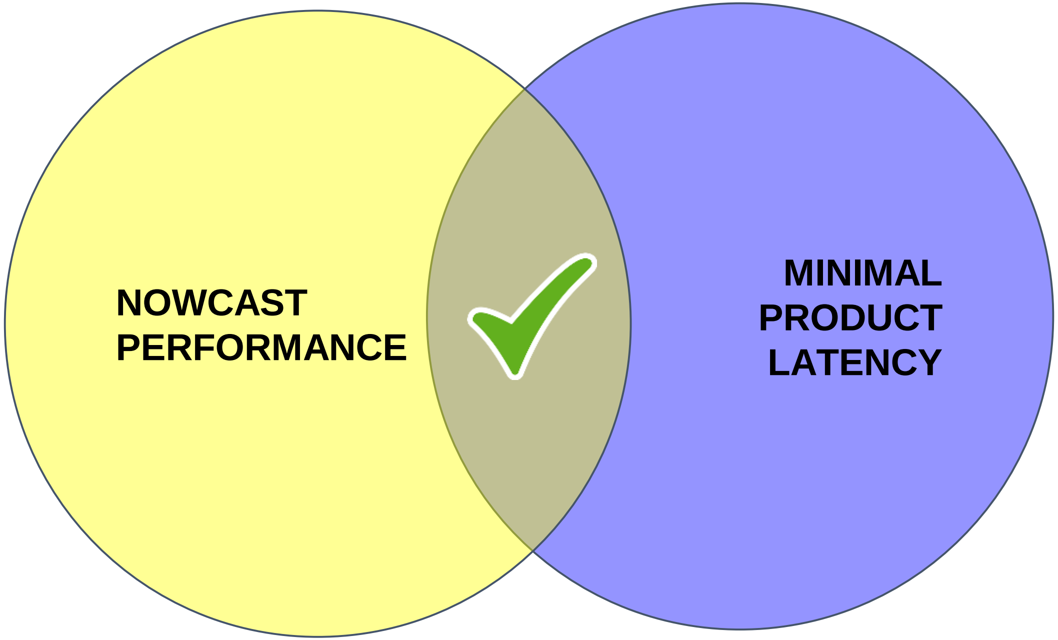
https://pysteps.github.io/

Operational Consideration of Method

We have to consider the operational use of nowcasting within the MRMS framework and how it would be paired with FLASH hydrologic output

Looking for a balance of skill and speed (fast computation time)

Studies and internal testing has shown that using the STEPS ensemble methodology allows us to meet both objectives



Work Plan for Establishing Nowcasts

Three-year plan using funding from the Bipartisan Infrastructure Law to make MRMS precipitation nowcasting operationally ready by the end of FY25

Milestone	Date	Status
Radar Nowcasting Literature Review	Q1 FY23	Complete
Develop Test Radar Nowcasting Code	Q3 FY23	Complete
Identify Cases for Testing	Q3 FY23	Complete
Develop Case Data and Test Scheme Iterations	Q4 FY23	Ongoing
Complete Case Performance Evaluations; Refine Techniques/Parameters for Use	Q3 FY24	Not Started
Compile Case and Computational Use Results	Q4 FY24	Not Started
Integrate into Cloud VMRMS, QVS Page	Q2 FY25	Not Started
Complete VMRMS Evaluations, Forecaster Feedback	Q4 FY25	Not Started
Compile Final Results; Package for Operational Use	Q4 FY25	Not Started

Different Parameters for Testing

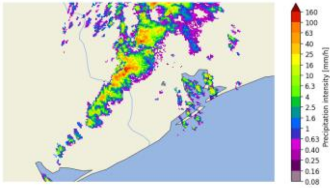
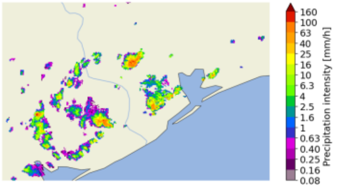
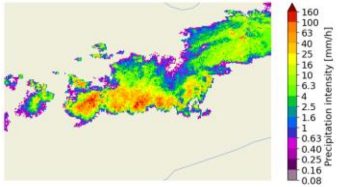
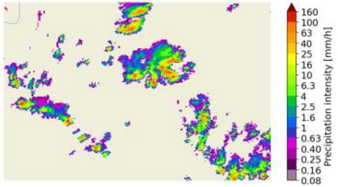
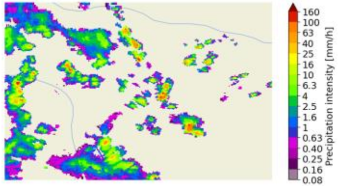
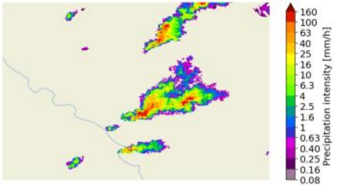
There are modifiable parameters and variables that are present within the STEPS program; Now it's a matter of finding the combination that works best for forecasting precipitation out to 60 minutes

Variable for Testing	Variable Settings	Status
Horizontal Resolution of Data	500-m, 1-km	1-km Complete
Rate Tracking Threshold	0.5, 10, 20, 40 mm h^{-1}	Complete
Number of Ensemble Members	10, 20, 30, 40	20-40 Complete
Seed Value (Random Generator)	24, None	Complete
Kmperpixel (Resolution)	1x, 2x, 4x	Complete
Velocity Perturbation	On, Off	Not Started

Due to time constraints, we will note that there were very little differences in performance with seed value and kmperpixel iterations…

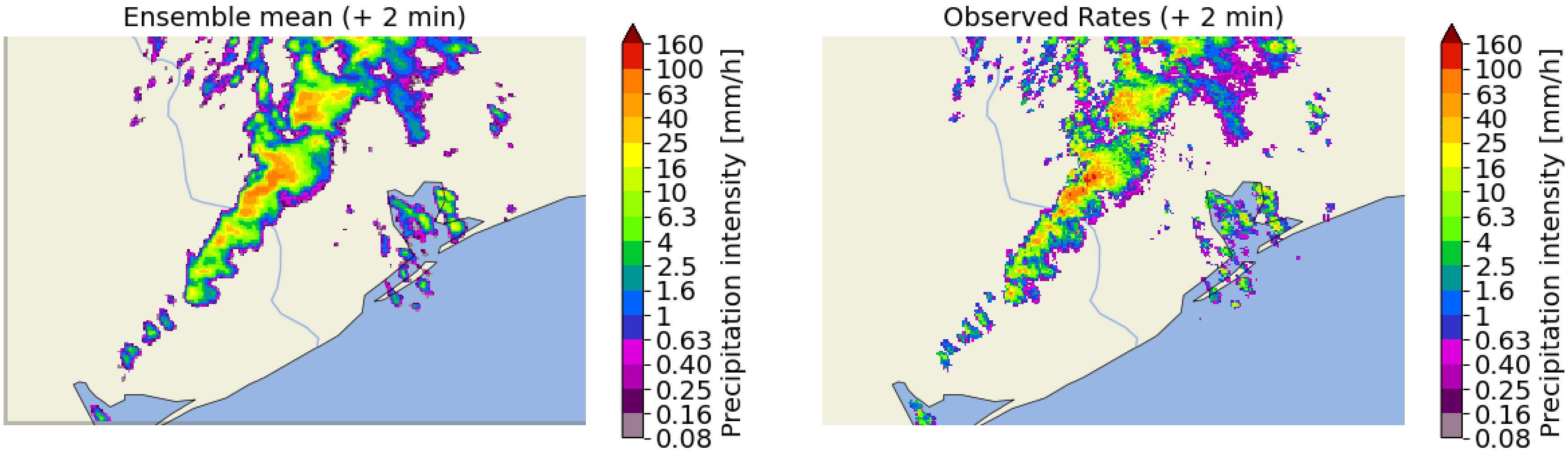
Selected Cases

Testing parameter changes were conducted through six different flash flood cases; Each domain is limited (2 x 3 degrees) and focus on a single initiation time

Case 1 - HGX 0530 UTC - 9 January 2022 Training Convection		**Case 2 - HGX** 1930 UTC - 21 July 2021 Seabreeze Event	
Case 3 - JKL 0300 UTC - 28 July 2022 QLCS with Bowing Segment		**Case 4 - FGZ** 1930 UTC 26 June 2022 Monsoon; Burn Scar & Urban	
Case 5 - PUB 2200 UTC - 31 July 2021 Monsoon; Burn Scar		**Case 6 - FWD** 2200 UTC - 16 March 2023 Supercells over Urban Area	

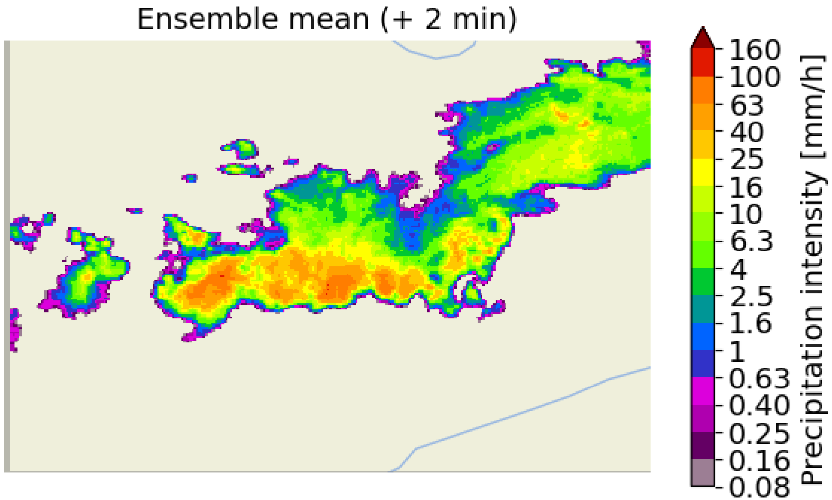
Nowcast Example - Case 1

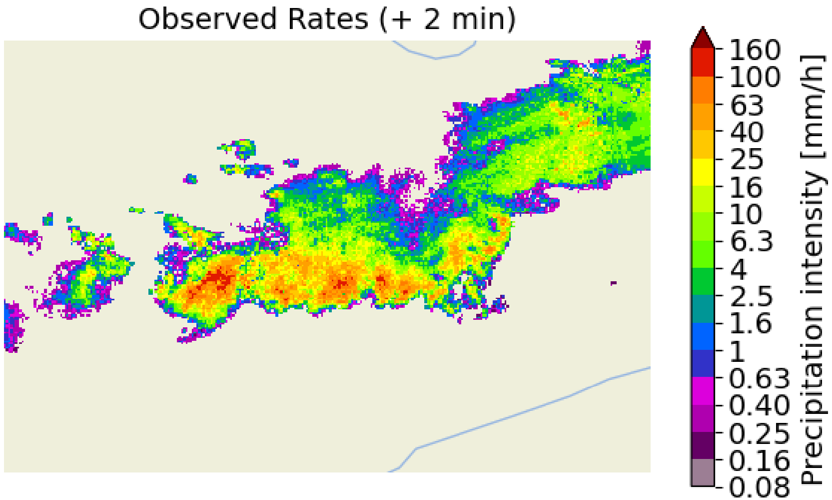
Test Parameters: 1-km Resolution, Rate Tracking = 10 mm h^{-1}, Ensemble Members = 30 , Seed = On, Kmperpixel = 1x, Velocity Perturbation = On



Nowcast Example - Case 3

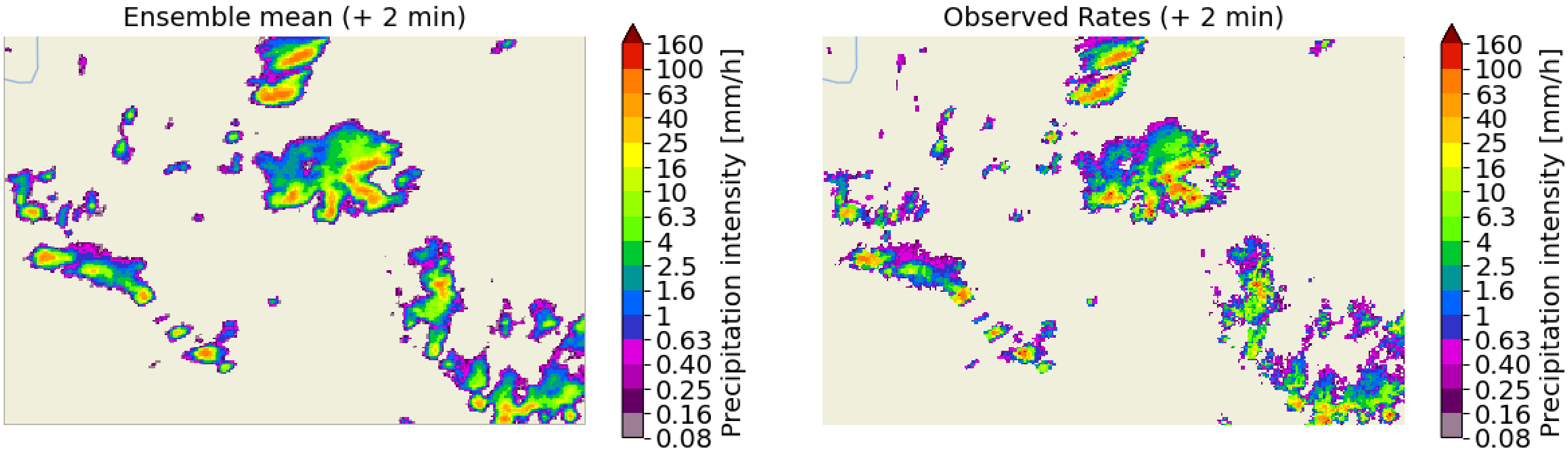
Test Parameters: 1-km Resolution, Rate Tracking = 10 mm h^{-1}, Ensemble Members = 30 , Seed = On, Kmperpixel = 1x, Velocity Perturbation = On





Nowcast Example - Case 4

Test Parameters: 1-km Resolution, Rate Tracking = 10 mm h^{-1}, Ensemble Members = 30 , Seed = On, Kmperpixel = 1x, Velocity Perturbation = On



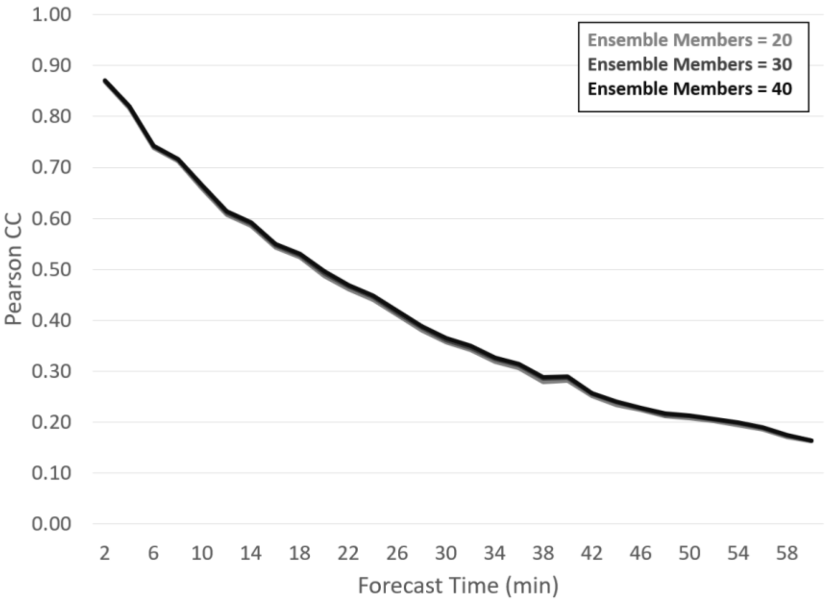
Statistical Evaluations

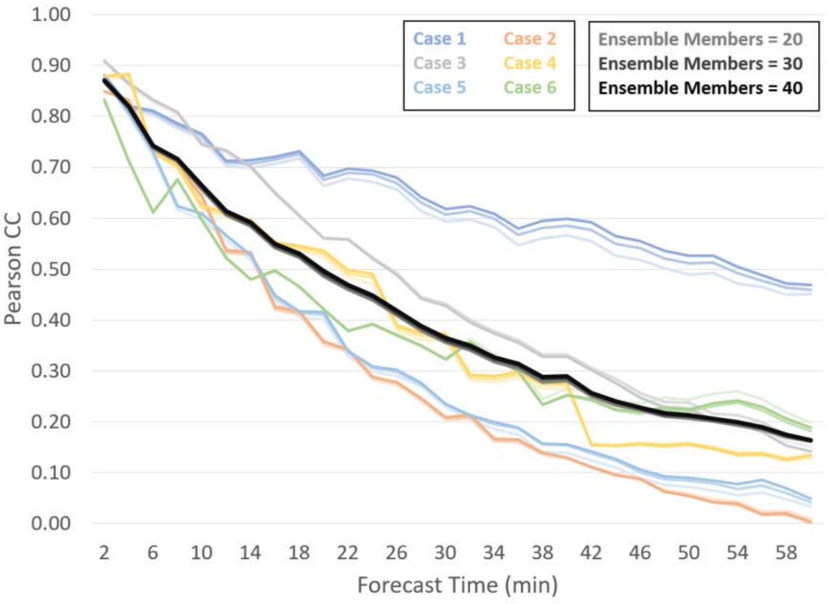
Parameter	Values/Grids Tested	Evaluation Period
Pearson Correlation Coefficient (CC)	All Grid Cells	Two minute time steps to T +60 min
Root Mean Square Error (RMSE)	All Grid Cells	Two minute time steps to T +60 min
Fractions Skill Score (FSS)	1, 10, 20 mm h^{-1}; Native resolution only	Two minute time steps to T +60 min
Receiver Operating Characteristic (ROC) Curve - Area Under Curve (AUC)	1, 10, 20 mm h^{-1}	At T +60 min only
Reliability Diagram	1, 10, 20 mm h^{-1}	At T +60 min only

FSS is the fraction of grid points exceeding a threshold within a forecast and observed field neighborhood (only using native resolution at this point)

ROC AUC and Reliability Diagram are ensemble-based evaluations; ROC curve visualises the effect of a chosen probability threshold on the classification efficiency; Reliability Diagram graphs the observed frequency of an event plotted against the forecast probability of an event

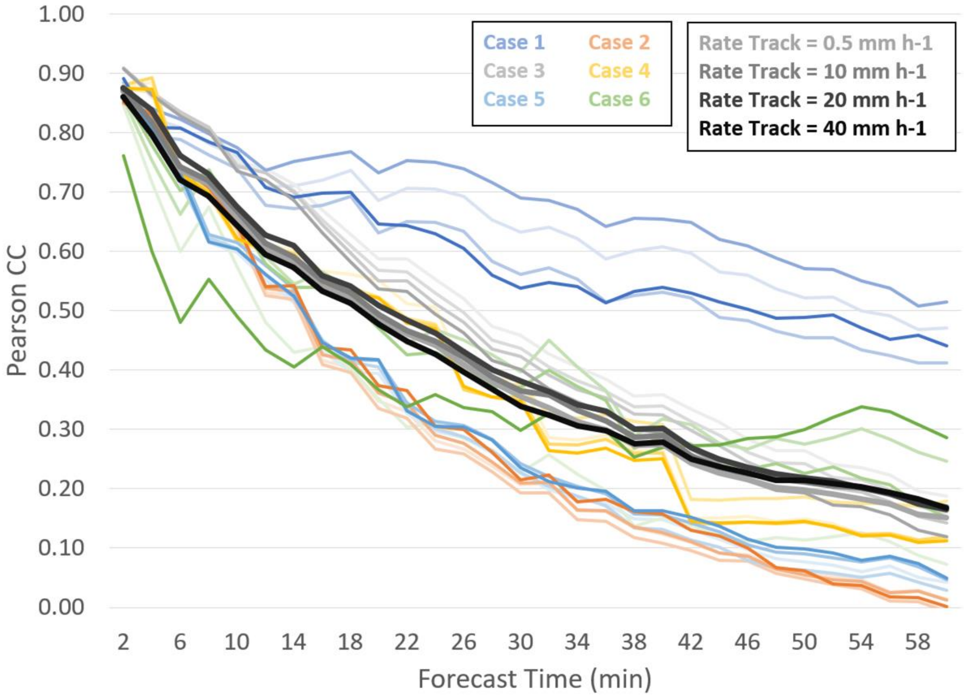
Pearson CC Values - Ensemble





Very small difference with ensemble members; Note variety with cases

Pearson CC Values - Advection Tracking

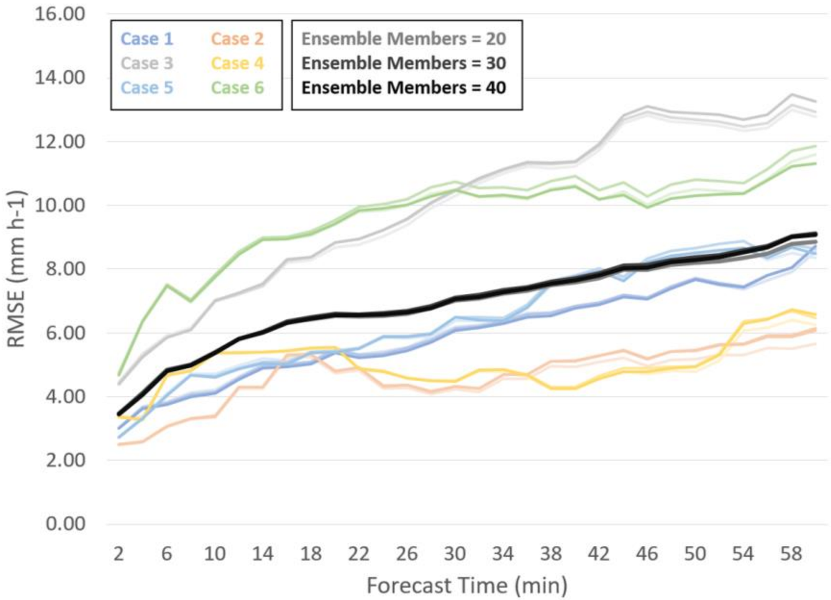


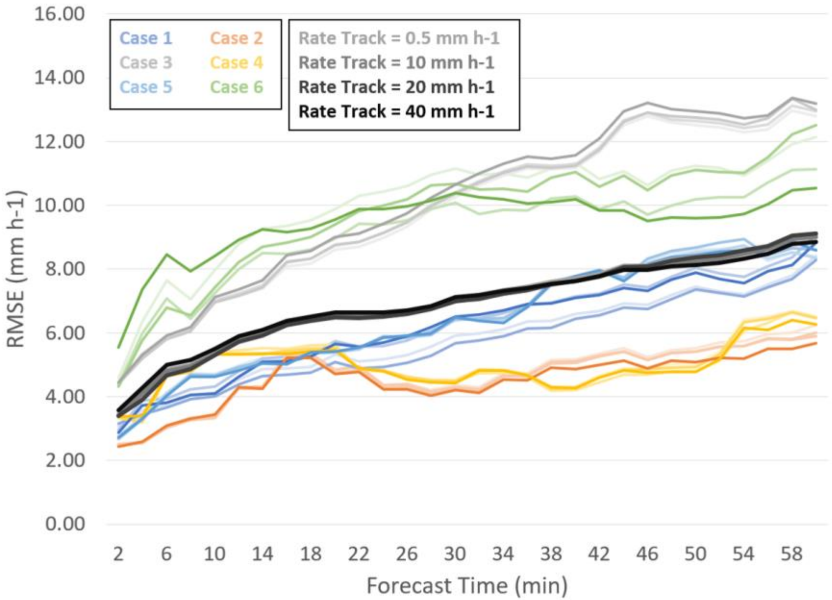
Notable differences between different advection tracking rates in the overall and between cases (some very significant)

Periods where the favored tracked rate would change in time

For the overall, best results were Rate ≥ 20 mm h^{-1} until T = +54 min (then best result was Rate ≥ 40 mm h^{-1}, which was the worst one until T = +38 min)

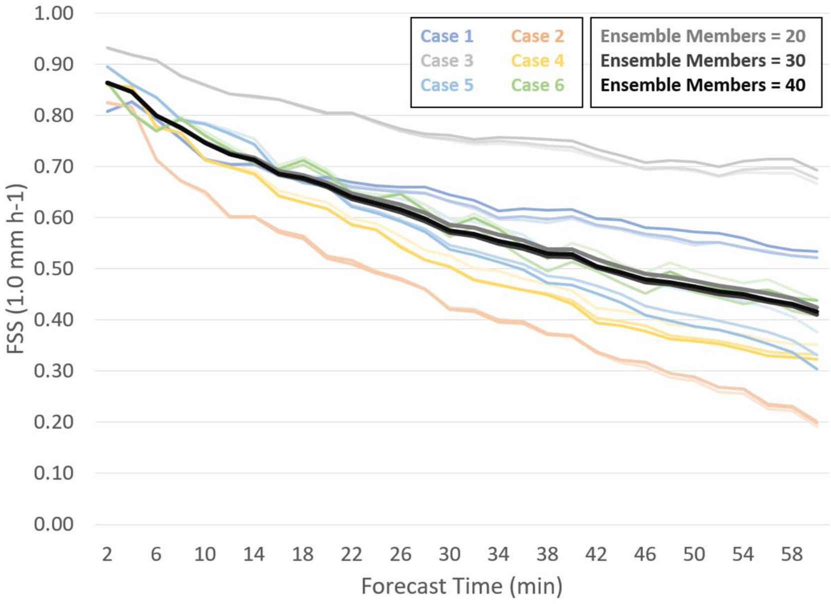
RMSE of Ensemble, Rate Tracking

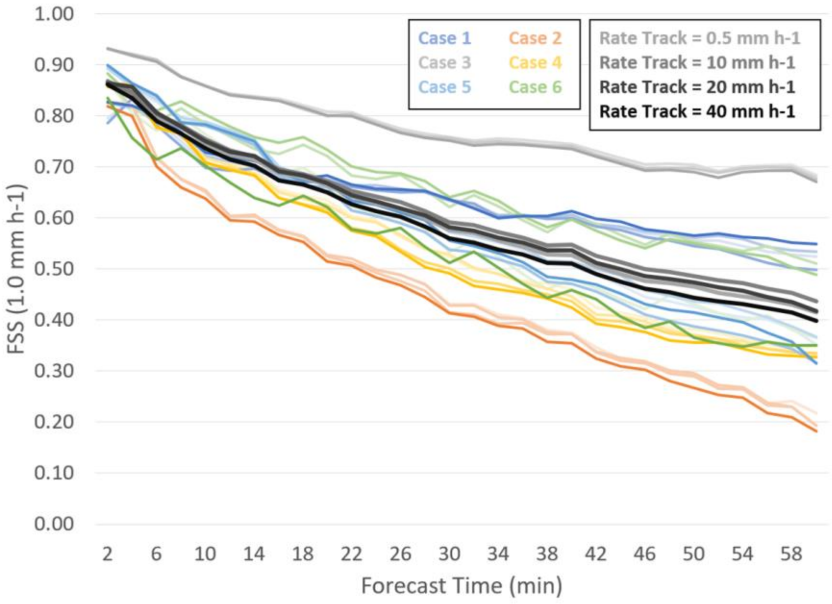




Very close values; 40 members better through T = +16 min, then 20 members better; Tracking of 10, 20 mm h^{-1} better through T = +42 min

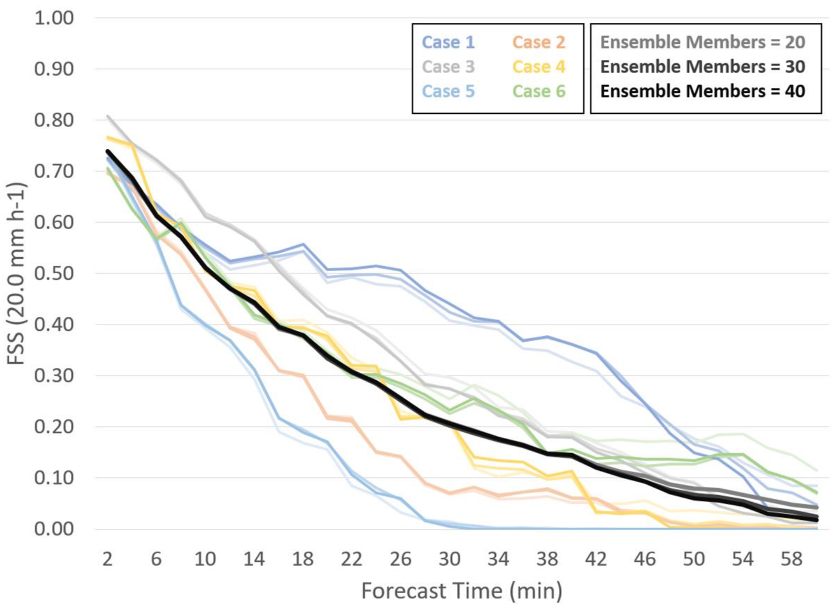
FSS ≥ 1.0 mm h^{-1} of Ensemble, Tracking

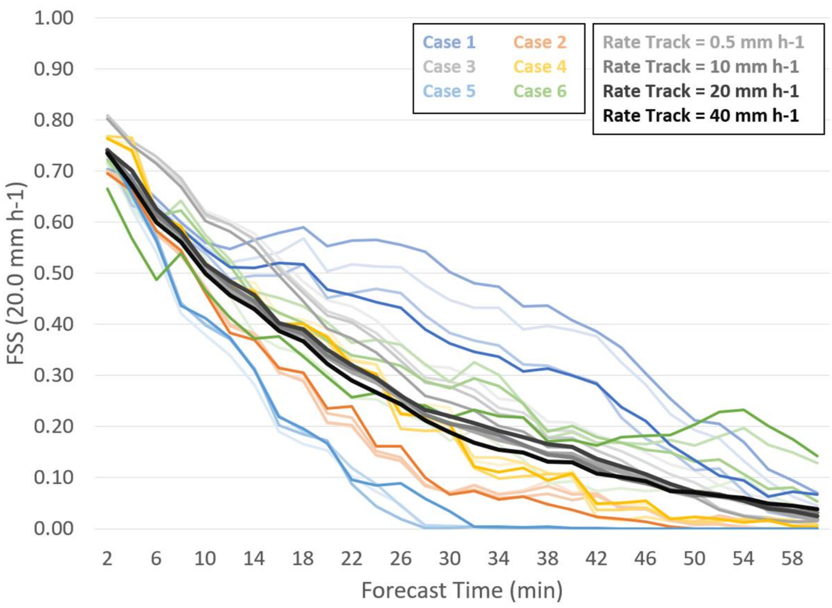




Generally good performance for assessing rate coverage; 20 ensemble members and rate tracking of 10 mm h^{-1} was predominant best

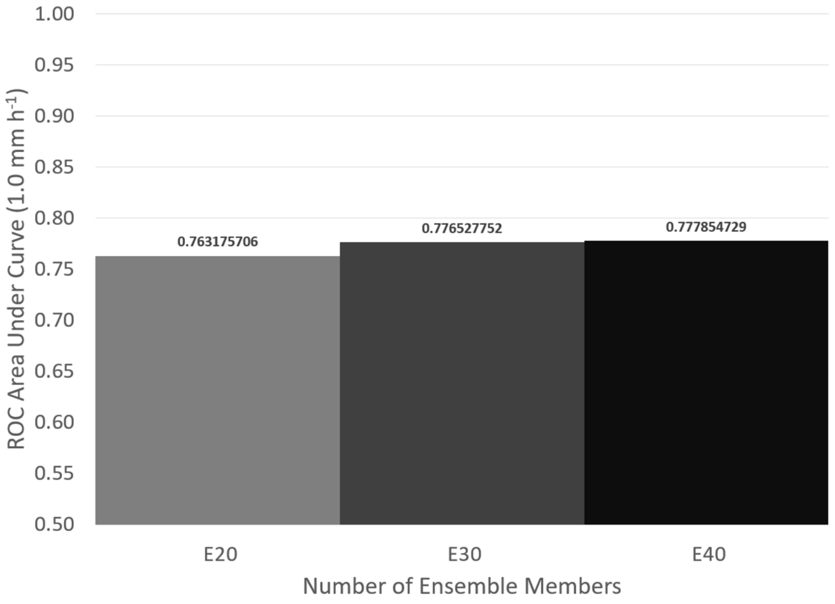
FSS ≥ 20 mm h^{-1} of Ensemble, Tracking

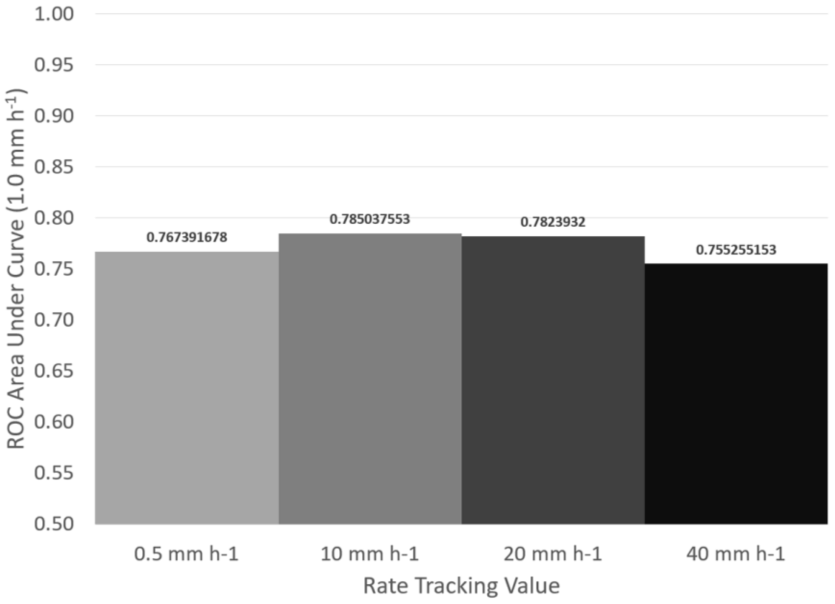




Notable variations with challenging cases showing no skill via FSS: Mostly 20 ensemble members and tracking of 10, 20 mm h^{-1} were more dominant

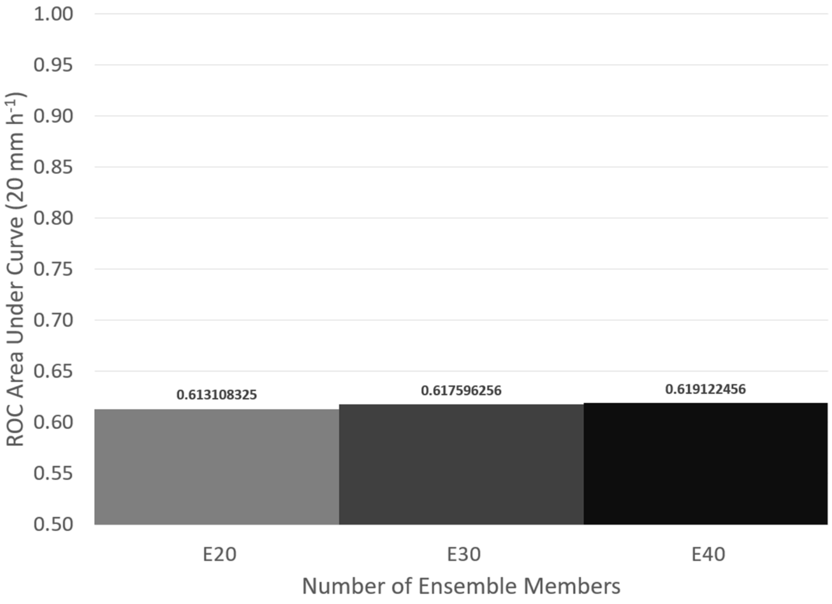
AUC ≥ 1 mm h^{-1} of Ensemble, Tracking

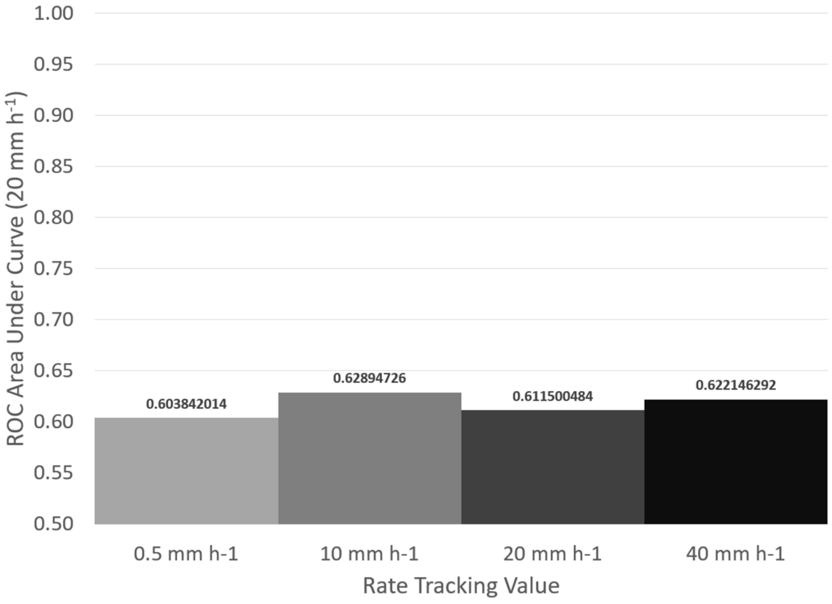




Probabilistic analysis showed that having 40 ensemble members and a rate tracking threshold of 10 mm h^{-1} showed to have the best performance

AUC ≥ 20 mm h^{-1} of Ensemble, Tracking





Continued degradation of performance with forecasting of higher rates (no surprise); 40 ensemble members and 10 mm h^{-1} tracking rates still prevailing

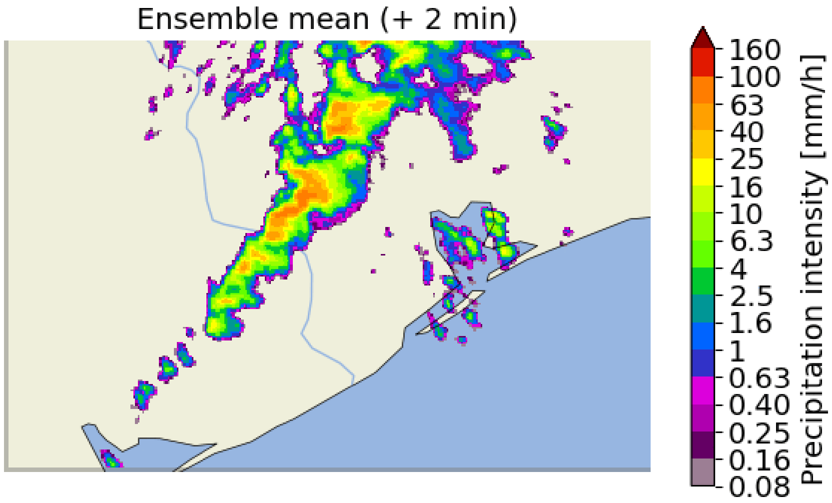
Future Testing - Velocity Perturbations

The excess noise found in the nowcast rates can be traced back to the velocity perturbations created within STEPS. Next series of tests will evaluate the performance of nowcasting with turning off the velocity perturbations.

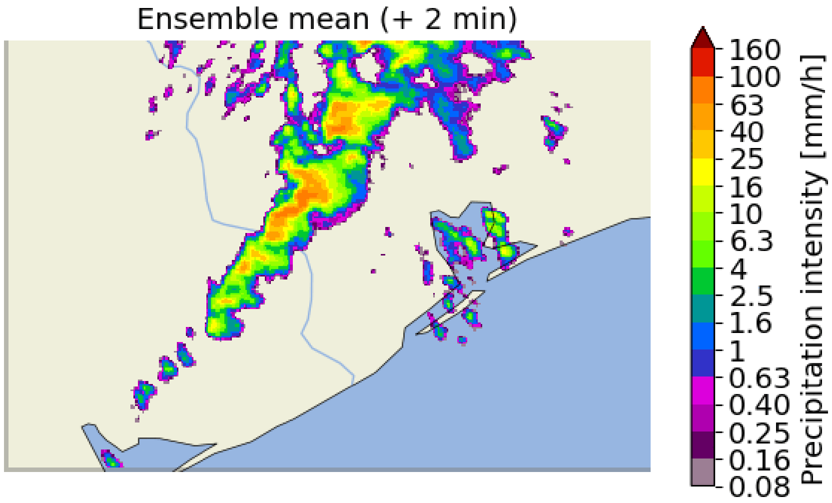
Let's step through what a couple of examples would look like if Velocity Perturbation = None...

Changes to Nowcast Rates - Case 1

Test Parameters: 1-km Resolution, Rate Tracking = 10 mm h^{-1}, Ensemble Members = 30 , Seed = On, Kmperpixel = 1x, Velocity Perturbation = On vs. Off



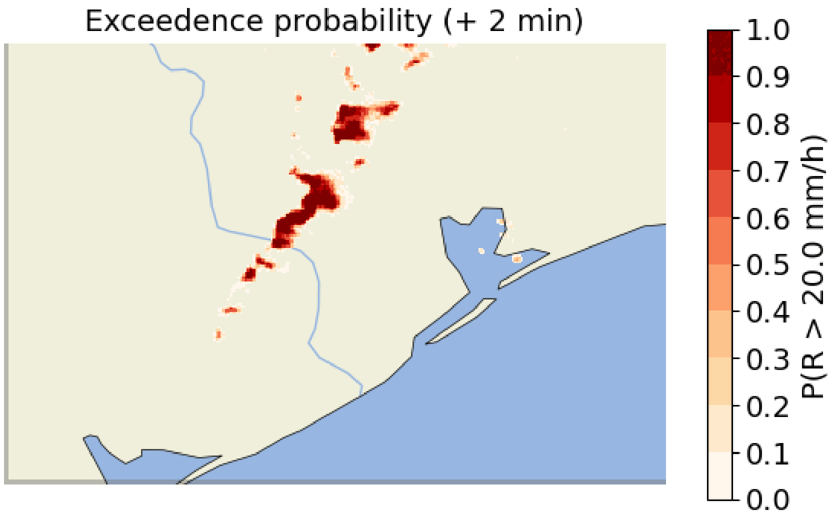
Velocity Perturbation = On



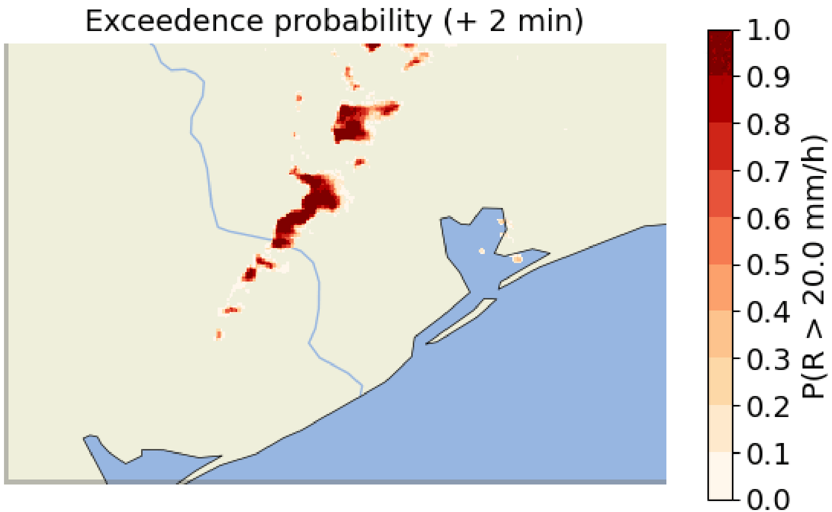
Velocity Perturbation = Off

Differences in Exceedance Probabilities

Probability of exceeding an instantaneous rain rate of 20.0 mm h-1 shown with Velocity Perturbation = On vs. Off



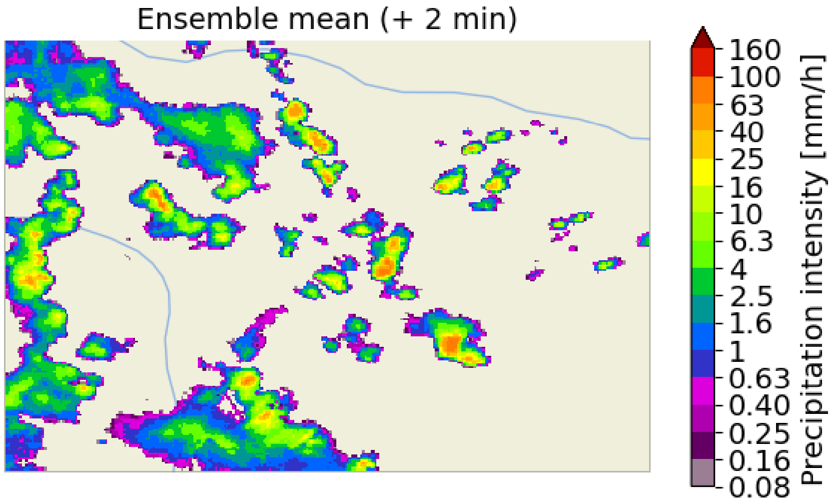
Velocity Perturbation = On



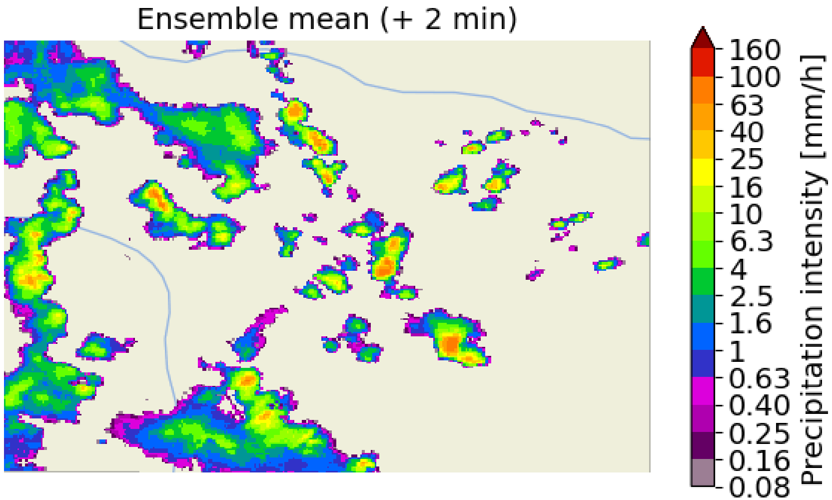
Velocity Perturbation = Off

Changes to Nowcast Rates - Case 5

Test Parameters: 1-km Resolution, Rate Tracking = 10 mm h^{-1}, Ensemble Members = 30 , Seed = On, Kmperpixel = 1x, Velocity Perturbation = On vs. Off



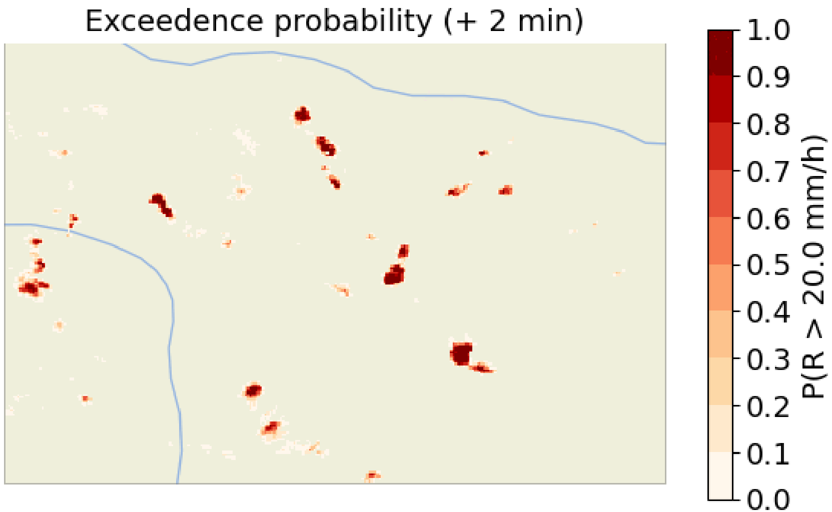
Velocity Perturbation = On



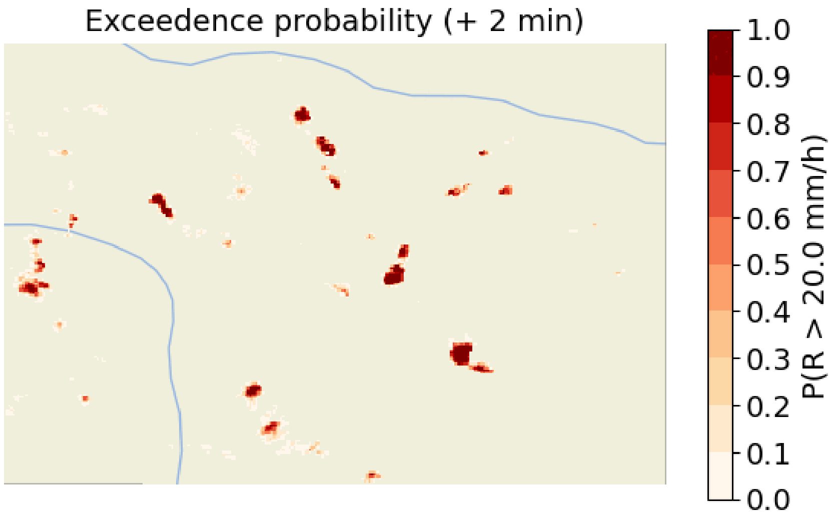
Velocity Perturbation = Off

Differences in Exceedance Probabilities

Probability of exceeding an instantaneous rain rate of 20.0 mm h-1 shown with Velocity Perturbation = On vs. Off



Velocity Perturbation = On



Velocity Perturbation = Off

Future Testing - Velocity Perturbations

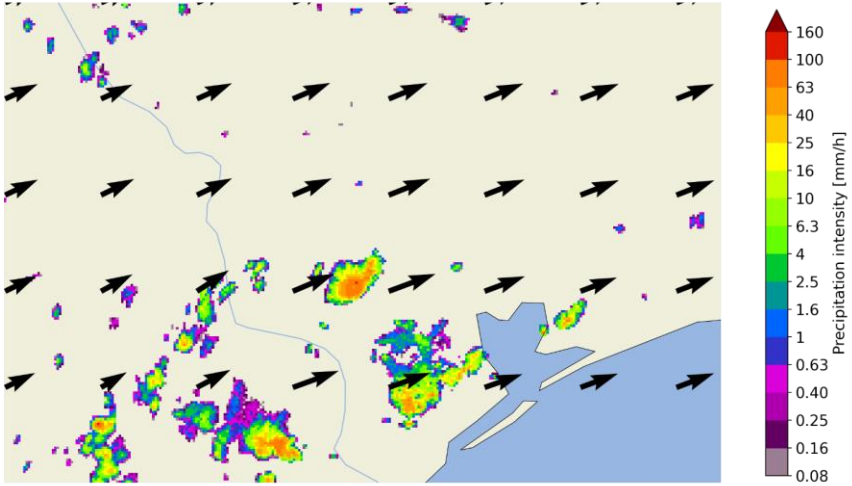
The question is what would be better for operations? Turning off velocity perturbations retains more storm structure, greater rates, and greater exceedance probabilities, but would placement of storms be an issue?

With predicting flash floods and issuing FFWs, the location is critical to knowing where will be impacted and where will the water be routed to.

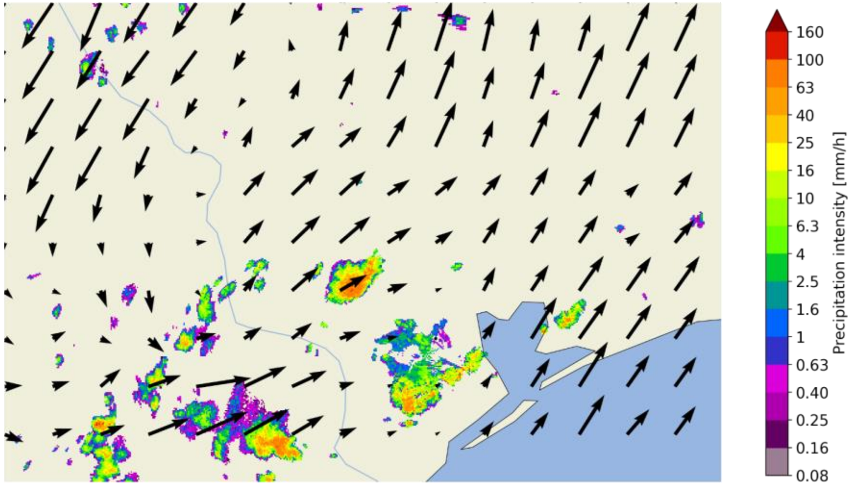
One hypothesis to consider is that with the potential better capturing of storm motions with 500-m data, there might not be a need for velocity perturbations within the STEPS program.

Future Testing - 500-m Resolution Data

Initial testing of pySTEPS showed that there are significant differences in how the LK advection field is generated based on the horizontal resolution of data; Conduct all variable tests with 500-m data when ready



1-km Resolution Advection Field



500-m Resolution Advection Field

Continued Testing of STEPS Parameters

There are still multiple aspects to test with the STEPS methodology. To find the right parameter settings, these tests will continue through probably October using the following outline and guidance:

1. Run the initial six cases with the ensemble members = 10
2. Run the initial six cases with velocity perturbation settings = on/off.
3. Conduct analyses of the two TC events using the current parameter iterations.
4. Run through all cases at the 500-m resolution.

Future Planning of MRMS Nowcasting

1. Complete Parameter Testing; Set Final Specifications
2. Conduct Performance Evaluation Across Several Cases
3. Integrate STEPS into MRMS Framework; Run in Cloud, QVS
4. Add Nowcasting into FLASH Product Suite
5. Develop AWIPS-Based Data; Conduct Forecaster Testbed Analysis
6. Deploy Operationally in MRMS and NWS

Thank You

Steven.Martinaitis@noaa.gov