Analog Ensemble Forecasting System for Low-Visibility Conditions over the Main Airports of Morocco

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Plan

NWP Limitations on forecasting LVC

Several challenges impede visibility forecasting systems using NWP models:

- The high cost of visibility-observing systems and their implementation being restricted to few locations (airports most of the time).
- The low density of visibility sensors over fog-prone locations.
- A limited understanding of the complex interaction between the physical processes leading to low-visibility conditions (fog or mist).
- Empirical parametrization approaches tends to over-/underestimates visibility depending on environmental conditions.

Available Alternatives

As an alternative, Ensemble Forecasting in addition to many statistical-based forecasting models and data-driven methods have been also explored:

- Ensemble Forecasting (Zhou et al 2007)
- Fuzzy logic based EPS (Hansen et al 2007)
- Artificial Neural Networks Algorithms (Marzban et al 2007)
- Decision-tree-based methods (Bari et al 2020)

We suggest a combination of the concepts of Ensemble Forecasting and Machine Learning via the Analog Ensemble method to forecast low visibility conditions.

Objectives

- Implement a low computational cost Ensemble Prediction System based on the Analog Ensemble method
- Assess the potential and performance of the Analog Ensemble method in predicting low visibility rare events.

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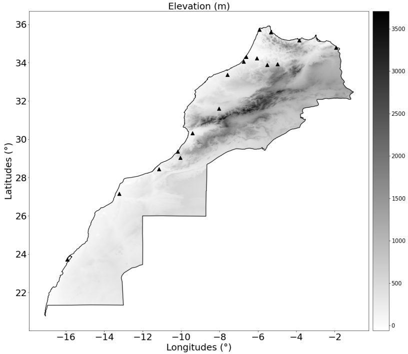
Study Domain and Datasets

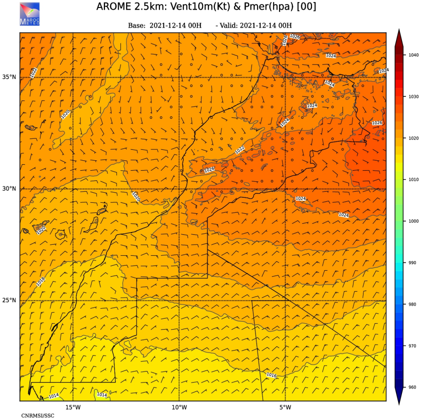
- 17 synoptic stations (24H operational airports)
- 4 years of hourly observation and forecasts data from 2016 to 2019
- 8 predictors (T2m, RH2m, MSLP, LWC2m, LWC5m, WS10m, WD10m, SURFP)
- 1 predictand : Atmospheric Visibility (VIS)
- The stations are well distributed over heterogeneous topography and climate regions



NWP Model AROME

3D AROME NWP (Seity et al. 2011, Hdidou et al 2020) characteristics:

- A non-hydrostatic model
- 2.5km horizontal resolution
- 90 vertical levels, first level starting at about 5m.



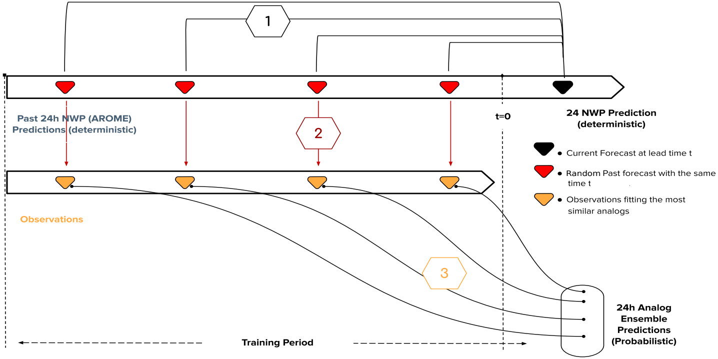
Analog ensemble Method (Delle Monache 2013)

Among ensemble prediction techniques, analog ensemble forecasting is considered as an intuitive and low cost method of generating ensemble members. It has been successfully applied for:

- Short-term predictions of:
    - 10-and 80-m wind speed, 2-m temperature, etc. (Delle Monache et al. MWR 2011, 2013, Junk et al. MZ 2015)
    - Wind and solar power (Alessandrini et al. RE 2015, AE 2015, Davo et al. SE 2016)
    - Energy load (Alessandrini et al. ICEM 2015)
    - Air quality predictions (ground level ozone, surface PM2.5) (Djalalova et al. AE 2015, Delle Monache et al. ACPD 2017)
    - Tropical cyclones intensity (Alessandrini et al. MWR 2016)
    - Surface weather parameters forecasting (Alaoui et al 2022)

Alaoui, B., Bari, D., Ghabbar, Y. (2022). Surface Weather Parameters Forecasting Using Analog Ensemble Method over the Main Airports of Morocco. Journal of Meteorological Research, 36(6), 866-881.

Analog Ensemble Construction : (Delle Monache et al., 2013)



$$\left\|\mathbf{F}_t, \mathbf{A}_{t'}\right\| = \sum_{i=1}^{N_\nu} \frac{w_i}{\sigma_i} \sqrt{\sum_{j=-\tilde{t}}^{\tilde{t}} \left(F_{i,t+j} - A_{i,t'+j}\right)^2} \qquad (1)$$

Stepwise Forward Selection

- Stepwise Forward Selection (Derksen 1992) is a method of selecting the most important variables and by the way simplifying the model.
- This method was used by Plenkovic et al 2020 to assess predictors weights in analog ensemble method.
- Stepwise forward selection is low cost when compared to massive weighting strategies as Junk et al 2015

From continuous visibility values to occurences or not of rare reduced visibility events

- Visibility is assessed both as continuous variable and as categorical variable reflecting rare LVC events.
- Three main metrics are used: The ensemble mean, best quantile (30%) and weighted average.
- The visibility target is treated as a single-value forecast variable by AnEn then converted to probabilistic forecasts of LVC depending on predefined operational threshold.
- The chosen thresholds are from 200m to 6000m by a step of 200m.

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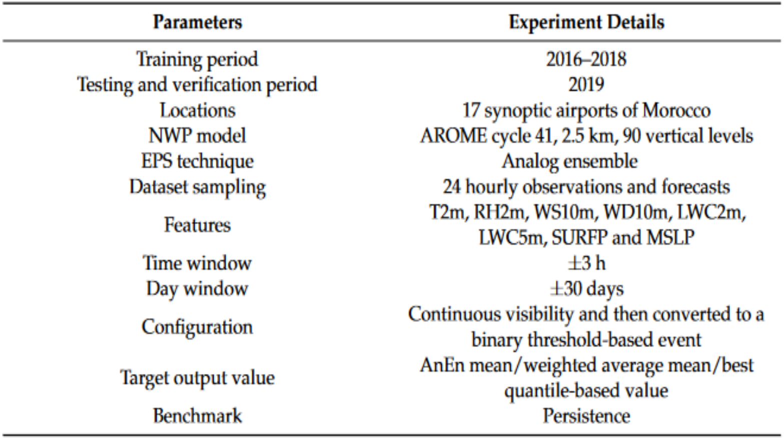
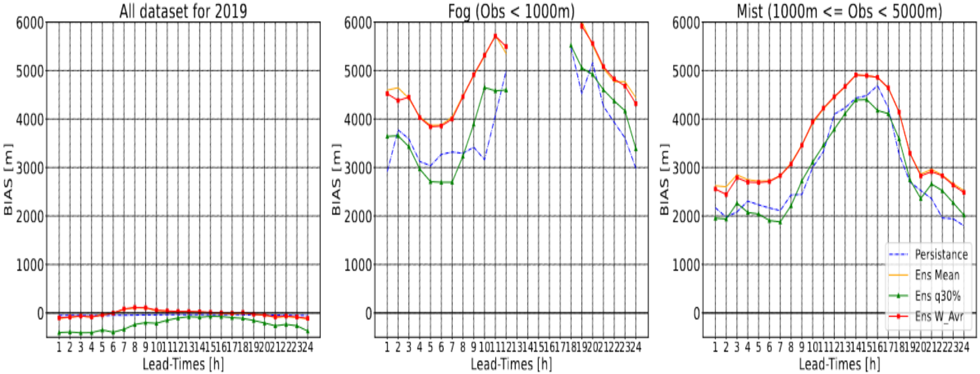
Experiment Design



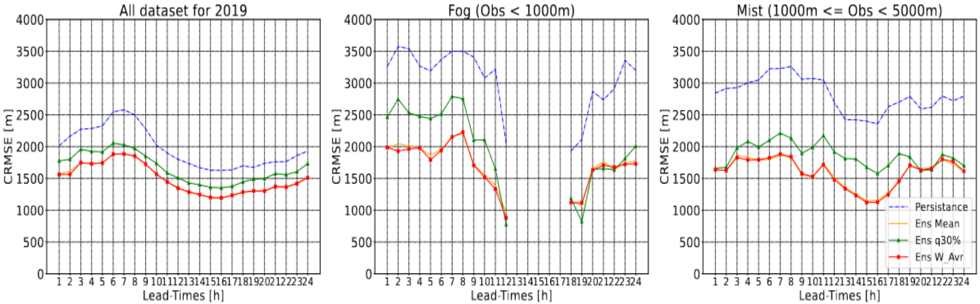
Parameters	Experiment Details
Training period	2016–2018
Testing and verification period	2019
Locations	17 synoptic airports of Morocco
NWP model	AROME cycle 41, 2.5 km, 90 vertical levels
EPS technique	Analog ensemble
Dataset sampling	24 hourly observations and forecasts
Features	T2m, RH2m, WS10m, WD10m, LWC2m, LWC5m, SURFP and MSLP
Time window	±3 h
Day window	±30 days
Configuration	Continuous visibility and then converted to a binary threshold-based event
Target output value	AnEn mean/weighted average mean/best quantile-based value
Benchmark	Persistence

Continuous Verification: Bias



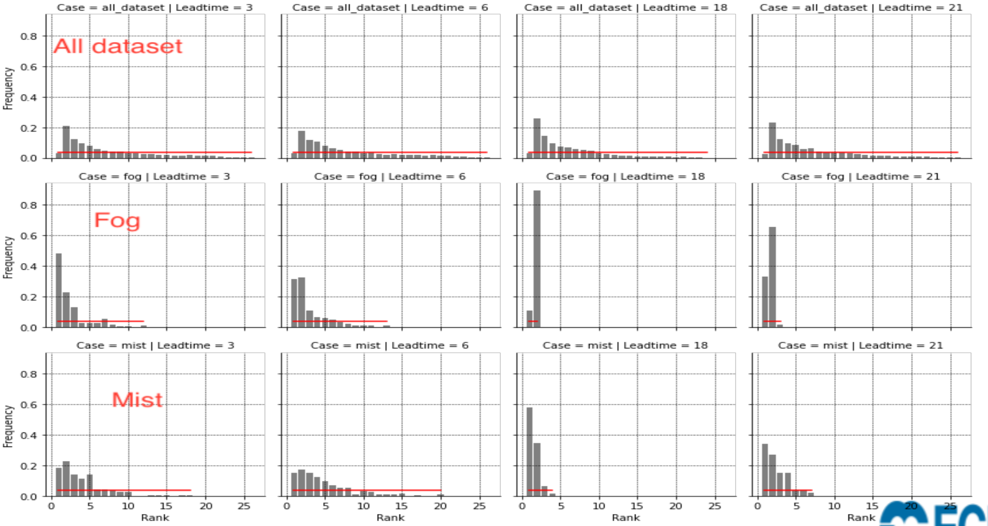
- For all visibilities case AnEn ensemble mean and AnEn weighted average show the lowest bias close to the reference line of zero, similarly to persistence.
- For fog events, the AnEn quantile 30% overestimates visibility and displays the lowest bias values.
- For mist events, persistence and AnEn quantile 30% display the lowest bias (positive), with tiny differences in magnitude.

Continuous Verification: CRMSE

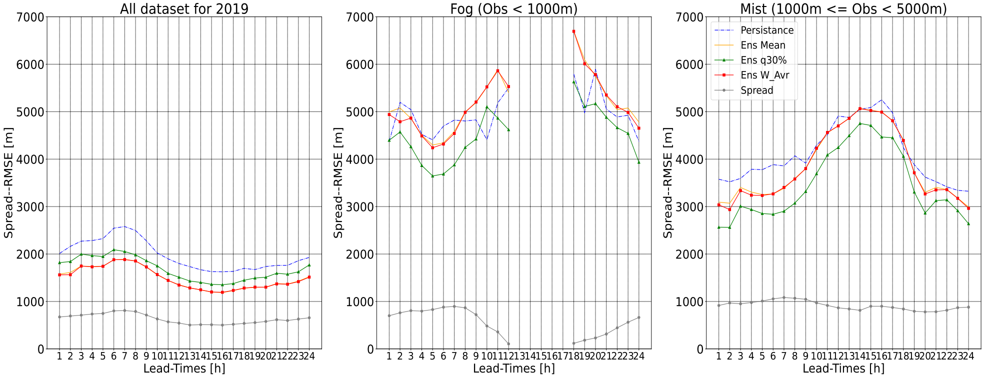


- $$CRMSE = \frac{1}{N} \sum_{i=1}^{N} \sqrt{(f_i - \overline{f}) - (o_i - \overline{o})^2}$$
- $$RMSE^2 = MSE = CRMSE^2 + (\overline{f} - \overline{o})^2$$
- AnEn configurations (mean, weighted mean, and quantile 30%) display a better CRMSE than persistence for all cases of low-visibility conditions including fog and mist.
- When removing bias from forecasts, the AnEn quantile 30% is outperformed by the AnEn mean and weighted average in terms of CRMSE for fog and mist cases.

Rank histograms



Spread-RMSE



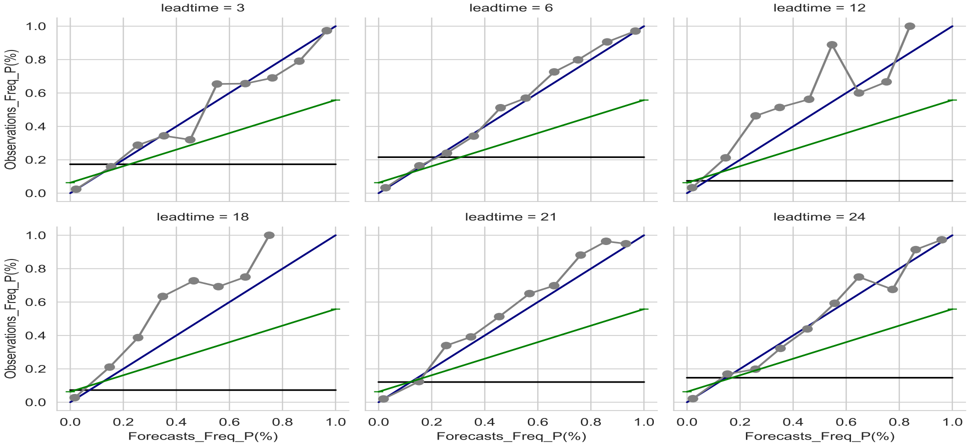
From Rank Histograms and Spread-RMSE diagram :

(+) AnEn is under-dispersive for all lead times.

(+) Positive bias for fog and mist events.

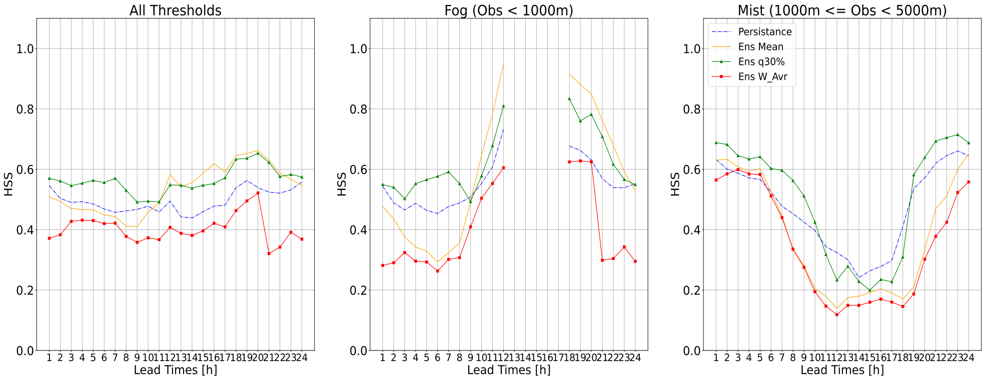
(+) AnEn is quite statistically consistent for the whole dataset.

Reliability Diagrams for all the dataset



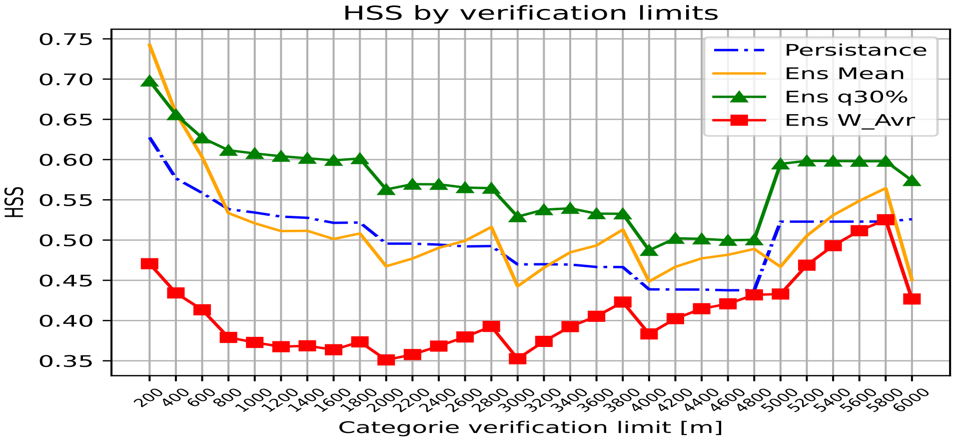
(+) AnEn exhibits good reliability for night lead times (3 h, 6 h, 21 h, and 24 h).
(+) AnEn underestimates low visibilities for 12h and 18h.

HSS by leadtimes



(+) Best HSS scores exhibited by AnEn quantile 30%,for night and early-morning lead times.
(+) For fog events, AnEn 30% quantile had the best HSS only for lead times below 6 h. For lead times above 18h AnEn mean was superior.
(+) For mist events, the best quantile of AnEn outperformed persistence during night and early-morning lead times. For day lead times, their performances were quite the same.

HSS by operational thresholds



(+) HSS is highly dependent on the chosen threshold.
(+) Best HSS is found for thresholds lower than 1800 m or greater than 4900 m.

Summary

- AnEn EPS is under-dispersive for all lead-times, and draws a postive bias for fog and mist events.
- AnEn EPS is reliable for night lead-times (Time of the day prone to low visibility occurrence).
- For probabilistic forecasts, the AnEn quantile 30% outperforms the ensemble mean and weighted average.
- The choice of the metric is very influential to the results. The quantile 30% is good during night till 6h, however the ensemble mean is better during the evening lead-times.

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Future works

- To enhance the chances of finding the best analogs, one could extend the search space by integrating neighboring grid points.
- Using calibration methods for rare events to overcome the disproportionality of such events in the sampling.


THANK YOU :)

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