AWARE: Appraisal of "Challenging WeAther" FoREcasts

http://www.cosmo-model.org/content/tasks/priorityProjects/aware/default.htm
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Focus of the study is to provide COSMO Community with an overview of forecast methods and forecast evaluation approaches that are linked to high impact weather.

weather parameters of interest
mainly convection related:
(thunderstorms, heavy precipitation, lightnings)
visibility (fog)

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Appraisal of "Challenging WeAther" (CW) FoREcasts

TASK 1
Challenges in observing CW

TASK2
Overview of verification measures

TASK3
CW Verification applications based on spatial methods

TASK4
Overview of CW forecast methods, representation and user-oriented products

Observation issues

Verification approaches

Forecast methods & representation

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TASK 1

Challenges in observing CW

- **Overview of CW/HIW observational data sources characteristics**

Review of available sources, estimation methodologies and associated error. Properties of on non conventional observations to consider for verif purposes.

- **Approaches to introduce observation uncertainty**

Analysis of observation uncertainty contribution to verification scores focused on HIW forecasts

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Challenges in observing High Impact Weather – observational data sources characteristics

Basic data sources

Every weather element can be treated as an impact source, including (1) ”regular” elements – temperature, precipitation, wind speed or (2) ”specific” elements – visibility limitations, thunderstorms, tornadoes …

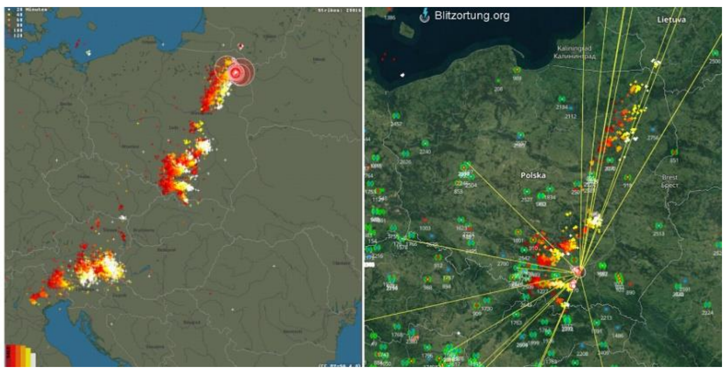
Ad. 1. Data from SYNOP stations, climatological stations, rain gauges, telemetry stations includes measurements of the temperature, precipitation, visibility range/limitations, wind speed, wind gusts, occurrence of fog/haze, occurrence of thunderstorm with lightning (limited to a remark as "day with lighting" or similar).

Ad. 2. Lightning Detection Networks (thunderstorms, lightnings)

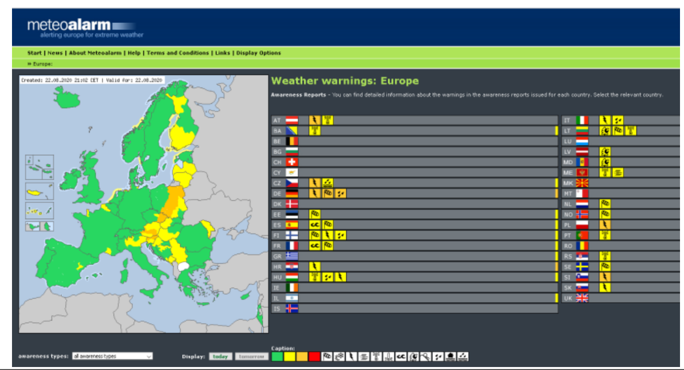
Ad. 1 and 2 Radar data, Doppler radar data – precipitation intensity and type, wind speed, lightning occurrence, thunderstorm tracking surveillance.

Ad. 1.2 Satellite data: occurrence of fog/haze, detection of convective storms (direct measurement of moisture and instability), also via convective indices and CAPE.

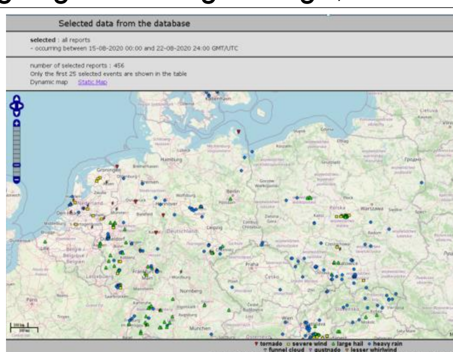
Other data sources – mostly websites. Examples below:



blitzortung.org. Discharge image, detectors’ locations



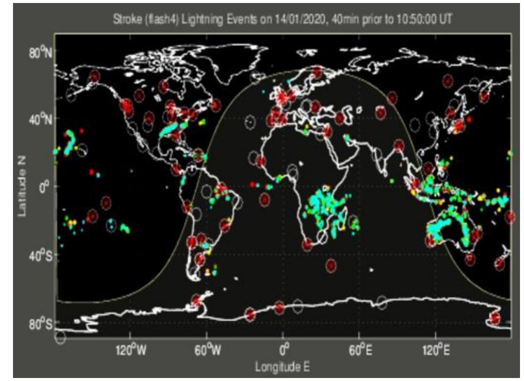
www.meteoalarm.eu. Main page.



eswd.eu. Event type, time, location, quality control

www.meteoalarm.eu. Warnings for selected country

Overview of convection-related HIW observational data sources characteristics:



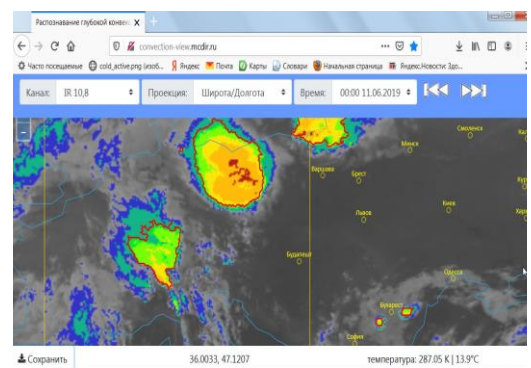
1. Data of SYNOP stations: **visual thunderstorm occurrence** at a given obs time and between obs times in a radius 5 km
2. Global Network maps: http://wwlln.net/TOGA_network_global_maps.htm
Lightning stroke positions are shown as coloured dots which "cool down" from blue for the most recent (occurring within the last 10 min) through green and yellow to red for the oldest (30-40 minutes earlier). Red asterisks in white circles are active WWLL lightning sensor locations Very Low Frequency sensors

- Regional lightning detection networks: sensors in the real time within 100-300 km radius, also Very Low Frequency, **two types of lightnings: cloud-earth and cloud-cloud**. In Russia, it is the lightning detection system of Roshydromet ALVES 9.07
- **In Gubenko I., PhD thesis, 2016, A study the physical processes in convective clouds during thunderstorms based on numerical simulation (In Russian), a comparison of the accuracy of LDNs is given**

3. Radar data
4. Meteorological satellite data.

- In the areas of recognized Cb clouds, a function is calculated to diagnose the **intensity of convective events** (*Alekseeva, Bukharov et al., 2006 in Russian)*

- Based on calibrated radiative temperature from Seviri, Meteosat-11, using a threshold, a **mask of deep convection areas** is found. Then the cell shape is determined. The cells are traced in time based on the normalized overlapping area. Cell destroying is also taken into account (Gorlach, Shishov). **Plan: to study the feasibility of using the model analogue of calibrated radiative temperature to apply the same algorithm for convective cell indentification and to perform verification**



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Overview of appropriate commonly used verification measures

- Survey for assessment of proper verification of phenomena – continuous vs. discrete verification
- Role of SEEPS and EDI-SEDI for the evaluation of extreme precipitation forecasts
- Extreme Value Theory (EVT) approach- Fitting precipitation object characteristics to different distributions

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Assessment of proper verification of phenomena (on the example of lightning intensity)

Basic methods applicable to the problem:

1. Neighborhood-based approaches *)
2. Coverage–Distance–Intensity (CDI) verification*)
3. SAL (Structure/Amplitude/Location) Verification**)
4. FSS (Fraction Skill Score) verification**)
5. Standard evaluation at the grid scale (ME, MAE, RMSE) **)
6. Categorical analysis (contingency tables and predictands) **)
7. Cross- (space-lag) correlation approach and verification

*) To be done

**) Done/partially done, cf. results presented in slide 5

Observations: lightnings from the Polish lightning detection network PERUN; forecast: CAPE-based FLR (Flash Rates) as follows:

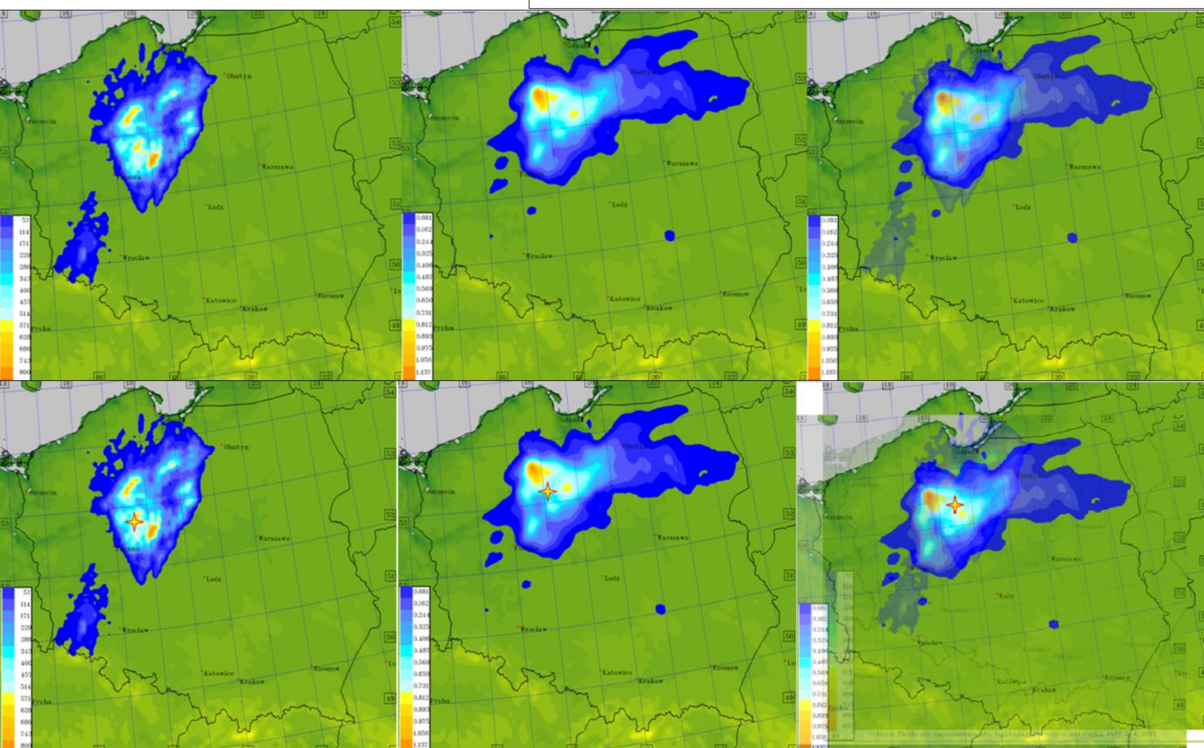
$$W = 0.3 \cdot \sqrt{2 \cdot CAPE}$$

$$FR = \left(\frac{W}{14.66} \right)^{4.54}$$

$$\text{if} \quad CTT > -15°C \quad FR = FR \cdot \left[\max\left(\frac{-CTT}{15}, 0.01 \right) \right]$$

$$\text{if} \quad CBT < -5°C \quad FR = FR \cdot \left[\max\left(\frac{CBT + 15}{10}, 0.01 \right) \right]$$

Cross-correlation and Vector Of Displacement approach



Comparison of observations (left) and "raw" forecasts (middle) – overlapped (right).

Computation of Vector Of Displacement (VOD) for cross-correlation:

☑ Calculate coordinates of "centres of mass" (asterisks) for both distribution patterns – obs. vs. fcst

☑ Compute VOD as a difference of the two above

☑ Displace linearly every value of fcst by the vector of displacement

Role of **SEEPS** and **EDI-SEDI** metrics for evaluation of extreme precipitation

ΕΘΝΙΚΗ ΜΕΤΕΩΡΟΛΟΓΙΚΗ ΥΠΗΡΕΣΙΑ
HELLENIC NATIONAL METEOROLOGICAL SERVICE

D.Boucouvala, F.Gofa and Ch. Kolyvas
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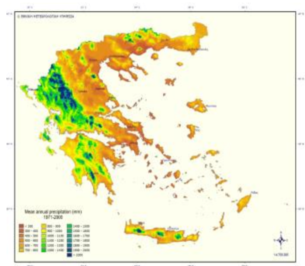
SEEPS score :. is a matrix precipitation score based on climatology of each region by defining light and heavy threshold precipitation values for each station and month. It can give an estimate if climatologically 'heavy' precipitation is forecasted as 'light' or 'dry'

Each matrix element represents specific errors (0 is best)

HD Heavy OBS, Dry FCS-
LD Light OBS, Heavy FCS
DL Dry OBS, Light FCS
DH Dry OBS, Heavy FCS
HL Heavy OBS, Light FCS
LH Light OBS, Heavy FCS-

$$SEEPS=\begin{bmatrix} 0 & LD & \mathbf{HD} \\ DL & 0 & HL \\ DH & LH & 0 \end{bmatrix}$$



SEDI score : Suitable for extreme events
Independent of base rate
H: Hit rate
F: False alarm rate

$$SEDI = \frac{\ln F - \ln H + \ln(1-H) - \ln(1-F)}{\ln F + \ln H + \ln(1-H) + \ln(1-F)}$$

$$EDI = \frac{\ln F - \ln H}{\ln F + \ln H}$$

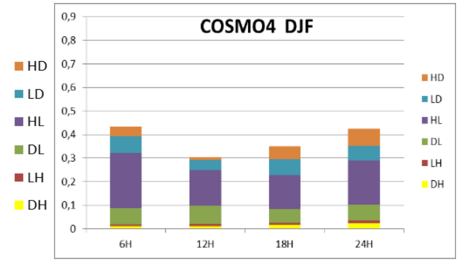
Methodology

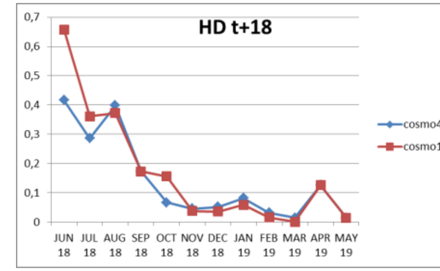
6- hourly Precipitation forecasts from COSMOGR4 and COSMOGR1 models are verified against synop observations over Greece using the SEEPS score for one year (June 18 to May 19).

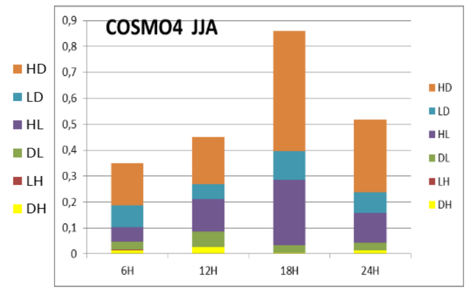
Thresholds (light to heavy) and climatological probabilities for the score calculation are taken from the 30-year Europe database with climatological data for each individual station and each month **(provided by ECMWF)**.

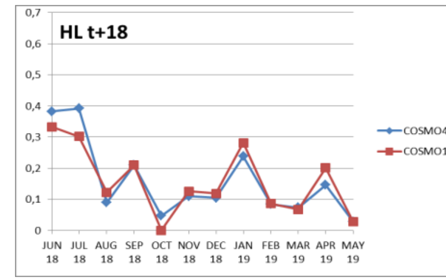
Scores are averaged by season.

SEDI and EDI scores for each season are calculated for different thresholds-high climatological percentiles . Percentiles for each station and each month are taken from the 30-year database

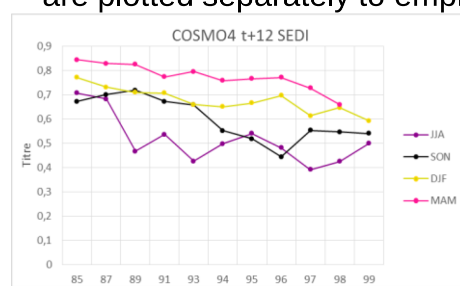


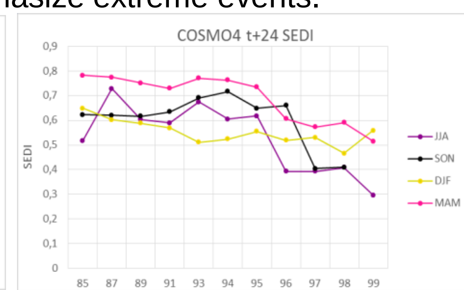






SEEPS total values (left) are higher in JJA mainly by the contribution of **HD** (HEAVY rain is Predicted as DRY more often). **HL** is more significant in DJF . HL and HD elements are plotted separately to emphasize extreme events.





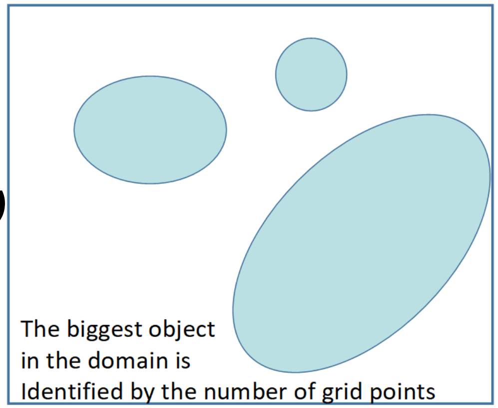
SEDI for each season: Worse in JJA and higher percentiles. Better in MAM (season with no extremes). Very similar values EDI-SEDI

The intercomparison of these measures is still into investigation in order to define the best way to verify extreme events

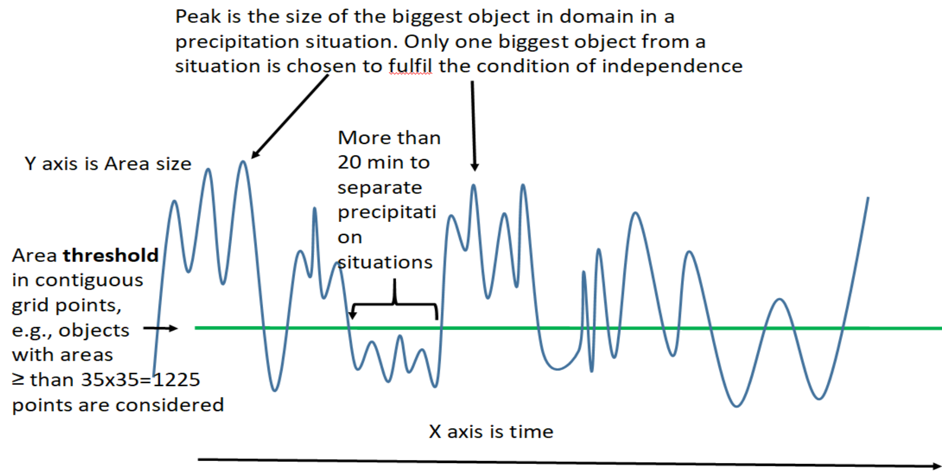
Extreme Value Theory (EVT) approach: Verification of large contiguous precipitation areas using Generalized Pareto distribution (*Anatoly Muraviev, RHM)*

Object identification: 1h precipitation greater than a certain value, e.g. >1mm/h, Convolution smoothing with a radius of 7 grid points

The core of the system is the statistical STEPS scheme (Short Term Ensemble Prediction System) (Bowler N. et al., 2006)



Peaks over threshold (POT) for area size



The area peaks are fitted to Generalized Pareto (GP) distribution

- If PoT method is used, the Generalized Pareto (GP) distribution has two parameters: scale (σ), and shape (ξ).
- Fitting is made using the GMLE (Generalized Maximum Likelihood Estimation), the standard errors (se) are calculated, and the confidence intervals for GP parameters estimates are calculated as CI = x±1.96*se; *R-extRemes, module fevd is used for fitting (author: E.Gilleland)*

A measure of STEPS quality introduced: intersection ratio of confidence intervals of Generalized Pareto parameters estimates (σ and ξ) in STEPS and in observations (radars). It gives a diagnostic estimate of model ability to reproduce vast contiguous precipitation areas (or other extremes)

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Verification applications with spatial methods (MesoVICT)

- Verification of intense convective phenomena with object oriented methods (CRA, SAL, etc)
- Lightning potential index (LPI) in mountain regions.
- LPI verification and correlation of convective events with microphysical and thermodynamical indices
- DIST methodology tuned on high-threshold events for flash floods – Tool for issuing Civil Protection alerts
- Work on the comparative verification of NWC and NWP results using spatial verif methods (SINFONY project)

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Verification of forecasts of intense convective phenomena (lightning frequency, Flash Rate)

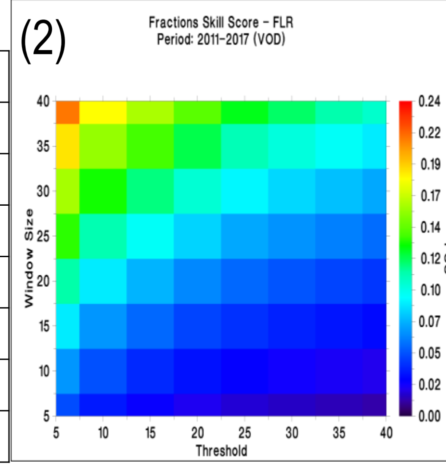
"Discrete" (1-3) vs. "Continuous" (4) verification

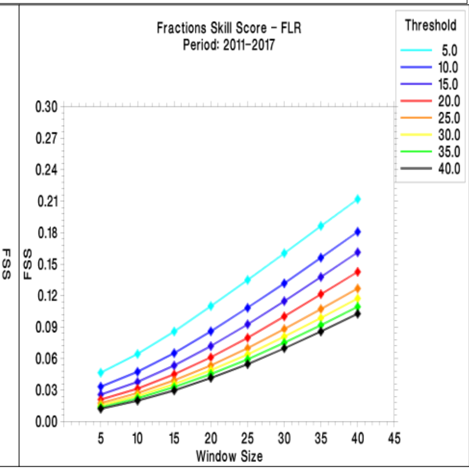
1. Contingency tables analysis.
2. Fraction Skill Scores (FSS) assessment . FSS = 1 - perfect match
3. SAL (Structure-Amplitude-Location) approach. The perfect forecast S = A = L = 0
4. Mean Error, Mean Absolute Error, Root Mean Square Error

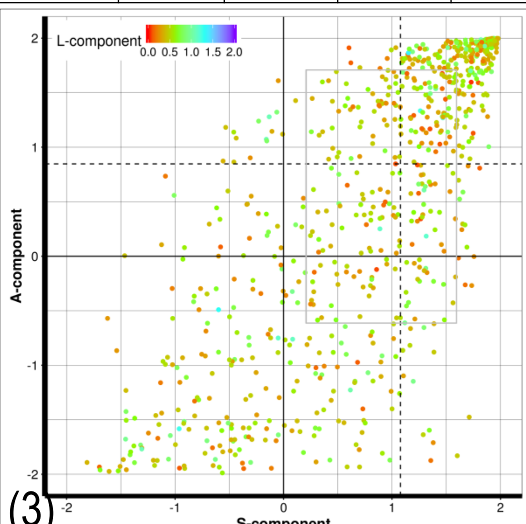
$$FSS = 1 - \frac{\frac{1}{N}\sum_{i=1}^{N}\left(p_f - p_o\right)^2}{\frac{1}{N}\sum_{i=1}^{N}p_f^2 + \frac{1}{N}\sum_{i=1}^{N}p_o^2}$$

(1)	EQS	FAR	FBI	PFD	POD	SUC	THS	TRS
2012	0.030	0.883	2.720	0.174	0.237	0.117	0.083	0.075
2013	0.077	0.825	2.468	0.148	0.325	0.175	0.125	0.201
2014	0.030	0.906	3.495	0.155	0.219	0.094	0.068	0.094
2015	0.026	0.879	2.171	0.131	0.166	0.122	0.070	0.054
2016	0.056	0.853	2.730	0.159	0.264	0.147	0.103	0.130
2017	0.051	0.830	1.911	0.118	0.198	0.170	0.093	0.100
Mean	**0.042**	**0.868**	**2.316**	**0.150**	**0.235**	**0.132**	**0.090**	**0.107**
Perfect	1	0	1	0	1	1	1	1

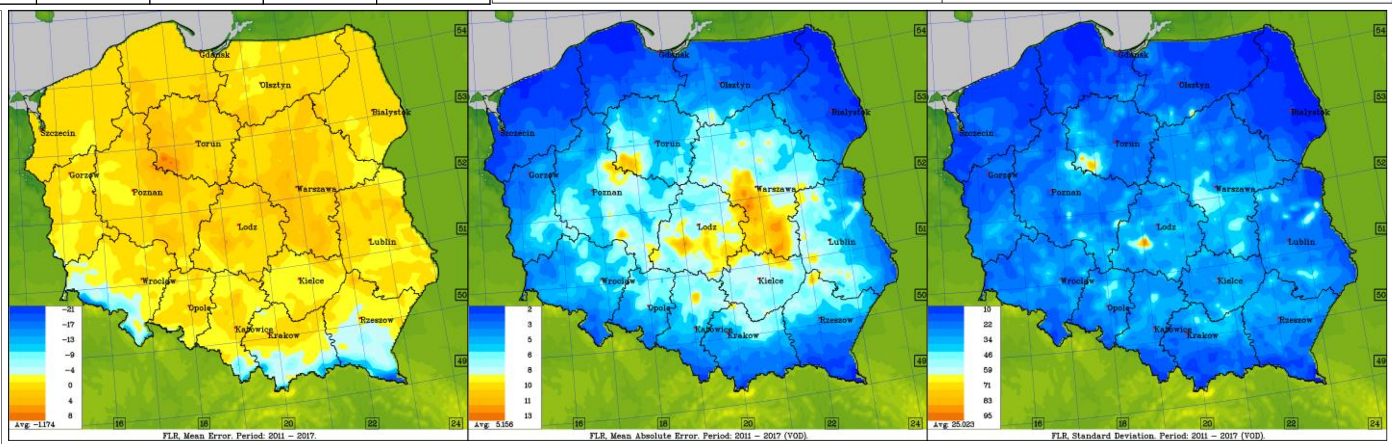
(2)







(3)



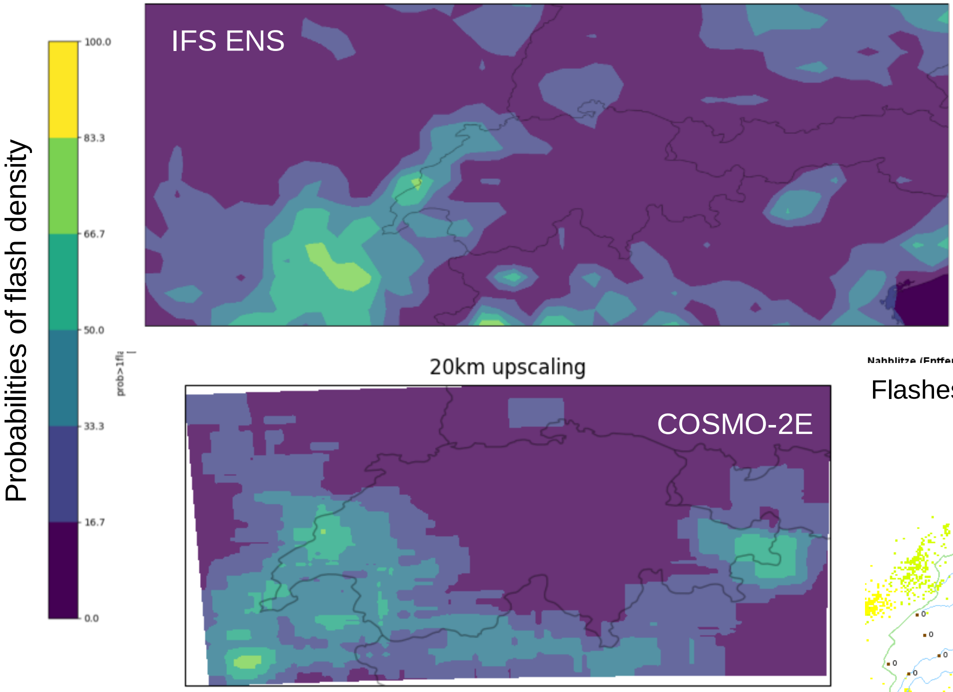
(4) Mean Error | Mean Absolute Error | Root Mean Square Error

SAL – all cases, 2012-2017
Dotted lines - the median of S/A

! Cross-correlation (lagged-correlation, cf. slide 2) improves results even upto 45%!

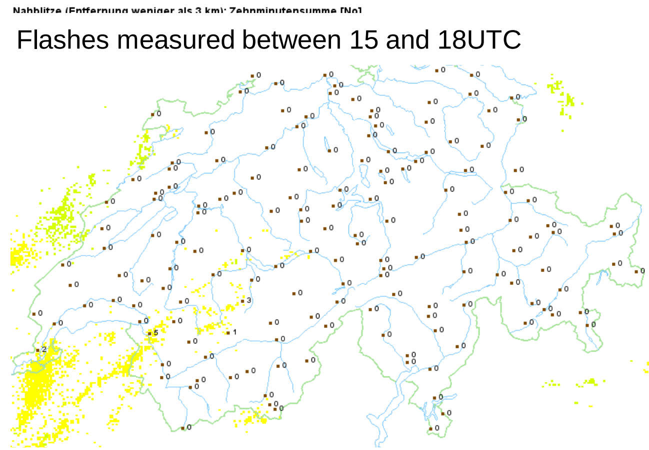
Comparison of prob of flash densities IFS ENS – COSMO 2E

Case study August 13th 2020



Models runs 00UTC, VT 16 UTC

A study is under way to evaluate the probability thresholds, spatial upscaling and time intervals that allow to make benefit of flash density predictions as needed in products. The verification is based on probabilistic models COSMO-2E and IFS ENS.



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Flash floods forecast evaluation approaches as a tool for issuing of Civil Protection alerts

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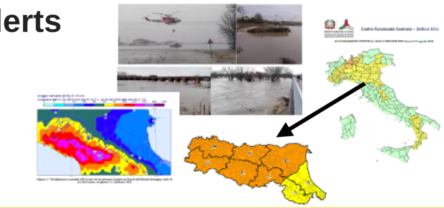


The estimation of QPF on river basins for purposes related to the issue of Civil Protection alerts for hydro-geological or hydraulic criticality is one of the main activities carried out operationally at the Hydro-Meteo-Climate Service of Arpae-Emilia Romagna (Italy).

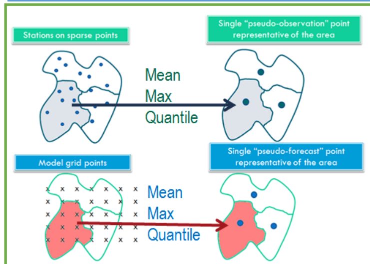
Many tools have been developed to help forecasters and hydrologists to evaluate mean, max, or percentiles of the precipitation field on the warning areas used by the National Civil Protection Department using data from different NWP models (e.g. IFS-ECMWF, COSMO-5M or COSMO-2I)

- Exceeding predefined thresholds can give useful indications for situations of intense precipitation possibly leading to floods

On the other hand, there is the need to develop a system to verify the products used to estimate the QPF over catchment areas:

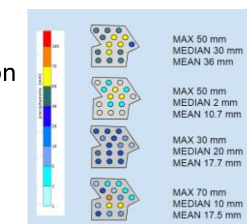
- It should allow to carried out verification operationally on a seasonal basis using the available observational data
- Verification results should be used directly to interpret how to use the forecast system and to decide in which situations one system is better than another

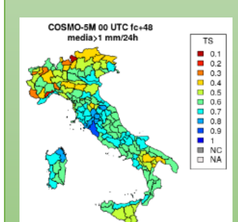
DIST method applied to catchment areas



The verification is performed evaluating some characteristics of the precipitation field:

- **Average**: it can be used to investigate the ability of models in reproducing different amounts of precipitation
- **Maximum**: the use of the maximum of precipitation over the areas can provide some information on high precipitation, even if not in the correct location but in the neighborhood, represented by the catchment area.
- **Median & Maximum**: the combination of a condition on the median and one on the maximum of precipitation can separate high localized precipitation from extensive precipitation

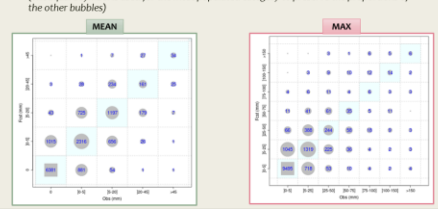




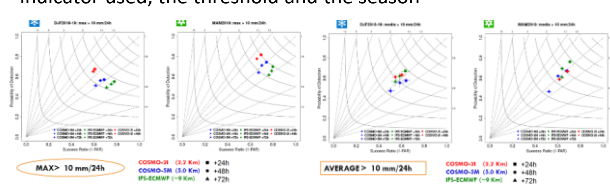
Verification scores can be provided on each catchment area for a easier and more direct communication of the information about the usability of NWP data directly to forecasters or hydrologists

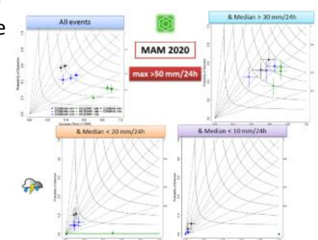
Visual verification with "bubble plots"

- Bubble plot is a sort of the scatter plot, in which the data points are replaced with bubbles. The sizes of the bubbles are determined by the number of events. *(The square symbol is used for the most populated category to preserve the proportions of the other bubbles)*



The use of the performance diagram makes it possible to compare various models highlighting the different behavior according to the indicator used, the threshold and the season





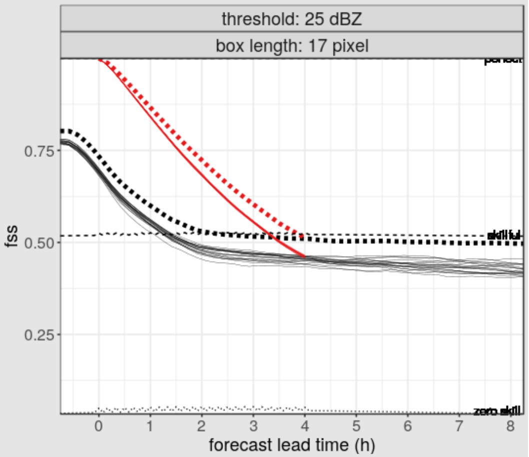
Neighborhood Verification Efforts at DWD

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

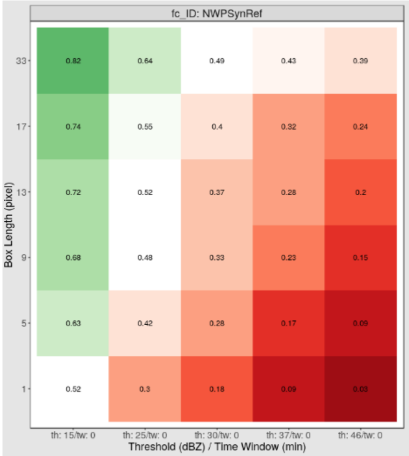
Review of existing neighborhood verification methods for deterministic and ensemble forecasts

- methods & scores from Ebert 2008
- neighborhood contingency table after Stein & Stoop 2019
- reliability and ROC diagrams
- Displacement-FSS (Skok & Roberts 2018)
- All methods based on NP*, EP* and/or NEP*
- time fuzzyness (Duc et al. 2012,2013) planned for future

*	EP	– Ensemble Probabilities
	NP	– Neighborhood Probabilities
	NEP	– Neighorbood Ensemble Probabilities (Schwartz et al., 2010)



FSS (reflectivity) as function of lead time. NWP (black), Nowcasting (red), NEP in dashed lines.

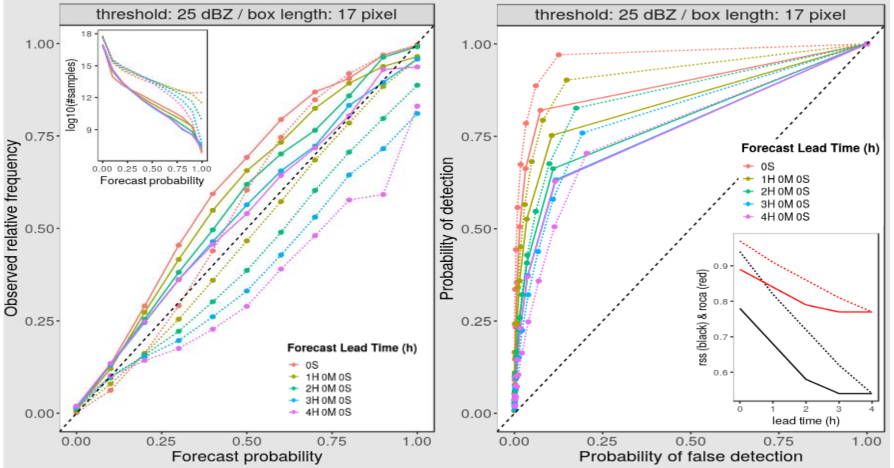


FSS tiles plot (reflectivity), threshold vs. box length, for NWP.

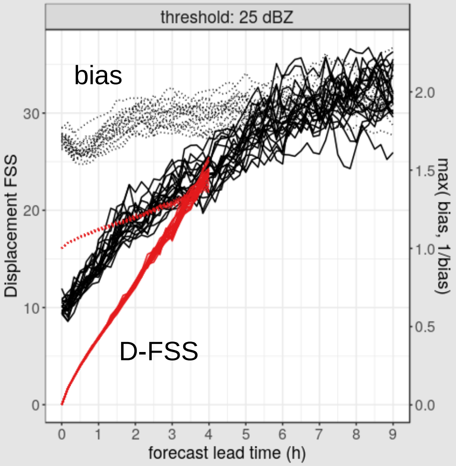
R package

- currently in test mode internally.
- Namelist control (xml)
- Reading capability for common data formats
- Aggregation functionality (important for routine verification)
- Interactive Alignment forecast data from different experiments/ models
- visualization of scores via R-shiny server
- *No pre-processing (e.g. regridding, restructuring)*

1px = 2km



Reliability (left) and ROC (right) diagram for predicted NEP vs. binary observation. Variable: reflectivity. NWP (solid) and Nowcasting (dashed) for five different lead times.



Displacement-FSS (solid) and bias (dotted) for NWP (black) and Nowcasting (red). Variable: reflectivity.

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SINFONY

Object-based Verification Efforts at DWD

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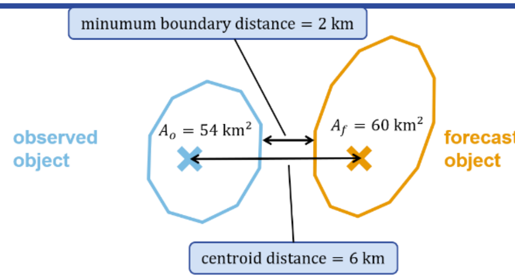
Wetter und Klima aus einer Hand

Object-based verification for det. forecasts and new developments

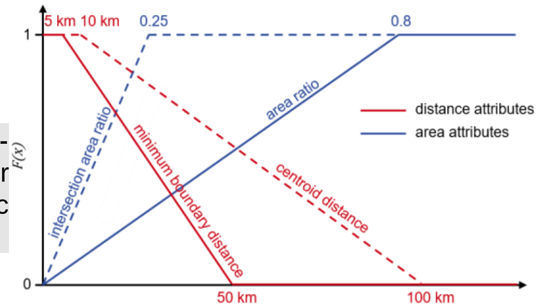
- Object identification based on KONRAD3D (DWD internal)
- Total Interest (TI) & Median of Maximum Interest (MMI) after Davies et al., 2009
- “Gridded Objects” (i.e. TI & MMI applied to predefined overlapping sub-boxes in domain)
- Error-statistics for “matched” objects (e.g. TI > 0.8) in development
- Adapt to ensemble forecasts (single member or probability objects) planned for future
- Contingency tables from matched objects planned for future
- Structure Amplitude Location planned for future

R package

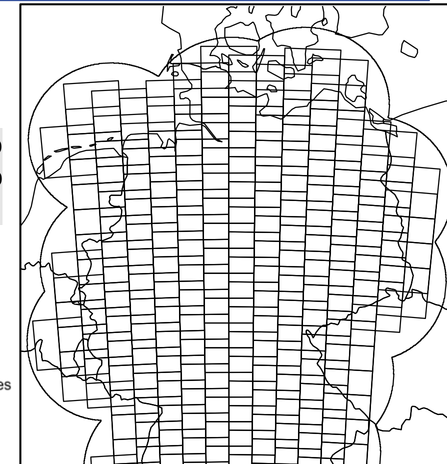
- currently in development
- Namelist control
- Reading capability currently for KONRAD3D data, only
- Aggregation functionality (important for routine verification)
- Interactive Alignment forecast data from different experiments/models
- visualization of scores via R-shiny



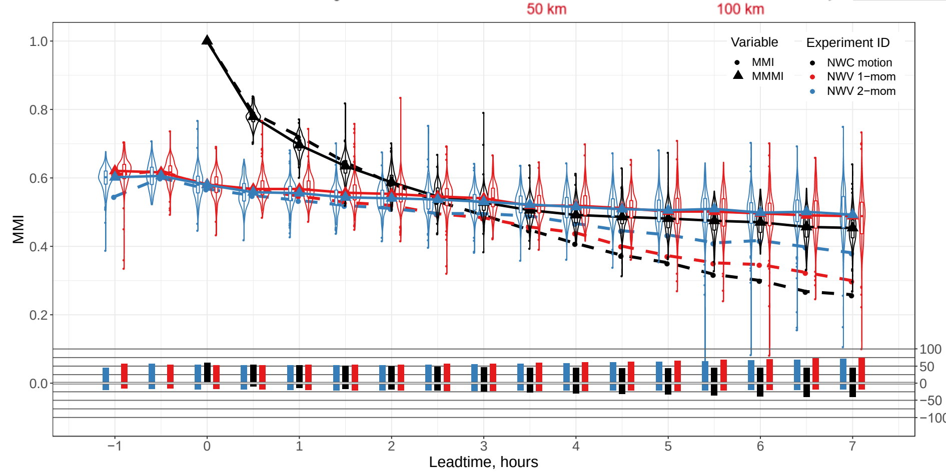
Left: Sketch of two idealized objects to compare with.



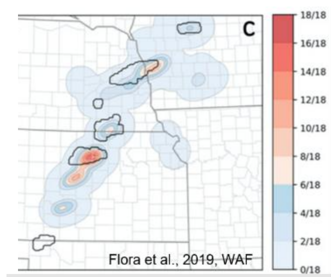
Right: Used Fuzzy-logic functions for four different geometric attributes.



German radar composite with 50% overlap sub-boxes for „gridded objects“ verification.



MMI for Nowcasting (black), NWP (red, blue). Violin plots show distribution of MMI over all sub-boxes in domain. Lower panel: #sub-boxes with zero objects (positive) and #sub_boxes with zero objects on either obs or fcst (negative).



Probability objects (EPS) after Flora et al., 2019 which we try to adapt.

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SINFONY

AWARE

Overview of forecast methods, representation & user-oriented products

- Postprocessing methods to predict phenomena vs. direct model output (DMO)
- Improving existing post-processing methods Machine Learning techniques : MLR, A-RLS, ANN
- QPF evaluation representation for Civil Protection
- Representing and communicating CW forecast for decision making

CONSORTIUM FOR SMALL SCALE MODELING COSMO

Various methods of post-processing (lightning rate); tested over 5-years period (2011-2015).

- Multi-Linear Regression (MLR) – class of LMS methods with multidimensional input data vector, yet constant over time

Solution for regression coeffs

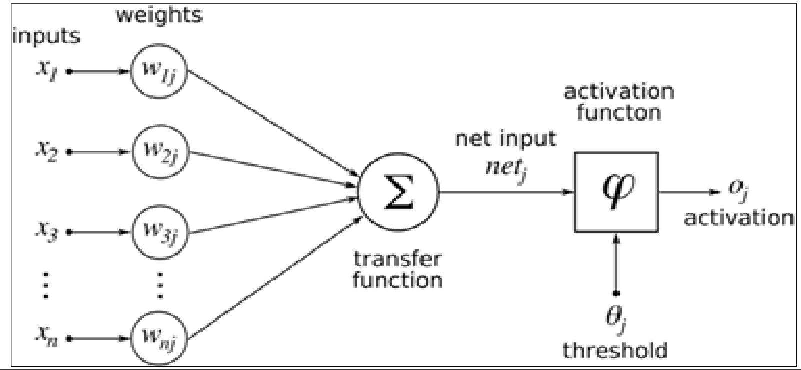
$$\hat{y}_n = \sum_{j=0}^{J} b_j h_{nj}$$

$$\bar{b} = (\hat{H}^T \hat{H})^{-1} \hat{H}^T \bar{y},$$

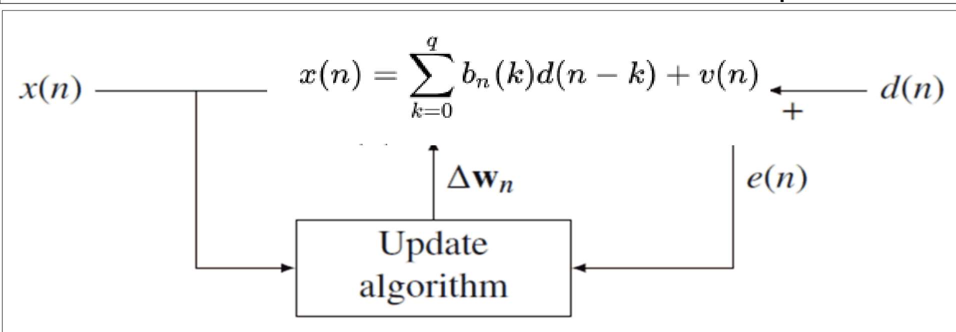
where

$$\hat{H} = \begin{bmatrix} 1 & h_{11} & \dots & h_{1J} \\ 1 & h_{21} & \dots & h_{2J} \\ \dots & \dots & h_{nj} & \dots \\ 1 & h_{N1} & \dots & h_{NJ} \end{bmatrix}; \bar{y} = \begin{bmatrix} y_0 \\ y_1 \\ \dots \\ y_N \end{bmatrix}; \bar{b} = \begin{bmatrix} b_0 \\ b_1 \\ \dots \\ b_J \end{bmatrix}$$

- ANN – Artificial Neural Network methods



- Adaptive/Recursive LMS methods

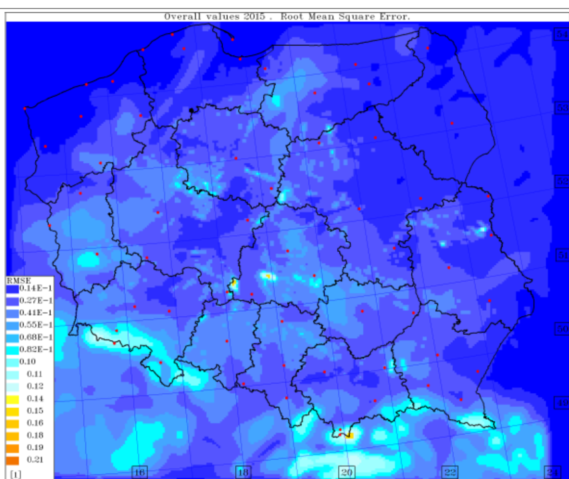


$$e(n) = d(n) - \hat{d}(n)$$

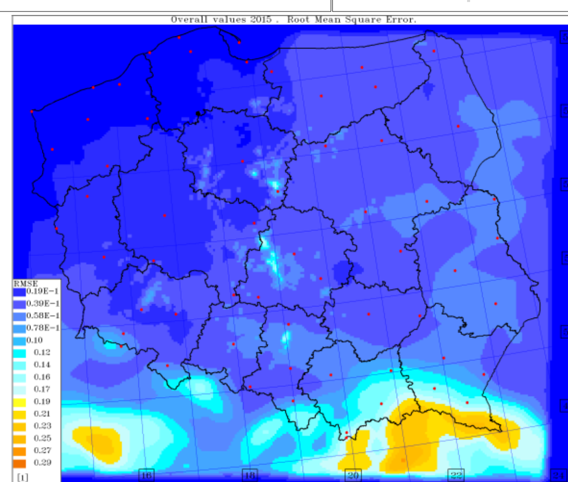
$$C(\mathbf{w}_n) = \sum_{i=0}^{n} \lambda^{n-i} e^2(i)$$

$$d(n) \approx \sum_{k=0}^{p} w(k)x(n-k) = \mathbf{w}^T \mathbf{x}_n$$

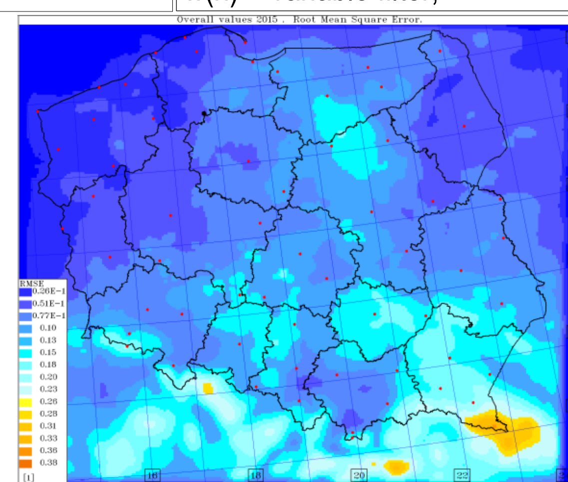
$C(w_n)$ – cost function to be minimized;
λ – forgetting factor; small – bigger impact from recent data
d(n) – data to recover;
x(n) – output data;
x(n-p:n) – most recent output data;
v(n) – additive noise
w(n) – variable filter;



ANN (MAE/RMSE best)



RMLS



MLR

RMSE 2011-15

Representing and communicating HIW forecast for decision making (RHM, Rozinkina, Bundel)

- A document is under preparation: "**How to provide high-res NWP for adverse weather forecasting"** It will take into account many factors: different geographical areas (moderate, subtropical, plane and mountain), grid steps, events
- *A study on the best data transfer channels to communicate HIW forecasts (internet sites, sms lists, e-mail, radio, mobile apps vs. "common" transfers) W*arnings via sms (mainly about strong winds and gusts, heavy precipitation, and road icing) **are often delivered too late because of queuing problems at the sms aggregator**
- Other ways to alert the whole population are explored

Contact e-mail: a.bundel@gmail.com