Observations for high-impact weather and their use in verification

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with the contribution of the WMO JWGFVR

Outline

- Verification for high-impact weather
- A framework for the verification of high-impact weather
  - identify the predicted quantity
  - look for suitable observations
  - match forecasted and observed quantities
  - choose the verification method
- "New" observations
- Some applications to thunderstorms and fog verification
- Concluding remarks

Aim of this work

- review the new observations which can be used for the verification of high-impact weather phenomena
- provide the NWP verification community with an organic “starter-package” of information about new observations suitable for high-impact weather verification, with hints for their usage
- “new” observations: observations which are not already commonly used in the verification of weather forecasts (choice necessarily subjective), but may be familiar to meteorologists (e.g. for monitoring and nowcasting)

Paper:

Observations for high-impact weather and their use in verification

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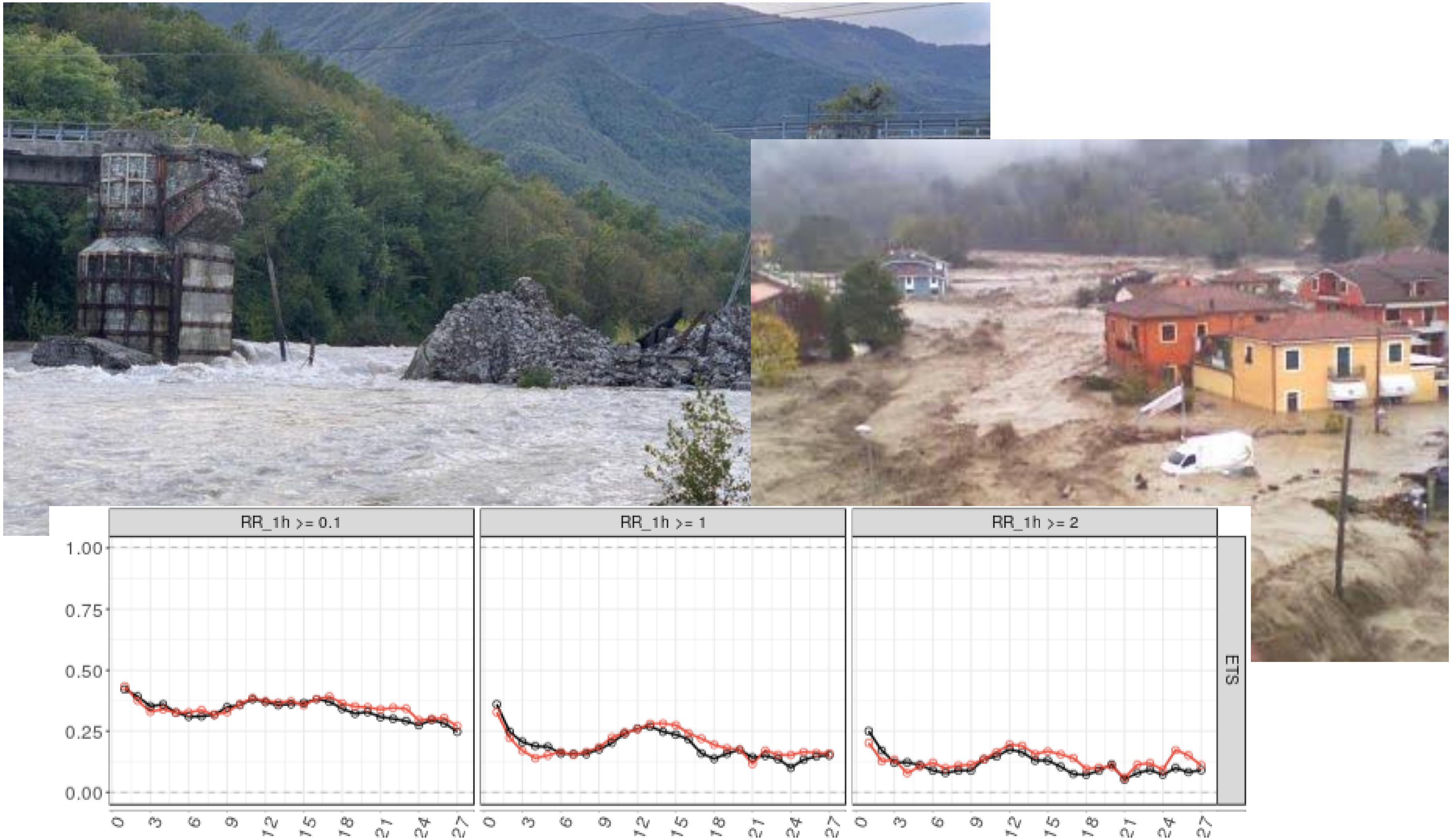
Submitted to NHESS for online discussion

A motivation



High-impact weather verification

- The newly developed products used in operations for the forecast of high-impact weather need to be verified
- => Complement the traditional verification of the meteorological parameters involved in the occurrence of a high-impact weather phenomenon (precipitation, temperature, wind) with a specific verification of these products
- The verification of these products requires a different approach to the objective verification process

A framework for the verification of high-impact weather using new observations

1. define the quantity or object to be verified, referred to as “forecast”

2. choose the “observation,” or reference, against which to verify the forecast

3. create the pair, called a verification set

4. compute the verification metrics

1. Definition of the forecast

- define the quantity or object to be verified, representative of the phenomenon
- e.g. for thunderstorm: verify the object “convective cell” instead of the precipitation associated to it
- it may not be a direct model output or a meteorological variable (e.g. an area identifying the thunderstorm, a lightning index, a product used for nowcasting, …)
- it should be a quantity which can be either directly observed, or for which an “observable” exists, which can provide the reference

2. Choice of the observation

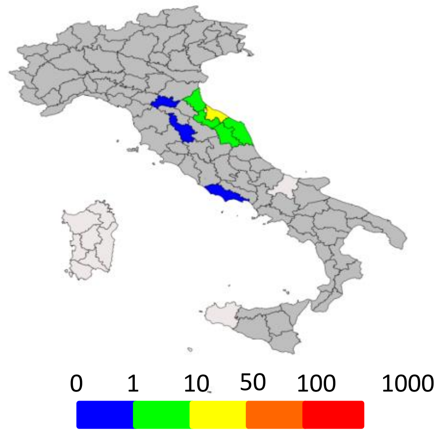
- quantity really representative of the high-impact weather phenomenon
- these observations may already exist, used only qualitatively, or for the monitoring of the events
- they should have a usable spatial and temporal coverage and a documentation of the quality
- the quality of the observations should be assessed:
  - using observed data coming from different sources
  - include the observation uncertainty in the verification process (e.g. Ben Bouallegue et al. (2020) and the references therein)
- there may not be a previously viable evaluation of this forecast!

3. Creation of the pair

- check the matching of the two quantities:
  - make sure that forecast and observation represent the same phenomenon (sample stratification)
  - find the thresholds which identify the phenomenon in the forecast and observation (comparison should be as unbiased as possible)
  - assess spatial and temporal representativeness -> average or re-grid the forecasts and/or observations
- when the forecasts and observations show a good degree of correspondence, one can provide the reference for the other and objective verification can be performed

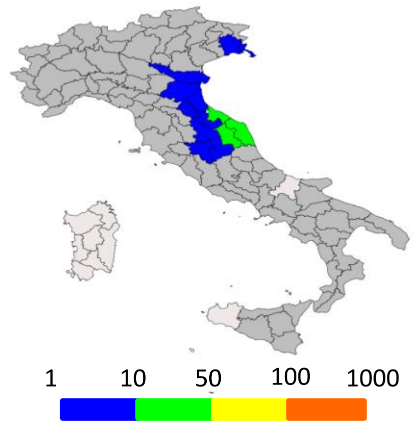
Matching between prediction and observation

obs: lightning



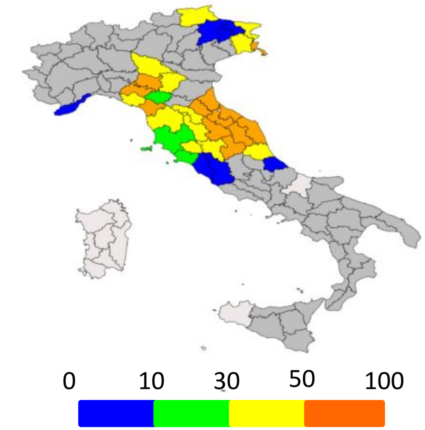
Number of lightnings

obs: radar



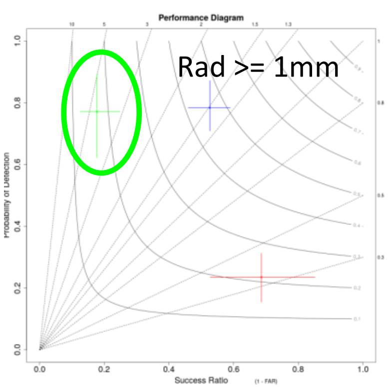
Precipitation (mm)

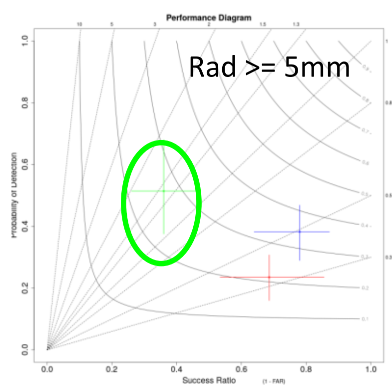
forecast: ensemble



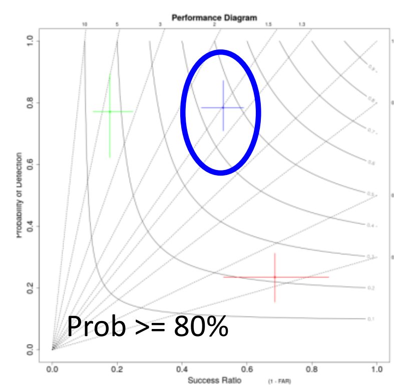
Probability of rain > 1mm

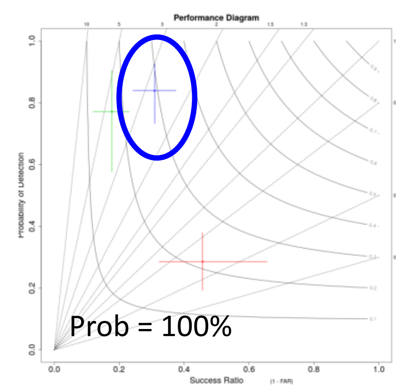
radar vs lightning





ensemble vs radar

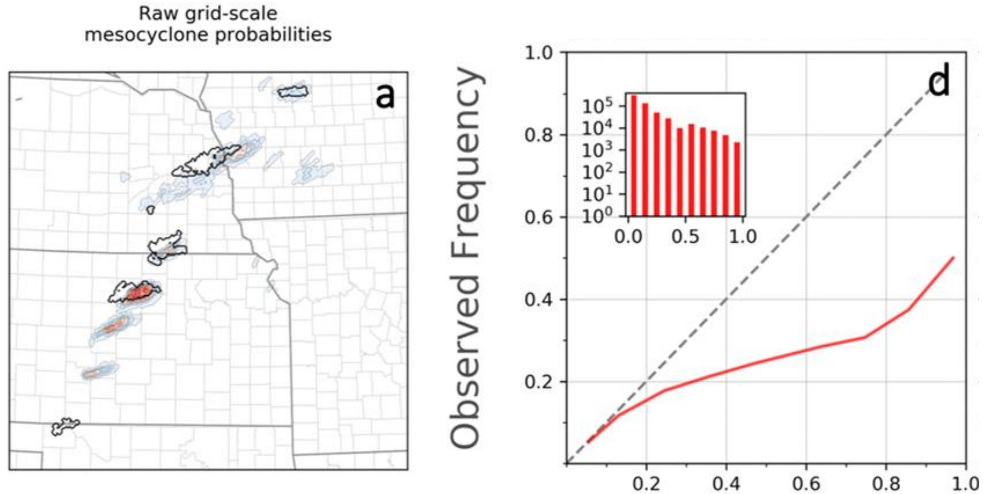




3. Creation of the pair

- this approach can be extended to probabilities: an area where the probability of occurrence of a phenomenon exceeds a certain threshold can be considered as a predictor for the forecast of the phenomenon

verification of probability objects (Flora et al., 2019)



3. Creation of the pair

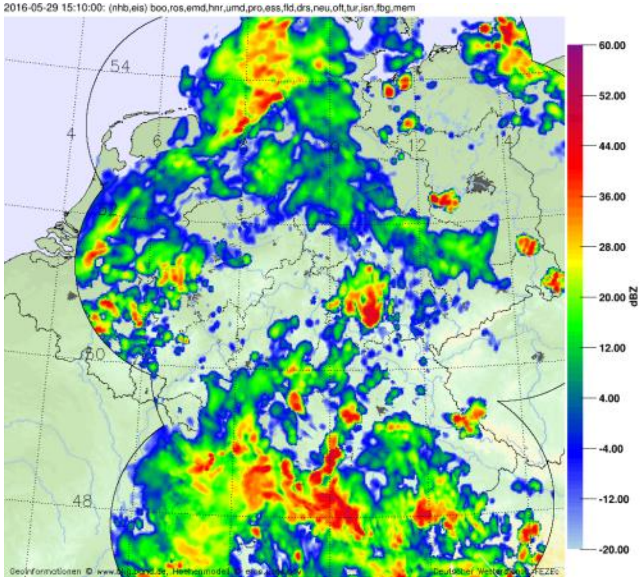
- if the observation is an object identified by an algorithm, should the same algorithm be applied also to the model output for identifying the forecasted phenomenon?
- two possibilities:
  - the forecast is a model output variable while the reference is derived by applying an algorithm to the observations

  or

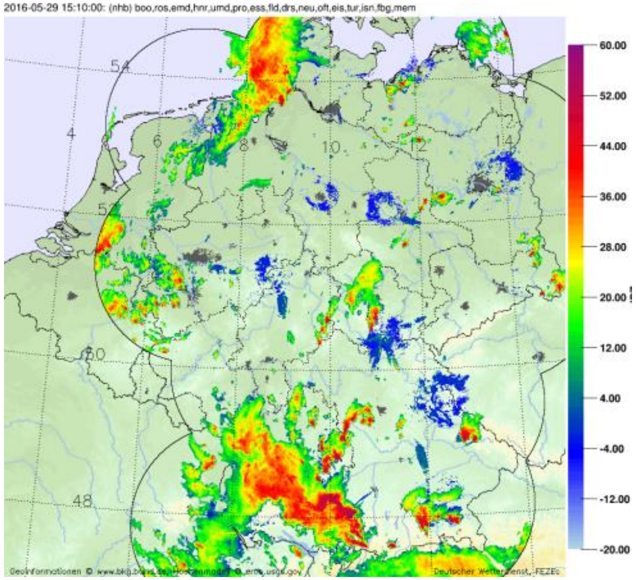
  - an algorithm (observation operator) is applied to the same set of meteorological variables in both the observed data and the model output
- the latter provides greater homogeneity between the variables, but errors resulting from the transformation of the model output may be introduced

Homegeneity between forecast and observation

Predicted radar reflectivity



Observed radar reflectivity

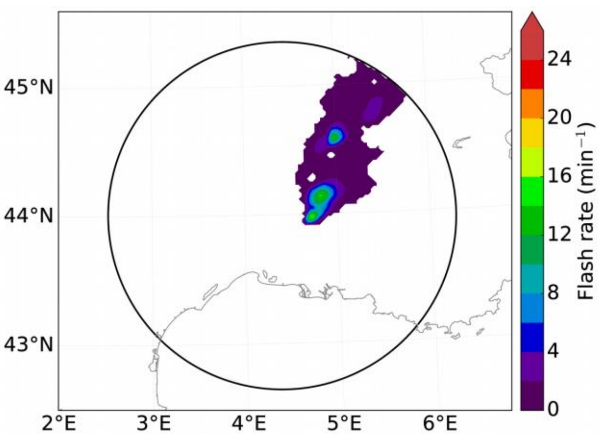


- model results in observation space (dBZ)
- comparing apples with apples (?)

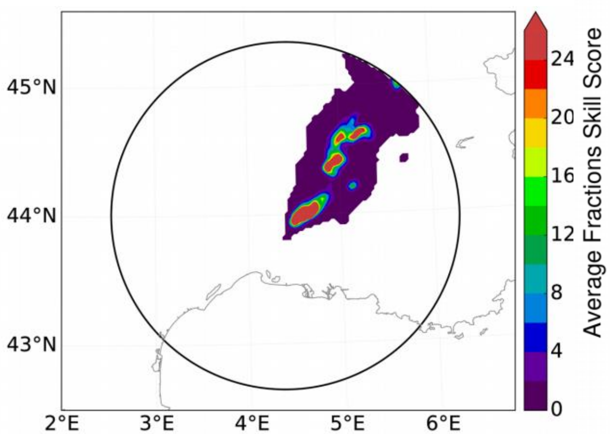
4. Computation of the verification metrics

- in high-impact weather verification an exact matching between forecast and observation is rarely possible, therefore verification naturally tends to follow fuzzy and/or spatial methods

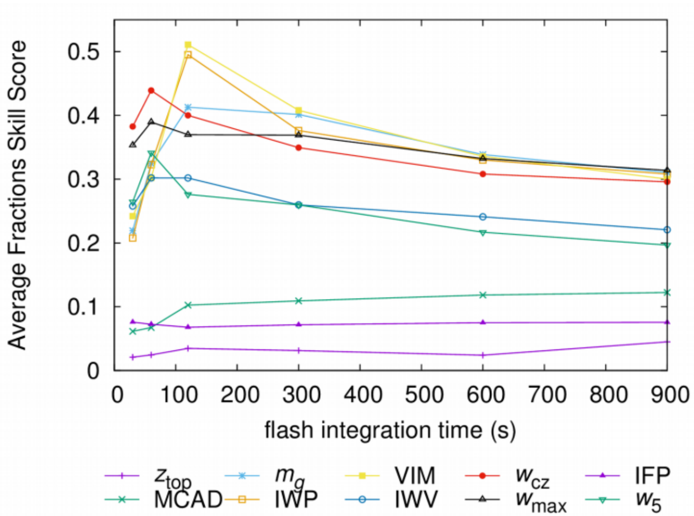
Flash rate observation



Flash rate model



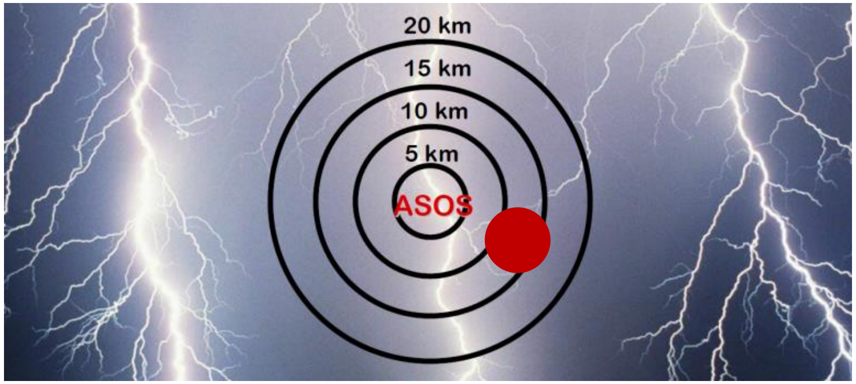
Fraction Skill Score



Caumont, 2017

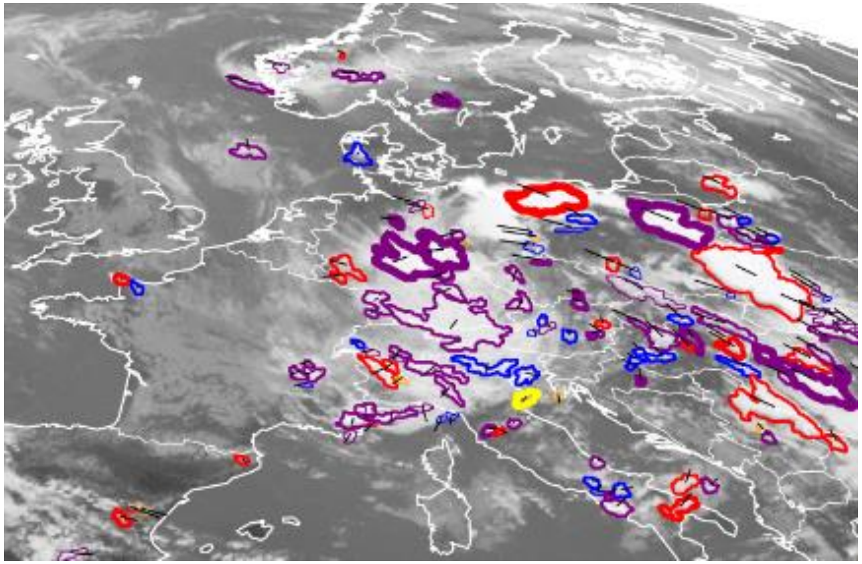
Observations: **lightning detection**

- several ground based networks, national and international
- detection from satellite: data over data-sparse regions (e.g. oceans)
- some issues on data usage:
  - how many strokes are needed to detect the occurrence of a thunderstorm? (identification of thresholds)
  - which surrounding of the detection point is affected by the thunderstorm?
  - how to identify the no-lightning event?
  - combine with other observations (radar, satellite) to improve the detection of the phenomenon



Observations:
nowcasting products

- National Meteorological Services develop tools for nowcasting, where data from different sources (satellite, radar, lightning, …) are integrated in a coherent framework
- the detected variables/objects of nowcasting (thunderstorm cells, hail, …) can become observable against which to verify the model forecast
- nowcasting products are proposed as observed data instead of prediction tools: consider the step 0 of the nowcasting algorithm as an “analysis”



Observations: **nowcasting products**

- advantage:
  - high spatial continuity over vast areas
  - detection of high-impact weather phenomena
- disadvantage:
  - some data have only a qualitative value
  - but qualitative evaluation could become quantitative by "relaxing" the comparison through neighbourhood/thresholding
- strengthen the link with the nowcasting groups, to explore the possible usage of the variables/objects identified through nowcasting algorithms for forecast verification

Convection Working Group

https://cwg.eumetsat.int/satellite-guidance

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

1. Pre-Convective Environment

Refers to the 4-D thermodynamic and wind field present before the convective initiation occurs.

Useful tools:

NWP data, Radiosonde and aircraft measurements
MSG GII/RII Product – instability & moisture
iSHAI Products – instability & moisture
HRW Product – wind fields
METOP/IASI level2 – temp & moisture vert. profiles

2. Convective Initiation

Refers to the process where an existing cumulus cloud begins rapid vertical growth.

Useful tools:

Radar, lightning data
Cloud Type
Cloud Top Temperature and Height
Cloud Microphysics
Convection Initiation – demonstrational
Optimal Cloud Analysis – demonstrational

3. Mature Convective Storm

Refers to the presence of convective clouds with tops at or above their local equilibrium level

Useful tools:

Radar, lightning data
RDT Product – storm tracking
Precipitating Clouds
CRR Product – precipitation
NEFODINA
Overshooting Top Detection
MSG Sandwich Product (HRV+IR10.8 enhanced)
Lightning Density

Suitable RGB Imagery for Convection monitoring at different stages of development (EUMeTrain Quick Guides)

SEVIRI HRV Cloud RGB
SEVIRI Severe Storms RGB
SEVIRI Day Microphysics RGB

Suitable RGB Imagery for providing visual information on atmospheric water vapour content in cloud-free areas (EUMeTrain Quick Guides)

SEVIRI Night Microphysics RGB
SEVIRI 24 Hour Microphysics RGB
SEVIRI Dust RGB

EUMETSAT · ARSO METEO Slovenian Environment Agency · EUMETSAT NWC SAF · CZECH HYDROMETEOROLOGICAL INSTITUTE · NASA

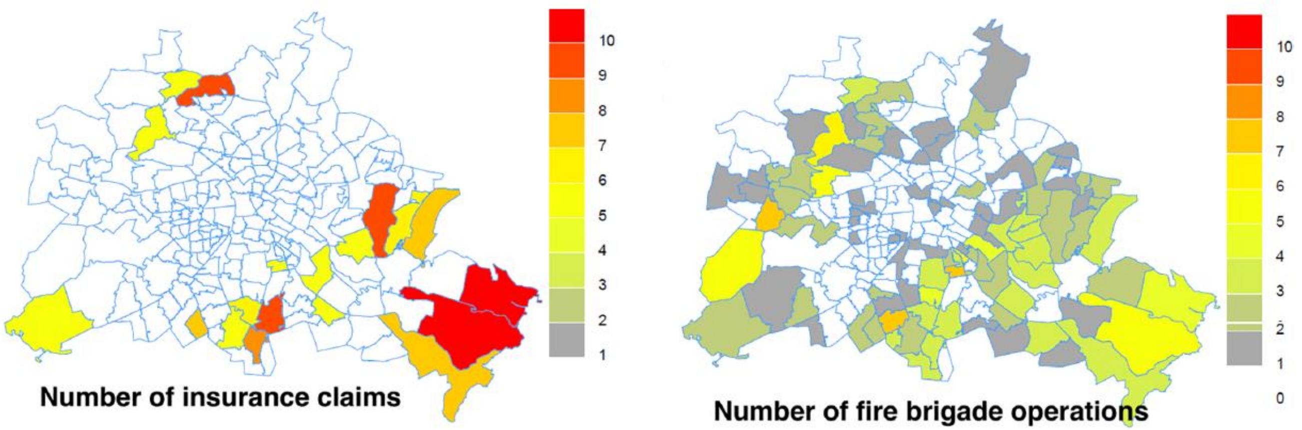
✓ OT climatologies have been demonstrated in several peer-reviewed studies (see Additional Information), enabling assessments of climatological severe storm risk and regional/temporal storm distributions.

✓ OTs detected near ~60% of wind, hail, and tornadic storms.

✓ The first product of its kind for discriminating likely aircraft engine icing conditions at the storm cell scale.

X It is impossible to identify only the OT updraft areas and none of the nearby cold outflow using IR imagery alone.

- organised databases: e.g. the European Severe Weather Database of the European Severe Storms Laboratory: https://www.eswd.eu/
- data from insurances
- data from citizens, cars, …
- impact data (emergency calls, fire brigade operations, …)
  - very high spatial resolution



Summer convection case over Berlin area

Pardowitz, 2018

Applications of **thunderstorm** verification: cloud properties from satellite

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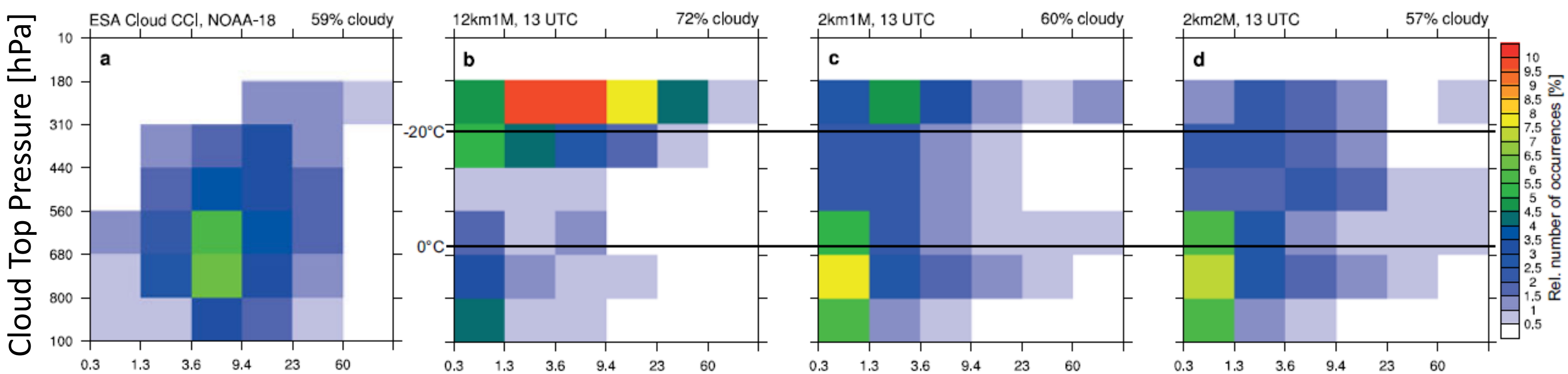
Simulated: COSMO model at 12 and 2 km + RTTOV
Observed: satellite-derived (AVHRR on NOAA-18 satellite)

observed — simulated: 12 km, 2 km 1M, 2 km 2M



Cloud Optical Thickness | Cloud Optical Thickness | Cloud Optical Thickness | Cloud Optical Thickness

Histograms of cloud frequency

Keller et al., 2015

Applications of **thunderstorm** verification: **reports and lightning**

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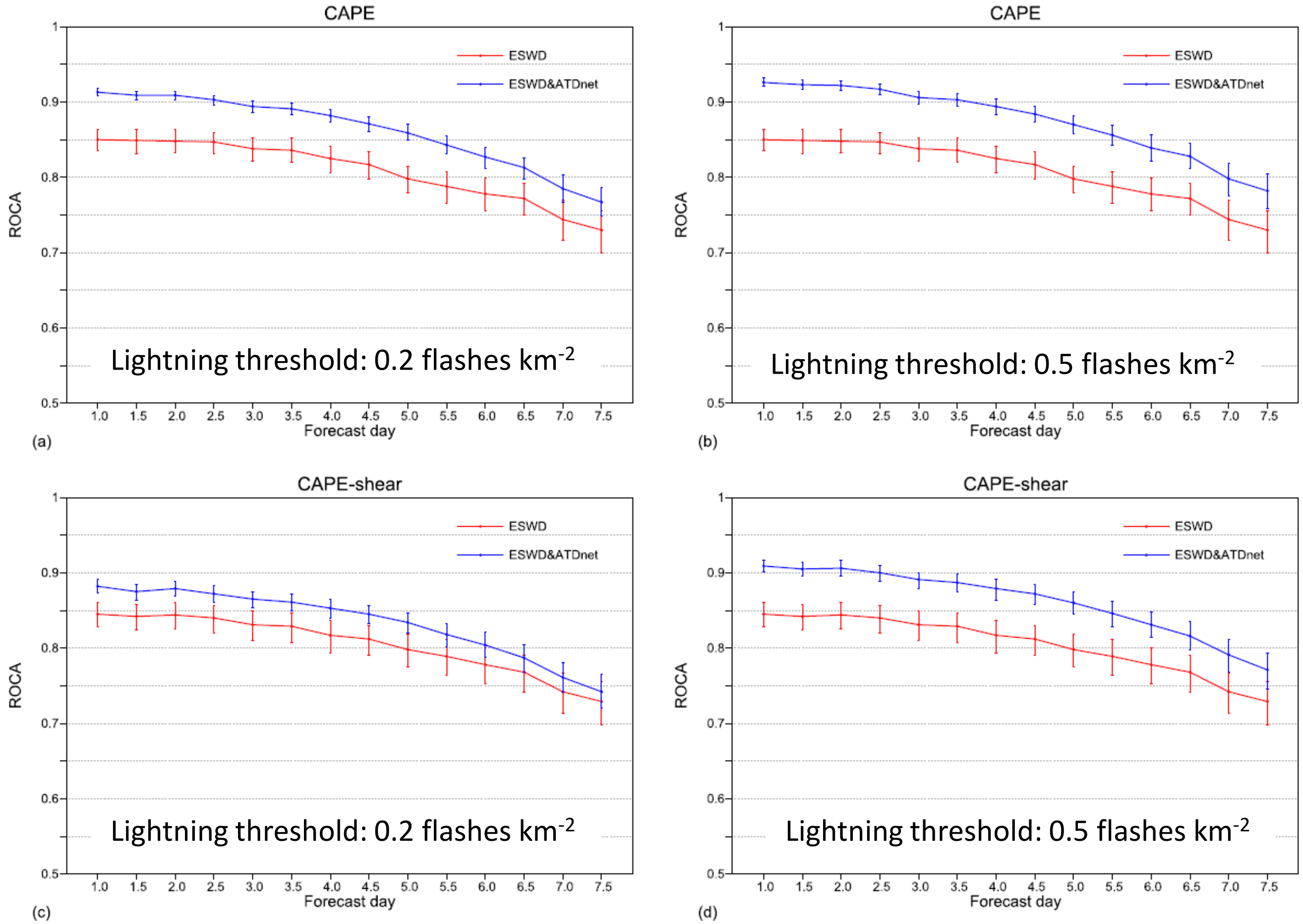
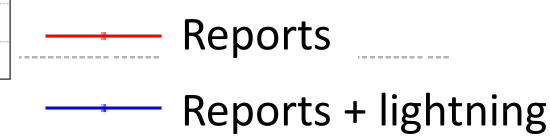
Simulated: EFI of ECMWF ENS for CAPE and a composite CAPE-shear parameter

Observed: Reports provided by ESSL; Reports from SPC; lightning data from ATDnet





Tsonevsky et al., 2018

EFI is combined with Probability of Precipitation (PoP) from ENS, to exclude unstable cases where convection does not initiate

Applications of **thunderstorm** verification: **lightning, pointwise vs areal method**

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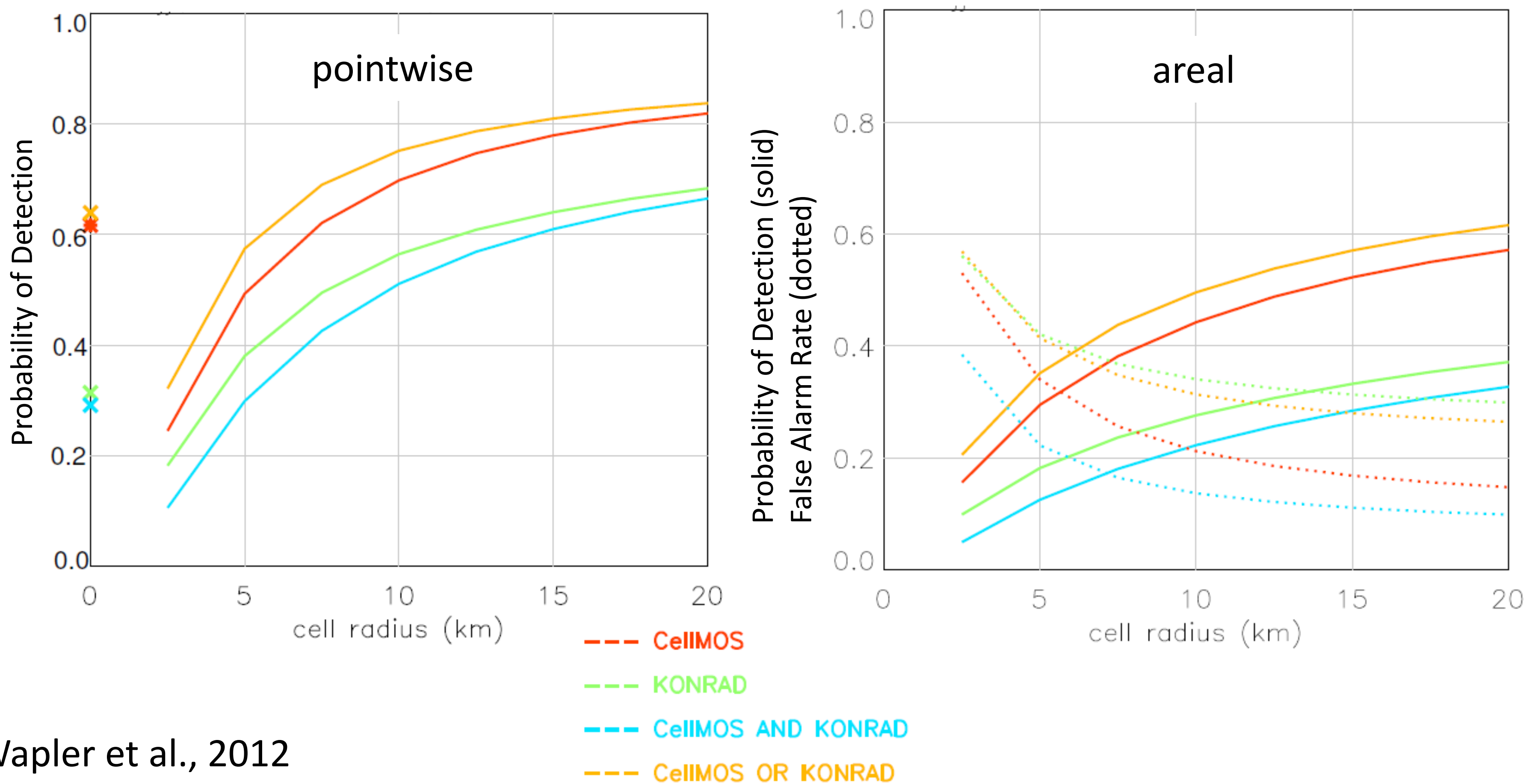
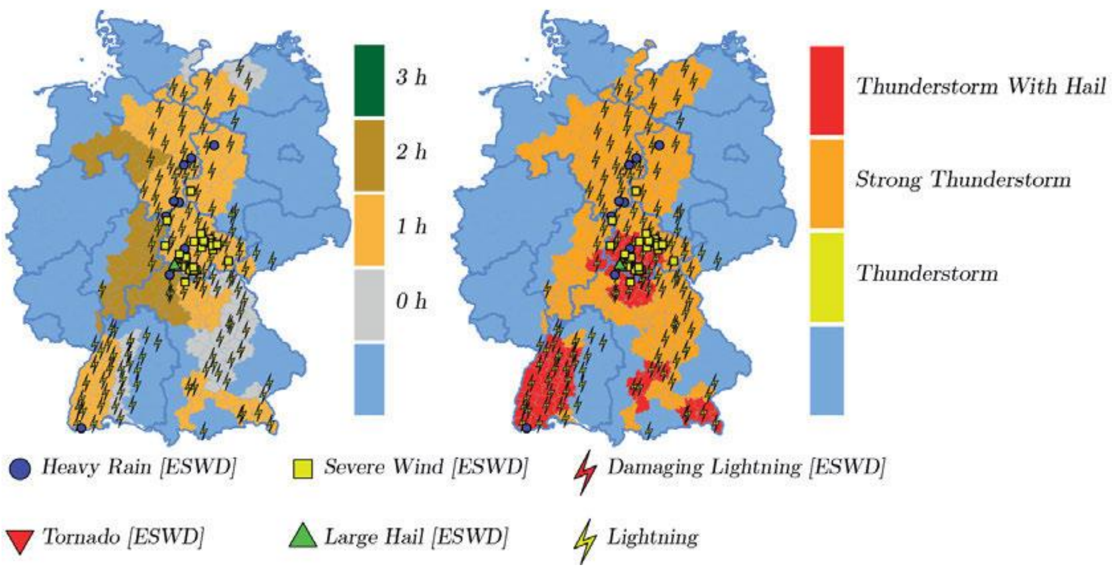
Simulated: Cells detected by 2 nowcasting algorithms
Observed: lightning (LINET)

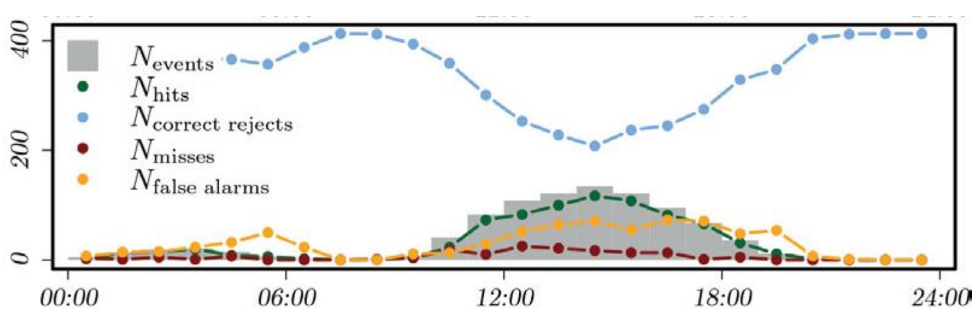


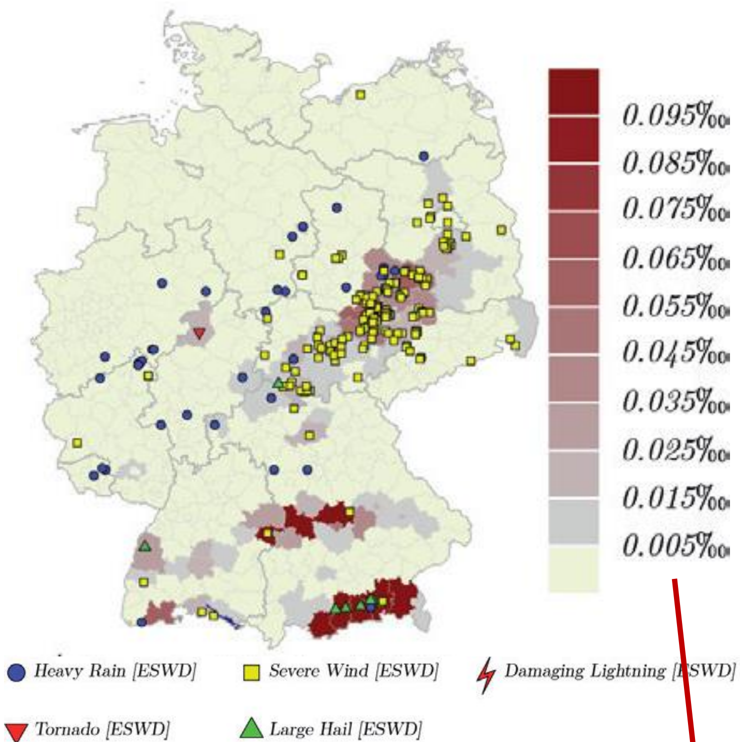
Wapler et al., 2012

Applications of **thunderstorm** verification: **reports and insurance data**

Deutscher Wetterdienst
Wetter und Klima aus einer Hand







Loss ratio (per thousand) on district basis

Wapler et al., 2015

Applications of **thunderstorm** verification: **subjective evaluation of testers**

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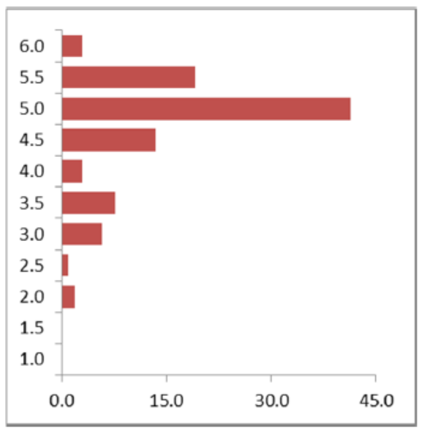
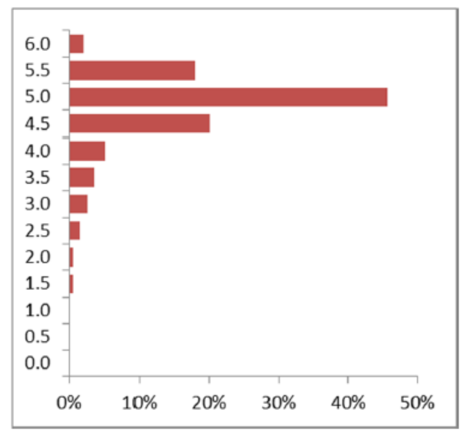
Simulated: thunderstorm warning from nowcasting sent to the testers
Observed: testers subjective evaluation, marks

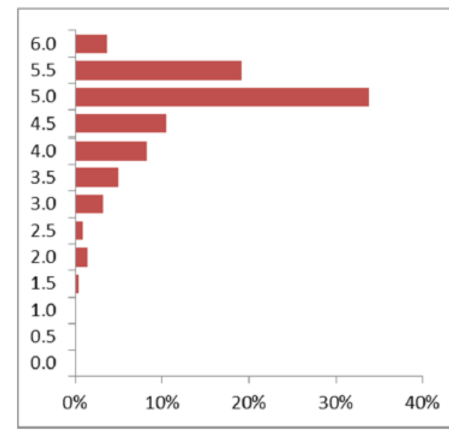
*Experimental Thunderstorm Information from MeteoSwiss: a **developing** / **moderate** / **severe** / **very severe** thunderstorm is expected in the next XX min. in (NAME of municipality).*



2014 (104 responses)



2015 (195 responses)



2016 (219 responses)

2014	2015	2016
POD: 75 %	POD: 88 %	POD: 67 %
FAR: 25 %	FAR: 33 %	FAR: 29 %

subjective evaluation of the beta tester (feedback after each warning)

Gaia et al., 2017

Applications of **thunderstorm** verification:
fire brigade operations

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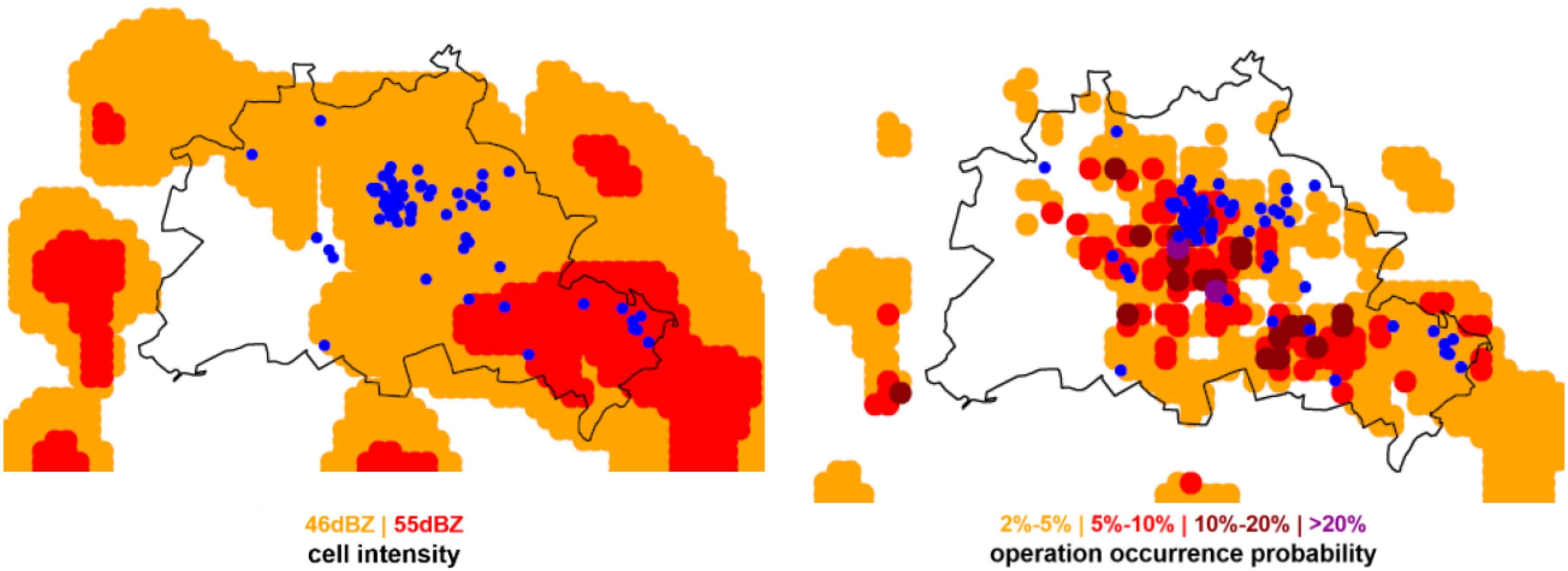
Simulated: „footprint“ of convective cell detected by a nowcasting algorithm
Observed: fire brigade operations (water related)



strong dependence also on exposure and vulnerability

Pardowitz and Göber, 2017

Applications of **fog** verification:
reports at locations

Simulated: SREF ensemble for Beijing Olympics 2008 + multivariable diagnostic method
Observed: fog reports issued by local weather services or airports in 13 cities in eastern China

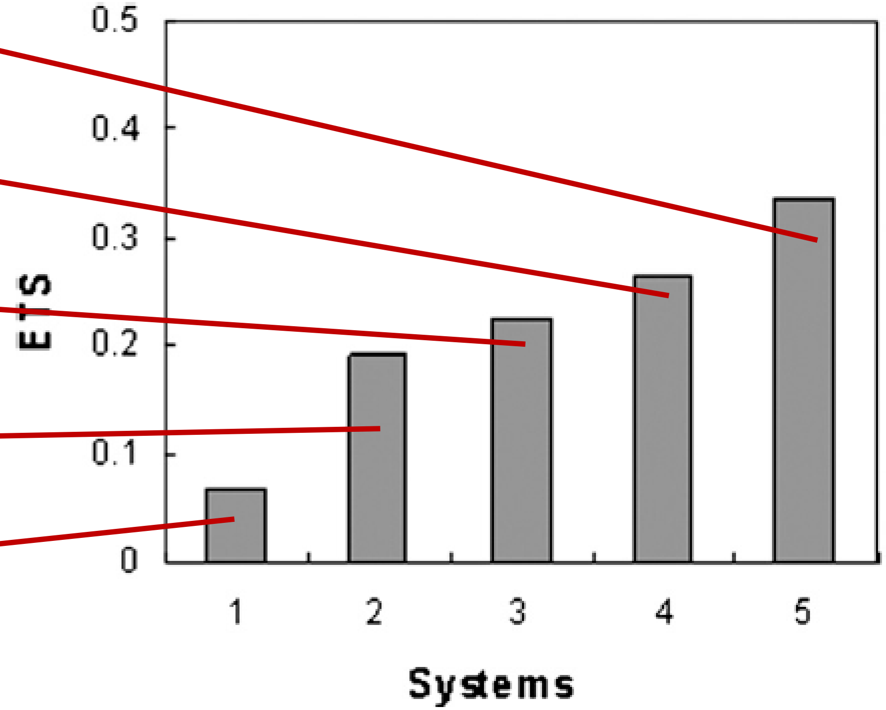
40% probability from 10-member multi-model ensemble

40% probability from 5-member multi-model ensemble

40% probability from 5-member single model ensemble

Control run, multivariable diagnostic

Control run, simple diagnostic



Zhou and Du, 2010

Applications of **fog** verification:
SAL metric

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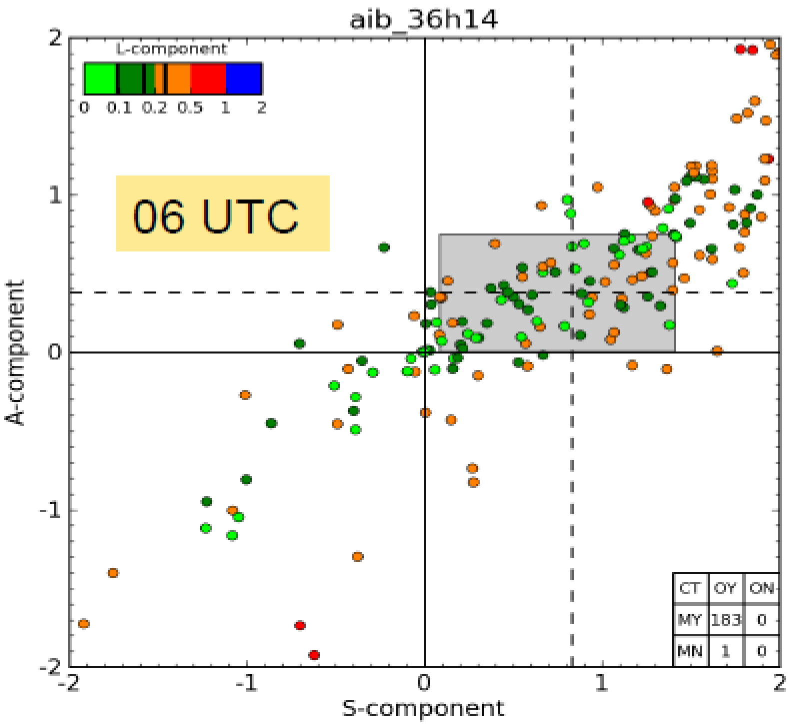
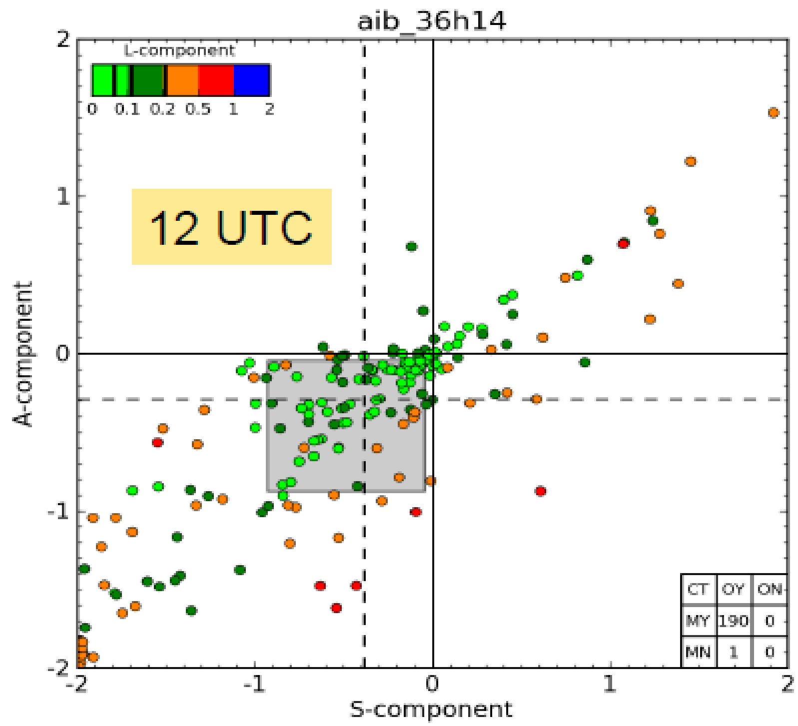
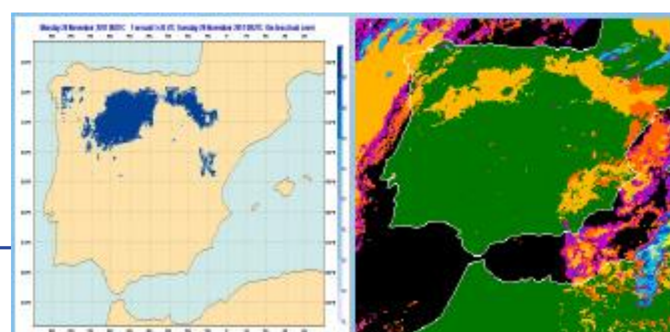
Simulated: AROME model at 2.5 km hor. res., low clouds
Observed: Cloud Type Product (NWC-SAF, Satellite Application Facility for Nowcasting)





Morales et al., 2013

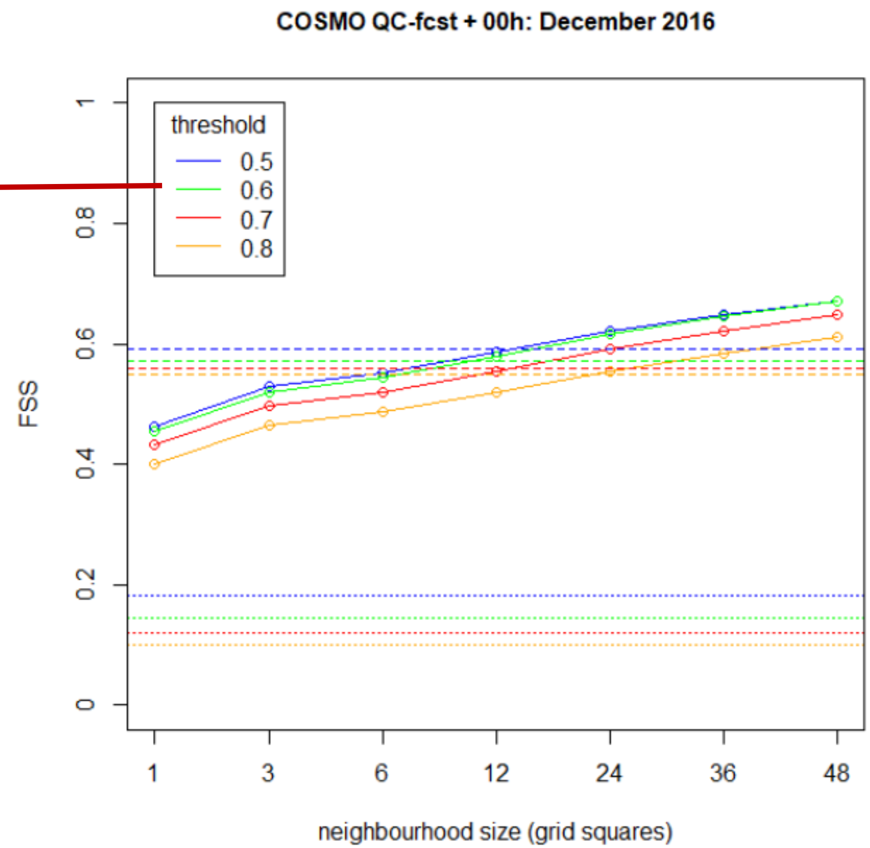


http://www.nwcsaf.org/
EUMETSAT

Applications of **fog** verification: Fractions Skill Score

Simulated: COSMO model at 7 and 2.8 km hor. res., Liquid Water Path
Observed: Satellite data (channel combination) to give a Cloud Confidence Level (CCL)

Threshold for computation of FSS from observed data (CCL)



Grid-points with high- or mid- level clouds are filtered out (using NWC-SAF Cloud Type), both in observation and forecast

Ehrler, 2018; Westerhuis et al., 2018

Concluding remarks

- Recommend the usage of new observations for verifying products for high-impact weather
- Usage of reports, impact data, crowdsourcing data
- Careful matching between predicted and observed quantities
- Data quality and data uncertainty assessment: usage of multiple data sources
- Closer cooperation with nowcasting, where products for high-impact weather detection are developed
- Fuzzy/spatial approaches often adopted, due to the non-exact matching between forecast and observation

Thank you for your attention!

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