Nowcasting of deep convective systems over Germany - based on lifetime characteristics in multi-source data

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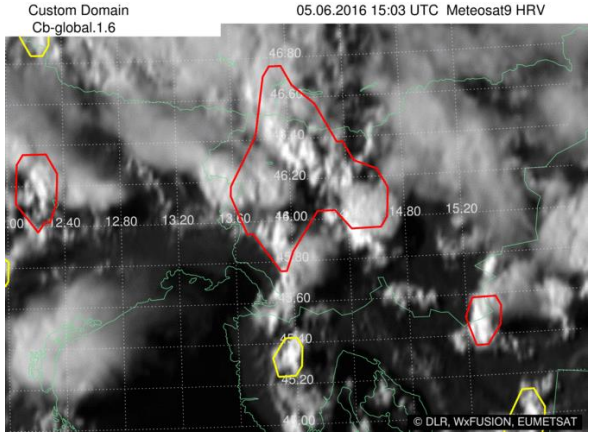
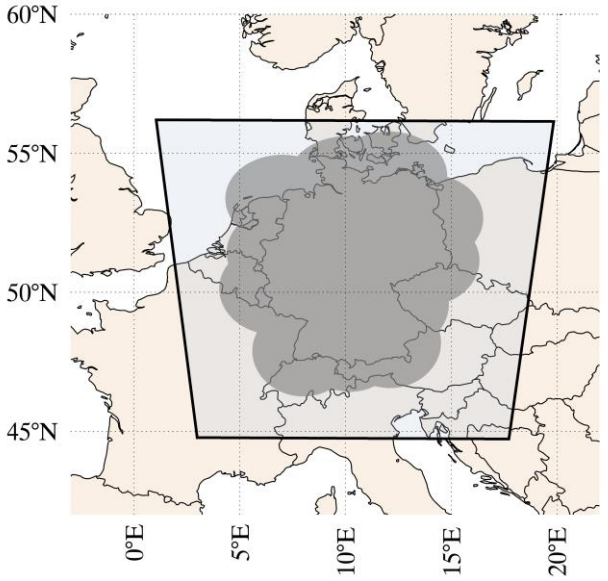
Aim: How long will an existing thunderstorm last?

Basics

To improve the nowcasting of the lifetime of thunderstorms the operationally satellite-based thunderstorm detection algorithm **Cb-TRAM** (Cumulonimbus tracking and Monitoring (Zinner et al. 2008, 2013)) is used to define a thunderstorm. Cb-TRAM detects thunderstorms **independently of their organization type**. Consequently, the following analyses consider single cells, multi cells and supercells. The red contour in the middle of the figure shows a multi cell with several regions of updraft.

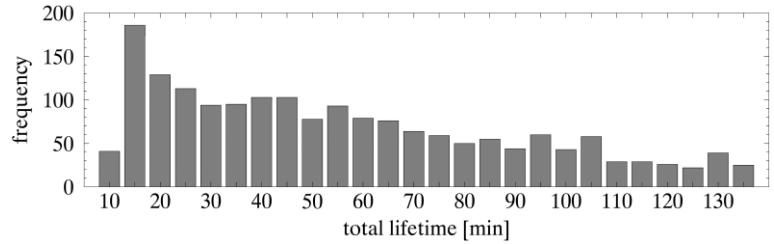




Parameters from **satellite, radar, lightning** and **NWP model** (COSMO-DE) are analyzed to identify lifetime signatures. As all data sources should be available for every thunderstorm analyzed, the area of interest is limited to the data set of the smallest coverage (the radar data, dark grey shaded area)

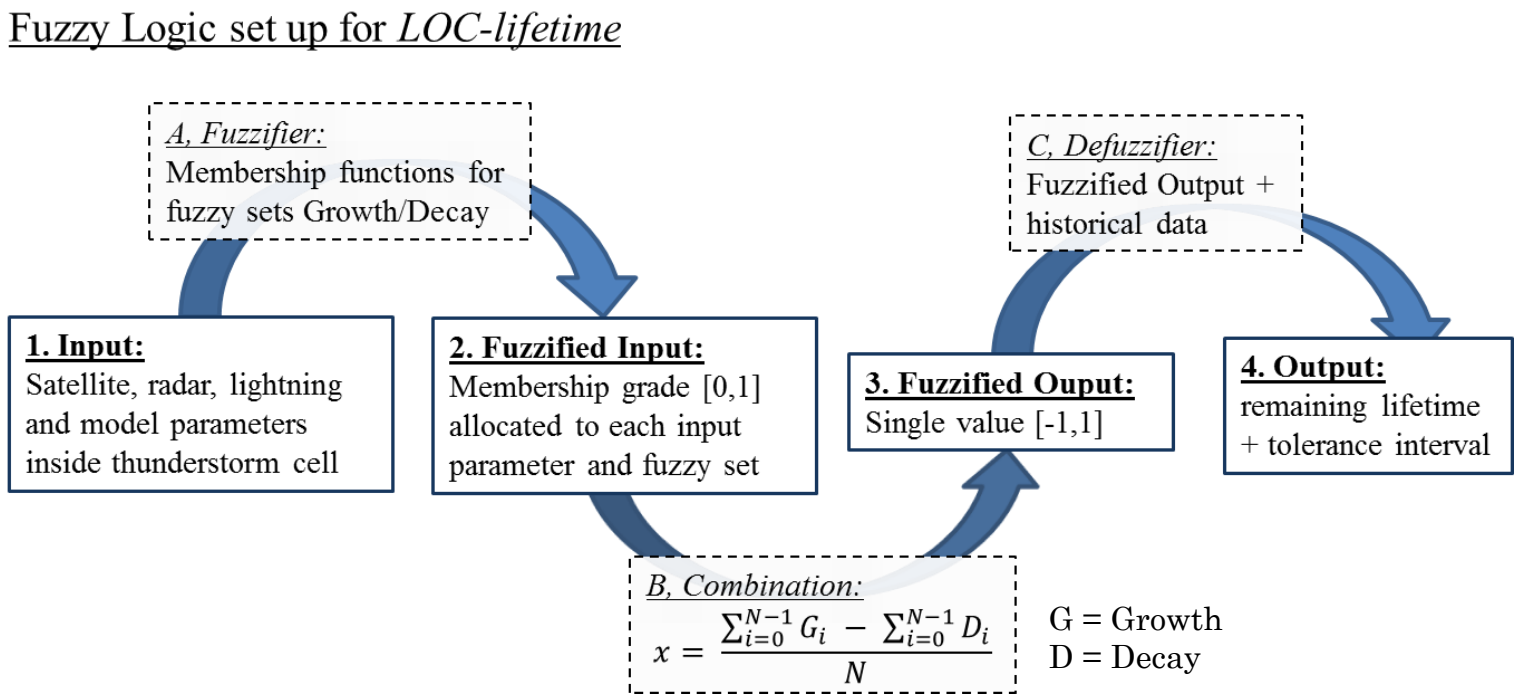
Over Germany all thunderstorms occurring in **June 2016, May, June, July 2017** and **June 2018** are analyzed and nowcasted. The nowcasting algorithm ***LOC-lifetime*** is based on the mathematical method *fuzzy logic*. *LOC-lifetime* is validated via *cross-validation* (one month is left out acting as „current thunderstorms“ and the other four month are used as basis data set).

During the analyzed period, most of the thunderstorms lived 15 min (3 detection steps a 5 min). Only thunderstorms that lived maximum 135 min are part of this study since thunderstorms with lifetimes greater than 135 min occur very rarely.



Aim: How long will an existing thunderstorm last?

Concept of the nowcasting algorithm *LOC-lifetime* (Life cycle Of deep Convection)



Concept of *LOC-lifetime*: Input and Membership functions

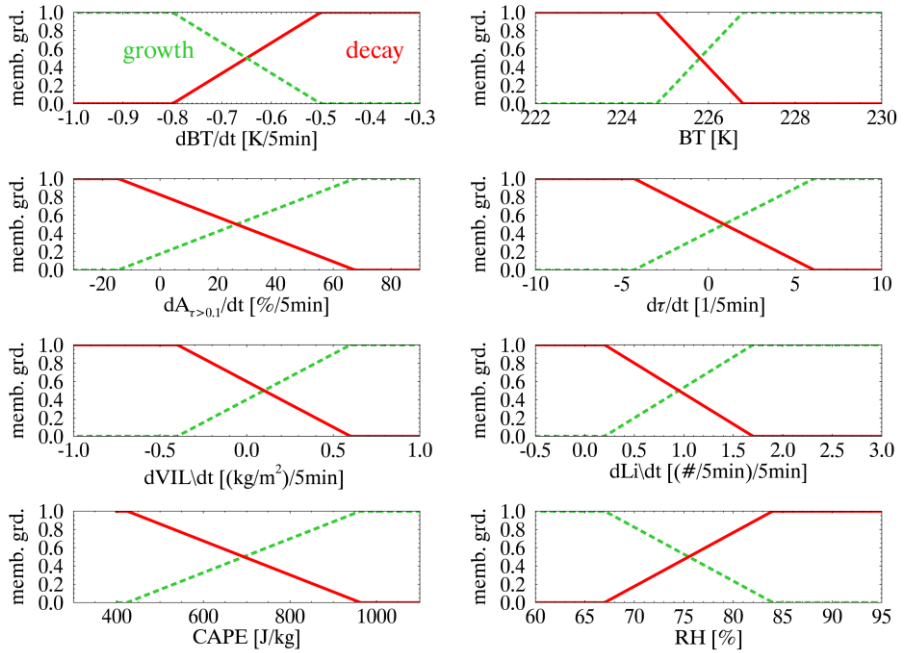
Input:

Parameters from satellite, radar, lightning and NWP model (COSMO-DE) data were analyzed to identify lifetime signatures. The cells colored light blue show characteristic signatures for lifetime / life cycle phases (Zöbisch et al., in review.)

Data source	Parameter	Abbrev.	unit
Satellite	minimum Brightness Temperature	BT_{min}	K
	cloud optical thickness	τ	-
	effective radius	r_e	μm
	ice fraction at the cloud top	$icefraction$	%
	Area inside A_{cb} where $\tau > 0.1$	$A_{\tau>0.1}$	km^2
Cb-TRAM	Area of the Cb-TRAM cell	A_{cb}	km^2
Radar	maximum Vertically Integrated Ice	VII_{max}	kg m^{-2}
	maximum Vertically Integrated Liquid water	VIL_{max}	kg m^{-2}
Rad-TRAM	Area of the 46 dBZ contour	RA_{46}	km^2
	maximum Reflectivity	R_{max}	dBZ
LINET	Lightning detection during 5 min	Li	# 5min^{-1}
COSMO-DE	*mixed layer Convective Available Potential Energy*	$CAPE_{max}$	J kg^{-1}
	Relative Humidity at 700 hPa	RH	%
	minimum vertical velocity at 700 hPa	ω_{min}	Pa s^{-1}

Membership functions:

The membership functions are used to allocate every parameter to a **growing** (green dashed line) or **decaying** (red solid line) thunderstorm (values between [0,1] for every fuzzy set). The values are combined to one fuzzy output where 1 indicates a strong growth and -1 a strong decay.



Concept of LOC-lifetime: Defuzzifier and Nowcasting

Defuzzifier:

The „Defuzzifier“ converts the fuzzy output by means of historical data to a readable output.

For every thunderstorm, at every detection step a fuzzy output was calculated and sorted by its total lifetime, then the average was calculated (see Table). The red color indicates a **decaying** thunderstorm (negative values close to -1), the green color indicates a **growing** thunderstorm (positive values close to 1) and the yellow color indicates a thunderstorm in its **mature** stage.

Averaged fuzzified output

total lifetime [min] \ detected lifetime so far [min]	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135
10	-0,89	-0,71																									
15	-0,72	-0,59	-0,49																								
20	-0,59	-0,49	-0,39	-0,23																							
25	-0,68	-0,45	-0,35	-0,26	-0,34																						
30	-0,56	-0,41	-0,31	-0,23	-0,31	-0,35																					
35	-0,42	-0,40	-0,30	-0,20	-0,30	-0,36	-0,41																				
40	-0,55	-0,36	-0,27	-0,16	-0,27	-0,33	-0,38	-0,42																			
45	-0,35	-0,31	-0,23	-0,11	-0,23	-0,30	-0,36	-0,40	-0,43																		
50	-0,22	-0,18	-0,11	-0,02	-0,15	-0,23	-0,29	-0,35	-0,38	-0,40																	
55	-0,13	-0,12	-0,07	0,01	-0,11	-0,20	-0,27	-0,33	-0,38	-0,41	-0,43																
60	-0,12	-0,11	-0,04	0,04	-0,09	-0,17	-0,24	-0,30	-0,35	-0,40	-0,44	-0,48															
65	-0,29	-0,16	-0,09	0,01	-0,09	-0,16	-0,22	-0,28	-0,34	-0,40	-0,45	-0,48	-0,49														
70	-0,35	-0,12	-0,05	0,02	-0,08	-0,15	-0,20	-0,25	-0,31	-0,38	-0,43	-0,46	-0,48	-0,50													
75	-0,03	-0,09	-0,04	0,06	-0,03	-0,09	-0,13	-0,19	-0,26	-0,33	-0,38	-0,42	-0,44	-0,46	-0,46												
80	-0,02	-0,01	0,01	0,09	0,00	-0,04	-0,11	-0,16	-0,23	-0,29	-0,33	-0,38	-0,41	-0,44	-0,45	-0,45											
85	0,08	-0,05	-0,04	0,07	0,01	-0,02	-0,09	-0,14	-0,21	-0,25	-0,28	-0,34	-0,37	-0,41	-0,44	-0,47	-0,49										
90	-0,04	0,03	0,01	0,07	0,02	-0,01	-0,09	-0,14	-0,20	-0,22	-0,25	-0,30	-0,34	-0,40	-0,44	-0,47	-0,48	-0,46									
95	0,26	0,07	0,05	0,11	0,03	-0,02	-0,09	-0,14	-0,20	-0,21	-0,25	-0,31	-0,36	-0,40	-0,44	-0,49	-0,50	-0,49	-0,48								
100	0,22	0,15	0,11	0,14	0,06	0,01	-0,05	-0,08	-0,11	-0,13	-0,17	-0,24	-0,29	-0,33	-0,38	-0,43	-0,46	-0,47	-0,48	-0,48							
105	0,18	0,10	0,08	0,13	0,04	-0,01	-0,07	-0,10	-0,14	-0,15	-0,19	-0,23	-0,27	-0,30	-0,34	-0,40	-0,45	-0,47	-0,47	-0,47	-0,49						
110	-0,01	0,17	0,14	0,14	0,07	0,02	-0,03	-0,07	-0,10	-0,13	-0,16	-0,18	-0,19	-0,22	-0,26	-0,33	-0,38	-0,41	-0,42	-0,45	-0,49	-0,55					
115	0,41	0,17	0,18	0,18	0,11	0,06	0,01	-0,06	-0,11	-0,17	-0,19	-0,20	-0,21	-0,22	-0,24	-0,30	-0,35	-0,36	-0,36	-0,40	-0,47	-0,52	-0,53				
120	0,01	0,30	0,27	0,24	0,18	0,14	0,09	0,01	-0,05	-0,10	-0,11	-0,14	-0,17	-0,19	-0,23	-0,29	-0,34	-0,33	-0,34	-0,41	-0,50	-0,56	-0,55	-0,56			
125	0,48	0,28	0,26	0,26	0,21	0,17	0,12	0,04	-0,01	-0,04	-0,05	-0,09	-0,14	-0,17	-0,22	-0,28	-0,34	-0,33	-0,33	-0,41	-0,51	-0,55	-0,53	-0,51	-0,50		
130	0,30	0,35	0,29	0,26	0,19	0,15	0,11	0,04	-0,01	-0,04	-0,06	-0,09	-0,14	-0,19	-0,24	-0,28	-0,32	-0,33	-0,34	-0,42	-0,50	-0,55	-0,53	-0,52	-0,51	-0,51	
135	0,43	0,33	0,25	0,22	0,17	0,13	0,08	0,02	-0,01	-0,03	-0,05	-0,08	-0,12	-0,15	-0,18	-0,21	-0,27	-0,31	-0,34	-0,40	-0,44	-0,47	-0,48	-0,50	-0,53	-0,55	-0,56

Nowcasting - an example:

A current thunderstorm has been detected for **25 min**. The combined fuzzy output is **-0.14**.

We have a look at the values in column *„25 min detected lifetime so far“* and compare the historical values with the fuzzy output of the current thunderstorm. The value -0.15 in row *„50 min total lifetime“* is closest to this.

Resulting a nowcasting of the currently detected thunderstorm of **25 min future lifetime**.

Validation of LOC-lifetime

For validation, the following verification scores are presented:

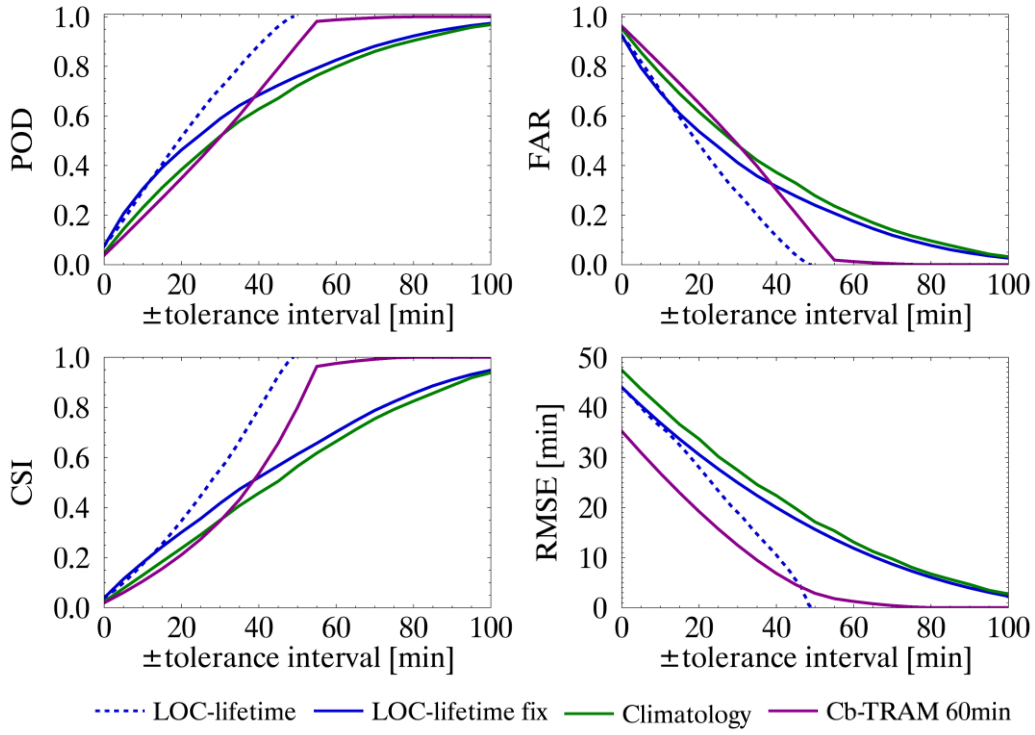
Forecast \ Observed	YES	NO
YES	*Hit*	*False alarm*
NO	*Misses*	*Correct negative*

- *Probability of detection*:
  $POD = \frac{hits}{hits+misses}$

- *False alarm ratio:*
  $FAR = \frac{false\ alarms}{hits+false\ alarms}$

- *Critical success index:*
  $CSI = \frac{hits}{hits+false\ alarms+false\ alarms}$

- *Root mean squared error:*
  $RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{N}}$



LOC-lifetime: Nowcasting based on fuzzy logic table + tolerance interval calculated with the standard deviation
LOC-lifetime fix: Nowcasting based on FL table + fix tolerance interval
Climatology: A nowcasting based on the climatology + fix tolerance interval
Cb-TRAM 60 min: The nowcasting of Cb-TRAM suggest for every detection a remaining lifetime of 60 min

Overall, *LOC-lifetime* shows higher *POD* and *CSI* values and lower *FAR* values for every tolerance interval (range where the prediction is counted as a hit). However, the RMSE of Cb-TRAM is lower than that for *LOC-lifetime*.

Nevertheless, *LOC-lifetime* shows better results than a nowcasting based on the climatology for all verification scores.

There are **still high tolerance intervals needed** for high *POD*, *CSI* and low *FAR* values. This is the case, since the standard deviations of the fuzzy logic (FL) values are relatively high compared to the mean FL values. As thunderstorms of **all organization types** and thunderstorms with incomplete life cycles (e.g. due to splitting events) are considered in the analyses and nowcasting **to ensure operational applicability**, the power of the nowcasting is reduced.

A reliable **identification** of the organization type (ideally in the early phases of the life cycle) would enable a separation of the predictions into "*reliable*" – e.g. for separated single cells – and "*less reliable*" – e.g. for multi cells with splitting and merging events.