Analysis of deep convection distribution in the middle latitudes of Europe using satellite data and the European Severe Weather Database

Shishov A.E.
The Hydrometcentre of Russia, 123376 Moscow, Russia, B. Predtechensky per.
shandruha@gmail.com

In order to study rapidly developing mesoscale phenomena like deep convection clouds (also referred to as deep convection objects or, briefly, DCOs), characterized by high variability through both time (from 15 minutes to 3 days) and space (1- 600 km or more in diameter), a long series of continuous geostationary satellite observations with a high spatial resolution (~5 km) and a low repeat cycle (15 minutes) was analyzed. Only latitudes from 40 to 72 degrees north and longitudes from 20 to 65 degrees east for the period of 2013-2021 (from April to September) were considered.

The presented paper is dedicated to two goals.

1) A study of DCO frequency in the midlatitude regions of Europe based on satellite data in the three infrared channels: 10.8, 6.2, and 7.3 μm. The brightness temperature $T_{10.8}$ provides an estimate of DCO cloud top temperature and height; the brightness temperature difference $T_{6.2} - T_{10.8}$ describes cloud thickness; the brightness temperature difference $T_{6.2} - T_{7.3}$ describes the thickness of the upper part of a DCO.

2) A verification of a DCO detection algorithm based on satellite imagery against two databases: surface synoptic observations (SYNOP) and reports of categories QC1 (verified by a reliable source) and QC2 (scientific case study) from the European Severe Weather Database (ESWD) [3].

Although modern DCO detection algorithms based on satellite imagery are known to suffer from high false alarm rates (20-63%, depending on detection method, dataset, and validation approach), they are still useful in detection and tracking tasks, since satellite data provide valuable information about DCO lifecycle, size, and cloud top texture [1,2]. Hence, the first stage of our analysis involved calculation of the following DCO features: lifetime (DCO tracking duration in hours) and maximum size (maximum area in sq. km of DCO cloud top region with temperatures below -50 degrees Celsius).

In total, 10 683 356 unique DCOs were detected using a thresholding detection method used in the Hydrometcentre of Russia [4]. Overall, less than 1% (0.03%) of DCOs had lifetimes exceeding 13 hours, and more than 90% (99.73%) had lifetimes lower than 5 hours, which coincides with the findings of similar studies for the Western Pacific and Australia for the period of November 2009-January 2010 despite the differences in datasets and detection methods [5]. Most DCOs, on average, were detected in May (see Figure 1), which corresponds to the thunderstorm activity peak in Southern Europe. Since severe weather phenomena do not always coincide with detected DCOs, sometimes due to false alarms (some DCOs may be falsely classified as deep convection), DCOs collocated with severe weather (SW) occurrences (DCO-SWs) were selected for further analysis. The number of DCO-SWs has a peak in June, which corresponds to the thunderstorm activity peak in Central and Eastern Europe and may be related to the geographical features of the region, the proximity of the warm Atlantic waters, the greater number of synoptic stations where severe weather is observed and severe weather reports submitted by the citizens (also related to higher population density) [6].

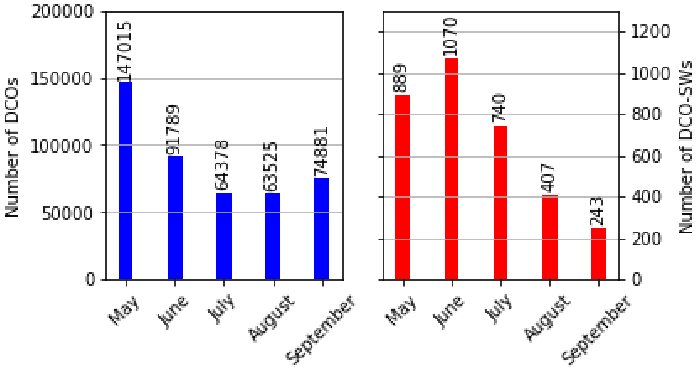

Figure 1. Mean annual number of detected DCOs (left) and DCO-SWs (right)

Table 1. DCO-SW to DCO ratio for different lifetime and size groups

Size (sq. km)	Lifetime (hours)				
	< 1	1-6	6-12	12-24	24+
0-25	0.17	0.45	-	-	-
25-80	0.22	0.00	-	-	-
80-310	0.37	1.69	-	-	-
310-700	0.70	3.46	0.00	-	-
700-100000	1.58	15.64	51.69	65.77	73.68
100000-200000	20.0	71.43	87.50	92.03	86.21
> 200000	-	66.67	88.89	93.94	88.24

The study of the DCO-SWs to DCO ratios has revealed that severe weather is observed in 0.05% of cases. The high temporal and spatial variability of DCOs precludes reliable frequency estimation. Thus, approximately 95% of DCOs either did not produce severe weather phenomena or were false alarms. It is also possible that corresponding severe weather phenomena did occur, but were not reported. Statistics from Table 1 suggest that severe weather is most likely to be observed near long-lived large-size DCOs. Probably, most of such DCOs fall into the category of mesoscale convective systems or mesoscale convective complexes, which are associated with the highest risk of severe weather. At the same time, DCOs with lifetimes less than 1 hour are collocated with severe weather phenomena in less than 0.45% of cases (0.17-0.45%, depending on size), which suggests that most of the DCOs are either false alarms or too weak to produce severe weather [7]. However, the lack of severe weather cases can also be explained by the incompleteness of ESWD and SYNOP data.

The results of this study confirm that DCO detection algorithms based on thresholding methods alone are far from perfect. Strong correlation of severe weather occurrences with lifetime and size of a DCO implies that additional criteria involving these parameters can significantly improve the detection skill of such algorithms. Since the process of picking the most effective set of criteria is difficult and labour-intensive, it should be automated using machine learning algorithms.

References

1. Zinner T., Forster C. of the Meteosat storm detection and nowcasting system Cb-TRAM with lightning network data - Europe and South Africa // Atmospheric Measurement Techniques. – 2013. – Vol. 6. – P. 1567-1583.
2. Silva Neto C.P. da, Barbosa H.A. A method for convective storm detection using satellite data // Atmósfera. – 2016. – Vol. 29. – No 4. – P. 343-358.
3. Dotzek N., P.Groenemeijer, B. Feuerstein, and A.M.Holzer. Overview of ESSL’s severe convective storms research using the European Severe Weather Database ESWD // Atmos. Res. – 2009. – No. 93. – P. 575–586.
4. Shishov A., Gorlach I. An Algorithm for the Detection and Tracking of Deep Convection Using Satellite Data and Integer Programming // Proceedings of the Hydrometeorological Research Center of the Russian Federation. – 2020. – Vol. 376. – No 2. – P. 39-59.
5. Hagos S., Feng Z. Environment and the Lifetime of Tropical Deep Convection in a Cloud-Permitting Regional Model Simulation // Journal of the Atmospheric Sciences. – 2013. – Vol. 70. – No 8. – P. 2409-2425.
6. Taszarek M., Allen J. A Climatology of Thunderstorms across Europe from a Synthesis of Multiple Data Sources // Journal of Climate – 2019. – Vol. 32. – P. 1813-1837.
7. Wilson J., Roberts R. Summary of Convective Storm Initiation and Evolution during IHOP: Observational and Modeling Perspective // Monthly Weather Review. – 2006. – Vol. 134. – P. 23-47.