Derecho of 11 August 2017 confirms the Thunderstorm Thermometer approach.

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1 Introduction

Let us refer to formulas presented on the EMS2012 meeting, Expo 2013 and confirmed in Newsletter 16 (Parfiniewicz J., 2014, Parfiniewicz J. and Konarski J., 2016) . The 1st Formula (*), the best filter for strong Tornado or Downburst events expresses Fujita scale as a square root function merely of the Intra-Cloud discharges densities, while, the 2nd (**) for less severe events takes into account both: IntraCloud and Cloud-to-ground lightning discharges densities. It has occurred, that both formulas might have clear physical interpretation. Indeed, Formulas (1) and (2) distinctly differentiate lightning activity that is characteristic for two various developing thunderstorm stages, i.e., for the mature one and the second for the dissipation thundercloud formation, In the mature, active stage IntraCloud lightning prevails, while the second is dominated by Cloud-to-ground lightning discharges.

Operational monitoring of tornados showed that extreme Tornado or Downburst events are strictly correlated to IntraCloud number of flashes aggregated in cells over approximately 15 km radius area. However working on the 7 by 7 km (or 2.8 by 2.8 km) square grid these densities are being enhanced to remain the accordance with typical supercells diameter.

Let's turn to Nowcasting and Forecasting Strong Convective Events (SCE). The 3 categories are highlighted to distinguish between Nowcast and Forecast: ,.i.e., lead time, the method used, and finally the targeted product. For lead time: we have tens of hours against 1 hour, for methodology: probabilistic interpretation of the model against tendency plus probabilistic interpretation plus possibly HD accurate simulations - if occurred, and finally: danger zones against accurate location. The successful nowcasting in fact is measured in minutes (after James Anderson, EXPO2013).
What we have practiced in Poland it is the Observed Storms category which might serves merely as an introduction to Nowcasting SCE showing their possible growth or decay and helps to understand how will they propagate.

Now the issue is how to embrace this extremely strong convection process and express it within conventional Euler - Lagrange approach fluid dynamics models.

2 Recapitulation EXPO_2013 – EMS_2012

What is essential to obtain an effective thunderstorm prediction is, firstly, **to operate self-learning algorithms**, secondly, **to possess skills to quantify the strength of convection and thunderstorm severity**, and, finally, **to organize an end-user oriented warning system**.
The prediction system (lead time 36 hours) is fed by the SYNOP (code WW) data and the PERUN data. Initially, PERUN data was only used to confirm or deny the occurrence of a storm, but not to determine its strength.

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It turned out, however, that in cases of tornado incidents such a passive scale of storm severity is not adequate for teaching the prediction system about these extreme cases. Therefore, a hybrid scaling system was introduced by modifying WW observations with the information on the severity of storms from the SAFIR / PERUN system in accordance with the formulas (*) and (**). The SAFIR/PERUN network system provides lighting information in six categories: cloud-to-ground (CG) flashes divided into return and subsequent strokes (Rs and Ss), intracloud discharges (IC), where the emission (nodal) points of IC strokes are subdivided into (ICs)tart, (ICi)ntermediate and (ICe)nd points and Isolated emission points (Is).

The following topics will be covered:

1. Thunderstorm quantification issue
2. Scaling Convection Strength
3. Universal to local. Optimum Interpolation / Interpretation (OI)
4. Self-learning Engine
5. Forecasting vs. Nowcasting
6. How was it practiced in Poland
7. On the way to understand stormy weather

2.1 Thunderstorm quantification issue: the Thunderstorm Thermometer

The review of the polish press reports and investigation of the SKYWARN POLSKA $http://lowcyburz.pl/$ archives, including personal contact with A. Surowiecki (the Polish Skywarn representative) led to collecting twenty dates with extreme ToD (Tornado or Downburst - ToD) events. More, A.Surowiecki has been given an eye-witness Fujita value to each event. Now, the statistics over 27887 aggregated cells, filtered in many possible ways has been constructed to fit to expected Fujita [F] values.

The best filter for strong ToD events with $[F] \geq 1$ (more or even) giving correlation $R \approx 0.85$ reads:

$$[F] = a * (b * IC\_s + c * IC\_i)1/2 + d$$

under condition

$$Rs > 1 \& IC\_s > 70[NoF](*)$$

$$where : a = 0.047, b = 0.7, c = 0.3, d = 0.22 and IC\_s, IC\_i$$

are measured in $[NoF/\pi 15km^2 \cdot 10min.]$

For less severe events with $0 < [F] \leq 2.5$ another indicator-filter which includes CG flashes (Rs¿0) is being recommended:

$$[F] = a * (b * IC\_s + c * Rs + d * (IC\_s * Rs)1/2)1/2(**)$$

where: a=0.088, b=0.624, c=0.112, d=0.264

Thunderstorm Thermometer Formulae : lightning discharges density function.

Operational monitoring of tornados that were observed over Poland in summer season of 2012/2013 showed that extreme ToD events are strictly correlated to IC number of flashes [NoF] aggregated in cells over a 15 km radius area $[\pi \cdot 15km^2]$(what is equivalent to significant enhancement regarding 7x7 km resolution) within 10 minute interval. PERUN's signal conversion is carried out on 7x7 and 2.8 x 2.8 grids, but for each grid node, the surroundings up to 15 km are screened. If the PERUN signal is present in this environment, the value of the discharge density in a given localization is amplified.
The relationship between virtual Fujita scale [F] and the 'classical' measurement from PERUN for selected thresholds generally depends on the grid resolution and statistics. For the COSMO_07 km reference grid in

Table 1: Relationship between [F] and PERUN measurement for selected thresholds 07km grid

IC_s	IC_i	RS	thresholds
139.	117.	78.	1.0
636.	361.	233.	2.0
1514.	1036.	347.	3.0
2652.	2073.	590.	4.0
4128.	2839.	1090.	5.0

Table 2: Relationship between VFS and PERUN measurement for selected thresholds 2.8km grid

IC_s	IC_i	RS	thresholds
68.	39.	24.	0.5
137.	93.	105.	1.0
644.	532.	175.	2.0
1499.	1092.	274.	3.0
2696.	1503.	384.	4.0
5384.	2960.	860.	5.0

10 min. intervals and data for the whole day of 11 August 2017 we have Tab. 1, for the COSMO_2.8 grid Tab. 2 :

In Sketch 1, the densities are computed on a 2.8 by 2.8 km square grid. In order to conform to the typical diameter of supercells, it is necessary to amplify the commonly used values by a factor that ranges from 0 to 36, according to a weighting function that increases with distance from the center of the square.

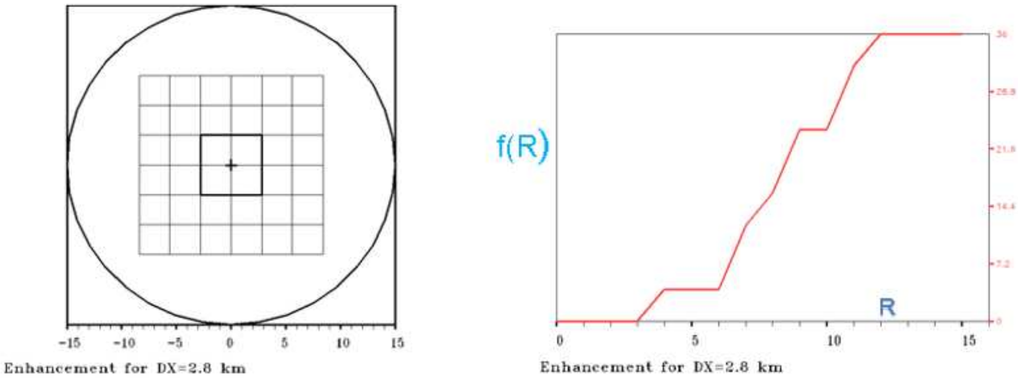

Figure 1: Sketch 1-Equivalent enhancement for 2.8 by 2.8 km square grid

Interpretation. Formulas (*) and (**) distinctly **differentiate** between specific **lightning activity** that is**characteristic for two** various developing **thunderstorm stages**, i.e., for the **mature and very active** one , **with dominant IC flash** generation and the second for **the dissipation thundercloud formation, when CG flash generation** is increasing and **is more pronounced**.
Expression (*) by explicit inclusion of the **ICi** component is confirming well known fact (see e. g., Rakov and Uman, 2003) that so-called **spider lightning** with great number of branches, with the great **ICi are appearing** frequently **during mature stages of supercells**. (P.Barański 2009,2012)

2.2 Scaling Convection Strength

Let's now discuss the Convective Scale (CS) which is essential to build up Self-learning Stochastic Forecasting Model. At 1st, the synop weather code was squeezed into seven-step scale of natural gradation. This seven step scale starts with No Convection and finishes with Thunderstorm with hail along with clouds development : starting with Cumulus and finishes with Cumulonimbus Capilatus. But since storm is not equal to storm, it has become necessary to extend this scale.
To build up the New CS scale we may simply add to the 7th step SYNOP scale the 5th step of Fujita scale thus obtaining twelfth step scale which covers Strong Convective Events including tornados. Now, we have seven classical steps from No Convection to Thunderstorm with hail and additional 5 steps devoted to tornados and supercells. Possibly there exists a correlation between this Convection scale and with the Beaufort scale of wind strength.

2.3 Universal to local. Optimum Interpolation / Interpretation (OI) vs Kalman Filter (KF)

Predicting storms and tornadoes with traditional hydrodynamic (HD) methods by NWP systems does not seem realistic. We propose an approach: the HD model generates a "universal" prognostic signal at the Input, and the self-learning engines provide a local stochastic response at the Output. The sum of the local responses is an estimate of the storm forecast field. In fact, the same (or a similar) idea was behind the: "WMO Symposium on the interpretation of broad-scale NWP products for local forecasting purposes" (11-16 October 1976; Warsaw, Poland). On the other hand, the problem of physic-statistical forecasting methods has a rich tradition of the Russian school, including such authoritative names as A.N.Kolmogorov, A.M.Obukhov, M.I. Yudin, A.M.Yaglom (Yaglom, 1963).

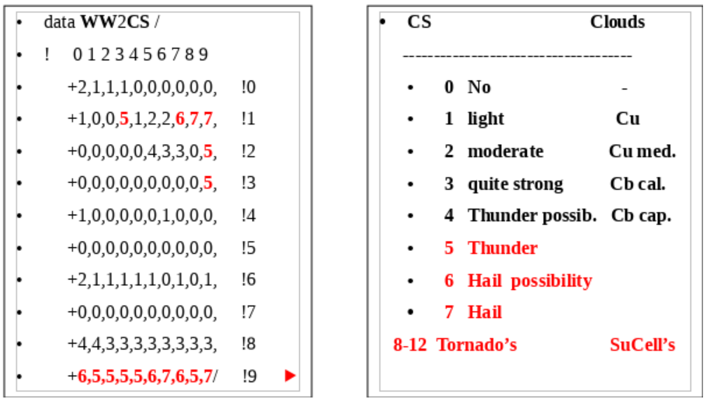

Figure 2: Sketch 2 - New CS scale = CS/WW [0-7] + [0-5] FUJITA = [0-12]

Following this path (Gandin L.S. 1963, Kagan R.L. 1966, Rukhovets L.V. 2006), a simple (but effective) method of Gandin's Optimal Interpolation was adopted to local forecasting (statistical interpretation of the NWP), replacing or even extending the functionalities obtained with the KF.
The OI formalism itself is trivial and comes down to solving a simple system of equations: $\mu\Pi = \mu 0$, where Π are weights of linear regression of individual predictors, and μ, $\mu 0$ are the predictors correlation matrix and the correlation vector between predictor - predictors .
The catch is that the statistical structure behind this system of correlation, dispersion and means matrices is location dependent, monitored and moderated to create a pseudo "climate" on a domain of forecast. The great advantage of OI is that each regression set has its own accuracy metric in the form of a total correlation coefficient R (see & compare Yaglom, 1963 and Gandin, 1963):$R^2 = \sum(\mu 0 * \Pi)$. An important moment is also the limitation of the number of predictors to 5 (Yaglom, 1963), with the 5th being selected again from a much larger number of potential predictors (here 21).

2.4 Self-learning Engine

The physical-stochastic approach has been applied to improve ideas referred to very early,-1976, work: *"The prediction of air mass thunderstorms and hails" by Lityńska , Parfiniewicz & Piwkowski.* With the particularity to statistical method the method used is almost identical to Collins & Tissot (CT), 2007 ($http://lighthouse.tamucc.edu/dnrpub/nn-channel-3.wmv$). Here the OI – i.e. self-learning statistical structure (generalised to automatic renewal of the new multi-regression set of parameters), there – self learning Artificial Neural Net. The genesis of these two works is quite independent, however from the CT the idea of the ROC curves has been adopted to reverse continues (quantitative) probabilistic input signal onto qualitative [0,1] output. The actual proposition recapitulate the earlier authors searches concerning Tornado prediction, (Parfiniewicz et all, 2011), from which clearly indicates that the current NWP models would not be able to predict strong convection events in frame of pure hydro-dynamical approach.
The algorithm is learning of "good forecasting" basing on meteorological stations (observations by SYNOP WW key) and lightning activity detected by the SAFIR/PERUN network system, all restored every 1h. The "universal" forecasting signal is generated by COSMO-7km (2.8km) model and the local stochastic response is then taken every 1h on each grid network via interpolation from neighbouring stations statistical characteristic (called "modified climate"). To forecast thunderstorm (convectivness) the 21 predictors (the physical parameters calculated from COSMO model) has been chosen. They might be gathered into 5 categories that describe the state of the atmosphere via: humidity (the several indexes), available convective (instability) energy (the several indexes, including CAPE derivatives), the stratification of the atmosphere (including the heights of the isotherm 0 C and -20 C), the synoptic background (vorticity, pressure tendency, vertical velocity). These 21 potential parameters guarantee that the maximum part of thunderstorm dispersion was described for each of 57 synoptic stations separately (an example Tab.1).

From these 21 potentially available indexes every 1h the set of 5 is automatically renewed (what means some generalisation). Parallel to predictability of the thunderstorm the Strength of Convection in the 0-7 scale (from absence to thunderstorm with hail) is being taken basing on the WW SNOP key. The predictions in form maps and diagrams was tested on the IMGW aviation portal. The currently calculated POD and FAR indicators are relatively high (0.6-08, 0.2-0.4) depending on the station the correlation (1point/1h) is about 0.5 but for time/space surroundings much higher.

Kasprowy_Wierch			**Ustka**		**ALL**	
k	**name**	**R**	**name**	**R**	**name**	**R**
1	Q850	0.585	vLEVclc	0.606	Wlt_T_Td	0.506
2	Sumaqcqv	0.631	P0_MODEL	0.657	PLNB_CTH	0.566
3	z20	0.659	z20	0.677	vLEVclc	0.587
4	PLNB_CTH	0.672	PLNB_CBH	0.683	z20	0.599
5	vLEVqc	0.684	DP0_MODEL	0.691	vLEVqcqv	0.608
6	P0_MODEL	0.694	Qsrf1E3_MO	0.697	CINS	0.613
7	CINS	0.696	slin	0.699	DP0_MODEL	0.616
8	slin	0.696	CINS	0.701	Wmin	0.620
9	Qsrf1E3_MO	0.699	Wlt_T_Td	0.703	P0_MODEL	0.623
10	Wmin	0.700	HLNB_CBH	0.704	zt0_20mx	0.624
11	vLEVclc	0.700	Wmax	0.706	Q850	0.625
12	vLEVqcqv	0.700	Sumaqv	0.707	RRRmm_24_M	0.626
13	DP0_MODEL	0.700	RRRmm_24_M	0.708	PLNB_CBH	0.626
14	RRRmm_24_M	0.700	Q850	0.709	HLCL	0.626
15	HLCL	0.701	HLCL	0.714	Sumaqcqv	0.629
16	zt0_20mx	0.701	vLEVqc	0.714	vLEVqc	0.629
17	PLNB_CBH	0.701	Wmin	0.714	slin	0.630
18	HLNB_CBH	0.701	PLNB_CTH	0.716	Wmax	0.630
19	Wlt_T_Td	0.701	zt0_20mx	0.716	Qsrf1E3_MO	0.630
20	Wmax	0.701	vLEVqcqv	0.716	Sumaqv	0.630
21	Sumaqv	0.701	Sumaqcqv	0.716	HLNB_CBH	0.630

Table 3: An example of finding the optimal set of predictors for storm prediction [0/1] for mountain's (Kasprowy Wierch), marine's (Ustka) and all regions.

nicknames	description of predictors
P0_MODEL	Surface pressure [Pa]
Qsrf1E3_MO	Surface specific humidity
RRRmm_24_M	Model rainfall for the last hour in [mm/24h]
DP0_MODEL	Surface pressure tendency [Pa]
CINS	CIN [J/KG] Convective inhibition energy
HLCL	Height OF LCL [m] - Lifting Condensation Level
HLNB_CBH	Height of lowest EQULIBRIUM Level (Takahashi,2012)
PLNB_CBH	Pressure of lowest EQULIBRIUM Level (Takahashi,2012)
slin	Showalter Index - measure of thunderstorm severity
PLNB_CTH	Pressure of highest EQULIBRIUM Level (Takahashi,2012)
Wmax	Max. vertical speed in the profile
Wmin	Min. vertical speed in the profile
z20	Height of the isotherm T = -20C
Q850	Specific humidity at 850 hPa
vLEVqc	Specific cloud water content [kg/kg] above isotherm 0
vLEVqcqv	QC&QV [kg/kg] (cloud water & humidity)above isot.0
vLEVclc	Sum of CLC (% of Cloud Cover) in the profile
zt0_20mx	Height difference: H (T: -20C) - H (T: 0C)
Sumaqv	Sum of QV (specific humidity) in the profile
Sumaqcqv	Total sum of (humidity) qv and qc (cloud water)
Wlt_T_Td	Humidity indicator (Sum T-Td/850,700,500hPa; Lityńska 1976)
Storms01	Storms [0/1]

Table 4: Predictor nicknames and their description

2.5 Self-learning Engine

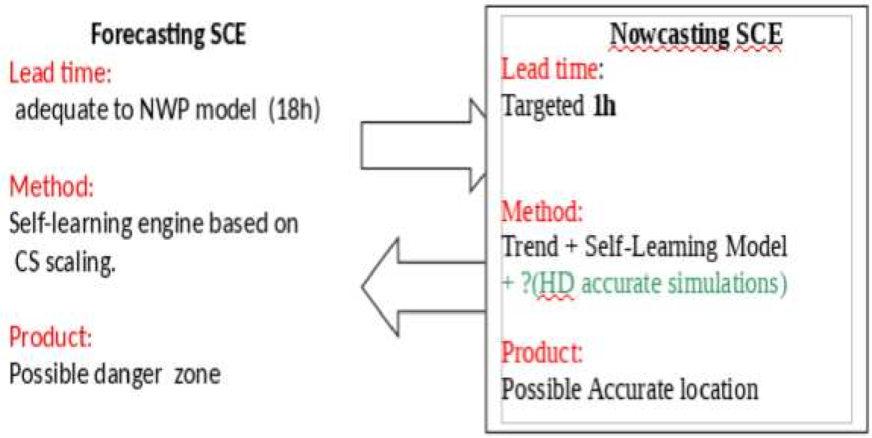

Figure 3: Sketch 3 -Forecating and Nowcasting schemes depend on each other.

2.6 How was it practiced in Poland

1. Observed Storms category serves as an introduction to Nowcasting and it illustrates the tendency of showing possible growth or decay and movement of Strong Convective Events (SCE). This in fact ensures their monitoring - one may overlap the graph in time of self-predicted potential probabilities on it to better recognize the future position of supercell. Finally the Supercells animation helps us understand how will they propagate.
2. It is important to compare the Observed storms and Possible danger zone, just to form one's own meaning of what is the value of forecasted fields. We have also the possibility to distinguish generated forecasted fields by changing resolution model (COSMO-2.8km, 07km, 14km), and some other categories.

2.7 On the way to understand stormy weather

The way to understand stormy weather led through the study of particularly severe cases:
1st: 28 MARCH 1997 – dry stratospheric intrusion with severe storm over Poland
2end: 20th of July 2007 – explosive convection over Europe
3ed derecho 20170811

The conclusions of these cases reads as follows:

1. Explosive Convection is governed by NonHydrostatic Pressure. (seems trivial, but here the wind acceleration – is taken in the sense given by Gal-chen).
2. Despite, the assimilation of Doppler wind provide a quite realistic approximation of the tornado's, the prediction via traditional H-D methods seems unreal. (because it is rather unrealistic to retrieve accurately initial NonHydrostatic oscillations).
3. So the remedy, H-D model might generate "universal" forecasting signal but Self-learning Engines will provide the local stochastic response

28 MARCH 1997 – severe storm over Poland :**"Good Friday case"**

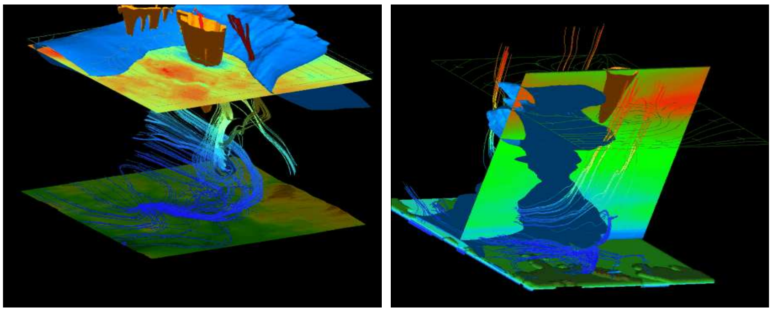

Figure 4: **Sketch 3** - Represents subsynoptic background (organization of motion) + Nonhydrostatic Pressure Fluctuations. We see the strong convergence in the lower troposphere associated with the active low pressure center, the compensating upper inflow (due to dry stratospheric intrusion) has been found near tropopause folding center with the hole in maximum velocity field of Jetstream (in brown).

20th of July 2007 – explosive convection over Europe with **severe Tornado over Poland**.

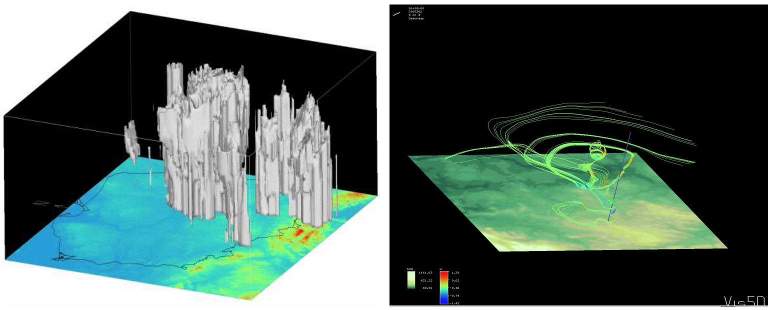

Figure 5: **Sketch 4**-Left panel: 3D composite model image of radar reflectivity- case: 20 July 2007 Right panel: Vis5d was used to obtain 3D streamlines as set of characteristic trajectories

Comment: complementing the article (Parfiniewicz, 2010) the formulas that allows on retrieving the tornado vortex are attached: "... retrieval of tangential wind component on polar grid circles (or part of them depending on the domain) by solving differentiated continuity equation by tridiagonal TDMA solver.
The continuity equation for polar components , , reads: V_R, V_θ, V_Z.

$$\frac{\partial R * V_R}{R * \partial R} + \frac{\partial V_\theta}{R * \partial \theta} + V_Z = 0$$

Differentiating above due to θ and neglecting tangential changes V_Z reads:

$$\frac{\partial(R * \triangle\theta * \frac{\partial R * V_R}{R * \partial R})}{\partial \theta_i} = \frac{\partial^2 V_\theta}{\partial \theta_i^2}$$

where vectors of tridiagonal matrix a(i) = 1., b(i) = -2., c(i) = 1. and boundary forcing values f(0) = 0, f(Nx+1) = 0 or f(0) = f(Nx+1). "

11th of Augest 2017 – severe Derecho over Poland.

Figure 3 is a summary of the analysis of the derecho on August 11, 2017 that swept through Poland. The main path of the disturbance was abstracted, practically coinciding with the eastern path. In the figure it is shown as a bold purple line, superimposed on the circles (which converge into 1 serpentine line) colored according to the VFS (virtual Fujita scale) graduation for each of the 68 scans.The thin green line corresponds to the western flank and, as previous analysis showed, at least until 20:00 UTC must coincide with the main track.

This means that at that time the convective system moving over Poland was coherent in the sense of the understandable similarity of the successive images of electrical activity and - probably - the organization of motion.Between 20:00 and 21:00 UTC there was some formation of a separate storm focus in the Suszek area, which would retain its subjectivity (coherence) in the northward movement. This is a creation, detachment or split (whatever we call it), and the green line detached from the main track is a side path of the derecho disturbance.The picture shows 24 telemetric measurements of gusts exceeding 20 m/s.

Although these characteristic values on both sides of the main track,wind activity seems to prevail on the west side and correlates with the most spectacular casualties and damage, e.g. in Bory Tucholskie, while in its eastern part prevailed the electric activity of the derecho. The western flank is also better documented with radar data from Poznań and Gdańsk.

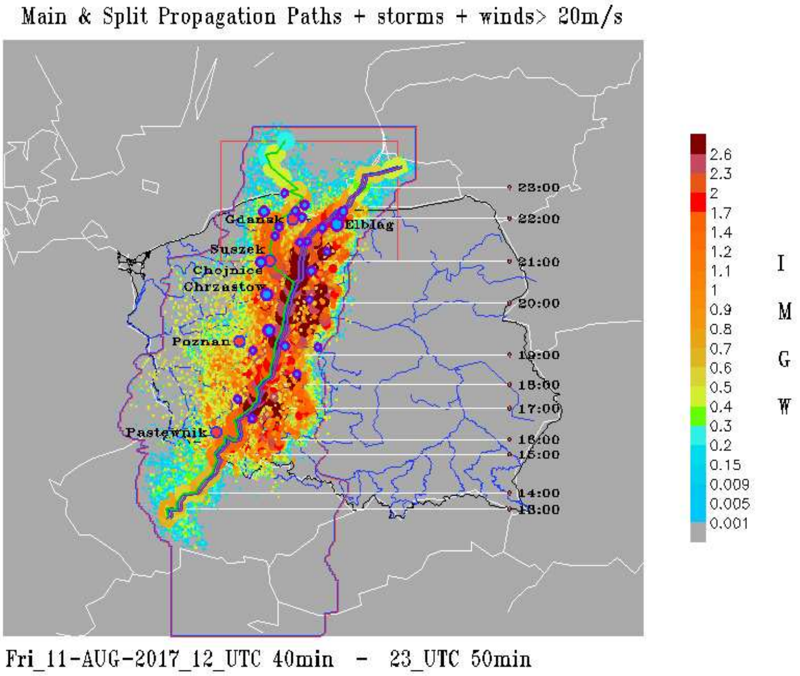

Figure 6: Main /Right & Left Propagation Paths + storms + winds ¿ 20 m/s. (). Winds ¿ 20 m/s (in blue and violet) and circle sizes are proportional to wind strength.

According to Fig. 3. the main path of propagation is expressed in the coordinates of the COSMO_2.8 model and was used to determine the velocity. The speed is based on the position of the system + -10 minutes in relation to the moment. The highest estimated speeds (up to 40 m/s) occurred around 19:30 UTC, preceding the split stage.
Note that the estimation of the propagation speed of the western track during the division period (20:00 - 21:00 UTC) is possibly distorted by a significant error. The basic characteristics of the derecho were estimated: distance, time and average speed. And so: the total distance - 864.42 km, covered in 11.17 hours, with an average speed of 21.50 m/s (77.4 km/h).

3.Conclusions remarks

As it was pointed above the issue is to embrace the whole convection process and express it via fluid dynamics methods. Usually we use one of number convection parameterizations algorithms which allows on convective precipitation prediction giving latent heat feed back to the model. Convective precipitation is directly related to radar reflectivity (eg. via Marshall – Palmer formula). What if we merge convective precipitation with thunderstorms using lightning discharges density function.

Finally we will have referencing reflectivity with numbers beneath 55 dBz as real, and numbers above 55 (till presume 110) artificially representing this convection strength which is related to Fujita scale. This referencing reflectivity might be treated by conventional fluid dynamics models as continuum scalar value allowing on it propagation and evolution.

Acknolegmets

To Piotr Barański, Wiesław Łazarewicz,..

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