To the prognostic meaning for the one of criteria for helicity estimation in atmosphere

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Abstract. A new informative and evident criterion for estimating the integral helicity is introduced - the gradient of integral helicity. On the example of a convective storm in Moscow on May 29, 2017, its prognostic property is shown (lead time is 12 hours). Its applicability as a prognostic indicator of adverse and dangerous weather phenomena is shown.

1. Introduction
In modern studies on geophysical hydrodynamics and dynamic meteorology, the concept of the helicity of the velocity field of atmospheric motions is widely used. First of all, it is used as a diagnostic characteristic of intense vortices. In a number of cases, helicity also has prognostic significance as a predictor of cyclogenesis for tropical and Mediterranean cyclones [1], polar mesocyclones [2] or monsoon circulation origination patterns [3]. For this purpose, use has been made of various estimation criteria or helicity index predictors (integral, relative, vortex). However, the helicity predictors used as forecast criteria lack theoretical justification and need more information content.

In view of high importance of analysis and forecast of the atmospheric processes determining hazardous weather phenomena as well as potential characteristics of integral helicity, the objectives of the work are as follows:

Revealing some new properties of the integral helicity of perspective in the analysis and forecast of atmospheric movements using reanalysis data;

Introduction of a novel, more informative and evident integral helicity criterion.

2. Reanalysis-based novel integral helicity features
Use has been made of the data covering 4 observation terms (00, 06, 12, 18 UTC) of the following ECMWF reanalyses:

(i) Above the territory covering the European part of Russia, Siberia and Eastern Europe: within 19.04.2018 to 23.04.2018 (20 observation terms) and within 28.05.2017 to 30.06.2018 (136 observation terms);

(ii) Above the territory covering Atlantics and Eastern part of North America: within 28.08.2011 to 11.09.2011 (60 observation terms – tropical hurricane ”Katia”).
Figure 1. Field $h$ ($m^2/s^2$) and isohyps field $H$ (m) over 1000 GPa surface at 00 UTC on 29.05.2017.

Analysis of the sequential maps plotted in 6-hr increments as per the above reanalysis data, shows the following:

The fields of integral helicity represent alternation of maximums and minimums. The latter are essentially agiler than baric formations (BF), as their velocity may exceed 100 km/hr.

For the reanalysis data considered, the total area of the regions featuring positive values of the integral helicity exceeds that featuring negative values, i.e. cyclonic circulation prevails therein.

In the helicity field of a well-developed BF, often observed is a dipole structure of maximum and minimum values. This occurrence is distinctly traceable with tropical hurricanes. In mid-latitudes, counterclockwise rotation of dipole structures around cyclones is observed.

The cyclones move, as a rule, close to the straight line connecting the extreme points towards maximum. The anticyclones move likewise, but towards minimum and are weaker.

The more is the difference between dipole maximum and minimum in a helicity field, the deeper is the cyclone.

The more is the distance between the extremes, the higher, as a rule, is the cyclone velocity. Disappearance of a dipole leads to the settlement of the cyclone.

Some of the above observations are represented in Figures 1, 2.

3. On forecast significance of integral helicity

The integral helicity of the atmospheric motion velocity field $h$ is defined as:

$$ h = \int_0^{H_u} s \, dz, \quad s = \nabla \cdot \text{rot} \nabla$$

(1)
Figure 2. Field $h$ (m$^2$/s$^2$) and isohyps field $H$ (m) over 1000 GPa surface at 12 UTC on 11.09.2011 (Tropical hurricane "Katia").

where $z$ is the height, $H_u$ is the upper edge of atmosphere, $\vec{V}$ is the wind velocity vector.

As is known, the tendency of the height of the isobaric surface $q$ depends on the values of the initial fields at all points in space. This dependence is established by means of an integral of convolution type of initial fields with the Green function of an elliptic differential equation [4]. In the case of the Green function, the integral sign is the advection of the temperature field, which is proportional to the helicity in the quasigeostrophic approximation.

It is interesting to estimate empirically whether the isobaric surface 1000 GPa height trend is proportional to geostrophic flow integral helicity.

Hence, the constant pressure This circumstance interprets and clearly demonstrates on physical level the forecast value of atmospheric motions velocity field integral helicity.

Figure 3 shows field $q$, calculated over 1000 GPa surface with the use of formula $q \approx \frac{H^{t+\delta t} - H^{t-\delta t}}{\delta t}$, where $\delta t = 12$ hr. The checking calculations, performed using expression $H^{t+\delta t} \approx H^{t-\delta t} - \delta t \cdot b \cdot h_g$, have shown good correlation between the calculated field $H^{t+\delta t}$ and the observed one. The coefficient $b$ was taken to be equal $\frac{l}{g}$, where $g$ is the acceleration of gravity, $l$ is the Coriolis parameter.
4. Integral helicity gradient as a new forecast criterion

In view of a dipole nature of the helicity field structure, it is only logical to consider using the integral helicity gradient as a new forecast criterion

\[ M = \nabla h. \]  

where \( \nabla \) is Hamilton operator, in which the upper line means averaging at calculations over horizontal surface within two grid steps from the calculation point.

On 29.05.2017, there was a convective storm in Moscow region [5], resulting in 11 deaths and over 160 injuries. The squall wind came down on Moscow in the afternoon between 15 and 16 hr local time. Over the Moscow region, the wind velocity ranged from 12 to 30 m/s.

The weather pattern was defined by the south border of the migratory cyclone moving from the Gulf of Finland eastwards. Early in the morning, the warm atmospheric front crossed the metropolis, Moscow occurred in the warm region of the cyclone and the temperature raised up to +25 deg.C. In the afternoon, there approached a cold front. Being aggravated in the period of maximum heating, it had become the reason of such adverse and hazardous weather.

On the weather ring map (ref. RH insert in Figure 4) at 12 UTC on 29.05.2017, there is a cold front visible along the M criterion vectors convergence zone featuring heavy storm activity, and there is an area of high south-west wind southwards.

Figure 4 shows criterion field, field \( q \) and field \( H \) at 00 UTC on 29.05.2017 over the territory covering European part of Russia, part of Siberia and Eastern Europe. According to this figure,
at 00 UTC on 29.05.2017, there was the area of high (up to 900 m$^2$/s$^2$) values of integral helicity formed in the Moscow region. That event is clearly reflected in the field of criterion. Also observed is a sharp convergence of criterion vectors: south of Moscow the vectors are directed from South to North and reach the values of 600 m/s$^2$, while north of the convergence area the vectors originate from either North-West or North-East and their values amount to about 300 m/s$^2$.

Comparison of the areas of sharp convergence of $M$ criteria vectors at 00 UTC and the areas featuring storms and high winds at 12 UTC points to forecasting capability (with 12 hrs advance time) and demonstrativeness of the integral helicity gradient suitable for a forecast indicator of adverse and hazardous weather events.

The above described convective storms may occur every season as well as several times a season. However, according to statistics, the average recurrence interval of such factor combination is 5 years. It is important to note that convective storms of the kind can only be forecasted with about two-hour or even a few tens of minutes lead time [5]. Therefore, the offered $M$ criterion ensuring a forecast-time interval about 12 hrs may become an important link of hazardous weather events forecasting facilities.

5. Conclusion
As can be seen from the above, the subjects in view have been achieved.

Using reanalysis data, some novel properties of integral helicity have been revealed looking promising from the point of analysis and forecasting of atmospheric motions. To our opinion, detection of dipole structures in integral helicity fields, the study of which has only been outlined herein, is of the utmost importance.

It is shown that the 1000 GPa constant pressure surface height trend is proportional to integral helicity of a geostrophic flow.

This paper introduces a novel, more informative and vivid criterion of integral helicity
estimation. In view of dipole nature of a helicity field structure, it offers integral helicity gradient for a new forecast criterion. On the example of the convective storm occurred on 29.05.2017 in Moscow, it demonstrates its forecasting potential (featuring 12-hr advance time) and suitability for forecasting adverse and hazardous weather events. Since the convective storms alike are usually forecasted only with two-hour or even several tens of minutes advance time, the offered $M$ criterion ensuring the advance time about 12 hours may become an important link of hazardous weather events forecasting facilities.

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References
[1] Kurgansky M V Helicity in Atmospheric Dynamic Processes Izv. Atmos. Ocean. Phys. 2017 53 127
[2] Vazaeva N V, Chkhetiani O G, Maksimenkov L O, Kurgansky M V Integral Characteristics of Polar Lows https://elibrary.ru/item.asp?id=30690481 Accessed on 2018-05-05
[3] Makosko A, Rubinstein R Study of Asian Monsoon Helicity Based on Reanalysis Data and Results of Digital Simulation of Atmospheric Circulation with Account of Nonuniformity of Gravity Dokl. Earth Sci. 2014 459 237-42
[4] Buleev N I, Marchuk G I The dynamics of largescale atmospheric processes Trudy IFA Akad. Nauk SSSR 1958 2 66
[5] Convective Storm in Moscow: Details, Reasons, Statistics. 30.05.2017. https://www.gismeteo.ru/news/klimat/23835-konvektivnaya-burya-v-moskve-detali-prichiny-statistika/ Accessed on 2018-05-05