НАУКИ ОБ АТМОСФЕРЕ И КЛИМАТЕ / ATMOSPHERIC AND CLIMATE SCIENCES

DOI: https://doi.org/10.60797/IRJ.2024.148.88

A HAIL FORECASTING BY DISCRIMINANT FUNCTION BASED ON GLOBAL ATMOSPHERIC MODEL OUTPUT DATA (TRANSLATION OF THE ORIGINAL PUBLICATION INTO ENGLISH)

Research article

Sozaeva L.T.[1,] *, Kagermazov A.K.[2]
[1] ORCID : 0000-0002-9840-3566;
[2] ORCID : 0000-0002-8126-6008;
[1, 2] High-Mountain Geophysical Institute, Nalchik, Russian Federation

* Corresponding author (ljk_62[at]rambler.ru)

Abstract

Translation of the original publication Созаева Л.Т. Прогноз града по дискриминантной функции на основе выходных данных глобальной модели атмосферы / Л.Т. Созаева, А.Х. Кагермазов // Международный научно-исследовательский журнал. — 2023. — №11 (137). DOI: doi.org/10.23670/IRJ.2023.137.85

A discriminant model for hail forecasting is proposed, the distinctive trait of which is the use of atmospheric model prognostic data instead of actual aerological atmospheric sounding data. The global atmospheric model GFS NCEP is suggested as a prognostic atmospheric model. The materials of this study were actual observational data on hail occurrences provided by the North Caucasus Service for Active Impact on Meteorological and Other Geophysical Processes. The obtained discriminant model allows to predict hail with the total validity of 85,3% and meets the criteria of forecast quality. The model is intended for use in paramilitary hail services in the North Caucasus.

Keywords: hail forecasting, aerological probing, global atmospheric model, advance, meteorological parameters.

ПРОГНОЗ ГРАДА ПО ДИСКРИМИНАНТНОЙ ФУНКЦИИ НА ОСНОВЕ ВЫХОДНЫХ ДАННЫХ ГЛОБАЛЬНОЙ МОДЕЛИ АТМОСФЕРЫ (ПЕРЕВОД ОРИГИНАЛЬНОЙ СТАТЬИ НА АНГЛИЙСКИЙ ЯЗЫК)

Научная статья

Созаева Л.Т.[1,] *, Кагермазов А.Х.[2]
[1] ORCID : 0000-0002-9840-3566;
[2] ORCID : 0000-0002-8126-6008;
[1, 2] Высокогорный геофизический институт, Нальчик, Российская Федерация

* Корреспондирующий автор (ljk_62[at]rambler.ru)

Аннотация

Перевод оригинальной публикации Созаева Л.Т. Прогноз града по дискриминантной функции на основе выходных данных глобальной модели атмосферы / Л.Т. Созаева, А.Х. Кагермазов // Международный научно-исследовательский журнал. — 2023. — №11 (137). DOI: 10.23670/IRJ.2023.137.85

Предложена дискриминантная модель прогнозирования града, отличительной особенностью которой является использование прогностических данных атмосферной модели вместо фактических данных аэрологического зондирования атмосферы. В качестве прогностической атмосферной модели предлагается глобальная атмосферная модель GFS NCEP. Материалами настоящего исследования послужили фактические данные наблюдений за градообразованием, предоставленные Северо-Кавказской службой активного воздействия на метеорологические и другие геофизические процессы. Полученная дискриминантная модель позволяет прогнозировать град с общей обоснованностью 85,3% и соответствует критериям качества прогноза. Модель предназначена для использования в военизированных противоградовых службах на Северном Кавказе.

Ключевые слова: прогнозирование града, аэрологическое зондирование, глобальная модель атмосферы, заблаговременность, метеорологические параметры.

Introduction

The proposed hail forecasting method was originally developed based on the concept of «perfect prediction» using atmospheric meteorological parameters calculated from actual observation data. The implementation of such methods in practice faces some difficulties, as such data is only available at individual weather stations located quite far apart, and the frequency and timing of measurements do not correspond to the moment of maximum convection development.

Currently, in meteorology, schemes for calculating atmospheric parameters based on the MOS (Model Output Statistics) concept – using forecast data from atmospheric models - have been developed.

In this study, the global forecast system of the US National Centers for Environmental Prediction (GFS NCEP) is proposed to be used as a forecast atmospheric model, which was put into operation in the early 1990s [7], [8], [9] and has since been modified multiple times.

The validity of replacing the actual aerological sounding data obtained at the «Mineralnye Vody» and «Divnoye» weather stations with meteorological fields from the global model for the geographical coordinates of these weather stations was confirmed by the results of [3].

In meteorology, statistical methods, particularly discriminant analysis [2], [10], are widely used to assess the possibility of convection development accompanied by hail. In this case, the discriminant function is composed based on actual aerological sounding data of the atmosphere with a lead time of no more than 12 hours.

The purpose of this study is to calculate a discriminant function for hail forecasting in the case when atmospheric parameters are calculated using data from the global atmospheric model, with a lead time of 30 hours. To this end, the following tasks were solved:

1. Collecting data on «hail» and «no hail» events during the 2023 hail season and calculating atmospheric parameters using the output of the global atmospheric model with a lead time of 30 hours.
2. Developing a discriminant function for hail forecasting and evaluating its quality.

The observation data were provided by the North Caucasus Specialized Service for Active Influence on Meteorological and Other Geophysical Processes.

The construction of the discriminant function was carried out using the SPSS statistical software package [1].

Research methods and principles

The primary task in implementing a statistical forecasting scheme (for convection and related phenomena) is the selection of features that describe the phenomenon and characterize the physics of convective processes in the atmosphere.

About 45 features (meteorological parameters of the atmosphere) that determine the occurrence, development, and intensity of dangerous convective processes, including hail, are calculated [4]. The calculation of these parameters is based on the stratification of air temperature and humidity, wind direction and speed, which are forecast output data of the global atmospheric model [5].

Such a large number of features not only makes the computational procedure extremely laborious, but also imposes too strict requirements on the volume of empirical data. Therefore, there is a need to select the most informative ones. This selection was made using the biserial correlation coefficient, and as a result, it was found that the following atmospheric parameters have the greatest influence on the formation of convective phenomena (hail, heavy rain, etc.) [4]:

DTM – maximum temperature difference between the cloud and the surrounding air;

HM – the level at which the temperature difference between the cloud and the surrounding air is maximum;

DTK – vertical temperature gradient in the layer above the condensation level at 4–4.5 km;

SQZ5 – total specific humidity in the Earth–5 km layer;

TDSR5 – average humidity deficit in the layer above the condensation level at 5 km;

PH1 – convection level;

TH1 – temperature at the convection level;

DJ – George instability index;

TTMI – Miller's integral sum index;

DSS – energy characteristic of the sub-cloud layer.

Based on the selected parameters, a discriminant function was constructed:

$$D = a_0DTM + a_1HM + a_2DTK + a_3SQZ5 + a_4TDSR5 + a_5PH1 + a_6TH1 + a_7DJ + a_8TTMI + a_9DSS + c$$

where:

D is the dependent nominal variable;

a_n are the coefficients for the independent variables;

c – the constant term.

The dependent nominal variable *d* has two values: *D=1* ("hail") and *D=0* ("no hail").

Main results

According to the observation data of the North Caucasus Service, 109 events were included in the calculation, of which hail was recorded in 34 cases, and no hail was recorded in 75 cases.

The separation of events into «hail» or «no hail» was carried out according to the following principle: the event was classified as «hail» if hail was recorded on the ground according to ground-based observations, as well as in the cloud according to radar observations. In all other cases, «no hail» was recorded.

For all events, atmospheric parameters were calculated based on data from the global atmospheric model with a lead time of 30 hours, and a discriminant function was constructed, taking into account all the selected features (stepwise analysis with exclusion).

Discriminant analysis assumes the exclusion of dependent variables based on the criteria of equality of group means. To conduct a test for equality of group means, the Wilks' Lambda coefficient is used. In this study, the significance of this coefficient was *Sig.>0,05* for the variables *DSS* and *DTK*, which required their exclusion from further analysis.

Next, the remaining variables are checked for independence from each other, for which correlation coefficients between all the variables characterizing the relationships between them are calculated. It turned out that there is a strong relationship between the following pairs of variables:

$$PH1 - TH1 : PH1 - DTM; \quad DJ - TTMI : DJ - SQZ5.$$

The contributions of the variables *DTM*, *TH1*, and *DJ* to the discriminant function, according to the values of the unstandardized canonical coefficients, were the smallest, which allowed them to be also excluded from the analysis.

Then, the discriminant function was reconstructed, and its coefficients were determined (tab. 1).

Table 1 - Unstandardized coefficients of the canonical discriminant function

DOI: https://doi.org/10.60797/IRJ.2024.148.88.1

Atmospheric parameters	Function
	1
HM	0.00008
SQZ5	-0.0732
TDSR5	-0.0555
TTMI	0.0697
PH1	0.0002
(const)	-1.929

Based on the data in tab. 1, a predictive discriminant model was constructed:

$$D = 0,00008HM - 0,0732SQZ5 - 0,0555TDSR5 + 0,0697TTMI + 0,0002PH1 - 1,929.$$

The parameters included in the discriminant function mainly reflect the energy reserve of instability and moisture content, which are used to varying degrees in other alternative hail forecasting methods. This indicates that the reserves of convective instability in different layers of the troposphere play a key role in the formation of intense convection.

The classification results of the proposed model are presented in tab. 2, which provides row-by-row information on the value of the discriminant function («1» or «0») and the predicted membership in one of the two groups «hail» and «no hail» for each observation.

Table 2 - Classification results

DOI: https://doi.org/10.60797/IRJ.2024.148.88.2

	D	Predicted group membership		Total
		0	**1**	
Frequency	**0**	64	11	75
	1	5	29	34
%	**0**	85,3	14,7	100
	1	14,7	85,3	100

It was found that out of 34 "hail" events, 29 were correctly classified as "hail", and out of 75 "no hail" events, 64 cases were "no hail", and also 85,3% of the initial grouped observations were classified correctly (tab. 2).

The results of testing the "perfect prediction" methodology on long-term data of actual aerological sounding of the atmosphere at several points in the North Caucasus at the High-Mountain Geophysical Institute research site (Nalchik) showed a 78% reliability with a lead time of 3-12 hours [6].

Thus, the reliability of hail forecasting based on data from the global atmospheric model with a lead time of 30 hours turned out to be somewhat higher than the reliability of hail forecasting based on actual aerological sounding data, which indicates their certain advantage.

Conclusion

The hail forecasting scheme based on the use of the output of the Global Forecast System of the US National Centers for Environmental Prediction (GFS NCEP) has shown its operability on independent data in the 2023 hail season.

The study shows that the discriminant function constructed based on the output of the global model retains its forecasting potential in hail forecasting even with an increase in the lead time to 30 hours.

The obtained result will be useful in the work of hail suppression services.

Конфликт интересов

Не указан.

Рецензия

Все статьи проходят рецензирование. Но рецензент или автор статьи предпочли не публиковать рецензию к этой статье в открытом доступе. Рецензия может быть предоставлена компетентным органам по запросу.

Conflict of Interest

None declared.

Review

All articles are peer-reviewed. But the reviewer or the author of the article chose not to publish a review of this article in the public domain. The review can be provided to the competent authorities upon request.

Список литературы / References

1. Бююль А. SPSS: Искусство обработки информации. Анализ статистических данных и восстановление скрытых закономерностей / А. Бююль, П. Цёфель. — СПб. : ДиаСофтЮП, 2005. — С. 608

2. Имас Л.И. Обзор работ по дискриминантному анализу / Л.И. Имас // Труды САРЖШИ. — 1976. — Вып. 31. — С. 3–26

3. Кагермазов А.Х. Валидация выходных данных глобальной модели атмосферы в дни с развитием конвекции по данным аэрологического зондирования с двухсуточной заблаговременностью / А.Х. Кагермазов, Л.Т. Созаева // Труды ГГО. — 2019 — Вып. 593. — С. 150–159.

4. Кагермазов А.Х. Цифровая атмосфера. Современные методы и методология исследования опасных метеорологических процессов и явлений / А.Х. Кагермазов. — Нальчик : Печатный двор, 2015. — 215 с.

5. Официальный сайт Национальных центров экологического прогнозирования США. Центр экологического моделирования. — URL: https://www.emc.ncep.noaa.gov/ (дата обращения: 16.04.2023).

6. Федченко Л.М. Использование статистических методов для прогноза градовых процессов и их характеристик / Л.М. Федченко, А.Х. Кагермазов // Метеорология и гидрология. — 1988. — № 4. — С. 41–50.

7. Kalnay E. Global Numerical Weather Prediction at the National Meteorological Center / E. Kalnay, M. Kanamitsu, W.E. Baker // Bull. Amer. Meteor. Soc. — 1990. — Vol.71. — P. 1410–1428.

8. Kanamitsu M. Description of the NMC Global Data Assimilation and Forecast System / M. Kanamitsu // Wea and Forecasting. — 1989. — Vol. 4. — P. 335–342.

9. Kanamitsu M. Recent Changes Implemented into the Global Forecast System at NMC / M. Kanamitsu, J.C. Alpert, K.A. Campana [et al.] // Wea. and Forecasting. — 1991. — Vol. 6. — P. 425–435.

10. Miller R.G. Statistical Predication by Discriminant Analysis. Meteorological Monographs / R.G. Miller // American Meteorological Society. — 1962. — Vol. 4. — № 25. — P. 54.

Список литературы на английском языке / References in English

1. Buyul A. SPSS: Iskusstvo obrabotki informacii. Analiz statisticheskih dannyh i vosstanovlenie skrytyh zakonomernostej [SPSS: The Art of Information Processing. An Analysis of Statistical Data and Recovery of Hidden Patterns] / A. Buyul, P. Zöfel. — SPb. : DiaSoftJuP, 2005. — P. 608. [in Russian]

2. Imas L.I. Obzor rabot po diskriminantnomu analizu [Review of Works on Discriminant Analysis] / L.I. Imas // Trudy SARZhShI [Proceedings of SARZHSI]. — 1976. — Iss. 31. — P. 3–26 [in Russian]

3. Kagermazov A.H. Validacija vyhodnyh dannyh global'noj modeli atmosfery v dni s razvitiem konvekcii po dannym ajerologicheskogo zondirovanija s dvuhsutochnoj zablagovremennost'ju [Validation of the Global Atmospheric Model Output Data on Days with Convection Development from Airborne Sounding Data with Two-Day Advance] / A.H. Kagermazov, L.T. Sozaeva // Trudy GGO [Works of GGO]. — 2019 — Iss. 593. — P. 150–159. [in Russian]

4. Kagermazov A.H. Cifrovaja atmosfera. Sovremennye metody i metodologija issledovanija opasnyh meteorologicheskih processov i javlenij [Digital Atmosphere. Modern Methods and Methodology of Research of Hazardous Meteorological Processes and Phenomena] / A.H. Kagermazov. — Nalchik : Printing House, 2015. — 215 p. [in Russian]

5. Oficial'nyj sajt Nacional'nyh centrov jekologicheskogo prognozirovanija SShA. Centr jekologicheskogo modelirovanija [Official website of the US National Centres for Environmental Prediction. Centre for Ecological Modelling]. — URL: https://www.emc.ncep.noaa.gov/ (accessed: 16.04.2023). [in Russian]

6. Fedchenko L.M. Ispol'zovanie statisticheskih metodov dlja prognoza gradovyh processov i ih harakteristik [Use of Statistical Methods for Forecasting of Hail Processes and Their Characteristics] / L.M. Fedchenko, A.H. Kagermazov // Meteorologija i gidrologija [Meteorology and Hydrology]. — 1988. — № 4. — P. 41–50. [in Russian]

7. Kalnay E. Global Numerical Weather Prediction at the National Meteorological Center / E. Kalnay, M. Kanamitsu, W.E. Baker // Bull. Amer. Meteor. Soc. — 1990. — Vol.71. — P. 1410–1428.

8. Kanamitsu M. Description of the NMC Global Data Assimilation and Forecast System / M. Kanamitsu // Wea and Forecasting. — 1989. — Vol. 4. — P. 335–342.

9. Kanamitsu M. Recent Changes Implemented into the Global Forecast System at NMC / M. Kanamitsu, J.C. Alpert, K.A. Campana [et al.] // Wea. and Forecasting. — 1991. — Vol. 6. — P. 425–435.

10. Miller R.G. Statistical Predication by Discriminant Analysis. Meteorological Monographs / R.G. Miller // American Meteorological Society. — 1962. — Vol. 4. — № 25. — P. 54.