METEOROLOGICAL OPTICAL RANGE PREDICTABILITY WITH THE USE OF HIGH RESOLUTION MESOSCALE MODELS

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ABSTRACT

The report describes and argues in favor of the data base for numerical experiments with hydrodynamic and photochemical atmospheric models with the purpose of the meteorological visibility forecast. The obtained results demonstrate methodological potential of this approach.

Keywords: meteorological optical range, high resolution mathematical model, forecast.

Definition of the atmospheric visibility near the ground and at heights has a big applicational significance. All means of transport need information on the visibility, and for aviation this characteristics of the atmospheric state is determinant for flight execution. Definition of the slant visibility of ground objects is required for aircrafts and space crafts. Visibility in the atmosphere is mostly a derivative of meteorological conditions, in particular, of the atmospheric stability. Currently, the development of meteorological visibility forecast techniques with the use of the modern mathematical atmospheric model options is very relevant.

Visibility in the atmosphere depends on numerous factors. The main factors are as follows: properties of observed bodies, state of the surface defining horizon distance; background brightness and color; air transparency; observation conditions (daytime, illumination); light receiver properties (human eye, photocell, other devices) [1]. Horizontal visibility is defined near the earth surface. The slant one is the visibility range when observing a flying object from the earth and vice versa. Vertical visibility is a particular case of the slant visibility.

A notion of meteorological optical range is introduced into the meteorology. MOR is the greatest distance from which a black body of a pretty big angular size (more than 15 angular minutes) can be distinguished (differentiated) in daylight hours against the background of the sky near the horizon (or against the atmospheric fog) [2]. So, MOR is by definition only a parameter of atmosphere transparency. MOR is defined visually or with instruments.

Visibility forecast is based on the possibility of appearance or retention as well as weakening of the phenomena degrading visibility. Conditions leading to visibility degrading in the surface layer of the atmosphere are the following:

- phenomena associated with water vapor condensation or sublimation;
- precipitations;
- optical haze due to the income into the atmosphere of the minute particles of dust and sand lifted by the wind from the soil surface and snow from the snow cover surface;
- incomplete combustion and smog formation products coming into the atmosphere;
- combination of the aforesaid conditions [3].

Visibility reduction can be local (radiation fog, storm rainfalls), can cover relatively large areas (advective and frontal fog, widespread precipitation, dust storms), can cover very large areas (fogs under subsidence inversion in vast continental anticyclones, advective haze).

In practice visibility is predicted with the help of the synoptic-statistical methods developed for each of the aforementioned conditions and represented in [4].

Synoptic-meteorological visibility forecast methods

Forecast of visibility in haze and fog. Visibility significantly varies depending on the fog water. The hypothesis of the equal size drops recommends using semi-empirical formula to define the visibility range in the radiation fog (after sunset and before sunrise) [4]:

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$$S_m = \frac{60}{\sqrt{w}}, \quad (1)$$

where S_m is the meteorological optical range (*MOR*) (m); w is the fog water (g/m^3).

Forecast of visibility in precipitations. In case of precipitations, visibility depends on their intensity. There are a lot of the diagrams of dependency of S_m on rain intensity *I*. With available information on the rain intensity a formula for visibility calculation can be used [4]:

$$S_m = 13.6 \cdot I^{-0.71}, \quad (2)$$

where *I* is the precipitation intensity (mm/hour), it can be defined either as the sum of precipitations per an hour or as the sum of precipitated moisture for a period divided by time. S_m is defined in km.

Results

Currently, the main predictors for the visibility forecast can be obtained from the results of computations with the help of the hydrodynamic model.

A high resolution non-hydrostatic model TSU-NM3 [5] predicting the whole set of atmosphere state characteristics as well as a photochemical model allowing to predict a set of contaminants including those influencing visibility have been developed and tested in Tomsk University [6].

MOR is a parameter of atmosphere transparency which can be defined indirectly. The goal of the study is to verify the dependencies (1), (2) with the output model data for the visibility forecast in accordance with the modern physical concept of its formation [4].

In order to reveal the possibilities to use these models for *MOR* forecast a database was formed for numerical experiments for situations with different actual visibility in Tomsk district stipulated by particular meteorological conditions. The table represents an excerpt of a database with the indication of dates and brief characteristics of weather conditions for a warm period of year.

Table 1. Dates of experiments and weather characteristics

Date	Weather phenomena around Tomsk	Observed meteorological conditions	Weather forecast over the territory
June 05– 06, 2013	Rain shower	Cyclonic field, pressure trough, secondary cold fronts	Cloudy weather with clearings. Light rains, occasional moderate rain, thunderstorms are possible. North-western 2–7 m/s, occasional wind gusts 10–15 m/s. Temperature (*t*) at night 1–6°C, during day time *t* is 8–13°C, occasional *t* is 13–18°C.
August 01–02, 2013	Smoke, haze, fog. Occasional rain shower	Flat pressure gradient, occlusion front	Cloudy weather with clearings. Light rains, occasional moderate rain. Thunderstorm is possible during the day time. North-western 2–7 m/s, occasional wind gusts 10–15 m/s. *t* during the day time is 12–14°C. High fire risk due to the high temperature.
May 12– 13, 2014	Rain shower	Pressure trough axis. Atmospheric fronts.	Temperature increase during the 24-hour period is by 8. Wind direction change from northern to southern, humidity is 30–60 %. *t* is close to the norm.

Formula (1) was applied in the work for verification of the possibility to define *MOR* with the help of the model in case of cooldown fog appearance. A model calculated characteristics – *QCLOUD* (kg/kg – cloud moisture content in the atmosphere) was used as fog water w (g/m^3).

The calculation results for the case of August 1–2, 2013 are represented below.

Table 2. Actual weather and model calculation results of the main characteristics. Tomsk, Bogashevo airport, Aug. 2, 2013.

Time GMT	Time loc	t_f, C	U_f, %	MOR_f, m	$Phenomena_f$	t_{mod}, C	$U_{mod.}$,%	$QCLOUD_{mod}$,	W_{mod}, g/m^3	S_m, m
16	23	15.1	99	4200	haze	19.8	82	1.47E-05	0.018081	446
17	0	14.7	99	1000	fog	19.8	82	0	0	
18	1	13.3	99	150	fog	18.4	86	0	0	
19	2	13.9	100	150	fog	17.6	89	0	0	
20	3	14.2	100	1500	haze	17.2	90	6.54E-05	0.080454	212
21	4	14.3	100	3800	haze	16.9	91	1.04E-04	0.127428	168
22	5	14.4	100	2500	haze	16.7	91	1.63E-04	0.200613	134
23	6	13.4	100	3200	haze	16.4	92	1.61E-05	0.019791	427
Legend: *t* – air temperature; *U* – relative humidity; *MOR* – meteorological optical range; *W* – humidity content in the atmosphere. Index "f" stands for actual data, "mod" – model forecast										

Table 2 data analysis has revealed some difference between the actual visibility and predicted one both in terms of its value and the period of time when the considered visibility was registered. The minimum error in value deviation is about 20 m., and the one in time deviation is the delay of approximately 2 hours, and the period of retention of minimum visibility values is extended. Within the period from 5.00 p.m. –7.00 p.m. GMT, the calculated visibility is close to infinity due to the absence of the modelled cloudy moisture. Actually, high visibility range was observed until 2.00 p.m., then the visibility range started reducing, haze (visibility from 10 to 1 km) was observed, but smoke was recorded. A potential reason of the deviations is stipulated by model errors in temperature-humidity characteristic forecast. The MOR calculation result obtained should be acknowledged as reassuring enough. A set of sufficient number of cases is required for quantitative index obtainment.

For the considered case, the predicted data overestimate air temperature by 3–5 °C, underestimate relative humidity approximately by 10%.

Formula (2) was used for *MOR* assessment in case of rain on June 5-6, 2013 and May 12-13, 2014. Required rain intensity *I* was assessed as a model value *PREC* (m/s – precipitation rate) which was brought to the measurement unit mm/hour common for the meteorology. Table 3 represents the experiment results.

Table 3. Actual weather and model calculation results for the case of rainfall.

Date, GMT time	Local time	*t*, C	*U*, %	*MOR*, m	Phenomena	t_{mod}, C	U_{mod}, %	*PREC*, m/s	*PREC*, mm/h	S_m, km
June 5, 08	15	8.3	83	3500	rain shower	11.2	71	5.00E-07	1.80E+00	8.96
June 5, 09	16	9.9	73	10000		13.2	74	1.00E-07	3.60E-01	28.09
June 5, 10	17	11.3	66	10000		13.5	75	1.00E-07	3.60E-01	28.09
June 5, 11	18	9.5	77	10000	rain shower	13.3	75	1.00E-07	3.60E-01	28.09
June 5, 12	19	11.7	63	10000		13.4	75	1.00E-07	3.60E-01	28.09
June 6, 05	12	12.6	53	10000		12.8	83	1.00E-08	3.60E-02	144.07
June 6, 06	13	10	71	10000		13.7	81	1.00E-08	3.60E-02	144.07
June 6, 07	14	12.2	62	10000		13.8	78	1.00E-07	3.60E-01	28.09
June 6, 08	15	14.4	52	10000		14.3	76	1.00E-07	3.60E-01	28.09
June 6, 09	16	13.1	58	10000		14.5	75	1.00E-08	3.60E-02	144.07
June 6, 10	17	13.7	63	10000		14.1	75	1.00E-07	3.60E-01	28.09

Table 3. (continued) Actual weather and model calculation results for the case of rainfall.

Date, GMT time	Local time	t, C	U, %	MOR, m	Phenomena	t_{mod}, C	U_{mod}, %	$PREC$, m/s	$PREC$, mm/h	S_m, km
June 6,11	18	15.3	51	10000		14.2	75	1.00E-07	3.60E-01	28.09
June 5,12	19	15.2	53	10000		14.1	75	5.00E-07	1.80E+00	8.96
June 6,13	20	14.8	51	10000		13.3	84	5.00E-07	1.80E+00	8.96
May 13, 00	7	9.9	49	10000		7.5	92	5.00E-05	1.80E+02	0.34
May 13,01	8	8.5	70	10000	rain shower	8	91	1.00E-05	3.60E+01	1.07
May 13,02	9	8.7	75	10000	rain shower	8.2	90	1.10E-05	3.96E+01	1.00
May 13,03	10	8.3	83	10000	rain shower	9.2	89	9.70E-06	3.49E+01	1.09
May 13,04	11	8.1	89	10000	rain shower	11.3	89	1.60E-05	5.76E+01	0.76
May 13,05	12	8.2	95	10000	rain shower	12.7	90	5.30E-05	1.91E+02	0.33
May 13,06	13	9.1	94	10000		13.3	90	7.90E-05	2.84E+02	0.25
May 13,07	14	9.4	95	6000	rain shower	13.4	89	8.40E-05	3.02E+02	0.24
May 13,08	15	9.5	97	5000	rain shower	13.5	89	8.10E-05	2.92E+02	0.24
May 13,09	16	10	98	7000	rain shower	13.9	89	8.20E-05	2.95E+02	0.24
May 13,10	17	10.7	99	7000	rain shower	15	91	7.30E-05	2.63E+02	0.26
May 13,11	18	11.4	98	9000	rain shower	14.7	92	8.90E-05	3.20E+02	0.23
May 13,12	19	11.8	96	10000	rain shower	14.5	93	9.90E-05	3.56E+02	0.21
May 13,13	20	11.8	95	10000	rain shower	14.5	93	9.90E-05	3.56E+02	0.21
May 13,14	21	11.9	95	10000	rain shower	14.9	95	1.00E-04	3.60E+02	0.21
May 13,15	22	11.8	91	10000	rain shower	14.4	95	1.00E-04	3.60E+02	0.21
May 13,16	23	11	94	10000	rain shower	12.5	95	1.00E-04	3.60E+02	0.21
May 13,17	24	11	92	10000		11.8	95	1.00E-04	3.60E+02	0.21
May 13,18	1	10.3	90	10000		11.5	96	1.10E-04	3.96E+02	0.19
May 13,19	2	10	89	10000		11.3	96	1.10E-04	3.96E+02	0.19
Legend: t – air temperature; U – relative humidity; MOR – meteorological optical range. Index, "mod" stands for model forecast										

Model calculation for June 5-6 concurred with the end of rain, and Sm mod as well as the actual *MOR* corresponded to the "clear visibility" gradation.

In the second case (May 13), the model performed calculations for the whole rainfall period. Therefore, visibility in rain was predicted from 1000 m at the beginning of rainfall to 190 at the end of rainfall. It corresponds to the classic situation of visibility formation in rainfall. There are no reasons for distrust to the model forecast. However, the actual *MOR* exceeded the predicted one.

The mean square error of air temperature calculation for the cases with rain was 2.7 °C, that of the relative humidity was about 15 %, humidity was predominantly overestimated by the model.

Visibility forecast model application experience demonstrates its promising outlook with a potential refinement of coefficients in the formulas when forming a sufficient number of model calculations.

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