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Temporal and Spatial Variation of Fog in Latvia

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Abstract **- Fog is a hazardous weather phenomenon, which can impact traffic (especially air traffic) and air quality. The aim of this study is to analyse fog climatology, the trends of long-term changes of fog events and factors affecting them in general, in Latvia, but especially at Riga airport. For a 50-year period of observations, the analysis of fog frequencies, long-term changes and atmospheric conditions favourable for the occurrence of fog events in Latvia has been studied. During the analysis, two inter-annual maxima of fog frequency were found in spring and autumn, and the seasonal differences in the formation of fog were also approved by the satellite data on low cloud cover.**

Key word **- fog, aviation, long-term trends, occurrence**

I. Introduction

Fog is a hydrometeor consisting of a visible aggregate of minute water droplets or ice crystals, suspended in the atmosphere near the Earth's surface and reducing horizontal visibility below one kilometre [1]. Fog is a hazardous weather phenomenon worldwide, which can cause accidents and affect urban air quality, especially in combination with impacts of air pollutants [2, 3]. Traffic obstacles such as flight delays, automobile and marine accidents due to poor visibility can be considered as the most common negative effects of fog [4, 5]. At the same time, fog can be associated with critical conditions of air pollution (especially with particulate matter), because air pollutants can be trapped in the fog droplets and can reach high concentrations, causing the formation of smog or in some cases acid fog [6, 7]. On the other hand, fog as a source of humidity is also very important to the health of ecosystems and humans [8], and as fogs have an important influence on the radiation balance, the long-term changes in their frequency can play an important role in the accuracy of the climate model predictions [6].

Fog is a very local phenomenon, which can form as a result of advection, radiative cooling or a weather front moving over an area, and its frequency and spatial distribution are closely related to orography and proximity to the sea [7, 9-11]. The occurrence of fog is related to the atmospheric circulation and local geographical features of a site and thus fog climatology studies are of especial importance for airports, where local meteorological conditions (lowland and flatland territories) may support increased occurrence of fogs, but the impacts might have serious consequences. To assess the intensity of fog, the measure of horizontal visibility or the persistence of fog can be used [9, 12]. The most intense fogs in both persistence and density were observed in many sites of the industrialized world in the 1940s and 1950s, when some famous low visibility episodes in combination with heavy air pollution such as the Great Smog of London in 1952 occurred [13]. During that event visibility below 10 m lasted for nearly 48 hours in Heathrow - such intense and persistent low visibility is almost unheard of today [7, 13]. Since then, due to the introduction of clean air legislation and a decrease in total suspended particulates, fog climatology has changed considerably and many sites have experienced a decrease in the fog frequency [6, 7, 14], also in Riga. However the presence of particulates in the air still remains high where presence of particulates in air remain high [15]. High quality observation data of various parameters describing fog are not available in many countries because of the sparse observation networks, and consequently it is practically not possible to carry out a reliable and spatially coherent analysis of fog distribution based only on the surface observation data [6]. However, satellite data can provide important information on the spatial distribution, dynamics and properties of fog [4]. Despite the importance of fog both from the applied research point of view, and in respect to a better understanding of extreme climate events, there have been no studies of fog meteorology carried out in the Baltic region. The aim of this study is to analyse fog climatology, the trends of long-term changes of fog events and factors affecting them in general, in Latvia, but especially at Riga airport, as well as to evaluate possibilities to use satellite data for the detection of fog.

II. Data sources and Methods

Daily observation data on fog events and precipitation amount were provided by 15 major meteorological observation stations in Latvia (Figure 1). Data obtained from the Latvian Environment, Geology and Meteorology Centre covered a 52-year period from 1960 to 2012. The methods of fog observations vary depending on the meteorological stations – in automatic observation stations, such as Riga airport, horizontal visibility is observed automatically by the use of sensors, while in other observation stations in Latvia observations of horizontal visibility and fog are performed visually by the meteorologist. Visual observations of horizontal visibility are performed by evaluating the distance between the observer and predefined existing objects such as trees, buildings, towers etc., or objects established specially for this purpose [16].

In addition to the surface observations, satellite data were also used for the analysis. For the climatological characterisation of the occurrence of fog, satellite observations of low clouds for the period 2005-2011 provided by the Satellite Application Facility on Climate Monitoring (CM SAF) were used as an indicator of the most favourable sites for the formation of fog [17]. Monthly and seasonal mean amounts of low clouds were calculated from the satellite data with statistical programmes CDO (*Climate Data Operators*) and R, and compared with the surface observation data.

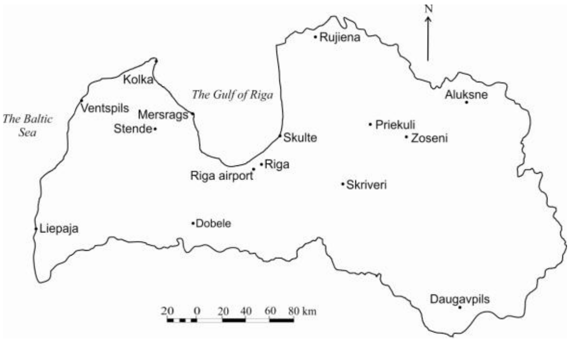

Fig. 1. Major meteorological observation stations in Latvia

The visualization of the location of meteorological observation stations used in this study (Fig. 1) was performed by using Corel Draw, but the spatial distribution of fog in Latvia (Fig. 2) was visualised by using the FiSynop software with linear interpolation on a triangular grid.

Trends in the annual number of days with fog were analysed by using the non–parametric Mann–Kendall test [18, 19]. The Mann–Kendall test was applied separately to each variable at each site at a significance level of $p \leq 0.01$. The trend was considered as statistically significant if the test statistic was greater than 2 or less than -2.

III. Results and Discussion

A. Fog climatology in Latvia

Climate in Latvia is influenced by strong cyclonic activity over Latvia and location in the northwest of the Eurasian continent (continental climate impacts) and by its proximity to the Atlantic Ocean (maritime climate impacts). These variable conditions over the territory contribute to differences in the regimes of air temperature and humidity [20-22], and also to the spatial inhomogeneity in the occurrence of fog.

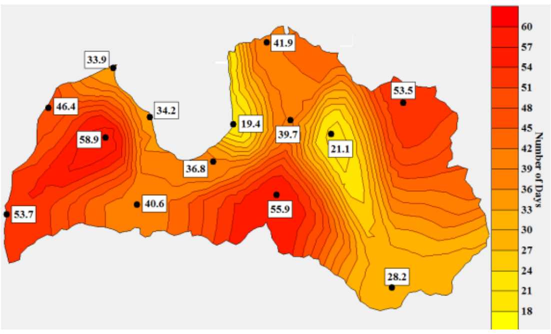

Fig. 2. Annual mean number of days with fog in Latvia over the period 1960-2012

Fog can be classified by its formation in the processes of advection, radiative cooling or a mix of both processes [23], and each of these processes can trigger the formation of fog in Latvia throughout the year. Fog is a rather frequent weather phenomenon in Latvia, and it can be observed 19-59 days a year on average (Figure 2). The formation of fog is closely related to the local geographical features of a site, such as orography and slope exposure, proximity to the Baltic Sea and the Gulf of Riga, and the different meteorological processes favourable for the occurrence of fog; therefore, there are significant differences in the annual mean number of days with fog in Latvia. As a result, fog most commonly can be observed in the western parts of the highland areas of Latvia, while the lowest number of days with fog is observed in the eastern parts of highlands and in the coastal areas of the Gulf of Riga. Overall fog frequency is larger in the western part of the country.

Figure 3 illustrates the long-term variability of fog in Latvia. The bold line represents the median of the annual number of days with fog, the upper and lower sides of the boxes are the upper and lower quartiles, the whiskers represent the greatest and lowest annual number of days with fog, but the dots represent outliers, which are more than 1.5 times greater or smaller than the quartiles. The range of the annual number of days with fog in Latvia varies from 0 days in Zoseni to 110 days in Aluksne, and also the annual variations within each station are considerable. For most of the stations, the data distribution is positively skewed, which means that there are more years with the annual number of fogs exceeding the long-term average than years with a smaller number of days with fog. Under the influence of the highly variable weather pattern in three observation stations of the western part of the country – Liepaja, Mersrags and Dobele - outliers of both minimum and maximum annual number of days with fog can be found. In general, the graph shows significant differences in the spatial and temporal distribution of the annual number of days with fog in Latvia.

The inter-annual variability of fog (Table 1) shows significant differences in the months of the maximum occurrence of fog in coastal and inland observation stations. The coloured cells indicate 3 months with the greatest frequency of fogs in each observation station. In the inland stations the maximum of fog occurrence is characteristic for the second half of the year - beginning from August to December. During the autumn months the radiation fogs form more frequently, but during winter and spring advection fogs gradually become more frequent. Therefore in the coastal observation stations the maximum frequency of fog occurs in spring – during March, April and May, when warm advection from the west triggers the formation of adjective fogs.

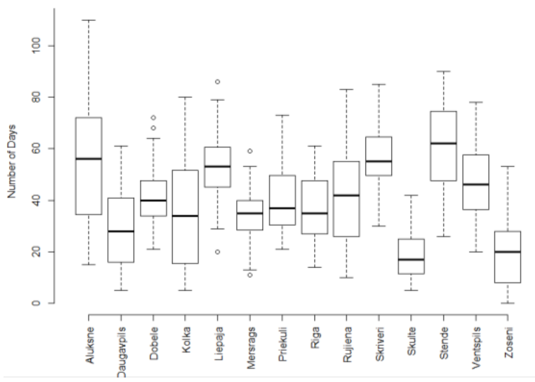

Fig. 3. Variations in the annual number of days with fog in Latvia over the period 1960-2012.

TABLE 1

MONTHLY EAN NUMBER OF DAYS WITH FOG OVER THE PERIOD 1960-2012

	January	February	March	April	May	June	July	August	September	October	November	December
Aluksne	4.9	4.6	4.7	4.2	2.4	1.2	2.5	4.0	5.5	7.3	9.2	7.0
Daugavpils	1.5	2.0	2.4	1.8	2.0	1.3	1.9	3.3	4.3	4.5	3.1	2.6
Dobele	4.2	3.4	4.1	2.9	1.7	1.1	1.6	2.8	4.5	5.3	4.3	4.8
Kolka	2.7	3.3	5.4	5.9	4.6	2.1	1.7	1.9	1.9	2.3	2.6	2.0
Liepaja	3.9	4.6	6.5	7.3	7.1	5.2	3.7	3.7	2.8	4.1	3.7	4.4
Mersrags	2.3	2.4	3.6	4.5	3.4	1.8	2.8	3.6	3.2	3.2	3.2	2.3
Priekuli	3.9	3.9	3.8	3.2	2.7	1.3	2.2	3.8	4.2	4.5	4.8	4.8
Riga	3.3	3.3	3.8	3.0	2.3	1.4	2.3	3.0	3.5	4.2	5.0	4.4
Rujiena	3.6	3.7	3.7	3.1	2.2	1.7	3.0	4.8	5.0	5.2	4.8	4.5
Skriveri	5.2	4.5	4.5	3.1	2.4	2.2	3.5	6.2	4.8	7.3	7.1	6.8
Skulte	1.7	2.3	3.0	2.7	2.5	0.9	0.7	1.3	1.3	1.8	2.0	1.6
Stende	5.5	5.1	5.9	4.9	3.8	3.5	5.3	6.3	4.7	5.5	6.6	6.5
Ventspils	3.7	3.6	5.8	6.8	6.2	4.6	3.4	2.9	2.3	3.0	3.3	3.3
Zoseni	1.3	1.5	1.6	1.6	1.0	0.8	1.4	2.2	2.9	3.1	3.4	2.0

The annual number of days with fog in Latvia has decreased significantly during the past 50 years (Figure 4). The most significant decrease in the frequency of fog is evident for the 20 year period between the years 1980 and 2000 and could be associated with the rapid decrease in the industrial activities in the country, but in the past decade the frequency of fog has again increased slightly.

In spite of the observed decrease in the frequency of fog in Latvia, it is still considered as one of the most dangerous meteorological phenomena negatively affecting transportation, especially air traffic, and causing flight delays and cancellations which lead to great financial loss.

Especially low visibility (intensive fog) events have been observed under the conditions of increased atmospheric pressure (Figure 5), which indicates the great importance of radiation fogs in the area. Radiation fogs are common in the lowland area near Riga airport, because the wetlands and swamps located to the south of the airport provide extra moisture essential for the development and persistence of dense radiation fogs.

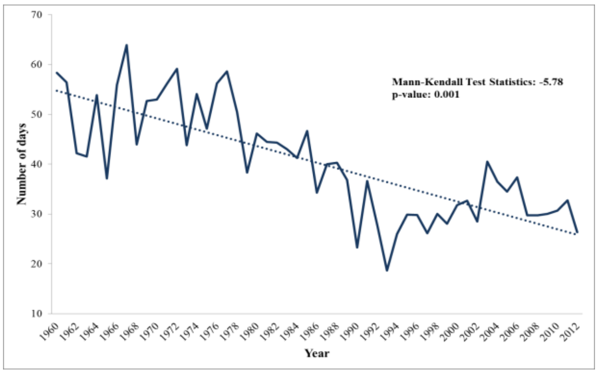

Fig. 4. Time series in the annual number of days with fog in Latvia overall over the period 1960-2012

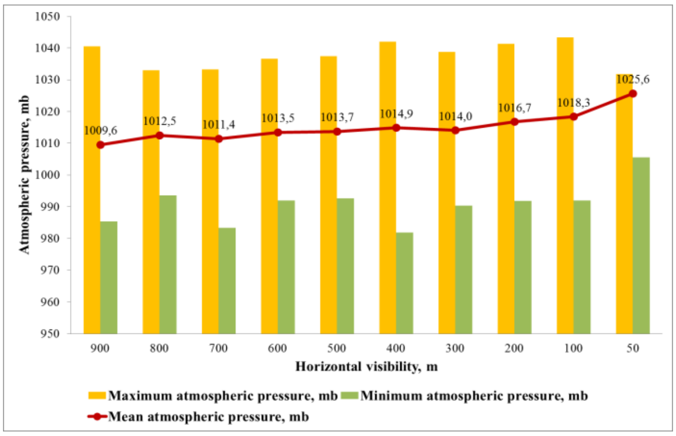

Fig. 5. Atmospheric pressure during fog events at Riga airport over the period 2010-2012.

In-depth analysis of fog climatology at Riga airport indicates several major factors affecting fog occurrence (Figure 5 – 7), such as atmospheric pressure, air humidity and wind speed, as well as presence of atmospheric precipitation during fog events.

The relations between humidity and wind speed on visibility during fog events have an opposite character – increase of wind speed supports the dissipation of fog, and the most intensive fog events happen at low wind speeds as such conditions deteriorate vertical mixing of air near the surface (Figure 6). Relative humidity is a well-known indicator used for the forecasting of fog, since fog most frequently forms in the conditions of relative humidity exceeding 90% [23], which is also approved by data from the Riga airport, since the increase of air humidity supports the increase of fog thickness.

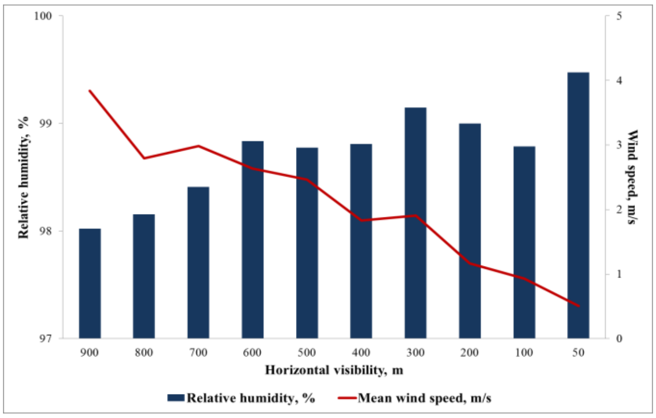

Fig. 6. Relative humidity and mean wind speed during fog events at Riga airport over the period 2010-2012.

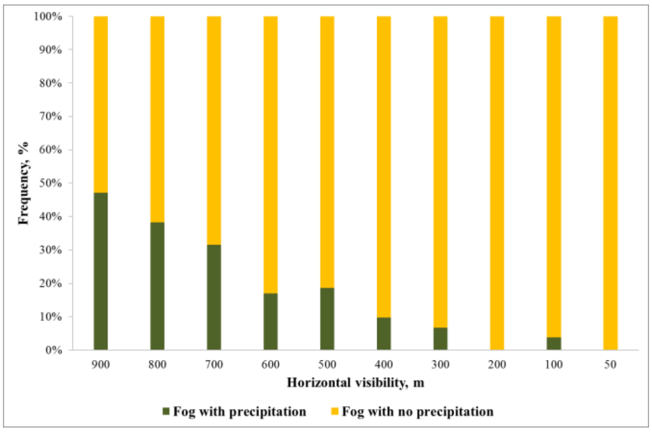

Fig. 7. The frequency of dry days and days with precipitation during fog events at Riga airport over the period 2010-2012.

The analysis of fog occurrence during days with precipitation can also be an indicator of the formation process. As radiation fog commonly occurs in the conditions of clear skies, usually there is no precipitation during days with radiation fog. However in cases of very dense radiation fog, very small amount of precipitation (up to 0.1-0.2 mm) can be caused by the fog itself. Advection fogs are usually associated with frontal systems, so such fogs are frequently accompanied by precipitation. Figure 7 illustrates the relation between patterns of formation of fogs during days with precipitation. At Riga airport most of the most intensive observed fogs have formed during days with no precipitation, which could be associated with the specific local factors of the observation station favourable for the development of radiation fogs. Nevertheless, advection fogs are also observed commonly at the airport, especially in the winter and spring seasons, since the inflow of warm and moist air over the snow-covered ground is favourable for the formation of fog. In some cases in winter and spring fog can be advected to the airport also from the ice-free areas of Gulf of Riga. It is characteristic for the radiation fogs to form in the second part of the night or early morning and dissipate soon after sunrise, however advection fogs can form any time of the day and may remain for a prolonged period of time, therefore advection fogs can be considered as a greater danger for the air traffic.

B. Use of satellite data for identification of fog

Nowadays satellites are considered as a powerful tool for the observations of fog, as satellite observations provide both wide spatial and temporal coverage which is essential for the detection and characteristics of such a variable phenomenon. In essence, fog is very similar to low stratus clouds, and it differs from low cloudiness only by its base being located near the ground [1]; therefore, for the climatic characterisation of fog occurrence, it is possible to compare the surface observations of fog to the low cloud observations from satellites provided by the CM SAF. If compared the surface observations of fog and the satellite observations of low clouds in the autumn season (Figure 8) over a six-year period, one can see similar features: the greatest amount of low clouds (up to 47%) can be observed in the south and west regions of Latvia, while in the coastal areas the amount of low clouds is the smallest (38-44%). In the winter season, the low cloudiness in Latvia is smaller in general, and it does not exceed 44% (Figure 9). In winter, a more expressed formation of fog is evident over the valley of the river Daugava and especially over the west regions of Latvia, where it could be triggered by the influence of periodic thaws.

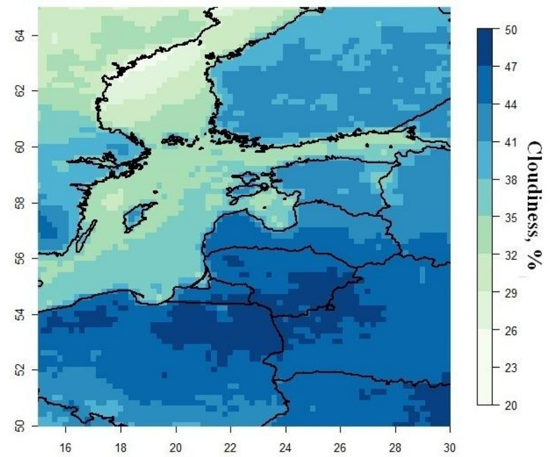

Fig. 8. Mean amount of low clouds (%) in autumn (SON) over the period 2005-2011.

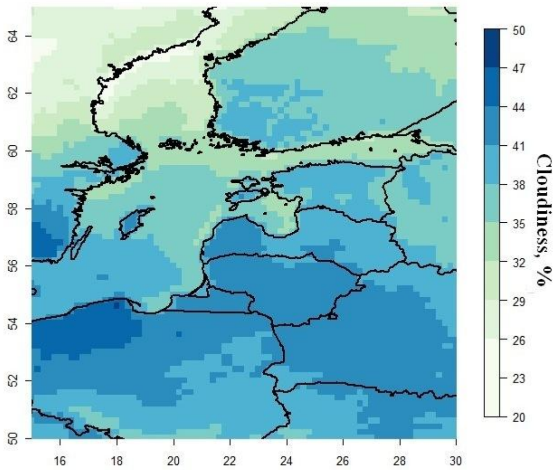

Fig. 9. Mean amount of low clouds (%) in winter (DJF) over the period 2005-2011.

In spring, some differences in the low cloud and fog formation processes appear (Figure 10). In the western regions, where, under the influence of warm advection from the west, advection fogs form more frequently, the mean amount of low cloudiness is higher than in other parts of the country and reaches 40-42.5%. But at the same time in the highland areas of Latvia, a gradual increase in the occurrence of radiation fogs begins. Also in summer (Figure 11) the low cloudiness is the greatest over the highland areas, where it reaches up to 40% of the total cloudiness due to the dominance of radiation fogs.

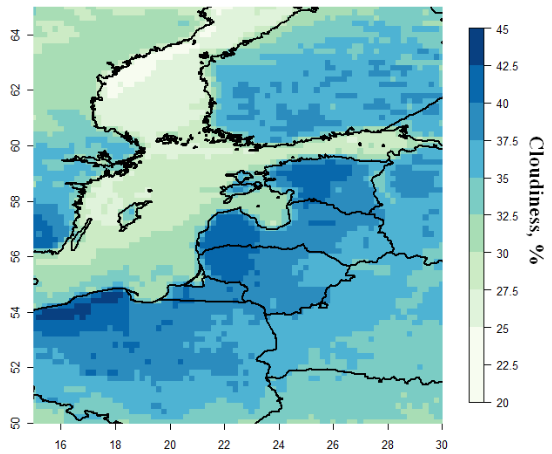

Fig. 10. Mean amount of low clouds (%) in spring (MAM) over the period 2005-2011.

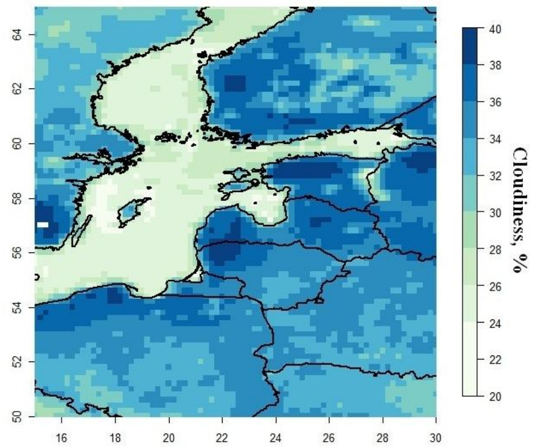

Fig. 11. Mean amount of low clouds (%) in summer (JJA) over the period 2005-2011.

Satellite information can be also efficiently used to evaluate development of fog conditions locally, for example at Riga airport on the 25th of October in 2011 when a wide area of dense fog approached Latvia from the south, and moved over the central regions of the country to the Gulf of Riga (Figure 12). The south-east regions of Latvia were covered with clouds, but in the central regions at night the skies were clearing and a dense radiation fog formed. In the conditions of a strong low-level inversion the fog remained throughout the whole day, slowly moved to the north and in the evening covered the Gulf of Riga. During the fog in the morning in Riga the visibility was reduced to 100 m, but in the middle of the day in Dobele to 70 m, besides in Dobele visibility below 500 m remained for 28 hours. In this case satellite data were an essential source of information on the spatial coverage, movement and characteristics of fog, providing much wider view on the process than the surface observation network.

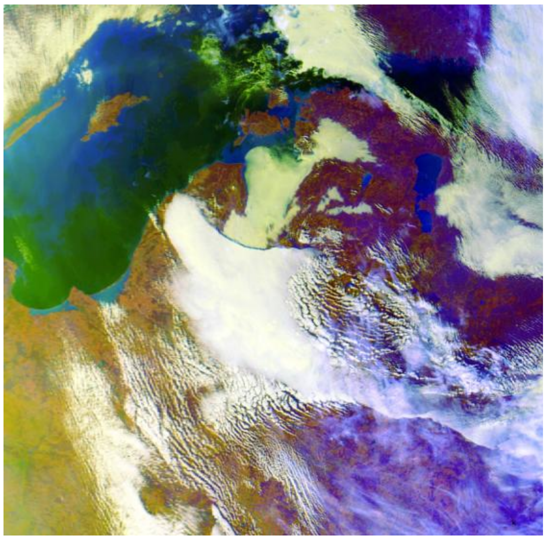

Fig. 12. NOAA satellite image (channel combination 2-1-4, fog and low stratus appears as light yellowish area) at 11:10 UTC 25.10.2011.

In spite of the observed decrease in the frequency of fog in Latvia, it is still considered as one of the most dangerous meteorological phenomena negatively affecting transportation, especially air traffic, and causing flight delays and cancellations which lead to great financial loss. Therefore, in the conditions of ever increasing demand for air transport, it is essential to be aware of the general climatic characteristics of fog occurrence and synoptic patterns favourable for their development.

IV. Conclusions

Fog is a frequent weather phenomenon in Latvia, which is characterised by a significant spatial and temporal inhomogeneity in its occurrence. Since the middle of the past century, the annual mean number of days with fog has decreased significantly but, in spite of the observed decrease, fog is still one of the most dangerous and harmful meteorological phenomena affecting aviation in Latvia. The analysis of fog formation in the area of the Riga airport revealed that the majority of fog events observed can be classified as radiation fogs, which due to their short persistence are not of as great danger to the aviation traffic as advection fogs. Since advection fogs play an important role in the air traffic organization, timely information provided by satellites is an essential tool for the forecasting of movement and persistence of the fog and low-cloud areas.

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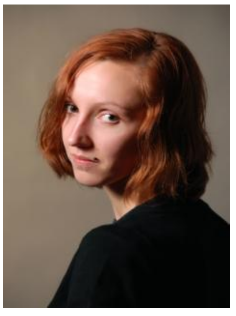

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