



AVIATION METEOROLOGY – ITS PAST, PRESENT, AND FUTURE

Miriam Jarošová
Air Transport Department
University of Žilina
Univerzitná 8215/1
010 26 Žilina
jarosova20@uniza.sk

Timon Havlík
Air Transport Department
University of Žilina
Univerzitná 8215/1
010 26 Žilina
Havlik3@stud.uniza.sk

Abstract

Meteorology has been connected with aviation since its beginnings. Weather has always significantly influenced flight possibilities and pilot safety; however, only with the development of air transport did a distinct field called aviation meteorology begin to take shape. Over time, this discipline evolved and adapted to technological progress, which influenced not only observation methods but also the processing and dissemination of meteorological information. Aviation meteorology is not only about forecasting but also about the development of communication networks, data standardization, and the role of international organizations in the distribution of data essential for aviation safety, efficiency, and overall economy. The article shows the path from basic and very simple information about the atmosphere and weather in aviation to today's methods of obtaining information important for ensuring aviation safety. It also shows how important it is to cooperate at the international level and to obtain and distribute information in a comprehensive way – from ground observations to data from meteorological satellites and numerical forecasting models.

Keywords

Aviation meteorology, ICAO, WMO, EUMETSAT

1. Introduction

Meteorology is one of the oldest natural sciences. Since ancient times, people have looked at the sky and tried to identify what changes in the amount and shape of clouds mean. They also tried to recognize changes in weather through variations in wind direction and speed. Although sailors were the first to study meteorology as a science, meteorology and rapid changes in meteorological elements soon began to interest the early pioneers of aviation.

2. History of Aviation Meteorology

The origins of meteorology as a scientific discipline date back to antiquity, when Aristotle became the first philosopher to systematically study meteorology. The result was his work *Meteorologica*, written in the 4th century BC. In this work, he addressed atmospheric phenomena such as rain, wind, lightning, fog, and others. (Neves, Gallardo and Vecchia, 2017) Although his claims were not based on practical evidence, his work represented the first attempt to explain meteorological phenomena. He attempted to explain them based on the four elements – water, fire, air, and earth. Although most of his conclusions were incorrect, his work became the foundation of meteorological studies for many centuries.

Meteorology began to develop as an observation- and measurement-based science in the 19th century. The first meteorological stations were established, systematically collecting and recording atmospheric data. Robert FitzRoy was the first to introduce meteorological forecasting. (Neves, Gallardo and Vecchia, 2017).

From the very beginning of aviation, pilots recognized that weather was a crucial factor in flight safety. World War I had a

major impact on the development of meteorology in general, and especially on aviation meteorology. Weather forecasts were essential for both military and civil aviation, leading to the development of specialized military meteorological units focused on weather prediction. Data and forecasts needed to be distributed quickly. Radiotelegraphy enabled such rapid exchange of meteorological data, forming the foundation for today's information exchange and distribution systems, such as METAR and TAF. During this period, the first attempts at mathematical weather calculation were carried out by British mathematician Lewis Fry Richardson, laying the groundwork for modern numerical weather modelling. (US Department of Commerce, n.d.) (Zindel, 2020)

2.1. Aviation Meteorology Between the World Wars

From the mid-1920s, civil aviation in Europe began to develop more rapidly, increasing the demand for accurate meteorological information. Czechoslovakia responded by establishing specialized services at airports. For example, in 1923, the airline Czechoslovak State Airlines (ČSA) was founded and operated routes such as Prague–Bratislava–Zagreb. Monitoring weather conditions and developing forecasts was essential for these routes. (Musil, 2016)

In response to these needs, the first specialized aviation meteorological stations were established in present-day Slovakia. The Košice Airport station was founded in December 1921 as Aviation Weather Station No. 2, and Bratislava-Vajnory followed in July 1922 as Station No. 3. These stations were among the first professional observation points in the country, specifically focused on aviation needs and providing data for the increasing number of civil and military flights. (Slovenský hydrometeorologický ústav, 2024)

In professional literature, 1937 was a significant year. Gustav Swoboda published *Aviation Meteorology and Aviation Weather Service*, focusing in detail on weather observation and forecasting for aviation purposes.

2.1.1. Aviation Meteorology and World War II

Similar to World War I, World War II represented a major milestone for aviation meteorology. The renewed military conflicts created an urgent need for improved weather forecasting to support aviation, naval, and airborne operations. Around the world, including in the United Kingdom, Germany, the United States, and the Soviet Union, meteorology evolved from a supplementary discipline into a key element of military planning. (Galvin, 2020)

The importance of weather for successful air missions led to significant investments in personnel training, data collection, and the development of new technologies. The development of aviation meteorology was characterized not only by the establishment of specialized groups but also by technological advancements. Before the war, upper-air measurements were limited mainly to balloon observations with restricted range. During the war, radiosondes began to be used regularly. These devices transmitted atmospheric data wirelessly from higher layers of the atmosphere to the ground.

Another important development was radar meteorology. Radar, originally developed to detect enemy aircraft, began to be used during the war to detect precipitation systems and storm clouds. (Povetrie.sk, 2023)

Meteorology played a significant role during the war, as demonstrated by Operation Overlord – the Allied invasion of Normandy in June 1944. Thanks to accurate weather forecasts prepared by Allied meteorologists, the invasion was postponed, surprising German command. With the introduction of new computational methods and physical modelling, principles of atmospheric dynamics and mathematical forecasting began to be applied to meteorology. This trend was strongly developed by the Chicago School of Meteorology, building on the work of the Bergen School. As a result, meteorology gradually transformed from a descriptive science into a quantitative predictive discipline. The operational use of weather forecasts in wartime laid the foundation for modern aerological networks, aviation forecasting services, and radar meteorology, which later became fundamental for both military and civil aviation. (news.uchicago.edu, 2020)

3. Meteorology After World War II

The end of World War II marked a reorganization of global meteorological services, as military meteorology, previously controlled mainly by armed forces, began transitioning into civilian use. Since aviation was rapidly developing, it required the establishment of new institutions, standards, and forms of international cooperation.

The Chicago Convention was signed in 1944, but its principles were fully implemented only after the war. These principles led to the creation of the International Civil Aviation Organization (ICAO), whose goal was to ensure efficient and safe international air transport operations, including meteorological support. In

1948, ICAO adopted its first meteorological regulations, which later became the basis for Annex 3 to the Convention on International Civil Aviation, focusing on meteorological services for civil aviation. (Čech, n.d.)

At the same time, there was a need to establish a unified global meteorological institution. The World Meteorological Organization (WMO), founded in 1953, cooperates with ICAO in developing regulations, methodologies, and meteorological infrastructure for aviation. (Čech, n.d.) (Icao.int, 2026)

Formats for exchanging meteorological data were also developed. This led to the introduction of international codes such as SYNOP (surface observations), TEMP (upper-air measurements), and AIREP (pilot weather reports). These codes enabled countries to share acquired data efficiently in a unified format, forming the basis of standardized meteorological communication in aviation and paving the way for later formats such as METAR and TAF. (Icao.int, 2026)

The post-war period created conditions for meteorology to become an integral part of aviation. The introduction of upper-air measurements, the establishment of international institutions, and the first standards for simple and unified data exchange were just the beginning of processes that continued to evolve in the following years.

3.1. Aviation Meteorology in the Era of Digitalization and International Standardization

The period after 1957 marked significant progress in meteorological technologies and intensified global cooperation. In 1957, the Soviet satellite Sputnik 1 was launched, initiating the era of space-based technologies. Another major milestone was the launch of the American satellite TIROS-1 in April 1960. TIROS provided the first cloud images from orbit, opening the possibility of regularly using satellite data in practice, including weather forecasting for aviation. (Spivey, 2024)

In 1968, METAR and TAF reports were introduced based on ICAO and WMO regulations. These codes continue to provide current observations and future weather forecasts at airports. Their introduction significantly improved and simplified international communication and enhanced aviation safety.

At the same time, numerical weather prediction based on mathematical modelling of atmospheric processes was developing. The first predictive models, such as LFM and NMC, provided information useful for planning flight routes. (Icao.int, 2026) (US Department of Commerce, n.d.)

Automation during the 1970s and 1980s led to the introduction of meteorological measurement systems such as ASOS and AWOS. These systems provided continuous and up-to-date information about atmospheric conditions at airports without requiring human operation. The data were then supplied to forecasting centres for decision-making purposes. (US Department of Commerce, n.d.)

On the international level, meteorological data exchange developed through the Global Telecommunication System (GTS), operated by WMO. The European organization EUMETSAT manages meteorological satellite operations, providing near real-time data exchange between continents and

improving the reliability of large-scale weather forecasts, thereby enhancing aviation safety. (EUMETSAT, 2020)

Currently, international cooperation is developing through various platforms that use meteorological data to predict weather conditions worldwide based on numerical prediction models, both at the surface and at various flight levels. These data are used daily, making aviation safer and flights more comfortable. For example, significant weather charts allow flights to be planned effectively with respect to hazardous weather phenomena. Programs such as C-SRNWP (Coordination of Short-Range Weather Prediction) enable cooperation among national services in developing and sharing regional prediction models such as AROME, ALADIN, and ICON. (Srnwp.eu, 2026) The attached images show current possibilities for displaying meteorological information for aviation.

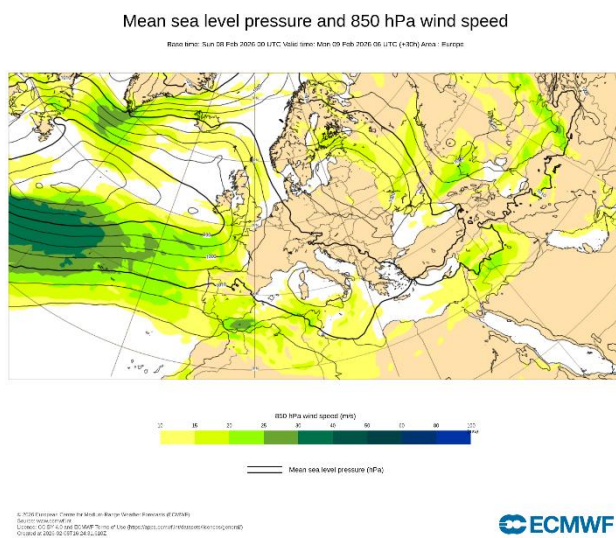


Figure 1. (ECMWF) shows the output from a numerical forecasting model – mean sea level pressure (MSLP) and wind at the 850 hPa level.

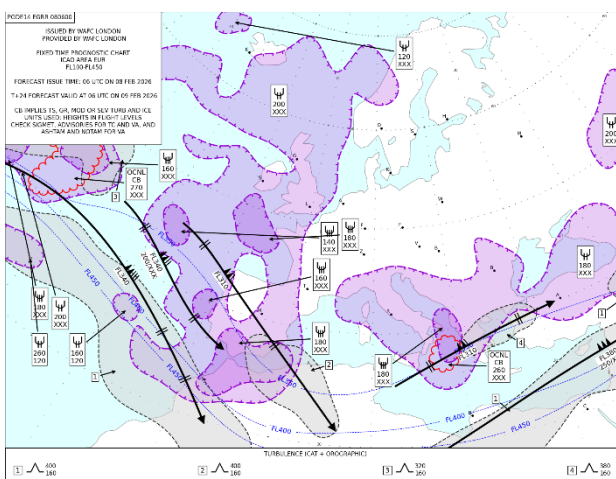


Figure 2. shows hazardous weather phenomena between flight levels FL100 and FL450.

4. The Future of Aviation Meteorology

The use of satellites, meteorological radars, and numerical models has become standard practice. However, aviation faces

several challenges that aviation meteorology must address in the future.

In recent decades, the impact of climate change on aviation has become increasingly important. Continuous global temperature increases, more frequent occurrences of severe turbulence in jet stream levels, and higher risks of extreme weather events such as heat waves or heavy rainfall have affected flight times and route planning. Organizations such as Climate Central warn that adverse phenomena caused by climate change will increasingly influence the efficiency of air transport. Modern times are characterized by the integration of new technologies. (Climatecentral.org, 2025)

At the national level, fully automated reports such as METAR AUTO have been introduced, and meteorological institutes, including the Slovak Hydrometeorological Institute (SHMÚ), are incorporating diagnostic tools for identifying hazardous phenomena, moving toward the use of artificial intelligence.

As unmanned aerial systems (UAS/UAV) are increasingly used, there is also a growing need for meteorological support for these operations. New forecasting methods are being developed for low-cost operations, particularly in urban areas where data on wind conditions, temperature, and precipitation at low altitudes are crucial.

Modern aviation meteorology is characterized by fundamental transformation through digitalization, globalization of data exchange, automation, and intelligent systems. (Engage 2 - Engage 2 project website, 2023)

5. Conclusion

Over the past decades, aviation meteorology has undergone remarkable transformation. From a field based on individual observations and limited technology, it has gradually become part of highly automated, digitally interconnected systems. Technological development, output standardization, and the integration of international organizations have created the foundation for reliable exchange of meteorological data, which is now essential for safe and efficient aviation operations.

Current trends in aviation meteorology show increasing emphasis on information personalization, artificial intelligence, automated systems, and predictive models. The importance of meteorology is not declining – on the contrary, it is becoming even more essential with the development of new forms of aviation, such as unmanned systems and urban air mobility. Reliable weather information remains one of the most important pillars of aviation, both today and in the future.

References

Čech, I. n.d. *Univerzita Karlova v Praze Právnická fakulta Civilní letectví v EU a ČR z pohledu unijního práva Diplomová práce*. Available at: https://dspace.cuni.cz/bitstream/handle/20.500.11956/80844/DPTX_2013_1_11220_0_177424_0_145560.pdf

Climate Central 2025. *Study: Warming leads to longer flights, more emissions*. Available at: <https://www.climatecentral.org/news/warming-longer-flights-more-emissions-19234>

EUMETSAT 2020. *What we do*. Available at:
<https://www.eumetsat.int/about-us/what-we-do>.

Engage 2 project website 2023. *Home – Engage 2*. Available at:
<https://engagektn.com/wp-content/uploads/2021/11/C14-METSIS-executive-summary.pdf>

Galvin, J. 2020. 'Meteorology and the Second World War'. *Weather*. Available at: <https://doi.org/10.1002/wea.3687>.

International Civil Aviation Organization 2026. *The Chicago Convention 1944*. Available at:
https://applications.icao.int/postalhistory/1944_the_chicago_convention.htm

Musil, L. 2016. *Historie ČSA – díl 1. 1923–1939*. Available at:
<https://www.czechairliners.net/index.php/letecke-spolecnosti/1047-historie-csa-dil-1-1923-1939.html>

Neves, G., Gallardo, N. and Vecchia, F. 2017. 'A short critical history on the development of meteorology and climatology'. *Climate*, 5(1), p. 23. Available at:
<https://doi.org/10.3390/cli5010023>.

Povetrie.sk 2023. *História vývoja meteorologických prístrojov a meracích zariadení*. Available at:
<https://www.povetrie.sk/2023-05/historia-vyvoj-meteorologickych-pristrojov-meracich-zariadeni>.

Slovenský hydrometeorologický ústav 2024. *100 rokov od založenia meteorologickej stanice Košice-letisko*. Available at:
<https://www.shmu.sk/sk/?page=2049&id=1186> .

Slovenský hydrometeorologický ústav 2024. *Storočnica letiskovej meteorologickej stanice v Bratislave*. Available at:
<https://www.shmu.sk/sk/?page=2049&id=1188> .

Spivey, S. 2024. *Celebrating Earth Day: The first satellite images of the earth were taken 64 years ago*. Available at:
<https://www.ksat.com/weather/2024/04/23/celebrating-earth-day-the-first-satellite-images-of-the-earth-were-taken-64-years-ago> .

SRNWP 2026. *35th EWGLAM and 20th SRNWP meetings*. Available at:
<https://www.srnwp.eu/content/annualMeetings/2013/default.htm> .

University of Chicago News 2020. *The World War II-era Chicago school of meteorology that decoded weather forecasting*. Available at: <https://news.uchicago.edu/story/world-war-ii-era-chicago-school-meteorology-decoded-weather-forecasting>.

US Department of Commerce, National Weather Service n.d. ASOS. Available at: <https://www.weather.gov/asos>.

US Department of Commerce, National Weather Service n.d. *December 17, 2013 marks the 110th anniversary of the Wright Brothers' first flight*. Available at:
<https://www.weather.gov/mhx/FirstFlight>.

Zindel, H. 2020. 'Ballooning: Aeronautical techniques from Montgolfier to Google'. *De Gruyter eBooks*, pp. 107–128. Available at: <https://doi.org/10.1515/9783110647044-007>.