DEVELOPMENT OF WEATHER SERVICES FOR AVIATION PERSONNEL

Daniel Nyberg | LUND UNIVERSITY

Development of weather services for aviation personnel

Daniel Nyberg

Lund 2021

Development of weather services for aviation personnel
Daniel Nyberg

Keywords
Meteorology, weather, weather development, weather presentation, pilot, aviation

Abstract
The following paper focuses on an operational view of aviation weather development. It intends to create a discussion about the current presentation models and available technology. **Method**: Literature review and use of other technological fields related to aviation. The study is limited to a pilot's operational view. **Result**: Weather presentations have had a slow development within the aviation community since the middle of the 20th century. The paper intends to point out the slowness, given the available meteorological information, big data processing capabilities, aircraft systems for data usage, and available software used within the aviation community. Economic and environmental aspects related to weather are discussed. **Discussion**: The author provides suggestions for improvements and emphasizes the importance of combined and updated software and big data processing for comprehensive and extensive use. The paper also highlights potential economic savings and environmental benefits. Possibilities of improvement and the benefits of the weather presentation development and economy are examined.

Acknowledgements
A special thank you goes to Dr. Nicklas Dahlström for providing a great deal of support through the university studies with extraordinary patience and incredible feedback. The support made the author wanting to walk the extra mile and perform better.

An additional special thank you goes to Michael Johansson, Lund University School of Aviation, that pointed the author towards the subject and supported the paper with discussions. Without Michael's interest, help and expertise, this paper would have never been possible to write.

Lunds Universitet Trafikflyghögskolan
Lunds tekniska högskola
Lunds universitet
Box 118
221 00 Lund

http://www.tfhs.lu.se

Telefon: 0435 – 44 54 00

Lund University School of Aviation
Faculty of Engineering
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden

http://www.lusa.lu.se

Telephone: +46 435 44 54 00

0.4 Table of Content

0.5 Abbreviations

ACARS	Aircraft Communication Addressing and Reporting System
ACS	Aeronautical Common Services
ADAS	Automated Weather Observing Systems
ADIRU	Air Data Inertial Reference Unit
ADS-B	Automatic Dependent Surveillance-Broadcast
AFSS	Automated Flight Service Stations
AIRMET	Airmen’s Metrological Information
APU	Auxiliary Power Unit
ASOS	Automated Surface Observing Systems
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATOP	Advanced Technologies and Oceanic Procedures
AWC	Aviation Weather Center
AWD	Aviation Weather Display
AWDE	Aviation Weather Development and Evaluation
AWOS	Automated Weather Observing System
AWRP	Aviation Weather Research Program
AWSS	Automated Weather Sensor Systems
CB	Cumulus Nimbus
CDTI	Cockpit Display of Traffic Information
CPDLC	Controller-Pilot Data Link Communication
CSS-Wx	Common Support Services - Weather
CWA	Center Weather Advisories
CWSU	Center Weather Service Unit
DOTS+	Dynamic Ocean Tracking System Plus
EASA	European Union Aviation Safety Agency
ERAM	En Route Automation Modernization
FAA	Federal Aviation Authority
FDP2K	Flight Data Processor 2000
FMC	Flight Management Computer
GEOS	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
HF	High Frequency
ICAO	International Civil Aviation Organization
IDS-R	Integrated Display System - Replacement
IoT	Internet of Things
ITWS	Integrated Terminal Weather System
LAW	Landing Weight
LLWAS	Low Level Wind Shear Alert System
METAR	Aerodrome Routine Meteorological Reports
MicroEARTS	Microprocessor En Route Automated Radar Tracking System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NESG	NAS Enterprise Security Gateway
NEXRAD	Next Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration

NWP	National Weather Processor
NWS	National Weather Service
OGC	Open Geospatial Consortium
SAT	Static Air Temperature
SATCOM	Satellite Communication
SESAR	Single European Sky Air Traffic Management Research Program
SIGMET	Significant Meteorological Information
SIGWX	Significant Weather Chart
SMHI	Sveriges meteorologiska och hydrologiska institut
SPECI	Aerodrome Special Meteorological Reports
SWIM	System Wide Information Management
TAF	Terminal Area Forecast
TAT	Total Air Temperature
TBFM	Time Based Flow Management
TDWS	Terminal Doppler Weather Radar
TFDM	Terminal Flight Data Manager
TFMS	Traffic Flow Management System
TOW	Take-Off Weight
TWEB	Transcribed Weather Broadcasts
VHF	Very High Frequency
VOLMET	Meteorological Information for aircraft in flight
WMSCR	Weather Messaging Switching Center Replacement
WTIC	Weather Technology in the Cockpit
ZFW	Zero Fuel Weight

1 Introduction

1.1 Purpose and Problem statement

The purpose of the paper is to open a discussion and point out the limited and slow development of weather presentations since the 1950s for pilots. (ICAO 2010) The author researched the reasons for this limited advancement and the potential services available today, such as the weather service Windy. (Windy n.d.) Aviation is often perceived as high-tech and innovative within avionics and other technological fields. Hence the aviation community should have embraced newer technology such as live updates from other aircraft and big data processing. Big data provides endless possibilities for information gathering, distribution, and research. (Hung 2016) The paper will explain how and why big data collection from aircraft is useful and how it can be used in dynamic graphical weather models generated for specific times and routes.

The METAR, TAF, VOLMET models, and the SIGMET and AIRMET coordinate system are reviewed with alternate ways of marking SIGMET areas. Potential software improvements will be presented, easing the operational burden for pilots. (ICAO 2010) The paper will present economic and environmental benefits if the aviation community's weather presentation through software could be updated and better utilized. (ATAG 2020, Rapajic 2016) The scientific community is divided regarding environmental impact. It lacks proper pollution data from aviation. (ATAG 2020) The potential gain using information from big data collection giving more precise calculations would be beneficial for both the economic departments in airlines and for environmental research.

The author further elaborates the ideas and visions by combining the technology in the discussion part of the paper. The intention is to point out available technology and the means to utilize it to the full extent by further integrating the software and hardware.

During the research, the author has not been able to find any relevant material related to the subject. According to SMHI (2021), only ICAO's minimum requirements are fulfilled due to limited budgets and lack of interest from investors. The main research focus is Air Traffic Management Systems with limited weather information connected to traffic flows under NextGen and SESAR. (FAA 2021a, ECA 2014) No known research has been or is currently being conducted towards commercial operation regarding weather presentations for pilots. Any form of research beyond the minimum requirements would be an improvement for the operative staff.

1.2 Limitations, Defined research area

The research area will be limited to a pilot's operational view as the author is a commercial pilot on the Boeing 737 as commander, with worldwide experience. The paper explores possibilities with big data, aircraft systems, and meteorology within a pilot's capability and operational field. The Boeing 737 has been used as a reference aircraft. The difference between the aircraft types is relatively marginal when comparing ACARS, air data systems, aircraft weather radar, and internet connections. Further potential discussions and developments have to be performed by professionals within their respective fields.

2 Method

2.1 Method, Disposition, and Problematization

The method used to create this paper is based on fact collection from meteorological institutes and other aviation-related institutions such as FAA and EASA. Information has also been gathered from established researchers within meteorology, aviation, and other technological fields. Quantitative and qualitative information gathering has been conducted and reviewed within the mentioned fields, and all facts and sources were revised and verified.

The selection of the collected information creating the paper was based on the usefulness from a pilot's operational view. Also, gathered information regarding technology that explains the current technological state and could aid the development of new and improved weather presentations and products.

The paper will initially point out the poor development of weather presentations for operational staff since the 1950s, progressing to collected facts, followed by qualitative and quantitative reviews. The result will then follow with possible improvements and potential developments applicable within the operational part of aviation. The lack of published research material within the field has been the biggest problem to overcome.

2.2 Material and Information Evaluation

The materials used are from various established researchers and authors within organizations, governments, the aviation field, the technological field, and the meteorological field. The sources have been appropriately assessed and evaluated as credible. Quantitative and qualitative information gathering has been conducted within the fields. All personal credentials involving experts within the areas with provided opinions, facts, and sources have been revised and verified. The author tried to conduct interviews with meteorological institutions and collect data based on a survey among pilots. Due to the Covid 19 situation and limited resources in offices, this could not be conducted. The author has been doing extended research in multiple databases. These involve LUBsearch via Lund University, DISA and Google Scholar via Uppsala University, FAA, EASA, SMHI, DMI, libraries, book shops, and internet search engines. The search words and phrases have been, among others, the following: Aviation meteorology, meteorology, aviation weather, weather presentation development, aviation weather development, pilot weather, SESAR, NextGen, and multiple combinations of the words mentioned. At times the author had to use close related research fields as a reference that has progressed further than the meteorological field. The primary available material is ICAOs Annex 3 Meteorology, but it mainly regulates how the presentation of weather should be performed and what information shall be available for operative staff. The pictures used from the FAA and NASA are not copyright protected and free to use. The author has used technological solutions and then used meteorology to connect the different areas to make the paper more practical and over-viewable for operational staff within aviation.

2.3 Background

Pilots work daily in an exceptionally dynamic environment where multiple aspects must be taken into consideration. Complex information must be gathered and analyzed before and during flight to make proper decisions to optimize the flight path. Weather information is one of the main things pilots work with extensively. Despite being so dependent on the weather, the presentation models have not been developed much.

The following chapters will describe meteorology, current weather presentations, and information pilots work with daily, technological hardware and software systems. The background will finish by briefly touching on economic and environmental aspects.

2.3.1 Aviation Meteorology

The weather is, for obvious reasons, influencing aviation in various ways. The phenomena that directly affect aviation and are of importance for operational staff are the following:

- Visibility: Despite having advanced landing systems in many commercial aircraft, visibility is of utmost importance for ground maneuvering, take-off, and landing.
- Wind: take-off and landing performance are directly related to wind velocity, but also crosswinds and cruise winds will impact the aircraft. Wind shear possesses direct threats.
- Precipitation: having effects on visibility and aerodynamic capability of the aircraft.
- Turbulence: for the comfort and safety of the aircraft regarding structural loads.
- Icing: directly affects the aircraft's aerodynamic surfaces and could potentially disrupt the aircraft's airflow, leading to a decrease in performance and aerodynamic stall on wings and the engines.
- Runway contamination: is directly affecting the aircraft's performance regarding acceleration and stopping capability.
- Lightning and convective weather: Lightning can lead to fear among passengers but also affecting structural parts of the aircraft. Burn damage on the aircraft's skin, problems with avionics, and other technical issues would potentially bring the aircraft to remain on the ground for maintenance checks, with economic losses as a consequence.

2.3.2 Current weather presentations

When researching the subject, the author had problems finding available published material outside the scope of ICAO Annex 3 Meteorology. One direct problem that might be affecting the slow development of weather services is the slow update rate of the controlling document ICAOs Annex 3. All published weather is in accordance with ICAO's Annex 3 with minor national differences. The first edition of ICAO Annex 3 was published in 1948, while the current ICAO Annex 3 is the 17th edition from July 2010 (ICAO 2010). The update rate equals out to a new edition every fourth year on average. However, the current Annex has not been updated for 11 years while the technological sectors have advanced considerably in comparison.

2.3.2.1 METAR, TAF, and VOLMET

METAR is a local meteorological routine report issued every 30 minutes. The METAR standard was developed during the 1960s and was taken into use internationally in 1968. The current model of METAR was brought into service in 1996 in the 12th edition of ICAO Annex 3. (ICAO 2010) The information provided in a METAR consists of the station's location, time issued, wind information, visibility, precipitation, cloud ceiling, temperature, dew point, and air pressure. Some airports may include a short forecast called TREND or runway condition. (ICAO 2010)

TAF was developed during the 1950s and use the METAR system to issue forecast information. New information should be sent out every 6 hours and should cover 12-30 hours forward in time. The current model of TAF was taken into use in 2001. (ICAO 2010) The information provided in a TAF is the station's location, time issued, validity time, wind information, visibility, precipitation, and cloud ceiling. The forecast can be divided into several groups by time, describing temporary changes, potential changes, or continuous changes. (ICAO 2010)

VOLMET is transmissions in designated areas that send out information about METAR, SPECI, TAF, and SIGMETs. When VOLMET was introduced according to Annex 3 is not clear at the time of writing, but an early form of VOLMET was in use by the early 1950s. (ICAO 2010, IAA n.d.)

Below is an example of a METAR and a TAF:

- SA 182020 36010KT CAVOK 03/M02 Q1022 NOSIG=
- FT 181700 1818/1918 35008KT 9999 FEW015 BKN045 TEMPO 1818/1822 SHRA PROB40 1822/1909 BKN012 BECMG 1909/1911 22010KT=

The raw data code from METAR, TAF, and VOLMETs is written in a code called GFS and will later be transferred to servers within the NextGen and SESAR systems, also called SWIM, once these systems are operational. (SMHI 2021) The author will discuss SESAR and NextGen systems further in the paper.

2.3.2.2 Weather charts

Weather charts have been developed since the early 1900s with the breakthrough by using the Norwegian cyclone model to predict frontal movement. The presentation and weather predictions have been further developed with the help of big data usage. (Ahrens 2014, Ohlhorst 2013) The Significant Weather Chart (SIGWX) can be divided into different types, generally low, medium, and high altitude. The low altitude chart usually spans from ground level up to flight level 100, the medium ranges between flight level 100 and 450, and the high level typically ranges between flight level 250 and 630. (ICAO 2010) The Significant Weather Chart is generally issued every 6 hours and shows the forecast for the specific hour stipulated on the chart. The weather displayed in the Significant Weather Chart are clouds, clear air turbulence (CAT), jet streams, tropopause height, tropical cyclones, sandstorms, volcanoes, and frontal systems. (ICAO 2010)

The main shortcoming of the weather chart is that it is subjective as a person not working in the tactile environment selects the weather. Even if computers are slowly taking over chart production, a meteorologist is still selecting the displayed weather on the charts. Due to lack of space, it might not indicate all weather. (Met Office n.d.) Examples of two weather charts may be found below.

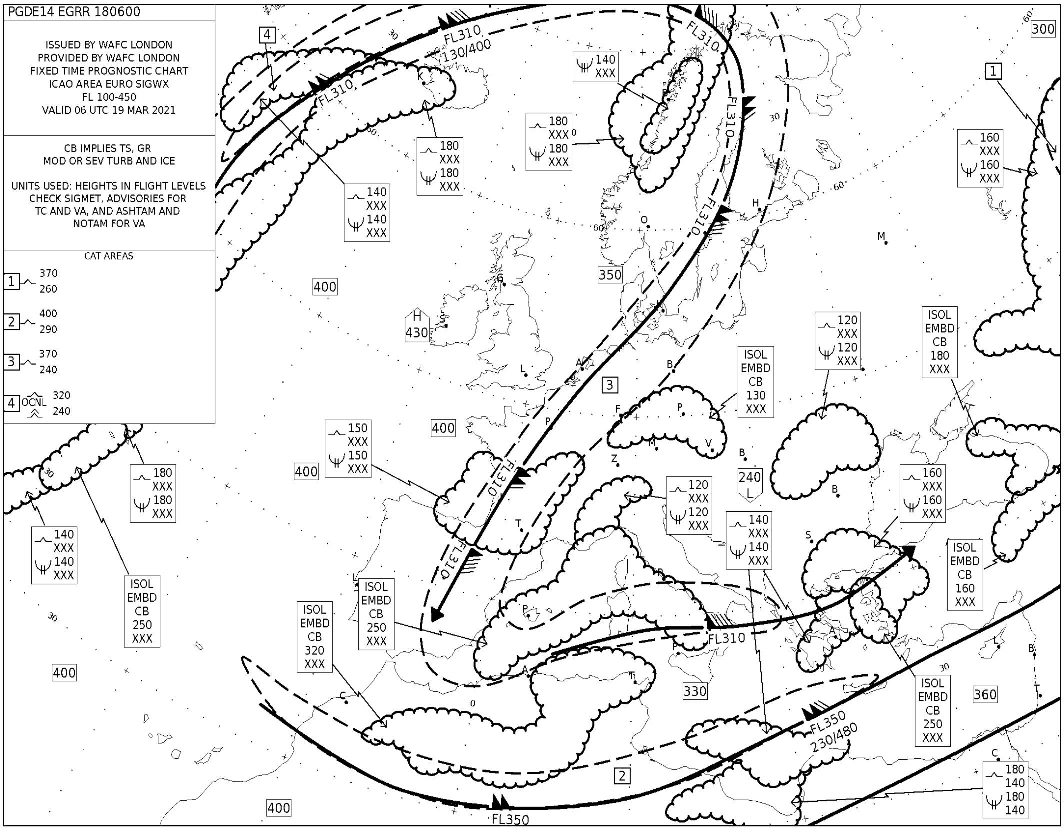


Figure 1. SIGWX (Lido 2021)

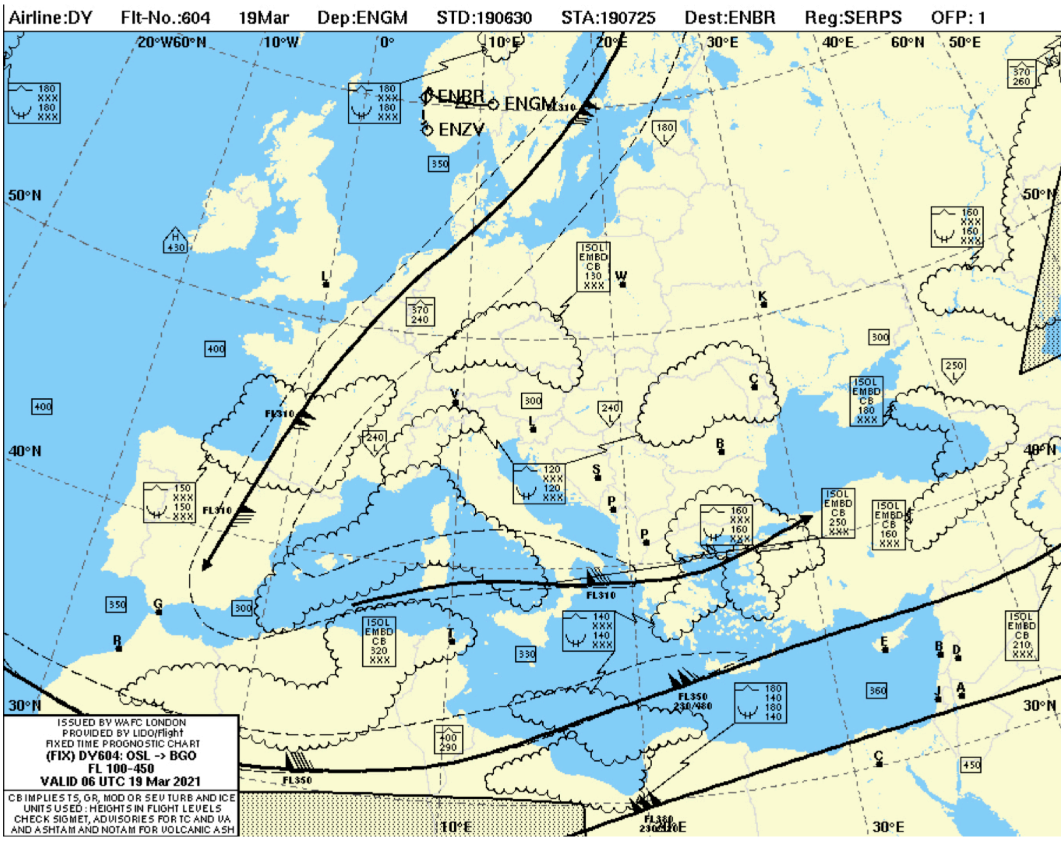


Figure 2. Prognostic weather chart (Lido 2021)

2.3.2.3 SIGMET and AIRMET

The following definitions are stated in Annex 3:

- ”SIGMET information. Information issued by a meteorological watch office concerning the occurrence or expected occurrence of specified enroute weather phenomena which may affect safety of aircraft operations.” (ICAO 2010 p.1-6)
- ”AIRMET information. Information issued by a meteorological watch office concerning the occurrence or expected occurrence of specified enroute weather phenomena which may affect safety of low-level aircraft operations and which was not already included in the forecast issued for low-level flights in the flight information region concerned or sub-area thereof.” (ICAO 2010, p1-2)

SIGMETs were first mentioned in the fourth edition of ICAO Annex 3 from 1957, and AIRMET was specified in the twelfth edition in 1995. The reporting format and information provided are similar in both SIGMETs and AIRMETs. As the definition describes, they cover different altitudes. The definition of SIGMETs has been updated through the years to involve more conditions to specify the weather better, such as wind shear, icing, and volcanic ash. However, the development of the presentation itself has been poor and limited. The SIGMETs and AIRMETs are sent out in coded text, GFS, and used in a coordinate form framing an area with adverse weather. (ICAO 2010) Once NextGen and SESAR are operational, the SIGMET and AIRMET information will be transferred to these computer systems. (SMHI 2021)

The information provided in a SIGMET is thunderstorms, tropical cyclones, turbulence, icing conditions, mountain waves, dust storms, sandstorms, volcanic ash, and radioactive clouds. (ICAO 2010) The information provided in an AIRMET is up to an altitude of 10000 feet. It contains surface wind speed, surface visibility, thunderstorms, mountain obstruction, clouds layers, cumulonimbus clouds, towering cumulus clouds, icing, turbulence, and mountain waves. (ICAO 2010) When using the SIGMETs and AIRMETs, the operating pilot needs a detailed gridded map to pinpoint the coordinates where the weather is located.

Below is an example of a SIGMET.

- KZOA SIGMET DELTA 2 VALID 081530/081930 KKCI - OAKLAND OCEANIC FIR FRQ TS WITHIN AREA BOUNDED BY N3935 W16920 – N3414 W17050 – N3010 W17325 TOPS FL470 MOV NNE 10KT NC.

2.3.3 NextGen Weather and SESAR

NextGen and SESAR is the next generation ATM (Air Traffic Management) system that is being developed. The system will optimize the traffic flow and be able to predict traffic conflicts ahead of time. The intention is that NextGen and the SESAR system will be overlapping and compatible so aircraft can use both systems irrespective of where they originate. The weather section and weather service are just a marginal part of these systems where little published information is provided to the public for further studies.

EASAs program called SESAR will be a similar system to NextGen in the USA, where the main difference is that NextGen will be providing all needed information about weather directly for pilots. SESAR enables commercial users or institutions to use the available weather data in their own developed products. (ECA 2014) Due to the lack of published material, the author will use the FAAs NextGen system as the primary reference, although some information will be provided about SESAR. The author has not been able to find a large amount of information regarding NextGen but the information used is sufficient to provide the reader with a general overview of the system. The NextGen Weather is an FAA product and is not yet implemented in FAAs National Airspace.

NextGen Weather is a collaboration between FAA, NOAA, and NASA to develop future air traffic management and weather services. The Aviation Weather Development and Evaluation (AWDE) will be conducting studies and surveys and working with National Weather Service (NWS). The results will be transitioned and translated into useable applications for the NWS and NextGen Weather Processor (NWP). The FAAs Aviation Weather Research Program (AWRP) aims to minimize weather impact within the National Airspace System (NAS). The researched areas are automated turbulence, convection, icing, ceiling, and visibility forecasts, combined with flight planning tools and guidance. (FAA 2021a) The NextGen Weather Processor (NWP) uses Aviation Weather Research Program (AWRP) to identify airspace hazards and provide traffic flow support. The NWP can predict routes and airspace constraints up to 8 hours in advance. The NWP Aviation Weather Display combines current weather displays and provides better quality weather for the users. (FAA 2021b)

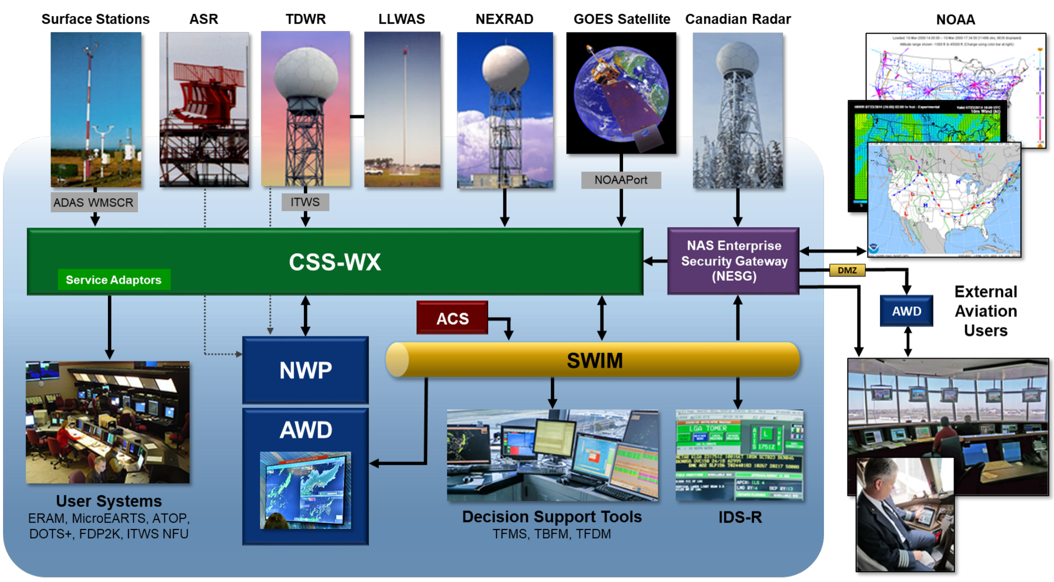


Figure 3. NextGen technical architecture (FAA 2021b)

A figure of the technical architecture of the NextGen Weather is pictured above. Common Support Service - Weather (CSS-Wx) will provide custom weather products within the NAS via System Wide Information Management (SWIM). (FAA 2021b) CSS - Wx combined with the NWP is the main component in the system. Multiple inputs are provided to the system through a wide variety of components, as pictured. The NWP processes the information, while CSS - Wx focuses on weather information. When combined, the users can receive information via the Open Geospatial Consortium (OGC) formats or the Aviation Weather Display. (FAA 2021b) The CSS - Wx offers service to users and is the only provider for weather presentations, data and imagery, and they distribute the weather via SWIM. NOAA and FAA NWP create weather products, ATC support tools, aid traffic management decisions, and reduces ATC workload. All the data is available via web services using recognized data access and formats. (FAA 2020d)

The improvements with CSS - Wx is the following:
- Consistent weather information.
- Increased weather access with weather information and map creation.
- Reduction in costs.
- Reduction in infrastructure and bandwidth cost due to user-specific selections. (FAA 2020d)

The NextGen Weather Processor (NWP) is fully automated, and the system intends to detect safety risks related to weather. The system will merge all previous systems into one for more accessibility and better usability. The NWP can predict routes and airspace constraints up to 8 hours in advance by taking information from multiple sources as pictured above, such as weather radars, satellites, observations, and combining it with NOAA forecast models. This system allows ATC to utilize the airspace more efficiently to reduce weather-related delays. (FAA 2020e) The weather information from the NWP can be displayed on a single screen, the Aviation Weather Display, with the option to add or retract different layers or user preferences. (FAA 2020f)

The FAA (2020g) states that NWP will provide four categories of products:
- Mosaic - This product is updated rapidly without distortion, and it is time-synchronized. It will match what the pilots encounter. The information comes from multiple sources like radars and satellites and will show precipitation, cloud layers, base, tops, visibility, and infrared views.
- Analysis - This product takes information mainly from Doppler radars. The information provided is storm information with motion vectors, position, intensity trends, cloud tops with hail, and lightning. Other information is wind shear and microbursts, tornado detection, and winds between ground and 18000 feet with an update sequence every five minutes.
- Predictive - The NWP will generate an 8-hour prediction based on previous radar detections. Between 0-2 hours, the system can give accuracy scores and front information. Between 0-8 hours, the system predicts precipitation, precipitation type, cloud tops, and confidence matrix.
- Translation - Combines information from radar mosaics and predictive products translated into altitude-dependent impact areas creating Convective Weather Avoidance Fields. This product can predict the no-fly zones and traffic restrains areas due to weather up to eight hours in advance. Between 0-2 hours, the system provides a Route Availability Planning Tool and Arrival Route Status and Impact updates. Between 0-8 hours, the system provides Convective Weather Avoidance Fields and Polygons. (FAA 2020g)

The Weather Technology in the Cockpit (WTIC) is researching to resolve gaps in cockpit weather information and technology, pilot knowledge, pilot training, and weather decision making. (FAA 2020b) Weather Technology in the Cockpit (WTIC) also studies how information is presented in the cockpit. They are still investigating the impact of weather information with the help of quality, presentation and integration, and missing information. The weather presentation will include convection, ceilings and visibility, icing, and turbulence. (FAA 2020h)

SESAR is, as mentioned previously, a system that is currently being developed in Europe to create a single European airspace, and it will resemble NextGen. The objective of SESAR is to have an interoperable global air traffic management system where the users share information and knowledge. (SWIM Reference 2021) System Wide Information Management (SWIM) is also developed under SESAR, and the system intends to combine and coordinate various data for easy access and overview. All information comes from many different countries under the European Union and Eurocontrol, where all information in the system will be standardized. The data in the system will consist of aeronautical information, meteorological information, cooperative network information, and flight information. (Eurocontrol 2017) SWIM will provide improved safety, efficient and collaborative decision-making, shared situational awareness, interoperability, increased performance, and lower maintenance costs. (SWIM Reference n.d.)

One of the main goals in the SESAR project is implementing trajectory flights, otherwise called 4D trajectory flights, giving the ATM real-time updates about the aircraft's position, altitude, and time. (SESAR innovation pipeline 2021) One of the systems that will be implemented is DYNCAT, Dynamic Configuration Adjustment in the TMA. The European airspace system will utilize 4D trajectories to optimize the flight routing in real-time. The result will be less fuel consumption, resulting in lower environmental impact. (DYNCAT n.d.) In addition to SESARs trajectory 4D modeling, TBO-MET with the Toplink project and FMP MET will implement weather trajectory planning, storm avoidance, and sector analysis considering meteorological forecast uncertainties. Once the system is operational, the ATM will predict potential traffic restraints due to weather. (SESAR innovation pipeline 2021) The weather modeling will be called the 4DWxCube, where the meteorological data is retained from the SWIM. The 4DWxCube should be viewed as a layered interface between SWIM and the meteorological data providers. (ECA 2014)

2.3.4 Big Data Purpose, function and potential

The following chapter will initially describe a general technical overview of big data and its use today. The author will show the potential of big data processing, analytics, and their usage in various sectors. The chapter will finish by describing how weather predictions may use big data.

Big data describes a large amount of organized or disorganized data analyzed and evaluated for further information or decisions. The data can be collected from various sources. Any form of device that produces electronic data such as geolocations, web history, or even aircraft data can be uploaded to a database for further processing and analysis. Big data consists of complex data that would overwhelm the processing power of traditional databases. (Hung 2016)
Big data can be divided into three categories: Volume, variety, and velocity.

- Volume refers to the amount of data available from big data usage.
- Variety is about the variety of available data. It can be uniform data that is needed.
- Velocity refers to the speed of processing. It is the most important factor to ensure that the available data is current and updated in real-time. (Hung 2016)

The concepts going into big data are Traditional Business intelligence, Data mining, Statistical applications, Predictive Analysis, and Data Modeling. (Ohlhorst 2013)

- Traditional Business intelligence is a broad category for gathering, storing, analyzing, and providing data access.
- Data mining is data analyzed from different perspectives and is turned into summary data for predictive use. This type of data is normally at rest or being stored.
- Statistical applications are based on statistical data, and the primary source is empirical data. It is useful for estimations, tests, and predictive analysis.
- Predictive Analysis is a sub-category below statistical applications and is intended to be predictive, based on trends and information from databases.
- Data Modeling is used to predict multiple scenarios. (Ohlhorst 2013)

The usage of big data is unlimited as it has been proven to drive innovation, economy, and productivity forward. Many examples can be shown, like mortality decrease in health care and reduction in telecommunication processing time. The power industry could improve power generation by 99%. Targeted marketing through the usage of big data is also becoming more common, and it has been proven to increase revenue for companies. Behavioral profiling via social media and data collection can further improve the marketing strategies by predicting the consumer's behavior. (Hung 2016)

Pervasive data, also known as ubiquitous computing, is a form of data collection. This means that electronics are connected and always available in real-time. It may be any form of electronic such as phones, smartwatches, or even smart homes. The electronic units are connected via Wi-Fi, voice recognition, Bluetooth, networks, and various other ways. The possibilities for connected devices are endless and may gather data continuously. Internet of Things (IoT) has, despite privacy concerns, further increased the data collection rate via the usage of various gadgets such as smartwatches and smart homes. (Hung 2016)

By using big data analytics, the benefits may be significant provided the companies are utilizing the available technology. Usually, the companies that already use big data analytics outperform within their industry. The available data creates greater processing speed resulting in a better understanding of consumer needs and consequently a better consumer experience. The analytics may also predict different types of behaviors. (Hung 2016) Big data analytics may mitigate risk giving the user more available data to make a better quality decision. Organizations or companies that use big data analytics may build up sufficient data to improve operation, identify, and prepare an organization for various types of behaviors. With big data analytics, a product may be varied in thousands of ways for fast and cost-efficient evaluations. (Hung 2016)

The examples below are taken directly from Hung's book Big Data Applications and Use Cases, showing the capability of big data usage. (Hung 2016)

- Oslo, Norway, was able to decrease street light energy consumption by 62%.
- Portland, USA, optimized the traffic signals to reduce CO2 emissions. The result was a reduction of 157000 tons during six years.
- Canadian healthcare has reported multiple improvements such as reducing monitors emitting patient data and providing timely and meaningful insights to staff who can work proactively, resulting in reduced stress levels among staff.
- UCLA Medical Center, LA, USA takes 80.000 data inputs generated each minute in critical care units to identify patients' worsening conditions proactively.
- The Canadian retail industry has adopted widespread use of big data analytics, and the result was an increase in revenue by making the shopping patterns more transparent. The analytics gave precise data regarding inventory with the highest demand products. The data minimized overstocks and optimized inventory. Further, the analytics could precisely predict demands from, for example, various social media channels and weather predictions.
- Canadian insurance has been able to speed up the processes and decrease fraud through pattern identification. The industry can identify low-risk claims and high-value clients by analyzing data such as transactions, demographics, location, and other variables. They are further able to detect potential fraud before a claim is paid.
- T-mobile in the USA reduced the number of lost customers by 50% by using big data in various ways. (Hung 2016)
- Ohlhorst (2013) mentions that NOAA analyzes climate, ecosystems, weather, and research, while NASA uses big data for aeronautics and other research.

IBM started developing Deep Thunder in 1996, a system that uses big data to develop forecast models based on statistical data collected for a longer time. The system divides the affected area into a grid of 3-D blocks that is one kilometer in size. By implementing mathematical models of the atmosphere combined with statistical data, the system can predict the weather with high accuracy. (Hamm n.d.) As the system considers not only the atmosphere but also surface features, Deep Thunder also predicts flooding by using geographical and hydrological data with a resolution of one square meter. (Gallagher 2012) For example, during heavy snowfalls in New York, the system accurately predicts the start and the end with snow amount falling. In Rio de Janeiro, the system can predict storms and precipitation levels up to 40 hours in advance with 90% accuracy. (Hamm n.d.) The Rio de Janeiro forecast production starts by taking data from a global weather model from NOAA with a resolution of 27 kilometers. By adding the previously mentioned variables such as terrain and surface, Deep Thunder can extract data to a resolution down to one square meter. The benefit when using Deep Thunder is that companies and rescue services can prepare for the aftermath of storms. (Gallagher 2012)

2.3.5 Aircraft system possibilities

An aircraft has several ways to collect, process, send and receive data. The author will describe potentially useful aircraft systems to collect data that would aid situational awareness for pilots and ATC. By using big data analytics, the users get a better overview of the current weather situation. Systems capable of data transfer will be described.

2.3.5.1 Weather Radar

The weather radar system detects and locates various types of precipitation-bearing clouds giving the pilots a visual indication in color about the intensity of the clouds. The radar antenna sweeps forward in a 180-degree arc. (Boeing 2020) The weather radar uses radar beams to scan the area in front of the aircraft by sending out one upper beam for long-range detection and a lower beam for short and long-range weather detection. (Boeing 2020 p 11.20.11)

The intensity of the precipitation is displayed in colors on a black background. The heaviest precipitation areas are displayed in red, the next lower level is pictured amber, and the least is colored green. The weather radar may have a turbulence mode indicating turbulence associated with precipitation. When the weather radar detects a horizontal flow of 5 m/s or more towards and away from the antenna, the weather target becomes magenta. Magenta is associated with heavy turbulence, and the detection range for turbulence is typically limited to 40 nautical miles. (Boeing 2020)

Depending on the weather radar version, some radars can also detect wind shears on the ground and below certain altitudes. Recent developments provide weather radars the ability to swipe over larger areas, up to 320 nautical miles, in two swipes storing the weather information in a database and decreasing the ground clutter with the help of an integrated terrain database. (Boeing 2020)
The radars may also have Overflight protection keeping the thunder cells displayed to a maximum of 6000ft below the aircraft, even though the aircraft is flying above the cloud, making the pilots aware of the potential risks. Other functions may include temperature calculations, wind calculations, potential electrified regions, core threat adjustments, two-level turbulence detection

colored solid magenta or magenta dots depending on intensity, and predictive wind shear warnings. (Boeing 2020 11.20.12-11.20.13)

2.3.5.2 Air Data Inertial Reference Unit

The Air Data Inertial Reference Unit (ADIRU) produces flight data such as position, speed, altitude, and attitude. Inertial track and position data are sent from the ADIRU to the FMC, Flight Management Computer, combined with attitude, altitude, and speed information to the flight deck displays. The ADIRU processes data measured by internal gyros and accelerometers, the Inertial Reference System, IRS, air data module inputs, alpha vanes, and other systems. (Boeing 2020)

The air data collected derives from the pitot-static system measuring both static and dynamic air pressure. The pneumatic pressure is converted to electrical signals and sent to the ADIRU. Total Air Temperature (TAT) is measured from the ambient air, and Static Air Temperature (SAT) is calculated from the Total Air Temperature for use in the ADIRU. (Boeing 2020) The combination of data gives the aircraft possibility to calculate the wind direction and speed. The information is also sent to the weather radar as it uses the data for weather calculations, displaying potential wind shear warnings and turbulence areas. (Boeing 2020)

2.3.5.3 ACARS

ACARS (Aircraft Communication Addressing and Reporting System) is a communication system installed in most modern commercial airliners today. ACARS is an addressable digital data link system that permits data and message exchange between aircraft and ground stations operating over a VHF and SATCOM communication system. In addition, CPDLC (Controller-Pilot Data Link Communication) allows data exchange between Air Traffic Control and the aircraft. ACARS provides the option for manual entry of routine data and the possibility to address parties on the ground for voice communication. The ACARS is often connected to a printer in the aircraft. (Boeing 2020)

The company operating the aircraft can add additional functionality to the ACARS by enabling the system to communicate over HF, VHF, and SATCOM. The current data transfer rate is currently set to 31,5 kbps over VHF and 3-4 kbps over SATNAV. (EASA 2018) The messages are referred to as uplinks and downlinks, allowing two-way communication for applications such as digital ATIS, clearances, weather reports, turbulence reports, delay reports, and free text messaging between aircraft and ground-based stations. The aircraft can also send and receive information about flight times, engine data, and position reports, to mention a few functions. (Boeing 2020)

2.3.5.4 ADS-B

ADS-B (Automatic Dependent Surveillance-Broadcast) Enables the aircraft to both send and receive traffic and weather information. Many countries are being involved in the development of ADS-B, and the two most significant contributors are the USA with FAA and Europe with EASA. (Richards, O'Brian, Dean 2010) ADS-B intends to improve traffic flow, capacity efficiency, and safety where the system can track aircraft in the air and on the ground. The ADS-B system is a part of the NextGen system in the United States of America and SESAR in Europe, where ADS-B will replace conventional radar and allow ATC to monitor aircraft with better accuracy and precision for a lower cost. (Richards et al. 2010)

The system relies on GPS satellites and ground stations for surveillance and information transfer, as pictured above. ADS-B can be divided into ADS-B In and ADS-B Out. The ADS-B Out transmits information from the aircraft to satellites and ground stations for ATC usage in traffic flow and other aircraft for position information. The information sent is coordinate position, altitude, speed, emergency status, and flight number. The information presented in the flight deck of the receiving airplane is called ADS-B In. (Richards et al. 2010)

According to Richards (2010), the components needed for this system is the following:

- ADS-B Out requires a GNSS receiver with antennas that can receive and send the needed information.
- ADS-B In requires an airborne collision avoidance system/traffic alert and collision avoidance system unit with associated antennas to receive an ADS-B Out message. The information will be displayed on a separate display called Cockpit Display of Traffic Information (CDTI) or directly on the cockpit displays depending on the aircraft's capability. Other systems may be included in the system, such as the FMC, control panels, electronic flight bags, and displays.
- The ground components require antennas for receiving and sending information, a receiver, power supply, communication links via ground stations or satellite, and finally, data security.

(Richards et al. 2010)

ABS-B improves the crew's situational awareness in relation to other aircraft in real-time, where all ADS-B users will have the same information giving a common and shared picture of the current situation. Both air and ground traffic can be a part of the system providing immediate updates of the situation and providing warnings to other traffic. Once the system is fully operational, the minimum separation between aircraft may be reduced, and more direct routings can be achieved. Airlines can also use more optimum routes and altitudes regarding favorable weather and winds if the information is available. General aviation aircraft that use ADS-B can receive graphical weather and flight advisories in text form. (Richards et al. 2010)

2.3.5.5 Internet

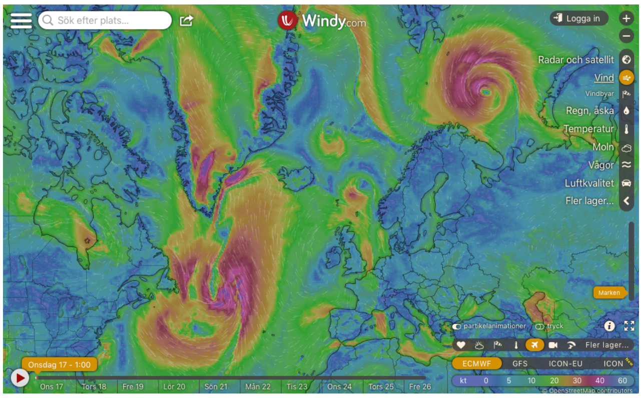
Several providers exist for onboard internet in aircraft, for example, Global Eagle with ROW 44, OnAir, and GoGo. The systems use satellite or ground-based stations, providing internet to aircraft. The systems may be configured into different networks such as prioritized networks, hidden networks, crew networks, and customer networks. (GoGo 2020) By dividing up the networks, one network that is hidden and prioritized, the crew may access high-speed continuous internet via the Wi-Fi connection on the electronic flight bags (EFB) or any other unit used onboard. Private and prioritized networks enable the crew to do updates and check the latest information that might be required.

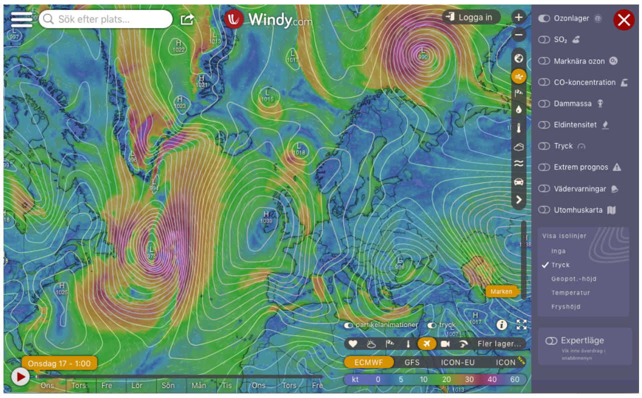
Up and coming internet provider Starlink project with Elon Musk's SpaceX will provide users with high-speed worldwide internet coverage using satellites in lower earth orbit. Once the system is further developed and not dependent on specific geolocations, the system would provide an invaluable worldwide connection to aircraft due to the sheer number of satellites in orbit with a much higher data transfer speed. (Starlink n.d.)

2.3.6 Software

In the following part, the author briefly describes available and used software or applications with potential uses within aviation. The author also points out a few shortcomings. The technical descriptions are limited due to business secrets.

Windy: The homesite www.windy.com launched in 2014 as a hobby project by a Czech programmer to depict weather in a layered form for the public. Throughout the years of development, applications became available for handheld devices. The weather data used is the Global Forecast System (GFS) with a resolution of 22 km, the European Centre for Medium-Range Weather Forecasts (ECMWF) with a resolution of 9 km, ICON with a resolution of 6 km for Europe and 13 km for global display. (Windy n.d.) When using the homesite or application, the user can select the information needed in a layer form where various colors will display the weather intensity. The user may choose different time frames, winds, isobar lines, water temperature, or other needed information. When the user zooms in and selects an airport, the current METAR, TAF, and NOTAM are displayed and updated continuously. (Windy n.d.)

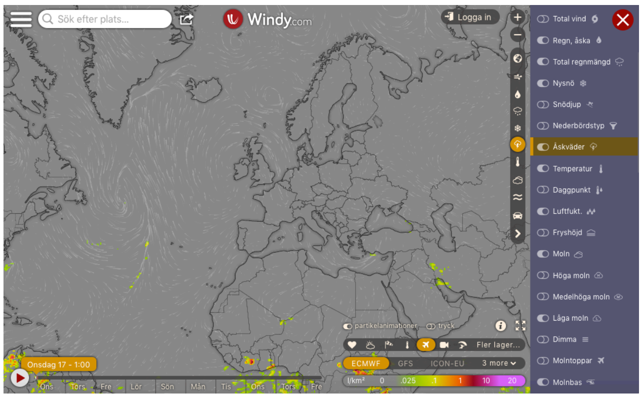




Figures 4 and 5. Screen dump with winds and screen dump with isobars (Windy n.d.)

Figures 6 and 7. Screen dump with temperature and screen dump with thunder cells (Windy n.d.)

Figures 8 and 9. Screen dump with METAR and TAF and screen dump with airport information (Windy n.d.)



Skybreath: The software's primary goal is to save fuel by processing large amounts of data obtained from various sources. The software analyzes the fuel consumption of an aircraft by using big data algorithms, artificial intelligence, and machine learning. The data is collected from flight data recorders, operational flight plans, ACARS, and more. Then, the program combines the aircraft information with actual flight conditions, for

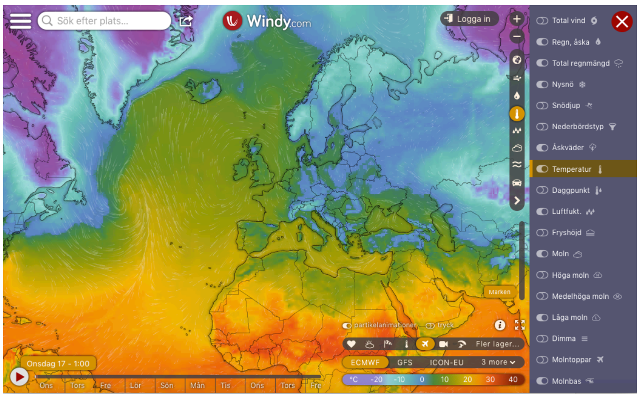
example, payload, weather, and ATC constraints, to identify the most efficient way of operating the aircraft to save fuel. (Openairlines n.d.)
Pilots can later access the collected data via an application or a homesite and compare the planned with the actual fuel burn in the different segments. It can be displayed in either alphanumerical form or as a graphically projected flight path in different colors to show where the operator can save fuel. The application registers everything consuming fuel, from starting the Auxiliary Power Unit (APU), taxi times, climb out, cruise segment, descent, approach, and taxi in to gate. The program has been proven to increase the pilot’s awareness of fuel usage. (Openairlines n.d.)

Flight planning software: This software is crucial to be able to conduct a flight. The flight planning software plans and calculates all needed information for the crew to plan and perform the flight optimally. Much of the information provided in the flight plans are similar between the different providers. A few good examples would be Lufthansa's Lido, Sabre Airline Solutions, Air Support PPS, Universal, and Jeppesen.

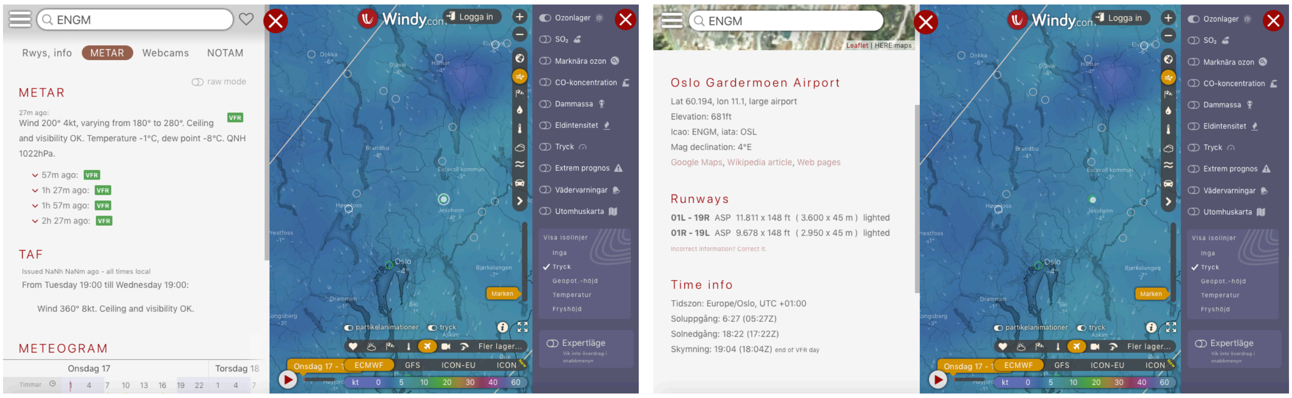
2.3.7 Environment and Economy

Aviation contributes to climate change and global warming by emitting various chemicals into the atmosphere. When the author has been researching aviation's environmental footprint, the information from various sources differs considerably. The author understands the complexity of measuring the exact footprint as many factors are unknown to scientists. As an example, when condensation trails are being debated, no one can estimate their impact on radiation reflection. The same goes for the difference in releasing greenhouse gases higher up in the atmosphere as compared to the ground. It is safe to assume that most people agree that aviation contributes to global warming, even if the impact of pollution is argued over. The author only points out some key facts regarding pollution due to consuming fuel and other facts that might affect development towards a sustainable aviation market.

The goal is to reduce the environmental footprint by 50% by the year 2050 compared to 2005. Between 2009 and 2019, the aviation sector has increased fuel efficiency by more than 2% per year. (ATAG 2020) In 2019 aviation's estimated consumption was 363 billion liters of fuel that is 8% of the world's liquid fuel use. Aviation released 914 million tons of CO_2, about 2.1% of the world's CO_2 emissions. (ATAG 2020) According to other sources, aviation stands for 2,5% of the world's CO_2 emissions and 3,5% of global warming. (Ritchie 2020)



If disregarding the current Covid19 situation, aviation global economic impact is over 3.5 trillion USD per year, including Direct, Indirect, Induced, and Tourism Catalytic. The amount equals out to 4.1% of global GDP, and the business employs 87.7 million people. Another affecting group is Other catalytic, and it is almost impossible to determine its economic value. By the year 2038, the aviation sector expects the economy to turn over 6.3 trillion USD, supporting 143 million jobs. (ATAG 2020) To further explain the groups and factors involved according to ATAG:



- Direct: airlines, airports, airport services, air navigation service providers, and civil aerospace.
- Indirect: Off-site services, goods manufacturing, service companies.
- Induced: Economic spending of direct or indirect employees.
- Tourism Catalytic: The tourism sector.
- Other Catalytic: Global trade, labor supply, productivity of other sectors, education, healthcare, family ties, connectivity, lifelines for remote areas, investments, and research. (ATAG 2020)

During the year 2019, airlines paid 188 billion USD for fuel. Fuel is, on average, 23,7% of an airline's expenses. (ATAG 2020)

Delays are a significant cost for airlines. According to FAA, the weather was the cause in 69% of the cases when the delay was more than 15 min. (FAA 2021j) Eurocontrol reports that 25.5% of all delays in 2017 were due to weather. Between 2013 and 2018, the delay minutes had increased by 80%. (Eurocontrol 2018) According to Rapajic (2016), putting the numbers mentioned above in an economic context, the following are brought up:

- ATC delay costs over 12 years in the USA, 170 billion USD
- Annual disruption costs in the USA, 22 billion USD
- Annual delay cost in the USA, 41 billion USD for airlines, passengers, and economy
- Annual delay cost in Europe, 10 billion USD
- Cost per minute delay in Europe, 39,4-48,6 Euros for airlines
- Cost per minute delay in the USA, 70 USD
- Direct and indirect delay cost worldwide 0,6-2,9% of revenue

(Rapajic 2016)

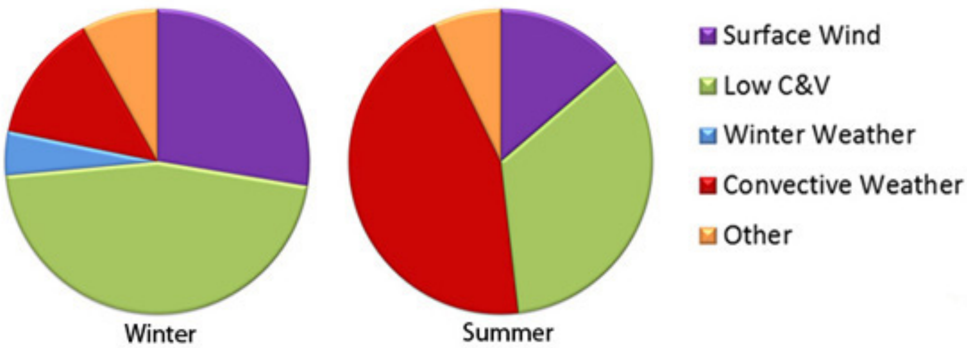


Figure 10. FAA Weather delay reasons during winter and summer (FAA 2021j)

Nowadays the cost is probably higher as the number of flights, passengers, and the delay minutes have increased. (Eurocontrol 2018) The author emphasizes the importance of minimizing the delays, primarily when the FAA reports 69% and Eurocontrol reports that 25,5% of delay is due to weather. Improving the weather forecasts and presentation models for pilots would minimize the weather delays and prevent misunderstandings.

3 Results and Discussion

Much of the information is the author's vision of what he believes would improve the weather presentations, briefings, and operations.

3.1 Weather presentation

The current weather presentations have had a slow development since the mid 20th century, and the weather presentation progress is moderate compared to other sectors. Information technology is a prime example where rapid development has taken place and continues to do so. The technology and data are available; utilizing it in the right way will improve the weather presentations.
The Annex is the primary regulating publication providing the bare minimum requirements. It could be reasoned that its slow update rate is one of the causes that prevent faster progress. Updating the Annex with regulations and recommendations would pressure the governing bodies and companies to update and develop the weather presentation models and presentation tools.

The author thinks METAR, TAF, and VOLMET in the current format is a good standard and efficient way to distribute weather information. However, it does not exclude that presentations may be developed further with a higher degree of standardizations and by adding extra information after the main message, such as runway conditions. A visual weather presentation would help the understanding of the current weather situation. The European airports add the runway conditions to the NOTAM. The author subjectively thinks that this type of information should be located with the weather information.

Weather charts have the most significant potential to be updated. Much of the provided information is, as mentioned, not relevant for the flights performed. The information is also subjectively selected by meteorologists. The lack of space on the charts and lack of color-coding also leaves out information about location and intensity regarding the pictured weather. The information should be presented in color, and the charts should be relevant to the flight being performed. (ECA 2014) As illustrated with the weather chart found in chapter 3.3.2.2, for the flight conducted domestically in Norway, the author has a problem seeing the relevance of receiving charts covering entire Europe, North Africa, parts of the Middle East, and the Canary Islands. The charts should be relevant, color-coded, and less subjective. The less subjective part can be achieved by big data processing and feedback loops from pilots that operate in the conditions. As time passes, statistical data would show the relevant data to be distributed, such as crucial local weather phenomena.

SIGMET and AIRMET also have the potential for improvements. Many companies do not have an in-person dispatch office providing relevant and highlighted information to the pilots, and the briefing is normally conducted under time pressure. When using SIGMETs and AIRMETs, the operating pilot needs a map to pinpoint the coordinates where the weather is located, which is a relatively slow process. The problem can be overcome by including a detailed map with the weather phenomenon or, if possible, using waypoints, navigational aids, or geographical points such as cities to cover the affected area. The chart would make it easier and faster for pilots to visualize it.
To highlight the importance of improvements in SIGMET and AIRMET, the author would like to point out that the most common reason for injuries in the air, according to FAA (2011), is due to turbulence. IATA also states that weather is the leading cause of 31% of accidents and 43% of fatal accidents between 2012 and 2016. (IATA 2017)
NextGen and SESAR are taking development steps by combining various weather inputs into one system, SWIM. The system will increase the overall overview of the weather by using big data

processing with highly advanced algorithms and artificial intelligence capabilities. (SWIM Reference n.d.) The main shortcoming of the SESAR system is that it does not provide weather developments or presentations for pilots either before or during the flight. Much of that responsibility is put on private companies to offer presentation models and tools. NextGen is trying to improve the pilot's situation with the Weather in Cockpit project. However, there is still potential for improvements, and it is far from being ready to be deployed into active use.
(FAA 2020h)

According to SMHI (2021), much of the raw data weather is sent to various sources for central processing, presentation creation, and redistribution. The raw data is made available to the public without costs and can be used freely. The central processing creates a problem where local variations are not fully considered and may be overlooked. The weather information is available, but it appears that there are no regulations in place except ICAOs Annex 3 on how to utilize the weather data. An overview of the current presentation models would be beneficial to increase the productivity and understanding of the pilot's work with weather situations.

The foremost thing pilots in Europe would benefit from is a meteorological portal, a ”one-stop-shop” for weather and weather presentation, similar to www.avationweather.gov and flight planning software like the now-defunct DUATS and current WXbrief in the United States of America. (ECA 2014) A complete weather service would be a significant improvement as all weather from SWIM would be collected, presented in a user-friendly way, and available flight planning software with trajectory flights would be made available for operators at a lower cost.

3.2 Hardware

3.2.1 NextGen and SESAR

NextGen and SESARs SWIM project standardizes and unifies the weather models into one type, which is a significant development. However, as of today, these systems do not include rules or regulations regarding presentations for pilots. According to the available information, the system’s main shortcomings are that it lacks live updates from other aircraft and the ability to present the weather for flying staff more understandably.

Once NextGen and SESAR are operational to the full extent, using trajectory flights in 4D, weather and weather models should be quite easy to integrate into other software as the data will be made available and standardized according to SWIM. SWIM will give a better overview for both ATC and pilots, under the condition that the information is made accessible for both parties, giving them a shared situational awareness to act and plan for the problematic weather. A function that is not planned to be developed in either system is additional input from aircraft operating in the airspace with weather radar scans, winds, temperatures, and turbulence. Air Traffic Management's situational awareness would increase if aircraft data were integrated, giving faster updates in the planning software and the trajectory planning.

3.2.2 Big Data

Big data processing is one of the most significant developments regarding data collection and processing. It is already in use by many aviation institutions and companies. The purpose of analyzing a large amount of data differs, however. An example would be weather data by meteorological institutions. The potential is limitless and would serve aviation very well as the industry is data-driven to a large extent. The potential for big data collection from the various aircraft systems, operation departments in airlines, and air traffic control could be advantageous when developing possible products and using them. Combining big data analytics with artificial intelligence and machine learning could minimize the mistakes and mishaps by air traffic control, using advanced calculations for traffic flow based on statistical data. The current traffic situation and weather could be combined with the statistical models to optimize traffic flow.

After conducting thorough research, the author has concluded that meteorology is a data-driven area where big data processing is significantly used in various forms of weather modeling. The information is provided to different parties utilizing the data in multiple ways. The main shortcoming is that the weather predictions are not yet integrated into SWIM and the Air Traffic Management system (ATM). If the weather data were made available on a larger scale for integration in other software systems with live updating, the system's predictability would significantly increase.

3.3 Aircraft systems

Today, most airliners use digitalized systems enabling the aircraft to collect data from various sources throughout the aircraft systems. The aircraft's digital information may derive from internal and external sources. The computing power of today's airliners and many small aircraft are capable of handling data beyond the current usage. (EASA 2018) It would be a benefit to improve the aircraft sensors, enabling measurement of humidity. That would enhance aircraft systems and give meteorological institutions more data to produce better weather forecasts. (SMHI 2021)

The author has observed the weather radar's limitations when using it in adverse weather with heavy precipitation, especially in tropical conditions. Weather avoidance is based on the known displayed weather. With an increase in precipitation intensity, however, the weather radar's range will decrease. Once the precipitation is heavy enough, the weather radar will only display the first convective cells. Everything behind the first cells will not be displayed, making the weather invisible. The uncertainty is a direct threat, especially when operating in darkness. The aircraft operators might not have a complete picture of the current weather situation when avoiding the initial convective cells. Two more shortcomings are that the weather radar is unable to detect icing conditions and volcanic ash.

All inputs in an aircraft are converted into data before being presented on screens, for example, aircraft position, winds, weather radar scans, temperature, and g-loads. The data could be sent through various data links, ADS-B, ACARS, or even internet connections if available to a big data processing unit for further distribution back to aircraft and ATC. The aircraft could receive the combined, processed data via similar channels, ADS-B, ACARS, or internet connections.
As previously mentioned, the weather radar cannot "see through" adverse weather. Instead, the radar can only picture what is in front of the operator. With more aircraft in the area, the pictures could be combined and create a better situational awareness of the current weather situation, a form of 3D modeling.

All aircraft data made available for big data processing gives the users a live update of weather, improving climb out performance, optimizing cruise altitudes concerning wind, turbulence, and finally, a better planned descent saving money and giving less environmental impact. It would also improve safety as adverse weather, wind shear, and other weather would be better overviewed and planned. One more benefit is that governing bodies would get a much better overview through big data collection, enabling systems development based on needs.

3.4 Software

The software providers on the market today, either commercial, governmental, or hobby programmers, are showing that technological capability is available. If the software providers would enable the software to integrate the functionality and benefit from each software's strength, the potential is limitless. By combining the weather presentation of windy.com, the fuel-saving possibilities of Skybreath, and the flight planning software available, the safety, comfort, and potential fuel saving would be improved. Except for sustainable aviation fuel mixtures, software development can probably make the most significant improvements quickly as airplane technology requires long certification processes, and the next generation ATM is years away from being fully operational.

The author has occasionally used Windy when the weather has been poor and on the limit for landing and when intense weather systems have been moving through Europe. It helped to increase the overview of the weather systems in more detail. The application provides user-friendliness, a graphical weather explanation, and easy access. It is an excellent complement to the flight planning documentation provided at briefings. The author recommends the reader to enter www.windy.com to view how the program is depicted and explore functions.

The main shortcoming is the weather presentation in the flight plans. For example, when performing a short flight within Norway, the weather charts will be displayed over entire Europe, North Africa, and parts of the Middle East. (Lido 2021) Due to the large area covered, the weather charts might not contain detailed enough information. The two weather charts pictured previously in chapter 3.3.2.2, taken from an actual flight between Oslo and Bergen in Norway, illustrate the problem. Satellite pictures present the same issue as they cover a great area. The author understands that much of the information is distributed from central distribution centers. Still, when meteorological information lacks relevancy and accuracy, flight safety might be affected as important information might be overlooked or not published due to lack of space. Also, when issuing weather charts from central distribution centers, local meteorological conditions might not be known. The flight planning programs have one more problem. They plan a flight several hours in advance without updates regarding routing, optimum flight levels, and weather. The programs should continuously update the flight plans until the last possible moment. After that, frequent updating of the weather and optimization of flight levels should occur to maximize the aircraft's performance and minimize the fuel burn.

3.5 Operational practices

The author intends to briefly describe how a working model of how the system could function in the chapters below. The description is subjective and a vision of what the author thinks would be a good development. The following description is also where the author tries to combine the current and up-and-coming technology into one product. By combining and optimizing all products, the software would overlap and work in harmony using each strength.

One of the concerns to evaluate is whether the information provided to pilots is too much to process and handle. The good thing with the described suggestions is that only relevant data would be presented as layered information. No unnecessary METAR, TAF, SIGMET, and NOTAMs would appear. The selection of data does not exclude other meteorological information and NOTAM about the surrounding airports. It may be available if selected or additionally in the raw data form we use today. This type of layering of information would limit the risk of information overload on the flight crew.

3.5.1 Preflight

When discussing presentation development, the author pictures that the weather presentation would be an online or application type of briefing dynamically generated for a specific route with ETD -1 hour to ETA of +2 hours. The weather could be presented as windy.com. For example, adding a trajectory, shaped in a 4D tube of a certain size, scrollable from departure to arrival with SIGMET and AIRMET potentially affecting the flight included in the briefing. The size of the 4D tube could be variable. At the departure airport, the weather would be detailed from ground to the cruise altitude plus additional height above cruise altitude, and the horizontal coverage could extend out like a cone up to 100 nautical miles to each side. Once reaching cruise altitude, the weather displayed could be up to 100 nautical miles left and right of the flight track and +-10.000 feet of altitude, depending on settings. The horizontal cone would be reversed once starting to descend towards the destination ending with a circle extending 50 nautical miles from the airport. The vertical weather could be displayed from cruise altitude to ground level. The area outside the cone would have less resolution and information but still sufficient information for pilots to decide for usage in case of diversion. The picture below illustrates how it could look.

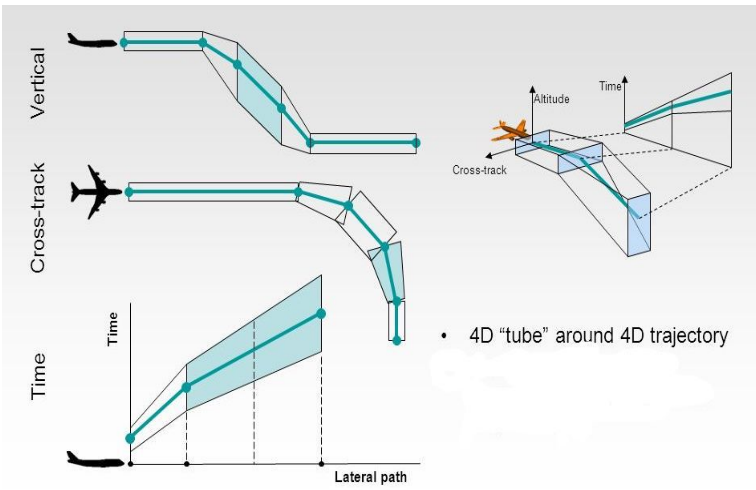


Figure 11. 4-D tube based on Vivona (2008)

The departure airport, potential departure alternate airport, arrival airport, and alternate arrival airports could have the METAR and TAF published on the side available at all times. The relevant

SIGMET and AIRMET would be highlighted at the coordinates mentioned and in the specified altitudes. When scrolling through the tube, the user should be able to stop and analyze the weather in a time-lapse to see the movements of fronts, winds, and other weather. The weather could be layered, enabling the user to see specifically selected and relevant weather phenomena. Relevant NOTAMs could also appear as the operator scrolls through the flight. When following the planned route, the flight path could include:

- The expected fuel burn.
- The expected remaining fuel.
- Weights of the aircraft with the help of a program like Skybreath and the flight planning software.

3.5.2 Airborne

Once the crew arrives at the aircraft, the system has continuously been updated with live data from SWIM and live data from other aircraft. Big data algorithms would be processing the information from the available software previously mentioned. If any threats or unplanned changes have occurred before departure, the crew could then account for it. The system could also calculate and recommend if it is worth departing using new data from SWIM and weather trends. If not an economic gain to depart, the software could give recommendations to the operation department with replanning options to minimize the delay impacts on other flights.

Before departure, the crew could load the current departure winds in the flight management software to optimize climb-out performance. When airborne, the aircraft will send and receive weather information via various technological ways for a real-time update. Information from big data processing will calculate the best cruise level for optimum fuel saving. If the flight would expect a rapid deterioration in weather along the route, information from ATM, SWIM, and the flight planning software, combined with a program like Skybreath, could recalculate the trajectory and recommend an optimized route with current conditions to avoid the weather ahead. The system could also provide statistical data on regular shortcuts for the airport, giving the crew a chance to plan ahead.

When the flight is approaching the arrival airport, the latest descent winds would be available from other aircraft. The winds could give optimum descent planning with idle descent as long as possible, maximizing the fuel-saving. In case of poor weather, the software could compare the gain in returning to the departure airport, enter a holding to wait for improvements, or divert directly to the alternate airport where the weather conditions would be better. The inflight recalculations would give a potential economic and environmental gain as no fuel would be wasted.

3.5.3 Post Flight

The post-flight could be performed by analyzing the data created during the flight for feedback for air traffic control, airline, and pilots.

- Air traffic control would get a better picture of aircraft performance and traffic flows.
- The company would be able to optimize the payloads accordingly to maximize the revenue.
- The pilots would get direct feedback to improve the operation by improving passenger comfort, safety, and fuel-saving.
- The system would gain more statistical data to perform better predictions in the future.

3.6 Environment and Economy

As previously mentioned, aviation spent 188 billion USD on fuel. The spending on fuel resulted in 363 billion liters of liquid fuel, which gave 914 Million tons of CO2, according to ATAG (2020). By combining all the technologies mentioned above, the author expects that a minimum of 2-5% saving in fuel would be possible, potentially more. The fuel savings could be even more significant than individually using the programs and applications by optimizing all software and planning tools available. The author has made a table showing the amount of savings possible if reducing fuel consumption. The numbers are based on the 2019 numbers in the ATAG report and are the worldwide consumption. As seen in the diagram, even minor improvements give substantial savings on both the economy and the environment.

Save in %	1	2	3	4	5	6
Dollars saved	1,88 B	3,76 B	5,64 B	7,52 B	9,4 B	11,28 B
Liters of fuel	3,63 B	7,26 B	10,89 B	14,52 B	18,15 B	21,78 B
CO2	9,14 M ton	18,28 M ton	27,42 M ton	36,56 M ton	45,7 M ton	54,84 M ton

Table 1. Savings regarding Economy, Fuel Quantity and CO2

The author supports the ideas of making aviation socially acceptable in the future, where multiple aspects must be considered. The four primary areas that would make the most significant impact are aircraft technological advancement, air traffic management optimization, sustainable aviation fuel, and implementing economic measures. The main concern is how to create incitements for the business to switch over to greener options. The author believes that as long as the options would decrease the economic growth, the airlines and developers would not consider the alternative. Therefore, the solutions must be driven by financial gain for airlines and developers.

3.7 Conclusion

The author believes that much is needed to improve the weather presentations for pilots. A good starting point is that research must be conducted within the field, combined with updating ICAO the Annex 3 with recommendations and regulations.
The following is needed according to the author:

- Updating regulations and recommendation
- Research development of weather presentations
- Integrate weather presentations for pilots into NextGen and SESAR
- Updating weather charts to make them relevant for the flight conducted
- Mandatory color usage on all weather charts
- Create a feedback loop from pilots to meteorologists creating the weather charts
- Utilize the available data produced from aircraft systems to combine in various applications

- Provide recommendations to software developers for integration and combining of various software into one product
- To provide a ”one-stop-shop” weather portal in Europe like WxBrief in the United States.

3.8 Final words

The author understands that this vision would require a certain amount of recommendations and regulations to be in place to be able to change the weather presentations for operational staff. However, commercial interests may develop their own software that fulfills ICAO, EASA, FAA, and company requirements. The author believes that it is possible to develop new improved software as the regulatory requirements are set relatively low. The additional requirements are small additions to the main program regarding EASA, FAA, and company demands.

The author finds it astonishing that so little weather presentation research is performed towards pilots and operational staff as they work in the operational environment. The research areas are focused on traffic flow management and a bit towards air traffic management with storm avoidance. There is practically nothing conducted towards pilots, and there is no feedback loop from the staff working in the tactical environment except company reporting systems. The lack of research is a major flaw that has to be improved to optimize the weather presentations and flight conditions pilots work in and not leave it up to people with no or limited experience working in aircraft.

4 References

Ahrens Donald, Henderson Robert (2014) Meteorology Today: An Introduction to Weather Climate, and the Environment Eleventh edition, Canada: Cengage Learning ISBN: 13:978-1-305-26500-4

ATAG (2020) Aviation Benefits Beyond Borders September 2020, Air Transport Action Group 2020 Retrieved 2021-03-19

Boeing (2020) Boeing 737-800 Flight Crew Operations Manual Norwegian Revision Number 32 Seattle: Boeing Company

Christodoulou, Aris, Demirel, Hande (2018) Impacts of climate change on transport - A focus on airports, seaports and inland waterways. Luxembourg, Publications Office of the European Union ISBN 978-92-79-97039-9, DOI:10.2760/378464, JRC108865

DYNCAT (n.d.) DYNCAT - Dynamic Configuration Adjustment in the TMA https://www.sesarju.eu/projects/DYNCAT Retrieved: 2021-03-27

EASA (2018) Weather Information to Pilots Strategy Paper, An Outcome of the All Weather Operations Project Retrieved 2021-03-27

ECA (2014) Pilots Vision on Weather ECA Piloting Safety, European Cockpit Association Retrieved 2021-03-30

Eurocontrol (2018) Weather responsible for a third of delay https://www.eurocontrol.int/news/weather-responsible-third-delay Retrieved 2021-03-21

Eurocontrol (2017) Eurocontrol Specification for SWIM Information Definition Eurocontrol-Spec-169 ISBN 978-2-87497-095-5

FAA (2011) InFO, Information to Operators InFO 11001, Date: 1/6/11 Washington DC; Flight Standard Service

FAA (2021a) NextGen Weather https://www.faa.gov/nextgen/programs/weather/
Retrieved 2021-03-04

FAA (2021b) NextGen Weather Architecture https://www.faa.gov/nextgen/programs/weather/architecture/ Retrieved 2021-03-04

FAA (2020c) Aviation Weather Research Program https://www.faa.gov/nextgen/programs/weather/awrp/ Retrieved 2021-03-04

FAA (2020d) Common Support Services - Weather (CSS-Wx) https://www.faa.gov/nextgen/programs/weather/csswx/ Retrieved 2021-03-04

FAA (2020e) NextGen Weather Processor https://www.faa.gov/nextgen/programs/weather/nwp/
Retrieved 2021-03-04
FAA (2020f) Aviation Weather Display (AWD) https://www.faa.gov/nextgen/programs/weather/nwp/awd/ Retrieved 2021-03-04

FAA (2020g) NWP Products https://www.faa.gov/nextgen/programs/weather/nwp/nwpproducts/ Retrieved 2021-03-04

FAA (2020h) Weather Technology in the Cockpit https://www.faa.gov/nextgen/programs/weather/wtic/ Retrieved 2021-03-04

FAA (2020i) Support for Strategic Traffic Flow Management https://www.faa.gov/nextgen/programs/weather/tfm_support/ Retrieved 2021-03-04

FAA (2021j) FAQ: Weather Delay https://www.faa.gov/nextgen/programs/weather/faq/ Retrieved 2021-03-21

Gallagher Sean (2012) How IBM's Deep Thunder delivers ”hyper-local” forecasts 3-1/2 days out https://arstechnica.com/information-technology/2012/03/how-ibms-deep-thunder-delivers-hyper-local-forecasts-3-12-days-out/ Retrieved 2021-06-07

Gogo (2020) GoGo Connected Aircraft Service Brochure https://www.gogoair.com/learning-center/gogo-connected-aircraft-services-brochure/ Retrieved 2021-03-16

Hamm Steve (n.d.) How big data can boost weather forecasting https://www.wired.com/insights/2013/02/how-big-data-can-boost-weather-forecasting/ Retrieved 2021-04-12

IAA (n.d) North Atlantic Communications, History https://www.iaa.ie/air-traffic-management/north-atlantic-communications/north-atlantic-communications---history Retrieved 2021-03-16

IATA (2017) IATA Safety Report 2016 Issued April 2017 Quebec, Canada; International Air Transport Association ISBN: 978-92-9229-473-1

ICAO (2010) Annex 3 Meteorological Service for International Air Navigation Quebec: International Civil Aviation Organization ISBN 978-92-9231-507-8

Hung Patrick C.K (2016) Big Data Applications and Use Cases Switzerland: Springer Nature ISBN: 978-3-319-30146-4

Lido (2021) Norwegian computer generated flight plan package. Retrieved 2021-03-19

Met Office (n.d) What is a WAFC? https://www.metoffice.gov.uk/services/transport/aviation/regulated/mo-wafc Retrieved 2021-03-21

Noessel Christopher (n.d.) Tunnel in the sky Displays https://scifiinterfaces.com/tag/tunnel-in-the-sky/ Retrieved 2021-03-28

Ohlhorst Frank (2013) Big Data Analytics Hoboken, Turning Big Data into Big Money New Jersey: John Wiley & Sons ISBN: 978-1-118-23904-0

Openairlines (n.d.) How does it work? https://www.openairlines.com/fuel-management-software/ Retrieved 2021-03-18

Richards R. William, O'Brian Kathleen, Miller C. Dean (2010) New Air Traffic Surveillance Technology, Boeing Aeromagazine Issue 38 Q2 2010 Retrieved 2021-03-12

Rapajic Jasenka (2016) Beyond Airline Disruptions New York: Routledge ISBN: 978-0-7546-7440-5

Ritchie Hannah (2020) Climate change and flying: what share of global CO2 emissions come from aviation? https://ourworldindata.org/co2-emissions-from-aviation Retrieved 2021-03-22

SESAR Innovation pipeline (2021) Air traffic management research & innovation 2020 highlights Luxembourg: Publications Office of the European Union ISBN 978-92-9216-165-1 DOI: 10.2829/861551

SMHI (2021) Discussion with Maria Lundblad, meteorologist at SMHI, Sweden. Discussion conducted 2021-03-26

Starlink (n.d.) Frequently Asked Questions https://www.starlink.com/faq Retrieved 2021-03-16

SWIM Reference (n.d.) FAQ https://reference.swim.aero/faq.html Retrieved 2021-03-26

SWIM Reference (2021) What is SWIM? https://reference.swim.aero/what-is-swim.html Retrieved 2021-03-26

TUDelft (n.d.) Air Traffic Management, 4-D Guidance https://cs.lr.tudelft.nl/simona/projects/4-d-guidance/ Retrieved 2021-03-29

Vivona Robert A. (2008) Nasa ASAS Activities: Decision Support for Airborne Trajectory Management & Self-Separation, ASAS TN2.5 Workshop, Rome, Italy, November 13, 2008 https://slidetodoc.com/national-aeronautics-and-space-administration-next-generation-air/ Retrieved 2021-03-29

Windy (n.d.) About Windy https://community.windy.com/topic/4/about-windy Retrieved 2021-03-17