ATM CONTROLLER SUPPORT IN CASE OF SPATIOUS SEVERE WEATHER CONSTELLATIONS ILLUSTRATED USING TWO AIRSPACE EXAMPLES

Lennard Nöhren[1], Olga Gluchshenko[1], Marco-Michael Temme[1] & Kathleen Muth[1]

[1]Institute of Flight Guidance,
German Aerospace Center (DLR),
Braunschweig, Germany

Abstract

An Extended Arrival Manager and an air traffic controller's radar display were expanded with procedures and functionalities needed to support approach controllers and pilots in severe weather situations. The sequencing and the 4D trajectory calculation processes can start long before the top of descent and consider available weather information and forecasts for more reliable approach planning. Moreover, the route planning can already be adjusted before convection zones develop when the weather forecast has a sufficient quality and current weather measurements and short-term forecasts – nowcasts – by different weather models are combined. As a consequence, a route change request by the pilot can often be avoided. Weather animations using both measured and predicted weather data can be activated on the radar screen to increase air traffic controller's situational awareness of the meteorological development in the airspace in certain situations. These support functionalities were then applied to the airports Munich and Milano/Malpensa. The corresponding airspaces were implemented in an Extended Arrival Manager and a traffic simulation environment to illustrate benefits of a controller support in the case of severe weather conditions.

Keywords: ATC; air traffic controller support; weather avoidance routes; trajectory-based automation; sever weather

1. Introduction

As a part of the H2020 project SINOPTICA, an Extended Arrival Manager (E-AMAN) and a prototypical radar display were expanded with procedures and functionalities needed to support approach controllers in severe weather situations. Additionally, scheduling, sequencing and the guidance horizon with full advisory support was extended to a circle area of a 150 NM radius around an airport with the possibility to start the calculation and incorporate aircraft into the arrival sequence of metering fixes and runways when first radar signals of aircraft arrive. In this way, the sequencing and the 4D trajectory calculation processes can start long before the top of descent of each arrival and consider available weather information and forecasts for more reliable sequencing and routing [1].

Adverse weather conditions such as thunderstorms and convective cells are one of the biggest challenges in aviation impacting safety, efficiency and capacity of air traffic control (ATC) [2]. Going ahead, climate change impacts atmospheric processes, that will increase effect on air traffic management activities [3]. In particular thunderclouds constitute a main safety risk during approach and landing. They can disrupt air traffic flow requiring rerouting, that leads to increased delays and to a lower cost-efficiency. As global air traffic has continued to grow in recent years, capacity potential of many major airports is already largely exhausted [4]. Further high density of flight movements increases the probability of flight delays in adverse weather conditions. For more than 9% of the days at the first half of 2018, Munich airport was affected by thunderstorms around or close to the Alps [5]. In accordance with EUROCONTROL Performance Review Report [4], 21% of the delayed flights in Europe were caused by adverse meteorological conditions. Moreover, approximately 10% of all European departure flight delays result from adverse weather, varying between 2% at Charles de Gaulle in Paris and 20% in Istanbul [6]. Adverse weather caused about 95% of airport traffic delays in Austria in 2018 [7]. Different weather situations can be also responsible for the complete closure of airports [8], where, for example, the costs of a hub airport closure can exceed three million EUR per hour for all stakeholders combined [9].

An early and coordinated avoidance of adverse weather conditions based on qualitative weather forecasts and nowcasts can make en-route flights and approaches more efficient [10]. This paper illustrates advantages of an air traffic controller support system for adverse weather situations in the vicinity of airports. It is important that the automatically generated avoidance strategies correspond to those that local air traffic controllers (ATCO) would also use in the same or similar situations. In addition to the usual altitude and speed clearances, these strategies naturally also include the route suggestions that would be cleared depending on the overall meteorological and traffic situation, considering the constraints prescribed in the Aeronautical Information Publications [11]. This also applies to the landing sequences calculated by a supporting E-AMAN and the target times at significant waypoints and runway thresholds. If these do not correspond to the usual local procedures or are even contradictory to them, the acceptance of the controllers would decrease and the support systems would be ignored [12].

ATCOs are responsible for maintaining separations between aircraft. However, spacing to severe weather is the responsibility of the pilot in the event of occurring convective cells. When adverse weather occurs on the aircraft's planned or assigned route, the pilot decides whether to fly through it, fly over it, or avoid it to the left or right. In addition to the onboard weather radar, pilots can also use external live weather applications such as eWAS, which can transmit current weather data to the cockpit via a fast SatCom data link [13]. The ATCO clears this avoidance maneuver and ensures that it does not lead to critical separation with other traffic. Center controllers, responsible for approach, lower, and upper airspace, usually have no appropriate weather radar available for their sectors. The systems, visualizations, and procedures developed by the German Aerospace Center's (DLR) Institute of Flight Guidance presented in this paper use available weather information to initiate 4D route rescheduling and arrival sequencing. These tools provide appropriate rerouting advisories for ATCOs at an early stage using forecasts from 30 to 60 min. in advance so that pilots do not have to avoid adverse weather situations at short notice. This relieves both the pilot and the ATCO and allows them to react in sufficient time in advance and at a reasonable distance so that rerouting trajectories stay safe and efficient [14].

2. Related Work

In recent years, there have been several approaches to guide aircraft automatically or at least semi-automatically around severe weather areas. To this end, routes are calculated and displayed on the radar screen either to the crew in the cockpit or to the air traffic controllers in charge. MITRE developed and tested the "Dynamic Route-Planning in Convective Weather", proposing weather avoidance routes for en-route flights and approaches with the goal to sustain metering during severe weather periods [15]. The used Advanced Flight-Specific Trajectories (AFST) base on a historical route database of Dallas Fort Worth airport and are dynamic before a fixed freezing horizon. In highly dynamic weather conditions, however, freezing the planning can somewhat limit the usefulness of this method.

Not with the aim of supporting pilots, but rather flight dispatchers, the Dynamic Weather Routes (DWR) from NASA was developed to propose more efficient routes around weather for flights in their en-route phase [16]. A variant of DWR is NASA's Multi-Flight Common Route (MFCR), adapted for Traffic Management Coordinator's use in Centers [17]. To reduce controller workload for implementing the reroutes, MFCR detects groups of en-route flights that can be diverted together for a shortcut through a weather-free area previously forecast to be occupied by convective weather. However, neither DWR nor MFCR offers any assistance for arrival metering or sequencing for controller guidance support.

NASA also developed the support tool Dynamic Reroutes for Arrivals in Weather (DRAW) for Traffic Management Coordinators (TMCs) at the Federal Aviation Administration's Air Route Traffic Control Centers [18]. It proposes weather-avoidance reroutes for en-route arrival flights subject to metering restrictions when transitioning into a terminal airspace. Results demonstrated, if weather forecast is reasonably accurate, the DRAW use reduces both controllers' workload during busy periods, and the number of manual adjustments of frozen scheduled times of arrival implemented by the controllers and Traffic Management Coordinators.

An additional overview on related work dealing with weather in air traffic control can be found in [10]. As follows, the meteorological situational awareness of ATCOs should be much better today. However, to the best of our knowledge, there exists no detailed study considering an operational support system (E-AMAN) with meteorological assistance tools.

3. E-AMAN Methodology

In adverse weather conditions, arrival controllers can be supported by the E-AMAN at two levels. One of them is routing where detours with target times for significant waypoints are calculated and aircraft are integrated into the landing sequences with guidance instructions for clearances to follow the preplanned 4D trajectories. The second one is visual support where affected aircraft get a mark in the label to depict that the route was adjusted to the weather situation and actual nowcasts. The weather development itself is shown and animated on request on the controller's primary screen (radar display) so that air traffic controllers can understand at any time why routes have been diverted accordingly. In this way, they can decide for themselves which detour is a safe and efficient option for them in the current traffic and weather situation.

Additionally, to the aircraft labels, guidance instructions to follow pre-planned and optimized 4D-trajectories as well as current and nowcasted adverse weather areas can be displayed. For this purpose, the weather areas, classified as severe and their forecasted development, are converted into time-dependent 2D-polygons without self-intersections. Afterwards, the E-AMAN checks for conflicts between all trajectories and these polygons. If a conflict exists, an alternate route is calculated around the actual and the predicted positions of the areas. The E-AMAN always tries to plan ahead and generate detours according to the further course of the route. If a severe weather area blocks a route, the direction of the detour is influenced among other things by the further course of the route and the moving direction and speed of the weather area. So, if an aircraft had planned to change heading to a more southerly route during the rest of the flight, the E-AMAN will also make the severe weather diversion to a more southerly route. Of course, this only applies as long as no traffic or meteorological restrictions such as moving speed of the considered area or other severe weather regions prohibit it. Deviations from the original Standard Arrival Route (STAR) that cross other neighboring STARs, for example, do not lead back to the original STAR, but only to the nearest STAR and integrate the approach into the current approach sequence of the STAR accordingly. More detailed description of diversion route finding, arrival sequencing, trajectory generation, dynamic severe weather visualization on a traffic display, and an algorithm for advanced weather visualization are described in [10].

A particular challenge is the quality of the weather forecast procedures evaluating severe weather areas used for the trajectory calculation. Figure 1 illustrates trajectories through a severe weather area with weather polygons provided by the two different meteorological forecasting techniques Weather Research and Forecasting with Rapid Update Cycle (WRF-RUC) and the Phase-diffusion model for Stochastic nowcasting (PhaSt) [19].

The calculation of the 4D trajectory by the E-AMAN works in the following way. The module "waypoint finder" defines the route using Aeronautical Information Publications (AIP) waypoints of STARs (assimilated in a waypoint list). The module "trajectory generator" calculates two 4D top-down and bottom-up trajectories, merged at a point with constant flight parameters. The "weather module" is part of the "waypoint finder".

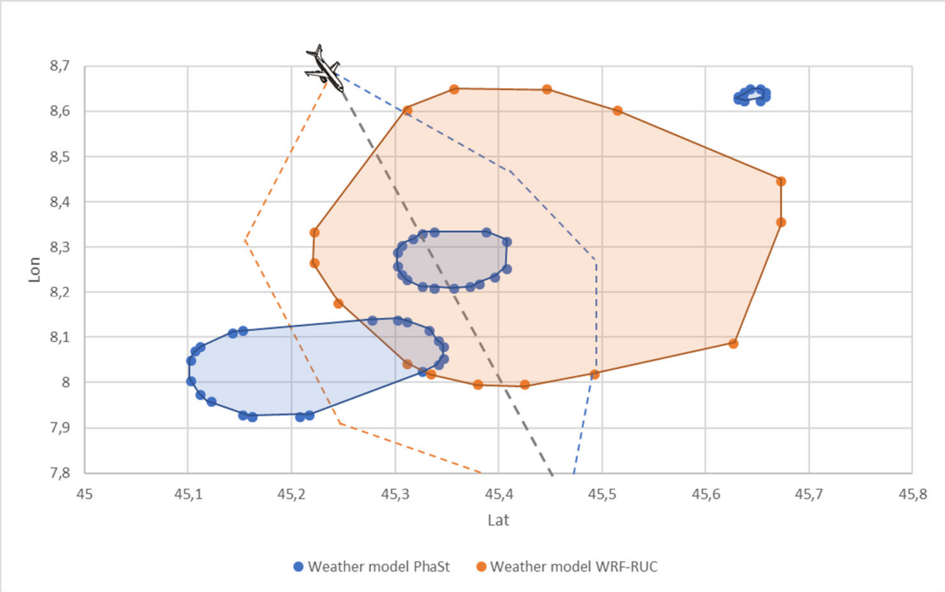


Figure 1 – Weather polygons predicted by PhaSt (blue) and WRF-RUC (orange) weather forecast models and E-AMAN detour trajectories. The original route in gray crosses the predicted severe weather areas from both weather models. However, based on the forecast from the PhaSt model, a left-sided alternative route would be recommended; if the WRF-RUC model is used, a right-sided alternative route would be recommended.

After a conflict detection based on the calculated trajectory, the module adds waypoints outside of actual and forecasted weather polygons and deletes waypoints inside polygons. The newly added waypoints defining the diversion are than completed by constraints for speeds and altitudes of the approach region which will be flown through on the new route. The "trajectory generator" now uses the weather-dependent waypoint list and calculates a new 4D trajectory.

4. Scenarios, Traffic, and Weather Representation

As far as possible, the arrival manager should demonstrate the same guidance behavior as a controller would in the same situation. This involves routes, altitudes, speeds, and directional clearances, which of course also depend on the constraints of the local airspace and the waypoints to be flown over. By using an existing trajectory generator based on EUROCONTROL's BADA, basic parameters such as airspeeds, turn behavior, deceleration behavior, and descent rates can be maintained. In order to simulate the typical guidance behavior of local air traffic controllers, usually cleared routes and holding patterns under severe weather conditions must be analyzed and simulated in the waypoint generation of E-AMAN. To this end, we analyzed extreme weather events in the vicinity of Malpensa and Bergamo from May and August 2019 which led to airport closures and flight diversions to alternate airports due to thunderstorms with lightning strokes, hail, and heavy rainfall. The analysis considered routes and holding patterns. These results were then incorporated into the route calculation as framework conditions.

For validation, traffic scenarios from Malpensa airport[1] were prepared for the E-AMAN and the traffic simulation environment and reproduced together with recorded and predicted weather events. It was verified whether the E-AMAN is able to generate realistic 4D avoidance trajectories to be flown in the given situations and to support controllers via an adapted radar display with guidance instructions to guide and organize traffic in these non-nominal conditions in a meaningful and safe way.

For a profound assessment, detailed trajectories with reliable flight parameters regarding positions, altitudes, times, and scheduling are necessary. Real flown trajectory data with this grade of detail and requested accuracy were not available. Moreover, the simulation environment has to reproduce all aspects of aviation, weather, local operation guidance, rules and individual pilot decisions. Such extensive data was not available in the scope of the project. For this reason, a direct comparison

[1] Selected Italian air traffic data was kindly provided by CIMA/Italy as part of SESAR's SINOPTICA project.

between flown trajectories and simulation results would be not compelling.

As an alternative, an indirect comparison between reality and simulation results was chosen, in which the two performance indicators – flight times (time in air) and flight distance (track miles) – could ultimately be included and compared. For this indirect comparison, the selected traffic scenario from Malpensa airport on 11.05.2019 was planned by the E-AMAN under normal visual (VFR) weather condition and was used as a baseline for validation. Figure 2 illustrates the measured travel times on this day starting at a distance of 150 NM from the airport, which even had to be closed for more than one hour between 03:00 PM and 04:30 PM due to adverse weather conditions on this day. These traffic records were used as input data to generate the traffic scenarios for the Malpensa and Munich airspace and traffic simulations.

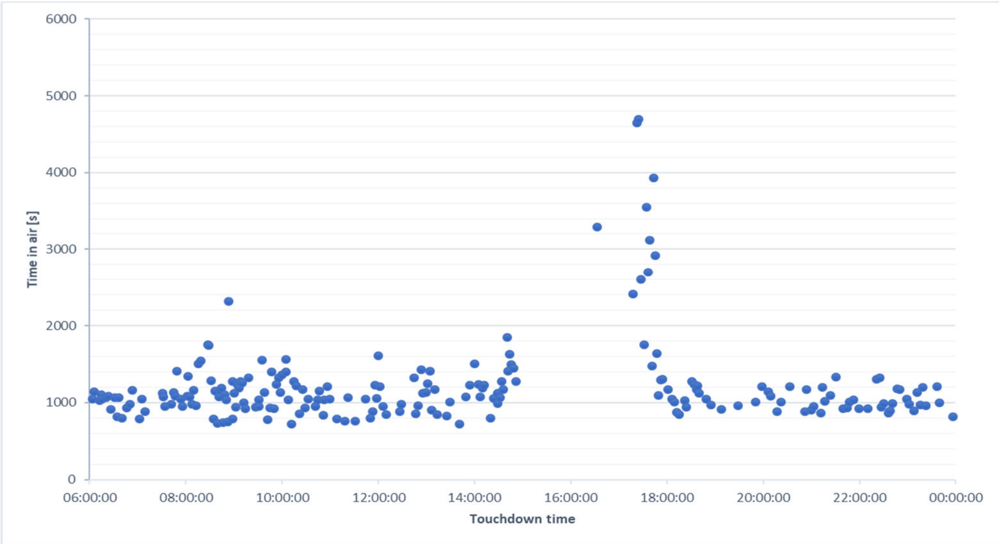


Figure 2 – Times in air against touchdown times at Milano Malpensa airport on 11.05.2019.

Another performance indicator which can be used for evaluating E-AMAN route planning in comparison with ATCO's guidance in severe weather situations is the initial Terminal Maneuvering Area (TMA) entry flight direction. In Figure 3, the flight distribution into Malpensa TMA in a disturbed (orange) and an undisturbed weather situation (blue) shows that the airspace was restricted in some areas due to the moving thunderstorms. This was particularly true for approaches from a direction between 270° and 340°, between 100° and 130°, and for approaches directly from the north. Due to blocked STARs, all approaches from these directions had to be diverted to other areas of the TMA, which led to further congestion of the STARs there in addition to the weather-related restrictions in the neighboring sectors. But with the help of a controller support system, there is still enough free space between the severe weather areas in which traffic might be organized safely and efficiently, summarized in Figure 3.

The comparison of a traffic scenario without weather disruptions within the last 180 minutes before airport closure on 11.05.2019 from a direct distance of 150 NM to the Milano Malpensa airport shows the average changes of flight times and flight distances with respect to the baseline without weather disruptions. These three hours were chosen because thunderstorm cells were increasingly moving from west to east in the greater airport area during this time, blocking more and more STARs, so that controllers and pilots were forced to take ever greater detours until the airport Malpensa closed finally. At this point, all further approaches had to be routed into holding patterns or to an alternate airport.

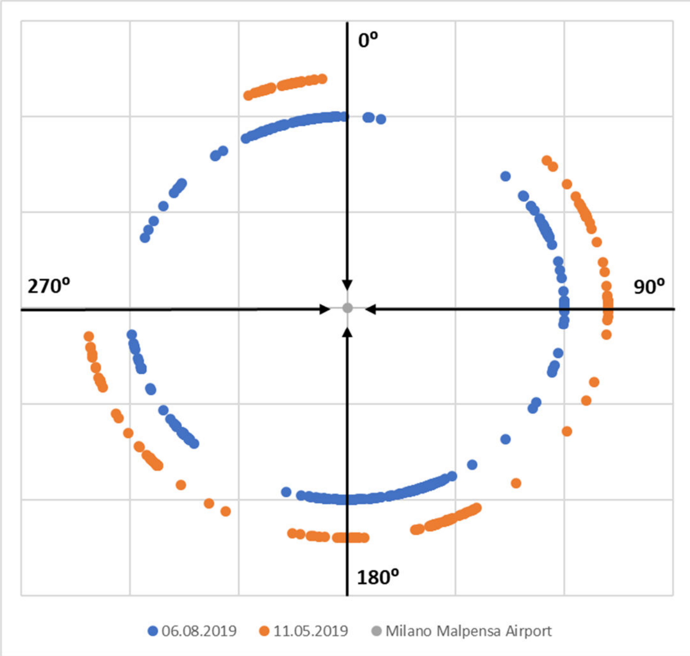


Figure 3 – Direction to Malpensa airport at the extended TMA entry point on 06.08.2019 without weather disruptions and on 11.05.2019 with an adverse weather situation. Each colored point represents an aircraft that has flown into the TMA from that direction. For display reasons, the orange ring has a larger diameter than the blue one.

In the traffic simulation summarized in Table 1, the E-AMAN manages to route a large proportion of the approaches around the severe weather areas or, in situations where no further diversions were necessary due to the forecast, to route traffic almost regularly. While flight times were extended by 12.6% and routes by almost 9.8% in the original weather and traffic scenarios considered, these extensions could be reduced to an average of around 1.6% and 1.2% respectively compared to undisturbed approaches for the same weather and traffic scenarios. This corresponds to a reduction in spatial detours and time delays of more than 87%. It was not possible to record this in the validations, but it can be assumed that this would also significantly reduce the workload of controllers in corresponding adverse weather situations.

Table 1 – Comparison of the flight times and the flight distances of the trajectories flown during severe weather around Malpensa airport and the results of the E-AMAN scheduling and routing for the same weather and traffic scenario. In this scenario, we showed that weather forecast-based approach planning can reduce both additional routes and flight times to around 13% of the values flown without E-AMAN support. However, by blocking entire approach areas due to severe weather, conflict free detours and delays cannot be completely avoided.

	Real flown tracks in relation to undisturbed traffic	**Supported by E-AMAN trajectory planning in relation to undisturbed traffic**	**Reduction**
Additional flight times	+12.6%	+1.59%	-87.4%
Additional flight distances	+9.8%	+1.22%	-87.6%

5. Results of Automatic Trajectory-Generation

For the verification and illustration of the routing algorithms, several real and artificial weather and traffic scenarios were generated to simulate a wide variety of situations and to test the E-AMAN for its behavior. In addition, extreme weather events at different Italian airports and TMAs were evaluated to understand the operational guidance principles of air traffic controllers in these situations and to implement them into the E-AMAN.

These principles were then applied to the airports Milano/Malpensa (Italy) and Munich (Germany), for which corresponding airspaces were implemented in the E-AMAN and the traffic simulation environment. Munich Airport was therefore selected as the test and comparison airspace, as its TMA has a more complex structure than Malpensa, has more approach routes and some of these are much closer together, so that their traffic can influence each other when avoidance routes during approach are used. This meant that diversion strategies had to be developed and tested for Munich that would not have been used at Malpensa.

To calculate 4D trajectories around adverse weather areas for arriving aircraft, the airspace does not need to include all waypoints and sector boundaries of the real airspace. Only the waypoints that are describing relevant STARs have been inserted. Departure routes were not implemented, so that the display looks less complex and simpler than usual radar images of this area. For the sequencing, all STARs with the related Flight Management System (FMS) waypoints are connected with constraints regarding maximum and minimum altitudes as well as maximum and minimum speeds. This data is needed for the 4D trajectory calculation, since the speed and the flight altitude influence possible conflicts and the flight times until touchdown.

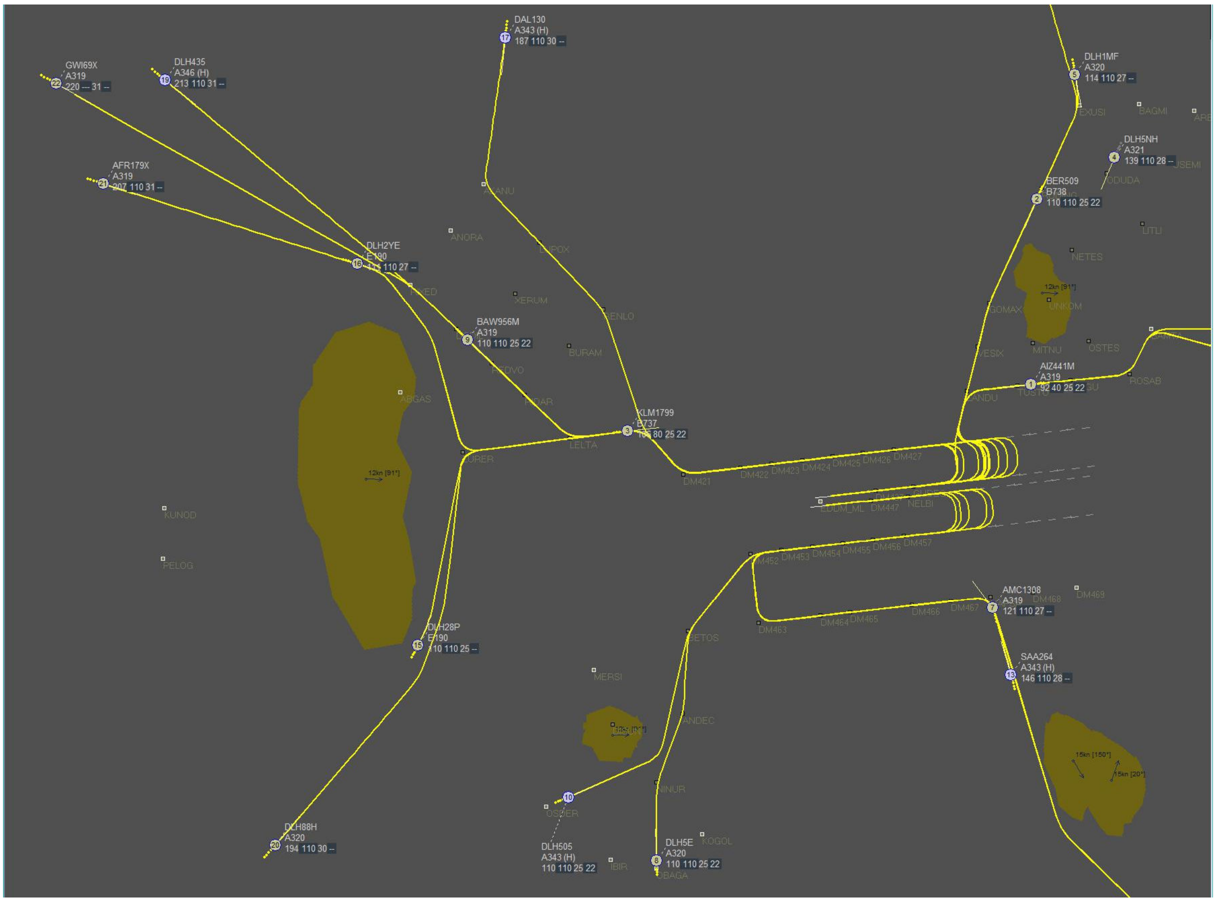


Figure 4 – Simulation run covering the simplified Munich TMA with a combination of artificial traffic- and weather-scenarios. The numbered circles symbolize aircraft (grey: weight class medium, purple: weight class heavy) and the values their current position in the approach sequence regardless of the assigned runway. The yellow lines are the actual 4D trajectories planned by the E-AMAN. The E-AMAN can also deal with colliding and separating weather areas or areas that are currently rotating around each other. The dark-orange areas show severe weather areas with moving directions and speeds. Controllers and pilots must also expect obstructions due to weather outside these marked areas, but these are classified as less dangerous due to reduced precipitation and wind.

Figure 4 shows a case of Munich TMA with a combination of artificial traffic and weather scenarios. This screenshot illustrates different rerouting trajectories proposed by the E-AMAN algorithm. The methodology for route finding around current and predicted severe weather areas can be explained using an artificially generated frontal system in the west of Munich and an aircraft coming from the northwest that was predicted to fly through this area based on its flight plan.

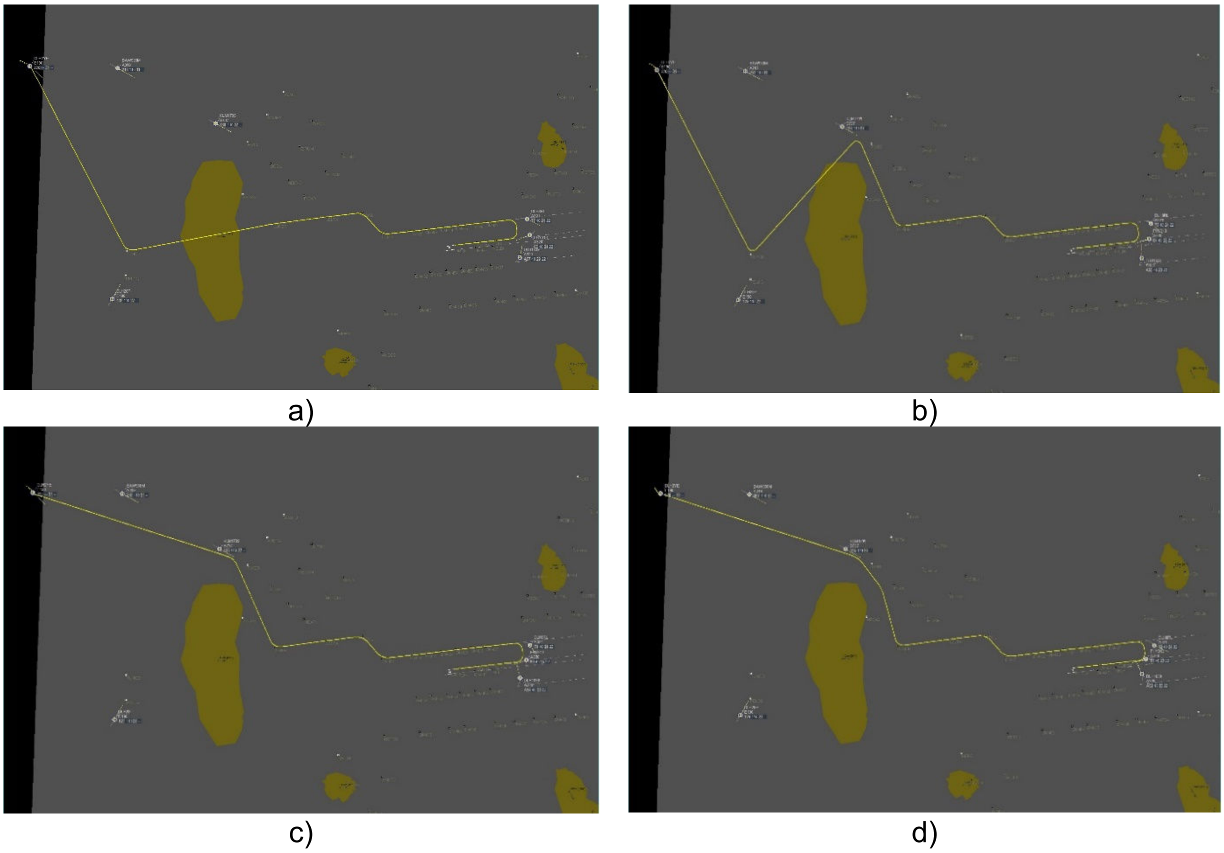
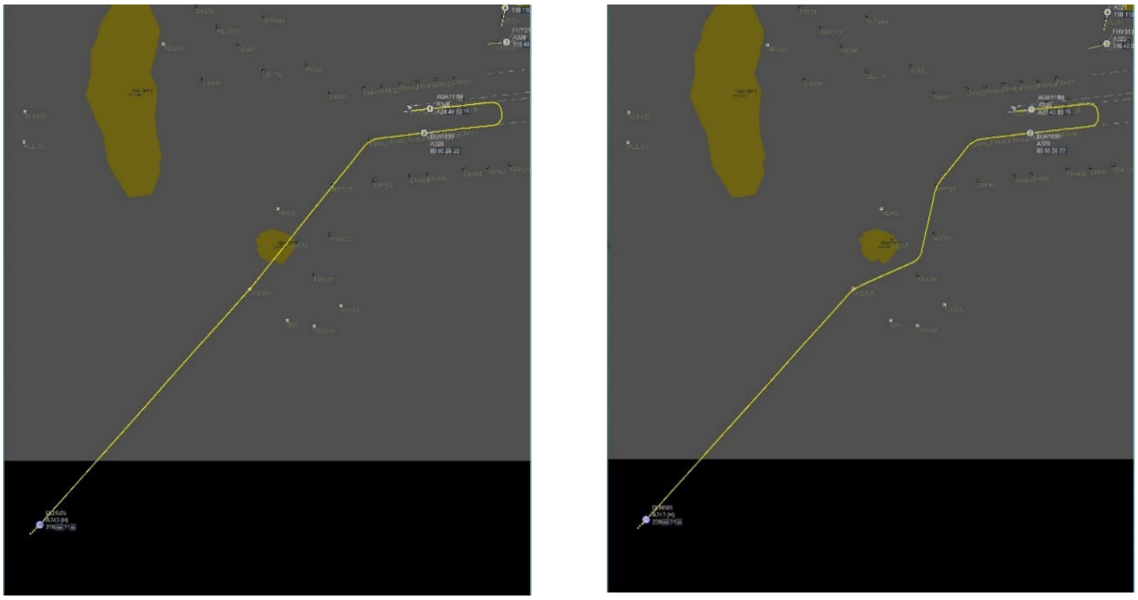


Figure 5 – a) Initially calculated trajectory based on flight plan leads through a thunderstorm cell; b) the first rerouting, where as few waypoints as possible are inserted; c) straightening of the rerouting trajectory; d) partial rerouting due to later conflict with the thunderstorm cell. Steps a) to c) are completed in a few seconds, step d) only takes place if a route needs to be adjusted again due to the weather forecast.

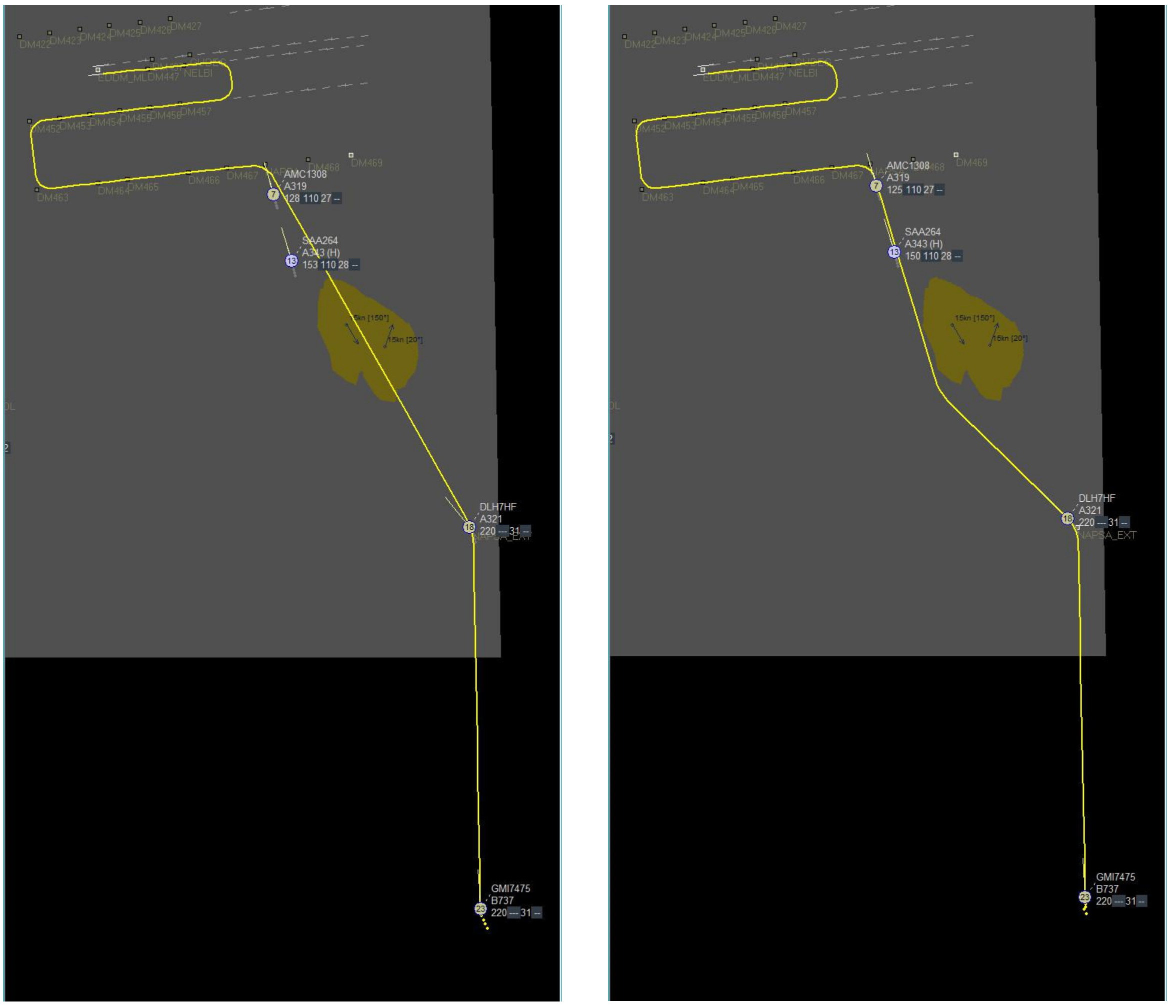
In the western part of the TMA, a widespread storm front blocks arrival from the west and forces all aircraft to use detours. Figure 5 shows the process of a detour calculation for an aircraft trajectory disturbed by the large-area cell. Coming from the west, an aircraft gets its 4D approach trajectory from the E-AMAN following the STAR of the flight plan (Figure 5 a)). The screenshot in Figure 5 b) displays the first recalculation of the trajectory to avoid an intersection of one route segment with the thunderstorm cell. The E-AMAN always tries to modify original routes by integrating as few as possible additional waypoints. As the next step, the recalculated trajectory is optimized, considering actual and planned STAR filed in the flight plan (Figure 5 c)). This is done by analyzing the continuing route direction, number and positions of curves and heading changes to guide diverted aircraft as smooth as possible back to a STAR. Since the recalculated trajectory still has a conflict of one segment with a predicted position of the thunderstorm cell, this segment is changed by the routing algorithm. An additional waypoint is introduced to have no intersections anymore with the actual and the forecasted position and shape of the thunderstorm cells (Figure 5 d)).

The two severe weather areas in the south and south-east shown in Figure 4 cause some arrivals on side tracks before or behind the thunderstorm areas. The planned distance to the core areas of the storms areas depends on their forecasted moving speeds and shapes. The screenshots in Figure 6 illustrate a detour in the same direction and Figure 7 in the opposite direction of the thundercloud movement. One can see clearly in Figures 6 and 7 that a greater buffer distance to the thunderstorm cell is necessary if detour is planned in the same direction so that one still has enough distance if the cloud moves further.



a) b)

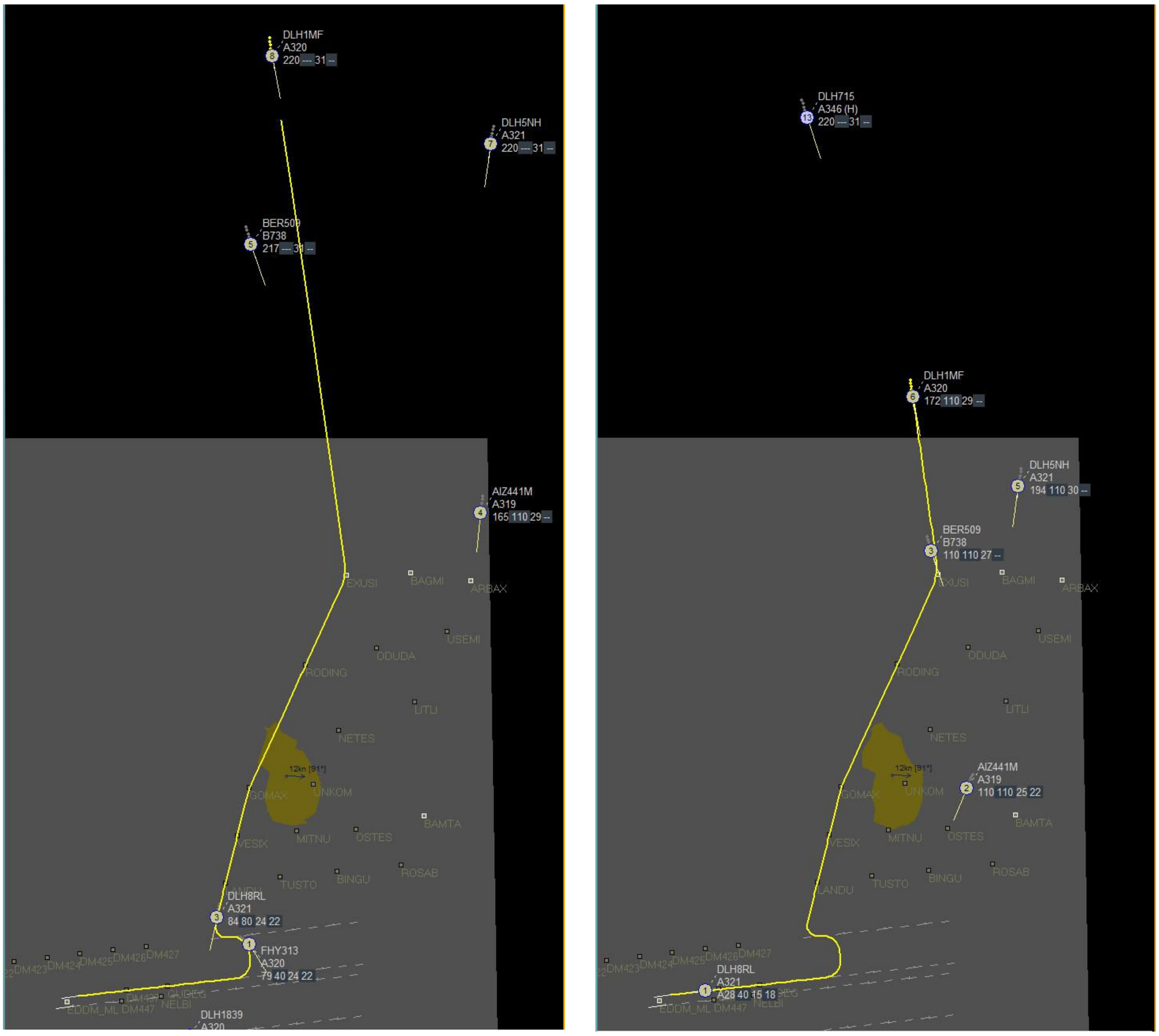
Figure 6 – Rerouting in the same direction of the thunderstorm cell. a) original trajectory intersects the thunderstorm cell; b) performed rerouting.



a) b)

Figure 7 – Rerouting in the opposite direction of the thundercloud movement. a) original trajectory intersects the thunderstorm cell; b) performed rerouting.

In the north-east corner of the TMA in Figure 4, routes are planned for aircraft via a more northerly STAR, even if the predicted turn would probably be flown somewhat flatter by pilots in reality. This happens because the route algorithm always strives to guide aircraft back to a STAR as quickly as possible after a diversion. The aim is to ensure that controllers have to guide aircraft outside their standard routes as rarely as possible, which always requires special attention and concentration, as too many special treatments due to route deviations could pose a safety risk, especially in severe weather situations in the vicinity of airports.



a) b)

Figure 8 – a) In this example, the original trajectory for DLH1MF approach from the north seems to be in a conflict with the weather area on STAR; b) a few minutes later, there is no conflict, because the weather area moves in the east direction and at the time the aircraft is close to the area there are no more intersections with the trajectory predicted.

Figure 8 illustrates a trajectory that seems to intersect the thunderstorm cell. However, a rerouting is not necessary because there is no conflict due to the forecasted movement of the weather when the aircraft comes near the area. All presented routes are complete 4D trajectories including speeds and altitudes in dependence of aircraft type and flight phase. This means that all target times at significant waypoints and the threshold are also known for each aircraft depending on their diversion. At the same time, all trajectories are structured in such a way that the landing sequence considers all minimum separations depending on the individual weight classes.

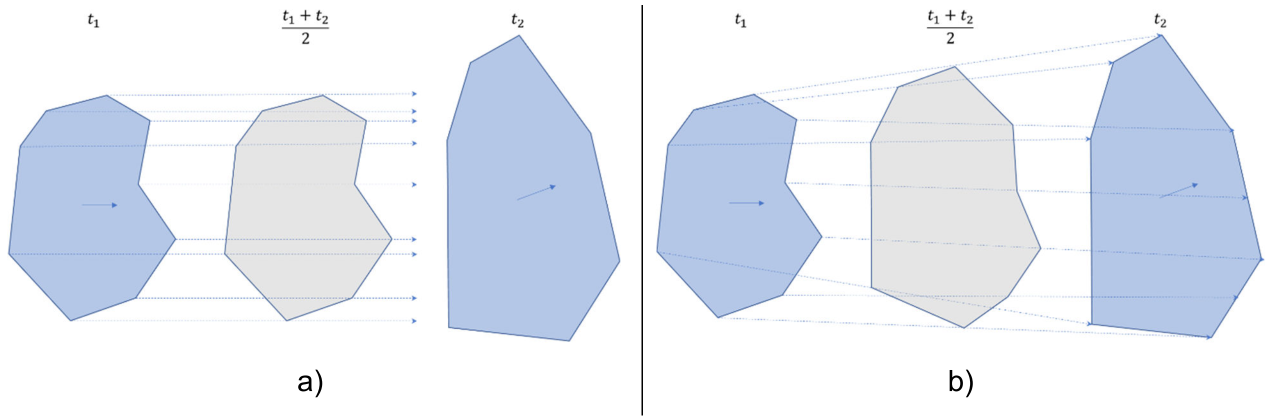


Figure 9 – Comparison of the two functional principles of the display methods implemented for the animation of extreme weather areas on a radar screen. Both pictures visualize forecasted areas at the consecutive time moments t_1 and t_2 and an approximated area at the time moment $\frac{t_1+t_2}{2}$. a) On the left-hand side, the corner points of the weather polygons are shifted in five-second steps along the last measured movement vector of the geographical center of gravity of the polygon. b) On the right-hand side, each current polygon point is assigned a predicted polygon point. A speed and direction vector is formed from the connection, which in turn is divided into five-second sections. The points are then shifted along their individual vectors with each radar image update. In this way, movements and changes in shape from the last measurement to the next prediction can be transformed into almost smooth movements.

In order to represent adverse weather areas on the radar display, two weather animation methods were implemented in the E-AMAN (Figure 9). The first one is "moving", where the last measurement of the weather area is moved along the last direction vector with last measured speed. There are no changes in the shape or size of the polygons representing weather areas until the next update of the weather measurement. The second one is "morphing", where a fluent shape transformation from the last measurement to the next nowcast is performed. In the morphing developed by us, the edge points of the weather polygons of the last measurement and the next forecast are mapped onto vectors and these are divided into five-second steps according to their direction of movement and speed. The polygon points are now shifted along these vectors every five seconds to match the updates of the aircraft radar points, so that after the time until the forecast corresponds to the present, all points have shifted to the forecast polygon [10]. If the number of polygon points of the measurement and the forecast differs, these points must be added or removed in such a way that a uniform change in shape results in the temporal development of the extreme weather area on the primary display. This procedure considers shape and size changings and allows the fusion and the disjunction of weather areas. In order to avoid jumps by updates of the weather data, moving as well as morphing needs reliable weather information and forecasts for the next 10 to 15 minutes at least.

6. Conclusions and Outlook

Even with the support of an E-AMAN, there will be delays in approaches under severe weather conditions, but these can be significantly reduced under favorable circumstances. We showed that the guidance in the approach phase can be much more precise and adapted in adverse weather situations when using reliable meteorological nowcasts and an E-AMAN which can consider highly dynamic closed airspaces in its route and sequence planning. The wider the calculation horizon of an E-AMAN, the more effectively it works. In our case, we have set the calculation horizon to 150 NM. This means that even larger weather areas in the vicinity of airports can be covered, alternative routes can be planned more extensively and guided by controllers.

The validation could only be performed indirectly because, on the one hand, the data basis from publicly accessible and available air traffic data is constricted. Furthermore, it is not possible in a simulation environment to reproduce all parameters that have an influence on performance indicators as controller workload or fuel consumption in non-nominal situations. However, the results of the indirect validation indicate that the E-AMAN achieves a significant reduction in additional flight distances and flight times while aircraft avoid adverse weather areas. We were able to show that in the best case, both the additional flight time generated by detours and the additional distance can be reduced to less than 20% compared to situations without corresponding E-AMAN support.

The new developed approach enables early re-planning of the route long before the aircraft nears route blocking weather areas. Moreover, the route planning can already be adjusted before convection zones develop when the weather forecast has a sufficient quality and current weather measurements and short-term forecasts (nowcasts) by different weather models are combined. As a consequence, a route change request by the pilot can often be avoided. Weather animations using both measured and predicted weather data can be activated on the screen to increase air traffic controller's situational awareness of the meteorological development in the airspace in certain situations. This changes the role of the air traffic controller, who remains in his usual active role even in severe weather situations. Today, after a severe weather message coming from a flight crew, controller change from an active into a reactive role, in which they have to respond to the pilots' wishes. With the knowledge, where convections are building up and how they will develop in the near future, controllers can adapt their own organization of the airspace in good time and remain the active shaper of air traffic at all times. This works at least as long as the final and the airport do not have to be closed for approach traffic. In this case, an E-AMAN may help in organizing holdings and resuming flight operations.

7. Contact Author Email Address

mailto: lennard.noehren@dlr.de

8. Copyright Statement

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