IMPROVED WEATHER INFORMATION FOR COCKPIT AND TOWER

Thomas Gerz, Arnold Tafferner*, Sonja Rosczyk,**
Andrew Mirza, Debi Turp*, Christine Le Bot******

***Institut für Physik der Atmosphäre, DLR-Oberpfaffenhofen, 82234 Wessling, D;**
****Institut für Meteorologie und Klimatologie, Universität Hannover, 30419 Hannover, D;**
*****Met Office, Exeter, Devon EX1 3PB, UK; **** Météo France, 31057 Toulouse, F**

Keywords*: weather hazards, aviation, FLYSAFE*

Abstract

Thunderstorms, in-flight icing, clear-air turbulence, and aircraft wake vortices can imperil aviation. For these significant weather hazards a set of Weather Information Management Systems is being developed within the European Integrated Project FLYSAFE. This paper describes the design and the state of development of the systems and outlines future applications and usage for the flying aircraft as well as for air traffic management and airline operations centres.

1 Introduction

Air traffic is expected to triple world-wide within the next 20 years. With the existing on-board and on-ground systems to manage and control aviation, this would lead to an increase of aircraft accidents, in the same, or a higher proportion. Despite the fact that accidents are rare, this increase is perceived as unacceptable by society and new systems and solutions must be found to maintain the number of accidents at its current low level. Although adverse weather is seldom the exclusive cause of accidents, it is nevertheless one of the most disruptive factors in aviation. It jeopardises the safety and economic efficiency of the entire air transportation sector. Moreover, the disturbance caused by any individual weather event depends on a complex network of non-meteorological factors. Therefore, flight dispatchers, pilots and controllers must be equipped with new surveillance systems allowing them to make the right decision at all times. The provision of timely, dedicated and improved weather information for flight crews as well as airline operations centres (AOC) and air traffic management (ATM) is an essential part of such a system. A concrete need for research and development is evident.

Within the 6th Framework Programme of the European Commission the Integrated Project FLYSAFE [1] has been launched which aims at designing, developing, testing, and validating a complete ‘Next Generation Integrated Surveillance System’ (NGISS) for cockpits. The aim is to mitigate the potential risk factors ‘terrain’, ‘traffic’, and ‘adverse weather’ and, thus, contribute to the safety of flights for all aircraft. Among other objectives, FLYSAFE enhances the on-board capability to detect adverse weather elements and also develops solutions to enable all aircraft to retrieve tailored weather information from the ground.

The continuing increase in global air traffic requires a rigorous investigation of the impact of weather upon aviation, and the development of measures to confine that influence. To this end, a Working Group on Aviation and Weather (‘Arbeitskreis Luftverkehr und Wetter’) has been organised to address this need in Germany. It is the forum where all involved companies, organisations, associations, and institutes, from research, industry, and services act in partnership. Some Group members are also partners in the FLYSAFE project. The Working Group has published a Position Paper [2] giving an overview of the impact of various weather factors on aviation and scrutinising the German situation in the international context.

This paper describes four major hazards for aviation which may emerge from aircraft wake vortices, clear-air turbulence, in-flight icing, or thunderstorms (section 2) and outlines the general concept followed in the FLYSAFE project (section 3). The design and the state of development of the four ‘weather information and management systems’ are described in sections 4 through 7. Section 8 introduces the ground weather processor and section 9 ends this study.

2 Four major weather hazards

The FLYSAFE Consortium as well as the German Working Group has identified *thunderstorms*, *in-flight icing*, *wake vortices*, and *clear-air turbulence* as significant weather hazards. Fig. 1 shows examples of the weather and wake phenomena or their impact on aircraft.

Thunderstorms (CB) are a possible threat to aircraft for more than one reason. Areas of strong wind-shear with downbursts, turbulence, icing, heavy rain, lightning stroke and hail exist simultaneously at the same or different places within the CB. All of these phenomena can alter the aerodynamic state of flight, damage the hull or engines of the aircraft (Fig. 1a) or cause malfunctions of the on-board equipment.

In-flight icing of aircraft may occur when an aircraft flies through air masses with liquid water droplets at temperatures below 0°C. Those droplets can remain liquid down to temperatures of -40°C unless they hit a cold body like wings or fuselage of an aircraft where they then freeze immediately and disturb the aerodynamics or sensors of the aircraft (Fig. 1b). Usually, aircraft are certified and equipped to overcome such situations but especially the existence of so-called super-cooled large drops (SLD) causes a significantly higher safety risk to aviation than is associated with non-SLD icing conditions.

Clear-air turbulence (CAT) is commonly perceived as being turbulence encountered outside of clouds. The safety risk and loss of comfort originate from the invisibility of these events which often prevent pre-cautious actions. CAT can be generated by wind shear, gravity (mountain) waves (Fig. 1c), and thunderstorms.

Aircraft wake vortices (Fig.1d) can become a risk for aircraft which follow too closely behind another one as its vortex may cause the encountering aircraft to roll severely.

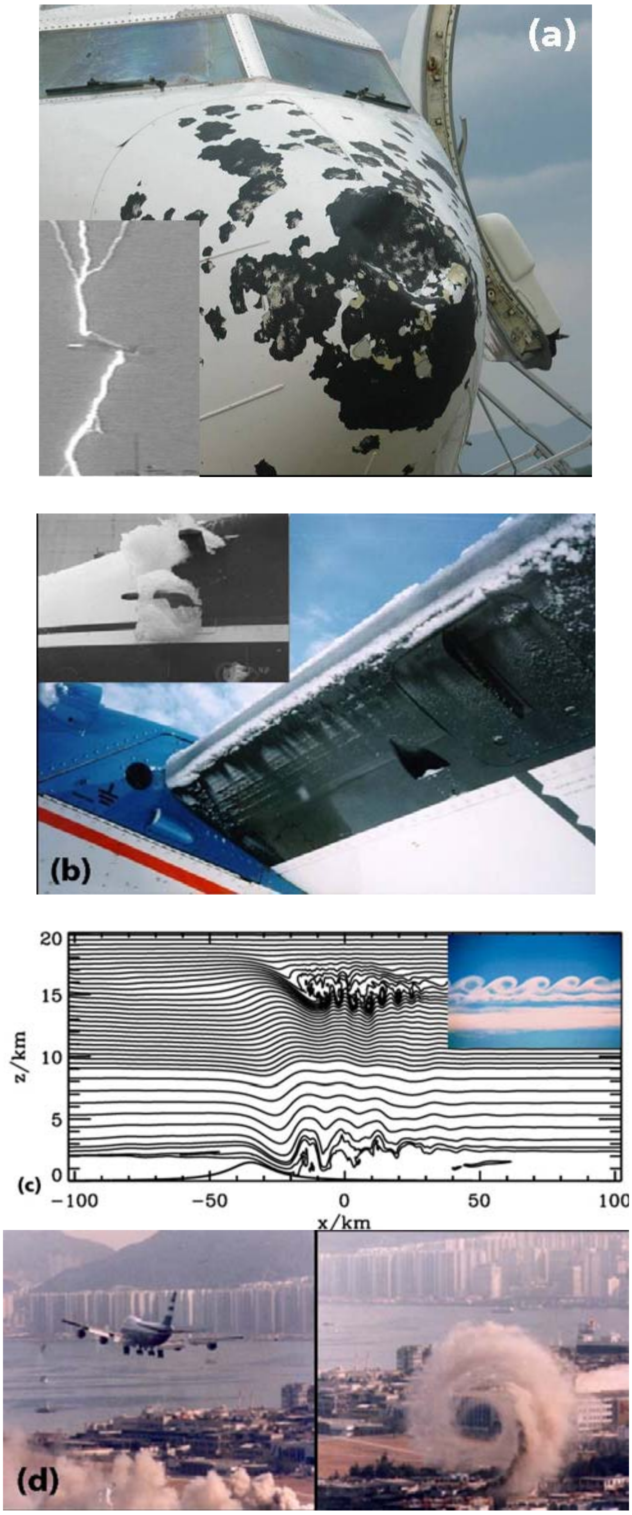

Fig. 1. Weather hazards for aviation: (a) B737 after flight through a thunderstorm with large hail, (b) icing on wing and sensors of a Do 28, (c) simulation and photography of breaking gravity waves as a source of clear-air turbulence, (d) aircraft vortex made visible by industrial smoke.

The possibility to encounter wake vortices is highest in the vicinity of airports and especially during the final landing phase when aircraft follow the same or are crossing paths. Also since the reduced vertical separations of aircraft routes at cruising altitudes have become effective, encounters of wake vortices are more frequently reported because wake vortices trail downward and occasionally more than 300 m.

3 The FLYSAFE concept

One object in FLYSAFE is the development of a set of expert systems, the ‘Weather Information Management Systems’ (WIMS) for these four hazards which shall enable all aircraft to get timely, dedicated, and improved weather information. The WIMS provide all atmospheric data which are necessary to describe the hazards and to suggest alternative trajectories.

Fig. 2 elucidates the flow of information starting from the observed or forecast hazards, through the WIMS to a ground-based weather processor which transfers the information to the aircraft, the air traffic control and management and the airline operating centres. Atmospheric phenomena and weather hazards that impact the aircraft are monitored by observation systems (satellite, aircraft, radar networks, wind-temperature profilers, lidar, etc) but also seen by the pilot and by various on-board weather sensors. The observation data will be processed by each WIMS, using dedicated and up-to-date forecasting and nowcasting tools. The optimum information about type, location and strength of the respective weather hazard will be evaluated and formatted as object-oriented or gridded 3-D data, respectively 4-D data if several output times are considered.

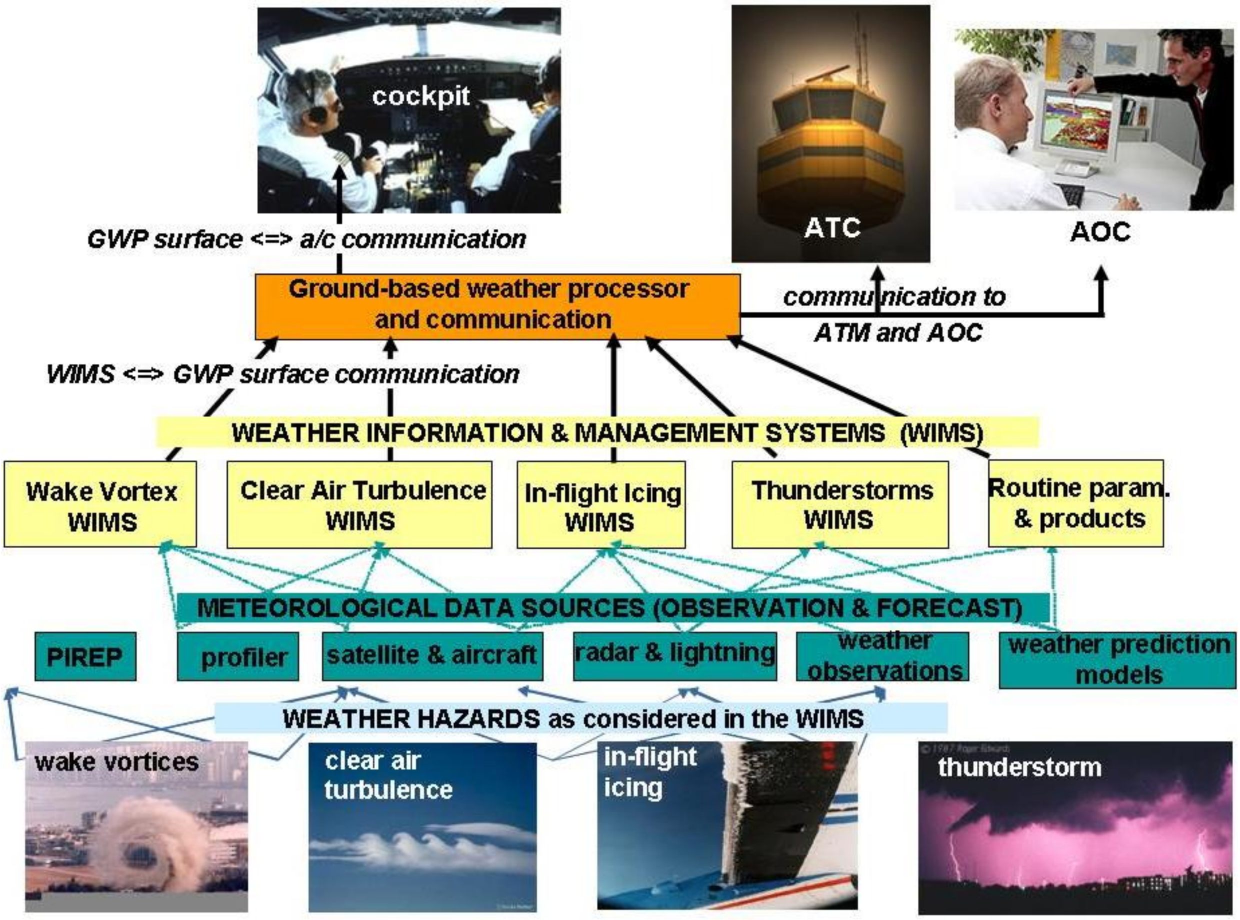

Fig.2. Provision of consistent, timely and tailored information on hazards like wake vortex, clear-air turbulence, in-flight icing and thunderstorm as well as the standard weather parameters through ground-based weather information and management systems (WIMS) to the flight crew, air traffic controllers (ATC) and airline operation centres (AOC).

The WIMS products, together with routinely disseminated conventional aviation weather data, will be stored in so-called 'Ground (based) Weather Processors' (GWP) which store the information, tailor the data for particular aircraft requirements and communicate them to the aircraft. Data will be fused on-board with data from on-board sensors and displayed to the pilot. Likewise, the data are transmitted to AOC, ATM and ATC.

Weather information is required 24 hours in advance by AOC and ATM for planning on a strategic scale (e.g. long-haul flights) and down to the order of a few minutes (e.g. wake vortex warnings at the final approach) or an hour (e.g. thunderstorm warnings) for alerting air crews and ATC on a tactical scale. Such a large diversity of scales and terms cannot be addressed with a single technique. Weather forecasting techniques, which rely on numerically solving the equations of state of the atmosphere and provide 'long-term' predictions of more than an hour, and the nowcasting techniques, which combine recent weather monitoring data with simpler 'short-term' predictions of minutes to an hour, must be used in smart combination to obtain optimum results for aircraft en-route as well as flying in the terminal area.

4 WIMS for Wake Vortex

The WIMS for aircraft wake vortices (WV WIMS) is designed for two purposes. First it provides weather parameters relevant for on-board wake vortex (WV) predictions to the aircraft en-route and in the TMA. Second it computes minimum safe aircraft separation times for ATC to schedule aircraft at the final approach and for departure routes. The aim here is to eventually replace the ICAO separation standards by a dynamic separation procedure which optimises capacity and keeps the high safety level. The WIMS mode for the en-route airspace takes input parameters from the Unified Model, a global forecast model run by the UK Met Office, whereas the WIMS mode for the TMA airspace consists of a wake vortex prediction and monitoring system, DLR's WSVBS. The former predicts vertical profiles of wind, turbulence and temperature for aircraft en-route. The latter predicts the same parameters for the TMA plus the minimum time separations of aircraft for ATC.

For the TMA, the WIMS is based on DLR's WSVBS (German for Wake Vortex Prediction and Monitoring System) [3]. The WSVBS combines tools to forecast the local weather on an airport (NOWVIV) and to predict the wake vortex transport and decay (P2P) with tools to observe the weather (wind and temperature profilers) and to monitor the wake vortices along the aircraft glide path (LIDAR).

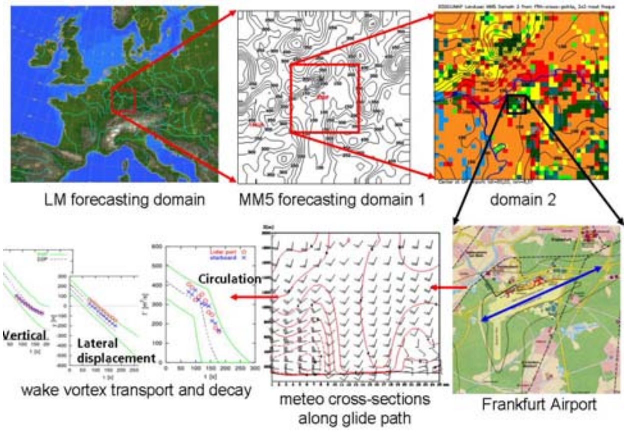

Fig. 3. Illustration of weather and wake forecast used in the WSVBS [3].

As of today, the NOWVIV tool of WSVBS receives 4d synoptic-scale meteorological forecast data from the 'Lokalmodell' of the German Weather Service (DWD) and local meteorological measurements from monitoring equipment installed at Frankfurt Airport. The predicted vertical profiles of wind, turbulence and temperature are transferred to both the GWP for transmission to the aircraft and to the wake predictor P2P which computes probability bounds for trajectories (positions) and circulation of aircraft wakes (Fig. 3). The computation is done in a series of 'gates' along the glide path from the final approach fix down to the runway threshold of Frankfurt Airport and accounts for the hazardous areas around each vortex. When the resulting safety zone and the approach corridor occupied by the follower aircraft do not overlap, the minimum safe separation time is predicted. After cross-checking against wake vortex monitoring by LIDAR (Fig. 4), the minimum separation times are confirmed and transferred to ATC.

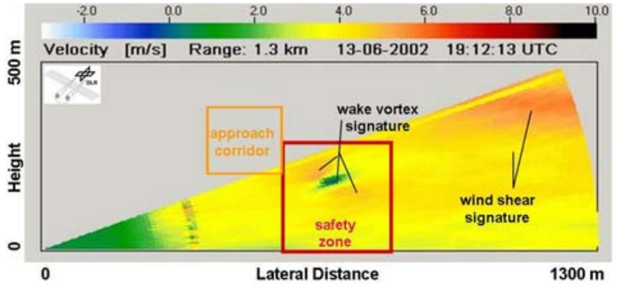

Fig. 4. Velocity as measured by LIDAR (quick-look after one scan) with signatures of wind shear and a wake vortex pair. Also indicated are the approach corridor and the predicted safety zone.

The time horizon for the local weather predictions is 120 minutes with an up-date rate of 60 minutes providing vertical meteorological profiles each 10 minutes. The time horizon for the wake vortex predictions for TMA is 40 minutes with an update-rate of at least 10 minutes and a resolution of 2 minutes.

5 WIMS for Clear-Air Turbulence

The WIMS for clear-air turbulence (CAT WIMS) receives numerically simulated data and aircraft measurements of acceleration levels which serve as a measure for turbulence. The CAT WIMS function will provide very short range forecasts of CAT, taking into account all known sources of CAT, such as vertical wind-shear, terrain effects and thunderstorms. It will operate on two scales, the global and continental (commencing with the European) scale. The WIMS will generate forecasts both on a timetabled basis and on an on-request basis. In the latter case a forecast would be generated for an appropriate amount of airspace to each side of the aircraft.

Classically CAT is linked to a highly non-linear, highly differentiated function of the wind and temperature fields but also simpler, innovative functions are likely to provide predictions which enhance flight safety, according to the safety metrics. The accuracy of CAT forecasts will depend both on the accuracy of the forecasts for the selected CAT predictor and how well turbulence in the real atmosphere correlates with the CAT predictor.

Global forecasts of CAT will be provided by the UK Met Office using its WAFTAGE (Winds Analysed and Forecast for Tactical Aircraft Guidance over Europe) system whereas forecasts over the continental scale will be provided by Météo-France using output of numerical weather prediction models.

5.1 Global scale CAT WIMS

For the global forecasts of CAT the WIMS will be based on forecasts of a CAT predictor calculated by the UK Met Office's WAFTAGE system. The system uses forecasts from a numerical weather prediction model (such as the Met Office's Unified Model or UM) as a basis and adjusts them according to observations of wind and temperature using optimal interpolation to produce high resolution nowcasts of wind and temperature. These could then be used to produce forecasts of CAT using predictors such as the Dutton index (Fig. 5, [4]) or the Ellrods TI1 index (TI1=Vertical Wind Shear x Deformation, [5]).

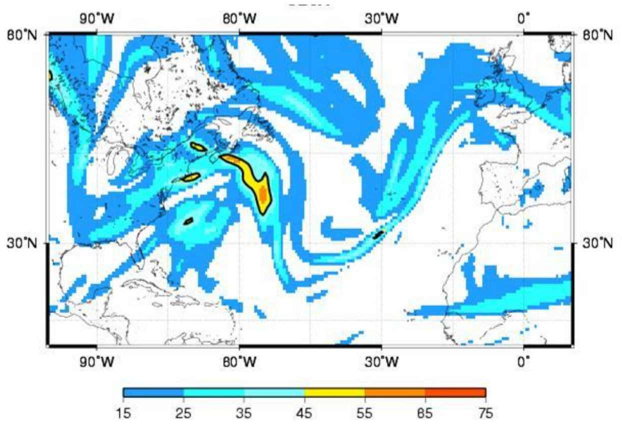

Fig. 5. A chart of the North Atlantic area displaying a predicted CAT index (Dutton [4]) for flight level 400. Regions of severe CAT are marked in yellow and red.

It may also be possible to adapt WAFTAGE to produce CAT forecasts directly, using input observations of CAT to modify the initial forecasts. There is also the potential for stress tensors to be used as a technique for diagnosing turbulence from numerical wind and temperature data.

The WAFTAGE system can be set up to run at any time and it's time resolution can be adjusted. However the quality of the output will be constrained by the time resolution of the input Unified Model forecasts (currently 3 hours).

It is also envisioned that algorithms for forecasting CAT associated with mountain waves and convective clouds will be developed for inclusion in the global scale CAT WIMS. It is likely that the Unified Model will be used to produce these forecasts.

5.2 CAT WIMS for the continental scale

For the continental scale, Météo-France uses the output of the numerical weather prediction model ALADIN (a mesoscale model) to evaluate several CAT indices (Dutton [4], Ellrod (TI1 and TI2) [5], and Brown [6]) and to create combinations thereof to overcome short-comings of a single index [7-9]. These indices will be compared against a set of on-board turbulence measurements included in AMDAR messages. The best combination of indices will be determined by analysing an intensive observation period (IOP) during November and December 2005. The new combination index will be evaluated over a two year period of AMDAR data (excluding the IOP). AMDAR messages contain meteorological parameters collected on-board of commercial aircraft. The turbulence information contained in AMDAR consists of a turbulence index and an equivalent vertical gust [10].

6 WIMS for In-Flight Icing

The WIMS for in-flight icing (ICE WIMS) consists of three so-called scale sub-systems, operating on the global, continental (European) and local (TMA) scale. These scale products will be based on existing meteorological expert systems, namely the UM, ADWICE [11, 12] and SIGMA [13], which have been developed and are maintained by FLYSAFE partners and, in case of ADWICE, by the German Meteorological Service (DWD). The update frequency and applicable forecast horizon will vary according to the different scales. The systems are fed by meteorological data from observations such as standard and airport synoptic observations (SYNOP & METAR), radar and satellite data as well as numerical models. The output describes the icing situation in terms of intensity and occurrence of super-cooled large drops (SLD) conditions, either in grid or in the form of icing objects. The icing information will be delivered to the GWP on a timetabled basis, according to the specific scale, to be tailored for a/c and ATM specific needs.

6.1 The local ICE WIMS

Météo-France has developed a system for the identification of icing areas, named SIGMA (System of Icing Geographic identification in Meteorology for Aviation). This system is based on the combination of three sources of data: (i) an icing risk index calculated from Météo-France's numerical weather prediction model, ARPEGE, which is run 4 times a day with a resolution of 0.25° (about 25 km), (ii) the infrared data from the geostationary Meteosat-8 satellite, available every 30 minutes with 6 km resolution, and (iii) Météo-France's operational centimetric radar network, composing a 1536 x 1536 pixels radar mosaic every 15 minutes.

Each kind of data can thereby confirm or infirm the information deduced from the others. The algorithm is based on the theory of the warm tops clouds [14], saying that within clouds with 'warm' tops (CTT between 0 and -15°C) the icing risk is significantly increased compared to 'cold' cloud tops (temperature below -15°C). Clouds with positive CTTs are considered free of icing.

SIGMA currently delivers a map of the icing risk in real time, as a bi-dimensional image, which shows the cloudy areas with conditions favourable to icing in four different intensities (see Fig. 6). The images are available every 15 minutes with a horizontal resolution of 1536 x 1536 pixels of about 1 km side.

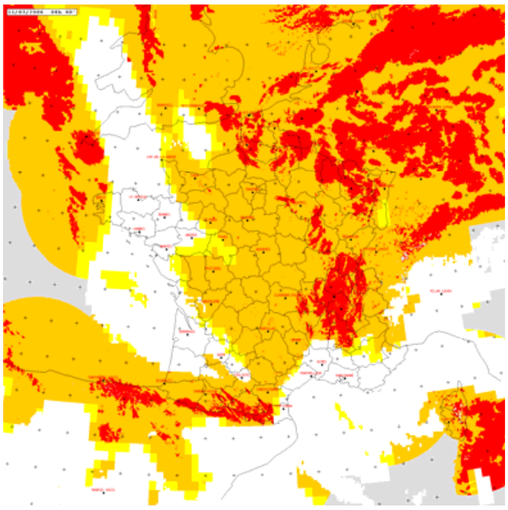

Fig. 6. SIGMA output for 11.03.06, 0800 UTC. Colour code: red = moderate-severe icing, orange = moderate icing, yellow = light icing, white = no icing.

Modifications to SIGMA are foreseen regarding the input data sources, aiming at the implementation of the numerical model AROME with a higher resolution and additional microphysical parameters, additional cloud data from Meteosat-8 and improved radar outputs from the national composite.

6.2 The European ICE WIMS

The Advanced Diagnosis and Warning system for aircraft ICing Environments (ADWICE) has been developed in a joint co-operation between the German Weather Service (DWD), the German Aerospace Center (DLR) and the Institute of Meteorology and Climatology of the University of Hannover. Currently ADWICE is running operationally at the DWD, producing two 3D products: (i) an hourly diagnosis of icing conditions, based on both observations and model data, and (ii) a purely model-based 21-hour forecast, derived two times a day (T00+21h, T12+21h UTC).

The area covered by ADWICE corresponds to the one of the German Weather Service's Local Model Europe (LME). Currently ADWICE produces gridded output fields with a horizontal resolution of about 7 km on 15 different pressure, respectively flight, levels from surface up to FL 300.

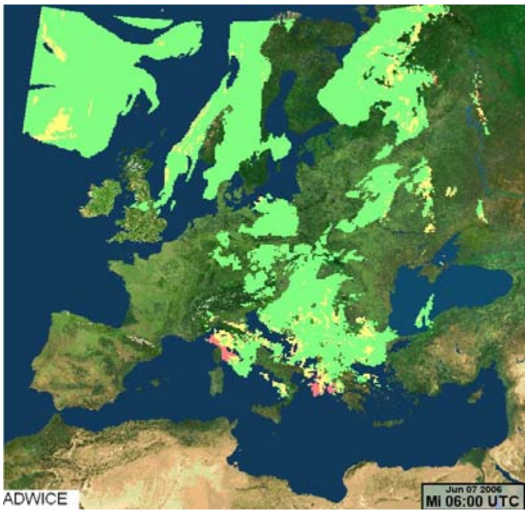

Fig. 7. ADWICE icing intensity output (LME area) on FL 100 for 07.06.2006, 06 UTC. Colour code: red = severe icing, yellow = moderate icing, green= light icing.

The system merges observation data from the DWD's European Radar composite, SYNOP and METAR data with three model parameters: temperature, relative humidity and convection scheme data. Based on several algorithms using meteorological knowledge of the state of atmosphere related to different observations (described e.g. in [11] and [12]), ADWICE produces two types of output: the icing scenario (based on weather/cloud type), indicating the presence of SLDs, and an estimate of icing intensity (see Fig. 7). Further development plans include an improved icing intensity forecast, an extension of the radar network and the future implementation of satellite data.

6.3 The global ICE WIMS

The Unified Model is the suite of atmospheric and oceanic numerical modelling software developed and used by the UK Met Office. It is used operationally to provide numerical forecasts of the atmospheric state for periods of a few hours to several days ahead. Global and regional configurations may be used, and several runs are performed each day. Data are available covering 6-hourly periods, issued at 00z, 06z, 12z and 18z. As of December 2005, the global model output has a resolution of approximately 41 km (0.375° x 0.5625° grid) and is available on ten different pressure levels.

The UM can predict precipitation from a convection scheme and a large-scale precipitation scheme. The latter represents atmospheric processes occurring over distances comparable to the grid-scale, whilst the former represents convective processes, which affect moisture on smaller scales. The precipitation scheme is described in [15], and a detailed description of the convection scheme is given in [16].

In the large-scale precipitation scheme, the water in the atmosphere is classified using four quantities: vapour, liquid droplets, raindrops and frozen water. For computational reasons, the quantity 'ice' is used to describe all states of frozen water in large-scale clouds and covers aggregated snow, pristine ice crystals and rimed particles. The four quantities are linked by transfer terms (explained in more detail in [15]). The condensation/evaporation of cloud liquid water is treated diagnostically by this scheme, whilst ice content is treated as a prognostic variable.

The main output fields from the UM relevant to icing are super-cooled liquid water content (SLWC) and cloud fraction in the temperature range of -20 to 0°C (Fig. 8). Cloud ice content, relative humidity, wind (meridional, zonal and vertical) and temperature fields are also readily available.

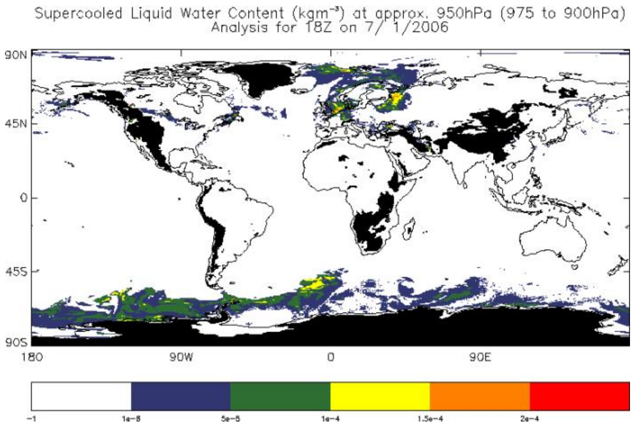

Fig. 8. UM output of super cooled liquid water content for 07.01.06 2006, 18 UTC, on 950 hPa.

7 WIMS for Thunderstorms

The WIMS for thunderstorms (CB WIMS) aims at providing information on the hazards lightning, turbulence, wind shear, hail, heavy rain and icing occurring within or next to thunderstorms, as indicated in Fig. 9.

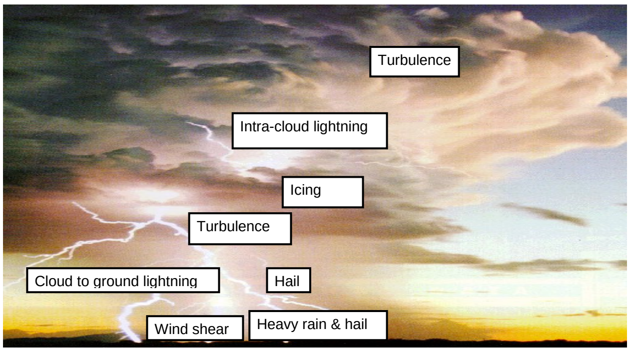

Fig. 9. Photograph of a thunderstorm with location of hazards indicated.

However, the complex nature of the dynamic evolution of thunderstorms renders exact detection and nowcasting or even several hours forecasting of these weather features an ambitious task. Convective cells may evolve within minutes, life times vary from rather short - about 20 minutes for single convective cells -, to several hours for propagating meso-scale convective complexes; individual cells may split or merge, new cells might form ahead of existing cells; cloud physical processes resulting in lightning, hail, turbulence etc. are strongly varying in intensity during the life time of a thunderstorm and also among different storms; and last not least, the resulting hazards to aircraft do not occur within one place or volume but are spread out through the thunderstorm (Fig. 9).

In the following a system designed to identify and forecast these hazards is introduced and its realisation within the scope of FLYSAFE is outlined. CB WIMS will deliver so-called ‘thunderstorm weather objects’ (CB-WO) which are specified for the three different scales, depending on data availability and appropriate nowcasting and forecasting tools.

An ideal thunderstorm weather information and management system would use all available observational data, remote sensing as well as in-situ measurements, and combine them within a data fusion procedure with various nowcasting and forecasting applications in order to detect and monitor thunderstorms, identify their physical characteristics and forecast the future state. For the three scale products TMA, continental and global scale, only those characteristics would be delivered which, firstly, can be described with sufficient accuracy by monitoring and forecasting tools and, secondly, meet the requirement of the users. Such a system is schematically displayed in Fig. 10.

Here, the top row of icons represents relevant data sources and the bottom row nowcasting and forecasting tools. In the middle, a thunderstorm weather object CB-WO is defined which specifies information details about CBs as required by users, e.g. present and future areal extent, height, direction of movement, occurrence of specific weather hazards to aircraft, etc. These information details are identified within a data fusion process from the various data sources and nowcasting and forecasting tools [17].

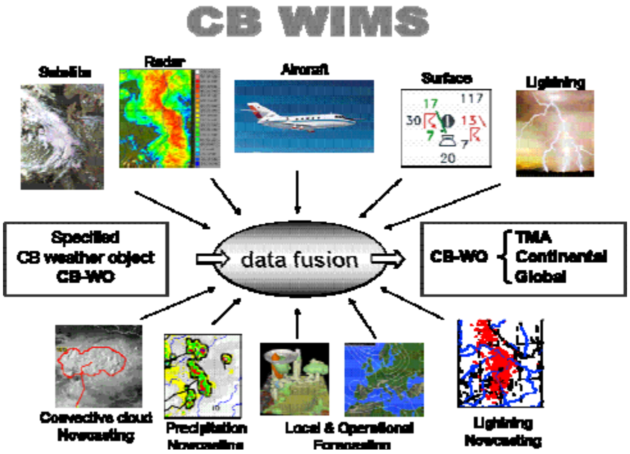

Fig. 10. Schematic depiction of the operational procedure of an ideal thunderstorm weather information system CB WIMS. Further explanation see text.

The complex nature of thunderstorms is simplified by idealised thunderstorm objects. They consist of hazard volumes such that (i) its physical characteristics can be observed by nowadays observation systems with sufficient accuracy and that (ii) the future state can be nowcast up to an hour by available nowcasting tools [18-20].

Fig. 11 depicts schematically the specified hazard volumes, rendering a thunderstorm as composed of a top volume and one or more bottom volumes.

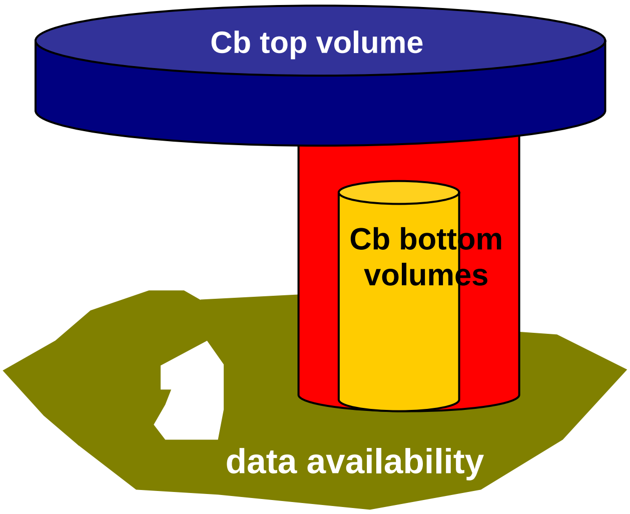

Fig. 11. A thunderstorm divided into different simplifying objects in the form of hazard volumes. Further explanation see text.

Note that the volumes must not necessarily be cylinders as indicated in the figure, rather, polygons will be used to encompass the horizontal extension. The horizontal extent of the upper volume will be defined using satellite data, as in High Resolution Visible channel, where the occurrence of convective cloud tops and overshoots is an indirect signature of turbulence.

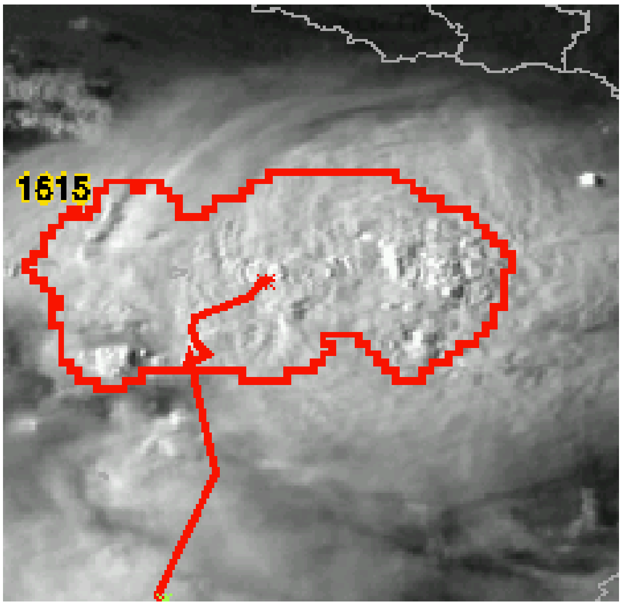

Fig. 12. MSG high resolution visible image of a thunderstorm cloud over France, approximately 50 km in diameter. The contour marks the convective cell as detected by CB-TRAM. The line marks the past track of the centre.

Fig. 12 shows an example of a tracked thunderstorm cloud where the red contour marks the envelope of the convective region as identified by the DLR cloud tracker CB-TRAM [20].

The top of the top volume (Fig. 11) will be defined using the height of the cloud top (derived from cloud top temperature and atmospheric profile) plus 1 km vertical extension for taking into account convective turbulence above the CB. The trend in intensity will only be qualitative (growing, decaying) based on changes in cloud top temperature and possibly of cloud top area change, or radar echo top or intensity change. The top volume specified in this way is expected to incorporate hazardous regions of convective turbulence and lightning.

For CB bottom volumes available observations may provide a more or less direct measurement of the following physical phenomena generating hazards: hail, heavy rain, convective shear/turbulence, and lightning. The hazard volumes will be defined at two levels of severity, i.e. moderate and severe risk. For moderate risk the horizontal area extent will be identified by combining radar data (with reflectivity thresholds around ~30 to 33 dBZ) and lightning density observations. The top of the bottom volume will be identified using the height of radar top (at same radar threshold); if not available it may be defined as the bottom of any top CB volume located on the same area (as a minimum value). Alternatively it may also be found as the equilibrium level for an air parcel with ground characteristics derived from a simple buoyancy model with the tropopause level setting the ultimate default value. The bottom will be set at the ground, because of the so quickly evolving value of the respective parameters. The trend in intensity will be only qualitative (growing, decaying) based on changes in the radar echo top or intensity.

Bottom volumes of severe risk will be based on the observation of lightning cores or of higher radar reflectivity (threshold ~42 dBZ). The top will be based on the height of radar top. Additionally a binary flag will indicate when hail is diagnosed.

For nowcasting of hazard volumes the area (contour) and displacement vector will be provided for every forecast time and for each volume. The forecast range will be 60 min for the moderate risk volume. Due to the state-of-the-art predictability of severe phenomena, the forecast range will be limited to 20 or 30 min for the severe risk volumes.

Additionally to the top and bottom volumes a data coverage object (indicated in Fig. 11 as a flat surface) will be provided which describes the various aspects of the CB WIMS processing, e.g. for observations the area of data availability, furthermore WIMS CB output update rates and the sequence of forecast intervals.

As regards to the CB WIMS products for the TMA and continental scales, differences stem primarily from differences in data availability, primarily as regards to 2d and 3d radar observations. Lightning and satellite observations are equally available for both scales. Therefore, products for these scales will be quite similar, differing mainly in update frequency and accuracy of the hazard volumes description. For the global scale, CB WIMS objects have to be compiled based on numerical weather prediction output as some or all of the available data for TMA and continental scale might not be available in remote areas.

8 The Ground Weather Processor

The Ground Weather Processors (GWP) will be the ground segment that links output from the WIMS to aviation users, i.e., flight crew, ATC, AOC and others. The GWP will exist in two forms: a local weather processor (LWP) and a central weather processor (CWP). The LWP will store weather information for the Terminal Manoeuvring Area (TMA) and up to 100 x 100 km² and several 1000 feet high. This information will be high-resolution forecasts at one hour ahead available at a high refresh rate. The CWP will store weather information for the en-route segment of the flight. This information will be at continental and global (i.e. lower) resolutions, available at a lower refresh rate. The GWP will store weather information as objects, as provided by the WIMS, 4-D gridded data and routine weather products, e.g., volcanic ash alerts, tropical cyclone alerts, METAR, SigWX charts, etc.

8.1 Communication NGISS – GWP

We assume a scenario of a flight from Toulouse to London. Prior to movement of the aircraft, the on-board Next Generation Integrated Surveillance System (NGISS) receives weather information for the TMA (Toulouse) from the LWP, which is located at the airport. The connection between them is via a cable thus a high volume of information can be sent, which includes weather information for the en-route flight phase. When the aircraft is moving, communication is via radio thus only a lower volume of information is available due to bandwidth restrictions. At instance when radio-communication operates the NGISS polls the LWP at regular intervals for updates to weather information. Whilst the aircraft remains under local air traffic control the LWP furnishes the NGISS requests.

Following take-off, flight control transfers to France National Air Traffic. At the transfer of control, the NGISS connects to the CWP, co-located at the national air-traffic control centre. The NGISS continues to poll for updates, at a lower request rate. This is the ‘en-route’ stage of flight, thus the available weather information will be at a lower resolution but with greater forecast ranges (~ 6 hrs at 1 hr resolution). During this phase of flight, routine weather observations, e.g., AMDAR, are sent to the GWP for onward transmission to the National Meteorological Centres.

During the flight, control of the flight transfers from France to UK national air-traffic (NATS). Now the NGISS connects to a CWP located at NATS. During the en-route phase of flight, the flight crew can request weather information on demand. The flight-crew’s request is sent via the NGISS to the CWP. The same route returns the weather information to the flight crew.

As the aircraft approaches its destination, flight control transfers from NATS to local air-traffic control, this would occur around 30 minutes before landing. At this point, the NGISS connects to the LWP at London, requesting weather information updates for the TMA of London. The NGISS request rate increases to ensure that the most recent weather information is available to the flight-crew. Once the aircraft has landed and it is stationary, a cable link is established and any remaining routine weather observations recorded by the on-board systems is transferred to the LWP for onward transmission to the National Meteorological Centres.

8.2 Flight and Weather Corridor

The GWP will provide on request, from the NGISS or flight-crew, weather information (the ‘corridor weather’) relevant to an aircraft’s flight corridor in the horizontal and vertical (Fig 13). The calculation of the flight corridor uses the aircraft’s telemetry sent by the NGISS. The flight corridor comprises a volume of space in which the flight crew would have response times available at the strategic level, e.g., a minimum flight time that corresponds to the aircraft’s radar range (~ 20 mins); a maximum flight time range (~ 60 mins); flight time ~ 5 - 10 mins for all other directions; thus enabling the flight crew to avoid hazardous airspace.

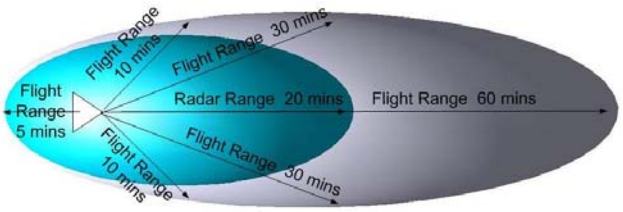

Fig. 13. Illustration of the aircraft’s horizontal flight corridor with two ranges. The small blue ellipsoid corresponds with the radar range (~20 min or 200 nautical miles), the large grey ellipsoid corresponds with the flight path ahead (~60 min).

8.3 GWP Adapter and Broadcast Functions

Clearly, there are many different types of aircraft and each will have an (NG) ISS of differing capability. To accommodate this feature, the GWP will adapt the weather information to the specific on-board system; this is the role of the GWP adapter function. The adaptation may be of a kind to reduce the data resolution to enable timely delivery using the available radio bandwidth; to prioritise up-linking of weather information, e.g., volcanic ash alerts to aircraft whose flight corridor enters a hazardous volume of space.

Aviation users currently have access to a range of routine weather products (RWX) for flight planning and en-route planning. These products include NOTAMS, SIGWX charts, OPMET, TAFs, METARs and SIGMETs, also VAAC and Tropical Cyclone reports. Each GWP would maintain a range of routine weather products that are relevant to their area of responsibility. Thus the LWP would maintain RWX products for the TMA in which it is located; the CWP would maintain RWX products relevant to aircraft en-route through its area of responsibility. The aircraft can request any or all of these RWX products which are relevant to the particular flight. Those data are then up-linked from the GWP to the aircraft.

9 Conclusion

Four major weather hazards to aviation, namely aircraft wake vortices, clear-air turbulence, in-flight icing, and thunderstorms have been described. Ways of improving the situation awareness of flight crew, flight control & management (ATC/ATM) and airline operation centres (AOC) have been outlined: Within the European Integrated Project FLYSAFE, Weather Information Management Systems (WIMS) for these hazards are under development. The products of the WIMS are collected in central and local processors where the information is tailored in a consistent and timely way to meet the specific requirements of aircraft. The resulting ‘corridor weather’ is communicated to the aircraft systems where it will be fused with data from on-board sensors and displayed to the pilot. At the same time the weather hazard information is also available for AOC, ATM and ATC.

The products of the Integrated Project FLYSAFE will in particular enhance the on-board awareness of adverse weather elements and the capability of the flight crew to make the right and flight-optimum decisions. For example, the different hazard volumes of lightning, hail and turbulence in the upper part of a thunderstorm will be displayed in the cockpit. Compared to today’s rule of thumb methods by day and nothing during night operations, the FLYSAFE outcome will allow rational distance keeping from thunderstorms during cruise flight and it may possibly lead to less disturbed routings around weather systems allowing more traffic to be handled.

Acknowledgements

We acknowledge the co-authorship from Sally Close, Bob Lunnon and Rebecca Quaggin (UK Met Office), Agathe Drouin, Patrick Josse, Christian Pagé and Stéphane Sénési (Météo France), Christoph Leifeld (DWD), Thomas Hauf and Michael Theusner (Uni Hannover), Michael Frech and Frank Holzäpfel (DLR).

The timely comments by a reviewer, Wim Huson (USE2ACES), are highly appreciated.

This work is funded by the European Commission under contract FP6 – 516167, Integrated Project FLYSAFE.

References

[1] Huysseune J. A major initiative of European cooperation in flight safety: FLYSAFE. Proc 25th International Congress of the Aeronautical Sciences, Hamburg, 2006.

[2] Hauf T, Leykauf H and Schumann U. Luftverkehr und Wetter - Statuspapier. DLR-Mitteilung 2004-2, DLR, 2004.

[3] Gerz T, Holzäpfel F, Bryant W, Köpp F, Frech M, Tafferner A, Winckelmans G. Research towards a wake-vortex advisory system for optimal aircraft spacing. Comptes Rendus Physique, Académie des Sciences, Paris, Vol. 6, No 4-5, pp 501-523, 2005.

[4] Dutton M J O. Probability forecasts of clear-air turbulence based on numerical model output. *Meteorol. Magazine*, Vol 109, pp 293-310, 1980).

[5] Ellrod G P, Knapp D I. An Objective Clear Air Turbulence Forecasting Technique: Verification and

Operational Use. Weather Forecasting Vol. 7, pp 150-165, 1992.

[6] Brown R. New indices to locate clear-air turbulence. *Meteorol. Magazine*, Vol 102, pp 347-361, 1973.

[7] Buss S, Jäger E, Schmutz C. Evaluation of turbulence forecasts with the aLMo. Technical Note, Meteo Schweiz, 2005.

[8] Brown B G, Mahoney J L, Bullock R, Henderson J, Kane T L. Turbulence Algorithm Intercomparison 1998-99, Initial Results. NCAR Techn. Note, 1999.

[9] Sousounis P J. Short term turbulence forecasts over the Atlantic Ocean using WRF. Proc. WSN, 2005.

[10] WMO AMDAR Reference Manual. WMO Technical Publication No. 958.

[11] Leifeld C. Weiterentwicklung des Nowcasting-systems ADWICE zur Erkennung vereisungs-gefährdeter Lufträume. Berichte des Deutschen Wetterdienstes Nr 224, Offenbach am Main, 118pp, 2004

[12] Tafferner A, Hauf T, Leifeld C, Hafner T, Leykauf H, Voigt U. ADWICE – Advanced Diagnosis and Warning system for Aircraft Icing Environments. *Weather and Forecasting*, Vol. 18, 2, pp 184-203, 2003.

[13] Le Bot Ch. SIGMA système d’identification du givrage en météorologie aéronautique. Technical Note, Météo-France, 2000.

[14] Pobanz B, Marwitz J, Politovitch M. Conditions Associated with large-drop regions. *J. applied Meteorol*, Vol. 33, pp 1366-1372, 1994.

[15] Wilson D R, Ballard S P. A microphysically based precipitation scheme for the UK Meteorological Office Unified Model. *Q.J.R. Meteorol. Soc.* Vol. 125, pp 1607-1636, 1999.

[16] Gregory D, Innes P, Maidens A, Wong R. Unified Model Documentation Paper 27: Convection Scheme. Internal Met Office Documentation, 2005.

[17] Tafferner A, Hagen M, Keil C, Zinner T, Volkert H. Development and Propagation of Severe Thunderstorms in the Upper Danube Catchment Area: Towards an Integrated Nowcasting and Forecasting System using Real-time Data and High-resolution Simulations. Subm. to *Meteorol. Atmos. Phys.*, 2006.

[18] Morel C, El Mahdaoui F, Sénési S, Koffi E. Comparing lightning detection and satellite-based detection for convective system identification: the case of impact technology versus Meteosat Rapid Scan data. *Eumetsat Satellite Data User's Conference*, 2003.

[19] Autones F, Sénési S, Morel C, Guillou Y. Tuning the Rapid Developing Thunderstorm Product for Meteosat Second Generation, and Comparing to GOES-EAST and to RAPID Scan Service. *Proc. WMO Symposium on Nowcasting and Very Short Range Forecasting*, Toulouse, 2005.

[20] Zinner T, Mannstein H, Tafferner A. Cb-TRAM: Tracking and monitoring severe convection from onset over rapid development to mature phase using multi-channel Meteosat-8 SEVIRI data. Subm. to *Meteorol. Atmos. Phys.*, 2006.