

## Tailored and On-time Winter Weather Information for Road Traffic Management

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### ABSTRACT

Recent developments are reported on techniques to determine the onset, duration, amount and type of precipitation as well as the snow and icing conditions at the surface. The algorithms, still under development, will be used to forecast the weather in short to medium lead times, i.e. for the next 30 minutes up to a few hours (“nowcasting”). An algorithm aims at detecting potential areas of snow fall by combining reflectivity data of precipitation and surface temperature data from a numerical model as well as surface stations in high spatial resolution. Another approach combines profiling measurements (e.g., meteo data measured by aircraft and polarimetric radar data) with numerical weather forecast products.

**Keywords:** type and amount of precipitation, nowcast, anticipating the weather

### 1 INTRODUCTION

Weather phenomena contribute to congestions, accidents and delays in all traffic modes. The road traffic in particular is derogated by adverse weather like snow, ice, fog, rain, strong wind and wind gusts. Increasing traffic makes transportation even more vulnerable to adverse weather conditions. Today stakeholders and participants in transportation (be it air-borne or ground-based) most of the time only react on adverse weather when the disruption has already happened or is just about to happen. Future road management systems should proactively anticipate disruptive weather elements and their time scales of minutes to days well in advance to avoid or to mitigate the impact upon the traffic flow.

But “weather” is not a technical problem that can be simply solved. Predicting the weather is a difficult and complex task and only possible within certain limits. It is therefore necessary to observe and forecast the changing state of the atmosphere as precisely and as rapidly as possible. Moreover, measures are required that translate “weather” to “impact” and minimise those impacts on traffic flow and its management.

To inform traffic participants and traffic management centres in due time on (expected) adverse conditions, tailored and accurate meteorological information is required on short notice. This information must be integrated in the process of information distribution and decision making to allow for tactical as well as strategic decisions.

The Institute of Atmospheric Physics of the Deutsches Zentrum für Luft- und Raumfahrt (DLR) in Oberpfaffenhofen, Germany, and the company Hydrometeorological Innovative Solutions S.L. (HYDS) in Barcelona, Spain, develop a meteorological decision support system for aviation (MEDUSA) within the EU’s People Programme, Industry-Academia Partnerships and Pathways, and DLR’s Research Activity “Weather Optimised Air Transportation”. Its goal is to augment safety and efficiency of air transportation. Many of the developed methods focus on the ground level and, therefore, can well be adapted and applied for weather-dictated issues in road transportation, too.

We demonstrate our logic, first developed for the aviation transport sector, to combine various meteorological parameters to simple, self-explaining weather objects. Further we report on recent developments to determine the onset and duration of icing conditions at the surface. An algorithm aims at detecting potential areas of snow fall by combining scanning reflectivity data of precipitation and surface temperature data from a numerical

model as well as surface stations in high spatial resolution (1 km). Another approach combines profiling measurements (e.g., meteo data measured by aircraft and polarimetric radar data) with numerical weather forecast products.

For forecasting winter weather conditions up to about 24 hours or more, one can rely on operational numerical forecast models. Numerical models have made remarkable progress during the last few years in forecasting the overall weather state, e.g. the surface pressure distribution or whether it will rain or not. The forecast of winter weather phenomena, however, like freezing rain or drizzle, or light or heavy snow fall is still a demanding task. These phenomena result from the subtle interplay of various factors, like the vertical distribution of temperature and humidity, cloud cover and type, snow cover, soil moisture and the composition of the atmosphere with aerosols which again influence cloud and precipitation processes. The situation gets even more complicated as these processes result from instabilities which are triggered by small changes in the atmospheric parameters, e.g. whether the temperature at the ground or through a certain depth of the atmosphere is slightly above or below 0° C. In order to better estimate the future atmospheric state ensemble models give better guidance than a single model run. Combined quantities like ensemble mean, spread and others allow probabilities to be estimated which can be used for advanced planning. Here output of the KENDA ensemble model from the German Meteorological Service, DWD [5], can be used in future to provide this probability information.

However, in order to mitigate the impact of wintry weather conditions on airport operations more efficiently, the focus should be laid on short-term forecasting (termed “nowcasting”) these conditions. This comprises the onset, duration and type of precipitation as rain, snow, freezing rain, or fog. DLR is developing a nowcasting system that provides users in aviation with 0 to 2 hour forecasts of these winter weather conditions [8]. We argue that a similar system imbedded in the process of information sharing for collaborative decision making would also be beneficial for operations on road networks.

## 2 WINTER WEATHER OBJECTS

A certain winter weather phenomenon, like e.g. freezing precipitation, can be thought of a certain volume of air within which this phenomenon can be observed. Various observations are suited for describing one or the other attribute of that phenomenon, as e.g. the surface temperature, the precipitation type. With no doubt the actual weather phenomenon can be determined more precisely when data from various sensors are combined [7]. It is therefore advisable to think of such volumes as weather objects with certain inherent attributes. For our purposes, a winter weather object (WVO) in a certain limited area, e.g. an airport or a dense motorway network, can be defined through the following parameters:

- a vertical column of air consisting of several layers
- issued time
- valid time
- next update time
- layer description, e.g.:
  - Snow: upper and lower boundary with intensity: light, moderate, severe
  - Rain: upper and lower boundary with intensity: light, moderate, severe
  - Freezing rain: upper and lower boundary
  - Freezing drizzle: upper and lower boundary
- surface conditions
- trends, e.g. intensity increasing, change to melting, etc.

Figure 1 sketches how weather parameters from various sources are combined by data fusion to a winter weather object, WVO (yellow cylinder), with different attributes in different layers. SYNOP and automatic sensors (as from SWIS) allow determining surface conditions, in this example rain with temperature above zero. The temperature/humidity sounding can be provided from a numerical weather forecast model, aircraft measured data (AMDAR), or constructed from both depending on data availability. Radars observe the precipitation height and may also be able to determine the hydrometeors within the cloud (polarimetric capability and related algorithms). ADWICE – the Advanced Diagnosis and Warning System for Icing Environments – [6,4] uses the information of reported weather at the ground together with the soundings of temperature and humidity and radar measurements to determine the icing threat to aircraft in flight. ADWICE is now further expanded to diagnose and predict snow and icing conditions at the surface, too, see following Section. Taken together, the derived analysis can be compacted into the WVO which is shown schematically as a yellow cylinder on the right of Figure 1. It is obvious that the object can have several different hazard layers in the vertical. For the given case there would be a near surface layer with temperatures above freezing up to height H1 which contains rain drops, a second layer from H1 to H2 which contains super-cooled droplets with corresponding icing threat, and a precipitating cloud layer on top.

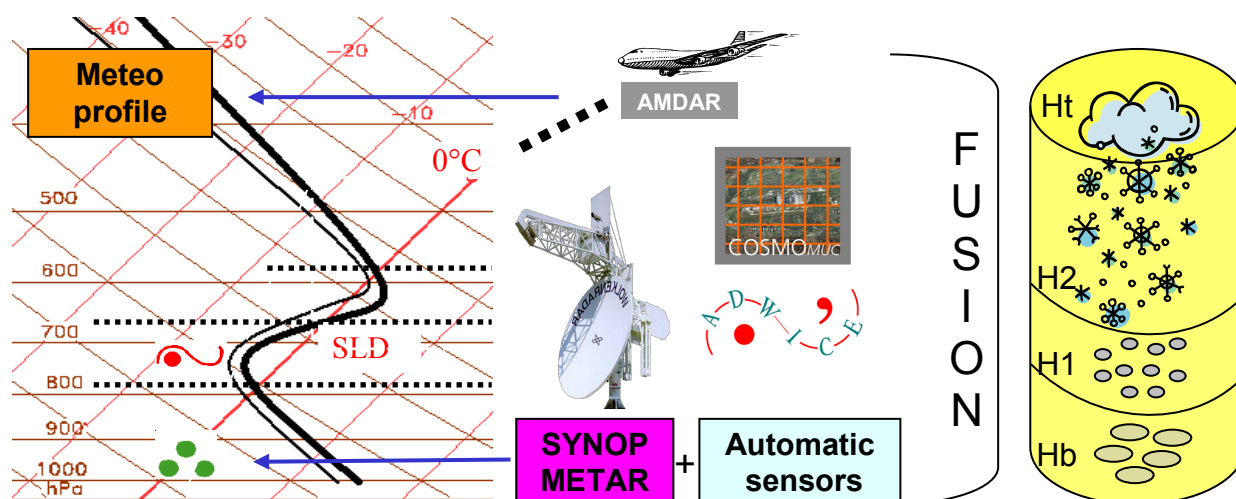


Figure 1. Fusion of different data into a winter weather object, WWO, (from [8])

For nowcasting icing & snow conditions at the surface one has to consider weather changes due to advection of air with different characteristics and, especially demanding, possible changes resulting from precipitation and cloud physics processes which can occur within short time spans at the observation site. For capturing both of these effects an approach is followed where WWOs are determined at the various observation sites around an airport or along motorways where data from SYNOP, radar and SWIS stations are available. Changes in WWOs around the location can then provide guidance for the expected change at the location.

### 3 DIAGNOSIS AND PROGNOSIS WITH ADWICE

ADWICE stands for **A**dvanced **D**iagnosis and **W**arning system for aircraft **I**cing **E**nvironments. Based on the expert system IIDA (Integrated Icing Diagnostic Algorithm) by NCAR/RAP [4], to detect and predict clouds and precipitation with super cooled liquid water, it has been designed at DLR in Oberpfaffenhofen in 2003 [6] and further developed by the German Meteorological Service (DWD) [3]. Its purpose is the detection and forecast of areas with super cooled large droplets (SLD) and possible three dimensional icing areas, respectively, which pose a significant threat to aircraft.

ADWICE provides a diagnostic procedure to analyse the current icing situation of the investigated part of the atmosphere. Figure 2 schematically illustrates the proceeding of the diagnostic part of ADWICE. The most important information is ground measurements received from observation sites. The current version of ADWICE uses observations of the present weather as well as the cloud amount and an estimation of the cloud base height. In combination with radar reflectivity measurements, these data are used to get a first guess information for a certain icing scenario above the observation sites. At stations where these data indicate an icing weather situation, the ADWICE algorithm is used to search for the vertical extend of the possible danger zone. On the basis of observed or model forecast profiles of humidity and temperature as well as some derived convection parameters, like cloud base height and cloud thickness or specific cloud water and cloud ice content, the icing algorithm is designed to detect possible icing areas. Four different icing scenarios are classified, which rest upon different types of formation processes. For example, the icing scenario *freezing* describes the typical formation process of super cooled rain. It is mainly characterized by a warm atmospheric layer (temperatures above 0°Celsius) embedded in colder ( $T < 0^\circ \text{C}$ ) layers or above the cold ground. Solid precipitation experiences a phase transformation from solid to liquid in the warm layer and gets super cooled in cold layer beneath or on the ground without changing the phase again.

In the prognostic part of ADWICE solely the output of a numerical weather prediction model is used to forecast three dimensional areas with the possible occurrence of super-cooled droplets. The current version of ADWICE, which is operationally used by DWD, is operating with the output of the COSMO-EU model. Twice a day hourly icing predictions up to 21 forecast hours are created. Figure 3 illustrates the operational processing. The prognostic algorithm is started at 03UTC on the basis of the 00UTC model run and at 15UTC on the basis of the 12 UTC model run.

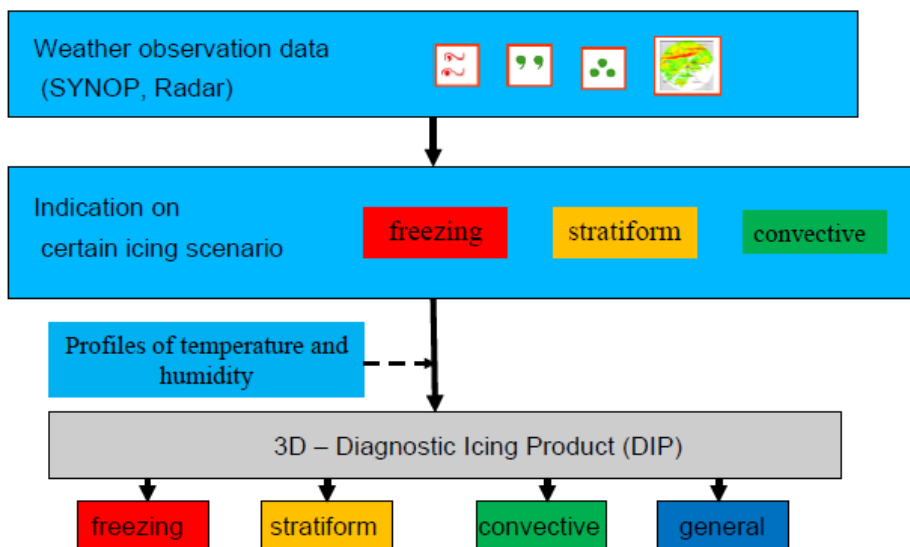


Figure 2. Diagnosis with ADWICE

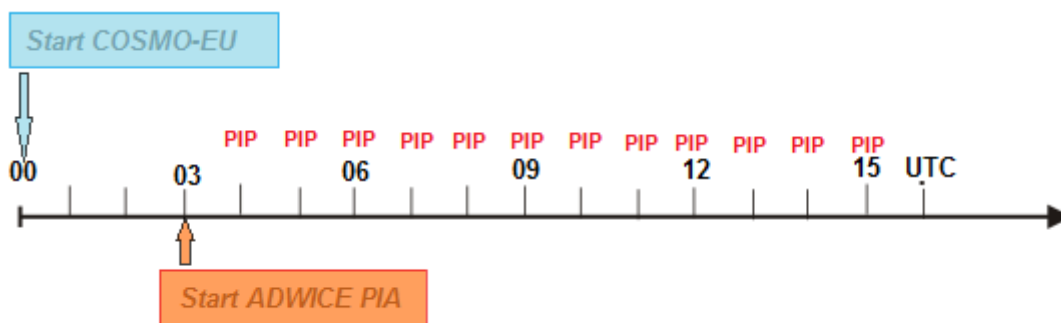


Figure 3. Operational production of output from ADWICE's prognostic icing algorithm

We are about to modify ADWICE by using the local area, high resolution numerical weather prediction model COSMO-DE. It covers the areas of Germany, Switzerland, Austria and parts of their neighbouring countries and has a horizontal resolution of 2.8 km. In contrast to the regional model COSMO-EU, COSMO-DE is able to explicitly simulate (large) convective processes. A major change in the prognostic part will be the use of some directly derived convection parameters of the COMSO-DE model. Also the diagnostic icing product will be enhanced further through the combination with additional local data. For example, measured profiles from starting and landing aircraft instead of model profiles will be applied as well as polarimetric radar data from POLDIRAD instead of conventional radar information (European radar composite). Where available, also surface data from 'Strassenwetterinformationssystem – SWIS' along major highways will give information on freezing conditions. The observation of present weather, cloud amount and cloud base height will furthermore be used after the modifications.

#### 4 NOWCAST OF POTENTIAL SNOW FALL AREAS

To nowcast potential areas of snow fall in a region we utilize

- Synoptic (large scale) maps of 1000-500 hPa and 1000-850 hPa thickness providing the region of cold air obtained from METAR (standard hourly observation) or numerical weather prediction (NWP) models
- Surface temperature below/above 0~2°C or/and wet-bulb temp less than 0°C based on NWP model outputs and observation
- Volumetric radar reflectivity observation
- Snow depth measurement
- Soundings from radiosonde and aircraft measurements or/and numerical weather prediction models.

The Potential Snow Fall Area (PSA) algorithm is based on real-time hourly operational data, like regional model surface temperature, precipitation composite estimated from low-level radar scans, and surface observations. This allows that the output, a warning in terms of PSA, can be generated in real-time and at low-cost. Also, the output can be used in building more complicated algorithms of winter weather warnings based on various other sources (e.g., the ADWICE introduced in the previous section).

#### 4.1 Data sources

The algorithm is constructed with data available over Cataluña including 1) terrain height from DEM, 2) temperature from model, surface station, soundings, and 3) radar reflectivity. The deployment of the observational sources is shown in Figure 4 overlaid on orography. More detail on each source is provided in the following points.

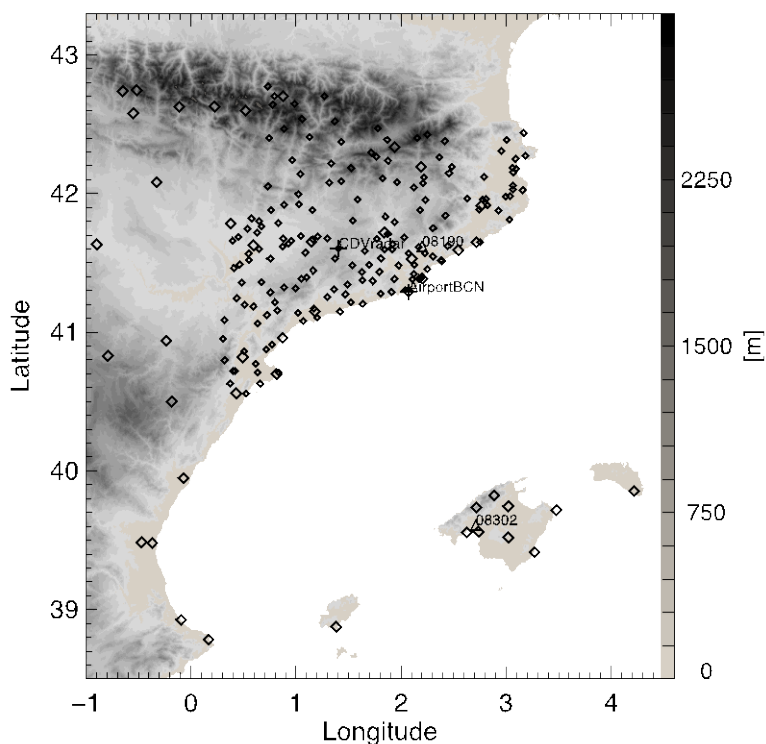


Figure 4. Data available around Barcelona over orography: Crosses indicate the location of CDV-Radar and Airport Barcelona. Similarly, large diamond for AEMET surface stations, small diamond for SMC surface stations, and triangles for soundings.

Digital elevation model (DEM) data used here are from ASTER GDEM (Advanced Space-borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model<sup>1</sup>) which has a horizontal resolution of 1 arc-second, both in longitude and in latitude. This high-resolution terrain height is re-mapped with a grid spacing of 0.01° in the horizontal as shown in Figure 4 and used not only as the background of the output but also for the adjustment of atmospheric temperature in the vertical.

Surface Stations: In real-time, surface station data (e.g., temperature [°C], relative humidity [%], and precipitation [mm/h]) at 2 m height were available every 10 minutes from La Agencia Estatal de Meteorología (AEMET) over the Iberian Peninsula as well as from the additional denser network of surface measurements of Servei Meteorològic de Catalunya (SMC) over Cataluña. However, for the selected case, these were provided in hourly updated values.

Radar reflectivity: Real-time and quality checked radar reflectivity fields at 0.5° elevation angle are generated with SMC's CDV operational C-band radar. The algorithm takes instantaneous scans corresponding to the forecast time (e.g., 1 hour forecast) with 0.01° grid spacing.

<sup>1</sup><http://www.ersdac.or.jp/GDEM/>

Numerical weather prediction model: The model output for the surface is generated over the Iberian Peninsula by meteoblue AG, a private company that runs NMM (Non-hydrostatic Mesoscale Model [2]) in 13-km spatial resolution twice a day with 1-hour forecast up to 72 hours.

## 4.2 Analysis of potential snow area

The PSA is determined mainly based on temperature (obtained from both model output and surface stations) and precipitation (obtained from radar reflectivity and/or model output) at near-ground level. The algorithm interpolates each input field onto the common grid with  $0.01^\circ$  by  $0.01^\circ$  resolution and modifies the model temperature field by height adjustments and taking into account the measured temperatures. The spatial variability (or the structure) of the temperature is obtained from the model output. Figure 5 shows a preliminary result of a potential snow fall area determined with the thresholds of temperature  $< 2^\circ\text{C}$  and radar reflectivity  $> 15$  dBZ shown as light yellow filled areas for 08 March 2010 at 14:00 UTC. At this analysis time, it snowed in the city of Barcelona, which is not captured using only the model temperature (Figure 5a). On the other hand, after the modification (Figure 5b), the selected area becomes more realistic, suggesting that such interpolation can be useful when erroneous model outputs are used in the PSA. Cross validation of the interpolation technique will be performed over longer-term period in the future.

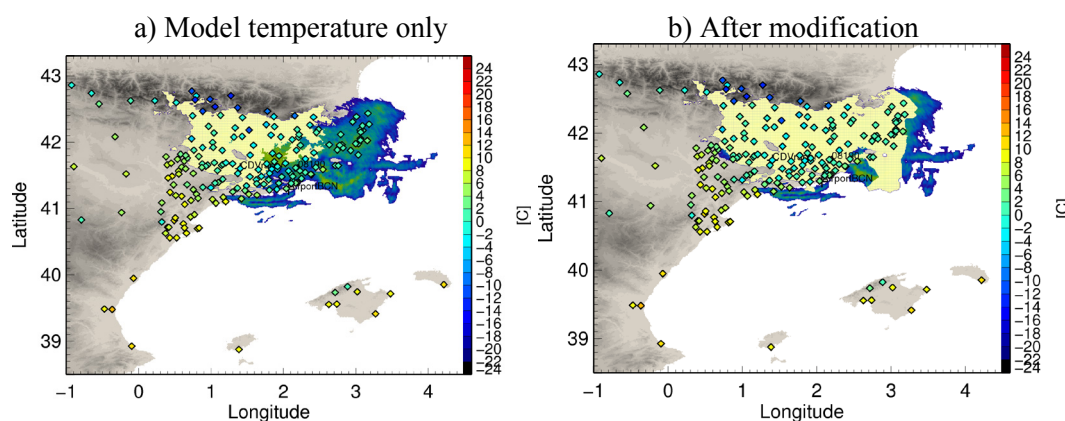


Figure 5: Potential Snow Areas (in yellowish filled-contour) at 14:00 UTC 08 Mar 2010: a) model temperature only, b) after modification. Grey background is orography, diamonds are surface stations, and their colors correspond to temperature [ $^\circ\text{C}$ ] shown in the color Bar. Bluish filled contour indicates reflectivity larger than 15 dBZ.

## 4.3 Forecast of potential snow area

The forecast update frequency depends on the update time of observational data, and the forecast lead-time depends on those of the model and the radar precipitation nowcasting. Four forecast strategies are proposed:

- A. Model: It is initialized at 00 and 12 UTC and actualization is between 4 and 6 hour after initialization. In other words, for verification time at 00 UTC, a model run is chosen at lead-time 12 hour of the runs initialized previously at -12 UTC. On the other hand for verification time at 06 UTC, the model run is chosen from the runs initialized at 00 UTC.
- B. Model tendency (Mtendency): Tendency is referred to as the forward changes of model temperature in time ( $^\circ\text{C}/\text{hour}$ ). Although the model values may be wrong, their changes in time still represent a part of reality. Hence, extrapolation of a corrected initial condition can be performed using the computed tendency from initial time to each lead-time. Here, the station temperature is used as the initial value (forecast lead time zero; FLT0 hereafter).
- C. Conditional merging (CM): This strategy assumes that the initial observation persists in the future and only the forecasted spatial variability of the temperature field is used. This frozen reality assumption may work for short lead times (2 to 3 hours) because it reflects the reality better than the model initialized 12~6 hours earlier. Of course, quick changes as in frontal passages would reduce the useable lead-time.
- D. Relaxation: A weighting function is applied [1], where the observation data have a higher weight than the model data for short forecast lead times and vice versa for longer lead times.

Figure 6 shows an example of a temperature-forecast verification in terms of mean absolute error for the different model strategies. For this particular case, the conditional merging strategy C seems to be more accurate than using model only strategy A or model tendency strategy B. Up to now, the algorithm has been tested with one event only. A long-term verification of temperature, precipitation and potential snow fall area nowcasts will be performed in the future.

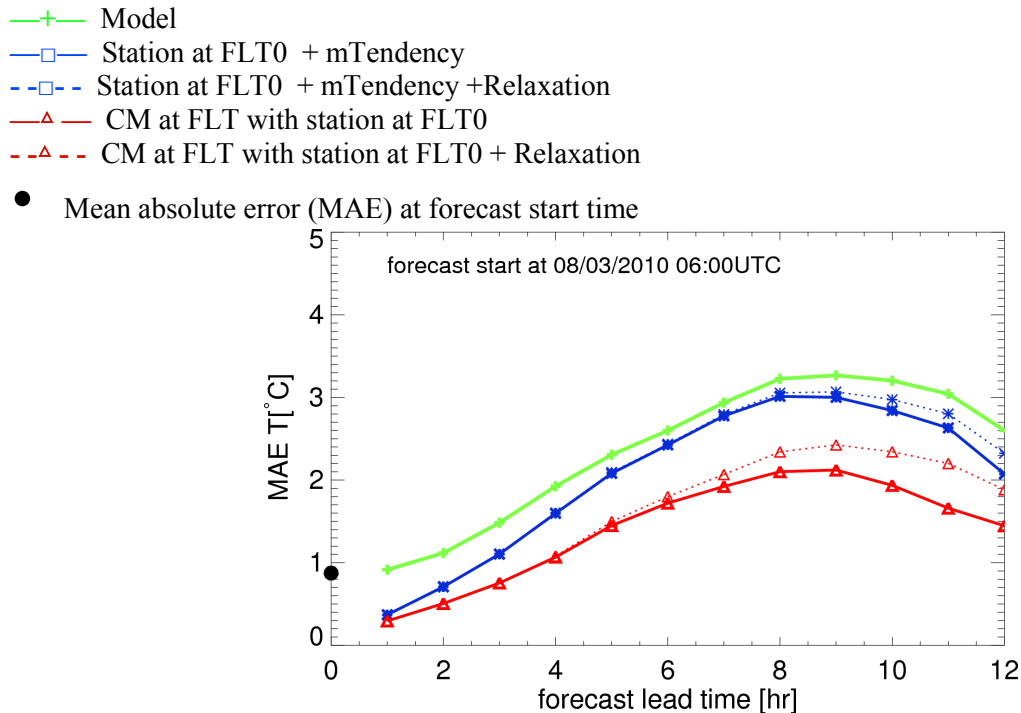


Figure 6. Mean Absolute errors as a function of forecast lead-time (FLT) at 00:00 UTC.

## 5 CONCLUSIONS AND OUTLOOK

Algorithms to diagnose and nowcast snow fall and icing conditions in limited areas have been described. Providing end-users adequate and easy to understand ground level warnings for winter precipitation at a local position or area is not an easy task. Besides the problem of understanding and modelling complex physical processes like icing, snow formation and precipitation to the ground, also the combination of data from different sources such as radar, satellite, and surface stations with model outputs is a big challenge. Not only are model forecasts often inaccurate, but also observations can be difficult to handle because of regionally different data availability, data quality and observation representativeness due to the different temporal and spatial resolutions and station heights. It is expected that the experience gained from many winter weather cases will enable the build-up of a fuzzy logic procedure which can improve the nowcasting of winter weather and thus provide a reliable source of information for decision makers in aviation as well as ground transportation sectors.

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