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The use of advanced meteorological tools for monitoring the Weather hazards in roads

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ABSTRACT

Catalonia is a country with a very complex terrain, which implies rapid changes in meteorological parameters in short distances. These rapid changes sometimes are dramatic, so road conditions can change suddenly, causing accidents. These accidents are mainly slides off due to the ice or the water accumulated in the road, the sudden changes in visibility due to the fog or strong precipitations and the strong lateral winds. To take into account all the meteorological features for monitoring the weather hazards in roads, a high resolution forecasting system has been developed. The models used to simulate the different road hazards are specifically designed for each phenomenon. The forecast system combines a model designed to simulate the road conditions, a model designated for fog formation forecast, and another for hail probability. The relationships between them have to be taken in account. In order to manage all this information it's important to integrate all them into a platform useful for the end users.

Keywords: Road weather, fog forecasting, METRo, hail, ice..

1 INTRODUCTION

The weather information is very useful for road users and for public and private road administrators. The visibility and the asphalt conditions (ice, wet, etc...) are very influenced by the meteorological parameters that have to be calculated with high resolution in order to take into account the local features. A part of the visibility and the road conditions, it's very important to know the winds at high resolution, because sometimes the wind blows so strong and overthrow trucks.

The different meteorological parameters needed for road safety are calculated using several models with very high resolution. For road conditions, the mircoscale METRo model designed to account the energy budget between the soil and the atmosphere is used [10]. For visibility the microscale model COBEL designed to simulate the boundary layer features related with fog formation [5]. The wind at high resolution is obtained using a microscale model CALMET [15] that uses the mass conservation principle to downscale the wind. Finally, the hail is nowadays calculated applying statistical relationships between the radar reflectivity and the isotherm of 0ºC [16], though in a future is planned to adapt a microscale model for hail called HAILCAST [8].

To manage all the information it's important to have a visualization system adapted to the end users. It's web based, which ensures compatibility among different systems. The webpage contains maps, reports and graphics with the most relevant information from each model.

2 TOOLS

Observational data and high resolution model are used to develop new tools that will be useful for surveillance, monitoring, and prediction of weather and roadway conditions. Different data used to generate this tool are listed below.

2.1 Observational data

The data is used both for monitoring the meteorological conditions in real time and also to give initial conditions to the numerical models used for forecasting. The observational data used is:

- Authomatic weather stations (AWS) of Castelldans. Castelldans is a village located at 41.52N latitude and 0.79E longitude, in the Central Depression of Catalonia. This point was chosen to test the surveillance system because there are two AWS, one from the MSC and another one from Abertis (Private Highway Management and Administrator). The data obtained from the AWS are: temperature (1.5 m), humidity (1.5 m), wind speed (10 m), wind direction (10 m), visibility, subsurface temperature (-40 cm) and road temperature. This data will be used for monitoring and as initial conditions for microscale models.

Figure 1. Map of Catalonia where is represented the Central Depression (red circle) and the AWS of Castelldans (star)

- Radar data: The weather radar data used is a volumetric composition of four radar volumes that covers Catalonia with high, temporal and spatial, resolution. The temporal resolution is 6 minutes and the spatial horizontal resolution is 1 km. Despite the radar reflectivity is used for monitoring the precipitation in real-time, there is an interesting parameter that will be useful to calculate the hail probability: the echotop. Given a value of reflectivity, the echotop is the highest altitude at which this reflectivity appears, for hail probability the echotop of 35 or 45 dBz will be used. On the other hand, the radar reflectivity is also used to initialize the precipitation in the mesoscale models.

2.2 Numerical models

The meteorological hazards on road include a wide range of phenomenon that have to be treated separately and with different tools. The presence or not of snow or ice in the road surface have to be modelled by a model that must represent in detail the exchange between the soil and the atmosphere, to forecast local strong wind a high resolution model is needed with very fine grid to model correctly the topography, the fog forecasting needs a model representing the boundary layer in detail using many vertical levels near the ground.

2.2.1 WRF-model

The Weather Research and Forecasting (WRF) model is a numerical weather prediction (NWP) and atmospheric simulation mesoscale model non-hydrostatic and fully compressible. It uses a terrain-following vertical coordinate and a horizontal Arakawa C-grid staggering. In addition, it has multiple physical parametrization options incorporated: The microphysics used is WSM6 [11], the convection is a modified version of the Kain-Fritsch scheme [13], the unified Noah LSM [9] is the land surface model, the (YSU) PBL [12] is the planet boundary layer scheme and the radiative schemes are the Rapid Radiative Transfer Model (RRTM) for long wave radiation and the MM5 Dudhia for shortwave radiation.

The simulation scheme followed in MSC is based in three nested domains: 27-km, 9-km and 3-km grid size with 60 vertical levels. The lateral boundary conditions for the outer domain (27-km resolution) came from the GFS.

2.2.2 LAPS

The Local Analysis and Prediction System (LAPS) [1-2] is specifically designed to create multi-instrument analysis fields for the assimilation into local area models. The analysis provided with LAPS is the result of a complex cycle of assimilation suited to ingest and merge measurements from virtually all the available sources of meteorological information in a computationally efficient manner. Roughly speaking, the analysis is the combination of a successive correction process with a variational procedure used to dynamicaly adjusts the wind and pressure fields. This analysis represents an optimal estimation of the atmospheric state to be provided as initial conditions to numerical meteorological models.

The LAPS that operatively runs at the MSC is able to ingest reflectivity and wind from weather radar, radiance from several channels of the Meteosat satellite, radiosonde data, METAR and SYNOP data and the data from our local AWS. The LAPS system is used is used to initialize the WRF model.

2.2.3 COBEL

The COBEL (Couche Brouillard Eau Liquide) is a one-dimensional model designed to simulate the formation and the evolution of radiation fog [5]. The model solves the equations derived from the Reynolds system using the Boussinesq hypothesis, the turbulence is resolved with a parametrization based in TKE and mixing length (1.5 order closure), there is also a radiative transfer model and a parametrization of the microphysics based in Kessler scheme. To take into account the interactions between the soil and the atmosphere the model COBEL is coupled with ISBA (Interactions Soil-Biosphere-Atmosphere) model [13].

The initial conditions and the forcings for the COBEL model are provided by the mesoscale model WRF. Also the model COBEL is provided by a data assimilation system [5].

2.2.4 METRo

The METRo model is a model specifically designed for road condition forecast, in order to know if there is ice rain, snow or water over the road [10]. For this reason it's important to know the energy fluxes that go from the soil to the atmosphere through the asphalt. METRo is composed of three modules: an energy balance of the road surface (the central part), a heat-conduction module for the road material, and a module to handle water, snow, and ice accumulation on the road.

The road model METRo uses both observation and numerical models data as initial and boundary conditions. The road model initialization process have two stages: the first one is called initialization phase where the model is run with real data as initial and boundary conditions, the aim of this phase is to obtain an initialized profile that will be used as initial condition for the next stage. The second part of the initialization process is called coupling phase where the observational and the model data must overlap. In this phase the METRo model is run combining observational and modelled data in order to account the discrepancies between observations and forecasts that will be applied at the forecast phase. After the initialization phase the forecast phase takes place, in this phase the model is initialized with the observational data and the boundary conditions provided by the numerical model forecasts are adjusted according to the results obtained in the coupling phase through a relaxation function.

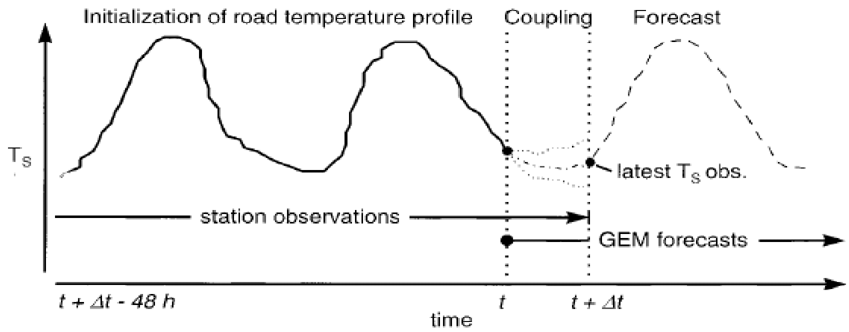

Figure 2. Structure of the METRo simulations with three phases: initialization, coupling and forecast

2.2.5 CALMET

CALMET is a meteorological model which includes a diagnostic wind field generator containing objective analysis and parameterized treatments of slope flows, kinematic terrain effects, terrain blocking effects, and a divergence minimization procedure, and a micrometeorological model for overland and overwater boundary layers [14]. The model CALMET is initialized using a first guess coming from the inner domain (3 km) of the WRF model. The model CALMET is run with a resolution of 400 meters over Catalonia.

3 METHODOLOGY

In this section will be explained how the tools used for forecasting local weather on the roads are configured. Also, some results of a real case will be presented to show the models work and the results obtained.

3.1 Fog forecast

The COBEL model uses an atmospheric vertical profile of temperature and humidity as initial conditions. This vertical profile is obtained from the output of the inner domain (3 km) of the model WRF, combined with observation data using 3DVar. In order to take into account the exchanges between soil and atmosphere, the model ISBA will be run and subsoil data of temperature and liquid water content will be needed as initial conditions, the subsoil data will be provided by the WRF model inner domain. Besides the initial conditions, the model COBEL needs large scale forcing terms of radiation and wind that are obtained from the coarser run of the WRF model (27 km).

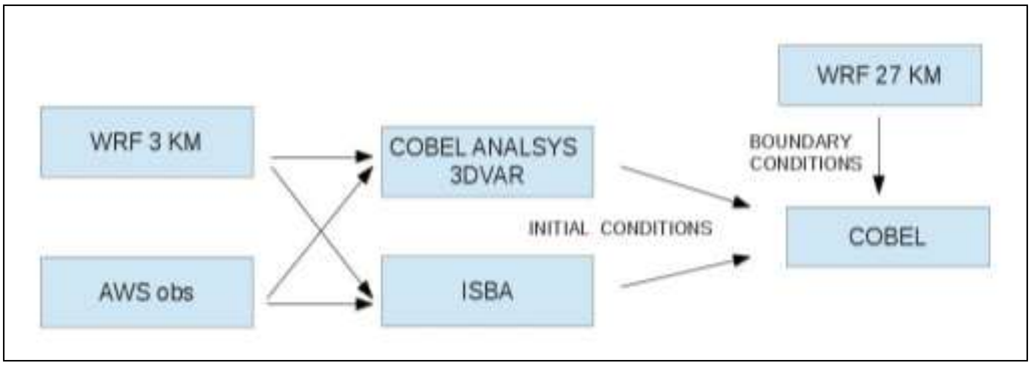

Figure 3. Flow chart of the COBEL simulations indicating the origin of the boundary and initial conditions

The model COBEL is run twice a day, every 12 hours and produces an hourly forecast with a horizon of 24 hours of temperature, humidity and visibility.

Two different cases are simulated using the COBEL model for the point of Castelldans where there is the AWS. The first one is for the 21st January of 2012, and it's an example of fog that becomes weak as the sun rises; the other one is the case of 08th January of 2013 where the fog is persistent during al day.

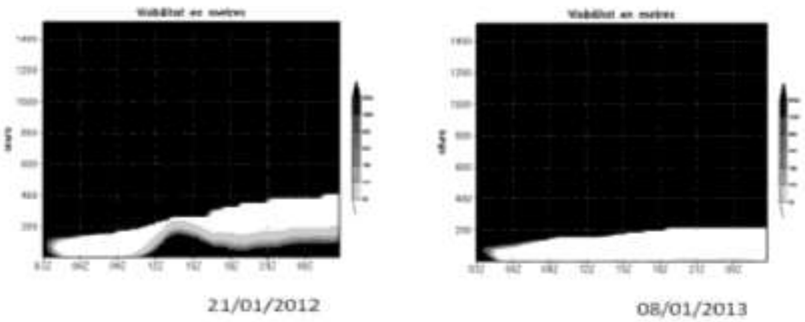

Figure 4. COBEL output of visibility in different cases: on the right one case that the fog disappears with sun and on the left a case of persistent fog.

3.2 Road forecast

The METRo model needs forecasted and observational data to be initialized and coupled. The observational data is provided by the AWS and the forecasts by the mesoscale numerical model WRF-LAPS inner domain (3 km).

Following the same structure as other experiments [7] the phases of METRo simulations were distributed as below:

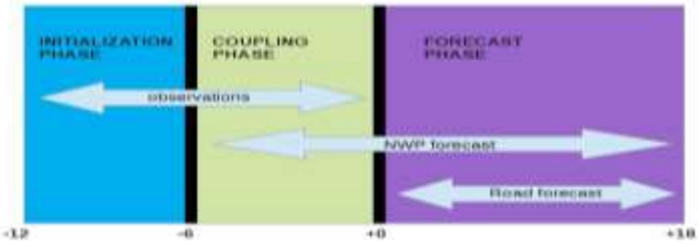

Figure 3. Structure of the simulation run in MSC

The model was run with the default pre-configured values of 29 vertical levels. Also is assumed that the road is composed by two layers one of 20 cm of asphalt and another one of 45 cm of gravel.

The METRo model was run for Castelldans for 08th January of 2013, which have persistent fog. The simulation shows that from 03 UTC till 08 UTC there are temperatures near to zero degrees and a thin layer of water accumulation over on the road between 08 UTC and 11 UTC. The combination of accumulation of water over the road and temperature below zero degrees implies that the road condition appears as Frost/Black Ice at 07 UTC. This situation changes at 08 UTC when the temperature begins to increase.

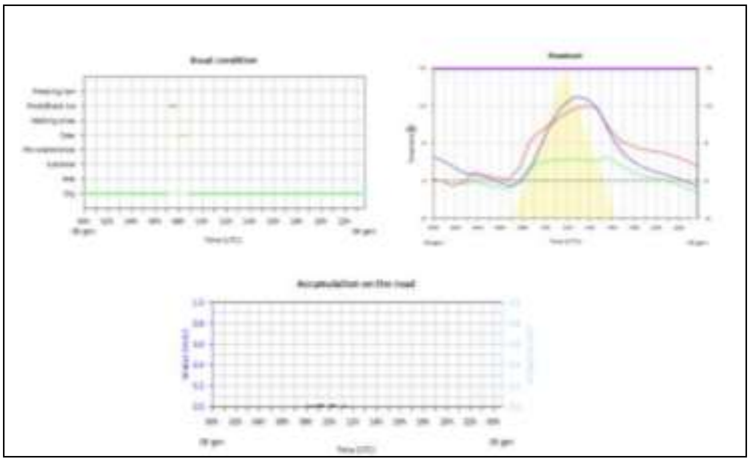

Figure 4. In this figure are shown the outputs of the METRo model. The upper-right picture is the road conditions the upper-left the air and road temperature, the dew point, the sun radiation and the cloud cover. The picture of the bottom is the accumulation of precipitation over the road.

The METRo model isn't able to catch the fog presence, due to the limitations of the mesoscale WRF model running at 3 km grid size to simulate the fog formation.

3.3 Wind forecast

The wind is very influenced by the orography and the mesoscale models aren't able to catch the real wind in zones of complex terrain. The increase of computer performance in the last decades allows running numerical models with very high resolution that provides realistic representations of the wind in complex terrain.

The high resolution wind is diagnosed by the meteorological model CALMET, this model is running operationally at SMC in a domain that includes all Catalonia regions with a high horizontal resolution of 400m. The model CALMET uses as initial and boundary conditions the WRF inner domain (3 km) and produces and output every 1 hour.

The case presented is for 13th January 2014 where a cold front crosses the Iberian Peninsula producing general showers till afternoon. After the rain, the NW wind rises in the coast and the mountains in the south of Catalonia.

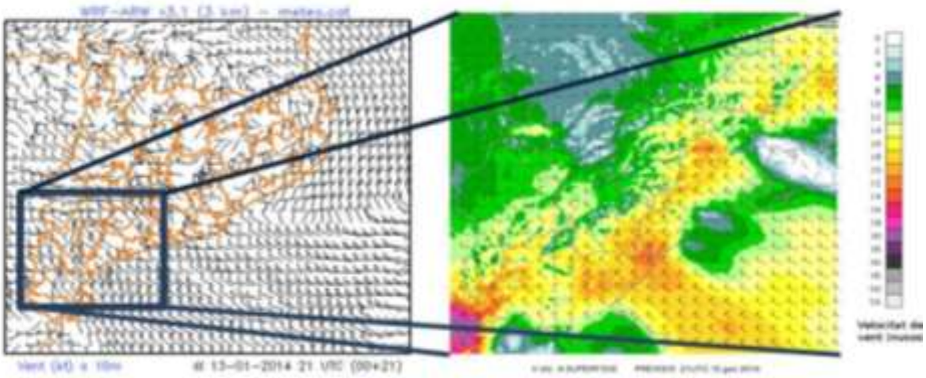

Figure 5. On the right there is an output of the mesoscale model WRF inner domain for 31th January of 2014, on the left there is the output of the CALMET model for the zone of Tarragona at same day.

3.4 Hail forecast

The hail product is obtained combining statistically the echotop of 35 or 45 dBZ and the 0ºC isotherm following the Waldvogel method [16] and adjusted to Catalonia [3]. There are two derived products: the diagnostic and the prognostic of hail.

In this work the diagnostic of hail is calculated using real-time radar data to calculate the echotop and the mesoscale model WRF inner domain to approximate the 0ºC isotherm. To obtain the forecast no real-time data could be used and the radar reflectivity is forecasted using the WRF model inner domain species by the numerical model microphysics (vapour, rain, ice, graupel, snow).

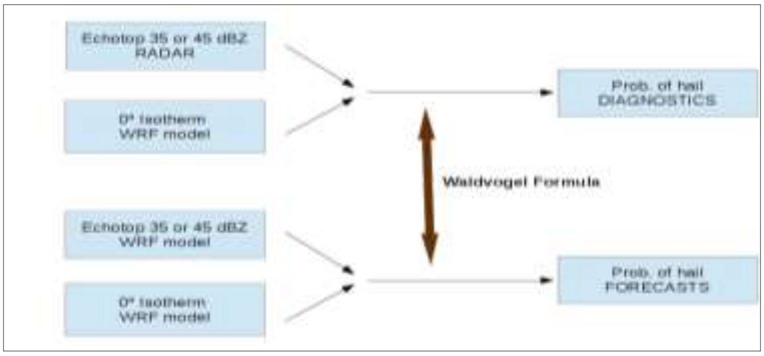

Figure 6. Flow for the calculation of forecasts and diagnostics of hail probability

The study case presented is a hailstorm produced at 10th April 2012. The radar image at 14 UTC (figure 7) shows a strong precipitation area could be seen, but considering only the reflectivity levels, it seems that there is no hail precipitation (figure).

The diagnostic for probability of hail at 14 UTC using the improved Waldvogel method shows areas where the probability of hail is over the 90%, mainly in the mountains of Tarragona and west Barcelona (figure 7). Despite there isn't hail pads to measure the hail size and intensity is this zone, there is some observers that informs for hail occurrence.

The forecast of probability of hail shows high values for afternoon at the Tarragona Mountains and in the west of Barcelona (figure 7). The results obtained are not good as the diagnostics, and depend on the precipitation forecast skill of the model, but provides a suitable approximation about the possibility that the precipitation becomes hail.

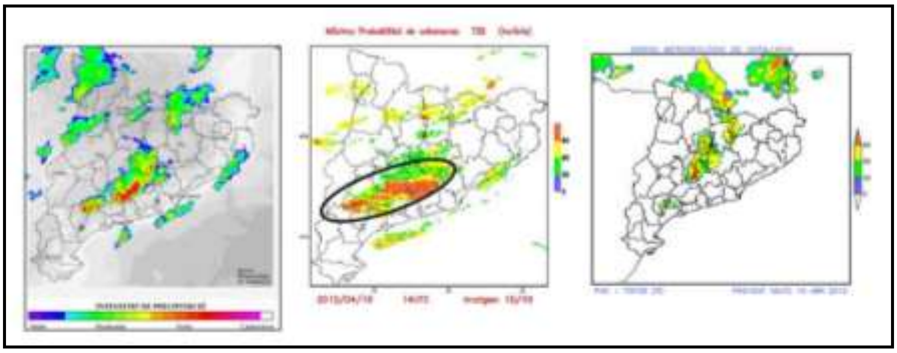

Figure 7. From left to right: the first one is the reflectivity of the radar composition, the second is the output of the hail probability diagnostic product and finally there is the output of the hail probability forecasting product.

A part of forecasting hail with the Waldvogel formula, another system is now being explored using a 1-D model called HAILCAST [7] that is used operatively at the Meteorological Service of Canada.

4 RESULTS

All the local meteorological information about weather in roads presented above must be integrated in a friendly end user tool. This tool integrates all the information in a web graphical interface that summarizes all the information.

First of all it's important to assign a warning threshold at each of the parameters calculated: road condition, visibility, wind and hail:

road conditions.

- Stage 1: dry, wet.
- Stage 2: ice/Snow, mix water/snow, dew.
- Stage 3: melting snow, frost black/ice, freezing rain.

wind speed.

- Stage 1: 0-30 km/h
- Stage 2: 30-70 km/h
- Stage 3: over 70 km/h

visibility.

- Stage 1: over 5000 meters
- Stage 2: 1000-5000 meters
- Stage 3: 0-1000 meters

probability of hail:

- Stage 1: below 80 %
- Stage 2: 80-90%
- Stage 3: over 90%

The visualization of the warning stages defined above will be done in combined graphics, for example:

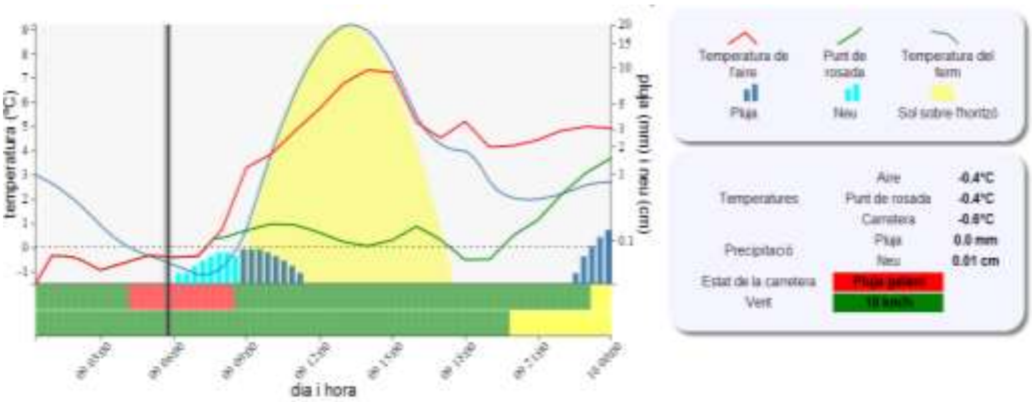

Figure 8. Example of the new graphical interface proposed that merges the information of the METRo model and CALMET

The figure 3, shows an example of visualization of different information: the road and air temperatures, the dew point temperature, the precipitation type and quantities, the solar radiation and in the two bars located below the curves are represented the road condition and the wind with the colours representing the level of warning (stage 1= green, stage 2=yellow, stage 3= red).

The end user tool is under development and new features have to be added a part of the shown above. In particular an advanced visibility module is being prepared where the visibility produced by the fog and the precipitation will be taken in account. On the other hand, the lack of visibility produced by the sun when the angle over the horizon is low at the sunset and the sunrise. The main frame of the end user's tool will be a map of roads with coloured spots every 10 kilometres indicating the general status of the road:

Figure 9. General view of the warning system over a road map, every colour indicates a level of warning.

The red colour will indicates that at least one of road conditions, visibility, wind or hail has been overpasses the stage 3 threshold; the yellow colour indicates that there isn't any value of the parameters higher than the threshold of stage 3 and at least one of them has a value in the stage 2; finally the green colour indicates that none has overpass the threshold of stage 1 and there isn't any hazard in the road.

5 CONCLUSIONS

The objective of this paper is to determine the feasibility of designing a tool using an integrated emergency alerts system with all weather information and roads conditions, in order to mitigate the risks associated with weather and reduce accidents. The integrated weather system provides information related to warnings of visibility, wind at high resolution, hail and road condition. This tool will be destined to the Local Authorities, companies dedicated to construction of roads and railways, bridges and tunnels and

The future work will be focused in add new features related to wind representation, hail and visibility. The visibility module will have information about the lack of visibility due to the fog, but also will include the effects of precipitation and the blind of the sun in the sunrise and the sunset. The hail module shows the hail probability but also will include the hail size. The wind module will contain a map with barbs indicating the wind speed and direction an also, the rugosity to characterize the gusty winds. Also as future work is planned to improve the determination of the type of precipitation using [4].

On the other hand, the Metro Model is influenced by the information provided by the mesoscale model that usually isn't able to take into account some local features that will influence the road condition. For example, the presence of fog implies lower temperature and higher humidity that will change the road conditions, the presence of hail events also will change the road conditions. To take into account the local scale phenomenon in Metro Model, it's necessary to coupling all the information provided by the different modules.

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