How can SINOPTICA support ATM and ATC during severe weather events?

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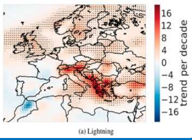
The prediction of rapidly developing thunderstorms in small and localized areas is a challenge for the scientific community. Quickly developing but intense thunderstorms are usually characterized by large hail size, huge amount of rain in a short period, high lightning frequency and strong winds thus potentially capable to affect people and socio-economic activities/infrastructures. These phenomena affect also the flight safety, when aircrafts have to fly through or nearby storms, and the aviation management, or triggering flight re-routing, delays or cancellations. Weather-related flight cancellations and delays have increased over the past two decades in the US and Europe and this trend is going to increase due to the human-induced climate change. The objective of the H2020 SESAR Satellite-borne and IN-situ Observations to Predict The Initiation of Convection for ATM (SINOPTICA) project is to improve the performances of the numerical weather prediction model to nowcast severe weather events locally developed. In this work, we assimilate different ground based and satellite data into the Weather Research and Forecasting model, we nowcast the severe weather in the surrounding of four airports in Italy and we show the innovative approach to integrate the meteorological results with the Air Traffic Control procedures.

Statistical analyses reported in scientific literature show that the context is constantly evolving but they clearly show high frequency of severe weather events over the Alpine area, over the Balkans and central Europe. However, a deeper analysis of the decadal trends of the severe events (Rädler et al., 2018) shows that northern Italy is particularly subject to the extremes and this area is also the one with the highest number of large airports.

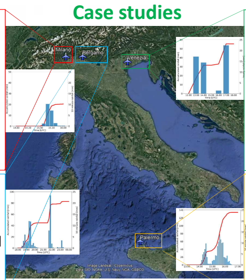


Here a couple of examples of severe hail events affecting the Milano Malpensa airport in the latest years. The 11th of May 2019 the airport was closed for some hours because a storm was too strong and it covered the runways by a think layer of hail. The 13th of July 2021 the flight EK205 was forced to return to Malpensa after the plane suffered damages due to a hail storm. The plane took off from Milan at 16:23 (local time) to New York JFK and entered hold for almost 2 hours before a safe landing.

Case studies

Milano Malpensa
11 May 2019
A squall line hit the airport between 14 and 15 UTC. The presence of hail on the runways caused some flight delays and 9 planes were diverted to other airports.

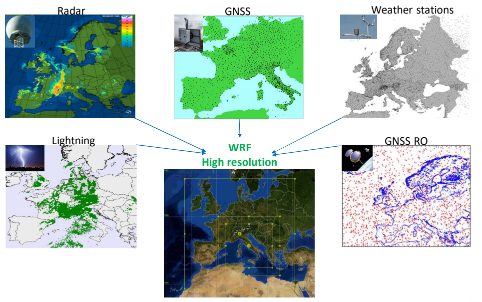
Bergamo Orio al Serio
6 August 2019
Convective storm producing heavy precipitation, strong wind gusts and small hail.



Venice Marco Polo
7 July 2019
Precipitation with a prevalent character of thunderstorms, locally very intense, associated in various cases with light and strong wind gusts.

Palermo Punta Raisi
15 July 2020
Localised thunderstorm with huge amount of rain concentrated in a short time.

WRF is a next-generation mesoscale atmospheric model, developed at National Center for Atmospheric Research (NCAR), which uses a fully compressible non-hydrostatic set of equations, Arakawa C-grid staggering, terrain-following hydrostatic-pressure vertical coordinates, and multiple-nesting capabilities. Three domains in two-way nesting with respectively 22.5 km (216 × 191 grid points) 7.5 km (523 x 448 grid points) and 2.5 km (430 x 469 grid points) grid spacing are used for the numerical experiments. For each domain, 50 unequally spaced vertical levels are used, from ground level up to 50 hPa. Several physics options are eligible for the WRF model but we set the same configuration as the hydro-meteorological chain at CIMA Research Foundation (Lagasio et al., 2019). We assimilate the ground based information from GNSS and weather stations, the radar and lightning data and the vertical information from GNSS Radio occultations.



Results

A total of four simulations were carried out in order to improve the nowcasting of the case studies in terms of localization and timing. The radar data (RDR), more specifically the Constant Altitude Plan Position Indicator (CAPPI) reflectivity at 2000 m, 3000 m and 5000 m, were assimilated alone or in combination with GNSS Zenith Total Delay (GNSS), in-situ weather stations (WS) and lightning data (Lig), respectively. Finally, a control run without assimilation was performed. The initial and boundary conditions for all experiments were provided by the Global Forecast System (GFS) with a horizontal resolution of 0.25°x0.25°. To assess the performance of data assimilation, an object-based verification was performed by using the Method for Object-Based Evaluation (MODE). The high Vertically Integrated Liquid (VIL) values may denote intense convective cells. In addition to the numerical simulations, a nowcasting technique called PHAse-diffusion model for STochastic nowcasting (PHAST) (Metta et al., 2009) has been investigated in order to improve the ATM procedures in case of severe weather. This technique has been applied to precipitation originally, but for the project purposes, we showed that it can be applied to Vertical Integrated Liquid (VIL) or VIL density (VIL/Echo Top height) as well. Then, we applied the technique using different approaches, but the best solution appears to be the rapid update cycle (RUC) with 10-, 15- or 20-minute frequency to better forecast localized convective events.

Milano Malpensa

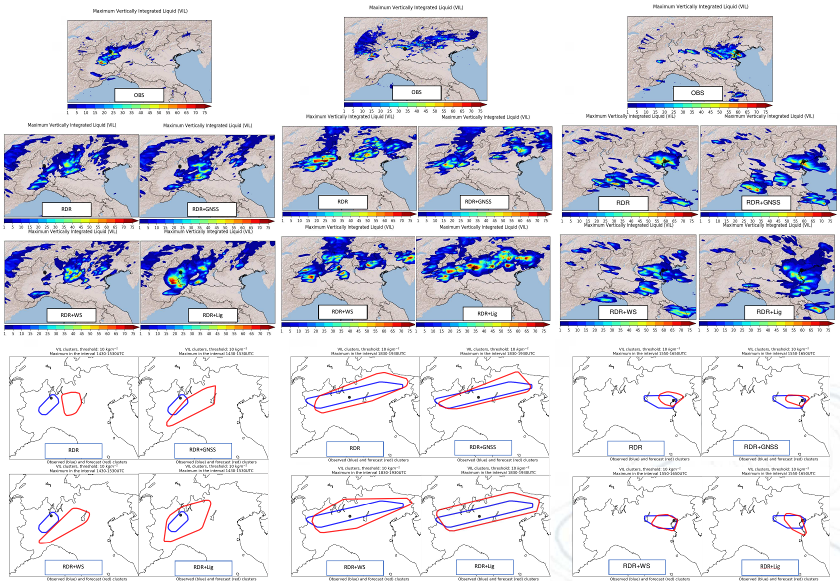
Experiment	Centroid distance	Observed area	Forecast area	Intersection area	Interest
RDR	62,41	874	1342	0	0,69
RDR+GNSS	50,10	874	1947	75	0,80
RDR+WS	70,53	874	1451	0	0,68
RDR+Lig	21,92	874	3500	822	0,91

Bergamo Orio al Serio

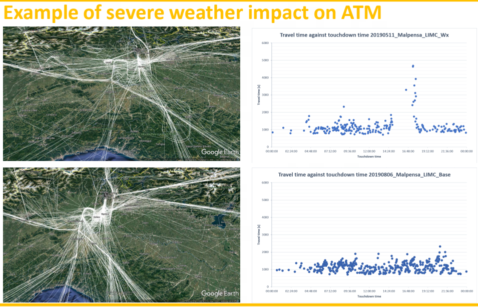
Experiment	Centroid distance	Observed area	Forecast area	Intersection area	Interest
RDR	20,10	1209	4557	477	0,92
RDR+GNSS	8,00	1209	2166	298	0,96
RDR+WS	7,56	1209	2703	373	0,95
RDR+Lig	29,92	1209	6343	1070	0,91

Venezia Marco Polo

Experiment	Centroid distance	Observed area	Forecast area	Intersection area	Interest
RDR	23,28	1286	1119	595	1
RDR+GNSS	18,06	1286	812	619	0,98
RDR+WS	7,71	1286	1165	904	1
RDR+Lig	13,27	1286	1146	697	1



Example of severe weather impact on ATM



On top, the trajectories (left) and the travel times against touchdown times for the case study of Milano Malpensa May 11th, 2019. Below, the corresponding trajectories and travel times on a clear sky day not affected by severe weather, are displayed.
This shows how a convective storm lasting almost two hours affects the approach time of several aircraft.

Integration of MET and ATC

The last measured weather data and the nowcasts based on them are spatially assigned and classified for a period of about half an hour with regard to their degree of obstruction for civil air traffic. These severe weather areas are described by time-dependent mathematical 2D polygons and sent to the DLR Arrival Manager (AMAN) "4-Dimensional Cooperative Arrival Manager" (4DCARMA), which is an approach controller support system that performs temporal and spatial approach planning for an airport based on the current traffic situation. For each aircraft, a 4D trajectory is calculated based on EUROCONTROL's BADA with the scheduled target times at all significant waypoints as well as the runway threshold. For the implementation of each approach, controllers receive target times, guidance advisories as well as graphical displays support directly on the radar screen.
The system is fully adaptive, so that any change in the traffic or weather situation can be reacted to within a very short time. Receiving weather data, the AMAN treats the polygons in the defined time periods as restricted areas that aircraft cannot fly through. After detecting conflicts between 4D trajectories and polygons, the AMAN starts searching for points and routes outside these areas. For this purpose, different deviating routes are initially considered. In the AMAN waypoint lists, all points that would lead to a conflict with one of the polygons are removed from the current routes. At the same time, new waypoints guiding around the polygons with a safety distance are integrated. Finally, a new 4D trajectory is calculated using the waypoints as supporting points and with target times and advisories for each significant waypoint and their local constraints. All diverted aircraft are integrated in the actual arrival sequence.

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