Large-scale EXecution for Industry & Society

Deliverable D9.9

Impact on Productivity and Business Process Improvement for Weather & Climate

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GLOSSARY

ACRONYM	DESCRIPTION
EMF	Electro-Magnetic Field
IFS	Integrated Forecasting System
GFS	Global Forecast System
KPI	Key Performance Indicator
OEE	Overall Equipment Effectiveness

TABLE OF PARTNERS

ACRONYM	PARTNER
Avio Aero	GE AVIO SRL
Atos	BULL SAS
AWI	ALFRED WEGENER INSTITUT HELMHOLTZ ZENTRUM FUR POLAR UND MEERESFORSCHUNG
BLABS	BAYNCORE LABS LIMITED
CEA	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
CIMA	CENTRO INTERNAZIONALE IN MONITORAGGIO AMBIENTALE - FONDAZIONE CIMA
CYC	CYCLOPS LABS GMBH
ECMWF	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS
EURAXENT	MARC DERQUENNES
GFZ	HELMHOLTZ ZENTRUM POTSDAM DEUTSCHESGEOFORSCHUNGSZENTRUM GFZ
ICHEC	NATIONAL UNIVERSITY OF IRELAND GALWAY / Irish Centre for High-End Computing
IT4I	VYSOKA SKOLA BANSKA - TECHNICKA UNIVERZITA OSTRAVA / IT4Innovations National Supercomputing Centre
ITHACA	ASSOCIAZIONE ITHACA
LINKS	FONDAZIONE LINKS / ISTITUTO SUPERIORE MARIO BOELLA ISMB
LRZ	BAYERISCHE AKADEMIE DER WISSENSCHAFTEN / Leibniz Rechenzentrum der BAdW
NUM	NUMTECH
O24	OUTPOST 24 FRANCE
TESEO	TESEO SPA TECNOLOGIE E SISTEMI ELETTRONICI ED OTTICI

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EXECUTIVE SUMMARY

The weather forecasting services market size is projected to grow to an estimated USD 2.3 billion by 2025, at a Compound annual growth rate (CAGR) of 9.3% during the forecast period (2020-2025) [1].

Weather forecasting services are a set of decision-support solutions used to carry out weather-sensitive operations to safeguard people, assets, and profits and improve business performance. The services will differ in terms of their usage, technology, and forecast purposes. These services are required in aviation, marine, agriculture, energy & utilities, oil & gas, among other industries, to plan weather-sensitive operations in advance. Thus, the increasing scope of weather forecasting services in end-use industries to improve safety and reduce losses are the key factors driving the growth of the market. Accurate weather forecasting also allows governments and businesses to better prepare their responses to natural disasters that impact the lives of millions.

Overall, this market growth can be attributed to the increasing safety concerns in governments and end-use industries as well as a rise in climate change patterns resulting in uncertainties related to rainfall, temperature, wind, and other atmospheric variables.

The process of weather forecasting is complex due to the intrinsic non-linearity of weather forecast models. Also, the proper integration and analysis of a huge amount of available observational data make the process even more complex. Long and large-scale weather patterns can be made with greater accuracy, but there are still challenges to carry out an accurate weather analysis in the short term. This can restrain the growth of the weather forecasting services market, as the entire weather forecasting process entails various functions that need to be considered to arrive at an accurate analysis.

Along these lines, the Weather and Climate LEXIS pilot developed two interesting opportunities, the IoT Smart Gateway by TESEO and a set of workflows for meteo-hydrological downscaling.

Position of the deliverable in the whole project context

The deliverable role in the context of the LEXIS project is to report the impact strategy related to the Weather and Climate LEXIS pilot. It was scheduled at the end of the project because of the availability of results. This brings the possibility to have a vision about the possible impact on the market in terms of business process improvements or whatever other foreseen impacts we envision.

Description of the deliverable

This deliverable provides a general overview of the possible implications of the LEXIS results on productivity and business improvement for the weather and climate sectors. Promising opportunities emerge for the environmental monitoring sectors with the IoT Smart Gateway developed by TESEO. Concerning the high accuracy weather forecast, the most important achievement is the setup of a powerful workflow for meteo-hydrological downscaling including civil protection, air quality, and agriculture applications. However, it is important to bear in mind that these workflows are strongly dependent on available computational resources, on access to many not freely available data sources (e.g Italian Civil Protection and Meteo France radar data, IBM Wunderground weather stations, ECMWF weather data), as well as time scheduling, and efficient data management. Still, the improvement in the overall workflow management, if supported by additional future tests and experiments, can pave the way to very interesting exploitation opportunities.

1 INTRODUCTION

This deliverable offers an overview of the possible impacts of LEXIS on productivity and business improvement for the weather and climate sectors. The topics are addressed from two different perspectives: on one side by introducing an innovative IoT Smart Gateway as a market-ready unit capable to measure meteorological, chemical, magnetic variables, on the other a rich portfolio of hydrometeorological workflows addressing applications from the prediction of severe events and related impacts, through air-quality modelling, to agriculture production predictions.

2 IOT SMART GATEWAY

In a new era of computing and communication technology, the Internet of Things (IoT) and connected objects play the role of technology tools aimed at combining complex information and computing infrastructures to physical data acquisition, efficient data exchange, Artificial Intelligence, Big Data, and Cloud. The diffusion of IoT is so promising and successful that the number of devices is forecast to be more than 25 billion in 2030 [2]. In front of such numbers, common sense tells that the impact will be across all application fields and that all kinds of industry, scientific, research, and consumer market are fertile grounds for connected objects.

2.1 THE SMART GATEWAY CONCEPT AS A MARKET READY UNIT

The block diagram in Figure 1 gives a simplified view of the Smart Gateway focusing on the main unit characteristics: an edge computing connector between real-life magnitudes (like temperature, pressure, rainfall, moisture, electric field, etc.) and an HPC and Cloud infrastructure that abstracts the physical world and presents the information in a structured and uniform fashion; a device that synchronizes the communication between different devices and communication protocols, where data is aggregated and summarized to minimize the volume to be forwarded to the Cloud.

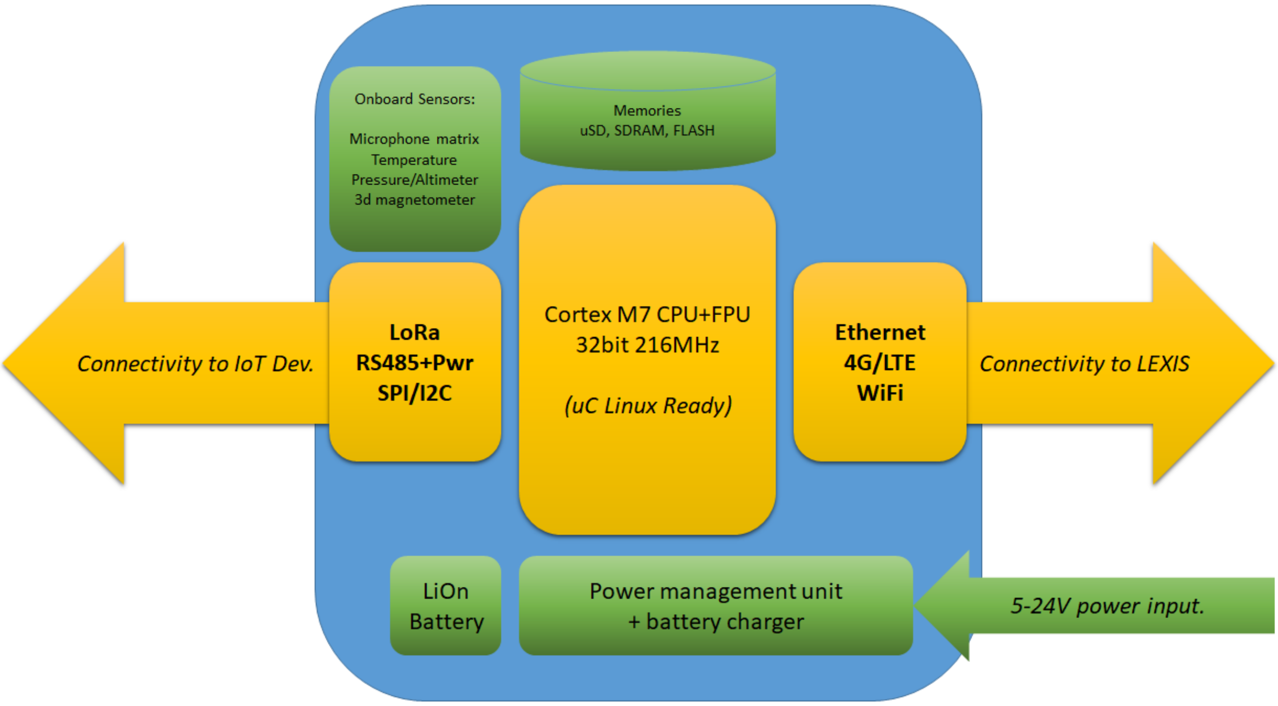

Figure 1 Smart Gateway simplified block diagram

The Smart Gateway is a fully engineered TRL 8 edge computing unit ready for mass-manufacturing, that allows running complex IoT projects. Starting from the software/firmware developed for the LEXIS project, the end-user should integrate the communication routines with his IoT-sensors ecosystem and provide for the data pre-processing algorithms. This task is demanded by the system integrator since it falls in the domain of the customization of the application.

The Smart Gateway communicates with the LEXIS infrastructure through an existing Internet connection, the Ethernet link can be established with an UTP cable or via Wi-Fi. In case the installation location does not offer these two possibilities, the Smart Gateway will communicate through the optional 4G module to establish an Internet connection on the mobile data network.

The security is guaranteed by the TLS encryption layer that leverages a private and a public key to ensure the message is validated and read-only by the owner of the private key. This method creates a virtual point-to-point tunnel that allows for communication between the Smart Gateway and LEXIS through the public Internet. This way, messages are exchanged in a private and non-accessible way.

A second security layer requires the Smart Gateway authentication to the broker server via private username and password. Finally, only the recognized Smart Gateways can exchange data, the unique device ID is checked in a device list, and only recognized devices are permitted.

2.1.1 Fields of application and market trends

Because of its role and its location inside the IoT ecosystem, the fields of application of the Smart Gateway *‚by itself‘* are theoretically unlimited. In a real life, the IoT nodes that send data to the gateway are constraint in the sense that, as far as a sensor or an actuator exists to manage a physical magnitude, there will be a potential application.

If there are virtually infinite applications for the Smart Gateway and LEXIS HPC/Cloud combination, some of them are most attractive to the market because of their benefit-to-cost ratio and their ability to fulfil a certain need in that field. Nevertheless, it is worth mentioning that most of the IoT projects are not *‘off the shelf’* because each application domain has its peculiarities or specific problems to solve, making hardware/software customization or system configurability necessary in most cases. The prime example is a home automation system that matches all intents and purposes in the IoT domain: every house, building, or facility is different from another, thus requiring a dedicated setup.

Authoritative sources report [3] that in 2020, smart-manufacturing and industry 4.0 IoT applications made up 22% of the market share and drove the digital transformation in such domains, enhancing operational performance and providing a measurable business benefit as a result. The trend for future years is forecasted to be stable.

Mobility and energy are the next two sectors where most of the IoT applications belong with 15 and 14% of the shares, respectively, and the trend is forecasted to be stable.

The other two sectors with shares above 10% are retail and smart cities. The first is forecasted to be growing, but the second is expected to decrease.

Other sectors such as healthcare, agriculture, and smart buildings see the implementation of IoT infrastructure to manage, monitor, and improve tasks efficiency.

In all cases, it is well established that the market favours an “Equipment as a Service” business model where the end-user has a single reference supplier that provides the equipment, the Cloud service, after-sales maintenance, and software updates.

2.1.2 Exploitation of the Smart Gateway & Development Roadmap

In Deliverable D7.7 [4], it was mentioned that the weather station was improved with an Isotropic Electric Field probe with dedicated signal conditioning and acquisition electronics. At that time, the consolidation of this feature was still ongoing, in fact, laboratory tests were in progress. From July 2021, the water station together with the Electric Field monitor is fully functional, and a unit is performing with no interruptions since August 2021.

Figure 2 Smart Gateway integrated in the weather station with Electric Field monitor (see for details Deliverable D7.7 [4])

Further development is now undergoing: the design is being enriched with an Isotropic Magnetic Field probe, thus making the unit a complete instrument that provides weather, air quality, and electromagnetic pollution measurements. Figure 2 shows the Magnetic Field probe in the middle of the stack, highlighting the pick-up coils and dedicated signal conditioning electronic board.

The LEXIS portal is being enriched with a dedicated Smart Gateway section. The portal frontend will be extended with dedicated instrument dashboards, and the portal backend will carry extended APIs and UserOrg-DB (repository of the data coming from the weather station) extension that will make the Weather+EMF instrument and LEXIS-based Cloud service as a market-ready turnkey solution.

Needless to say that the more instruments will be deployed, the more data will be collected for a more accurate mapping of the territory on electromagnetic field pollution from radio stations, industry, power lines, etc.

2.1.3 Potential Stakeholders

The audience of the potential stakeholders is as wide as the fields of application of the IoT/Cloud paradigm, where the Smart Gateway plays the role of the connector between the equipment and end-user services.

It is worth listing the most common outcomes of an IoT project or system and relating each to a potential stakeholder.

At the upper level, a targeted dashboard may provide one or several performance indicators of a business case, of a manufacturing process, of a product or service usage, and so forth. Performance indicators all fall in the sphere of competence of a management figure.

Similarly, alerts, KPIs, OEE, and device reporting are of primary interest to an operations manager.

Engineering figures, as well as customer support and after-sales servicing can benefit from an IoT Cloud-based system because it provides useful information about diagnostics, alerts, warranty reporting (issues and part replacement), product performance data, and can eventually perform failure analysis.

Other potential stakeholders within the corporate and business compartment are: legal, IT and sales because IoT and Cloud-based platforms may provide data security and data integrity validation rather than reporting and alerts or elaborate up-sell and cross-sell strategies.

The purpose of the brief above was to display some classes of potential stakeholders. It's worth to notice that designing and setting up an IoT infrastructure is all but a small undertaking, because each figure will look at specific outcomes for their business and will so require specific tools for it.

3 HIGH ACCURACY WEATHER FORECAST

In the context of LEXIS, WP7 partners, led by CIMA, were responsible for the development of Meteorological large-scale use cases. WP7 has developed several workflows for state-of-the-art regional downscaling of Integrated Forecasting System (IFS) and Global Forecast System (GFS) global forecasts and domain-specific application of the high-resolution forecasts such as hydrological simulation, wild-fire risk assessment, farming, and air-quality advisory services.

Beside the specific applications showcased by WP7, the most relevant result is the setup of a powerful workflow for meteorological downscaling. Such workflows depend on HPC and cloud resource availability, timely scheduling and efficient data handling, and access to a number of different data sources. In particular, we need initial and boundary conditions and in the case of data assimilation, we need radar/satellite imagery and time-series from weather stations.

The LEXIS platform is currently hosting several different weather workflows adopting initial and boundary conditions generated by the world-leading global-scale models, IFS, developed and executed by ECMWF and GFS developed and executed by the National Centers for Environmental Prediction (NCEP). Moreover, we have modules for data assimilation of radar and ground weather stations.

An external user can benefit from some of such possibilities out of the box (i.e. a regional weather downscaling running the Weather Research and Forecasting (WRF) Model forced by GFS initial and boundary condition only requires an agreement for HPC resource consumption since data are open to everyone).

IFS initial and boundary conditions require licensing (a free licence can be granted for research purposes, or with a fee for commercial exploitation/usage).

There are multiple options to exploit the LEXIS weather forecast workflows. The following subsections clearly define the steps for every possible scenario.

3.1 WRF DOWNSCALING SCENARIOS

3.1.1 WRF downscaling of GFS and IFS initial and boundary conditions

We consider two alternative options, with WRF downscaling of initial and boundary conditions extracted from GFS and IFS global circulation models.

In the first case we adopt GFS. This is the easiest case because GFS data are available to everyone with a permissive license (commercial exploitation is allowed), and WRF is a community model released as open source. LEXIS has developed the platform and model configurations (in the form of model name lists) to perform high-resolution weather forecasts over parts of Europe. This use case supports domain nesting and the whole process can be automated (data fetching from NOAA servers, pre-processing with WPS, downscaling with WRF). Output data are encoded in the well-known NetCDF data format and stored in the LEXIS DDI.

The second scenario is based on IFS downscaling, similar to the previous one, with a notable exception: access to IFS data requires a license agreement with ECMWF (direct or through one of the ECMWF member state representatives). The license can be granted for free, as in the case of research experiments, or with a fee that can be computed using the online tool.[1] Data retrieval from IFS is guaranteed by the Weather and Climate Data API

[1] ITHACA ERDS: https://erds.ithacaweb.org/

(WCDA) developed in the context of the LEXIS project and deployed on multiple computing centres (LRZ, IT4I and ECMWF). WRF pre-processing has to be adapted to deal with IFS data, while the rest of the workflow is almost identical to the GFS case.

3.1.2 WRF downscaling with data assimilation

This scenario is more complex since it requires, in most cases, real-time access to satellite, radar, or weather-station time series. Licensing agreements to access those data are outside the scope of this deliverable.

The LEXIS workflows demonstrated the ability to build WRF-DA data-assimilation workflows exploiting radar data from Meteo France, the mosaic of Italian weather radar provided by Civil Protection, institutional weather stations as well as personal weather stations acquired through the IBM Weather Channel (the former Weather Underground).

Data assimilation requires a preliminary step to compute model sensitivity to observational data (the computation of the covariance error matrix), and additional steps in the operational real-time workflow to fetch the data from a heterogeneous data source, data conversion to comply with WRF input format, data assimilation and eventually execution of the regional down-scaling.

The computation of the covariance error matrix is a supervised task that has to be executed once for each domain by experienced users, and can then be used for operational purposes. The matrix has to take into account the initial and boundary condition data source (IFS/GFS), the geographical domain and the season. We usually suggest the creation of a set of 4 error matrices, one for each season to better deal with the climate of the selected domain.

To conclude, this case requires licensing agreement for the acquisition of observational data and one-off consultancy for the computation of the error matrices. The operational execution can then be fully automated.

3.1.3 Extreme Rainfall Detection, Hydrological and forest fire risk workflows

LEXIS is managing several modelling tasks of interest for civil protection, namely RISICO, Continuum, ADMS industrial and urban air-quality forecasts, and ERDS.

RISICO (RISchio Incendi e COordinamento/Fire Risk and Coordination) is a mathematical model developed by the CIMA Research Foundation to support operators in forest-fire prevention activities (Fiorucci et al. 2008). RISICO processes a continuous data flow consisting of meteorological information as weather forecasts and satellite records. Parameters such as the moisture content of the vegetation, the wind, and the orography of the territory allow users to quantitatively assess the danger resulting from an eventual triggering of a forest fire, both in terms of propagation speed and linear intensity of the flame front.

The ADMS industrial and urban air-quality forecasts are parts of systems which are named Plum'air for industry and Urban'air for city. These systems developed and implemented by NUM for its clients use the ADMS-5 model[2] for the industrial use case and ADMS-urban model[3] for the urban one. Objective is to anticipate and manage air-quality events, so they first provide various alerts in case of forecasted pollution events. Users could then test different emission scenarios (it could be to stop a process for an industrial source or decide to reduce speed limitations for cars for a city) in order to decide actions to avoid or reduce such pollution events.

The Extreme Rainfall Detection System (ERDS), developed and implemented by ITHACA, is an early warning system for the monitoring and forecasting of rainfall events, with near-global spatial coverage [5]. The system can provide

[2] ADMS-5 model: http://cerc.co.uk/environmental-software/ADMS-model.html
[3] ADMS-urban model: (http://cerc.co.uk/environmental-software/ADMS-Urban-model.html

alerts about heavy rainfall events using both near-realtime measurements and rainfall forecasts. The information is accessible through a WebGIS application, developed in an open-source environment[4].

All these modelling tasks have proven to be usable on the LEXIS platform and in general, their predictive capability has benefited the selected case studies from the WRF downscaling with data assimilation. However, it is important to highlight a few aspects when considering potential business opportunities:

- Radar data are provided by the Italian Civil Protection Department and they are not meant to be used outside the purely civil protection domain,
- Adding Wunderground observations, if it is demonstrated that they are a key element for assimilation, will request a discussion with IBM for possible business applications.

These points, therefore, deserve further consideration in the future before moving to real exploitation and business opportunities for the civil protection-related workflows.

3.1.4 Real-time access to IFS forecasts

IFS weather forecasts are highly praised for their accuracy, but automated timely access to those data was only granted to national weather services of member and cooperating states and institutional customers. The procedure to get access is not straightforward since each user has to specify upfront the required data, that are generated and post-processed during the time-critical window, together with the IFS model execution, and pushed to users through the ECMWF data dissemination system.

In the context of LEXIS, ECMWF developed a Weather and Climate Data API to provide an effective RESTful API service for realtime data access. It can provide access to realtime data as well as the whole content of the MARS archive[5]. Requests can be specified using the MARS language and polytope-client[6] open-source python applications can be used in automated scripts as well as imported in Python applications, providing convenient access to IFS data.

3.1.5 Potential stakeholders

Numerical methods for weather forecasts require a global approach, with models accurately describing the atmosphere, the land and the ocean and their interaction. The current state-of-the-art numerical weather prediction (NWP) model is IFS, which produces 9 km forecasts. To achieve cloud-resolving resolution (3-5 km) or better, the only approach so far is to select a sub-domain and downscale the output of the global NWP model.

Downscaling of global-scale weather forecasts is a powerful tool for increasing the resolution and thus accuracy of weather forecasts in a specific domain. Moreover, the assimilation of additional observations collected in the area of interest can play a big role in improving accuracy and timeliness.

Many weather related applications can benefit from the improved accuracy of regional down scaling (both in case of open-loop downscaling and in case of data assimilation), such as hydrological simulations, wild-fire forecasts, forecast of energy production from renewable sources. Moreover, the improved accuracy, is crucial in the assessment of the water-energy-food nexus.

The availability of high-resolution WRF downscaling with data assimilation is particularly appealing for the forecast or energy production from renewable sources. In fact, wind-mill farms are usually co-located with weather stations providing accurate observational data that can be adopted in regional downscaling with data assimilation, boosting confidence in the forecasted data and supporting the activity of traders in the energy market.

[4] WebGis application: https://erds.ithacaweb.org/
[5] MARS archive: https://www.ecmwf.int/en/forecasts/access-forecasts/access-archive-datasets
[6] Polytope-client: https://git.ecmwf.int/projects/LEX/repos/polytope-client

4 IMPACT ON NUM BUSINESS PROCESS

4.1 EXPLOITATION OF THE LEXIS WEATHER CONFIGURATION FOR FRANCE

We demonstrated that the WRF modelling performed during LEXIS leads to positive results since the forecast KPI was achieved or even exceeded (see Deliverable D7.9 [6]), especially for the industrial and agriculture use cases.

These results were obtained on a limited period and number of case studies, and the first steps must be to consolidate them on a longer period, especially for the agriculture application for which the impact seems important but for which also the validation period must be longer (3 to 6 months) according to the decision tools tested.

But the main point in defining a commercial exploitation plan is to run further simulations to identify the key elements which contribute to observed good results.

Indeed, the WRF modelling for France inside LEXIS is based on:

- The use of a recent version of WRF,
- A configuration of WRF by CIMA, which probably differs from NUM configuration,
- The use of IFS global forecast from ECMWF as boundary conditions for the forecast,
- The use of the Meteo France precipitation radar observations during the assimilation phase at the start of the forecast
- The use of the Wunderground temperature observations during the assimilation phase at the start of the forecast.

The reason to explore how each element impacts the result is directly linked to a key point: some are not free to use for commercial exploitation.

In particular, it is interesting to determine the effects of:

- The assimilation at the start compared to the use of IFS global forecasts,
- The impact of Meteo France data versus Wunderground data in the assimilation process.

In terms of future exploitation after some further validations, NUM can plan for this WRF simulation over France:

1. Exploit the WRF configuration from CIMA inside its operational chain, using GFS as forecast and without assimilation in the first step.
2. To add assimilation phase using French Meteo France radar. The LEXIS assimilation for forecasts required to have radar observation for 6 hours (18 h, 21 h and 00 h for cycle 00; 6 h, 9 h, and 12 h for cycle 12) each day, so a cost of around 5,800.00 € for a full year. This cost is reasonable and acceptable when we consider that it will be divided between all meteorological dataset sold by NUM over France. Indeed, France forecast simulation is not specific to a unique customer, but can exploited to all clients and needs over France.
3. To add Wunderground observations if it is demonstrated that they are a key element for assimilation, but this will request a discussion with IBM since the acquisition of these data is not so easy now.

Concerning the assimilation part, we must point out that perhaps the most important exploitation from NUM will be the use of the LEXIS results not for forecast simulations but for analysis simulation. The forecast is a simulation for the next days produced each day. The analysis is a simulation of the previous day produced each day. In this case, the objective is to produce numerical weather data for which the initialization period (generally the simulation starts 6 hours in past before the forecast start) is forced by observation (using assimilation approach) in order to have an initial start as much as possible close to reality before to let simulation calculate alone the atmospheric evolution. Today, such analysis data are one of the most important sales (and in progress) for NUM, especially to provide data over one or three past years for regulatory air-quality impact studies for which local observations are not available at a short distance (below 10 km). Today, NUM does not use Meteo France radar observations for this analysis. If the further tests show the importance of these data, even if the cost will be higher (we need 24 hours and not only 6 hours), exploiting the CIMA configuration for the assimilation of this data could be a key commercial point for NUM.

Concerning IFS global forecast for boundary conditions, probably further simulations will demonstrate (as expected) the key role of these data. The problem is the cost which will be more than 100k € per year. Today, even if the cost will be divided between clients using France forecasts, such cost will be impossible to manage for NUM considering its specific market.

4.2 EXPLOITATION OF THE NEW URBAN MODELLING OF PARIS

The new ADMS urban modelling for the Paris region will be used firstly as a showcase by NUM of its expertise. To do that, NUM will see how to deploy the system in an "operational" way to simulate everyday forecasts for Paris in order to have an active demonstrator. In this case, the execution time is not a key point during the first stage.

The first exploitation will be probably inside an R&D project for which a partner needs to access highly detailed local air-quality simulation over a big city for various applications/tests (for example test the exploitation of mobile measurements to improve air-quality maps, or to test the effect of same emission reduction system installed at various locations in a city, etc.).

In a second step, NUM will contact AIRPARIF (French regulatory institution to survey air-quality over Paris) to see how they can exploit/integrate the LEXIS results.

4.3 EXPLOITATON OF LEXIS PLATFORM/SERVICE

The three pilots of NUM have tested three kinds of simulations:

- Weather WRF simulations for the three uses cases,
- Air-quality ADMS urban simulations,
- Air-quality ADMS industrial simulations.

For the ADMS industrial use case, considering the required resources (only one CPU core), it is simpler to maintain such simulations on NUM's server.

For the ADMS urban use case, it is the same conclusion if we are not in the framework of a daily operational forecast. Indeed, in this case, execution time is not so much important, so there is no need to activate a service as LEXIS: the interest of LEXIS platform is to activate easily a high number of cloud cores for complex urban simulations. In the case of an operational forecast, for which execution time is a constraint and so requires to use as much as possible a lot of cloud cores, we demonstrate that the LEXIS platform can be a technical solution. We can note that NUM's urban clients like AIRPARIF (official agency to survey air-quality over Paris) begin to think about cloud externalization compared to maintain in-house servers, so it is a good timing. But to explore this way, it requires to clarify the cost of the LEXIS cloud (windows) servers.

In fact, the main exploitation point concerned the WRF simulation which required lots of CPU on HPC servers.

The first point is that we demonstrate the easiness to develop and integrate workflows inside the LEXIS infrastructure for the three NUM's use cases. Their execution was also easy to manage for basic users whereas execution of the workflows can be split between different European HPC/cloud resources and European Data storages. The second element to point out is now the availability of workflows to execute WRF inside the LEXIS platform (including a specific API to get ECMWF dataset as input) which could attract users of WRF. CIMA communication about the WRF demo cases will help to disseminate such results inside the WRF community.

To exploit the LEXIS platform for WRF simulations, there are three main questions for a company like NUM:

- What are the access costs compared to the market?

  The first information for HPC costs provided by IT4I shows that LEXIS platform will be a very competitive compared to existing known by NUM (Amazon, French HPC centres like CRIAN, etc.). The remaining question is if there are additional costs for data storage or downloading data like it is done for some of these others platforms. Such information must be clarified for future clients.

- What is the performance associated to these costs?

  Today, the full execution time, compared to execution on NUM's in-house servers, seems slightly longer on LEXIS. But this comparison is not so simple since we do not compare the same WRF chain (LEXIS France WRF simulations add an assimilation phase for example). In the next weeks, we need to further explore how the execution time is divided between each element of the workflow to have a fair comparison, and to see how specific LEXIS-management elements add to the execution time. Of course, additional execution time is normal if we consider that the LEXIS platform allows for simulation distribution between different HPC servers in Europe, using the same security level and easy access, etc.

- What is the robustness of the LEXIS platform for daily simulations?

  In order to provide daily operational services, we need to assess the capacity of the infrastructure/system to manage operational runs (for example, do we need to wait too long for available resources in order to start a run ?) and the reliability of the platform (for example, what is the Service Level Agreement (SLA) if we compare to NUM's in-house servers used for daily operational weather simulations for which SLA is 99.2% in one year = % of simulations–twice per day–without HPC problem during execution). For the operational execution, the automatic daily tests performed by CIMA for the next weeks will confirm how the platform will evolve towards full operational service. We can remind the TRL of the LEXIS platform is 8 at this stage, so such open questions are normal at this stage.

To conclude, at this stage according to the existing information, NUM could consider exploiting the LEXIS services (as deployed on IT4I servers for example) using WRF:

- First, for R&D project since operational execution time (or even strong SLA) is not required. It is already the case in the framework of the EVEREST project[7].
- Second, for simulations limited in time such as historical simulation over a specific past period for which also the robustness of the execution is less crucial than for operational simulations.

For operational simulations, some additional tests and analysis as discussed above are required.

[7] EVEREST project: https://everest-h2020.eu/

5 SUMMARY

LEXIS in the framework of WP7 activities achieved some interesting results with a potential for business opportunities:

- IoT science gateway: this is a fully engineered TRL 8-ready edge computing unit for mass-manufacturing, that allows for running complex IoT projects by collecting different weather and air-quality related observables.
- LEXIS workflows demonstrated the ability to build WRF-DA data-assimilation workflows exploiting radar data from Meteo France, the mosaic of Italian weather radar provided by Civil Protection, Institutional weather stations as well as personal weather stations acquired through the IBM Weather Channel (the former Weather Underground). These WRF-DA data-assimilation workflows subsequently drive application models for flood, forest fire, air quality, and agriculture predictions activities. The project demonstrates that the LEXIS platform and connected infrastructure can be a solution for public and private entities to run these modelling chains instead of using another HPC and cloud computing provider. Still, open questions remain about the observational data access, the time of execution of the workflows, and reliability of the computing services which will require in the future some additional tests and analyses.

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