One coastal multi-model forecasting systems

D.4.1.2

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1 Introduction

The STREAM project deals with territorial challenges connected to flooding in the Adriatic region. In this context, numerical modelling has become a fundamental tool for describing the dynamics of terrestrial and marine environments, investigating the impact of severe weather events and promoting flood forecasting services and early warning systems (EWS). Early warning is a major element of flood risk management and disaster risk reduction. It can prevent loss of life and reduce the economic and material impacts of hazardous events including disasters. To be effective, early warning systems need to actively involve the people and communities at risk from a range of hazards, facilitate public education and awareness of risks, disseminate messages and warnings efficiently and ensure that there is a constant state of preparedness and that early action is enabled (Valentini et al., 2019).

Within the framework of the Interreg Adriatic-Ionian I-STORMS project (Integrated Sea sTORm Management Strategies), a sea conditions probabilistic forecasting system was developed to combine the outcomes of the existing ocean and wave modelling systems for providing flooding alerts over the entire Adriatic-Ionian macro-region (Ferrarin et al., 2020). In the framework of the STREAM project, we further developed the multi-model ensemble by restructuring the computational procedure and by integrating more operational systems into the operational chain.

Sea conditions obtained by the multi-model ensemble are used as boundary conditions for modelling and forecasting coastal flooding in the different pilot areas (Emilia Romagna, Po Delta).

The MMES software is released as an Open Source *Python* library that can be downloaded and installed from GitHub repository https://github.com/CNR-ISMAR/mmes.

2 The multi-model forecasting system

The multi-model ensemble is implemented as an internal processing engine that interacts directly with the resources to access the datasets and to produce the ensemble results (mean and standard deviation).

The ensemble creation was mainly composed by a series of *bash* scripts tailored on specific forecasts with a lot of hard-coded parameters. *Python* scripts were used as a wrapper for bash scripts and executed everyday at specified intervals. The main *Python* executables are designed to be implemented as a scheduled job in a GNU/Linux based server. The software developed within the I-STORMS project has been improved and rewritten entirely in *Python*, but it still requires that *cdo* and *nco* binaries are installed in the system.

The main improvements developed in the Activity 4.1 of the STREAM project are:

- conceptual and physical separation between install directory and data directory;
- generalization of data directory structure;
- the use of separated configuration files to store all the information of resources to be collected (including remote server credential), the processing steps for each forecast, the general ensemble attributes (like ensemble output filename and minimum number of sources requested to create the ensemble);
- a management tool to write and edit config files;
- new function to check the downloaded datasets (to delete and retry interrupted downloads)
- a fail-over procedure that fills the gaps creating the ensemble not only for the present day but also for a limited number of days in the past (in case of sources not available, network or system downtime).

2.1 MMES workflow

Ocean forecast results are collected by the system every day in the morning: the program contacts each provider of the list, checks if an updated model exists, downloads it and stores it on a local filesystem using one folder for each node with current and historical data. If the updated forecast is not present in the node, the system will pass to the next node and retry later. Once all forecasts available are downloaded, the multi-model builder prepares the data harmonizing all different forecasts. The ensemble creation procedure can be three main task:

1. retrieve and download each single forecast file provided from different sources;

2. process each forecast with appropriate operations;

3. create the ensemble with mean value and estimate error as standard deviation value and archive old ensemble.

At the present stage, the download and processing tasks are executed in sequence for each source and the cycle is repeated at specified intervals, including new available resources. The choice of

Python scripts instead of *bash* shells procedure allows to execute more than one task in parallel shortening the time of the whole cycle. The software is capable of downloading data from *ftp* or *http/https* servers using credentials stored in the configuration files or using a custom command to be executed on the system shell. The software can retrieve virtually any kind of source.

1. Retrieve and download phase

The source forecasts are provided in different formats and from different types of sources (ftp or http or other). The diagram of the download stage of MMES software is shown in Figure 1. The Daily forecasts are usually published in the morning, but they are not available at the same time and therefore the software contacts all source nodes at regular intervals and checks if the current file is available. If the file is already downloaded and processed the software will pass to the next node.

For *http* sources the exact path of the file to download is needed, for *ftp* sources the software needs the directory name and filename. The naming schema of the files is different for each provider but usually can be constructed using a constant pattern and current date value.

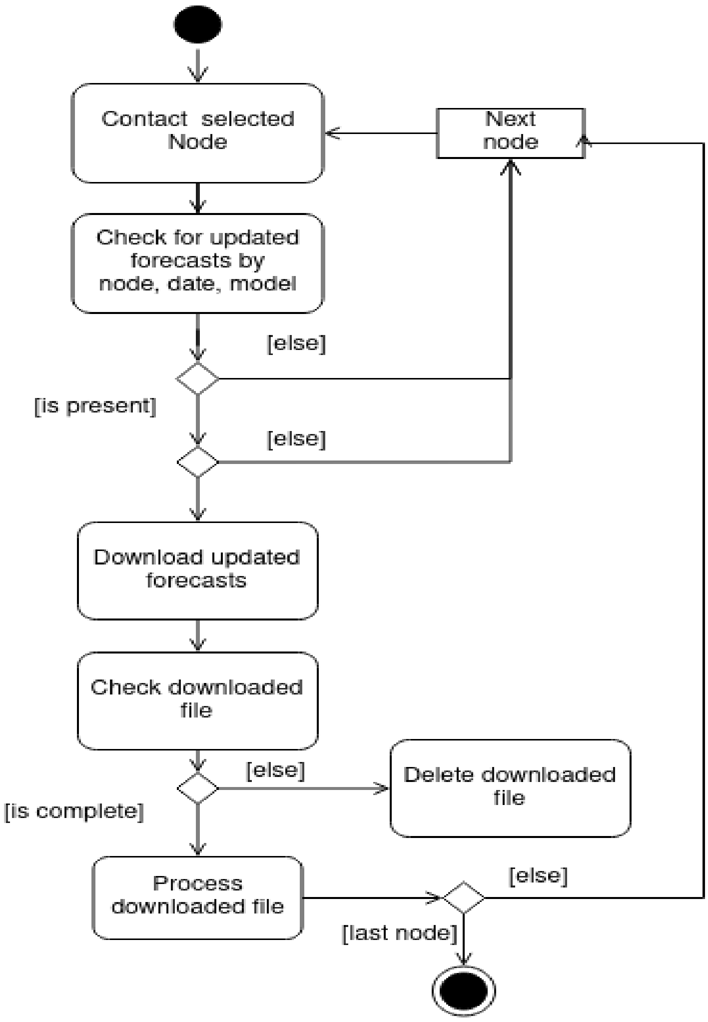

Figure 1: Diagram of the download stage of MMES software.

If the download process is interrupted due to network issues or other causes, the file can be incomplete and not suitable to create the ensemble. The forecast duration is checked after download (start time, end time) to ensure that it covers at least the time period of the ensemble (2 days), otherwise the file is deleted so it can be downloaded on the next cycle.

2. *Processing phase*

If the file is valid, the software will pass to the processing phase. The diagram of the processing stage of MMES software is shown in Figure 2. Each forecast has to be processed in a different way: all the possible steps are implemented in the code (e.g. merge or split variables, rename variables, spatial interpolation on the final grid, temporal interpolation, add tide and offset for sea level, invert wave direction and so on). The processing steps and relative parameters required for each forecast are declared in the configuration files as a JSON object.

On each step, a temporary output file is created: the *Python cdo* wrapper library manages temporary filenames and makes available the data as a *Python* variable, then clears all temporary files at the end. Then the result is saved as a NetCDF file inside the component’s directory. At the end of each processing cycle, the software goes to the ensemble creation phase.

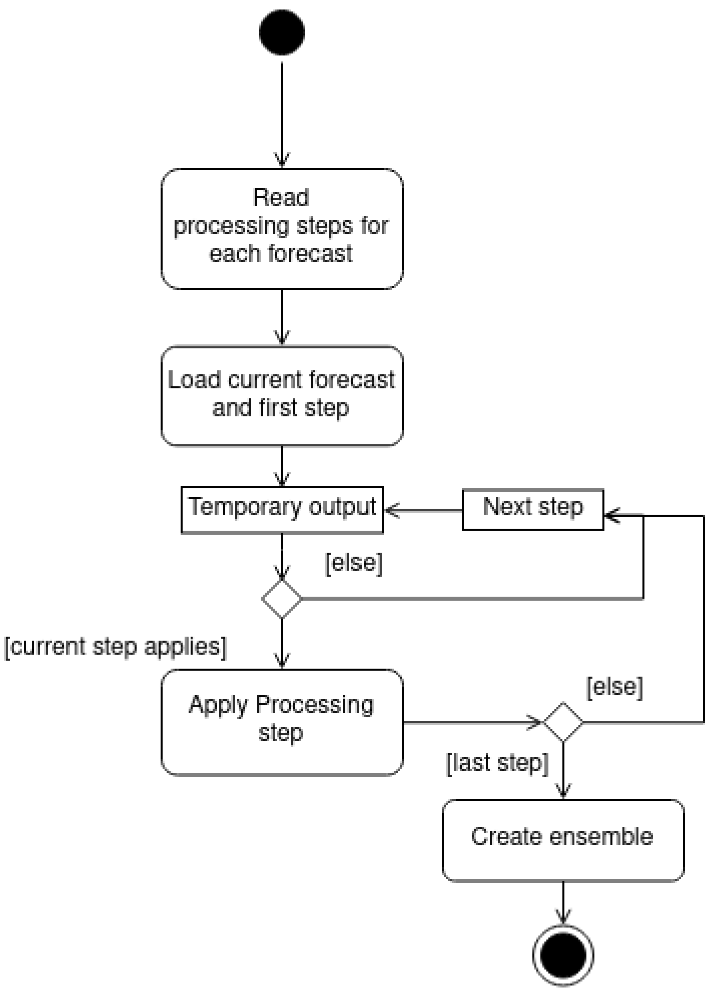

Figure 2: Diagram of the processing stage of MMES software.

3. *Ensemble creation phase*

The general configuration sets a minimum number of files for the ensemble creation: the ensemble output is overwritten on the next cycles adding more forecasts, when available (last execution is scheduled at 14.00). The diagram of the ensemble precaution stage of MMES software is shown in Figure 3.

All numerical model results are interpolated, through a distance-weighted average remapping of the nearest neighbours, on a common regular lat-lon grid covering the Adriatic Sea with a resolution of 0.02 deg.

For coastal flooding hazard purposes, the total sea level height must be forecasted. Therefore, the astronomical tidal level values obtained by a specific SHYFEM application over the Mediterranean Sea (Ferrarin et al., 2018) are added to the residual sea level simulated by the operational systems not accounting for the tide (e.g. SHYMED, ISSOS). The obtained sea level heights simulated by the different models are all referred to the geoid.

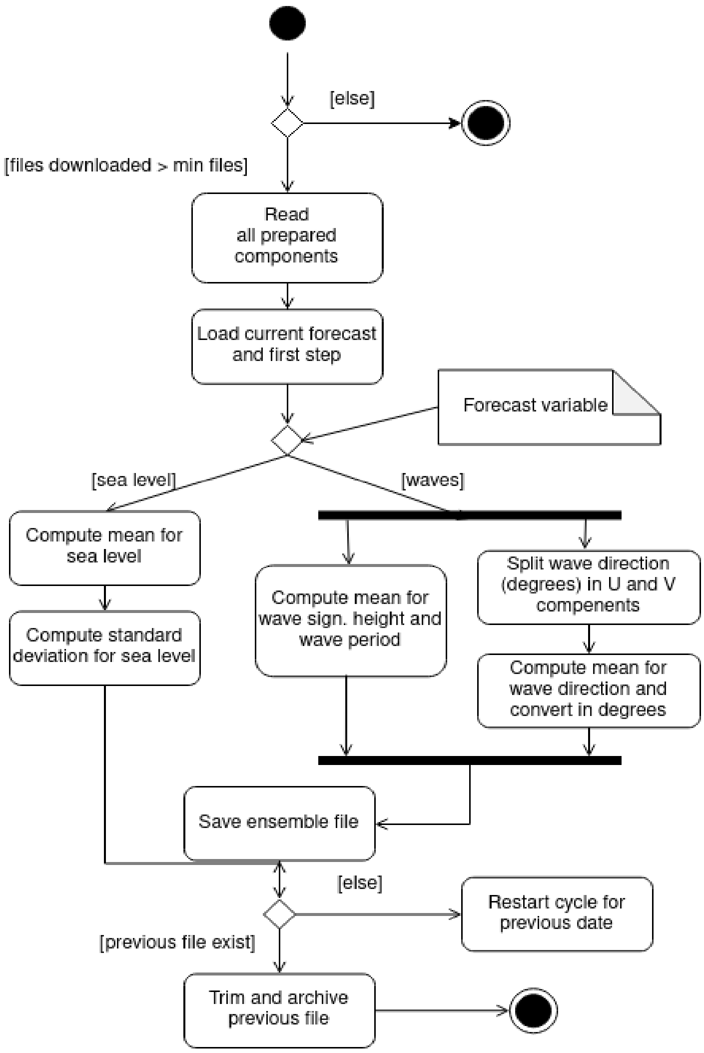

Figure 3: Diagram of ensemble creation stage of MMES software.

The *CDO* library provides simple commands to compute the mean and standard deviation of a variable. For the wave ensemble we have three different variables, wave significant height, wave period and wave direction: the wave direction is expressed in degrees and must be splitted in the *U* and *V* components, then merge the ensembles again.

The ensemble forecast duration is 2 days with 48 hourly timesteps, but users can set a different duration in configuration files. When the new ensemble is ready, the previous day is trimmed to the first 24h hours and archived in the history folder: the Thredds data server will publish the whole collection so can be downloaded a subset of custom duration for the past multi-model files.

2.2 MMES members

Several operational ocean models are currently available for the Adriatic Sea. In the multi-model ensemble system, we implemented all available forecasting systems, with 10 predicting sea level height (either storm surge or total water level) and 10 predicting the wave characteristics. The general characteristics of the forecasting systems are summarised in Tables 1 and 2 for the sea level and wave, respectively. The implementation of forecasting systems highlighted in red is ongoing and therefore they are still not included into the operational MMES chain. The MMES procedure easily allows the inclusion of other forecasting systems.

Managing authority - Country	System name	Domain	Horizontal resolution	Core engine	Tide	Baroclinic	Meteorological forcing
City of Venice - IT	SHYMED	Mediterranean Sea	Variable, up to 200 m	SHYFEM	no	no	ECMWF
CNR - IT	Kassandra	Mediterranean Sea	Variable, up to 100 m	SHYFEM	yes	no	BOLAM, MOLOCH
CNR - IT	ISSOS	Mediterranean Sea	Variable, up to 200 m	SHYFEM	no	no	WRF
CNR - IT	Tiresias	Adriatic Sea	Variable, up to 10 m	SHYFEM	yes	yes	MOLOCH
ARPAE - IT	AdriaROMS	Adriatic Sea	2 km	ROMS	yes	yes	COSMO-5M
ARPAE - IT	Adriac	Adriatic Sea	1 km	ROMS	yes	yes	COSMO-2I, COSMO-5M
ARSO - SL	SMMO	Adriatic Sea	1/72 deg	NEMO	yes	yes	ALADIN

CMCC - IT	MFS Med-Currents	Mediterranean Sea	1/24 deg	NEMO	yes	yes	ECMWF
ISPRA - IT	Ulisse	Mediterranean Sea	Variable, up to 200 m	SHYFEM	no	no	BOLAM
CMCC - IT	AdriFS	Adriatic-Ionian seas	Variable, up to 300 m	SHYFEM	yes	yes	ECMWF

Table 1: Details of the sea level forecasting systems used in the MMES.

Managing authority - Country	System name	Domain	Horizontal resolution	Core engine	Meteorological forcing
City of Venice - IT	Pelmo	Adriatic Sea	2 km	WW3	ECMWF
City of Venice - IT	SHYMED	Mediterranean Sea	Variable, up to 200 m	WWM	ECMWF
ARPAE - IT	SWAN-ITA	Adriatic seas	8 km	SWAN	COSMO-5M
CNR - IT	Kassandra	Mediterranean Sea	Variable, up to 100 m	WWM	BOLAM, MOLOCH
ARPAE - IT	Adriac	Adriatic Sea	1 km	SWAN	COSMO-2I, COSMO-5M
HCMR - GR	MED-waves	Mediterranean Sea	1/24 deg	WAM	ECMWF
ARSO - SL	SMMO	Central Mediterranean Sea	1/60 deg	WAM	ALADIN
DHMZ - HR	WWM	Adriatic Sea	Variable, up to 10 m	WWM	ALADIN
CMCC - IT	AdriFS	Adriatic-Ionian seas	Variable, up to 300 m	WW3	ECMWF
ISPRA - IT	SIMM	Adriatic Sea	10 km	WAM	BOLAM

Table 2: Details of the wave forecasting systems used in the MMES.

The different operational models are forced at the surface boundary by several meteorological models (ECMWF, BOLAM, MOLOCH, COSMO, WFR and ALADIN) with horizontal resolution ranging from 16 to 1.4 km. The length of the ocean forecast is mostly related to the length of the meteorological forecast and varies from 2 to 10 days. There is a large variability in the model's set-up in terms of spatial resolution, temporal frequency, spatial domain (Mediterranean Sea, Adriatic Sea, Ionian Sea), grid arrangement (e.g. structured or unstructured) and data format (NetCDF, GRIB). Only two of the considered systems (Kassandra and Adriac) account for the current-wave coupling and only one system (Ulisse) performs data assimilation of sea-level observations in the operational chain.

2.3 MMES outputs

MMES produces 2-day probabilistic forecasts in terms of the ensemble mean and standard deviation for both the sea level height and wave over the whole Adriatic Sea and part of the Ionian Sea. The spread (i.e. standard deviation) among the operational simulations is expected to represent a measure of the uncertainty of the prediction and should be linked to the forecast error so that cases with the largest spread are those with the highest uncertainty and where a large error of the ensemble mean (and also of the deterministic forecast) is more likely (Flowerdew et al., 2010).

It is not straightforward what averaging weights should be used for the multi-model ensemble forecast and therefore we used equally weighted ensemble members, despite the forecasts which are more precise than others should have more importance in the MMES (Salighehdar et al., 2017; Schevenhoven and Selten, 2017). Here we applied a simple average of the forecasts at every timestamp to compute the ensemble mean, but more sophisticated methods based on weighting function determined by comparison of the single model results with near real-time observations will be implemented in future (Di Liberto et al., 2011; Salighehdar et al., 2017). Taking advantage of the near real-time observations acquired by the aggregated monitoring network, the root mean square error of the individual forecast will be next evaluated and stored for long-term statistics.

MMES forecasts are produced each day. MMES outputs (in terms of ensemble mean and standard deviation of the sea level and waves) in NetCDF format are available to the end-users and external portals through the CNR-ISMAR Thredds Data Server at the webpage's url https://iws.ismar.cnr.it/thredds/catalog/tmes/catalog.html. The results of the multi-model ensemble system can be visualized via the I-STORMS Geoportal web interfaces (https://iws.seastorms.eu/). The results will be next delivered through the STREAM International Flood Platform.

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