Technical Annex to the MoU for
Short range forecasting methods
of fog, visibility and low clouds

A. BACKGROUND

Meteorological forecasting at a very short notice (hereafter, up to 12 hours) is called nowcasting. Many important human and economic activities depend on nowcasting (e.g. traffic, special public events). Numerous customers (e.g. airlines, surface transport companies, traffic management authorities) particularly request nowcasting of fog, visibility and low clouds. The most critical challenges in nowcasting or very short range forecasts of fog formation and dissipation are especially the development of horizontal visibility and of the cloud base.

Effective, useful nowcasting of visibility, fog and low clouds is constrained by the availability and quality of observational data, by the meteorological situation and by the quality of the forecast methods. Furthermore, the production and dissemination of various nowcasting products which are tailored to the needs of the individual customers require a flexible and user-friendly application software.

The development of visibility, fog and low clouds is influenced by many parameters (e.g. cloudiness, temperature, humidity, windspeed, topography, vegetation). Fog is especially very sensitive to small changes in the relevant meteorological parameters in the lowest layers of the atmosphere, so that very high-quality measurements are required. Therefore, high forecast skill is dependent on accurate knowledge of the vertical distribution of the relevant input parameters.

The horizontal representativity of ground-based observational data may be restricted to a few kilometres or even less. The requirement for observations at this scale can be partly fulfilled by using satellite data: e.g. Meteosat Second Generation (MSG), NOAA series (National Oceanographic Atmospheric Administration). Furthermore MSG data will be available every 15 minutes, whereas NOAA data are available approximately four times per day.

The forecast methods (models and statistical methods) also exhibit deficiencies due to imperfect representation of the physical processes or statistical estimation. To improve this situation it is necessary to reach a deeper understanding of the relevant mechanisms through detailed investigations of observational data and derived parameters (e.g. energy fluxes).

Models (1-D- or 3-D) are designed to represent relevant physical processes through parameterisation to calculate the development of fog, visibility and low clouds. However, 1-D-models lead only to point forecasts and they do not take account of advection. Nevertheless they have the advantage of a relatively short running time and can represent some processes in better detail. With 3-D-models, on the other hand, area forecasts for any weather situation can be produced. They can also be used as a research tool to investigate the relevant mechanisms. However, highly sophisticated 3-D-models may have a rather long running time: in operational circumstances, a balance has to be struck between running time requirements and the accuracy of representation of physical processes. Probability forecasts are a suitable alternative to deterministic model forecasts because forecasts of fog, visibility and low clouds are sensitive to initial conditions.

Various statistical methods (e.g., regression, neural network, decision trees) have been used to forecast fog, visibility and low clouds. Some have the disadvantage that they are only valid for a given location. Transferring the algorithm to another location is not straightforward, because it...
Effective production and dissemination of forecasts requires application software consisting of i) a user-friendly and versatile tool for preparing the forecasts, ii) a set of powerful forecast methods, iii) a module for fast dissemination of individual forecast products. An effective cooperation can be achieved if different forecast modules and data sets can be exchanged between all involved partners in such a way that they can be adapted to the user’s system.

In the frame of the Action COST-78 „Improvement of Nowcasting Techniques“ some activities on nowcasting of fog and low clouds were performed. However, the question of fog and low cloud diagnosis and modelling was recognised as too broad to be fully developed within the Action, but was recognised as an activity deserving a fully dedicated project.

Several critical deficiencies for forecasting fog, visibility and low clouds can presently be identified:

- The mechanisms relevant for the formation and dissipation of fog and low clouds are not yet well understood
- Current methods are mostly applicable for specific weather situations
- Current methods are mostly tuned for specific locations
- Current methods lead mostly to point forecasts
- The quality, the amount and the representativity of observational data are not sufficient
- Standards for exchange and incorporation of forecast tools are either not well defined or not widely adopted
- Training material both for the forecaster and for the customer is not available

Thus to improve significantly the quality of forecasts of visibility, fog and low clouds would require an intense scientific research effort in: (a) understanding and simulating the main processes, (b) measurement requirements, and (c) analysis methodologies of satellite data and ground based measurements; taking into account the need for eventual implementation within operational systems. The required research is multidisciplinary in nature and has wide applicability across the nations of Europe. Therefore a new COST Action is entirely appropriate to address this question, since it will draw together the scattered national activities in this area.

Adaptation of existing knowledge to operational nowcasting with special regard to satellite data is taking place within the EUMETSAT Satellite Application Facility (SAF) on Nowcasting. For that reason, the COST Action proposed here will take account of the work and outputs of the Nowcasting SAF.

B. OBJECTIVES AND BENEFITS

The main objective of the Action is to develop advanced methods for very short-range forecasts of fog, visibility and low clouds, adapted to characteristic areas and to user requirements. This overall objective includes:
- the development of pre-processing methods of the necessary input data;
- the development of the appropriate forecast models and methods; and
- the development of adaptable application software for the production of the forecasts.

In order to fulfil this overall objective the project will have the following detailed objectives:
- To assess the requirements from the customers and the forecasters, in respect to scale, timeliness, quality, critical thresholds
- To undertake scientific research of the phenomena relevant for visibility, fog and low clouds
- To foster continuous cooperation in research & development and by the exchange of knowledge, of data and methods between all participants
• To regularly assess the state-of-the-art of tools and of developments in progress

• To support the development of fog climatologies for validation purposes and to establish its relationship with very short-range forecasting

• To develop methods that are suitable for operational implementation

• To produce detailed documentation on the methods, its quality and the software

• To recommend measurement requirements

• To disseminate existing expertise and the results of the Action to a wide range of users and scientists

Achieving the above objectives will lead to the following **direct benefits**:

• Effective advanced methods for processing observational data and forecasting of fog, visibility and low clouds

• Increased understanding of physical processes responsible for the development and dissipation of fog, poor visibility and low clouds

• Validation of satellite data against ground observations

• More synergetic cooperation between European countries in the development of nowcasting methods of fog, visibility and low clouds and for the exchange of forecasting tools

**Consequential benefits** will arise from the operational implementation of the results of this Action:

• A more effective management of sea, air and road transport and improvement of safety

• Planning aids for traffic systems, tourism, outdoor sports and other special open-air events

• Reduction of costs due to personal injury, material damage and traffic congestion

• New tailored products and services

• Possibility to develop new observation systems and devices based on the recommendations for standard measurement equipment

• Potential for increased earnings for developers and providers of meteorological services

• Increased level of skill and better trained personnel within the operational and scientific staff

### C. SCIENTIFIC PROGRAMME

The scientific programme consistent with these objectives falls into the following areas (which will be elaborated in greater detail by the Management Committee and by the working groups).

#### C.1 INVENTORY

It is envisaged to have a preparatory phase focusing on inventories of needs, activities and of available models, data and procedures. During this phase two working areas will be considered:

1. **Existing forecasting methods**
   The goal will be to gather and assess existing forecasting systems (type of input data, methods, validation level, procedure) and ongoing activities related to them. The inventory will provide:
   - A description of the methods/models and their quality
   - A list of projects and activities in research and development in relation to this field
   - Recommendations and a road map for further steps

2. **Requirements from the forecasters and from the customers**
   The goal of this inventory will be to assess the the various requirements of different groups of users concerning nowcasting or very short range forecasting systems of fog, visibility and low clouds in terms of scale, timeliness, quality and critical thresholds.
   **Deliverables:**
   
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• Publication of the inventories
• Segmentation and qualification of users requirements
• Workshop to discuss results and establish next steps

C.2 RESEARCH AND DEVELOPMENT

As sketched in section A and B and based upon the inventory 4 areas of activities (corresponding to different working groups (WGs)) will be considered: Initial data, Models, Statistical Methods, and Application Software.

Alongside the activities listed below, all WGs will in general:
• Continuously review recent developments/activities and actual requirements
• Maintain documentation:
  - description of the methods, their quality and limitations
  - description of the software, e.g. interfaces, installation
• Recommendation for future work

C.2.1 INITIAL DATA (WG1)

Methodologically, it is advisable to distinguish between satellite data and in-situ measurements, because the necessary expertise is different. But it is acknowledged that fog and low cloud forecasting is very sensitive to initial conditions. Consequently, the expected accuracy of input data must be exactly specified. Moreover, it is necessary to clearly define which parameters should be measured and with which levels. For example, precise temperature and humidity data are mostly needed near the ground, when wind seems more important at the top of the atmospheric boundary layer. All available data sources should be explored, and optimal combinations of available measurements will be looked for.

C.2.1.1 SATELLITE DATA

Within this area, data from MSG, NOAA and EOS (Earth Observation System)-Aqua -Mission will be investigated. The following set of input data which are necessary for forecasts of fog, visibility and low clouds can be gathered from products of the Nowcasting SAF (at pixel resolution): cloud type, fog and cloud analysis, top and thickness of the cloud layer, optical thickness. The Climate Monitoring SAF (horizontal resolution 15x15km²) provides monthly and daily means, monthly mean diurnal cycles plus standard deviation, respectively, and hourly values of cloud cover, cloud type, cloud top temperature, cloud top height, cloud phase, cloud optical thickness and cloud liquid water path. From EOS data, one can obtained vertical atmospheric profiles, as well as digital data of elevation and vegetation (e.g. leaf area index). Vertical profiles of temperature and of humidity are retrieved from the NOAA data four times a day. However, only a poor information on the vertical structure is available. In spite of this poor temporal and vertical resolution, these NOAA data could be useful for the preparation of initial data and this will be investigated.

The observational data at different altitudes are derived from measurements of radiation flux densities from the satellite orbit. However, measurements in the lower part of the atmosphere (e.g. temperature of the top of fog layer) are often masked by conditions within the upper parts of the atmosphere (e.g. humidity, upper clouds). Satellite data are transmitted in form of pixel values. Each pixel of the MSG images over Middle Europe will cover an area of approximately 5x5 km (IR) and of 3x3 km (VIS) The radiometer measures radiation intensities which represent the average of a given pixel. If the fog/low cloud layer does not cover a whole pixel, radiation measurements are very likely to be misleading due to the mixed signal originating partly from the top of the fog/low cloud layer and partly from the remainder of this pixel. Thus, using concomitant ground measurements, correction methods will be developed in order to fulfill input data requirements for forecasting fog, visibility and low clouds, e.g. in cooperation with WG3
“Statistical Methods”.
The following steps will be performed:

- Study the potential of satellite data for initialising the forecast models
- Specify the most required input data
- Develop a pre-processing procedure for initial data (meteorological parameters, topography data and vegetation)
- Combine satellite data and ground observations to distinguish between fog and low clouds and to validate satellite data
- Contribute to a fog climatology (distinguishing between fog types) for typical weather situations and locations
- Validate/verify the methods and, if necessary, adapt calibration algorithms.

### C.2.1.2 IN-SITU MEASUREMENTS

Since all necessary input parameters for forecasts of fog, low clouds and of visibility cannot be obtained from satellite observations they must be complemented by ground observations and measurements. Moreover, ground-based observations are more suitable to investigate the relevant processes for the formation and dissipation of fog and low clouds and for the validation of the models. The latter includes not only the model output (visibility, fog and low clouds) but also the model physics (e.g., transport mechanism and cloud microphysics).

Since an optimum measuring programme with all relevant input parameters would require sophisticated measurement equipment (e.g. measurement tower, vertical profiler, measurements within the soil) it will be necessary for economic reasons to identify the minimum set of required observations and parameters (including resolution, format, etc.) for initialising a forecast.

In particular the following tasks will be considered:

- Assess the potential and limitation of current measurement techniques
- Specify the minimum measurement requirements
- Develop tools for the derivation of required input parameters and for validation (e.g., a relationship between visibility and spectra of aerosol and droplets)
- Develop procedures for combining ground measurements with satellite data and extract information from them

**Deliverables from C.2.1:**

- Improved calibration and analysis of satellite data
- Recommendation for economically-priced (standard) measurement equipment
- Optimal combinations of available measurements in different situations
- Deeper understanding of the relevant processes for the formation and dissipation of fog and low clouds and the development of visibility
- Exchange of knowledge and of methods between all involved countries
- Basis for the development of training packages for forecasters and customers

### C.2.2 MODELS (WG2)

1-D and 3-D models as well as probability forecast methods will be considered. Some of the available 1-D and 3-D models will be reviewed and tested to assess their potential and weaknesses, separately and in combination. In cooperation with WG1 „Initial Data” and WG3 „Statistical Methods”, pre-processed input data will be used together with numerical weather prediction data.

In order to improve our understanding of the mechanism of the development of visibility, fog and low clouds, scientific research of all relevant processes will be undertaken in detail. Improvements based on the results will be implemented and tested.
The basis for extracting a fog climatology hindcast data bases from well-behaved forecast models for typical weather situations and typical geographical characteristics could be investigated. This would avoid having to collect a long data set in order to get representative results.

Visibility, fog and low clouds react very sensitively to small changes in the meteorological conditions so that forecasts of them are subject to a rather high uncertainty. The uncertainty will be assessed by applying the well-known technique of ensemble forecasting. However, a compromise must be looked for between the required—at times prohibitive—running time, and the precision required in operational forecasting situations.

Within this working area the particular tasks will be considered:

- To investigate the potential and limitation of different models
  - to specify their demands as to input data
- To investigate the mechanisms relevant for visibility, fog and low clouds based upon all available input data (inclusive digital data on topography, vegetation)
- To specify the model design (e.g. stand-alone, nested)
- To improve and develop the model physics
- To develop initialisation procedures for all relevant input data
- To develop probability forecasts
- To carry out continuous validation of the various models/methods
  - product output (visibility, fog, top and base of low clouds)
  - model physics (e.g. transport mechanism, cloud microphysics)
- To adapt the models to routine purposes (or providing simplified routine versions)
  - investigation of relevant input parameters which could be retrieved at many locations
  - limitation of running time
  - high degree of flexibility and adaptability to existing computer platforms and numerical weather prediction models
- To support the development of a fog climatology

**Deliverables**

- Highly sophisticated models, applicable for any characteristic area, also applicable for routine purposes in a range of environments
- Deeper understanding of the relevant processes influencing visibility, fog and low clouds
- Exchange of knowledge and if possible of portable software modules
- Basis for the development of training scripts
- Recommendations for an economically priced measurement strategy

**C.2.3 STATISTICAL METHODS (WG3)**

Statistical methods are used for producing forecasts and for the correction of input data and of model outputs. They are especially useful to compensate for spin-up and spin-down problems of models. Probability forecasts will be applied in order to assess the uncertainty of deterministic forecasts of fog, visibility and low clouds.

Statistical methods lead mostly to point forecasts and the transfer of a statistical method to another location requires a new tuning with a long set of relevant data. In cooperation with WG1 „Initial Data“, methods will be developed to extend point forecasts to area forecasts and to achieve the transfer of statistical methods from one location to another.

Input data from satellite contain errors which could be corrected with statistical methods (e.g. perfect-prog based upon a fog climatology and/or ground measurements). In cooperation with WG „Modelling“ the input data will be pre-processed.
The model results are never perfect because of deficiencies in the model physics which could only be reduced by time consuming calculations. Statistical methods (e.g. model output statistics) will be developed for reducing or correcting these errors (in cooperation with WG2 „Modelling“).

The following tasks will be performed:

- Study the potential and limitations of different statistical methods of probability forecasting
- Specify the requirements for input data
- Determine the most important input parameters for statistical forecasts of visibility, fog and low clouds (e.g. by pruning technique)
- Validate and improve the available statistical methods
- Develop techniques to transfer forecast methods developed for one location to another
- Develop methods for statistical pre-processing of satellite data and post-processing of model outputs
- Adapt the various methods to routine/operation purposes
  - high degree of flexibility (for easy adaptation and incorporation at other meteorological service organisation)
  - limitation to input parameters that can be retrieved at most meteorological organisations

**Deliverables:**

- Powerful and highly sophisticated statistical methods
- Improved expertise on statistical methods
- Exchange of knowledge and (if possible) of software tools which can be used for any location and for routine purposes
- Sound basis for the preparation of training material

**C.2.4 APPLICATION SOFTWARE (WG4)**

This area is concerned with the implementation of the research results at meteorological organisations, in connection with other applications for nowcasting. For the purpose of software exchange it is not necessary to use a standard application software, but it is essential that the interfaces are clearly defined and the source code is exchanged. The purpose is to permit easy incorporation of software modules and of data at the different organisations.

The following tasks will be performed:

- Study the possibilities for the exchange of existing applications amongst existing development groups
- Set up standards to support easy interfacing to a range of environments
- Develop some prototypes to be shared between all participants within this Action
- Survey opinions of forecasters and customers on the prototypes
- Exchange
  - of the software to the involved meteorological organisations
  - of test data

**Deliverables:**

- Standards for portability of application software modules
- Prototype software
- Basis for demonstration, e.g., for training purposes

**D. ORGANISATION AND TIMETABLE**

The Management Committee (MC) will implement the Technical Annex of this Memorandum of
Understanding (MoU) by developing a work programme that will take into account the expertise and the interest of the participating institutions.

According to the Scientific programme it is provisionally envisaged that the work programme will be carried out within two working groups (WG) during the inventory: (i) inventory of existing methods and, (ii) inventory of the requirements by the customers and by the forecasters. During the development-phase, 4 WGs will be established: (WG1) Initial Data, (WG2) Modelling, (WG3) Statistical Methods, and (WG4) Application Software.

Each WG will appoint a chairperson. The chairperson and the MC will constitute the leading structure of the Action. They will be responsible for defining, implementing, monitoring and reviewing the work undertaken by the Action. The COST Technical Committee for meteorology will appoint among its membership an observer to this Action in order to advise the MC if necessary.

Each WG will meet once/twice a year, preferably in conjunction with MC-meetings and their work will be regularly reported to the MC. Short-Term-Scientific Missions (STSM) will be used as much as possible in order to maximise the exchange of experiences among the participants and to foster training of young scientists.

The MC will meet twice a year. One of its main responsibilities should be to link and integrate the activities of the WGs in such a way that the information, the needs and the results of each WG will serve as inputs to the other WGs. The MC-members will use personal networking in order to integrate as much as possible the scientific community, data providers, users and service providers outside the Action.

The project will have a total length of 5 years. It is split into 4 phases with the following milestones:

**Phase I: Inventory** (year 1, 12 months)
- MC: establish initial WGs and define initial work
- MC: organise 1st workshop
- WGi: prepare inventory of existing methods and ongoing projects with recommendations
- WGii: investigation of requirements by the customers and by the forecasters
- WGii: report to the MC
- WGi/ii/MC: preparation of the text of a publication with the outcome of Phase I

**Phase II: Research and development** (years 2-4, 36 months)
- 1st workshop
  - reporting about phase I
  - establishing of WGs
  - preparation of detailed plan of work based upon the outcome of phase I
  - preparation of the proceedings
- MC/WGs: publication of the proceedings
- WGs: report to the MC every 6 months about the progress of work
- WGs: regular WG-meetings for reviewing, syntheising and planning the work
- MC: Short Term Scientific Missions as appropriate
- MC: organisation of 2nd workshop

At the end of Phase II the following will be achieved:
- tested prototypes of methods, algorithms and models
- exchange of prototypes and of data
Phase III: Development and applications (years 3-5, 30 months, overlapping with Phase II)

- 2\textsuperscript{nd} workshop
  - reviewing the state of the art
  - determining the final workplan
  - preparation of the proceedings
- MC/WGs: publication of the proceedings
- WGs: report to the MC every 6 months about the progress of work
- WGs: regular WG-meetings for reviewing, synthesising and planning the work
- MC: Short Term Scientific Missions as appropriate
- At the end of Phase III the following will be achieved:
  - fine-tuned methods for any characteristic area
  - routine versions available
  - methods delivered to any institute/service within the involved countries

Phase IV: Dissemination of Action results (year 5, 12 months, overlapping with Phase III)

- WGs: exchange of the application and of the training material
- WGs: contributions to the final report
- MC: organisation of the Final Conference
- MC: finalisation of the final report
- MC: end of the Action by the Final Conference

Dissemination plan

The results of the Action will be disseminated in the following way:

- A web-site that acts as a meeting point for informing the participants, research institutes and potential end-users. It is to be constructed as soon as possible after the start of the Action. The selected institution to run the web-site will have also the responsibility of keeping it up to date by using materials provided by and following the instructions of the MC.
- Workshops for participant organisations and other institutes
- Publications in the form of COST-documents, proceedings, articles in scientific journals, etc.
- A data volume (e.g. CD-ROM) with sample data sets, demonstrations, tutorials, documentation will be available to research institutes, scientific libraries and participants.
- Joint meetings with WGs from other relevant COST-Actions
- The results of this Action will be put in a Final Report, supported by a Final Conference. The sample data set and the developed applications will be made available to all participants and for other involved institutes. However, the rights and responsibilities to use these data sets and developed applications have to be agreed upon separately.

Cooperation with other fora

- With EUMETSAT for the analysis of MSG data and to use products of Nowcasting-SAF and Climate Monitoring-SAF
- With NOAA and later EUMETSAT for the interpretation of vertical profiles observed with the vertical humidity sounder and the vertical atmospheric sounding interferometer
- With existing short-range numerical weather prediction modelling groups (UM, HIRLAM, ARPEGE, LM)
- With EGOWS (European Group on Operational Meteorological Workstation Systems) in order to coordinate the activities within WG 4 of this Action with other activities in Europe
- With COST 719 (The Use of Geographic Information Systems in Meteorology and Climatology) in order to use information about the topography.
- With COST 720 (Integrated Ground Based Remote Sensing Stations for Atmospheric Profiling) in order to use the expertise for the preparation of initial data
- With Conference on Fog and Fog Collection (takes place every 2 years) in order to
exchange knowledge also with countries outside Europe.
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Risk management

The main risks that can be envisaged are:
- Rapid technology progress outside the Action
- Rapid changes of the requirements by the customers and the forecasters
- Poor cooperation with the above fora
- Delay of work due to the lack of human resources

The first two risks are addressed during Phase I of this Action and afterwards by all WGs by keeping pace with the state of the art and with the requirements by the customers and by the forecasters. The MC and WGs will organise the work in order to pursue the most valuable cooperations and will make use of personal networking to encourage cooperation. Concerning the last risk each WG-chairperson is strongly recommended to replace a leaving member of his working group by a successor.

E. ECONOMIC DIMENSION

The following countries have participated in the preparation of this Action: Finland, France, Germany, Hungary, Slovenia, Sweden, The Netherlands and The United Kingdom. At least 5 additional countries have indicated a provisional interest to participate in the Action.

The following conditions are assumed for the preliminary calculation of the budget:
- Number of participating countries 15
- Number of participants for each country 03
- Number of additional WG-members per WG 05
- Costs for one travel 1,000 €
- Person power per country and per year 0.2 person year (py)
- Personal costs for 1 py 60,000 €
- Length of the Action 5 years
- Consumables, computer time 700,000 €

a) National fundings:
- Person power 60,000 € x 0.2 x 3 x 5 x 15 = 2,700,000 €
- Consumable, computer time = 700,000 €
- Sum = 3,400,000 €

b) EU-Fundings:
- MC-Meetings 1,000 € x 2 x 2 x 5 x 15 = 300,000 €
- WG-Meetings 1,000 € x 4 x 2 x 5 x 4 = 160,000 €
- STSMs 11,000 € x 5 = 55,000 €
- Workshops 1,000 € x 3 x 5 = 15,000 €
- Study contracts 11,000 € x 4 = 44,000 €
- Publications = 20,000 €
- Sum = 594,000 €

Total EU + countries amounts to 3.9 M€. The EU-share is about 15%.

This total estimate is valid under the assumption that the foreseen 15 countries will participate in the Action. Any departure from this will change the total costs accordingly.