DEVELOPMENT AND OPERATIONALIZATION OF A FORECAST VERIFICATION SYSTEM

(Contract ID No: PPCR/DHM/S/CQS-54)

December, 2017

1. BRCH Objective and components

The objective of the Building Resilience to Climate Hazards (BRCH) project is to enhance capacity of the Department of Hydrology and Meteorology (DHM) of the Ministry of Population and the Environment (MoPE) to mitigate climate related hazards in Nepal. The project will aim at improving accuracy and timeliness of weather and flood forecasts and warnings for climate vulnerable communities, as well as developing Agricultural Management Information System (AMIS) services to help farmers mitigate climate related production risks. The project comprises four components:

A.   Institutional strengthening, capacity building and implementation support of DHM;

B.   Modernization of observation networks and forecasting;

C.   Enhancement of the service delivery system of DHM; and

D.   Creation of an agriculture management information system (AMIS).

Forecast verification is part of Component C Enhancement of the service delivery system of DHM and is referred to in section 1.3 of the Project Appraisal Document's Paragraph 76.

2. Introduction

This Terms of Reference (ToR) is for a Consulting firm (here after Consultant) to build and integrate a forecast verification system as part of DHM's ITC and data management infrastructure and to train the personnel to use and further develop the system.

In the context of this ToR, the forecast verification system consists of a set of software packages that produces various statistical scores to assess the quality of a weather forecast. The scores measure different statistical aspects of the forecast quality, e.g. systematic or random deviation from an assumed perfect forecast[1], this being typically verified against weather observations at a specific location. In a basic verification system forecasts to be verified are selected to represent a particular point of time and location of the observation to evaluate the quality of forecast. Depending on the parameter in question appropriate statistical scores such as 'hit rate', 'mean error' or 'standard deviation' (and many other scores) are used as indicators of the quality of forecast. To help out analyzing the verification results the system should include a Graphical User Interface (GUI) e.g. to select the wanted time period, foracst variables and to view the results as tables and graphs or plotted on a map.

Ideally the verification system should handle simultaneously all main forecast methods used routinely by the National Meteorological Weather Service. When preparing the weather forecast the forecaster typically compares output from several different Numerical weather

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[1]   Complete presentations of verification theory the are available e.g. at: *http://www.cawcr.gov.au/projects/verification/*

Prediction (NWP) models. The forecaster may also modify the model output by means of manual or automated post-processing methods with the intention to improve the forecast accuracy.

The verification scores for a particular forecast method may vary depending on the location selected for verification, weather situation, time of day, season of the year, etc.. By analyzing the verification scores and having a sufficient amount of verification points (observation stations) and long enough statistical samples it is possible to determine which forecast method is suitable for a certain location or weather condition.

Eventually the goal of verification is to be able to identify sources of uncertainty in the methods causing inaccuracy in the forecast, alleviate them and thereby continuously improve quality of forecasts.

3. Current capacity of DHM to provide weather forecasts

With help of the BRCH project the DHM is currently renewing its observation networks, ICT infrastructure, data management, and forecasting tools with possibility to create automated routines for product generation. DHM will have access to a few global NWP models such as Global Forecast System (GFS) model and the European Center for Medium Range Weather Forecast (ECMWF) model. DHM has also started to run the local area and high resolution Weather Research Forecast (WRF) model on a routine basis.

The different elements of the production process being acquired or developed are illustrated in Figure 1 in which hydro-meteorological data, acquired from different local and international sources, flows through various data processing stages and is finally transformed into added products and delivered to end-users. Observation data from hydro and met stations are Quality Controlled (QC) before storage in the DHM relational database as 'point data'. Also lightning detection data and sounding data are stored in this data base. File based binary data such as Weather radar images, weather satellite data and Numerical Weather Prediction (NWP) grid data are processed separately and stored in the file servers. These data can then go through various types of post-processing depending on the application to bring the data in useable form. Extracts from NWP model output data will be generated and stored in the database as 'point' data representing surface station locations thus allowing for comparison with surface observations and to perform verification of NWP forecasts. Blue boxes in Figure 1 represent supply of data and information, hardware and off-the-shelf software. Orange boxes represent consulting works through which new software and applications are generated. The circulated red box represents the position of forecast verification in the production process.

Selected data can be further processed by calculation of derived variables (e.g. statistical values, potential evaporation, and drought index, etc.) and finally transformed into specialized data products according to user needs. Automated routines are developed to allow for dissemination of products via various media such as Internet, mobile networks and Wide Local

Area Network (WLAN) and/or stored to user data bases such as AMIS and (WMO Information System (WIS). Workstations and corresponding user interfaces provide tools for the forecaster to visualize, analyze, control and edit data to improve forecasts and to prepare specialized products such as weather warnings. A personnel capacity building is provided in scychronization of the commissioning of systems to make the staff competent to maintain and use the new systems established.
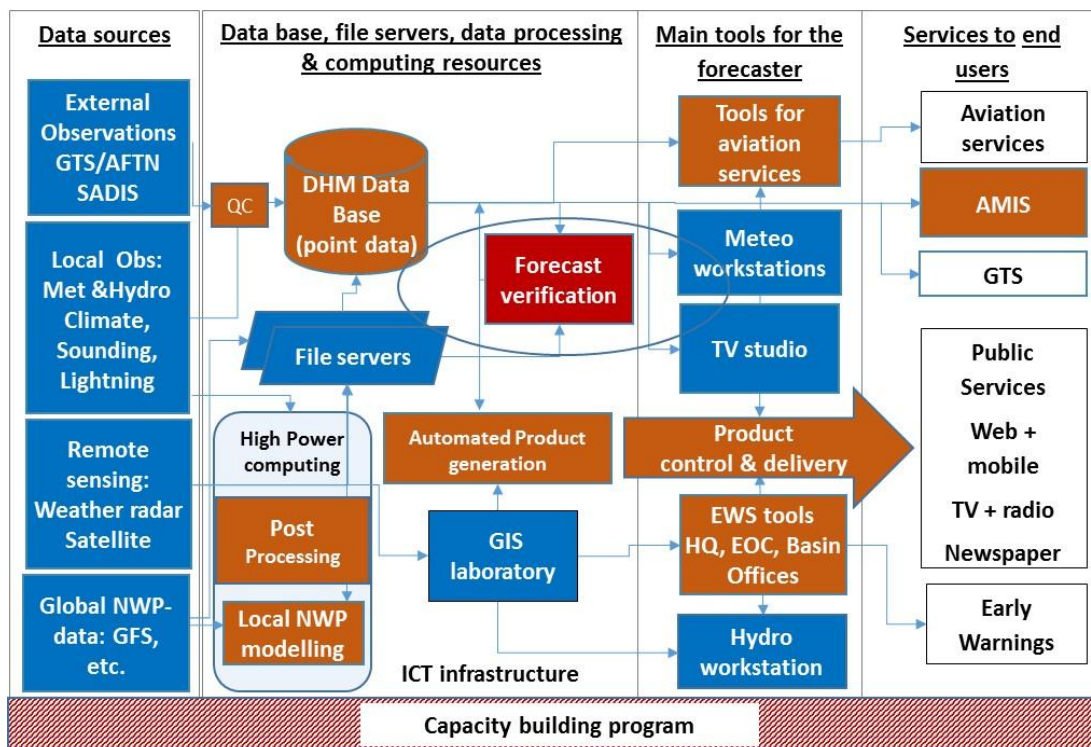

Figure 1. A simplified diagram of the enhanced DHM production process.

The forecast parameters (or variables) to be verified are: Instantaneous Air temperature at 2 m height (at minimum 3 hourly intervals), daily Max and Min temperature at 2 m height, precipitation amount (with various accumulation periods), probability of precipitation (PoP), wind speed at 10 m height and total cloud cover. Both direct NWP model outputs and post-processed values (such statistically adjusted or manually edited data) should be verified.

In this consultancy a sub-set of automated weather stations are selected across Nepal to provide the 'ground truth' against which the forecasts will be verified. Tentatively the set of stations to be included in the verification consists of 29 automated agrometeorological stations and 11 SYNOP stations located mainly at airports. These stations are predominantly located at smooth terrain environments thus making the observations representative of the relatively coarse resolution of a NWP forecast. The station list will be finalized during the course of the consultancy. Time allowing, the verification should be extended to all 88 automated weather stations. The works of the consultant can start after the data from the NWP models and the automated stations is available in the DHM data base.

4. Objectives

The main objective of the Consultancy is to develop a forecast verification system for use by DHM that provides measurable scores as indicators of forecast quality.

The functionality of the objective will be cognizant of:

a. Reference to international forecast verification standards

b. Ensuring interoperability with observation and forecast databases and other data archives as well as over the DHM intranet

c. Building the capacity for DHM personnel to maintain and develop system and to understand the meaning of the quality metrics.

d. To enable DHM to continuously increase the quality of weather forecasts and products for use by the citizens of Nepal.

5. Scope of Work

The assignment covers the development, installation, testing and commissioning of the verification system, as well as training provided to the DHM personnel to understand and interpret the content of the forecast verification output, to maintain and further develop the system. The work consists of two main tasks:

Task 1: Development of the forecast verification software and Graphical User Interface

- Creating a data base of point forecasts representing the location and time of observations in the data base.
- Developing software code to calculate standard verification scores for each forecast parameter.
- Constructing the Graphical User Interface

Task 2: Training of DHM personnel to

- Understand the scientific background and methodology of forecast verification
- Develop competence of DHM staff to operate and maintain the system;

The Tasks are specified in more detail as follows:

Task 1: Development of the forecast verification software and Graphical User Interface

Sub-Task 1.1 Creating a data base of point forecasts representing the selected locations and time of observations in the data base.

This task involves development data parsers for each forecast method to store the forecast data for each available time step (lead time) as point values at selected locations (observation stations) and points of time of observation. Due to the mountainous terrain of Nepal not all station sites, such as with highly varying topography, are suitable for forecast verification. To maximize consistency of results, a number of sites which have typically flat surroundings such as agriculture and airport sites shall be included.

The point forecasts are calculated/selected by using the model grid data to make the value representative of the station locations[2].

The time resolution of forecast data varies from 3h, 6h, 12h, and 24 h depending on the forecast model or method used and the predicted parameter. Some parameters (e.g. Maximum/Minimum daily temperature or daily mean temperature) will be stored only once for each day, whereas for most parameters, NWP models provide at least 3 hourly data for the first 3-5 days.

The forecast-methods, number and type of stations and the forecast lengths to be typically included are listed in Table 1:

Table 1. Forecast methods, points of verification and lead times to be verified

Forecast Model/Method	Number of observation station locations	Forecast period (lead time) & time steps
Global Forecast System (GFS)	29 agrometeorological stations and 11 airport weather stations	1-10 days with 3h time steps 4 runs/day (0.1°x0.1° horizontal resolution)
European Centre for Medium Forecast (ECMWF) (if available)		1-10 days (3-6h time steps)
Weather Research and Forecast (WRF) Model		6h – 72 h (3h time steps)
Tmax/Tmin issued by the Forecaster	29 agrometeorological stations and 11 airport weather stations	1-5 days; once daily
Precipitation amount issued by the forecaster		6h-72h (6h, 12h and 24h accumulation, from daily data
PoP issued by the forecaster	29 agrometeorological stations and 11 airport weather stations	6h-72h (6h, 12h and 24h accumulation, from daily data for preset intensities of precipitation (TBD)
MOS statistics (optional)	29 agrometeorological stations and 11 airport weather stations	Air temperature and precipitation as above

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[2]   *See e.g. User guide to ECMWF forecast products: pp. 10-15: Retrieving forecasts. Available at http://www.ecmwf.int/sites/default/files/User_Guide_V1.2_20151123.pdf*

Task 1.2 Developing program code to calculate standard verification scores for the forecast parameters.

The Consultant shall prepare, test and document program code to calculate the various scores according to standard algorithms available in the literature[3]. Table 2.

Table 2. Acronyms for the verification scores

Score	Acronyms
Hit Rate with different thresholds	HR
Mean Error	ME
Mean Absolute Error	MAE
Root Mean Squared Error	RMSE
SKILL over persistency	SKILL
Frequency Bias Index	FBI/BIAS
Proportion Correct	PC
Probability Of Detection	POD
False Alarm Rate	FAR
False Alarm Ratio	F
Hanssen-Kuippers Skill Score	KSS
Threat Score	TS
Equitable Threat Score	ETS
Heidtke Skill Score	HSS
Relative Operating Characteristic	ROC
Brier Score	BS
Brier Skill Score	BSS
Ranked Probability Score	RPS
Ranked Probability Skill Score	RPSS

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[3]   *See e.g.:*

-     *http://www.cawcr.gov.au/projects/verification/*

-     *http://www.ecmwf.int/sites/default/files/elibrary/2003/11401-recommendations-verification-local-weather-forecasts.pdf*

-     *http://www.wmo.int/pages/prog/arep/wwrp/new/Forecast_Verification.html*

Score	Acronyms
ROC area	ROC_A

A tentative[4] list of scores to be used for each variable are listed in Table 3.

Table 3. Parameters to be verified and tentative list of the scores to be implemented (marked with x).

Variable/ Score	HR	ME	MAE	RMSE	SKILL	POD	FAR	PC	F	HSS	KSS	TS	ETS	BS	BSS	ROC	ROCA	RPS	RPSS
Air temperature at 2 m height	x	x	x	x	x	x	x												
Daily Max & Min Air temperature	x	x	x	x	x														
Precipitation amount in: 1h, 3h, 6h, 12, 24h		x	x	x	x														
Probability of precipitation														x	x	x	x	x	x
Total cloudiness (threshold)	x					x	x	x	x	x	x	x	x						
Wind speed (threshold)	x					x	x	x	x	x	x	x	x						
Wind gust (threshold)	x					x	x	x											

SubTask 1.3 Constructing the Graphical User Interface

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[4] *The list will be finalized at the time of contract signing*

In this Sub-Task the Consultant shall design and implement a browser based Graphical User Interface to be used on the DHM Intranet by which the user can select, calculate, view and extract verification results. The GUI shall enable the user to provide free selection of parameters, available scores, selection of time periods, averaging times etc. The different view options shall include tables, 2D graphs and maps showing the selected station points colored according to the value of the selected score.

The different view options for graphics and tables will be discussed during the contract signing and fine-tuned during the course of work. The data in tables should be extractable as a csv file to be further processed in other programs.

As a default, the GUI shall display a set of latest verification results for each forecast method for pre-selected key variables and their scores (e.g. for 2m temperature, Tmax, Tmin and daily precipitation at selected verification locations), show comparison of verification scores between different forecast methods, show a time series for a selected set of scores etc.

The consultant will prepare documentation and user guide of the system for operation and maintenance.

Deliverables of Task 1.

- Program code for parsing the forecasts, calculating the scores and constructing the GUI

- GUI with a default display to show key results of verification and drop down widgets (or similar tool) for free selection of parameters, available scores, selection of time periods, averaging times etc.

- Readymade set of Graphics and tables representing freely selected time periods and locations to show the key verification results (see examples in Appendix 1:

  - Forecasts (user specified lead times and time periods) compared against Observations (Scatter plots, Time series plots)

  - Verification scores compared between forecast methods (for different lead times and time periods)

  - ROC curve for probability forecasts

  - Reliability Diagram

  - Histograms and box plots as applicable

- Documentation of the program code

- Instructions to use the GUI

- Instructions for maintenance of the system.

Task 2: Training for DHM selected DHM staff to use, maintain and develop the system.

a. Training workshop for users of the system (forecast verification in general and the framework, the meaning of different scores, use of verification information to increase the quality and streamline the forecast process)

b. Training workshop for IT personnel and developers of the system (maintenance training and code level training for developers to build up new potential verification scores and graphics).

Deliverables of Task 2

- Reports on the objectives, contents and learning outcomes of training workshops, evaluation of the workshops based on feedback from participants (feedback template will be provided)

- Hard copies and an electronic copy of the training material

- Video recordings on the lectures

- Summary of training workshop evaluation feedback.

6. Guidance, Supervision and Quality Assurance

Main activities and deliverables including software, designs, output visualizations and setup will be subjected to supervision and quality assurance by client at various stages. On technical matters, the Consultant shall work in close consultation with DHM staff, PMU and SI. The Consultant can get technical support and guidance from SI as and when required during the period of implementation.

7. Client's Commitments (Inputs)

Staff of DHM/PMU will facilitate basic administrative support to the Consultant.

At the request of the Consultant, DHM will provide the following documents.

1. Information and data related to the forecast verification system setup (forecast data sources and interfaces, web output design etc.).

2. Office space at the DHM facility will be provided

3. List of present customers/stakeholders and forecast products including contact information to carry out the forecast utility survey.

4. Administrative, legal and regulatory documents in support of activities.

5. Project Appraisal Document (PAD), reports of missions and other relevant publications related to this consulting service.

6. Any other documents relevant to support the work of the Consultant

8. Obligation of the Consultant

The Consultant is expected to be fully self-sufficient in terms of accommodation, transport, office stationaries and personal computing equipment.

The consultant shall provide all software code, software documentation and associated scripts as well as all training material (lecture material, maintenance guide, mentioned in the annexure of this document. The Consultant shall execute the work in close consultation with System Integrator (SI), DHM's ICT and data management and forecasting office staff.

Upon handing over the system for operational use at DHM, the Consultant shall demonstrate that the forecast verification system is functioning well and complying with the objectives of the ToR.

Consultant shall provide on-line support, maintenance and repair services system malfunctions/errors in the program code or methods as necessary for one year after commissioning the system.

9. Consultant's qualification and Experience

9.1 Company requirements

The Consultant shall provide evidence as hard copy on:

a.   Company standing for at least five years in development/consulting of meteorological applications (≥ 3 refs[5]).

b.   Company's financial statement

c.   Proven <u>track record with statements of satisfaction of at least three (3)</u> similar application development <u>projects</u> <u>during the last ten (10) years</u>.

d.   The offered software and code shall be based upon open source code and shall be the latest release in past 5 years.

9.2 Staff requirements

The Consultant shall put forward a team consisting required professional experts best qualified to carry out the assignment. The client has assessed that x number of professional experts with A lead expert and two technical experts: one international and one national will be required.   The proposed experts must be fluent in both spoken and written English. However, the consultant shall make its own assessment on the requirement of professional

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[5]   *(≥ 3 refs) stands for: 'at least 3 relevant references'*

experts. Tentative staffing requirements are provided below:

Lead Expert on verification (1 person; 1 month)

The lead expert shall conduct the Consultant team to fulfill all its obligations, make sure the Tasks are executed on-time and with required quality, organize the meetings with stakeholders, conduct the compilation of reports and organize the trainings for DHM staff as specified.

Qualification

- Master's degree in Meteorology or equivalent degree in Physical sciences or Engineering. A PhD degree will be an advantage.

- Experience in organizing and holding training courses on forecast verification methodology or similar topics such as numerical weather prediction.

- 5 year of experience in planning, designing, establishing analyzing and visualizing forecast verification data and operating of a forecast verification system.

- Proven experience in successful design, development, and management of similar projects; at least three references.

International Verification expert (1 person; 5 months)

The experts shall:

- Design the operational architecture of the verification system, provide program code for data ingest and handling, test the code for calculation the verification results and construct and test the graphical user interface for users to display the verification results.

- Participate in training for DHM personnel to use, maintain, develop and operate the system.

- Work together with DHM experts to build the interfaces for data ingest and processing (observations, forecasts) and to use the GUI.

- Conduct regular consultation with concerned staff/expert of DHM and SI's and PMU with regard to the tasks specified in Scope of work

Qualifications:

- Master's degree in Information Technology/ Engineering, Meteorology or equivalent.

- Proven technical skills on ICT and programming.

- 10 years of experience in planning, designing, establishing, analyzing and visualizing forecast verification data or corresponding systems.

National verification analyst (1 person, 2 months)

The analyst will assist the international experts to analyze the verification scores, prepare verification reports and participate in providing training to DHM staff.

Qualifications:
- M.Sc. degree in Information Technology, Meteorology or equivalent discipline.
- Proven skills on numerical and statistical analysis and data visualization.
- 10 years of experience in analyzing and visualizing statistical data.

10. Time Schedule and Deliverables

S. No.	Description of deliverables	Timeline (from the date of contract signing)	Deliverables
1	Submission of inception report	1 month	Inception Report
2	Finalisation of specifications for software and Graphical User Interface		
3	Finalisation of training plan	2 months	1st Progress Report
4	Survey and design of the system		
5	Creation of forecast verification data base (data parsers to store point forecasts)	3 months	2nd Progress Report
6	Development and testing of the forecast verification software code	4 months	
7	Development and of Browser based Graphical User Interface for visualizing of the verification results (tables, graphics)	5 months	
8	Technical support to system maintenance and repair, software update, and user manual	6 months	Draft Final report
9	Organisation of the training workshop for maintenance, and technical aspects of the verification system		
10	Operational test by users and feedback		
11	Finalization of software and manual	7 months	
12	Organization of 2 forecast verification training workshops as specified		
13	Hand over forecast verification system to DHM	8 months	Final Report

11. Reporting

All reports shall be submitted with 3 hard copies along with e-copies. Reporting requirements shall be as follows:

Report No.1 - Inception Report (due in 1 month from contract signing)

The Consultant shall submit an Inception Report within one month from the day of contract agreement. The report will be based on elaborated discussions with DHM, PMU and SI. The Consultant shall review and verify the content of the tasks, and system software requirements and specifications. Specifically, the Consultant shall review the ToR to identify gaps and make specifications of goods and services necessary for filling task and requirement gaps in development of forecast verification system. The Consultant will also elaborate on: (i) additional tasks and specification of the system requirements with specifications, (ii) work and staffing plans, and (iii) reporting modalities. The report must also clearly specify all risks and issues, which may negatively affect project deadlines and effective execution of project activities (See Task 1 to Task 3 of Scope of work)

Report No.2 – 1st Progress report (due in 4 months from contract signing)

The Consultant will submit the 1st progress report within 4 months from the day of contract agreement, which will cover the details of deliverables, described in SN 1-4 of the Table under section 10. The report will also cover planned work for the next reporting period.

Report No.3 –2nd Progress Report (due in 5 months from contract signing)

The Consultant will submit 2nd Term progress report within 5 months from the day of contract agreement. It will include the forecast verification system set up with details of deliverables up to SN 7 of the Table under Section 10, i.e., accomplishment of **Task 1 and 2** of Scope of work. The report will also cover planned work for the remaining period.

Report No. 4- Draft Final Report (due in 7 months from contract signing)

Draft Final Report including Report on the entire tasks and obligations completed by the firm/service provider within 7 months and up to SN 12 from the day of contract agreement. It will also include training manual and training activities as specified in **Task 3** of Scope of work**.**

Report No. 5 - Final Report (due in 10 months from contract signing)

The report must provide a concise description of the Forecast verification system developed with list of completed results. The details system and Standard Operational Procedures (SOPs) in the form of a 'User Manual' shall be attached in Appendices.

12. Payment

- 10 percent on signing of contract as advance against a bank guarantee.
- 10 percent after submission and approval of Inception Report,
- 30 percent after approval of 1st Progress Report, ,

- 30 percent after submission and approval of 2nd Progress Report on well-functioning system,
- 20 percent within 4 months after confirming the well-functioning of the system and acceptance of the acceptance of Final report.

13. **Duration of service**

8 months

14. **Selection procedure and form of contract**

The selection will follow the Guidelines: Selection and Employment of Consultants under IBRD Loans and IDA Credits and Grants by World Bank Borrowers using the selection based on consultant qualification (CQS).

Appendix 1. Examples of Graphs and Tables to appear on the Graphical User Interface.

Example 1: Comparison of different versions of the ECMWF model based forecasts (lead time 24h) against observation(s).
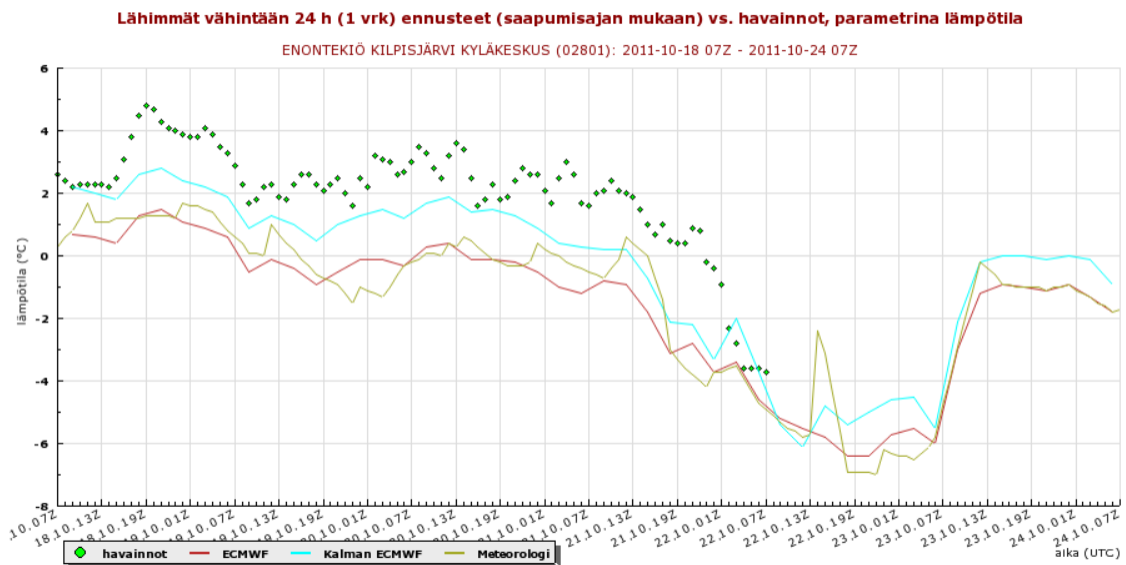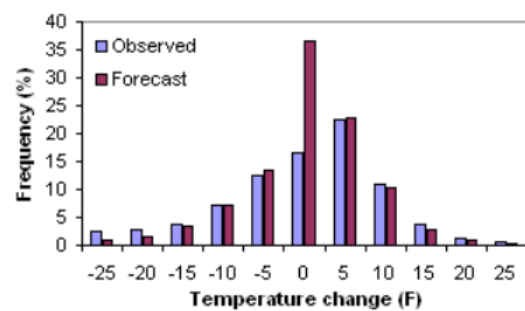

Legend: Green dots: observations; Red line: EMWF model forecast, Blue line: ECMF modified by Kalman filter method; Brown line: ECMWF modified by meteorologist.
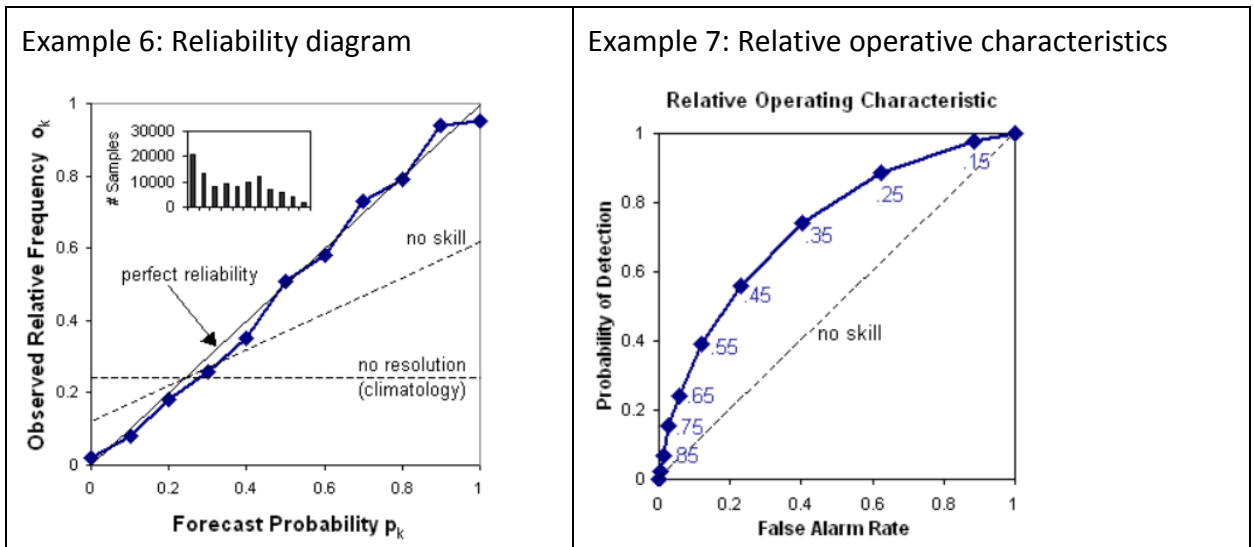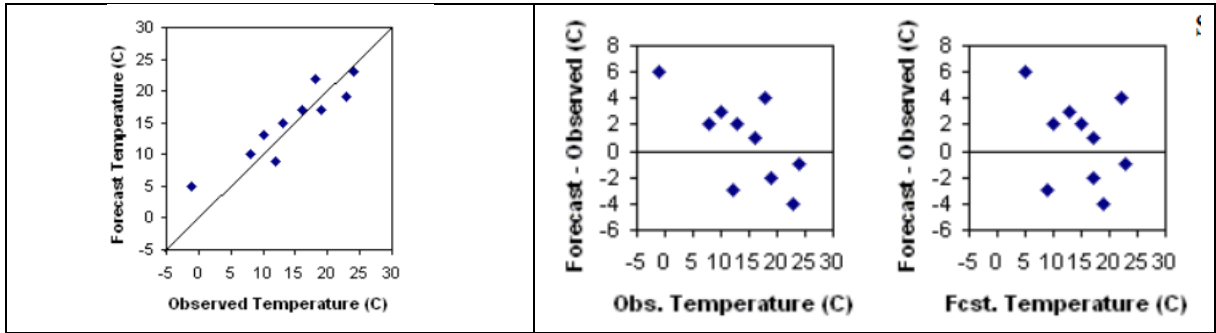
| Example 2: Box plot, comparison of distributions	Example 3: Histogram; plot of frequency of forecast(s) and observations against selected categories of the forecast parameter.
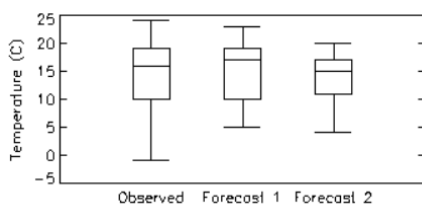
Example 4: Scatter plots

Example 6: Reliability diagram	Example 7: Relative operative characteristics

Example 8. Plot of daily 12h precipitation forecasts (HIRLAM model; red dots) against observations for a three month period.
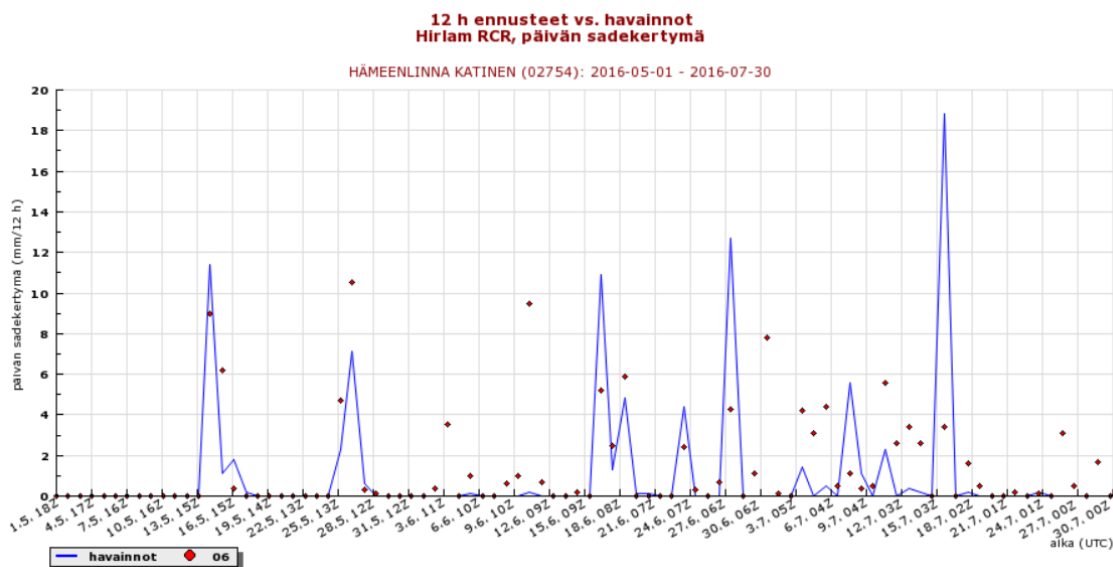
Example 9: Running average of Hit Rate (HR) for air temperature (2m height) forecasts averaged over the inland stations. Legend Red line 24h, Blue line 2-5 day forecasts. The horizontal dashed line represents the target set for year 2016.