

On admission to the examination room, you should acquaint yourself with the instructions below. You must listen carefully to all instructions given by the invigilators. You may read the question paper, but must not write anything until the invigilator informs you that you may start the examination.

You will be given five minutes at the end of the examination to complete the front of any answer books used.

DO NOT REMOVE THIS QUESTION PAPER FROM THE EXAM ROOM.

January 2015

MTMA39 / 2014/15 A001

Answer Book
Data Sheet
Additional figure for question 2
Any bilingual English language dictionary permitted
Any non-programmable calculator is permitted

UNIVERSITY OF READING

Operational Forecasting Systems and Applications (MTMA39)

Two hours

Answer **ANY TWO** questions

The marks for the individual components of each question are given in [] brackets. The total mark for the paper is 100.

- 1.(a) (i) List a set of equations that, if solved together, form the core *dynamics* of a Numerical Weather Prediction (NWP) model. You do not need to write the equations in algebraic form – simply list their names and give a very brief description of their functions. [14 marks]
- (ii) A set of dynamical equations in an NWP model contains 3 terms which are not explicitly defined in terms of variables on the model grid, and hence the system of equations is not fully closed. In general terms, what do these 3 terms represent? [6 marks]
- (iii) What is the method used to quantify these 3 terms in an NWP model? Describe briefly how this method works in general terms. [8 marks]
- (iv) List 4 physical processes which would need to be treated by this method in a global NWP model with a horizontal grid-spacing of 20km. [4 marks]
- (b) Most major operational weather forecasting centres run more than one numerical model to produce their forecasts. Explain how a forecasting centre might take account of the following list of constraints when designing a suite of NWP models.
- Customer requirements
 - Numerical considerations
 - Available computing power
- [12 marks]
- (c) One use of the output from NWP models is as input to another forecast model. List 2 types of model which are driven partly or wholly by output from an NWP system, and include the meteorological variables which are used to drive these models. [6 marks]

- 2.(a) (i) Write a short description of the purpose of data assimilation. You do not need to describe in detail any specific method of data assimilation but your answer should include a brief discussion of what data assimilation is used for, and the elements which are needed to perform an operational data assimilation scheme.

[6 marks]

- (ii) Describe in detail how the process of *4D variational data assimilation* (4D-VAR) works to produce the best possible representation of the initial state of the atmosphere for a numerical weather forecast.

Your answer should include a brief description of all the steps in the 4D-VAR process and a consideration of how these steps lead to the best possible specification of the initial conditions. You should also state the elements that 4D-VAR is attempting to minimize. You may wish to use diagrams to illustrate your answer.

[25 marks]

- (b) (i) Uncertainty in the initial conditions of a numerical weather forecast is the main source of error in operational short-to-medium range forecasts. Ensemble methods are used as one way of addressing this issue. List 3 potential benefits of using ensemble forecasts over single deterministic numerical forecasts.

[6 marks]

- (ii) Describe the singular vector method of calculating perturbations to the initial conditions of the ensemble forecasts used at ECMWF. Your answer should include a brief description of how the perturbations are calculated, how many perturbations are calculated and how they are combined in order to generate the 51 member operational ensemble at ECMWF.

[9 marks]

(iii) Figure 1 on the additional sheet provided with the exam paper shows the box-and-whisker symbols from an EPS Meteogram from the ECMWF forecast system. Explain the meaning of the “box-and-whisker” symbols on the figure.

You may write your explanation on the figure and hand in the figure with your answer book.

[4 marks]

3.(a) A commonly used tool in verifying probability forecasts is a *reliability diagram*, where the observed frequency of a particular event is plotted against the forecast probability of the event occurring.

(i) Sketch one reliability diagram for a set of forecasts which are *under-confident* and one for a set of forecasts which are *over-confident*, and, with reference to your sketches, explain briefly what is meant by these 2 terms.

[8 marks]

(ii) Using your sketches, indicate how this type of diagram can be used to determine the numerical value of the *reliability* of a set of probability forecasts, where numerically the reliability is given by

$$REL = \frac{1}{N} \sum_{i=1}^I n_i (f_i - o_i)^2$$

N = total number of forecasts

I = number of forecast probability bins

n_i = number of forecasts in bin i

f_i = the forecast probability of bin i

o_i = the observed frequency of event when forecast with probability f_i

[4 marks]

(iii) Explain in words what is meant by the *resolution* of a set of probability forecasts, and use a sketch of a reliability diagram to indicate how the resolution can be indicated on such a diagram.

[8 marks]

(iv) Reliability and resolution can be combined with one other variable to give the Brier Score for a particular set of probability forecasts. What is this third element of the Brier Score and how is it calculated numerically?

[3 marks]

- (b) (i) What is the generally accepted limit of deterministic prediction for numerical weather forecasts, and what is the main factor in determining this limit?

[4 marks]

(ii) Despite the deterministic limit on weather forecasting, several forecasting centres run numerical predictions on the monthly and seasonal timescales. List 2 sources of potential predictability for forecasts at these longer time ranges which can be exploited in NWP forecasts at these longer time ranges. For each one discuss briefly how an NWP model designed for short-to-medium range weather forecasts might be adapted to take account of these sources of predictability.

[6 marks]

- (c) (i) Some forecasts at the seasonal time-range are produced using empirical forecast techniques. Describe how such methods work. Your answer should include a discussion of the concept of *teleconnections*.

[13 marks]

(ii) List 2 advantages and 2 disadvantages of empirical forecast techniques.

[4 marks]

[End of Question paper]