UNIVERSITY OF ESWATINI

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF PHYSICS

MAIN EXAMINATION: 2021

TITLE OF THE PAPER: NUMERICAL WEATHR PREDICTIONS

COURSE NUMBER : PHY636

TIME ALLOWED : 3 HOURS

INSTRUCTIONS:
THE ARE TWO SECTIONS IN THIS PAPER:

- **SECTION A** IS A WRITTEN PART. ANSWER THIS SECTION ON THE ANSWER BOOK. IT CARRIES A TOTAL OF **60** MARKS.
- **SECTION B** IS A PRACTICAL PART FOR WHICH YOU WILL WORK ON A PC AND SUBMIT THE PRINTED OUTPUT. IT CARRIES A TOTAL OF **40** MARKS.
- You may proceed to do Section B only after you have submitted your answer book for Section A

Answer **all** the questions from **section A** and **all** the questions from **section B**. Marks for different sections of each question are shown in the right hand margin.

THE PAPER HAS 4 PAGES, INCLUDING THIS PAGE.

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Section A

Question 1

(a) **(5 marks)** Describe scientific weather forecasting in a nutshell.

(b) **(3 marks)** What are the main factors leading to the substantial improvement operational Numerical Weather Prediction in the past two decades.

(c) **(4 points)** Define the following processes in numerical weather predictions:

(i) Data assimillation

(ii) Parameterization

(d) **(3 marks)** List three reasons for verifying model simulations in numerical weather predictions.

Question 2

Consider the following set of shallow water equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fv = -g\frac{\partial h}{\partial x}$$
$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + fu = -g\frac{\partial h}{\partial y}$$
$$\frac{\partial h}{\partial t} + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} = -h\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) \quad (1)$$

(a) **(6 marks)** State the significance of each equation and roles of each term.

(b) **(9 marks)** List three different types of meshes that utilized in NWP simulations. For each grid mesh state its advantages and disadvantages.

Question 3

(a) **(4 marks)** There are a number of NWP models used by different organization, all based on the primitive equations. How are these models different?

(b) **(5 marks)** State Lorenz's theorem about the predictability of the atmosphere. How did he derive it in 1963?

(c) **(6 marks)** Show mathematically that on average the best ensemble forecasts of an nonlinear event represented by the nonlinear function $f(t)$ does not result from the use of the best estimate of the initial conditions (ensemble mean). You may choose a hypothetical example of the nonlinear function to demonstrate this point.

Question 4

Consider the 1D SWE problem describe as

$$\frac{\partial u}{\partial t} = -g\frac{\partial \eta}{\partial x}$$

$$\frac{\partial \eta}{\partial t} = -H\frac{\partial u}{\partial x}$$

(a) **(10 marks)** Show that the iterative algorithm is the given as

$$u_i^{n+1} = u_i^n - g \cdot \mu(\eta_{i+1}^n - \eta_{i-1}^n)$$

and

$$\eta_i^{n+1} = \eta_i^n - H \cdot \mu(u_{i+1}^n - u_{i-1}^n)$$

(b) **(2 marks)** What is value of c?

(c) **(3 marks)** Your numerical weather prediction simulations blows up, what is the most likely cause for this modelling instability?

Section B

The answers to this question must include the computer code and output, in addition to any writing that might be needed.

Question 5

Consider the description of the wind in the atmosphere by the linear shalllow wave equations

$$\frac{\partial u}{\partial t} - fv = -g\frac{\partial \eta}{\partial x}$$

$$\frac{\partial v}{\partial t} + fu = -g\frac{\partial \eta}{\partial y}$$

$$\frac{\partial \eta}{\partial t} = -H\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)$$

(a) **(20 marks)**Write a program solving the equations with the forward-in-time and central-in-space difference scheme.

- Let$f = 0.3$, $H = 1$, $g = 9.8$, $\Delta x = 0.025$, and $\Delta t = 0.005$ such that the Courant number $c = \sqrt{gH}\Delta t/\Delta x < 1$.
- Set the initial conditions:

$$\eta(x, y, t = 0) = 0.5 + 0.5e^{-4((x-5)^2+(y-5)^2)}$$

  for $0 \leq x \leq 10$ and $0 \leq y \leq 10$.
- Let $u(x, y, t = 0) = v(x, y, t = 0) = 0$ to mimick a still wind initial condition and apply periodic boundary conditions. **You may refer to your previous SWE codes to solve this question.**

(b) **(20 marks)** Plot 2D snapshots of the wind velocity $\mathbf{V} = (u, v)$ and the pressure fluctuations η at $t = 0$, $t = 120$, and $t = 240 \cdot \Delta t$. Describe the tendency of the wind patterns at late times.