Frontier Informatics (0AL5437)

Graduate School of Science and Technology
Degree Programs in System and Information Engineering
English Class for 6 and 13 July 2022

Contents of the Lecture ：

Students will learn basics about 4 dimensional data analysis in meteorology. First, an introductory lecture about dynamical system for numerical weather forecasting will be lectured. The concept of chaos in numerical weather prediction is the first subject of the class. Observational error in the initial data grows exponentially. That is the chaos. Then, students will lean about data assimilation to obtain a good initial condition of the numerical model, including optimal interpolation, 3D variation method, 4D variation method, and Kalman filter. Among those the Kalman filter is the best assimilation method, which is known as one of machine learnings, and is the second subject of the class.

Time and Date： 12:15-15:00, 6 and 13 July, 2022 Spring C
Instructor： Hiroshi L. Tanaka, Professor （CCS-302, Tel: 853-6482）
Theme of Lecture： Meteorological data analysis using Kalman filter
Place： CCS WS room (with Zoom) and exercise using icho server
Text：R. Daley 1991: Atmospheric Data Analysis. Cambridge Univ. Press
F. Bouttier and P. Courtier 1999: Data assimilation concepts and methods. ECMWF Internal Report
E. Kalnay 2003: Atmospheric Modeling, Data Assimilation and Predictability. Cambridge Univ. Press
and a Handout by H. L. Tanaka: Data Assimilation

Schedule：

1. **Weather forecasting** Dynamical system
2. **Discovery of chaos** Future prediction、
3. **Exercise 1** Chaos model
4. **Data assimilation** Optimal interpolation
5. **Kalman filter** Machine learning
6. **Exercise 2** Kalman filter

Score： Attendance 0%, Report 100%

Lecture 1 :

Numerical Weather Prediction and the Problem of Chaos

○ Introduction :

There was an era called Physics Imperialism where people beleived that all of the events in the world is governed by a theory of cause and effect, so that all events should be predictable if the detail of the causality is found. Is it true? If so, all events are determine in advance. Such an Physics Imperialism came to the end by the discovery of Chaos in 1960s by a meteorologist Dr. Edward Lorenz of MIT in USA.

In meteorology, the deterministic long-term weather prediction was proven to be impossible theoretically by the finding of chaos contained in the nonlinearity of the continuous fluid mechanics. In this laboratory experiment, we review the consept of chaos and attmpt to understand why the long-range weather prediction is impossible by the chaos.

○ Definition of Chaos:

- Even for a deterministic system with an established causality, an initial error, if we admit it, would grow exponentially in the nonlinear dynamical system so that the long-term prediction becomes meaningless. Such a nature of deterministic system is called deterministic chaos.

○ Objective of the experiment is :

- To understand how the numerical weather prediction is produced, using an analogy of an easiest dynamical system of a pendulum.
- To understand why the long-term weather prediction is impossible due to the nature of chaos in the system.

○ Contents :

1. Description of the dynamical system
2. Description of numerical weather prediction
3. Chaos in Lorenz system
4. Calculation of chaotic system with calculator
5. Summary

○ Report 1 on Ogra and Lorentz Chaos system

○ Dynamical system :

◎ A system represented by the following form is called a dynamical system

$$\frac{dV}{dt} = f$$

where V is a variable as a function of time t under the force f. When the differentiation is approximated by a forward difference scheme,

$$\frac{V(t+\Delta t) - V(t)}{\Delta t} = f$$

then we can rewite the equation in a prediction form in which the causality is established:

$$V(t+\Delta t) = V(t) + f\Delta t$$

◎ Equation of motion is a typical dynamical system because:

$$F = ma \quad \Longrightarrow \quad a = \frac{F}{m} \quad \Longrightarrow \quad \frac{dV}{dt} = f$$

◎ Dynamical system of a pendulum: $V = (X, Y)$, g gravity, and l a length of the string:

$$\begin{aligned} \frac{dX}{dt} &= Y \\ \frac{dY}{dt} &= -\frac{g}{l}X \end{aligned}$$

◎ Dynamical system of Lorenz chaos: $V = (X, Y, Z)$ is a dynamical system in 3D space.

$$\begin{aligned} \frac{dX}{dt} &= -10X + 10Y \\ \frac{dY}{dt} &= 28X - Y - XZ \\ \frac{dZ}{dt} &= -\frac{3}{8}X + XY \end{aligned}$$

◎ The numerical weather forecasting is a typical dynamical system of dimension $N(\approx 10^9)$ for all meteorological variables $V = (X_1, ..., X_N)$ over the 3D grids on the globe.

$$\frac{dV}{dt} = f$$

◎ Dynamical system of Ogra chaos: $V(0)$=0.1

$$V(t+\Delta t) = \frac{21}{8}V(t) - \frac{28}{8}V(t)^3$$

○ Excercise : (ubuntu : icho)

Log into ubuntu (icho) by using VNC Viewer.
Copy a subdirectory named chaos form Tanaka's home

pwd : present working directory, /home/student-number

ls -la : list the directory,

cp /home/tanaka.hiroshi.fw/.cshrc . : copy C-shell setting

cp /home/tanaka.hiroshi.fw/.gmtdefaults4 . : copy GMT plotting

cp -r /home/tanaka.hiroshi.fw/chaos . : copy all directory

tcsh : tcshell activate

cd chaos : change directory to chaos

more 000readme : read me instructions

Chaos model

run ogra.f : run Ogra model, see output

csh ogra.sh : run Ogra model, see the plots

csh ogra1.sh : run Ogra model, see the plots i.c. 0.100001

csh chaos.sh : run Lorentz chaos model, see output NMAX=10000000

csh chaos1.sh : run the model and see the plot chaos1.data plot1.sh in: chaos1.data

csh chaos2.sh : run the model and see the plots chaos2.data plot2.sh out: chaos2.data

  plot1.sh in: chaos1.data

  plot2.sh in: chaos1.data chaos2.data (two lines)

Note: Initial data X=8.0 8.8 8.00008

END