2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Turbulence, waves and momentum transfer in geophysical fluids

Yoshi-Yuki Hayashi[1]
[1] Department of Planetology/Center for Planetary Science, Kobe University
shosuke@gfd-dennou.org

Early researches, which can be now categorized as geophysical fluid dynamics (GFD), appeared after the failure of Richardson's weather prediction experiment by hand [1] during the world war I. However, vigorous development of GFD begun in the 1950s [2], originating out of the need for "re-try" of numerical weather prediction as an application target of the von Neuman's electric computer project after the world war II. Those people involved, gathering mainly from the fields of applied mathematics, fluid dynamics and physics, realized that the heuristic approaches and knowledge prevailing in the fields of meteorology and oceanography of those days should be reconstructed into a general theoretical system by the use of more common languages of mathematics and physics before trying to pursue realization of numerical weather prediction [3, 4]. They aspired for not only development of fundamental methods for numerical integration but accumulation of understandings of the physical structures of the subjects to be computed especially by the computers of the early days. GFD thus emerged through the efforts of those people revealing the fluid mechanical structures which underlie the phenomena of the atmosphere and the oceans and abstracting characteristics of rotating and/or stratified fluids in general. Not only the motions in the atmosphere and the oceans of this planet, but those of the atmospheres of the various planets and the Sun, even the fluid motions of planetary interiors have been tried to be recognized under the same framework. They found, for instance, fluid motions in a tea cup have some common characteristics with those of tropical cyclones.

There have been a number of important outcomes, now becoming basic concepts or frameworks to understand various phenomena in the atmospheres, the oceans and the planetary interiors and to construct numerical simulation models of them. Those concepts include two dimensional turbulence and energy upcascade, potential vorticity and its conservation, wave properties in rotating and/or stratified fluids, pseude (angular) momentum associated with a wavepacket, wave-mean flow interaction, formation of jets, stability of shear flow, and so on.

Shear instability has been one of the fundamental topic in GFD, since it has been recognized as the key issue in disturbance meteorology. However, the physical structure of shear instability had not been well understood until 1980's [5], although the mathematical procedure of linear stability analysis was developed in the early days; westerly shear flow was found to be unstable by Charney in 1947 [6]. For a given profile of shear flow, the mathematical procedure simply answers its stability by consulting the imaginary part of the frequency of disturbance; it does not tell why the flow is stable of unstable. We had to pile up understandings of momentum associated with disturbances to obtain the mechanistic picture of shear instability. The development of concepts was advanced during 1960's - 1970's when the stratospheric circulation was clarified and people realized that the momentum transfer associated with wave propagation plays a fundamental role in the general circulation of the atmosphere. Redistribution of momentum in a given circumstance is predicted by understanding generation of waves and their propagation characteristics. Instability emerges when two types of disturbances which have positive and negative momentum, respectively, can coexist and interact.

The real geophysical fluids are mixture or jigsaw of wave and turbulence [7]. People have also recognized, through the studies on the stratospheric circulation, that conservation of potential vorticity plays a central role in the planetary scale phenomena. It forms the basis for the existence of Rossby waves and their propagation. Formation of jets are controlled by generation and dissipation of those waves, and end up with mixing of potential vorticity.

The equator is a singular point of dynamics, and there are special waves trapped around the equator [8]. Although they were understood in the middle of last century [8], their roles in forming equatorial jets are being clarified in recent years through considering exoplanet atmosphere [9].

References

[1] Richardson, L. F., 1922: Weather Prediction by Numerical Process. Cambridge University Press, 236pp.
[2] Cushman-Roisin,B.,1994: Introduction to Geo-physical Fluid Dynamics, Prentice-Hall, 320pp.
[3] Veronis, G., 1981: A theoretical model of Henry Stommel. in Evolution of Physical Oceanography, B. A. Warren and C. Wunsch, Eds., MITpress 623pp, xix-xxiii.
[4] Smagorjnsky, J., 1983: The Beginnings of numerical weather prediction and general circulation modeling: early recollections. Adv. Geophys., 25, 3-37.
[5] Lindzen, R. S., 1988: Instability of plane parallel shear flow (toward a mechanistic picture of how it works). PAGEOPH, 126, 103-121.
[6] Charney, J. G., 1947: The dynamics of long waves in a baroclinic westerly current. J. Meteor., 4, 136–162.
[7] McIntyre, M. E., 2008: Potential-vorticity inversion and the wave-turbulence jigsaw: some recent clarifications. Adv. Geosci., 15, 47-56.
[8] Matsuno, T., 1966: Quasi-Geostrophic Motions in the Equatorial Area. J. Metor. Soc. Japan, 44, 25-43.
[9] Showman, A. P. and L. M. Polvani, 2011: Equatorial superrotation on tidally locked exoplanets. ApJ., 738:71, 24pp.