RESEARCH PROJECT PROPOSAL

Name of Candidate: Tianxiang Gao

Date of Admission to this programme: November 1, 2017

Full time mode

1. Project Title:

Sinuosity in Geophysical Flows and Its Dynamical Role

2. Project Objectives:

First of all, define and obtain the sinuosity of different regions e.g. Kuroshio Extension, Gulf Stream and its variability with observation data (AVISO adt, for example) and simulation data. At the same time, compare the difference in result between two types of data. Additionally, introduce differential geometry into geophysical fluid dynamics to establish a connection between the geometric pattern of ocean system and its dynamics (control equations).

3. Scope and Background of Research:

Sinuosity, i.e. the length of the current along its course between two points divided by the short-est length between the same points, which is examined in river formation by geomorphologists, is related to the information content and symmetry of the system. Besides, many conservative dynamical systems in mathematical physics describe geodesic flows on appropriate Lie groups. Hence, there is a clear relation between the (differential) geometry and the dynamical system.

In addition, though it is difficult to understand nonlinearity and chaos, the machine learning, or neuro-networks present an empirical approach to a system as a supplement to theoretical analysis. Long short-term memory method is well-suited to classify, process and predict time series given time lags of unknown size and duration between important events. It can be used as a forecast instrument for sinuosity, deepening the understanding of ocean dynamic process, in turn we could describe the behavior of air-sea system better.

4. Research Methodology:

Firstly, this project requires a fine technique or algorithm to extract dimensionless sinuosity (take average width as 1) from absolute dynamic topography. The major problem is to get average width of a current and the axis when the flow swings violently just as Antarctic Circumpolar Current region. Secondly, apply some empirical analysis to examine the dynamic behavior with the help of machine learning. For instance, use cluster method to divide time into different modes and its robustness. And implement information flow analysis to check if the information content follows Rossby Wave propagation direction. Thirdly, apply topological fluid dynamics and nonlinear dynamics to the sinuosity time series and propose a plausible mechanism. Last, synthesize all result above, forecasting the dynamics region like Kuroshio Extension.

5. **Project Significance and Value:**

   It goes without saying that ocean plays a significant role in global climate. Regions as Kuroshio Extension have huge impact on climate through intensive air-sea interaction. Furthermore, the dynamics of those regions determine the upper ocean productivity even fishery via mesoscale physics-biology interaction. Apart from that, unveil the vague dynamic process of ocean will help us understand climate variability (e.g. ENSO). In conclusion, the introduction of differential geometry approach into physical oceanography may start a bright new era.

6. **Details of Any External Collaboration:**

   Generally, this project is highly theoretical, however, it can help a lot if the high resolution data is implemented to obtain sinuosity and other dynamical properties. Moreover, the collaboration with experts with background of mathematical physics, especially of topological fluid dynamics is like to be a huge benefit. Last but not least, a decent compute platform (better with GPU Parallel computing feature) is needed for machine learning.

7. **Project Schedule**

   Aug, 2018 - Aug, 2018 Test and modification of topic focus (peers, supervisors and etc)
   Sep, 2018 - Dec, 2018 Establishment of bibliography, Library Research
   Jan, 2019 - Mar, 2019 Data collection and preprocessing
   Apr, 2019 - Jun, 2019 Calculation and analysis
   Jul, 2019 - Sep, 2019 Theoretical modeling
   Oct, 2019 - Dec, 2019 Paper drafting and seeking feedback
   Jan, 2020 - Apr, 2020 Revise paper and conduct further research if needed

8. **Bibliography**

   1. Arnold, V. I. (1966). Sur la géométrie différentielle des groupes de Lie de dimension infinie et ses applicationsa l' hydrodynamique des fluides parfaits. Ann. Inst. Fourier, 16(1), 319-361.
   2. Arnold, V. I., & Khesin, B. A. (1999). Topological methods in hydrodynamics (Vol. 125). Springer Science & Business Media.
   3. Cheney, R. E., & Richardson, P. L. (1976, February). Observed decay of a cyclonic Gulf Stream ring. In Deep Sea Research and Oceanographic Abstracts (Vol. 23, No. 2, pp. 143-155). Elsevier.
   4. Yuan, G., Nakano, I., Fujimori, H., Nakamura, T., Kamoshida, T., & Kaya, A. (1999). Tomographic measurements of the Kuroshio Extension meander and its associated eddies. Geophysical research letters, 26(1), 79-82.
   5. Hansen, D. V. (1970, June). Gulf stream meanders between Cape Hatteras and the Grand Banks. In Deep Sea Research and Oceanographic Abstracts (Vol. 17, No. 3, pp. 495-511). Elsevier.
   6. Ikeda, S., Parker, G., & Sawai, K. (1981). Bend theory of river meanders. Part 1. Linear development. Journal of Fluid Mechanics, 112, 363-377.
   7. Kelly, K. A., Small, R. J., Samelson, R. M., Qiu, B., Joyce, T. M., Kwon, Y. O., & Cronin, M. F. (2010). Western boundary currents and frontal air–sea interaction: Gulf Stream and Kuroshio Extension. Journal of Climate, 23(21), 5644-5667.
   8. Khesin, B., & Arnold, V. I. (2005). Topological fluid dynamics. Notices AMS, 52(1), 9-19.
   9. McGillicuddy Jr, D. J. (2016). Mechanisms of physical-biological-biogeochemical interaction at the oceanic mesoscale.
   10. Mizuno, K., & White, W. B. (1983). Annual and interannual variability in the Kuroshio current system. Journal of physical oceanography, 13(10), 1847-1867.
   11. Stølum, H. (1996). River Meandering as a Self-Organization Process. Science, 271(5256),

1710-1713.

12. Olson, D. B., & Backus, R. H. (1985). The concentrating of organisms at fronts: a cold-water fish and a warm-core Gulf Stream ring. Journal of Marine Research, 43(1), 113-137.

13. Parker, G., Sawai, K., & Ikeda, S. (1982). Bend theory of river meanders. Part 2. Nonlinear deformation of finite-amplitude bends. Journal of Fluid Mechanics, 115, 303-314.

14. Parker, G., & Ikeda, S. (1989). River meandering.

15. Pierini, S. (2014). Kuroshio Extension bimodality and the North Pacific Oscillation: A case of intrinsic variability paced by external forcing. Journal of Climate, 27(1), 448-454.

16. Qiu, B., Chen, S., Schneider, N., & Taguchi, B. (2014). A coupled decadal prediction of the dynamic state of the Kuroshio Extension system. Journal of Climate, 27(4), 1751-1764.

17. Qiu, B., & Chen, S. (2005). Variability of the Kuroshio Extension jet, recirculation gyre, and mesoscale eddies on decadal time scales. Journal of Physical Oceanography, 35(11), 2090-2103.

18. Qiu, B. (2003). Kuroshio Extension variability and forcing of the Pacific decadal oscillations: Responses and potential feedback. Journal of Physical Oceanography, 33(12), 2465-2482.

19. Qiu, B. (2002). The Kuroshio Extension system: Its large-scale variability and role in the midlatitude ocean-atmosphere interaction. Journal of Oceanography, 58(1), 57-75.

20. Richardson, P. L. (1980). Gulf Stream ring trajectories. Journal of physical oceanography, 10(1), 90-104.

21. San Liang, X. (2016). Information flow and causality as rigorous notions ab initio. Physical Review E, 94(5), 052201.

22. San Liang, X. (2015). Normalizing the causality between time series. Physical Review E, 92(2), 022126.

23. San Liang, X. (2008). Information flow within stochastic dynamical systems. Physical Review E, 78(3), 031113.

24. Spall, M. A., & Robinson, A. R. (1990). Regional primitive equation studies of the Gulf Stream meander and ring formation region. Journal of Physical Oceanography, 20(7), 985-1016.

25. Tracey, K. L., & Watts, D. R. (1986). On Gulf stream meander characteristics near Cape Hatteras. Journal of Geophysical Research: Oceans, 91(C6), 7587-7602.