MPO 712 - LARGE-SCALE OCEAN CIRCULATION

W. JOHNS - SPRING 2018

The course will cover basic theories of the wind driven and thermohaline circulation of the oceans. Numerical models of ocean circulation and relevant observations will also be reviewed. The course will be organized around a series of seminal papers which will form the basis of classroom lectures and discussion. Grading will be based on homework assignments to follow up the reading, a mid-term or class project, and a final exam, with the following weights:

| | |
|---|---|
| Homework | 30% |
| Mid-term or Project | 30% |
| Final | 40% |

**Reference Books**:

Pedlosky, J., *Ocean Circulation Theory*, Springer-Verlag, N.Y., 1998

Pedlosky, J., *Geophysical Fluid Dynamics,* Springer-Verlag, N.Y., 1979

Gill, A.E., *Atmosphere-Ocean Dynamics,* Academic Press, N.Y., 1982.

Stommel, H., *The Gulf Stream*, Cambridge University Press, London, 1965.

*General Circulation of the Ocean*, H. Abarbanel and W. Young, Eds., 1987

Schmitz, W., *On the World Ocean Circulation*, Vols. I and II, WHOI Tech. Reports, 96-03, and 96-08, 1996

*Ocean Circulation and Climate (WOCE Book),* G. Siedler, J. Church, and J. Gould, Eds., 2001.

Samelson, R. M., *The Theory of Large-Scale Ocean Circulation*, Cambridge University Press, N.Y., 2011.

Huang, R. X., *Ocean Circulation*, Cambridge University Press, N.Y., 2010.

**Reference Papers and visual materials**:

Reading from reference papers for each section of the course will be assigned in class. Copies of these papers, as well as visual materials shown in class, can be accessed from the MPO712 "Blackboard" on CaneLink, or from my faculty homepage
http://www.rsmas.miami.edu/users/bjohns/MPO612/MPO612_homepage.html

# MPO 712 - LARGE SCALE OCEAN CIRCULATION

## SYLLABUS

1. Wind Stress Fields; Ekman and Sverdrup Transports
   - Review of Sverdrup Theory
   - Global Wind Stress Fields
   - Global Gyre Circulation and Major Current Systems

2. Linear Wind-driven Models of Ocean Circulation
   - Stommel's Model (Bottom friction)
   - Munk's Model (Lateral friction)

3. Non-linear Wind Driven Models of Ocean Circulation
   - Free Inertial Circulation on Beta-plane (Fofonoff's Model)
   - Formation of Inertial Western Boundary Currents (Charney Model)
   - Numerical Models of mixed Frictional-Inertial Gyre Closure
   - Inertial Recirculations and Western Boundary Current Extensions

4. Western Boundary Currents
   - Observations of Western Boundary Currents and Non-linear Features
   - Comparison with Models

5. Adjustment to Variable Wind Forcing
   - Rossby Waves – Dynamical Modes in a Continuously Stratified Fluid
   - Excitement of Vertical Rossby Wave Modes by Wind Stress
   - The Gyre "Spin-up" Problem; Analytical and Numerical Models
   - Topographic Modifications of Sverdrup Theory
   - Seasonal Variability at mid-Latitudes; Comparison with Observations

6. Equatorial Circulation
   - The Observed Equatorial Circulation
   - Forcing of the Mean Equatorial Circulation
   - Review of Equatorial Waves
   - The Equatorial "Spin-up" Problem
   - Comparison of Adjustment Time Scales at the Equator and mid-Latitudes
   - Seasonal Variability of the Global Equatorial Circulation

7. Thermocline Theories
   - Diffusive Theories; Vertical Advective-Diffusive Balance (Munk)
   - Advective Theories (the "Ventilated" Thermocline; LPS)
   - Estimates of Global Diffusivity; Observational Methods

8. Abyssal Circulation and the Global Thermohaline Cell; Ocean Heat Transport
    - Thermohaline Circulation and Deep Water Production
    - Theory of Abyssal Circulation (Stommel-Arons Theory)
    - Observations of the Deep Circulation
    - Deep Western Boundary Currents
    - Role of the Southern Ocean
    - The Upper-Ocean Return Flow ("Warm" and "Cold" Routes)
    - Interaction of the Thermohaline and Wind-Driven Circulation
    - Ocean Heat Transport (Observations and Models)

9. Mesoscale Eddies and Their Role in the Large-scale Circulation
    - Sources of Mesoscale Energy
    - Eddy-Mean Flow Interaction
    - Eddy-Driven Recirculations
    - Role of Eddy-Induced Transport in the Thermohaline Circulation

REFERENCE PAPERS


I. Wind Stress Field/Ekman & Sverdrup Transports

1. Sverdrup, H.V., 1947: Wind driven currents in a baroclinic ocean with application to the equatorial currents of the eastern Pacific. *Nat. Acad. Sci. Proc.*, **33**, 318-326.

2. Bunker, A.F., 1976: Computation of surface energy flux and annual air-sea interaction cycles of the North Atlantic Ocean. *Mon. Wea. Rev*., **104,** 1122-1129. (rest is "optional").

3. Leetmaa, A. and A.F. Bunker, 1978: Updated charts of the mean annual wind stress, convergences in the Ekman layers, and Sverdrup transports in the North Atlantic. *J. Mar. Res*., **36**(2), 311-319.

4. Hellerman, S. and M. Rosenstein, 1983: Normal monthly wind stress over the world ocean with error estimates. *J. Phys. Oceanogr*., **13**, 1093-1104.

5. Josey, S. A., E. C. Kent, and P. K. Taylor, 2002: Wind stress forcing of the ocean in the SOC climatology: Comparisons with the NCEP-NCAR, ECMWF, UWM/COADS, and Hellerman and Rosenstein Datasets. *J. Phys. Oceanogr*., **32**(7), 1993-2019.

6. Leetmaa, A., P. Niiler, and H. Stommel, 1977: Does the Sverdrup relation account for the mid-Atlantic circulation? *J. Mar Res*., **35**(1), 1-9.

II. Linear Wind-Driven Models of Ocean Circulation

1. Stommel, H., 1948: The western intensification of wind-driven ocean currents. Trans. Amer. Geophys. Union, 29, 202-206.

2. Munk, W., 1950: On the wind-driven ocean circulation. *J. Meteor*., **7,** 79-93.

III. Nonlinear Wind-Driven Models

1 Fofonoff, N.P., 1954: Steady flow in a frictionless homogeneous ocean. *J. Mar. Res.*, **13**, 254-262.

2. Charney, J., 1955: The Gulf Stream as an inertial boundary layer. Proc. Nat. Acad. Sci., 41, 731-740.

3. Bryan, K. 1963: A numerical investigation of a non-linear model of a wind-driven ocean. *J. Atmos. Sci.*, 210, 594-606.

IV. Western Boundary Currents

1. Hogg, N.G., and W.E. Johns, 1995: Western Boundary Currents. *Rev. of Geophys.*, *Suppl*. 1311-1334.

V. Adjustment to Forcing

3. Anderson, D. and A. Gill, 1975: Spin-up of a stratified ocean with application to upwelling. *Deep Sea Res*., 22, 583-596.

4. Anderson, D., K. Bryan, A. Gill and R. Pacanowski, 1979: The transient response of the North Atlantic: Some model studies. *J. Geophys. Res*., 84, 4795-4815.

5. Anderson, D.L.T., and R.A. Corry, 1985: Seasonal transport variations in the Florida Straits: A model study. *J. Phys. Oceanogr.*, 15, 773-786

VI. Equatorial Dynamics

1. Philander, S.G.H., and R.C. Pacanowski, 1980: The generation of equatorial currents. *J. Geophys. Res*., **85**, 1123-1136.

2. Knox, R.A. and D.L.T. Anderson, 1985: Recent Advances in the study of the low-latitude ocean circulation. *Prog. Oceanogr.*, 14, 259-317.

VII. Thermocline Theory

1. Munk, W.H., 1966: Abyssal Recipies. *Deep-Sea Res.,* **13,** 707-730.

2. Welander, P., 1959: An advective model of the ocean thermocline. *Tellus*, 11, 309-318.

3. Luyten, J.R., J. Pedlosky, and H. Stommel, 1983: The ventilated thermocline. *J. Phys.Oceanogr.,* **13,** 292-309.

4. Pedlosky, J., 1989: Thermocline theories, (in General Circulation of the Ocean, H.D.I. Abaranel and W.R. Young, ed.), Springer-Verlag, N.Y., pp. 55-101.

VIII. Global Thermohaline Circulation/Ocean Heat Transport

1. Stommel, H. and A.B. Arons, 1960a: On the abyssal circulation of the world ocean. I. Stationary planetary flow patterns on a sphere. *Deep-Sea Res*., **6**, 140-154.

2. Stommel, H. and A.B. Arons, 1960b: An idealized model of the circulation pattern and amplitude in ocean basins. *Deep-Sea Res.*, **6**, 217-233.

3. Gordon, A.L., 1986: Interocean Exchange of Thermocline Water. *J. Geophys. Res.,* **91(C4),** 5037-5046.

4. Rintoul, S.R., 1991: South Atlantic Interbasin Exchange. *J. Geophys. Res*., **96(C2)**, 2675-2692.

5. Hall, M.M. and H.L. Bryden, 1982: Direct estimates and mechanisms of ocean heat transport. *Deep-Sea Res*., **29,** 339-359.

6. Bryden, H.L., D.H.Roemmich and J.A. Church, 1991: Ocean heat transport across 24°N in the Pacific. *Deep-Sea Res.,* **38(3),** 297-324.

7. Kuhlbrodt, T., A. Griesel, M. Montoya, A. Levermann, M. Hofmann, and S. Rahmstorf (2007), On the driving processes of the Atlantic meridional overturning circulation, Rev. Geophys., 45, RG2001,doi:10.1029/2004RG000166.

IX. Mesoscale Eddies and Their Role in the Large-scale Circulation.

1. Haidvogel, D.B., and W.R. Holland, 1978: The Stability of Ocean Currents in Eddy-Resolving General Circulation Models. *J. Phys. Oceanogr.,* **8,** 393-413.

2. Holland, W.R., and P.□. Rhines, 1980: An Example of Eddy-Induced Ocean Circulation. *J. Phys. Oceanogr..,* **10**, 1010-1031.

X. Supplemental Reading


1. Longuet-Higgins, M.S., 1964: Planetary waves on a rotating sphere. *Proc. Roy. Soc.* A, 279, 446-473.

2. Longuet-Higgins, M.S., 1965: Planetary waves on a rotating sphere. II. *Proc. Roy. Soc.*, A, 284, 40-68.

3. Anderson, D.L.T., and R.A. Corry, 1985: Seasonal transport variations in the Florida Straits: A Model Study. *J. Phys. Oceanogr.*, 15, 773-786.

4. Moore, D.W., 1963: Rossby waves in oceanic circulations. *Deep-Sea Res.*, **10**, 735-748.

5. Veronis, G., 1966L: Wind-driven ocean circulation. Pt. II. Numerical solutions of the non-linear problem. *Deep-Sea Res.*, **13,** 31-55.

6. Veronis, G.T., 1969: On theoretical models of the thermocline circula- tion. *Deep-Sea Res.*, 16, Suppl., 301-323.

7. Schott, F., and H. Stommel, 1978: Beta spirals and absolute velocities in different oceans. *Deep-Sea Res.*, 25, 961-1010.

8. Rhines, P.B. and W.R. Young, 1982: Homogenization of potential vorticity in planetary gyres. *J. Fluid Mech.*, 122, 347-367.

9. Luyten, J.R., J. Pedlosky, and H. Stommel, 1983: The ventilated thermocline. *J. Phys. Oceanogr.*, 13, 292-309.

10. Huang, R.X., 1986: Solutions of the ideal fluid thermocline in continuous stratification. J. Phys. Oceanogr., 16, 39-59.

11. Roemmich, D., and T. McCallister, 1989: Large Scale Circulation of the North Pacific Ocean. Prog. Oceanogr., 22, 171-204.

12. Neelder, G.T., 1967: A model for thermohaline circulation in an ocean of finite depth. J. Mar. Res., 25, 329-342.

13. Welander, P., 1971: The Thermocline Problem. Phil. Trans. A., 270, 415-421.

14. Pedlosky, J. and W.R. Young, 1983: Ventilation, potential vorticity homogenization and the structure of the ocean circulation. J. Phys. Oceanogr., 13 (7), 2020-2037.

15. Warren, B.A., 1980: Deep Circulation of the World Ocean. Evolution of Physical Oceanography, 6-36.

16. Sarmiento, J.L., 1983: A simulation of bomb tritium entry into the Atlantic Ocean. J. Phys. Oceanogr., 13(7), 1924-1939.