LARGE-SCALE ATMOSPHERIC DYNAMICS
ATS704
Fall 2013

Course Description: Potential vorticity concepts; quasi-geostrophic and semi-geostrophic equations; Rossby waves; barotropic, and baroclinic instability; frontogenesis; Madden-Julian oscillation; tropical cyclones; wave-mean flow interaction; theory of available potential energy and available energy; geophysical turbulence.

Prerequisites: ATS602.

There is no required textbook. Reading material is from the journal literature listed below.

Student learning objectives: To obtain a research-level understanding of problems in large-scale geophysical fluid dynamics, especially those related to current research in weather prediction and climate modeling.

Course Syllabus

1. The Potential Vorticity Conservation Principle
   - 1.1 Ertel's Derivation of the PV Principle (Ertel 1942)
   - 1.2 Conservation and Impermeability Theorems for PV (Haynes and McIntyre 1987, 1990)
   - 1.3 Review of Potential Vorticity Concepts (Hoskins et al. 1985)
   - 1.4 Particle Relabeling Symmetry and Ertel's Theorem (Salmon 1982, 1998)

2. Midlatitude Dynamics
   - 2.1 Baroclinic Instability and the Theory of Extratropical Cyclones (Bretherton 1966a,b, Hoskins 1990)
   - 2.2 Surface and Upper Level Frontogenesis (Hoskins and Bretherton 1972, Fulton and Schubert 1991)
   - 2.3 Semigeostrophic Theory on the f-Plane (Hoskins 1975, Hoskins and Draghici 1977, Hoskins and West 1979, Davies, Schär and Wernli 1991, Schär and Wernli 1993)
   - 2.4 Semigeostrophic Theory on the β-Plane and Hemisphere (Magnusdottir and Schubert 1990, 1991)
   - 2.5 Primitive Equation Models in Isentropic Coordinates (Hsu and Arakawa 1990)
   - 2.6 Baroclinic Life Cycles (Thorncroft et al. 1993, Hartmann and Zuercher 1998)
   - 2.7 Storm Tracks (Hoskins and Hodges 2002, 2005)
   - 2.8 Perspectives on Blocking (Pelly and Hoskins 2003, Berrisford et al. 2007, Tyrlis and Hoskins 2008a, 2008b)
   - 2.9 Quasi-Geostrophic Theory on the Sphere (Mak 1991, Verkley 2009, Schubert et al. 2009)
   - 2.10 Two-Dimensional Turbulence and Predictability (Lee 1951, Fjortoft 1953, Lorenz 1963)

3. Stratospheric Dynamics
   - 3.1 The Overworld, Middleworld and Underworld (Hoskins 1991)
   - 3.2 Stratospheric-Tropospheric Exchange (Danielsen 1968, Holton et al. 1995)
   - 3.3 Breaking Rossby Waves in the Stratosphere (Juckes 1989, Waugh and Plumb 1994, Norton 1994)
   - 3.4 Vertical Propagation of Rossby Waves (Charney and Drazin 1961, Matsuno 1970)
   - 3.5 Sudden Stratospheric Warming (Matsuno 1971)
   - 3.6 Effective diffusivity as a diagnostic of atmospheric transport (Nakamura 1996, 2001, 2004, Haynes and Shuckburgh 2000a,b)

4. Tropical Dynamics

- 4.1 The Intertropical Convergence Zone and the Hadley Circulation in the Climatological Mean (Schneider and Lindzen 1977, Held and Hou 1980, Lindzen and Hou 1988, Philander et al. 1996)
- 4.2 The Intertropical Convergence Zone and the Hadley Circulation on Synoptic Time Scales (Hack et al. 1989, Hack and Schubert 1990, Schubert et al. 1991)
- 4.3 The Shallow Hadley Circulation (Zhang et al. 2004, 2008, Nolan et al. 2007, 2010, Gonzalez and Mora 2013)
- 4.4 The Moisture Field in the Tropics (Cau et al. 2007)
- 4.5 Barotropic-Baroclinic Instability and Easterly Waves (Thorncroft and Hoskins 1994a,b, Nieto Ferreira and Schubert 1997)
- 4.6 Laplace's Tidal Equations and Equatorial β-Plane Theory (Matsuno 1966, Longuet-Higgins 1968)
- 4.7 Longwave Theory and the Walker Circulation (Gill 1980, Heckley and Gill 1984, Gill and Phlips 1986, Phlips and Gill 1987)
- 4.8 The MJO (Madden and Julian 1994, Majda and Klein 2003, Schubert and Masarik 2006)
- 4.9 Improvement of the Longwave Approximation (Ripa 1994, Schubert et al. 2009)
- 4.10 Monsoons and the Dynamics of Deserts (Rodwell and Hoskins 1995, 1996)
- 4.11 Subtropical Anticyclones and Summer Monsoons (Rodwell and Hoskins 1995, 1996, 2001)
- 4.12 The Simplest Theory of Tropical Cyclones (Ooyama 1969)
- 4.13 Full Physics Tropical Cyclone Models (Yamasaki 1983)
- 4.14 A Thermodynamic and Dynamic Foundation for Modeling the Moist Atmosphere (Ooyama 1990, 2001)
- 4.15 The Potential Vorticity Principle for a Moist Atmosphere (Schubert et al. 2001)
- 4.16 PV Mixing in Hurricanes (Schubert et al. 1999, Montgomery et al. 2002, Hendricks and Schubert 2010)
- 4.17 Vortex Rossby Wave Theory (Montgomery and Kallenbach 1997)
- 4.18 Interaction of Tropical-Cyclone Scale Vortices (Lander and Holland 1993, Ritchie and Holland 1993, Holland and Dietachmayer 1993, Prieto et al. 2003)
- 4.19 Scale Interactions in the Tropics (Holland 1995, Simpson et al. 1997, Ritchie and Holland 1999)
- 4.20 MPI Theory (Emanuel 1988, Holland 1997, Persing and Montgomery 2003)
- 4.21 Hurricane Concentric Eyewalls, Eyewall Cycles, and Moats (Willoughby et al. 1982, Willoughby 1990, Kuo et al. 2004, Rozoff et al. 2005, Weiss 1991, Hua and Klein 1998, Abarca and Corbosiero 2011)
- 4.22 The Boundary Layer of a Hurricane (Eliassen 1971, Eliassen and Lystad 1977, Smith 1968, 1980, 2003, Montgomery et al. 2001, Smith and Montgomery 2008, Smith and Vogl 2008, Kepert 2001, 2010a, 2010b, Kepert and Wang 2001, Williams et al. 2013)

5. Hamiltonian Fluid Dynamics (Salmon 1998, Chapter 7)
   - 5.1 Variational Principles in Continuum Mechanics (Seliger and Whitham 1968)
   - 5.2 Practical Use of Hamilton's Principle to Derive Filtered Models (Salmon 1983)
   - 5.3 New Equations for Nearly Geostrophic Flow (Salmon 1985)
   - 5.4 Review of Hamiltonian Fluid Mechanics (Salmon 1988a)
   - 5.5 Semigeostrophic Theory as a Dirac-Bracket Projection (Salmon 1988b)
   - 5.6 Planetary Semigeostrophic Theory (Shutts 1989)
   - 5.7 Non-hydrostatic Filtered Model (Miller and White 1984, White 1989, Salmon and Smith 1994)
   - 5.8 Poisson-bracket approach to the construction of algorithms for the shallow-water equations (Salmon 2004, 2005, 2009)

6. Wave-Mean Flow Interaction
   - 6.1 The Eliassen-Palm Theorem (Eliassen and Palm 1961)
   - 6.2 The Non-Acceleration (Charney-Drazin) Theorem (Charney and Drazin 1961)

- 6.3 The Transformed Eulerian Mean (TEM) Formulation, the Eliassen-Palm (EP) Flux, and the Generalized Eliassen-Palm Relation and Charney-Drazin Theorem (Andrews and McIntyre 1976a,b, 1978a)
- 6.4 The Generalized Lagrangian Mean (GLM) Formulation of Wave-Mean Flow Interaction (Andrews and McIntyre 1978b,c)
- 6.5 Casimir Invariants and the Construction of Two General Wave-Activity Relations: Pseudomomentum and Pseudoenergy (Haynes 1988)
- 6.6 The EP Flux as a Diagnostic of Wave Propagation in the Meridional Plane (Edmon et al. 1980)
- 6.7 On the Interpretation of the EP Flux Divergence (Andrews 1983)
- 6.8 Isentropic Coordinate Version of the Charney-Drazin Theorem (Andrews 1983, Tung 1986)
- 6.9 Available Potential Energy as the Non-Kinetic Part of the Pseudoenergy (Holliday and McIntyre 1981, Andrews 1981, Shepherd 1993)
- 6.10 Review of Wave-Mean Flow Interaction (Grimshaw 1984)
- 6.11 The "Downward Control" Principle and Stratosphere-Troposphere Exchange (Haynes et al. 1991)
- 6.12 The Quasi-biennial Oscillation (Baldwin et al. 2001)
- 6.13 Summary of Applications to the Stratosphere (McIntyre 1992)
- 6.14 A formulation of a phase-independent wave-activity flux for stationary and migratory quasi-geostrophic eddies on a zonally varying basic flow (Takaya and Nakamura 2001)

7. Nonlinear Stability Theory
   - 7.1 Fundamental Theory (Arnol'd 1966, 1969)
   - 7.2 Review of the Method (Holm et al. 1985, Abarbanel et al. 1986)
   - 7.3 Fundamental Geophysical Theory (Andrews 1983, McIntyre and Shepherd 1987, Swaters 1986)
   - 7.4 Nonlinear Saturation Bounds (Shepherd 1988)
   - 7.5 Symplectic Approach (Shepherd 1993)
   - 7.6 Extremal States of Hamiltonian Dynamical Systems (Vallis, Carnevale and Young 1989, Shepherd 1990)

8. Theory of Available Potential Energy and Available Energy
   - 8.1 Lorenz's Theory (Lorenz 1955, 1960)
   - 8.2 Andrews' Theory (Andrews 1981, 2006)
   - 8.3 Shepherd's Approach (Shepherd 1993)
   - 8.4 Generalization to a Moist Atmosphere (Lorenz 1978, 1979, Randall and Wang 1992)

9. Turbulence
   - 9.1 Kolmogorov's Theory
   - 9.2 Two-dimensional Turbulence (Kraichnan 1967, Batchelor 1969)
   - 9.3 Geostrophic Turbulence (Sadourny 1985; Salmon 1998, Chapter 6 and references therein)
   - 9.4 Effects of the Earth's Sphericity (Rhines 1975, Vallis and Maltrud 1993, Huang and Robinson 1998)
   - 9.5 Numerical Simulations of Geophysical Turbulence (McWilliams 1984)
   - 9.6 Zonal Jets (Cho and Polvani 1996a,b, Theiss 2004, Showman 2007, Scott and Polvani 2007, 2008)
   - 9.7 Numerical Simulations of Shallow Water Turbulence (Polvani et al. 1994)
   - 9.8 Spontaneous Radiation of Inertia-Gravity Waves (Ford et al. 2000, Schecter and Montgomery 2005, Hendricks et al. 2010)

10. Ocean Circulation Theory (Pedlosky 1997)
    - 10.1 The Wind-Driven Circulation
    - 10.2 The Ventilated Thermocline
    - 10.3 The Equatorial Undercurrent (EUC)

10.4 The Antarctic Circumpolar Current (ACC)
10.5 The Abyssal Circulation

The course will not cover all the above topics, but only selected topics that depend on student interest. There will be no exams. Grades will be based on oral presentations and the ppt file that is prepared for the audience.

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