AOSC 617: Atmospheric and Oceanic Climate

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Office hours: By appointment

Current Web Description

The general circulation of the atmosphere and oceans: historical perspective, observations, and conceptual models; wind-driven and thermohaline ocean circulation; seasonal cycle and monsoon circulations; interannual to interdecadal climate variability; climate change.

Background

Atmospheric and oceanic climate refers to the monthly/seasonal averaged distributions of circulation, temperature, moisture, and related eddy transports. The course will provide a dynamically oriented description of the observed distributions, with the intent of elucidating the dynamics of terrestrial climate. Both circulation structure and the underlying dynamical/thermodynamic constraints and mechanisms will thus be of interest. The availability of atmospheric and oceanic reanalysis data sets in recent decades has led to improved 3D descriptions and new insights into atmospheric and oceanic general circulation. Historical perspectives will be supplemented by modern views of the general circulation, supported by theory and simple models of the involved dynamical processes. The course will advance understanding of climate variability and climate change, and climate sensitivity.

Books

There is no single textbook for the course.
Material from various sources, including some books, will be used and shared to the extent possible.

AOSC617: Course Outline (Two 75-minute lectures per week)

1 Mid-Term Exam-35%; Final Exam-40%; Class Participation-25%

- **Course Structure and Content;** Scientific Revolution; Meteorological Observations – History & Evolving Networks
  LECTURE-1 (Varied Sources)
- **Climate Observing System**: In situ and remote sensing of the Oceans, Atmosphere, Land Surface, and Cryosphere: COSMIC 1-2 (atmosphere), TRMM/GPM (precipitation), SMOS/SMAP (soil moisture), GRACE (groundwater/cryosphere), ARGO (ocean soundings), AQUARIUS/SMOS/SMAP (sea surface salinity).
  LECTURE-2 (Varied Sources)
- **Data Assimilation**: Objective Analysis; Data Initialization; Asynoptic data and 4D assimilation; 3D and 4D-Var; ECMWF assimilation system, including data type and distribution used in today's forecast**;** Atmospheric and Oceanic Reanalyses.
  LECTURE-3 (Holton 4E; Section 13.7 sans nonlinear normal mode initialization)
- **Earth-Sun Geometry:** Earth's orbit (eccentricity); Earth's rotational axis (precession, obliquity); the 100K, 26K, and 41K periods, and the 21K perihelion cycle.
  LECTURE-4 (Varied Sources)
- **Paleoclimate:** Solar System evolution – Rise of O_2; Major Glaciations; Cretaceous and Post-Cretaceous periods**;** Quaternary period (from 2.5MYA) – The Pleistocene (2.5MYA to 20KYA): Ice Ages, Vostok ice core; Orbital Theory for Ice Ages – Oscillations (quadrature phase-delay and frequency modulation of forcing in the response). Is the 100K climate periodicity (e.g., during the Ice Age) now understood? The Holocene (20KYA to now): Younger Dryas (13KYA); African Humid Period (11-5KYA); Little Ice Age (14-19th century).
  LECTURES 4-6 (Wallace & Hobbs 2E; Section 2.5 + Other Sources)
- **Solar Radiation Today**: Latitude-month distribution, showing annual variability beyond the Tropics of Cancer/Capricorn, and semi-annual variability at the Equator; Eccentricity effects. Diurnal Variability – Solar Zenith angle, estimate insolation at any latitude and calendar day.
  LECTURE-6 (Hartmann 1E; Section 4.6 and Appendix A)
- **Static Stability**: Lifting Condensation Level, Level of Free Convection, and Level of Neutral Buoyancy – Brief Review (15 minutes)
  LECTURE-7 (Wallace & Hobbs 2E; Section 3.6)
- **Today's Climate:**
  - *Zonal-mean Circulation and Temperature Distribu*tions: Thermal Wind Balance and Subtropical Westerly Jets; Why are there Easterlies in the Tropics (both at the surface and aloft)? Why is Tropical Tropopause so Cold? Hadley Circulation; Tilt of the Subtropical Jet; Stratospheric Circulation: Polar Vortex and the Polar Night jet, Northern and Southern Hemisphere differences; Brewer-Dobson circulation. Why do significant Ozone holes occur only in the SH?
    LECTURES 7-8 (Varied Sources)

- *Zonal-mean Divergent Circulations*: Ageostrophic? Velocity potential and Streamfunction; South Asian Monsoon and the Tibetan Anticyclone; Hadley Circulation and its Seasonality.
  LECTURE-9 (Varied Sources)
- Zonal-mean Rotational and Divergent Circulations and Diabatic Heating in NCEP and ERA Reanalyses, and IPCC-AR5 historical climate simulations (for model evaluation).
  LECTURE-9 (Varied Sources)

- **Atmospheric Angular Momentum Cycle:** Viscosity & Surface Stress, σ-coordinate equations, Surface Torque; Zonal-mean Angular Momentum transport – Role of Synoptic-Scale Eddies in the sub-Tropics/Midlatitudes (Victor Starr's "negative viscosity") from their SW-to-NE tilt.
  LECTURES 10-11 (Holton 4E, Section 10.3 + Other Sources)
- **Planetary Angular Momentum (AM) Conservation:** Mass of the Atmosphere, Oceans, and the Solid Earth – how can each be estimated? How was the radius of the Earth first estimated? Moment of Inertia; Solid-body and Relative AM of each planetary component**.** AM exchanges lead to Length of Day variations, e.g., during El Nino episodes.
  LECTURE-12 (Piexoto and Oort, Section 11.1 + Other Sources)
- **Trade Winds**: Halley's and Hadley's explanation: Read/Critique Hadley's 1735 paper in the Philosophical Transactions.
  LECTURE-13 (Varied Sources)
- **Advances in General Circulation of the Atmosphere** (post-Hadley): Ferrel and Thomson's indirect cell in the midlatitudes; Bjerknes and Victor Starr's synthesis of the entrenched zonally-symmetric viewpoint with the newfound role of eddies; A modern synthesis by Michael J. Wallace.
  LECTURE-14 (Wallace, Encyc. of Atmos Sciences 2E, pgs. 821-829.)
- **Earth's Energy Balance:** Annual and *Global Average* View: Surface Energy Balance; Atmospheric Energy Balance, including All-Sky budget; Planetary Energy Balance (at the top of the Atmosphere); Role of Clouds and the Atmosphere in maintaining a habitable planet.
  LECTURE-15 (Graeme Stephens et al. 2012, Nature Geoscience)
- **Radiative Equilibrium Temperature:** Definition; Departures from its latitudinal profile indicate the need for poleward heat transport.
  LECTURE-15 (Vallis, AO Fluid Dynamics, Section 11.1.1)
- **Held-Hou model for Hadley Circulation**: A multi-century advance in Hadley Cell modeling, from consideration of thermal-wind balance during angular momentum conservation. An analytic model for the Cell's width, height, and intensity based on the planet's rotation rate, tropospheric height, and the equator-pole temperature drop; Hadley cell as a Carnot heat engine. A quasi-Lagrangian view of Hadley Circulation.
  LECTURE-16 (Ian James's book, Section 4.2; Vallis, Encyc. of Atmos. Sciences 2E)
- **Sea-Level Pressure Distribution:** Continental lows (highs) and oceanic highs (lows) in summer (winter). Precipitation distribution from the sea-level pressure field using large-scale vorticity dynamics (Sverdrup Balance). Why does the US West Coast exhibit a 'Mediterranean' climate? Seasonal evolution of NH Subtropical Anticyclones and the Hadley Cell – A Paradox?
  LECTURE 17-18 (Varied Sources; Nigam & Ruiz-Barradas 2006 and Nigam & Chan 2009)

- **Sea Surface Temperature (SST) –** *Seasonal Evolution***:** SST is a very influential boundary condition for the atmosphere. Why? How does the atmosphere (including insolation and clouds) influence SSTs? SSTs (and the equatorial SST gradient) exhibit a pronounced annual cycle in the Tropics despite the semi-annual cycle in insolation. Why? A Role for Stratus Clouds or Is it Coupled Ocean-Atmosphere-Land Interaction in the Eastern Equatorial Basins? Walker Circulation. The Gill and Lindzen-Nigam Models for Tropical Surface Winds. A simple analytic model for the annual westward phase propagation of SSTs in the eastern basins.
  LECTURES 19-21 (Varied Sources; Lindzen & Nigam 1987, and Nigam & Chao 1996)
- **Meridional Heat Transport**: Required *annual and zonal me*an transport from a radiative surplus (deficit) in the Tropics (high latitudes): Meridional transport in the oceans and atmosphere – Which is larger, and where do they peak? Basin and hemispheric differences. Key dynamical/thermodynamic processes behind the transport. Thermohaline Circulation.
  LECTURE-22 (Varied Sources; Trenberth 2022)
- **Non-Seasonal SST variability:** Mixed layer heat budget; frequency-modulation of surface forcing (e.g., white noise forcing to red response); decadal changes in SST observations density; EOFs and Extended-EOFs of SST anomalies: Canonical and Non-Canonical ENSO variability – Structure and mechanisms, Current ENSO conditions. North Pacific and Pan-Pacific decadal variability; non-stationary Secular Trend; Atlantic Multidecadal Oscillation. Modal evolution and hydroclimate impacts are emphasized.
  LECTURES 23-24 (Deser et al. 2010; Guan and Nigam 2008, 2009; Other Sources)
- **Climate Teleconnections**: Action at a distance; Correlations, Regressions, and the Teleconnectivity Map and Index; Wallace and Gutzler's (1981) classical extratropical 500-hPa analysis (PNA, NAO, NPO patterns); notably absent here is the ENSO response, which is not the PNA pattern. EOF analysis of upper-tropospheric (200-300 hPa) height anomalies reveals a distinct ENSO response. The occasional presence of a teleconnection in 'raw' monthly anomalies—called an Analog—is shown to illustrate that teleconnection patterns are not just statistical artifacts. The teleconnection patterns' nascent and mature phases, as well as precipitation and surface temperature impacts, are discussed.
  LECTURE-25 (Nigam, Encyc. of Atmos. Sci. 2003; Nigam & Baxter 2015)
- **Global Warming:** Global Greenhouse Reference Network – The Keeling Curve at Alaska, Mauna Loa, Samoa, and S. Pole; their seasonality. Observed global-averaged temperature, with sharp increases in 1910-1940s and 1970s-2000s, and modest cooling during 1940s-70s and the recent hiatus. Century-plus (1901-2020) trends in Surface Air Temperature (SAT) over NH Continents exhibit a factor of 2 difference between winter and summer; no such seasonality in the IPCC AR5 historical simulations! Why do the century-plus trends exhibit pronounced seasonality? The role of the land surface (notably, evapotranspiration) in the seasonal modulation of the warming over continents.
  LECTURE-26 (Nigam et al. 2017; Other Sources)

Important TOPICS LEFT UNCOVERED in the Spring 2024 (and a few other times)

- Arctic sea-ice distribution, variability, and trend: Seasonal structure; variability mechanisms.
- Climate sensitivity