## Atmospheric Sciences 6150: Cloud System Modeling

**Spring 2022**

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Visualization of cumulus clouds from a large-domain, high-resolution *simulation* of tropical oceanic deep convection. The realistic structure is associated with entrainment. (Image created by Ian Glenn using SHDOM, a 3D radiative transfer program.)

**Classroom:** 820 WBB

**Class Hours:** Tu Th 3:00 to 4:20
The class times may be adjusted to accommodate students who wish to take ATMOS 6040 Environmental Instrumentation.

**Prerequisites:** ATMOS 6010 and 6020 or instructor's consent

**Notable course content changes:** Students will now have an opportunity to use SAM (System for Atmospheric Modeling), a widely used high-resolution, 3D, non-hydrostatic cloud model, which has recently been coupled to a state-of-the-art wildfire rate of spread parameterization. Also, a new course topic will be how global warming affects precipitating cloud systems.

**Description:** Theory and modeling of atmospheric convection and cloud systems. Numerical modeling of turbulent, convective, and mesoscale motions associated with cloud systems. Formulation of physical processes in cloud-resolving models. Role of modeling efforts in understanding the structure and behavior of cloud systems, with an emphasis on convective cloud systems. Representation of convection, clouds, and cloud processes in numerical weather prediction and climate models.

The course complements ATMOS 6010 (Fundamentals of Dynamic Meteorology) by focusing on convective-scale (non-hydrostatic, ageostrophic) dynamics. It also complements ATMOS 5700 (Mesoscale Meteorology) and ATMOS 6510 (Tropical Meteorology) which focus on the observed properties of convection, as well as ATMOS 6500 (Numerical Weather Prediction) which is increasingly concerned with predicting mesoscale and convective-scale phenomena.

**Highlights:** Many local and regional NWP (numerical weather prediction) models are now using convection-resolving grid sizes of 4 km or less with non-hydrostatic dynamical equations. Some global climate models now use embedded cloud-resolving models with grid sizes of 4 km to represent the subgrid-scale processes in place of conventional parameterizations. Research and operational applications of cloud-resolving (and the closely-related large-eddy simulation) models now include simulating cloud systems (including severe storms and tropical cyclones), boundary layers, flows over complex terrain and around buildings, and dispersion and chemistry of air pollutants.

In this course, you will construct a 2D ($x$-$z$) non-hydrostatic model and use it to simulate convection between two parallel horizontal plates, one hot and one cold. After constructing the 2D model, you will have the opportunity to apply it, or a 3D high-resolution cloud model (SAM, System for Atmospheric Modeling, `http://rossby.msrc.sunysb.edu/~marat/SAM.html`), to a non-hydrostatic atmospheric flow of your choice. Some possibilities include:

**Density current (gust front) in shear** (relevant to squall line propagation): dependence of updraft structure on shear.

**Microburst downdraft:** dependence of outflow speed on lapse rate and boundary layer depth

**Thermal:** Dependence of entrainment/detrainment rate on size and buoyancy.

**Buoyant plume:** dependence of height on buoyancy flux and stability.

**Kelvin-Helmholtz instability:** Dependence on shear and stability.

**Radiatively destabilized cloud layers** (stratocumulus, altocumulus, cirrus): dependence of cloud structure on various parameters.

**3D dry convective boundary layer** : non-local turbulent transport and dispersion.

**Coupled wildfire spread and buoyant plume:** interaction of convective plume and fire spread.

**Squall line:** Under certain atmospheric conditions, a line of convective cells can propagate for an hour or more.

**Supercell convection:** Under certain atmospheric conditions, a single convective cell can persist for an hour or more.

**Tropical cyclone:** Under certain atmospheric conditions over a tropical ocean, a large-scale vortex can intensify into a tropical cyclone.

**Optional Textbook:** *Atmospheric Convection* by K. A. Emanuel

**Supplementary Textbooks:** *Cloud Dynamics* by R. A. Houze, Jr., *Storm and Cloud Dynamics* by W. R. Cotton and R. A. Anthes, *An Introduction to Dynamic Meteorology* by James R. Holton, and *Mesoscale Meteorology in Midlatitudes* by Paul Markowski and Yvette Richardson.

**Topics Addressed:** (E: Emanuel, H: Houze) [See the course web page for a more detailed list.]

1. Cloud system types and occurrence
2. The nature of convection in the atmosphere
3. Fundamental equations for convection (E: 1; H: 2.1, 2.3)
4. Dry convection from local sources (thermals and plumes) (E: 2)
5. Global dry convection (parallel-plate convection) (E: 3)
6. Moist thermodynamics and stability (parcel model)
7. Cumulus clouds: entrainment and mixing (E: 7, 8; H: 7.3)
8. Numerical modeling of convective clouds (E: 10; H: 2.10,3.3-3.6)
9. Numerical modeling of wildfires
10. Precipitating convective cloud systems (E: 9, 11; H: 8, 9)
11. Global warming and precipitating cloud systems.
12. Global moist convection (shallow-layer clouds) (E: 13; H: 5)
13. SAM (System for Atmospheric Modeling): An easy-to-use 3D cloud-resolving model

**Numerical Modeling Exercises and Projects:**

1. Construct a cloudy parcel model for saturated adiabatic ascent (MATLAB).
2. Construct and apply a 2D ($x$-$z$) numerical model (Fortran or MATLAB):
   (a) Numerical simulation of 1D conduction
   (b) Numerical simulation of 2D marginally unstable (linear) parallel-plate convection
   (c) Numerical simulation of 2D fully nonlinear parallel-plate convection
   (d) Application to a non-hydrostatic flow of your choice

**Grading:** The course grade will be determined from problem sets and projects (75%) and a final exam (25%).