Virtual Research Presentation Conference

Development of a 2D Circulation Model for Rapid Exploration of Exoplanet Atmospheres

Principal Investigator: Tiffany Kataria (3262)
Co-Is: Nikole Lewis (Cornell), Ekaterina (Kath) Landgren (Cornell), Alice N. Nadeau (Cornell), Carmen Boening (329), Lisa Kaltenegger (Cornell)
Program: SURP

Assigned Presentation # 019

Jet Propulsion Laboratory
California Institute of Technology

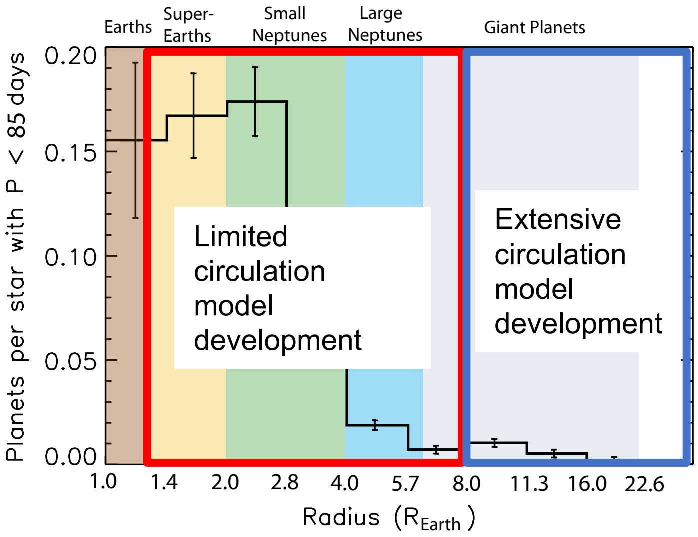
Tutorial Introduction

Abstract

The aim of this SURP is to develop a two-dimensional (2D) atmospheric modeling framework that is designed to capture the key physical processes in the atmospheres of Mini-Neptune and Super-Earth exoplanets, planets 1.6-6 times the radius of Earth. These models, which employ the ‘shallow water’ equations along with specialized parameterizations for radiative transfer, clouds and chemistry, will be the first of its kind to identify dynamical mechanisms for this population of planets. This talk will present initial results from our 2D model developed by Cornell graduate student Ekaterina (Kath) Landgren (neé Kryuchkova).

Problem Description

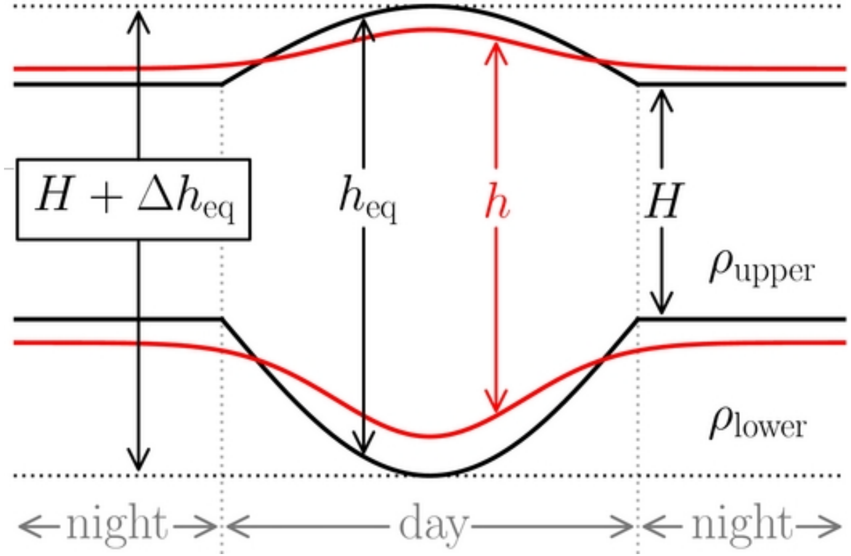
- Context
  - *Kepler* has shown super-Earths/mini-Neptunes, exoplanets 1.6-6 times the radius of Earth, are most common in our galaxy
  - Most super-Earth/mini-Neptune models are simple (1D) or complex (3D), and usually planet-specific
  - More super-Earths/mini-Neptunes continue to be found with TESS; prime targets for follow-up characterization with JWST
- Comparison or advancement over current state-of-the-art
  - First-of-its-kind 2D shallow-water models of super-Earths/mini-Neptunes, written fully in Python
  - 2D models will be fast, flexible and modular; can be readily used to make predictions of observations for mini-Neptunes/super-Earths discovered by TESS
  - Bridges model hierarchy between 1D and 3D models
- Relevance to NASA and JPL
  - Results could be applied to future missions with JPL involvement (e.g., HabEx, LUVOIR, Origins) and would serve as basis for larger ROSES proposals (e.g, XRP, NExSS, Habitable Worlds). Furthers 7x objectives to invest in exoplanet research (e.g., Exoplanetary Science Initiative).
  - Models can be used to make observational predictions for current/future facilities from ground (Palomar, Keck, TMTs) and space (HST, JWST, ARIEL/CASE)



Fressin et al. 2013

Methodology

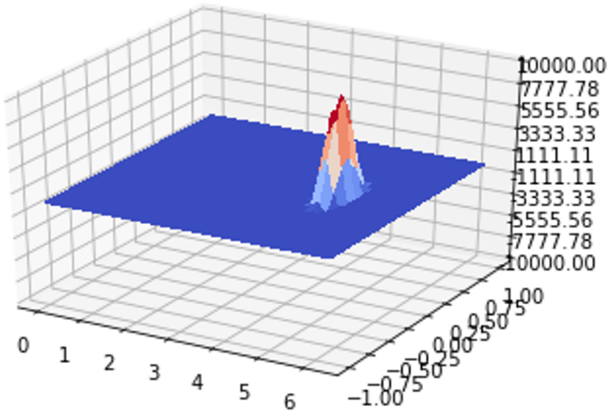
- 2D models for Super-Earths/mini-Neptunes written fully in Python by graduate student Ekaterina (Kath) Landgren, eventually open-source
- Initial setup base off of hot Jupiter 2D framework
  - Assume tidal locking, long horizontal length scales
  - Validate our model against previous predictions for hot Jupiter atmospheres (Perez-Becker and Showman 2013) that were derived from the Hack & Jakob (1992) shallow water model
- Physics to be included
  - Radiation, parametrized clouds/chemistry, surface-atmosphere interactions
  - Code will be flexible and able to model a broad range of exoplanet types and forcing conditions
- Once code is fully validated and benchmarked by graduate student Landgren, will conduct a systematic study to understand circulation of super-Earths/mini-Neptunes over broad phase space



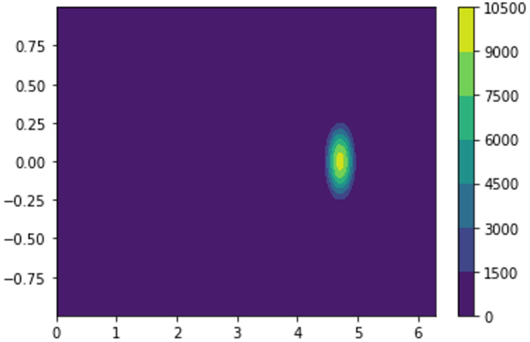
Perez-Becker and Showman 2003

Results

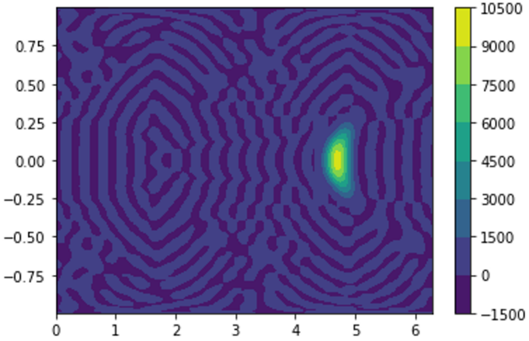
- 2D shallow water Python code currently in development
  - Replicated results from Hack and Jakob (1993) in producing a moving geopotential under advection of zonal (east-west) winds
- **Remarkable progress has been made in the past year, especially in the midst of a pandemic**
  - Utilize group telecons, Slack, other collaboration tools



Advection of a geopotential cosine bell with zonal winds



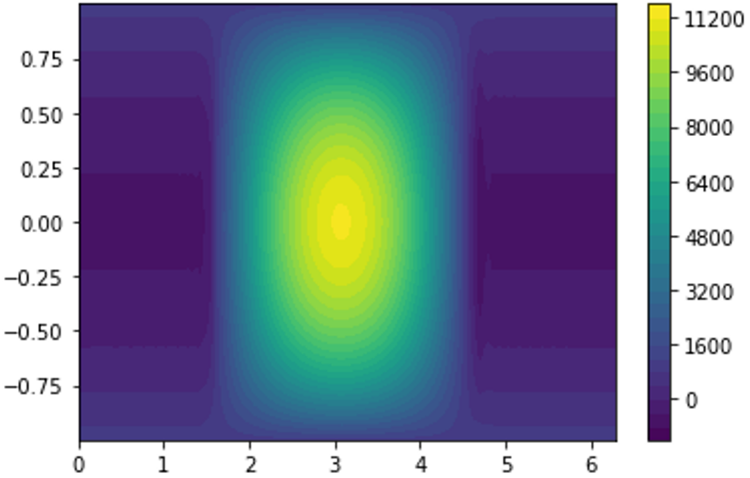
Initial condition for geopotential



The geopotential after having been advected fully around the planet

Results

- **Current benchmarking activity**: Replicate the results from Perez-Becker and Showman (2013)
- Next steps
  - Finish benchmarking
  - Continue detailed documentation
  - Vary planetary parameters to study the atmospheric dynamics of super-Earths/mini-Neptunes
  - Publish open-source code



Applying radiative forcing to the day side results in heating

Publications and References

Hack, J. J., & Jakob, R. (1992). Description of a Global Shallow Water Model Based on the Spectral Transform Method (No. NCAR/TN-343+STR). University Corporation for Atmospheric Research. doi:10.5065/D64B2Z73

Perez-Becker, D., & Showman, A. P. (2013). Atmospheric Heat Redistribution on Hot Jupiters. Astrophysical Journal. doi: 10.1088/0004-637X/776/2/134