Where are we in understanding Venus atmospheric dynamics?

There has been recent progress on the numerical modeling front, yet there are still

Major Unresolved Questions.

- **What processes are responsible for establishing and maintaining the zonal retrograde superrotation?**
- **What is the nature of the meridional circulation?**
  - **Is there a single Hadley cell or are there several cells, direct and indirect, stacked vertically?**
  - **How far poleward does the Hadley cell extend?**
- **What is the nature of the polar vortex?**
- **How does the atmosphere interact with the surface and what are the properties of the atmosphere in the lowest scale height?**
  - **Is the near surface atmosphere stably stratified?**
  - **Are there prograde winds at the surface at some latitudes?**
  - **What are the horizontal temperature contrasts (equator-pole)?**
  - **Does topography influence the atmospheric circulation?**
  - **Do the highlands launch gravity waves into the atmosphere?**
- **What are the processes that drive circulation in the upper atmosphere?**
- **Why is the upper atmosphere flow so highly variable in time?**

Recent Modeling Efforts to Explain the 4-day Retrograde Zonal Rotation

Yamamoto and Takahashi, Lee et al., Hollingsworth et al., Dowling

These efforts have so far produced cloud level zonal winds of the right magnitude, but so far, not for realistic Venus parameter values.

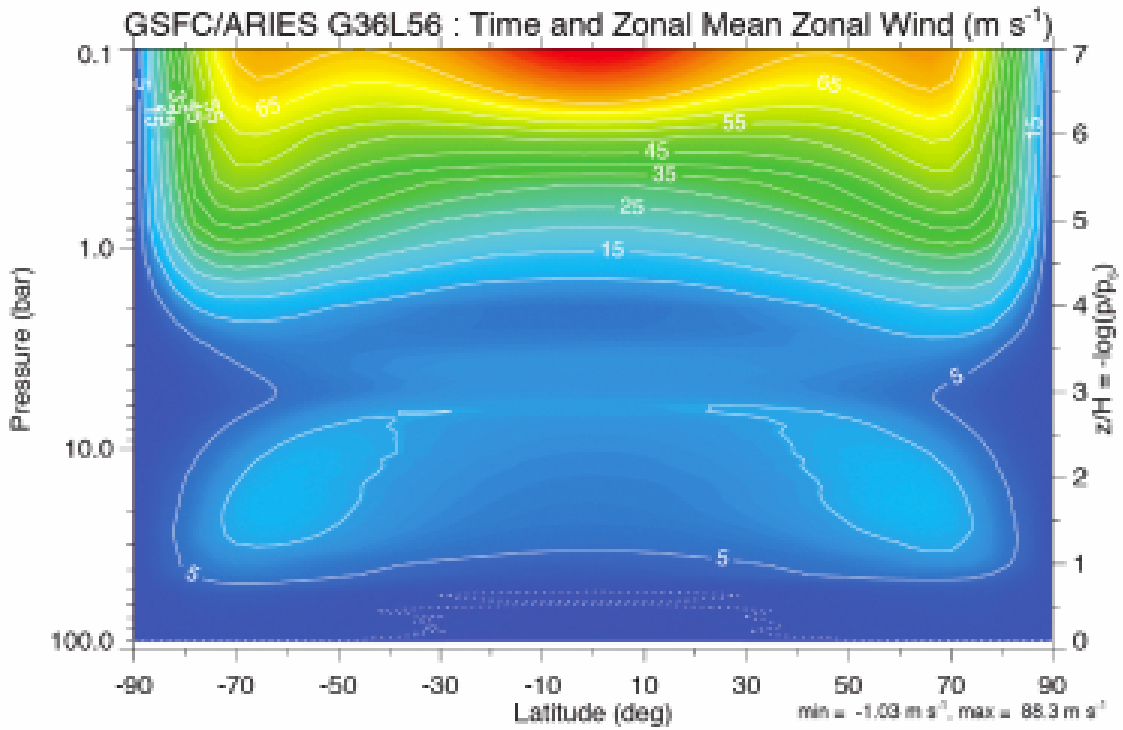
In general, they artificially enhance the Hadley cell transport of angular momentum so that the Gierasch mechanism produces high speed zonal winds at cloud heights.

Yamamoto and Takahashi (2006), in their most recent paper, conclude:

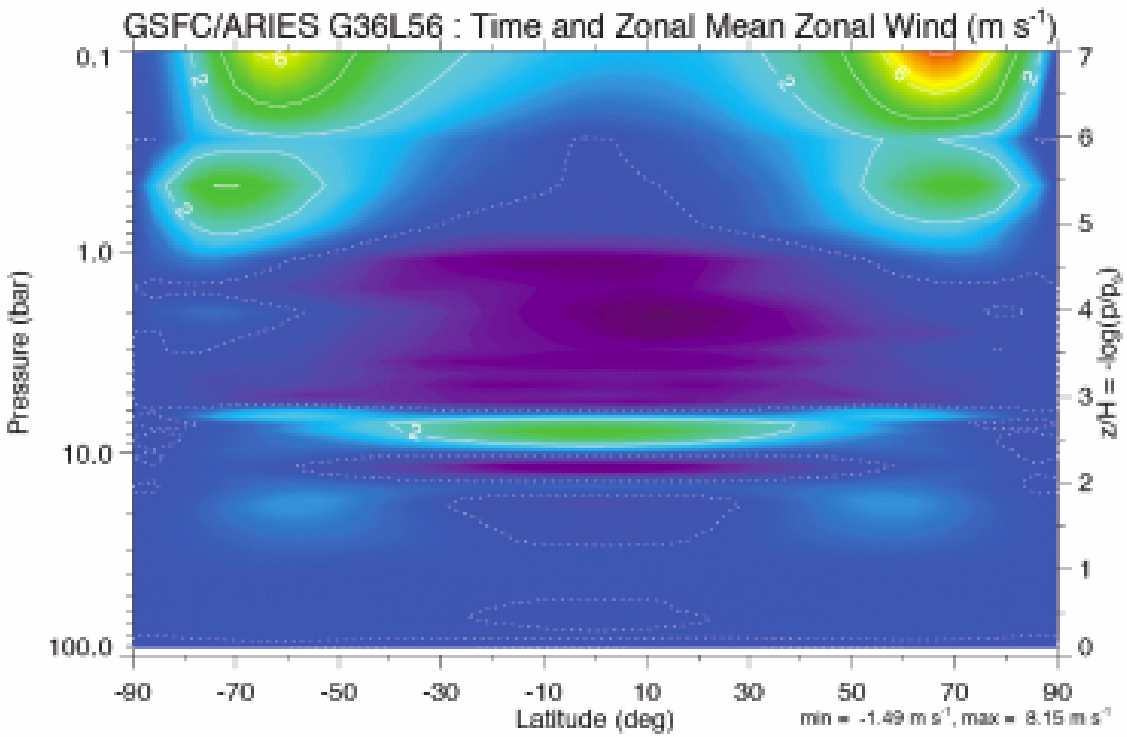
"Although the superrotation is produced in the simplified AGCMs, a real Venusian superrotation mechanism is still unknown at the present stage. In addition to the further observations, the further improvements of AGCMs are needed in order to elucidate the real superrotation mechanism. Together with the improvement of the radiation code, more realistic surface processes should be incorporated into Venus atmosphere AGCM."

Our preliminary results with a stripped-down Mars GCM (Hollingsworth, 2006)

Heating Rate prescribed similar to *Yamamoto and Takahshi* [2003; 2004]



Heating Rate altered to agree with Pioneer Venus LSFR data [*Tomasko et al.*, 1980]



What is Missing from Previous Simulations?

- **Zonally asymmetric heating, day-night effects, thermal tides (from most models).**
- **Radiative transfer-dynamics interactions.**
- **Clouds.**
- **Real Venus boundary conditions, atmosphere-surface interactions, topography.**
- **High numerical resolution.**
- **Modern supercomputer power.**

Venus Atmospheric Dynamics Modeling Group

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Why Now?

- **New data. VEX and VCO.**
- **Availability of state-of-the-art GCMs. CAM: Community Atmosphere Model**
  Our chosen model
  The flagship GCM for research in the United States (per Climate Change Science Program)
- **Powerful Supercomputers at LLNL (MCR, Thunder)**
- **New data for another superrotating atmosphere (Titan)**
- **Renewed interest in Venus, VEXAG (Venus Exploration and Analysis Group)**

Why Now?

- **Venus is scientifically interesting**
- **Venus is important for understanding changes in Earth's atmosphere**

  It provides a new test of a numerical model used to predict global warming

  - **Usual test is simulating climate of the 20th century**
  - **"Interpolation is safer than extrapolation." (Professor Marty Hoffert, NYU)**

What Measurements are Needed to Solve the 4-Day Circulation Problem?

Because we know almost nothing about the lowest scale height of the atmosphere and surface-atmosphere interactions are undoubtedly important, it is essential that we probe the near surface atmosphere in great detail. We want to measure the atmospheric temperatures near the surface so that we'll know the equator-pole and day-night thermal contrasts. We need to determine the vertical profiles of solar heating and atmospheric stability and wind speeds in the lower atmosphere. We need to know the nature of the near-surface boundary layer.

Measurements of wind velocities and temperatures are needed at all levels of the atmosphere and at different times in order to distinguish the thermal tides, large-scale wave systems, and meridional circulation.

Similar quantities need to be measured in the mesosphere and thermosphere to separate the subsolar-antisolar flow from the retrograde zonal circulation and determine the presence of waves and tides.