Global models of the lower and middle atmosphere of Venus

Conference or Workshop Item

How to cite:

© 2010 S. R. Lewis

Version: Version of Record

Link(s) to article on publisher’s website:
http://www.galaxyzooforum.org/index.php?topic=278317.0

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online’s data policy on reuse of materials please consult the policies page.
Global models of the lower and middle atmosphere of Venus

Stephen Lewis
Venus atmospheric dynamics

• What are the key mechanisms responsible for atmospheric super-rotation on Venus?
  – Role of the Hadley circulation
  – Role of large-scale waves, thermal tides and small-scale turbulence
  – Role of interaction with the solid surface
• What is the nature of the polar vortices?
  – Interaction with the large-scale super-rotation
• What are the properties of the large-scale waves seen in the clouds?
• What are the radiative feedbacks from the clouds?
• What is the nature of the circulation beneath the clouds?
• How do all of these processes vary with time?
Venus global modelling – challenges

• Slow rotation rate means primary balance is cyclostrophic, not geostrophic
• Venus atmosphere is ~90 times more massive than Earth’s and optically thick
  – Models have to be ‘spun-up’ over 50,000-100,000 days to equilibrate
  – Small residuals (and quantities which are not conserved by the dynamical cores) accumulate over model integration times giving rise to large net effects, e.g. global super-rotation, which are sensitive to model details
    • a weakly-forced system compared to Earth and Mars
• The Venus lower and middle atmosphere is poorly observed below the clouds and so models are not well constrained
• Venus is a severe test for terrestrial atmospheric models
Super-rotation in Venus GCMs

Yamamoto & Takahashi (2003)

Lee, Lewis & Read (2005)

Figure 1. Latitude–height cross section of longitudinally averaged zonal flow (m s\(^{-1}\)).

Figure 6. Latitude-height cross section of the zonal mean westward wind speed, averaged from 3 years of data at 100 years, \(\Delta = 5\) m s\(^{-1}\).

These models may assume unrealistic thermal forcing to get realistic winds.
Super-rotating winds in the OU VGCM

Zonal-mean zonal wind

Pressure / bar

0km

90km

SP

Latitude

NP

Color scale: 0 - 140
Surface/atmosphere AM exchange

Zonal-mean zonal wind

Surface friction torque
Mean meridional transport

Mean meridional circulation

Surface friction torque
Mid-latitude prograde jets

Zonal-mean zonal wind

Surface friction torque
Angular momentum

\[ s = \frac{m}{\Omega a^2} - 1 \]

\[ m = a \cos \phi (\Omega a \cos \phi + u) \]
Gierasch (1975)/GRW mechanism

Eddy momentum flux

Diagram showing the eddy momentum flux with contour lines indicating the distribution of momentum in the atmosphere.
Thermal tide/QBO-like mechanism

Eddy momentum flux

![Diagram showing atmospheric circulation patterns with labels for altitude, latitude, and sigma scale.](image)
ISSI Venus model intercomparison

Mean zonal wind field

CCSR (BS)  OU (base)  LMD (base)

LR10a2  LR10a1  LR10b2  LR10b1  LR10c2  LR10c1
# Venus Intercomparison experiments

<table>
<thead>
<tr>
<th></th>
<th>CCSR</th>
<th>LMD</th>
<th>OU</th>
<th>Ox</th>
<th>UCLA</th>
<th>LR10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>T21L50</td>
<td>base</td>
<td>T21L50</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sensitivity to vertical grid</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical grid</td>
<td>L52</td>
<td>L100, L200</td>
<td></td>
<td></td>
<td></td>
<td>LR10a1,b1,c1</td>
</tr>
<tr>
<td><strong>Sensitivity to boundary conditions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topography</td>
<td>BT / YT</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sponge layer</td>
<td>ND</td>
<td>spg3</td>
<td>eddies</td>
<td>x</td>
<td></td>
<td>LR10a2,b2,c2</td>
</tr>
<tr>
<td>Varying PBL</td>
<td>BL</td>
<td>kzfx/clmn/MY</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td><strong>Sensitivity to horizontal resolution</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low resolution</td>
<td>T10</td>
<td>x</td>
<td>T10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High resolution</td>
<td>T42</td>
<td>x</td>
<td>T42</td>
<td></td>
<td></td>
<td>(1°x1°)</td>
</tr>
<tr>
<td><strong>Sensitivity to initial state and forcing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diurnal cycle</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Varying initial state</td>
<td>Uini</td>
<td>Uini</td>
<td>Uini</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 2 Zonally and temporally averaged zonal wind fields obtained in all the baseline simulations. Unit is m/s. The first column is spectral models: (a) CCSR, (d) LR10-s, (g) OU. The second column is finite difference models: (b) LMD, (e) LR10-fd, (h) OX. The third column is the finite volume models: (c) UCLA, (f) LR10-fv. For the UCLA simulation (c), the resolution is much higher than the other baseline runs.
Impact of horizontal resolution

CCSR

LMD

Ox
Temporal variability (Parish et al. 2010)
Cloud-tracked zonal winds at ~65 km

Limaye (2007)
Summary

• Great progress in Venus global models in last decade, all capable of simulating a super-rotating atmosphere
  – Models may rely on unrealistic forcing to get wind magnitude right
  – Results are sensitive to many, poorly-known parameters

• More observations of Venus middle and lower atmosphere are needed to constrain models and processes
  – Venus Express and Akatsuki provide much new data at cloud level and above

• Venus provides a rigorous test of global atmospheric model dynamical cores

• Results of ISSI study to be published in “Towards understanding the climate of Venus – The application of terrestrial models to our sister planet” (Bengtsson et al., Springer, 2011)
The Open University Venus SGCM

- Simplified physics GCM similar to Yamamoto & Takahashi (2003) and Lee, Lewis & Read (2005)
- Pseudo-spectral dynamical core
  - Horizontal resolution: T10, T21, T42
  - Vertical resolution: 32, 50, 100, 200 levels
  - Typical integrations ~ 70,000 days
- Linear forcing, Newtonian cooling and Rayleigh friction
  - Future plans include more detailed PBL scheme and radiation scheme shared with the Oxford VGCM
- 8th order hyperdiffusion and ‘sponge’ in upper model levels
- Topography
- Diurnal cycle