1. Introduction

Purpose
We examine possible sensitivities of the behavior of simulated large scale vortices to the type and the intensity of the forcing that maintains zonal mean fields.

Background
Williams (1996) reproduced large scale vortex resembling the Great Red Spot within a three dimensional numerical model. However, the large scale vortex decayed after a long time integration. Is it caused by the decay of zonal mean field?

2. Model and Setup

**Basic equations:** 3D, spherical, Primitive equation model of the Boussinesq fluid

### Setup of Experiments
- **Four types of forcing**
  1. no forcing
  2. momentum forcing to damp the zonal mean winds to the initial structure
  3. thermal forcing to damp the zonal mean temperature to the initial
  4. both (momentum and thermal) forcing

- **Four values of damping time**
  - 30, 100, 300, and 1000 days

### Computational domain and resolution
- Zonal: cyclic
- Meridional: symmetric, no-flux (EQ)
- Vertical: no-slip, no-flux (South Boundary)

### Initial condition
- Vertical shear at around 22° latitude

### Boundary condition
- Slip, no-flux (EQ)

### Parameters
- Appropriate for Jupiter's atmosphere
  - T(φ, z): 2734, T=2734 K
  - T(φ, z): 2734, GHz: 2734 K
  - T(φ, z): 2734, GHz: 2734 K

### Diagnosis
- Baroclinic instability is weaker than strong forcing cases.

3. Results

The behavior of vortices is classified into 4 categories shown below.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No forcing</td>
<td>Only waves exist. (no large scale vortices appear)</td>
</tr>
<tr>
<td>Weak forcing</td>
<td>Large scale vortices generate but become weaker.</td>
</tr>
<tr>
<td>Strong forcing</td>
<td>One or two large scale vortices develop but their lifetime is short.</td>
</tr>
</tbody>
</table>

### Three cases representing long lived vortices (.), short lived vortices (.), and wavy (.) are shown below.

<table>
<thead>
<tr>
<th>Case</th>
<th>Potential Vorticity: Q (°F=204K)</th>
<th>T(φ, z) (contour), U(φ, z) (color)</th>
<th>EP flux (vector), T(φ, z) (contour) (color)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM1000 Weak</td>
<td>A large scale vortex is maintained.</td>
<td>Initial structure of zonal mean field is better maintained than the strong forcing cases shown below.</td>
<td>The activity of baroclinic and barotropic instability is weaker than strong forcing cases.</td>
<td>The vertical shear (AU=5m/s) can tear large scale vortices within 30 days.</td>
</tr>
<tr>
<td>M30 Strong</td>
<td>Many large scale vortices continuously develop but their life time is short.</td>
<td>Baroclinicity above -100km is almost vanished.</td>
<td>The activity of barotropic instability is strong.</td>
<td>The vertical shear (AU=5m/s) can tear large scale vortices within 30 days.</td>
</tr>
<tr>
<td>T30 Strong</td>
<td>Only waves exist. (no large scale vortices appear)</td>
<td>Vertical shear at around 22° S are generated.</td>
<td>The activity of baroclinic instability is strong.</td>
<td>The vertical shear (AU=5m/s) can tear large scale vortices within 30 days.</td>
</tr>
</tbody>
</table>

4. Summary

The behavior of simulated vortices depend on the type and the damping time of forcing.

- Weak forcing: Large scale vortices are maintained.
- Strong forcing: Large scale vortices are not maintained.

These difference might be caused by the differences of instability activities or types due to the differences of zonal mean fields.

*Latest results suggest that vertical shear is also important. For details, please ask me.*