Atmospheric Tides in WACCM and the Latest (CMIP5) Generation of Climate GCMs

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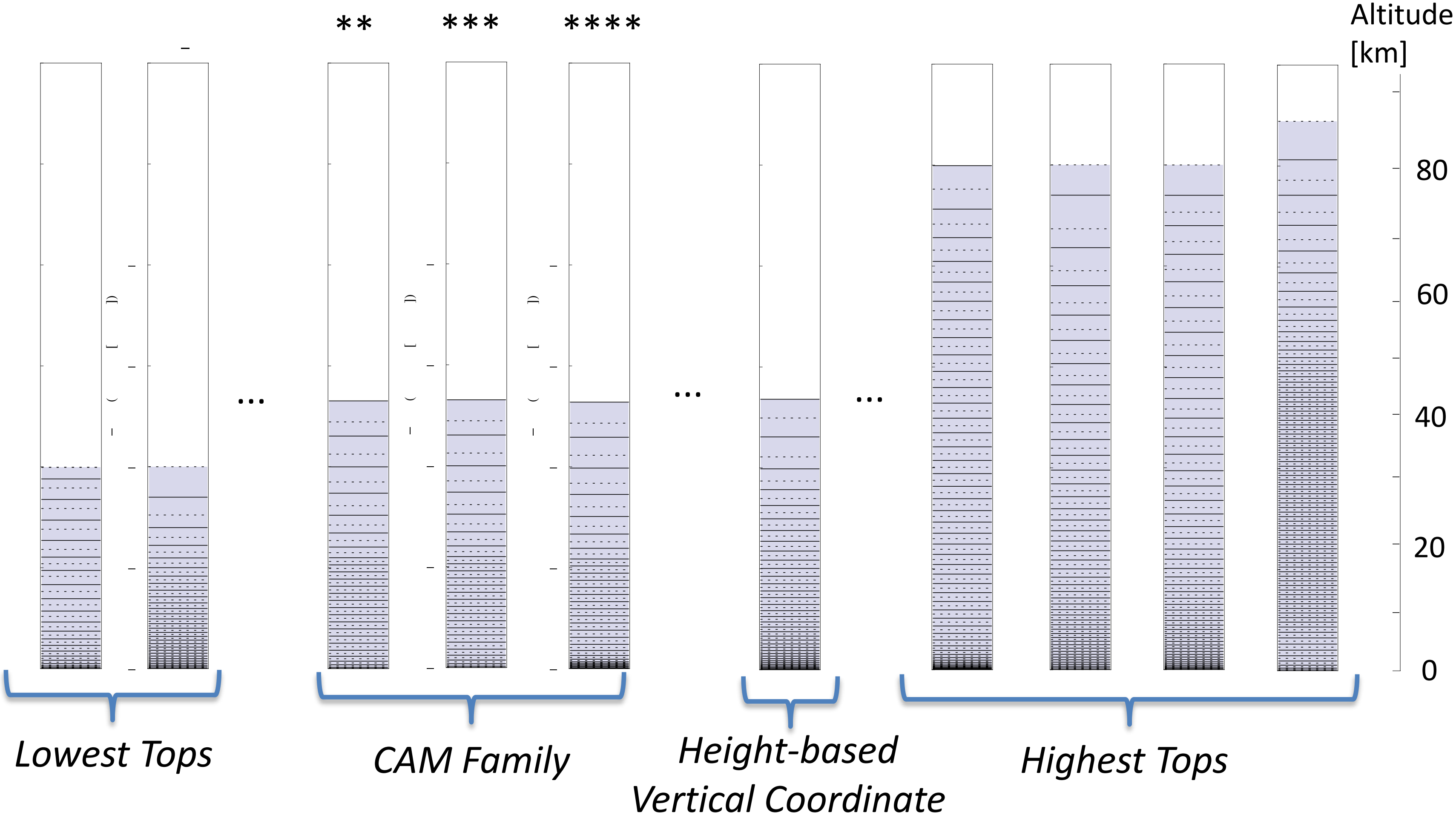
Levels for T, etc. (dotted lines) and E-flux, etc. (solid lines*) in 10 CMIP5 Models



*If p = 0 at top-most level, it's not shown and color-filling starts at the next level down.

**bcc-csm1-1 has exactly the same levels as CAM4.

***WACCM4 adds levels above CAM4's, reaching z ≈ 135 km.

****CAM5 adds to CAM4 lower levels, accommodating UW PBL / shallow convection.

Why tides care about model tops

- Introduction of “spurious resonances”
- Compensating errors: artificial enhancement of surface pressure response but less O_3 heating (Zwiers and Hamilton 1986, Hamilton et al. 2008)

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OSCILLATIONS IN ATMOSPHERES WITH TOPS

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ABSTRACT

Free and forced oscillations are compared for infinite and bounded atmospheres. Both continuous and two layer bounded atmospheres are considered. It is found that bounded atmospheres reproduce the free oscillations of the infinite atmosphere with accuracy that depends on top height—they, however, also introduce spurious free oscillations. In studying forced oscillations, the spurious oscillations of bounded atmospheres appear as spurious resonances. In general, bounded atmospheres do not properly respond to oscillations that propagate vertically.

1. INTRODUCTION

It is common practice to use simplified calculations in order to elucidate the nature of various more complicated atmospheric problems. As pointed out by Lindzen [3], a variety of such problems is included in the consideration of linearized perturbations on a static basic state (or one with a “constant” zonal flow). Such a study gives a remarkably good description of Rossby-Haurwitz waves, atmospheric tides, and other features. It is clear that various multilevel numerical models do not correspond precisely to the real atmosphere—especially as concerns vertical resolution and the upper boundary. If the above mentioned simplified calculations had been carried out for prototypes of the model atmospheres rather than of the real atmosphere, what would have resulted? In this paper we will consider the behavior of free and thermally forced linear perturbations on a static isothermal atmosphere for three different models:

1. An infinite atmosphere where disturbances are required to remain bounded as z (i.e., altitude) $\rightarrow\infty$. If the disturbances propagate vertically, a radiation condition is imposed at great altitudes.

1, they also produce spurious Rossby waves. Also, models 2 and 3 can badly misrepresent thermal tides. Model 2 has been included primarily because it is toward this model that multilevel models converge as the number of levels is increased.

2. EQUATIONS

We consider the problem of linearized oscillations in a rotating, isothermal, spherical gaseous envelope. For purposes of considering forced responses we will include a thermal excitation of the form

$$J=J(\theta,\varphi,t)e^{-x/3}, \qquad (1)$$

where θ=colatitude, φ=longitude, t=time, $x=z/H$, $H=RT_0/g$, R=gas constant, g=acceleration of gravity, T_0=basic temperature, and J=heating per unit time per unit mass. The particular vertical structure chosen for J is of no particular significance. It happens to be the structure for excitation by insolation absorption by water vapor (Siebert [5]). The oscillations that exist when $J=0$ are free oscillations; Rossby-Haurwitz waves are of this type.

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The Surface-Pressure* Signature of Atmospheric Tides in Modern Climate Models

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ABSTRACT

Although atmospheric tides driven by solar heating are readily detectable at the earth's surface as variations in air pressure, their simulations in current coupled global climate models have not been fully examined. This work examines near-surface-pressure tides in climate models that contributed to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC); it compares them with tides both from observations and from the Whole Atmosphere Community Climate Model (WACCM), which extends from the earth's surface to the thermosphere. Surprising consistency is found among observations and all model simulations, despite variation of the altitudes of model upper boundaries from 32 to 76 km in the IPCC models and at 135 km for WACCM. These results are consistent with previous suggestions that placing a model's upper boundary at low altitude leads to partly compensating errors—such as reducing the forcing of the tides by ozone heating, but also introducing spurious waves at the upper boundary, which propagate to the surface.

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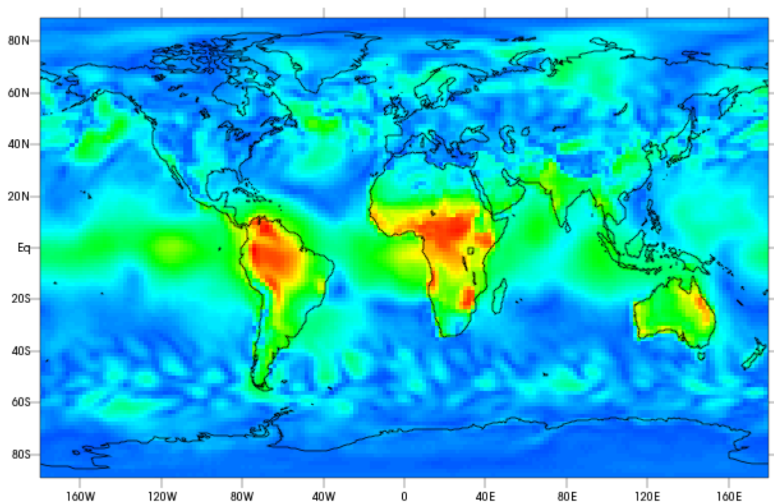
* Actually *sea-level* pressure in CMIP3 high-time-frequency output; changed to surface pressure in CMIP5 high-time-frequency output.

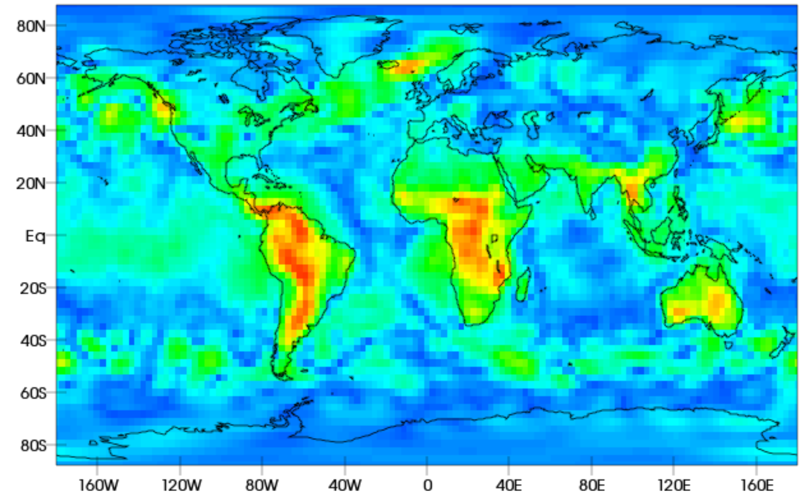
<u>Preliminary results from CMIP5: Diurnal tide amplitude</u>

Color scale runs from 0 (blue) to 3 (red) hPa

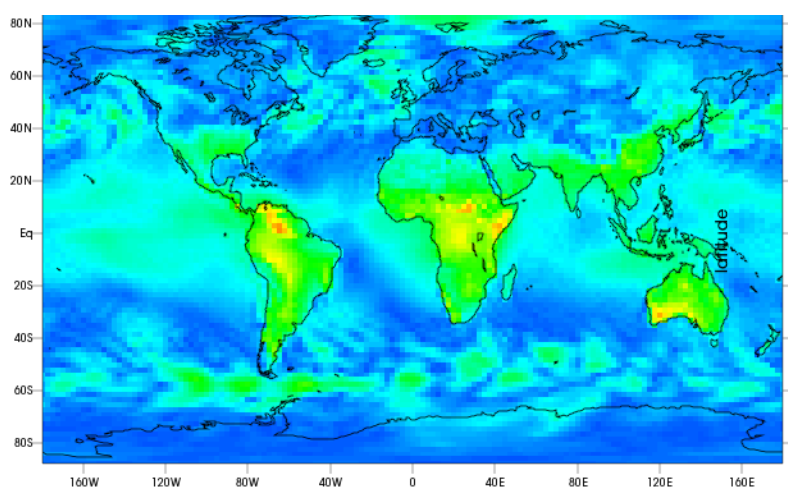
INMCM4: 30 km top



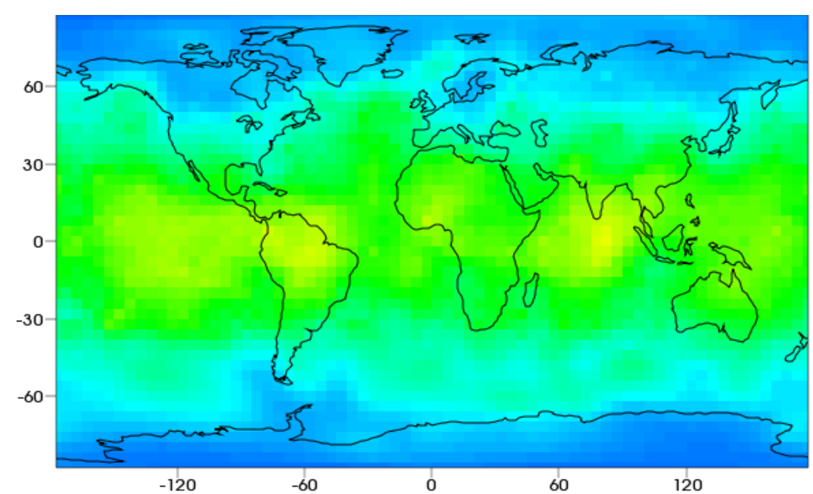
MIROC-ESM: 85 km top



WACCM4: 135 km top



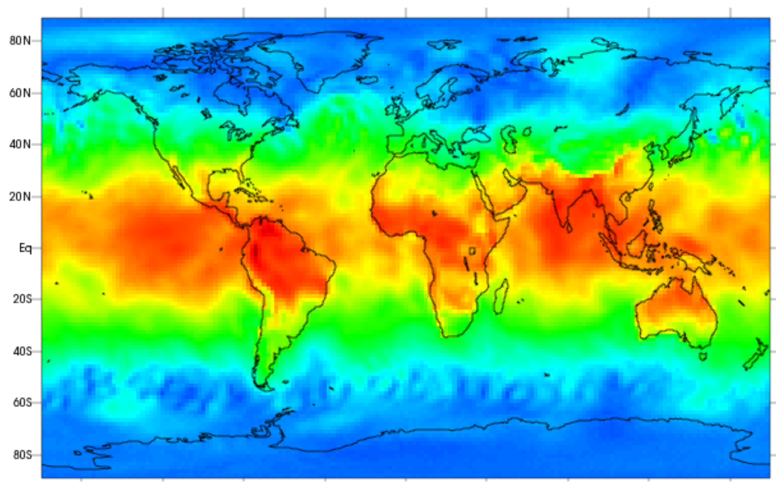
Observed (Dai and Wang 1999)



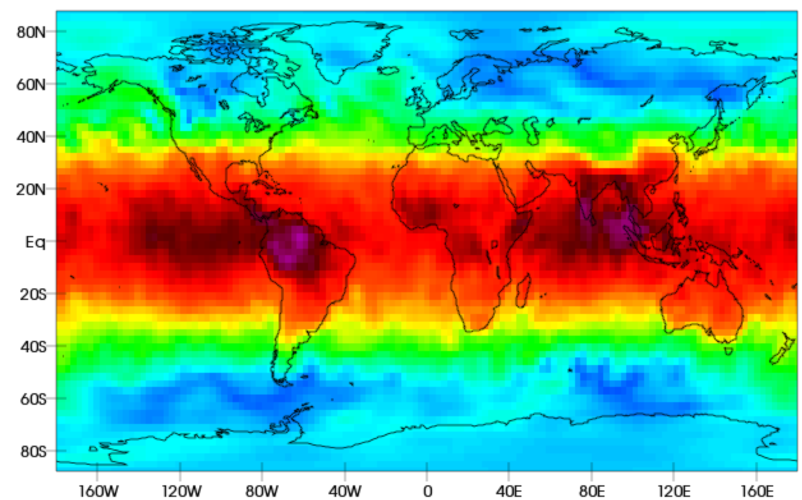
Preliminary results from CMIP5: Semidiurnal tide amplitude

Color scale runs from 0 (blue) to 2 (red-brown) hPa

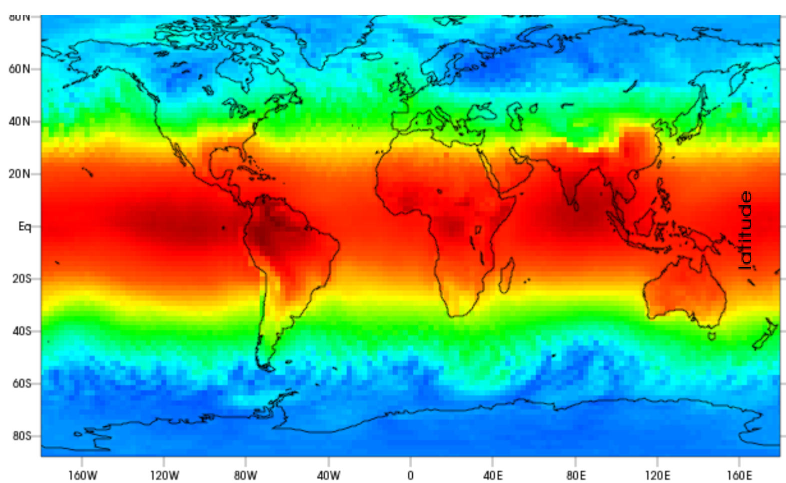
INMCM4: 30 km top



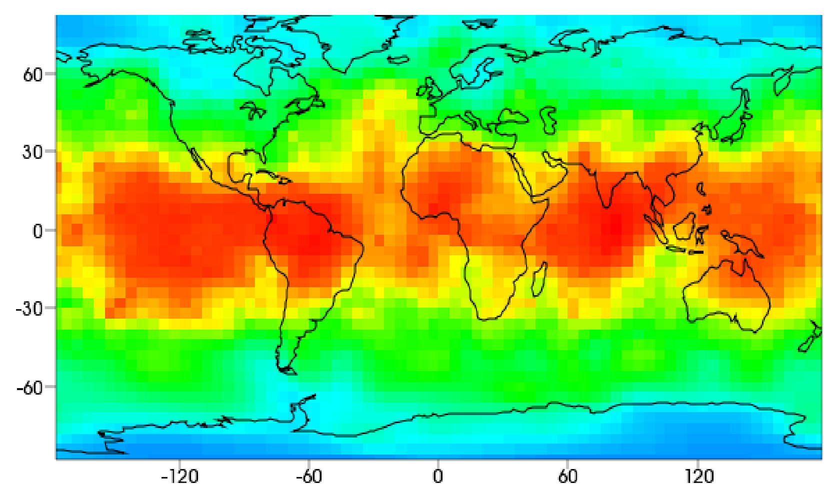
MIROC-ESM: 85 km top



WACCM4: 135 km top



Observed (Dai and Wang 1999)



Preliminary conclusion: CMIP5 output supports the "compensating errors" theory implied by CMIP3 and earlier GCM output.

Future directions: Beyond the surface-pressure signature:

- Connections with other near-surface fields
  - Available in CMIP5 3-hourly output: *p*, *T*, *u*, *v*, *q*, E-fluxes, precipitation, runoff and soil moisture near surface; total cloudiness (3hr data)
- Free atmosphere fields
  - Available in CMIP5 6-hourly output: *T*, *u*, *v*, *q* on all model levels (6hrLev data)
  - Good enough for diurnal but not semidiurnal harmonic
- Classical (linear) modeling with GCM vertical discretization
  - A diagnostic tool for understanding GCM simulation of tides
  - Extracting the forcing for each CMIP5 model will be difficult:
    - H_2O forcing from 6hrLev q on model levels
    - O_3 forcing from CMIP5 monthly mean output (includes O_3 *interpolated to 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 hPa, and "when appropriate," 7, 5, 3, 2, 1, 0.4 hPa* -- Amon data)
    - Latent heat release NOT archived at high time frequency. 3hr precip can be a surrogate; how to distribute vertically?
  - ... but is it necessary? Simple schematic choices can illustrate how such matters as lids and daily variations in rainfall can affect things.
- Related wave types
  - Planetary scale waves
  - Gravity waves