Global Scale Wave Model Version09 (GSWM-09) Description

GSWM-09 results provide the most recent comprehensive set of GSWM outputs that provide amplitudes and phases (UT of maximum at 0º longitude) of solar diurnal and semidiurnal tidal wind and temperature perturbations in Earth's atmosphere from pole to pole and from the ground to 245 km altitude. Their value lies in the use of realistic observational and empirical model data to specify the tropospheric and stratospheric forcing of the full spectrum of solar-synchronous (``migrating'' with the Sun) and solar-asynchronous (``non-migrating'') components of the tidal spectrum, along with diurnal mean winds and temperatures. Notably, GSWM-09 does not include tidal sources known to exist in the thermosphere above approximately 120 km altitude. GSWM-09 results are mainly intended 1) as a resource for the global array of ground-based radar and active and passive optical remote-sensing instruments that measure the dynamics of the atmosphere below about 110 km altitude, 2) for forcing the lower boundaries of thermosphere-ionosphere general circulation models, and 3) for the extrapolation of tidal structures to latitudes and heights where data are not available.

GSWM-09 was created as part of the dissertation research of Dr. Xiaoli Zhang in the Ann and H.J. Smead Department of Aerospace Engineering Sciences, University of Colorado at Boulder, in 2009:

> *Zhang, Xiaoli (2010). Atmospheric Tides Forced by Troposphere Heating: Longitudinal Variability of Upper Atmosphere Consequences, A thesis submitted to the Faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Department of Aerospace Engineering Sciences.*

and subsequently published in the open literature:

> *Zhang, X., J.M. Forbes, and M.E. Hagan (2010) Longitudinal variation of tides in the MLT region: 1. Tides driven by tropospheric net radiative heating, Journal of Geophysical Research, Space Physics, 115, A06316. doi:10.1029/2009JA014897*
>
> *Zhang, X. , J.M. Forbes, and M.E. Hagan (2010). Longitudinal variation of tides in the MLT region: 2. Relative effects of solar radiative and latent heating, Journal of Geophysical Research, Space Physics, 115, A06317. doi:10.1029/2009JA014898*

GSWM-09 follows on a series of earlier versions of the GSWM (e.g., Hagan and Forbes, 2002, 2003). The above Zhang et al. (2010) print publications are provided in this data repository, and include details about the GSWM, along with extensive references to earlier publications and earlier versions of the model, including Hagan and Forbes (2002, 2003). Also appended here are copies of tutorial-level descriptions of these earlier versions of the GSWM, with the list of references, that were previously archived in the now obsolete National Center for Atmospheric Research High Altitude Observatory (NCAR HAO) GSWM web site.

Guide to the GSWM-09 Data Files

GSWM09_all_components.tar --> GSWM09_all_components

This package includes data files containing monthly diurnal (_diur_) and semidiurnal (_semi_) amplitudes (am) and phases (ph, UT of maxima at 0 deg longitude) in zonal wind (U, m/s), meridional wind (V, m/s), vertical wind (W, m/s), temperature (T, K), relative density (R, no units), and geopotential height (H, m) for zonal wavenumbers -6 to +6 as a function of height, latitude and longitude, and an IDL script (read_all_tides.pro) to read the data with additional details about contents of the files.

GSWM-09_out_ascii

This directory includes data files containing the same information as in GSWM09_all_components, except in ascii form. The files in this directory use the convention D for diurnal; S for semidiurnal; E(W) for eastward(westward) followed by the integer zonal wavenumber corresponding to that tide. In these files the zonal mean winds (m/s) used in the tidal calculations appear early in the file. Also, the vertical coordinate X appears which is a non-dimensional stretched variable used in the calculations. The calculations were performed in in equal increments of $\Delta X = .025$, and consequently the Z vertical variable (altitude in km above Earth's surface) is given at unequal intervals of approximately 4 km. In these files, the variables U, V, W, and T are given in the form amplitude/phase.

GSWM09_recon_amph.tar --> GSWM-09

This package includes data files containing total (reconstructed from all migrating and non-migrating components) vector amplitudes (am) and phases (ph) of diurnal (D) and semidiurnal (S) tides in U (m/s), V (m/s), W (m/s), and T (K) at each 3D location on the globe, and an IDL script (READ_ascii.pro) to read the data with additional details about contents of the files.

Questions should be addressed to Dr. Xiaoli Zhang, Xiaoli.Zhang@Colorado.edu, zhangjc93122@gmail.com

A Numerical Model of Planetary Waves and Solar Tides in the Earth's Atmosphere

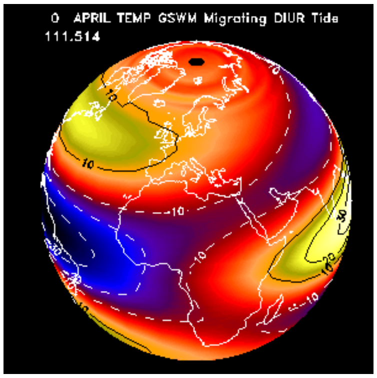
- Download tables of monthly GSWM-00 migrating diurnal and semidiurnal results.
- Download netcdf files of GSWM-02 results that mimic TIMED/CEDAR observations
- Download and plot GSWM-02/GSWM-09 results.

SCIENTIFIC BACKGROUND

Overview

Atmospheric solar tides are global-scale waves with periods that are harmonics of a 24 hour day. Migrating tidal components propagate westward with the apparent motion of the sun, so their zonal wavenumbers are identical to their frequency (in units of "tide maxima per day"). These components are thermally driven by the periodic absorption of solar radiation throughout the atmosphere, primarily the absorption of UV radiation by stratospheric ozone and of IR by water and water vapor in the troposphere.

It may not be immediately apparent from this description, but the migrating tides do not move relative to the sun, and they therefore act as a steady influence on the atmosphere. Their variation in time to an observer on Earth results from the Earth's rotation through this fixed excitation pattern. Seasonal variations in migrating tides occur as the Earth tilts within this pattern. The animation above illustrates this characteristic: see how a point on the Earth passes "underneath" the migrating tide, just as it passes "underneath" the rays of the sun through the day.



GSWM-98 24-hr Tidal Temperature Perturbation (K) for April, 111km. Alternating "Earth" vs. "Space" frame of reference(1.5M). Click to run animation.

These tides have been studied extensively with mechanistic models for more than 30 years. Ground-based and satellite-borne wind and temperature measurements reveal the strength and the variability of tidal signatures in the mesosphere and lower thermosphere (MLT; ~80-120km). These results confirm that tides often govern the dynamics of that region. Further, salient features of observational signatures agree with predictions of the mechanistic migrating tide models.

However, there are features in the measurements that remain unresolved by current numerical models based on either mechanistic approaches or first principles. Part of the discrepancy may be due to the contribution to the total tide of the non-migrating component. Non-migrating tidal components are also harmonics of a solar day, but unlike migrating tides, they do not have a zonal wavenumber equal to their frequency. This means that they may be stationary, or propagate either eastward or westward. Their driving sources appear to be dominated by the latent heat released by meteorological events in the troposphere.

Mechanistic Analysis of Atmospheric Tidal Waves

A mechanistic view of atmospheric tides breaks the problem into three components: Tidal forcing; the background propagation medium; and damping.

Two sources which drive the migrating tides were already mentioned: The UV energy which is absorbed periodically and re-radiated as heat by stratospheric O3, and IR energy absorbed by tropospheric H2O. Another thermal driver is the latent heat which is stored in water vapor and transported by complex meteorological activity, to be released again in other regions of the globe when the vapor precipitates. This source is theorized to be a less important influence on migrating tides, and more significant for non-migrating tides.

General atmospheric motion that underlies the tides comes from differences in net global heating between the northern and southern hemispheres. This difference results in a meridional energy exchange that causes wind jets, which characterize the unperturbed (background) atmosphere. The winds resulting from this equilibrium are referred to as "geostrophic." Background concentrations of water vapor and ozone also vary with altitude and location on the globe.

Tidal dampening may come from many strong and weak mechanisms. Other short-term or small-scale waves that originate according to terrain, called gravity waves, tend to disrupt tidal components by causing turbulence and accelerating the air along with the global-scale tide. Tides and gravity waves increase in amplitude with altitude due to the decreasing density of the atmosphere. Between 80-100km, at the mesopause, gravity waves become large enough to interfere with diurnal tides by "dragging" the background atmosphere to the phase speed of the tide, and by causing eddy currents that disrupt energy propagation.

Above about 90-100km in the lower thermosphere, the decreasing density of the air causes wave motion to be dominated by molecular diffusion rather than fluid flow, decreasing the efficiency of energy transfer, and further dampening the tides. Above the thermosphere, tides are dissipated by the radiation of energy into space (Newtonian cooling) and drag caused by the tides' acceleration of charged particles in the ionosphere.

Classical Solution

The "classical" solution simplifies the differential equations that describe the tidal motions, in order to make the problem more tractable for analytic approaches. The exclusion of dissipative terms, background winds, and latitudinal gradients in the background atmosphere renders the system of differential equations separable. Eliminating the derivatives with respect to time and longitude for the migrating tide and simplifying yields a single, separable partial differential equation for the perturbation geopotential in terms of altitude and latitude.

References

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DESCRIPTION OF GLOBAL SCALE WAVE MODEL

Major Features

- 2-dimensonal, linearized, steady-state assumptions
- Solves for non-migrating or migrating waves
- Realistic zonal mean atmosphere (a priori)|ASCII output format

Background Climatologies

- Realistic empirical wind, temperature, pressure, density, and ozone zonal mean backgrounds

Tidal Forcing

- Thermospheric absorption of solar extreme ultraviolet (EUV) radiation
- Absorption of solar radiation in the Schumann-Runge (S-R) bands and continuum in the mesopause region
- Strato-mesospheric absorption of solar ultraviolet (UV) radiation
- Tropospheric absorption of solar infrared (IR) radiation
- Tropospheric latent heating associated with deep convective activity (DCA)

Dissipation

- Ion drag
- Thermal conductivity
- Molecular diffusivity
- Eddy diffusivity
- Gravity wave drag

Description of Output

- Sample code to read ASCII output file.

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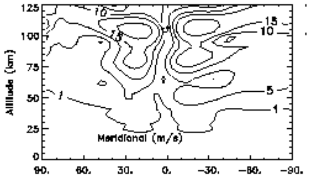
24-HOUR (DIURNAL) MIGRATING SOLAR TIDE

- Response to IR- and UV-Driven Thermal Forcing is Out of Phase, Reducing Amplitude of Perturbation
- Interactions with Gravity Waves in Mesosphere Reduces Amplitude in Lower Thermosphere

  - Higher Equinox
  - Amplitudes Amplitude Peaks occur in Mid- to Low Latitudes
  - ~25km vertical wavelength

Results: Select GSWM-98 Graphics and GSWM-00 ASCII Output (below)



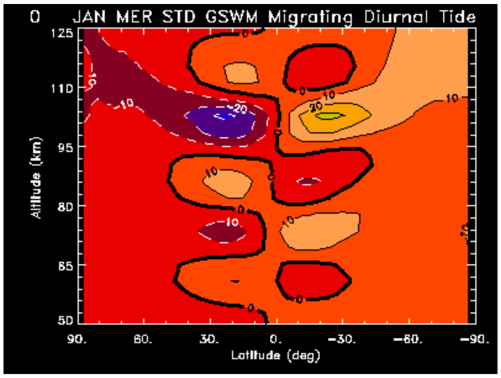
Zonal, Meridional, and Vertical Wind, & Temperature Perturbations, Diurnal

GSWM-98 8-Panel Amplitude and Phase Contour Plots on a Grid of Altitude vs. Latitude: Zonal, Meridional, and Vertical Wind, & Temperature Perturbations (8.5" X 11" .gif)

  - January (Solstice) in Color(25k) or in BW(18k)
  - April (Equinox) in Color(28k) or in BW(19k)
  - July (Solstice) in Color(26k) or in BW(18k)
  - October (Equinox) in Color(28k) or in BW(19k)

GSWM-98 Animated Diurnal Plots

  - January North Wind Color Contour .gif: Altitude vs. Latitude(180k)
  - April East Wind Color Contour .gif: Altitude vs. Latitude(223k)
  - April North Wind Color Contour .gif: Latitude vs. Longitude at 100km(176k)
  - April Temperature Color Contour .gif: Altitude vs. Latitude(202k)



Alt v. Lat Color Contour for January Diurnal Plots

GSWM-00 ASCII output files for Migrating Diurnal Calculations

- Pseudocode to read the files (FORTRAN)
- Procedure to read the files (IDL)
  - January (154k ASCII)
  - February (154k ASCII)
  - March (154k ASCII)
  - April (154k ASCII)
  - May (154k ASCII)
  - June (154k ASCII)
  - July (154k ASCII)
  - August (154k ASCII)
  - September (154k ASCII)
  - October (154k ASCII)
  - November (154k ASCII)
  - December (154k ASCII)

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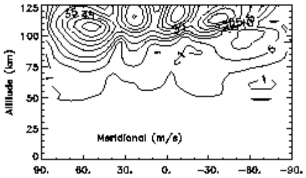
12-HOUR (SEMIDIURNAL) MIGRATING SOLAR TIDE

  - Smaller Amplitude Perturbations than Diurnal Tide in Mesosphere
  - Longer Wavelength than Diurnal Tide
  - Major Amplitude Peaks occur at Mid- to High Latitude, Shift with Season
  - Highest Amplitudes occur in Lower Thermosphere
  - ~50km vertical wavelength

Results: Select GSWM-98 Graphics and GSWM-00 ASCII Output (below)



Zonal, Meridional, and Vertical Wind, & Temperature Perturbations, Semidiurnal

GSWM-98 8-Panel Amplitude and Phase Contour Plots on a Grid of Altitude vs. Latitude: Zonal, Meridional, and Vertical Wind, & Temperature Perturbations (8.5" X 11" .gif)

  - January (Solstice) in Color(24k) or in Black and White(16k)
  - April (Equinox) in Color(25k) or in BW(16k)

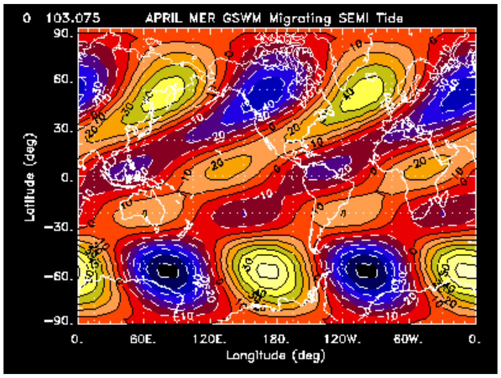
  - July (Solstice) in Color(23k) or in BW(15k)
  - October (Equinox) in Color(25k) or in BW(16k)

GSWM-98 Animated Semidiurnal Results

  - January North Wind Color Contour .gif: Altitude vs. Latitude(203k)
  - April East Wind Color Contour .gif: Altitude vs. Latitude(179k)
  - April North Wind Color Contour .gif: Latitude vs. Longitude at 100km(216k)
  - April Temperature Color Contour .gif: Altitude vs. Latitude(220k)

GSWM-00 ASCII output files for Migrating Semidiurnal Calculations

- Pseudocode to read the files (FORTRAN)
- Procedure to read the files (IDL)
  - January (154k ASCII)
  - February (154k ASCII)
  - March (154k ASCII)
  - April (154k ASCII)
  - May (154k ASCII)
  - June (154k ASCII)
  - July (154k ASCII)
  - August (154k ASCII)
  - September (154k ASCII)
  - October (154k ASCII)
  - November (154k ASCII)
  - December (154k ASCII)



Lat v. Lon Color Contour, April Semidiurnal Plots

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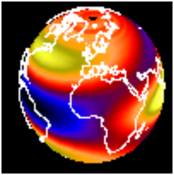
GRAPHICAL OUTPUT FROM COMBINED GSWM-98 MIGRATING HARMONICS

  - Semidiurnal Component Dominates in Lower Thermosphere
  - Semidiurnal Component Stronger at Higher Latitudes
  - Diurnal Component Dominates in Mesosphere near Equator/Subtropics
  - Seasonal Dependence due to Respective Diurnal, Semidiurnal Seasonal Shifts

January Meridional Latitude vs. Longitude at 100km.

GSWM References



Please also refer to references within the following documents

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Last Updated: 13 May 2003 by Maura Hagan: hagan at ucar.edu