WP-GITM User Manual

Xing Meng

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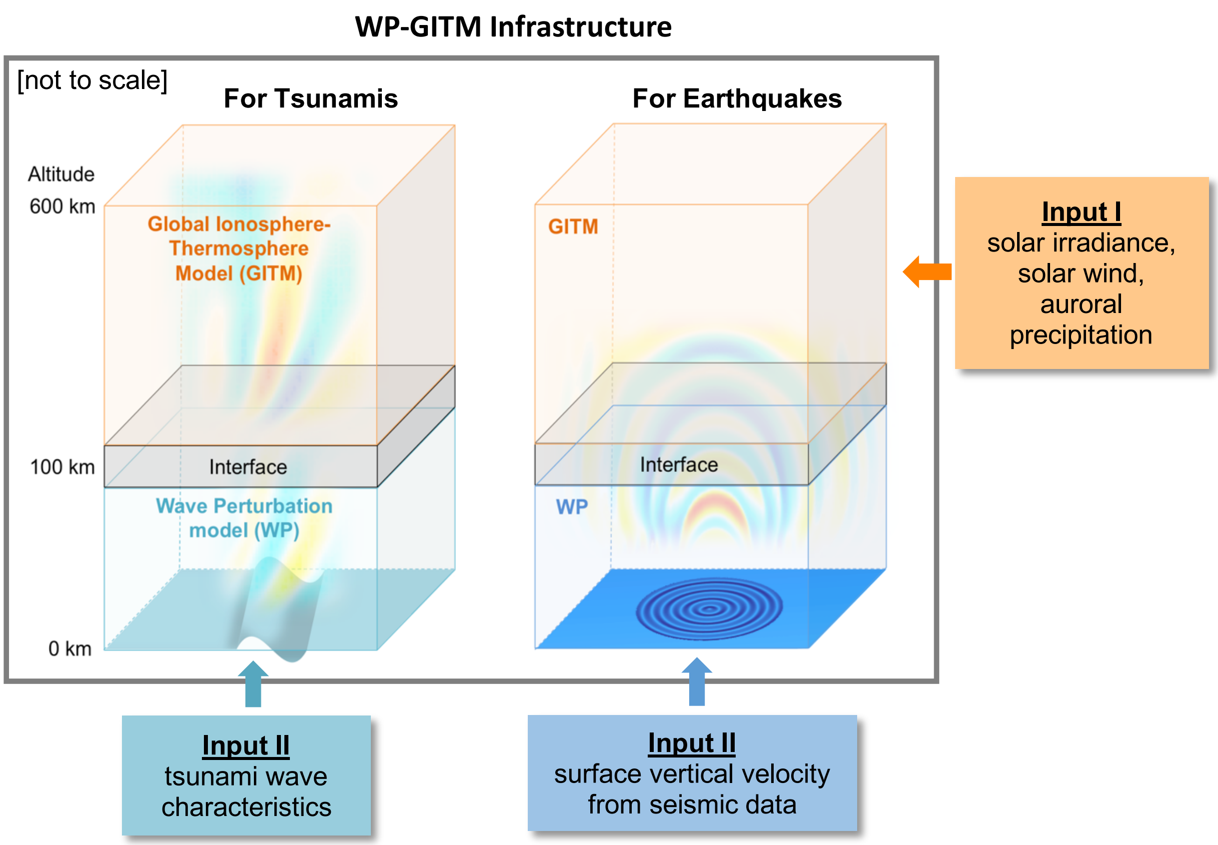
1. Introduction to WP-GITM

Wave Perturbation – Global Ionosphere Thermosphere Model (WP-GITM) is an extension of GITM to include atmospheric acoustic-gravity wave forcing generated from impulsive surface disturbances like tsunamis and earthquakes. WP-GITM consists of an analytical model WP [1,2] covering from 0 km altitude to the lower boundary of GITM [3], at around 100 km altitude, and GITM covering from about 100 to 600 km altitudes. The analytical model WP takes in surface disturbance characteristics, computes the acoustic-gravity waves as neutral density, velocity and temperature perturbations, and imposes the neutral perturbations to the lower boundary of GITM. The infrastructure of the WP-GITM is displayed below:



The current version of WP is capable of simulating 1) single-frequency plane acoustic-gravity waves from tsunamis, 2) multi-frequency plane acoustic-gravity waves from tsunamis, and 3) multi-frequency spherical acoustic-gravity waves from epicentral crustal movement during earthquakes. The next section describes how to use the above three capabilities.

2. How to Use WP-GITM

WP-GITM can be switched on with command `#USEBCPERTURBATION` in `UAM.in`. This command takes different parameters for different capabilities.

2.1 Single-Frequency Plane Wave

Assuming that the most significant ocean surface displacement during a tsunami is described by a single-frequency sine wave with constant characteristics, the resulting single-frequency plane acoustic-gravity waves can be solved by WP. To switch on this capability, use

```
#USEBCPERTURBATION
T                   UseBcPerturbation
0                   iTypeBcPerturb
(real)              PerturbTimeDelay
(real)              RefLon
(real)              RefLat
(real)              PerturbDuration
(real)              PerturbWaveSpeed
(real)              PerturbWaveDirection
(real)              PerturbWaveHeight
(real)              PerturbWavePeriod
```

`UseBcPerturbation = T` switches on WP, and `iTypeBcPerturb = 0` indicates the type of perturbation is single-frequency plane wave. The rest of the parameters are

`PerturbTimeDelay` – time delay in seconds from the simulation start time (specified by `#TIMESTART` in `UAM.in`) to the tsunami arrival at a user-defined reference location.

`RefLon` and `RefLat` – longitude and latitude, in degrees, of the reference location where the tsunami passes by. It can be anywhere in the path of the tsunami.

`PerturbDuration` – how long the tsunami lasts at the reference location, in seconds.

`PerturbWaveSpeed` – tsunami propagation speed in m/s.

`PerturbWaveDirection` – tsunami propagation direction in degrees counter-clockwise to the east direction. It can be a negative value.

`PerturbWaveHeight` – maximum ocean surface displacement in meters, i.e., the amplitude of the sine wave.

`PerturbWavePeriod` – tsunami (sine) wave period in seconds.

An example is provided in `srcTest/test.WPGITM/UAM.in.tsunami` for the 11 March 2011 Tohoku-Oki tsunami arrival at the US West Coast [1]. The reference solution, `solution_test_tsunami.pdf`, is obtained by subtracting the test result from the result of a baseline test with an identical UAM.in except `UseBcPerturbation = F`.

A note on `PerturbTimeDelay`: `PerturbTimeDelay` is the time delay from `#TIMESTART`. For a restart run, `PerturbTimeDelay` is the time delay from the start time of the initial run, not the start time of the restart run. Users need to make sure the perturbation is added at the desired time.

2.2 Multi-Frequency Plane Wave

A tsunami is better represented by a wave packet containing multiple frequencies. The wave packet, i.e., ocean surface vertical displacement waveform, can be obtained from actual measurement or extracted from tsunami models. The resulting multi-frequency plane acoustic-gravity waves can be solved by WP. To use this capability, specify

```
#USEBCPERTURBATION
T                   UseBcPerturbation
1                   iTypeBcPerturb
(real)              PerturbTimeDelay
(real)              RefLon
(real)              RefLat
(real)              PerturbDuration
(real)              PerturbWaveSpeed
(real)              PerturbWaveDirection
(string)            cSurfacePerturbFileName
```

`iTypeBcPerturb = 1` indicates the type of perturbation is multi-frequency plane wave. Other parameters are

`PerturbTimeDelay` – time delay in seconds from the simulation start time (specified by `#TIMESTART` in `UAM.in`) to the tsunami arrival at a user-defined reference location.

`RefLon` and `RefLat` – longitude and latitude, in degrees, of the reference location where the tsunami passes by. It is recommended to use the location where the ocean surface displacement waveform is obtained.

`PerturbDuration` – how long the tsunami lasts at the reference location, in seconds.

`PerturbWaveSpeed` – tsunami propagation speed in m/s.

`PerturbWaveDirection` – tsunami propagation direction in degrees counter-clockwise to the east direction. It can be a negative value.

`cSurfacePerturbFileName` – the name of an ascii file containing frequencies and Fast Fourier Transform (FFT) coefficients of the ocean surface vertical displacement waveform. The file should have the following format:

```
…
an arbitrary number of header lines
…
#START
   0.00000    5.28600000E-04    0.00000000E+00
   0.00500    1.02744401E-03    2.30385159E-03
   0.01000    8.64785101E-04   -8.72610330E-04
   …
```

The first column is frequency in Hz, the second column is the real part of the FFT coefficient at the given frequency, and the last column is the imaginary part of the FFT coefficient. A Python script, `srcPython/write_fftcoeff_wpgitm.py`, is offered to generate the FFT coefficient file in the required format from time series of ocean surface vertical displacement.

2.3 Multi-Frequency Spherical Wave

To describe the acoustic-gravity waves induced by epicentral crustal movement during earthquakes, WP assumes that these are spherical waves originated from a point source located at the epicenter and takes in the surface vertical velocity as input. The surface vertical velocity can be taken from seismic measurement near an epicenter. This capability is specified by

```
#USEBCPERTURBATION
T                   UseBcPerturbation
2                   iTypeBcPerturb
(real)              PerturbTimeDelay
(real)              RefLon
(real)              RefLat
(real)              PerturbDuration
(real)              EpicenterLon
(real)              EpicenterLat
(real)              SeisWaveTimeDelay
(real)              EpiDistance
(string)            cSurfacePerturbFileName
```

`iTypeBcPerturb = 2` indicates the type of perturbation is multi-frequency spherical wave. Other parameters are

`PerturbTimeDelay` – time delay in seconds from the simulation start time (specified by #TIMESTART in UAM.in) to the time of the earthquake main shock.

`RefLon` and `RefLat` – longitude and latitude, in degrees, of the location where the surface vertical velocity data is taken.

`PerturbDuration` – how long the surface motion lasts, in seconds. Typically, it is the duration of the most violent motion revealed by the surface vertical velocity data.

`EpicenterLon` and `EpicenterLat` – longitude and latitude, in degrees, of the epicenter.

`SeisWaveTimeDelay` – time delay in seconds from the main shock to the arrival of seismic waves at the location where the surface vertical velocity data is taken.

`EpiDistance` – the distance in meters from the epicenter to (`RefLon, RefLat`).

`cSurfacePerturbFileName` – the name of an ascii file containing frequencies and Fast Fourier Transform (FFT) coefficients of the surface vertical velocity waveform. The file has the same format as presented in Section 2.2 and can be produced by srcPython/write_fftcoeff_wpgitm.py given surface vertical velocity time series.

An example is provided in `srcTest/test.WPGITM/UAM.in.earthquake` for the 16 September 2015 Illapel earthquake [2]. The reference solution, solution_test_earthquake.pdf, is obtained by subtracting the TEC from the TEC of a baseline test with an identical `UAM.in` except `UseBcPerturbation = F`.

2.4 Grid Setting

To resolve acoustic-gravity waves with sufficient resolution and affordable computational resource, typical WP-GITM simulations only cover a local region instead of the entire globe. Recommended horizontal grid resolution 0.2 by 0.2 degrees for tsunami events and 0.05 by 0.05 degrees for earthquake events. Depending on the spatial scale of the waves to resolve, users may need to increase the vertical grid resolution by modifying `dHFactor` in `src/init_altitude.f90`.

3. Other Information

WP, including its interface to GITM, is developed by:

Xing Meng, JPL
Olga P. Verkhoglyadova, JPL
Attila Komjathy, JPL
Yue Deng, UT Arlington
Aaron Ridley, U Michigan

WP License:

Attribution:

For publishing any work using WP-GITM, please provide appropriate credit to the developers via citation or acknowledgement.

Contact:

Please contact Xing Meng (xing.meng@jpl.nasa.gov or xingm@umich.edu) for questions, issues, and bug reporting.

References

[1] Meng, X., A. Komjathy, O. P. Verkhoglyadova, Y.-M. Yang, Y. Deng, and A. J. Mannucci (2015), A new physics-based modeling approach for tsunami-ionosphere coupling, GRL, 42, 4736-4744, doi:10.1002/2015GL064610.

[2] Meng, X., O. P. Verkhoglyadova, A. Komjathy, G. Savastano, and A. J. Mannucci (2018), Physics-based modeling of earthquake-induced ionospheric disturbances. JGR Space Physics, 123, 8021-8038, https://doi.org/10.1029/2018JA025253

[3] Ridley, A. J., Deng, Y., & Toth, G. (2006), The global ionosphere-thermosphere mode, Journal of Atmospheric and Solar-Terrestrial Physics, doi:10.1016/j.jastp.2006.01.008.