

1. Introduction

History of Berkeley-Trent (BETR) Models

BETR-Research 3.0 is the newest member of the Berkeley-Trent (BETR) family of spatially-explicit multimedia chemical fate and transport models. The list below presents BETR family of models in chronological order together with the main references for each model:

- BETR North America (MacLeod et al. 2001)
- European Variant Berkeley-Trent (Evn-BETR) (Prevedouros et al. 2004)
- BETR-World (Toose et al. 2004)
- BETR-Global (Macleod et al. 2005)
- BETR-Global 2.0 & BETR-Research (MacLeod et al. 2011)
- BETR-Research 3.0 (2016)

BETR-Research

The first version of BETR-Research was based on BETR-Global 2.0, which is a well-developed and tested global fate model implemented in Visual Basic for Applications (MacLeod et al., 2011). BETR-Research was developed by re-implementing BETR-Global 2.0 in the Python programming language. The purpose of this re-implementation was to create a more flexible modeling platform using BETR-Global's model structure and taking advantage of efficient numerical packages in Python.

Figure 1 presents the global grid of BETR-Global 2.0 and BETR-Research at 15°×15° resolution. At this resolution the global environment is divided into 288 model regions.

Figure 2 is a representation of the environmental compartments included in the model regions of BETR-Global 2.0 and BETR-Research. The multimedia environment is represented as a collection of seven compartments in interaction with each other. Obviously, not all the environmental regions contain all of the seven compartments. The compartment volumes and other environmental characteristics are described for all the model regions. These descriptions are provided to the model within specifically formatted input files in BETR-Research.

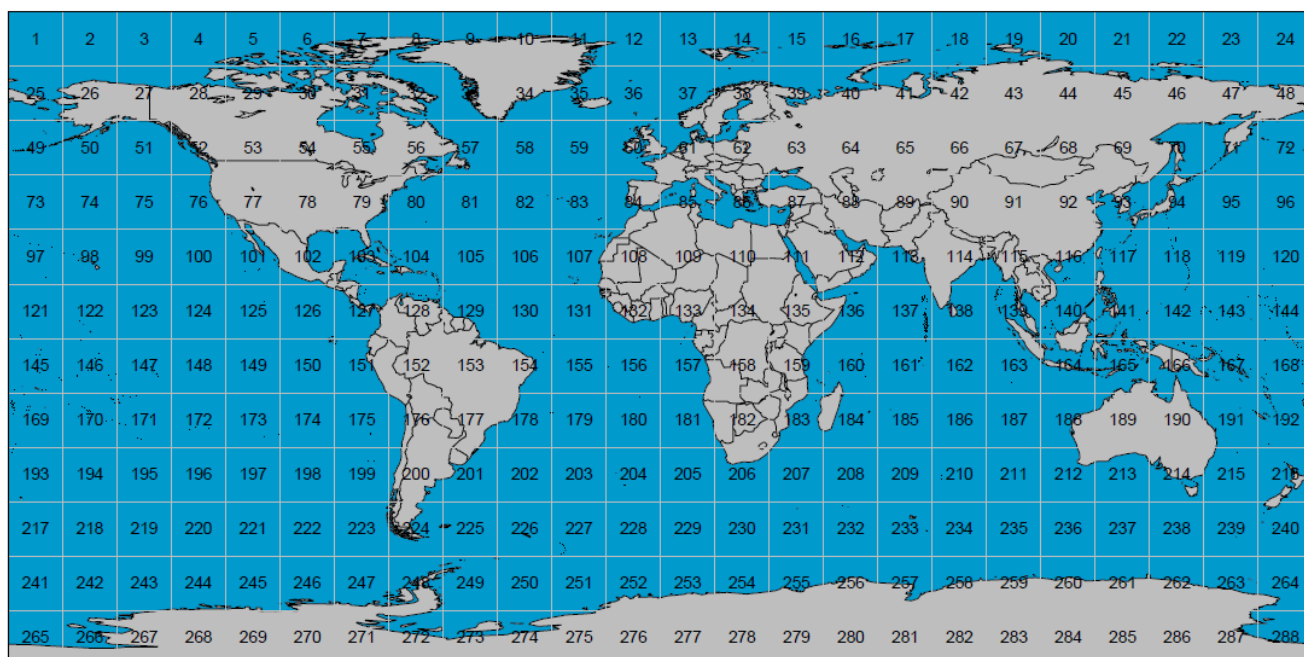


Figure 1: Global grid of *BETR-Research* at $15^{\circ} \times 15^{\circ}$ resolution, including nomenclature of its 288 model regions. Please note that the high resolution ($3.75^{\circ} \times 3.75^{\circ}$) *BETR-Research* has 4608 model regions.

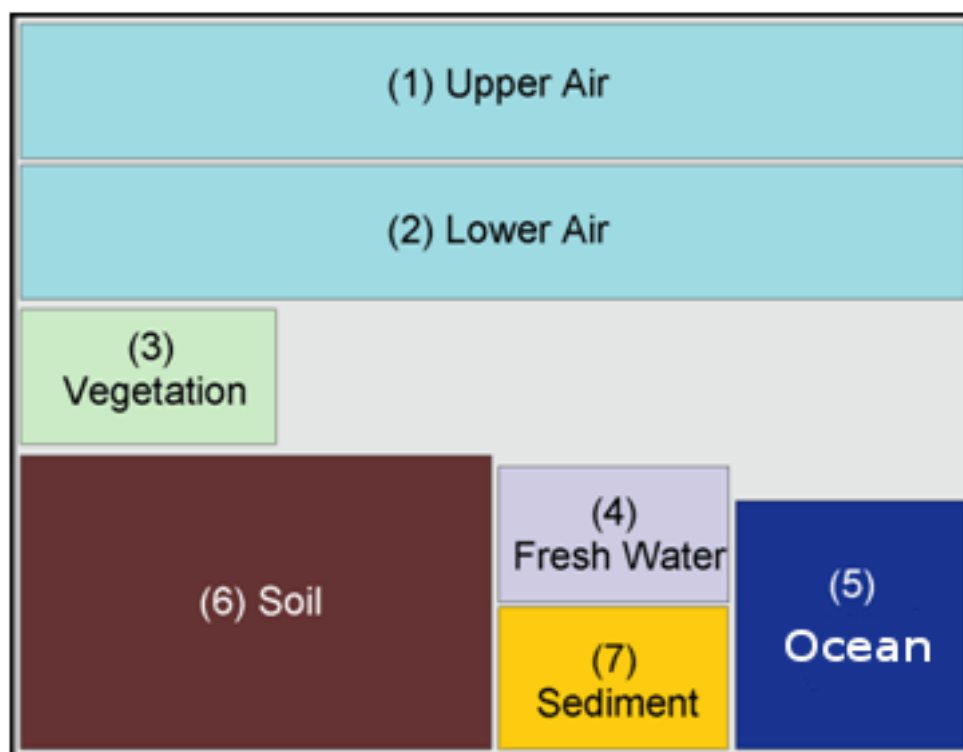


Figure 2: Environmental compartments included in the model regions of *BETR-Research*.

In recent years, the BETR-Research model source code has gone through several important modifications that lead to the new version: BETR-Research 3.0.

Main New Features in BETR-Research 3.0

- BETR-Research can run global model simulations in spatial resolutions of $15^{\circ}\times 15^{\circ}$, $7.5^{\circ}\times 7.5^{\circ}$ and $3.75^{\circ}\times 3.75^{\circ}$.
- Environmental databases that describe global atmospheric and oceanic flows, and climate properties have been updated; and now interannual variability can be accounted for.
- Some of the chemical fate process descriptions have been modified.
- A new algorithm for tracking chemical mass transfer fluxes throughout the simulations has been added.
- A fast differential equation solver library to be used in dynamic model simulations has been integrated to the model code.
- There are options for quantifying the contribution of secondary emissions to atmospheric concentrations.

Figure 3 presents the schematic description of mass transfer processes between and within model regions considered in BETR-Research 3.0.

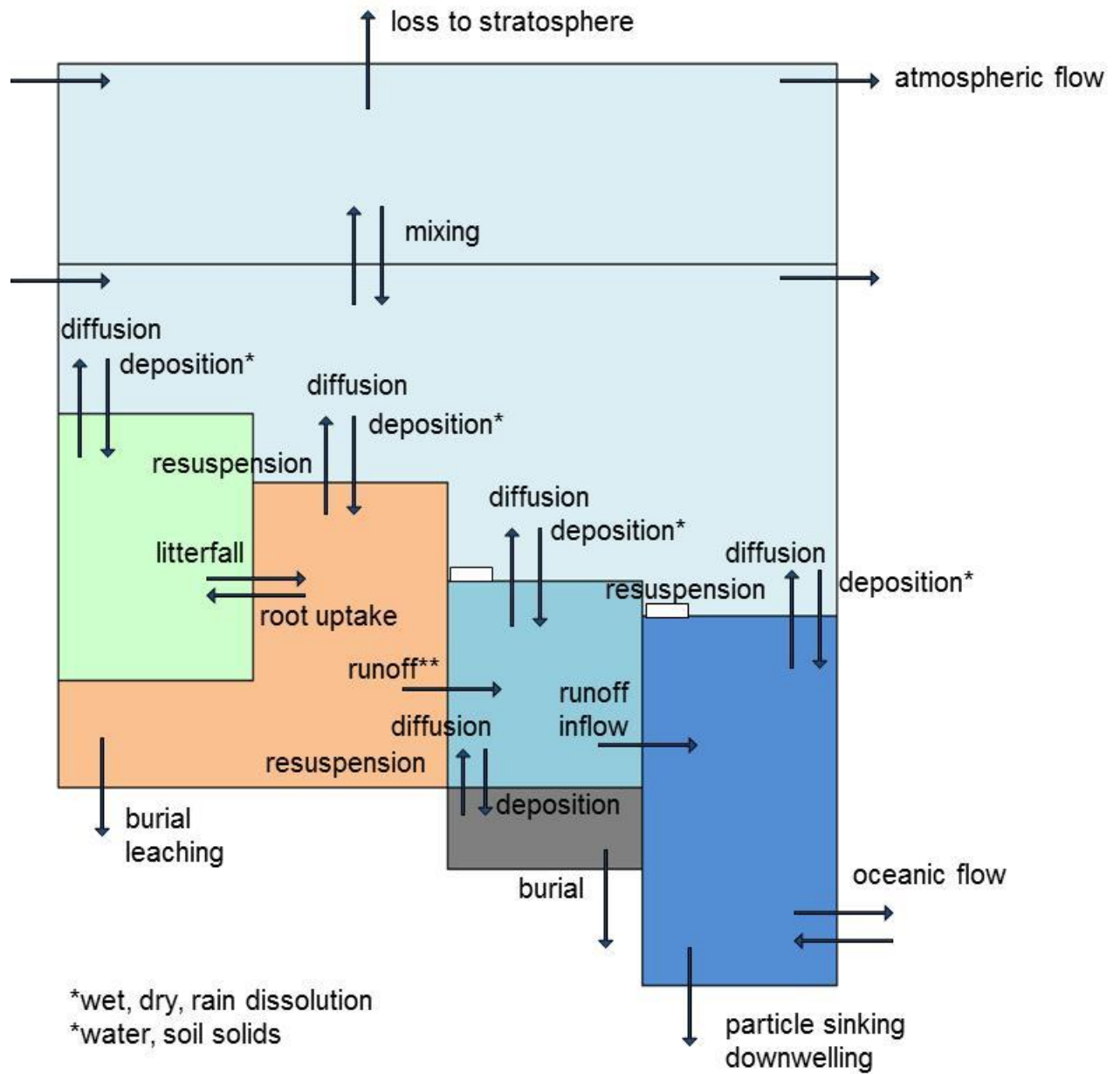


Figure 3: Mass transfers between and within the model regions of *BETR-Research*.

1. Installation

1.1. Installing the Required Software Packages

In order to run BETR-Research 3.0, a python interpreter and several add-on packages for scientific computing are required. BETR-Research 3.0 code is written in Python version 2 and all the add-on packages should also be compatible with Python 2.

Below is a list of required software packages:

- Python version 2.7.x (Currently BETR-Research 3.0 is not compatible with Python 3)
- Numpy (version 1.11.0 or later)
- Scipy (version 0.17.0 or later)
- netCDF4 (necessary for netCDF output)
- odespy (necessary for fast dynamic simulations)
- Matplotlib (not necessary but recommended to plot results).

It is possible to install the required software packages manually. However, it is also possible to install the Python 2.7 version of **Anaconda Python Distribution**, which is an open source data science platform. When Anaconda is installed, **Python interpreter**, **Numpy**, **Scipy** and **Matplotlib** packages are installed together. Anaconda's conda tool makes it very easy to install any additional packages.

netCDF4 can be installed through conda install using the following command in the terminal window:

```
conda install netcdf4
```

odespy can be installed through anaconda.org, using the following command in the terminal window:

```
conda install --c undy odespy=0.3.0
```

Using **odespy** as the differential equation solver module, substantially decreases the simulation time for dynamic simulations. However, we have not able to install and use the odespy module in Windows operating system at the time of writing this documentatin. However, it works perfectly on Linux machines

In order to easily visualize output in netCDF format, **Panoply** is recommended.

Downloading BETR-Research 3.0

After installing the required software packages, you can download BETR-Research 3.0 and start running your multimedia model simulations:

- Download BETR-Research 3.0 from the project website.
- Unpack BETR-Research 3.0 into an arbitrary directory.
- Go over the tutorials and start experimenting with the provided example run.files.

