PF3D: Technical Manual

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November 27, 2014

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1 Introduction

1.1 Purpose

The volcanic ash dispersion model FALL3D simulates the fallout of volcanic ash during explosive volcanic eruptions. It is used to simulate the dispersal of volcanic ash through the surrounding atmosphere and deposition at ground level. The purpose of this manual is to introduce a user of FALL3D to a scripted user-interface developed in python called PF3D. PF3D was developed jointly by Geoscience Australia (GA), the Australia-Indonesia Facility for Disaster Reduction (AIFDR), Badan Geologi (BG) and the Philippines Institute of Volcanology and Seismology (PHIVOLCS). PF3D consists of a series of Python scripts around the core dispersion model FALL3D which simplifies the modelling procedure. The manual details step-by-step instructions for installing and running simulations for deterministic (single eruption, single wind scenario), probabilistic (single eruption, multiple wind scenario) and forecast scenarios (forward modelling).

1.2 Scope

This technical manual provides instructions for installing and executing simulations with PF3D in a UNIX/Linux environment. It includes step-by-step instructions for creating and formatting the necessary input datasets, designing and executing an eruptive scenario and visualising the results. The package includes two validation scenarios based on historical volcanic eruptions in Indonesia and Papua New Guinea to familiarise users with the modelling procedure.

1.3 Audience

This resource is intended for geoscientists and natural hazard modellers who have a good understanding of the physics of explosive volcanic eruptions but little or no computer programming skills.

2 Background

The distribution of volcanic ash deposited during mildly to highly explosive eruptions has important safety, livelihood and economic implications for densely populated areas that are affected. A number of computational modelling tools have been developed in recent decades for forecasting the transport and deposition of volcanic ash. Geoscience Australia undertook a study to test and assess existing volcanic ash hazard computational models and evaluate each of these models for different purposes (e.g. deterministic, probabilistic and forecasting). Volcanic ash dispersal models can be loosely classified into two main groups based on their intended application.

1. Advection-diffusion-sedimentation (ADS) models which describe particle diffusion and sedimentation and can simulate volcanic ash fallout at ground level relative to an eruptive source. Examples of ADS models include FALL3D, HAZMAP, TEPHRA2 and ASHFALL.

2. Particle-tracking (PT) models which can simulate volcanic ash cloud height and extent at specific times. Examples of PT models include PUFF, HYSPLIT and VAFTD.

2.1 FALL3D

An existing ADS model has been identified, assessed and adapted for use here by government agencies mandated with understanding volcanic ash hazard. This model is the widely used, open source volcanic ash dispersal model FALL3D (Costa et al., 2006; Folch and Costa, 2010). FALL3D was developed jointly by the Instituto Nationale Geofiscia Vulcanologia (INGV) in Italy and the Barcelona Supercomputing Center (BSC) in Spain. FALL3D solves the ADS equation which governs the settling of ash particles through the atmosphere during a volcanic eruption, including aspects of ground level thickness, load and distribution. It has the ability to model ash dispersal in a fully 3-dimensional wind field that experiences changes in wind speed, direction and air temperature with altitude and over time. FALL3D also considers the interaction between topography and meteorological conditions and implications for the final ash footprint.

2.2 PF3D - a simplified user interface

A Python wrapper was developed jointly between GA, AIFDR, BG and PHIVOLCS which modifies the modelling procedure of FALL3D in order to simplify its use for those with little or no computer programming or computational modelling background (Bear-Crozier et al., 2012). Three modelling procedures are made available through a simplified user interface:

1. deterministic (single eruption, single wind)
2. probabilistic (single eruption, multiple wind)
3. forecasting (single eruption, predicted wind field up to 72 hours)

PF3D outputs are geospatially referenced in a standardised format which can be viewed and compared against other important datasets used for hazard and risk analysis including:

1. population data
2. building footprints
3. agricultural crop extents

Outputs produced by PF3D can be post-processed to contour volcanic ash hazard in terms of thickness (mm, cm, m), load (kg/m^2) or concentration (kg/m^3). Volcanic ash thickness, load (mass per unit area) or concentration (volume per unit area) will vary according to the volcanological, meteorological and temporal parameters of the simulated volcanic eruption. Validation of the underlying numerical model FALL3D against observed data from known historical eruptions represented a cruical phase in the two year development of PF3D. Validation, a measure of how accurately a model reproduces known volcanic ash deposits has important implications for the expected uncertainty in model outputs and the relative sensitivity of different input parameters (i.e wind speed versus granulometry (e.g. particle size, density)). FALL3D has been validated using observed data for a number of eruptions worldwide. GA undertook two validation scenarios and have included these in the PF3D distribution for users to reproduce.

3 Useful UNIX commands

PF3D is designed to run in a UNIX/Linux command line environment (e.g Ubuntu Linux). Although directories and output files can be viewed and edited in a Windows environment the source code is configured for execution on the UNIX/Linux command line only. The user must therefore become familiar with basic UNIX commands to execute a simulation. There are eight commands which are particularly useful when navigating through a UNIX/Linux environment using PF3D and these are summarised in table 1.

Command	**Description**	**Action**
cd $< \mathit{directoryname} >$	Change directory	The specified directory is opened
cd ..	Go up one directory	Close this directory and open the parent directory
cd ../..	Go up two directories	Keep adding $'/'$ so go up more than two directories
ls -l	List	Display a list of the contents of the current directory
pwd	Print working directory	She me the directory I am currently in
cp $< \mathit{filename} >< \mathit{directory} >$	Cope this file	Move them to this directory
cp $*. < \mathit{extension} >< \mathit{directory} >$	Copy all files with this extension	Move them to this directory
mkdir	Make new directory	New directory made here
python $< \mathit{script.py} >$	Calls python script $< \mathit{script.py} >$	Runs python script $< \mathit{script.py} >$
ln -s	Generate a link	A link or 'shortcut' is created to a directory or file

Table 1: Table of commonly used UNIX commands and descriptions of their function.

4 System requirements and dependencies

To run PF3D the following system requirements must be available:

- A standard PC with at least 4GB of RAM and a Linux operating system and;
- An internet connection (initial download only)

4.1 Downloading dependencies

If operating in a Ubuntu Linux environment (recommended) with a graphical user interface(e.g. NX client), the Ubuntu Synaptic Package Manager must be configured to locate the PF3D dependency programs using the procedure outlined below.

1. Open Ubuntu Linux and ensure an internet connection is established.
2. Select **System** from the toolbar menu.
3. Select **Administration**.
4. Select **Synaptic Package Manager**.
5. Select the tab **Repositories** and tick **all** the boxes (if not already checked).
6. Close **Synaptic Package Manager**.
7. Select **Applications** from the toolbar menu.
8. Select **Accessories** and then **Terminal** to open a new terminal.

4.1.1 Command line accessible dependencies

Instructions for downloading dependency programs which can be accessed through the command line (e.g. python-numpy):

1. Type **sudo apt-get install python-numpy**
2. Press Enter

The dependency program **python-numpy** will now be installed. Repeat for the following dependency programs.

- sudo apt-get install **python-scientific**
- sudo apt-get install **gfortran**
- sudo apt-get install **python-gdal**
- sudo apt-get install **gdal-bin**
- sudo apt-get install **libnetcdf-dev**

4.1.2 Manually configured dependencies

Instructions for downloading, configuring and building dependencies which must be installed manually. Download the latest version of each dependency program:

- **hdf5-1.8.14** http://www.hdfgroup.org/ftp/HDF5/current/src
- **netcdf-4.3.2** ftp://ftp.unidata.ucar.edu/pub/netcdf
- **netcdf4-python-1.1.1** https://github.com/Unidata/netcdf4-python/archive

Follow the instructions in the link below to configure and build these dependency programs:

https://code.google.com/p/netcdf4-python/wiki/UbuntuInstall

5 Installation

Instructions for creating a modelling environment and installing PF3D are detailed below. The procedure below includes suggested names for directories highlighted by the symbols ′ <′ and ′ >′. **Note: Do not type these symbols**.

1. Open a new terminal.
2. Create a sandpit (a modelling area) by typing **mkdir <sandpit>**
3. Change into the **sandpit** directory by typing **cd sandpit**
4. To download PF3D type (internet connection required):

   svn checkout https://pf3d.googlecode.com/svn/branches/fall3d_v6 pf3d −−username <gmail_address>

5. Change into the **pf3d** source code directory by typing **cd pf3d/fall3d_v6/source/aim**
6. To install PF3D type **python install_fall3d.py**

The installation of PF3D is now complete.

5.1 Environment variables

The user is required to configure three environment variables which determine the location of the FALL3D source code, the location of the PF3D source code and the directory where results are to be generated. The environment variables are named:

1. **FALL3DHOME** - the directory where the FALL3D distribution is installed
2. **PYTHONPATH** - the directory where the PF3D source code is installed
3. **TEPHRADATA** - the directory where the results are to be stored

These environment variables are specified in the system file named **.bashrc** located in the users home directory. To open your **.bashrc** file:

1. Open a new terminal. (**Important - must open a 'new' terminal**)
2. Type **gedit .bashrc** (or use your preferred editor - Options: nano,emacs etc)
3. First, scroll down to the line **export FALL3DHOME**

   e.g. export FALL3DHOME=/home/<username>/fall3d

4. Modify the path to the FALL3D source code if needed. An example is provided for 'alamba users'

   export FALL3DHOME=/home/<username>/fall3d

5. Scroll to the line **PYTHONPATH**

   e.g. export PYTHONPATH=/home/<username>/pf3d

6. Modify the path to the PF3D source code if needed. An example is provided for 'alamba users'

   export PYTHONPATH=/model_area/sandpits/<username>/pf3d/fall3d_v6/source

7. Lastly, scroll to the line **TEPHRADATA**

   e.g. export TEPHRADATA=/<home>/tephra

8. Modify the path to the where the results will be stored if needed. An example is provided for 'alamba users'

   export TEPHRADATA=/model_area/tephra

9. Save and **close** terminal window.

5.2 Testing for successful installation

A script has been designed to test the success of the installation procedure and configuration of the environment variables. The procedure for executing the test is described below.

1. Open a new terminal and navigate to your PF3D directory
2. Change to the directory **testing** by typing **cd testing**
3. Run the test script by typing **python test_all.py**

6 Validation scenarios

PF3D has been validated against a number of historical eruptions in order to measure how accurately the model reproduces known volcanic ash deposit extents, quantify the uncertainty in the modelled outputs and understand the relative sensitivity of the input parameters. Two validation scenarios are included in the PF3D distribution:

1. The 1840 eruption of Gunung Guntur, West Java Indonesia.
2. The 1994 eruption of Tavurvur, East New Britain Province, Papua New Guinea.

It is important that users run each validation scenario following the instructions provided and compare the generated outputs with the stored model outputs included in the reference data as part of the PF3D distribution. This serves to familiarise the new user with the modelling framework and provides another level of verification of successful installation.

6.1 Validation 1 - The 1840 eruption of Gunung Guntur, West Java Indonesia

This scenario was developed by N. Kartadinata (BG), A. Heriwaseso (BG), A. Bear-Crozier (GA), O. Nielsen (AIFDR), A. Costa (INGV), A. Folch (BSC), and K. Van Putten (AIFDR) at a workshop held at the AIFDR in Jakarta in July 2010. Observed data for volcanic ash thickness measurements associated with the 1840 eruption of Gunung Guntur were provided by N.Kartadinata and sourced from BG field investigations. Modelled outputs were compared with the observed data.

To run the scenario:

1. Open a new terminal.
2. Change to the directory **guntur** by typing **cd /sandpit/aim/validation/guntur**
3. To run the scenario type **python guntur1840.py**
4. To view the results navigate to **TEPHRADATA**
   e.g. **cd /<home>/<username>/<tephra>/guntur1840**
5. Compare the results with the example files provided for Guntur 1840 in figure 1.
   e.g. **cd /sandpit/aim/validation/guntur/referencedata/modeloutputs**

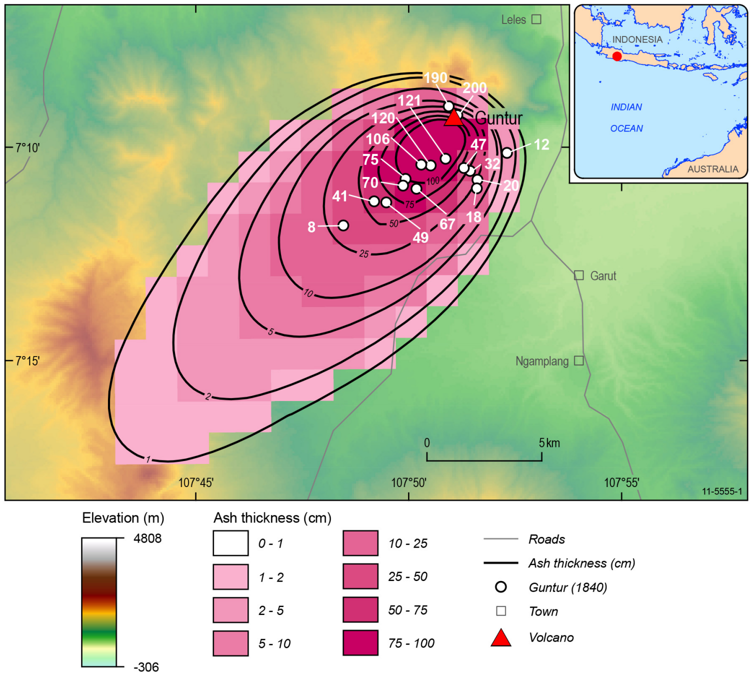

Figure 1: Stored model output for the 1840 eruption of Gunung Guntur showing good agreement with observed ash data collected at 15 localities. Observed ash thickness measurements(white dots; source N.Kartadinata), contours of volcanic ash thickness generated by PF3D (black lines), area affected by volcanic ash as a function of thickness generated by PF3D (pink).

6.2 Validation 2 - The 1994 eruption of Tavurvur, ENBP, Papua New Guinea

This scenario was developed by J. Goodwin and A. Bear-Crozier during the development of PF3D in 2010. Observed data for volcanic ash thickness measurements associated with the 1994 eruption of Tavurvur were provided by the Rabaul Volcanological Observatory and sourced from RVO field investigations. Modelled outputs were compared with the observed data (Blong and McKee, 1995; Blong, 2003).

To run the scenario:

1. Open a new terminal.
2. Change to the directory **tavurvur** by typing **cd /sandpit/aim/validation/tavurvur**
3. To run the scenario type **python tavurvur.py**
4. To view the results navigate to **TEPHRADATA**
   e.g. **cd /<home>/<username>/<tephra>/tavurvur**
5. Compare the results with the example files provided for Tavurvur in figure 2.
   e.g. **cd /sandpit/aim/validation/tavurvur/referencedata/modeloutputs**

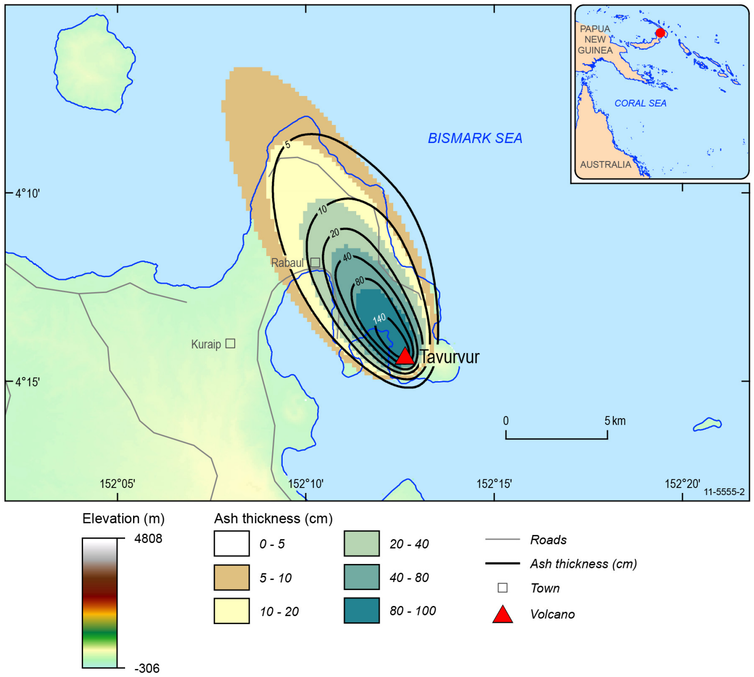

Figure 2: Stored model output for the 1994 eruption of Tavurvur showing good agreement with observed ash data reported by (Blong and McKee, 1995). Observed ash thickness measurements(white lines), area affected by volcanic ash as a function of thickness generated by PF3D (blue-beige).

7 Setting up a modelling area

PF3D has now been successfully downloaded and installed. A **sandpit** was created to store the source code and the installation has been verified by running the test script and both the validation scenarios included with the distribution. The user can now configure a **volcanic ash modelling** area. This will be the area in which the user will design and execute PF3D simulations. This volcanic ash modelling area will sit within the sandpit but remain separated from the source code directory **aim**.

7.1 Configuring a volcanic ash modelling area

A **volcanic ash modelling** area can be configured using the procedure outlined below.

1. Open a new terminal
2. Change directory into the **sandpit** by typing **cd sandpit**
3. Create a volcanic ash modelling directory by typing **mkdir volcanic_ash_modelling**

A volcanic ash modelling area has now been created in the sandpit and is ready to be populated with executable python scripts from the **templates** directory.

7.2 Template scripts

The **templates** directory contains example scripts which the user can copy into the **volcanic ash modelling** area, edit and run as needed. There are four template scripts:

1. **extract_wind_profiles.py** - used to create vertical wind profiles extracted from NCEP1 meteorological data
2. **convert_access_2_windprofile.py** - used to create vertical wind profile extracted from ACCESS-R meteorological data (forecast only)
3. **volcano.py** - the main project script used to run FALL3D
4. **create_hazard_map.py** - used to aggregate hazard outputs into probability of exeedance maps.

To copy these scripts to your **volcanic_ash_modelling** area:

1. Open a new terminal.
2. Change into the directory **templates** by typing **cd sandpit/aim/templates**
3. Print a list of the scripts in **templates** by typing **ls -l**
4. Copy all of these scripts to your **volcanic_ash_modelling** are by typing **cp *.py/sandpit/volcanic_ash_modelling**

All files with the extension *'.py'* will now have been copied to the **volcanic_ash_modelling** area specified. These files can be edited and executed as needed.

8 Meteorological data format

PF3D requires a meteorological input which characterises the prevailing wind conditions for volcanic ash dispersal. PF3D is configured for two meteorological data formats:

1. **NCEP/NCAR reanalysis-1** -Historical wind for deterministic and probabilistic modelling
2. **ACCESS-R** - Predictive wind data for forecast modelling

8.1 NCEP/NCAR reanalysis-1

The National Centre for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) reanalysis-1 global model incorporates observations and numerical weather prediction (NWP) model output from 1948 to present day. It is available as a global set of gridded weather data at a 2.5 degree by 2.5 degree (200 km) horizontal resolution and four times daily (00z, 06z, 12z and 18z) for 28 pressure levels figure 3. PF3D extracts a subset of meteorological variables from NCEP1 data (in netCDF format) including geopotential height, air temperature, u-wind and v-wind components across all pressure levels for a historical time period of interest in order to generate a wind profile(s) compatible with FALL3D
The procedure for downloading NCEP1 data is outlined below:

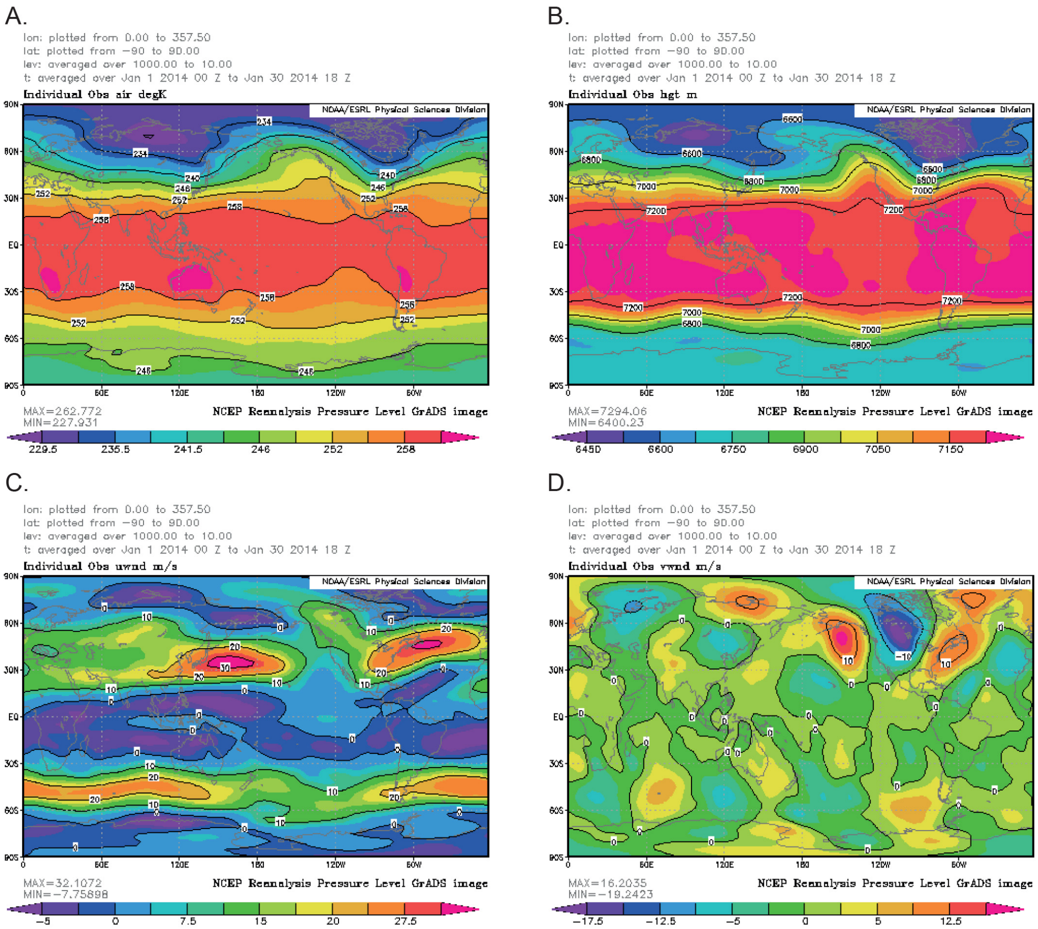

Figure 3: NCEP/NCAR reanalysis-1 data for the globe; A. Air temperature (deg K); B. Geopotential height (m); C. U-wind (m/s) and D. V-wind (m/s)

1. Open your prefered web browser and navigate to the website:
   http://www.esrl.noaa.gov/psd/data/reanalysis
2. Select from the list of dot-points:
   Pressure Level.
3. This page displays the meteorological variables available as 4 times daily, daily and monthly. PF3D requires the four times daily dataset for the variables listed above. Select the coloured map icon for **'Air temperature - 4 times daily'**, a new webpage will open.
4. Select the coloured map labelled **'Make a plot or subset'**
5. For **'Axis dimensions'** enter the cooridinates for the region of interest
   e.g. For Indonesia (total) enter **'late begin = 20N', 'lat end = 10S', 'lon begin = 95E' and 'lon end = 160E'**

6. For **’Other dimensions’** select **’1000.00 millibar’** from the pressure level list, hold down the shift key and **select all** the pressure levels (e.g 10 to 1000.00). This ensures that data for all pressures levels is captured.

7. Select the **start** and **end** dates in UTC time.

8. For **’Output options’** select **’Create a plot’**.

9. For **’Plot options’** select **’Plot on a white background’**, tick the box **’Colour plot’** and select **’Contour Fill’**.

10. Select **’Create plot of subset’**

11. An image of the requested variable for the requested domain at the requested time period is displayed. Verify the details are correct and right click on the image and select **’Save picture as’** to save a local copy for future reference.

12. Select **’FTP the data’** to start the download.

13. Rename the file **TMP.nc**

14. Repeat steps 3 - 13 for the variables **geopotential height, u-wind and v-wind** renaming the downloaded files as follows:

    - geopotential height - **HGT.nc**

    - u-wind - **UGRD.nc**

    - v-wind - **VGRD.nc**

8.2 ACCESS-R

The Australian Community Climate and Earth-System Simulator (ACCESS) is based upon the UK Met Office Unified Model system. ACCESS-R is the regional numerical forecast model operated by the BoM. It is run twice daily (00Z and 12Z) and provides forecast data out to 72 hours with a horizontal resolution of 12 km and 50 vertical layers figure 4. PF3D extracts a subset of meteorological variables from NCEP1 data (in netCDF format) including geopotential height, air temperature, u-wind and v-wind components across all pressure levels for a historical time period of interest in order to generate a wind profile(s) compatible with FALL3D.
The procedure for downloading ACCESS-R data is outlined below:

1. Open your preferred web browser and navigate to the Australian Bureau of Meteorology ACCESS-R ftp site (restricted access to registered users only).

2. Navigate down the list of netCDF files to the group of files with the naming convention:

   IDY25300.APS1.all-flds.all-lvls.YYYMMDDHH.HHH.pressure.nc4

   A description of the naming convention is provided in table 2.

3. Each file is timestamped with the forecast-hour in three hour increments up to a maximum of 72 hours.

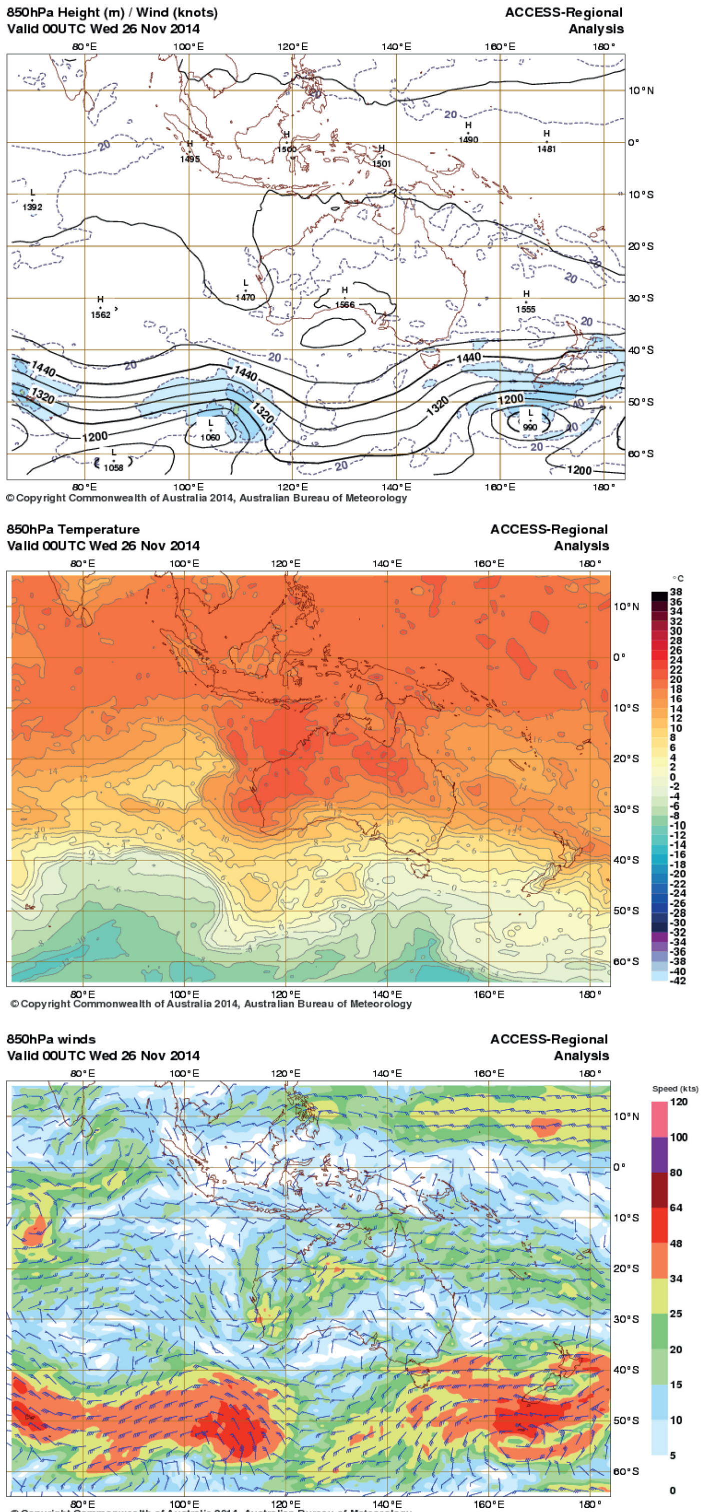

Figure 4: ACCESS-R data for the Australasian region (12 km resolution)

Field	Description
IDY25300	Grid file ID code which defines the model and the domain
APS1	File descriptor
all-flds	All meteorological fields available for the model, forecast hour and grid- coords
all-lvls	All levels available for grid-coords
YYYMMDDHH	Base-time: model run's UTC base time in the format YYYY=Year, MM=Month, DD=Day, HH=Hour (e.g. 2010122500)
HHH	Forecast-hour: Products validity time (model time step) as hours after base-time in the format HHH (e.g 000, 048, 240)
pressure	Descriptor of model grid co-ordinate level (e.g. surface, model, pressure)
.nc4	File-type extension (e.g netCDF4)

Table 2: Table of descriptors for fields associated with the ACCESS-R file naming convention.

4. Download for the time period needed (Warning: Each file is approximately 500 mb in size and will take time to download).

9 Meteorological data extraction

The PF3D distirbution includes four project scripts which are used individually or in combination depending on the modelling procedure chosen. These scripts are named:

1. **extract_windprofiles.py**
2. **convert_access_2_windprofile.py**
3. **volcano.py**
4. **create_hazard_map.py**

Input parameter names, descriptions, units, input options and example are detailed in the following subsections for each script.

9.1 Meteorological conversion script 1 (NCEP1 to PF3D)

Description and input options (where applicable) for each input parameter in **extract_windprofile.py**

BLOCK - LOCATION IN UTM COORDINATES OF THE VENT
These coordinates will be used to extract a vertical wind profile(s) at a location closest to the vent when the meteorological data format chosen is NCEP1.

- **vent_easting** - Location of the vent (UTM coordinates)

- **vent_northing** - Location of the vent (UTM coordinates)
- **vent_zone** - UTM zone of the vent
- **vent_hemisphere** - Hemisphere of the vent (Options: N or S)

BLOCK - TIME TO START EXTRACTION

The extraction start time indicates when the profile will begin and is usually the same time as the start of the eruption.

- **start_year** - Start year of the wind profile (YYYY)
- **start_month** - Start month of the wind profile (Options: 1, 2 . . 12)
- **start_day** - Start day of the wind profile (Options: 1, 2 . . 31)
- **start_hour** - Start hour of the wind the profile (Options: 0, 6, 12 or 18)

BLOCK - TIME TO END EXTRACTION

The extraction end time indicates when the wind profile will end and must be at least one hour after the input variable**post_eruptive_settling_duration** to ensure all the simulated volcanic ash has been deposited at ground level.

- **end_year** - End year of the wind profile (YYYY)
- **end_month** - End month of the wind profile (Options: 1, 2 . . 12)
- **end_day** - End day of the wind profile (Options: 1, 2 . . 31)
- **end_hour** - End hour of the wind profile (Options: 0, 6, 12 or 18)

BLOCK - PATH TO DIRECTORY OF NCEP FILES

This will indicate the path to the directory where the NCEP input data is stored.

- **NCEP_dir /<home>/<username>/<tephra>/<NCEP>** (a directory containing NCEP files)

The following files must be present:

1. **TMP.nc**
2. **HGT.nc**
3. **UGRD.nc**
4. **VGRD.nc**

BLOCK - PATH TO DIRECTORY OF GENERATED WIND PROFILES

This will indicate the pathway to the directory where the wind profiles generated from the NCEP data will be stored.

- **windfield_dir /<home>/<username>/<tephra>/<merged>** - directory of merged profiles (deterministic)

- **windfield_dir /<home>/<username>/<tephra>/<multiple>** - directory of multiple profiles (probabilistic)

BLOCK - WIND FIELD TYPE: OPTIONS - 'MULTIPLE' OR 'MERGED'

This script produces two types of ind profiles depending on the modelling procedure chosen.

- **wind_field_type** (Options: **'merged'** or **'multiple')**

9.2 Meteorological conversion script 2 (ACCESS-R to PF3D)

Description and input options (where applicable) for each input parameter in **convert_access_2_-windprofile.py**

BLOCK - VENT LOCATION (UTM)

- **x_coordinate_of_vent** - Location of the vent (UTM)
- **y_coordinate_of_vent** - Location of the vent (UTM)
- **zone** - UTM zone of the vent
- **hemisphere** - Hemisphere of the vent (Options: N or S)

BLOCK - PATH TO DIRECTORY OF ACCESS-R FILES (NETCDF4)

- **access_dir** - Path to location of ACCESS-R files (netCDF4)

10 Volcanological project script

Description and input options (where applicable) for each input parameter in
volcano.py, volcano_multiplewind.py and volcano_forecast.py

BLOCK - SHORT ERUPTION COMMENT TO APPEAR IN OUTPUT DIRECTORY

- **eruption_comment** - Name of output directory (will be added to timestamp)

BLOCK - TEMPORAL PARAMETERS (HOURS)

The wind profile determines the time limit of the simulated eruption (e.g. a 16 hour wind profile means the eruption cant exceed 16 hours). The user must input the eruptions start time relative to this wind profile in hours (e.g. 0 = eruption and wind begin together, 1 = eruption begins 1 hour after wind).

- **eruption_start** - Start time of the eruption (Given as the number of hours since time 0 hours - Default=0)

- **eruption_duration** - Duration of the eruption (Given as number of hours)

- **post_eruptive_settling_duration** - Duration of post-eruption settling of volcanic ash (Given as a number of hours)

BLOCK - LOCATION (VOLCANOLOGICAL INPUT FILE)

The topography (gidital elevation model - DEM)of the volcano and surrounding region are automatically read into PF3D and the user is only required define the vent location within that topography in UTM coordinates.

- **x_coordinate_of_vent** - x-coordinate (UTM) of the vent location (e.g. 439423; UTM zone extracted from DEM)

- **y_coordinate_of_vent** - y_coordinate (UTM) of the vent location (e.g. 9167213; UTM zone extracted from DEM)

BLOCK - VERTICAL DISCRETISATION OF THIS MODEL DOMAIN

The topography file (DEM) is used to define the horizontal extent of the model domain in the 'x' and 'y' directions. Vertical discretisation determines the vertical extent of the model domain in the 'z' direction. In combination they define the 3-dimensional space into which an eruption column is generated.

- **z_min** - Minimum altitude of vertical domain (Units: m)

- **z_max** - Maximum altitude of vertical domain (Units: m)

- **z_increment** - Division of vertical domain into discrete layers for volcanic ash dispersal

BLOCK - METEOROLOGICAL INPUT

There are three possible wind profile input formats: NCEP 'merged', NCEP 'multiple' and ACCESS The meteorological input will indicate where the wind data is stored as either a single (merged) profile, a directory of 'multiple' profiles or a single forecast profile (ACCESS).

- **wind_profile**

  Option 1:/<home>/<username>/<tephra>/<merged>/<merged.profile>(single profile)
  Option 2:/<home>/<username>/<tephra>/<multiple>/ (a directory of multiple profiles)
  Option 3:/<home>/<username>/<tephra>/<forecast>/<forecast.profile>(forecast_profile)

BLOCK - TERRAIN MODEL

The user must specify which topographic file to use (DEM) by providing the path to that file. PF3D will automatically read in the accompanying projection file (topography.prj). In this way the user can utilised a collection of DEM's at varying spatial resolutions.

- **topography_grid**

BLOCK - GRANULOMETRY

The grainsize data should be based on quantitative analysis of volcanic ash for the volcano being modelled or a suitable analogue (Bonadonna and Houghton, 2005; Legros, 2000; Carey and Sigurdsson, 1982). The values below will be derived from sieve data and calculation of the Inman parameters for grainsize distribution and sorting of volcanic ash deposits.

- **grainsize_distribution** - Gaussian (modal) or bi-Guassian (bi-modal)
- **number_of_grainsize_classes** - Number of particle classes PF3D will generate (Default=10)
- **mean_grainsize** - Calculate average grainsize (Units: phi)
- **sorting** - Calculated degree of sorting of volcanic ash particles
- **minimum_grainsize** - Calculated minimum grainsize (Units: phi)
- **maximum_grainsize** - Calculated maximum grainsize (Units: phi)
- **density_minimum** - Analytically determined density minimum (Units:kg/m^3)
- **density_maximum** - Analytically determined density maximum (Units:kg/m^3)
- **sphericity_minimum** - Analytically determined sphericity minimum (Value from 0 and 1)
- **sphericity_maximum** - Analytically determined sphericity maximum (Value from 0 and 1)

BLOCK - SOURCE

The source block is where the user defines the eruption style and magnitude (mildly explosive - highly explosive) by specifying the column height and/or a mass eruption rate (Carey and Sparks, 1986; Pyle, 1989; Sulpizio, 2005). FALL3D uses three source models for dispersing the volcanic ash particles: the possibilities are 'point', 'suzuki' and 'plume'. The user is required to choose a source model and input parameters as needed.

- **vent_height** - Height of the vent above sea level (Units: m)
- **source_type** - Models for source generation (Options: **point**,**suzuki** or **plume**)
- **mass_eruption_rate** - The rate at which magma is ejected from the vent(eruption intensity) (Units: kg/s, Options: whole number or 'estimate')
- **height_above_vent** - Height of the eruption column (Units: m, Options: whole number or 'estimate')
- **A** - Empirically derived Suzuki parameter for the position of neutral buoyancy with respect to column height. The greater the value for **A** the higher the mass sits in the simulated column (**Suzuki only** - Options: values typically between 1 and 4 where 1 = Strombolian and 4 = Plinian)

- **L** - Empirically derived Suzuki parameter for the spread of mass within the column with respect to the neutral buoyancy level. The greater the value for **L** the more horizontally dispersed across the column the mass will be. (**Suzuki only** - Options: values between 1 and 5 where 1 = Plinian and 5 = Strombolian)

- **height_or_MFR** - The **plume** model only requires the user to enter a column height or a mass flow rate (MFR). It will the calculate the other (**plume only** - Options: height or MFR)

- **MFR_minimum** - Minimum mass flow (eruption) rate (**plume only** - Units: kg/s)

- **MFR_maximum** - Maximum mass flow rate (**plume only** - Units:kg/s)

- **exit_velocity** - Magma exit speed (**plume only** - Units:m/s)

- **exit_temperature** - Magma exit temperature (**plume only** - Units: K)

- **exit_volatile_fraction** - Volatile fraction (what percentage of the melt is H_2O, CO_2 etc)(**plume only** - Units: percent)

BLOCK - FALL3D

This block is where the user sets the parameters for volcanic ash dispersal through the atmosphere following the initial eruption. FALL3D users one of four terminal velocity models for the settling of volcanic ash: the possibilities are **ARASTOOPOR**, **GANSER**, **WILSON** and **DELLINO**.

- **terminal_velocity_model** - Model for volcanic ash settling through the atmosphere (Options: **ARASTOOPOR**, **GANSER**, **WILSON** or **DELLINO**

- **vertical_turbulence_model** - Vertical turbulence experienced by the ash particles can be user-defined **'CONSTANT'** or derived from the wind profile **'SIMILARITY'** (Options: **CONSTANT** or **SIMILARITY**

- **horizontal_turbulence_model** - Horizontal turbulence experienced by the mass in the column can be user-defined **'CONSTANT'** or derived from the wind profile (Options: **CONSTANT** or **'RAMS'** - if **vertical_turbulence_model=CONSTANT** then **CONSTANT** else **RAMS**)

- **vertical_diffusion_coefficient** - Mixing of particles vertically within the simulated eruption column. (Only defined by user if **vertical** and **horizontal** turbulence models are **'CONSTANT'** else derived from wind profile (i.e **SIMILARITY/RAMS**). Options: High column (1-50) and low column (50-1000).

- **horizontal_diffusion_coefficient** - Mixing of particles horizontally within the simulated eruption column. (Only defined by user if **vertical** and **horizontal** turbulence is **CONSTANT** else derived from wind profile (i.e **SIMILARITY/RAMS**). Options: 1000 - 10000.

- **value_of_CS** - A constant value between 0.135 and 0.32 only used when horizontal turbulence is **RAMS** (**RAMS** only)

BLOCK - CONTOURING

PF3D generates raster files of volcanic ash thickness, load and concentration in the atmopshere. The model contours the values for viewing in GoogleEarth (kml) and ArcGIS or QGIS (shp). There are four options for customising the contour values.

1. **True** - the user can specify **'True'** and PF3D will calculate equally spaced breaks in contour values based on the spread of data (minimum and maximum) which gives the user a good first approximation of the results.

2. **Whole number** - the user can specify a whole number **e.g '5'** and PF3D will only generate that number of contours based on the spread of data.

3. **List of numbers** - the user can specify a list of numbers **[1, 2, 10, 50]** and PF3D will generate the number of contours intervals specified using the contour values specified in the list.

4. **False** - no contouring

- **thickness_contours** - Contouring volcanic ash thickness at ground level (Options: True, False, 'number' or '[list, of, numbers]')
- **load_contours** - Contouring volcanic ash load (kg/m^2) at ground level (Options: True, False, 'number' or '[list, of, numbers]')
- **thickness_units** - Units for contouring volcanic ash thickness (Options: mm, cm or m)

BLOCK - RUN MODEL USING SPECIFIED PARAMETERS

This block is to be configured **only** for probabilsitic scenarios as it configures the project script to use 'multiple' wind profiles and to generate 'multiple hazard outputs' which must then be post-processed by the script **create_hazard_map.py**.

- **windfield_directory** - Path to the multiple wind fields used for probabilistic analysis (This will be the directory created by the user after running the **extract_windprofile.py** script using the **'multiple'** option)
- **hazard_output_directory** - Name of or path to the hazard outputs directory (no need to create this folder as PF3D will do this in the location specified)

11 Hazard map generation script

Description and input options (where applicable) for each input parameter in **create_hazard_map.py**

BLOCK - VENT LOCATION IN GEOGRAPHIC COORDINATES (DECIMAL DEGREES)

This blockk described the location of the volcano

- **vent_easting** - Location of the vent (UTM coordinates)

- **vent_northing** - Location of the vent (UTM coordinates)
- **vent_zone** - UTM zone of the vent
- **vent_hemisphere** - Hemisphere of the vent (Options: N or S)

BLOCK - VALUES

Hazard maps generated by PF3D show probability (percent) of exceeding a threshold value of volcanic ash load (kg/m^2). The resulting maps contour the probability of exceedence given the multiple scenarios generated. One map is generated for each threshold value.

- **load_values** - Specify the volcanic ash load at ground level threshold values of interest (Options: a single threshold value (e.g. 0.1), a list of threshold values (e.g. [0.1, 1, 5]. The resulting map will contour percentage probability of exceedence in increment of 10 percent).
- **fl_values** - Specify the volcanic ash volume (concentration) in the atmosphere threshold values of interest (Options: a single threshold value (e.g. 0.002), a list of threshold values (e.g. [0.002, 00002]. The resulting map will contour percentage probability of exceedence in increment of 10 percent).

BLOCK - CONTOURS

PF3D contours both probability of exceedence **(PLOAD)** and accumulation rate in hours **(ISOCHRON)** for viewing and analysis in GoogleEarth (kml) and ArcGIS/QGIS (shp). There are four options for customising contour values (refer to Section 8.2.2).

- **ISOCHRON_contours** - Contours accumulation rate in hours(Options: True, False, 'number' or '[list, of, numbers]')
- **ISOCHRON_units** - Hours
- **PLOAD_contours** - Contour values for probability of exceedance maps (Options: True, False, 'number' or '[list, of, numbers]')
- **PLOAD_units** - Percent

BLOCK - LOCATION OF GENERATED WINDPROFILES, HAZARD MAPS AND CONTOURS

This directory should contain the multiple scenario outputs produced by **volcano.py** which will be used to create the hazard maps. The resulting hazard maps and contour files will be stored here at the completion of the analysis.

- **model_output_directory** - the path to the hazard outputs generated by **volcano.py**

12 Modelling procedure

There are three modelling procedures available to users of PF3D:

1. deterministic (single eruption, single wind)

2. probabilistic (single eruption, multiple wind)
3. forecasting (single eruption, predicted wind field up to 72 hours)

A description of each modelling procedure, the necessary input data, generated outputs and python scripts to be used are detailed in Table ?

12.1 Deterministic (single eruption, single wind)

This procedure details how to run a single volcanological scenario using a single wind field extracted using NCEP1-reanalysis meteorological data - a deterministic approach. This is a two step procedure as outlined below:

12.1.1 NCEP1 meteorological data extraction

1. Download NCEP1 data for the region and time period needed following the instructions in Section 8.1.
2. Open a new terminal
3. Navigate to your volcanic ash modelling directory by typing **cd sandpit/volcanic_ash_modelling**
4. Create a new directory with a name reflecting the volcano being simulated by typing **mkdir <volcano>**
5. Change into the volcano directory by typing **cd <volcano>**
6. Copy the scripts needed to execute a deterministic scenario from the templates folder. You can do this using a mouse if you have a GUI otherwise see below for the procedure using the command line:

   cp ../../pf3d/templates/extract_windprofile.py .

   cp ../../pf3d/templates/volcano.py .
7. Open the **extract_windprofiles.py** script by typing **gedit extract_windprofile.py**
8. Edit the input parameters to create a **'merged'** wind profile using the guidelines in Section 9.1.
9. Save and close
10. Run the script by typing **python extract_windprofiles.py**

The 'merged' windprofile needed for the deterministic scenatio has now been generated at the location specified by the user.

12.1.2 Deterministic scenario

1. Rename the **volcano.py** script by typing **mv volcano.py <volcano>.py**
2. Open the **volcano.py** by typing **gedit volcano.py**
3. Edit the input parameters as needed using the guidelines in Section 10.
4. Save and close
5. Run the script by typing **python <volcano>.py**

12.1.3 Monitoring progress of run

1. To monitor the progress of the run wait until the simulation is running FALL3D and the path to the Fall3d-ser.log file has been generated. this will be the last two- three lines currently displayed in the active terminal.
2. Using a mouse, highlight the full path to this log file in the terminal, right click and select 'Copy'. (Note - do not use Command C to copy as this will kill the run).
3. Open a new terminal, type **tail -f** and then right click and select 'Paste'
4. The log file will automatically open (if not press Enter to open the file)
5. Monitor the **'Elapsed time'** field to view the temporal progress of the run. It will indicated number of simulated minute elapsed and the percentage of the run complete. The file will update automatically as the run proceeds.

The deterministic scenario will run and the output files will be stored in the **TEPHRADATA** area. At the completion of the run, PF3D will printout the simulation time and the path the output files before returning the command line. Example maps for volcanic ash load and volcanic ash thickness at ground level generated using outputs for a deterministic scenario are shown in figure 5.

12.2 Probabilistic (single eruption, multiple wind)

This procedure details how to run a single volcanological scenario using multiple potential wind fields extracted from NCEP1-reanalysis meteorological data - a probabilistic approach. The results of each scenario are merged into a single hazard map(s) which characterise the probability of exceedence for a user-specified threshold value of volcanic ash load. This is a three step procedure as outlined below:

12.2.1 NCEP1 meteorological data extraction

1. Download NCEP1 data for the region and time period needed following the instructions in Section 8.1.
2. Open a new terminal

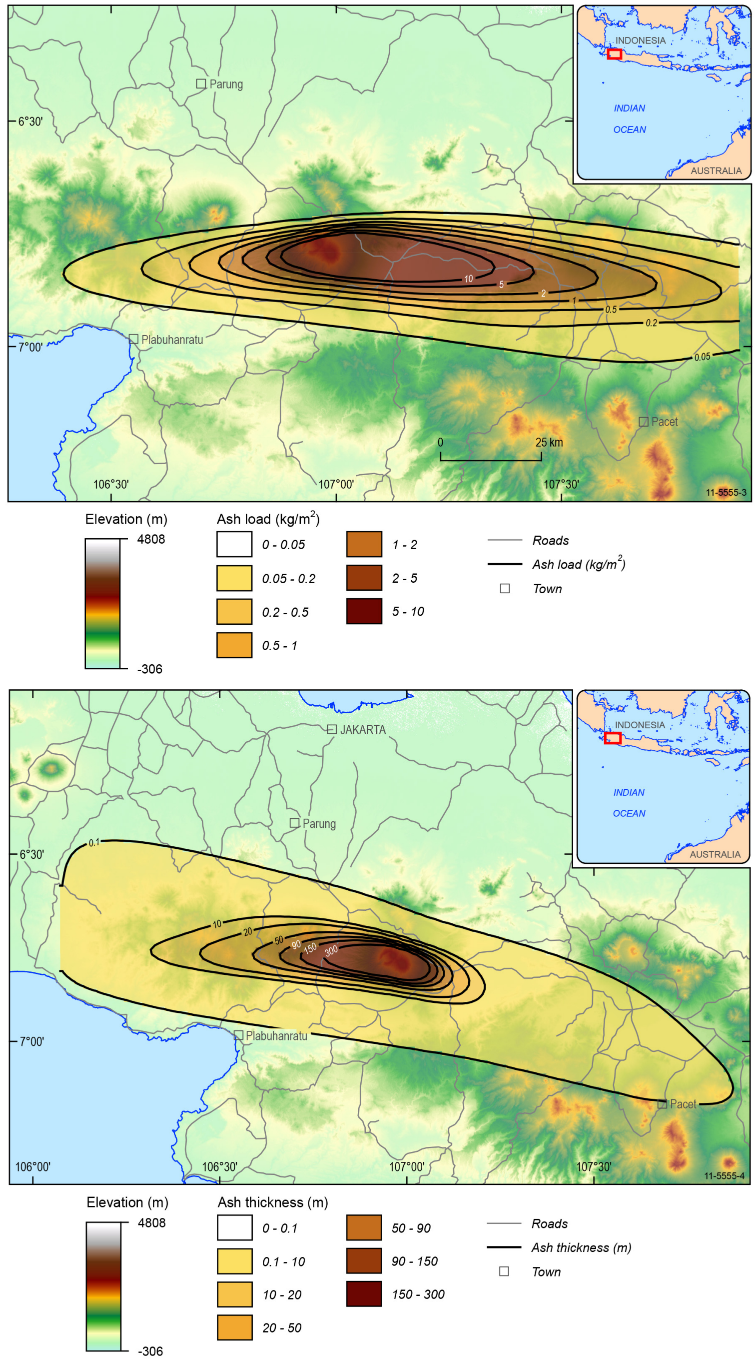

Figure 5: A. Example PF3D volcanic ash load map based on a deterministic scenario; B. Example volcanic ash thickness map based on a deterministic scenario

3. Navigate to your volcanic ash modelling directory by typing **cd sandpit/volcanic_ash_modelling**

4. Create a new directory with a name reflecting the volcano being simulated by typing **mkdir <volcano>**

5. Change into the volcano directory by typing **cd <volcano>**

6. Copy the scripts needed to execute a deterministic scenario from the templates folder. You can do this using a mouse if you have a GUI otherwise see below for the procedure using the command line:

   cp ../../pf3d/templates/extract_windprofile.py .

   cp ../../pf3d/templates/volcano.py .

   cp ../../pf3d/templates/create_hazard_map.py .

7. Open the **extract_windprofiles.py** script by typing **gedit extract_windprofile.py**

8. Edit the input parameters to create **'multiple'** wind profiles using the guidelines in Section 9.1.

9. Save and close

10. Run the script by typing **python extract_windprofiles.py**

The directory of 'multiple' wind profiles needed for the probabilistic scenario has now been generated at the location specified by the user.

12.2.2 Probabilistic scenario

1. Rename the **volcano.py** script by typing **mv volcano.py <volcano>_multiplewind.py**

2. Open the **<volcano>_multiplewind.py** by typing **gedit <volcano>_multiplewind.py**

3. Edit the input parameters as needed using the guidelines in Section 10.

4. Save and close

5. Run the script on single processor by typing **python <volcano>_multiplewind.py**

6. Run in parallel (across multiple processors and nodes) by typing

   mpirun -x FALL3DHOME -x PYTHONPATH -npernode <'number of processes'> –host node<node number>,node<node number> python <volcano>_multiplewind.py

The probabilistic scenario will run and the output files will be stored in the **hazard_output_directory** location specified by the user. At the completion of the run, PF3D will return the command line.

12.2.3 Create hazard maps

1. Open the **create_hazard_map.py** script by typing **gedit create_hazard_map.py**
2. Edit the input parameters as needed using the guidelines in Section 11.
3. Save and close
4. Run the script by typing **python create_hazard_map.py**

Example maps for volcanic ash load and volcanic ash thickness at ground level generated using outputs for a probabilistic scenario are shown in figure 6.

12.3 Forecasting (single eruption, predicted wind field up to 72 hours)

This procedure details how to run a single eruption scenario using forecast (predicted) meteorological data generated by the Australian Bureau of Meteorology's ACCESS-R model. PF3D converts ACCESS-R data into a FALL3D compatible format and integrates it for a predictive scenario up to 72 hours - a forecasting approach.

12.3.1 ACCESS-R meteorological data extraction

1. Download ACCESS-R data for the region and time period needed following the instructions in Section 8.2
2. Open a new terminal
3. Navigate to your volcanic ash modelling directory by typing **cd sandpit/volcanic_ash_modelling**
4. Create a new directory with a name reflecting the volcano being simulated by typing **mkdir <volcano>**
5. Change into the volcano directory by typing **cd <volcano>**
6. Copy the scripts needed to execute a deterministic scenario from the templates folder. You can do this using a mouse if you have a GUI otherwise see below for the procedure using the command line:

   cp ../../pf3d/templates/convert_access_2_windprofile.py .

   cp ../../pf3d/templates/volcano.py .
7. Open the **convert_access_2_windprofile.py** script by typing **gedit convert_access_2_windprofile.py**
8. Edit the input parameters to create a **forecast** wind profile using the guidelines in Section 9.2.
9. Save and close
10. Run the script by typing **python convert_access_2_windprofile.py**

The 'forecast' wind profile needed for the forecast scenario has now been generated at the location specified by the user.

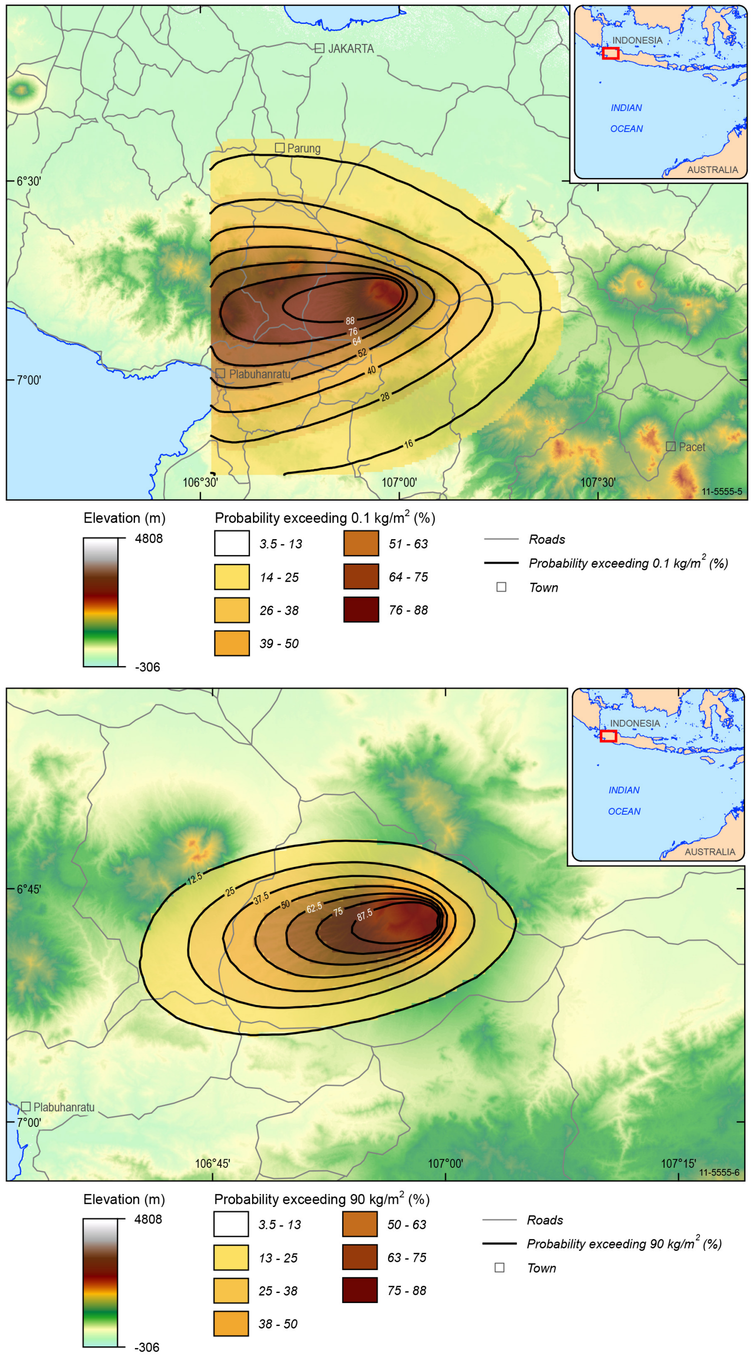

Figure 6: Example PF3D probability of exceedence maps based on a deterministic scenario for user-specified volcanic ash load thresholds of interest A. 0.1 kg/m^2 (significant damage to agricultural crops; B. 90 kg/m^2 (surficial damage to buildings)

12.3.2 Forecast scenario

1. Rename the **volcano.py** script by typing **mv volcano.py <volcano>_forecast.py**
2. Open the **<volcano>_forecast.py** script by typing **gedit <volcano>_forecast.py**
3. Edit the input parameters as needed using the guidelines in Section 10.
4. Save and close
5. Run the script by typing **python <volcano>_forecast.py**
6. Refer to Section 12.1.3 for instructions on monitoring the progress of the run.

Example maps for volcanic ash thickness at ground level and concentration in the atmosphere (kg/m^3) generated using outputs for a forecast scenario are shown figure 7.

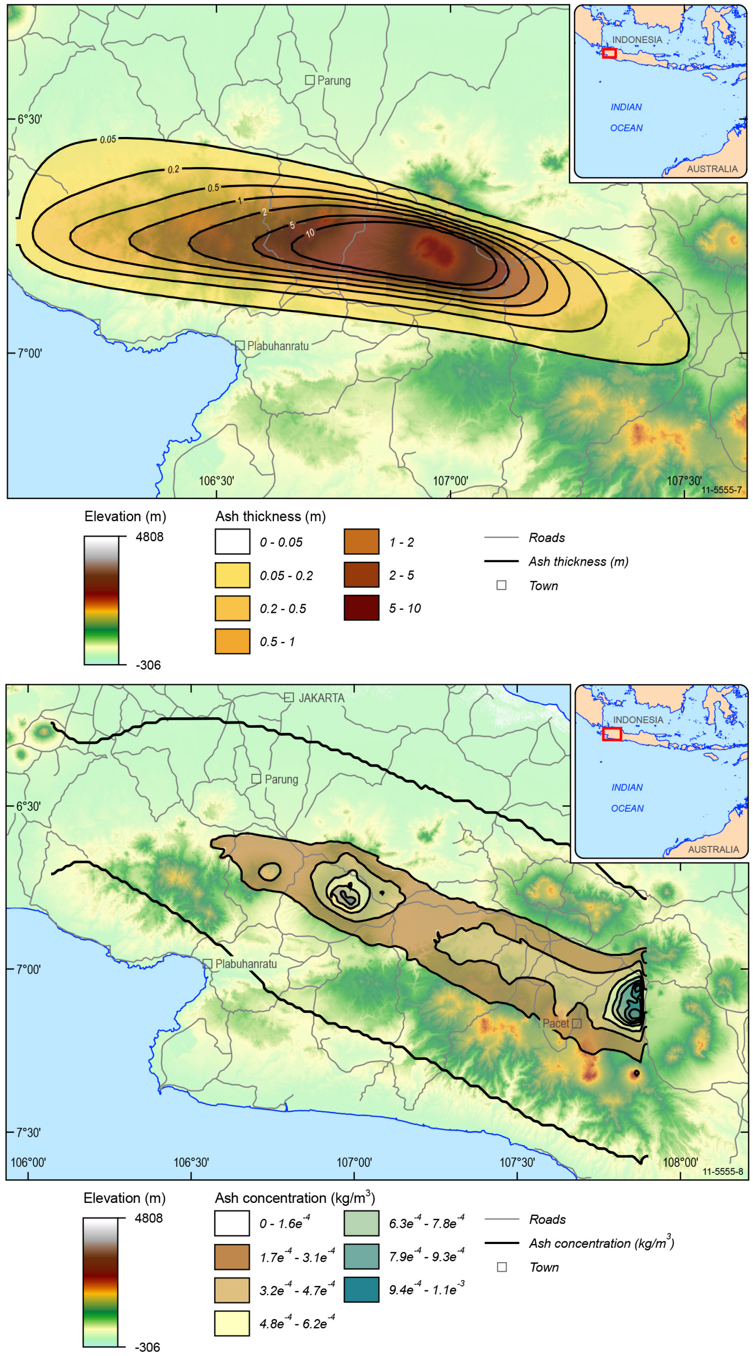

Figure 7: Example PF3D maps based on a forecast scenario A. volcanic ash thickness at ground level (m) B. Volcanic ash concentration in the atmosphere at FL300 (30,000 ft) (kg/m^3)

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13 Acknowledgements

The author greatly acknowledges technical contributions in the development of this manual made by but not limited to O. Nielsen (AIFDR), N. Kartadinata (BG), A. Heriwaseso (BG), P.J Delos-Reyes (PHIVOLCS), M. H. Mirabueno (PHIVOLCS), K. Van Putten (AIFDR), A. Folch (BSC), A. Costa (INGV) and J. Goodwin (GA). The author also gives thanks to T. Dhu (AIFDR), J. Sexton (GA) and A. Simpson (World Bank) for feedback provided during the development of this resource. Finally the authors would like to thank colleagues at Geoscience Australia for feedback provided on this manual.

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