Structured and Unstructured Grid
Relocatable Ocean Platform
for Forecasting

SURF-NEMO User Guide

Version 1.02

Francesco Trotta, Nadia Pinardi, Lucio Quadrani

Table of contents

1. Welcome to the SURF-NEMO User Guide

Welcome to the user guide for the structured grid component of the **Structured and Unstructured Grid Relocatable Ocean Platform for Forecasting** (**SURF**), release version 1.02. This guide provides comprehensive information and instructions to help you make the most of the SURF-NEMO platform.

For details on updates and changes in this version, please refer to the release notes.

Note

PDF Documentation: The full user guide is also available for download in PDF format:

surf_nemo_1.02.pdf.

For the latest SURF-NEMO release, you can access and download it directly from the official website:

https://www.surf-platform.org

License Information

2. Introduction

The **Structured and Unstructured grid Relocatable ocean platform for Forecasting (SURF)** is an open-source, on-demand ocean numerical modeling platform designed for setting up, running and analysing high-resolution nested ocean models in any region within a large-scale Ocean Forecasting System. Designed for flexibility and ease of use, SURF enables users, including those with minimal technical expertise, to easily set up downscaling experiments using a clear and well-documented JSON configuration file. SURF can be operated on commercially available personal computers or laptops, ensuring broad accessibility and flexibility.

SURF integrates two state-of-the-art ocean models, the structured grid model NEMO (Nucleus for European Modelling of the Ocean) and the unstructured grid model SHYFEM-MPI (System of HydrodYnamic Finite Element Modules). This User Guide covers the structured grid component of SURF, known as **SURF-NEMO**. For information on the unstructured grid component, SURF-SHYFEM, please refer to the corresponding manual, available here .

This manual provides step-by-step instructions for running the platform, along with detailed explanations of the scripts and data structures, enabling users to modify or extend SURF according to their needs.

The package also includes case studies, complete with input datasets for bathymetry, coastlines, atmospheric and tidal forcing, as well as coarser-resolution parent ocean data for initial and boundary conditions. Output datasets are also provided for validation and for checking the correct implementation.

For more information, please visit the SURF website at:

https://www.surf-platform.org

2.1 SURF-NEMO Relocatable ocean modelling platform

SURF-NEMO (Trotta et al. 2016, 2021) is a numerical platform designed for forecasting hydrodynamic and thermodynamic fields with high spatial and temporal resolution. It can be embedded into any region within a larger-scale ocean prediction system, which operates at a coarser resolution.

The platform utilizes a **one-way nesting** approach for downscaling, where coarser resolution parent model fields are interpolated onto the child grid, providing initial and lateral open boundary conditions for the fine-grid model. Additionally, it supports **multiple nesting capabilities**, allowing for consecutive nested models with progressively finer grid resolutions. Starting from a large-scale ocean model, it can achieve horizontal grid resolutions down to a few hundred meters. At each nesting level, the parent coarse-grid model supplies the initial and lateral boundary conditions for the nested SURF child components.

This relocatable ocean model system is intended to be a valuable tool for supporting various **Decision Support Systems (DSS)** that may require high-resolution ocean fields, such as oil spill monitoring, search and rescue operations, navigation routing, fisheries and tourism.

2.2 **Virtual Machine Environment**

SURF-NEMO is distributed as a **Virtual Machine (VM)** image created using **VirtualBox**. This VM contains all the necessary libraries and software required to set up, run, and analyze downscaling experiments. The source code includes the hydrodynamic **NEMO model**, along with several pre- and post-processing tools, all installed within the VM environment. Detailed instructions for downloading and installing the package are provided in Chapter 3.1 of the Installation Guide.

A virtual machine is a software-based system that emulates a computer's operating system with virtual access to hardware resources such as CPU, RAM, networking, and storage. The operating system running inside the VM is referred to as the **guest**, and it operates within a window on your physical computer's operating system, known as the **host**.

The virtualization software used is the free and open-source **Oracle VM VirtualBox**, with the **Debian Linux** operating system installed inside the VM.

Virtual machines offer several advantages. They encapsulate an entire computing environment—operating system, applications, and data—within a single file. This makes setup easier compared to installing a full suite of software that must work together. A VM can be distributed as a pre-configured, ready-to-use system, simplifying both configuration and distribution. Additionally, VMs are versatile and can run on various hardware platforms.

2.3 **Source Code**

The **SURF-NEMO** source code is distributed as a compressed **tar.gz** archive, which includes the NEMO model code, a suite of pre- and post-processing tools, and a template user configuration file. Detailed instructions for downloading and installing the package are provided in Chapter 3.2 of the Installation Guide.

NEMO is an open-source ocean modeling framework, written in **Fortran 90** and optimized for parallel execution using **MPI**-based domain decomposition. Simulation outputs are stored in the **NetCDF** format, a widely-adopted standard for scientific data storage and exchange.

SURF-NEMO includes a suite of **preprocessing tools** for tasks such as mesh generation, dataset downloading, and remapping of input data, including ocean data for initial and lateral boundary conditions, as well as atmospheric and tidal forcing. It also offers **post-processing tools** to visualize and analyze simulation results.

The pre- and post-processing scripts are developed in **Julia**, **NCL**, **Python**, and **Fortran** programming languages. To efficiently handle NetCDF datasets, the platform utilizes **NetCDF Operators (NCO)** and **Climate Data Operators (CDO)**, both optimized for SURF to reduce computation time and ensure efficient memory usage. Currently, these pre- and post-processing tools operate in **serial mode** (i.e., executed on a single processor).

The structure of the SURF source code package is detailed in Appendix B.

3. Getting Started

This chapter provides a step-by-step guide to help you quickly get started with the **SURF-NEMO** platform. It includes instructions for downloading and installing the **SURF Virtual Machine**, along with all the required SURF packages, **source code** and **static datasets** necessary to perform downscaling experiments. Additionally, this guide will show you how to compile the source codes, run a case study experiment in the Gulf of Taranto, followed by instructions on how to visualize and analyze the results. Finally, you will learn how to modify the user configuration file to execute new experiments, allowing you to customize the downscaling experiment according to your specific needs.

The **template experiment** makes it easier to run simulations without requiring in-depth knowledge of the underlying scientific details. For most applications, only a limited number of default values need to be adjusted. However, for more advanced use cases, such as changing turbulence models or adjusting numerical schemes, users should consult the **NEMO** User Manual for a deeper understanding. There are also video tutorials available online here, designed for beginners to walk through the basic features of the SURF platform step by step.

3.1 Download and Install SURF Virtual Machine (VM)

The SURF-NEMO platform is distributed as a **Virtual Machine (VM) image**, allowing for easy deployment. The VM image is packaged within a ZIP archive, with the naming format of the VM image releases as follows:

```
surf_vm_<VERSION>.zip
```

where `VERSION` refers to the specific version number of the release (e.g., `surf_vm_1.03.zip` for the current version).

The instructions below provide a step-by-step guide on how to download, install, and configure the SURF-NEMO VM using Oracle VirtualBox.

3.1.1 **Installing Oracle VirtualBox**

Before getting started, ensure that Virtual Box is installed on your system. If Virtual Box is not already installed, follow these steps:

1. Visit the VirtualBox download page and download the **VirtualBox base package** (version >=6) corresponding to your operating system (Windows, Mac, or Linux).

Figure 3.1. Downloads VirtualBox base package.

2. Follow the provided installation instructions.
3. In addition to the base package, download the **VirtualBox Extension Pack**, which adds functionality like USB device support and remote desktop support. Double-click the downloaded extension pack and follow the installation steps. Please install the same version extension pack as your installed version of the VirtualBox base package.

Figure 3.2. Downloads VirtualBox Extension Pack.

4. Once installed, verify that VirtualBox is working by running the following command in your terminal:

```
vboxmanage --version
```

This should display the current version of VirtualBox installed, confirming the installation was successful.

Tip: For more information on using VirtualBox, check out the VirtualBox Documentation.

3.1.2 **Downloading and Installing SURF VM**

- Visit the SURF platform website and download the current version of the SURF Virtual Machine Image (e.g., `surf_vm_1.03.zip`). To download the Image directly from the terminal, use the following commands:

```
cd /Users/USERNAME/VirtualBox\ VMs;
wget https://www.surf-platform.org/repository/surf_vm/surf_vm_1.03/surf_vm_1.03.zip
```

The default installation path for VirtualBox VMs is typically `/Users/USERNAME/VirtualBox VMs/` on macOS, with similar paths for other operating systems. In the virtual machines is installed the **Debian GNU/Linux 10 (buster)** operating system and all the necessary libraries required. The Guest Additions have been also installed to optimize the guest operating system for better performance and usability. Depending on your internet speed, the download may take a few minutes.

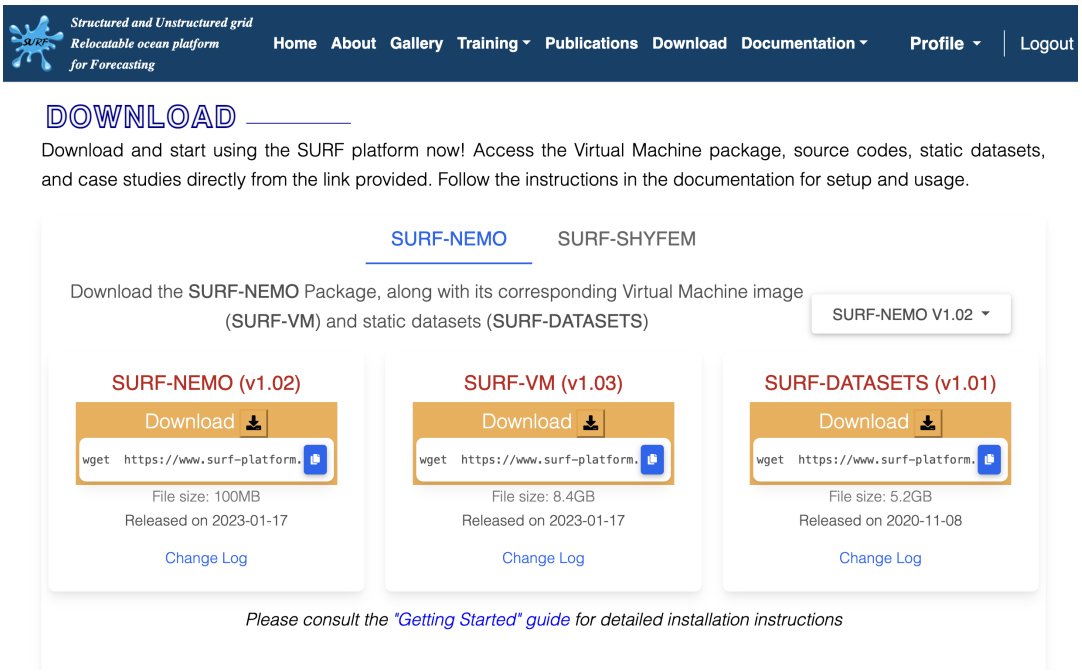


Figure 3.3. Downloads SURF Virtual Machine.

- Unzip the archive file into the VirtualBox directory:

```
unzip surf_vm_1.03.zip
```

- Open VirtualBox, navigate to **Machine > Add**, and select the `surf.vbox` file to add the SURF VM to the list of Virtual Machine. This file is an XML file that contains settings of the Machine.

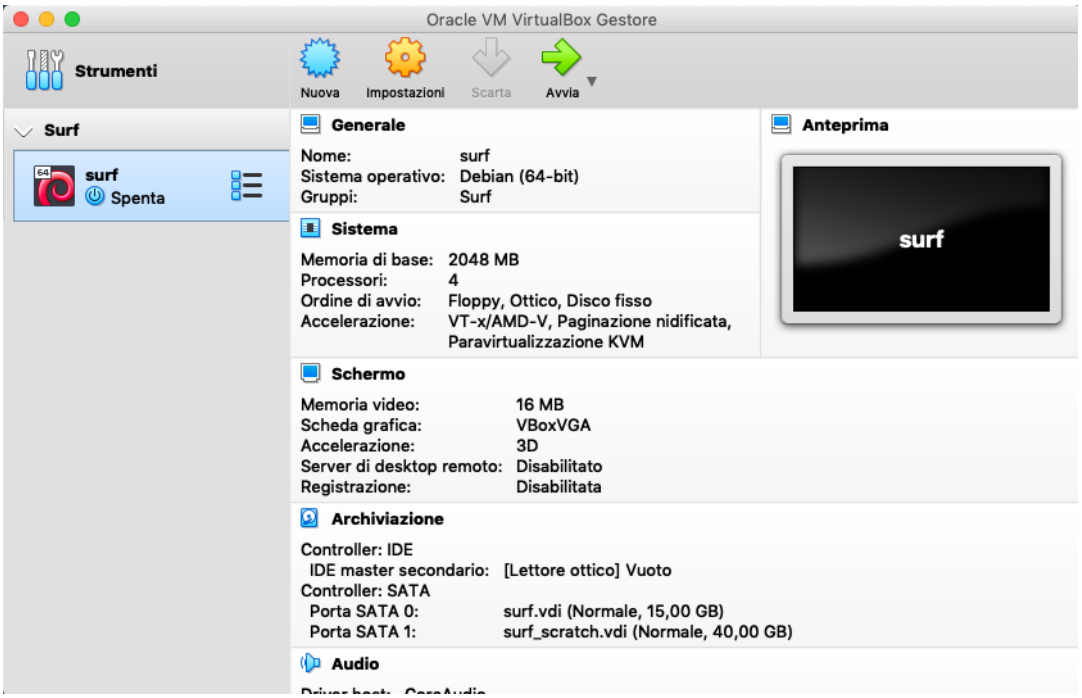


Figure 3.4. Add SURF-VM in VirtualBox.

- Start the VM from the VirtualBox Manager by selecting it and pressing **Start** button at the top of the window. The VM Login should look like the figure 3.5 .

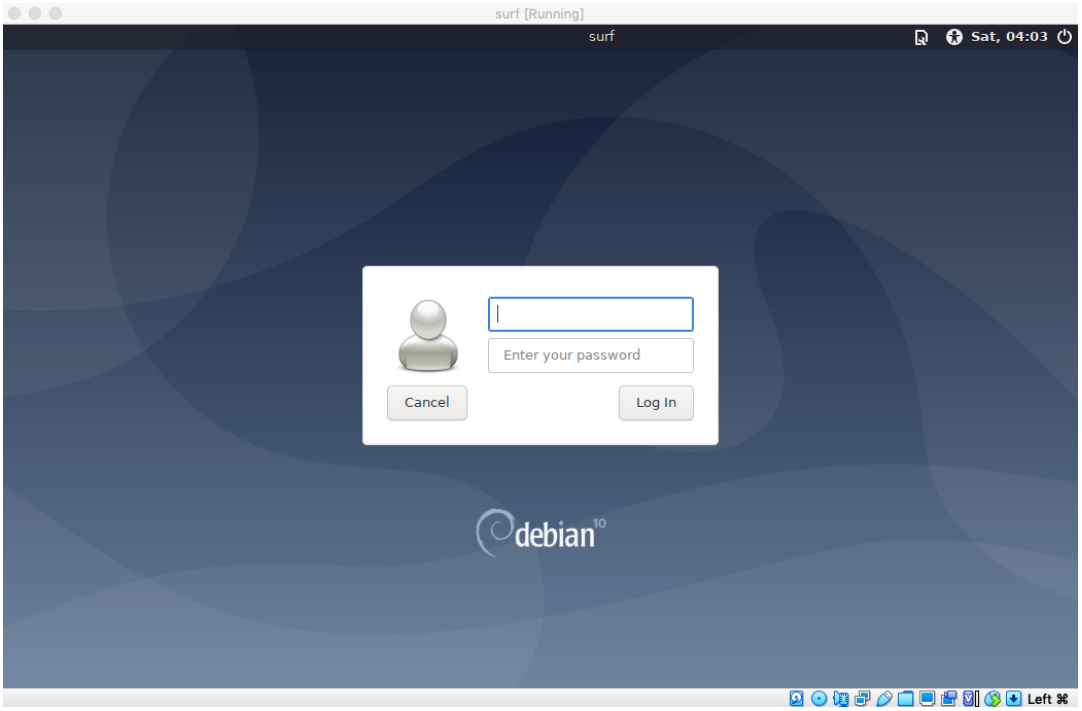


Figure 3.5. Start SURF-VM.

- Log in using the following credentials:
  - **Username:** surf
  - **Password:** surf2020

> **Note**
>
> The VM image comes pre-packaged with all the necessary libraries required to execute the SURF-NEMO code. However, to facilitate updates and keep the image size manageable, the SURF-NEMO source code and static datasets are not included and must be installed separately. Detailed instructions for this process are provided in the following section.

3.1.3 **Disk Partitions mounted on the SURF Virtual Machine**

The SURF VM package includes two VirtualBox Disk Image (VDI) files:

- `surf.vdi` : Contains the Debian GNU/Linux 10 (buster) operating system.
- `surf_scratch.vdi` : Contains source code files, sample datasets, and experiments.

It is divided into two main partitions:

- the disk `/dev/sda` "mounted" as filesystems to the root directory `/`
- the disk `/dev/sdb` "mounted" in the directory `/scratch` .

From the guest operating system you can see the list of partitions by typing the following command:

```
sudo fdisk -l
```

3.1.4 **Shared Folders Between Host and Guest Systems**

You can mount other physical hard disks with VirtualBox (see the VirtualBox Manual for details). VirtualBox has the ability to **mount a shared folder between host and guest** in order to access files of your host system from within the guest system. There are a few steps involved:

- Shut down the VM, go to **Settings** > **Shared Folders** in VirtualBox.
- Click the Plus button and select the folder you want to share. Check the **Auto-mount** option and click OK.
- Restart the VM, and the shared folder will appear in `/media` with the prefix "sf_".

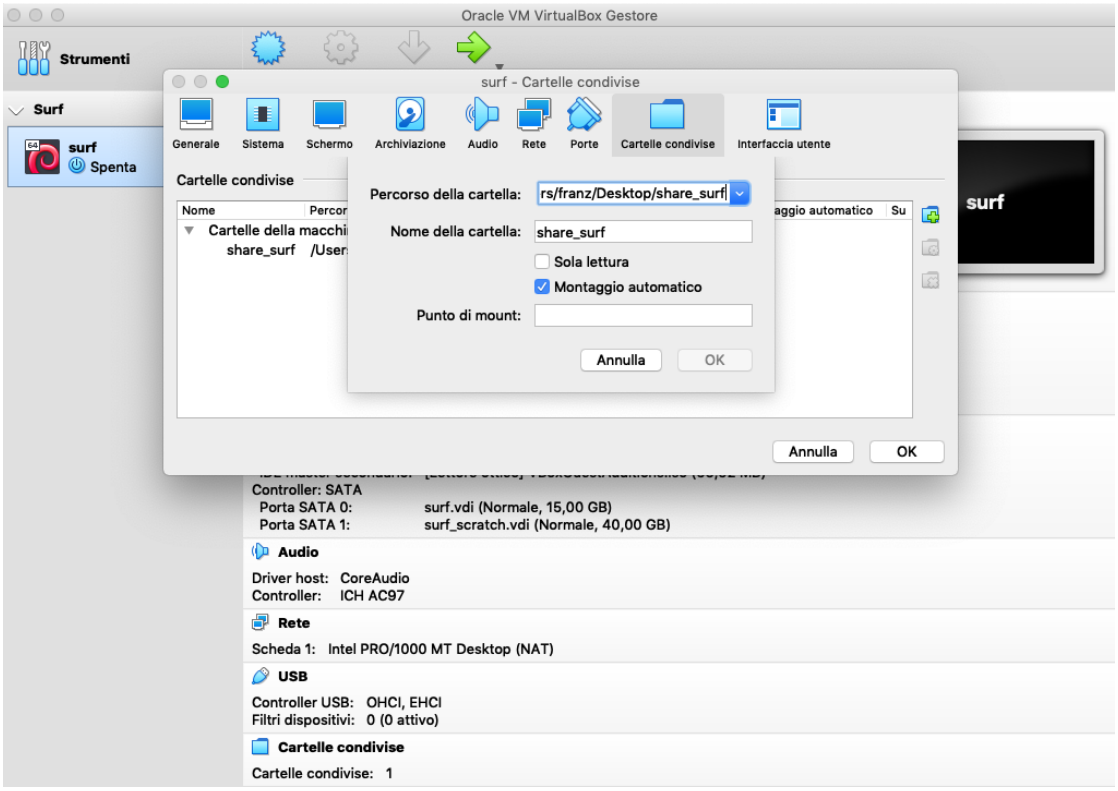


Figure 3.6. Mount shared folders.

3.1.5 **Configuring the SURF Virtual Machine**

By default, the VM surf is configurated as in table Table 3.1 . You can keep all defaults parameters or if it is not adequate for your application you can change settings. To change the configuration you need to shut down the virtual OS before you can edit settings.

- Select the surf VM in the VirtualBox Manager, right-click it and choose *Setting*.
- increase/decrease the number of cores based on your performance desires.
- increase/decrease the number of GB of RAM allocated to your VM according to the size of your computational domain.
- increase/decrease the video memory and scale factor of your screen

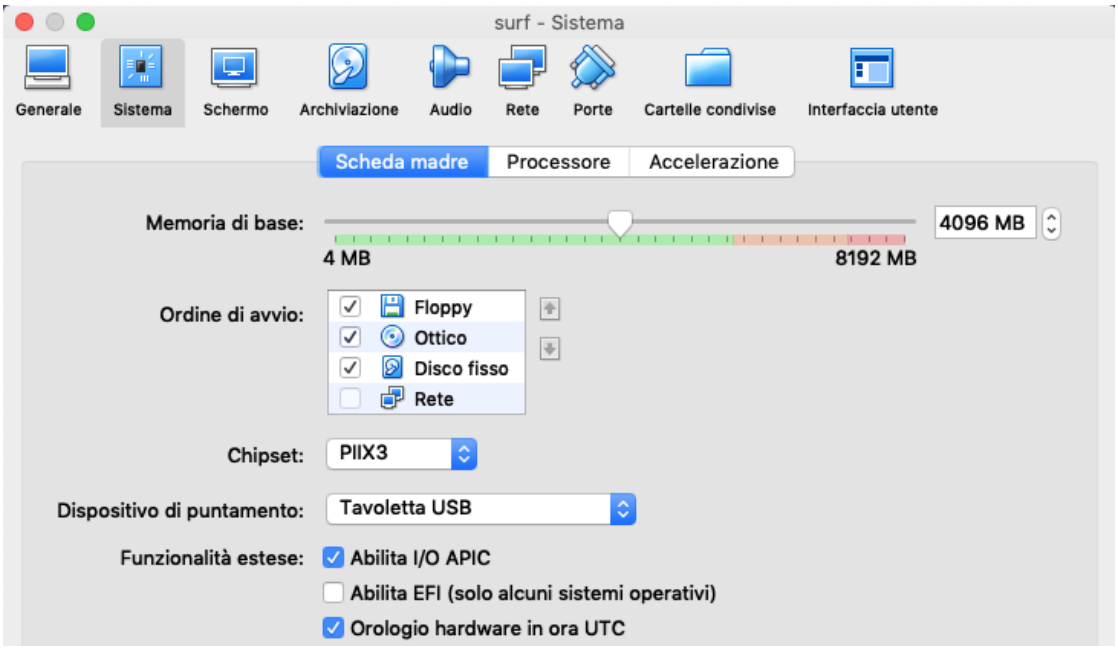


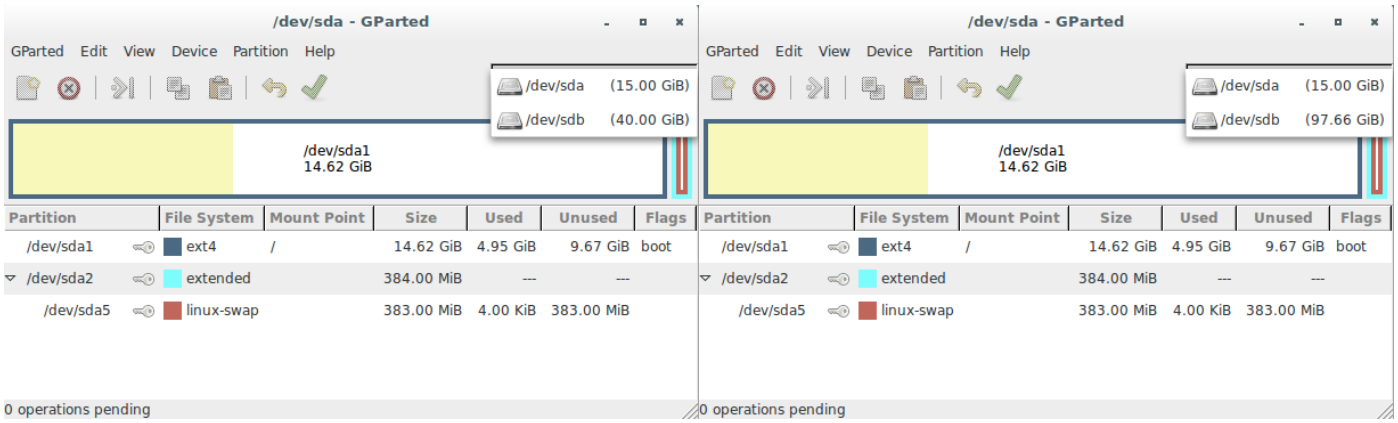
Figure 3.7. Change VM configurations.

If you want to add more storage space to a VM you can also expande the virtual hard disk. There are a few steps involved:

- With the VM Power off, open a terminal and move to the location of the surf_scratch.vdi file that you want to resize,
- At the terminal prompt, type the command:

```
VBoxManage modifyhd surf_scratch.vdi --resize SIZE_MB
```

- Restart the SURF VM and open the GParted application from the Application Menu
- Select the /dev/sdb partition (an unlocated drive space is now available). Resize to the unalocated area



(A) Before. *(B) After.*

Figure 3.8. Enlarge the virtual disk.

Parameter	Description	Values
Name	Name given to the VM	surf
Guest OS	Operating system running on this VM	Debian Linux
Memory	Amount of memory available to this VM	2 GB
Cores	Number of CPU cores being used by this VM	2
Disk Capacity	Total disk capacity available to this VM	40 GB
Network Adapters	Number of network adapters available to this VM	1
IP Address	IP address assigned to the VM	x

Table 3.1: Summary of Virtual Machine fields and configurations.

3.2 Download and Install SURF packages

The installed Virtual Machine (VM) does not include the SURF packages, which consist of **source codes** and **static datasets**. You will need to download and install them in the VM's scratch directory (`/scratch`, VM directory structure shown in Figure B.1).

The SURF packages are distributed as a GZIP Compressed Tar Archive file (with a `.tar.gz` extension). The naming convention for the releases follows this format:

```
packageName_<VERSION>.tar.gz
```

where `VERSION` refers to the specific version number of the release (e.g., `surf_nemo_1.02.tar.gz` for the current version of the SURF-NEMO package version).

The instructions below explain how to install the packages in the SURF VM.

- After logging into the SURF VM, download the latest version of the SURF-NEMO (`surf_nemo_1.02.tar.gz`) and SURF-DATASETS (`surf_datasets_1.01.tar.gz`) packages directly from the SURF platform website and save it in the directory `/scratch/surf/surf_install/releases/` (for simplicity, we abbreviate this location as `$SURF_RELEASES`). Use the following commands to download the packages:

```
# Download the SURF source code into the specified directory
wget -P /scratch/surf/surf_install/releases https://www.surf-platform.org/repository/surf_nemo/surf_r

# Download the static dataset into the specified directory
wget -P /scratch/surf/surf_install/releases https://www.surf-platform.org/repository/surf_datasets/su
```

- Go to the directory `$SURF_RELEASES` and run the installation bash script `install.sh` followed by the package name. Use the following commands to install both the SURF-NEMO and SURF-DATASETS packages:

```
cd /scratch/surf/surf_install/releases
install.sh surf_nemo_1.02.tar.gz
install.sh surf_datasets_1.01.tar.gz
```

  The installation process will extract the archive in the directory `/scratch/surf/surf_nemo/` and `/scratch/surf/surf_datasets/`, respectively, and will create a symbolic link `current` in this directory that points to the extracted folder (for simplicity, we abbreviate this location as `$SURF_NEMO`, `$SURF_DATASETS`, respectively).

For a detailed description of the directory structure and contents of each package refer to the Appendix B.

3.2.1 **Compiling the source code**

Once the installation of the SURF-NEMO package is complete, you need to compile the source codes in order to create the executable files needed to perform specific tasks. The executable files should not be recreated unless you need to modify the source code.

The compilation process is handled using the Unix/Linux `make` utility and the following tools:

- **Fortran 90 Compiler** – used for compiling the core numerical models.
- **C Preprocessor (`cpp`)** – processes C-style macros.
- **MPI Library** – required for running simulations in parallel mode.
- **netCDF Library** – allows reading and writing of data in portable netCDF format.

All of these tools are already installed and configured on the SURF platform, so no additional setup is required.

To compile the source codes go to the directory `/scratch/surf/surf_nemo/current/scripts/` and run the compilation bash script `compile.sh` followed by the package name (or by the word 'all' to compile all the packages):

```
cd /scratch/surf/surf_nemo/current/scripts;
./compile_codes.sh all
```

Compilation could take a few minutes and it will create the executable files for each program present in the SURF-NEMO package.

3.3 Running the Gulf of Taranto Case Study

With the SURF-NEMO VM-Image, source code and static datasets successfully downloaded, you are now ready to start using the SURF-NEMO platform. Follow the steps below to set up and execute the Gulf of Taranto case study.

In this case study, the SURF platform is used to implemente an high-resolution model in the Gulf of Taranto, located in the northern Ionian Sea. The simulation starts on 5 October 2014 at 00:00 and run until 7 October 2014 at 24:00. This section provides step-by-step instructions on how to set up, run, and analyze the downscaling experiment.

3.3.1 Setting Up the Experiment

1. Download and extract the **user configuration file** for this test case experiment (`gulfTaranto_20141005_config.tar.gz`) from the SURF website and saves it into the `/scratch/surf/from_GUI` directory by running the following commands:

```
# Download the configuration file directly into the specified directory
wget -P /scratch/surf/from_GUI https://www.surf-platform.org/repository/surf_nemo/surf_nemo_1.02/case_

# Extract the downloaded file
cp /scratch/surf/from_GUI; tar -zxvf gulfTaranto_20141005_config.tar.gz
```

This file contains the user configuration settings specific to this case study (see chapter 5 for more details). The folder name `gulfTaranto_20141005` will serve as the Experiment ID, uniquely identifying the experiment.

2. Download and extract the necessary input data required for this test case experiment (`gulfTaranto_20141005_indata.tar.gz`) from the SURF website and saves it into the `/scratch/surf/indata_offline` directory by running the following commands:

```
# Download the configuration file directly into the specified directory
wget -P /scratch/surf/indata_offline https://www.surf-platform.org/repository/surf_nemo/surf_nemo_1.02

# Extract the downloaded file
cp /scratch/surf/indata_offline; tar -zxvf gulfTaranto_20141005_indata.tar.gz
```

> **Note**
>
> If you want to change the local repository pat `indata_offline` to a different location, ensure that you update the path in the user configuration file accordingly.