Getting familiar with Numerical Weather Prediction models

Lesson 1

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Klima dynamic

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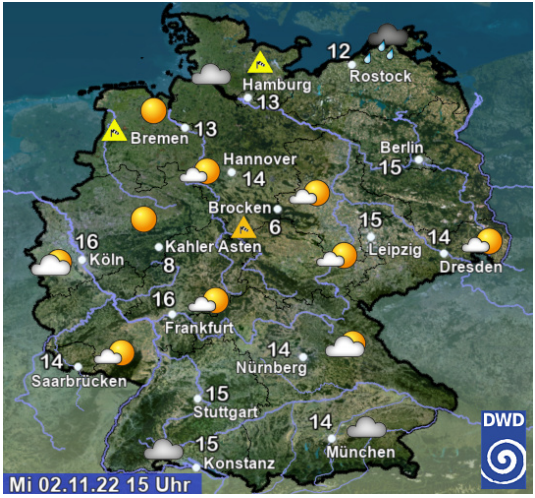
Outline

Introduction

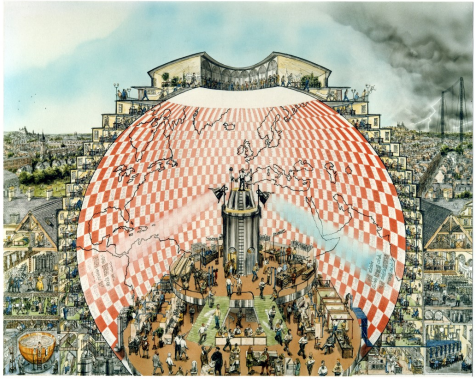
Why do we use a NWP?

Why do we use a Numerical Weather Prediction (NWP) model?



Why do we use a Numerical Weather Prediction (NWP) model?

- No analytical solutions to Navier-Stokes → approximations (e.g. turbulence closure)
- Atmospheric dynamics scales → discretization
- Initial condition and representativity → too many points
- ..



Richardson's Fantastic forecast factory

https://maths.ucd.ie/~plynch/Publications/RFFF-WX-02-NoAbs.pdf

For what do we use a NWP?

Typical applications:

- Weather forecast
- Seasonal-to-subseasonal (S2S) forecast
- Climate projection
- Reanalyses
- Research (atmospheric physics, chemistry, climate, detection and attribution, etc)
- Teaching

Hot topics:

- Climate change
- Coupled Earth system modelling
- Applications: air quality, wind energy, hydrology, etc

NWP is not only about momentum conservation

Tendency advection PGF in eta coordinates Coriolis, etc.

Conservation of momentum

$$\begin{cases} \partial_t U + (\nabla \cdot \mathbf{V}u) - \partial_x(p\phi_\eta) + \partial_\eta(p\phi_x) = F_U & \text{X-component} \\ \partial_t V + (\nabla \cdot \mathbf{V}v) - \partial_y(p\phi_\eta) + \partial_\eta(p\phi_y) = F_V & \text{Y-component} \\ \partial_t W + (\nabla \cdot \mathbf{V}w) - g(\partial_\eta p - \mu) = F_W & \text{Z-component} \end{cases}$$

Conservation of heat

$$\partial_t \Theta + (\nabla \cdot \mathbf{V}\theta) = F_\Theta$$

Conservation of mass

$$\partial_t \mu + (\nabla \cdot \mathbf{V}) = 0$$

Material derivative of geopotential

$$\partial_t \phi + \mu^{-1}[(\mathbf{V} \cdot \nabla\phi) - gW] = 0$$

Equation of State

$$p = p_0(R_d\theta/p_0\alpha)^\gamma.$$

Inverse-density diagnostic relation

$$\partial_\eta \phi = -\alpha\mu,$$

Expansion identities with *a* being a generic variable

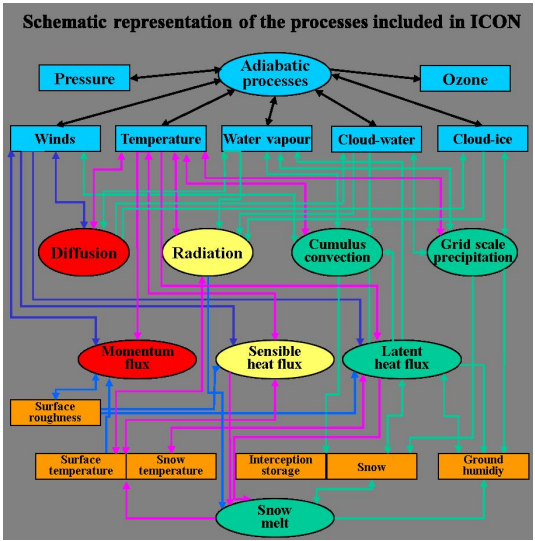
$$\nabla \cdot \mathbf{V}a = \partial_x(Ua) + \partial_y(Va) + \partial_\eta(\Omega a),$$
$$\mathbf{V} \cdot \nabla a = U\partial_x a + V\partial_y a + \Omega\partial_\eta a,$$

.. and it becomes worst with moisture

$$
\begin{aligned}
\partial_t U + (\nabla \cdot \mathbf{V}u)_\eta + \mu_d \alpha \partial_x p + (\alpha/\alpha_d)\partial_\eta p \partial_x \phi &= F_U \\
\partial_t V + (\nabla \cdot \mathbf{V}v)_\eta + \mu_d \alpha \partial_y p + (\alpha/\alpha_d)\partial_\eta p \partial_y \phi &= F_V \\
\partial_t W + (\nabla \cdot \mathbf{V}w)_\eta - g[(\alpha/\alpha_d)\partial_\eta p - \mu_d] &= F_W \\
\partial_t \Theta + (\nabla \cdot \mathbf{V}\theta)_\eta &= F_\Theta \\
\partial_t \mu_d + (\nabla \cdot \mathbf{V})_\eta &= 0 \\
\partial_t \phi + \mu_d^{-1}[(\mathbf{V} \cdot \nabla\phi)_\eta - gW] &= 0 \\
\partial_t Q_m + (\mathbf{V} \cdot \nabla q_m)_\eta &= F_{Q_m}
\end{aligned}
$$

More on the full equations (WRF guide): `http://dx.doi.org/10.5065/1dfh-6p97`

NWP structure



ICON (DWD forecast model)

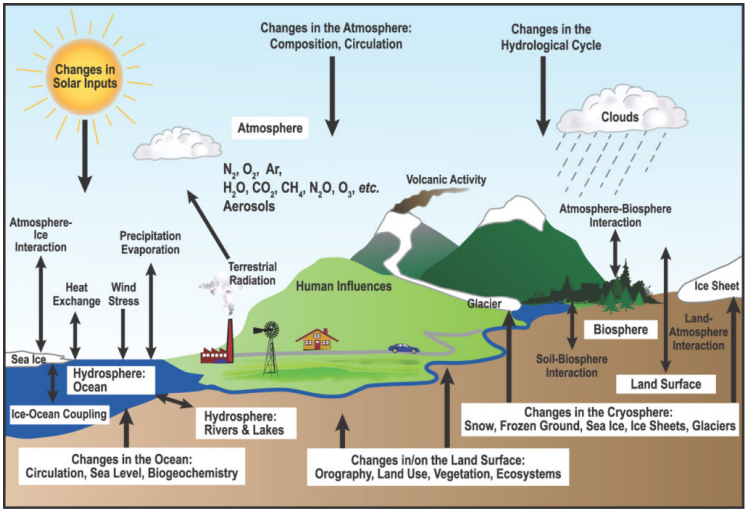
Code structure $\rightarrow$ modular:

- each box is its own contained routine
- interchanges between processes are regulated by the solver (or the driver)

.. But there is not only atmospheric processes! E.g.

- Snow
- Ground humidity
- .. but many more:

NWP is not only about the atmospheric dynamics equations



https://www.ipcc.ch/report/ar4/wg1/historical-overview-of-climate-change-science

NWP is not only physics

Preparing NWP simulations:

As a race..

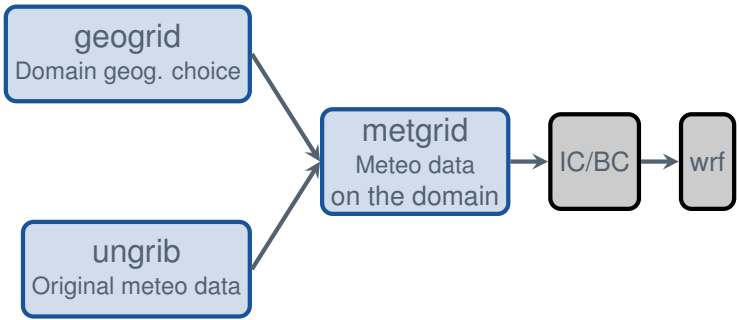
Initial condition: you need a starting line defined!

Boundary condition: you have to keep on track to run the race!

The Weather Research Forecast (WRF) model

Limited area model (LAM) → Needs initial and boundary conditions

WRF-specific Pre-processor (WPS):



Geographical informations:

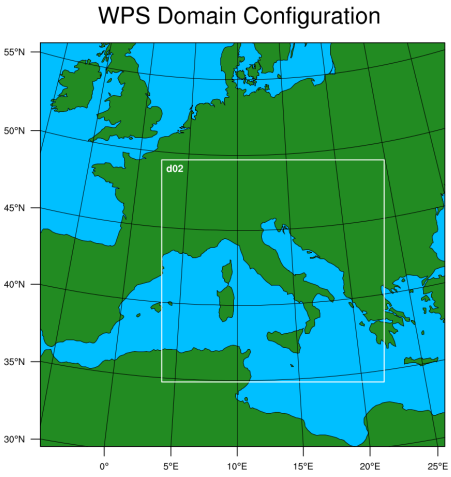
Geogrid is used for **time-independent** geographical informations.

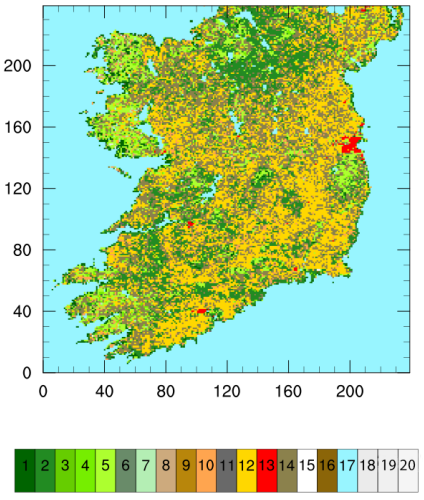
It defines:

1. Map informations: e.g. 2D gridded latitude and longitude, Coriolis parameter, *projection*..
2. Topographic informations: e.g. terrain elevation, vegetation fraction, soil categories, land use characterization..
3. Dimensions and resolution of the domains

N.B. The projection changes depending on the location, for mid-latitudes use: *Lambert conformal*.

Examples of invariant data:





Un-grib.. what is a GRIB?

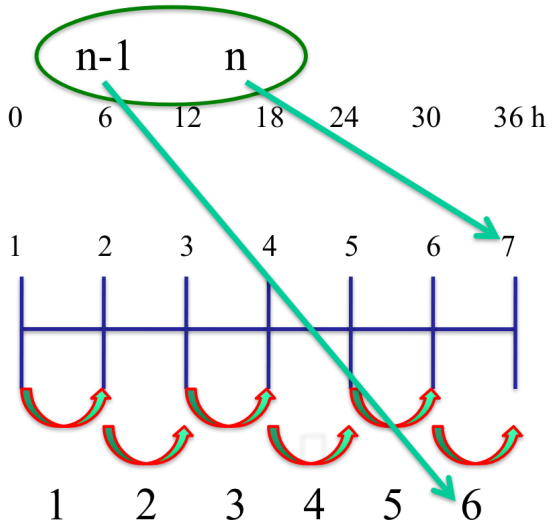
GRIB file format is a WMO standard file format for gridded fields. It is a binary compressed file, fields are identified with a code → you need a table with the code to determine the corresponding fields.

↓

This is why we need the so-called **Vtable** (stands for Variable table). WPS and WRF have an already coded table you always use, e.g.:

GRIB1 Param	Level Type	From Level1	To Level2	metgrid Name	metgrid Units	metgrid Description	GRIB2 Discp	GRIB2 Catgy	GRIB2 Param	GRIB2 Level
1	1	0		PSFC	Pa	Surface pressure	0	3	0	1
1	7	0		PTROP	Pa	Tropopause pressure	0	3	0	7
1	6	0		PMAXW	Pa	Pressure at max wind level	0	3	0	6
11	1	0		SKINTEMP	K	Skin temperature	0	0	0	1
11	100	*		TT	K	Temperature	0	0	0	100
11	105	2		TT	K	Temperature at 2 meters	0	0	0	103
11	112	0	10	ST000010	K	Soil temperature 0-10 cm below ground	0	0	0	106
11	112	10	200	ST010200	K	Soil temperature 10-200 cm below ground				
11	7	0		TTROP	K	Tropopause temperature	0	0	0	7
11	6	0		TMAXW	K	Temperature at max wind level	0	0	0	6
144	112	0	10	SM000010	fraction	Soil moisture 0-10 cm below ground	2	0	192	106
144	112	10	200	SM010200	fraction	Soil moisture 10-200 cm below ground				
2	102	0		PMSL	Pa	Pressure at mean sea level	0	3	1	101
33	100	*		UU	m s-1	u-wind component	0	2	2	100
33	105	10		UU	m s-1	u-wind component at 10 meters	0	2	2	103

Boundary conditions



Time periods from WPS

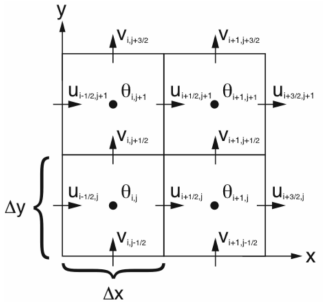
Time slices from WPS

Boundary tendency steps

Metgrid, put together ungrib and geogrid:

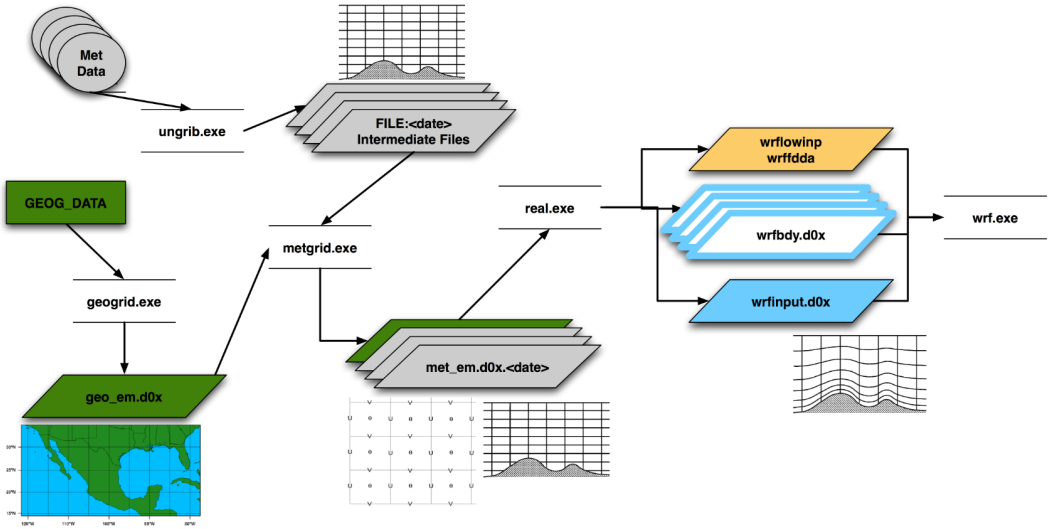
it interpolates horizontally the meteorological data (ungrib) to the chosen domain (geogrid). Here we:

- create the staggered grid:

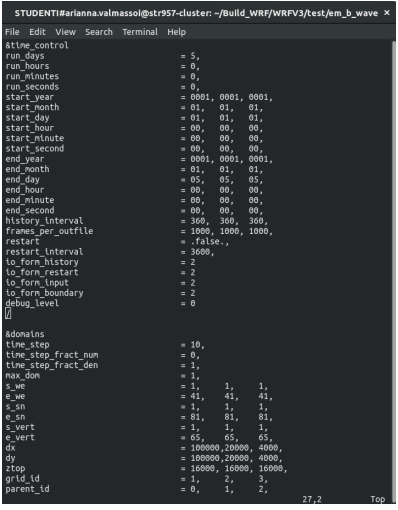


- interpolate the masked fields, e.g. you cannot have SST points in the Po Valley.
- rotate wind components, to have U and V along the WRF simulation grid.

A summary scheme of the main use of WPS and real



How do you tell the model all these info?



Use of namelist

- Decide time period and domain(s) location(s)
- Decide timestep and model integration
- Choose parameterizations
- Define boundary conditions timestep
- .. and much more!

↓

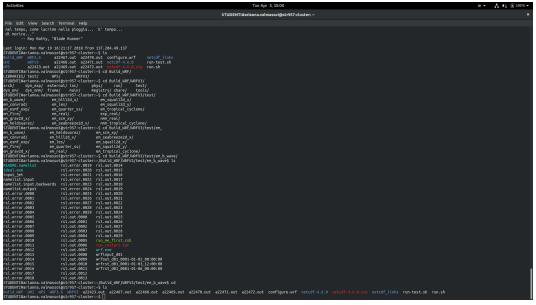
Most of simulations is done modifying *namelist.input*!

Linux

Linux Basics

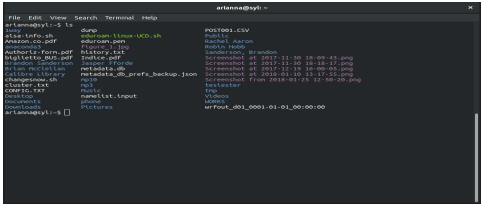
Linux shell: bash

- it's a *command line interface*, not a graphic one!
- it allows to interact directly with the operative system
- you can do everything with the terminal, and usually the mouse it's pretty useless!



Things to get familiar with:

- Open the terminal: Alt+T (if you work with Ubuntu settings)
- Where we are in our PC? Type *ls*:



this is my "home" folder!

- Enter a folder: cd namefolder, e.g. *cd Documents*
- Now go back to the previous folder as: *cd ..*
- Create a folder (or directory): mkdir namefolder, e.g. *mkdir wrf_tutorial* (**NO** space in names!)
- Remove: *rm -rf namefile/foldername*; it can be used to remove every kind of object.
- Copy: *cp file newfile*

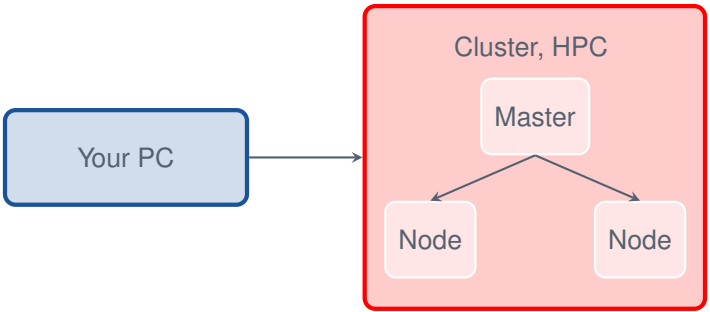
Text files: How it works if this is NOT a graphical interface?

vi

- On the terminal: type “vi test” ← this creates and open the file called "test"
- let’s type something.. Type “i” to enter the editing mode!
- Finish editing: press “Esc”
- To save and exit from *vi* type “:wq”
- To exit without saving the edits: type “:q!”

More infos at: `https://www.vim.org/docs.php`

Remote connection



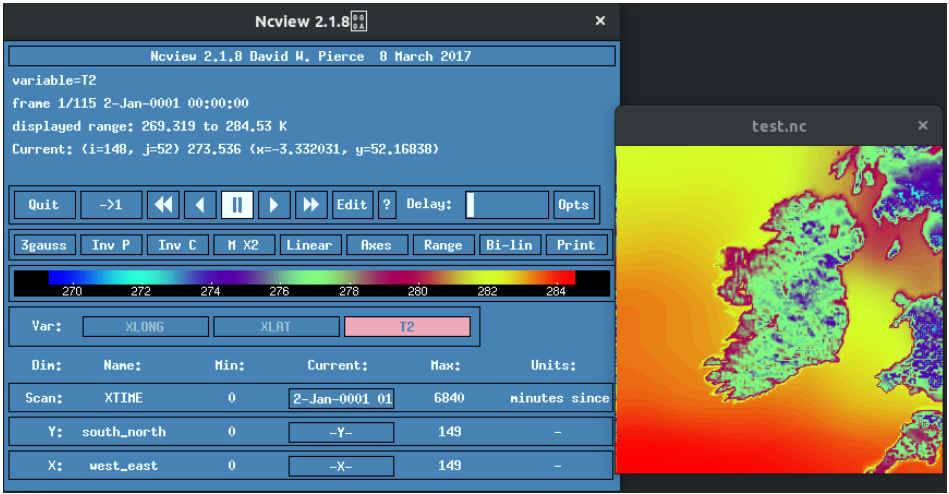
- Connection: ssh
  Type “ssh username@IPaddress”, e.g. *ssh user@137.204.50.71*
- Move files cluster-PC and vice-versa: scp
  Type “scp file_original_location file_wanted_location”, e.g.
  user@137.204.50.71:./WRF/wrfoutput.nc .

WRF output. Forget Excel: we use NetCDF!

- It is auto-descriptive dataset and machine-independent.
- On *your* PC install ncview and netcdf to work with it: *sudo apt-get install ncview netcdf**
- Copy on your PC one of my netcdf tests: *scp user@ip:./test.nc onlytest.nc*
- To **see** the output: *ncview onlytest.nc*

ncview

Let’s get familiar with it...



... even if you can’t present this plot in a paper/thesis!

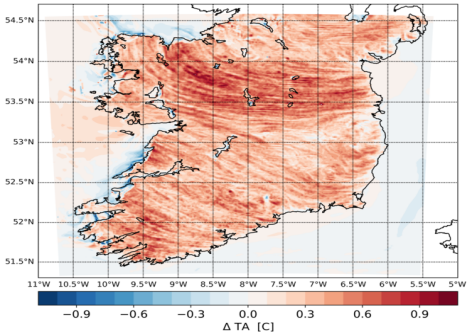
Python/MatLab.. R?

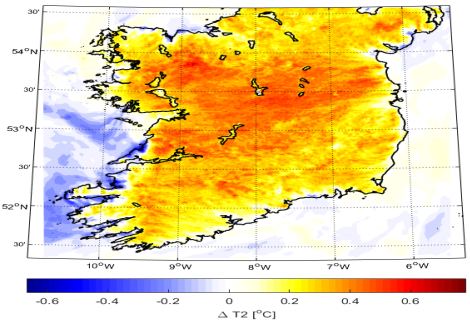
Python

- Free software.
- Widely used: from mobile phone games to high computing.
- A lot of free packages for applications and integrations.

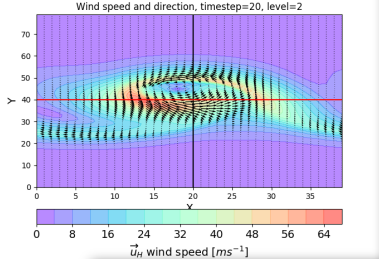
MatLab

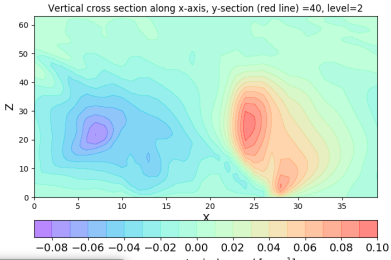
- Non-free software.
- Used for data analysis, not compatible for integrations.
- A lot of packages (free and not), some are not well maintained.

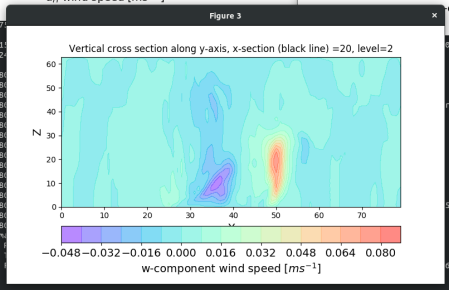




Other things you can do







Our exercise with python

Main aim:

1. Getting familiar with dealing with netCDF files
2. Do basic plots and operations

Things we will do:

1. map of the diurnal maximum temperature averaged over all timesteps
2. extract a specific longitude/latitude, and do a timeserie
3. select a region and plot the average values as a timeserie

If you get bored, try:

1. load the wrf.nc dataset and do the same
2. compare the t2 diurnal maximum and minimum temperatures between wrf.nc and exp1.nc: what and where is the difference between the two simulations?