An Introduction to the WRF Modeling System

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Virtual Tutorial, January 2025

Mesoscale and Microscale Meteorology Laboratory, NSF NCAR

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Outline

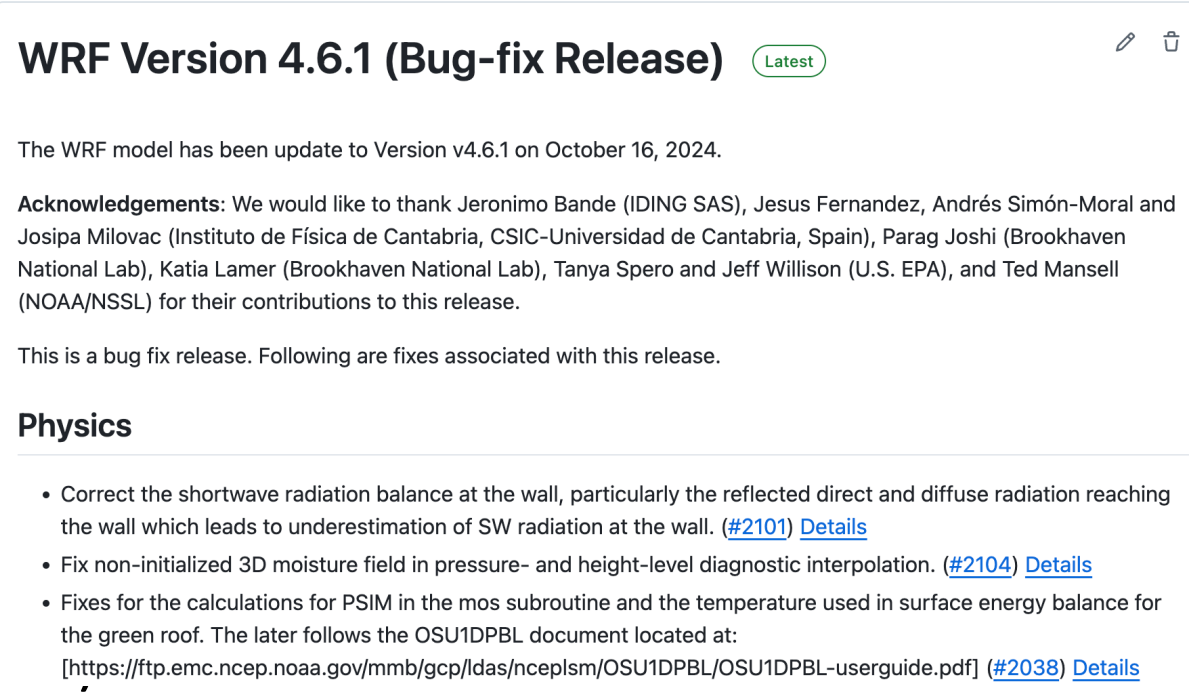
- What is WRF?
  - A brief history of WRF
  - WRF applications
- Some basic concepts about limited area modeling
- What does WRF look like to you, the user?
- What is covered in this tutorial?
- What should you expect to gain from this tutorial?

What is WRF?

- WRF: Weather Research and Forecasting Model
- It is a supported "community model", i.e. a free and shared resource with distributed development (via Github) and support (via User Forum)
- Its development was led by NCAR, NOAA/ESRL and NOAA/NCEP/EMC in early years with partnerships at AFWA, FAA, DOE/PNNL and collaborations with universities and other government agencies in the US and overseas.

WRF Community Model

- Version 1.0 WRF was released December 2000
- Version 2.0: May 2004 (added nesting)
- Version 3.0: April 20
- … (Major releases i
- Version 3.9: April 20
- Version 4.0 (June 20 default)
- Version 4.1 (April 20
- Version 4.2 (April 20
- Version 4.3 (May 20
- Version 4.4 (April 20
- Version 4.5 (April 20
  - Version 4.5.1, 4.5.2 – bug-fix releases
- Version 4.6 (May 2024)
  - Version 4.6.1 (the latest release)



WRF Version 4.6.1 (Bug-fix Release)

Latest

The WRF model has been update to Version v4.6.1 on October 16, 2024.

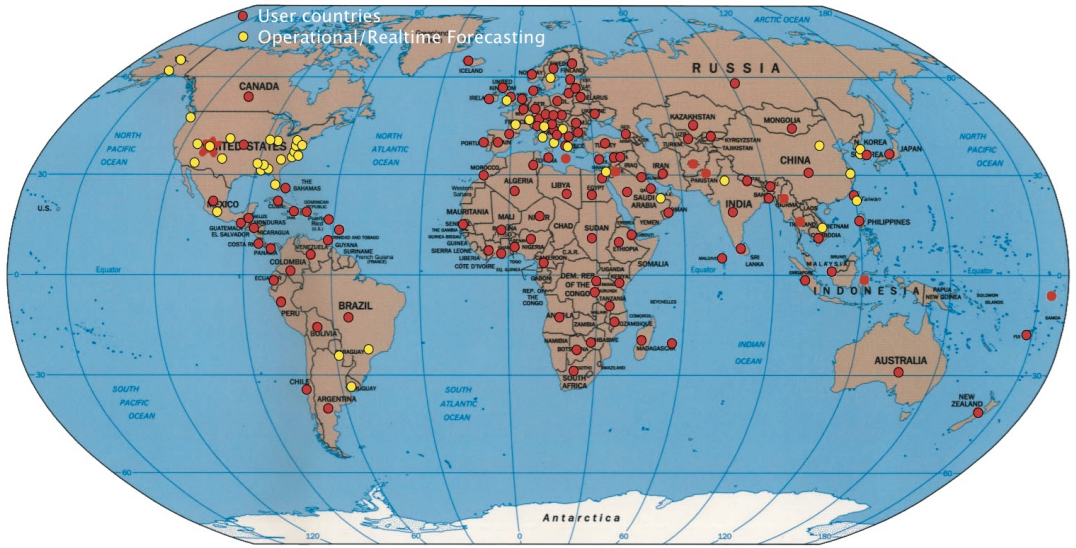
Acknowledgements: We would like to thank Jeronimo Bande (IDING SAS), Jesus Fernandez, Andrés Simón-Moral and Josipa Milovac (Instituto de Física de Cantabria, CSIC-Universidad de Cantabria, Spain), Parag Joshi (Brookhaven National Lab), Katia Lamer (Brookhaven National Lab), Tanya Spero and Jeff Willison (U.S. EPA), and Ted Mansell (NOAA/NSSL) for their contributions to this release.

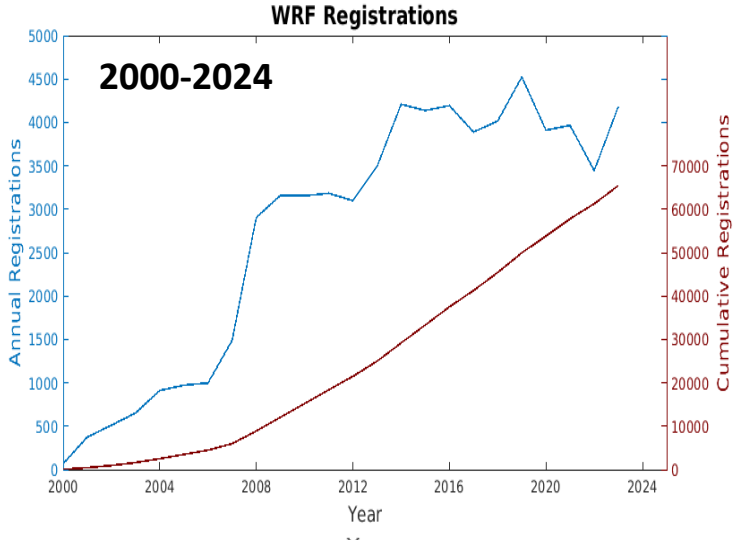
This is a bug fix release. Following are fixes associated with this release.

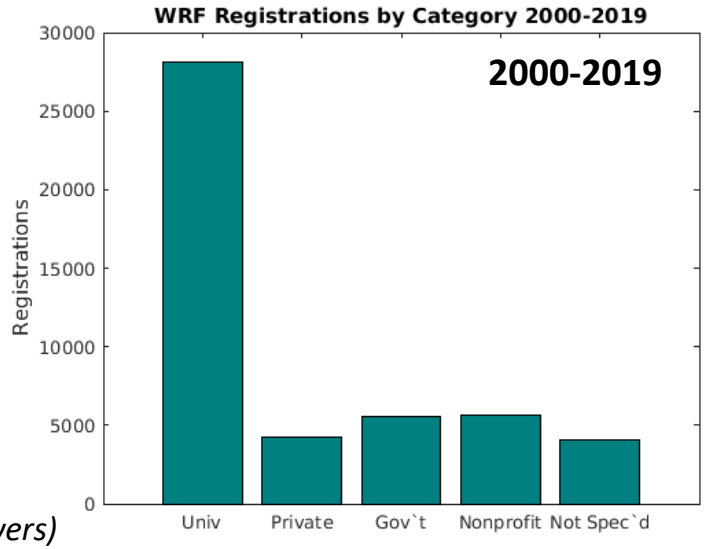
Physics

- Correct the shortwave radiation balance at the wall, particularly the reflected direct and diffuse radiation reaching the wall which leads to underestimation of SW radiation at the wall. (#2101) Details
- Fix non-initialized 3D moisture field in pressure- and height-level diagnostic interpolation. (#2104) Details
- Fixes for the calculations for PSIM in the mos subroutine and the temperature used in surface energy balance for the green roof. The later follows the OSU1DPBL document located at: [https://ftp.emc.ncep.noaa.gov/mmb/gcp/ldas/nceplsm/OSU1DPBL/OSU1DPBL-userguide.pdf] (#2038) Details

WRF Users







As of Jan 2025:

- *No. of countries*: 185
- *No. of users*: 69,000
- *US*: 19,360 (~ 28%)
- *Others*: 49,640
- Pub: ~12335 (2024/7)

(From Powers)

What is WRF-ARW?

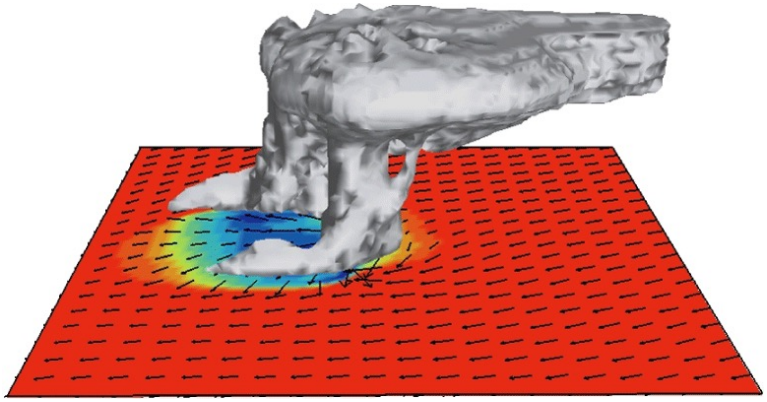
- WRF-ARW: The Advanced Research WRF (ARW)
  - WRF and WRF-ARW are synonymous.
  - Referring to its dynamical core: includes mostly advection, pressure-gradients, Coriolis, buoyancy, filters, diffusion, and time-stepping.
  - Since WRF v4.3.1, this is the only dynamical core.

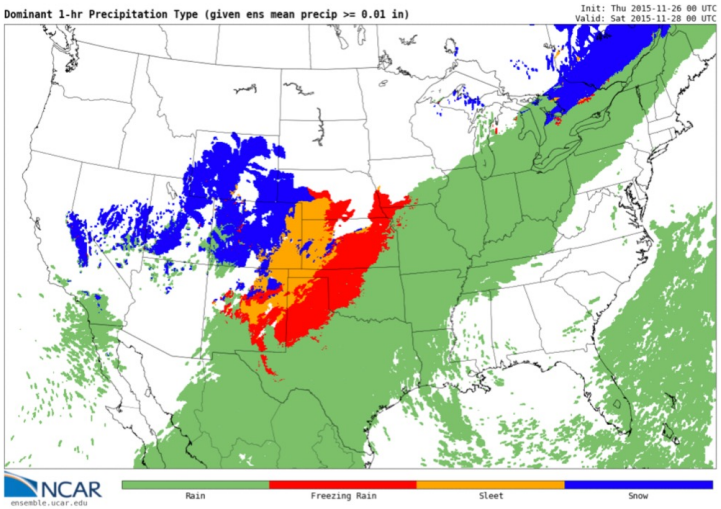
- WRF-ARW or WRF: its development, maintenance and support are centered at NCAR/MMM

What is WRF?

- A research tool:

Idealized simulations →



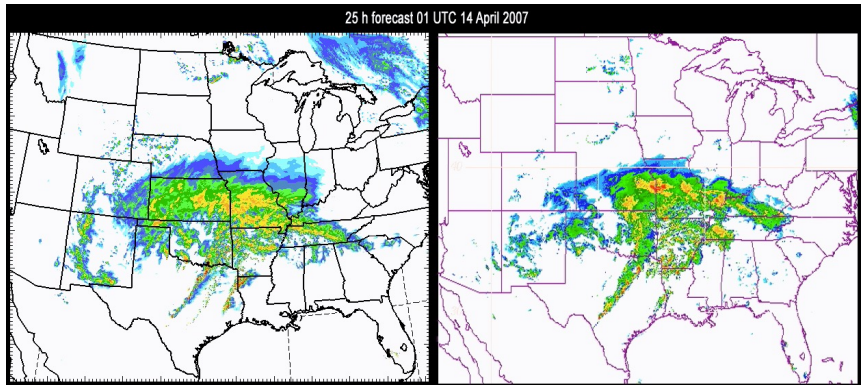


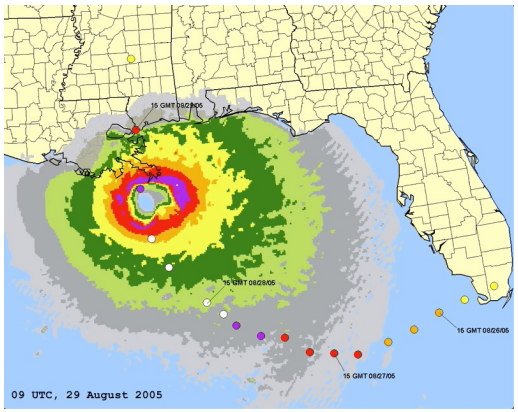
← Experimental real-time forecast

What is WRF?

- A research tool:

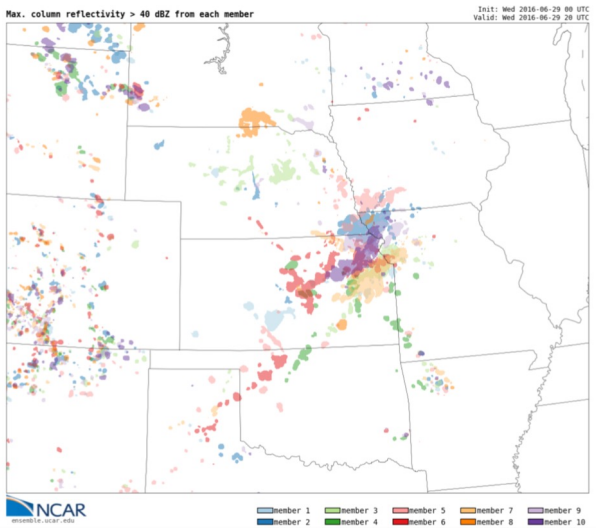
Convection forecast →





← High-resolution hurricane simulations

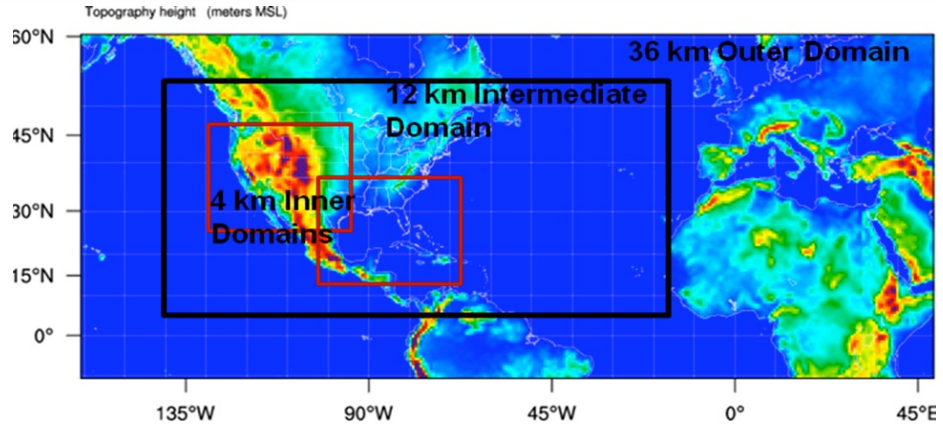
Development of ensemble forecasting technology →

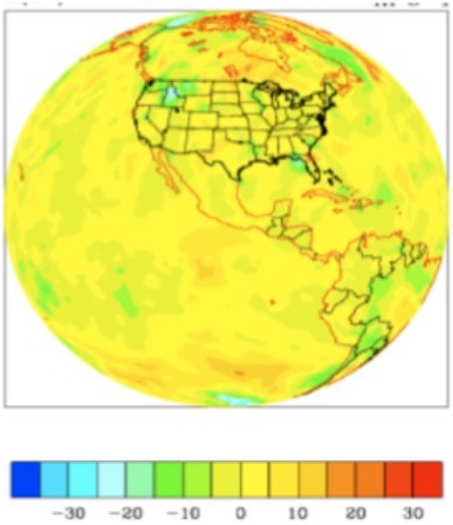


What is WRF?

- A research tool:

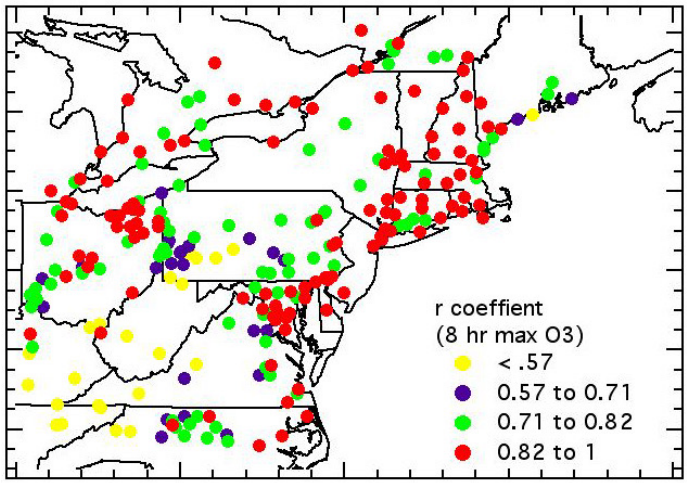
Regional Climate Modeling →





← Data assimilation (*analysis increments*)

WRF-Chemistry →
(*O3 forecast*)



What can WRF be used for?

- A tool for research
  - Develop and test physical parameterizations
  - Case-study research for specific weather events
  - Regional climate studies
  - Coupled-chemistry, fire, and hydrological applications
  - Data assimilation research
  - Teaching modeling and NWP

- A tool for numerical weather prediction
  - Hind-casting
  - Real-time (operational) forecasting
  - Forecasting for wind, solar and air quality (online and offline)

Basic Concepts

- How does a model work and what does time integration mean?

$$\frac{\Delta A}{\Delta t} = F(A)$$

ΔA = change in a forecast variable at a particular point in space

$F(A)$ = represents the dynamical and physical processes that can change the value of A

Δt = change in time or time step

A forecast at time N can be written as

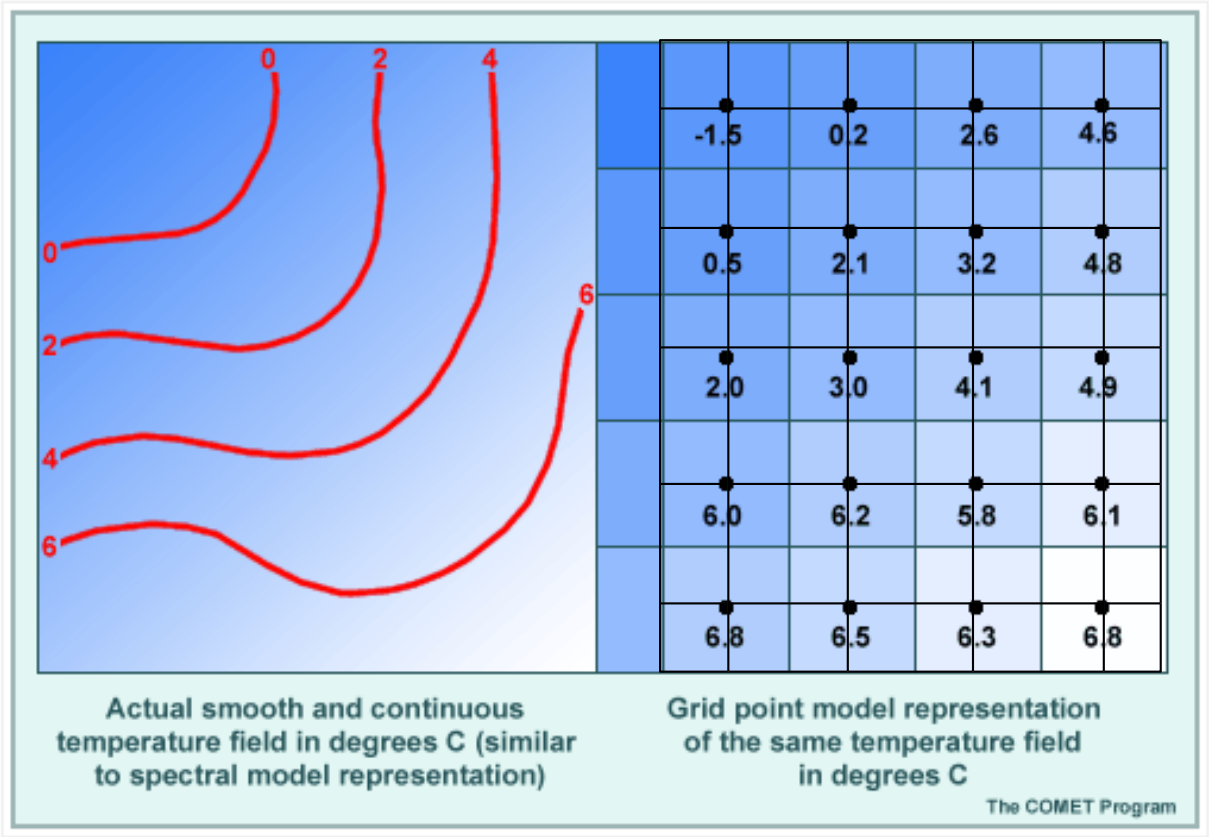
$$A^{n=1} = A^{n=0} + F(A^{n=0})\,\Delta t$$

$$A^{n+1} = A^{n} + F(A^{n})\,\Delta t$$

(adapted from COMET https://www.meted.ucar.edu/)

Basic Concepts

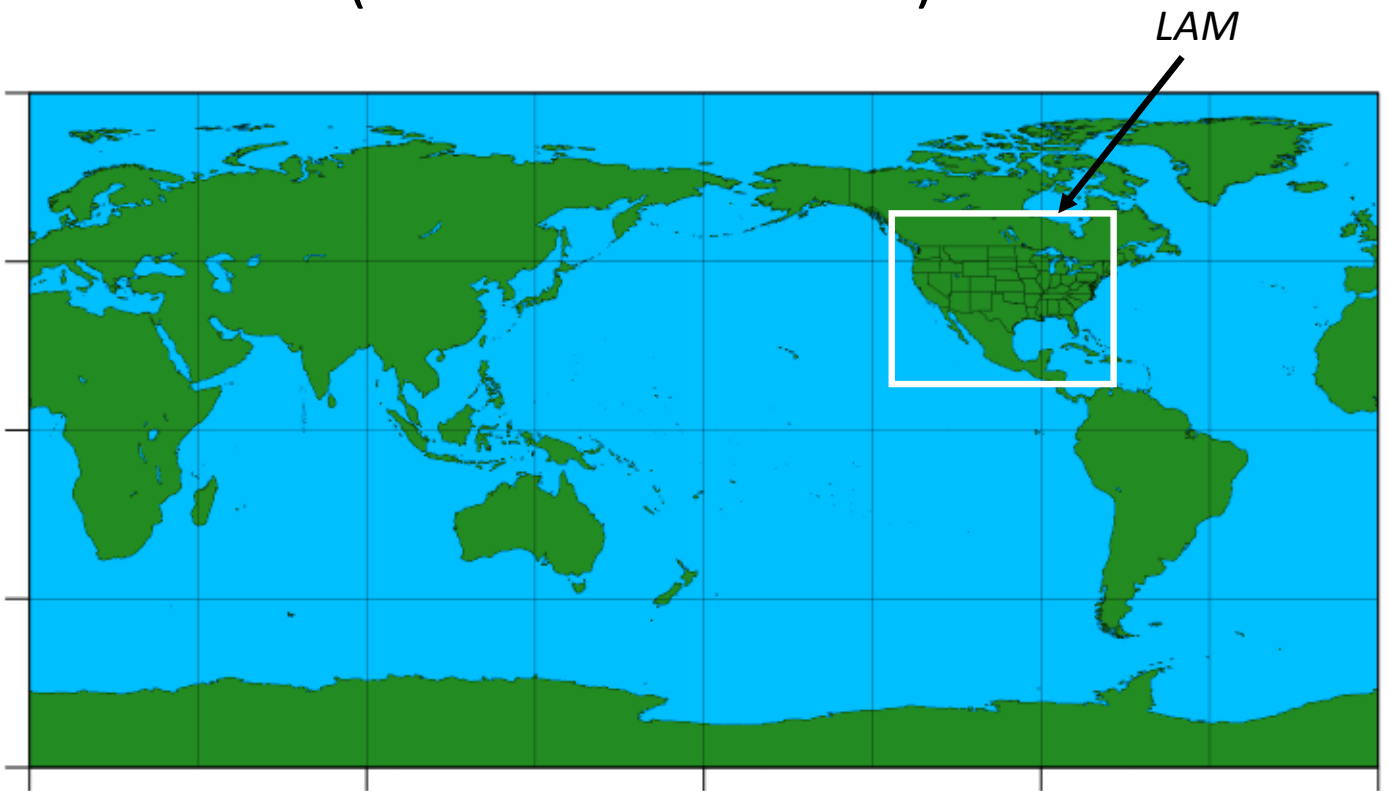
- How are data represented, and equations solved on a model grid?



(from COMET)

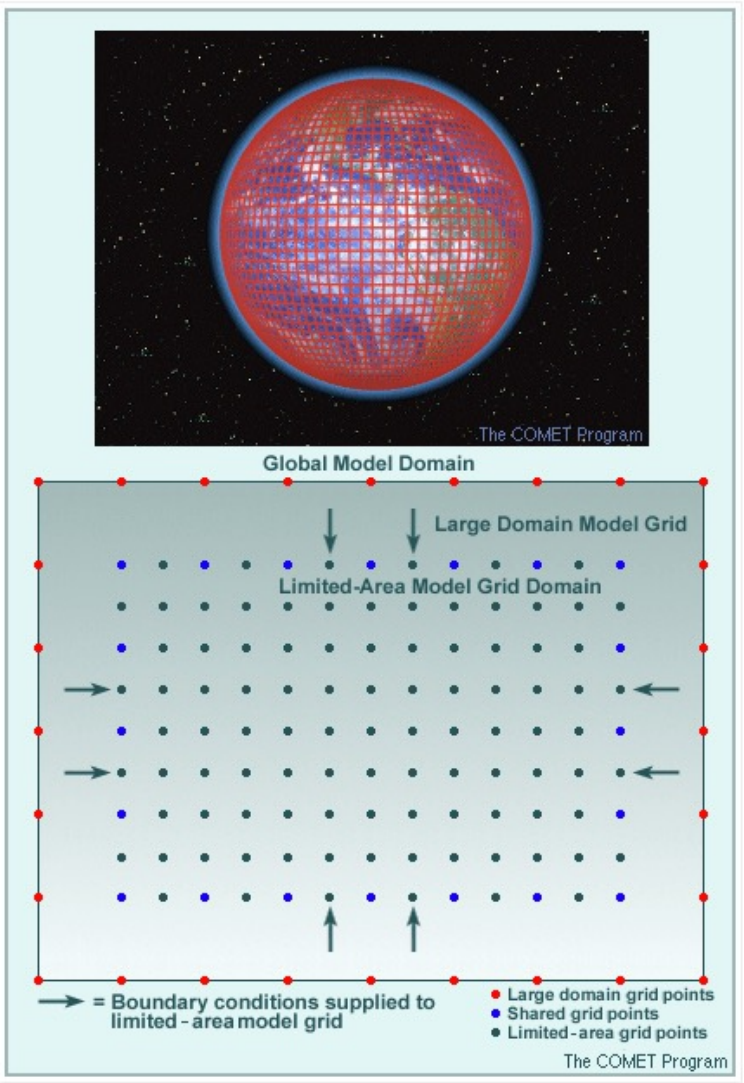
Basic Concepts

- What is a LAM (Limited Area Model)?

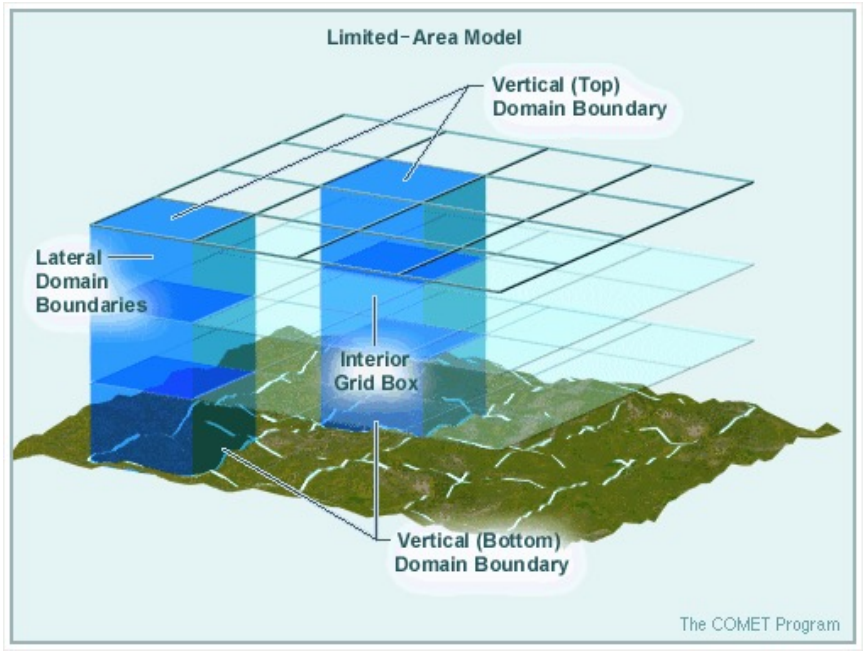


Global Model

Basic Concepts



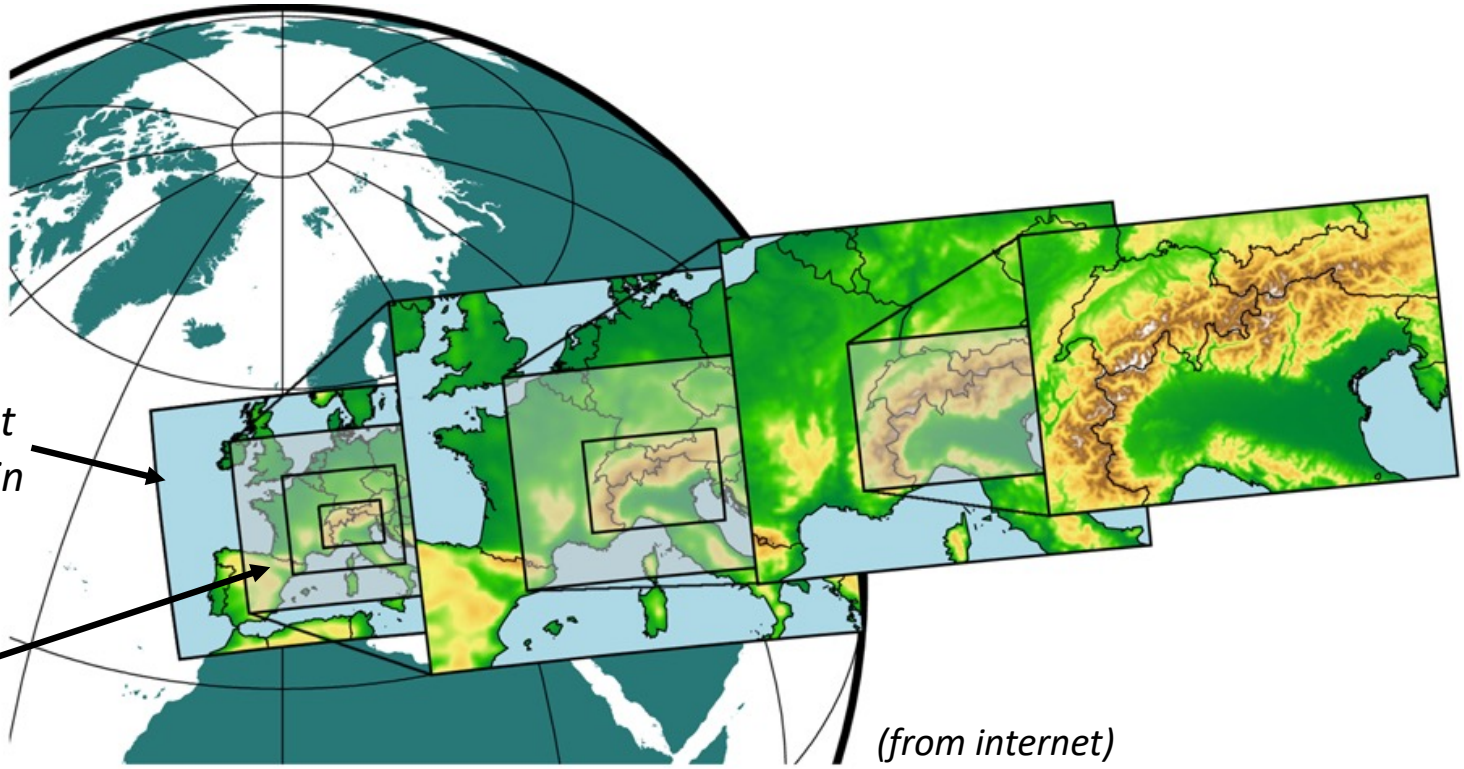
- What are LBCs (lateral boundary conditions)?



(from COMET)

Basic Concepts

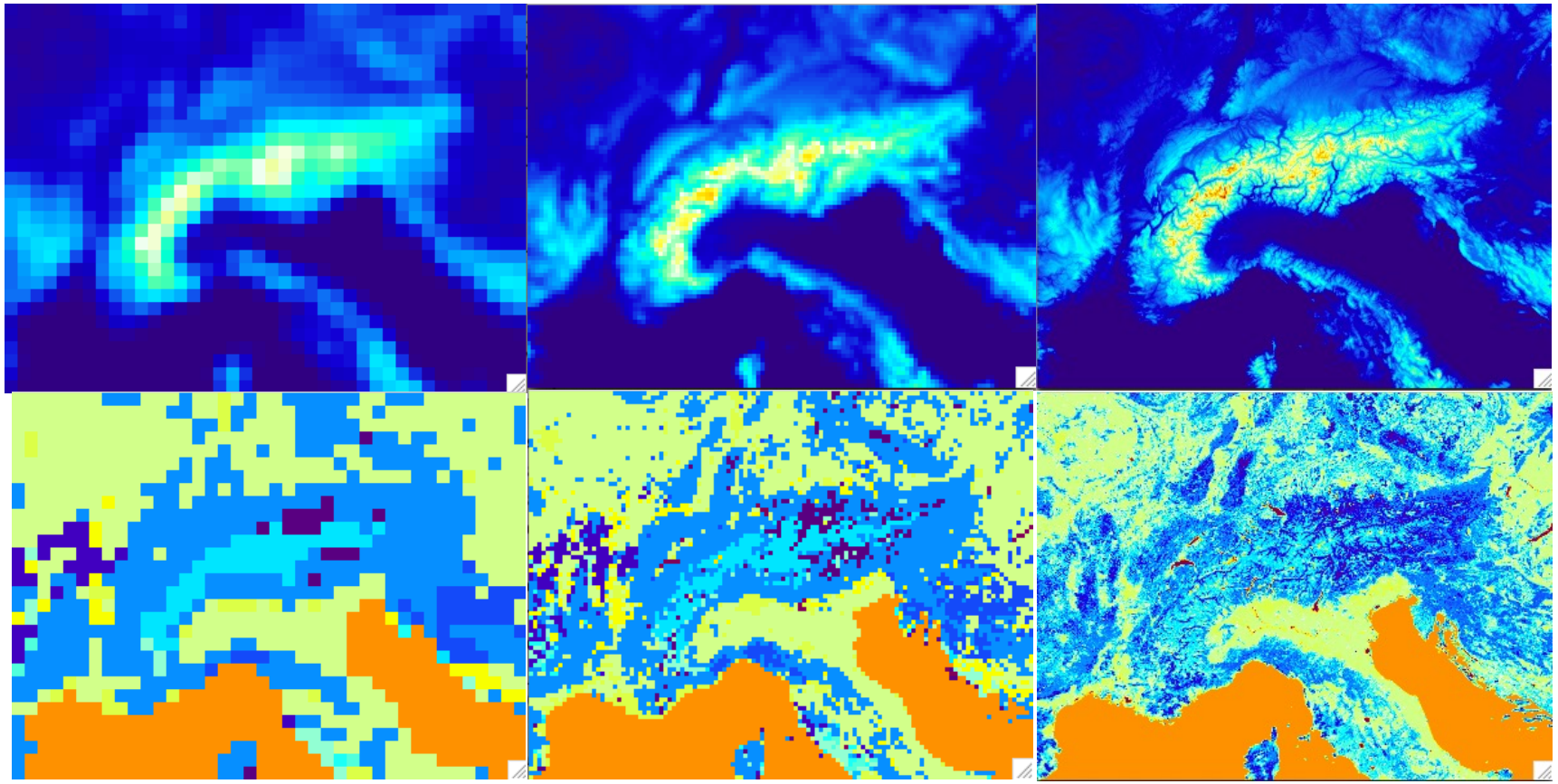
- Nesting in limited area model



(from internet)

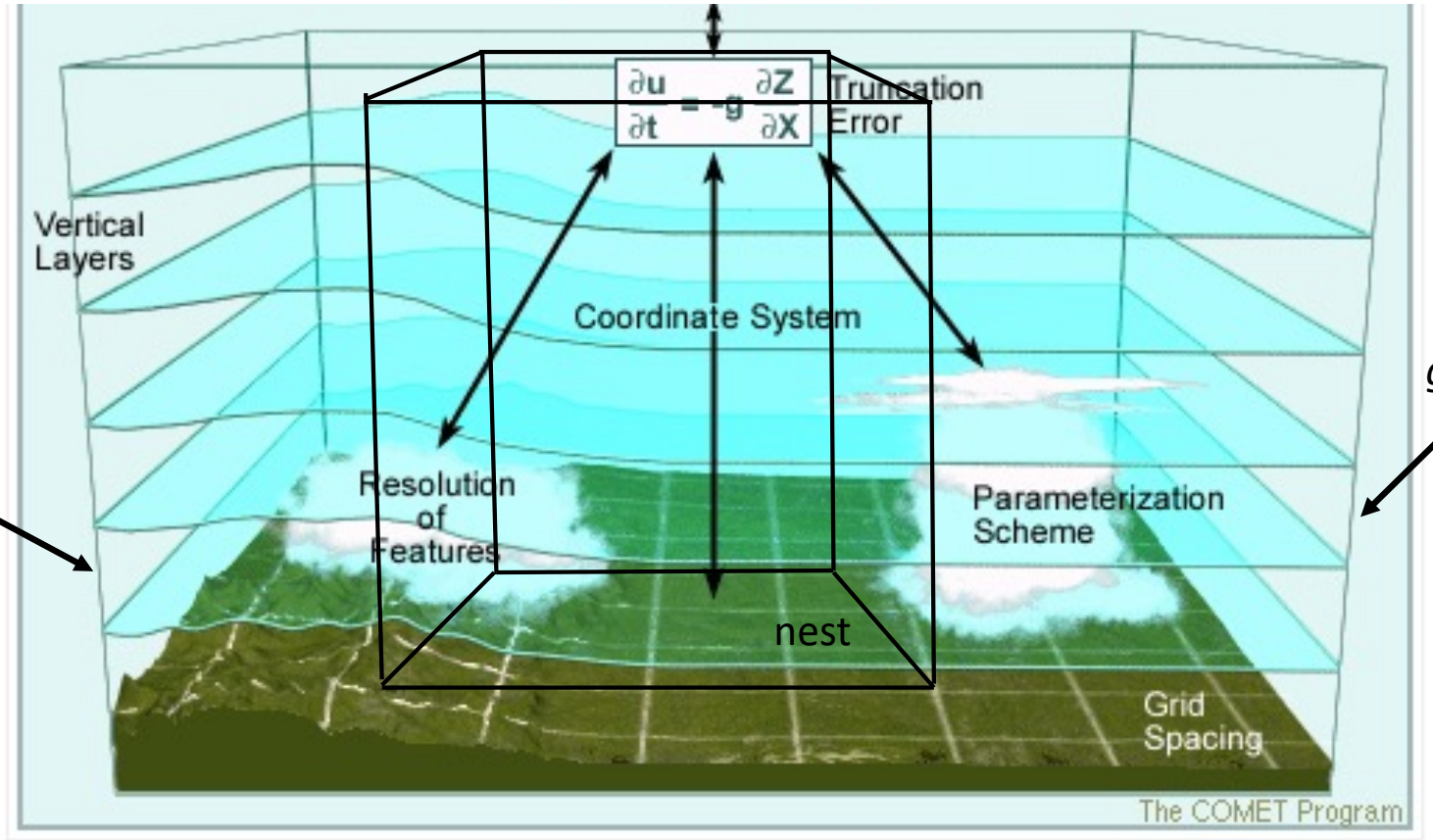
Basic Concepts

- Why nesting? An efficient way to obtain high resolution model solutions.



Basic Concepts

- A 3D view of LAM



Forcing from global models

Forcing from global models

(adapted from COMET)

What does WRF look like to a user?

- A set of programs (mostly in Fortran) and executables
  - No GUI;
  - Command-line;
  - Simple graphic tools to use along the way.

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```
> tar -xf WRF-4.1.2.tar.gz
> cd WRF-4.1.2
> configure
> compile em_real >& compile.log &
> cd run/
> ln -s ../../WPS-4.1/met_em.d01.* .
> mpirun -np 4 real.exe
> ls -l wrfinput* wrfbdy*
> mpirun -np 8 wrf.exe
```

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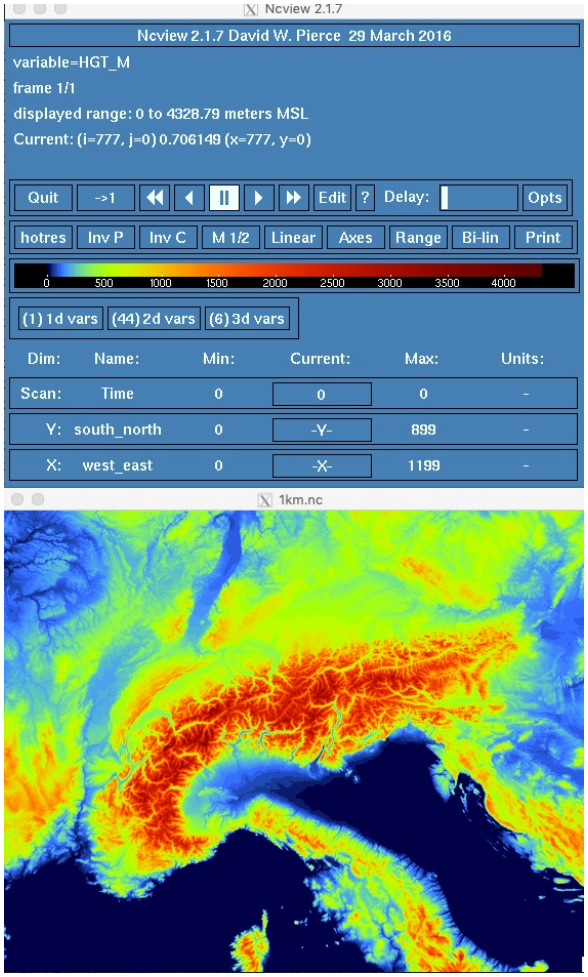

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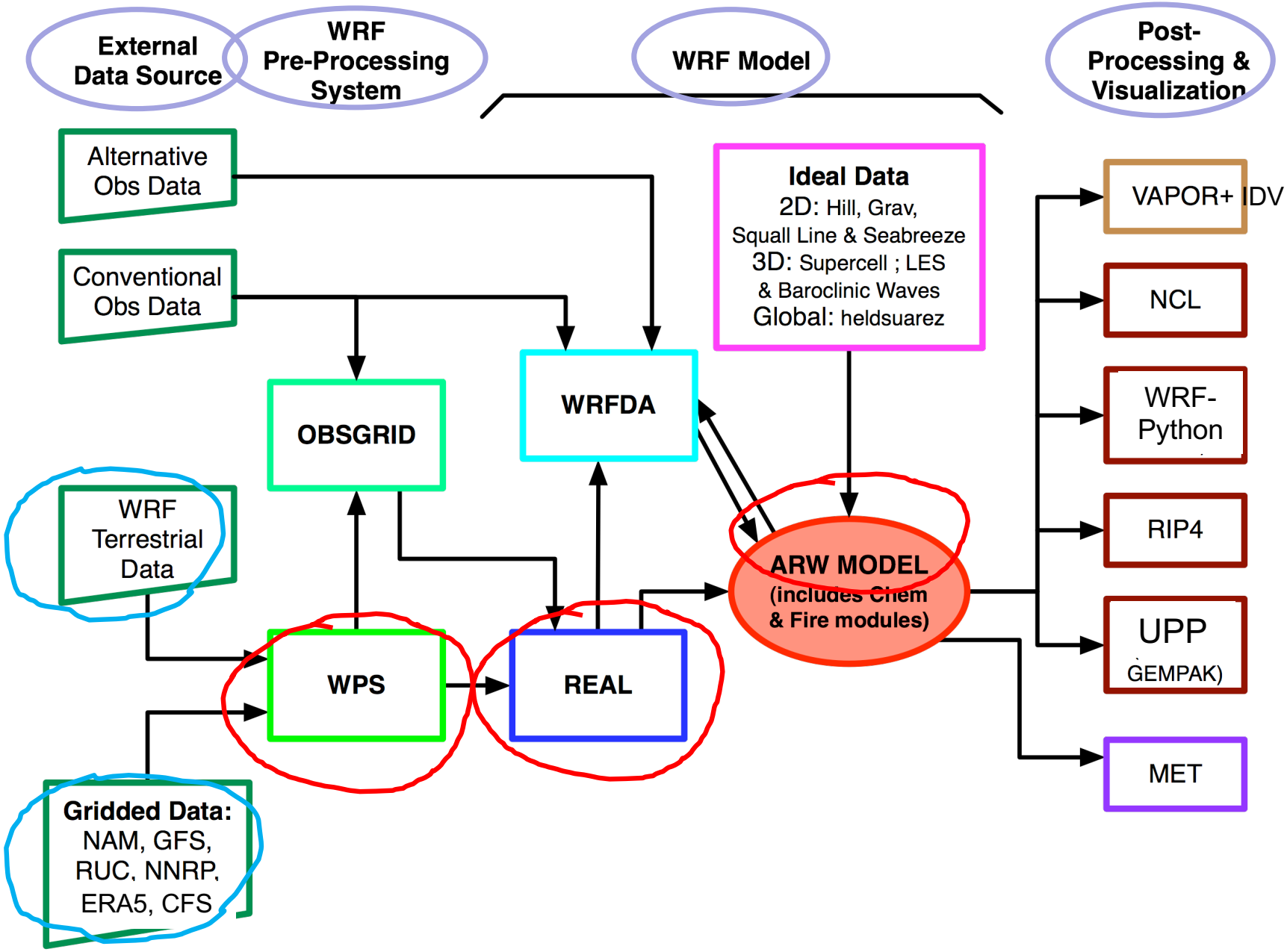
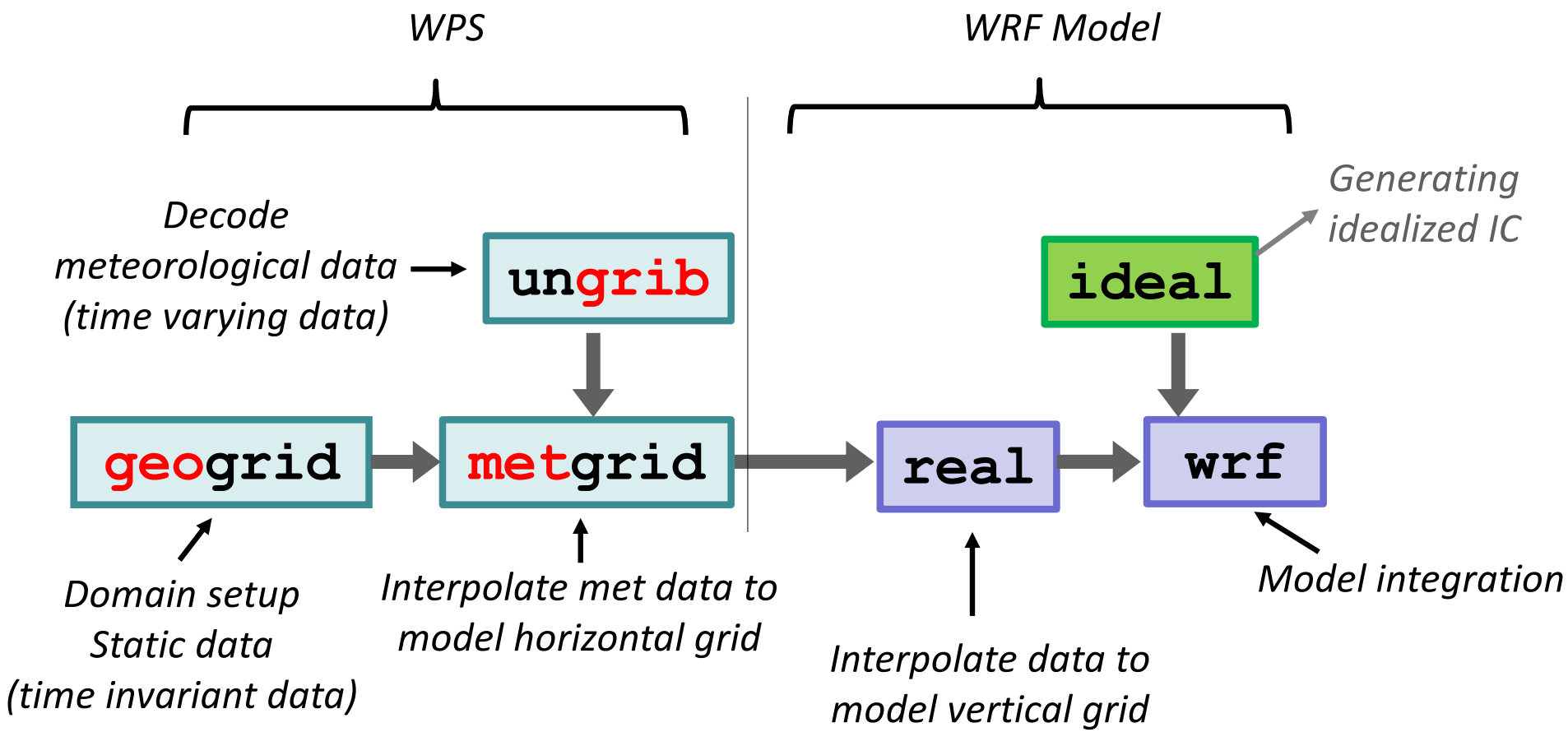
- A set of programs (mostly in Fortran) and executables
  - No GUI;
  - Command-line;
  - Simple graphic tools to use along the way.
- The modeling system programs have many functionalities
  - Many different ways to run a model;
  - Decisions needed at every step (input data, domain configuration, model options, etc.);
  - Best practices required.

WRF Modeling System Flow Chart



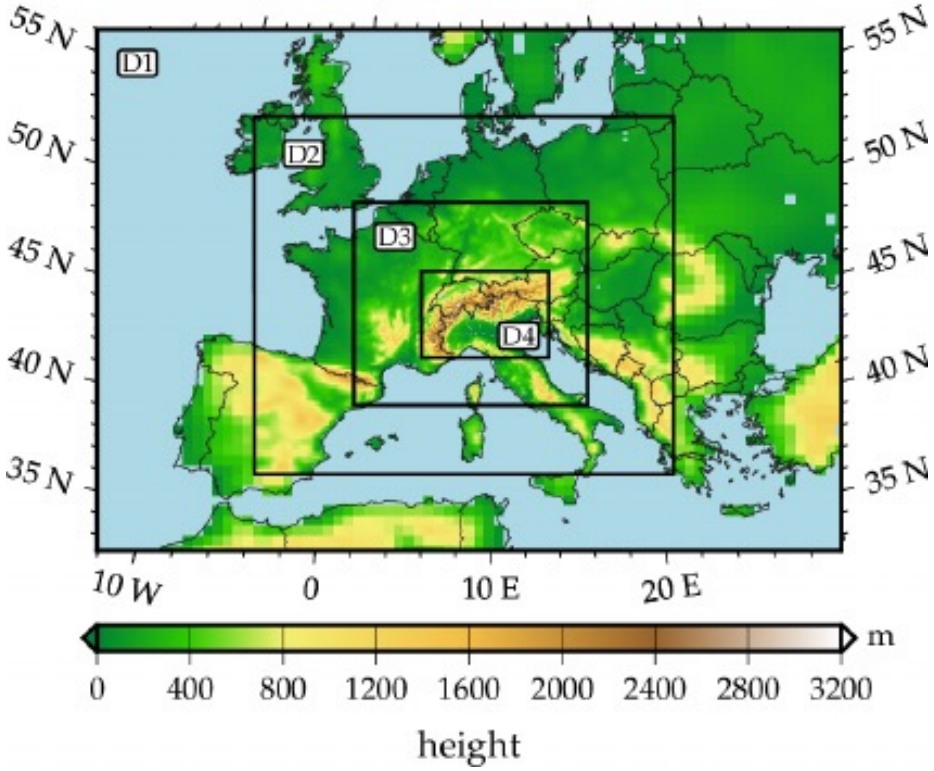
WPS and WRF Program Flow



For a real-data application

What will you learn in this tutorial?

a. Configuration of simulation domains



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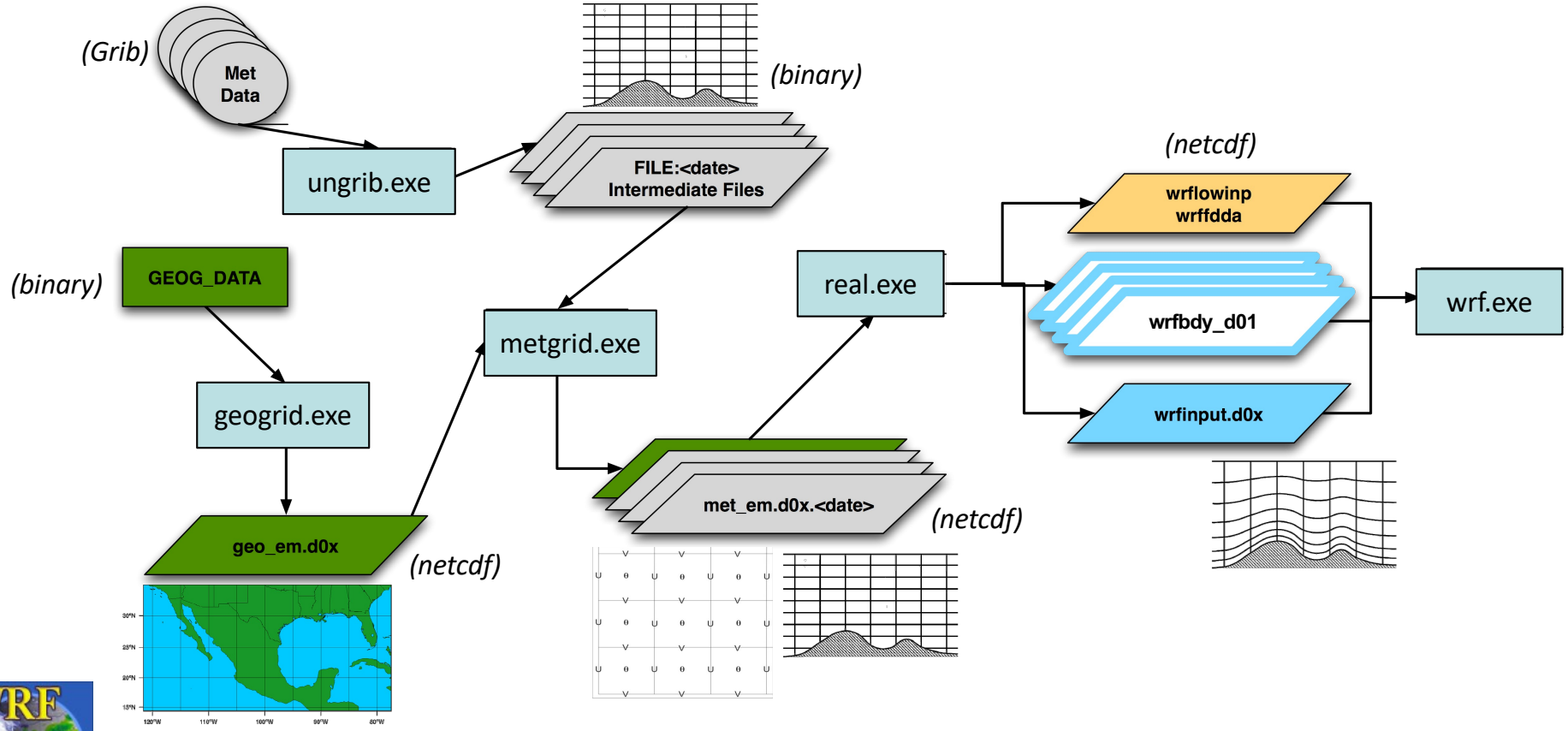
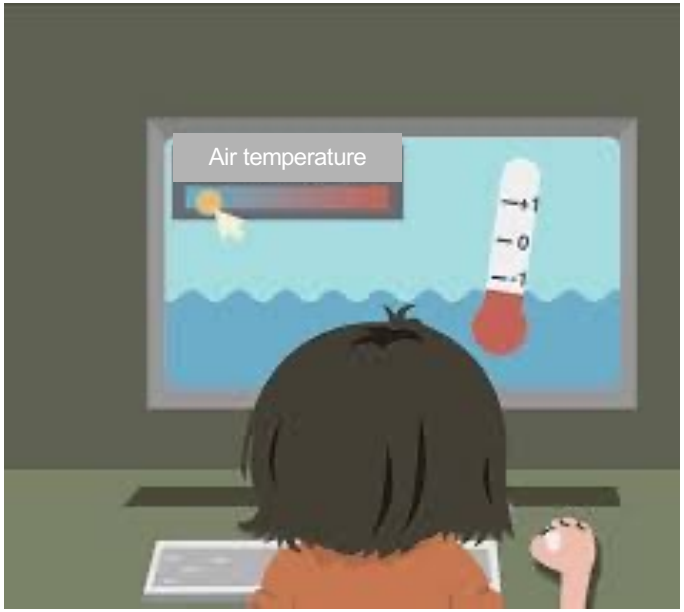


What will you learn in this tutorial?

a. Configuration of simulation domains
b. Preparation of data for initial and boundary conditions
c. Running the model



What will you learn in this tutorial?

a. Configuration of simulation domains
b. Preparation of data for initial and boundary conditions
c. Running the model
d. Model internals:
   i. Dynamics: formulation of compressible, non-hydrostatic equations

$$\frac{\partial W}{\partial t} + g\left(\mu_d - \frac{\alpha}{\alpha_d}\frac{\partial p}{\partial \eta}\right) = -\frac{\partial Uw}{\partial x} - \frac{\partial \Omega w}{\partial \eta}$$

$$\frac{\partial \mu_d}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial \Omega}{\partial \eta} = 0$$

$$\frac{\partial \Theta}{\partial t} + \frac{\partial U\theta}{\partial x} + \frac{\partial \Omega\theta}{\partial \eta} = \mu Q$$

$$\frac{d\phi}{dt} = gw$$

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   i. Dynamics: formulation of compressible, non-hydrostatic equations
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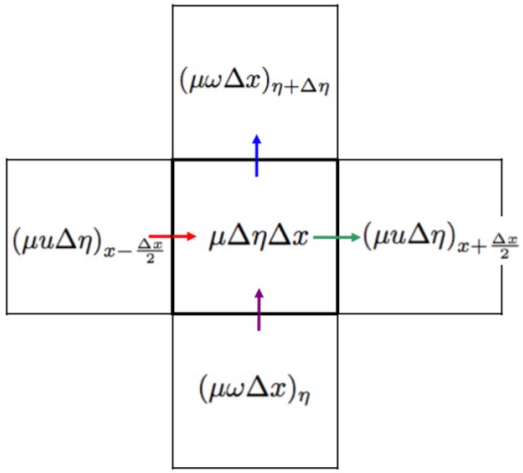

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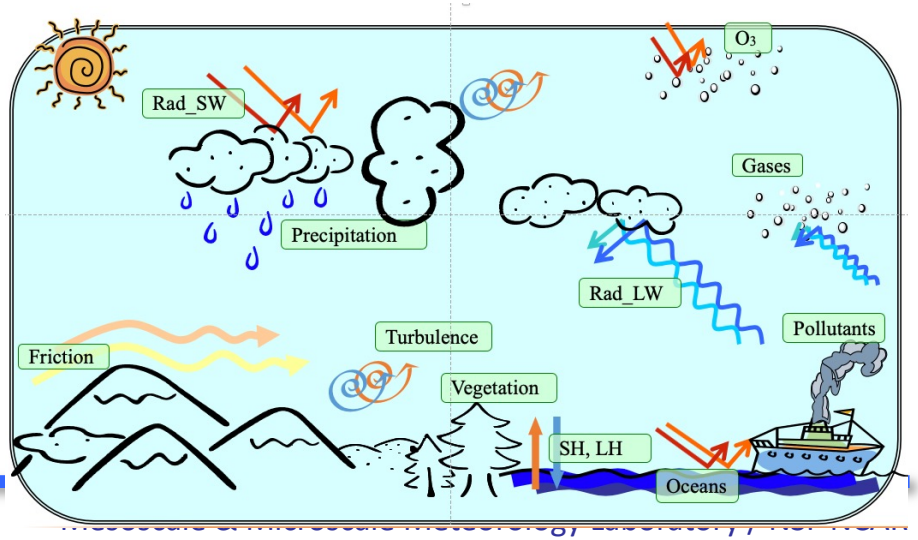

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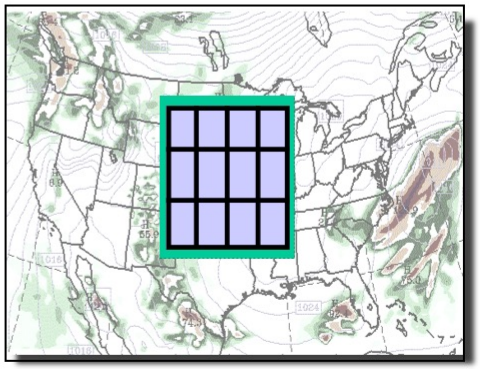
   iii. Physics: how are physical processes in the atmosphere are represented
   iv. parallel computing



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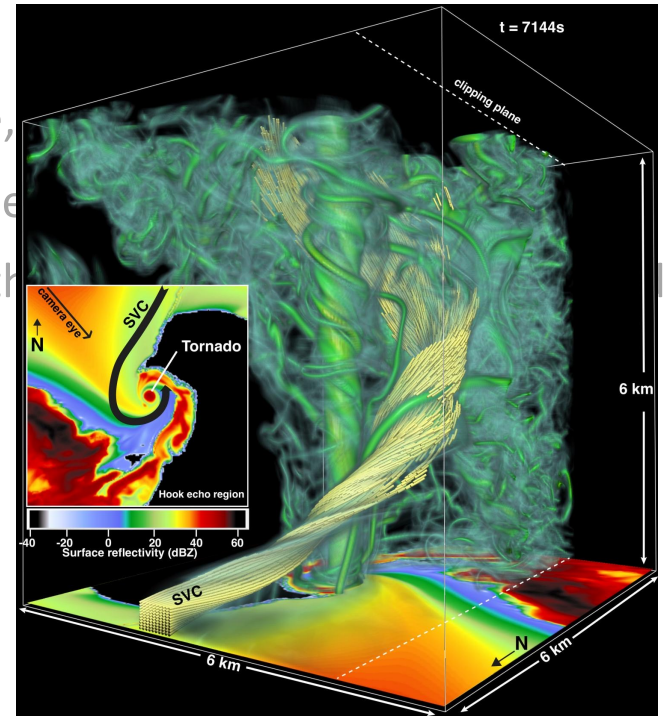
e. Tools to view and analyze model output



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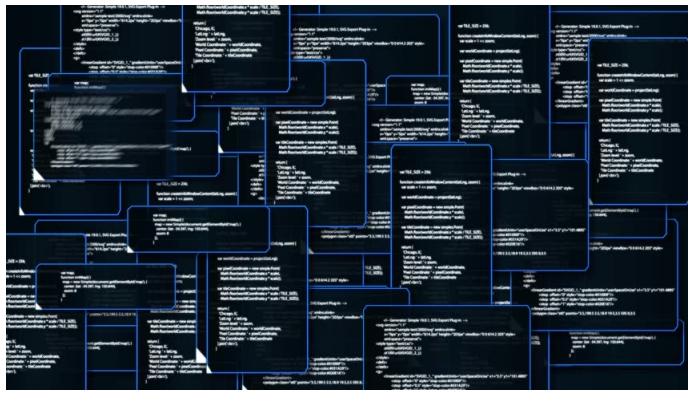
f. How to compile the modeling system code



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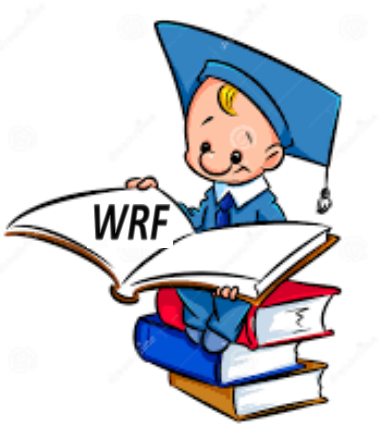
    iv. Software and parallel computing
e. Tools to view and analyze model output
f. How to compile the modeling system code
g. Best practices and verifying model output

What will you gain from this tutorial?

a. Knowledge needed to run WRF for basic applications
   i. Some understanding on how the model works
   ii. Familiarity with the process to run the model

b. Recognize what you learn here is a starting point
   i. Continue to learn after the tutorial
   ii. Read more and experiment
   iii. Practice, practice, and practice…



Reading (watch) Materials

Numerical Weather and Climate Prediction, 2011. By Thomas Warner, *Cambridge University Press*.

Warner, T., 2011. Quality assurance in atmospheric modeling. *Bull. Amer. Met. Soc. Dec. issue, p1601 – 1611.*

Stensrud, D., 2007. Parameterization Schemes: Keys to Understanding Numerical Weather Prediction Models. *Cambridge University Press*.

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