An Introduction to the WRF Modeling System

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Acknowledgement: figures contributed by many at MMM

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Outline

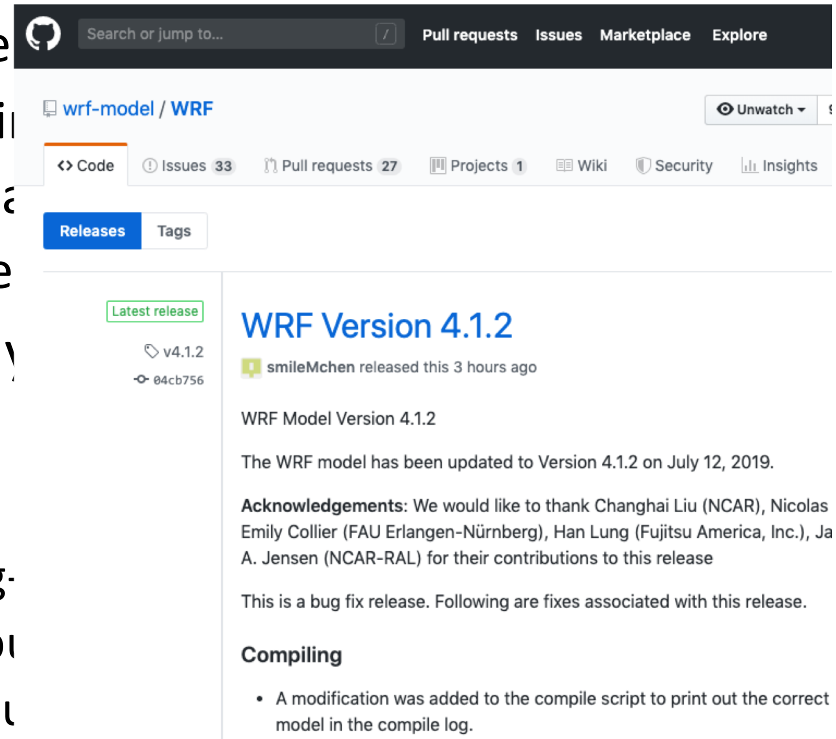
- What is WRF?
  - A brief history of WRF
- What does WRF look like to you, the user?
- Some basic concepts about limited area modeling
- What is covered in this tutorial?
- What should you expect to gain from this tutorial?

What is WRF?

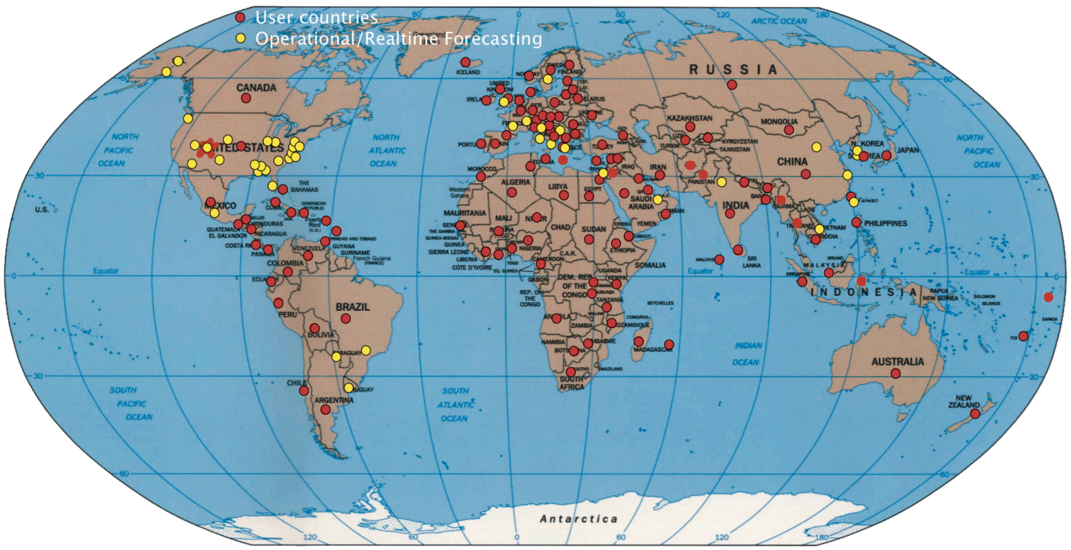
- WRF: Weather Research and Forecasting Model
- It is a supported "community model", i.e. a free and shared resource with distributed development and centralized support
- Its development is led by NCAR, NOAA/ESRL and NOAA/NCEP/EMC with partnerships at AFWA, FAA, DOE/PNNL and collaborations with universities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

WRF Community Model

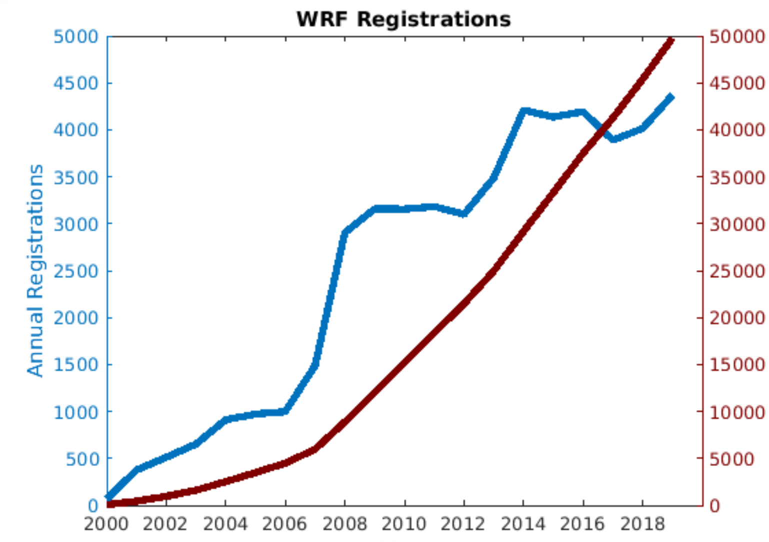
- Version 1.0 WRF was released Dece
- Version 2.0: May 2004 (added nesti
- Version 3.0: April 2008 (added globa
- … (major releases in April, minor re
- Version 3.9: April 2017 (added hy
  - Version 3.9.1 (August 2017)
- Version 4.0 (June 2018)
  - Version 4.0.1 (October 2018) – bug-
  - Version 4.0.2 (November 2018) – bu
  - Version 4.0.3 (December 2018) – bu
- Version 4.1 (April 2019) – last major release
  - Version 4.1.1 (June 2019) – bug-fix release
  - Version 4.1.2 (July 2019) – current release

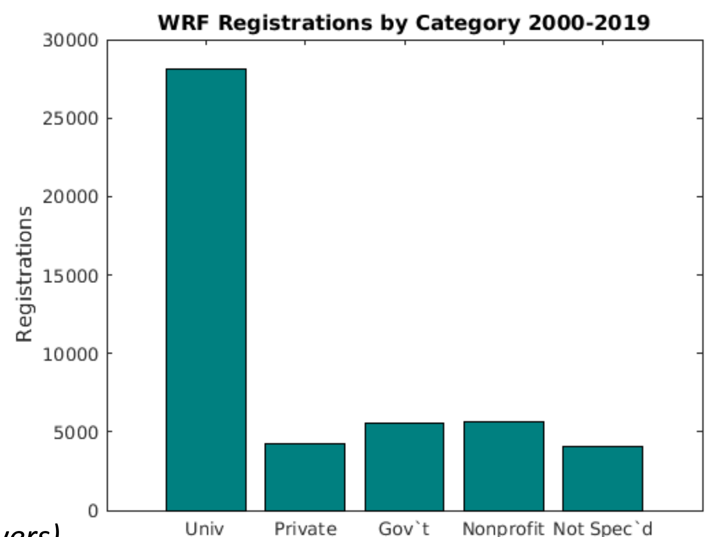


WRF Users



As of July 2019:
No. of countries: 185
No. of users: 47700
US: 12765
Foreign: 34935





(From Powers)

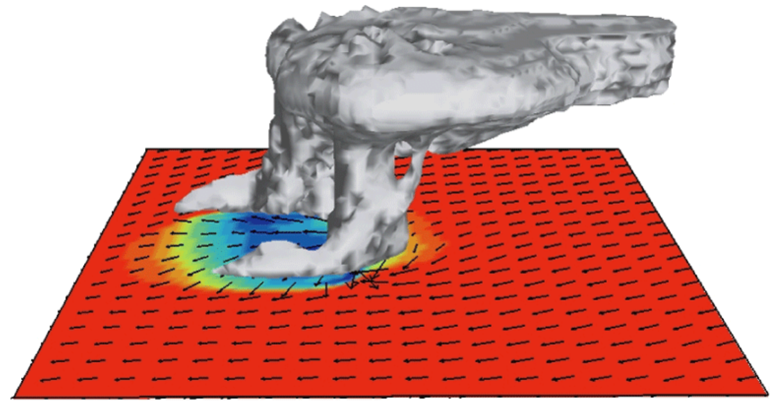
What is ARW?

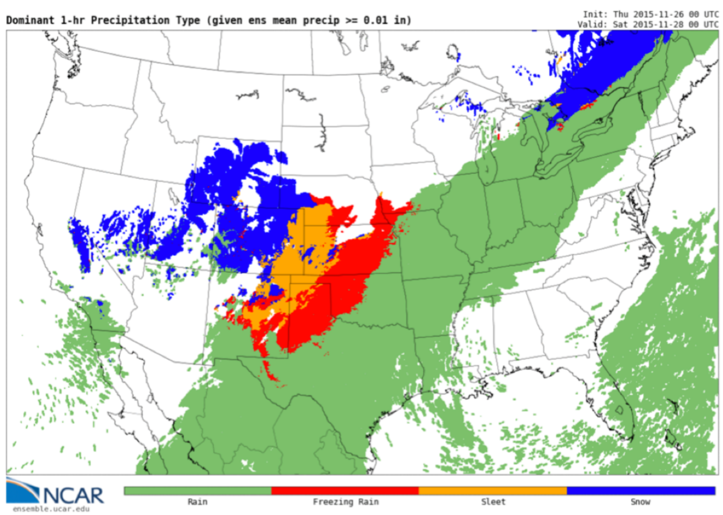
- WRF has two dynamical cores: The Advanced Research WRF (ARW) and Nonhydrostatic Mesoscale Model (NMM)
  - Dynamical core includes mostly advection, pressure-gradients, Coriolis, buoyancy, filters, diffusion, and time-stepping
- ARW support and development are centered at NCAR/MMM
- NMM development is centered at NCEP/EMC and support is provided by NCAR/DTC (now only used for HWRF)
- This tutorial is only for the ARW core

What is ARW?

- A research tool:

Idealized simulations →



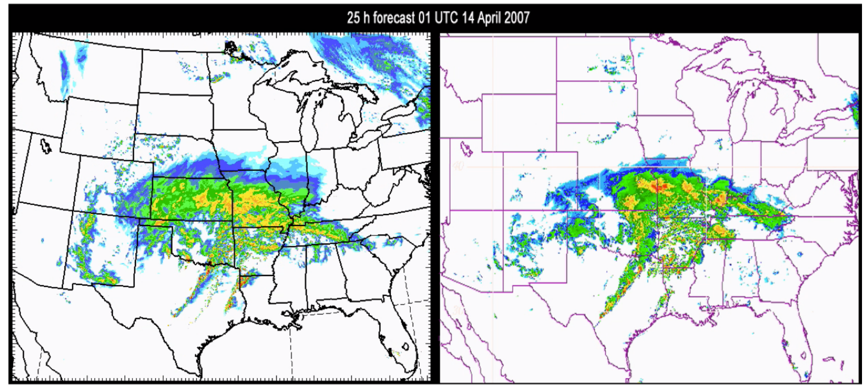


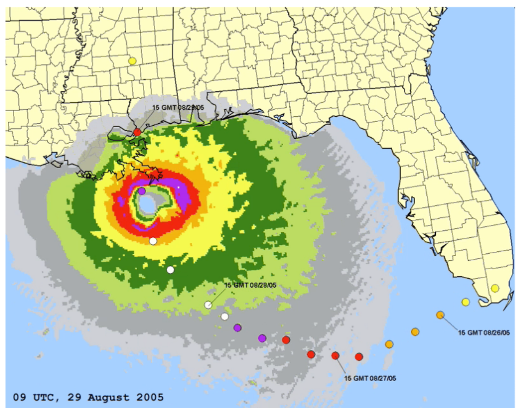
← Experimental real-time forecast

What is ARW?

- A research tool:

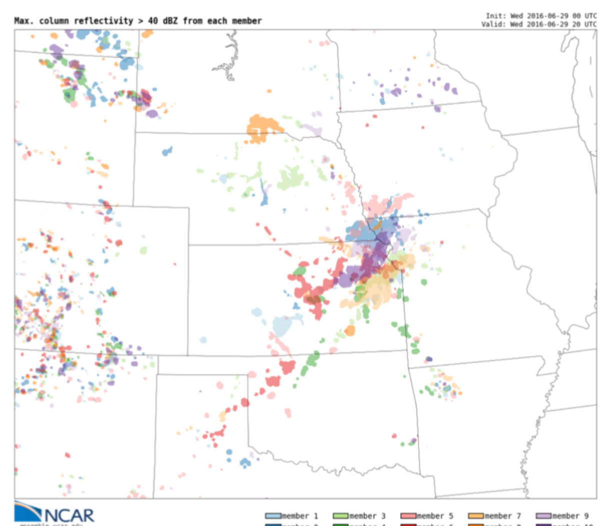
Convection forecast →





← High-resolution hurricane simulations

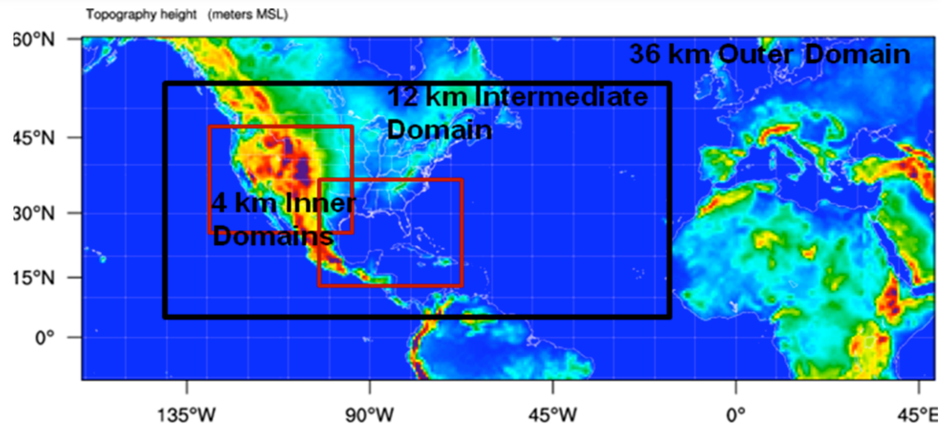
Development of ensemble forecasting technology →

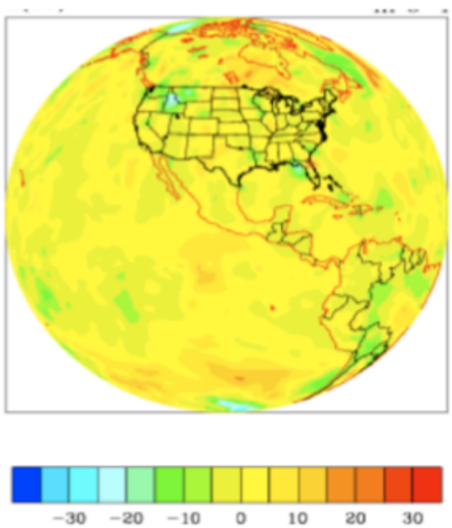


What is ARW?

- A research tool:

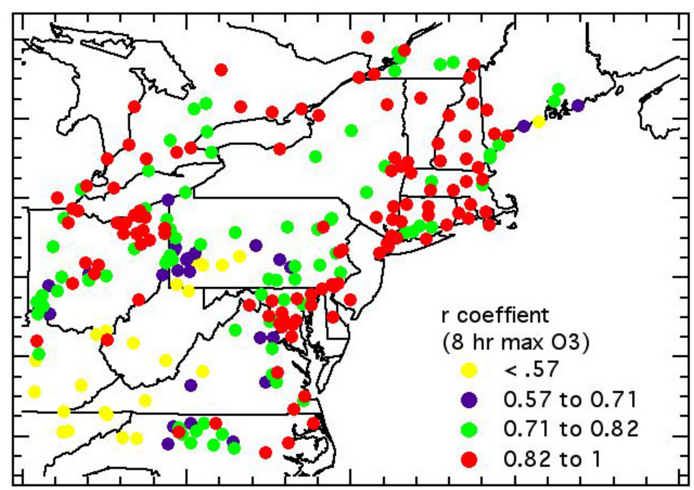
Regional Climate Modeling →





← Data assimilation

WRF-Chemistry →



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)

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.

What does WRF look like to a user?

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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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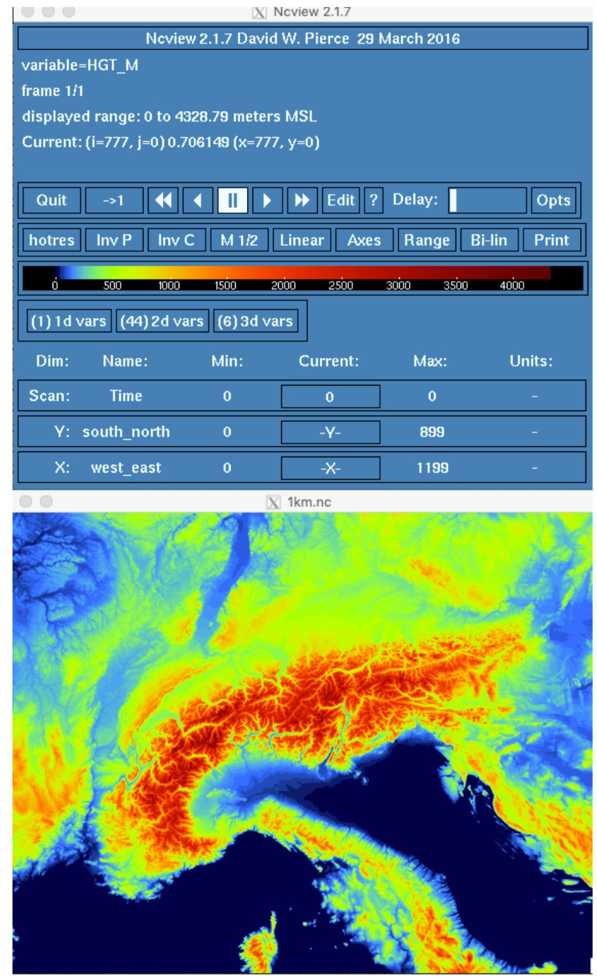
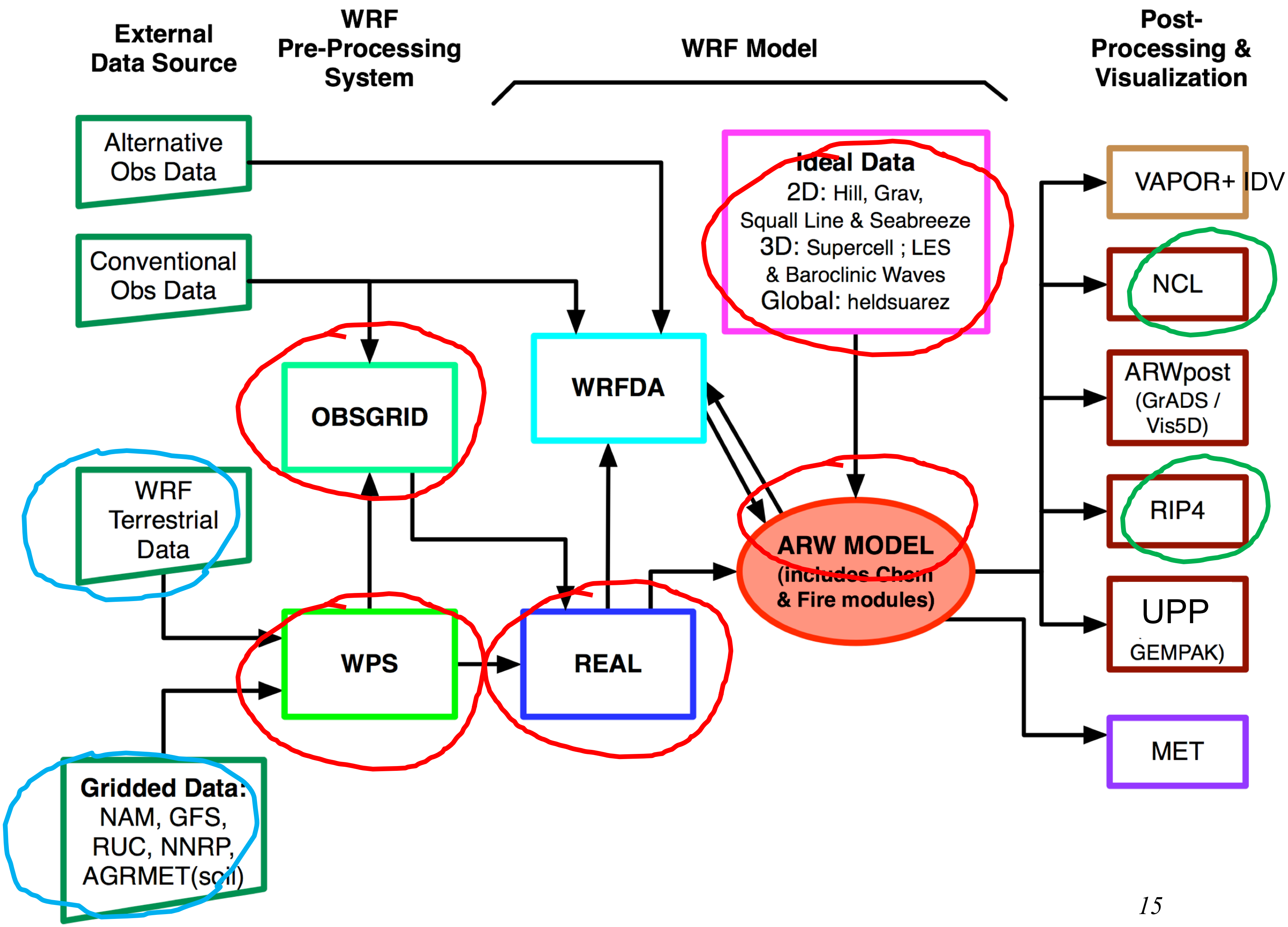


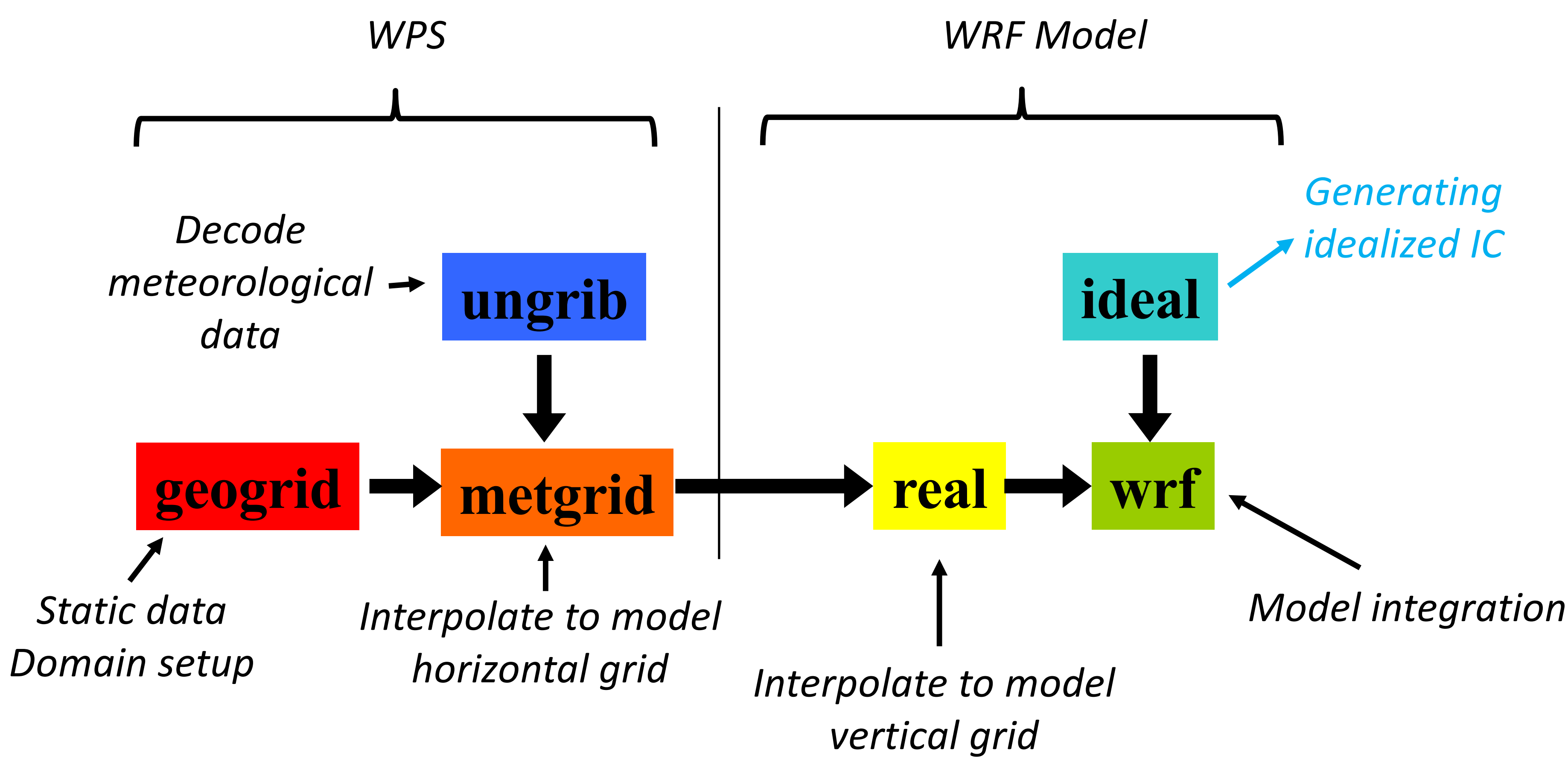
What does WRF look like to a user?

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

Some basic concepts

- What does model integration mean?

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

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

$F(A)$ = Describes the physical processes that can change the value of A

Δt = change in time

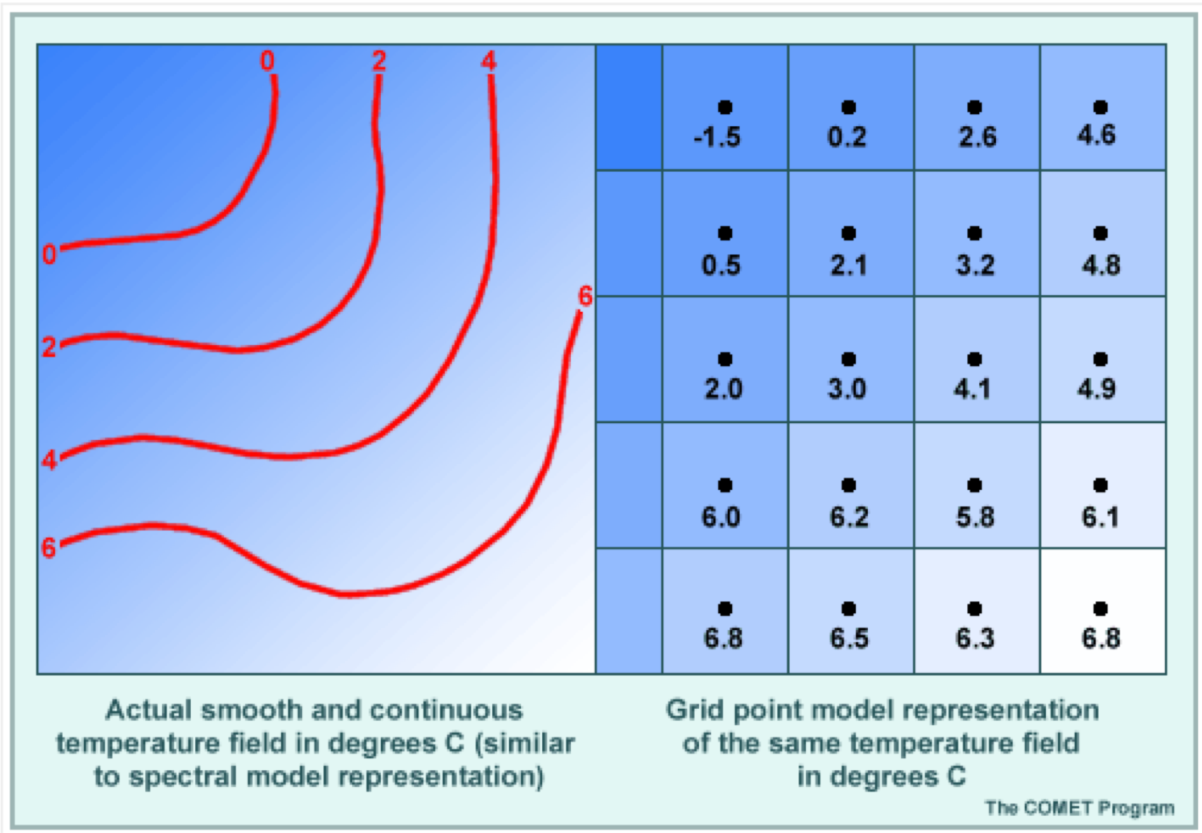
So a forecast is

$$A^{forecast} = A^{initial} + F(A)\,\Delta t$$

(adapted from COMET)

Some basic concepts

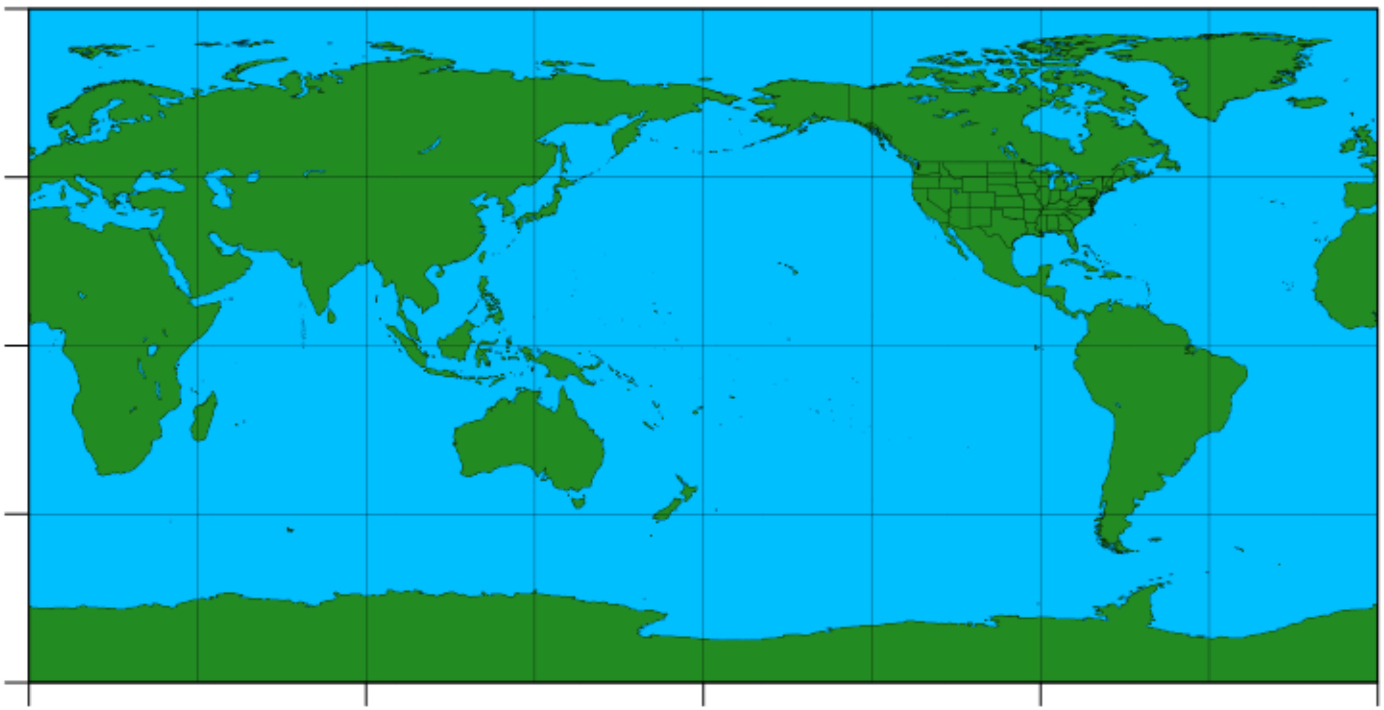
- How are data represented, and equations solved on a model grid?



(from COMET)

Some basic concepts

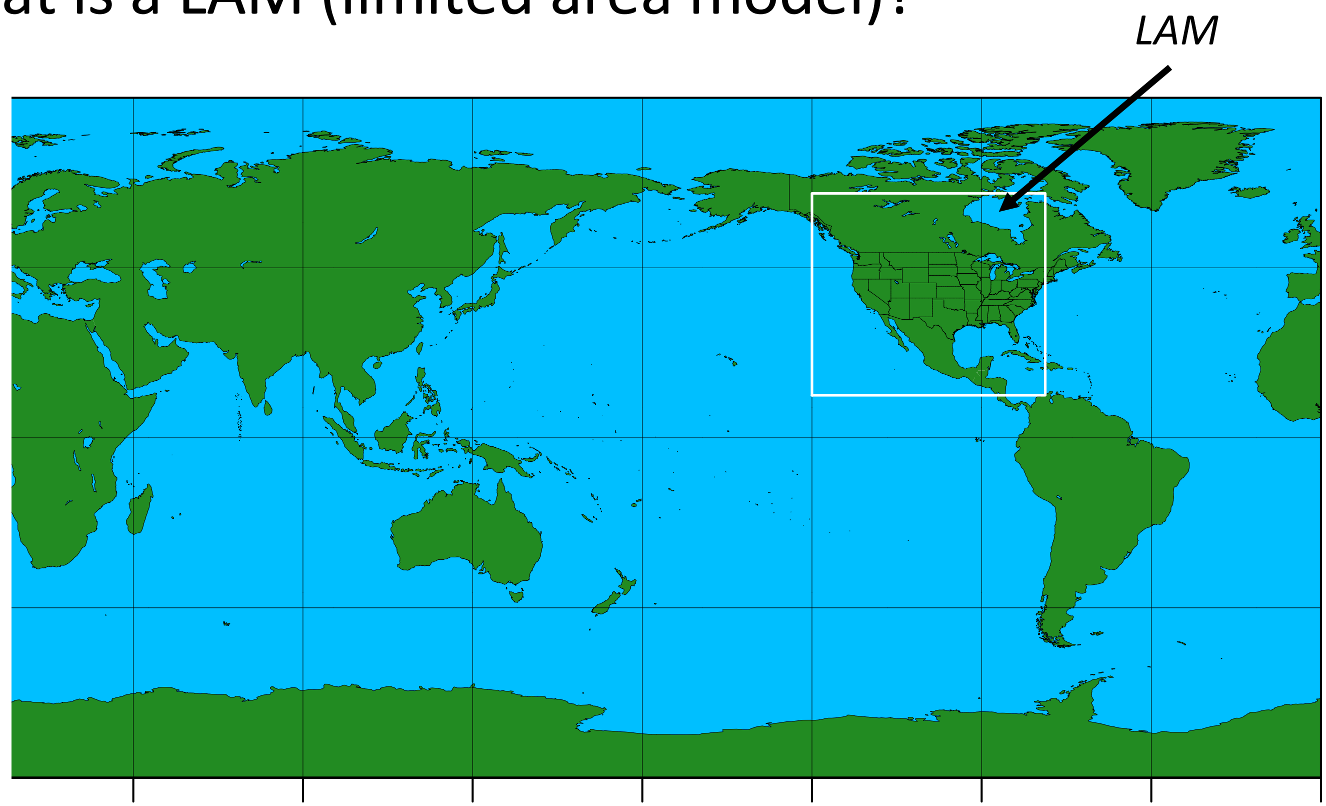
- What is a LAM (limited area model)?



Global Model

Some basic concepts

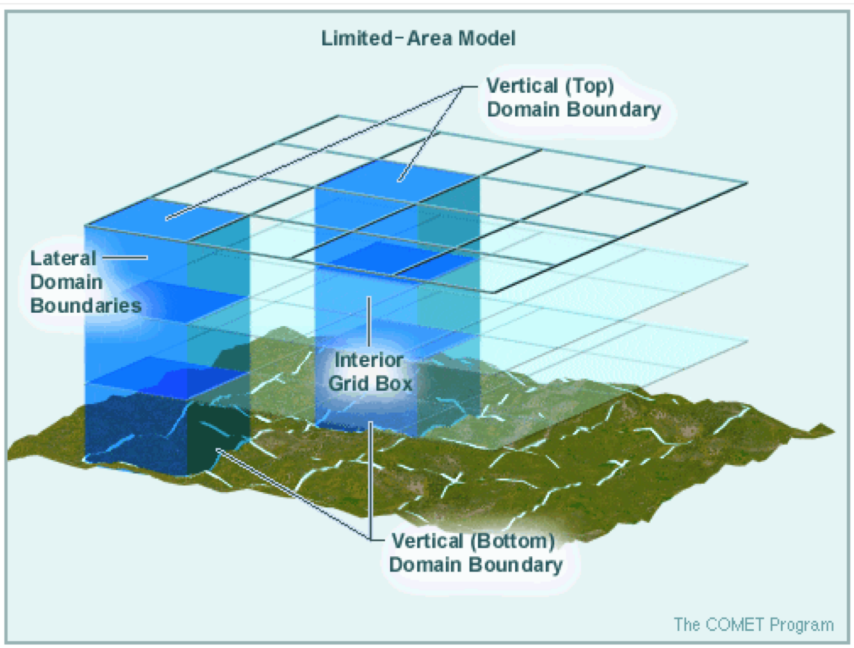
- What is a LAM (limited area model)?

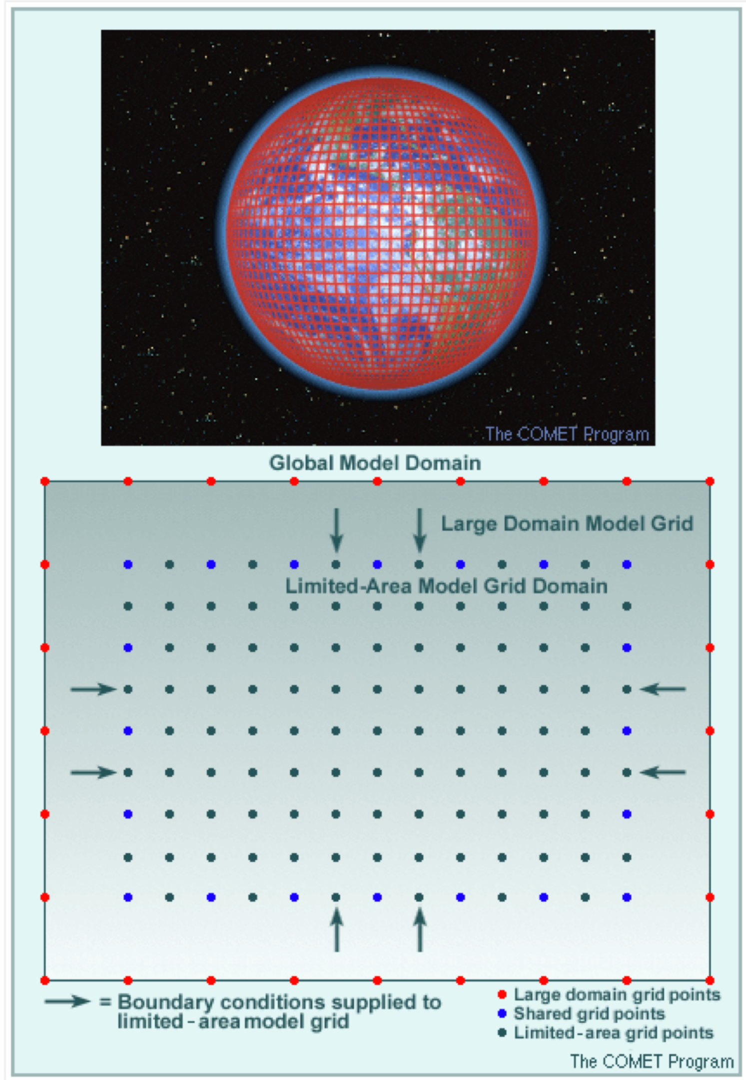


Regional Model

Some basic concepts

- What is a LBC (lateral boundary condition)?

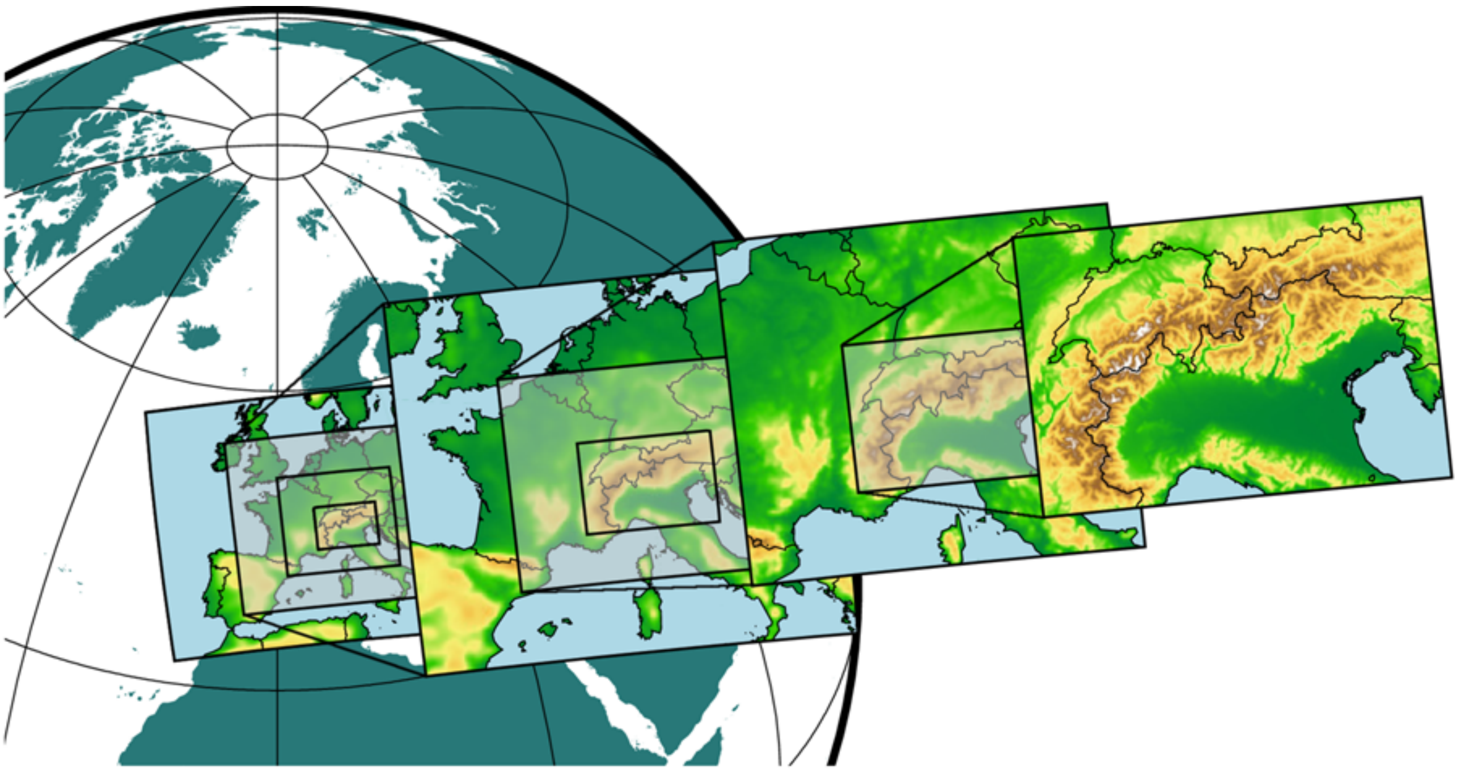




(from COMET)

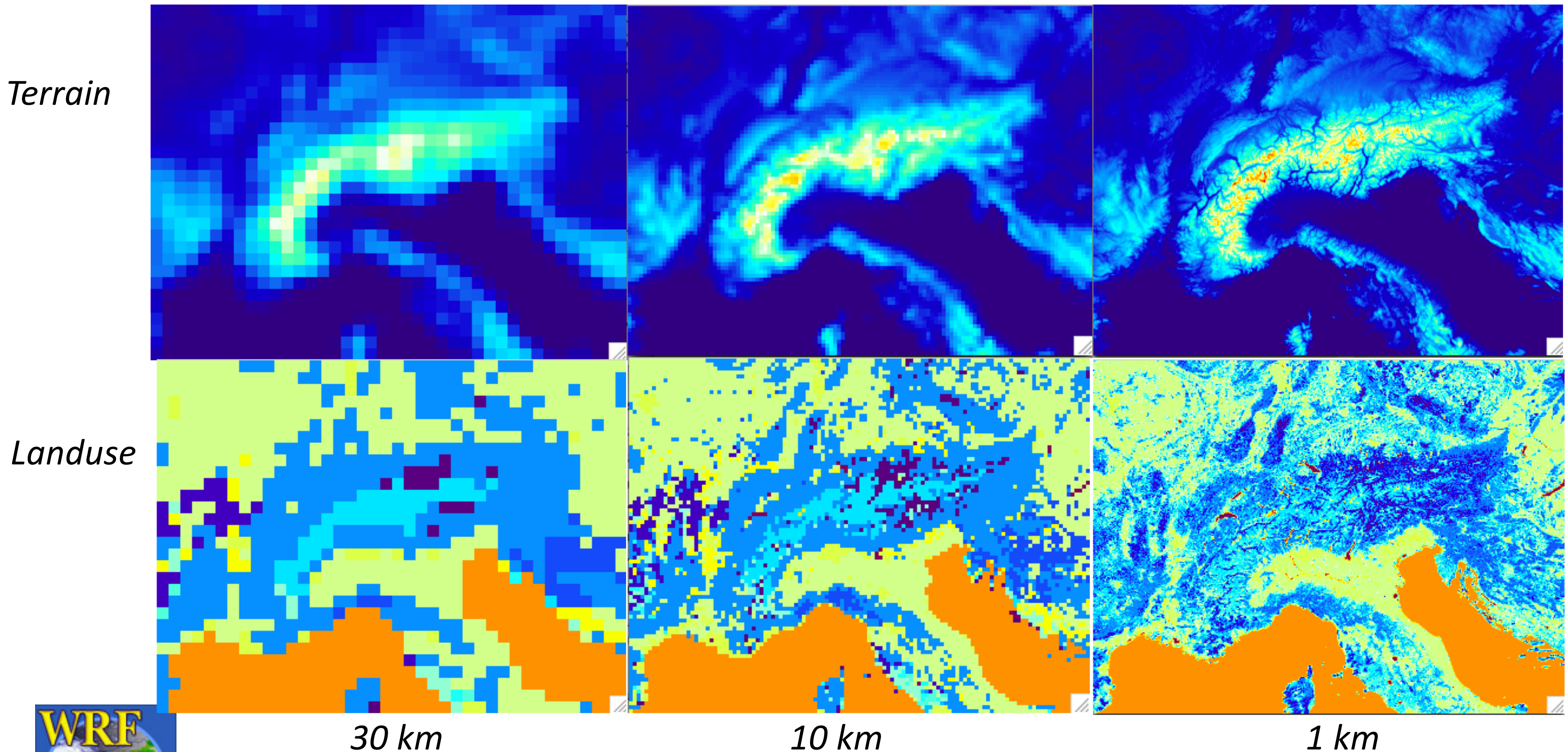
Some basic concepts

- Nesting in limited area model



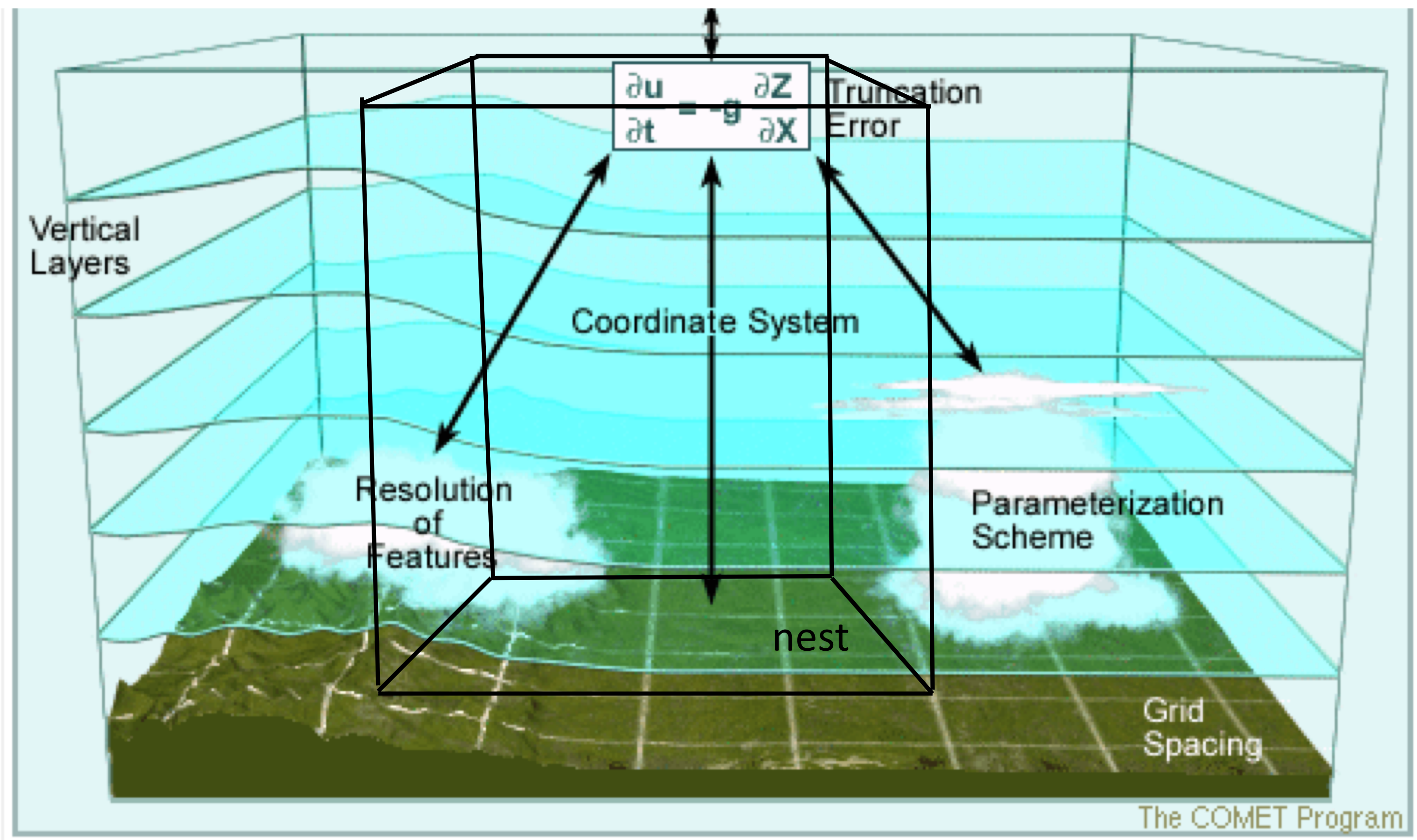
Some basic concepts

- Why nesting?



Some basic concepts

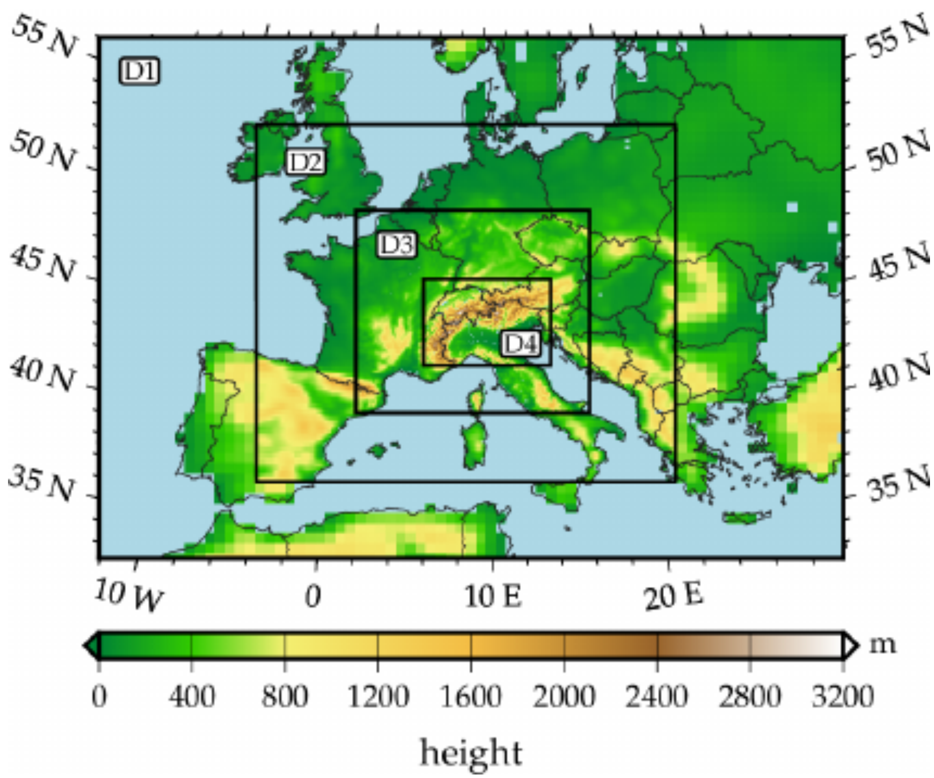
- A 3D view of LAM



(partially from COMET)

What will you learn in this tutorial?

a. Configuration of simulation domains



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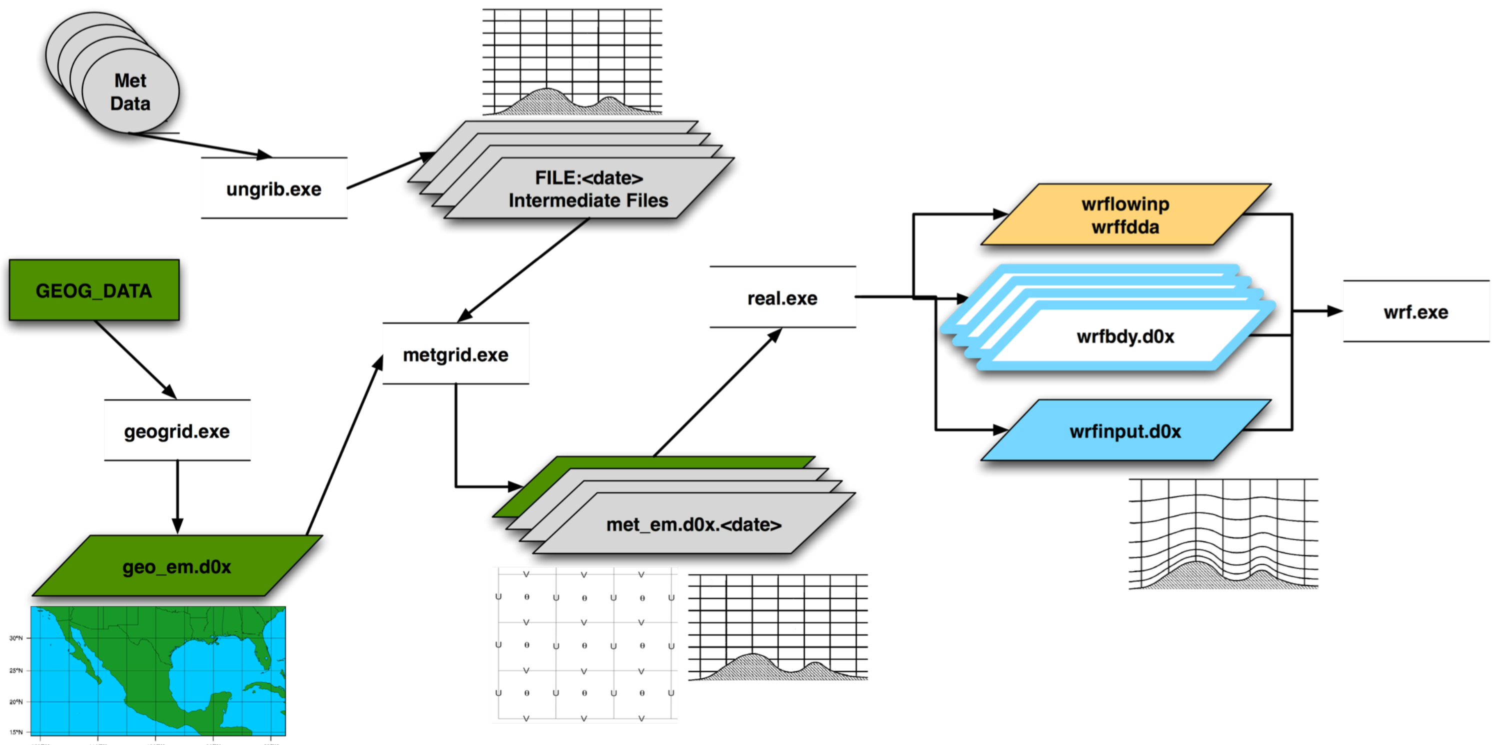

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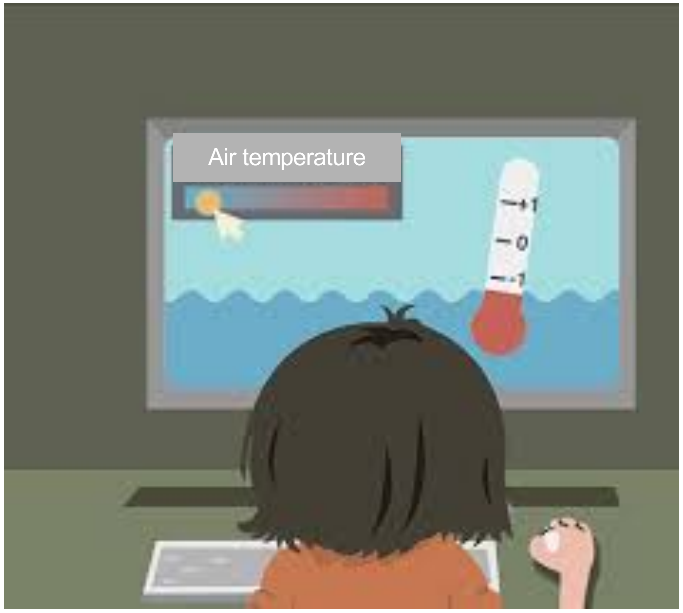
c. Running the model



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

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

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

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

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

What will you learn in this tutorial?

a. Configuration of simulation domains
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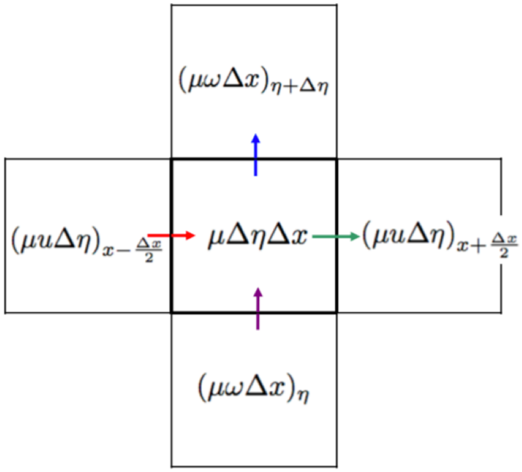
d. Model internals:
   i. Dynamics: formulation of compressible, non-hydrostatic equations
   ii. Numerics: how to solve equations numerically



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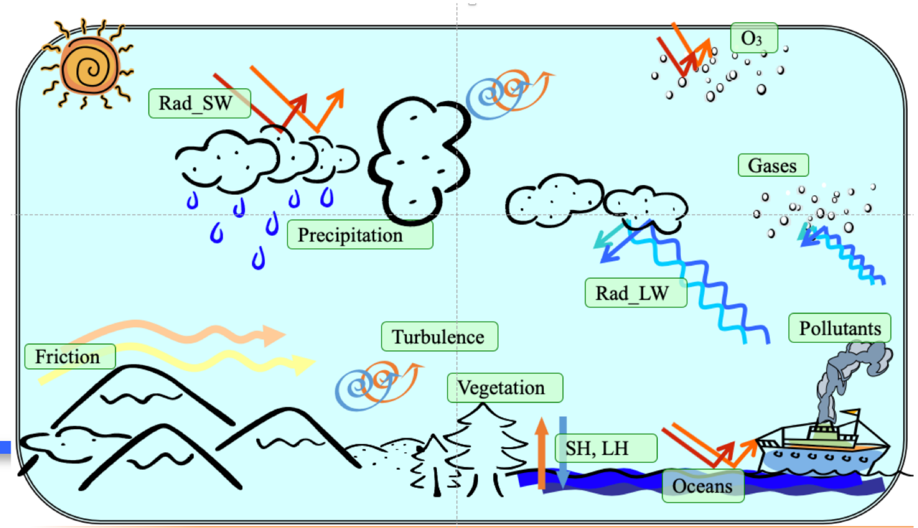

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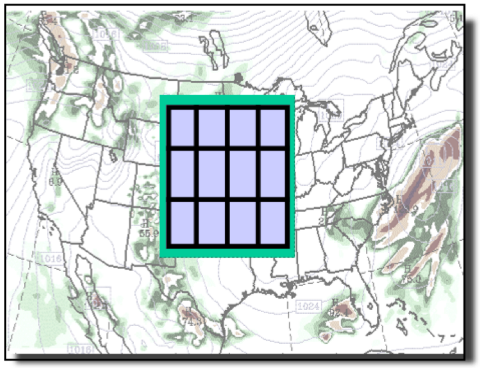
   iii. Physics: how are physical processes in the atmosphere are represented
   iv. Software and parallel computing



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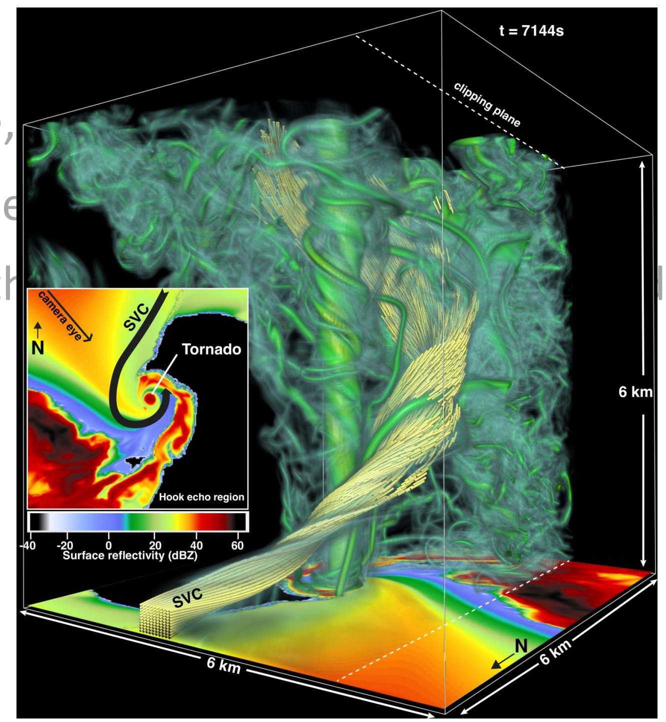
e. Tools to view and analyze model output



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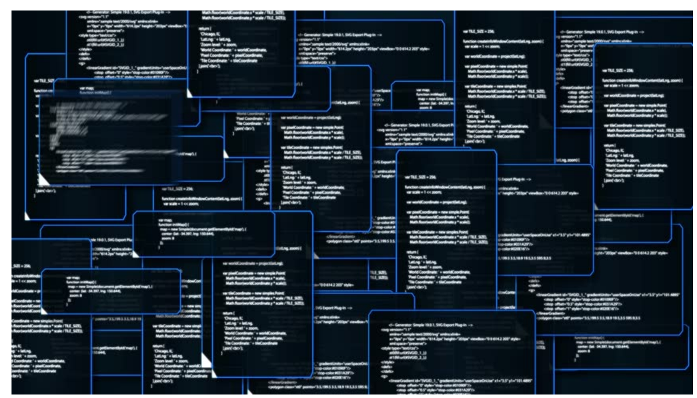

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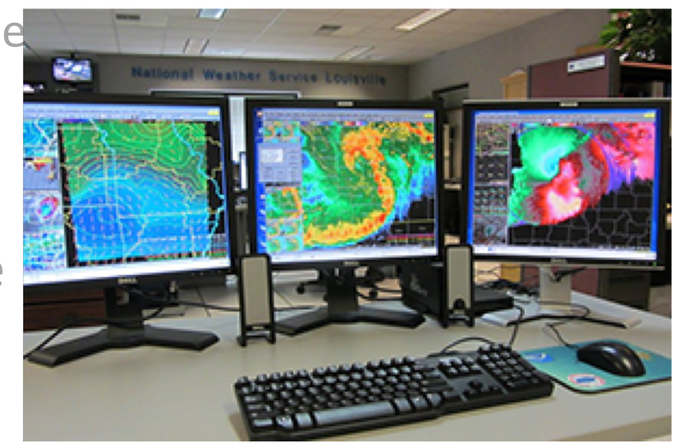
f. How to compile the modeling system code
g. **Best practices**



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. Learning a tool, or many pieces of a tool
   ii. Read more and experiment
   iii. Practice, practice, practice…