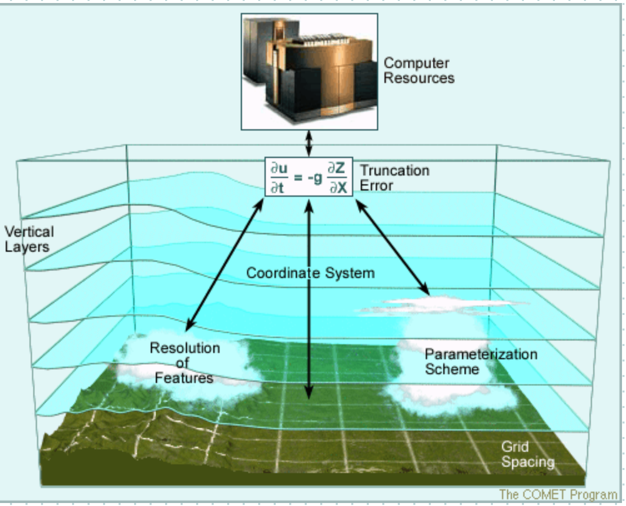
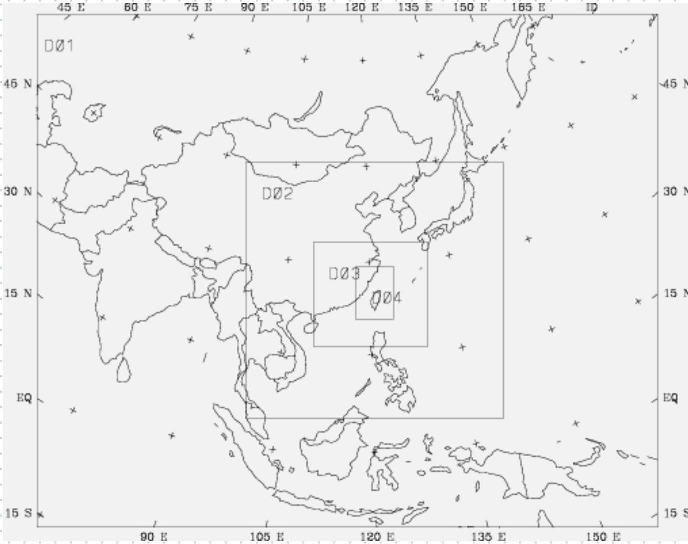
Mesoscale Atmospheric Models





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IAVCEI Working Group on Modeling Volcanic Tephra-Fall Hazards
Workshop, Cities on Volcanoes Conference, Hilo, Hawaii

Overview

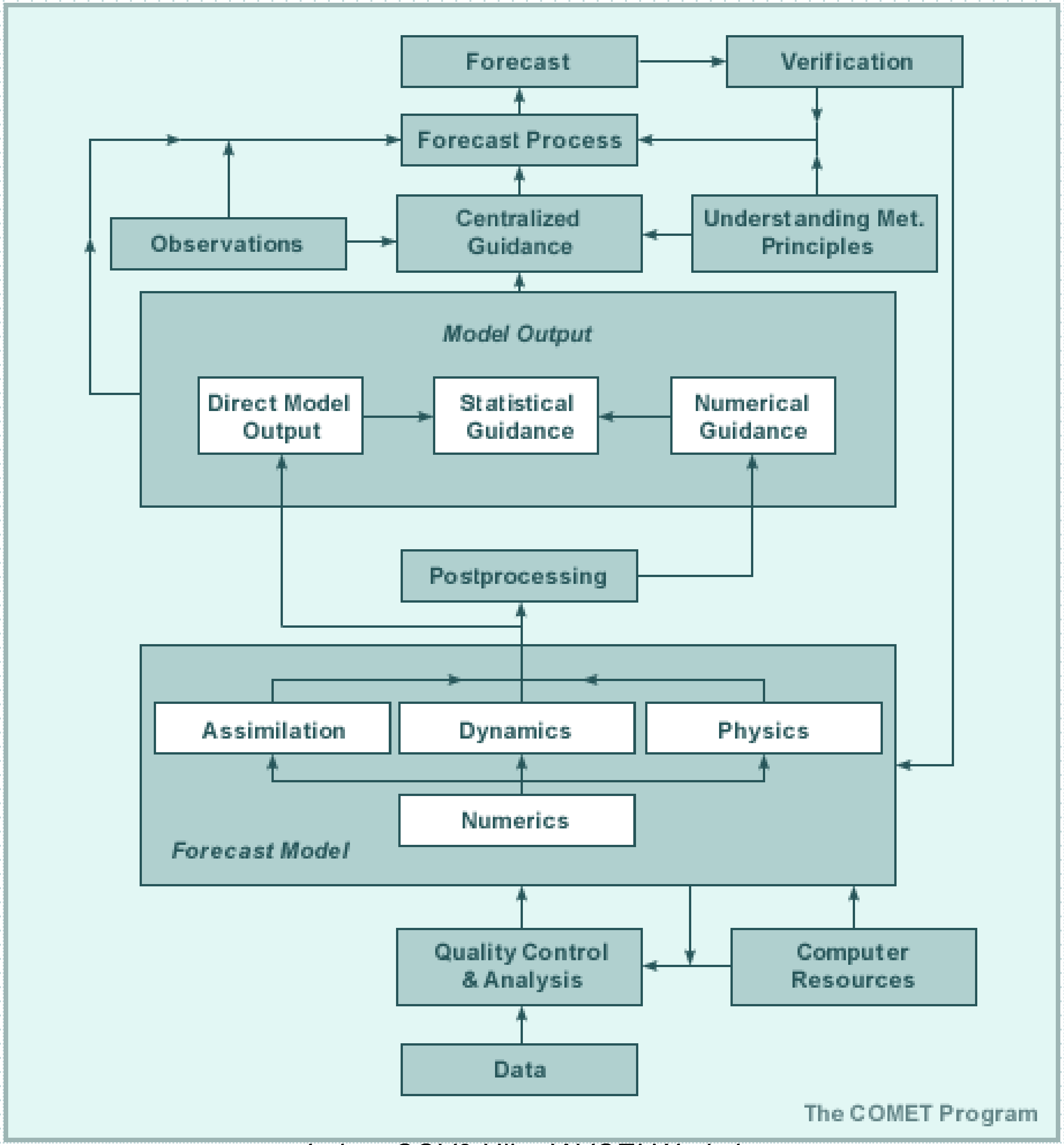
- Model Primer
  - Advantages
  - Modeling system
  - Error sources
- Some commonly used models
  - MM5, RAMS, RUC, WRF (new)
- Link to tephra models
- Use of mesoscale models

Mesoscale Model Primer

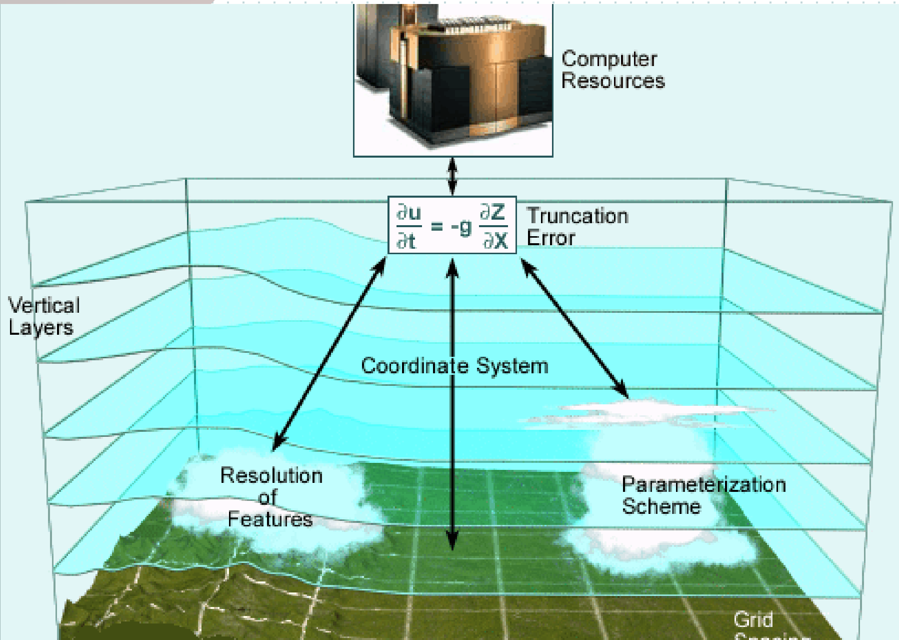
- Numerical Weather Prediction (NWP) model with sufficiently high horizontal + vertical resolution to forecast **mesoscale (10-100km, hrs-day)** phenomena

- Atmosphere evolves according to physical laws of motion, conservation of energy and mass

Mesoscale Model Primer



Model Primer: Grid Point vs Spectral



Derivative form of simplified moisture equation

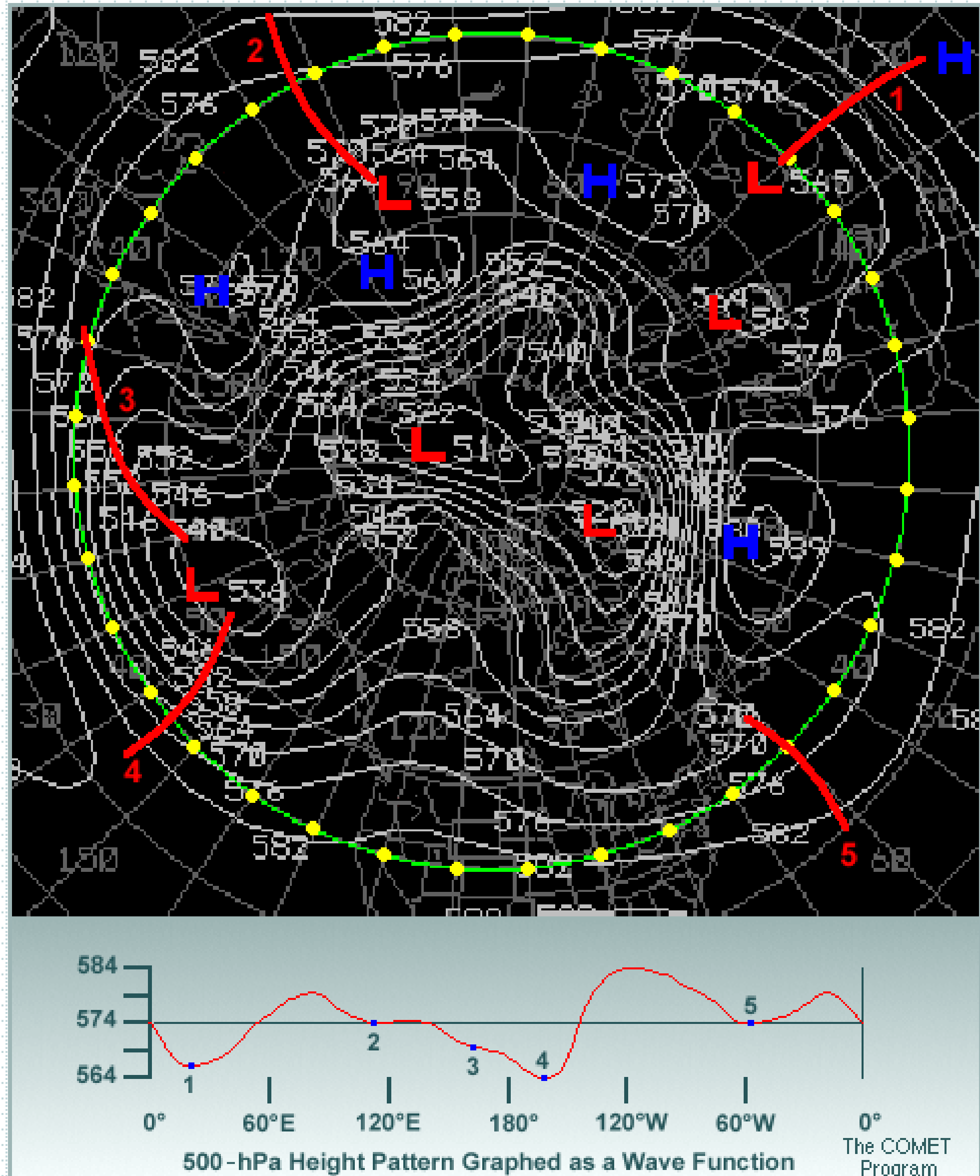
$$\frac{\partial q}{\partial t} = -\bar{U}\frac{\partial q}{\partial x}$$

Finite difference form of simplified moisture equation

$$\frac{\left(q^{t+1} - q^{t}\right)_{x,y}}{\Delta t} = -\bar{U}\,\frac{q^{t}_{x+1,y} - q^{t}_{x-1,y}}{2\Delta x}$$

Written more conceptually

$$q^{forecast} = q^{now} - \bar{U}\frac{\Delta t}{2\Delta x}\left(q_{east} - q_{west}\right)^{now}$$



Hydrostatic vs Non-hydrostatic

- Hydrostatic models assume hydrostatic equilibrium
  - downward weight of atmosphere balances upward-directed pressure gradient force

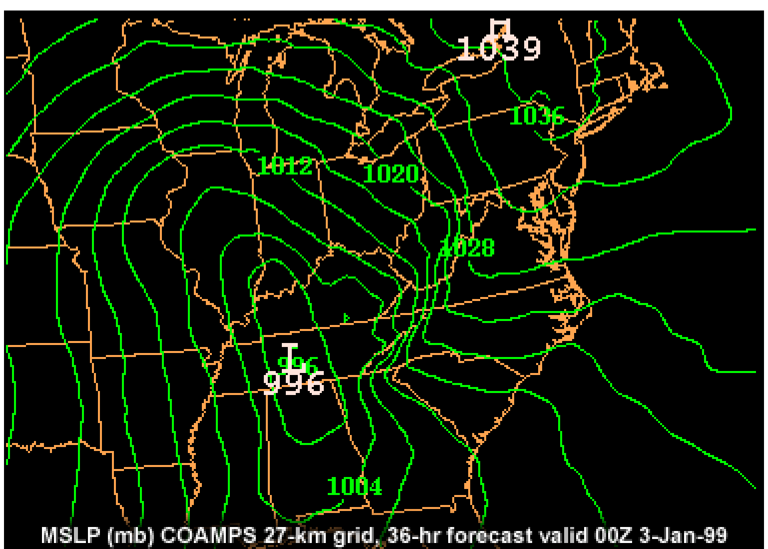
- **Non-hydrostatic processes/effects important when length of feature ≅ height (typically ≤10 km in size)**

- **High-resolution non-hydrostatic models somewhat realistically forecast changes in atmospheric buoyancy & associated potential for convection**

d (VERTICAL MOTION) =
d (ADVECTION)
+ d (LOCAL BUOYANCY)
+ d (NON-HYDROSTATIC VERTICAL PRESSURE GRADIENT)
– PRECIPITATION DRAG

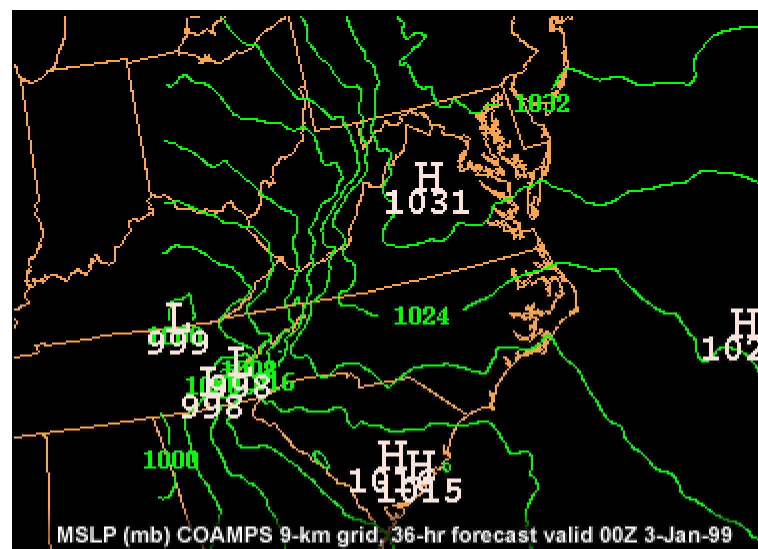
Advantages of Mesoscale Model

- Provide great detail & often accurately represent intensity of smaller-scale weather phenomena
- ***Mesoscale models often produce superior forecasts in coastal and mountainous regions when compared to traditional larger-scale models***



MSLP (mb) COAMPS 27-km grid, 36-hr forecast valid 00Z 3-Jan-99

Marine Meteorology Division, Naval Research Laboratory

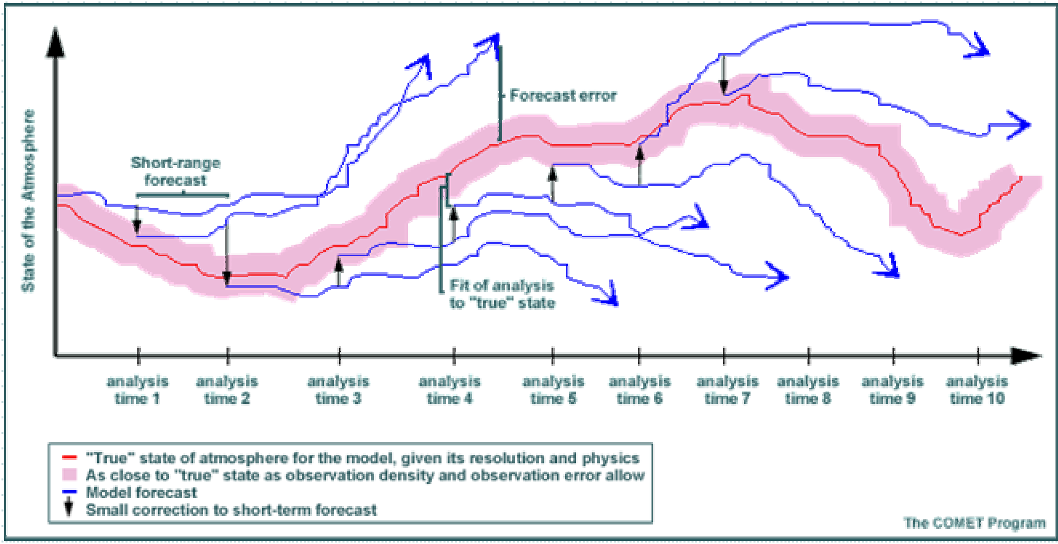


MSLP (mb) COAMPS 9-km grid, 36-hr forecast valid 00Z 3-Jan-99

Marine Meteorology Division, Naval Research Laboratory

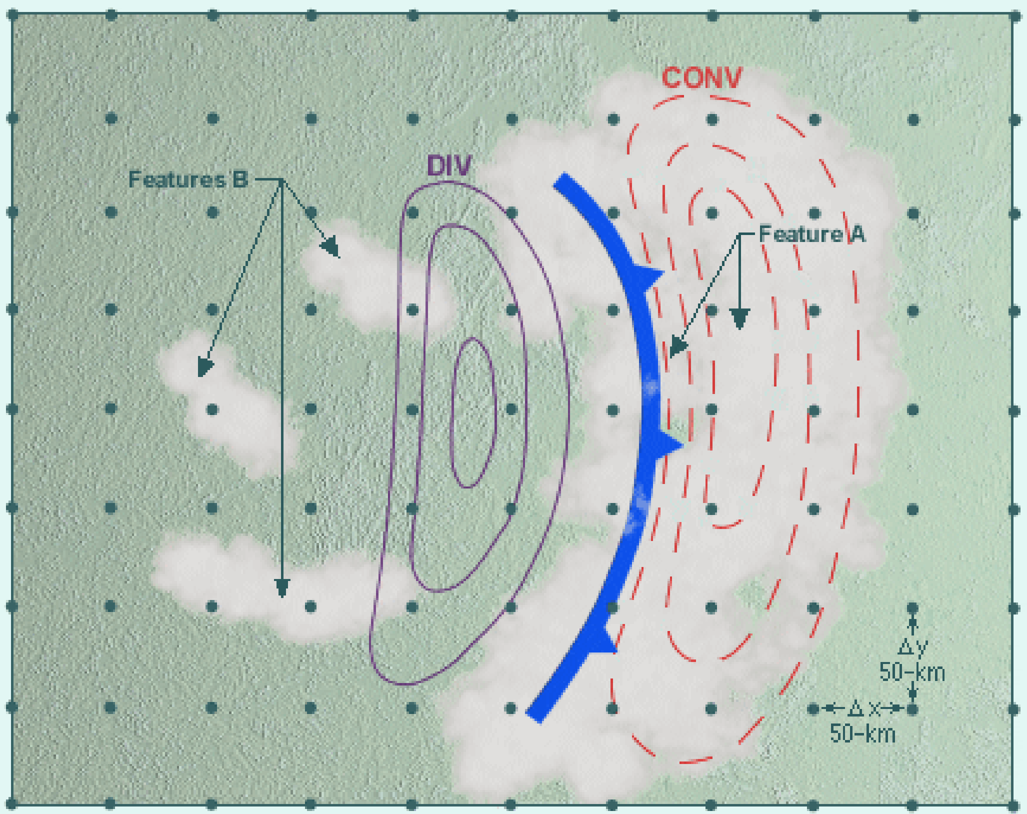
Error Sources

- Numerics
  - grid-point/spectral, resolution, coordinate system, computational domain
- Physics
- Parameterizations
- Initial Conditions
- Boundary Conditions



Horizontal Resolution

- **Adequately resolve only ≥ 5Δx**
  - Minimize aliasing with filtering at smaller scales

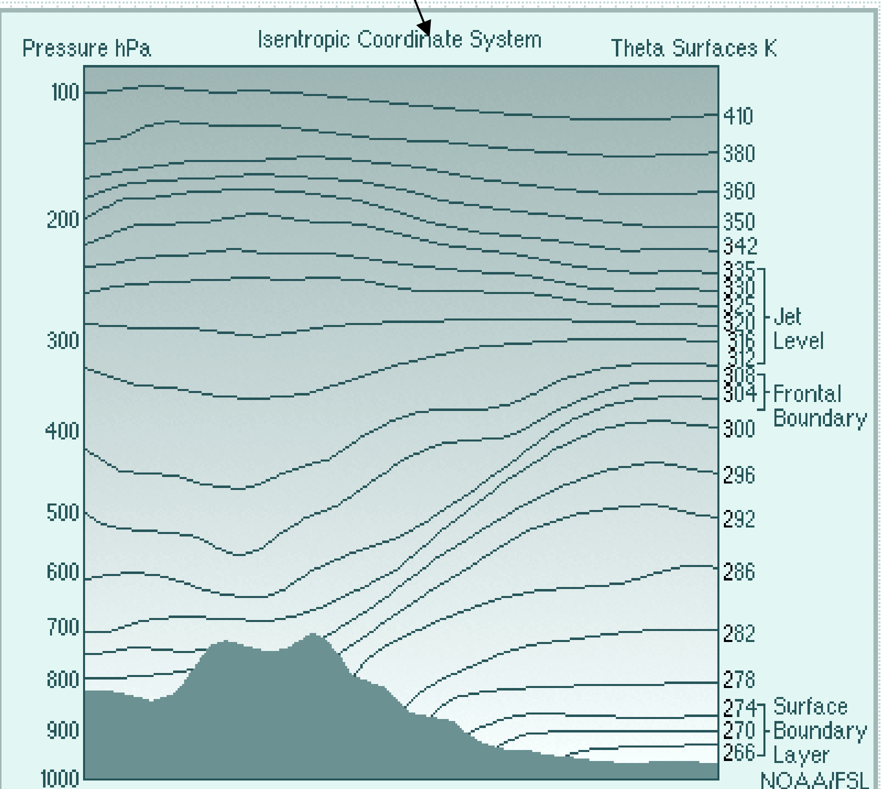


Feature A: Covers an area spanning > 5 grid points: May show up in model fields
Features B: Cover areas spanning only 1 or 2 grid points: Will not show up at all

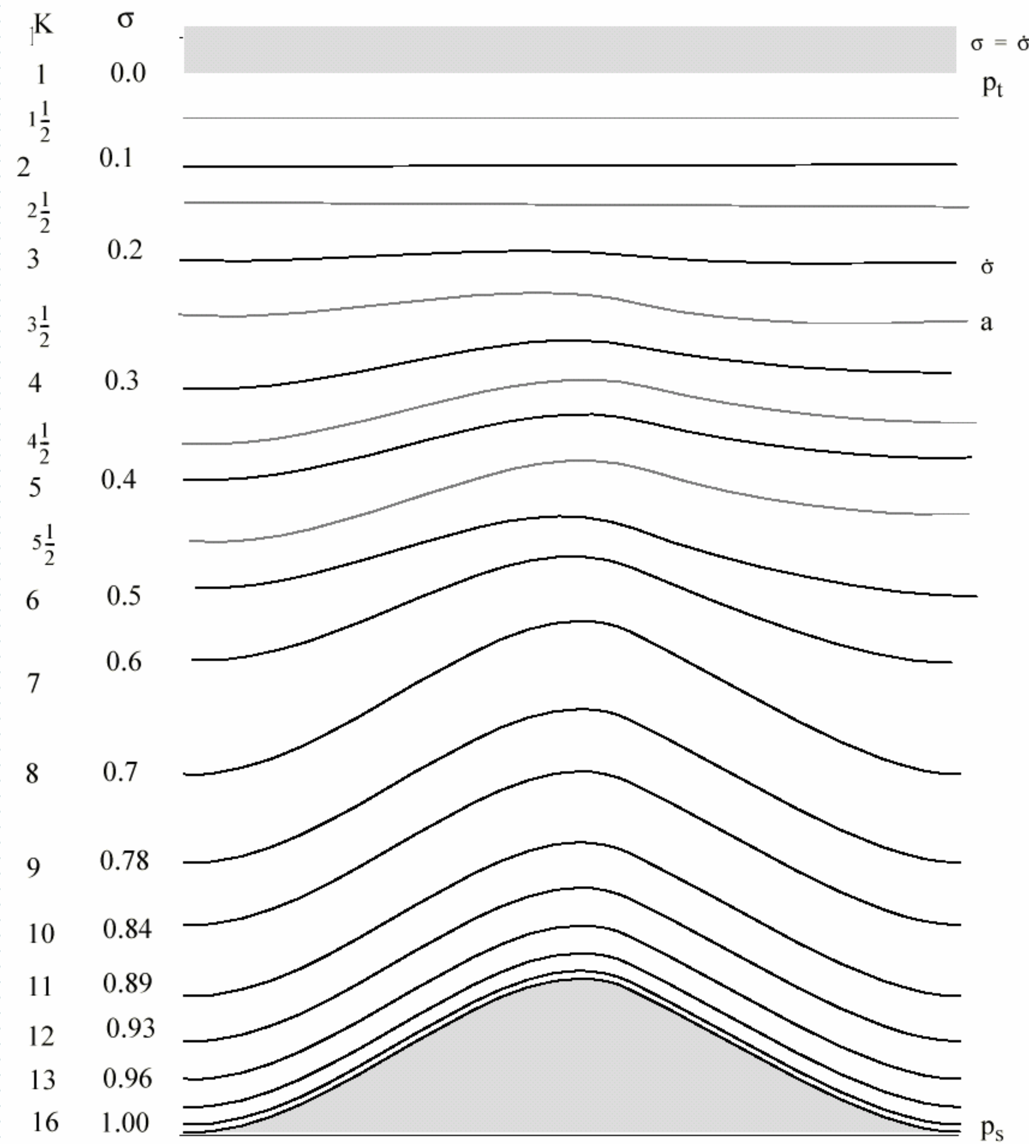
The COMET Program

Vertical Coordinates

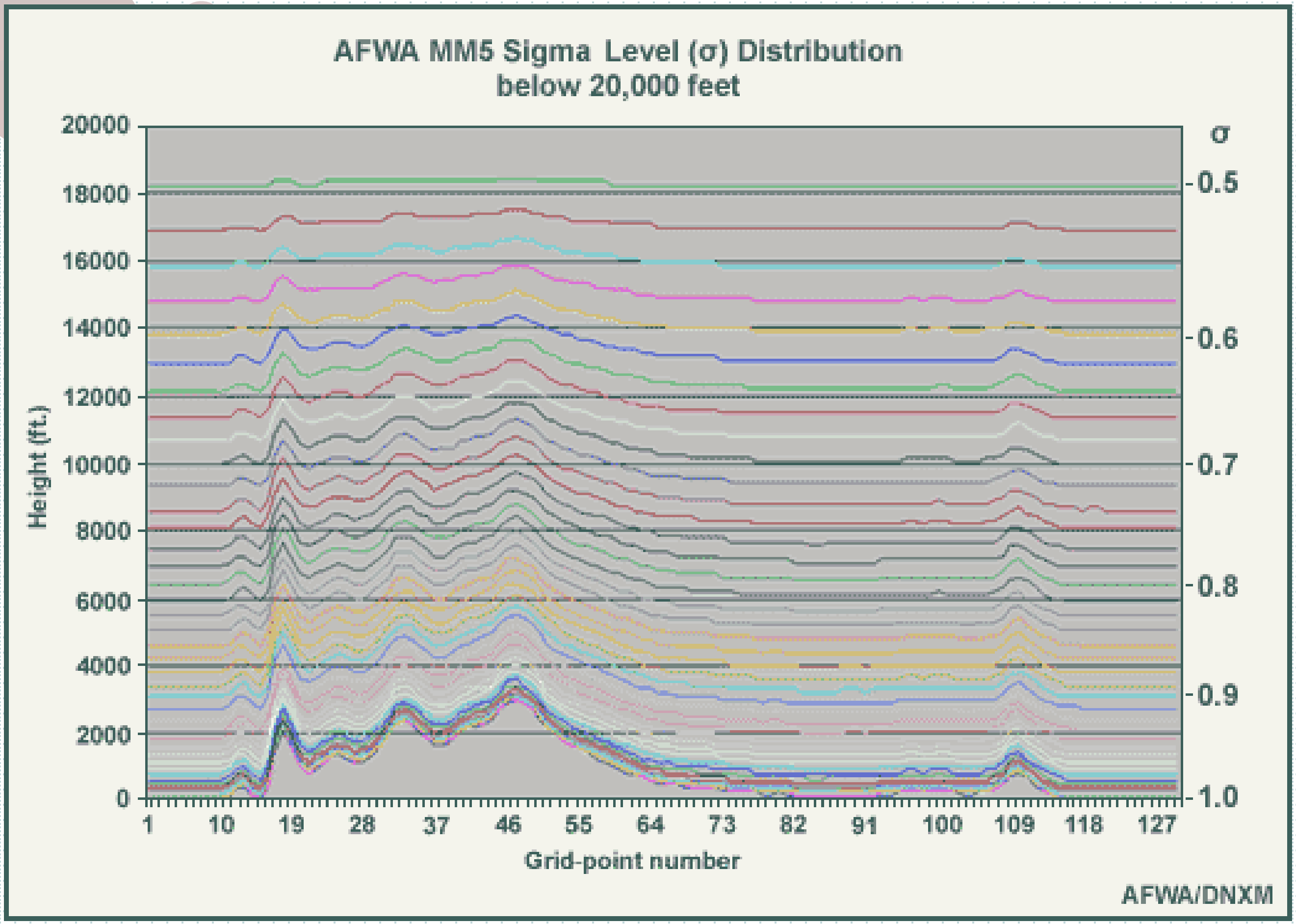
- Height
- Sigma
- Isentropic

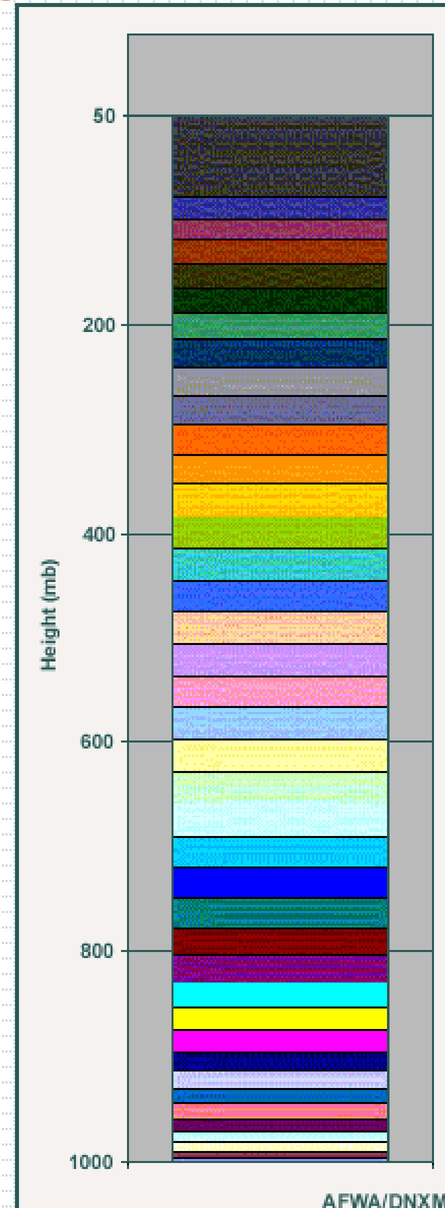


(constant potential temp)



Vertical Resolution



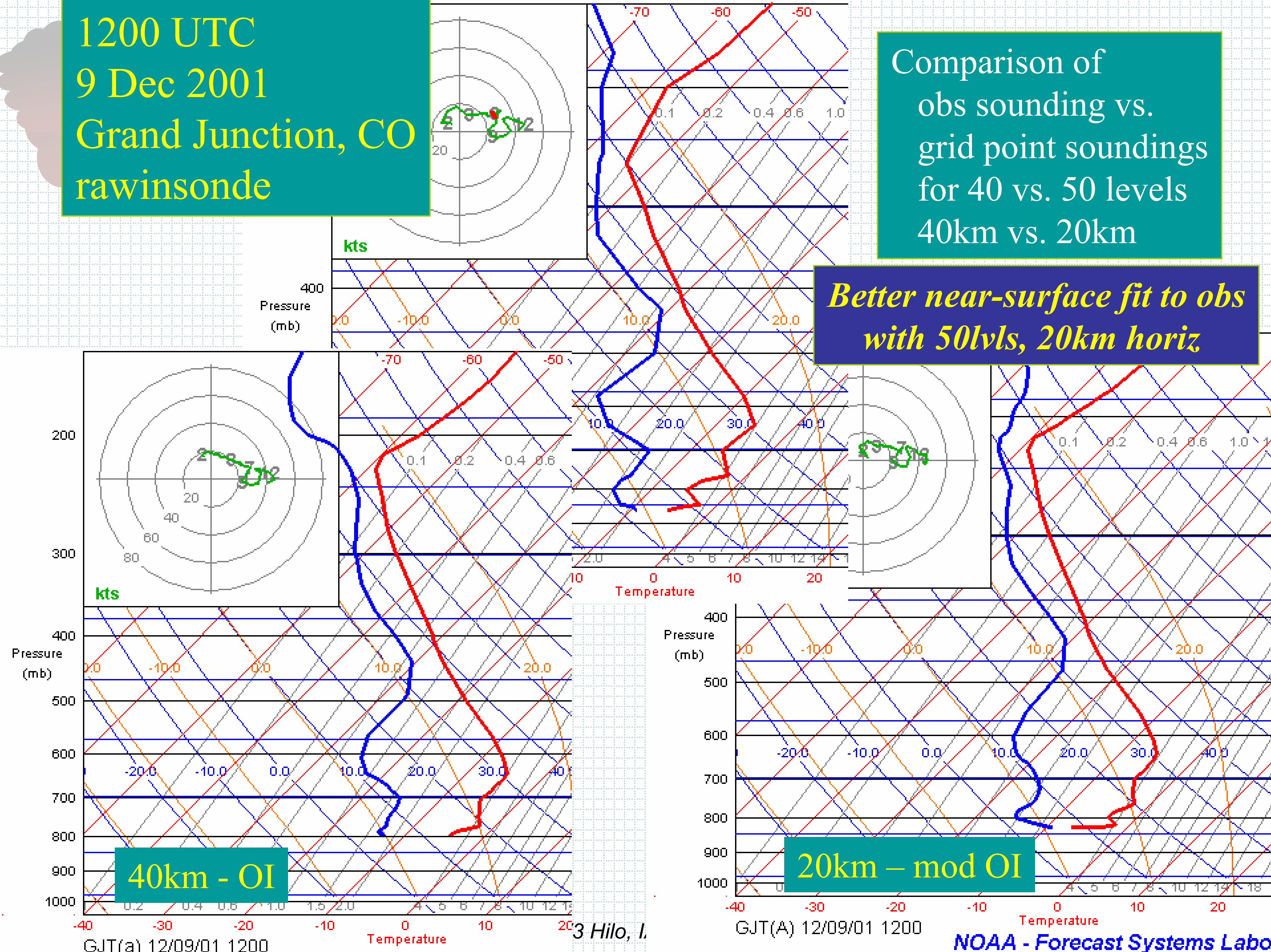


- more-complex applications, e.g. boundary layer pollutant dispersion, very sensitive to data resolution - large variations in vertical mixing and vertical wind shear

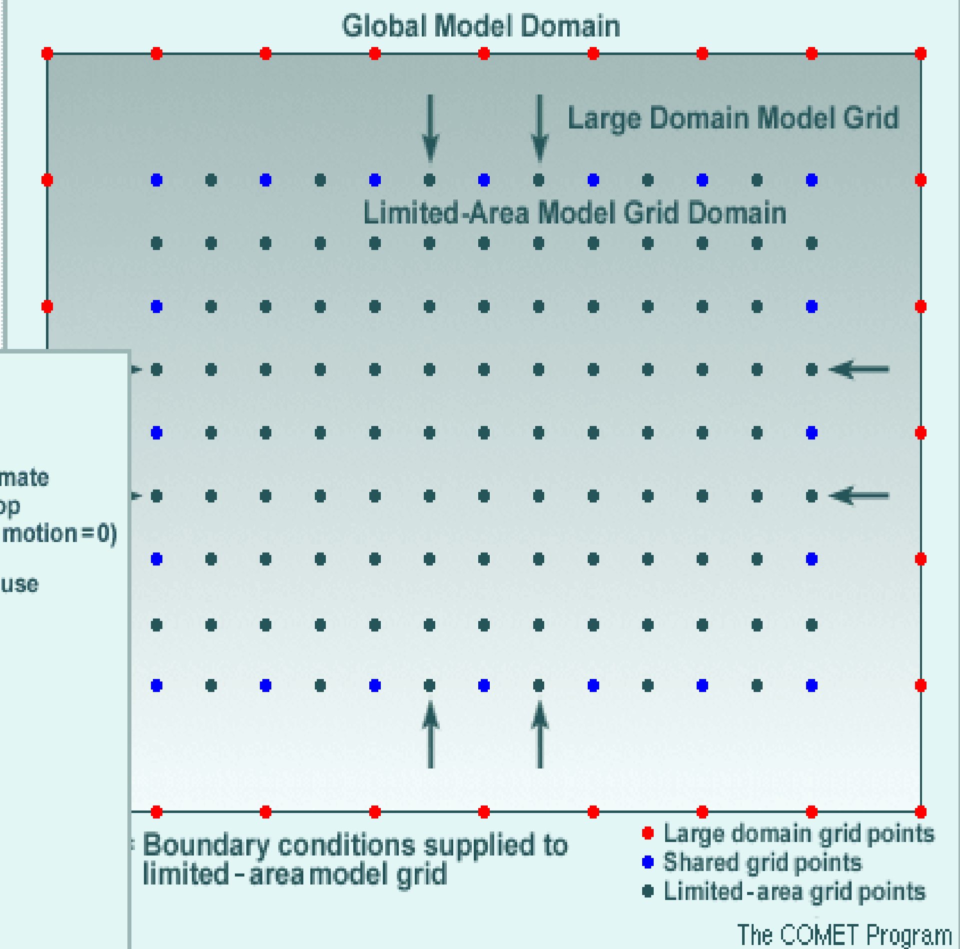
1200 UTC
9 Dec 2001
Grand Junction, CO
rawinsonde

Comparison of
obs sounding vs.
grid point soundings
for 40 vs. 50 levels
40km vs. 20km

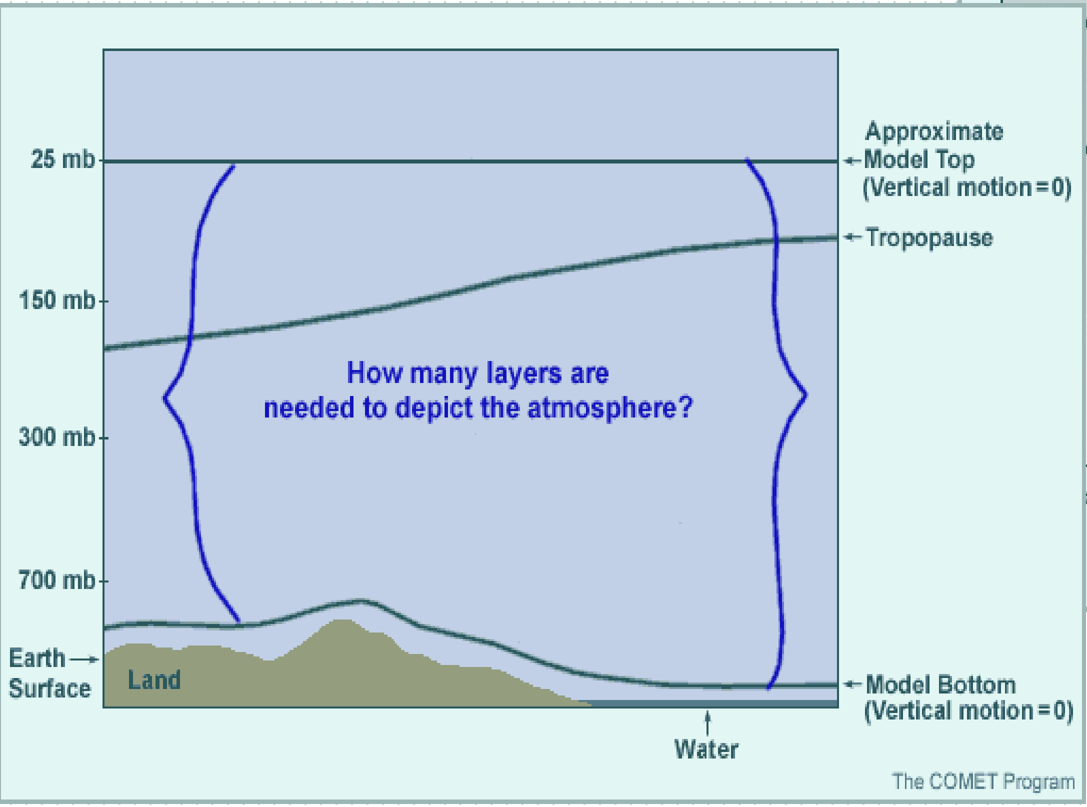
Better near-surface fit to obs with 50lvls, 20km horiz



Boundary Conditions



Horizontal



Vertical

Model Initialization

Spin-up: starting vertical motions and divergent circulations

- **Warm start: incorporates data over long time**

  Data assimilation merges obs to preserve ongoing circulation

  - Will typically produce better forecasts
  - Where no new obs, features left intact
    - Errant forecast -> into next model analysis
  - Computationally, warm starts not always feasible

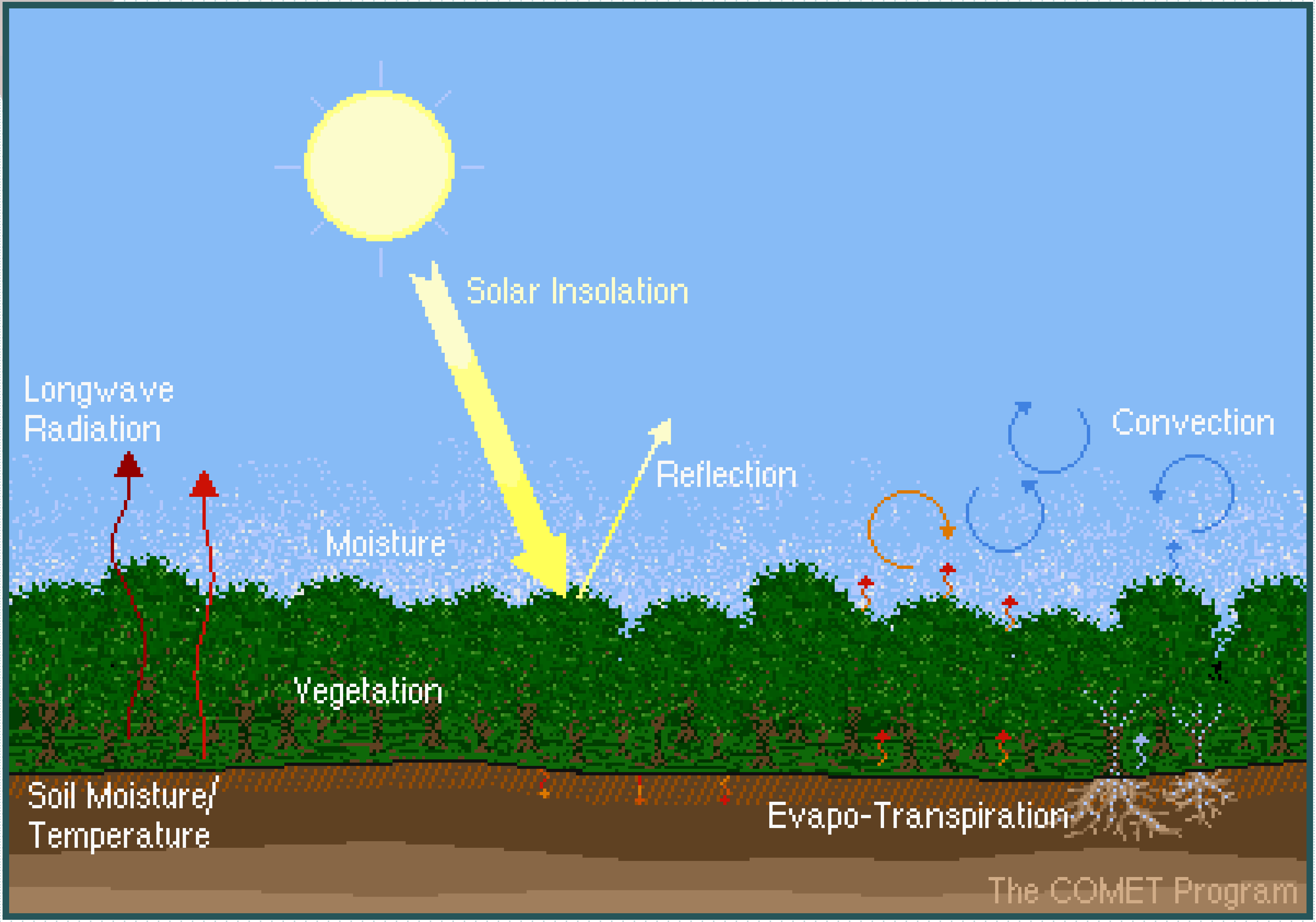
- **Cold start: analyses from other source**

  Require model to build up circulations.

  - Not incorporating forecast into analysis, no spurious predictions to correct

- Noticeable differences may persist 6 hrs into forecast period, but generally, negligible after 12 hrs

Parameterized Processes



Parameterization

NWP models cannot resolve features and/or processes that occur within single grid box

- Computers not yet powerful enough to directly treat them because phenomena too small or too complex to be resolved numerically
- Processes often not understood well enough to be represented by equation or data not available
- Effects profoundly impact model fields and crucial to creating realistic forecasts

Commonly Used Models

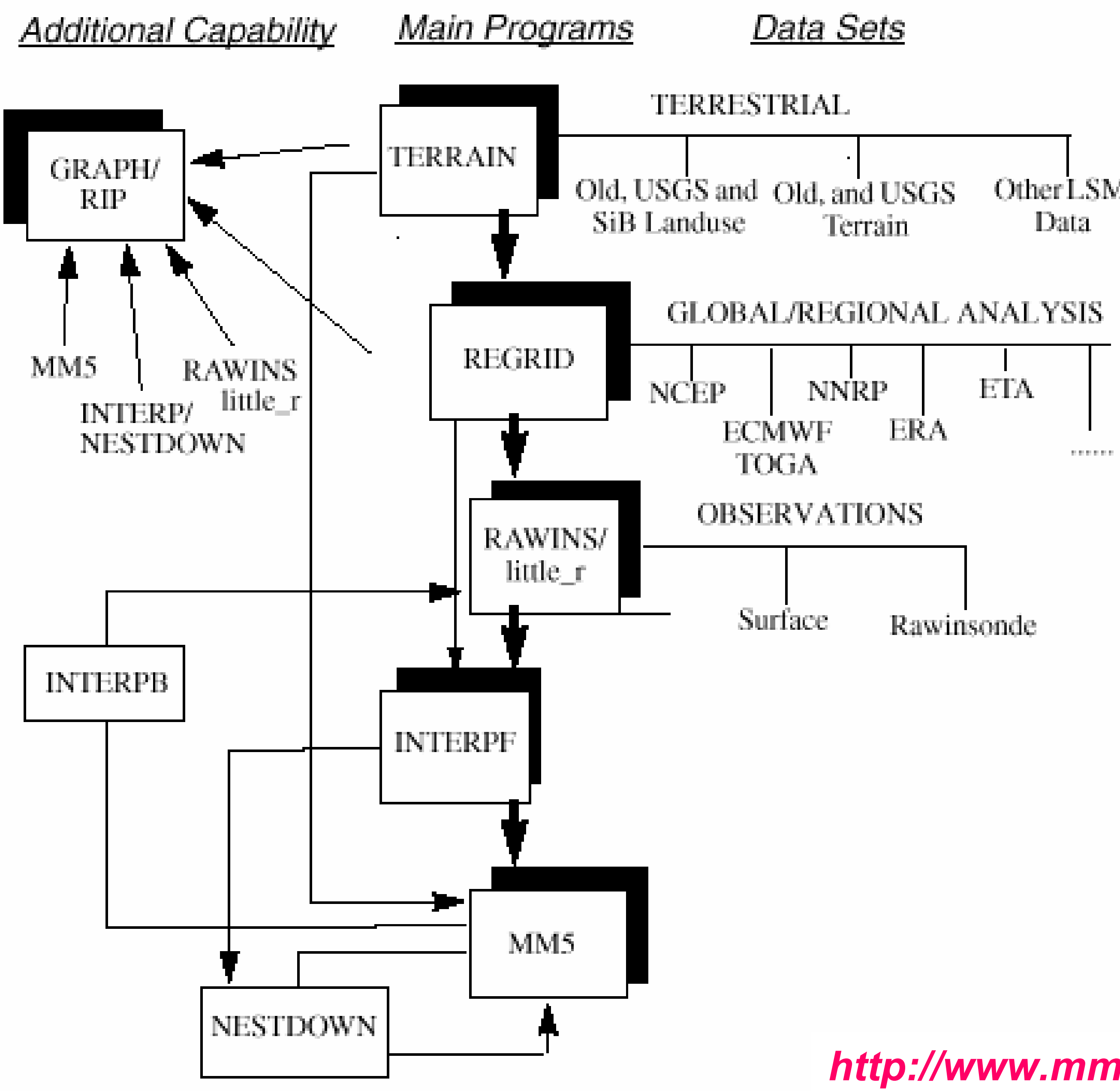
Primarily Research – multi-platform, parallel computing, multiple physics options, nesting

- MM5 (Penn State/National Center for Atmospheric Research –NCAR)
- RAMS (Colorado State)
- WRF (NCAR, NCEP, AFWA, etc…)

Operational

- ETA (NCEP)
- RUC (NCEP)

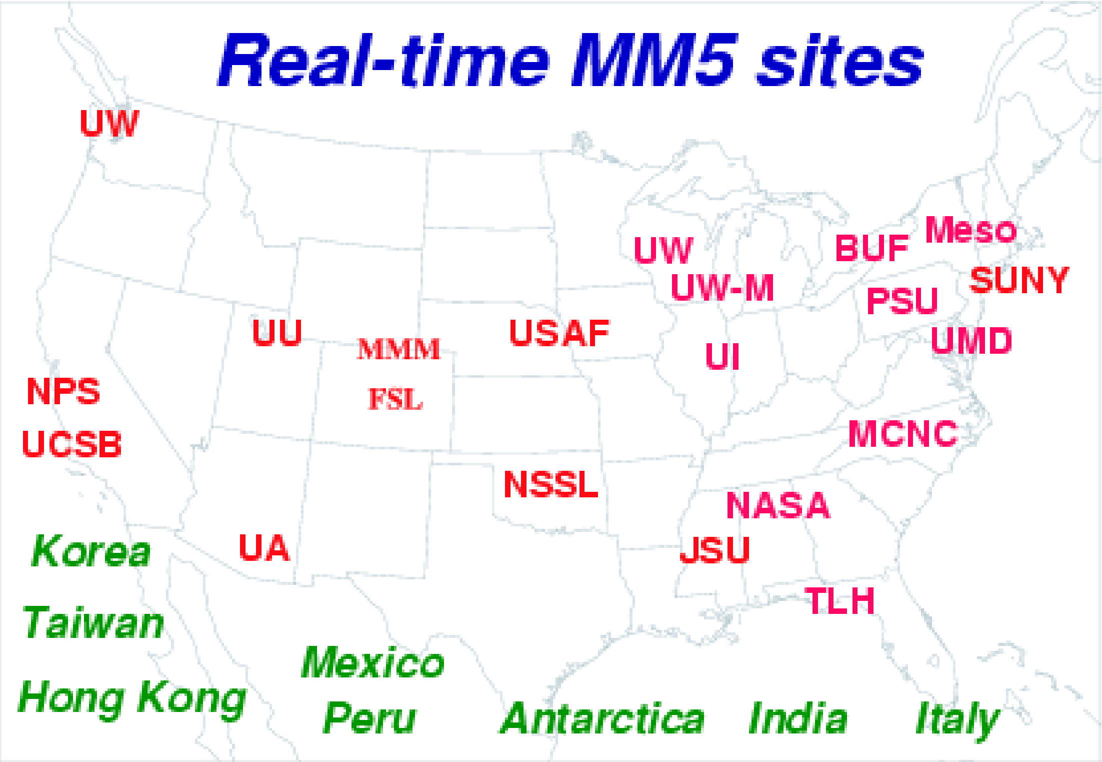
MM5 Modeling System



http://www.mmm.ucar.edu

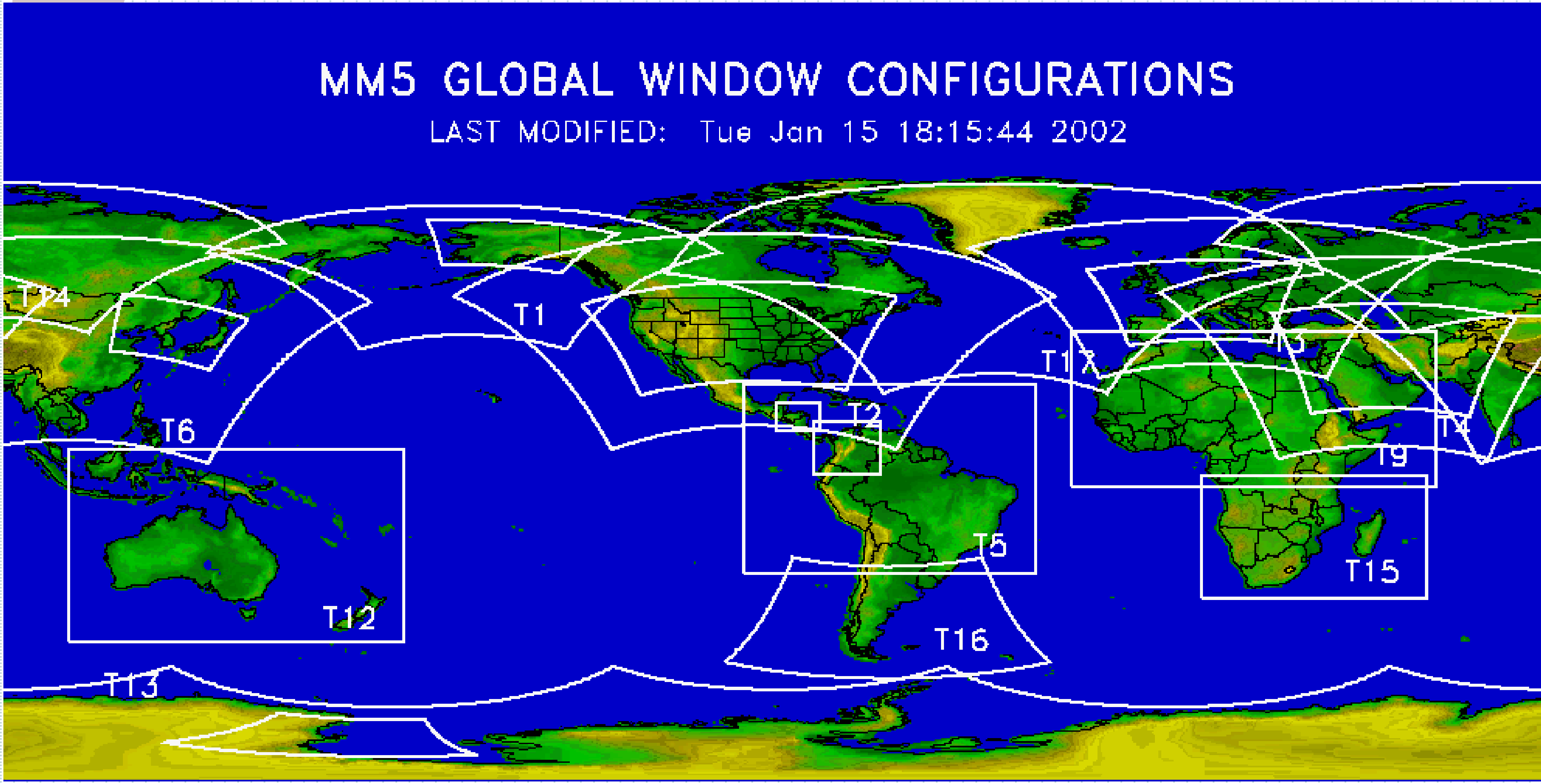
Real-time forecasting with MM5

- Sites using MM5 for real-time forecasting
  - Universities
  - Government
  - Military
  - Commercial
  - Foreign



(Dudhia, NCAR/MMM)

Air Force Weather Agency – Operational Domains of MM5



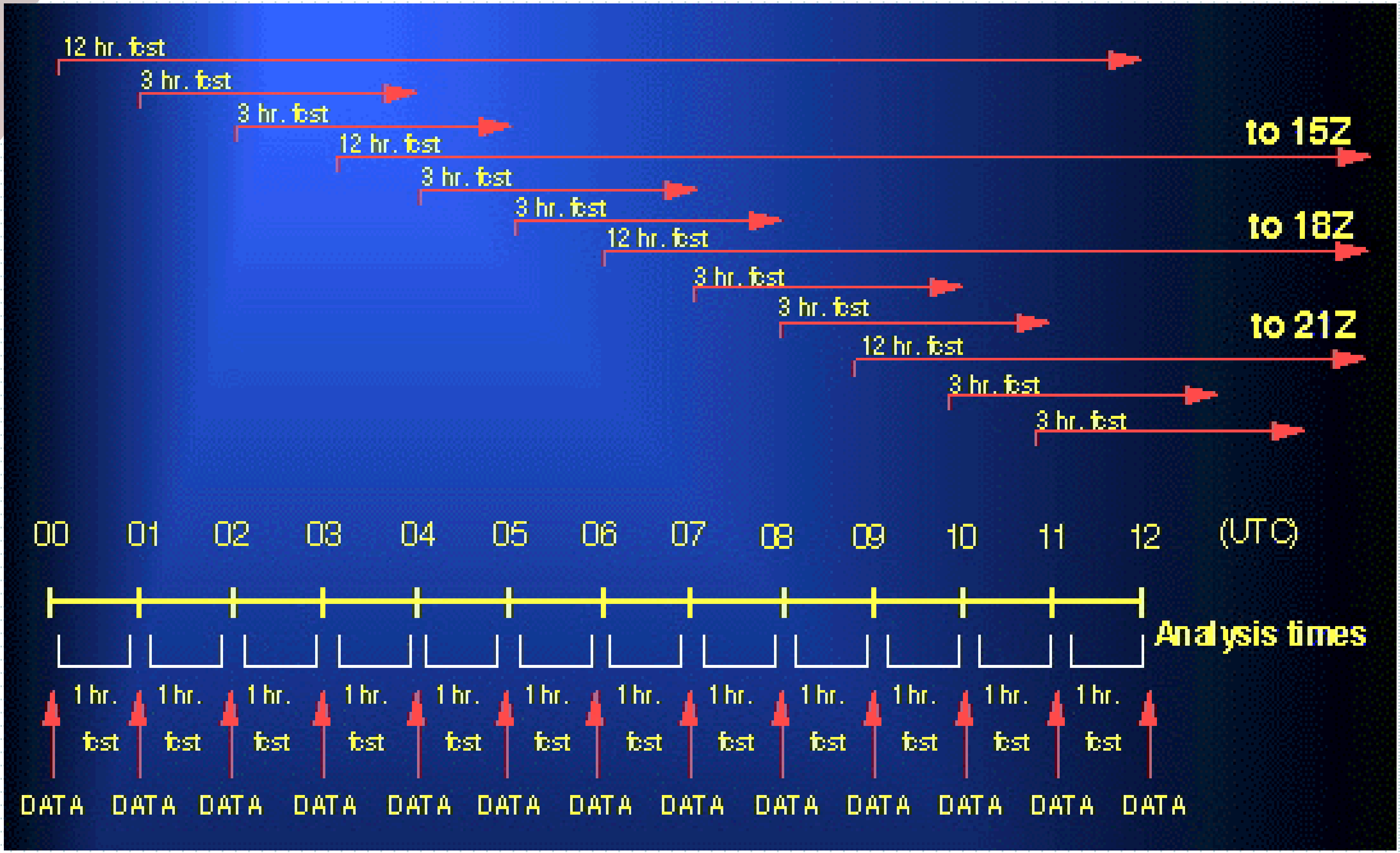
(Dudhia, NCAR/MMM)

Rapid Update Cycle (RUC)

http://www.fsl.noaa.gov

- Provide high-frequency mesoscale analyses and short-range numerical forecasts for users including:
  - aviation
  - severe weather forecasting
  - general public forecasting

1-h Version of Rapid Update Cycle at NCEP

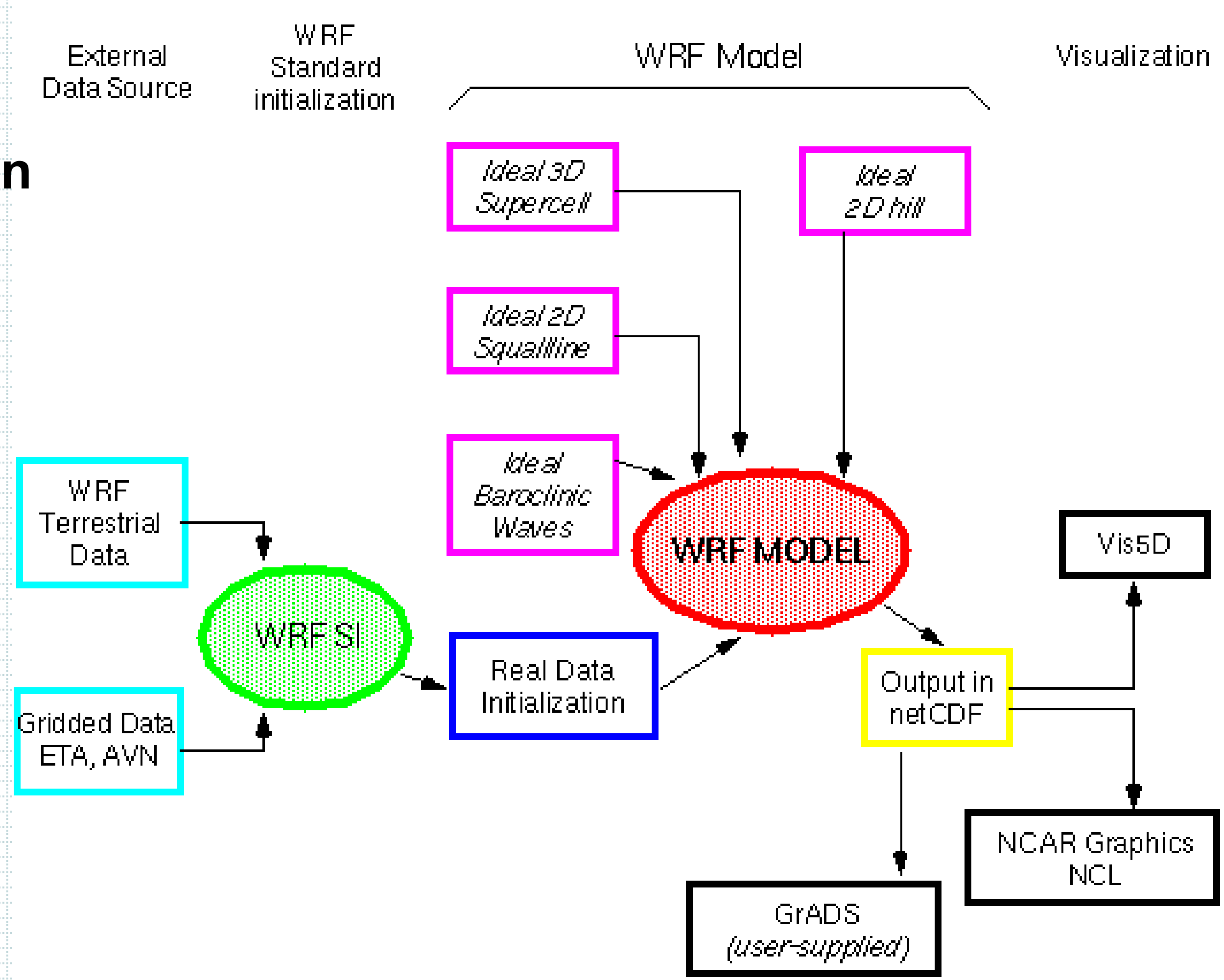


NCEP model hierarchy – RUC (1h frequency) → Eta (6h) → Global (6h)

Weather Research Forecast Model

- Priority: 1-10 km grid
- Portable and efficient on parallel computers
- Advanced data assimilation, model physics
- Well suited for broad range of applications
- Community model with direct path to operations

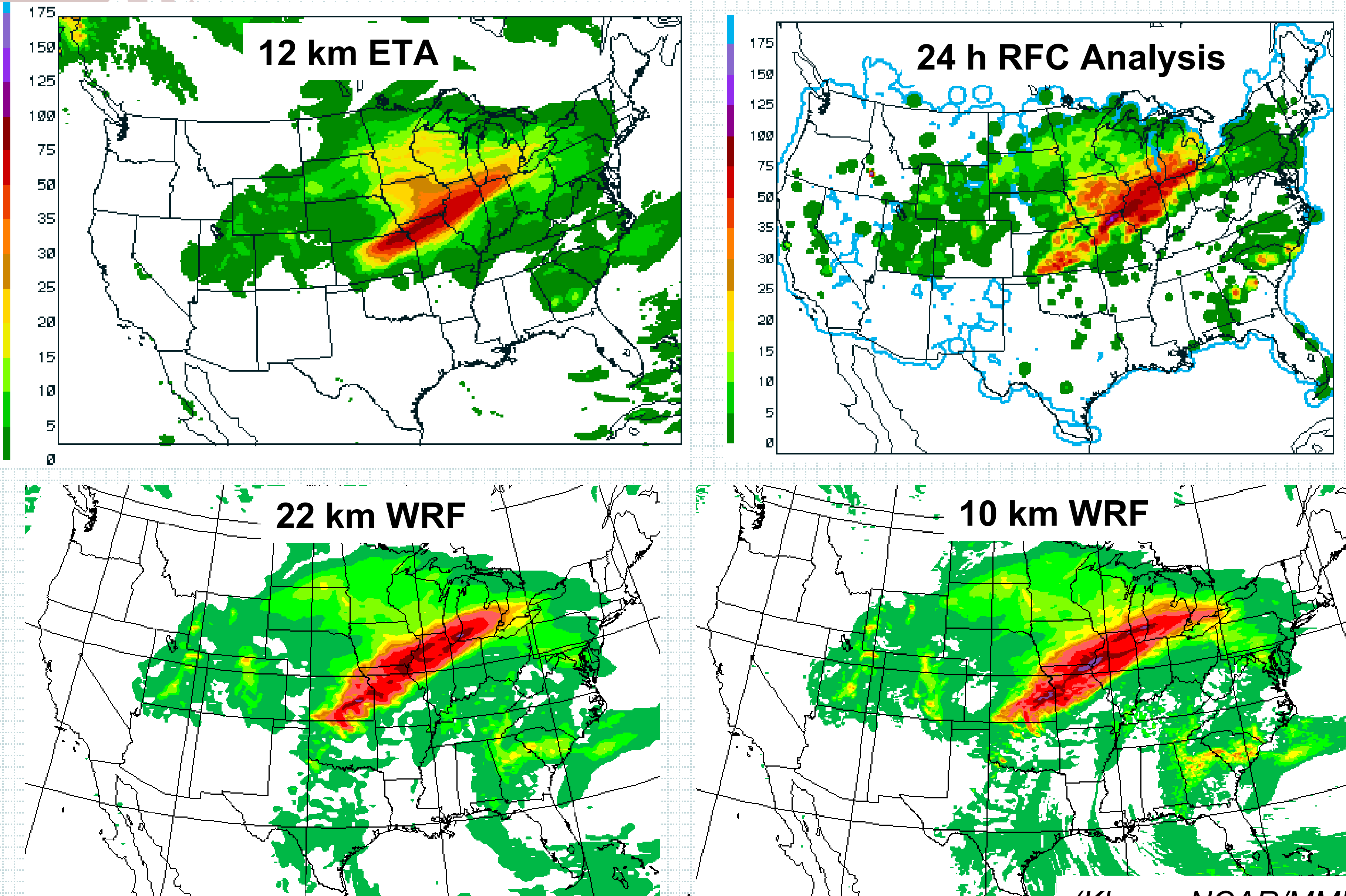
WRF Modeling System Flow Chart (*for WRFV1*)



http://www.wrf-model.org

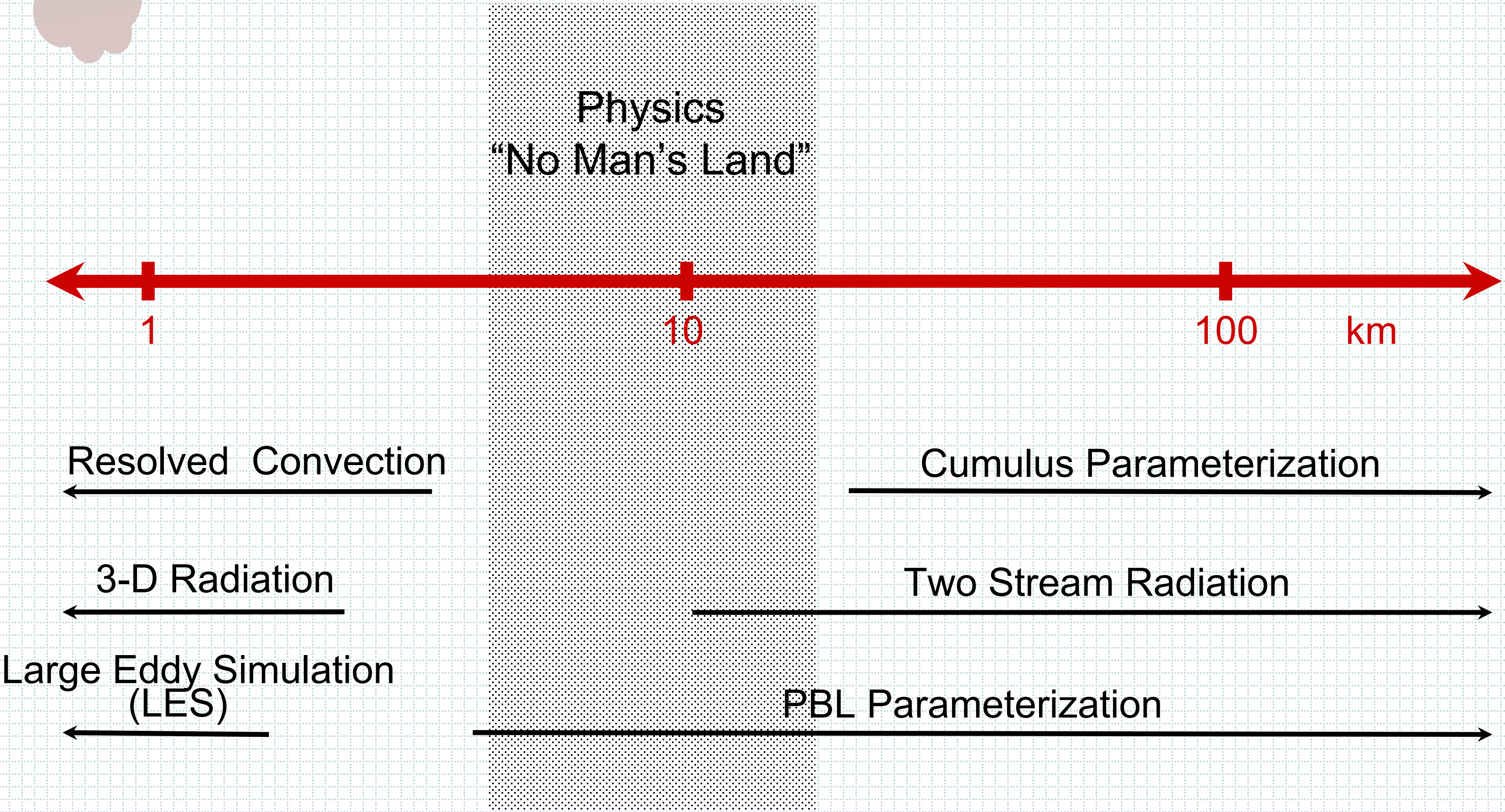
(Klemp, NCAR/MMM)

WRF - 36 h Fcst Valid 12Z 12 May 02, 24 h Precip



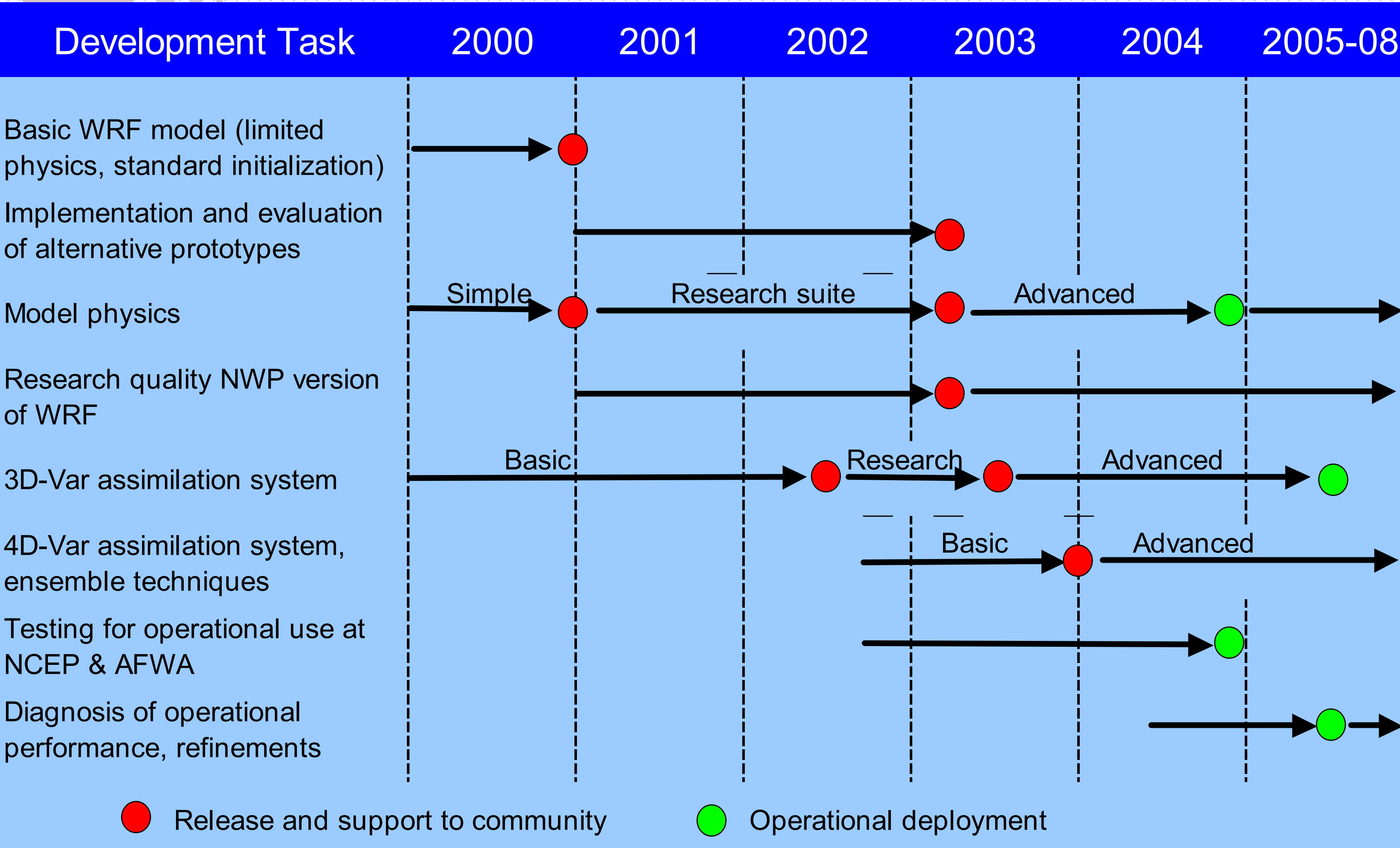
(Klemp, NCAR/MMM)

Model Physics in High Resolution NWP



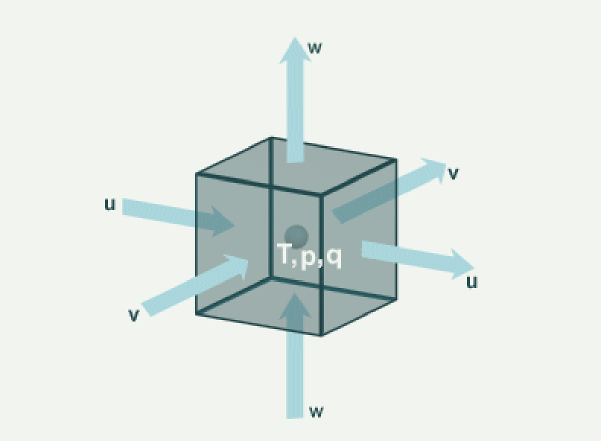
(Klemp, NCAR/MMM)

WRF Projected Timeline



Link to Tephra Models

- Primarily - Use of Model/Analysis Winds
- Better resolved small-scale circulations
- Microphysics - condensation/precipitation processes
- WRF-Chem Model – may be most useful for volcanic applications
  - Forward trajectories with cascade interpolation back to grid
  - Incorporates air-chemistry concentration/ dispersal
  - High order compact differencing
  - Terrain-following hybrid vertical coordinate (e.g. mass coordinate more realistic response to diabatic heating and cooling



Example of 3-D Grid Box in a Grid Point Model

Using Mesoscale Models

- Mesoscale detail is generally most reliably predicted when forced by topography or coastlines.

- Is mesoscale model forecast on target?
  - compare model's analysis, short-term forecast to obs
  - review series of previous forecasts to determine how accurate model has been recently
  - compare model to obs for synoptic features and trends
  - In some instances, model run that initialized with inaccurate boundary conditions may still prove useful Particularly true for predictions of topographically- or coastally-forced weather events