NCEP's "NAM" (North American Mesoscale) model WRF-MMM

• NMC changed its name to NCEP, National Centers for Environmental Prediction, in 1995

• Weather Research and Forecasting Non-hydrostatic Mesoscale Model (WRF-NMM)** model is run as the NAM – three names (NAM, WRF, or NMM) refer to the same model output. WRF replaced the Eta model on June 13, 2006

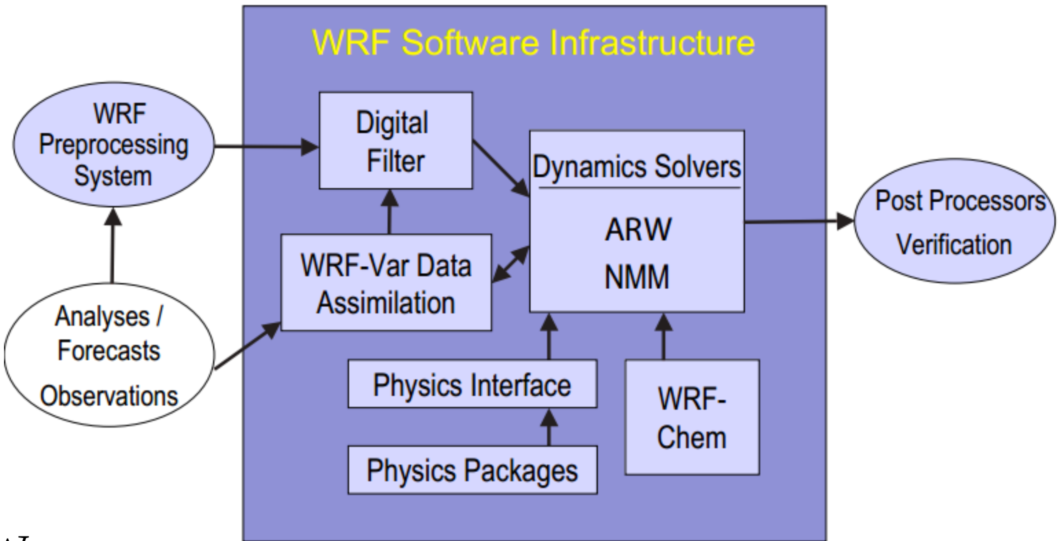
• run at 00,06,12,18Z and forecasting to 84 hours

• domain is regional, horizontal resolution Δ =12 km, outputs every hour

• dynamics: fully compressible, **non**-hydrostatic (with hydrostatic *option*)

• current release is Version 3

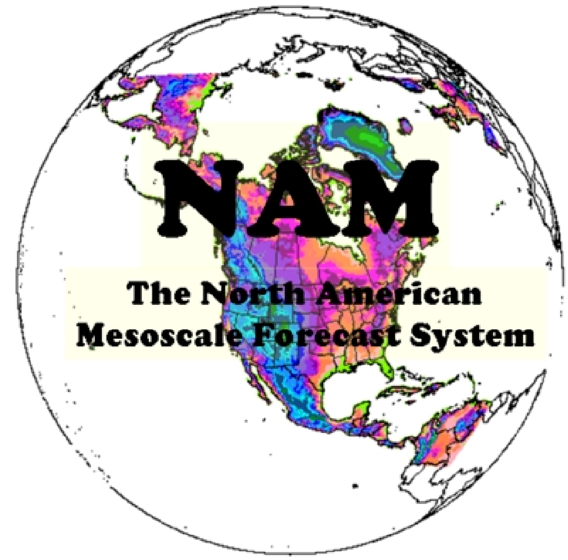
www.mmm.ucar.edu/wrf/users/wrfv3/wrf_model.html
www.dtcenter.org/wrf-nmm/users/index.php



**Distinct from WRF-ARW, which has the ARW "dynamical core". NMM core is much faster than ARW

NCEP's "NAM" (North American Mesoscale) model WRF-MMM

- vertical coord (60 levels) $\eta = \dfrac{\pi - \pi_T}{\pi_S - \pi_T}$

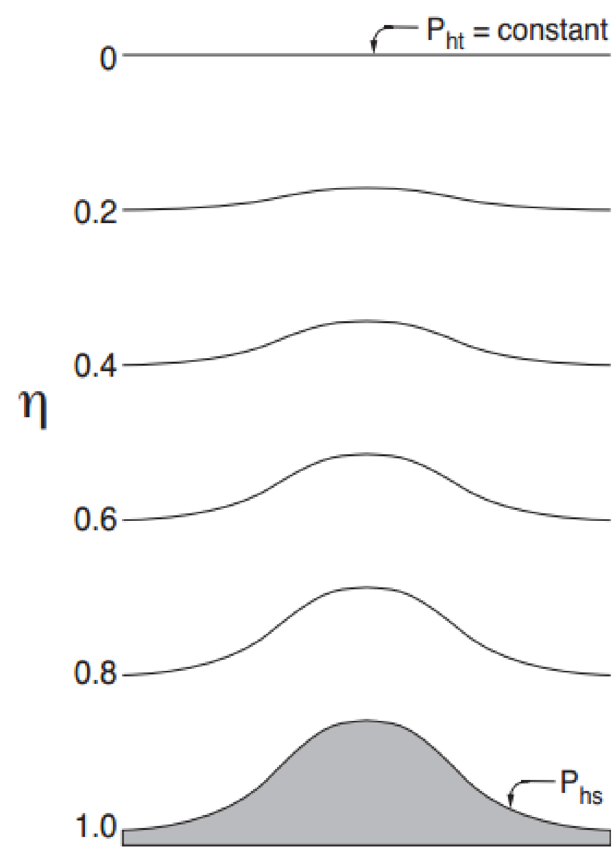


where π is the hydrostatic component of the pressure, computed using the dry air density

$$\pi(x, y, z, t) = \pi_T + \int_z^{z_T} \rho_d(x, y, z', t)\; g\; dz'$$

and π_S and π_T its values along the surface and top boundaries (Laprise, 1992; MWR Vol. 120). If z_T is placed at infinity then π_T=0 and π is simply the hydrostatic partial pressure of the dry air.

- η is a terrain-following coordinate

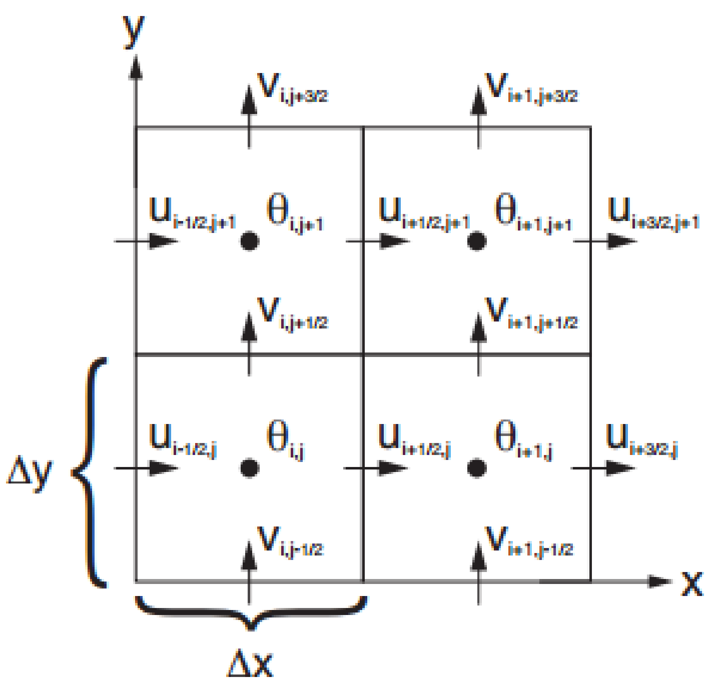


NCEP’s "NAM" (North American Mesoscale) model WRF-MMM

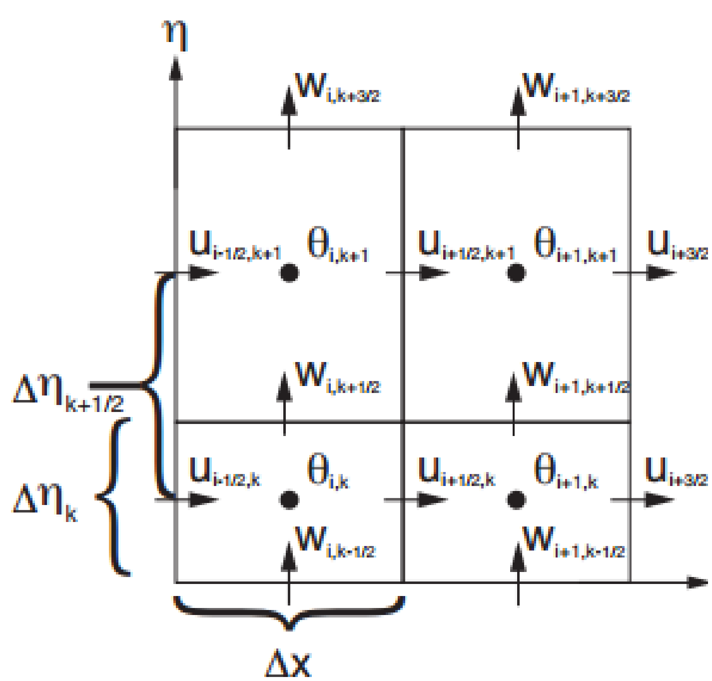
Introduce model variable $\mu = \pi_S - \pi_T$ then $\eta = \frac{\pi - \pi_T}{\mu}$

i.e. resolved scale – vol. avgs.

- prognostic variables: Cartesian velocity components *u,v,w*; perturbations of potential temperature θ, geopotential Φ (=*g Z*), and surface pressure of dry air μ from their values in a hydrostatic reference state; also turbulent kinetic energy *k*, water vapor mixing ratio *r*, rain/snow mixing ratio, and cloud water/ice mixing ratio



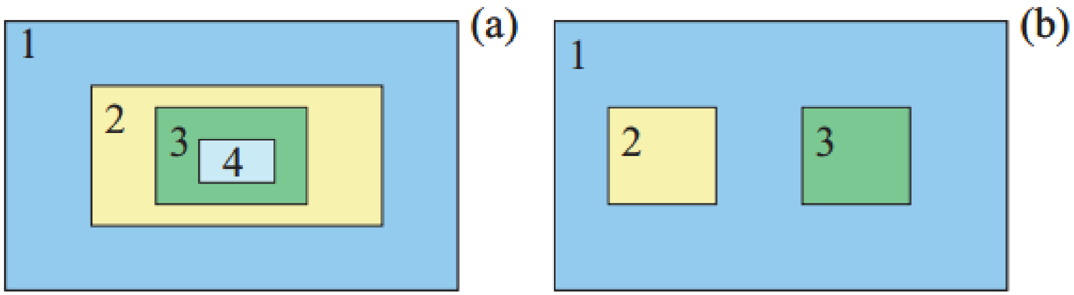
horizontal grid



vertical grid

“Staggered Grid”

NCEP's "NAM" (North American Mesoscale) model WRF-MMM



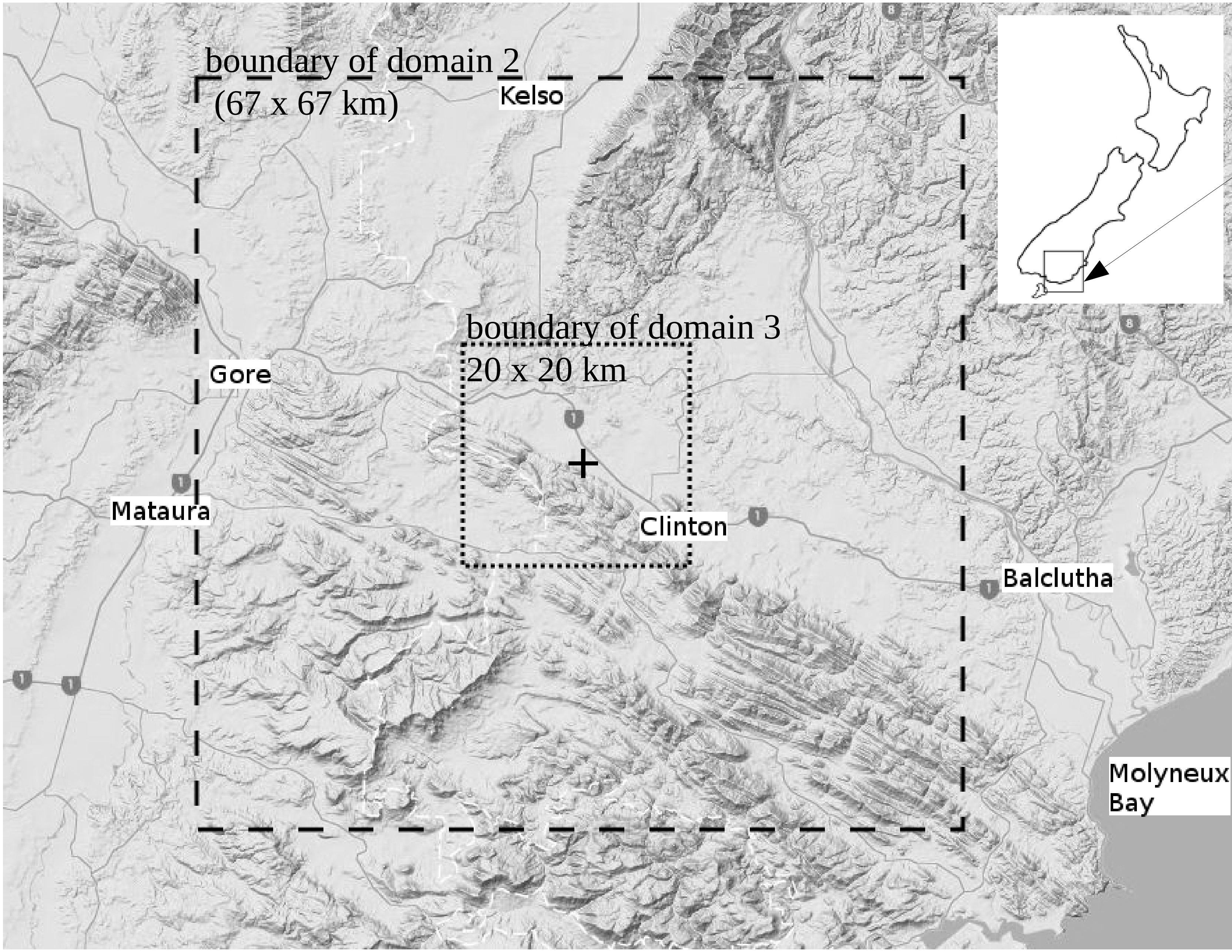
- one-way or two-way nesting

    - one way nesting: influence propagates from outer domain to inner: evolving solution on the outer domain furnishes evolving boundary conditions for the inner domain, but no feedback from inner domain back to outer

    - two way nesting: evolving solution on the outer domain furnishes evolving boundary conditions for the inner domain; inner solution revises elements of the outer solution

Example of using nested grids: downscaling a reanalysis (200 km) using WRF-ARW

- Nested subdomains of successively finer resolution, finest spans 20 x 20 km
- Reanalysis gives initial and b/conditions for domain 1 (i.e. coarsest domain, 200 x 200 km)



boundary of outer domain (domain 1)
200 x 200 km
Δx, Δx ~ 2 km

NAM's parameterizations

Vertical transport by unresolved scales of motion

• operational: Mellor-Yamada-Janjic (eddy viscosity/diffusivity *K* based on turbulent kinetic energy equation)

• also tested: Yonsei University (S. Korea) eddy viscosity/diffusivity *K* from a *K*-profile scheme ("non-local-*K* scheme with explicit entrainment layer and parabolic *K* profile in unstable mixed layer")

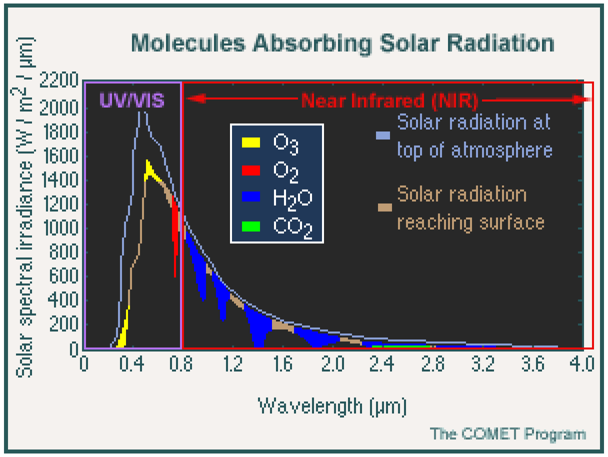
Radiation

• clear-sky absorbers: dynamic** water vapour; uniformly mixed (330 ppm) CO2; latitudinally- and seasonally- varying climatological ozone; solar constant chopped by 3% to account for aerosols

**meaning, interacts with (coupled to) model's resolved humidity field

• solar computations hourly; two streams diffuse & one (downward) stream direct; spectrum divided into two bands each carrying apprx. 50% of the energy: UV/visible and near infrared

• longwave computations in over 100 bands, done hourly



NAM's parameterizations (WRF-MMM)

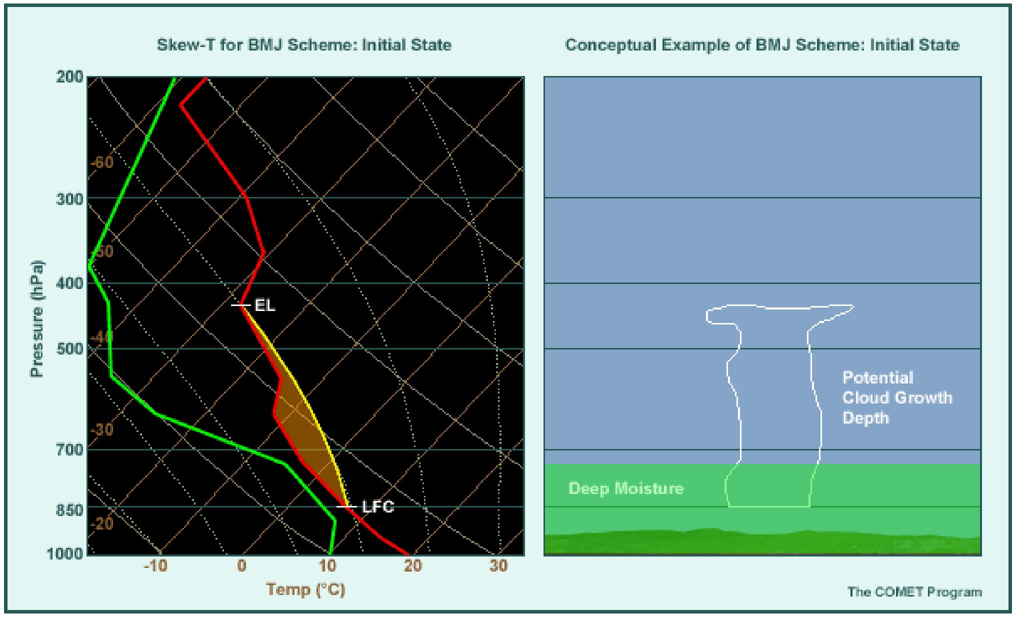
<u>Clouds and precip</u>

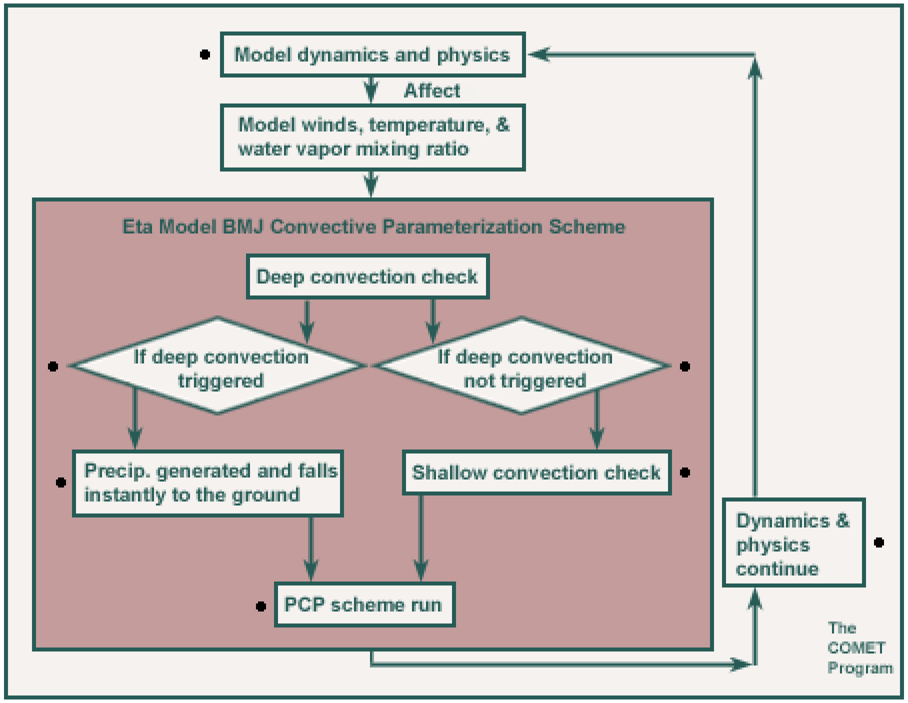
• operational: Betts-Miller-Janjic deep convection, column moist adjustment towards a well-mixed profile (moist adiabatic)

• tested: Kain-Fritsch (cloud model) deep & shallow convection (& others, incl. Grell 3d ensemble cumulus scheme for high resolution domains, allowing subsidence in neighboring columns

• convective precip (falls instantly) determined as change of precipitable water as model sounding forced to moist adiabat between LFC and EL (equil. lvl.)

• PCP scheme tracks 4 classes of hydrometeor… liquid cloud drops, raindrops, small and large ice particles



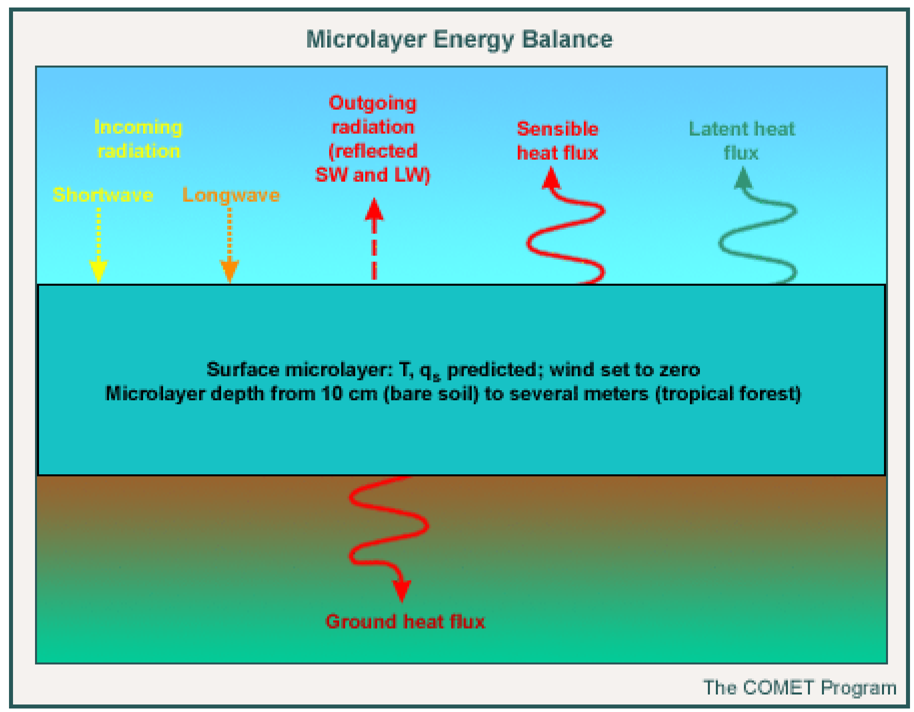


Coupling to surface

- 4 layer soil with vegetation. Remote sensing data for vegetation type and "greenness fraction"

- daily remotely sensed observations to update snow cover and water equivalent snow depth. A snow density variable is used, and the predicted percentage of frozen precipitation reaching the surface updates the snow budget

- water surfaces held at initially observed temperature. Each grid box is designated as having a land or water surface - but no subgrid structure



NCEP's "GFS" (Global Forecast System) & **Global Spectral Model**** (ver. 11.0.6)

- GFS model a coupled model: atmosphere model + ocean model + land/soil model + sea ice model

http://www.emc.ncep.noaa.gov/GFS/doc.php#pbl
http://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs

- Global Spectral Model used for NWP, & as atmos. for NCEP's coupled GCM

- **dynamics:** formulated in vorticity (η), horiz. divergence (D_p), log sfc pressure (log p_S), specific humidity, virtual temperature, cloud liquid and solid water

- run at 00,06,12,18Z and forecasting to 16 days (384 hours)

- global domain

** the Global Spectral Model has been operational since about 1980. Resolution, and model physics (parameterizations) have been steadily refined

- spectral discretization in horiz. (see over); week one T574, week two T190

- vertical discretization by finite difference, 64 sigma (σ) levels, where $\sigma = p/p_S$
  (if p_S = 1000 hPa, 15 levels below 800 hPa with top level at 0.3 hPa)

- timestep 7.5 minutes (except radiation: longwave 3 hours, shortwave hourly)

- artificial diffusion to smooth out short wavelength numerical noise in vorticity, divergence, virtual temperature, specific humidity, cloud water

What is a "spectral" model?

• at given time *t* on given σ level, the (2D) field of (e.g.) temperature is expressed as a superposition (sum) of wave components, each wave (or "mode") having its own amplitude:

$$T(\theta,\varphi,\sigma,t)=\sum_{0}^{l=L}\sum_{0}^{m=M} A_{lm}(\sigma,t)\; Y_l^m(\theta,\varphi)$$

where $$Y_l^m(\theta,\varphi)=e^{j\,m\,\varphi}\; P_l^m(\cos\theta)$$

and (recall) $$e^{j\,m\,\varphi} = \cos m\varphi + j\,\sin m\varphi$$

• Y_ℓ^m is "spherical harmonic function of degree ℓ and order *m*", and P_ℓ^m is the "associated Legendre polynomial" (also describe H atom & other systems with spherical symmetry)

• thus *T* (and other variables) are modelled as *continuous* functions of lat. & longitude

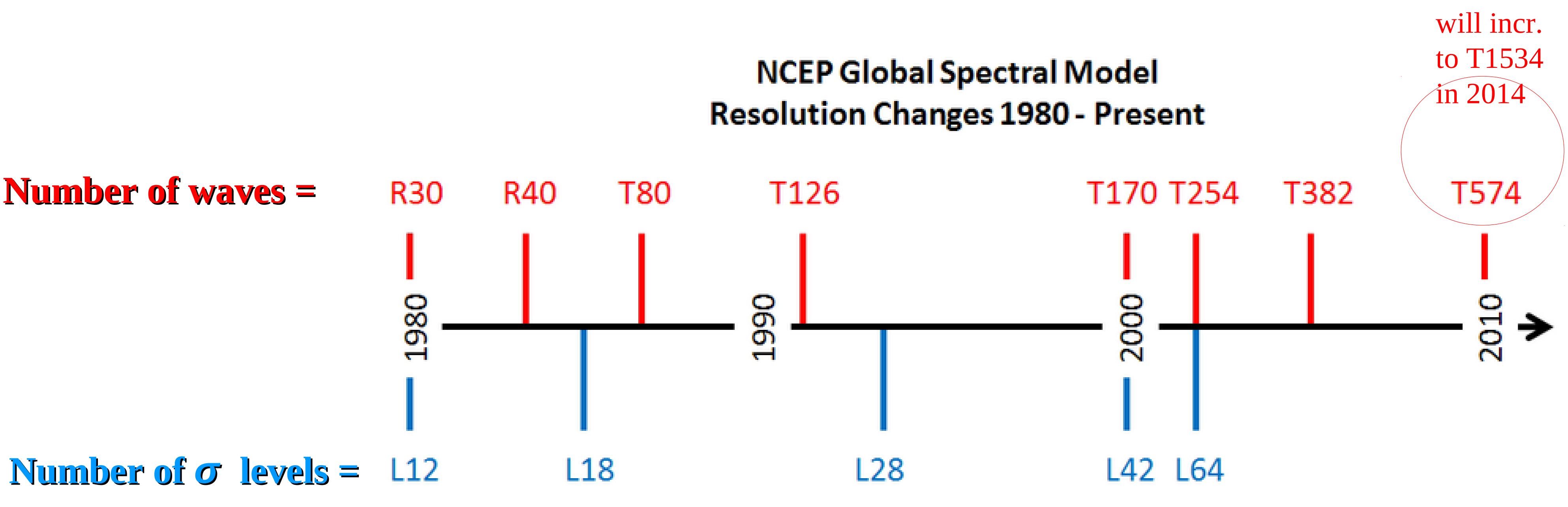
• the longitudinal waves ("modes") are sines and cosines

• The coefficients $A_{lm}(\sigma,t)$ carry the dependence on time *t* and height σ

What is a "spectral" model?

- T574 means 574 waves are carried
- wavelength of the shortest is 360°/574 = 0.63°
- grid model of corresponding resolution would require 2 gridpoints per each shortest wavelength, so would have grid spacing 1/2 x 0.63° (~ 35 km in latitude)**

**c.f. NOAA: "resolution 28 km (70 km for 2nd week)"

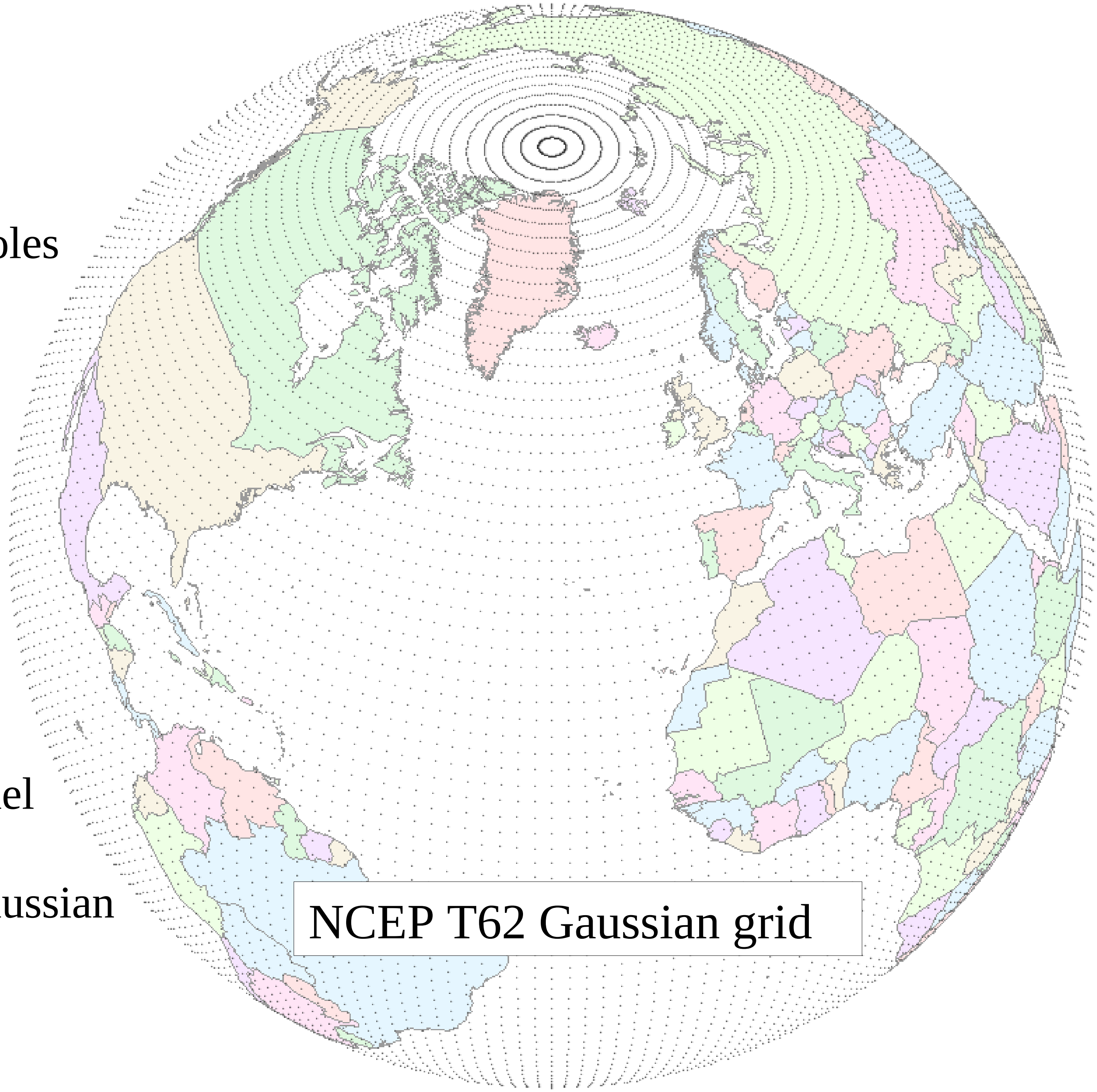


Parameterizations computed on “Gaussian grid”

- coordinate system for “physics” calculations

- no grid points at the poles

- at every time step model dependent variables are interpolated onto the Gaussian grid for the "gridpoint computations" (parameterizations)



NCEP's **Global Spectral Model** (ver. 11.0.6)

Why still spectral? (speculation)

- historical continuity (continuously evolving model)
- not subject to Courant condition (limiting time step)
- not subject to non-linear computational instability
- trivial to refine horiz. resolution when comput'l resources allow

Why still formulated in vorticity and divergence? (note: GSM is not subject to all the restrictions of the quasi-geostrophic model)

- historical continuity (continuously evolving model)
- solid theoretical justification (QG paradigm) to consider vertical vorticity,

horizontal divergence, & geostrophic vorticity- and thickness- advection as

basic to weather development