Why do we provide idealized cases?

1. The cases provide simple tests of the dynamics solver for a broad range of space and time scale:
   - LES - $\Delta x$ meters, $\Delta t < \text{second}$;
   - Baroclinic waves - $\Delta x$ 100 km, $\Delta t = 30 \text{ minutes}$.
2. The test cases reproduce known solutions (analytic, converged, or otherwise).
3. The cases provide a starting point for other idealized experiments.
4. They can be used to test physics development.
5. These tests are the easiest way to test the solver.
WRF ARW Tech Note

A Description of the Advanced Research WRF Version 3

http://www.mmm.ucar.edu/wrf/users/pub-doc.html
WRF ARW code

WRFV3

- test
- main
- phys
- dyn_em (ARW solver)

real

Idealized cases with README files

Initialization code +

dynamics solver code
Test Cases for the WRF ARW Model

- 2D flow over a bell-shaped mountain – `WRFV3/test/em_hill2d_x`
- 2D squall line (x, z ; y, z) – `WRFV3/test/em_squall2d_x, em_squall2d_y`
- 3D quarter-circle shear supercell thunderstorm – `WRFV3/test/em_quarter_ss`
- 3D baroclinic wave – `WRFV3/test/em_b_wave`
- 2D gravity current – `WRFV3/test/em_grav2d_x`
- 3D large-eddy simulation case – `WRFV3/test/em_les`
- 3D global: Held-Suarez case – `WRFV3/test/em_heldsuarez`
- 2D sea-breeze case – `WRFV3/test/em_seabreeze2d_x`
- 3D tropical cyclone – `WRFV3/test/em_tropical_cyclone`
What happens during the initialization

- A single sounding \((z, \theta, Q_v, u \text{ and } v)\), or a pre-computed, balanced 2D profile (in the case of b_wave), is read in.
- Full pressure and (inverse) air density is computed from the input sounding
- The thermodynamic reference state is computed based on the sounding without moisture (dry pressure, dry inverse air density)
- Dry column pressure \(\mu_d\) is computed, and then model \(\eta\) levels are assigned.
- \(\theta\) is interpolated to \(\eta\) levels, then inverse air density, geopotential and \(\mu_d\), are computed assuming a hydrostatic balance.
- Other fields are interpolated to model \(\eta\) levels.

Model levels are set within the initialization: code in initialization exist to produce a stretched \(\eta\) coordinate (close to equally spaced \(z\)), or equally spaced \(\eta\) coordinate.
2D Flow Over a Bell-Shaped Mountain

(dx = 2 km, dt = 20 s, T=10 hr)

\[
\begin{align*}
\text{w and perturbation } u \text{ (m/s)}
\end{align*}
\]
2D Flow Over a Bell-Shaped Mountain

Initialization module: dyn_em/module_initialize_hill2d_x.F
Case directory: test/em_hill2d_x
2D Flow Over a Bell-Shaped Mountain

Initialization code is in

\texttt{WRFV3/dyn_em/module_initialize_hill2d_x.F}

The terrain profile is set in the initialization code.

The thermodynamic sounding and the initial wind field is read from the ascii file

\texttt{WRFV3/test/em_hill2d_x/input_sounding}

The 2D solution is computed by integrating the 3D model with 3 points in periodic direction y; without an initial perturbation in y the solution remains y-independent.
Setting the terrain heights

In \textit{WRFV3/dyn_em/module\_initialize\_hill2d\_x.F}

\begin{verbatim}
SUBROUTINE init_domain_rk ( grid, &

hm = 100.  \hspace{1cm} \textcolor{red}{\text{mountain height and half-width}}
xa = 5.0   \hspace{1cm} \textcolor{red}{\text{mountain position in domain}}
icm = ide/2 \hspace{1cm} \textcolor{red}{\text{(center gridpoint in x)}}

DO j=jts,jte  \hspace{1cm} \text{Set height field}
  DO i=its,ite  \hspace{1cm} \text{! flat surface}
    grid\%ht(i,j) = hm/(1.+(float(i-icm)/xa)**2)
    grid\%phb(i,1,j) = g*grid\%ht(i,j)
    grid\%php(i,1,j) = 0.  \hspace{1cm} \textcolor{red}{\text{lower boundary condition}}
    grid\%ph0(i,1,j) = grid\%phb(i,1,j)
  ENDDO
ENDDO
\end{verbatim}
Setting the Initial Condition

In *WRFV3/dyn_em/module_initialize_hill2d_x.F*

SUBROUTINE init_domain_rk ( grid, &

... 
! get the sounding from the ascii sounding file, first get dry sounding and 
! calculate base state

write(6,*) ' getting dry sounding for base state ' 
dry_sounding = .true. 
CALL get_sounding( zk, p_in, pd_in, theta, rho, u, v, qv, dry_sounding, & 
  nl_max, nl_in, .true.)
...

! calculate full state for each column - this includes moisture.

write(6,*) ' getting moist sounding for full state ' 
dry_sounding = .false. 
CALL get_sounding( zk, p_in, pd_in, theta, rho, u, v, qv, dry_sounding, & 
  nl_max, nl_in, .false. )
...

WRF Tutorial January 2012
### Sounding File Format

File: \textit{WRFV3/test/em\_quarter\_ss/input\_sounding}

<table>
<thead>
<tr>
<th>Surface Pressure (mb)</th>
<th>Surface Potential Temperature (K)</th>
<th>Surface Vapor Mixing Ratio (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000.00</td>
<td>300.00</td>
<td>14.00</td>
</tr>
<tr>
<td>250.00</td>
<td>300.45</td>
<td>14.00</td>
</tr>
<tr>
<td>750.00</td>
<td>301.25</td>
<td>14.00</td>
</tr>
<tr>
<td>1250.00</td>
<td>302.47</td>
<td>13.50</td>
</tr>
<tr>
<td>1750.00</td>
<td>303.93</td>
<td>11.10</td>
</tr>
<tr>
<td>2250.00</td>
<td>305.31</td>
<td>9.06</td>
</tr>
<tr>
<td>2750.00</td>
<td>306.81</td>
<td>7.36</td>
</tr>
<tr>
<td>3250.00</td>
<td>308.46</td>
<td>5.95</td>
</tr>
<tr>
<td>3750.00</td>
<td>310.03</td>
<td>4.78</td>
</tr>
<tr>
<td>4250.00</td>
<td>311.74</td>
<td>3.82</td>
</tr>
<tr>
<td>4750.00</td>
<td>313.48</td>
<td>3.01</td>
</tr>
</tbody>
</table>

Each successive line is a point in the sounding.
2D squall line simulation

Squall-Line Simulations, T = 3600 s

dx = dz = 250 m, v = 300 m²/s

75 km

15 km

height coordinate model

mass coordinate model

vertical velocity

c.i. = 4 m/s, starting at = 2

cloudwater (g/kg)
2D squall line simulation

$squall2d_x$ is (x,z), $squall2d_y$ is (y,z); both produce the same solution.

Initialization codes are in

```
WRFV3/dyn_em/module_initialize_squall2d_x.F
WRFV3/dyn_em/module_initialize_squall2d_y.F
```

This code also introduces the initial perturbation.

The thermodynamic soundings and hodographs are in the ascii input files

```
WRFV3/test/em_squall2d_x/input_sounding
WRFV3/test/em_squall2d_y/input_sounding
```
3D supercell simulation

Height coordinate model
(dx = dy = 2 km, dz = 500 m, dt = 12 s, 160 x 160 x 20 km domain)
Surface temperature, surface winds and cloud field at 2 hours
3D supercell simulation

Initialization code is in

\texttt{WRFV3/dyn_em/module\_initialize\_quarter\_ss.F}

The thermodynamic sounding and hodograph is read from the ascii input file

\texttt{WRFV3/test/em\_quarter\_ss/input\_sounding}

The initial perturbation (warm bubble) is hardwired in the initialization code.
Setting the initial perturbation

In `WRFV3/dyn_em/module_initialize_quarter_ss.F`

```fortran
SUBROUTINE init_domain rk ( grid, &
    ... ! thermal perturbation to kick off convection ...
    DO J = jts, min(jde-1,jte)
        yrad = dy*float(j-nyc)/10000.
        yrad = 0.
        DO I = its, min(ide-1,ite)
            xrad = dx*float(i-nxc)/10000.
            xrad = 0.
            DO K = 1, kte-1
                ! put in perturbation theta (bubble) and recalc density. note,
                ! the mass in the column is not changing, so when theta changes,
                ! we recompute density and geopotential
                zrad = 0.5*(phb(i,k,j)+phb(i,k+1,j)) &
                       +phb(i,k)+phb(i,k+1,j))/g
                zrad = (zrad-1500.)/1500.
                RAD=SQRT(xrad*xrad+yrad*yrad+zrad*zrad)
                IF(RAD <= 1.) THEN
                    grid%t_1(i,k,j)=T_1(i,k,j)+delt*COS(.5*PI*RAD)**2
                    grid%t_2(i,k,j)=T_1(i,k,j)
                    qvf = 1. + 1.61*moist_1(i,k,j,P_QV)
                    grid%alt(i,k,j) = (r_d/p1000mb)*(t_1(i,k,j)+t0)*qvf* &
                                       (((p(i,k,j)+pb(i,k,j))/p1000mb)**cvpm)
                    grid%al(i,k,j) = alt(i,k,j) - alb(i,k,j)
                ENDIF
            ENDDO
        ENDDO
    ENDDO
```
Moist Baroclinic Wave Simulation

Height coordinate model \((dx = 100 \text{ km}, \ dz = 250 \text{ m}, \ dt = 600 \text{ s})\)
Surface temperature, surface winds, cloud and rain water
Moist Baroclinic Wave Simulation

Initialization code is in

*WRFV3/dyn_em/module_initialize_b_wave.F*

The initial jet (y,z) is read from the binary input file

*WRFV3/test/em_b_wave/input_jet*

The initial perturbation is hardwired in the initialization code.
Moist Baroclinic Wave Simulation

Default configuration in

\textit{WRFV3/test/em\_b\_wave/namelist.input}

runs the dry jet in a periodic channel with dimension

(4000 x 8000 x 16 km) (x,y,z).

Turning on any microphysics

(mp\_physics > 0 in namelist.input) puts moisture

into the model state.

The initial jet only works for dy = 100 km and

81 grid points in the y (south-north) direction.
Gravity Current Simulation

(Straka et al, IJNMF, 1993)

2D channel (x, z; 51.2 x 6.4 km)
Initial state: theta = 300 K (neutral) + perturbation (max = 16.2 K)
Eddy viscosity = 75 m**2/s**2 (constant)
Gravity Current Simulation

Default case, $dx = 100$ m, 5\textsuperscript{th} order upwind advection, uses namelist.input.100m

$dx = 200$ m, 5\textsuperscript{th} order upwind advection, use namelist.input.200m

$dx = 400$ m, 5\textsuperscript{th} order upwind advection, use namelist.input.400m
Gravity Current Simulation

5th order upwind advection, use namelist.input.200m and input_sounding.um=20

use namelist.input.100m with 2nd order advection and input_sounding.um=20

use namelist.input.200m with 2nd order advection and input_sounding.um=20

Translating Density Current, $U_m = 20$ m/s
Potential Temperature (c.i. = 1 K), $T = 15$ min

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Gravity Current Simulation

The turbulent Prandtl number in WRF 1/3, So the default WRF test case will give this solution.

To recover the Straka et al (1993) solution, change the parameter Prandtl to 1 (from 1/3) in

WRFV3/share/module_model_constants.F

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Gravity Current Simulation

Initialization code is in

\textit{WRFV3/dyn_em/module\_initialize\_grav2d\_x.F}

The initial cold bubble is hardwired in the initialization code.
Held-Suarez Case

Initialization code is in
\texttt{WRFV3/dyn_em/module_initialize_heldsuarez.F}

The initial model state is an isothermal atmosphere on flat earth with no winds, and random temperature perturbation

Test case directory is in
\texttt{WRFV3/test/em_heldsuarez}
Large-Eddy Simulation Case

Initialization code is in

\textit{WRFV3/dyn_em/module\_initialize\_les.F}

Test case directory is in

\textit{WRFV3/test/em_les}

The default case is a large-eddy simulation of free convective boundary layer with no winds. The turbulence of the free CBL is driven and maintained by namelist-specified surface heat flux.

An initial sounding with mean winds is also provided.

Reference: Moeng et al. 2007 MWR
Large-Eddy Simulation Case

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2D Sea-Breeze Simulation Case

Initialization code is in

\texttt{WRFV3/dyn_em/module\_initialize\_seabreeze2d\_x.F}

Test case directory is in

\texttt{WRFV3/test/em\_seabreeze2d\_x}

The initial state has no wind, and is perturbed by small random temperature changes

An example to show how to set surface parameters so that one may use full surface physics
Idealized tropical cyclone test case: Setup

Default vortex:
- weak (12.9 m/s) axisymmetric analytic vortex (Rotunno and Emanuel, 1987, JAS)
- placed in center of domain
- in “module_initialize_tropical_cyclone.F”
  users can modify initial size and intensity
  (see parameters r0, rmax, vmax, zdd)

Default environment:
- mean hurricane sounding from Jordan
  (1958, J. Meteor.)
- SST = 28 degrees C
- $f = 5e^{-5}$ s$^{-1}$ (20 degrees North)

Default domain:
- 3000 km x 3000 km x 25 km domain
- default dx,dy is only 15 km: useful for quick tests of new code (i.e., new physics schemes);
  research-quality studies should use smaller dx,dy

colors = relative humidity (%)
contours = azimuthal velocity (m/s)
Idealized tropical cyclone test case: Results

(a) $t = 1 \text{ d}$  
(b) $t = 3 \text{ d}$  
(c) $t = 5 \text{ d}$

colors = 10-m windspeed (m/s)  
contours = reflectivity (every 10 dBZ)
More on Idealized Cases..

Descriptions:

- WRFV3/README_test_cases
- WRFV3/test/em_*/README