Initialization for Idealized Cases

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, $\Delta t <$ second;
   - Baroclinic waves - $\Delta x$ 100 km, $\Delta t = 10$ 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.
Idealized Cases: Introduction

WRF ARW Tech Note
A Description of the Advanced Research WRF Version 3
http://www.mmm.ucar.edu/wrf/users/pub-doc.html
Idealized Cases: Introduction

WRF ARW code

```
WRFV3
```

```
<table>
<thead>
<tr>
<th>test</th>
<th>main</th>
<th>phys</th>
<th>dyn_em (ARW solver)</th>
</tr>
</thead>
</table>
```

```
<table>
<thead>
<tr>
<th>real</th>
</tr>
</thead>
</table>
```

```
| Idealized cases with README files |
```

```
| Initialization code |
```

```
| + |
```

```
| dynamics solver code |
```

Idealized Cases: Introduction

Idealized Test Cases for the WRF ARW Model V3.9

- 2D flow over a bell-shaped mountain – \textit{WRFV3/test/em\_hill2d\_x}
- 2D squall line (x, z ; y, z) – \textit{WRFV3/test/em\_squall2d\_x, em\_squall2d\_y}
- 2D gravity current – \textit{WRFV3/test/em\_grav2d\_x}
- 2D sea-breeze case – \textit{WRFV3/test/em\_seabreeze2d\_x (full physics)}
- 3D large-eddy simulation case – \textit{WRFV3/test/em\_les (+ a shallow convection case)}
- 3D quarter-circle shear supercell thunderstorm – \textit{WRFV3/test/em\_quarter\_ss}
- 3D tropical cyclone – \textit{WRFV3/test/em\_tropical\_cyclone (full physics)}
- 3D baroclinic wave in a channel – \textit{WRFV3/test/em\_b\_wave}
- 3D global: Held-Suarez case – \textit{WRFV3/test/em\_heldsuarez}
- 1D single column test configuration – \textit{WRFV3/test/em\_scm\_xy}
- 3D fire model test cases – \textit{WRFV3/test/em\_fire}
- 3D convective radiative equilibrium test – \textit{WRFV3/test/em\_convrad (full physics)}
Idealized Cases: 2d flow over a bell-shaped mountain

Running a test case: \emph{em\_hill2d\_x} example

2D Flow Over a Bell-Shaped Mountain

Initialization module: \texttt{dyn\_em/module\_initialize\_hill2d\_x.F}

Case directory: \texttt{test/em\_hill2d\_x}

\begin{center}
\begin{tikzpicture}
  \node (wrfv3) {WRFV3};
  \node (test) [below of=wrfv3] {test};
  \node (main) [below of=test] {main};
  \node (phys) [below of=main] {phys};
  \node (dyn_em) [below of=phys] {dyn\_em};
  \node (em_hill2d_x) [below of=dyn_em] {em\_hill2d\_x};
  \node (module_initialize_hill2d_x_F) [below of=em_hill2d_x] {module\_initialize\_hill2d\_x.F};
  \node (example) [below of=module_initialize_hill2d_x_F] {example};

  \draw[->] (wrfv3) -- (test);
  \draw[->] (test) -- (main);
  \draw[->] (main) -- (phys);
  \draw[->] (phys) -- (dyn_em);
  \draw[->] (dyn_em) -- (em_hill2d_x);
  \draw[->] (em_hill2d_x) -- (module_initialize_hill2d_x_F);
  \draw[->] (module_initialize_hill2d_x_F) -- (example);
  \draw[->] (example) -- (\ldots);
\end{tikzpicture}
\end{center}
Idealized Cases: 2d flow over a bell-shaped mountain

From the WRFV3 main directory:

> configure  (choose the no nesting and serial or SMP options)
> compile em_hill2d_x

Move to the test directory:

> cd test/em_hill2d_x
> ./ideal.exe  (this produces the ARW initial conditions)
> ./wrf.exe   (executes ARW)

Finish by plotting output using scripts downloaded from the ARW website (wrf_Hill2d.ncl)
Idealized Cases: 2d flow over a bell-shaped mountain

(dx = 2km, dt=20s, T=10 h, wrf_Hill2d.ncl)
Idealized Cases: 2d flow over a bell-shaped mountain

What happens during the initialization

Initialization code: $\text{WRFV3/dyn_em/module_initialize_hill2d_x.F}$

- 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.
- Terrain is set in the initialization code
- A single sounding ($z$, $\theta$, $Q_v$, $u$ and $v$) is read in from $\text{WRFV3/test/em_hill2d_x/input_sounding}$
- Sounding is interpolated to the ARW grid, equation of state and hydrostatic balance used to compute the full thermodynamics state.
- Wind fields are interpolated to model $\eta$ levels.

3D meshes are always used, even in 2D ($x,z$; $y,z$) cases. The third dimension contains only 3 planes, the boundary conditions in that dimension are periodic, and the solutions on the planes are identical in the initial state and remain so during the integration.
Idealized Cases: 2d flow over a bell-shaped mountain

Setting the terrain heights

In `WRFV3/dyn_em/module_initialize_hill2d_x.F`

```fortran
SUBROUTINE init_domain_rk ( grid, &

hm = 100.
xa = 5.0
icm = ide/2

DO j=jts,jte  ! flat surface
  DO i=its,ite
    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.
    grid%ph0(i,1,j) = grid%phb(i,1,j)
  ENDDO
ENDDO
```

Set height field

mountain height and half-width
mountain position in domain
(center gridpoint in x)

lower boundary condition
Idealized Cases: 2d flow over a bell-shaped mountain

Sounding File Format

File: *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>
<th>U (west-east) velocity (m/s)</th>
<th>V (south-north) velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000.00</td>
<td>300.00</td>
<td>14.00</td>
<td>-7.88</td>
<td>-3.58</td>
</tr>
<tr>
<td>250.00</td>
<td>300.45</td>
<td>14.00</td>
<td>-6.94</td>
<td>-0.89</td>
</tr>
<tr>
<td>750.00</td>
<td>301.25</td>
<td>14.00</td>
<td>-5.17</td>
<td>1.33</td>
</tr>
<tr>
<td>1250.00</td>
<td>302.47</td>
<td>13.50</td>
<td>-2.76</td>
<td>2.84</td>
</tr>
<tr>
<td>1750.00</td>
<td>303.93</td>
<td>11.10</td>
<td>0.01</td>
<td>3.47</td>
</tr>
<tr>
<td>2250.00</td>
<td>305.31</td>
<td>9.06</td>
<td>2.87</td>
<td>3.49</td>
</tr>
<tr>
<td>2750.00</td>
<td>306.81</td>
<td>7.36</td>
<td>5.73</td>
<td>3.49</td>
</tr>
<tr>
<td>3250.00</td>
<td>308.46</td>
<td>5.95</td>
<td>8.58</td>
<td>3.49</td>
</tr>
<tr>
<td>3750.00</td>
<td>310.03</td>
<td>4.78</td>
<td>11.44</td>
<td>3.49</td>
</tr>
<tr>
<td>4250.00</td>
<td>311.74</td>
<td>3.82</td>
<td>14.30</td>
<td>3.49</td>
</tr>
<tr>
<td>4750.00</td>
<td>313.48</td>
<td>3.01</td>
<td>14.30</td>
<td>3.49</td>
</tr>
</tbody>
</table>

File: *WRFV3/test/em_quarter_ss/input_sounding*

each successive line is a point in the sounding
Idealized Cases: 2d squall line

Squall-line simulation
T = 3600 s
\( \Delta x = \Delta z = 250 \) meters
\( u = 300 \, m^2/s \)
$squall2d_x$ 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

$WRFV3/test/em_squall2d_x/input_sounding$
$WRFV3/test/em_squall2d_y/input_sounding$
Idealized Cases: 2d gravity (density) current

(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 (constant)
Idealized Cases: 2d gravity (density) current

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

$dx = 200$ m, 5th order upwind advection, use namelist.input.200m

$dx = 400$ m, 5th order upwind advection, use namelist.input.400m
The turbulent Prandtl number in WRF is 1/3, and 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`
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
Idealized Cases: 3d quarter-circle shear supercell thunderstorm (quarter_ss)

Initialization code is in
WRFV3/dyn_em/module_initialize_quarter_ss.F

Test case directory is in
WRFV3/test/em_quarter_ss

The thermodynamic soundings and hodographs are in the ascii input files
WRFV3/test/em_quarter_ss/input_sounding
Idealized Cases: 3d Large Eddy Simulation (LES)

Initialization code is in

WRFV3/dyn_em/module_initialize_les.F

Test case directory is in

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
Idealized Cases: 3d Large Eddy Simulation (LES)
Idealized Cases: 3d tropical cyclone

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, 21 levels
- 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, and more vertical levels
Idealized Cases: 3d tropical cyclone

(a) $t = 1$ d

(b) $t = 3$ d

(c) $t = 5$ d

colors = 10-m windspeed (m/s)
contours = reflectivity (every 10 dBZ)
Idealized Cases: baroclinic wave in a channel

Height coordinate model (dx = 100 km, dz = 250 m, dt = 600 s)
Surface temperature, surface winds, cloud and rain water
Idealized Cases: baroclinic wave in a channel

Initialization code is in

\texttt{WRFV3/dyn\_em/module\_initialize\_b\_wave.F}

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

\texttt{WRFV3/test/em\_b\_wave/input\_jet}

The initial perturbation is hardwired in the initialization code.
Default configuration in

\texttt{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.
Idealized Cases: More information

Descriptions:

WRFV3/README_test_cases
WRFV3/test/em_*'/README

WRFV3 with README_test_cases

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

real

Idealized cases with README files

Initialization code
+ dynamics solver code
Idealized Cases: Introduction

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- 3D convective radiative equilibrium test – WRFV3/test/em_convrad (full physics)