Software Description

1 Description of code

This code is used for applying the Ensemble Tangent Linear Model (ETLM) to the Nonorographic Gravity Wave Drag (NGWD) scheme used by the Navy Global Environmental Model (NAVGEM). Description of the code and instructions for running the code are provided in this document. For questions please contact Douglas Allen at douglas.allen@nrl.navy.mil.

1.1 Main ETLM_and plotting codes

Interactive Data Language (IDL) code to calculate ETLM ensembles, create and validate the ETLM, and plot the results. There are three main programs and a number of supporting programs and data files.

etlm.pro – makes ensembles and calculates the validation
plot.pro – makes various plots
plot_schematic.pro – plots schematic diagram of non-orographic gravity wave drag parameters

1.2 ETLM_Code/PARAM

Sample parameter files for driving the ETLM.

Exp_gwsrc_analinc0_escale=1.0000_nwave=01.txt
Exp_gwsrc_analinc2_escale=1.0000_nwave=15_ntest=1000.txt
Exp_gwsrc_gtlm_escale=1.0000_nwave=15_ntest=1000.txt
Exp_gwsrc_random_escale=1.0000_nwave=15_ntest=1000.txt

1.3 ETLM_Code/GWD

IDL code for running the non-orographic gravity wave drag code.

calcflux_fast_1d.pro
calc_validation_all.pro
calc_validation_offline.pro
gw_bgnd_fast.pro
gw_drag_prof_fast.pro
gw_prof.pro
make_ensemble_all.pro
make_fabrinc.pro
pick_ens_type.pro
pick_expt.pro
plot_ensemble_offline.pro

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plot_ensemble.pro
plot_validation_all.pro
plot_validation_offline.pro
read_ensemble_all.pro
read_parameters_1d.pro
set_phase_speeds_1d.pro

1.4 ETLM_Code/MISC

IDL code for evaluation and plotting.

calcerror.pro
calc_pfull_prexp_2d.pro
calc_pfull_prexp_3d.pro
copy_navgem_data.pro
copy_navgem_netcdf
delete_navgem_data.pro
delete_navgem_netcdf.pro
file_exists.pro
gauleg.pro
get_geometry.pro
get_nlon_nglat.pro
labelbarcontour_nolines.pro
labelbarraster.pro
makearray.pro
makecircle.pro
make_etlm_file.pro
make_etlm_green.pro
make_etlm.pro
make_ghist_file.pro
pick_etlm.pro
plotoptionfile_1d.pro
pseudo_invert.pro
raster_plot_cool.pro
read_ghist_file.pro
read_ghist_netcdf.pro
read_navgem_data.pro
read_navgem_increment.pro
read_navgem_netcdf.pro
readnoggeom.pro
state_vector_1d.pro
table_blue_red.pro

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write_ghist_file.pro

1.5 ETLM_Code/NAVGEM

Sample data for etlm.pro and plot.pro. The first two are ASCII and the last two are netcdf.

NAVGEM geometry information
noggeom_T119L74.txt

Gravity wave parameters
t119l74k8b/gwsrc/gwsrc4.namelist.control_2015031500

Analysis increments: u, v, t, ps
t119l74k8b/analysis_inc/analysis_inc120_g2015031500.nc

Analysis: u, v, t, ps
t119l74k8b/specfiles/ghist_T0119L074_slfull_quad_2015031500_000000.nc

1.6 ETLM_Code/COVARIANCE

Covariance files used for creating fabricated analysis increments. Naming convention includes the longitude and latitude at which the covariance was calculated. The covariance is based on 600 analysis increments from 0000 UTC on 16 October 2014 to 1800 UTC on 14 March 2015, using 6-hourly increments. These are netcdf files.

B11_lon=005.0_lat=-89.2.nc
B11_lon=005.0_lat=-79.3.nc
B11_lon=005.0_lat=-69.3.nc
. . .
B11_lon=355.0_lat=069.3.nc
B11_lon=355.0_lat=079.3.nc
B11_lon=355.0_lat=089.2.nc

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2 How to use the code

2.1 The PARAM file

Most of the options for running etlm.pro are in the parameter file in the PARAM directory. Here is a sample of the contents for the random ensemble with scaling of 1.0000, which includes perturbations with standard deviations of 1 m/s, 1 K, and 1 hPa for zonal wind, temperature, and surface pressure, respectively. Four sample parameter files are provided.

PARAM/Exp_gwsrc_random_escale=1.0000_nwave=15_ntest=1000.txt

```
1200                dt              Time step (sec)
2015031500          dtg             Date-time-group
50                  kbmax           Maximum level
600                 nens_analinc    Ensemble for analysis increments for B
1                   nenstype        (1) Random (2) Analinc (3) GTLM (4) Fab Analinc
2000                nensuse         Number of ensemble members to use for etlm
1                   netlm           Option from pick_etlm, netlm
2                   nexp            NAVGEM experiment
1                   nfast           Speed up option
1                   ngwparam        (1) Use GWPR parameters (2) Use fixed parameters
2                   nleaveout       (1) Include Leave-One-Out (2) Don't inlcude
1                   nmatrix         (1) Full nstate x nstate ETLM (2) Reduced ETLM
1                   nprecision      (1) Single precision (2) Double precision
2                   nstate          (1) All (2) U Only (3) U nochange (4) U at P<1hPa
1                   nstdev          (1) Use fixed stdev (2) Use variable stdev
1000                ntestval        Number of tests for validation
15                  nwave           Number of waves = 2**pgwv+1
0                   verbose         Save extra fields
1                   nplotc          (1) Plot the phase speed (2) Don't plot c
0                   stamp           (1) File info on ps files (2) Don't include
1.                  ustd            Standard deviation for u for unscaled random incs
1.                  vstd            Standard deviation for v for unscaled random incs
1.                  tstd            Standard deviation for t for unscaled random incs
1.                  pstd            Standard deviation of ps for unscaled random incs
1000                useed           Seed for random perturbations to u
2000                vseed           Seed for random perturbations to v
3000                tseed           Seed for random perturbations to t
4000                pseed           Seed for random perturbations to p
201                 cseed0          Seed for stochastic wave generator
1001                fabrinc_seed    Random seed for fabricated ensembles
30.                 c0_spec         Used for ngwparam eq 2
1.                  wgt_spec        Used for ngwparam eq 2
5.                  tau_spec        Used for ngwparam eq 2
```

Some of the key variables include:
escale: the scaling of the ensemble
nenenstype: which type of ensemble to use
nensuse: how many ensemble members
nwave: the number of NGWD to be launched

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2.2 Setting up etlm.pro

Some of the main options are:

```
starttime=long(2015031500)
endtime=long(2015031500)
inctime2=24
```

These set the times in YYYYMMDDHH to run.

```
filename_all=['PARAM/Exp_gwsrc_random_escale=1.0000_nwave=15_ntest=1000.txt']
```

In this array you can put multiple filenames to run various tests (e.g., different scalings or different ensemble types). But by default the code selects one file. Here are some additional important settings.

```
nmakeensemble=1          ; Choose whether to make the ensemble
nreadensemble=1          ; Choose whether to read the ensemble
nplotens=0               ; Choose whether to plot the ensemble
ncalcvalidation=1        ; Choose whether to calc the validation
nplotvalidation=0        ; Choose whether to plot the validation
nens_to_plot=150         ; Number of ensemble members to plot
nvalidation=2            ; Chooses nsampleall for validation (see below)
nanalincfix=0            ; Remove analinc from the analysis
```

These establish the procedures to be run. The example above makes the ensemble, reads the ensemble, and runs through the validation for nvalidation option 2. The plotting options (nplotens and nplotvalidation) are also available to make plots for every grid point, but this is generally not done, rather plot.pro can be used to make these plots after running etlm.pro.

2.3 Running etlm.pro

Examples of running etlm.pro are provided in Section 3.

2.4 Output from etlm.pro

Output is placed in the following directory.

../ETLM_Data/t119l74k8b/2015031500/Exp_gwsrc_random_escale=8.0000_nwave=15

There is one folder for each grid point that is analyzed. For example the longitude=175, latitude=-79.3 data are in the following directory.

lon=175.0_lat=-79.3

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This contains the following files:

Settings.txt

Values of the key settings used for this run

background_2015031500_lon=175.0_lat=-79.3.idl

Results from running the background profiles through the NGWD routine

```
C               FLOAT     = Array[15]        Ground-based phase speed
CSTORE          FLOAT     = Array[15]        Intrinsic phase speed
KBOTS           FLOAT     = Array[1]         Index associated with launch pressure
PB              FLOAT     = Array[1, 74]     Background pressure profile [hPa]
PSB             FLOAT     =       995.133    Background surface pressure [hPa]
TB              FLOAT     = Array[1, 74]     Background temperature [K]
UB              FLOAT     = Array[1, 74]     Background zonal wind [m/s]
UT              FLOAT     = Array[74]        Background zonal wind acceleration [m/s/s]
VB              FLOAT     = Array[1, 74]     Background meridional wind [m/s]
XV              FLOAT     = Array[1]         Term to indicate direction of intrinsic phase speed
```

ensemble_2015031500_lon=175.0_lat=-79.3.idl

Results from running the background profiles through the NGWD routine

```
C               FLOAT     = Array[2000, 15]  Ground-based phase speed
CSTORE          FLOAT     = Array[2000, 15]  Intrinsic phase speed
KBOTS           FLOAT     = Array[2000]      Index associated with launch pressure
PE              FLOAT     = Array[2000, 74]  Ensemble pressure profile [hPa]
PSE             FLOAT     = Array[2000]      Ensemble surface pressure [hPa]
TE              FLOAT     = Array[2000, 74]  Ensemble temperature [K]
UE              FLOAT     = Array[2000, 74]  Ensemble zonal wind [m/s]
UT              FLOAT     = Array[2000, 74]  Ensemble acceleration [m/s/s]
VE              FLOAT     = Array[2000, 74]  Ensemble meridional wind [m/s]
XV              FLOAT     = Array[2000]      Term to indicate direction of intrinsic phase speed
```

ETLM_Validation3_gwsrc_random_escale=1.0000_nwave=15_t119l74k8blon=175.0_lat=-79.3_stdev=fixed_ntest=00001000_nstate=wind_shortval.idl

The validation results

```
IN_ERROR                    FLOAT     = Array[103, 19] In-sample error for all state variables
IN_ERROR_1D                 FLOAT     = Array[19]      Vertically-averaged in-sample error
IN_PERSISTENCE_ERROR        FLOAT     = Array[103, 19] Persistence error for all variables
IN_PERSISTENCE_ERROR_1D     FLOAT     = Array[19]      Vertically-averaged persistence error
LEV                         FLOAT     = Array[74]      All NAVGEM L74 nominal full levels
LMUSE                       INT       =       51       Number of vertical levels used
NSAMPLEALL                  INT       = Array[19]      Number of ensemble sizes tested
OUT_ERROR                   FLOAT     = Array[103, 19] Out-of-sample error for all variables
OUT_ERROR_1D                FLOAT     = Array[19]      Vertically-averaged out-of-sample error
OUT_PERSISTENCE_ERROR       FLOAT     = Array[103, 19] Out-of-sample persistence error
OUT_PERSISTENCE_ERROR_1D    FLOAT     = Array[19]      Averaged out-of-sample persistence error
OUT_PERT_SIZE_1D            FLOAT     = Array[19]      Averaged perturbation size
PERT_SIZE                   FLOAT     = Array[103, 19] Perturbation size for all variables
```

Note that the errors are given as mean squared errors (MSE) of the zonal wind for one time step (dt=1200 s) in units of m^2/s^2. To convert to root mean squared erorrs (RMSE) in m/s/day you need to do the following conversion (example using out_error_1d) which is included in plot.pro.

```
sqrt(out_error_1d)*86400./dt  ; converts from MSE to RMSE in m/s/day
```


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3 Creating the ensembles

Note that for the control the user can either choose the NAVGEM analysis or the NAVGEM background (i.e., analysis minus the analysis increment). This is set by nanalincfix in etlm.pro, which is by default set to use the NAVGEM background.

3.1 Running etlm.pro for analinc2 (a.k.a., Fabricated Analysis Increments) with escale=1.0000 for 2000 ensemble members

Start IDL

```
.r etlm
1. Create an ensemble
1. FAI: PARAM/Exp_gwsrc_analinc2_nwave=15_ntest=1000.txt
1 (scaling value)
```

Output is in ../ETLM_Data/t119l74k8b/2015031500/Exp_gwsrc_analinc2_escale=1.0000_nwave=15

3.2 Running etlm.pro for random (a.k.a., Uncorrelated Noise) with escale=1.0000 for 2000 ensemble members

Start IDL

```
.r etlm
1. Create an ensemble
2. UN: PARAM/Exp_gwsrc_random_nwave=15_ntest=1000.txt
1 (scaling value)
```

Output is in ../ETLM_Data/t119l74k8b/2015031500/Exp_gwsrc_random_escale=1.0000_nwave=15

3.3 Running etlm.pro for gtlm (a.k.a., Numerical Jacobian) with escale=1.0000 for 2000 ensemble members

Start IDL

```
.r etlm
1. Create an ensemble
3. NJ: PARAM/Exp_gwsrc_gtlm_nwave=15_ntest=1000.txt
1 (scaling value)
```

Output is in ../ETLM_Data/t119l74k8b/2015031500/Exp_gwsrc_gtlm_escale=1.0000_nwave=15

3.4 Running etlm.pro for analinc0 (a.k.a., Analysis Increments) with escale=1.0000 for 2000 ensemble members

Start IDL

```
.r etlm
1. Create an ensemble
4. AI: PARAM/Exp_gwsrc_analinc0_nwave=15.txt
1 (scaling value)
```

Output is in ../ETLM_Data/t119l74k8b/2015031500/Exp_gwsrc_analinc0_escale=1.0000_nwave=15

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4 Running the validation

For the validation, the user can either validate with the same sample set or use another set. Here are some examples.

4.1 Validating analinc2 with escale=1.0000 using the same sample set

Start IDL

```
.r etlm
2. Run the validation
1. FAI: PARAM/Exp_gwsrc_analinc2_nwave=15_ntest=1000.txt
1 (scaling value)
1. gwsrc_analinc2_escale=1.0000_nwave=15
2. 100,110,120,...,200,300,...,1000
```

4.2 Validating random with escale=1.0000 using analinc2 with escale=1.0000

Start IDL

```
.r etlm
2. Run the validation
2. UN: PARAM/Exp_gwsrc_random_nwave=15_ntest=1000.txt
1 (scaling value)
1. gwsrc_analinc2_escale=1.0000_nwave=15
2. 100,110,120,...,200,300,...,1000
```

4.3 Validating gtlm with escale=1.0000 using analinc2 with escale=1.0000

Note: here we need to choose option 3 for the validation with 103 members.

Start IDL

```
.r etlm
2. Run the validation
3. NJ: PARAM/Exp_gwsrc_gtlm_nwave=15_ntest=1000.txt
1 (scaling value)
1. gwsrc_analinc2_escale=1.0000_nwave=15
3. 103
```

4.4 Validating random with escale=1.0000 using analinc0 with escale=1.0000

Note: here we need to choose option 4 for the validation.

Start IDL

```
.r etlm
2. Run the validation
1. FAI: PARAM/Exp_gwsrc_analinc2_nwave=15_ntest=1000.txt
1 (scaling value)
4. gwsrc_analinc0_escale=1.0000_nwave=15
4. 100,110,120,...,200,300,...,1000 (use for analinc0 validation)
```


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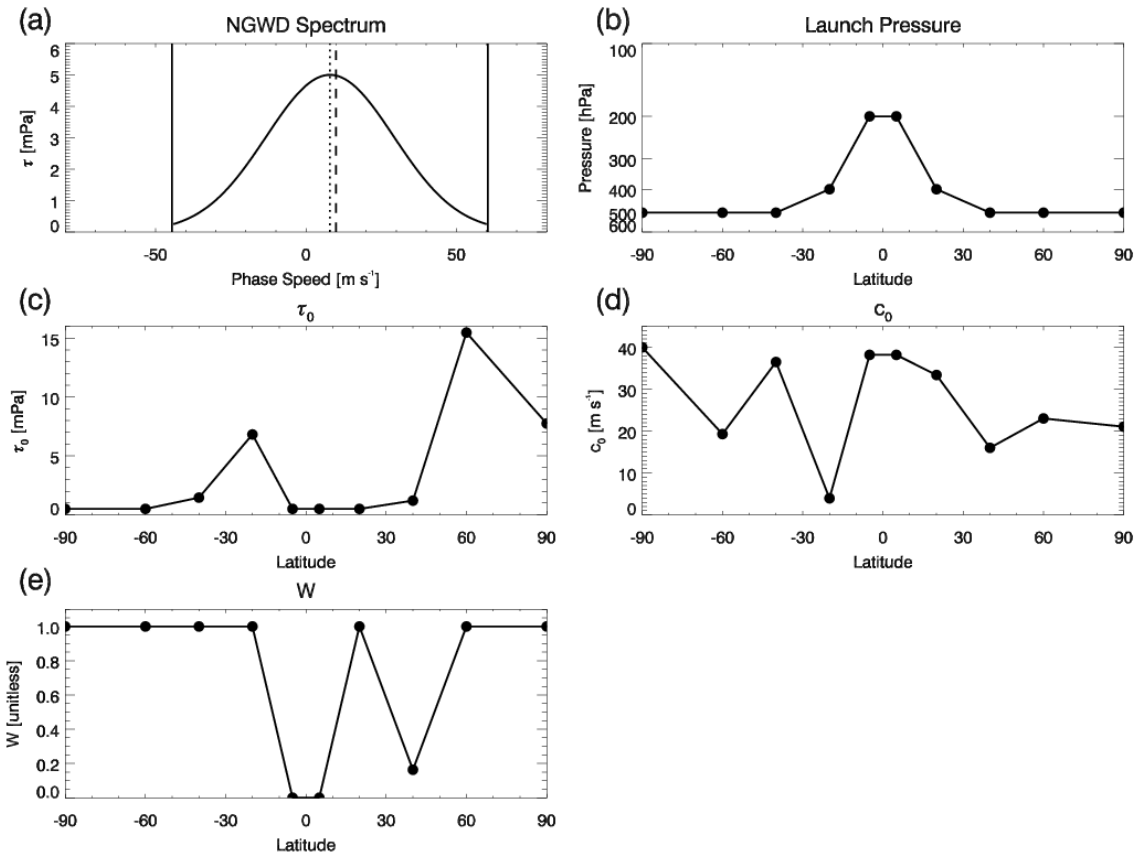
5 Plotting the results

5.1 Plotting the gravity wave parameters

This plots the gravity wave parameters for 2015031500 along with an example of the source spectrum.

Start IDL

```
.r plot_schematic
2015031500
../ETLM_Data/FIGURES/NGWD_parameters_2015031500.ps
```



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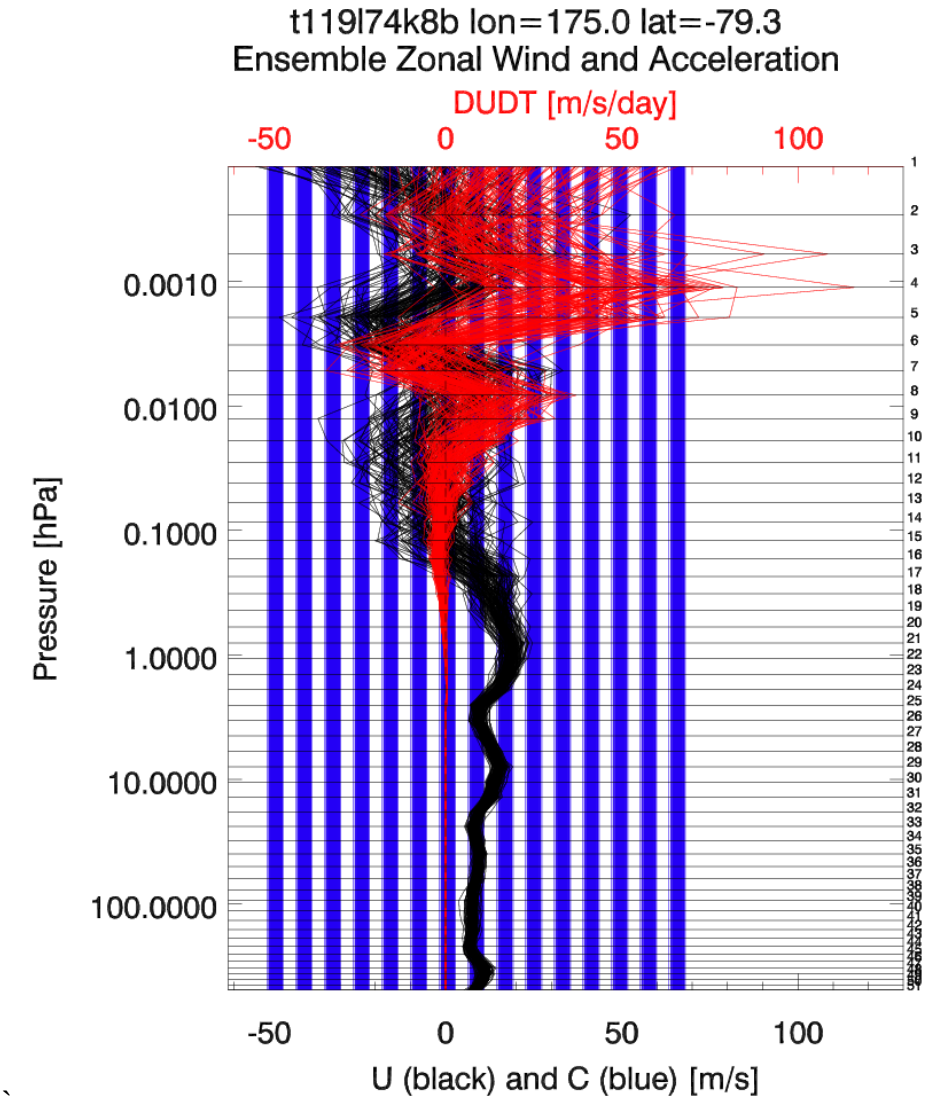
5.2 Plotting the ensemble at one location.

This plots the ensemble background zonal wind (black), ground-based phase speed (blue) and acceleration (red) converted to m/s/day for a chosen grid point. The user needs to specify the PARAM file that is used. An example plot is given below for FAI with escale=1.0000.

Start IDL

```
.r plot
1. FAI: PARAM/Exp_gwsrc_analinc2_nwave=15_ntest=1000.txt
1 (scaling factor)
1. Plot ensemble at one location
175      175.000
10     -79.2786
../ETLM_Data/FIGURES/ETLM_Physics_Ensemble_gwsrc_analinc2_escale=1.0000_nwave=15_t119l74k8blon=17
5.0_lat=-79.3_nensuse=00002000_c.ps
```



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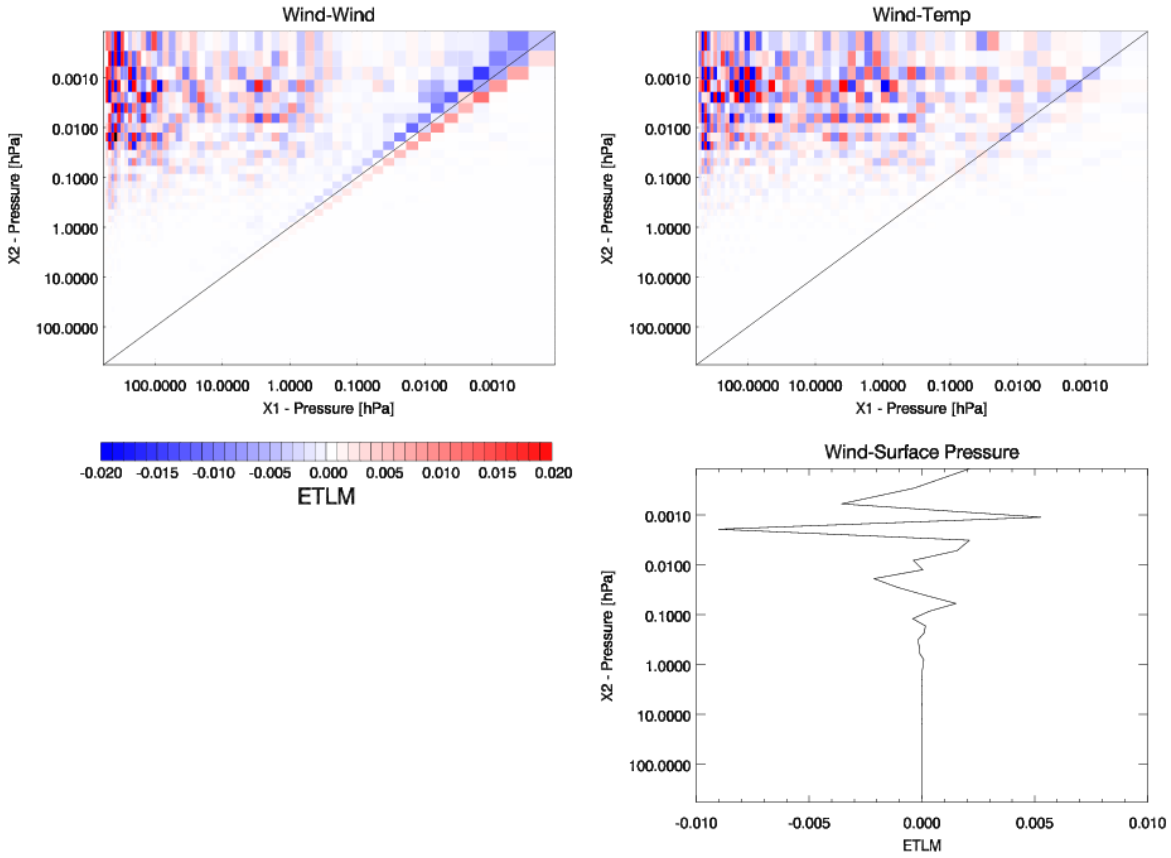
5.3 Plotting the ETLM matrix at one location

Start IDL

```
.r plot
1. FAI: PARAM/Exp_gwsrc_analinc2_nwave=15_ntest=1000.txt
1 (scaling factor)
2. Plot ETLM at one location          plotetlm
175      175.000
10     -79.2786
18    1000 (ensemble size)
2. Pick the min/max
-0.02 0.02

../ETLM_Data/FIGURES/LETLM_Raster_t119174k8b_expid=gwsrc_analinc2_escale=1.0000_nwave=15_nvaruse=
0103_nensuse=00002000_lon=175.0_lat=-79.3_minus1_cool.ps
```



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5.4 Plotting the validation at one location

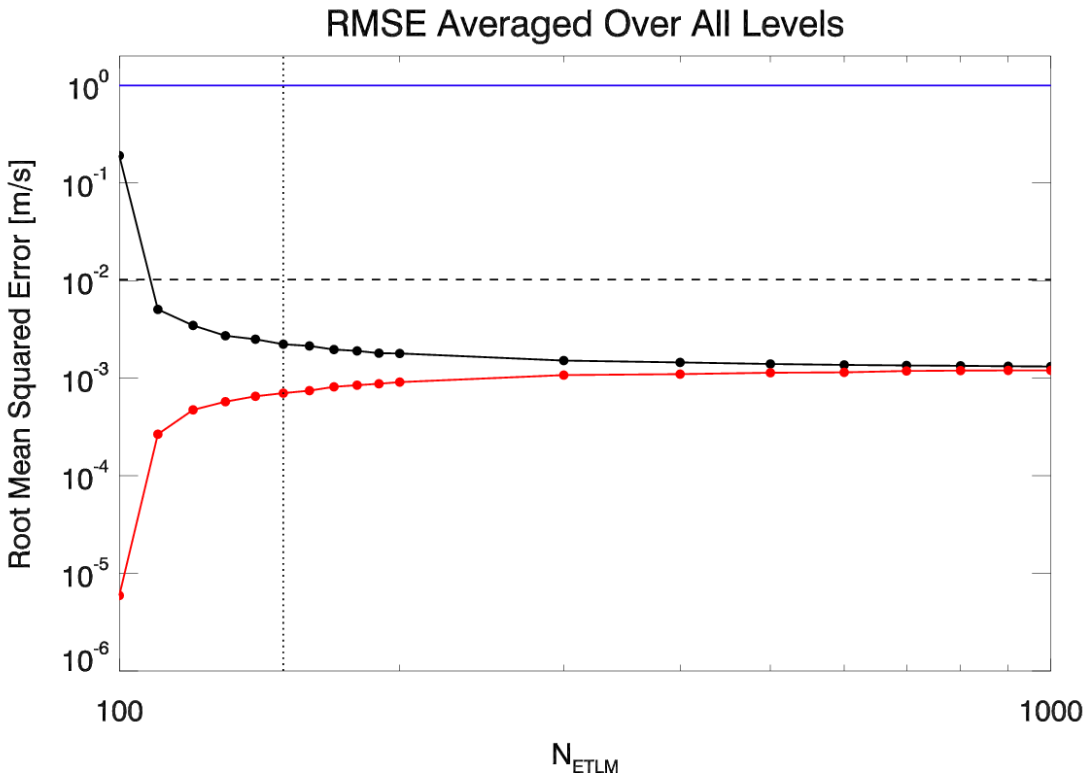
These examples are for the UN with escale=1, validated against the same sample set.

Start IDL

```
.r plot
2. UN: PARAM/Exp_gwsrc_random_nwave=15_ntest=1000.txt
1 (scaling factor)
3. Plot validation at one location
2 (validation option)
2. gwsrc_random_escale=1.0000_nwave=15
175      175.000
10      -79.2786
```

This creates several figures. First, Vertically-averaged RMSE [m/s] versus ensemble size. Here black is out-of-sample error, red is in-sample error, and blue is persistence error.

```
../ETLM_Data/FIGURES/ETLM_Validation_RMSE_gwsrc_random_escale=1.0000_nwave=15_t119174k8blon=175.0
_lat=-79.3_stdev=fixed_ntest=00001000_nstate=wind.ps
```



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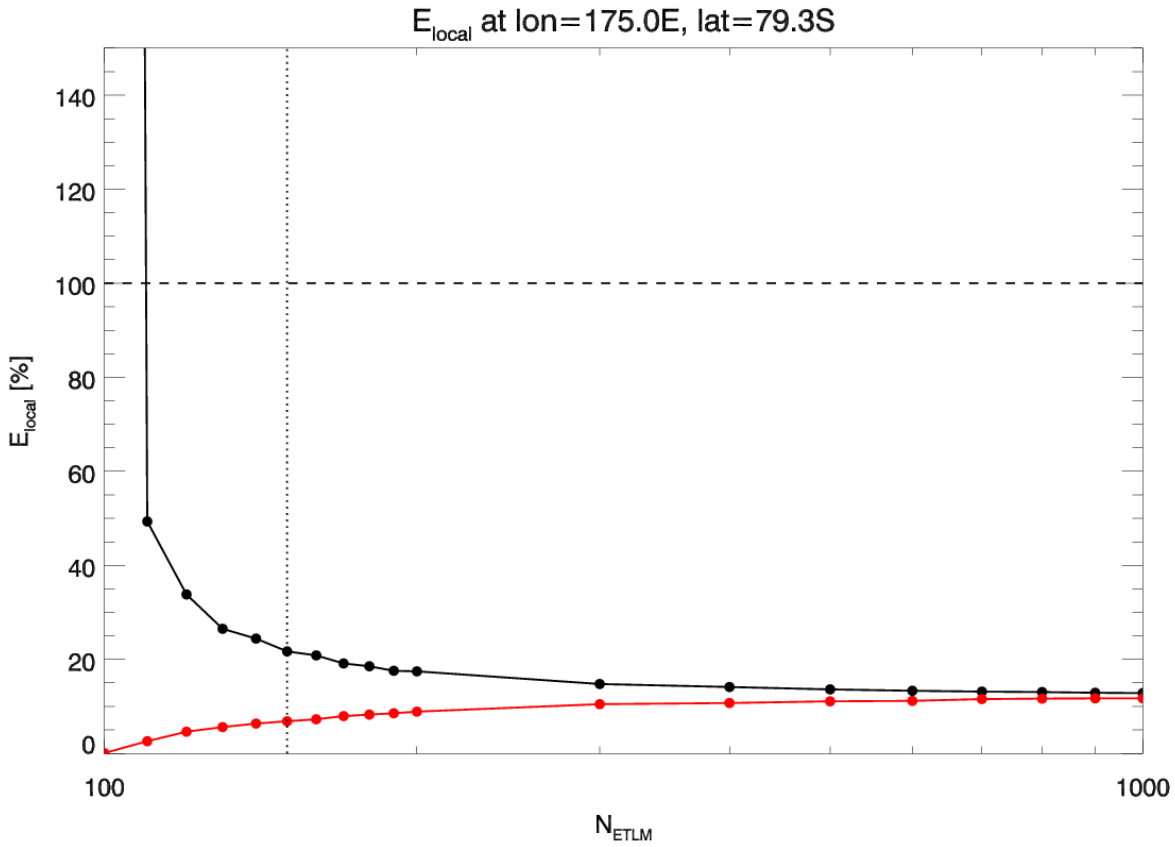
The percent error versus ensemble size. Black is out-of-sample, red is in-sample.

../ETLM_Data/FIGURES/ETLM_Validation3_gwsrc_random_escale=1.0000_nwave=15_t119174k8blon=175.0_lat=-79.3_stdev=fixed_ntest=00001000_nstate=wind_shortval_RMSE_Percent.ps



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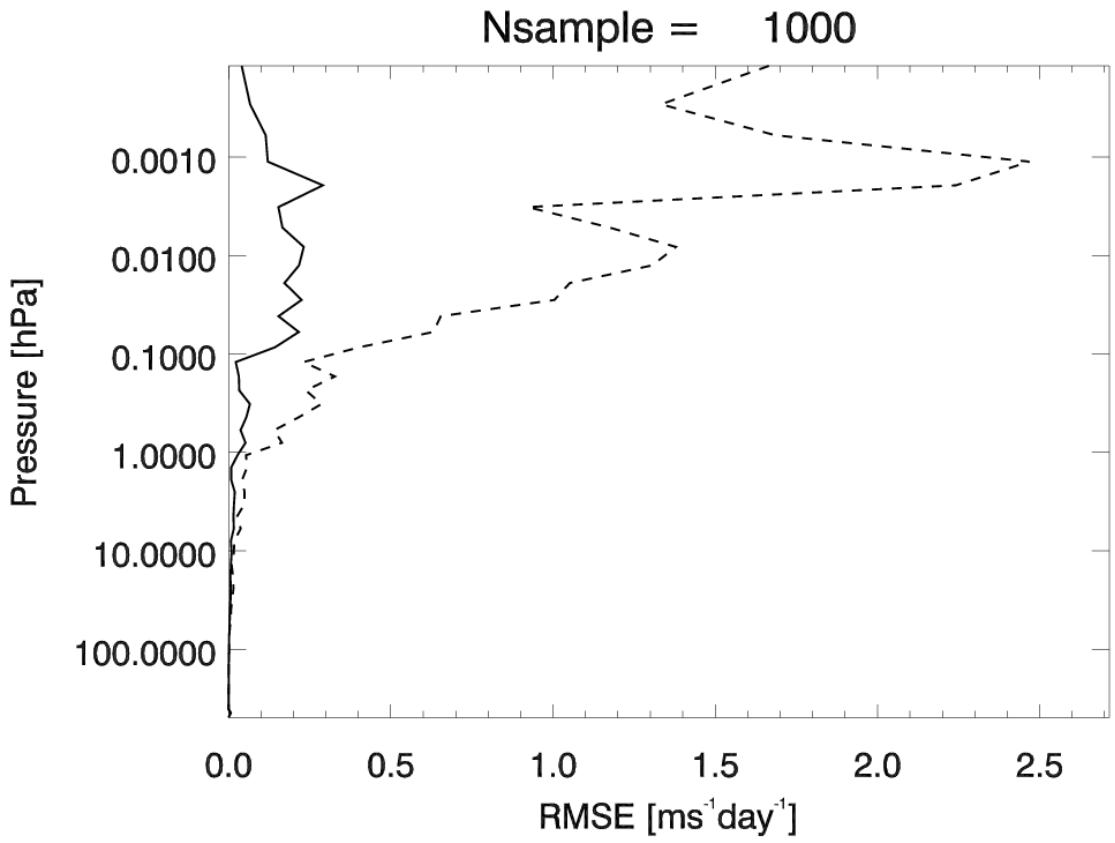
Profiles of errors in units of m/s/day. Dashed (solid) is persistence (out-of-sample) error.
../ETLM_Data/FIGURES/ETLM_Validation_RMSE_msecday_gwsrc_random_escale=1.0000_nwave=15_t119l74k8blon=175.0_lat=-79.3_stdev=fixed_ntest=00001000_nstate=wind.ps



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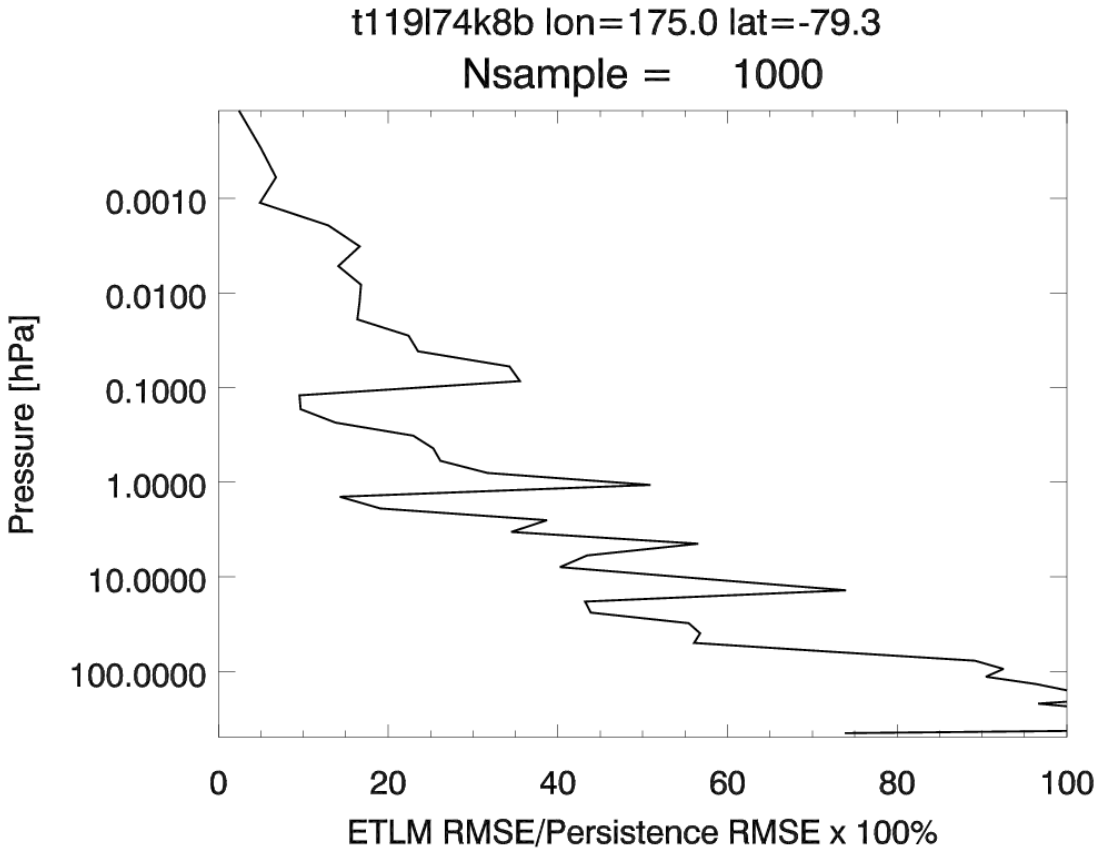
Profile of percent errors

../ETLM_Data/FIGURES/ETLM_Validation_Percent_gwsrc_random_escale=1.0000_nwave=15_t119l74k8blon=175.0_lat=-79.3_stdev=fixed_ntest=00001000_nstate=wind.ps



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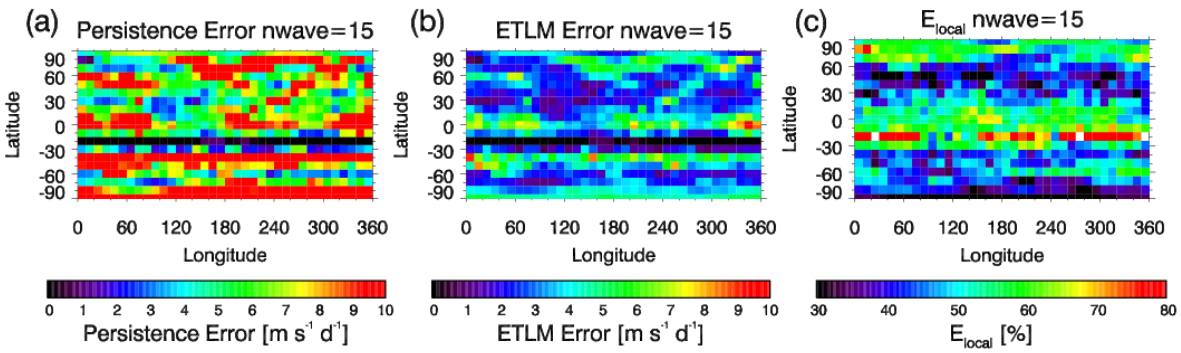
5.5 Plotting the validation at all locations

Here we plot the validation results at all grid points. User chooses the ensemble size and the vertical weighting option. Here we show results for FAI validated against the same sample set.

Start IDL

```
.r plot
1. FAI: PARAM/Exp_gwsrc_analinc2_nwave=15_ntest=1000.txt
1 (scaling)
4. Plot validation at all locations    plotmult
1. gwsrc_analinc2_escale=1.0000_nwave=15
2 (validation option)
18    1000 (ensemble size)
3. Thickness weighting, use 1 hPa and up
../ETLM_Data/FIGURES/ETLM_Validation_Plot_PERS_ETLM_ERROR_gwsrc_analinc2_escale=1.0000_nwave=15_v
al_gwsrc_analinc2_escale=1.0000_nwave=15_00001000.ps
```



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