# Shallow Water Model - DA System - V1.0

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# 1 Introduction

This document describes how to use the shallow water model (SWM) data assimilation (DA) system, including Ensemble Kalman Filter (EnKF) and 4D-Variational (4DVar) DA with various flavors of tangent linear models. The code is written in IDL and is assumed to be contained in the directory ~/Programs/SHALOM_HTLM. In the documentation below, red text is usually user input to the programs, while blue and black text is output, filenames, etc. The SHALOM_HTLM directory contains the following sub-directories.

| | |
|---|---|
| 4DVAR | 4DVar Code |
| Covariance | Miscellaneous Codes |
| Data | Data necessary for spectral transforms |
| EnKF | Ensemble Kalman Filter |
| ETLM_Patch | The ETLM used for the Hybrid TLM |
| Forecast_Model | The SWM forecast model |
| NNMI | Nonlinear normal mode initialization |
| Observations_4DVAR | Code for making observations |
| Observations_EnKF | Code for making observations |
| Plotting | Plotting codes |
| Scripts | Main scripts for running the DA |


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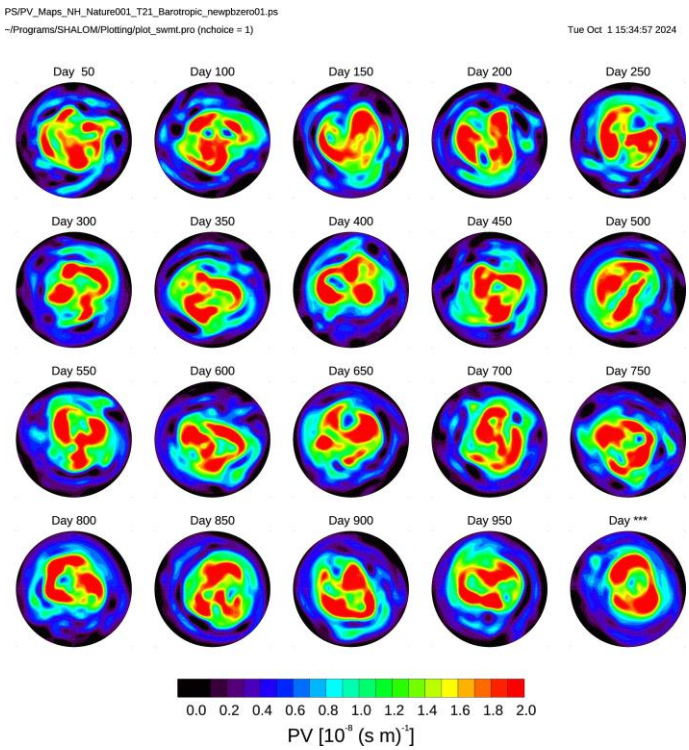
## 2 Running the SWM.

A free-running SWM forecast out to 1000 days.

```
scr (alias for cd ~/Programs/SHALOM_HTLM/Scripts)
idl
.r enkf_driver_ens
21 (Resolution)
9. Use /Data3/SHALOM_HTLM_newpbzero
01
1. Do Nature Run
Nature001_T21_Barotropic
13. Barotropic instability
5. Relaxation to mean state (zonal mean only)
86400
0 (first day to apply physics)
0 (hphase in degrees)
1 (scaling of height perturbation)

cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r plot_nature_run
10. Use /Data3/SHALOM_HTLM_barotropic
01
Nature001_T21_HTLM
1. Plot PV field (postscript)     plotpv
1. NH
1. Use day for skip
50 1000 50
```

PS/PV_Maps_NH_Nature001_T21_HTLM_barotropic01_Page1.png





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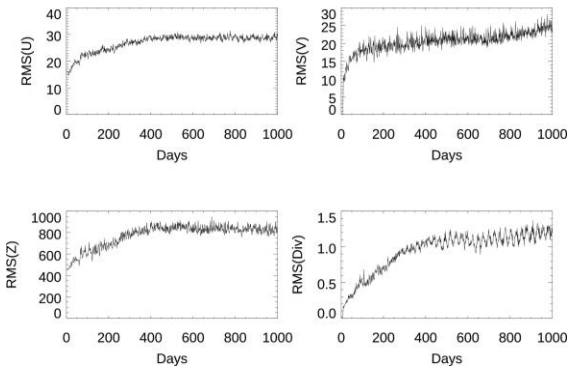
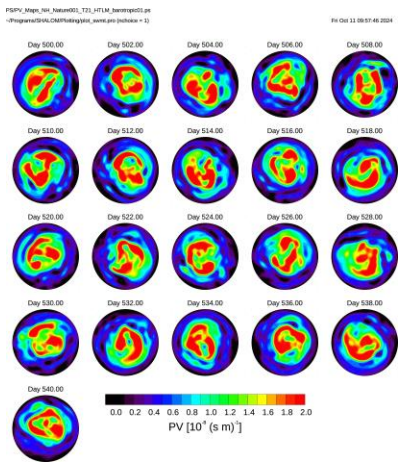
Plot global RMS values of these fields.

```
cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r plot_nature_run
9. Use /Data3/SHALOM_HTLM_newpbzero
01
Nature001_T21_NoForcing
5. Calculate RMS                    calcrms
0 1000 1
6. Plot RMS                         plotrms
RMS_Time_Series_Nature001_T21_Barotropic_newpbzero01_Page1
```




Here is a plot for the time period used for the DA

```
cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r plot_nature_run
10. Use /Data3/SHALOM_HTLM_barotropic
01
Nature001_T21_HTLM
1. Plot PV field (postscript)       plotpv
1. NH
1. Use day for skip
2. Do not overplot the height field500 540 2
PS/PV_Maps_NH_Nature001_T21_HTLM_barotropic01_Page1.png
```





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## 3 Experimental Design

Looks like things level out around 400 days. Let's try doing an EnKF starting at that point. There is an interesting oscillation in the divergence field. Here is the setup we'll use.

Days 000-399 – Spin-up of the Nature Run
Days 400-499 – Initialize ensemble using one file per day
Day 499.5 – Initialization of the EnKF mean analysis
Days 500-520 – Spin-up the EnKF
Days 520-540 – 4DVar testing period
Days 541-796 – Climatological Pbzero (using every hour for 256 days for 6144 files)


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# 4 The Nature Run

## Run the Nature run

First, we need to make the `FM_Parameters.txt` file.

```
mkdir -p /Data3/SHALOM_HTLM_barotropic01/Nature
cd /Data3/SHALOM_HTLM_barotropic01/Nature
mkdir Nature001_T21_HTLM
cd Nature001_T21_HTLM
vi FM_Parameters.txt
120             dt:             Choose time step
8.9e16          D:              Diffusion coefficient
0.              mountain:       Choose height of mountain forcing (in m)
10000           meanheight:     Mean height of fluid (in meters)
0               diabatic:       Choose whether to use diabatic forcing
60              umax:           Maximum wind speed
20              startdaytracer: Choose day of NR for init (4DVAR option)
6               houroffset:     Choose hour offset (4DVAR option)
0               nrandom:        (0) Use constant phase (1) Use random phase
100             seed:           Seed for random number generator
100             tau:            Diabatic forcing timescale (in days)
4.D0            spinup:         Spinup time for forcing (in days)
20.D0           cycling:        Cycling time for forcing (in days)
40.D0           delay:          Delay time between cycles (in days)
2               nchem:          (1) Use chem (2) Do not use chem
20              tchem:          Photochemical forcing timescale (in days)
0               dummy1
0               dummy2
0               dummy3
0               dummy4
0               dummy5
```

Next, run the forecast

```
scr (alias for cd ~/Programs/SHALOM_HTLM/Scripts)
idl
.r enkf_driver_ens
21 (Resolution)
10. Use /Data3/SHALOM_HTLM_barotropic
01

1. Do Nature Run
Nature001_T21_HTLM
13. Barotropic instability
2. Run with added physics (short)
5. Relaxation to mean state (zonal mean only)
86400
0 (first day of physics)
1. Do the Nature Run
0 (hphase)
1 (scaling of height perturbation)
```

## Plotting the Nature Run

Let's plot starting at day 400


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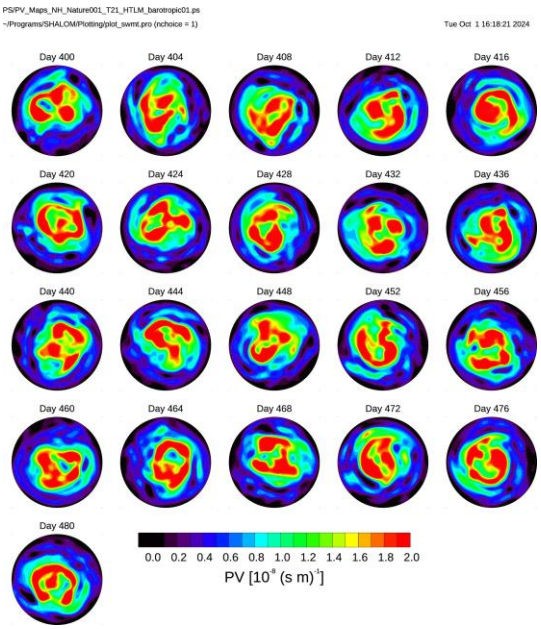
```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_nature_run
10. Use /Data3/SHALOM_HTLM_barotropic
01
Nature001_T21_HTLM
1. Plot PV field (postscript)     plotpv
1. NH
400 480 4
PS/PV_Maps_NH_Nature001_T21_HTLM_barotropic01.ps
```





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# 5 Running the EnKF Spin-up for L=7500 km

## Create the FM_parameters.txt file for the EnKF nonlinear forecasts

```
mkdir -p /Data3/SHALOM_HTLM_barotropic01/EnKF/EnKF_T21_N0100_L07500_E003_HTLM
cd /Data3/SHALOM_HTLM_barotropic01/EnKF/EnKF_T21_N0100_L07500_E003_HTLM
vi FM_Parameters.txt
```

```
120             dt:             Choose time step
8.9e16          D:              Diffusion coefficient
0.              mountain:       Choose height of mountain forcing (in m)
10000           meanheight:     Mean height of fluid (in meters)
0               diabatic:       Choose whether to use diabatic forcing
60              umax:           Maximum wind speed
400             startdaytracer: Choose day of NR for init (4DVAR option)
6               houroffset:     Choose hour offset (4DVAR option)
0               nrandom:        (0) Use constant phase (1) Use random phase
100             seed:           Seed for random number generator
100             tau:            Diabatic forcing timescale (in days)
4.D0            spinup:         Spinup time for forcing (in days)
20.D0           cycling:        Cycling time for forcing (in days)
40.D0           delay:          Delay time between cycles (in days)
2               nchem:          (1) Use chem (2) Do not use chem
20              tchem:          Photochemical forcing timescale (in days)
0               dummy1
0               dummy2
0               dummy3
0               dummy4
0               dummy5
```

## Create the DAS_Parameters.txt file

```
vi DAS_Parameters.txt
```

```
0       spinupdays:       Number of days to run w/o data assimilation
3600    cyclesec:         Cycling time in seconds
0       initialtime:      Initial time for this experiment
0       starttime:        Starting time for this particular run
1728000  endtime:          Ending time for this particular run
1       nfield:           Field to assimilate (1=Ozone, 2=N2O, 3=H2O)
850     theta:            Theta level to assimilate
1       ninitialize:      (1=initialize ensemble members, 2=do not initialize)
6       ntruth:           (1=use first, 2=use central, 3=use last, 4=use mean)
100     nensemble:        Number of ensemble members
400.    startday:         Starting day for ensemble
1.      skipday:          Interval for ensemble
4       nnature:          Pick the nature run to use (see code for options)
1       ntruthrun:        (1=run the truth forecast, 2=do not run the truth)
0       nforecasts:       (1=run unforced forecasts, 2=do not run unforced forecasts)
1       nlocalization:    (1=Include localization, 2=do not include localization)
7.5e6   length:           Length scale (m) for localization
5       ninflation:       (0=no inflation, 1=constant inflation, 2=adaptive inflation)
1.      inflation_factor: Constant inflation factor
0.3     sigmaq:           Standard deviation of the ob error (in ppmv)
1       seed:             Seed for random number generator for wave forcing
2       nenkf:            ENKF option (see options below)
1       nobfile:          See options in read_observations.pro
2       nvariable:        1=use U/V, 2=use psi/chi
1       ncorrectinit:     1=correct initial ensemeble, 2=do not correct
```



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```
2       npertphysics1:    1=perturb the diffusion coefficien, 2=do not perturb
1       ncleanup:         1=clean up files, 2=do not clean up
0       qcfac:            Quality control factor
0       nnmi:             0=no NNMI 1=use NNMI on the analysis, 2=incremental nnmi
3       nnmitruth:        1=nnmi on init truth, 2=nnmi on truth and init anal, 3=no nnmi
1.      cutoff:           cutoff frequency for nnmi (number of days)
5       niteration:       number of iterations for nnmi
1       ns:               number of time steps for nnmi
1200    nnmitime:         nnmi interval (seconds)
10000.  meanheight        mean height for nnmi (m)
2       varuse            (1)Ozone (2)Height (3)Ozone and Height
200     sigmaz            Standard deviation for the height error (in m)
3       zobfile:          Ob file for height
11      seed2:            Seed used for pertubed obs
4       nnaturemean:      Nature run used for mean state
2       nfunction:        Localization function (1)SOAR (2)GC
```

## Copy the "balanced" file over

Let's copy the balanced file to the EnKF directory

```
cd /Data3/SHALOM_HTLM_barotropic01/Nature/Nature001_T21_HTLM
cp phi_vor_balanced.idl ../../EnKF/EnKF_T21_N0100_L07500_E003_HTLM
```

## Running the EnKF Truth Run

I set this up now so I don't have to run the NR each time before doing the EnKF. But you do need to run through the setup for the NR, just skip the forecast.

```
scr (alias for cd ~/Programs/SHALOM_HTLM/Scripts)
idl
.r enkf_driver_ens
21 (Resolution)
10. Use /Data3/SHALOM_HTLM_barotropic
01

1. Do Nature Run
Nature001_T21_HTLM
13. Barotropic instability
2. Run with added physics (short)
5. Relaxation to mean state (zonal mean only)
86400
0 (first day of physics)
2. Skip the Nature Run
```

Continue as follows.

```
3. Run EnKF
1. Make new observations
EnKF_T21_N0100_L07500_E003_HTLM
500 (truthday)
499.5 (initday)
(1) Do the truth run now
```


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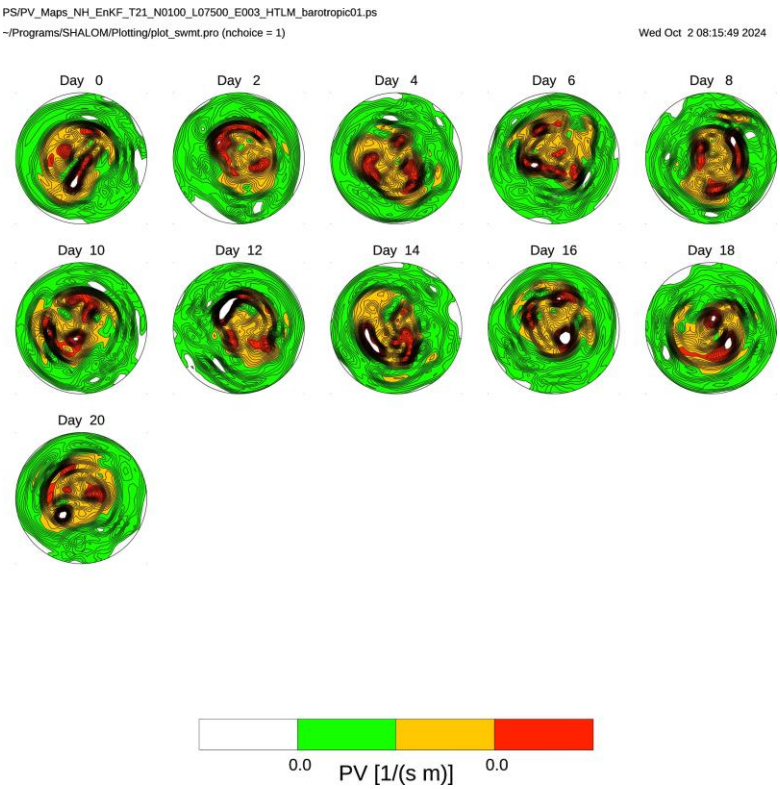
This makes a 20-day truth run in the Member_0000 directory. Let's look at it in another terminal. Keep the present terminal open!

## Plotting the EnKF Truth Run

```
cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r plot_swmt
21
Nature001_T21_HTLM
10. Use /Data3/SHALOM_HTLM_barotropic
01
2. Use the Member_0000
2. Plot PV field (postscript)                                plotpv
1. NH
0 20 2
PS/PV_Maps_NH_EnKF_T21_N0100_L07500_E003_HTLM_barotropic01.ps
```




So this is just like the Nature Run, but shifted by 500 days. So Day 0 is Day 500 of Nature run, Day 10 is Day 510, etc. Now let's continue with the EnKF simulation.

## Running the EnKF

Here we run the EnKF for 20 days to spin it up. We see immediate decrease in WEP, which is good.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```
2. Use new random 365-day zobfile
150 (Number of observations per hour)
20 (Number of days of obs)
```

## Plotting the EnKF results

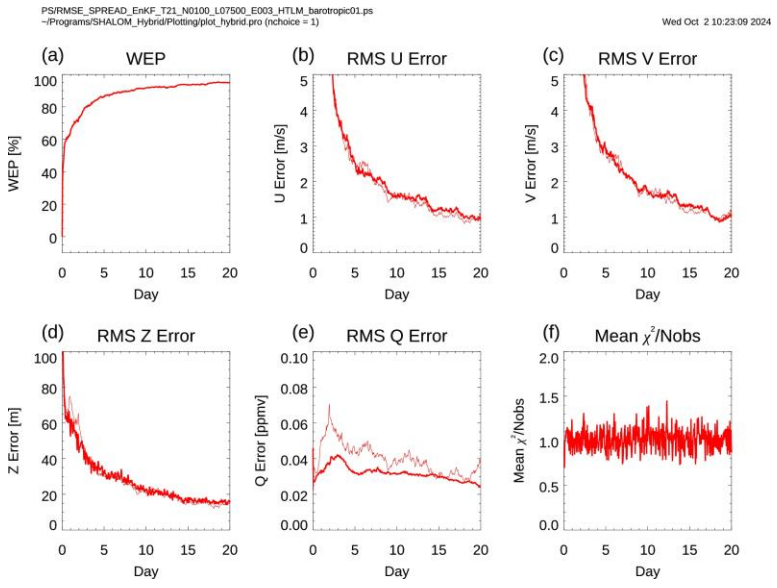
Add option for new run

```
vi ~/Programs/SHALOM_HTLM/Plotting/pick_hybrid.pro
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
```

```
cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r plot_hybrid
21
1. Read the RMSE, SPREAD, and Chi2 (multiple runs)
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
EnKF_T21_N0100_L07500_E003_HTLM
20 (endday)
01 (experiment number)
```

Here are results after **20 days** of assimilation. It looks like things have leveled off pretty well.

```
2. Plot the RMSE and SPREAD (multiple runs)
0 20
1. Overplot spread
PS/RMSE_SPREAD_EnKF_T21_N0100_L07500_E003_HTLM_barotropic01.ps
```





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# 6 Continuing the EnKF another 20 days

Now we'll start with the spun-up ensemble and run another 20 days.

We'll initialize the EnKF on day 20 of the barotropic01 run, since that is when the ensemble spun up. And we'll run for 20 days.

```
mkdir -p /Data3/SHALOM_HTLM_barotropic02/EnKF/EnKF_T21_N0100_L07500_E003_HTLM
cd /Data3/SHALOM_HTLM_barotropic02/EnKF/EnKF_T21_N0100_L07500_E003_HTLM
cp /Data3/SHALOM_HTLM_barotropic01/EnKF/EnKF_T21_N0100_L07500_E003_HTLM/FM_Parameters.txt .
cp /Data3/SHALOM_HTLM_barotropic01/EnKF/EnKF_T21_N0100_L07500_E003_HTLM/DAS_Parameters.txt .
cp /Data3/SHALOM_HTLM_barotropic01/EnKF/EnKF_T21_N0100_L07500_E003_HTLM/phi_vor_balanced.idl .

scr (alias for cd ~/Programs/SHALOM_HTLM/Scripts)
idl
.r enkf_driver_ens
21 (Resolution)
10. Use /Data3/SHALOM_HTLM_barotropic
02

1. Do Nature Run
Nature001_T21_HTLM
15. Barotropic instability (with spun-up initial state)
/Data3/SHALOM_HTLM_barotropic01/
20 (restartsec, converted to seconds)

2. Run with added physics (short)
5. Relaxation to mean state (zonal mean only)
86400
0 (first day of physics)
2. Skip the Nature Run
```

Continue as follows.

```
3. Run EnKF
1. Make new observations
EnKF_T21_N0100_L07500_E003_HTLM
(1) Do the truth run now

2. Use new random 365-day zobfile
150 (Number of observations per hour)
20 (Number of days of obs)
```

## Plotting the EnKF Truth Run

```
cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r plot_swmt
21
Nature001_T21_HTLM
10. Use /Data3/SHALOM_HTLM_barotropic
02
2. Use the Member_0000
2. Plot PV field (postscript)                          plotpv
1. NH
0 20 2
```


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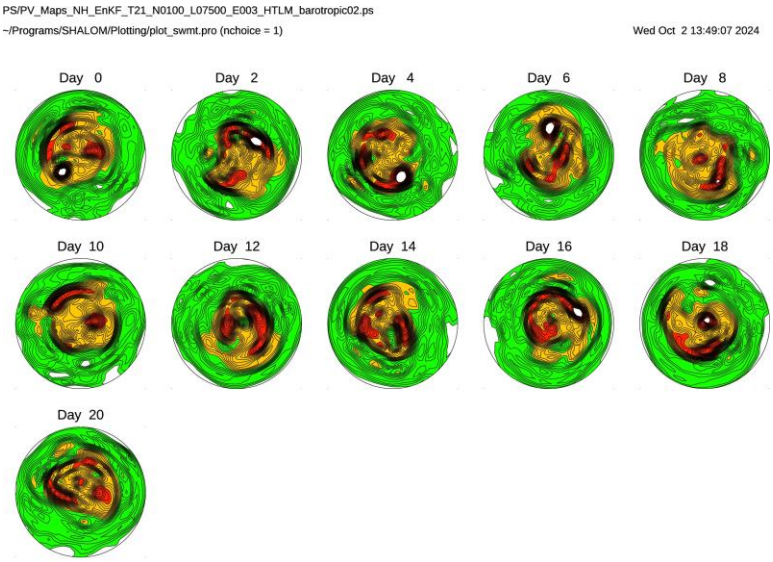
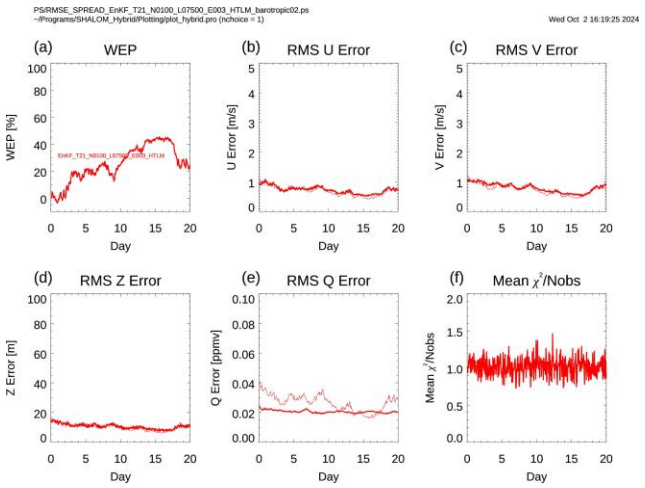
**PS/PV_Maps_NH_EnKF_T21_N0100_L07500_E003_HTLM_barotropic02.ps**




## Plotting the EnKF Results

Let's see how this 20 days went. First, set the EnKF option to just include 07500 again.

```
cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r plot_hybrid
21
1. Read the RMSE, SPREAD, and Chi2 (multiple runs)
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20 (endday)
02 (experiment number)
```



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## 7 Running 4DVar with no TLM error and cyclesec=86400

### Make the parameter directory and required files

Note that we want the obs to go out to 24 h, so the ob_endtime was changed from normal.

```
mkdir -p /Data3/SHALOM_HTLM_barotropic02/Hybrid/PARAMETERS_HOURLY
cd /Data3/SHALOM_HTLM_barotropic02/Hybrid/PARAMETERS_HOURLY
cp ../../EnKF/EnKF_T21_N0100_L07500_E003_HTLM/FM_Parameters.txt .
cp ../../EnKF/EnKF_T21_N0100_L07500_E003_HTLM/phi_vor_balanced.idl .
vi DAS_Parameters.txt
```

```
1               ntracersmooth:   Choose whether to smooth the tracer field
2               nadvection:      Choose which advection scheme to use
1               oberrscale:      Choose whether to scale ob error by innovation
4               nlength:         Choose method for varying length scale
3               nmu:             Choose method for varying mu
2               nsolver:         Choose variables to use for solving
3               nhorcorrelation: Choose correlation method
1               nfunction:       Choose correlation function
2               ngeometry:       Choose geometry method
2               ncoupling:       Choose whether to couple mass and wind
2               ndiagonal:       Choose diagonal terms
120             dt:              Choose time step for TLM
2               modbkgerr:       Choose whether to modify background error
3600            ob_starttime:    Choose starting time for obs
86400           ob_endtime:      Choose ending time for obs
3600            ob_inctime:      Choose increment time for obs
0.3             error:           Choose tracer error value
2               nrandomerror:    Choose whether to use random ob errors
1.              scale:           Choose scaling of random errors (used if nrandomerror eq 2)
1               nbias:           Choose whether to impose bias on observations
1.0             bias_scale       Choose scaling for bias (used if nbias eq 2)
0               ngrid            Choose grid
1.0             multfac:         Choose multiplicative factor for tracer observation error
4               nmethod:         Choose descent method
2               ngradchoice:     Choose gradient method
100             maxiter          Choose maximum iterations
20              goodfac          Choose goodfactor
8.9e16          d:               Choose diffusion coefficient for TLM
2               nwind:           Choose error option
1               ncycletype:      Choose cycling type
0               ndfi:            Choose whether to use digital filter
0               initialize:      Choose whether to use NNMI
```

### Pick the directory for the observations and set EnKF ensemble size

Need to correctly set the enkfexptdir

In Scripts/get_enkf_parameters.pro, under if(nenkf eq 19) choose

```
vi ~/Programs/SHALOM_HTLM/Scripts/get_enkf_parameters.pro
```

```
enkfexptdir0='/Data3/SHALOM_HTLM_barotropic02/EnKF/EnKF_T21_N0100_L07500_E003_HTLM/'
nensemble=100
```


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```
loclengthall=7.5e6
```

## Edit get_htlm_driver_parameters.pro

Make sure cyclesec is set correctly.

```
vi ~/Programs/SHALOM_HTLM/Scripts/get_htlm_driver_parameters.pro

;-------------------------------------------------------------------------------
npatch=0                    ; Patch size in km (see get_letlm_parameters_mult.pro)
letlmdt=long(3600)          ; Time step for LETLM (sec)
npseudo=5                   ; Pseudo-inverse cutoff (threshold=npseudo*eps)
nensletlm=100               ; Ensemble size for letlm
n4dvar=1                    ; n4dvar option (conventional hybrid)
ntuning=0                   ; (0) not run for tuning, (1) run for tuning
;-------------------------------------------------------------------------------
nenscale=0                  ; Scaling for ensemble perturbations (0) No (1) Yes
enscale=0.                  ; Scaling factor (used if nenscale = 1)
nrunbackground=1            ; Run background (0) No (1) Yes
nnmi=0                      ; (0) No NNMI (1) NNMI applied to 4dvar increments
alphamin=50                 ; Min alpha (%)
alphamax=50                 ; Max alpha (%)
alphainc=10                 ; Increment (%)
ob_inctime=3600             ; Time interval for observations (sec)
cyclesec=long(86400)        ; 4DVAR cycling (sec)
expt='Hybrid_T21'           ; Overall experiment name
naturestr='Nature001_T21_HTLM'   ; Nature Run
ndiagnostics=1              ; (1) Run cycle (2) diagnostics only
nrestart=0                  ; Restart option (see below)
nenkf=19                    ; EnKF option (see get_enkf_parameters.pro for details)
;-------------------------------------------------------------------------------
dir1='/Data3/SHALOM_HTLM_unstable_D=8.9e16_diabatic04_solar/Hybrid/Hybrid_T21_alpha=0.00_L=07500_
varuse=03_nenkf=19_n4dvar=01_nnmi=0/'
;-------------------------------------------------------------------------------
incscale=1                  ; Increment scaling
nscaling=2                  ; Scaling option for LETLM variables
nmiincrement=0              ; Apply NMI to the increment within the DA
nmiensemble=0               ; Apply NMI to the ensembles
modelerror=0                ; Model error option
```

## Running 4DVar with standard PBclim

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic
02
3. Run 4DVar
2. Run with added physics
5. Relaxation to mean state (zonal mean only)
86400

1. Use offline ensemble
1. Run normally
3. Run TLM with physics - forward_sweep_htlm_short_phys
2. Run TLM with ZM relaxation
86400
```


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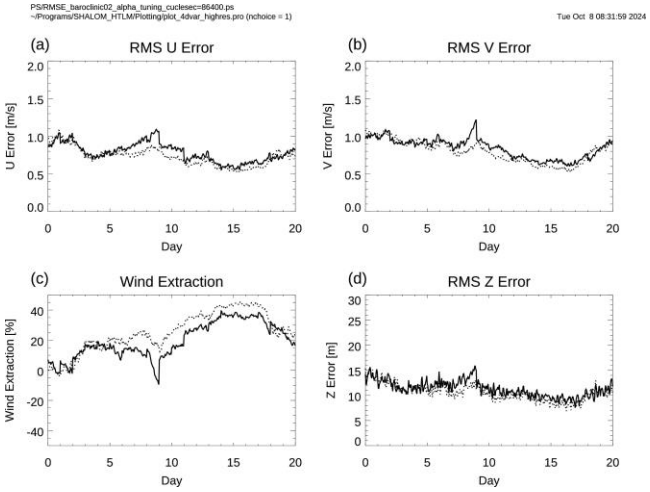
```
1. Ensemble Scaling
1. Recenter using xa-xamean+xcontrol
2 (varuse - manually overriding the nrestart option)
20 (number of days of cycling) - get_htlm_driver_parameters.pro
/Data3/SHALOM_HTLM_barotropic02/EnKF/EnKF_T21_N0100_L07500_E003_HTLM/Member0000/
0 (truthdayoffset)
1 whereistheanalysis (0 = beginning, 1 is the ending)
1. Use Daley pbzero
-1 (The first ninit to use - the EnKF analysis)
'Hybrid_T21_alpha=0.50_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-0086400'
```

## Plotting the results

```
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                              readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
75. Run with alpha tuning for perfect TLM (cyclesec=86400)
13. Plot RMSE for LETLM Paper            plotrmse4plots
PS/RMSE_baroclinic02_alpha_tuning_cuclesec=86400.ps
```




## Checking the variances

Let's look at the different variances.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r verification_pbzero
1. Read Pb and calc errors       calcerror
2. Use barotropic02
Hybrid_T21_alpha=0.50_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-0086400
```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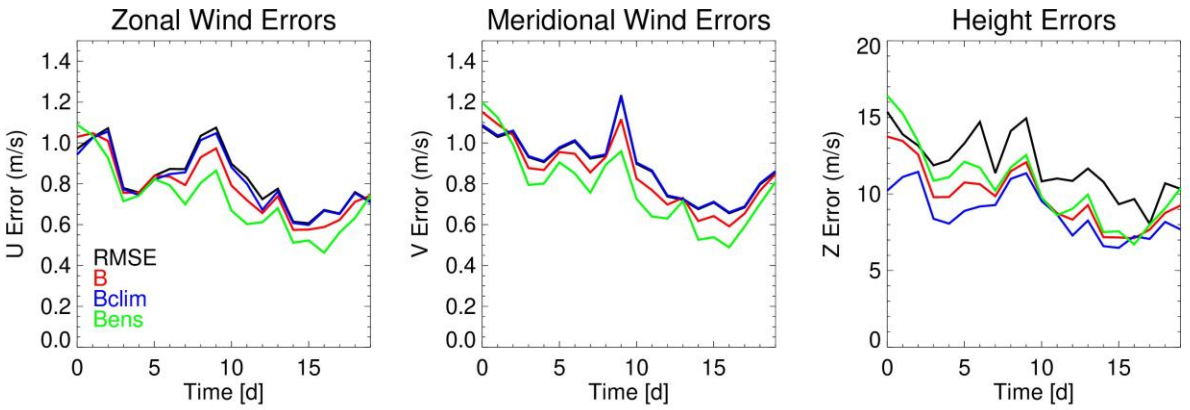
```
2. Plot forecast errors          ploterror
1.5 20
PS/Background_Error_Plot_barotropic02.ps
```



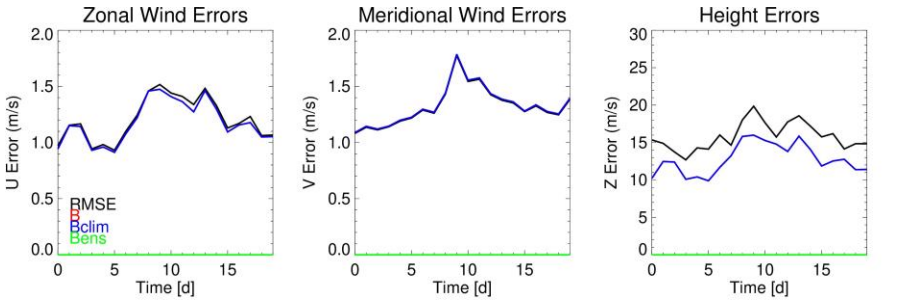

barotropic02 - Hybrid_T21_alpha=0.50_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-0086400

## 8 Tuning of alpha

### Results for alpha=0.0

Let's run through the different alpha values of 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r verification_pbzero
1. Read Pb and calc errors       calcerror
2. Use barotropic02
Hybrid_T21_alpha=0.00_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-0086400
2. Plot forecast errors          ploterror
2 30
PS/Background_Error_Plot_barotropic02.ps
```




barotropic02 - Hybrid_T21_alpha=0.00_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-0086400

Here the Bens is not initialized, so it is actually zero. The Bclim looks good for U and V, but is again a bit low for Z. But not by that much.

Let's look at the results for all alpha.

```
idl
.r plot_4dvar_highres
```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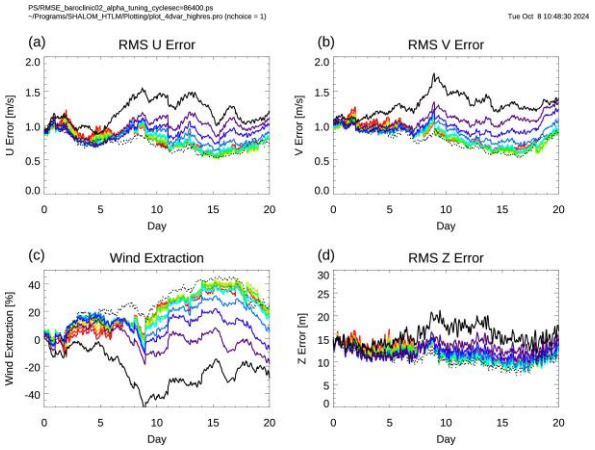
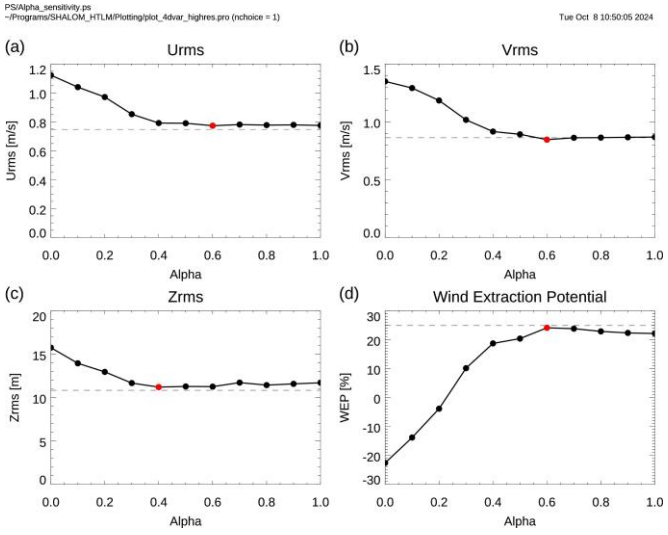
```
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                                readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
75. Run with alpha tuning for perfect TLM
13. Plot RMSE for LETLM Paper            plotrmse4plots
PS/RMSE_baroclinic02_alpha_tuning_cuclesec=86400.ps
```




```
15. Plot RMSE versus alpha                plotrmsealpha
PS/Alpha_sensitivity.ps
```

Looks like it's difficult for the 4DVAR to beat the EnKF consistently as before. But I would say this isn't looking too bad. The EnKF errors are plotted with the think dashed line for reference.





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## 9 Running with scaled Pbens (newpbzero4)

Let's run with the original Pbclim, but scale the pbens and see what happens. I automated the tuning so I only need one call. First, set

```
alphamin=0                  ; Min alpha (%)
alphamax=0                  ; Max alpha (%)
alphainc=10                 ; Increment (%)
```

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic
02
3. Run 4DVar
2. Run with added physics
5. Relaxation to mean state (zonal mean only)
86400

1. Use offline ensemble
1. Run normally
3. Run TLM with physics - forward_sweep_htlm_short_phys
2. Run TLM with ZM relaxation
86400

1 (ensemble scaling)
1. Recenter using xa-xamean+xcontrol
2 (varuse - manually overriding the nrestart option)
20 (number of days of cycling) - get_htlm_driver_parameters.pro
/Data3/SHALOM_HTLM_barotropic02/EnKF/EnKF_T21_N0100_L07500_E003_HTLM/Member0000/
0 (truthdayoffset)
1 whereistheanalysis (0 = beginning, 1 is the ending)
5. Use Daley pbzero and scale Pbens
-1 (The first ninit to use - the EnKF analysis)
'Hybrid_T21_alpha=0.00_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_newpbzero4'
```

This uses "_newpbzero4" in the directory name. Let's see how this does with the scaling. Definitely better with the Ensemble. The Z for the clim is still a bit low.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r verification_pbzero
1. Read Pb and calc errors       calcerror
2. Use barotropic02
Hybrid_T21_alpha=0.50_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_newpbzero4
2. Plot forecast errors          ploterror
2 30
PS/Background_Error_Plot_barotropic02.ps
```


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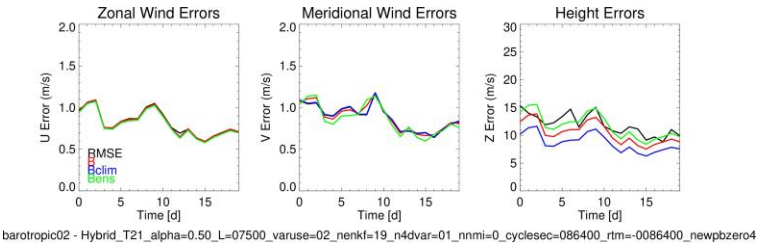
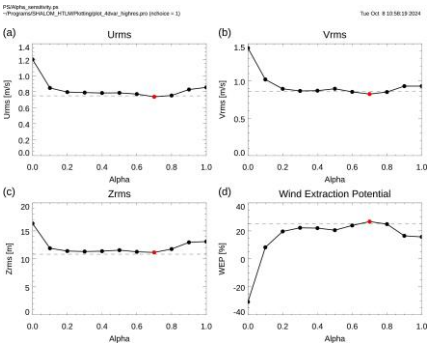



Now the ensemble variance lines up well for u, v, and z. The clim is still a bit small for z. Here are the results for all values of alpha for this case.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
76. Run with alpha tuning for perfect TLM with newpbzeroi (cyclesec=86400)
13. Plot RMSE for LETLM Paper               plotrmse4plots
PS/RMSE_baroclinic02_alpha_tuning_cyclesec=86400_newpbzero4.ps
15. Plot RMSE versus alpha                  plotrmsealpha
Alpha_sensitivity.png
```




This is really interesting. Seems to be that the self-tuning of the ensemble covariance somewhat smooths out the sensitivity to alpha. Maybe that's a good thing? I think the issue is likely that the main factor that controls the error is the variance. In this case the variances are both set to the RMSE, so they are very similar, and it doesn't really matter what blending you use. You get the same answer for the variance either way.

One nice thing about this is that likely the alpha sensitivity wouldn't be that big with the model error as well. We'll look at that next.

Seems like alpha=0.7 is consistently the best result here. Maybe we'll go with that for now.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## 10 Running 4DVar with TLM errors at ALL locations

### Run the 4DVAR

We'll use option 5 for the TLM errors

```
5. Run TLM with ZM relaxation and simple scaling
```

I'll use alpha=0.7 and TLM scaling of 1.1 (10% increase)

```
alphamin=70                  ; Min alpha (%)
alphamax=70                  ; Max alpha (%)
alphainc=10                 ; Increment (%)
```

And, I'll use the scaling of both Daley pbzero and Pbens. This will hopefully make the sensitivity to the alpha small.

```
5. Use Daley pbzero and scale Pbens

cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic
02
3. Run 4DVar
2. Run with added physics
5. Relaxation to mean state (zonal mean only)
86400

1. Use offline ensemble
1. Run normally
3. Run TLM with physics - forward_sweep_htlm_short_phys
5. Run TLM with ZM relaxation and simple scaling
86400
1.1 1.1 1.1 1.1 (Note: the last one doesn't matter unless were

1 (ensemble scaling)
1. Recenter using xa-xamean+xcontrol
2 (varuse - manually overriding the nrestart option)
20 (number of days of cycling) - get_htlm_driver_parameters.pro
/Data3/SHALOM_HTLM_barotropic02/EnKF/EnKF_T21_N0100_L07500_E003_HTLM/Member0000/
0 (truthdayoffset)
1 whereistheanalysis (0 = beginning, 1 is the ending)
5. Use Daley pbzero and scale Pbens
-1 (The first ninit to use - the EnKF analysis)
```

### Examine the TLM maps

```
cd ~/Program/SHALOM_HTLM/Plotting
idl
.r plot_tlm_final_errors
3. Contour plots of the trajectories      plottraj
6. TLM with simple scaling (cyclesec=86400)
```


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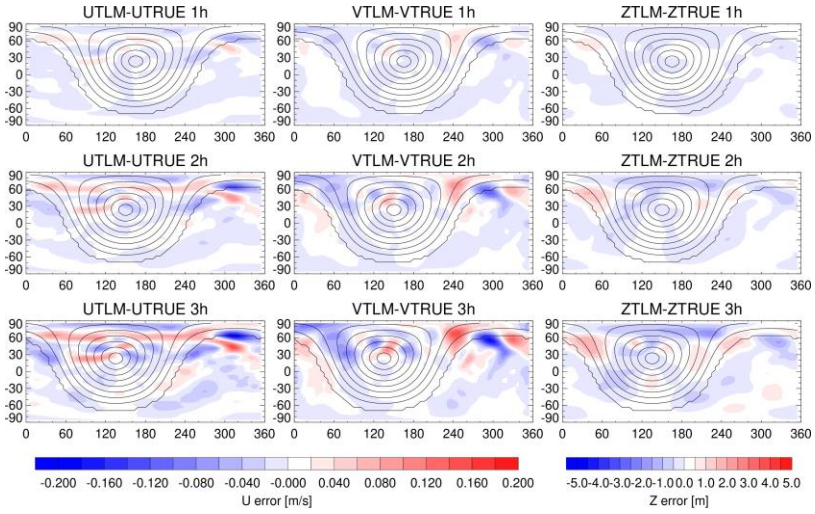
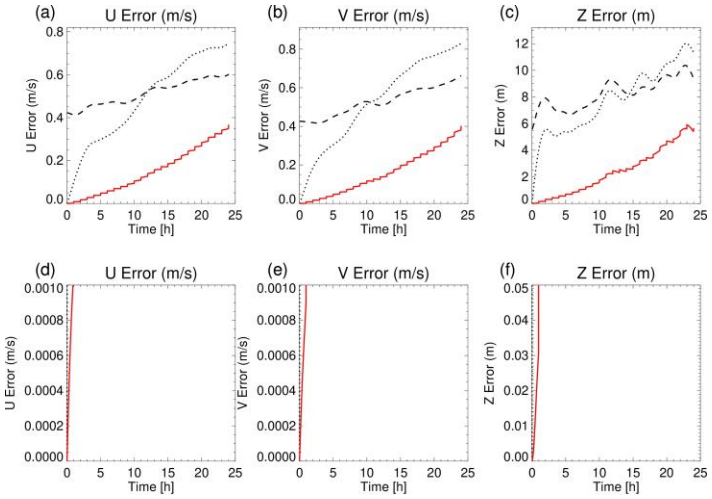
```
PS/Linearized_Map_Plot_Cyclesec=86400s.ps
```




This nicely shows that all three fields increase progressively with time, as expected. Let's make some line plots of the errors.

```
cd ~/Program/SHALOM_HTLM/Plotting
idl
.r plot_tlm_final_errors
1. Read the trajectory and the truth       readtraj
9. TLM with simple scaling (cyclesec=86400)
2. Plot the trajectory errors              ploterror
1. Plot error time series only
PS/TLM_Error_Plot.ps
```




## Plotting the 4DVAR Errors

Let's plot the 4DVAR errors for this case.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
```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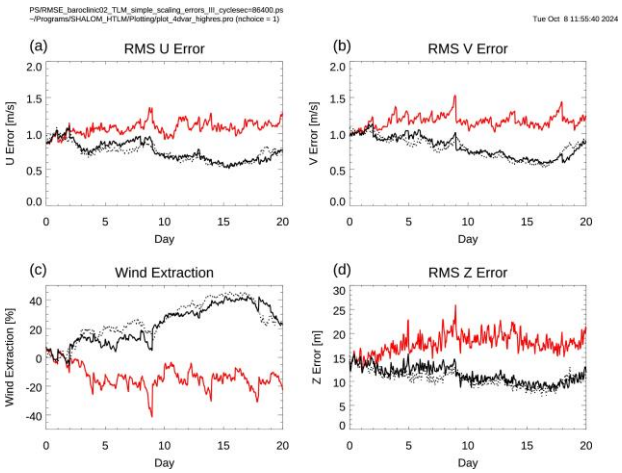
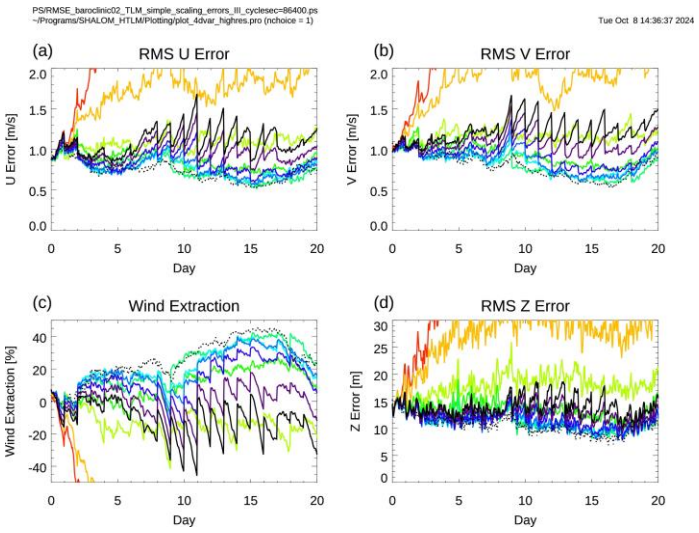
```
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
77. Run with TLM simple scaling errors (III, cyclesec=86400)
13. Plot RMSE for LETLM Paper               plotrmse4plots
PS/RMSE_baroclinic02_TLM_simple_scaling_errors_III_cyclesec=86400.ps
```




This nicely shows that TLM error the analysis is a lot worse (red) than if you used a perfect TLM (black). Let's try a few other values of error.

Here are results with 0.95, 0.96, 0.97, 0.98, 0.99, 1.00, 1.01, 1.02, 1.03, 1.04, 1.05
**PS/RMSE_baroclinic02_TLM_simple_scaling_errors_III_cyclesec=86400.ps**





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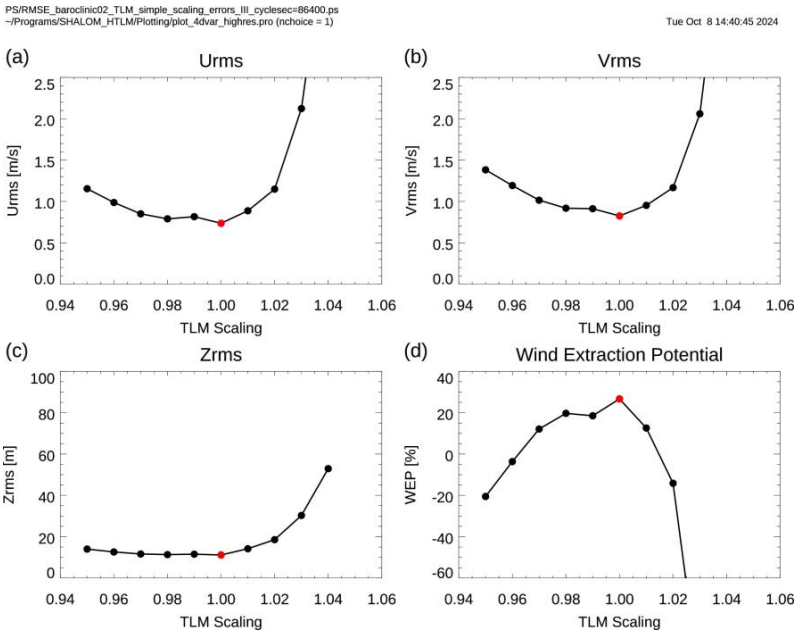
**16. Plot RMSE versus tlm error  plottlmerrpost**
**PS/RMSE_baroclinic02_TLM_simple_scaling_errors_III_cyclesec=86400.ps**





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## 11 Table of sensitivity tests

| | $\mathbf{M}_{\mathrm{pre}}$ | $\mathbf{M}_{\mathbf{inc}}^{\mathbf{T}}$ | $\mathbf{M}_{\mathbf{post}}$ |
|---|---|---|---|
| 0 bad TLMs | Perfect | Perfect | Perfect |
| 1 bad TLM | Imperfect | Perfect | Perfect |
| 1 bad TLM | Perfect | Imperfect | Perfect |
| 1 bad TLM | Perfect | Perfect | Imperfect |
| 2 bad TLMs | Imperfect | Imperfect | Perfect |
| 2 bad TLMs | Imperfect | Perfect | Imperfect |
| 2 bad TLMs | Perfect | Imperfect | Imperfect |
| 3 bad TLMs | Imperfect | Imperfect | Imperfect |

Trying to run with 0.95, 0.96, 0.97, 0.98, 0.99, 1.00, 1.01, 1.02, 1.03, 1.04, 1.05


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## 12 3 bad TLMs (imperfect, imperfect, imperfect)

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic                          npick          pick_datadir
02                                                             suffix         pick_datadir
3. Run 4DVar                                                   nchoice
2. Run with added physics                                      nphysics
5. Relaxation to mean state (zonal mean only)                  nmerror
86400                                                          relax_time

1. Use offline ensemble                                        nwhichens
1. Run normally                                                ngradient
3. Run TLM with physics - forward_sweep_htlm_short_phys        nhtlm
6. Run TLM with ZM relax and scaling (sensitivity loop)        nphystlm
86400                                                          tlm_relax_time
8. Run Imperfect, Imperfect, Imperfect                         nsensitivity

1 (ensemble scaling)                                           nensscale
1. Recenter using xa-xamean+xcontrol                           nrecenter
2 (varuse - manually overriding the nrestart option)           varuse         get_htlm_driver...
20 (number of days of cycling)                                 ndaysofcycling get_htlm_driver...
0                                                              truthdayoffset
1                                                              whereistheanalysis
5. Use Daley pbzero and scale Pbens                            npbzero
-1 (The first ninit to use - the EnKF analysis)                ninit_first    cycle_4dvar_htlm
```

Let's look at the results. Note that 1.05 stopped at starttime = 1296000

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
68. Run with TLM simple scaling errors (III)
13. Plot RMSE for LETLM Paper            plotrmse4plots
PS/RMSE_baroclinic02_TLM_simple_scaling_errors_III_cyclesec=86400.ps
```

Here are results with 0.95, 0.96, 0.97, 0.98, 0.99, 1.00, 1.01, 1.02, 1.03, 1.04, 1.05


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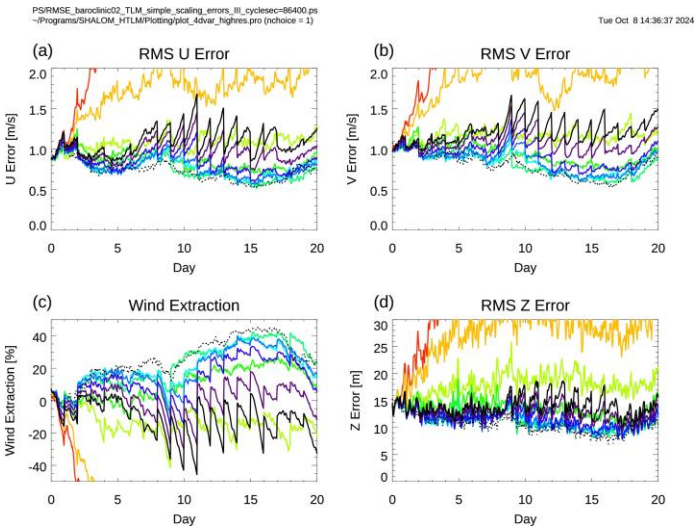
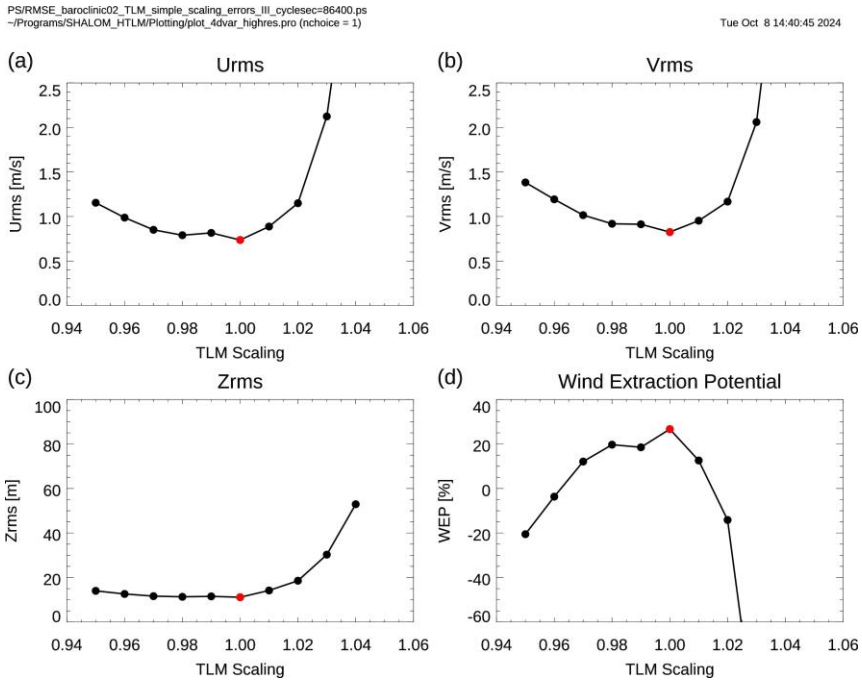



**16. Plot RMSE versus tlm error plottlmerrpost**
**PS/RMSE_baroclinic02_TLM_simple_scaling_errors_III_cyclesec=86400.ps**




This looks pretty good. Now I can go on to the other sensitivity tests.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## 13 2 bad TLMs (imperfect, imperfect, perfect)

Let's see how sensitive this is when the errors are everywhere except in the final sweep. This is a good test for us to see how well we can do with the perfect NLM in the final sweep.

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic                          npick          pick_datadir
02                                                             suffix         pick_datadir
3. Run 4DVar                                                   nchoice
2. Run with added physics                                      nphysics
5. Relaxation to mean state (zonal mean only)                  nmerror
86400                                                          relax_time

1. Use offline ensemble                                        nwhichens
1. Run normally                                                ngradient
3. Run TLM with physics - forward_sweep_htlm_short_phys        nhtlm
6. Run TLM with ZM relax and scaling (sensitivity loop)        nphystlm
86400                                                          tlm_relax_time
5. Run Imperfect, Imperfect, Perfect                           nsensitivity

1 (ensemble scaling)                                           nensscale
1. Recenter using xa-xamean+xcontrol                           nrecenter
2 (varuse - manually overriding the nrestart option)           varuse         get_htlm_driver...
20 (number of days of cycling)                                 ndaysofcycling get_htlm_driver...
0                                                              truthdayoffset
1                                                              whereistheanalysis
5. Use Daley pbzero and scale Pbens                            npbzero
-1 (The first ninit to use - the EnKF analysis)                ninit_first    cycle_4dvar_htlm
```

Let's look at the results.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                      readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
78. Run with TLM simple scaling errors (IIP, cyclesec=86400)
13. Plot RMSE for LETLM Paper            plotrmse4plots
PS/RMSE_baroclinic02_TLM_simple_scaling_errors_IIP_cyclesec=86400.ps
```


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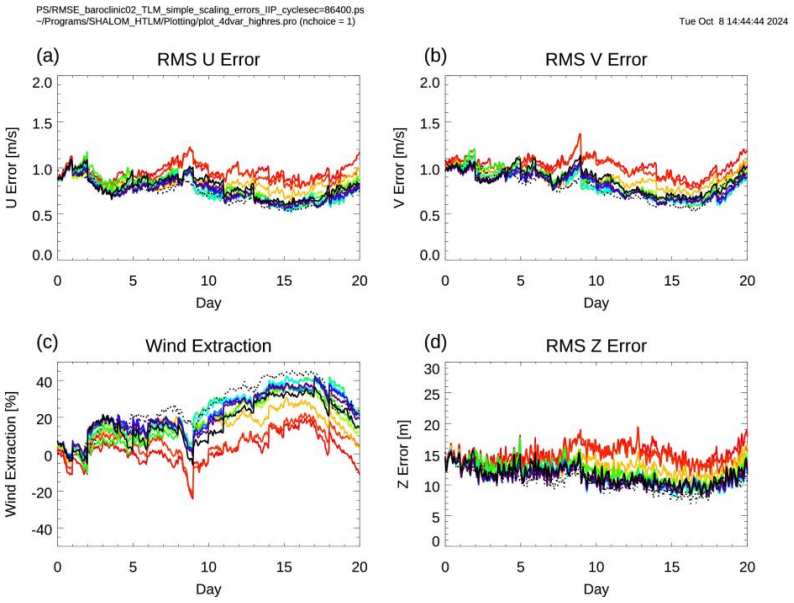
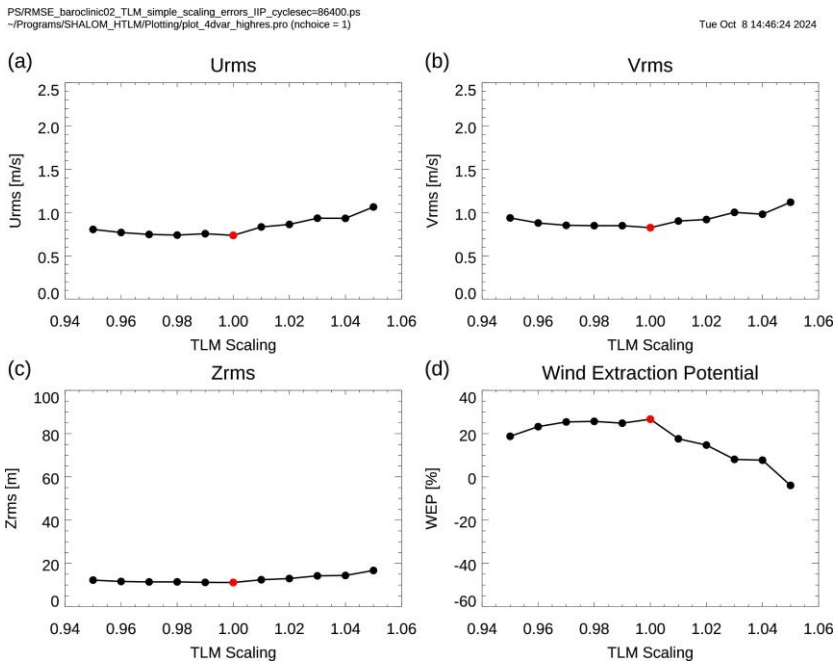



Wow, this shows very little sensitivity to the TLM that is used.

**16. Plot RMSE versus tlm error plottlmerrpost**
**PS/TLMerror_barotropic02_simple_scaling_IIP_cyclesec=86400.ps**





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## 14 1 bad TLM (imperfect, perfect, perfect)

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic                          npick          pick_datadir
02                                                             suffix         pick_datadir
3. Run 4DVar                                                   nchoice
2. Run with added physics                                      nphysics
5. Relaxation to mean state (zonal mean only)                  nmerror
86400                                                          relax_time

1. Use offline ensemble                                        nwhichens
1. Run normally                                                ngradient
3. Run TLM with physics - forward_sweep_htlm_short_phys        nhtlm
6. Run TLM with ZM relax and scaling (sensitivity loop)        nphystlm
86400                                                          tlm_relax_time
2. Run Imperfect, Perfect, Perfect                             nsensitivity

1 (ensemble scaling)                                           nensscale
1. Recenter using xa-xamean+xcontrol                           nrecenter
2 (varuse - manually overriding the nrestart option)           varuse         get_htlm_driver...
20 (number of days of cycling)                                 ndaysofcycling get_htlm_driver...
0                                                              truthdayoffset
1                                                              whereistheanalysis
5. Use Daley pbzero and scale Pbens                            npbzero
-1 (The first ninit to use - the EnKF analysis)                ninit_first    cycle_4dvar_htlm
```

Let's look at the results. Note that 0.95 crashed at starttime = 950400

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
79. Run with TLM simple scaling errors (IPP, cyclesec=86400)
13. Plot RMSE for LETLM Paper            plotrmse4plots
PS/RMSE_baroclinic02_TLM_simple_scaling_errors_IPP_cyclesec=86400.ps
```


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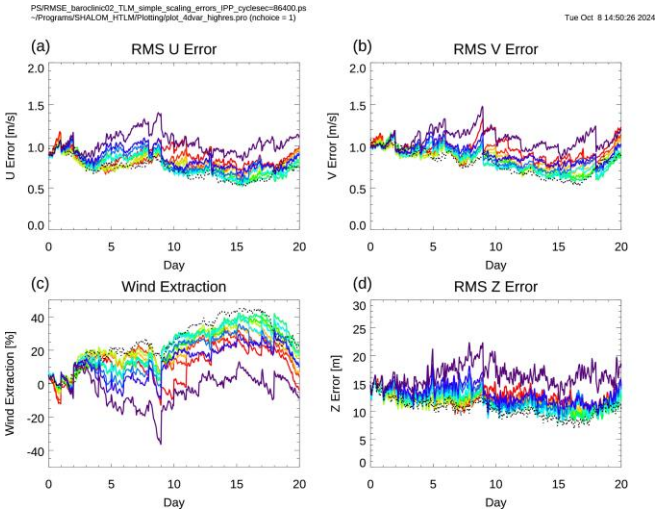
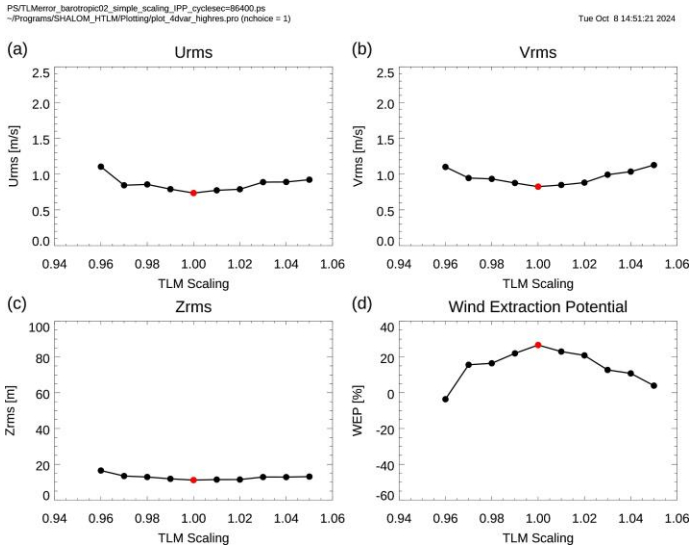



**16. Plot RMSE versus tlm error plottlmerrpost**
**PS/TLMerror_barotropic02_simple_scaling_IPP.ps**




Now this shows a bit more sensitivity, which is nice. Let's go on to the 3DVAR tests.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## 15 1 bad TLMs (perfect, perfect, imperfect)

Let's also plot the combined errors for all cases. To do this I first want to run the case with errors only in the final sweep.

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic                          npick          pick_datadir
02                                                             suffix         pick_datadir
3. Run 4DVar                                                   nchoice
2. Run with added physics                                      nphysics
5. Relaxation to mean state (zonal mean only)                  nmerror
86400                                                          relax_time

1. Use offline ensemble                                        nwhichens
1. Run normally                                                ngradient
3. Run TLM with physics - forward_sweep_htlm_short_phys        nhtlm
6. Run TLM with ZM relax and scaling (sensitivity loop)        nphystlm
86400                                                          tlm_relax_time
4. Run Perfect,   Perfect,   Imperfect                         nsensitivity

1 (ensemble scaling)                                           nensscale
1. Recenter using xa-xamean+xcontrol                           nrecenter
2 (varuse - manually overriding the nrestart option)           varuse         get_htlm_driver...
20 (number of days of cycling)                                 ndaysofcycling get_htlm_driver...
0                                                              truthdayoffset
1                                                              whereistheanalysis
5. Use Daley pbzero and scale Pbens                            npbzero
-1 (The first ninit to use - the EnKF analysis)                ninit_first    cycle_4dvar_htlm
```

Let's look at the results.

1.03 crashed at starttime = 1123200
1.04 crashed at starttime = 518400
1.05 crashed at starttime = 345600

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
79. Run with TLM simple scaling errors (IPP, cyclesec=86400)
13. Plot RMSE for LETLM Paper             plotrmse4plots
PS/RMSE_baroclinic02_TLM_simple_scaling_errors_IPP.ps
cd ~/Program/SHALOM_HTLM/Plotting
idl
.r plot_tlm_final_errors
```


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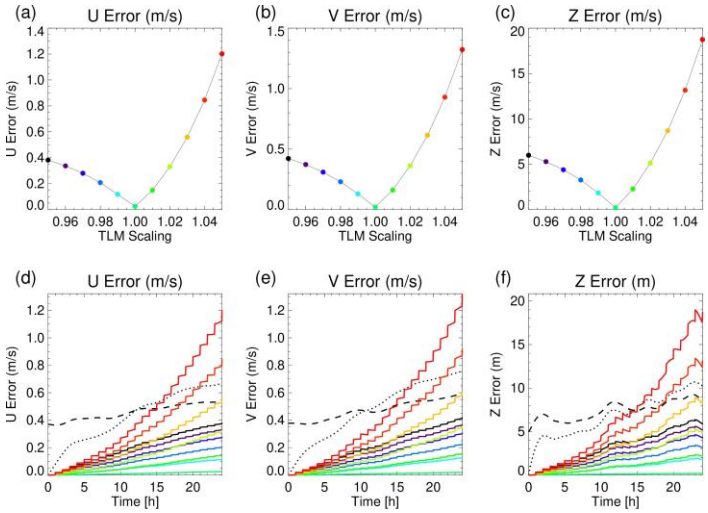
```
1. Read the trajectory and the truth       readtraj
11. Trajectories with different TLM scalings
2. Plot the trajectory errors              ploterror
3. Plot error time series and sensitivity to TLM scaling
```

```
PS/TLM_Error_Plot_Cyclesec=86400.ps
```





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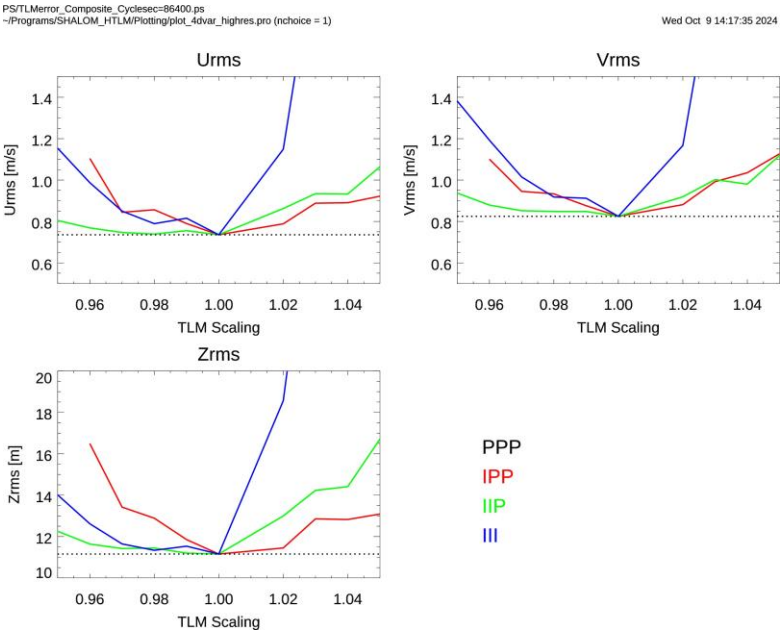
# 16 Combined Sensitivity Results

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
19. Read errors for multiple sensitivities readmult2 (scaling)
1. All tuning experiments
20. Plot errors for multiple sensitivities plotmult2 (scaling)
PS/TLMerror_Composite_Cyclesec=86400.ps
```





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## 17 Test with TLM as simple persistence (3DVAR)

Let's try running with a "3DVAR" test. Let's see what we get if we us persistence for the TLM. This is done by setting n4dvar=0 in get_htlm_driver_parameters.pro and then running htlm_driver. Note that we need to comment out the loop over scaling to run this.

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic                    npick          pick_datadir
02                                                       suffix         pick_datadir
3. Run 4DVar                                             nchoice
2. Run with added physics                                nphysics
5. Relaxation to mean state (zonal mean only)            nmerror
86400                                                    relax_time

1. Use offline ensemble                                  nwhichens
1. Run normally                                          ngradient
3. Run TLM with physics - forward_sweep_htlm_short_phys  nhtlm
1. Run TLM without extra physics                         nphystlm

1 (ensemble scaling)                                     nensscale
1. Recenter using xa-xamean+xcontrol                     nrecenter
2 (varuse - manually overriding the nrestart option)     varuse         get_htlm_driver...
20 (number of days of cycling)                           ndaysofcycling get_htlm_driver...
1. Use regular data                                      nodataflag
0                                                        truthdayoffset
1                                                        whereistheanalysis
5. Use Daley pbzero and scale Pbens                      npbzero
-1 (The first ninit to use - the EnKF analysis)          ninit_first    cycle_4dvar_htlm
'Hybrid_T21_alpha=0.50_L=07500_varuse=02_nenkf=19_n4dvar=00_nnmi=0_newpbzero4'
```

Let's plot the TLM for this case, which should just be the persistence error.

```
cd ~/Program/SHALOM_HTLM/Plotting
idl
.r plot_tlm_final_errors
3. Contour plots of the trajectories      plottraj
7. 3DVAR (persistence) with NLM that has only ZM relaxation (cyclesec=86400)
PS/Linearized_Map_Plot_3DVAR_cyclesec=86400.ps
```


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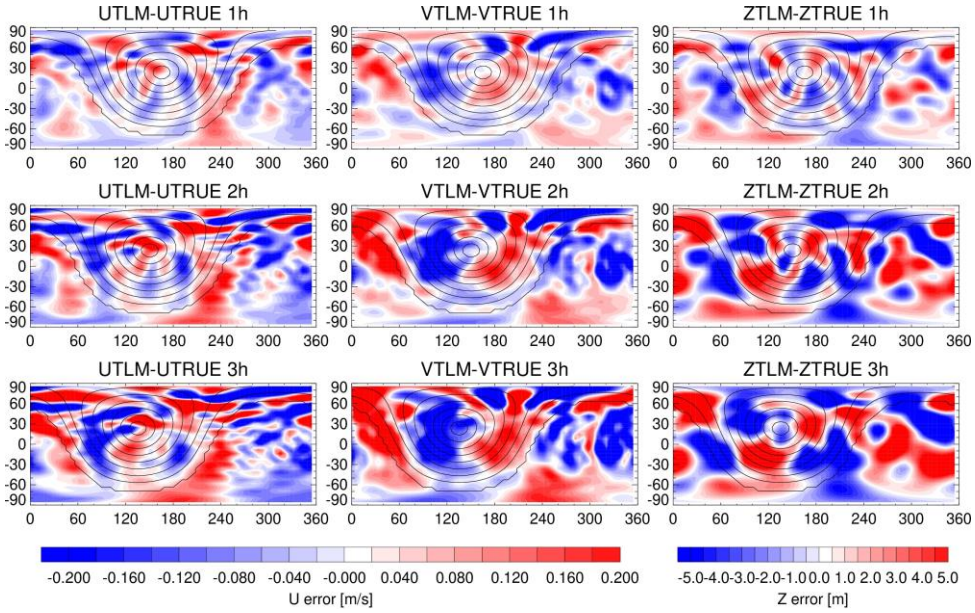
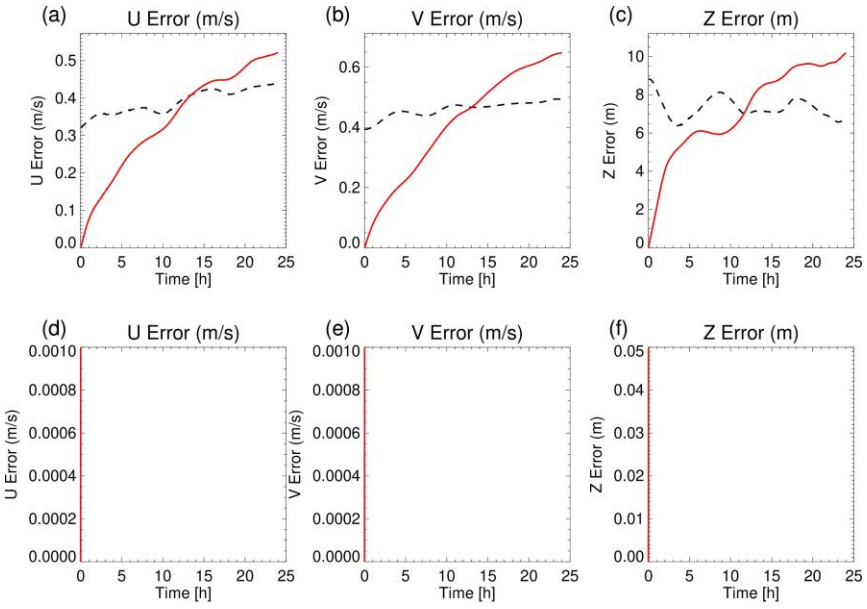



This looks reasonable. Errors grow steadily with time. Let's look at line plots.

```
cd ~/Program/SHALOM_HTLM/Plotting
idl
.r plot_tlm_final_errors
1. Read the trajectory and the truth       readtraj
8. 3DVAR (persistence with 24-h window)
2. Plot the trajectory errors              ploterror
1. Plot error time series only
PS/3DVAR_Error_Plot.ps
```




Persistence error is in black (dotted), but is overplotted with the model TLM error (red solid). So we are indeed getting persistence here. Now let's look at the "3DVAR" errors.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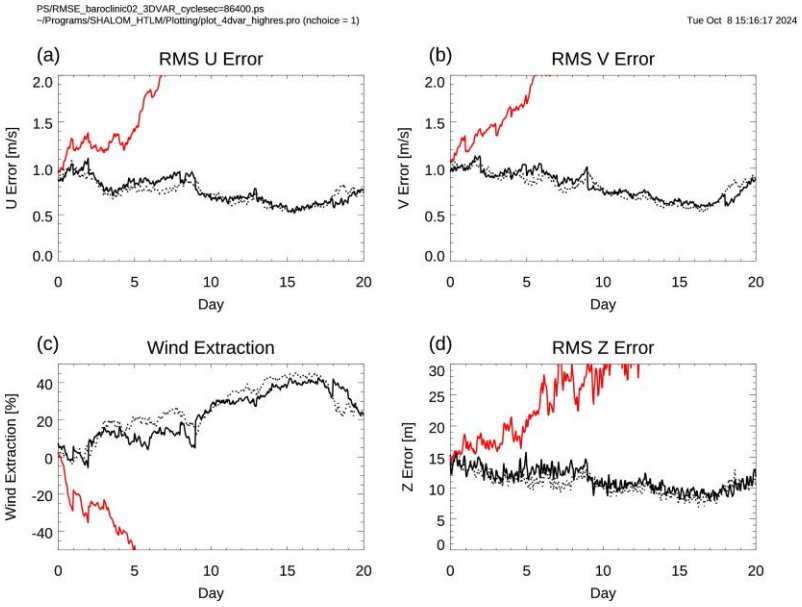
Here we include the “perfect” 4DVAR case with 3DVAR.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
80. Run with 3DVAR (cyclesec=86400)
13. Plot RMSE for LETLM Paper               plotrmse4plots
PS/RMSE_baroclinic02_3DVAR_cyclesec=86400.ps
```




OK, now 3DVar is doing really bad. Let’s see how it does with the perfect final sweep.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## 18 Running 3DVAR, but final sweep with the perfect NLM

I should also try 3DVAR, but running the final sweep with the NLM.

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic                          npick          pick_datadir
02                                                             suffix         pick_datadir
3. Run 4DVar                                                   nchoice
2. Run with added physics                                      nphysics
5. Relaxation to mean state (zonal mean only)                  nmerror
86400                                                          relax_time

1. Use offline ensemble                                        nwhichens
1. Run normally                                                ngradient
3. Run TLM with physics - forward_sweep_htlm_short_phys        nhtlm
1. Run TLM without extra physics                               nphystlm

1 (ensemble scaling)                                           nensscale
1. Recenter using xa-xamean+xcontrol                           nrecenter
2 (varuse - manually overriding the nrestart option)           varuse         get_htlm_driver...
20 (number of days of cycling)                                 ndaysofcycling get_htlm_driver...
1. Use regular data                                            nodataflag
0                                                              truthdayoffset
0: The analysis is at the beginning of the DA window           whereistheanalysis
5. Use Daley pbzero and scale Pbens                            npbzero
-1 (The first ninit to use - the EnKF analysis)                ninit_first    cycle_4dvar_htlm
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=00_nnmi=0_cyclesec=086400_Dan_newpbzero4
```

I included this run in the plotting for 3DVAR runs.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
80. Run with 3DVAR (cyclesec=86400)
13. Plot RMSE for LETLM Paper               plotrmse4plots
PS/RMSE_baroclinic02_3DVAR_cyclesec=86400.ps
```


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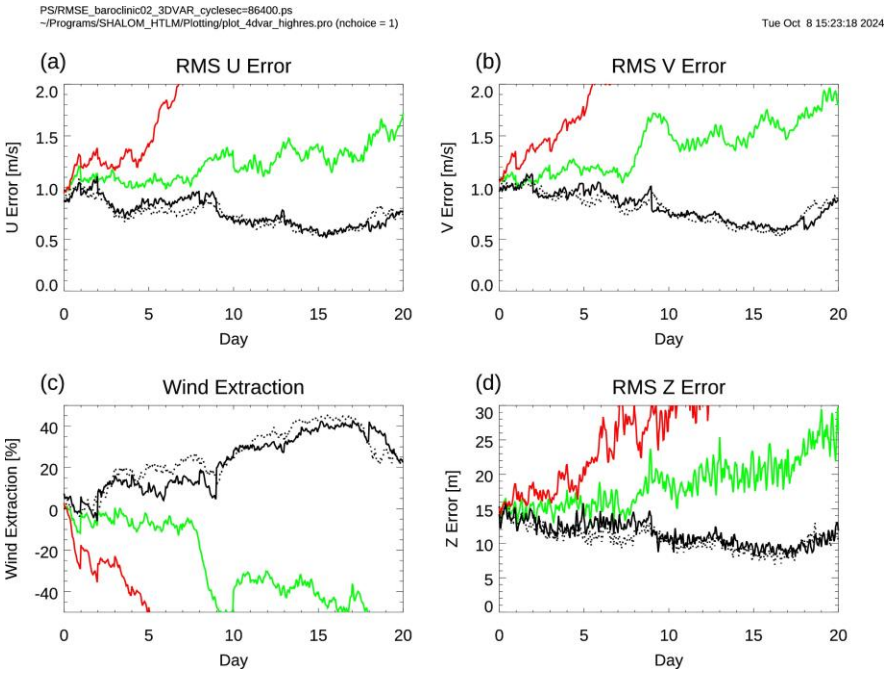


Wow, so the green line is a result without using ANY TLMs. This definitely has some pretty big errors.


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## 19 Test with NODATA

Now let's run the case with NODATA just to give a maximum range for what the errors could be. We can run this with 3DVAR if we want, since we don't need the TLM. Set n4dvar=0 in get_htlm_driver_parameters.pro.
To trick the system into thinking there's no data I increase the ob error in shalom_das_cycle_htlm.pro. There is an additional term called nodataflag that is passed through.

```
;------ Increase ob error for "NODATA" case ------
if(n_elements(nodataflag) eq 1) then begin
  if(nodataflag eq 2) then begin
    ob_err=ob_err*1.e10
  endif
endif
```

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic                          npick          pick_datadir
02                                                             suffix         pick_datadir
3. Run 4DVar                                                   nchoice
2. Run with added physics                                      nphysics
5. Relaxation to mean state (zonal mean only)                  nmerror
86400                                                          relax_time

1. Use offline ensemble                                        nwhichens
1. Run normally                                                ngradient
3. Run TLM with physics - forward_sweep_htlm_short_phys        nhtlm
1. Run TLM without extra physics                               nphystlm

1 (ensemble scaling)                                           nensscale
1. Recenter using xa-xamean+xcontrol                           nrecenter
2 (varuse - manually overriding the nrestart option)           varuse         get_htlm_driver...
20 (number of days of cycling)                                 ndaysofcycling get_htlm_driver...
2. Increase ob error to made NODATA                            nodataflag
0                                                              truthdayoffset
1                                                              whereistheanalysis
5. Use Daley pbzero and scale Pbens                            npbzero
-1 (The first ninit to use - the EnKF analysis)                ninit_first    cycle_4dvar_htlm
Hybrid_T21_alpha=0.50_L=07500_varuse=02_nenkf=19_n4dvar=00_nnmi=0_newpbzero4_NODATA
```

We see errors start to go up steadily, which is good.

Let's plot the 4DVAR errors

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
```


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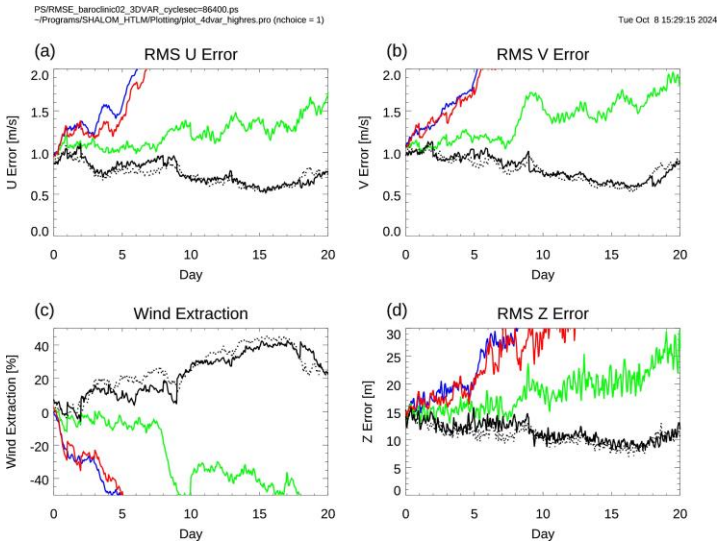
```
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
80. Run with 3DVAR (cyclesec=86400)
13. Plot RMSE for LETLM Paper           plotrmse4plots
PS/RMSE_baroclinic02_3DVAR_cyclesec=86400.ps
```

There are four cases here
Perfect TLM
3DVAR with persistence for final sweep
3DVAR with NLM for final sweep
3DVAR – NODATA

Woah, both NODATA's look bad. Why are the two final results the same? It's because we're propagating an increment that is basically zero either with the TLM or the NLM, and we get exactly the same answer. That's good to know.





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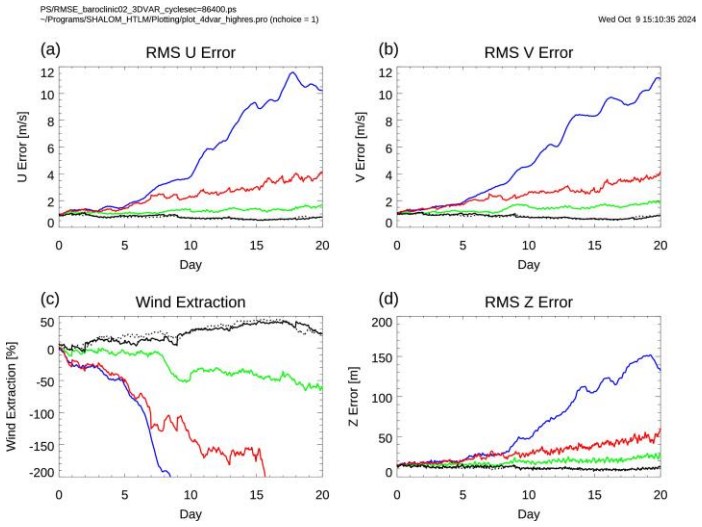



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## 20 Tests using the NLM in the final forward sweep

Let's include an additonal test where we use the NLM in the final forward sweep. We'll call this case IIN. Let's run a single test with the error of 1.02 and compare.

Perfect TLM

```
1.02 error case for III
1.02 error case for IIN
```

Let's see how sensitive this is when the errors are everywhere except in the final sweep. This is a good test for us to see how well we can do with the perfect NLM in the final sweep.

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic                          npick          pick_datadir
02                                                             suffix         pick_datadir
3. Run 4DVar                                                   nchoice
2. Run with added physics                                      nphysics
5. Relaxation to mean state (zonal mean only)                  nmerror
86400                                                          relax_time

1. Use offline ensemble                                        nwhichens
1. Run normally                                                ngradient
3. Run TLM with physics - forward_sweep_htlm_short_phys        nhtlm
5. Run TLM with ZM relaxation and simple scaling               nphystlm
86400                                                          tlm_relax_time
1.02 1.02 1.02 1.02                                            nsensitivity

1 (ensemble scaling)                                           nensscale
1. Recenter using xa-xamean+xcontrol                           nrecenter
2 (varuse - manually overriding the nrestart option)           varuse         get_htlm_driver...
20 (number of days of cycling)                                 ndaysofcycling get_htlm_driver...
0                                                              truthdayoffset
0 (The analysis is at the beginning of the DA window)          whereistheanalysis
5. Use Daley pbzero and scale Pbens                            npbzero
-1 (The first ninit to use - the EnKF analysis)                ninit_first    cycle_4dvar_htlm
'Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_Dan_rtm=-
0086400_tlmscale=01.02_adjscale=01.02_finscale=01.02_newpbzero4'
```

Let's look at the results.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
82. Run with NLM in the final sweep (cyclesec=86400)
```


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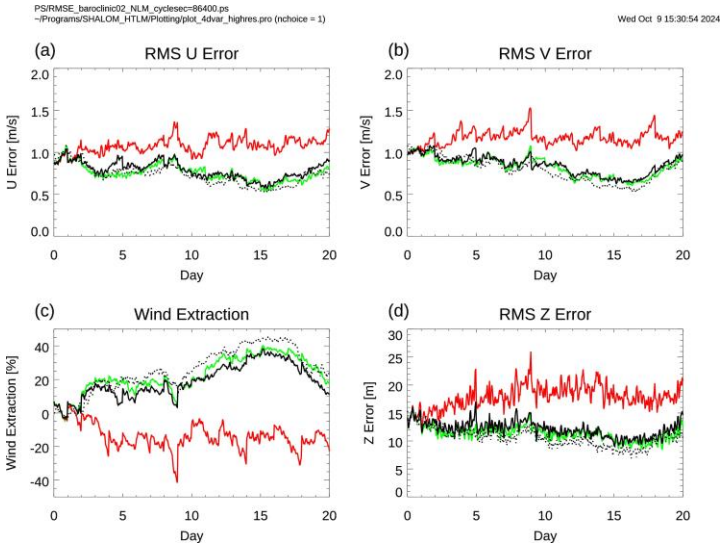
**13. Plot RMSE for LETLM Paper** **plotrmse4plots**
**PS/RMSE_baroclinic02_NLM_cyclesec=86400.ps**





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## 21 Testing the HTLM correction

Before doing a lot more sensitivity tests, let's see if the hybrid TLM does better for the case of 1.02 error. I need to modify the code to allow for corrections to be made to u, v, and phi.

letlm_single.pro – do a single state vector element at a time
letlm_adjoint_single.pro – do a single state vector element at a time

This is set up just about right, except that it has line where

```
if(xsza(istate) ge 90. or xvar(istate) ne 3) then tlmens=1. ; Turn off TLM in this case
```

Probably the best thing to do is to just comment this line out. I can always add it later.

These are called in forward_sweep_htlm_short_phys.pro and the same backward version.

These are called when patch_size=0

This is determined from npatch in get_htlm_driver_parameters.pro

So all I need to do to run the htlm version is to set n4dvar=-1 in get_htlm_driver_parameters.pro

Let's give this a try.

```
cd ~/Programs/SHALOM_HTLM/Scripts
idl
.r htlm_driver
10. Use /Data3/SHALOM_HTLM_barotropic
02
3. Run 4DVar
2. Run with added physics
5. Relaxation to mean state (zonal mean only)
86400

4. Create ensemble online - run hourly TLM forecasts
1. Run normally
3. Run TLM with physics - forward_sweep_htlm_short_phys
5. Run TLM with ZM relaxation and simple scaling
86400
1.02 1.02 1.02 1.02 (Note: the last one doesn't matter unless were

1 (ensemble scaling)
1. Recenter using xa-xamean+xcontrol
2 (varuse - manually overriding the nrestart option)
20 (number of days of cycling) - get_htlm_driver_parameters.pro
1 1 1 (when to use the HTLM)
/Data3/SHALOM_HTLM_barotropic02/EnKF/EnKF_T21_N0100_L07500_E003_HTLM/Member0000/
/Data3/SHALOM_HTLM_barotropic01/Nature/Nature001_T21_HTLM/ (naturedir)
0 (truthdayoffset)
1 whereistheanalysis (0 = beginning, 1 is the ending)
-1 (The first ninit to use - the EnKF analysis)
5. Use Daley pbzero and scale Pbens
```


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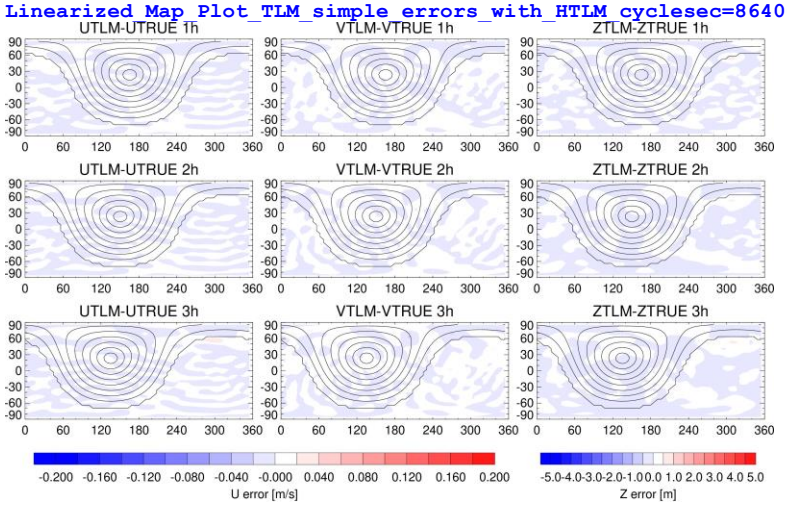
This experiment has an unwieldy name

```
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=-
1_nnmi=0_enscale=00000_npatch=0000_letlmdt=3600_npseudo=00005_nensletlm=0100_cyclesec=086400_nwhi
chens=4_rtm=-0086400_tlmscale=01.02_adjscale=01.02_finscale=01.02_usehtlm=111_newpbzero4
```

Let's see how it does. The first step does show a decrease in errors. Let's look at the TLM.

```
cd ~/Program/SHALOM_HTLM/Plotting
idl
.r plot_tlm_final_errors
3. Contour plots of the trajectories      plottraj
8. TLM with simple scaling and HTLM correction (cyclesec=86400)
```

```
Linearized_Map_Plot_TLM_simple_errors_with_HTLM_cyclesec=86400.ps
```




This worked a lot better than I thought. Let's look at the line plots.

```
cd ~/Program/SHALOM_HTLM/Plotting
idl
.r plot_tlm_final_errors
1. Read the trajectory and the truth       readtraj
10. TLM with simple scaling and HTLM correction (cyclesec=86400)
2. Plot the trajectory errors              ploterror
1. Plot error time series only

PS/HTLM_Error_Ploti_cyclesec=86400.ps
```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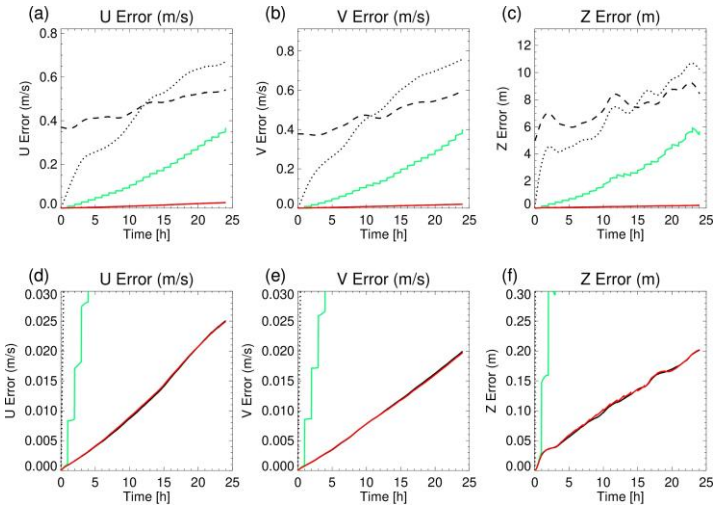


There should be a black line that is "perfect" and the red line is the "HTLM". The green line is the one with error. In the bottom row we zoom in and see that the HTLM does a really good job of correcting the errors. It isn't perfect, likely due to the spectral transformation that needs to happen. But it is really good. Cool!

Let's look at the 4DVar results.

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                    readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
81. Run with HTLM correction (cyclesec=86400)
13. Plot RMSE for LETLM Paper           plotrmse4plots
PS/RMSE_baroclinic02_HTLM_Correction_cyclesec=86400.ps
```

The perfect TLM is black and the HTLM is green. The run with model errors is red. This nicely shows that the HTLM performs very well.


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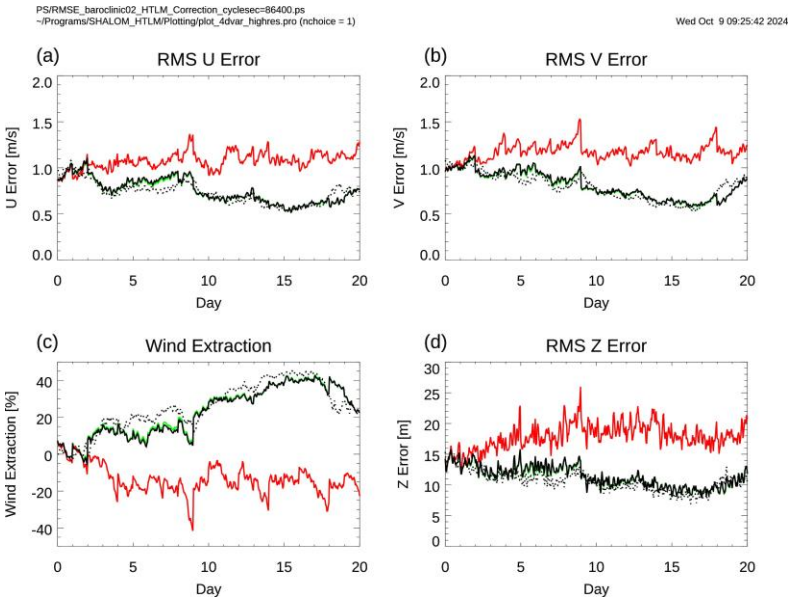
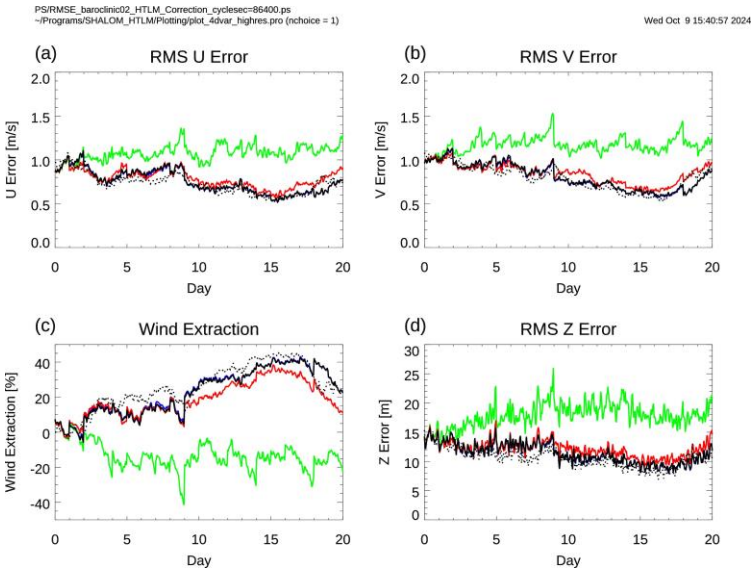



Here I include the following:

Perfect TLM
IIP
III
III - HTLM





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## 22 Forecast Errors

I'd like to compare results from "IIP" with the III and HTLM correction.

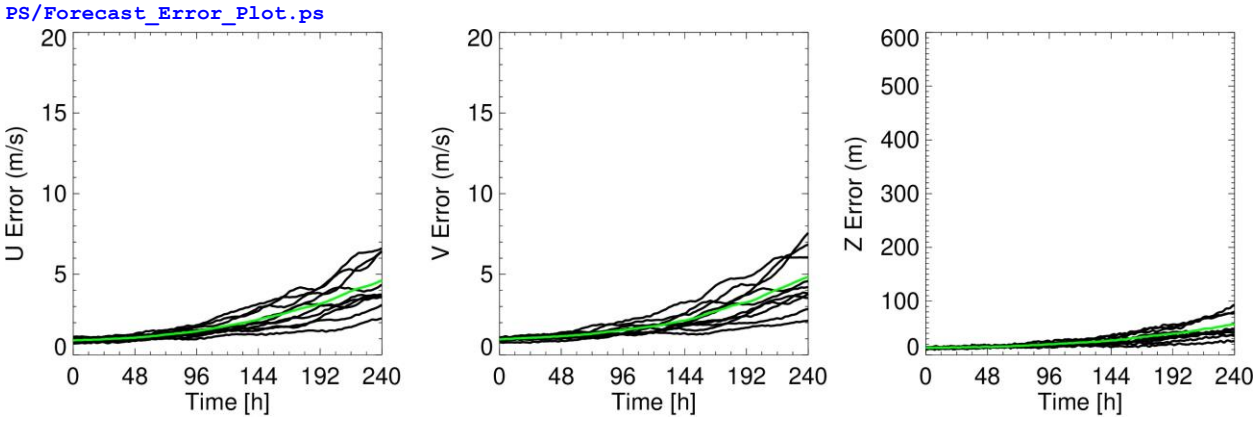
Run offline forecasts

```
scr (alias for cd ~/Programs/SHALOM_HTLM/Scripts)
idl
```

### HTLM

```
.r run_forecasts_offline
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=-
1_nnmi=0_enscale=00000_npatch=0000_letlmdt=3600_npseudo=00005_nensletlm=0100_cyclesec=086400_nwhi
chens=4_rtm=-0086400_tlmscale=01.02_adjscale=01.02_finscale=01.02_usehtlm=111_newpbzero4

.r verification
1. Calculate forecast errors     calcerror
2. Plot forecast errors          ploterror
PS/Forecast_Error_Plot.ps
```




### IIP (1.02)

```
.r run_forecasts_offline
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_tlmscale=01.02_adjscale=01.02_newpbzero4

.r verification
1. Calculate forecast errors     calcerror
2. Plot forecast errors          ploterror
PS/Forecast_Error_Plot.ps
```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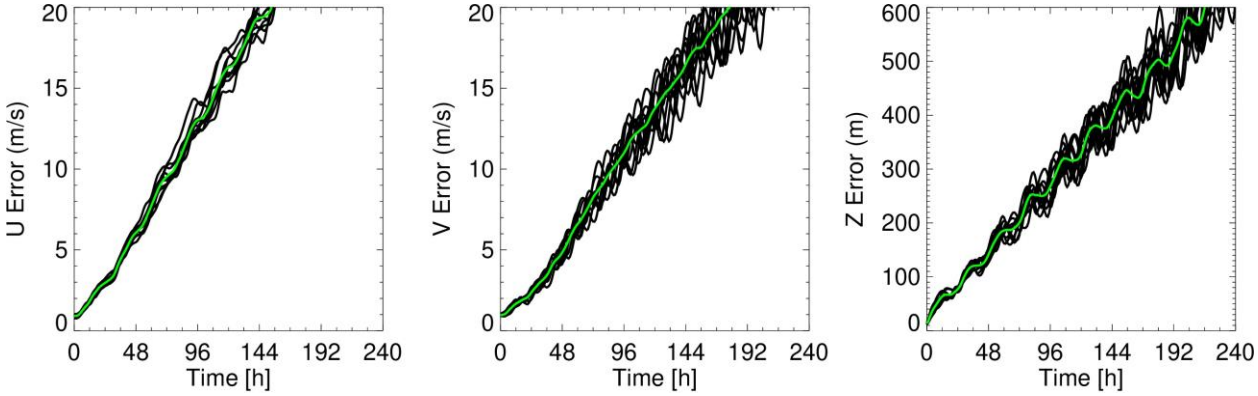
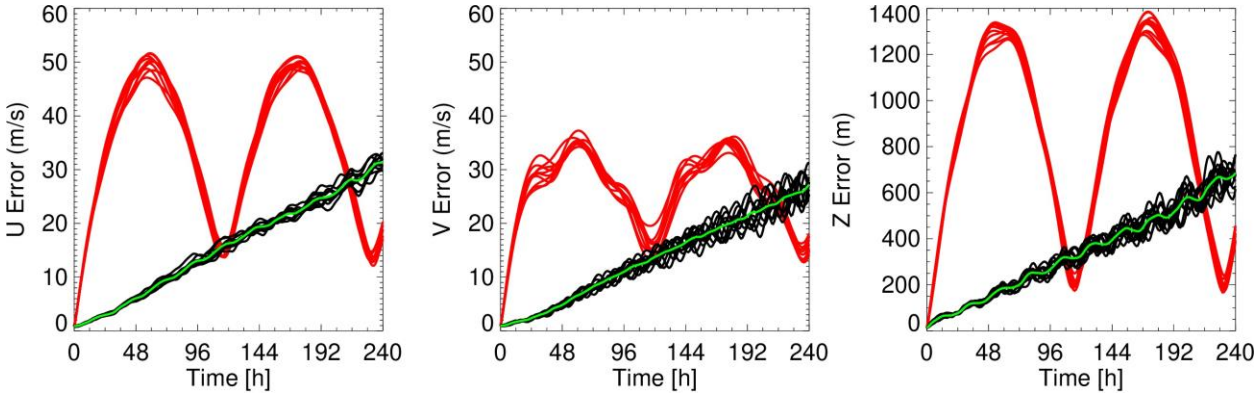


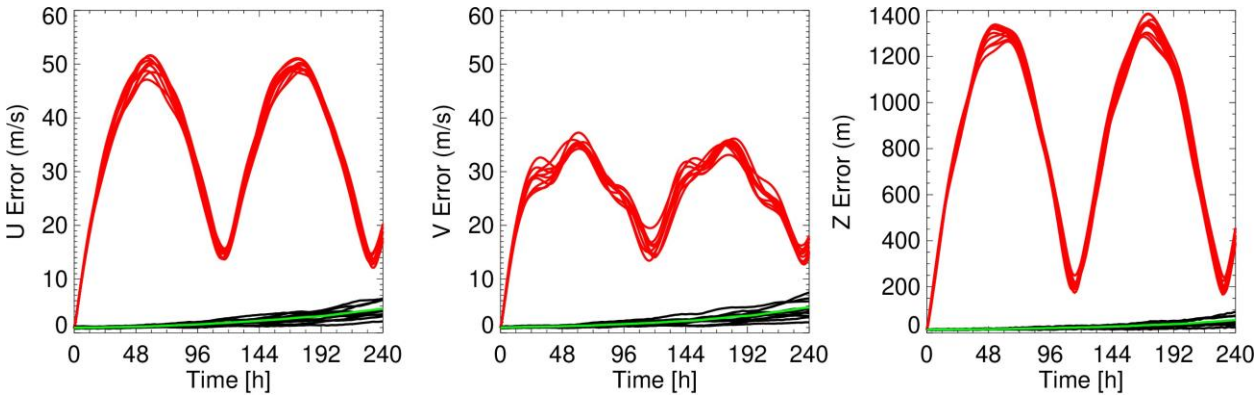

These errors seem really big. But if we include persistence errors...




**IIP (1.01)**

```
.r run_forecasts_offline
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_tlmscale=01.01_adjscale=01.01_newpbzero4

.r verification
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_tlmscale=01.01_adjscale=01.01_newpbzero4
1. Calculate forecast errors     calcerror
2. Plot forecast errors          ploterror
PS/Forecast_Error_Plot.ps
```





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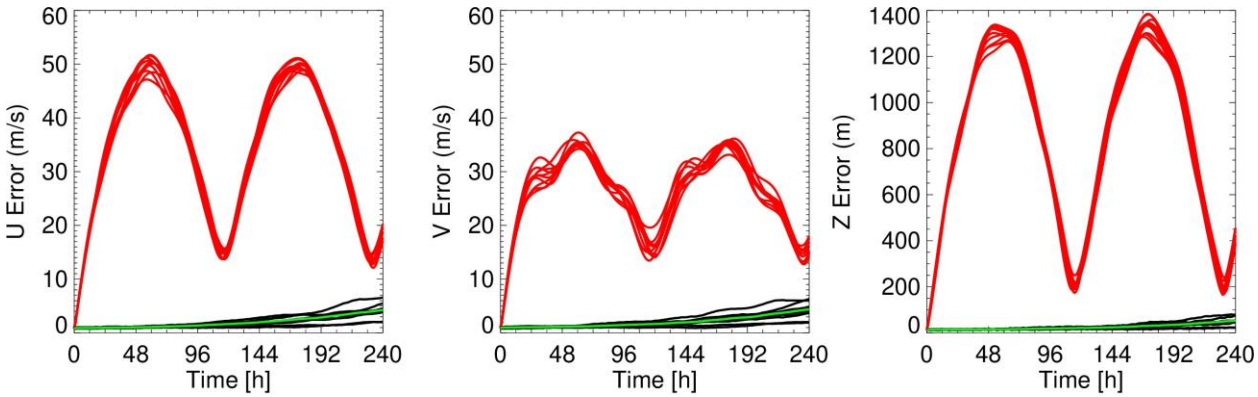
This one looks fine. What is the problem with 1.02?

## IIP (1.03)

```
.r run_forecasts_offline
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_tlmscale=01.03_adjscale=01.03_newpbzero4

.r verification
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_tlmscale=01.03_adjscale=01.03_newpbzero4
1. Calculate forecast errors     calcerror
2. Plot forecast errors          ploterror
PS/Forecast_Error_Plot.ps
```

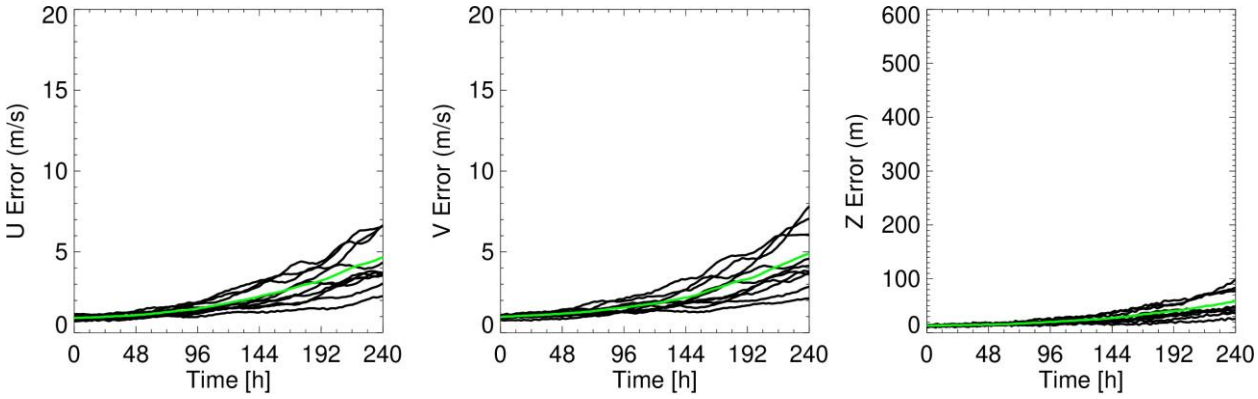



OK, this is odd. The 1.03 looks OK, but 1.02 is strange.

## PPP

```
.r run_forecasts_offline
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_newpbzero4

.r verification
1. Calculate forecast errors     calcerror
2. Plot forecast errors          ploterror
PS/Forecast_Error_Plot.ps
```





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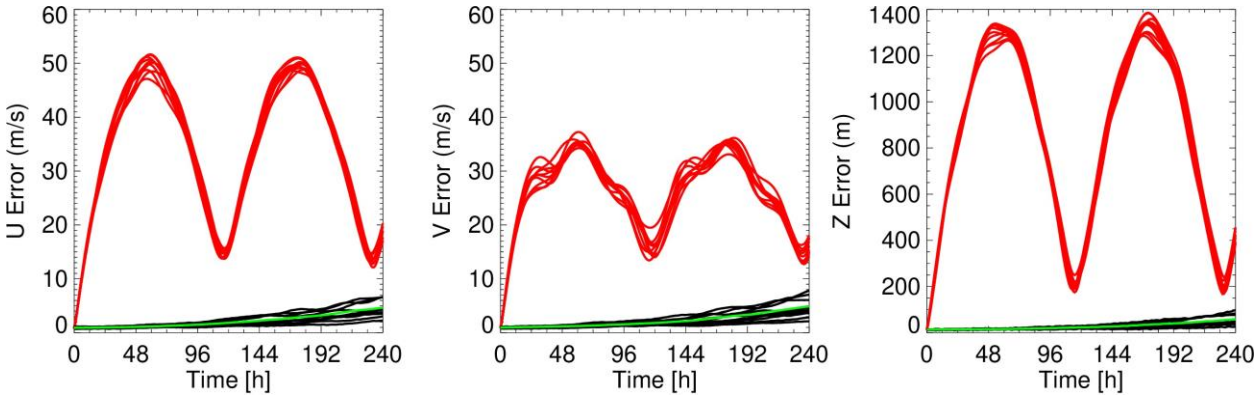
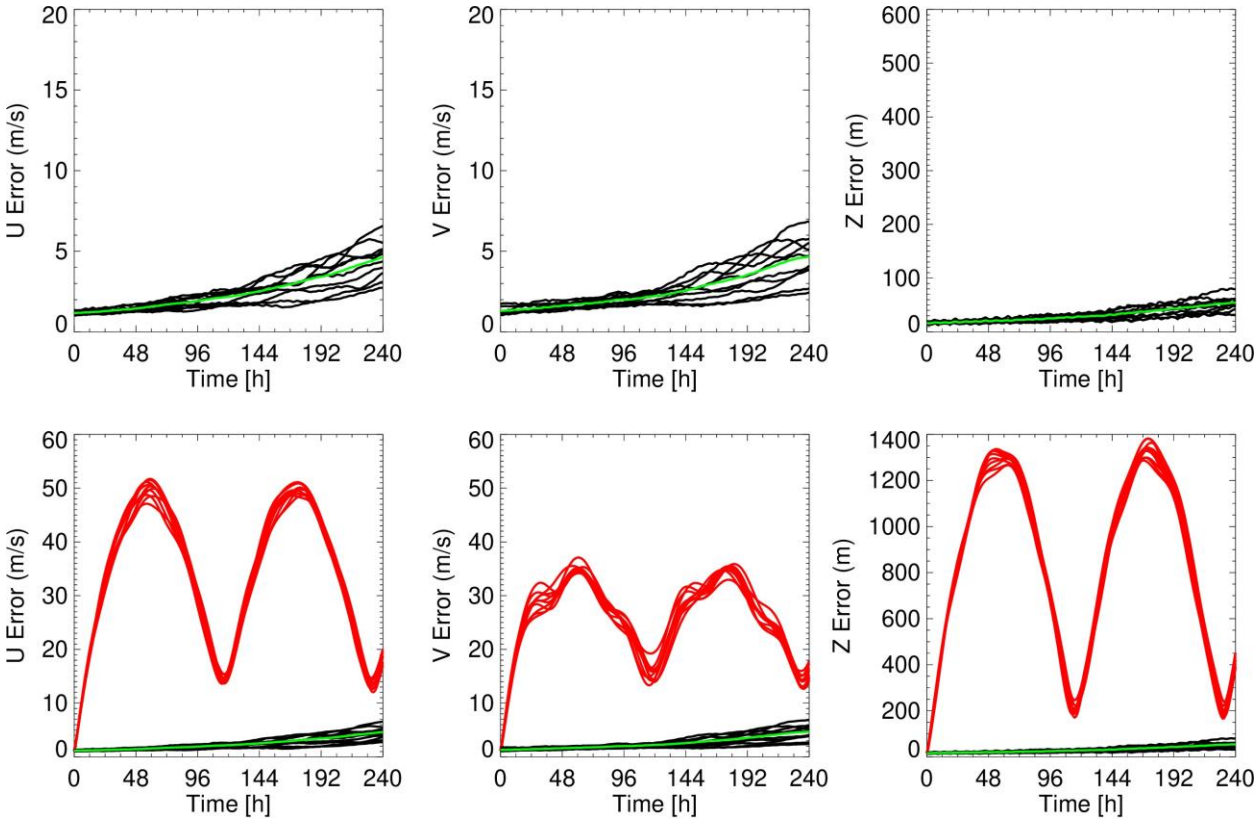



## 3DVAR with NLM as final sweep

```
.r run_forecasts_offline
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=00_nnmi=0_cyclesec=086400_Dan_newpbzero4

.r verification
1. Calculate forecast errors     calcerror
2. Plot forecast errors          ploterror
PS/Forecast_Error_Plot.ps
```




Plot the combined forecast errors

```
.r verification
```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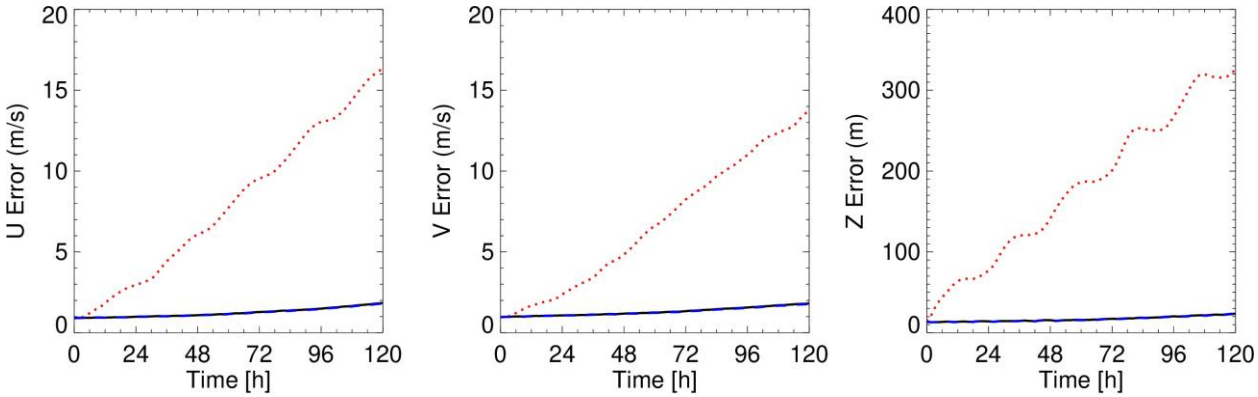
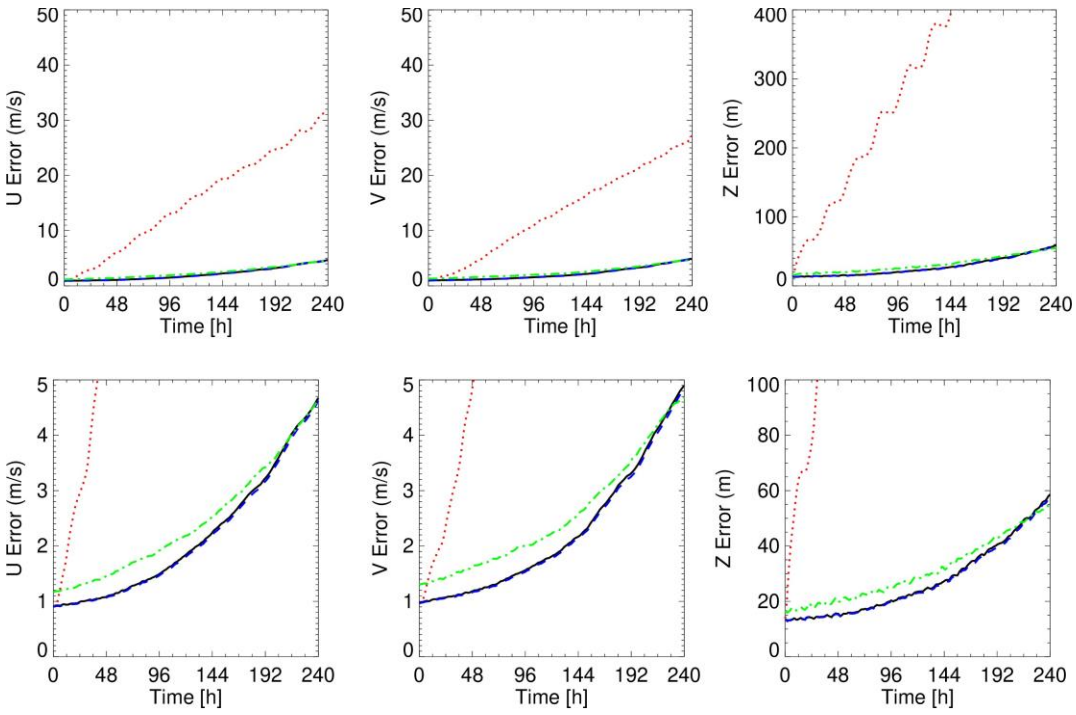
```
<Enter> No directory needed in this case
3. Plot errors for multiple runs ploterrormult
PS/Forecast_Error_Plot_Mult.ps
```




Interesting, this shows that the error sensitivity to initial conditions is quite large.

- The black line is the case for the perfect TLM
- The red line is the case where the TLM has scaling of 1.02
- The blue line is with the HTLM correction.
- The HTLM correction makes a huge difference.




This shows the results for 3DVar (green) along with HTLM (blue) and PPP (black). This is a nice result. It shows that there is better skill with the HTLM out to about 4 days.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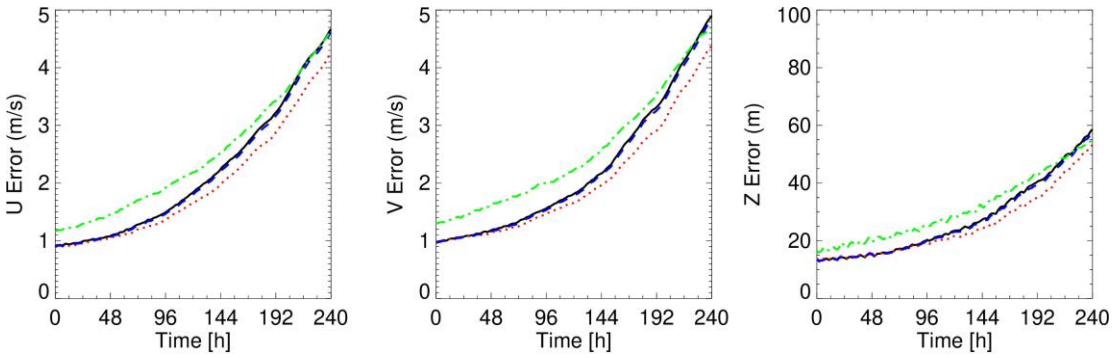
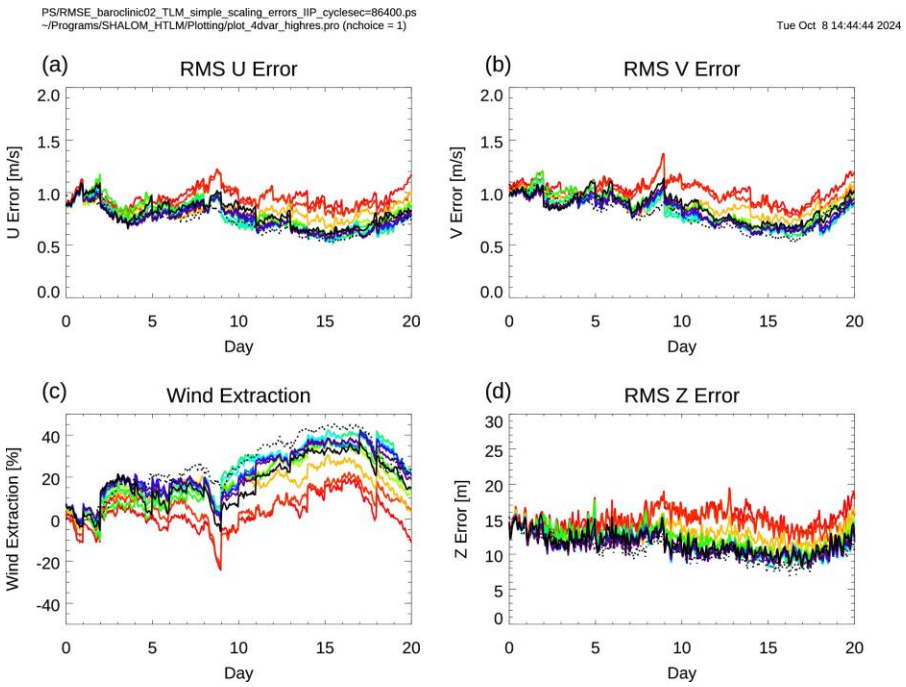
Why is the red line so whacky? I replaced it with the 1.03 case and got something even whackier. The run with model error has smaller forecast errors than with the perfect TLM!




There are several things wrong here. First, why is the initial error the same for both the perfect and the 1.03 IIP error cases. Below is the plot with all of the IIP errors.




If we just plot the perfect and 1.03 IIP cases we get....

```
plot (alias for cd ~/Programs/SHALOM_HTLM/Plotting)
idl
.r plot_4dvar_highres
10. Use /Data3/SHALOM_HTLM_barotropic
02
14. Read EnKF errors                        readrmsespread
1. Recalculate RMS error
1. Use the new chi formulation (based on ensemble mean innovation)
2. Use regular data
37. EnKF_T21_N0100_L0????_E003_HTLM - barotropic
20
02
```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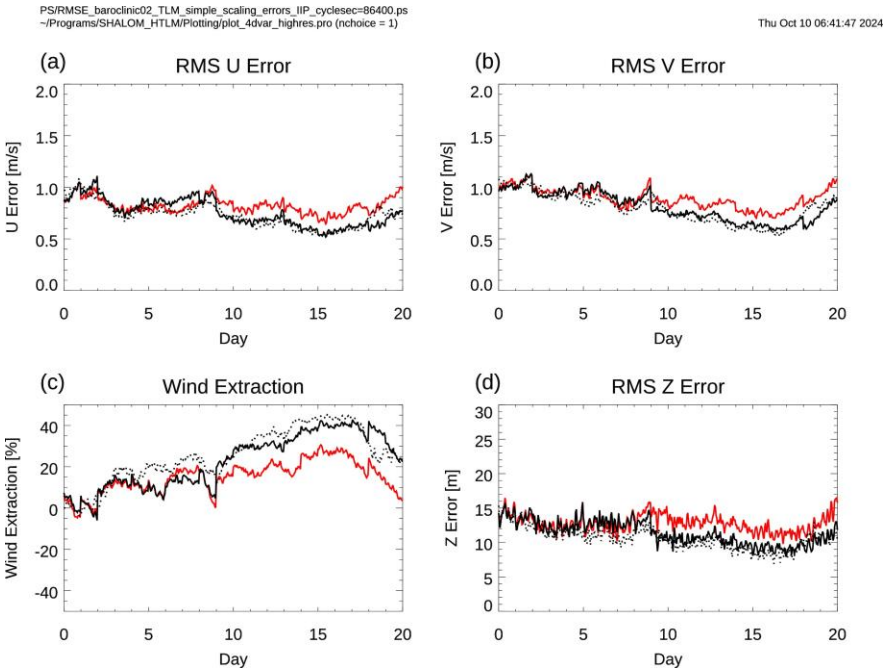
```
1. Read the RMSE and Chi2 (new fast version)    readrmsefast
78. Run with TLM simple scaling errors (IIP, cyclesec=86400)
13. Plot RMSE for LETLM Paper            plotrmse4plots
PS/RMSE_baroclinic02_TLM_simple_scaling_errors_IIP_cyclesec=86400.ps
```




So the IIP 1.03 error may be slightly lower over the first 10 days. Maybe I should do the forecasts out to 20 days. That should hopefully solve this issue.

What about 1.02? This should give similar results.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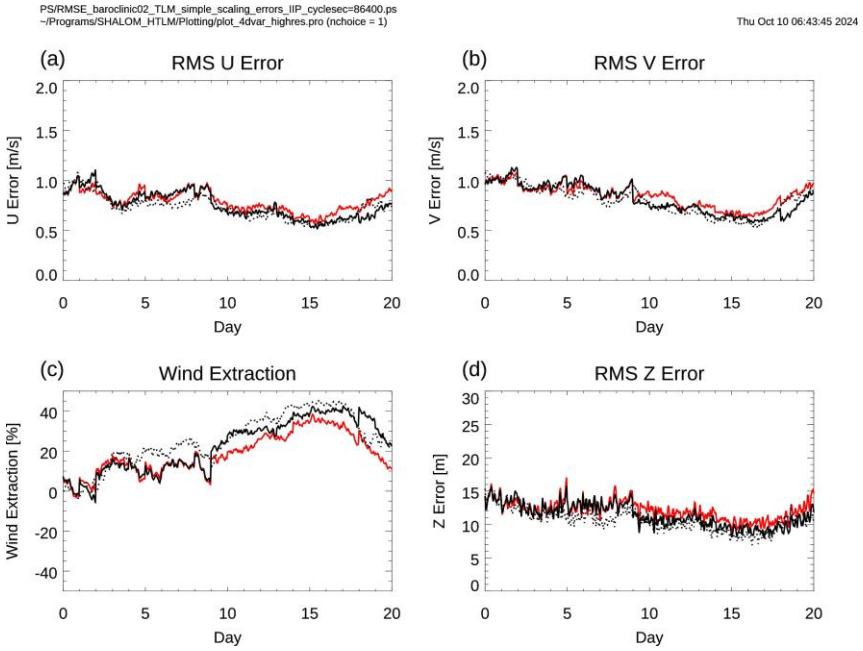


## Running forecasts out to day 20

I made an option for the code to use the original NR so we can run the forecasts out further.

```
cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r verification
10. Use /Data3/SHALOM_HTLM_barotropic
02
1. Calculate forecast errors     calcerror
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_tlmscale=01.03_adjscale=01.03_newpbzero4
2. Use the Nature Run for the truth
/Data3/SHALOM_HTLM_barotropic01/Nature/Nature001_T21_HTLM/
520
86400 1641600 86400
```

Run the same for the following experiments.

```
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_newpbzero4

Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=00_nnmi=0_cyclesec=086400_Dan_newpbzero4

Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=-
1_nnmi=0_enscale=00000_npatch=0000_letlmdt=3600_npseudo=00005_nensletlm=0100_cyclesec=086400_nwhi
chens=4_rtm=-0086400_tlmscale=01.02_adjscale=01.02_finscale=01.02_usehtlm=111_newpbzero4


3. Plot errors for multiple runs ploterrormult
Forecast_Error_Plot_Mult_Page1.png
```


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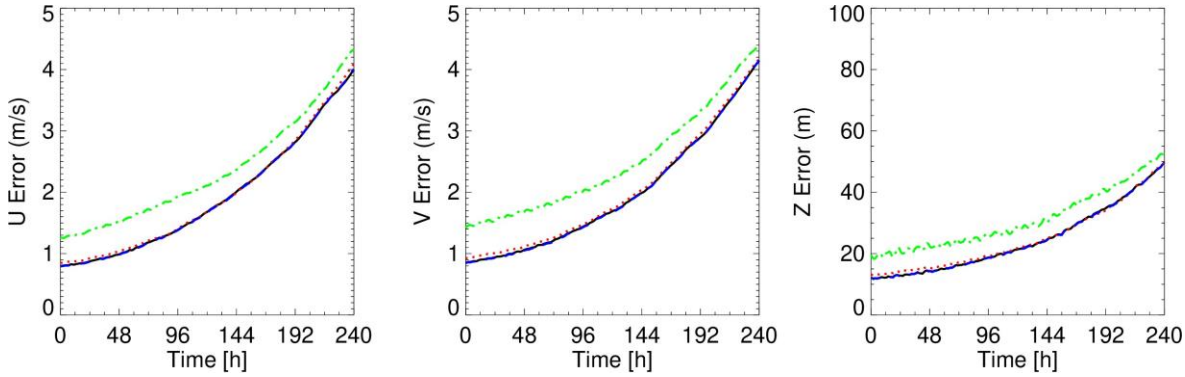
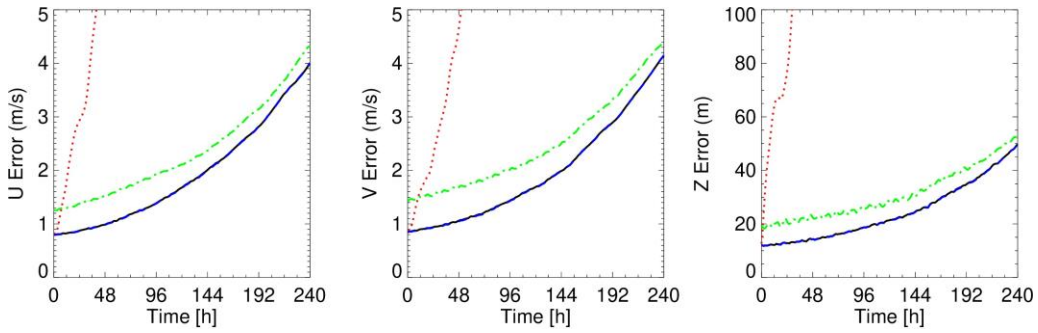


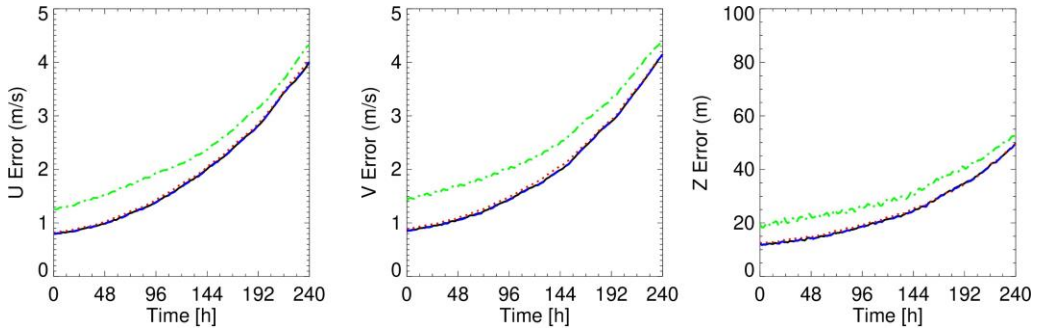

OK, this is looking a bit better. Now the 1.03 errors are indeed larger than the perfect model errors. Not by a lot, but still it looks good. And the size of the initial errors is larger, too. Maybe if I just ran forecasts from Day 10-19 it would be better. I could run every six hours to get some more statistics.

But first, let's check if the 1.02 case works. Still off by a lot.

**Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-0086400_tlmscale=01.02_adjscale=01.02_newpbzero4**




I tried re-running the offline forecasts for this case. Then I ran the verification again.




Whew! Now it seems to work. So the system is good. The only question now is whether the Truth Run is reasonable at Days 500-540.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**Doing the verification over the last 10 days at each 6 h interval**

Let's do the verification again with 1.02, but use the last 10 days only. This should amplify the differences between the runs.

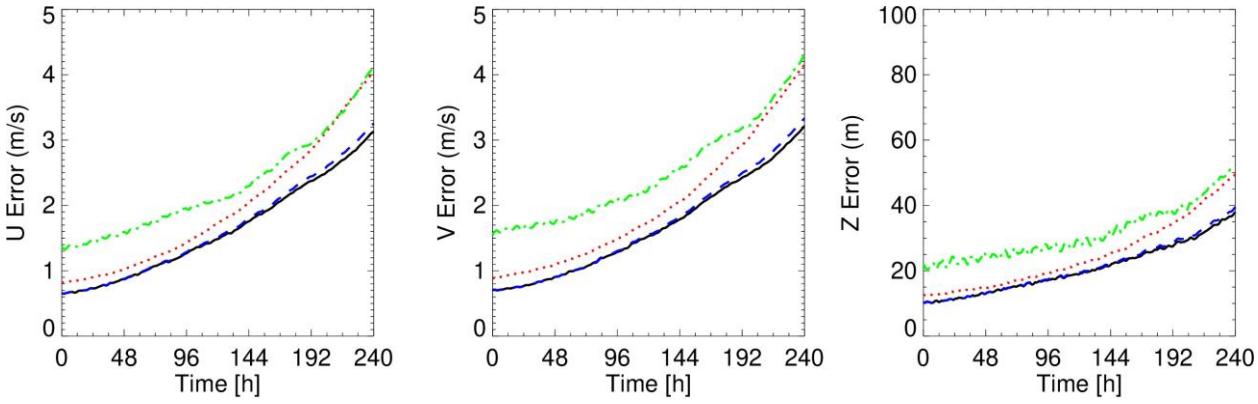
```
cd ~/Programs/SHALOM_HTLM/Plotting
idl
.r verification
10. Use /Data3/SHALOM_HTLM_barotropic
02
1. Calculate forecast errors     calcerror
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_tlmscale=01.03_adjscale=01.03_newpbzero4
2. Use the Nature Run for the truth
/Data3/SHALOM_HTLM_barotropic01/Nature/Nature001_T21_HTLM/
520
864000 1641600 86400
```

Run the same for the following experiments.

```
Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=01_nnmi=0_cyclesec=086400_rtm=-
0086400_newpbzero4

Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=00_nnmi=0_cyclesec=086400_Dan_newpbzero4

Hybrid_T21_alpha=0.70_L=07500_varuse=02_nenkf=19_n4dvar=-
1_nnmi=0_enscale=00000_npatch=0000_letlmdt=3600_npseudo=00005_nensletlm=0100_cyclesec=086400_nwhi
chens=4_rtm=-0086400_tlmscale=01.02_adjscale=01.02_finscale=01.02_usehtlm=111_newpbzero4
3. Plot errors for multiple runs ploterrormult
Forecast_Error_Plot_Mult_Page1.png
```




OK, this looks pretty good. Now there is a wider separation and the errors are more consistent.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