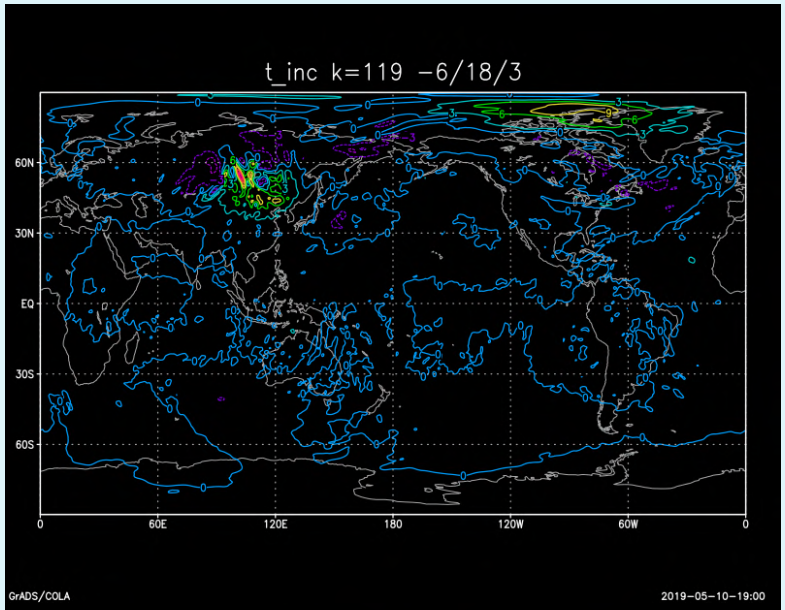
Data Assimilation Issues with Increased FV3GFS Vertical Levels

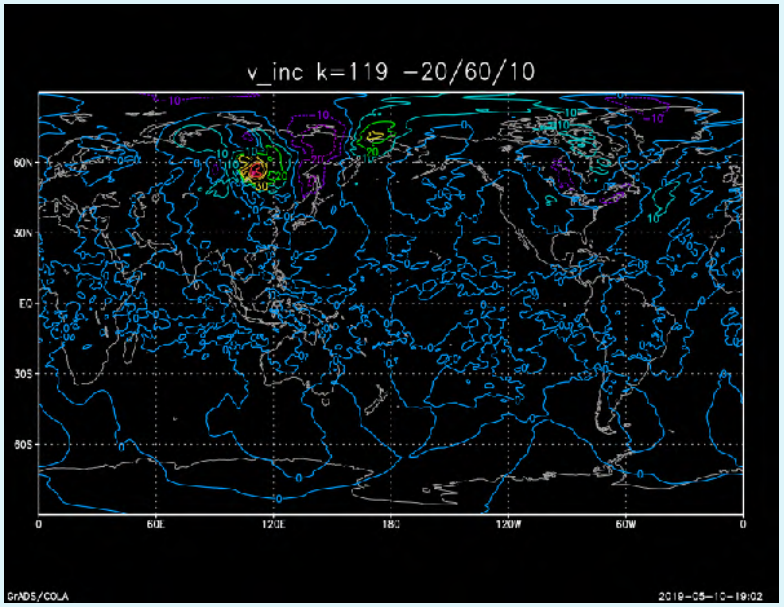
Wan-Shu Wu
Russ Treadon, Daryl Kleist, Jeffrey Whitaker, Funglin Yang
Catherine Thomas, Kristen Bathmann

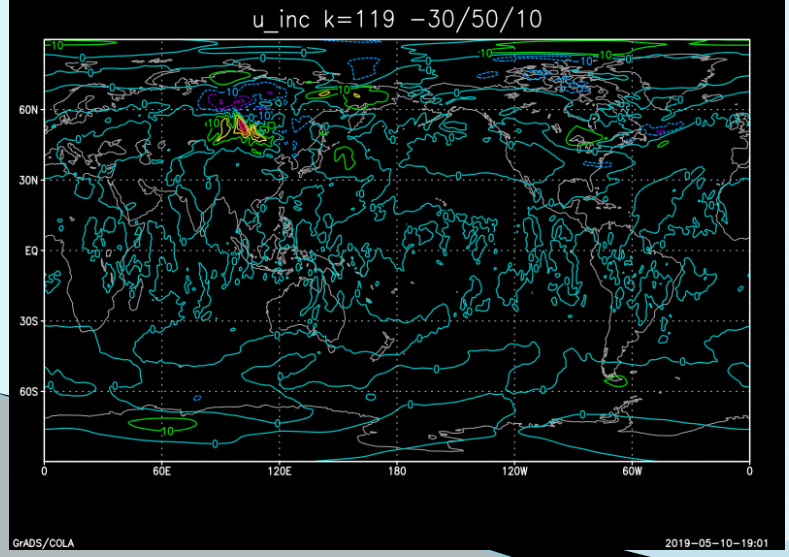
L127 & L64

~ mb	L127 =	L64 =
0.001 (80km)	127	
0.02 (55km)	120	64
10	85	41
100	68	33
250	58	28
500	47	22
700	37	18
850	26	13

Problem with Upper-Layers





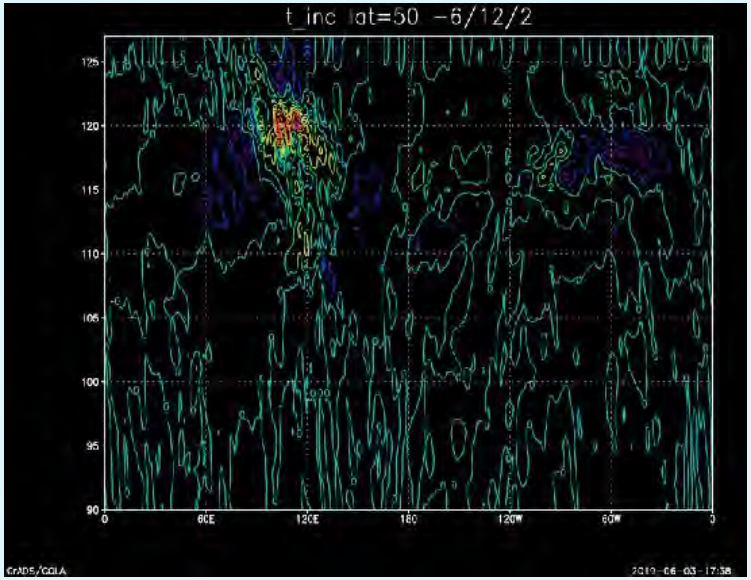


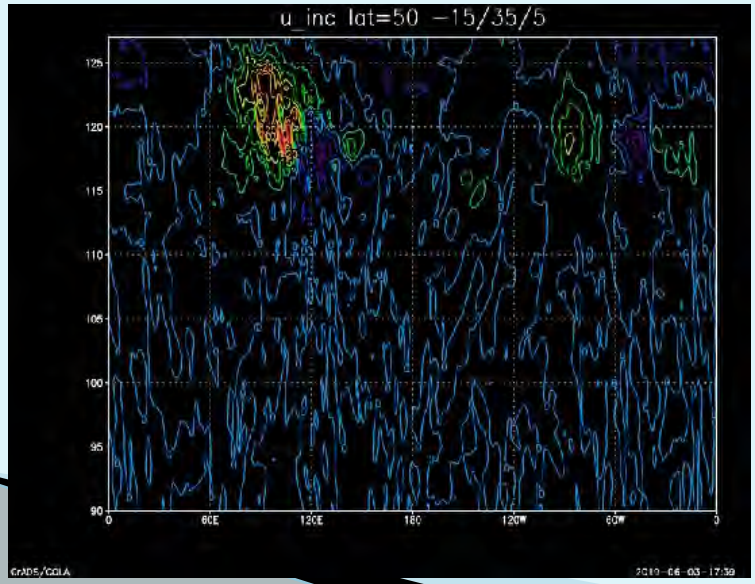
analysis increment at k=119

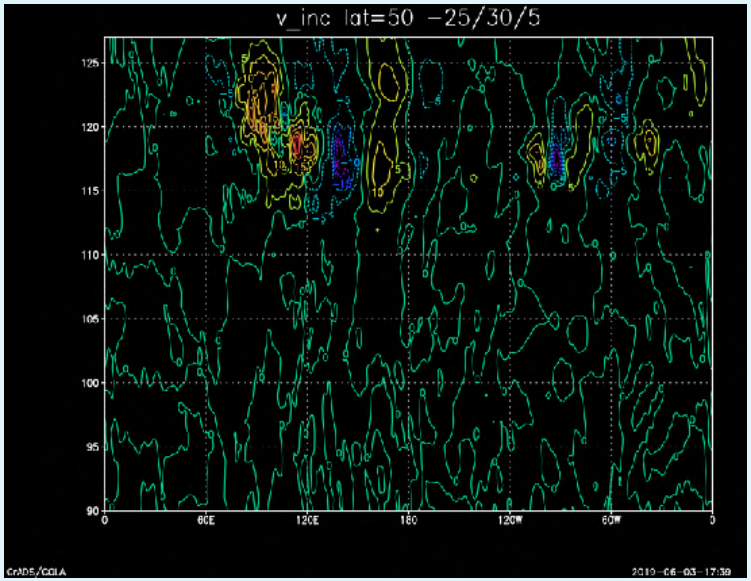
No conventional wind or temp above k=110

No GPS observations above k=118

Problem with Upper-Layers





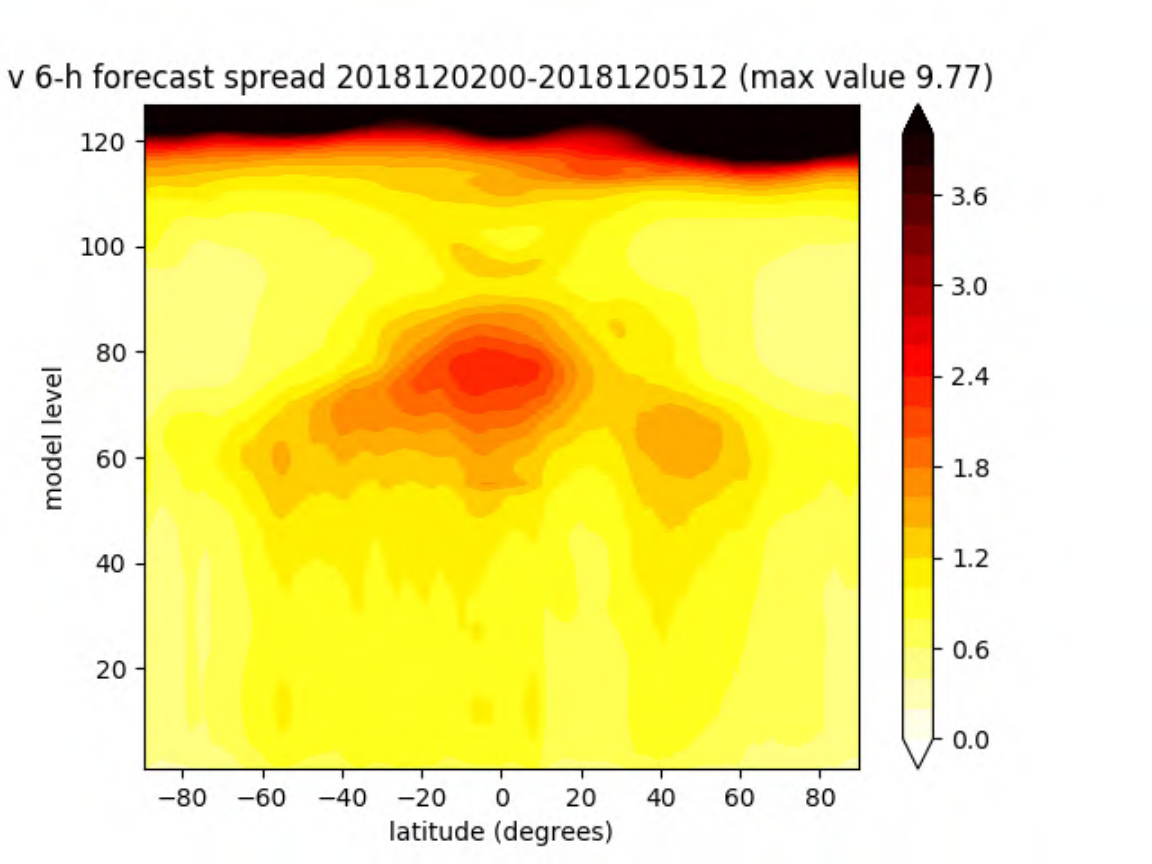


analysis increments

partial vertical cross section at 50N

Problem with Ensemble Spread

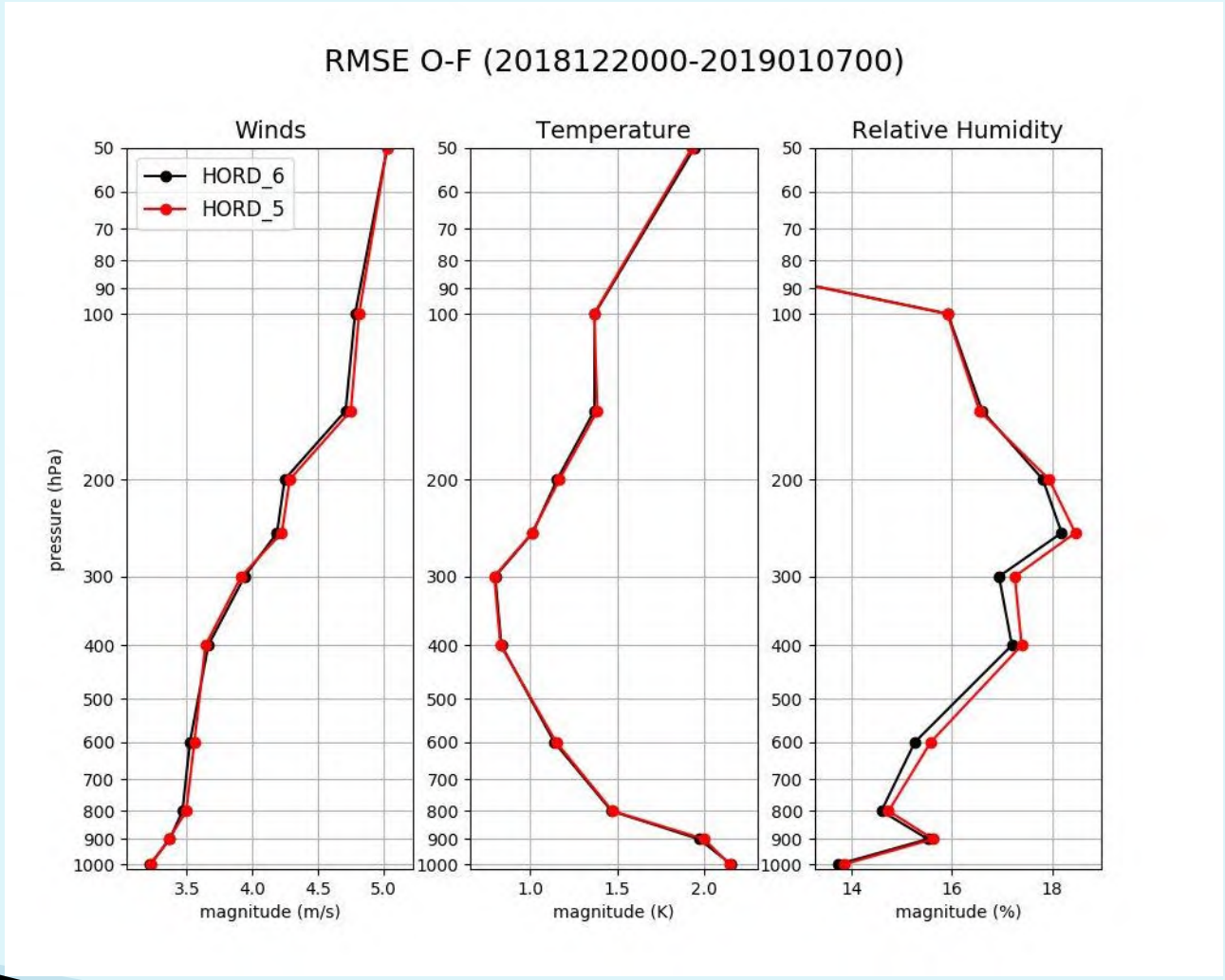
Jeff Whitaker



Zonal mean v spread (default damping)
dt_atmos=300 (k_split,n_split=1,6)

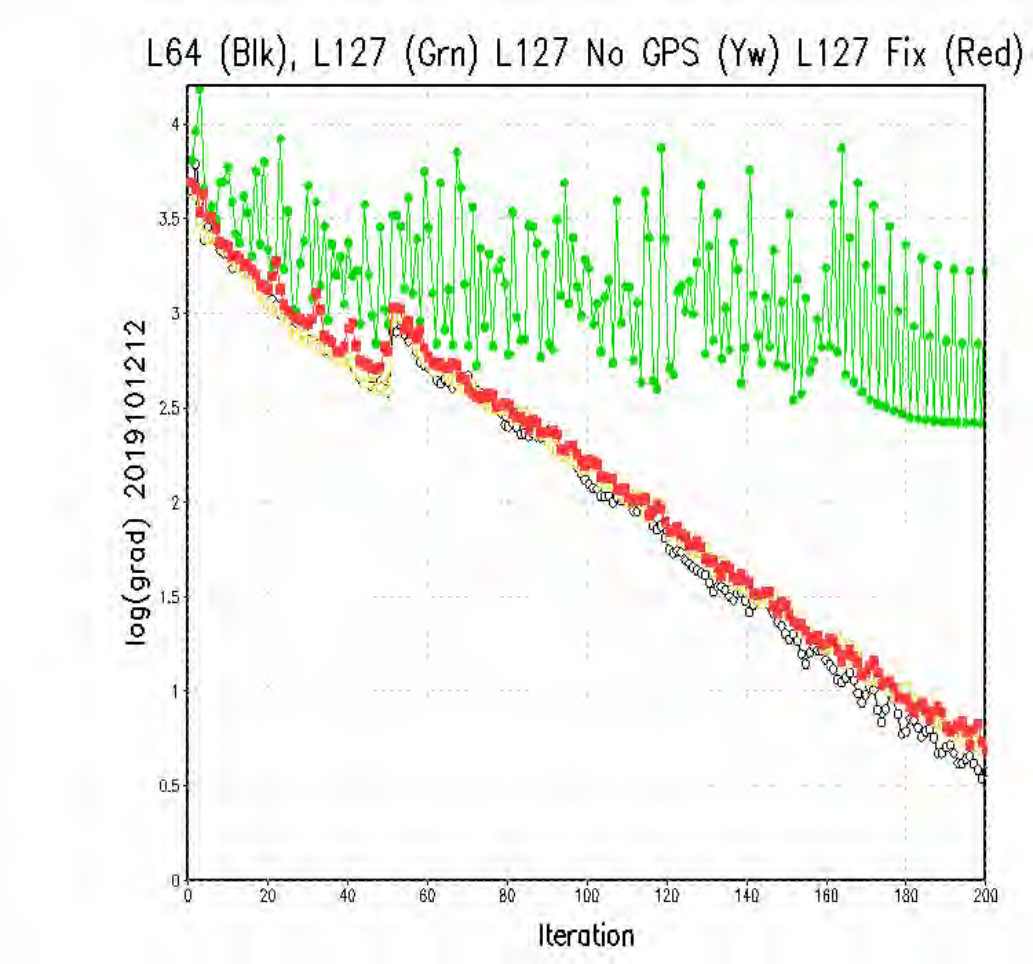
Problem with Humidity

Catherine Thomas



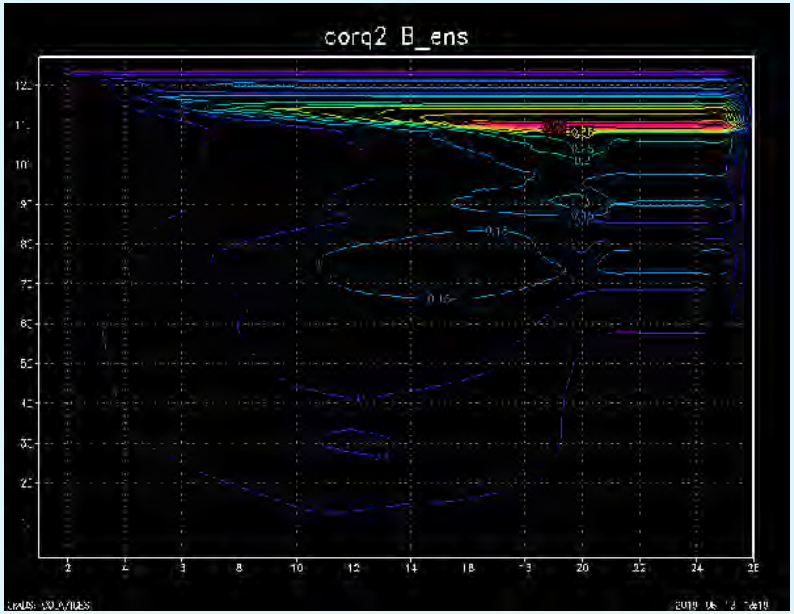
Minimization issues in L127

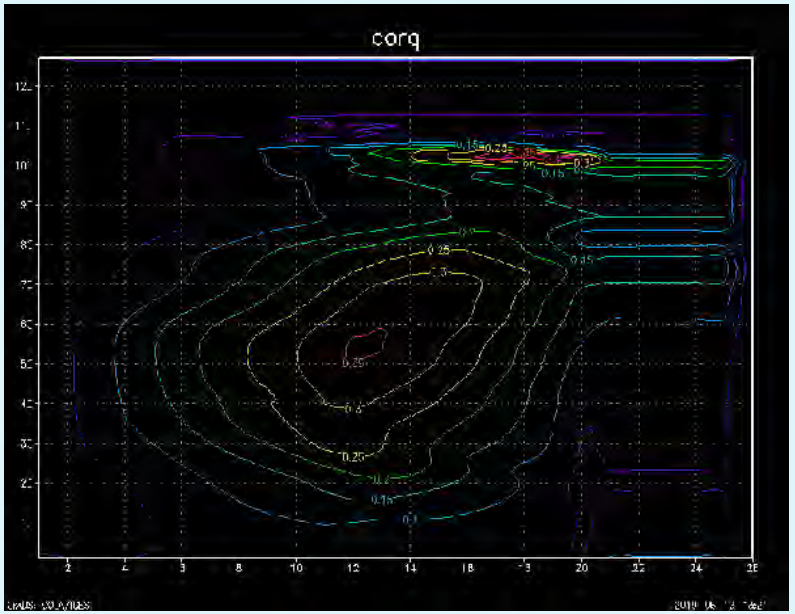
Kristen Bathmann

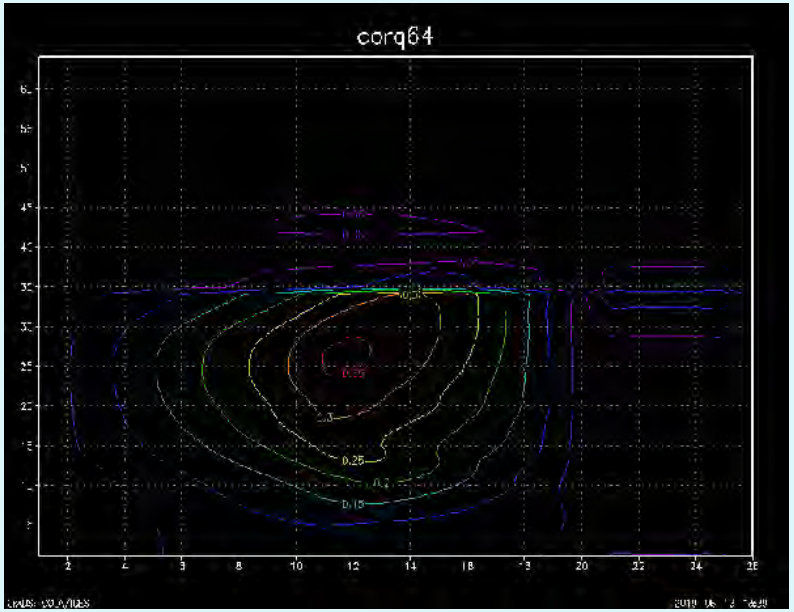


L127: conventional observation & possible reasons

- Max number of conv U/V obs at k=70-72
- Max number of conv T obs at k=72
- No conventional wind or temp above k=110
- No GPS observations above k=118*
- Hybrid ensemble-var
- Strong constraint with implicit normal mode Initialization
- Satellite Radiances
- Background error statistics



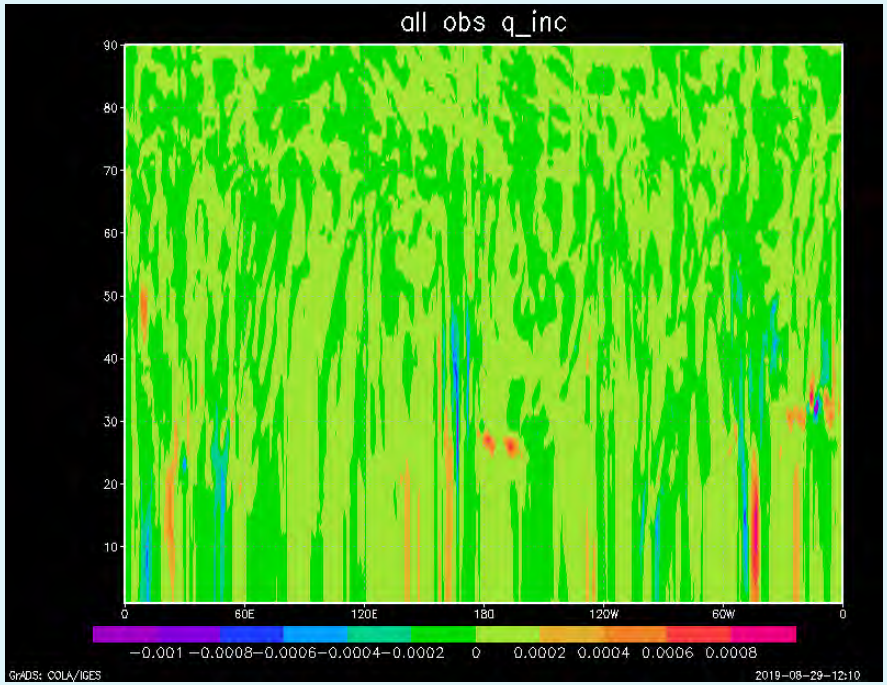


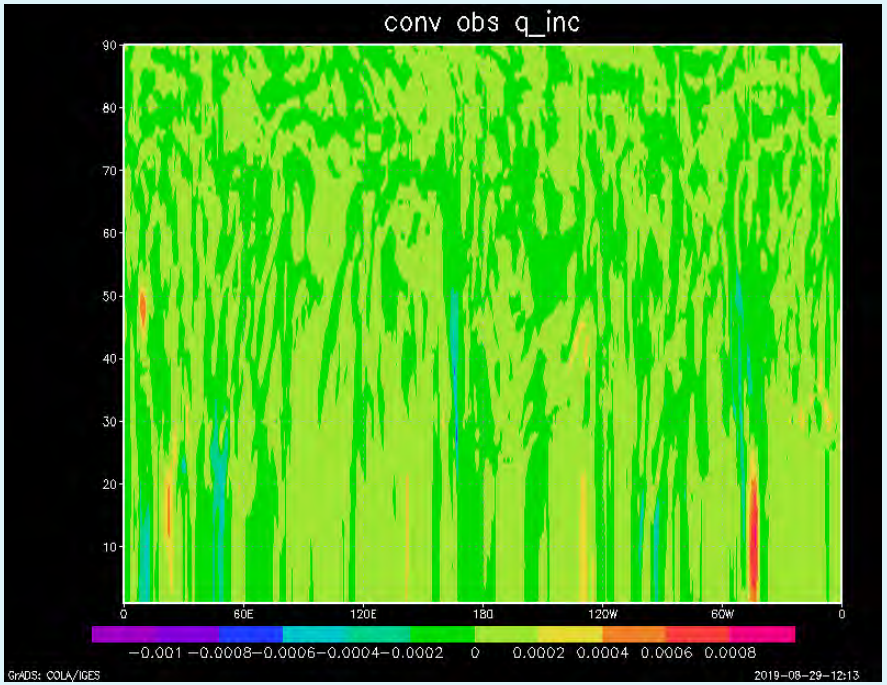


B for q_option 2:

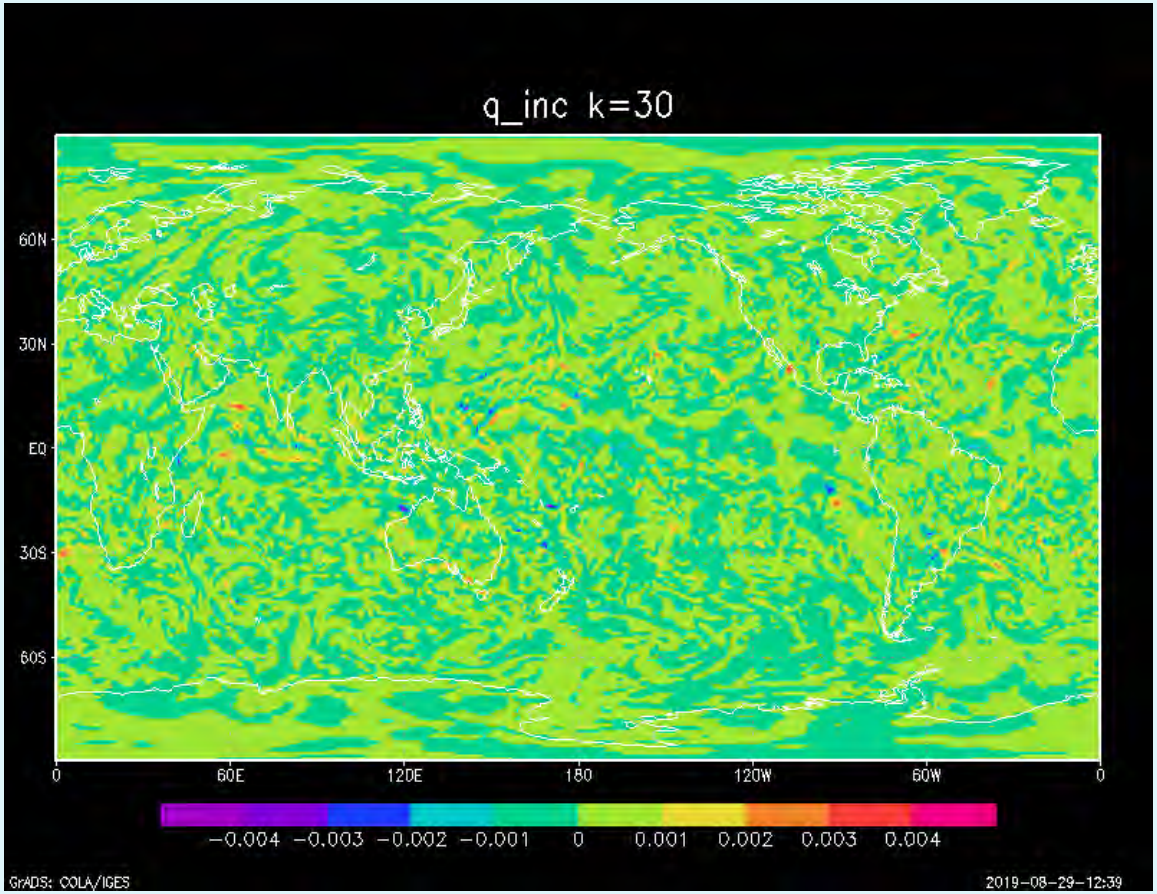
Error variances in B_ens needs adjustment

q_inc: w/o Satellite Radiances

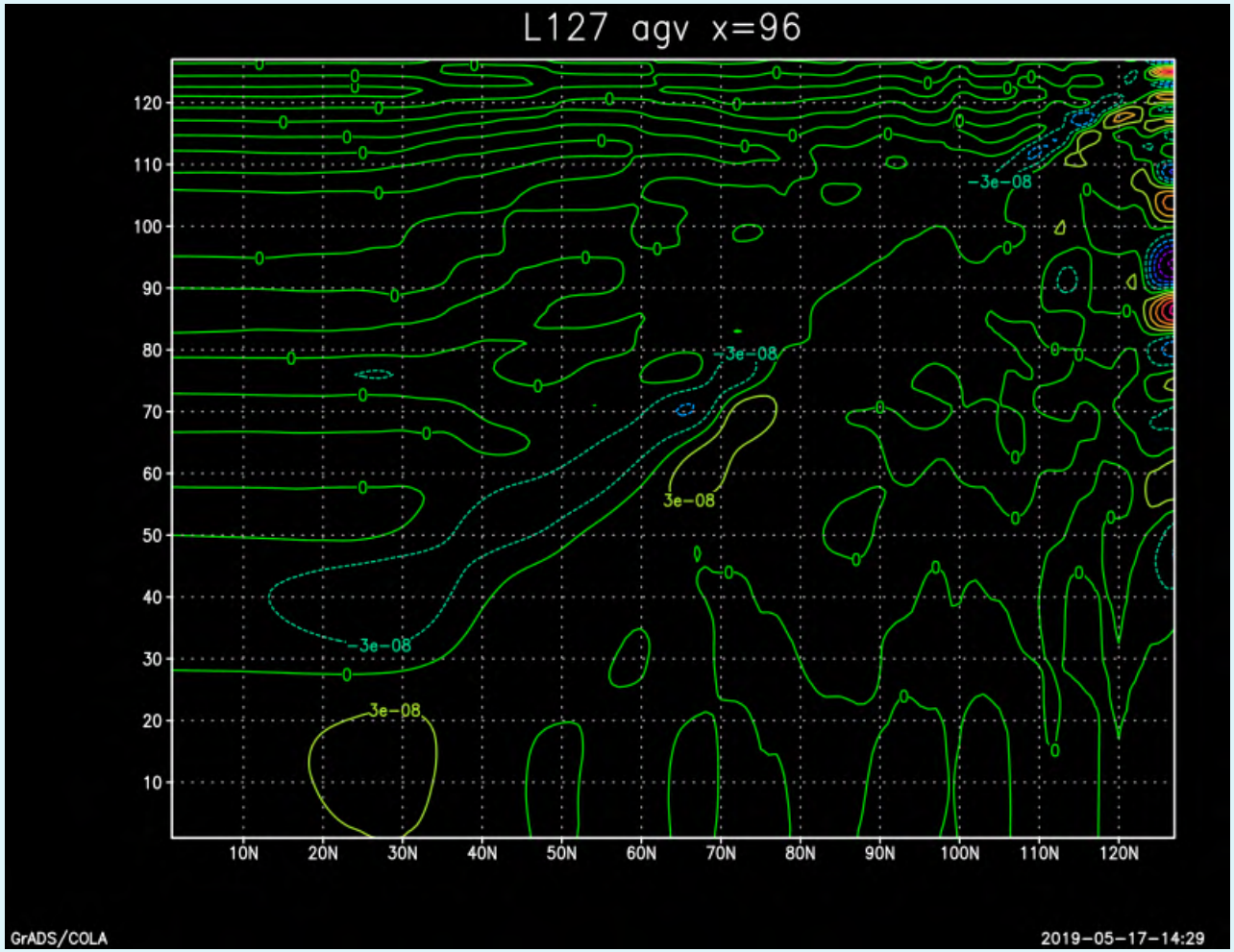




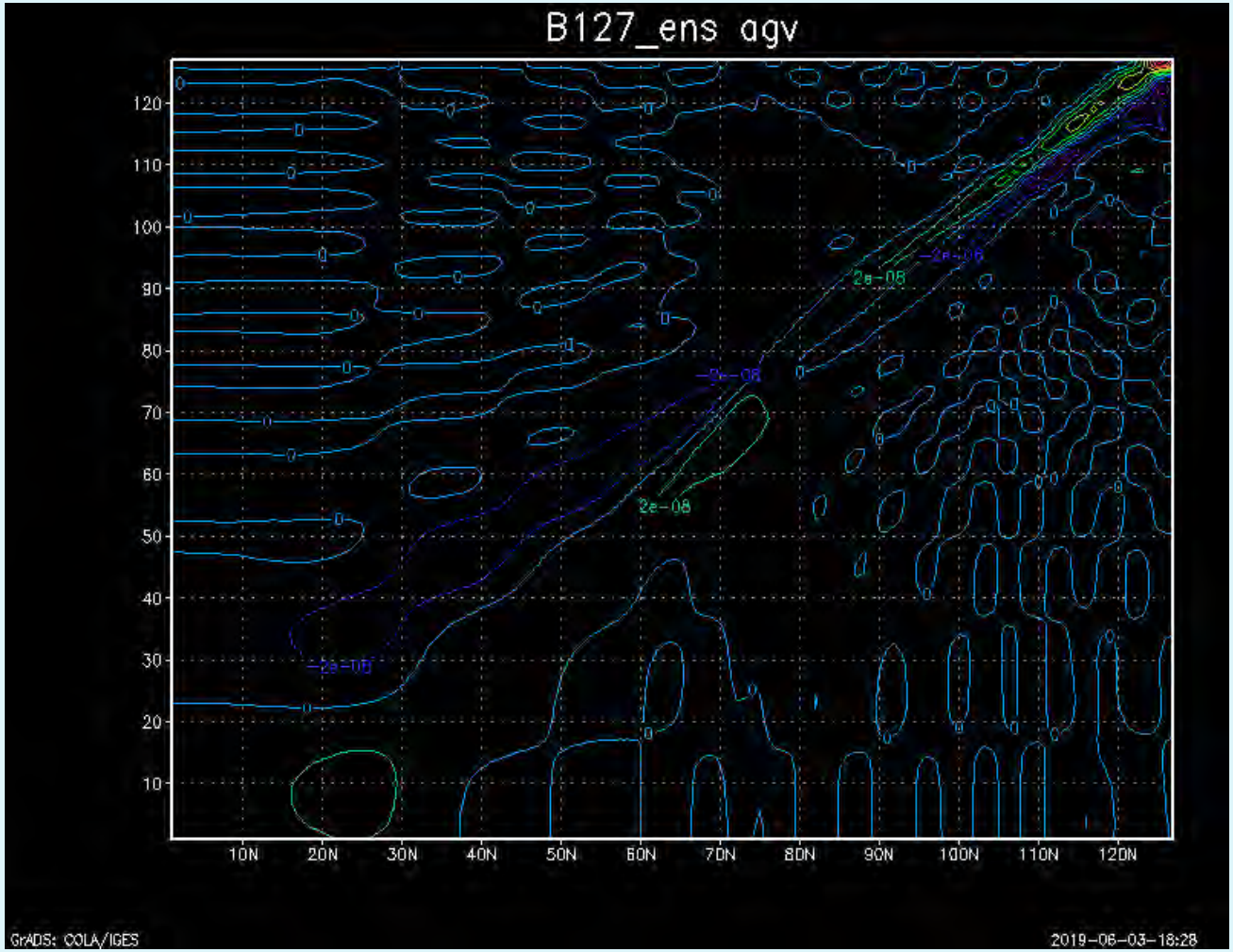
q_inc: impact of Satellite Radiances



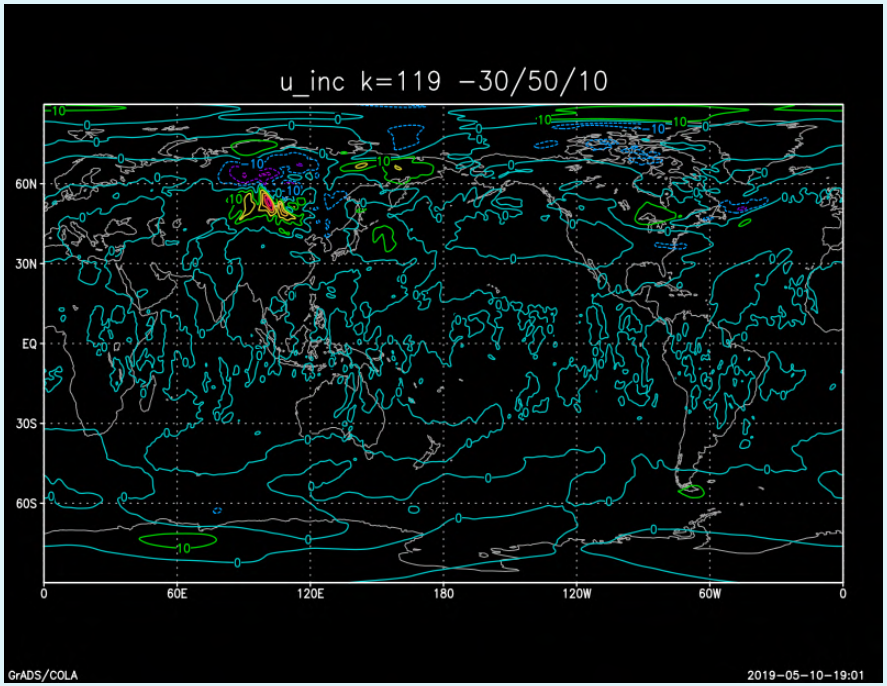
L127 old B: projection matrix btw ζ & T

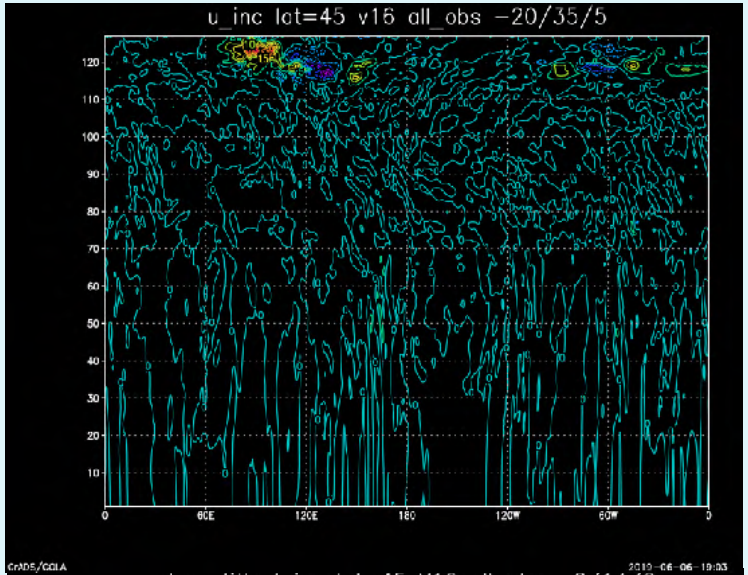


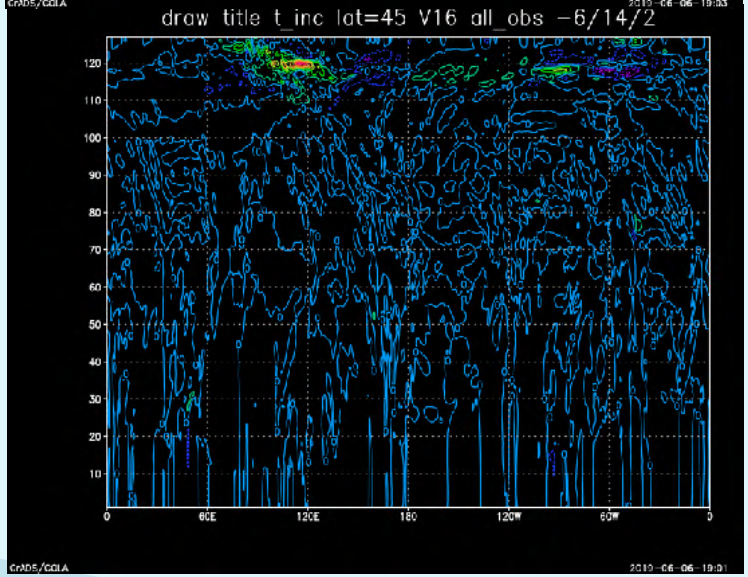
B_ens: projection matrix btw ζ & T



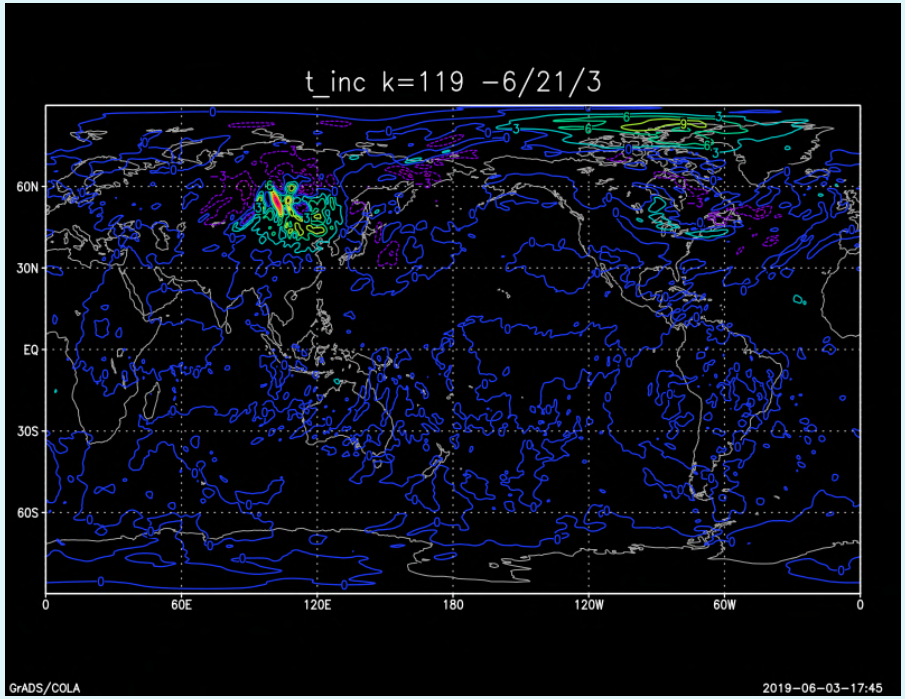
with B_ens

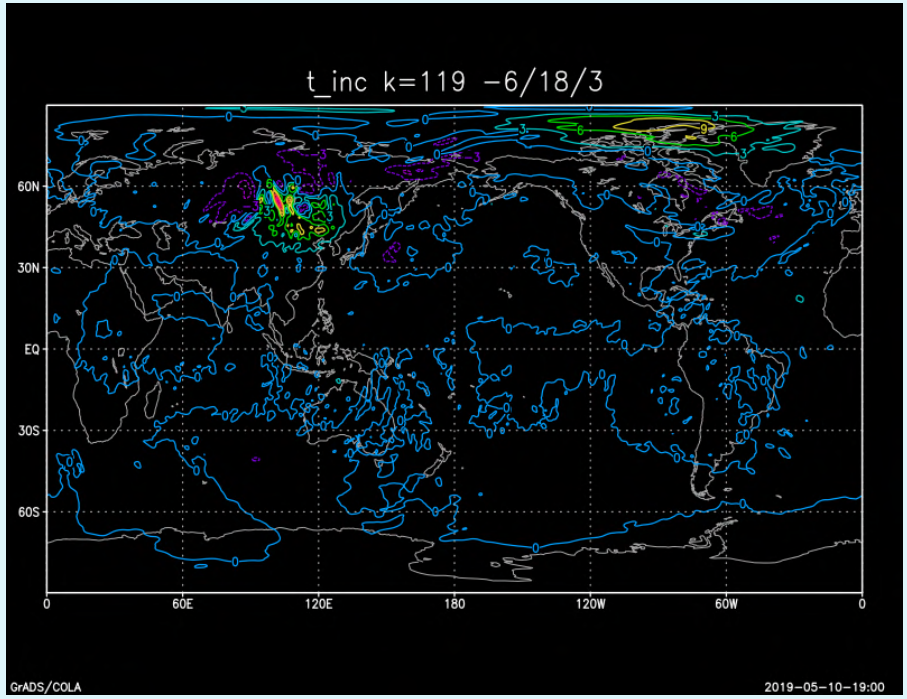

u_inc k=119 -30/50/10
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
GrADS/COLA
2019-05-10-19:01


u_inc lat=45 v16 all_obs -20/35/5
GrADS/COLA

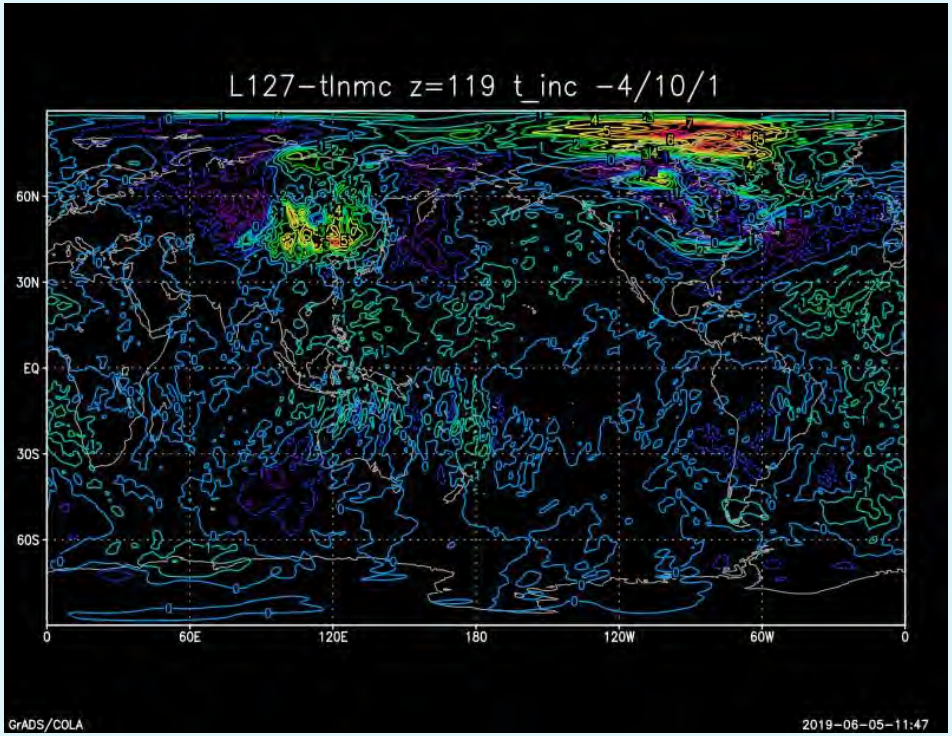

draw title t_inc lat=45 V16 all_obs -6/14/2
0
60E
120E
180
120W
60W
GrADS/COLA

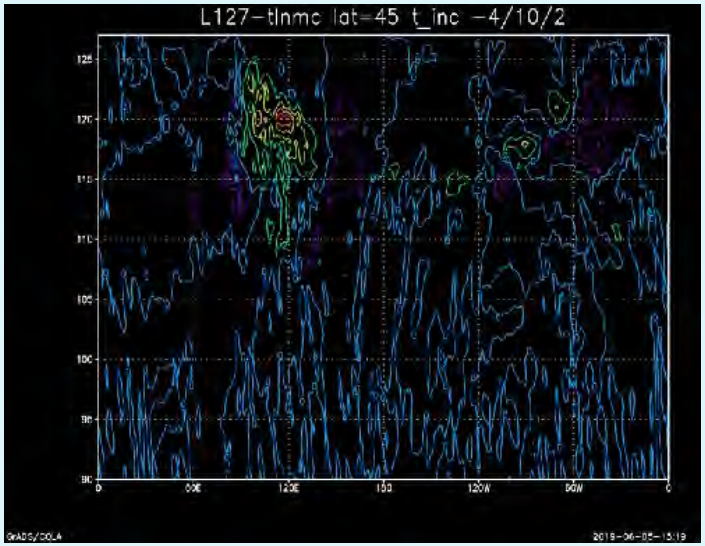
with B_ens & B_old

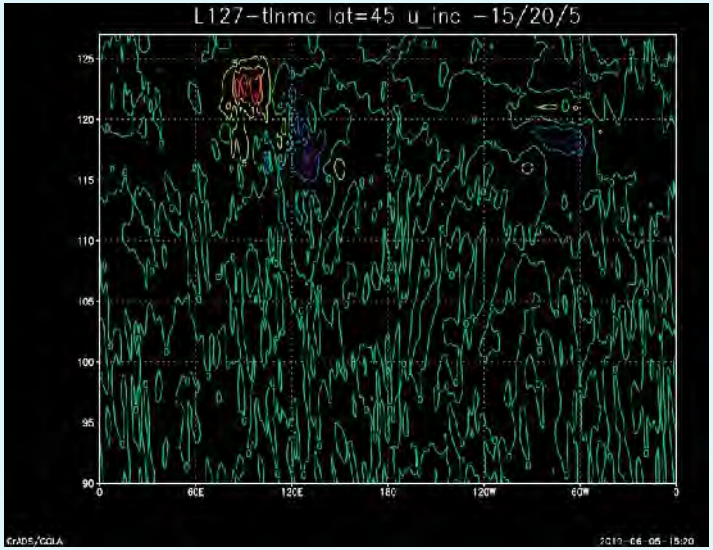




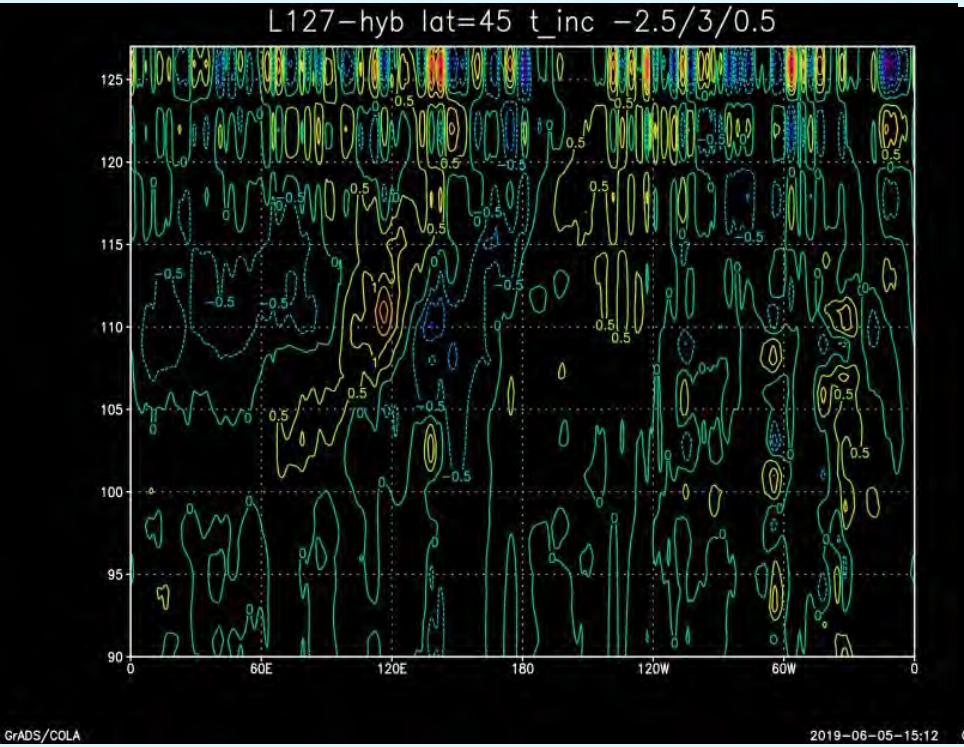
L127hyb-tlnmc

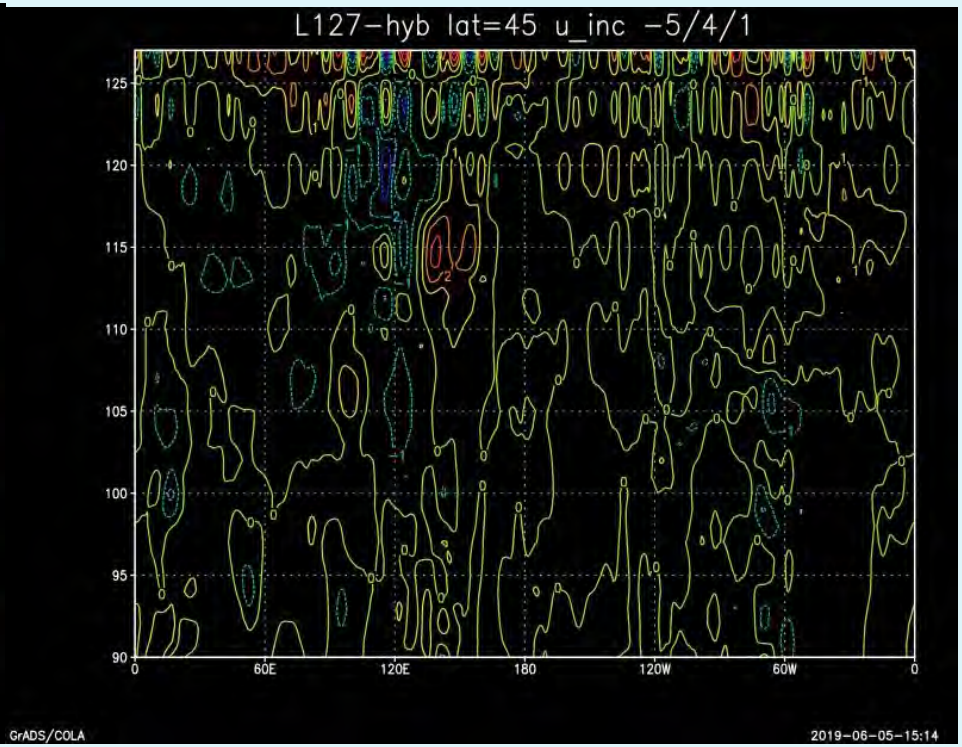




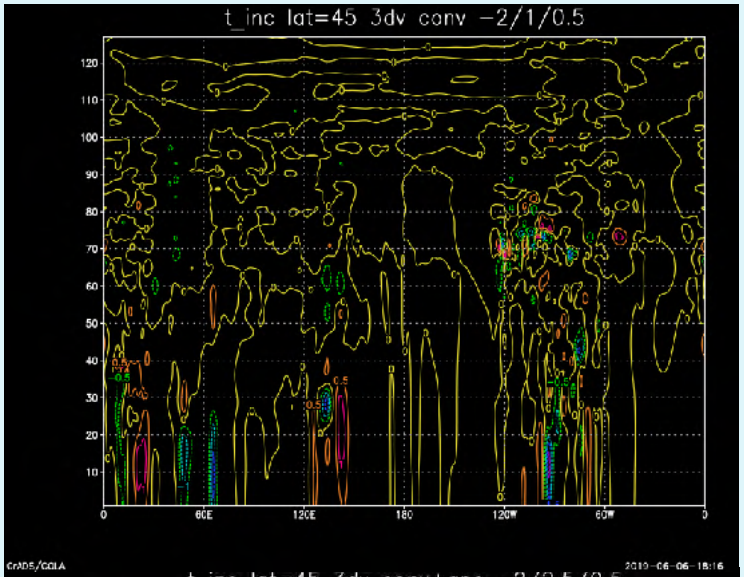


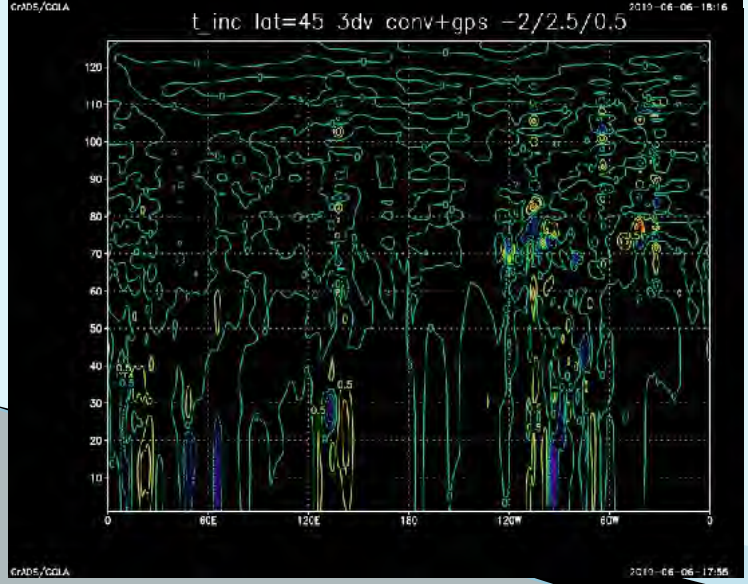
L127-hybens

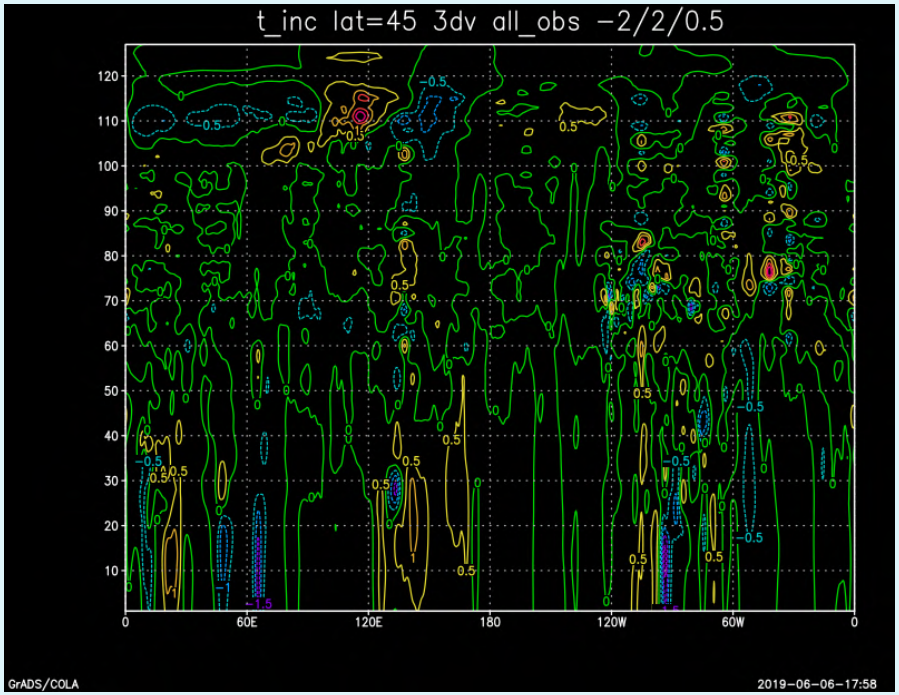

L127-hyb lat=45 t_inc -2.5/3/0.5
125
120
115
110
105
100
95
90
0
60E
120E
180
120W
60W
0
GrADS/COLA
2019-06-05-15:12


L127-hyb lat=45 u_inc -5/4/1
125
120
115
110
105
100
95
90
0
60E
120E
180
120W
60W
0
GrADS/COLA
2019-06-05-15:14

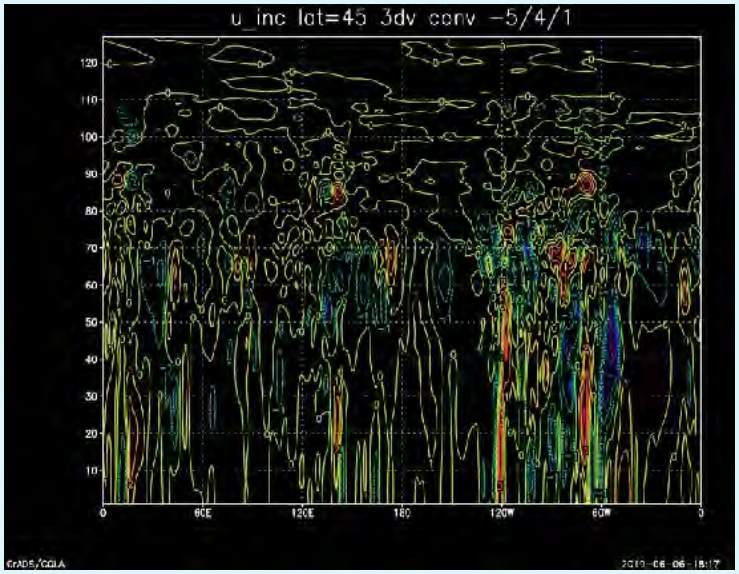
3dv t_inc

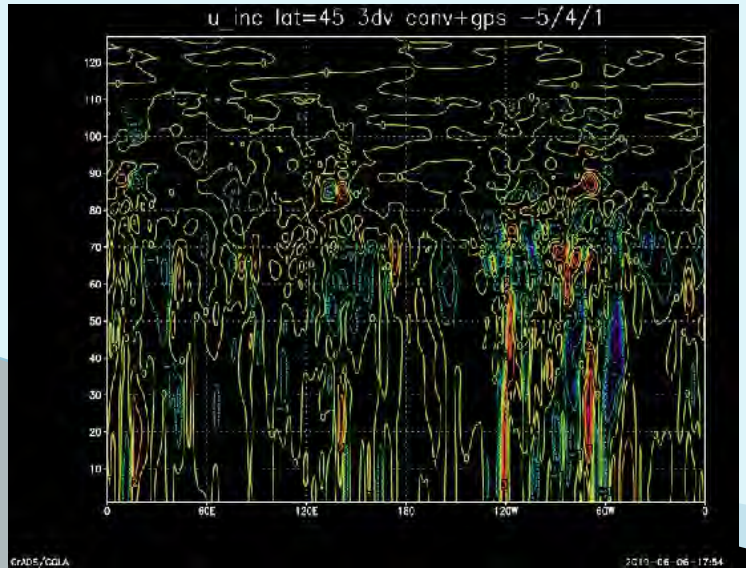

t_inc lat=45 3dv conv -2/1/0.5
GrADS/COLA

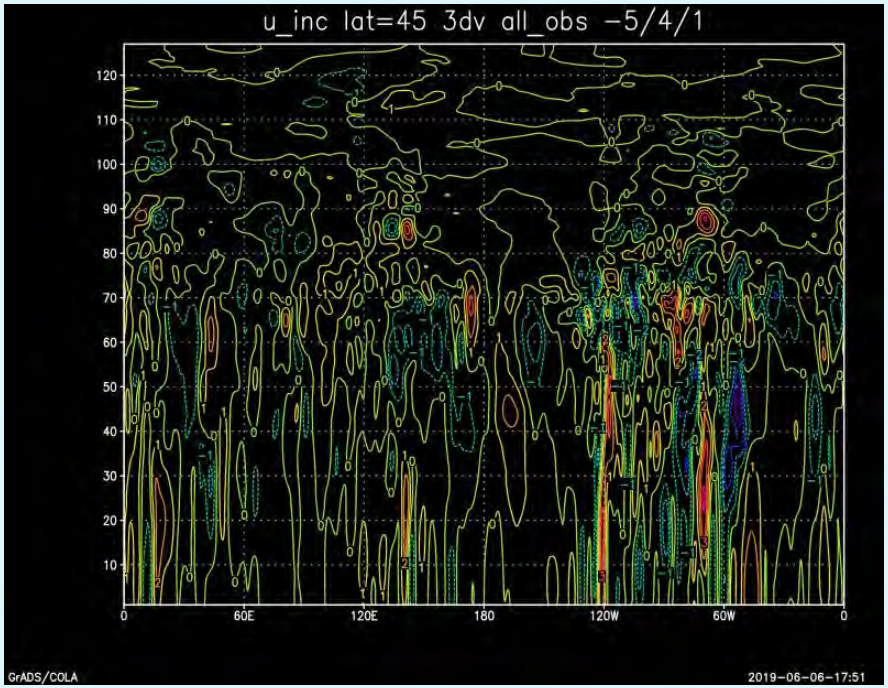

t_inc lat=45 3dv conv+gps -2/2.5/0.5
GrADS/COLA


t_inc lat=45 3dv all_obs -2/2/0.5
GrADS/COLA
2019-06-06-17:58

3dv u_inc

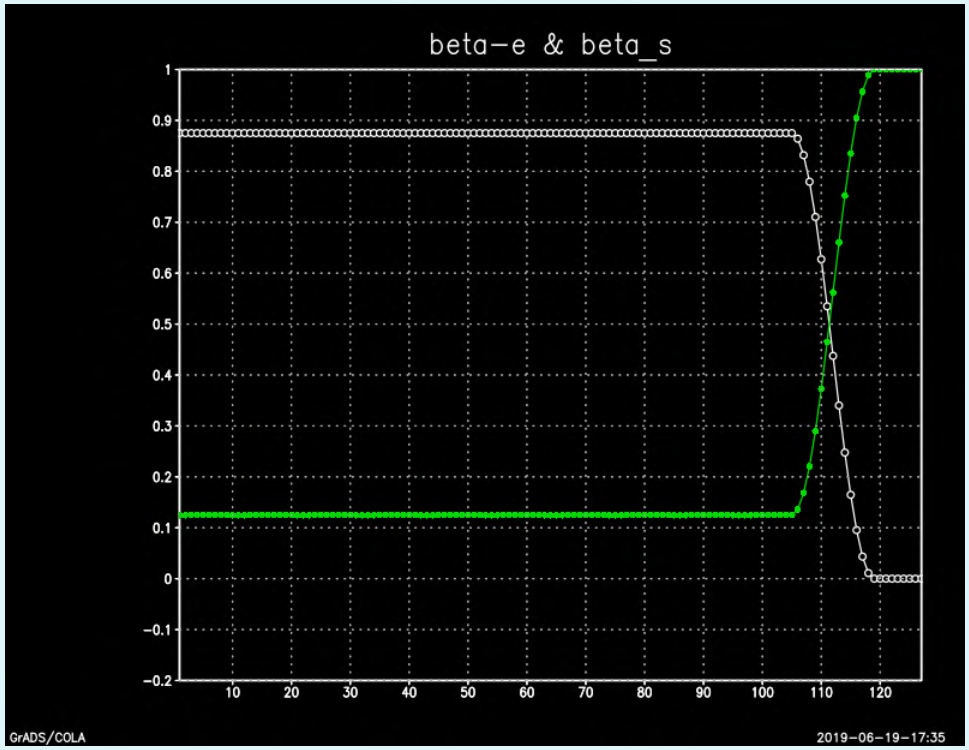

u_inc lat=45 3dv conv −5/4/1
120
110
100
90
80
70
60
50
40
30
20
10
0
60E
120E
180
120W
60W
0


u_inc lat=45 3dv conv+gps −5/4/1
120
110
100
90
80
70
60
50
40
30
20
10
0
60E
120E
180
120W
60W
0

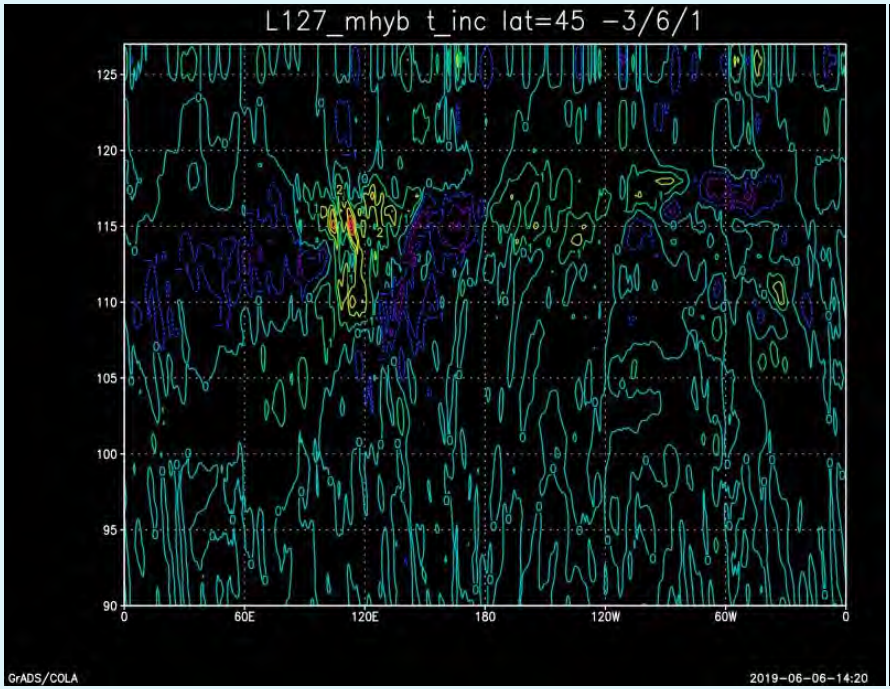

u_inc lat=45 3dv all_obs −5/4/1
120
110
100
90
80
70
60
50
40
30
20
10
0
60E
120E
180
120W
60W
0
GrADS/COLA
2019-06-06-17:51

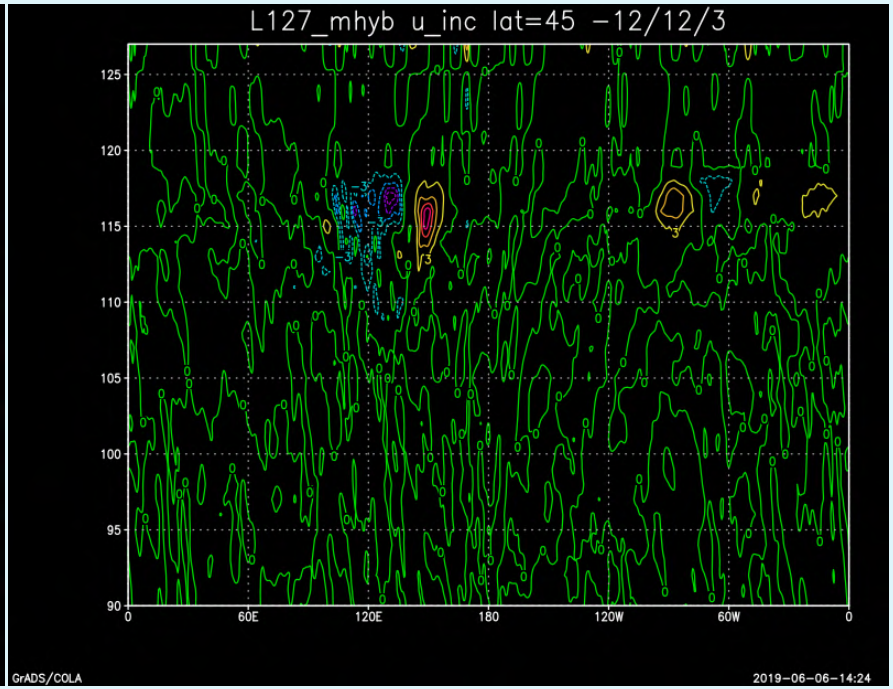
solutions

Modify hybens_info above 119 ->3dv



L127_mhyb


L127_mhyb t_inc lat=45 -3/6/1
125
120
115
110
105
100
95
90
0
60E
120E
180
120W
60W
0
GrADS/COLA
2019-06-06-14:20

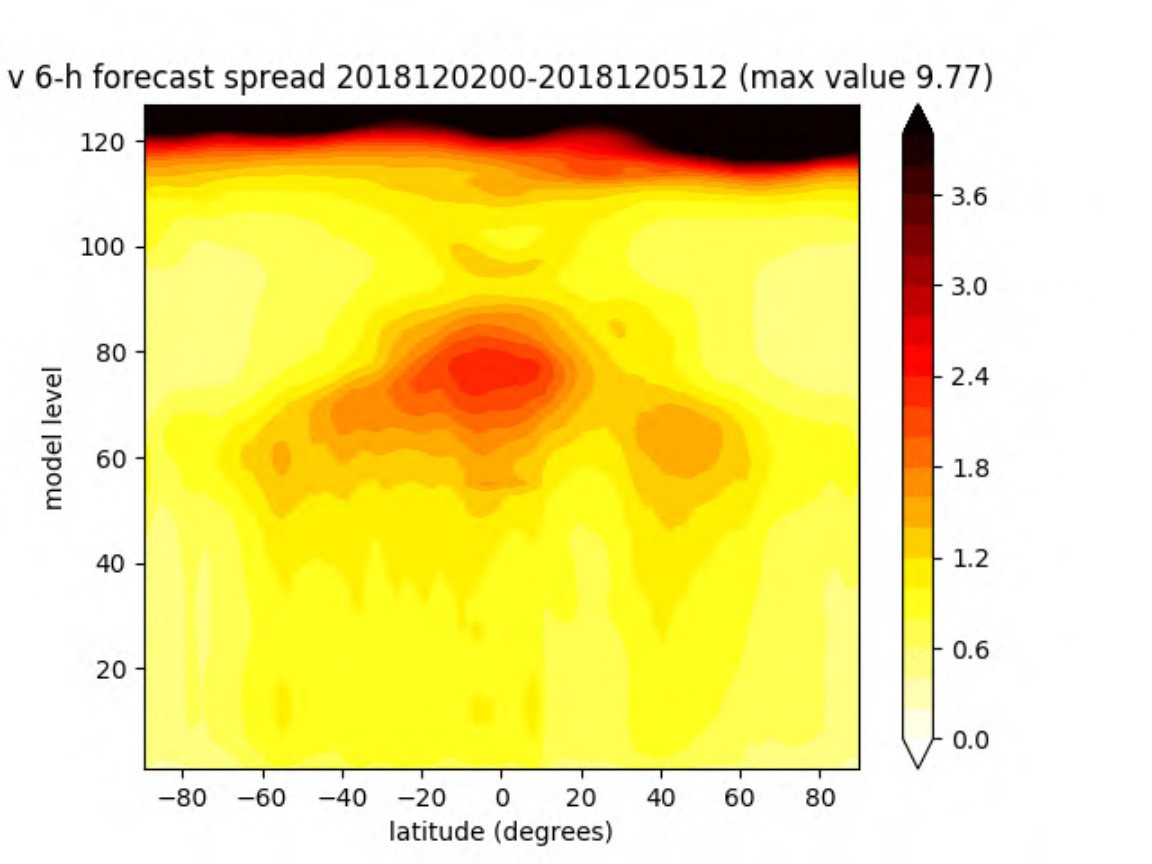

L127_mhyb u_inc lat=45 -12/12/3
125
120
115
110
105
100
95
90
0
60E
120E
180
120W
60W
0
GrADS/COLA
2019-06-06-14:24

Effect of enhanced sponge layer on ensemble spread (C192)

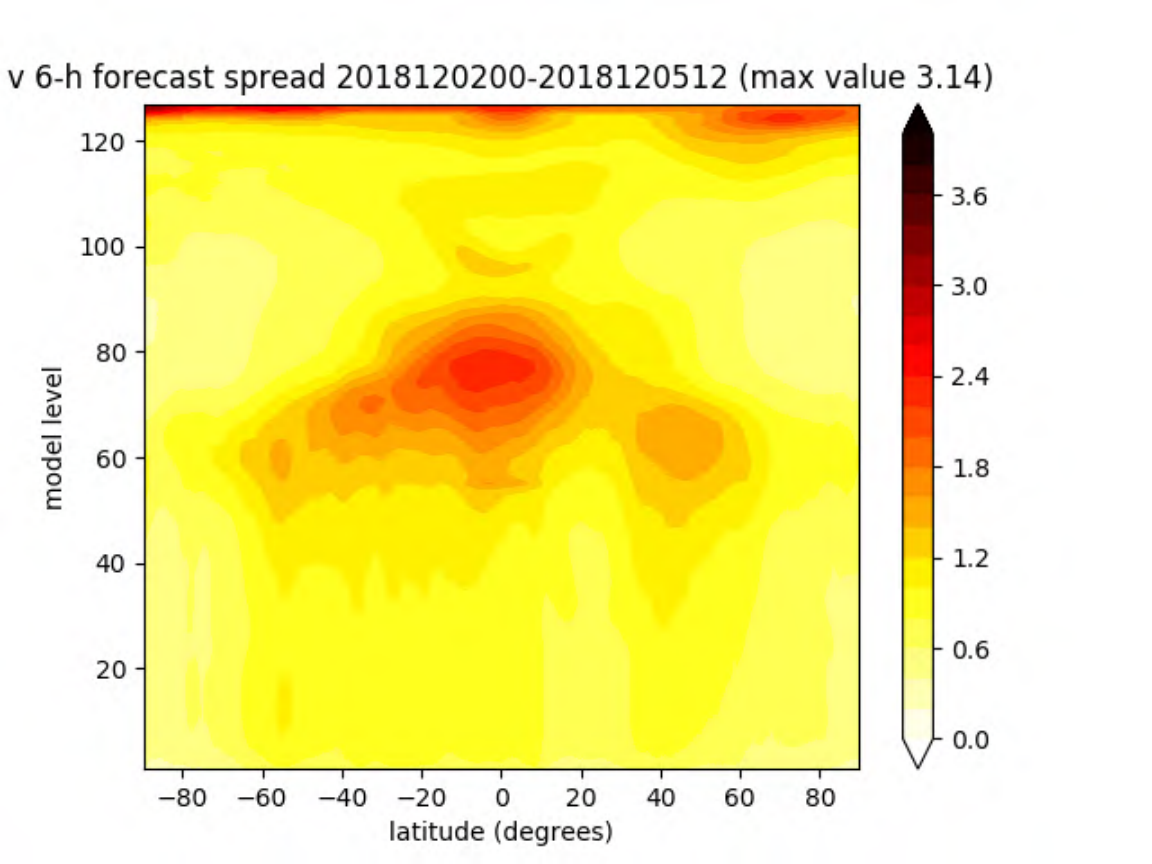
(with the new gravity wave drag scheme turned on)

Jeffrey Whitaker & Funglin Yang

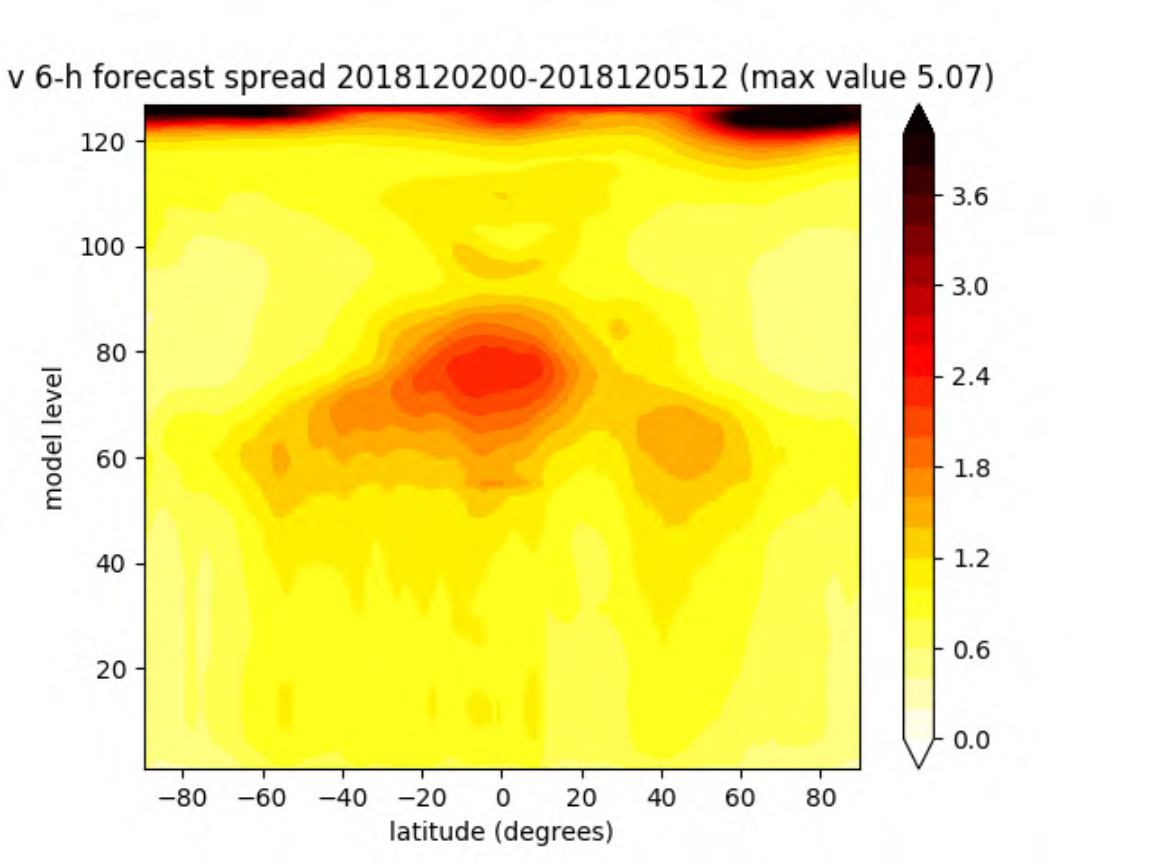
Zonal mean v spread (default damping) dt_atmos=300 (k_split,n_split=1,6)



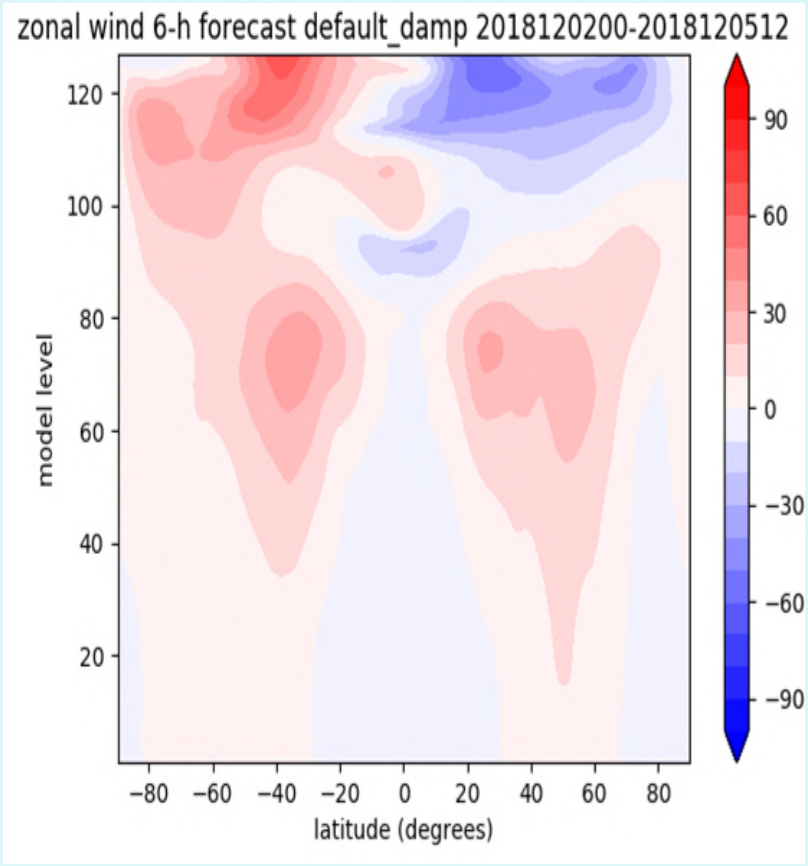
Zonal mean v spread (enhanced divergence damping, tau = 1) dt_atmos=450 (k_split,n_split=1,6)

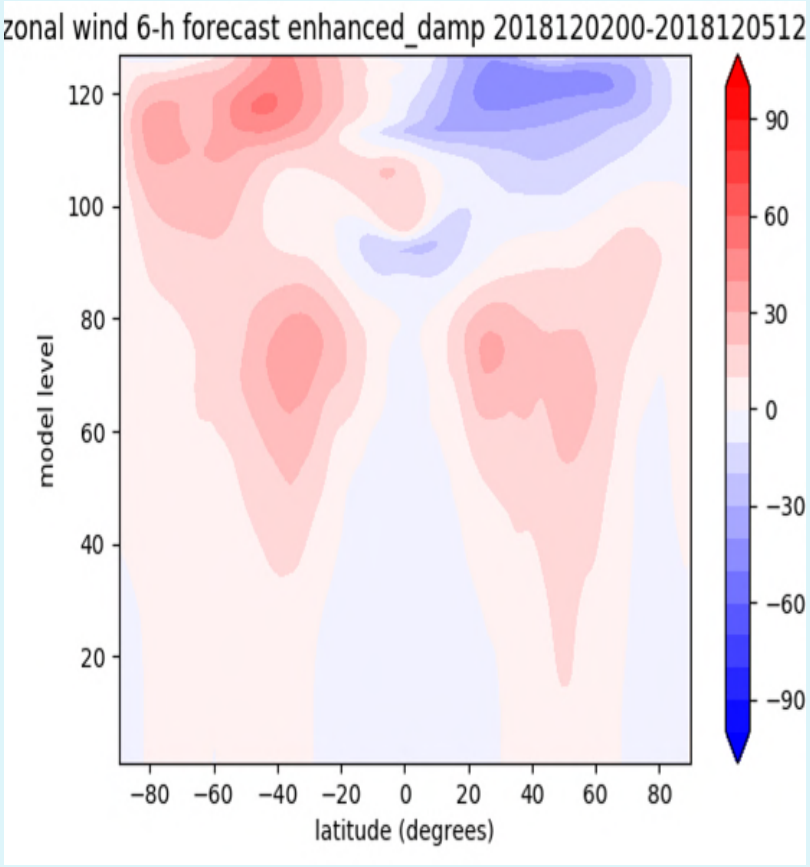


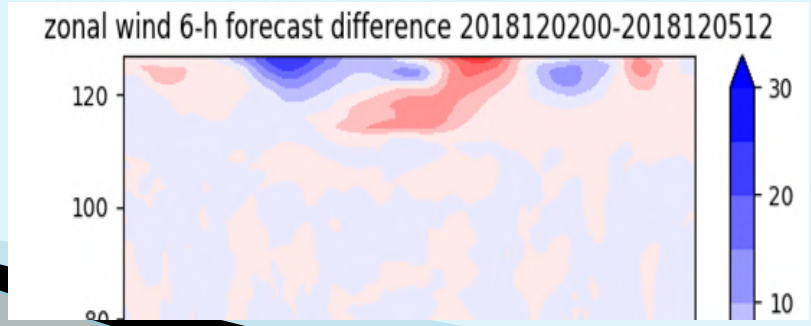
Zonal mean v spread (enhanced divergence damping, tau=5) dt_atmos=300 (k_split,n_split=1,6)



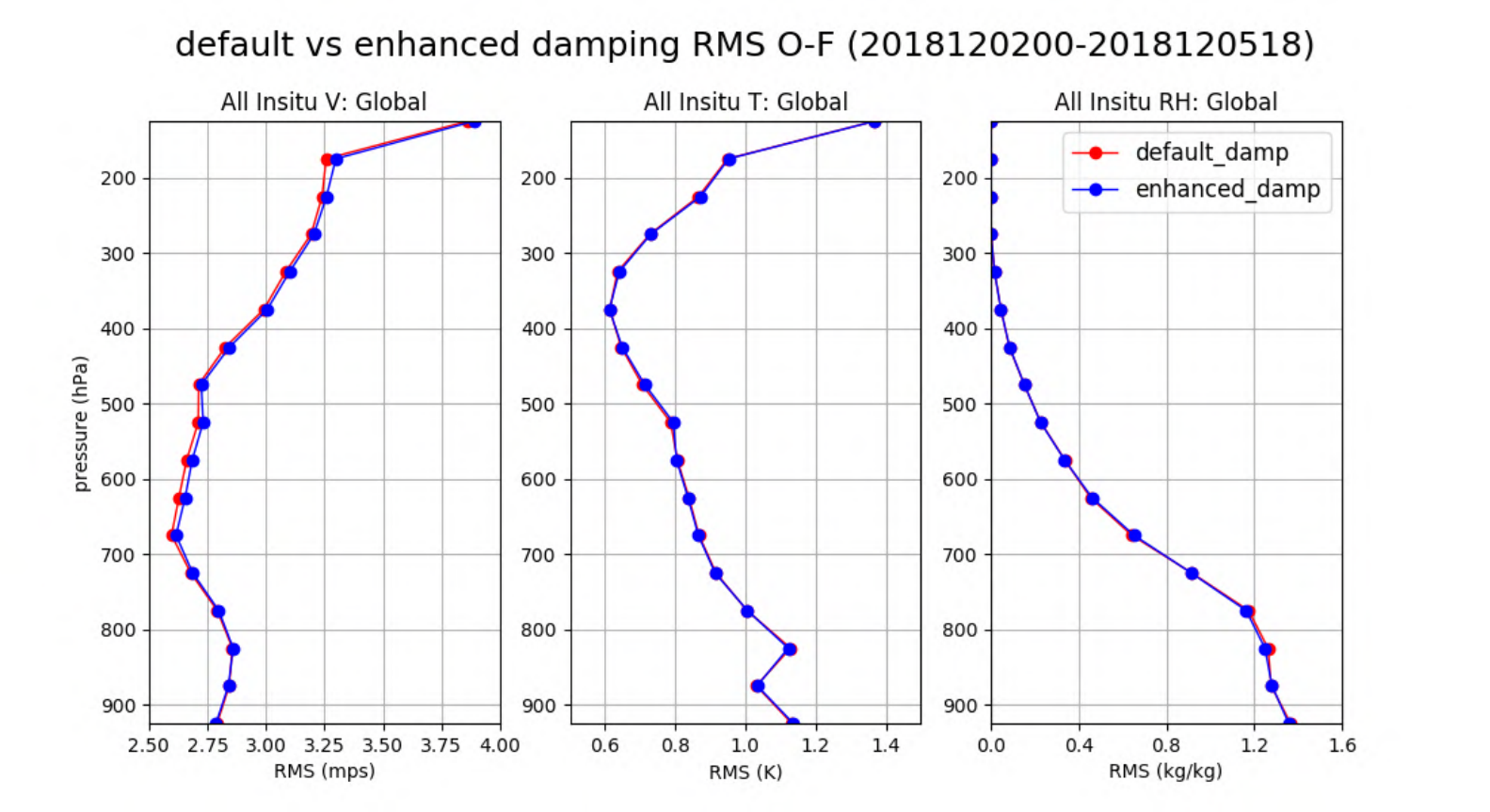
Ensemble mean zonal mean zonal wind impacts







Innov stats are about the same except winds



Model Damping Adjustment

- Spread gets up to 10 mps in the zonal mean near the model top with default damping
- Reduced by 3x with enhanced damping.
- Innovation statistics look about the same.
- Zonal wind speed reduced by up to 25 mps at top of model.
- Time step must be reduced with default damping to avoid occasional model crashes.

current numbers from Funglin Yang:

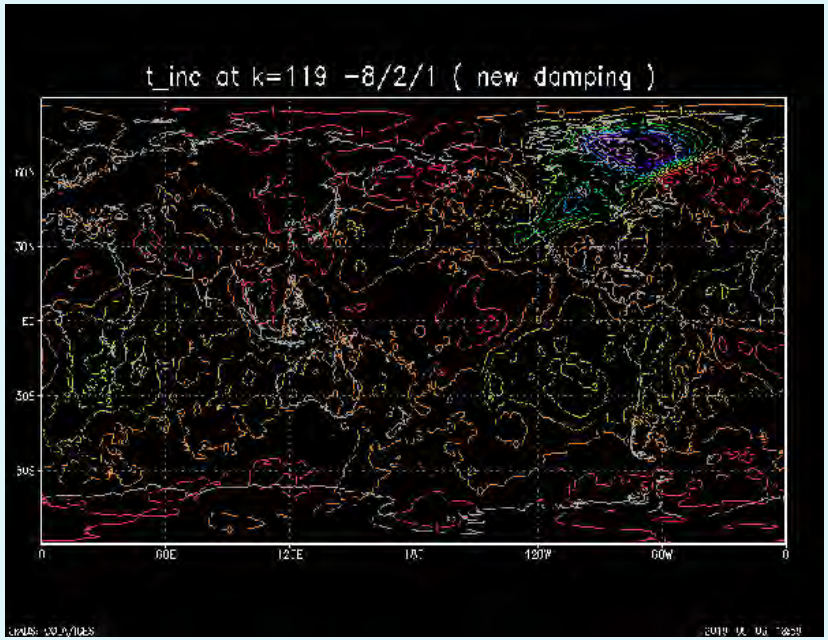
tau=5.0

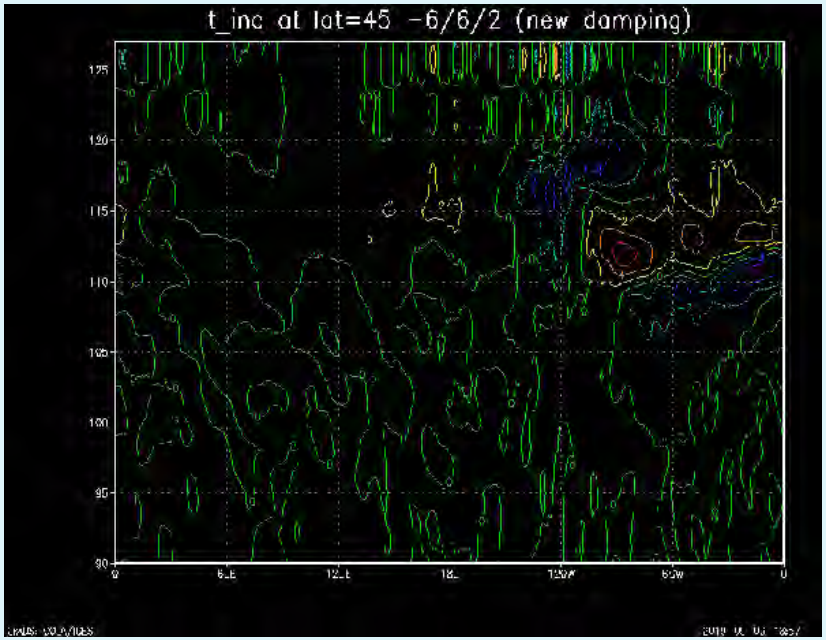
rf_cutoff=1000.

d2_bg_k1=0.20

d2_bg_k2=0.0

impact to upper layers from new damping





analysis increments with default damping -6/18

Minimization issues with GPSRO in L127 (Kristen Bathmann)

Super-refraction occurs when the atmospheric refractivity gradient is large enough that the ray does not leave the atmosphere- it is trapped within the layer. This can happen at the top of the boundary layer.

Below this layer, there are an infinite number of atmospheric states that could produce identical GPSRO profiles-an ill posed problem.

In setupbend, qc checks for this within the boundary layer, but the top of the boundary layer is hard-coded at level 23.

nsigstart=min(23,nsig)

Issues in setupbend: Integration Grid

Bending angle α is computed as

The integral is computed by the trapezoidal method over a vertical grid, using

80 grid points. This is too coarse when going to 127 layers.

In obsmod.F90:

grids_dim=80

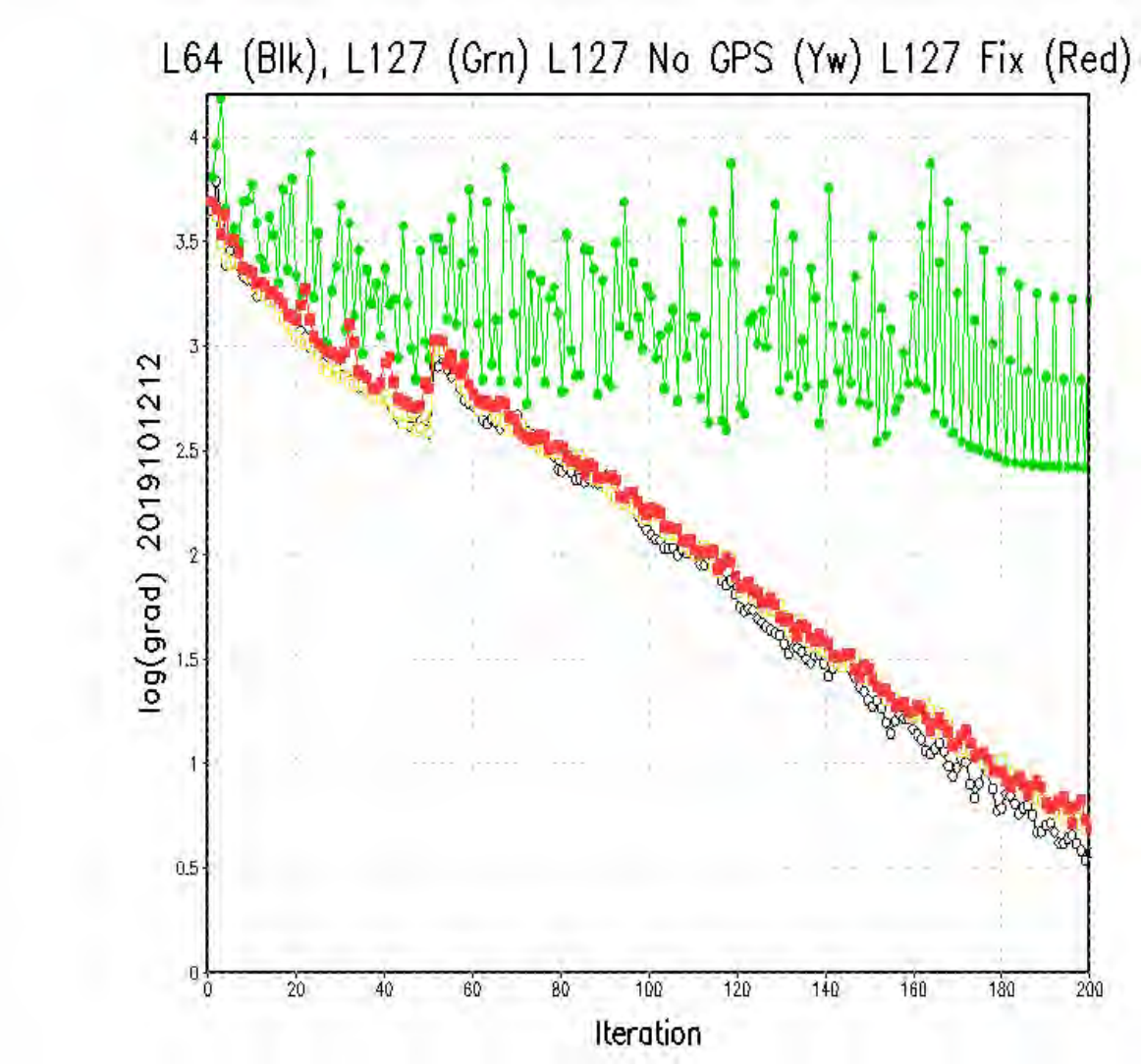
In setupbend.f90:

real(r_kind),parameter::ds=10000.0_r_kind

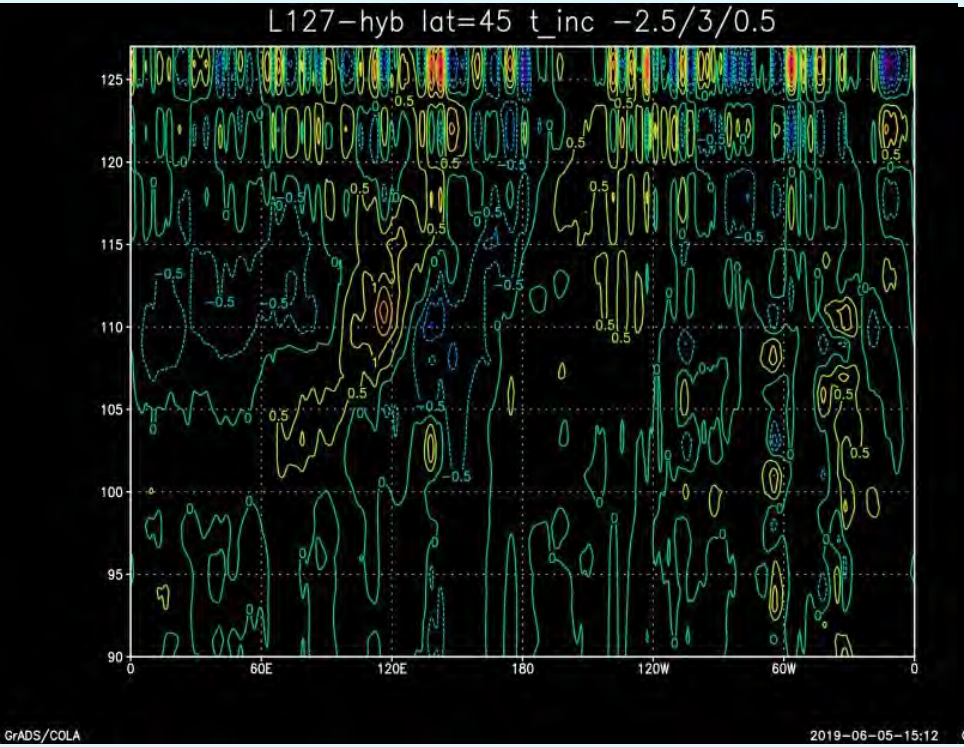
Issues in setupbend: Integration Grid

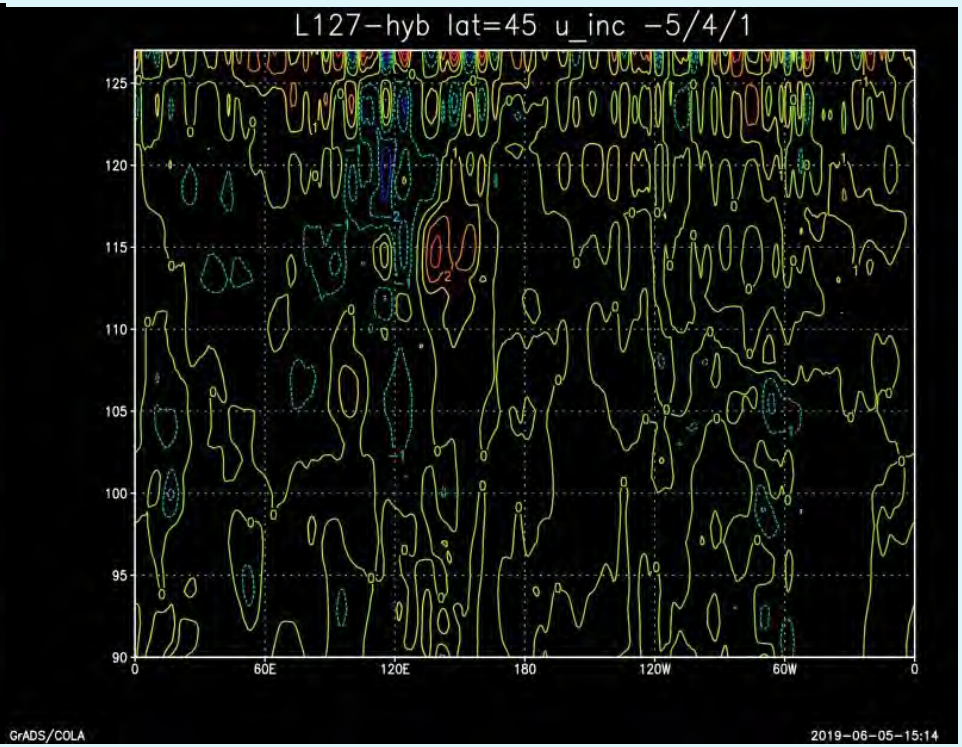
A simple test to try and fix this:
For super-refractive qc, change
nsigstart=min(23,nsig)
to
nsigstart=min(55,nsig)

For the integration grid, change
grids_dim=80
real(r_kind),parameter::ds=10000.0_r_kind
to
grids_dim=160
real(r_kind),parameter::ds=5000.0_r_kind
Also set gpstop to 60 km, as suggested.

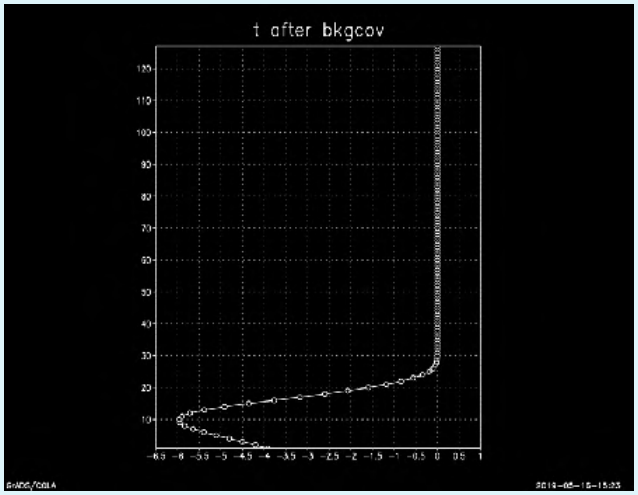

L64 (Blk), L127 (Grn) L127 No GPS (Yw) L127 Fix (Red)
log(grad) 20191012 12
Iteration
0
0.5
1
1.5
2
2.5
3
3.5
4
0
20
40
60
80
100
120
140
160
180
200

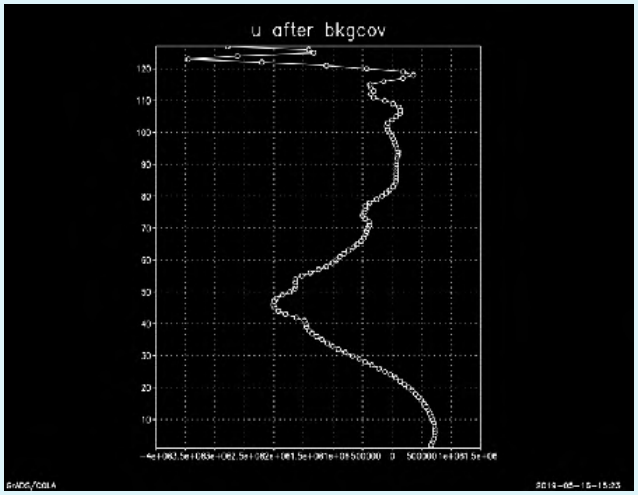
L127-hybens

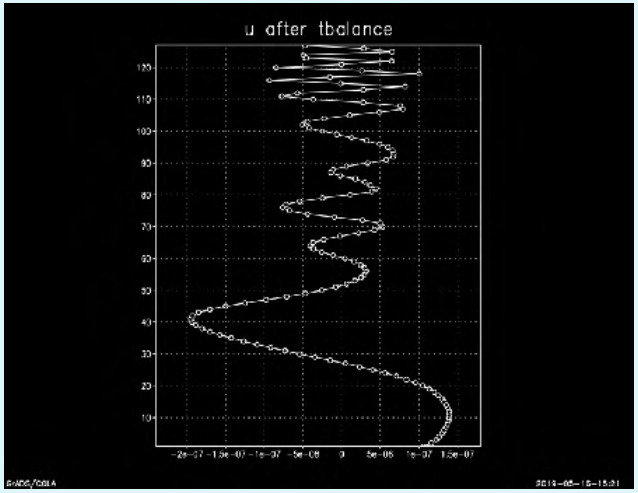

L127-hyb lat=45 t_inc -2.5/3/0.5
125
120
115
110
105
100
95
90
0
60E
120E
180
120W
60W
0
GrADS/COLA
2019-06-05-15:12

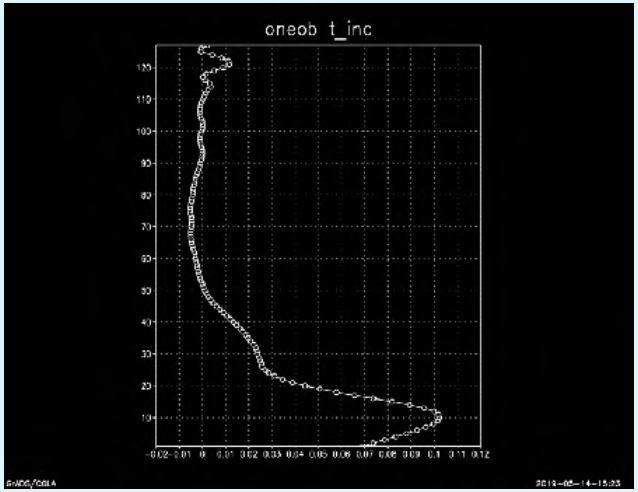

L127-hyb lat=45 u_inc -5/4/1
125
120
115
110
105
100
95
90
0
60E
120E
180
120W
60W
0
GrADS/COLA
2019-06-05-15:14

use oneob test to check B









Strong constraint

Implicit Normal Mode Initialization

Vertical functions for dynamic constraint:

input: vertical grid structure + global mean (reference) T & P

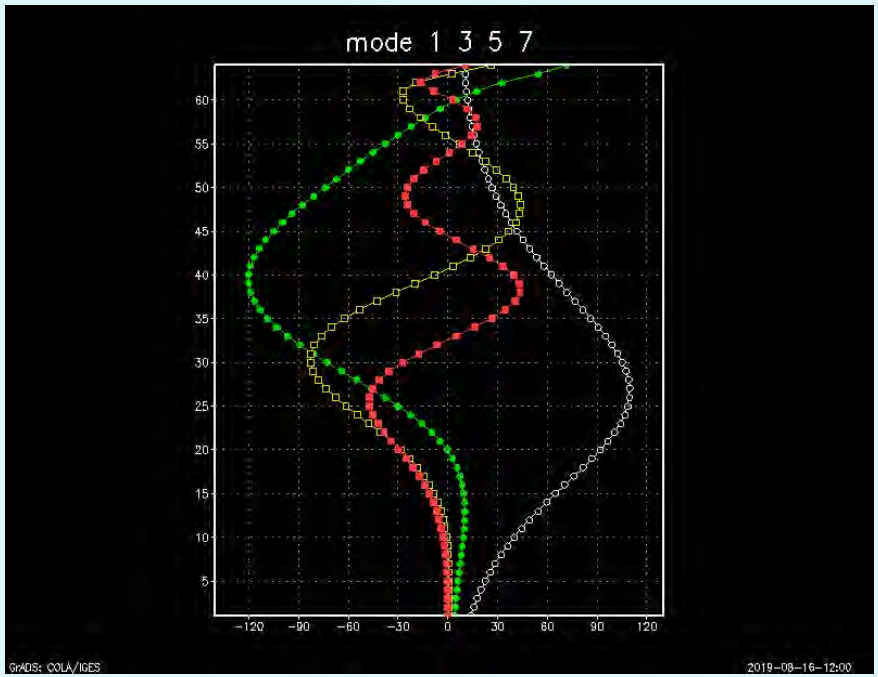
simplify linear eq's of divergence, surface pressure and virtual temperature to get

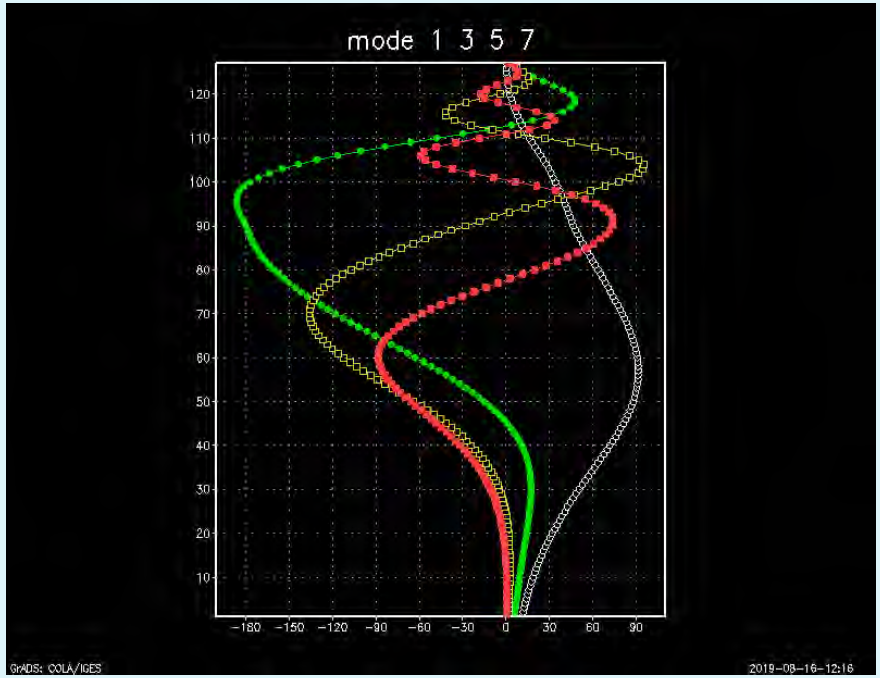
$$d2D/dt2 = -Q * \text{laplacian}(D)$$

$$Q = H*S + A*B$$

Linearization of dynamics about rest state, derive coupling matrix and obtain eigenvectors. The vertical modes are the right eigenvectors of Q and the scale geopotential values for each vertical mode are the eigenvalues of Q.

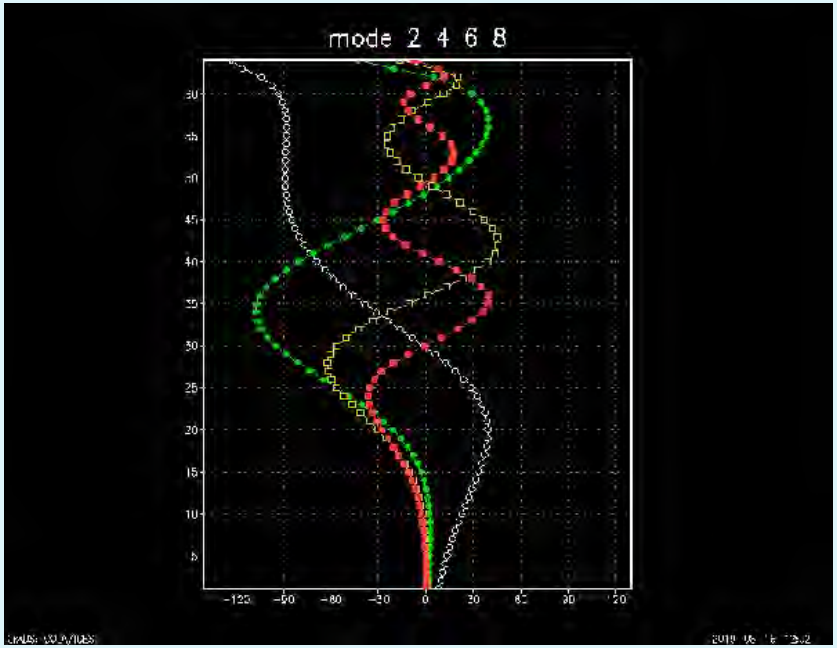
Vertical Structure functions: L127&L64

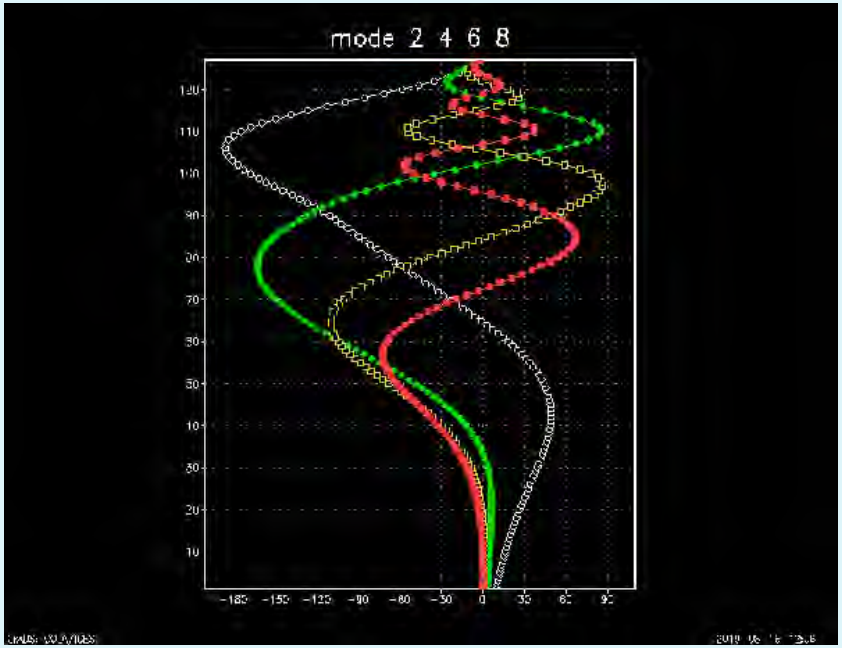




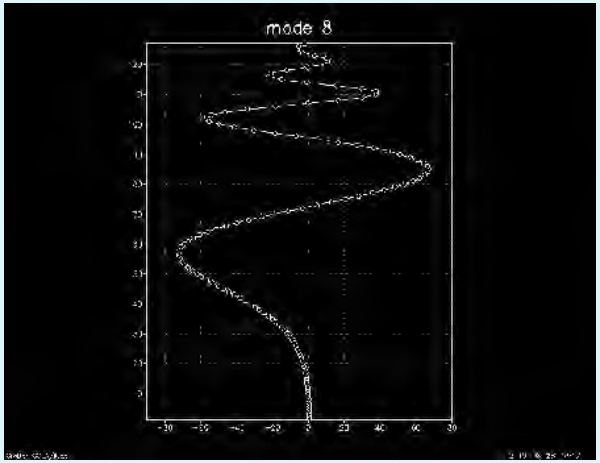
inmi adjustments (del_t) are the linear combination of these modes

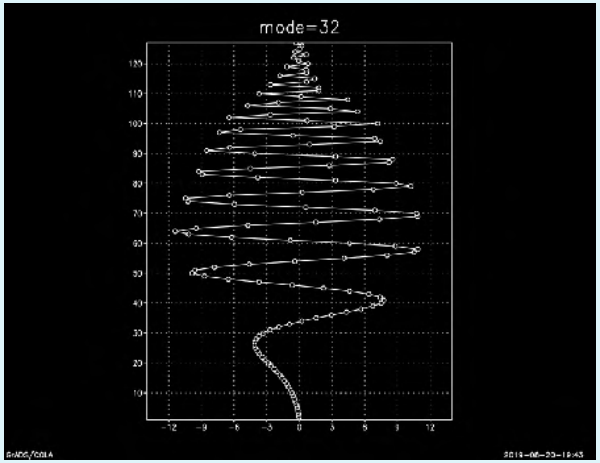
Vertical Structure functions: L127&L64

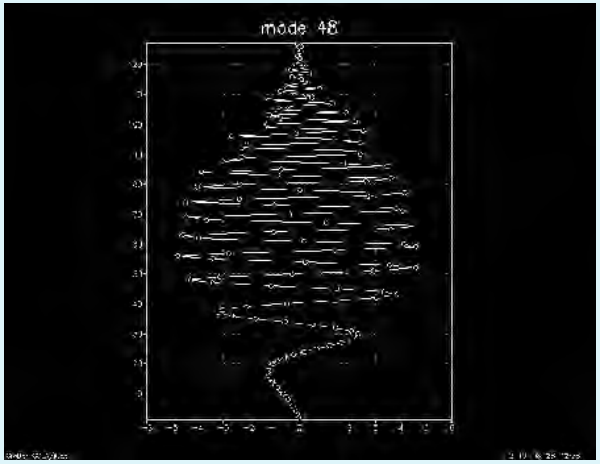


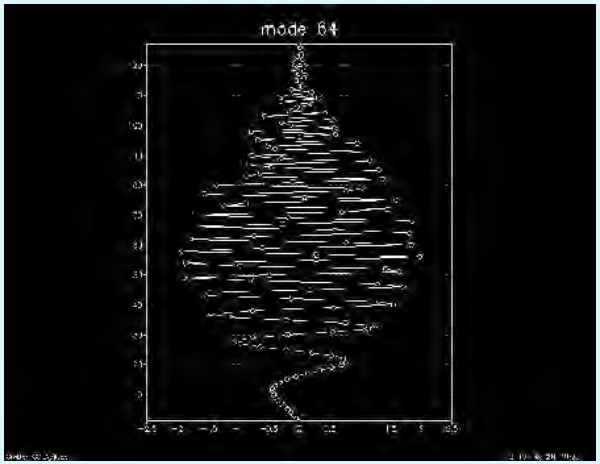


Vertical Structure functions: L127



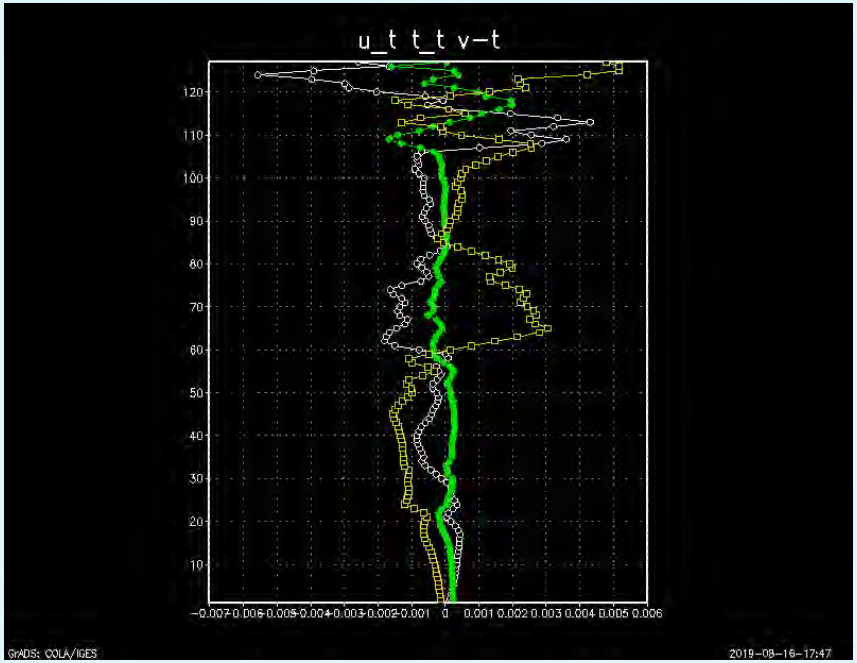


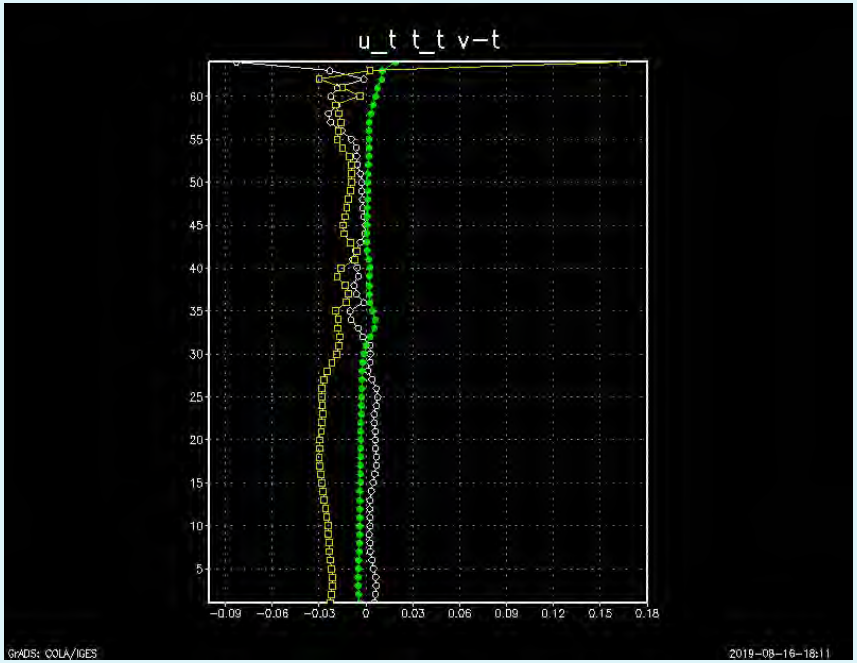




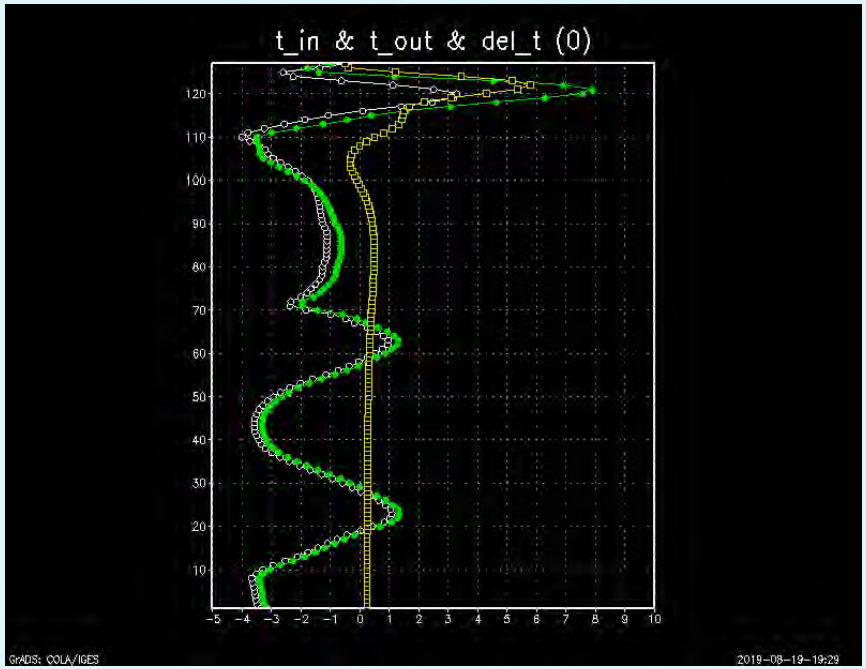
small top amplitude with vm64!

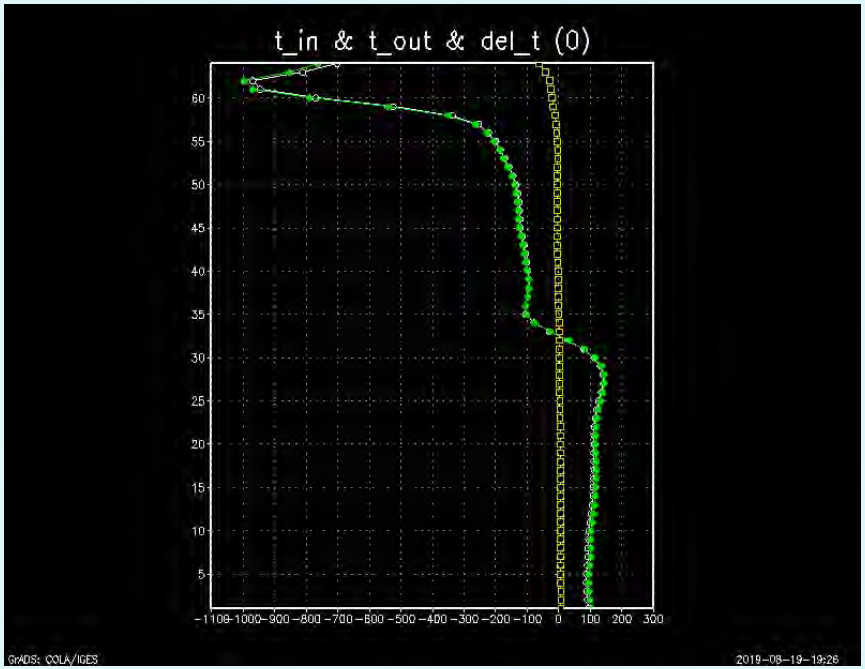
tendency 127 & tendency 64: input to INMI



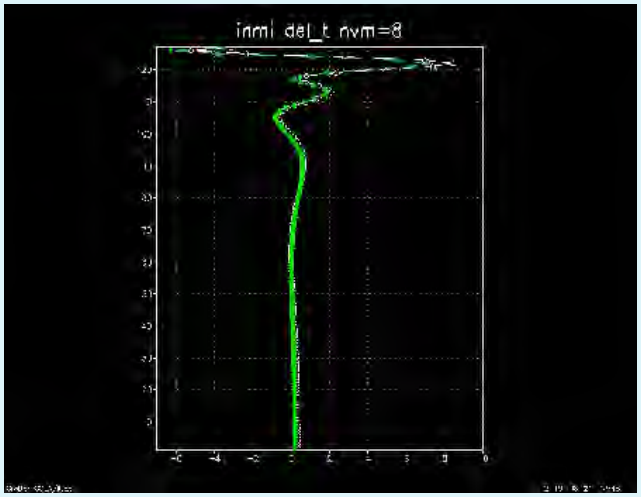


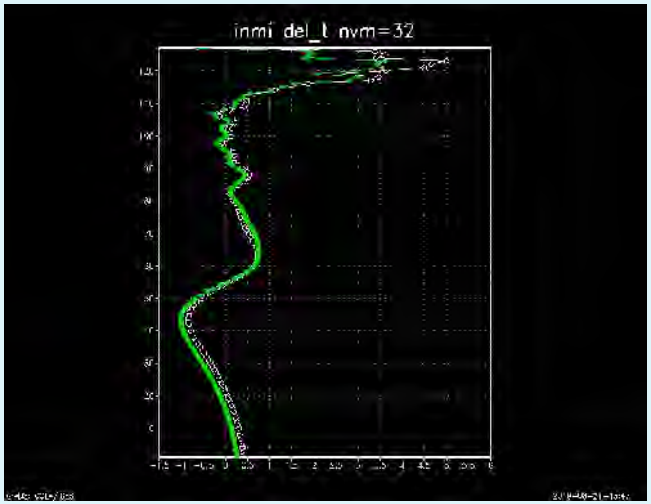
del_t for a iteration

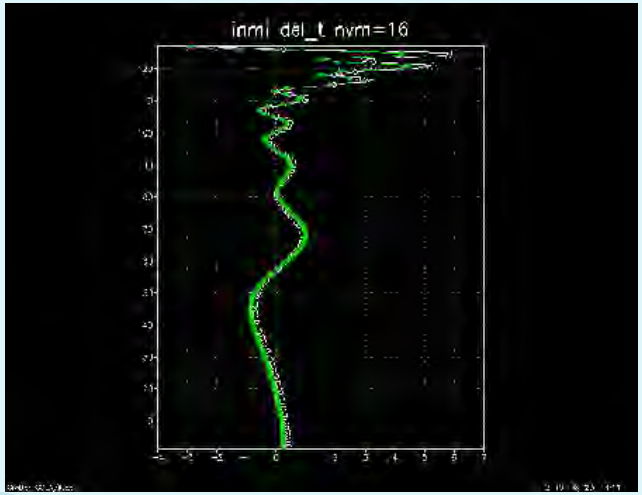


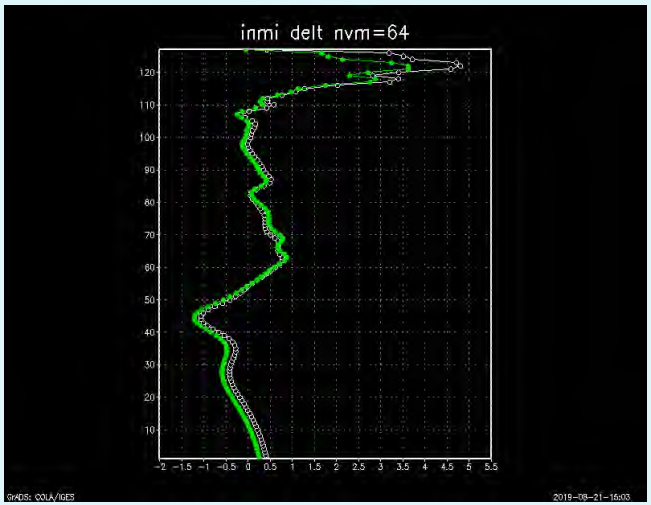


Need more modes to explain variances in the lower layers where there are forcings.

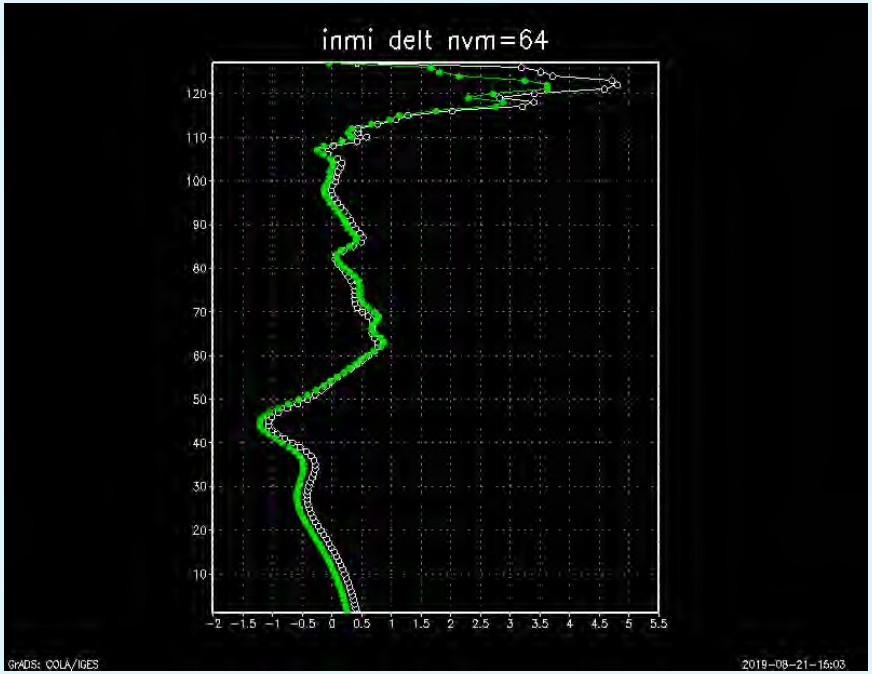


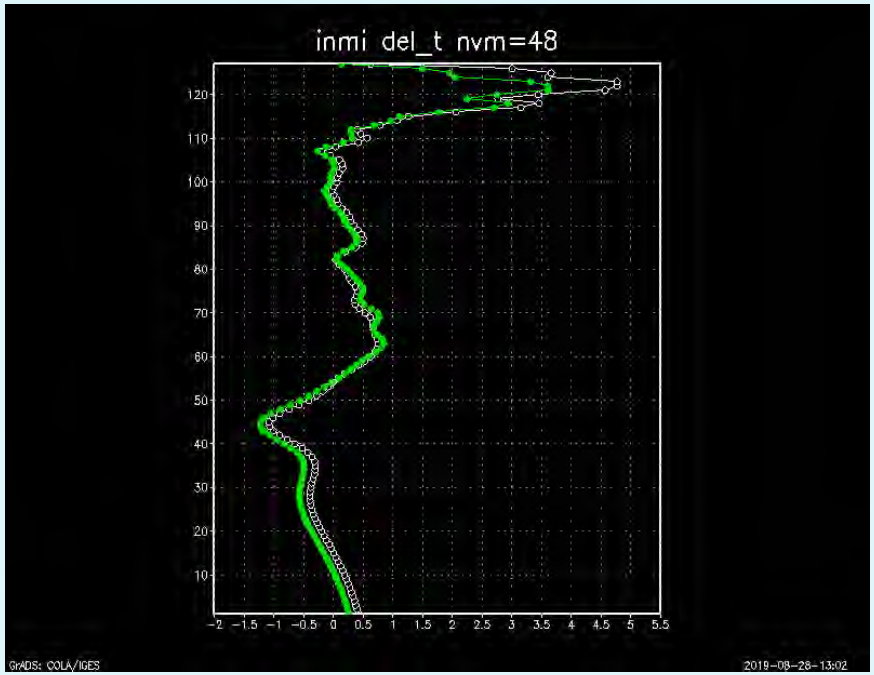




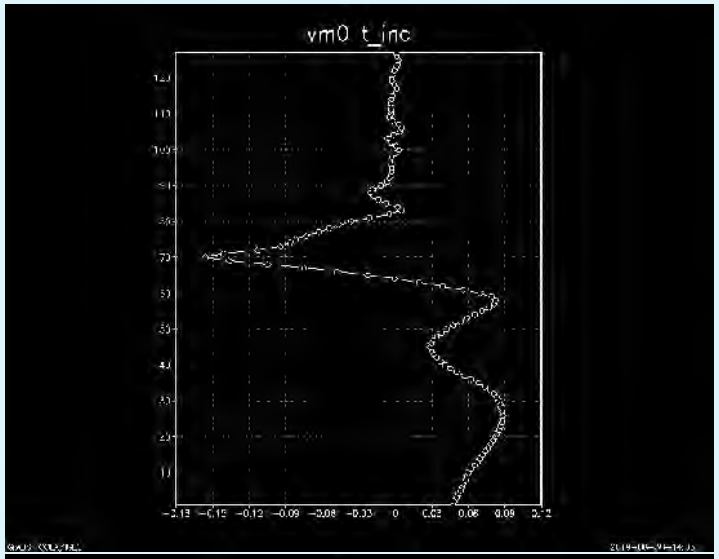


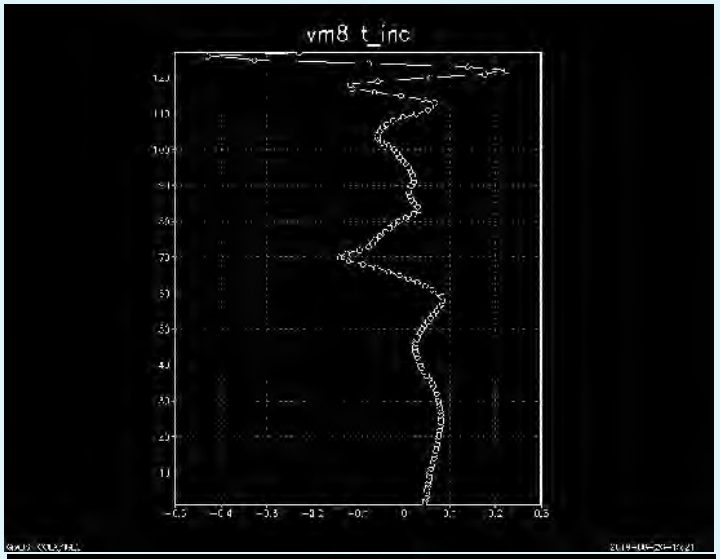
Resource Consideration: nvm64 & nvm48

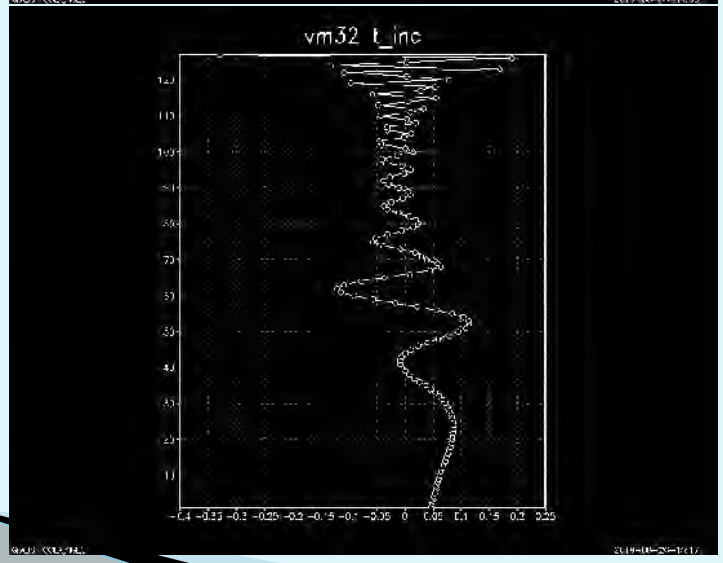


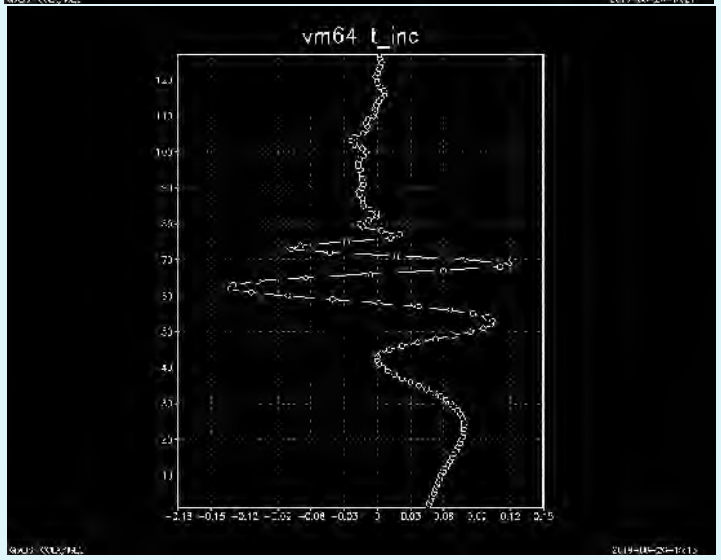


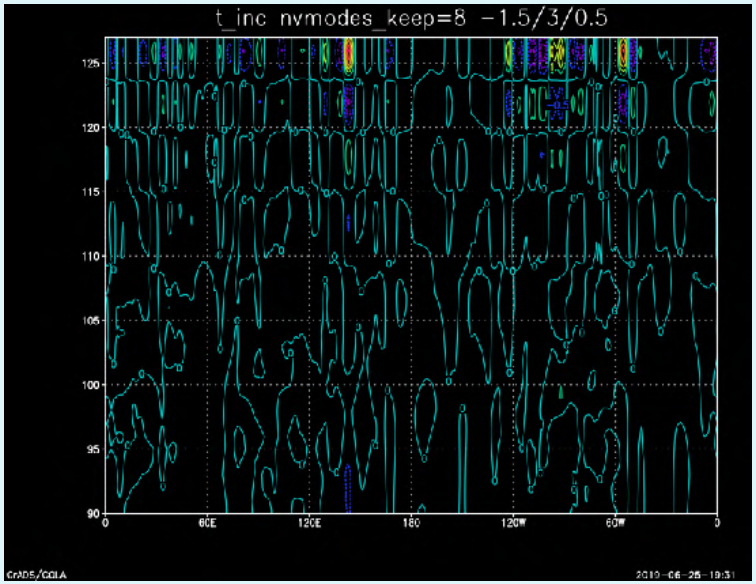
Example of Analysis T_inc

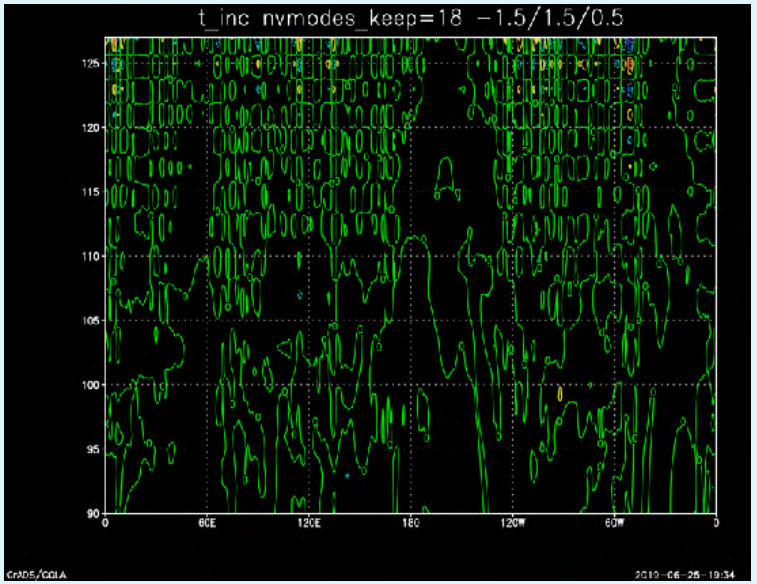


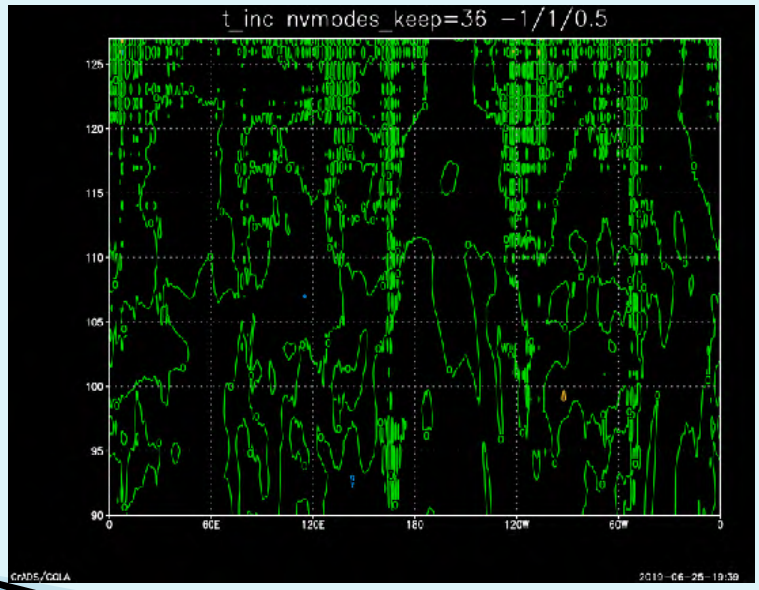


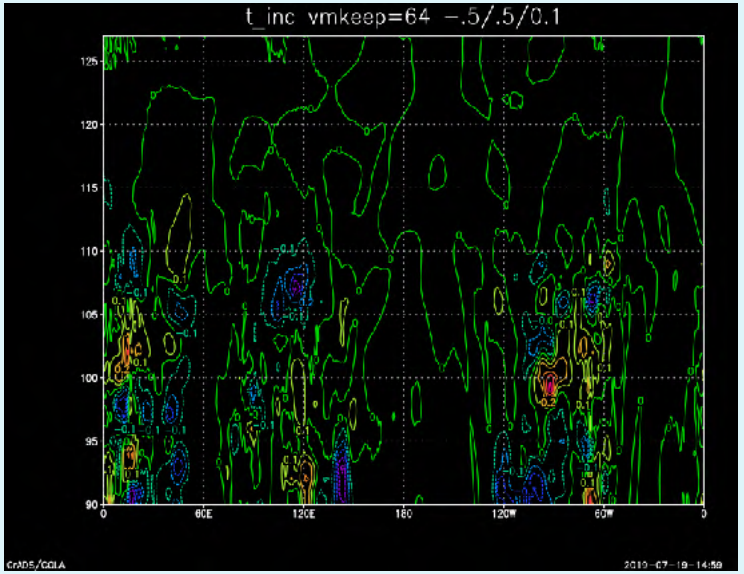












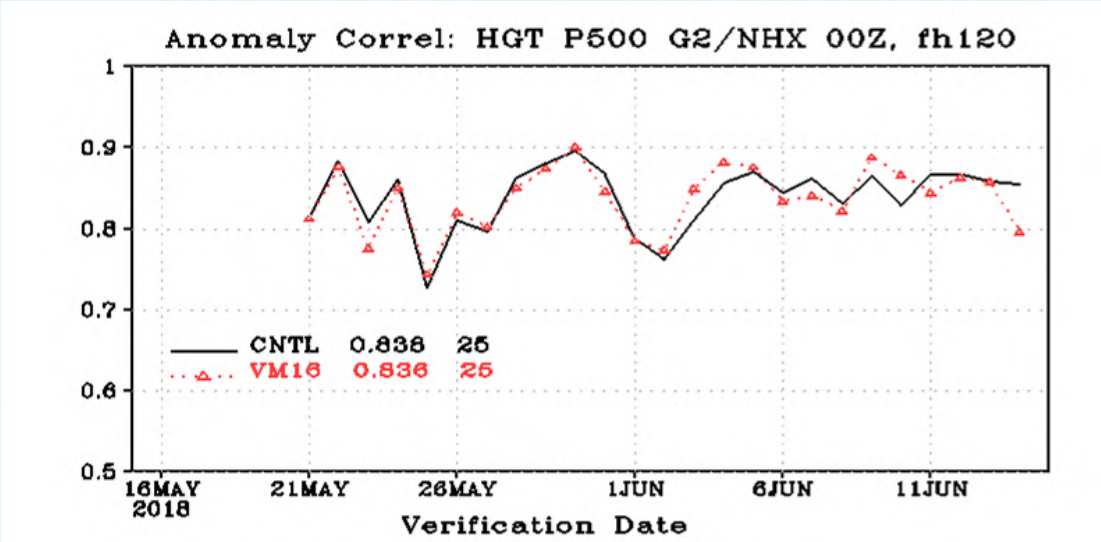
more nvmodes_keep less spurious amplitudes at the top

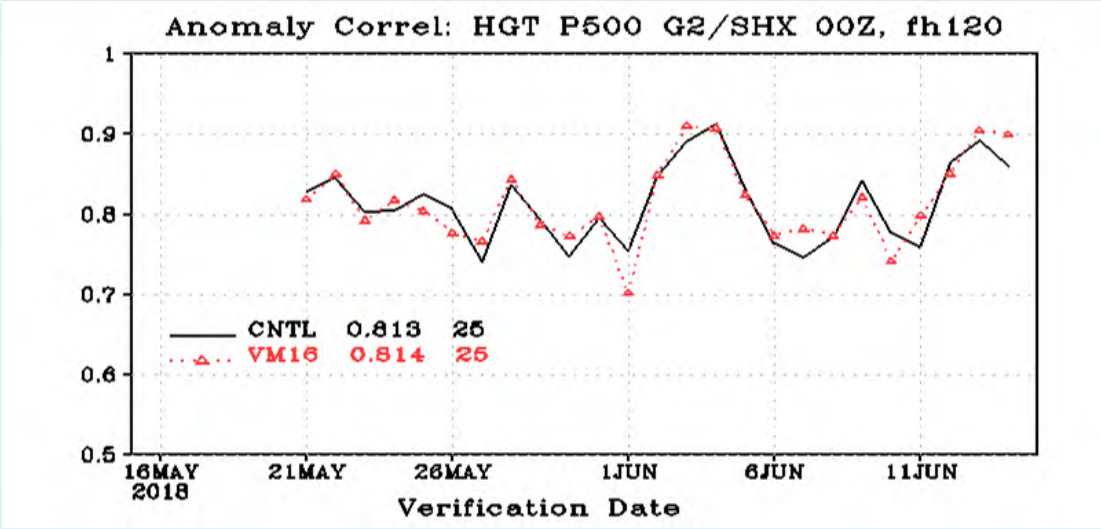
analysis fits to data (O-A)

nvmodes_keep	8	18	36	100
ps	0.8100 / 71640	0.8176 / 71640	0.8198 / 71640	0.8199 / 71640
u/v	2.92 / 66865	2.92 / 66861	2.92 / 66857	2.92 / 66855
t	1.54 / 37438	1.54 /37438	1.55 / 37439	1.55 / 37439
rh	13.46 / 16687	13.44 / 16687	13.44 / 16687	13.43 / 16687

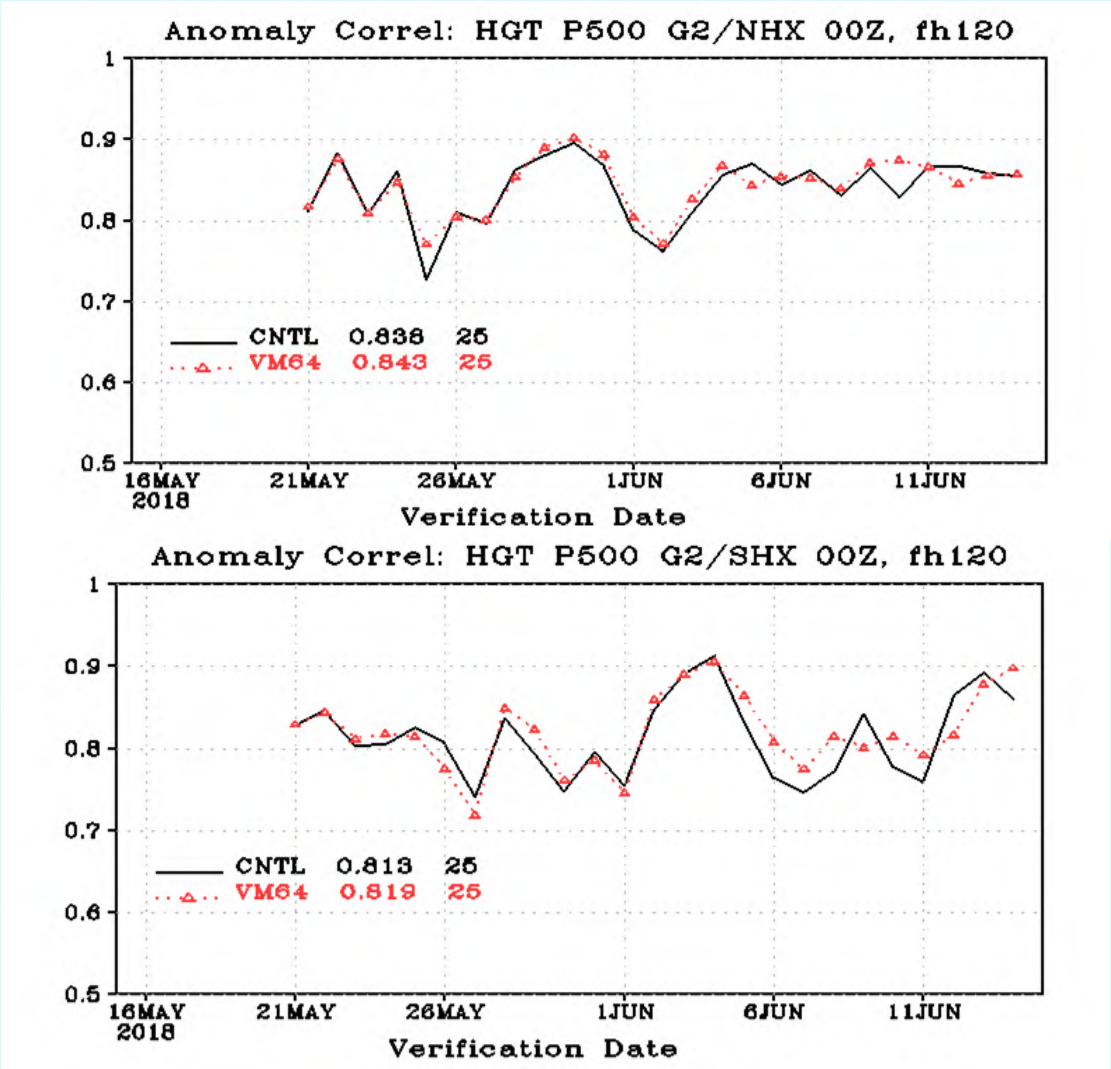
nvmodes_keep does not change the analysis fit to data

VM16

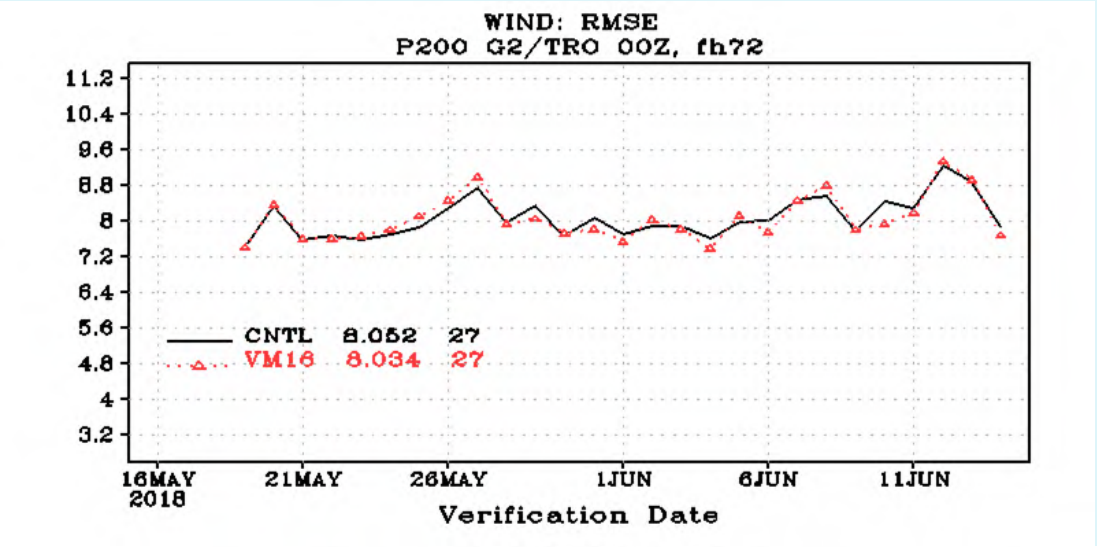

Anomaly Correl: HGT P500 G2/NHX 00Z, fh120
1
0.9
0.8
0.7
0.6
0.5
CNTL 0.838 25
VM16 0.836 25
16MAY
2018
21MAY
26MAY
1JUN
6JUN
11JUN
Verification Date

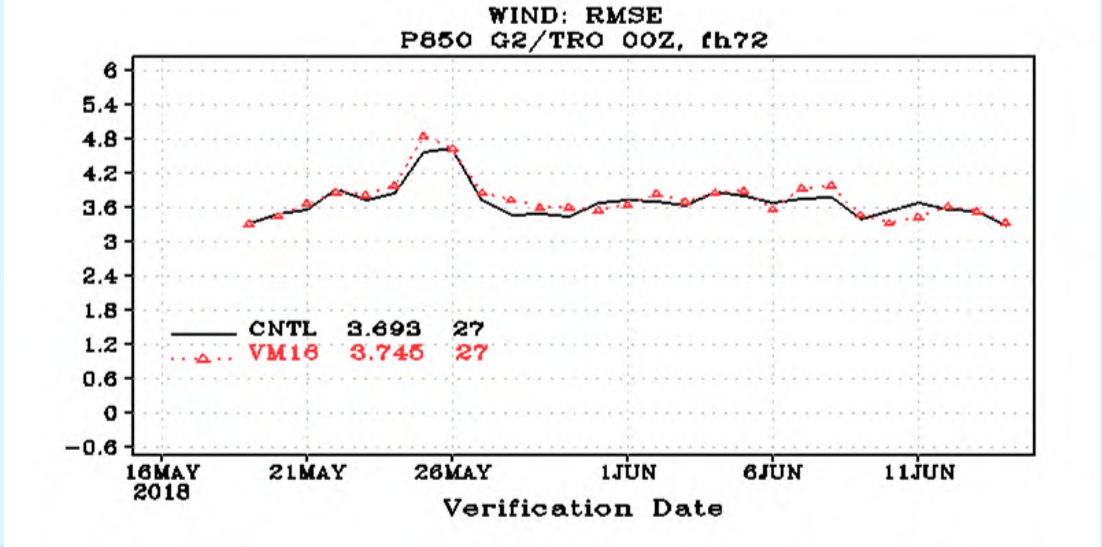

Anomaly Correl: HGT P500 G2/SHX 00Z, fh120
1
0.9
0.8
0.7
0.6
0.5
CNTL 0.813 25
VM16 0.814 25
16MAY
2018
21MAY
26MAY
1JUN
6JUN
11JUN
Verification Date

VM64

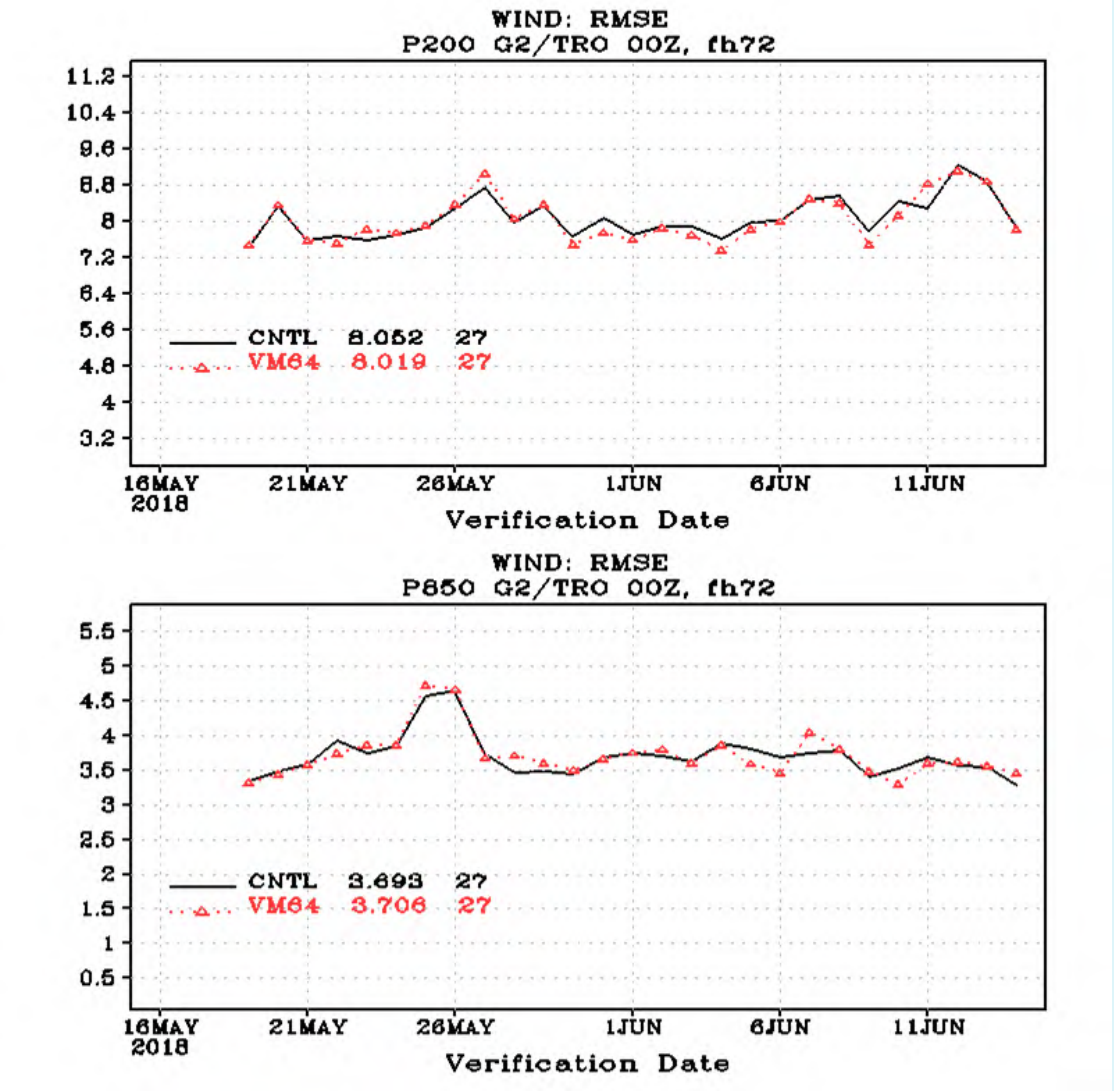

Anomaly Correl: HGT P500 G2/NHX 00Z, fh120
1
0.9
0.8
0.7
0.6
0.5
CNTL 0.838 25
VM64 0.843 25
16MAY 2018
21MAY
26MAY
1JUN
6JUN
11JUN
Verification Date
Anomaly Correl: HGT P500 G2/SHX 00Z, fh120
1
0.9
0.8
0.7
0.6
0.5
CNTL 0.813 25
VM64 0.819 25
16MAY 2018
21MAY
26MAY
1JUN
6JUN
11JUN
Verification Date

VM16


WIND: RMSE
P200 G2/TRO 00Z, fh72
11.2
10.4
9.6
8.8
8
7.2
6.4
5.6
4.8
4
3.2
CNTL 8.052 27
VM16 8.034 27
16MAY
2018
21MAY
26MAY
1JUN
6JUN
11JUN
Verification Date


WIND: RMSE
P850 G2/TRO 00Z, fh72
6
5.4
4.8
4.2
3.6
3
2.4
1.8
1.2
0.6
0
-0.6
CNTL 3.693 27
VM16 3.745 27
16MAY
2018
21MAY
26MAY
1JUN
6JUN
11JUN
Verification Date

VM64


WIND: RMSE
P200 G2/TRO 00Z, fh72
11.2
10.4
9.6
8.8
8
7.2
6.4
5.6
4.8
4
3.2
CNTL 8.052 27
VM64 8.019 27
16MAY
2018
21MAY
26MAY
1JUN
6JUN
11JUN
Verification Date
WIND: RMSE
P850 G2/TRO 00Z, fh72
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
CNTL 3.693 27
VM64 3.706 27
16MAY
2018
21MAY
26MAY
1JUN
6JUN
11JUN
Verification Date

Total wall time for GSI: Strong constraint on total increment over all time levels

nvmodes_keep	wall time
0	1966.142
8	2567.614
16	2619.706
32	2702.602
48	2873.093

Conclusions

- Reasons for the problems: background error, observations, hardwired vertical levels in code, satellite radiances, strong constraint & forecast model damping
- Truncation of the vertical functions in implicit normal mode initialization (strong constraint in GSI) should be adjusted according to the vertical grid structure.
- Quality of background error statistics is function of the sample used to derive them. Re-calculate when model forecasts are improved.
- GPS data used to anchor the bias correction of the satellite radiances have their own limit (55km). Upper channels of the satellite radiances can be used without bias correction.