ICHEC
Irish Centre for High-End Computing

Stabilizing High-Resolution HARMONIE

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Science Foundation Ireland

Ireland's EU Structural Funds Programmes 2007 - 2013

Co-funded by the Irish Government and the European Union

EUROPEAN REGIONAL DEVELOPMENT FUND

An Roinn Oideachais agus Eolaíochta | Department of Education and Science

HEA

Higher Education Authority
An tÚdarás um Ard-Oideachas

Irish Centre for High-End Computing

- Irish national HPC service, founded 2005
- Active member of PRACE
- Main system (SGI): 320 nodes of Xeon E5650 2 x 6-core (Westmere) processors, 24GB mem/node. **Total**: 3840 cores, 7.68 TB RAM
- Second system (Bull): 64 nodes of Xeon X5560 2 x 4-core (Nehalem) processors, 48 GB mem/node.   Total: 496 cores, 3 TB RAM.
  - 24 nodes have 2 x Nvidia Tesla M2090 GPUs.
- Runs operational forecasts for Met Eireann

Mission*

“A Usable**

High-Resolution***

HARMONIE”

*   (Thanks to support from Irish EPA grant CCRP-09-FS-5.2)

** (Able to run a ~24 hr forecast in ~1 hr wall-time)

*** (~ 0.5 km grid-size)

Simple, just edit "config_exp.h"...

Current Operational:

```
IRELAND25)
      TSTEP=60        # Time step
      NLON=540        # No. x points
      NLAT=500        # No. y points
      LONC=-7.5       # Central lon.(deg)
      LATC=53.50      # Central lat.(deg)
      GSIZE=2500.     # Gridsize in m (x,y)
      LON0=5.0        # Ref. lon.(deg.)
      LAT0=53.5       # Ref. lat.(deg.)
      BDNLON=600      # No. X intermed.pts.
      BDNLAT=540      # No. Y intermed. Pts
```

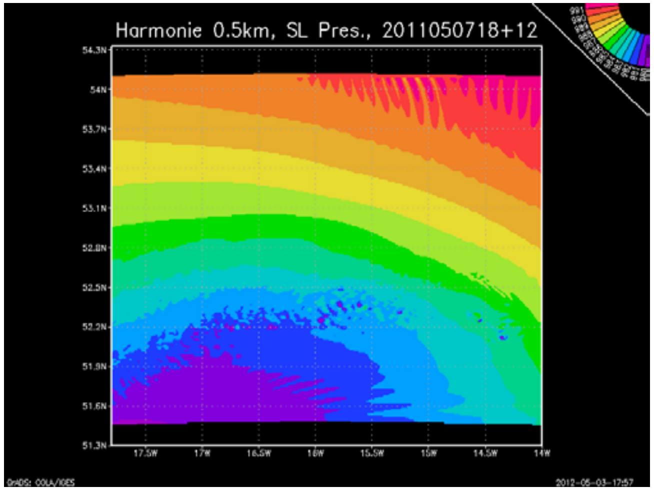
New High-Resolution:

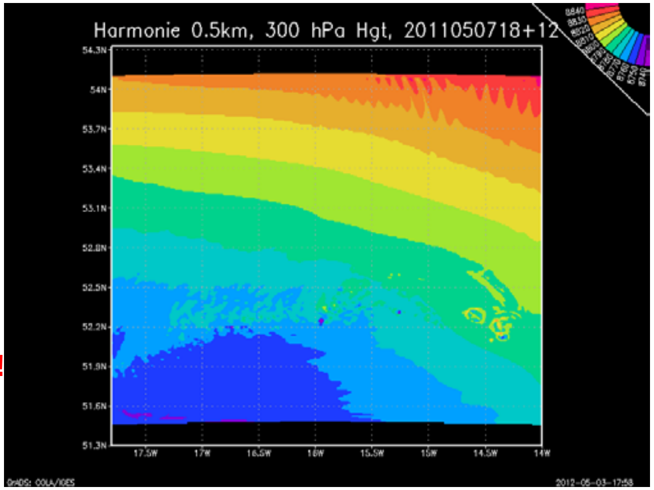
```
IRELAND05)
      TSTEP=12        # Time step
      NLON=600        # No. x points
      NLAT=600        # No. y points
      LONC=-9.0       # Central lon.(deg)
      LATC=52.80      # Central lat.(deg)
      GSIZE=500.      # Gridsize in m (x,y)
      LON0=-9.0       # Ref. lon.(deg.)
      LAT0=53.0       # Ref. lat.(deg.)
      BDNLON=600      # No. X intermed.pts.
      BDNLAT=600      # No. Y intermed. Pts
```

Allocate 6 x more nodes or system time, and run…
(N.B.: HARMONIE parameterizations are scale-adaptive)

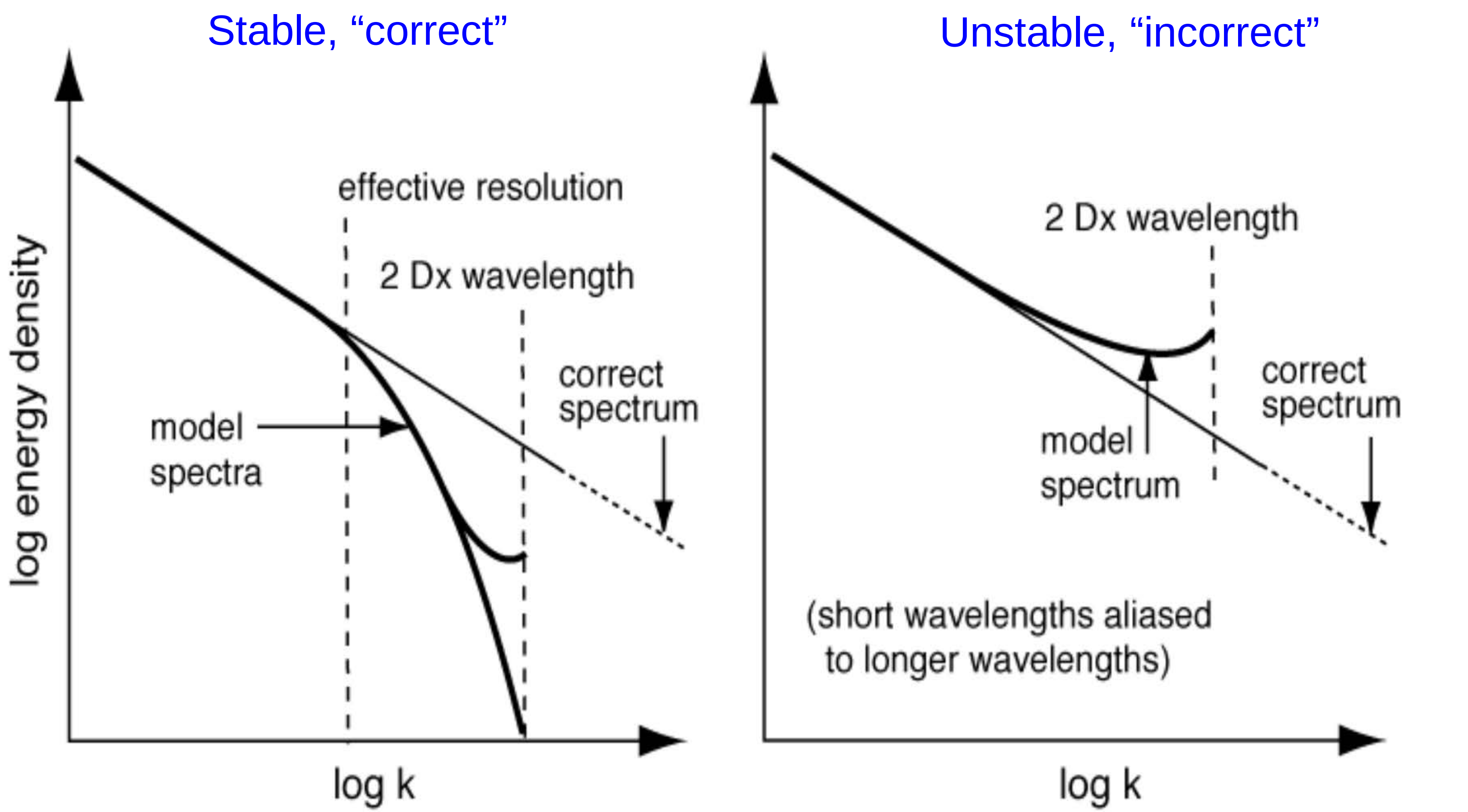
Frequently get, in Forecast.1...

```
...
...
  03:29:46 STEP 3668 H=  12:13 +CPU=  2.460
  03:29:49 STEP 3669 H=  12:13 +CPU=  2.564
  03:29:51 STEP 3670 H=  12:14 +CPU=  2.364
  MAX V WIND=   222.829526211251
  LEVEL=            7  POINT=          23
  PCOLON=   0.967007914304197
  PGEMU=   0.793557144704579
SMILAG TRAJECTORY OUT OF ATM      1 TIMES.
  03:29:53 STEP 3671 H=  12:14 +CPU=  2.152
  MAX V WIND=   355.429345651749
  LEVEL=           11  POINT=          11
  PCOLON=   0.966946123280087
  PGEMU=   0.793892880470571
  V WIND =   355.429345651749       IS TOO STRONG, EXPLOSION.
  LEVEL=           11  POINT=          11
  PCOLON=   0.966946123280087
  PGEMU =   0.793892880470571
 ABORT!  106  !V WIND TOO STRONG, EXPLOSION!!!
MPL_ABORT: CALLED FROM PROCESSOR    106 THRD     1
 MPL_ABORT: THRD           1    !V WIND TOO STRONG, EXPLOSION!!
```

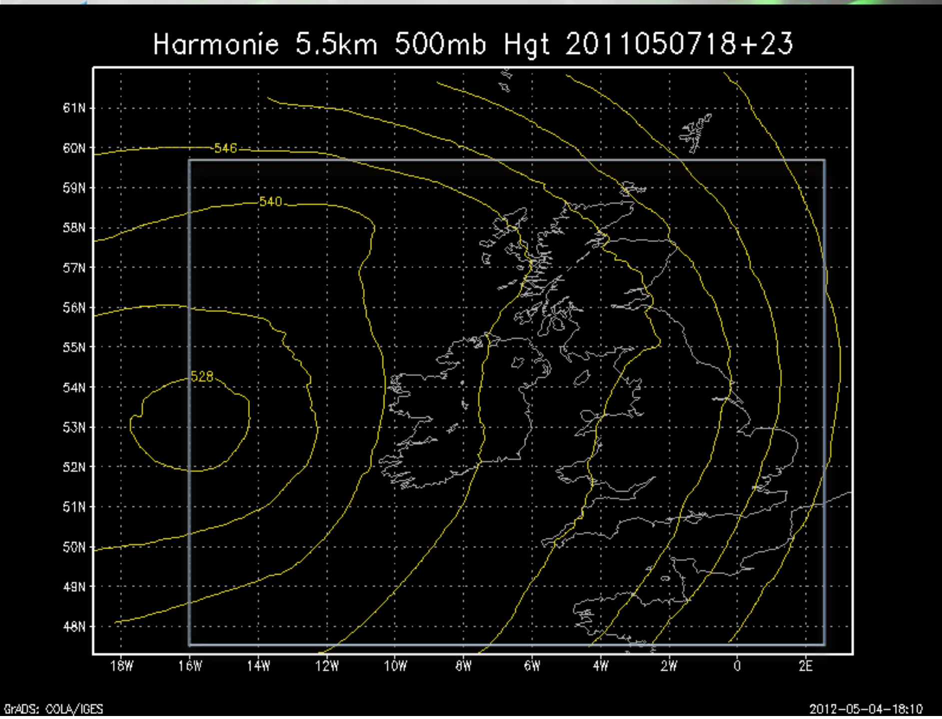


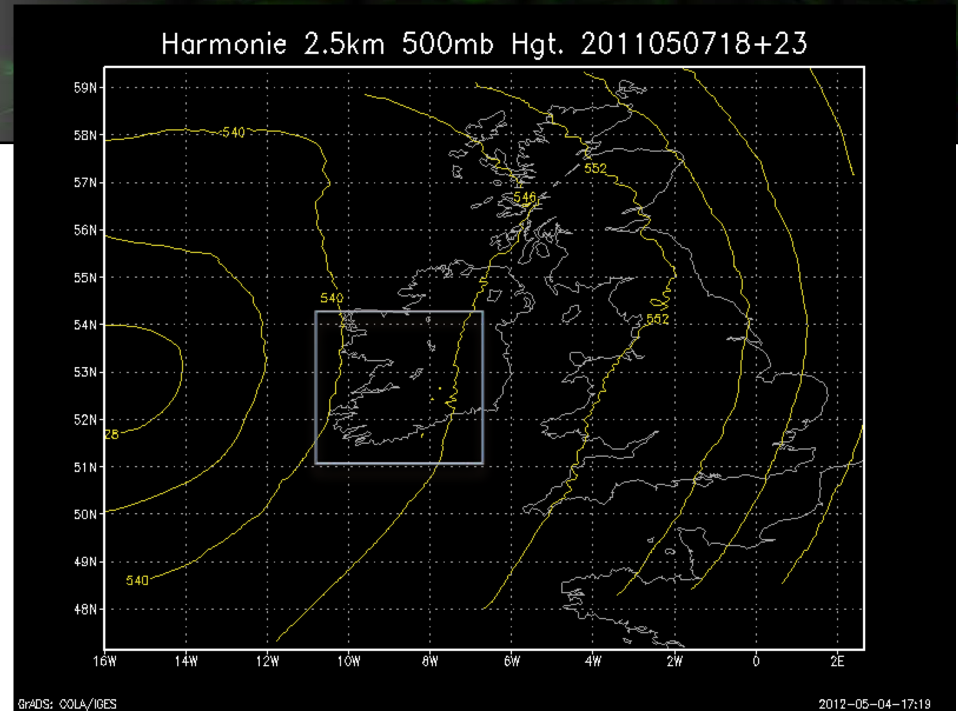


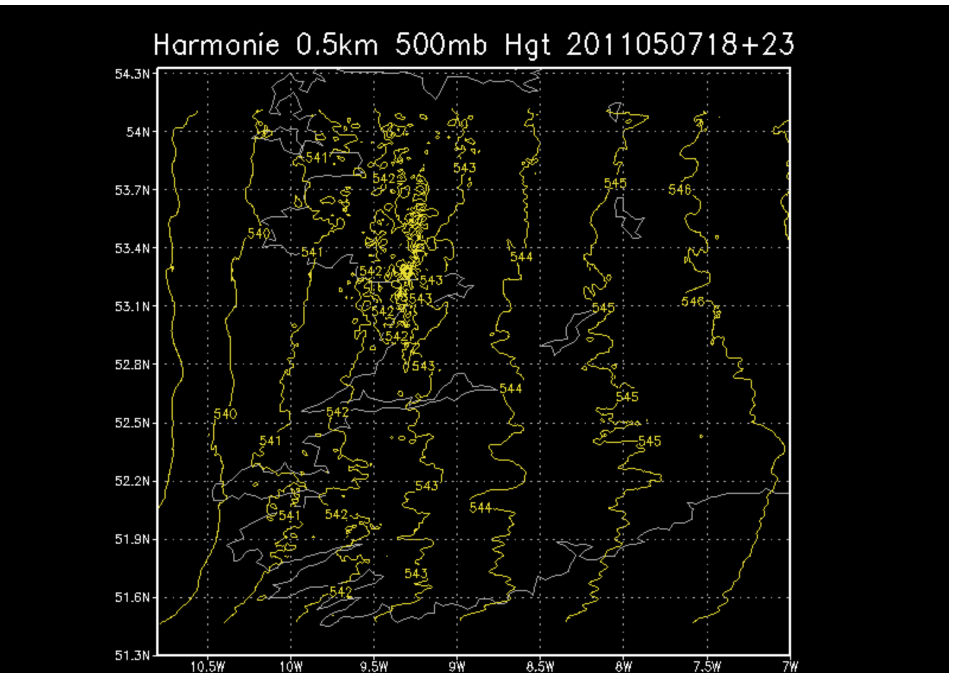
Schematic of some typical atmospheric spectra

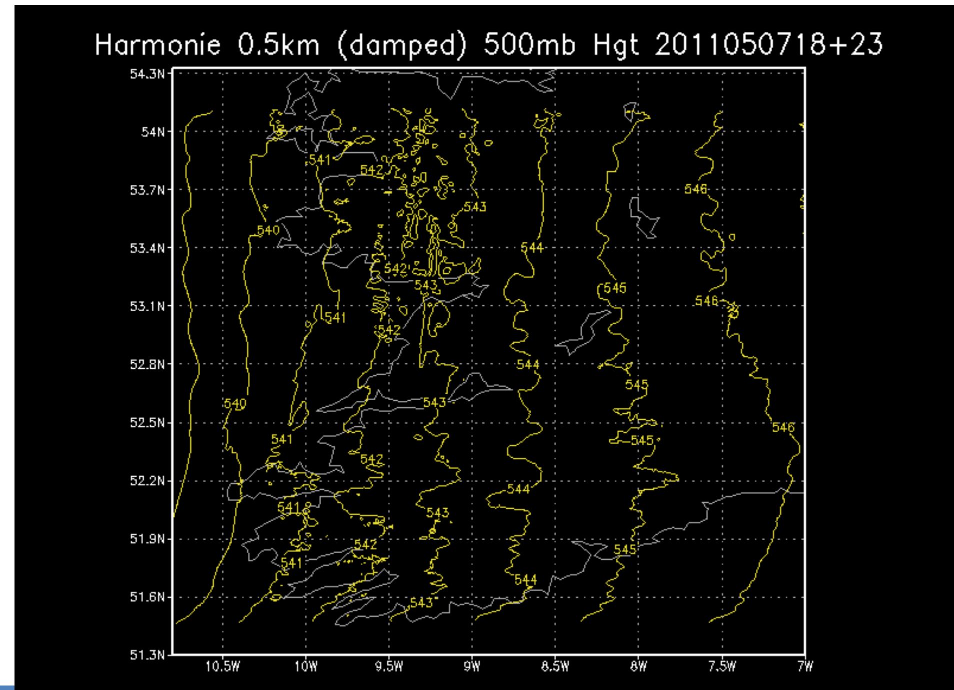


(from Skamarock, 2008)


Harmonie 5.5km 500mb Hgt 2011050718+23
GrADS: COLA/IGES
2012-05-04-18:10


Harmonie 2.5km 500mb Hgt. 2011050718+23
GrADS: COLA/IGES
2012-05-04-17:19


Harmonie 0.5km 500mb Hgt 2011050718+23


Harmonie 0.5km (damped) 500mb Hgt 2011050718+23

Enhanced Scale-Selective Damping

For variable X, default scale-selective damping has the form:

$$\partial X/\partial t = -\boldsymbol{K_X}\,|\nabla^r X|$$

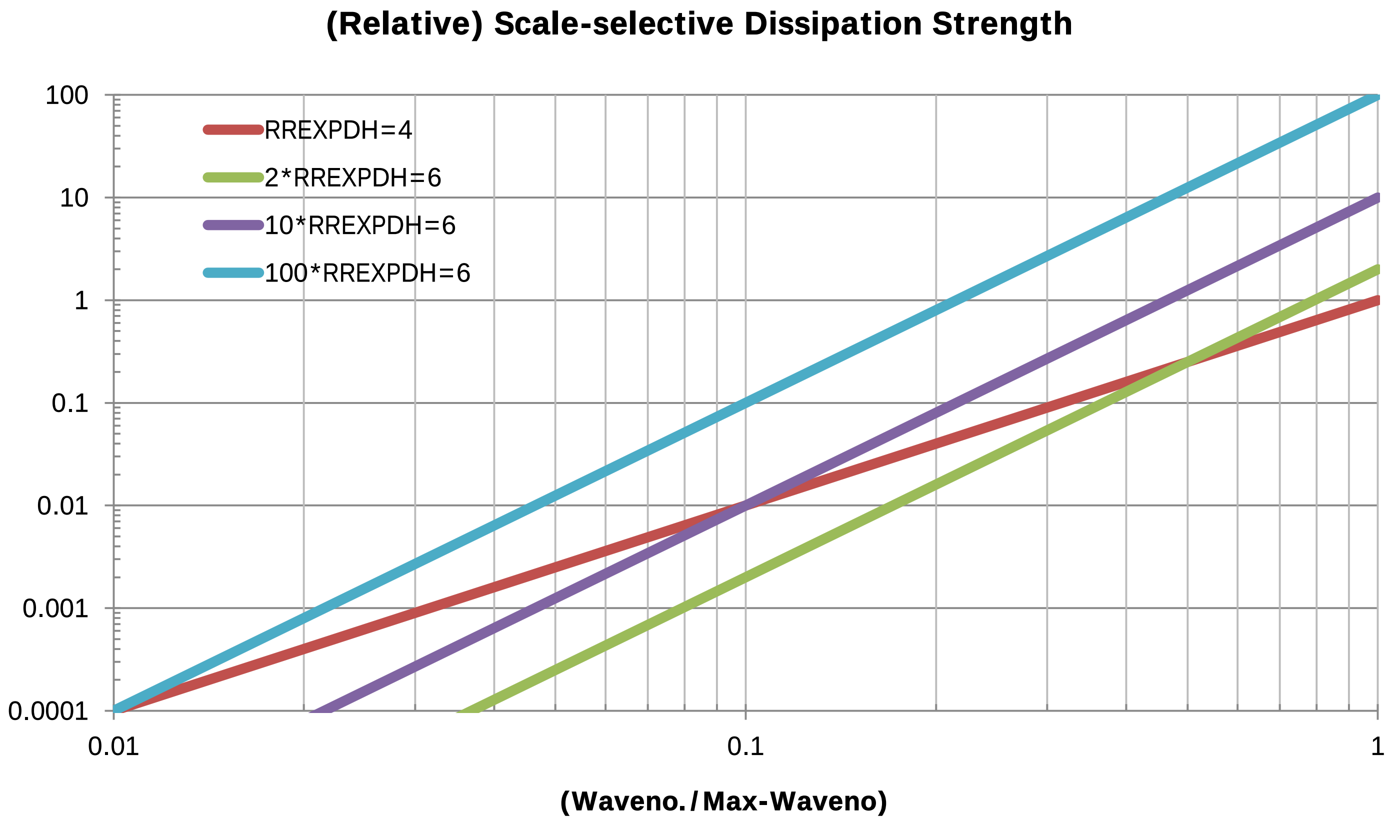
Exponent $\boldsymbol{r = 4}$ by default.

Coefficient $\boldsymbol{K_X = 123}$ by default.

To Stabilize High-resolution Harmonie, set:

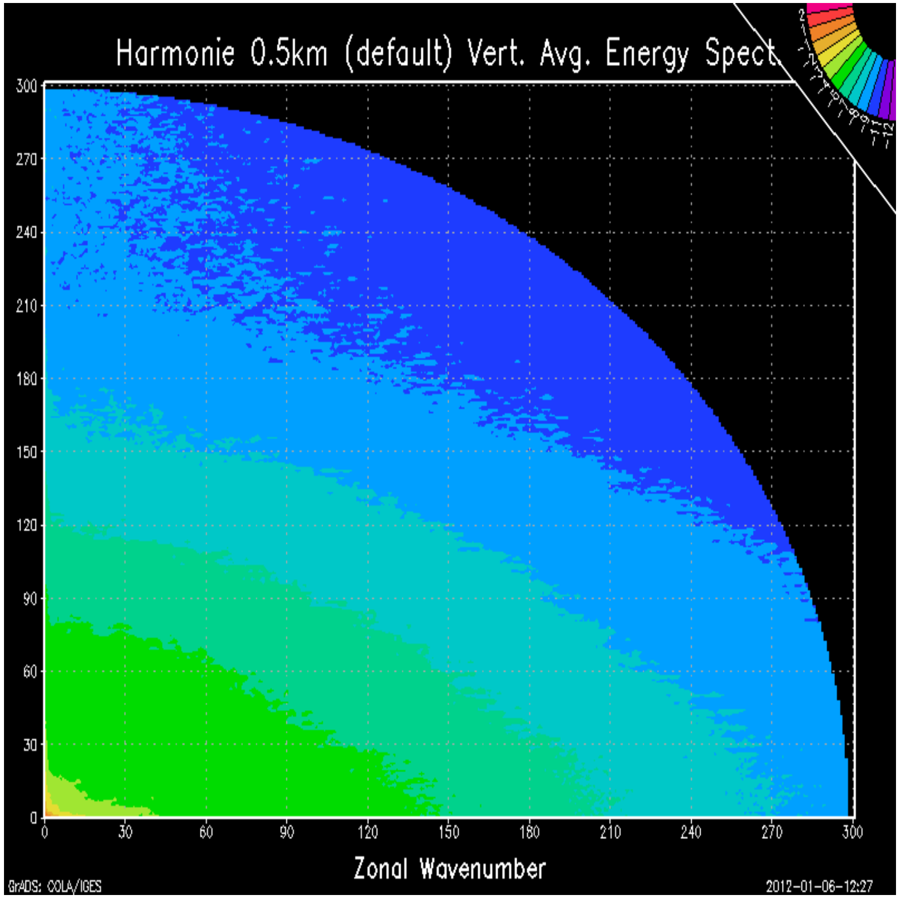
$$\boldsymbol{r = 6\,, \qquad K_X = 12{,}300}$$

Shape & Strength of Scale-Selective Damping

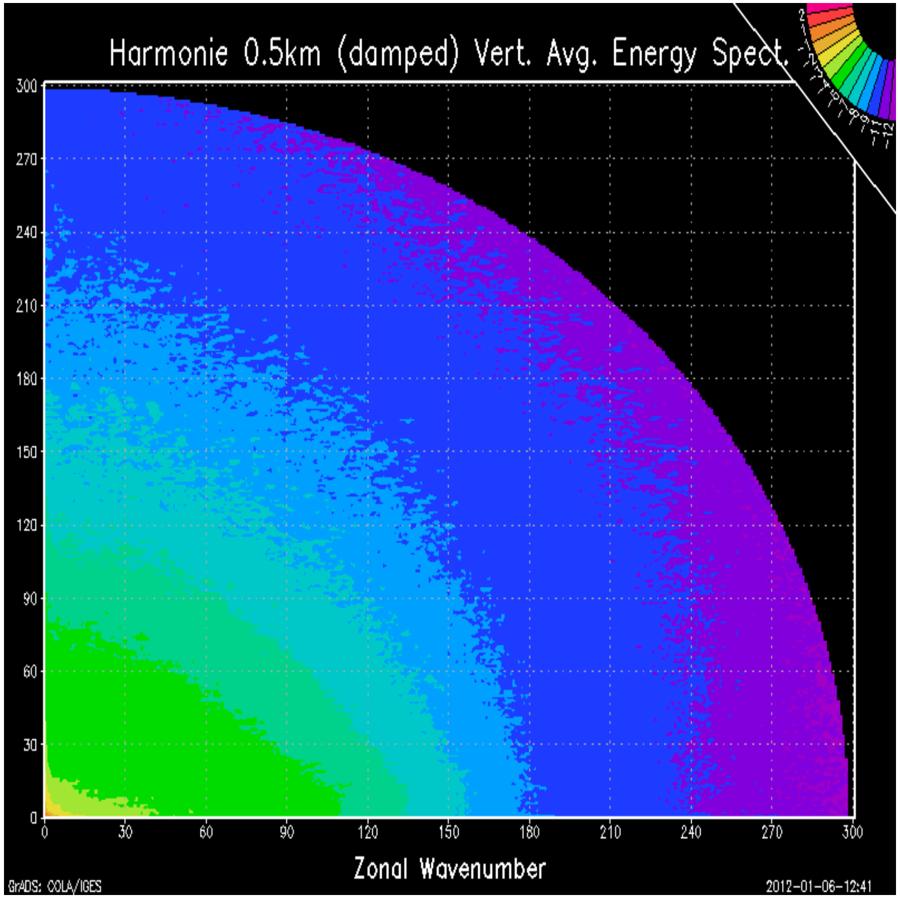


(Damping operates on normalized wavenumbers, between 0 and 1.
Larger exponent ***r*** reduces most values, so larger coefficient K_x is needed to compensate.)

2-d KE Spectra from Harmonie

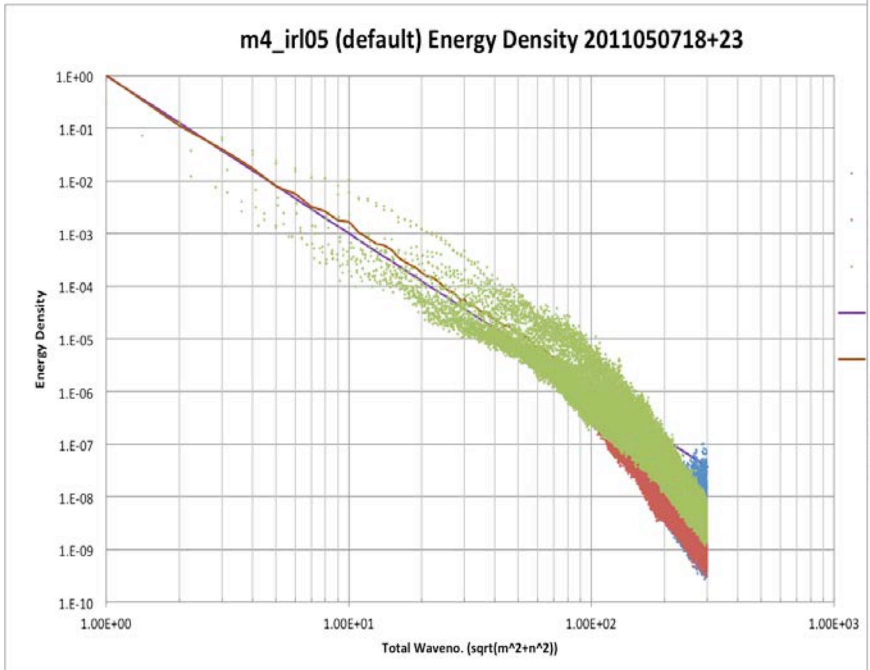


Standard (default) damping

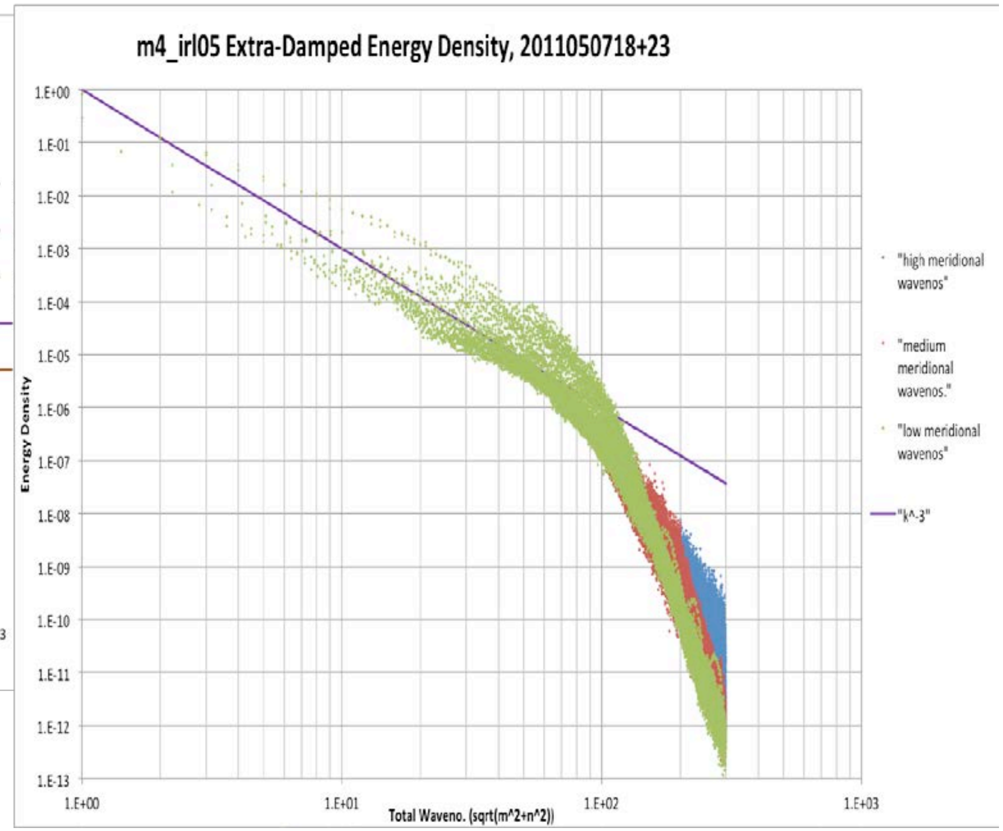


Enhanced scale-selective damping

Spectra Projected onto 1-D

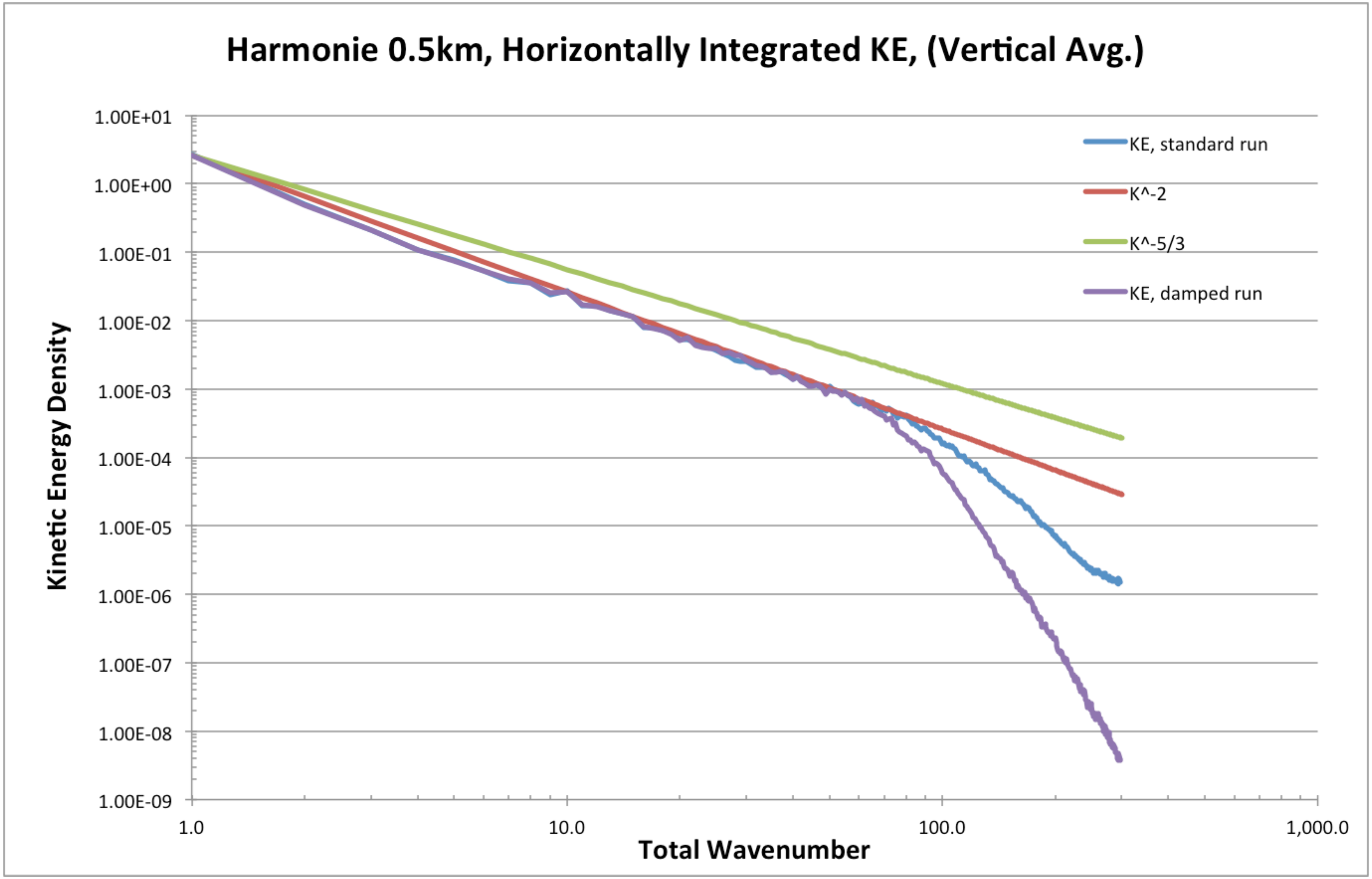


Standard (default) damping



Enhanced scale-selective damping

Both Vertically-averaged spectra, from single snapshot in time



Harmonie 0.5km, Horizontally Integrated KE, (Vertical Avg.)
KE, standard run
K^-2
K^-5/3
KE, damped run
Kinetic Energy Density
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.0
10.0
100.0
1,000.0
Total Wavenumber

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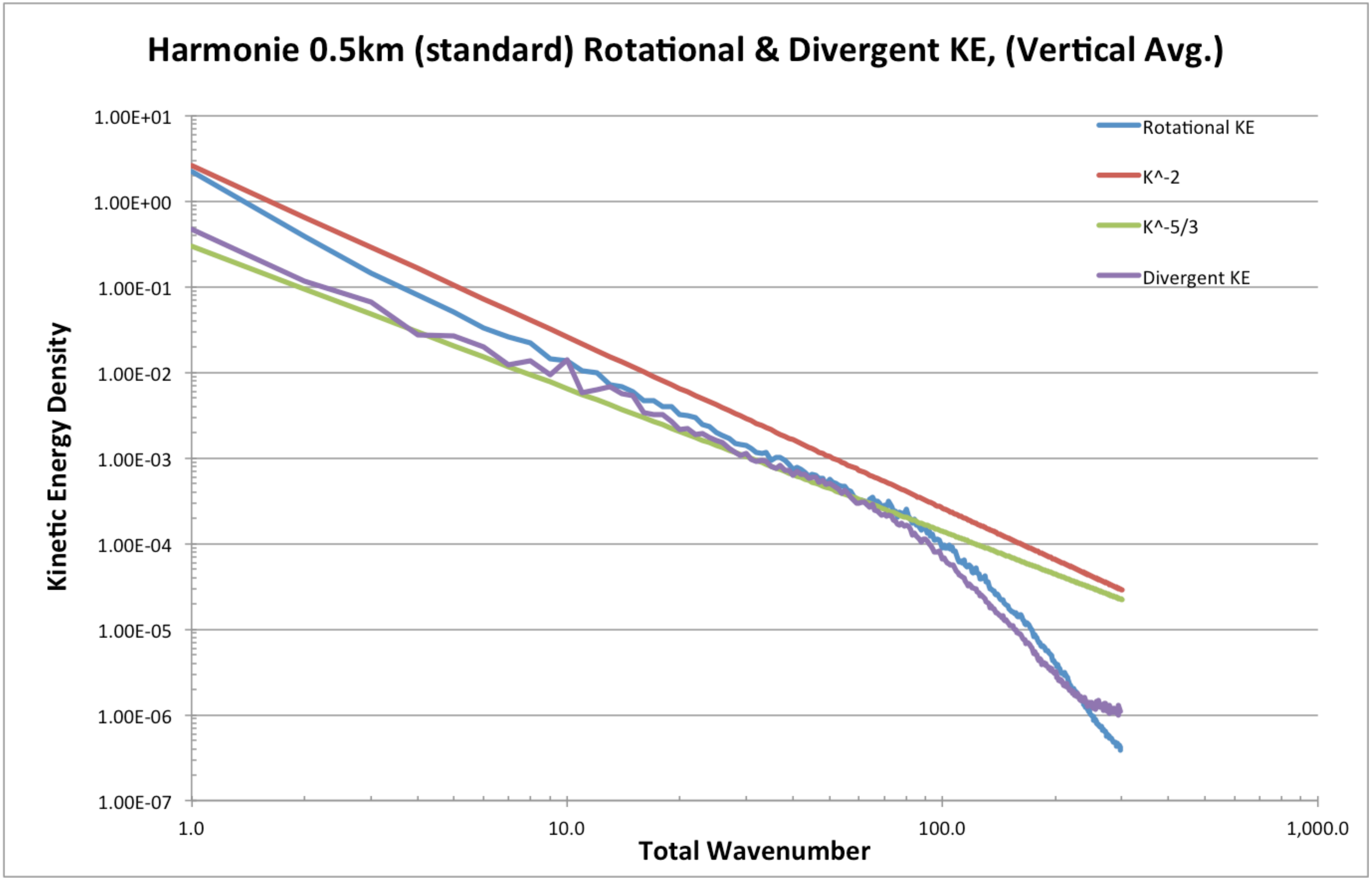
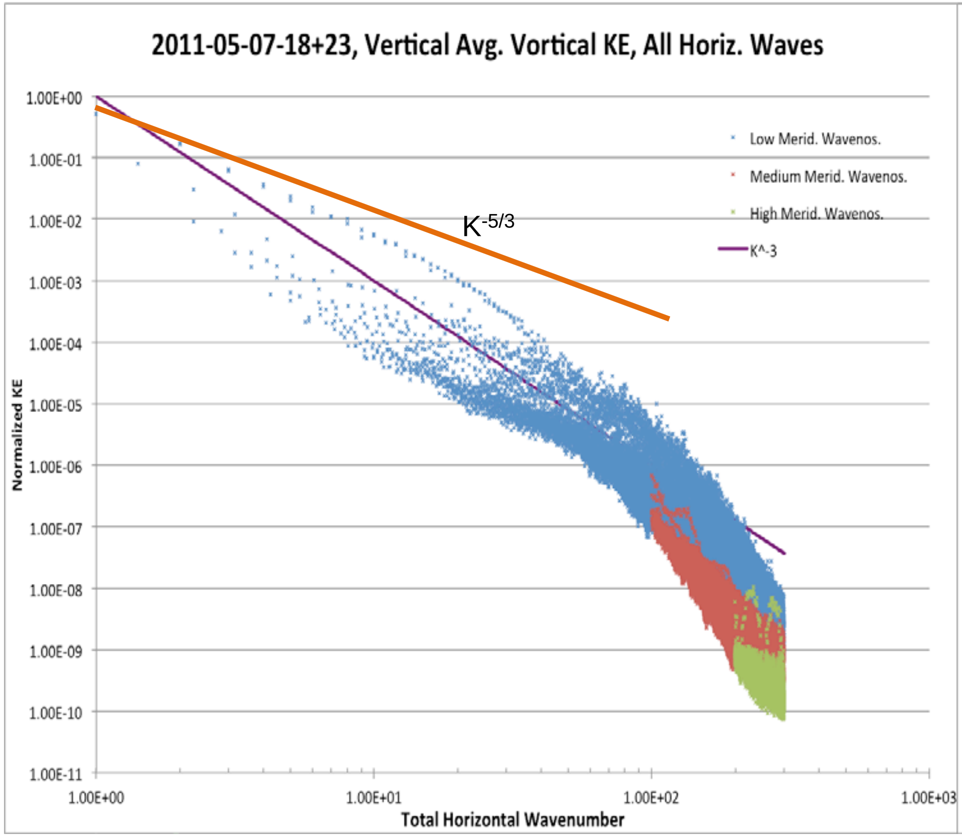
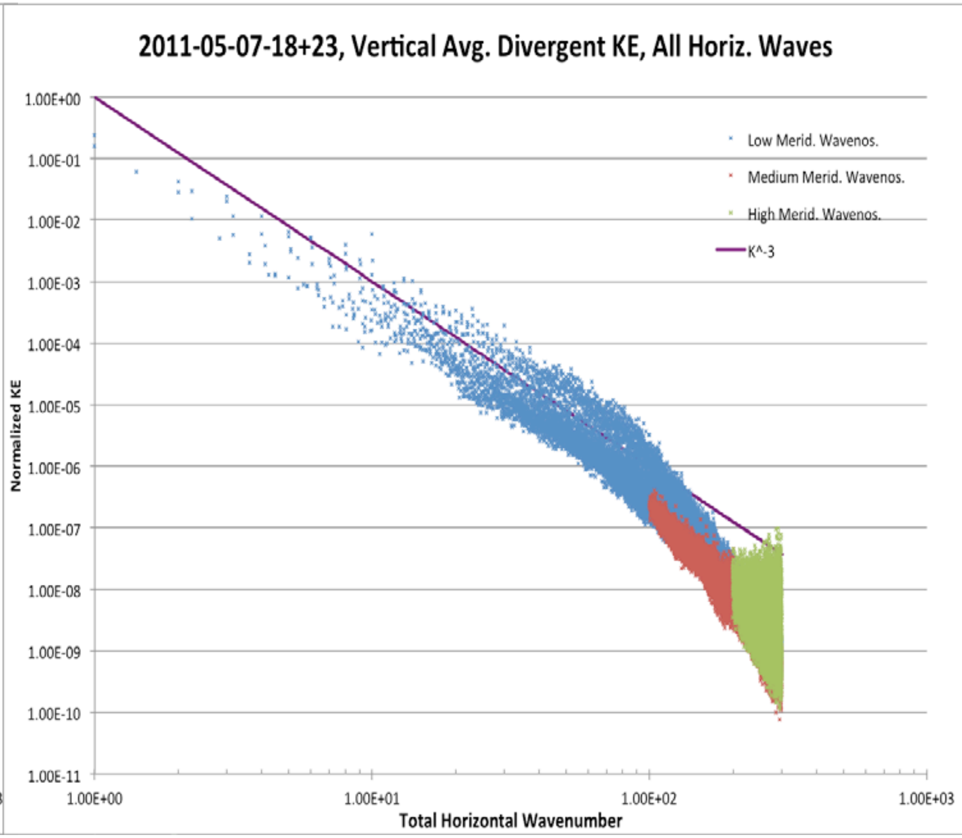


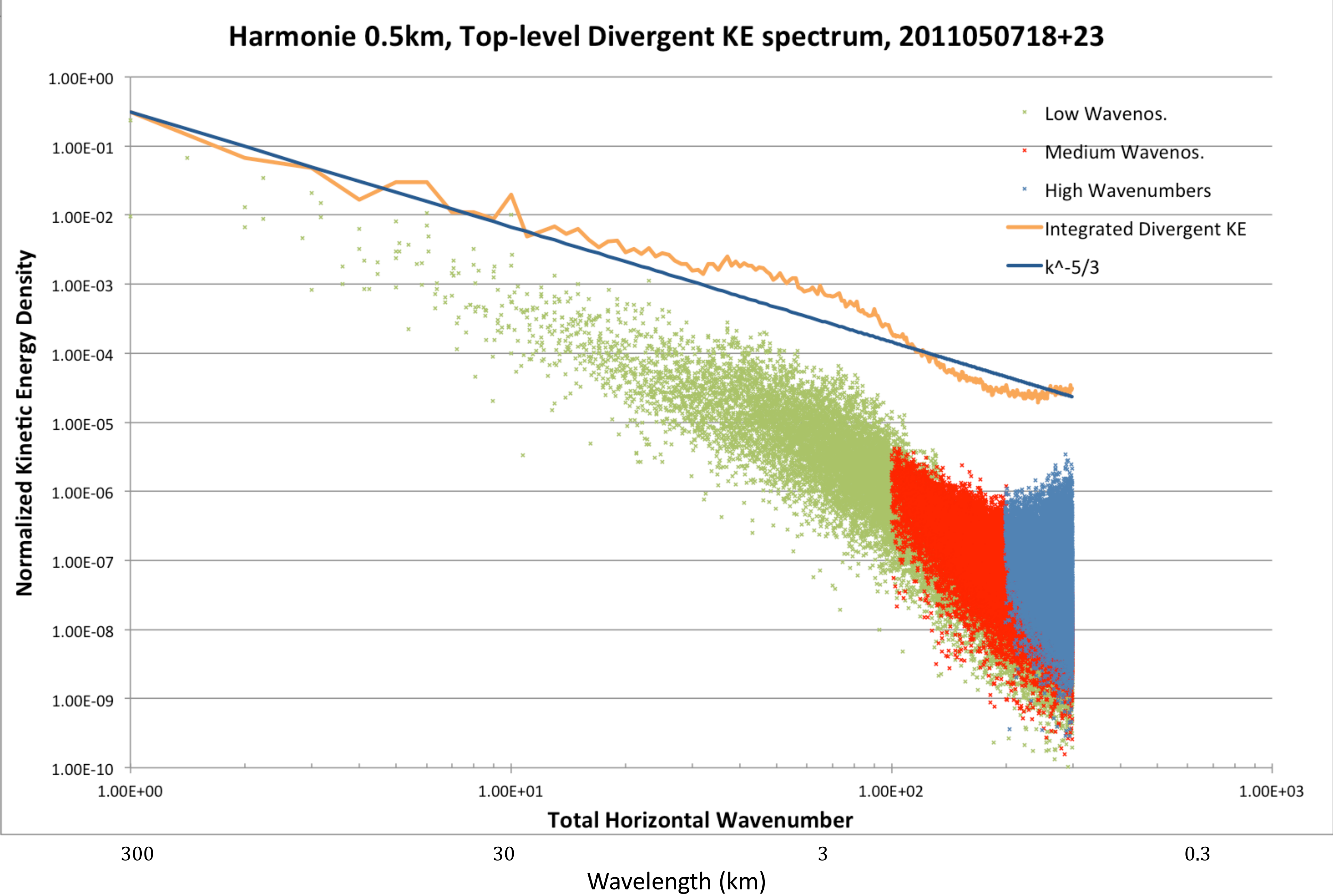
KE from Rotational & Divergent Winds
(default damping)

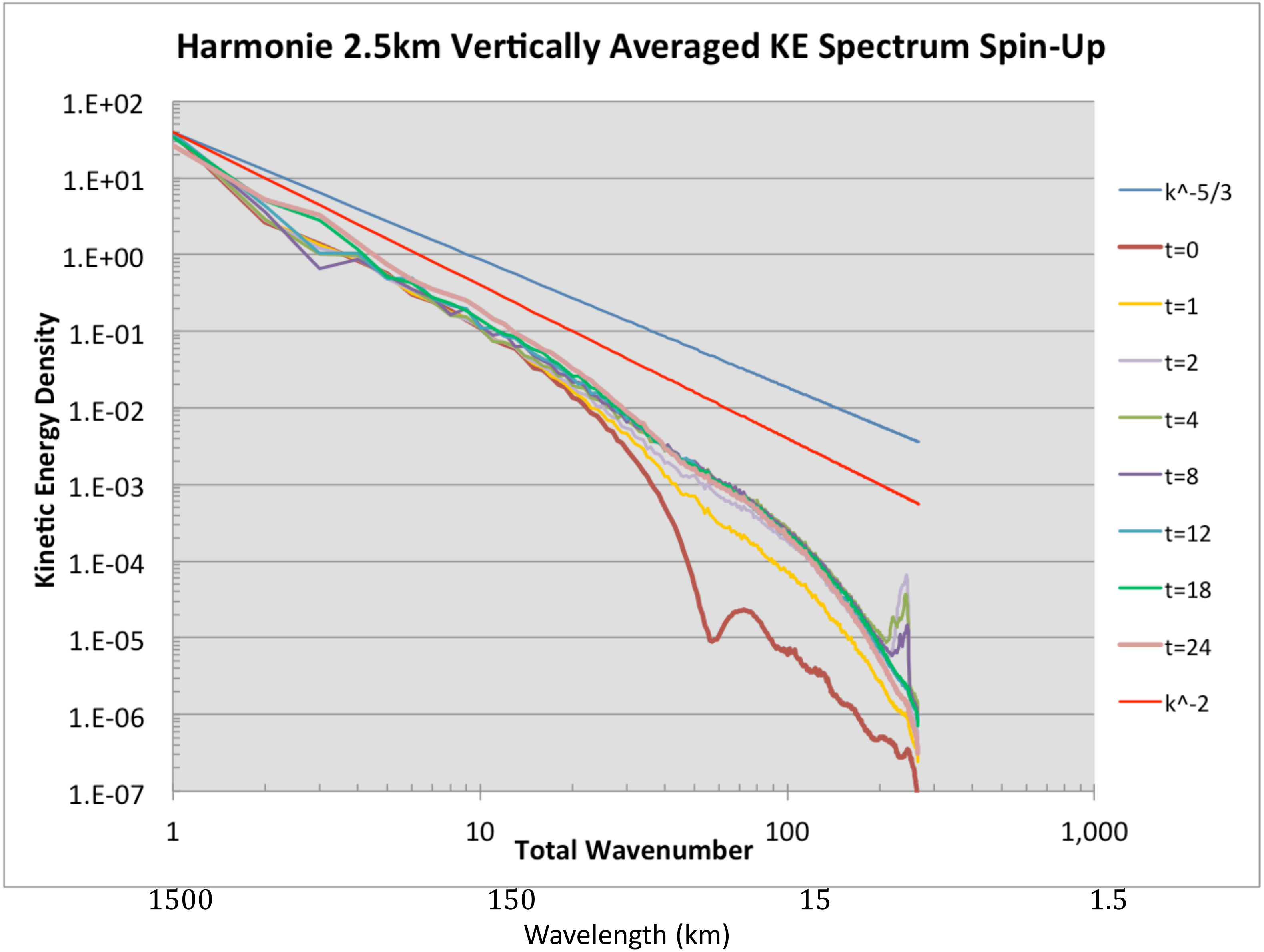


KE from “Vortical” winds only



KE from “Divergent” winds only


Harmonie 0.5km, Top-level Divergent KE spectrum, 2011050718+23
Normalized Kinetic Energy Density
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E+00
1.00E+01
1.00E+02
1.00E+03
Total Horizontal Wavenumber
Low Wavenos.
Medium Wavenos.
High Wavenumbers
Integrated Divergent KE
k^-5/3
300
30
3
0.3
Wavelength (km)


Harmonie 2.5km Vertically Averaged KE Spectrum Spin-Up
Kinetic Energy Density
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1
10
100
1,000
Total Wavenumber
k^-5/3
t=0
t=1
t=2
t=4
t=8
t=12
t=18
t=24
k^-2
1500
150
15
1.5
Wavelength (km)

Numerical Stability of Harmonie

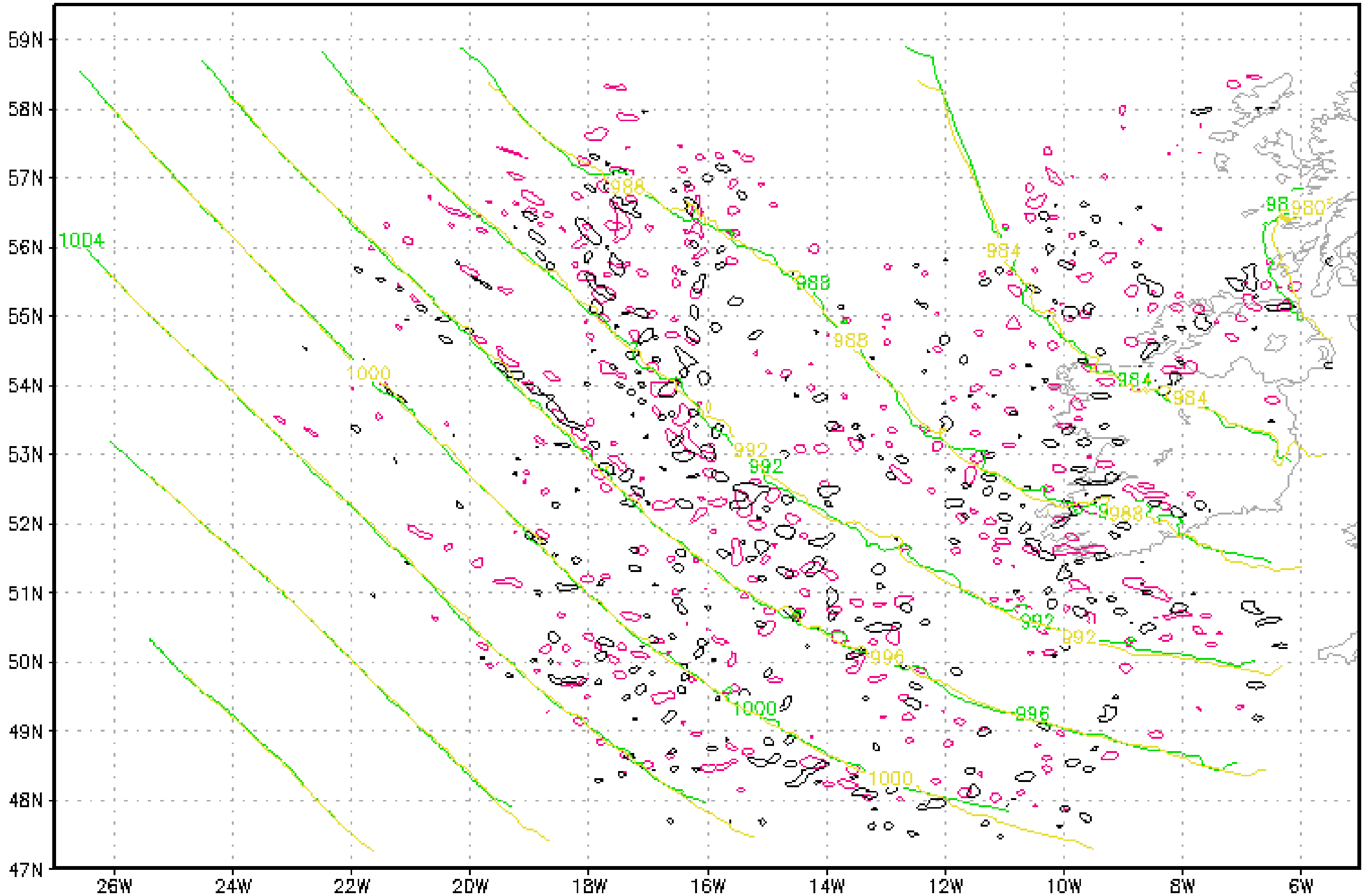
- Standard (scale adaptive) damping not strong enough to prevent spurious KE build-up at small scales in 0.5km Harmonie
- Short-wave KE build-up (“up-turned spectral tails”) associated with:
  - *Early adjustment phase of model spin-up*
  - *Divergent flow (rather than rotational flow)*
  - *Upper levels*
- 0.5km Harmonie can be stabilized e.g., by enhanced scale-selective damping. (Could be even more selective...)
  - *Requires changing just 2 namelist parameters*
  - *Physical fields remain unchanged outside localized unstable region.*
- More vertical resolution should help (though test runs with 91-level IFS boundaries were unstable too…)
- Inclusion of gravity-wave drag parameterization might be a better (more physical) solution.

KE Spectra

- Most KE spectra (integrated over all wave angles) closely follow a k^{-2} power law - shallower than the k^{-3} characteristic of 2-d, geostrophic turbulence.
  - *(Domain is too small to capture the k^{-3} range).*
- A $k^{-5/3}$ inertial range (characteristic of 3-d turbulence) appears only in the divergent wind component .
- In either case, robust spectral slopes in inertial range suggest control by strong general laws.

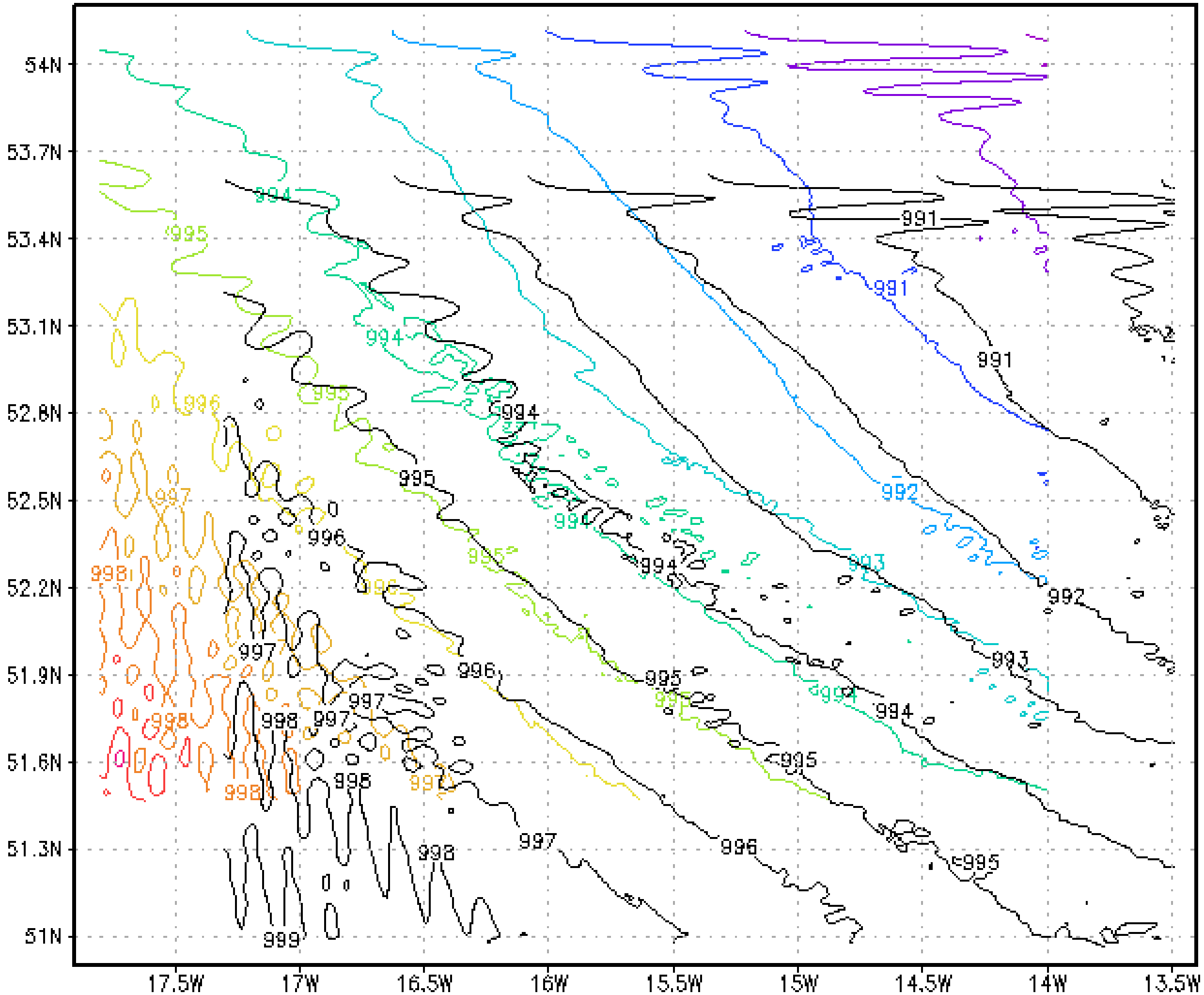
Sensitivity to domain boundary placement:

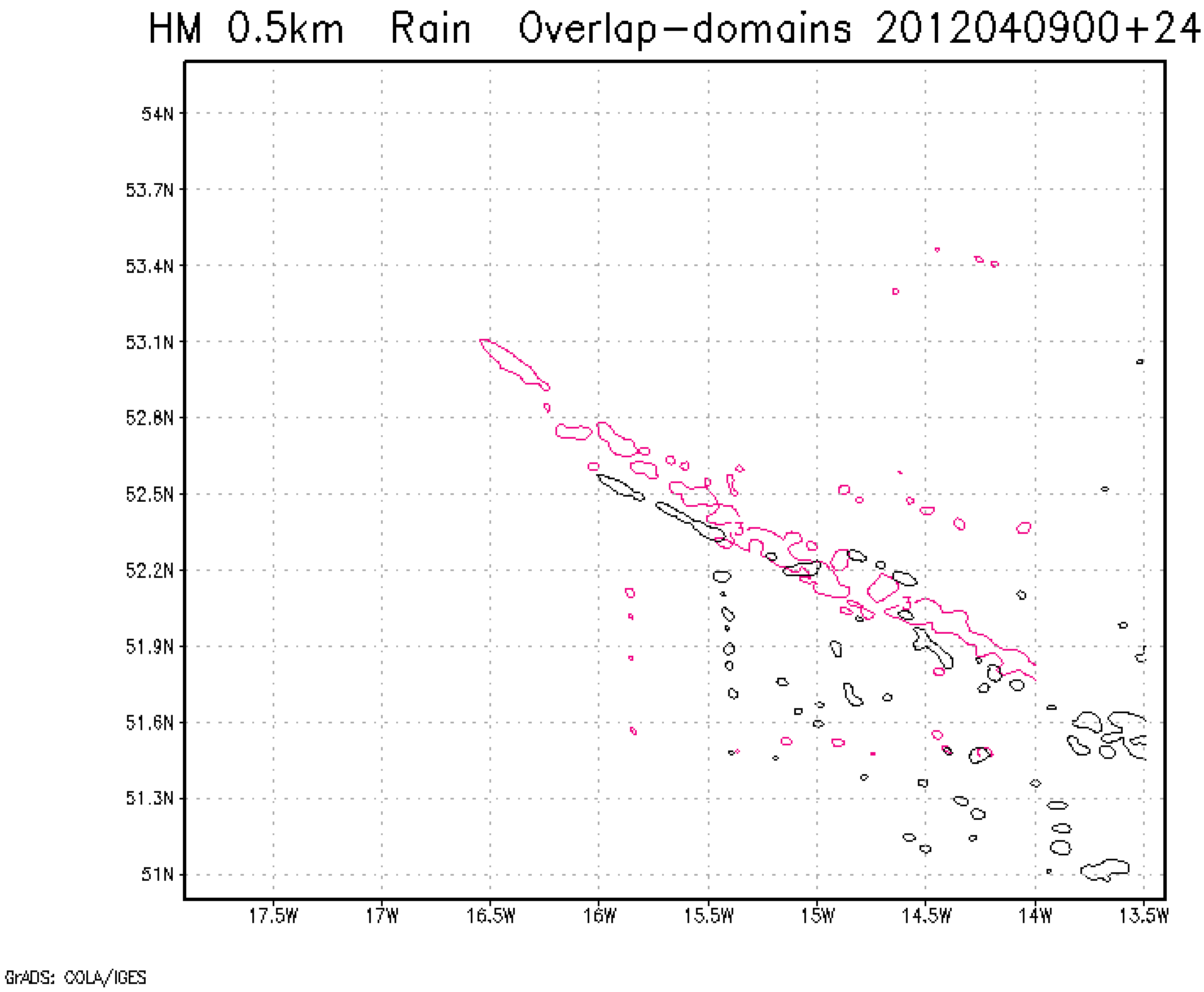
HM 2.5km MSLP Rain Overlap domains 2012040900+24



GrADS: COLA/IGES

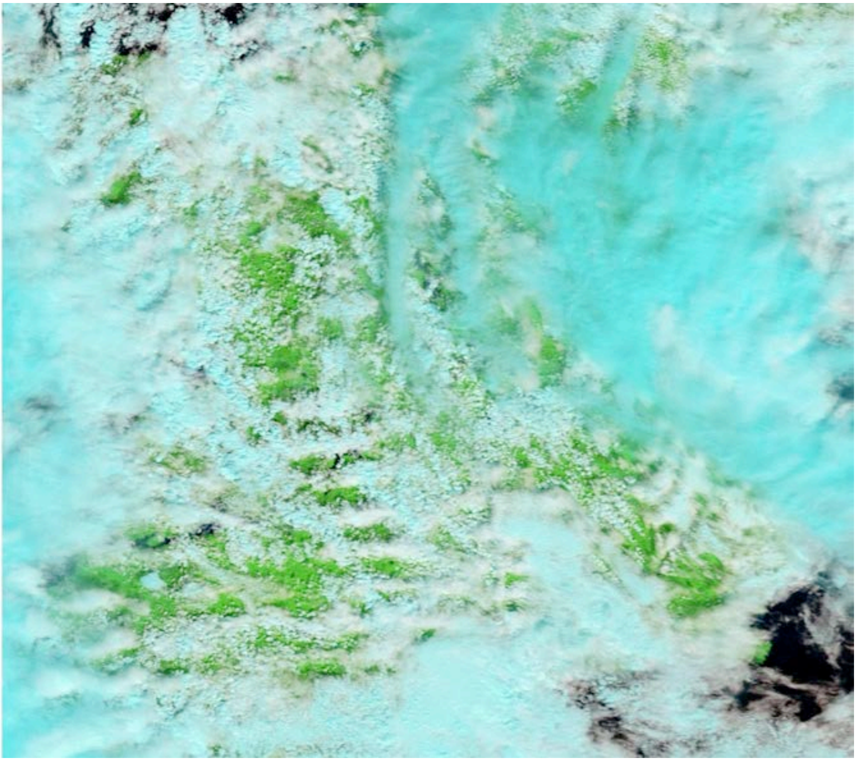
HM 0.5km MSLP, 2 Overlap-domains 2012040900+24

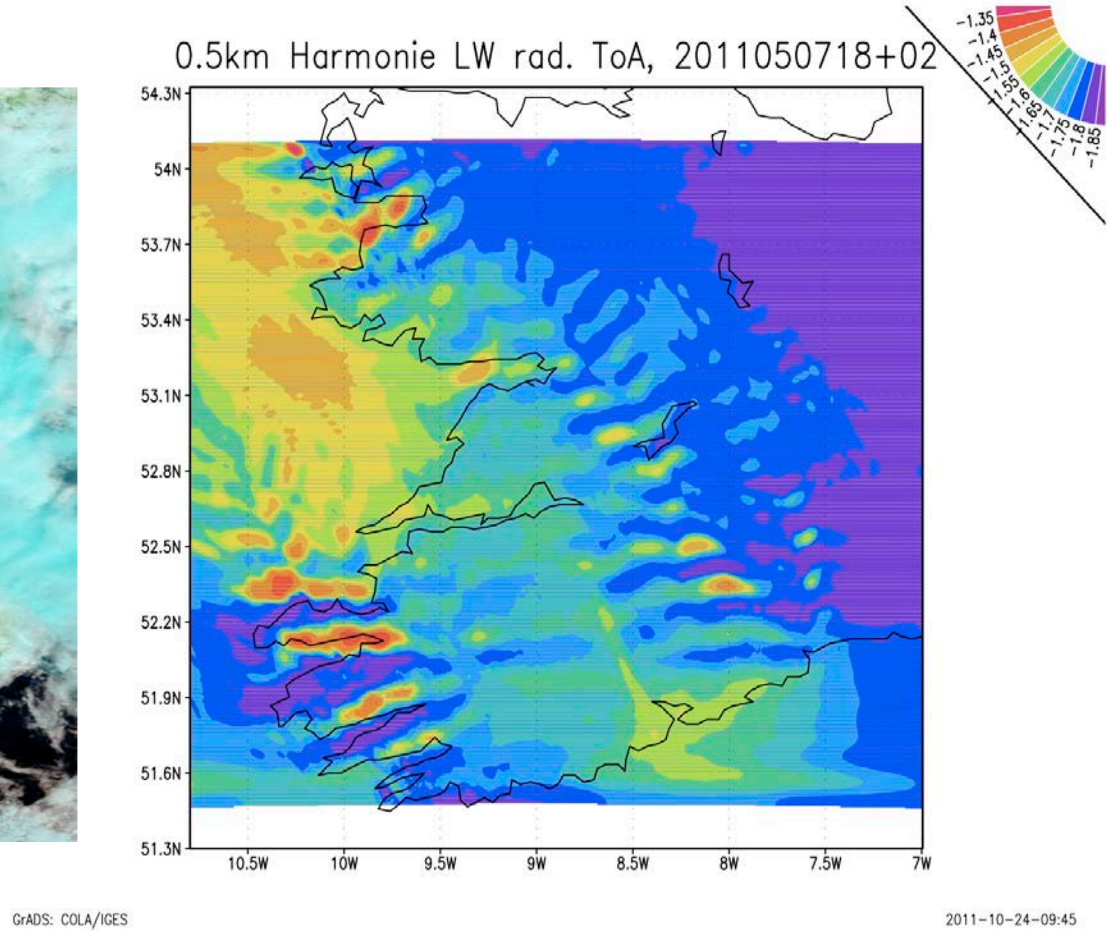


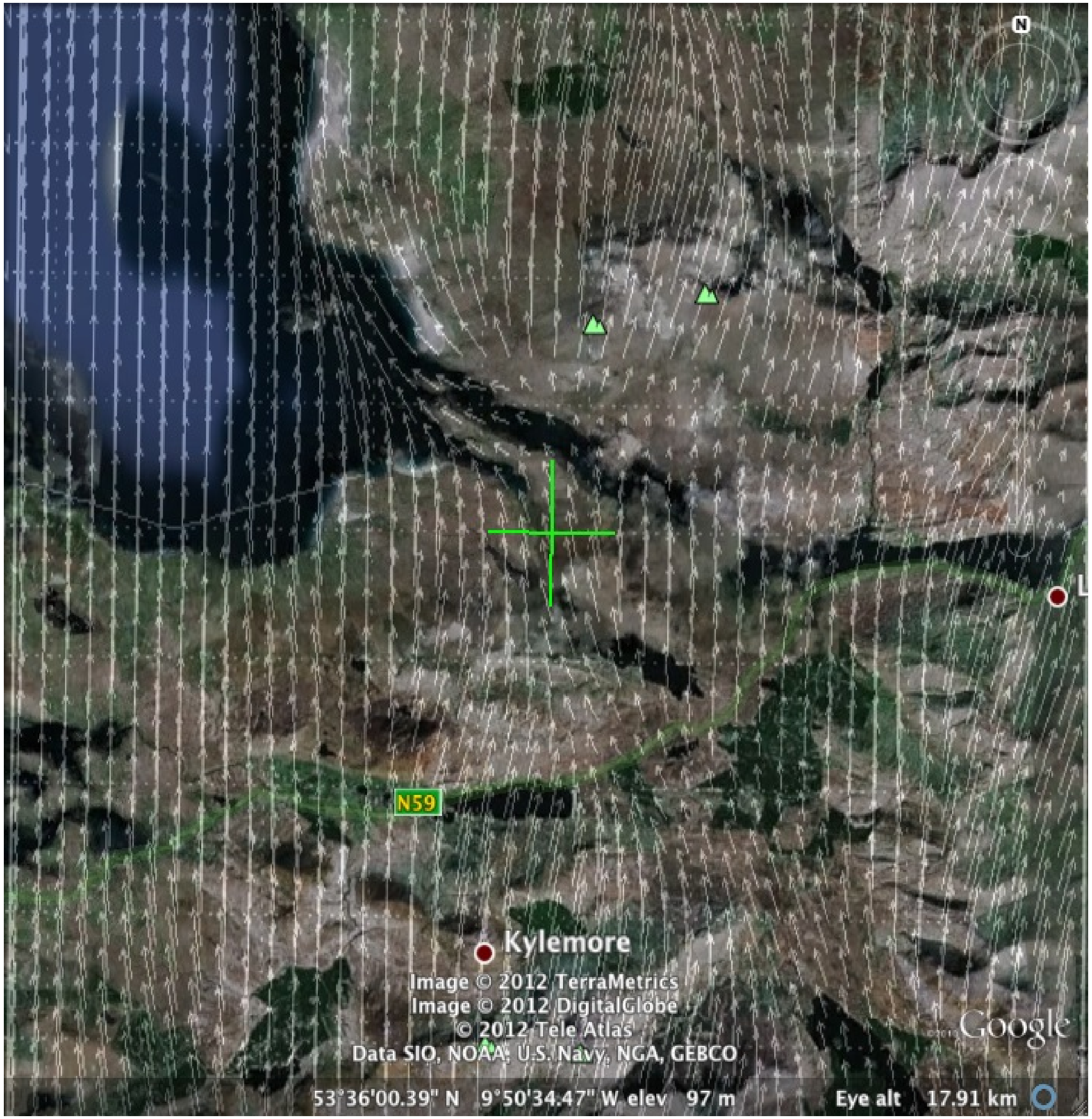

HM 0.5km Rain Overlap-domains 2012040900+24
54N
53.7N
53.4N
53.1N
52.8N
52.5N
52.2N
51.9N
51.6N
51.3N
51N
17.5W
17W
16.5W
16W
15.5W
15W
14.5W
14W
13.5W
GrADS: COLA/IGES

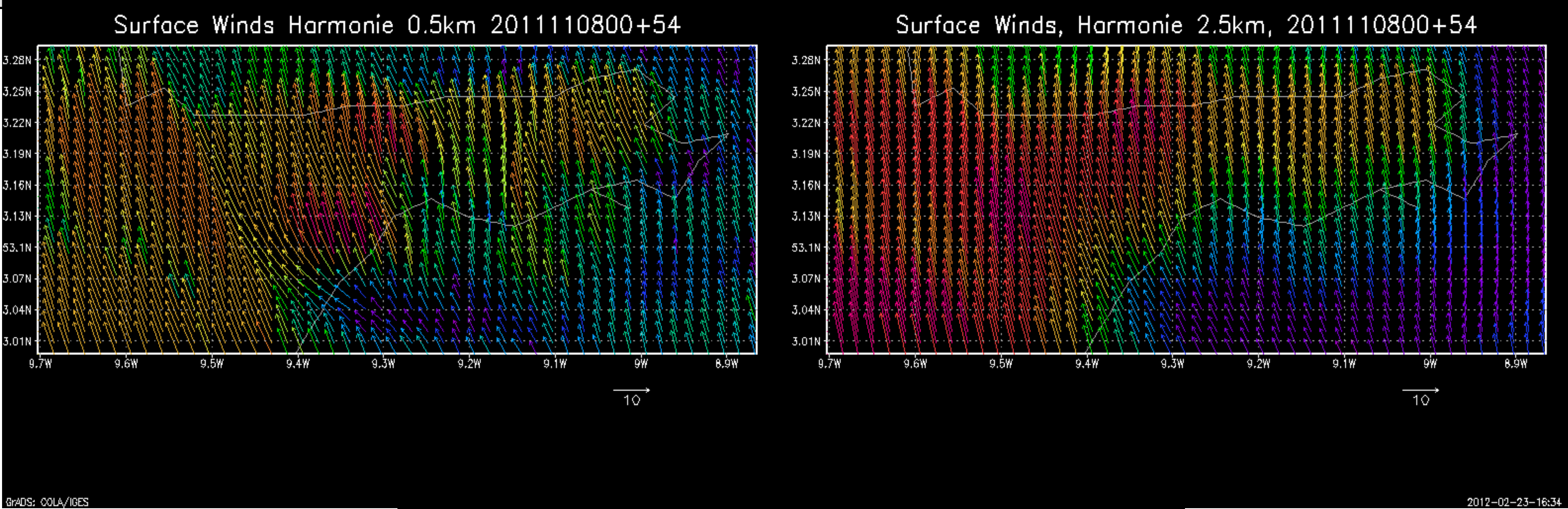
High-resolution HARMONIE not all bad...

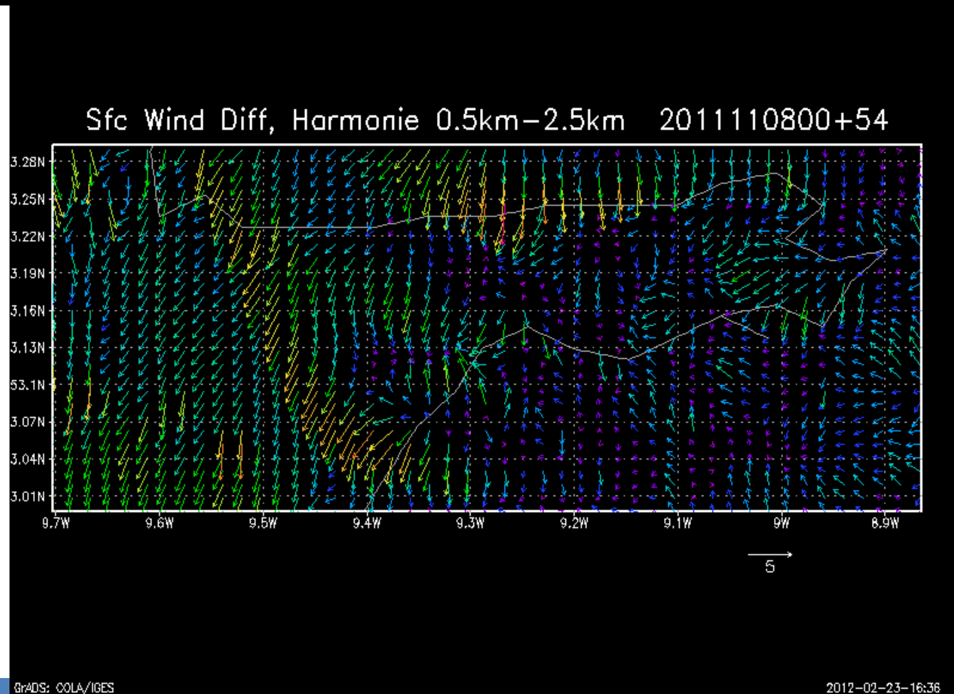
Modis Terra image vs. Harmonie 0.5km LWR at ToA:



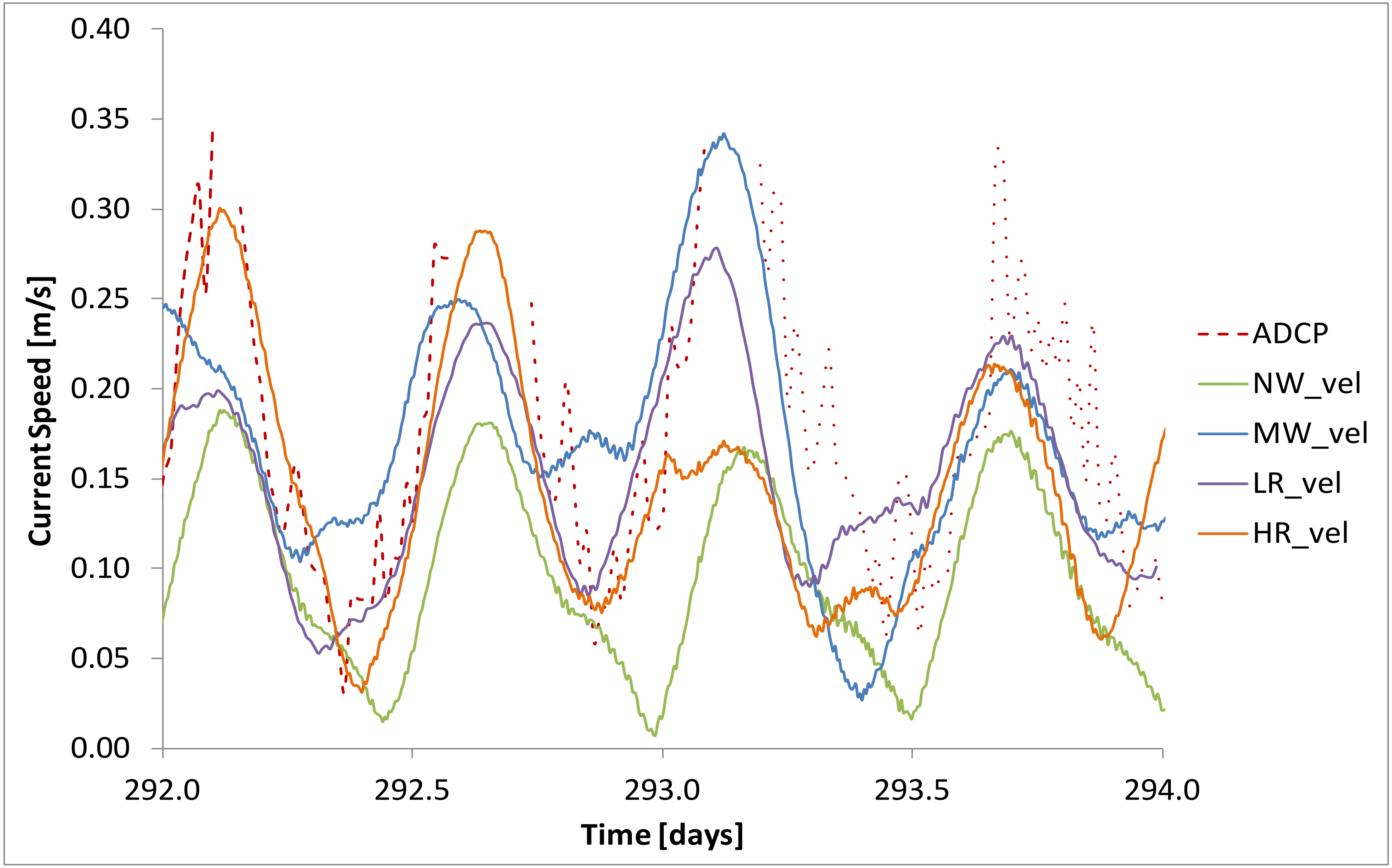



N
N59
Kylemore
Image © 2012 TerraMetrics
Image © 2012 DigitalGlobe
© 2012 Tele Atlas
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google
53°36'00.39" N 9°50'34.47" W elev 97 m
Eye alt 17.91 km


Surface Winds Harmonie 0.5km 2011110800+54
3.28N
3.25N
3.22N
3.19N
3.16N
3.13N
53.1N
3.07N
3.04N
3.01N
9.7W
9.6W
9.5W
9.4W
9.3W
9.2W
9.1W
9W
8.9W
10
Surface Winds, Harmonie 2.5km, 2011110800+54
3.28N
3.25N
3.22N
3.19N
3.16N
3.13N
53.1N
3.07N
3.04N
3.01N
9.7W
9.6W
9.5W
9.4W
9.3W
9.2W
9.1W
9W
8.9W
10
GrADS: COLA/IGES
2012-02-23-16:34


Sfc Wind Diff, Harmonie 0.5km-2.5km 2011110800+54
3.28N
3.25N
3.22N
3.19N
3.16N
3.13N
53.1N
3.07N
3.04N
3.01N
9.7W
9.6W
9.5W
9.4W
9.3W
9.2W
9.1W
9W
8.9W
5
GrADS: COLA/IGES
2012-02-23-16:36

Observed (ADCP) and modelled surface currents in Galway Bay



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Conclusions

- “Scale-adaptive” parameterizations in Harmonie not adaptive enough.
- “Something” is needed to remove spurious KE build-up at short scales (more scale-selective damping, more vertical resolution, gravity-wave drag...).
- Proper data assimilation and/or boundary filtering needed to damp boundary shock.
- Hi-res Harmonie has appeal even now in small domains where topography has strong influence on flow.
- Not to mention extra computational load, and need for better performance...