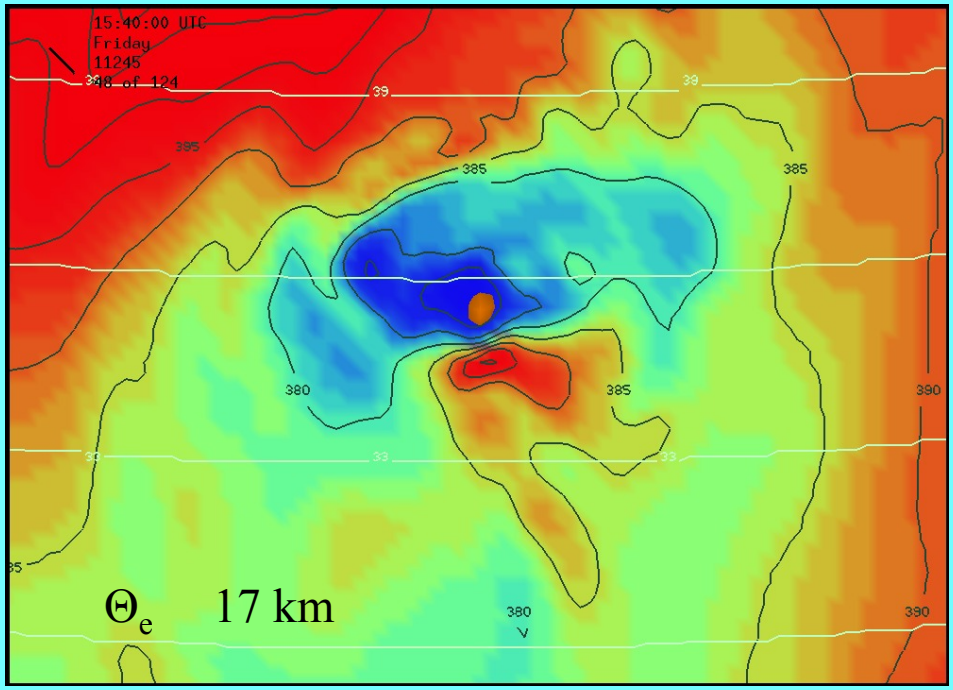
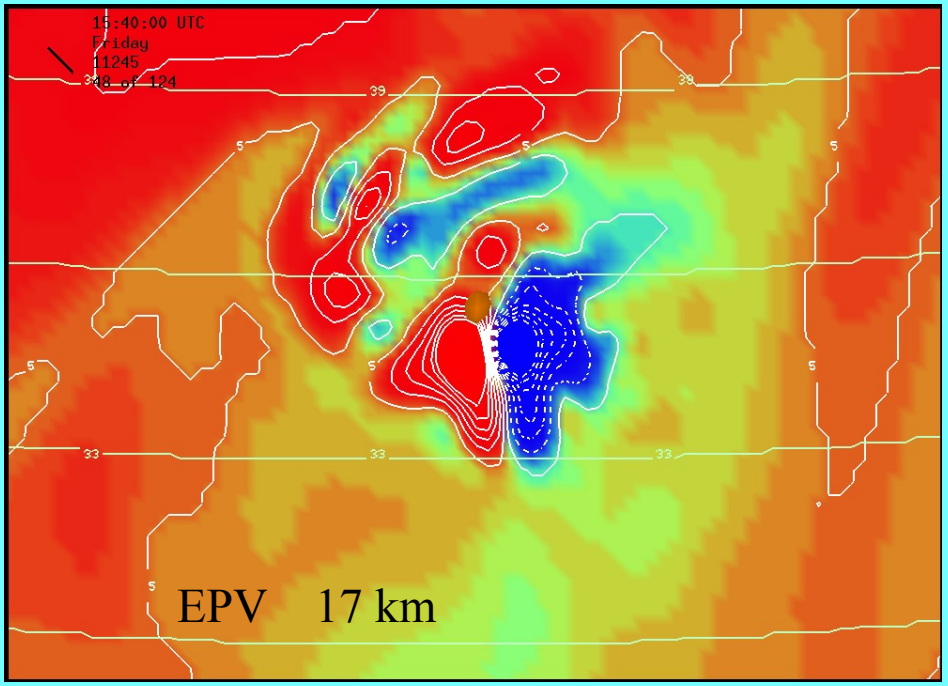
A Modeling Study of STE Near Tropical Cyclones Talas and Ita





Matthew H. Hitchman and Shellie M. Rowe

Department of Atmospheric and Oceanic Sciences,University of Wisconsin-Madison

IGAC Composition and Transport in the Tropical Troposphere and Lower Stratosphere

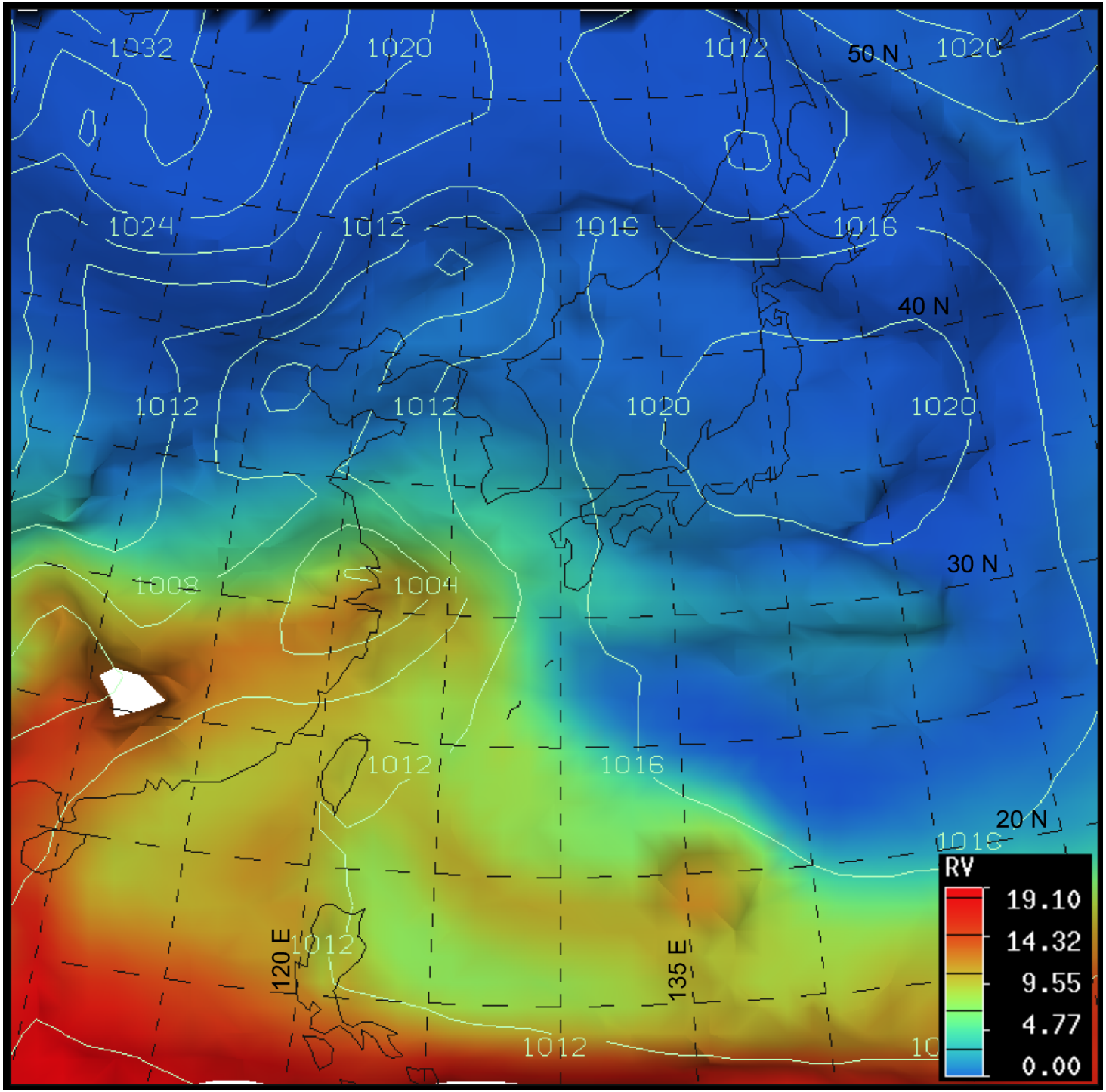
Boulder CO July 20, 2015

1. Example of STE on the periphery of deep convection

2. Inertial instability and PV dipoles

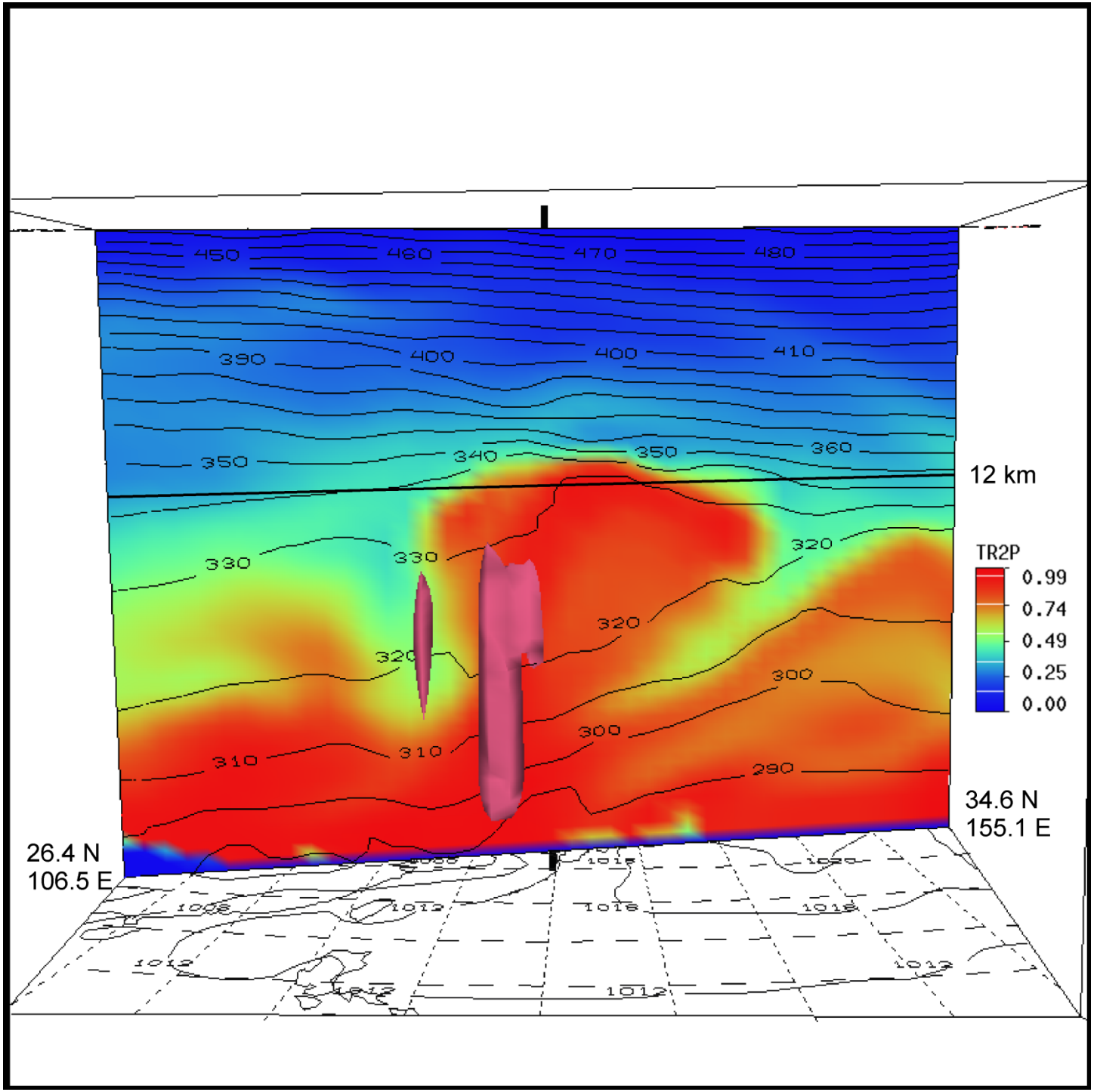
3. Tropical cyclone Talas, Japan, Sept 2011
   CIMSS Satellite loops
   UWNMS simulation Sept 2-4

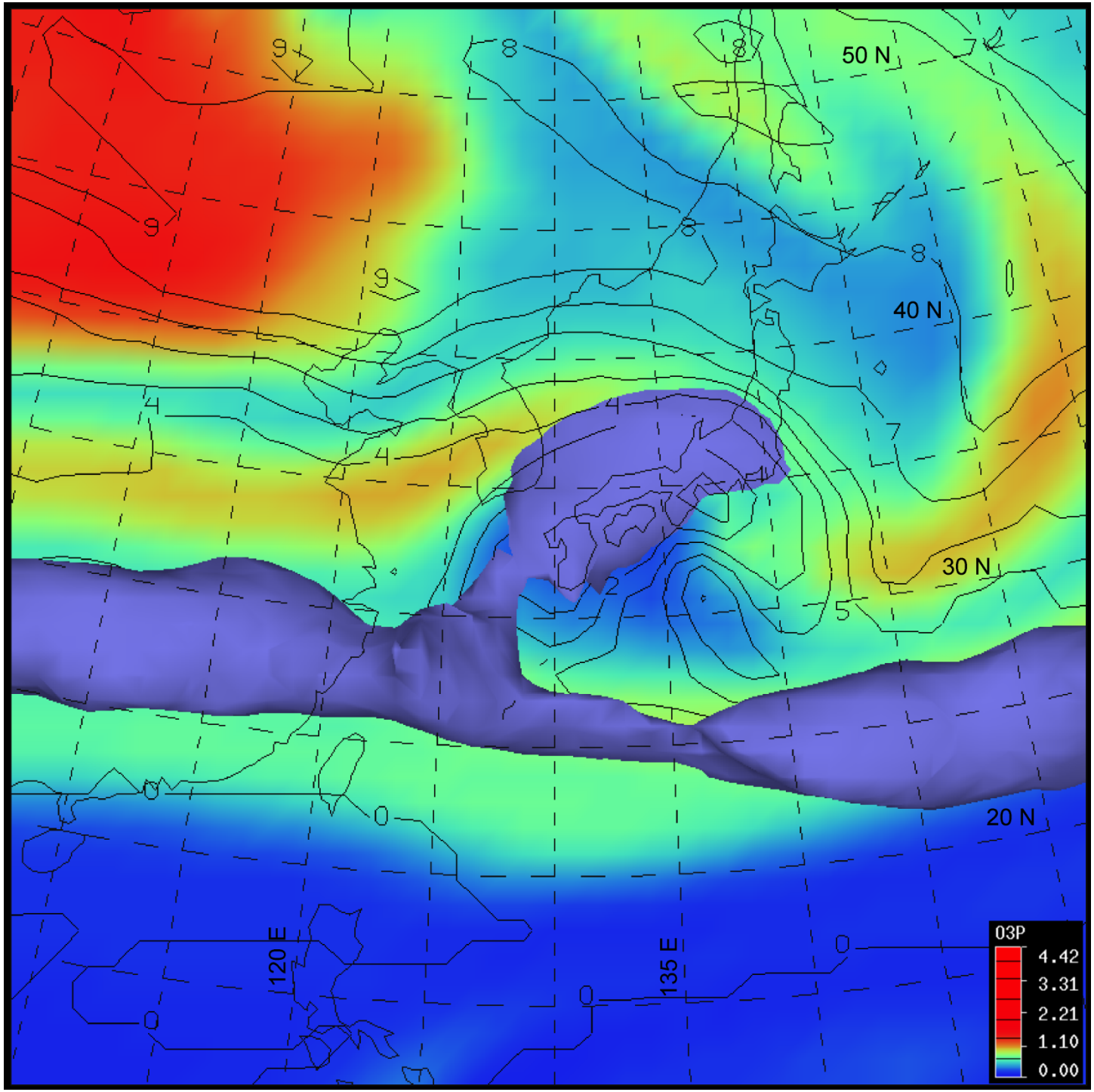
4. Tropical cyclone Ita, Queensland, April 2014
   UWNMS simulation April 10-11

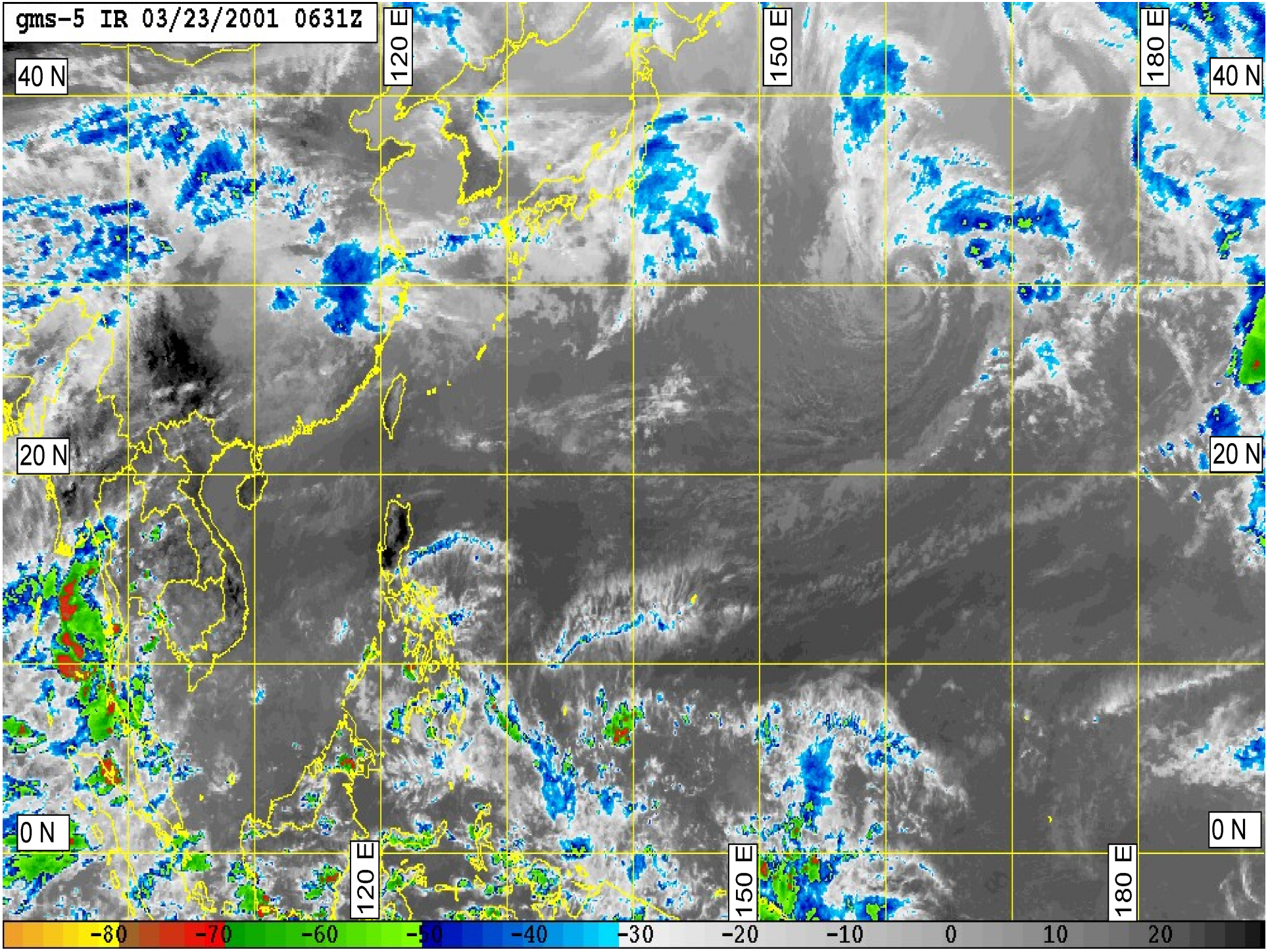


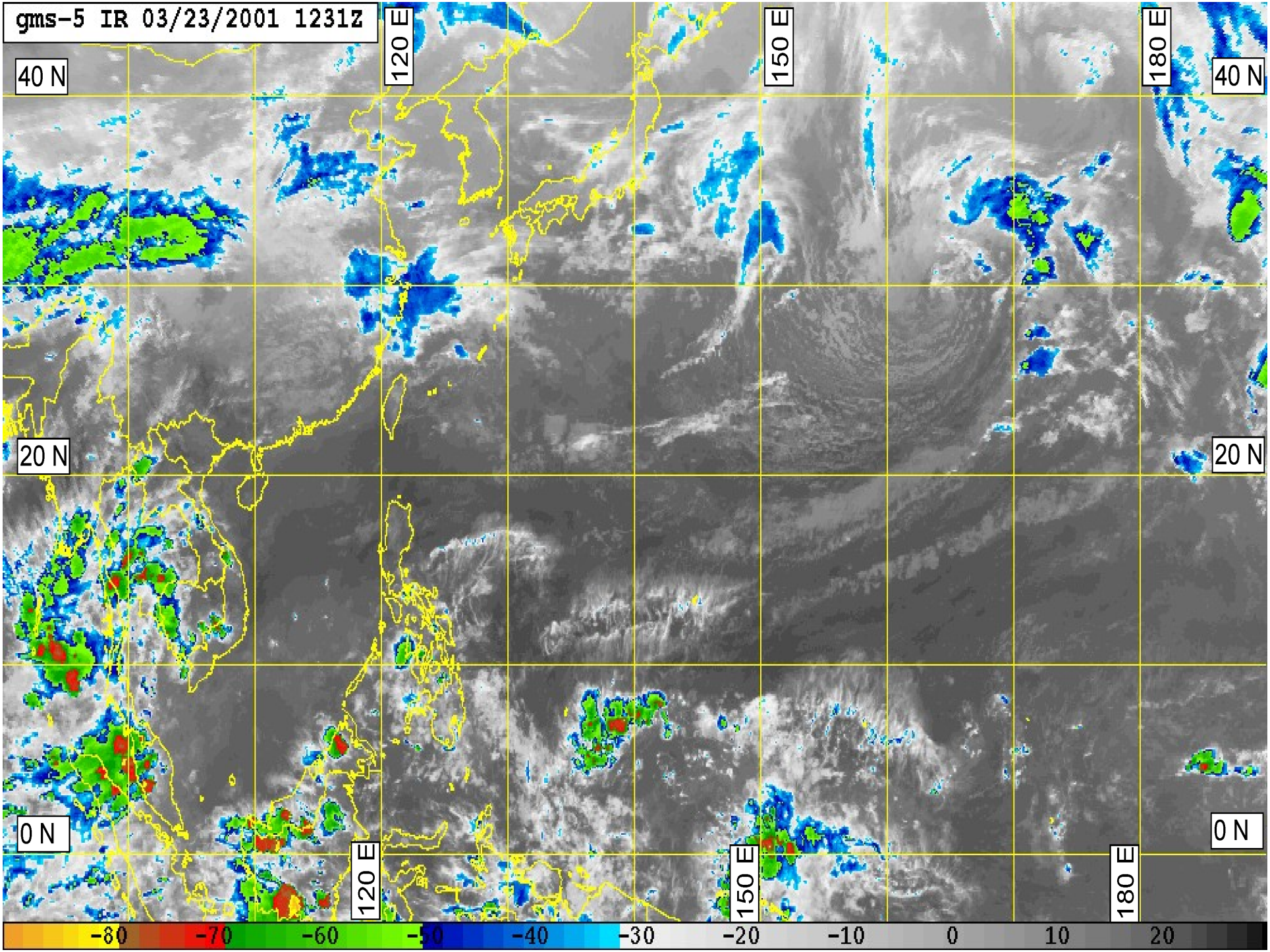
UWNMS
forecast
for TRACE-P

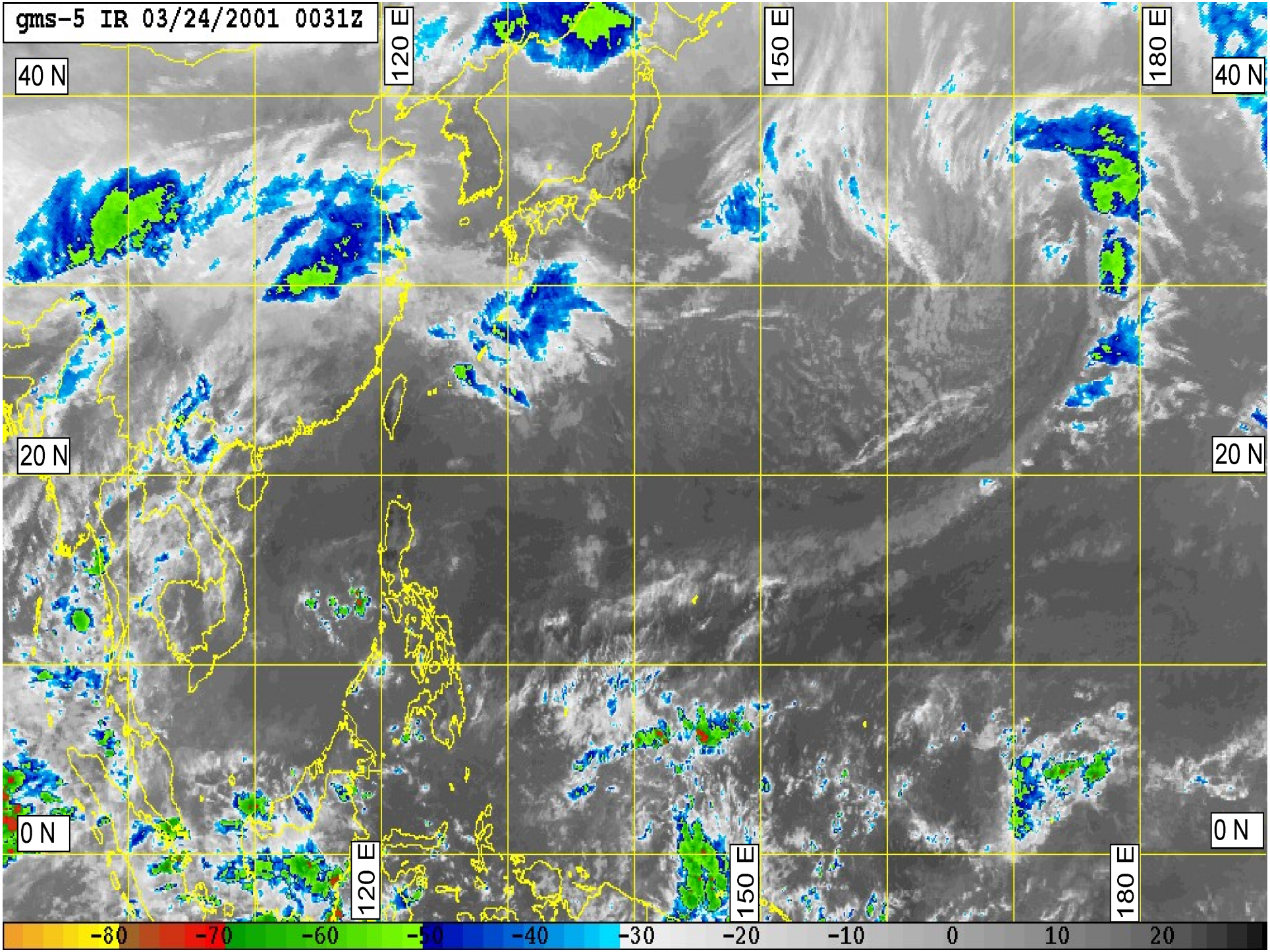
Mar 23, 2001

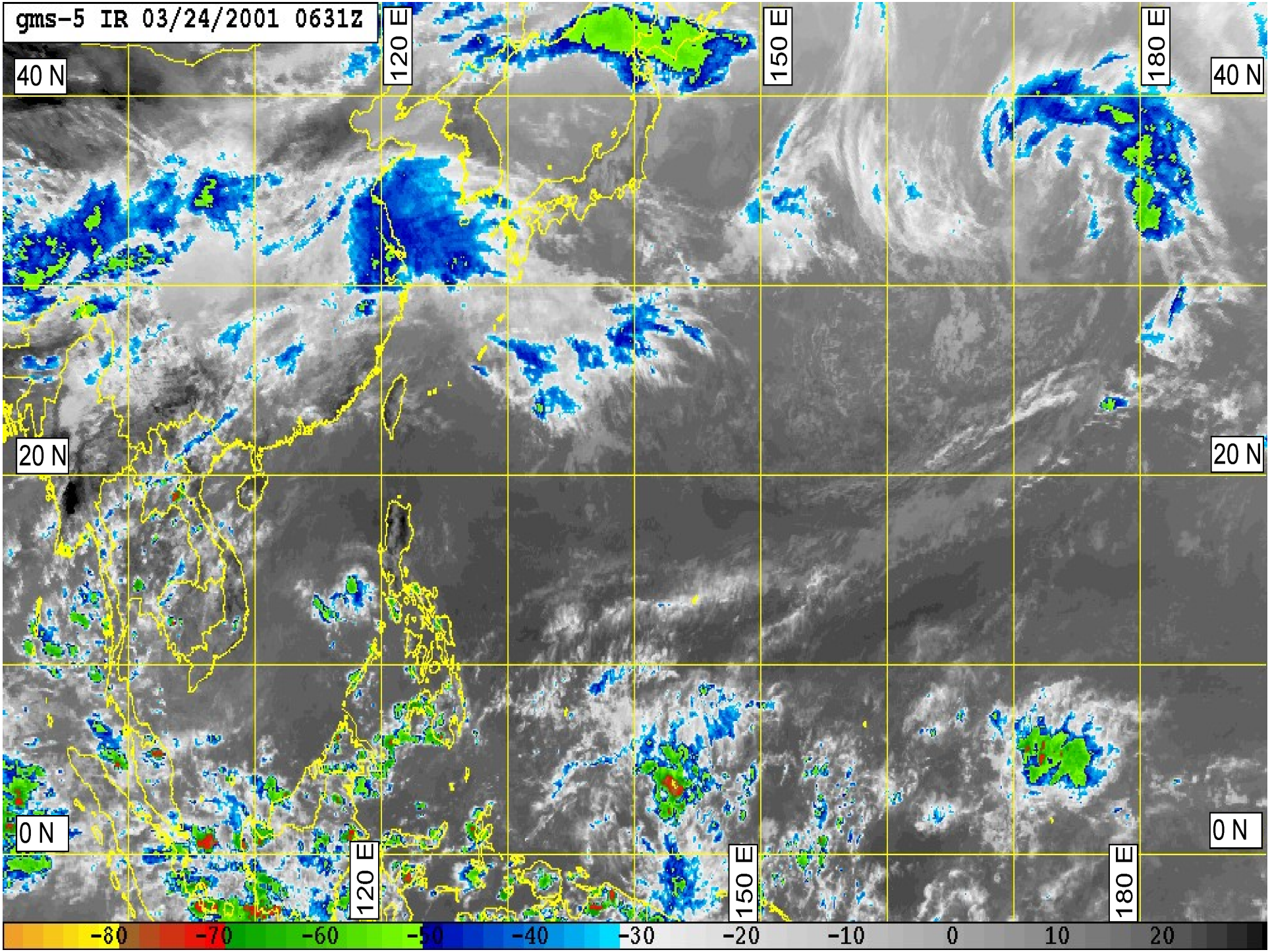

450
460
470
480
390
400
400
410
350
340
350
360
330
330
320
320
320
300
310
310
300
290
12 km
TR2P
0.99
0.74
0.49
0.25
0.00
34.6 N
155.1 E
26.4 N
106.5 E
1008
1012
1016
1012
1012

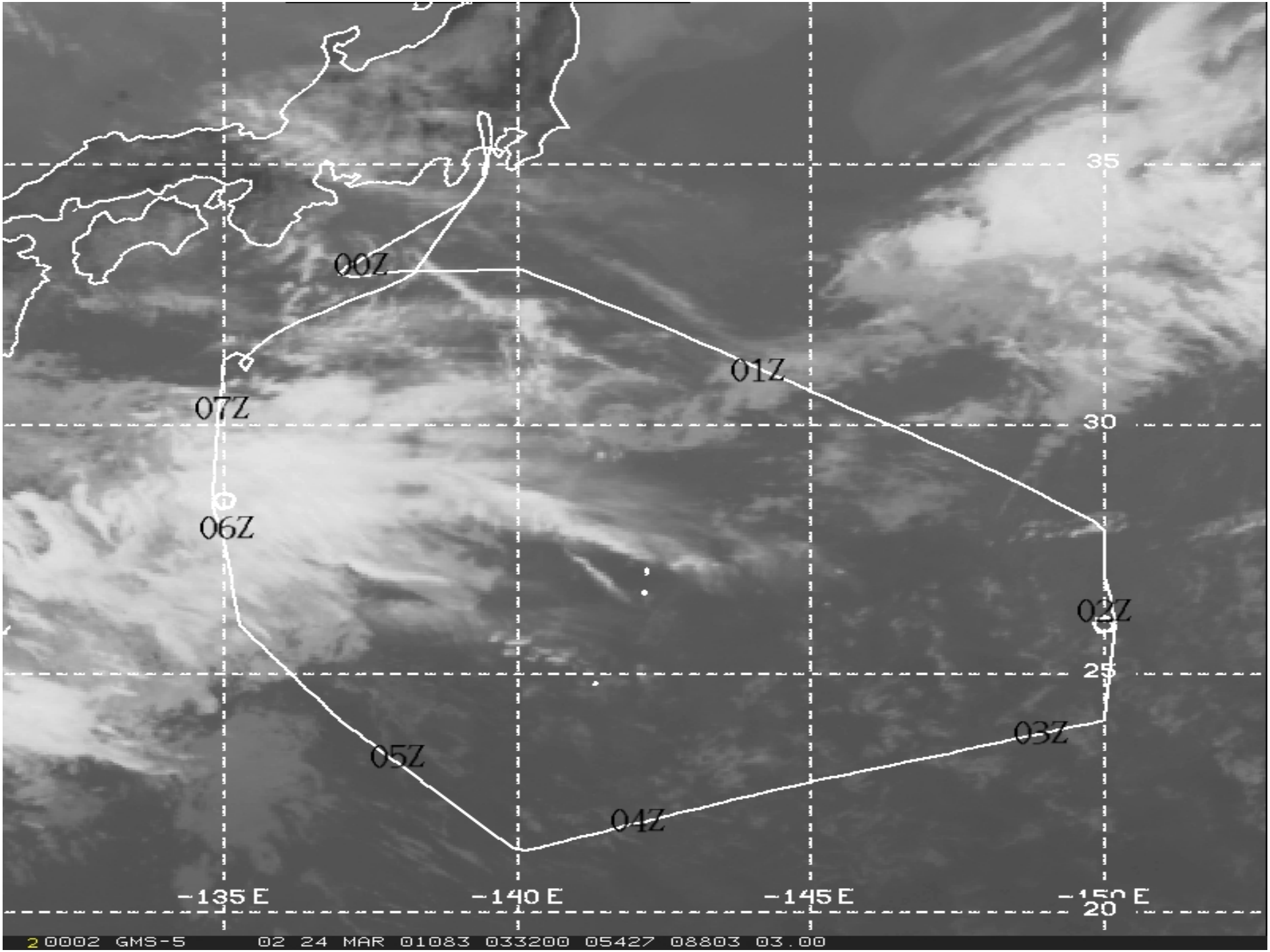

50 N
40 N
30 N
20 N
120 E
135 E
03P
4.42
3.31
2.21
1.10
0.00

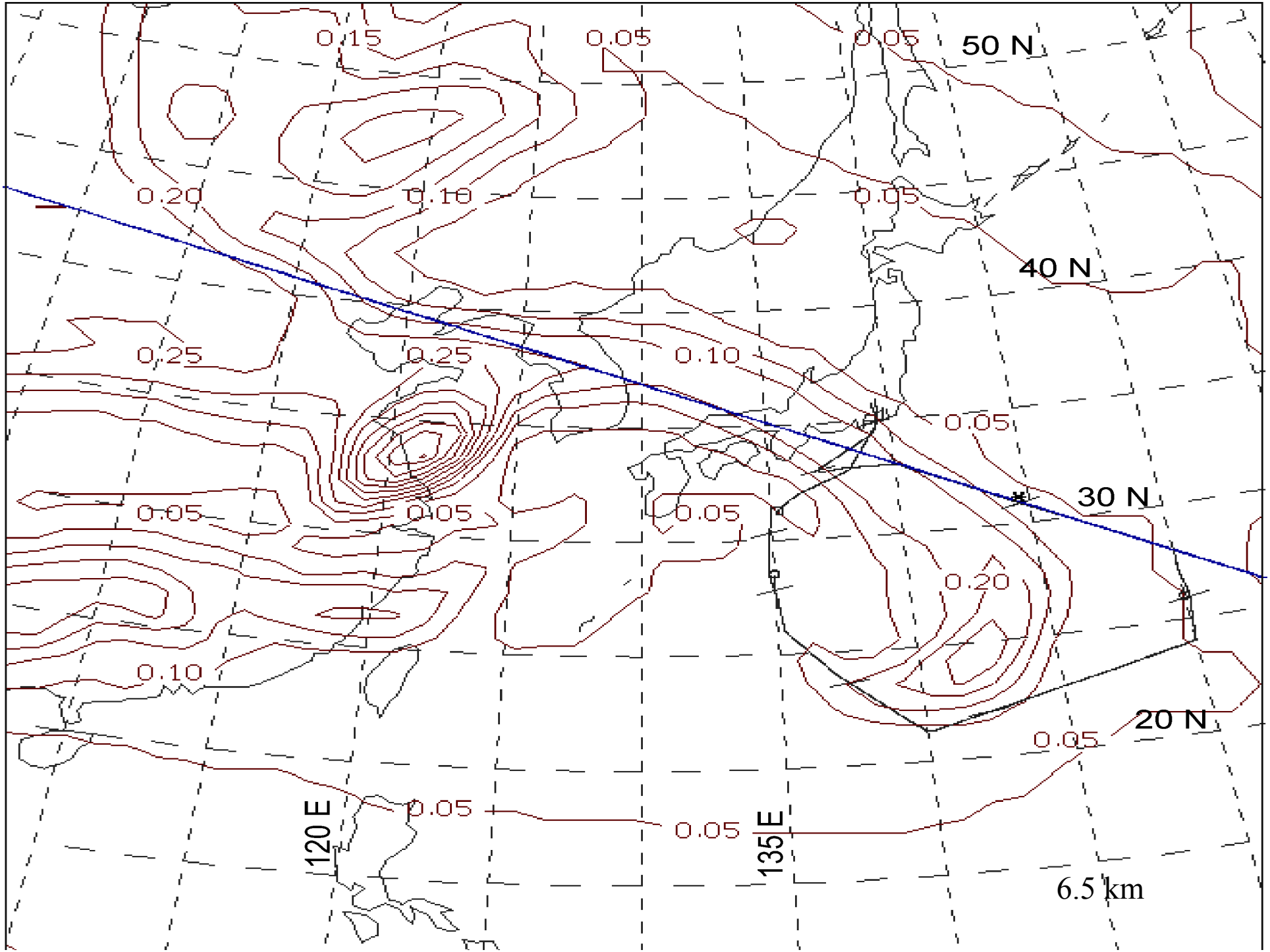

gms-5 IR 03/23/2001 0631Z
40 N
120 E
150 E
180 E
20 N
0 N
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20

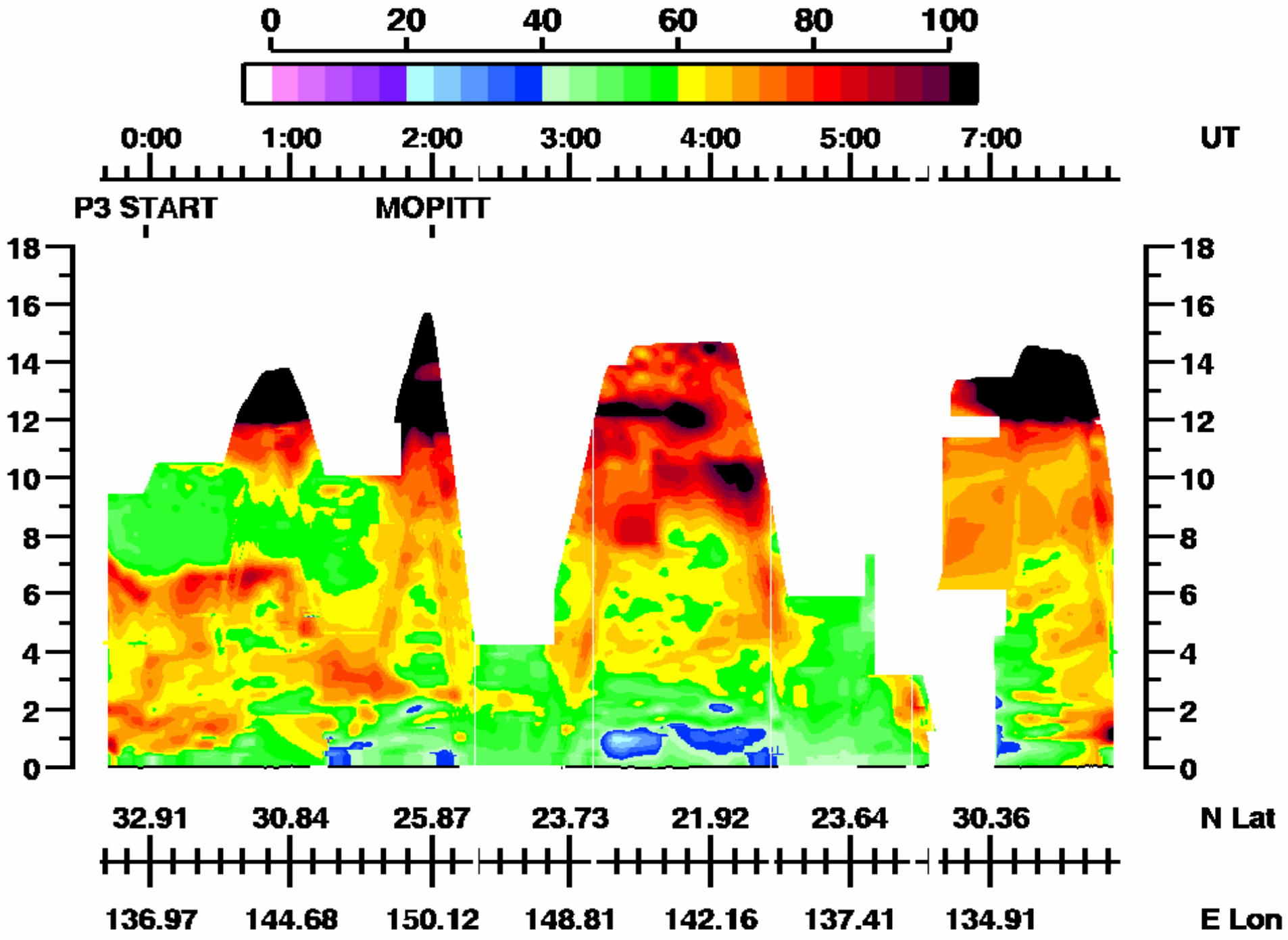

gms-5 IR 03/23/2001 1231Z
40 N
120 E
150 E
180 E
20 N
0 N
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20

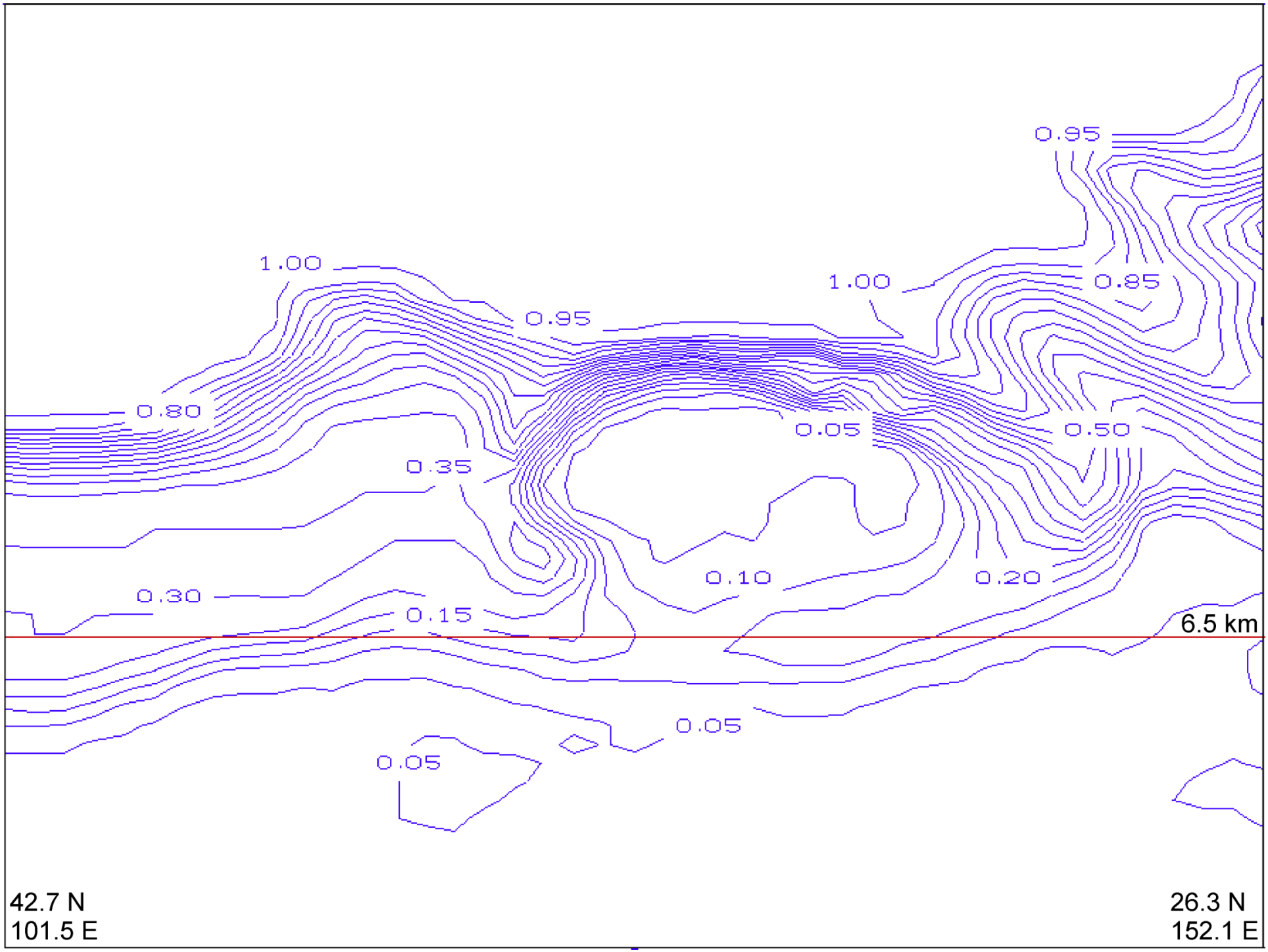

gms-5 IR 03/24/2001 0031Z
40 N
120 E
150 E
180 E
20 N
0 N
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20

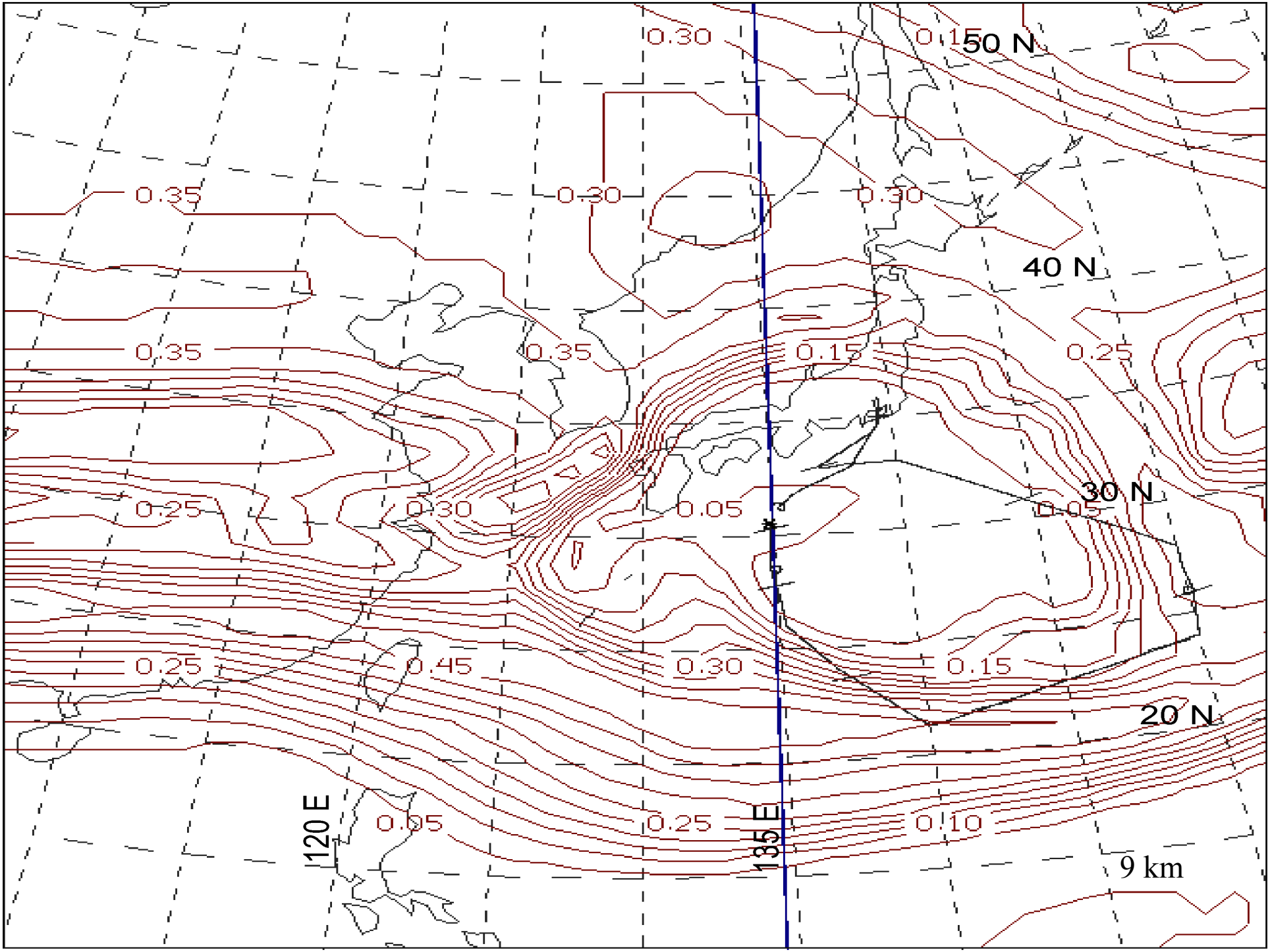

gms-5 IR 03/24/2001 0631Z
40 N
120 E
150 E
180 E
40 N
20 N
20 N
0 N
0 N
120 E
150 E
180 E
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20

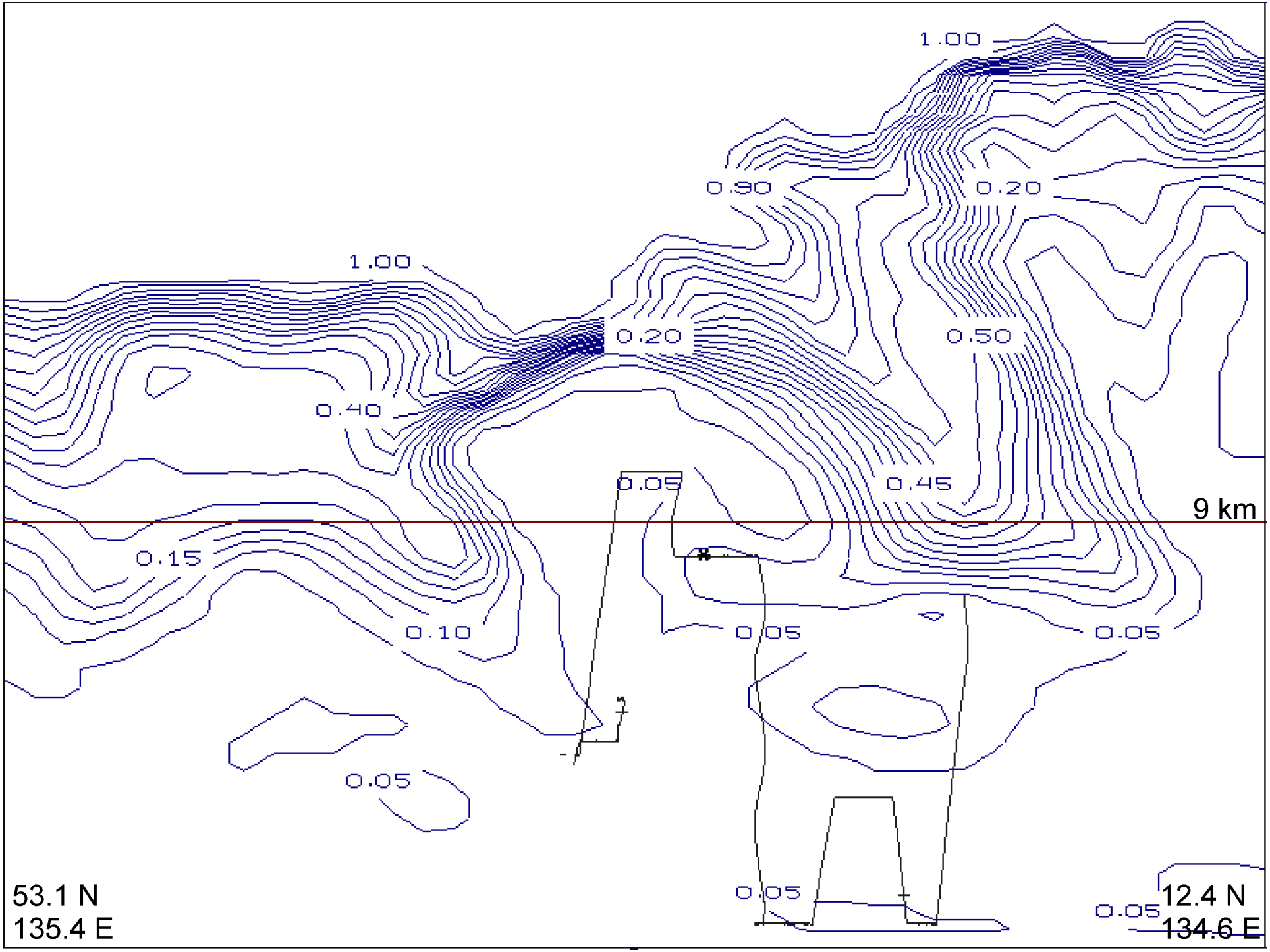

00Z
01Z
02Z
03Z
04Z
05Z
06Z
07Z
35
30
25
20
−135 E
−140 E
−145 E
−150 E
2 0002 GMS-5 02 24 MAR 01083 033200 05427 08803 03.00


0.15
0.05
0.05
50 N
0.20
0.10
0.05
40 N
0.25
0.25
0.10
0.05
30 N
0.05
0.05
0.05
0.20
0.10
20 N
0.05
0.05
0.05
120 E
135 E
6.5 km


0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
7:00
UT
P3 START
MOPITT
18
16
14
12
10
8
6
4
2
0
32.91
30.84
25.87
23.73
21.92
23.64
30.36
N Lat
136.97
144.68
150.12
148.81
142.16
137.41
134.91
E Lon

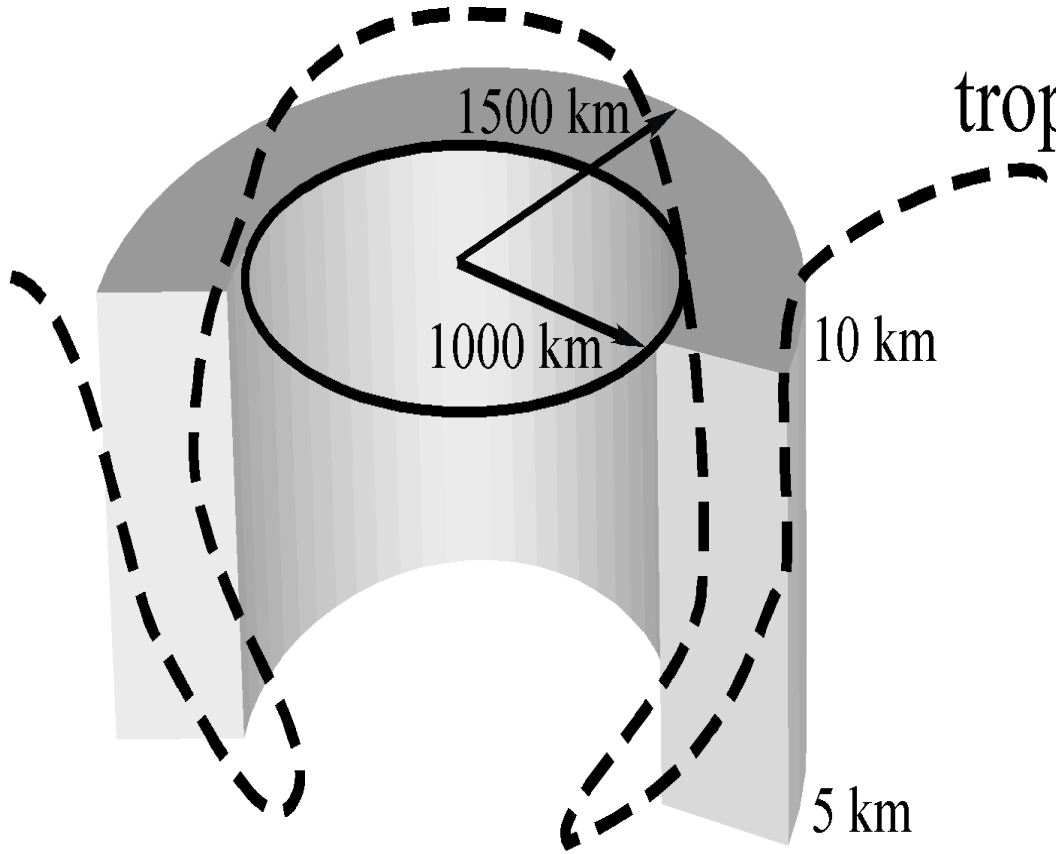

0.95
1.00
0.85
1.00
0.95
0.80
0.05
0.50
0.35
0.10
0.20
0.30
0.15
6.5 km
0.05
0.05
42.7 N
101.5 E
26.3 N
152.1 E


0.30
0.15
50 N
0.35
0.30
0.30
40 N
0.35
0.35
0.15
0.25
0.25
0.30
0.05
0.05
30 N
0.25
0.45
0.30
0.15
20 N
120 E
0.05
0.25
0.10
135 E
9 km


1.00
0.90
0.20
1.00
0.20
0.50
0.40
0.05
0.45
9 km
0.15
0.10
0.05
0.05
0.05
0.05
0.05
53.1 N
135.4 E
12.4 N
134.6 E

Annulus Method

Peripheral Downwelling - The "Medusa"



tropopause

100 ppbv ozone

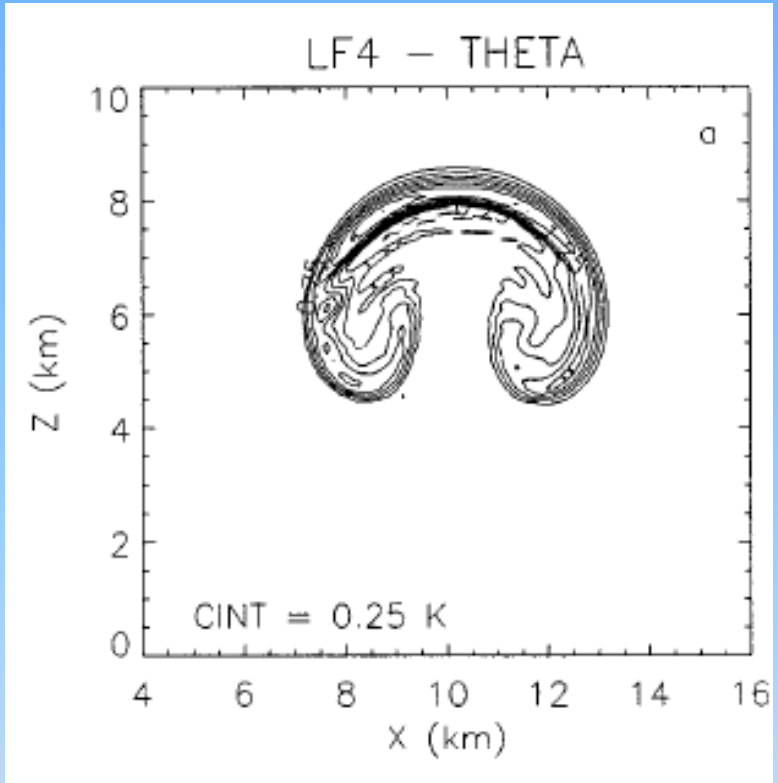
1 day

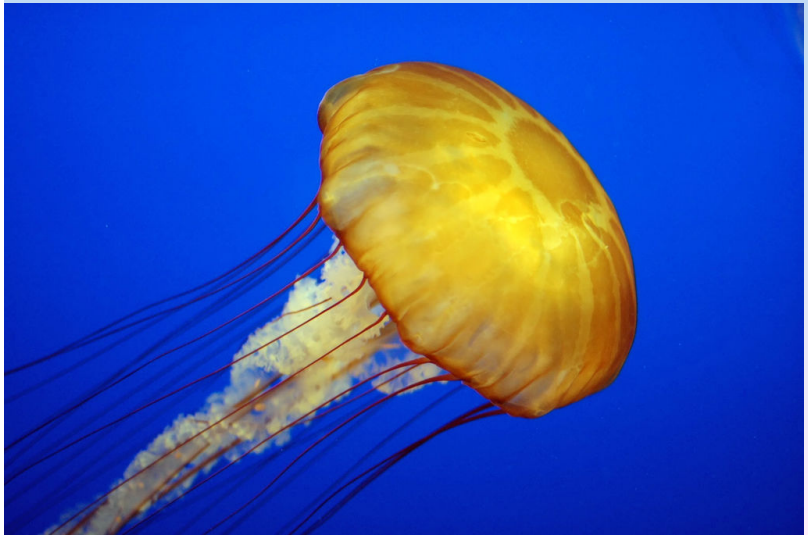
$\sim 10^{34}$ molecules/day

$\sim$ 1 Tg/day

Hitchman et al. JGR 2004

Wicker and Skamarock 1997 MWR





Inertial Instability

$$\frac{\partial^2}{\partial t^2}\delta s = - f\,(f + \zeta)\,\delta s$$

$$f\,(f + \zeta) < 0$$

$$M = r\,u + r^2\,\Omega \quad r = a\cos\varphi$$

$$f\ PV = \frac{1}{\rho}\frac{\partial \theta}{\partial z} f\,(f+\zeta) = -\frac{1}{r}\nabla_\theta M < 0$$

$$EPV = \frac{1}{\rho}\frac{\partial \theta_e}{\partial z}(f+\zeta) < 0 \qquad \theta_e = \theta\ exp\left(\frac{Lw_s}{c_p T}\right)$$

Signature: negative absolute vorticity, PV, or EPV
reversed absolute angular momentum contours

Implies: enhance div/conv, gravity wave excitation,
acceleration of outward and poleward flow

Chagnon and Gray, 2009, QJRMS

$$\frac{\partial q}{\partial t} = \left(f\frac{\partial}{\partial z} - \Lambda\frac{\partial}{\partial x} \right)\left(\frac{B}{N^2} \right) \qquad \Lambda = \mathrm{d}V/\mathrm{d}z \qquad B \text{ is the rate of heating}$$

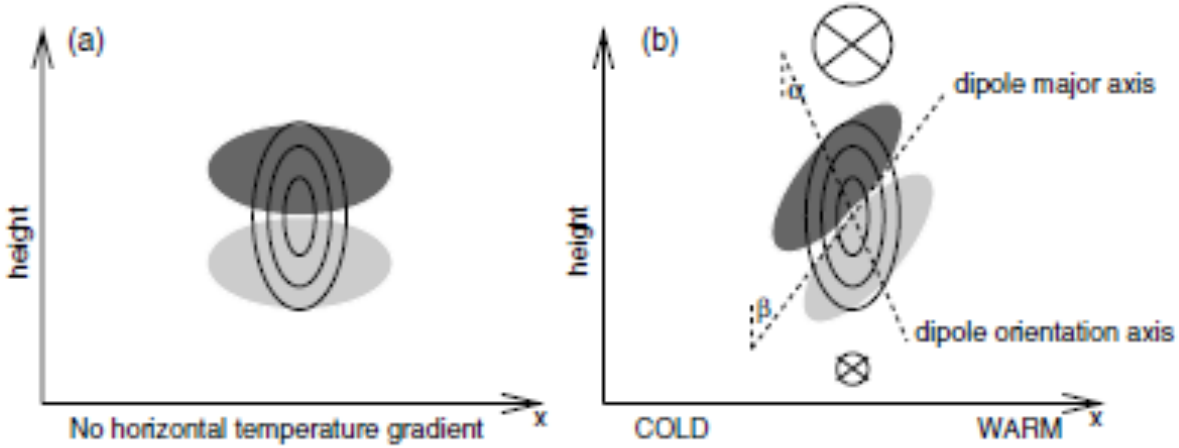
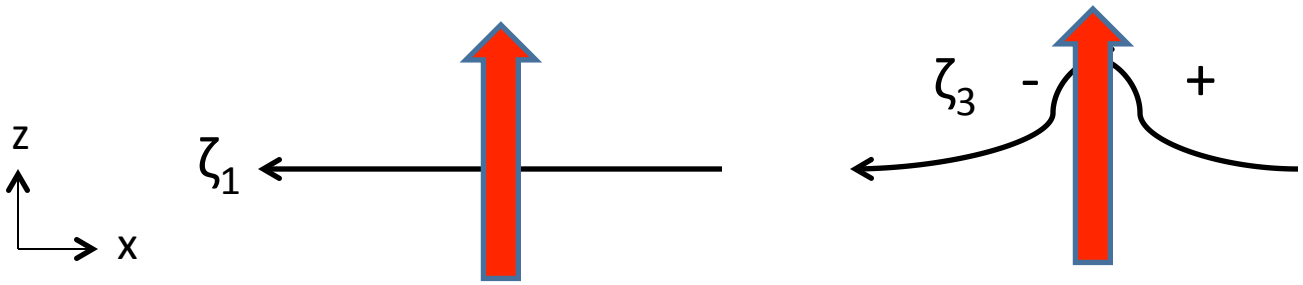


Figure 1. Schematic diagram depicting the orientation of the PV dipole arising from heating applied against (a) a barotropic environment having a background vertical (planetary) vorticity, and (b) a baroclinic environment containing vertical wind shear (directed into the page). Positive (negative) PV anomaly is indicated by light (dark) shading.



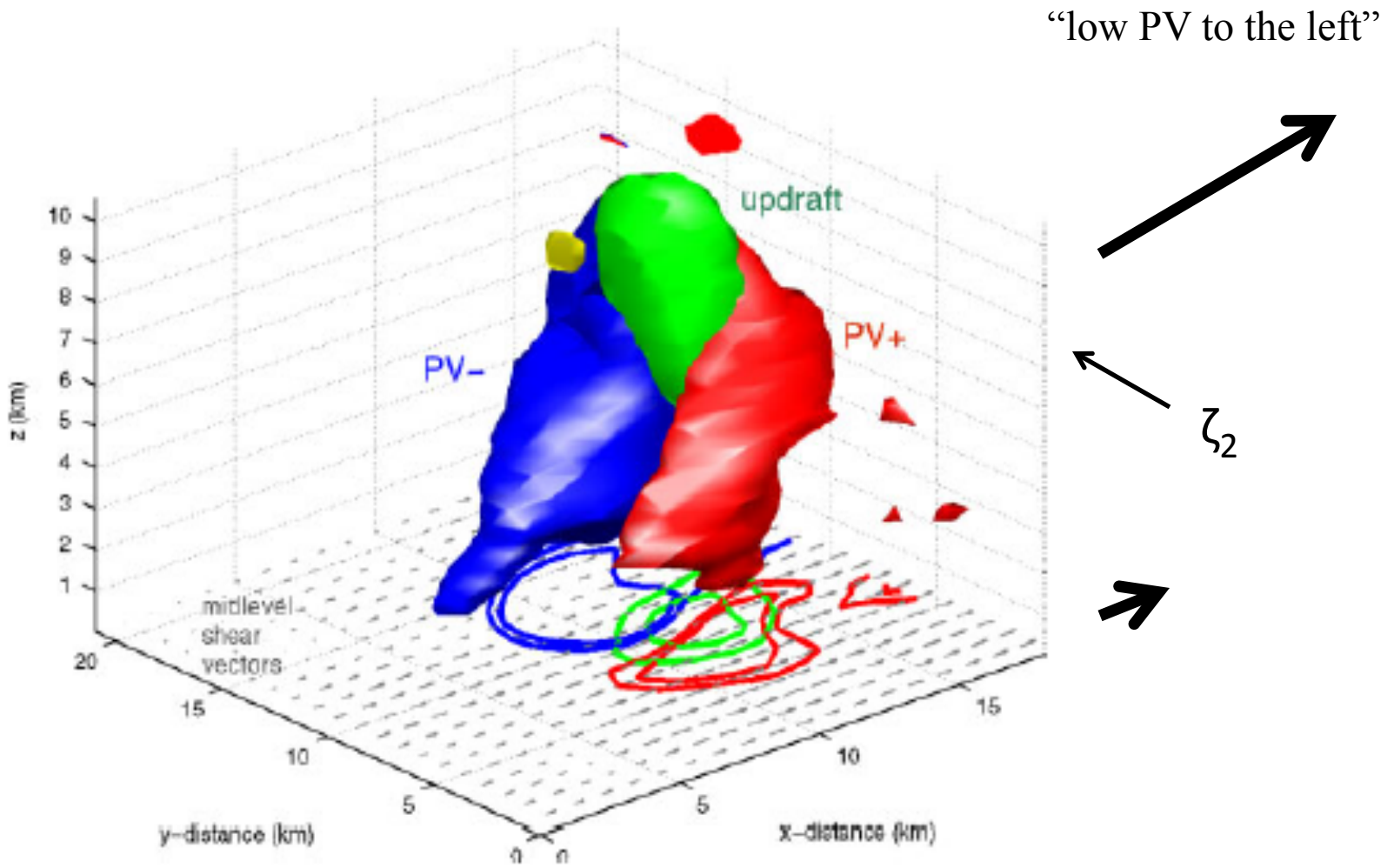
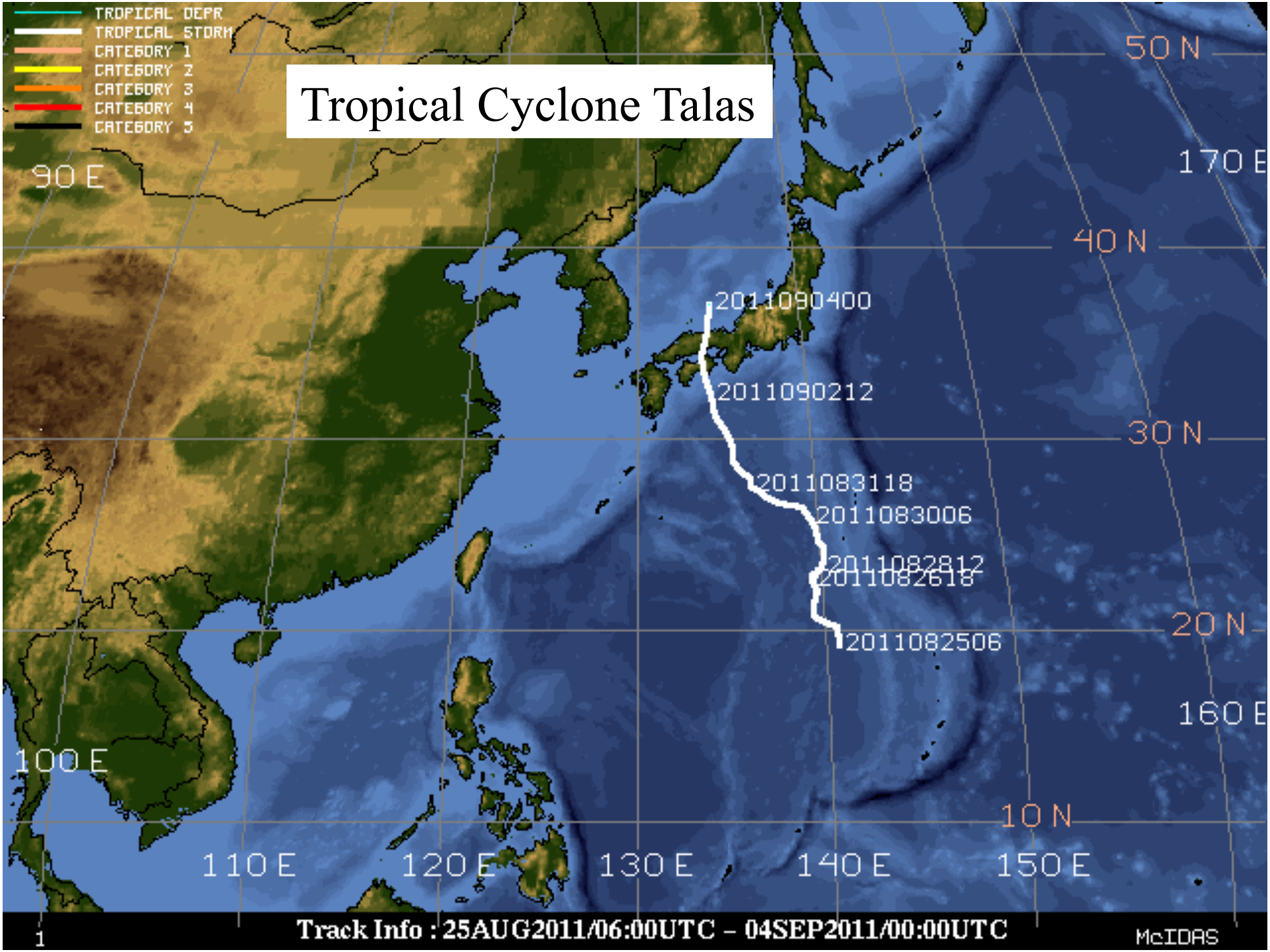
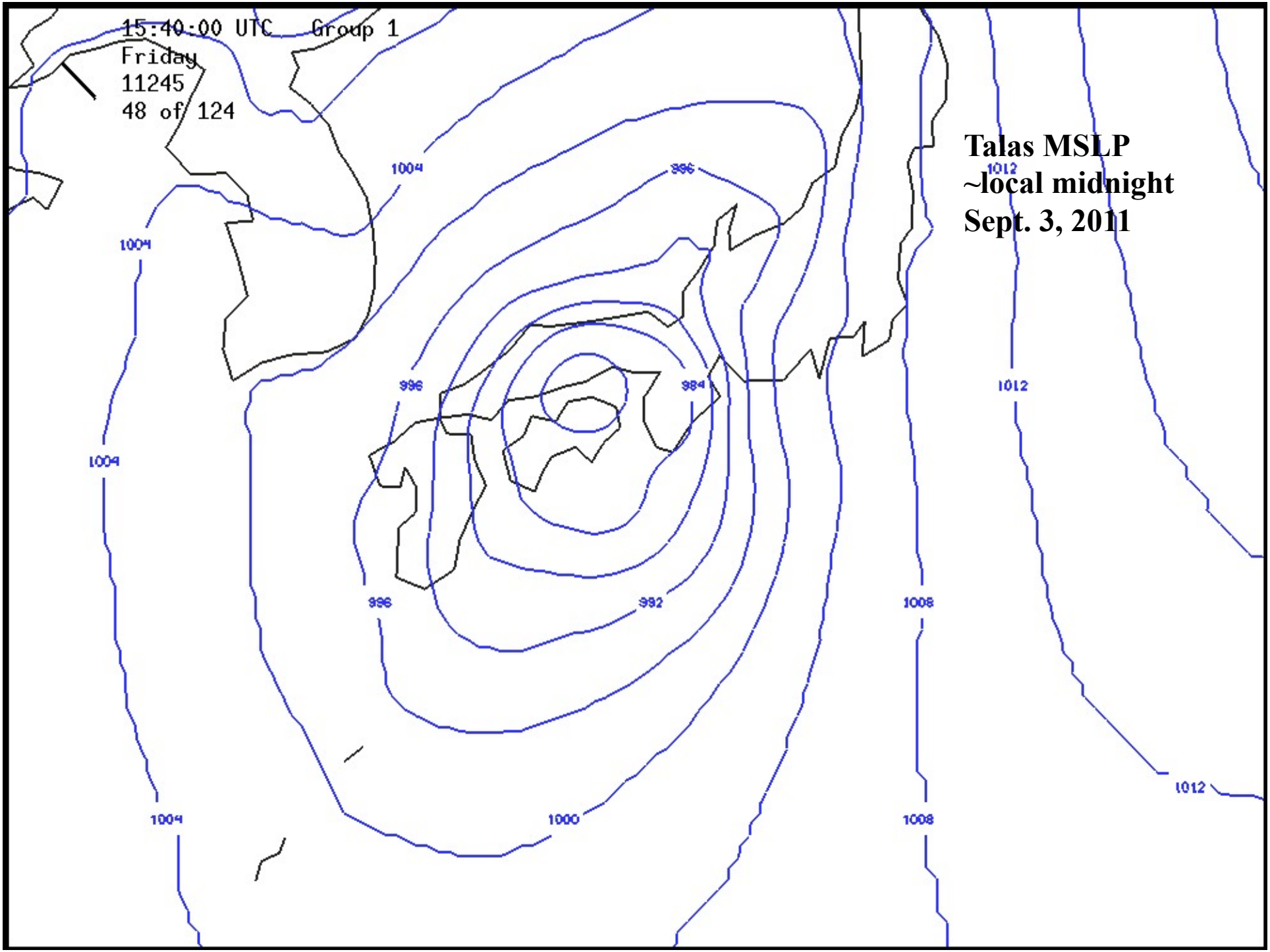


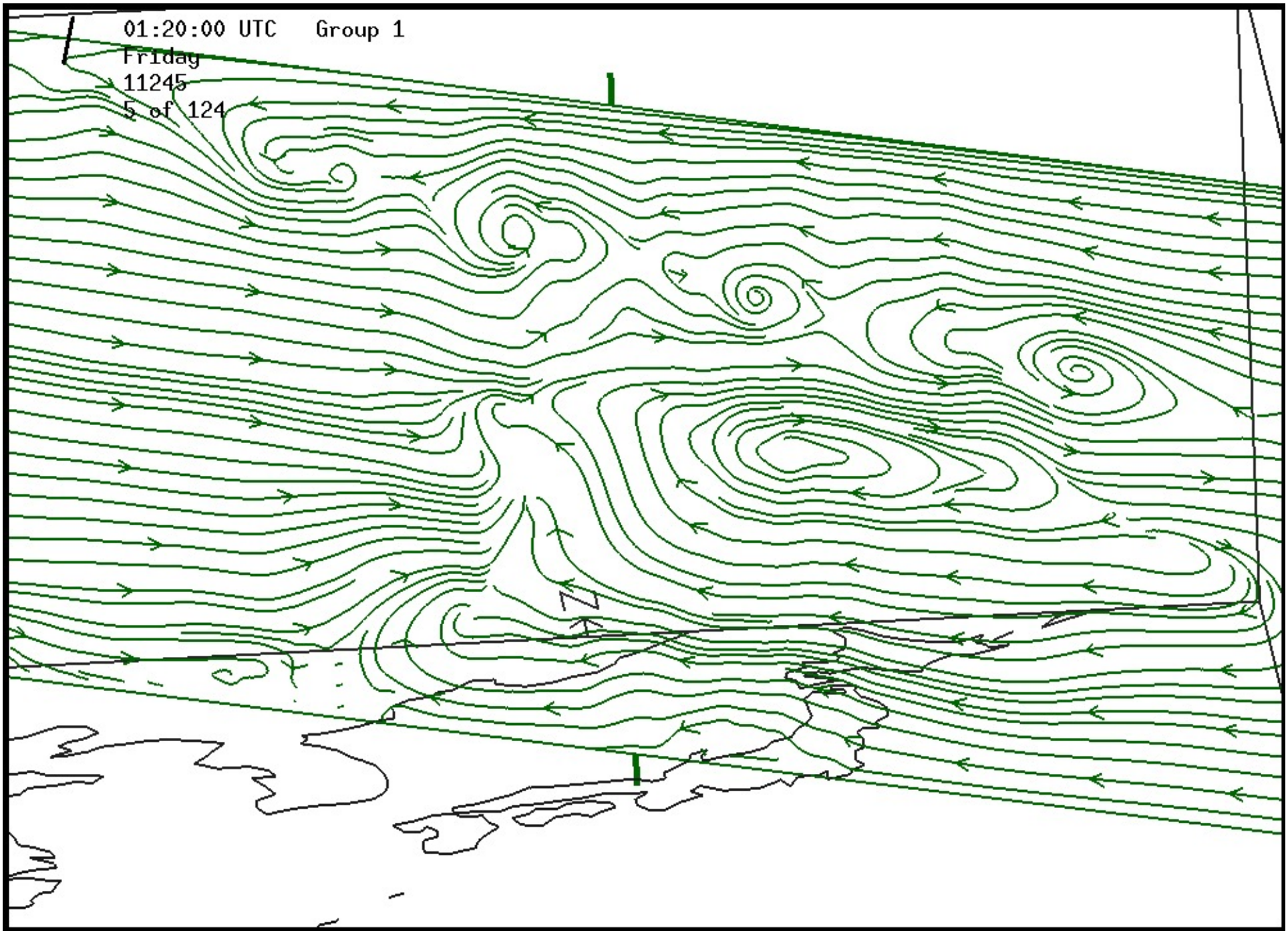
Figure 9. Three-dimensional rendering of the horizontal PV dipole. Plotted are isosurfaces of potential vorticity (in the online figure, the red surface denotes 15 PVU and the blue surface −15 PVU) and vertical velocity (in the online figure, the green surface is for 7 m s^{-1}). For reference, contours of PV (10 and 15 PV) and vertical velocity (5 and 7 m s^{-1}) at an elevation $z = 6.5$ km are projected on to the lower horizontal plane. Mid-tropospheric shear vectors (averaged from $z = 2$ to 7 km) are also plotted in the lower horizontal plane. A colour version of this figure is available online. This figure is available in colour online at www.interscience.wiley.com/journal/qj

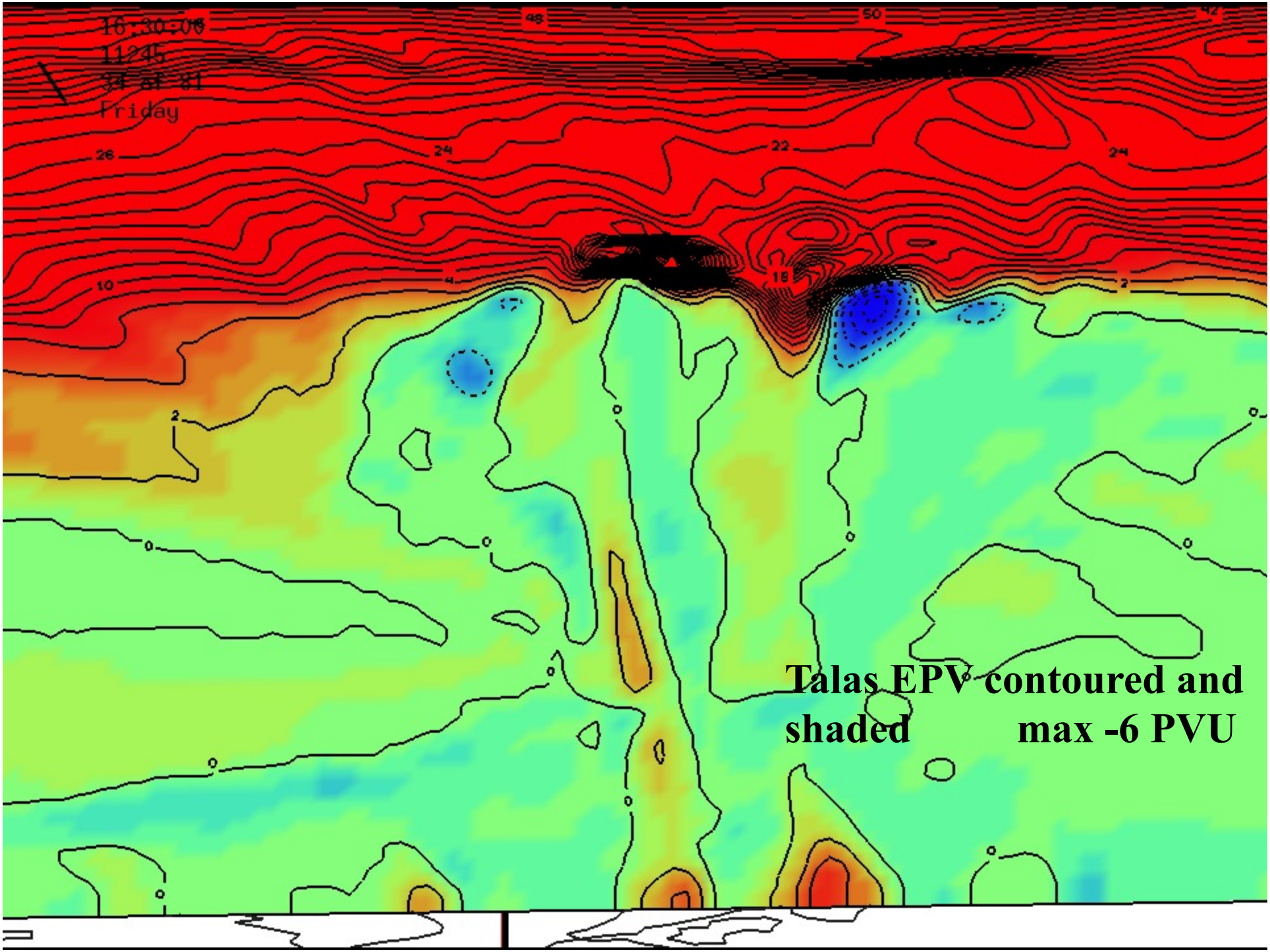

TROPICAL DEPR
TROPICAL STORM
CATEGORY 1
CATEGORY 2
CATEGORY 3
CATEGORY 4
CATEGORY 5
Tropical Cyclone Talas
50 N
40 N
30 N
20 N
10 N
90 E
170 E
160 E
100 E
110 E
120 E
130 E
140 E
150 E
2011090400
2011090212
2011083118
2011083006
2011082812
2011082618
2011082506
Track Info : 25AUG2011/06:00UTC – 04SEP2011/00:00UTC
1
McIDAS

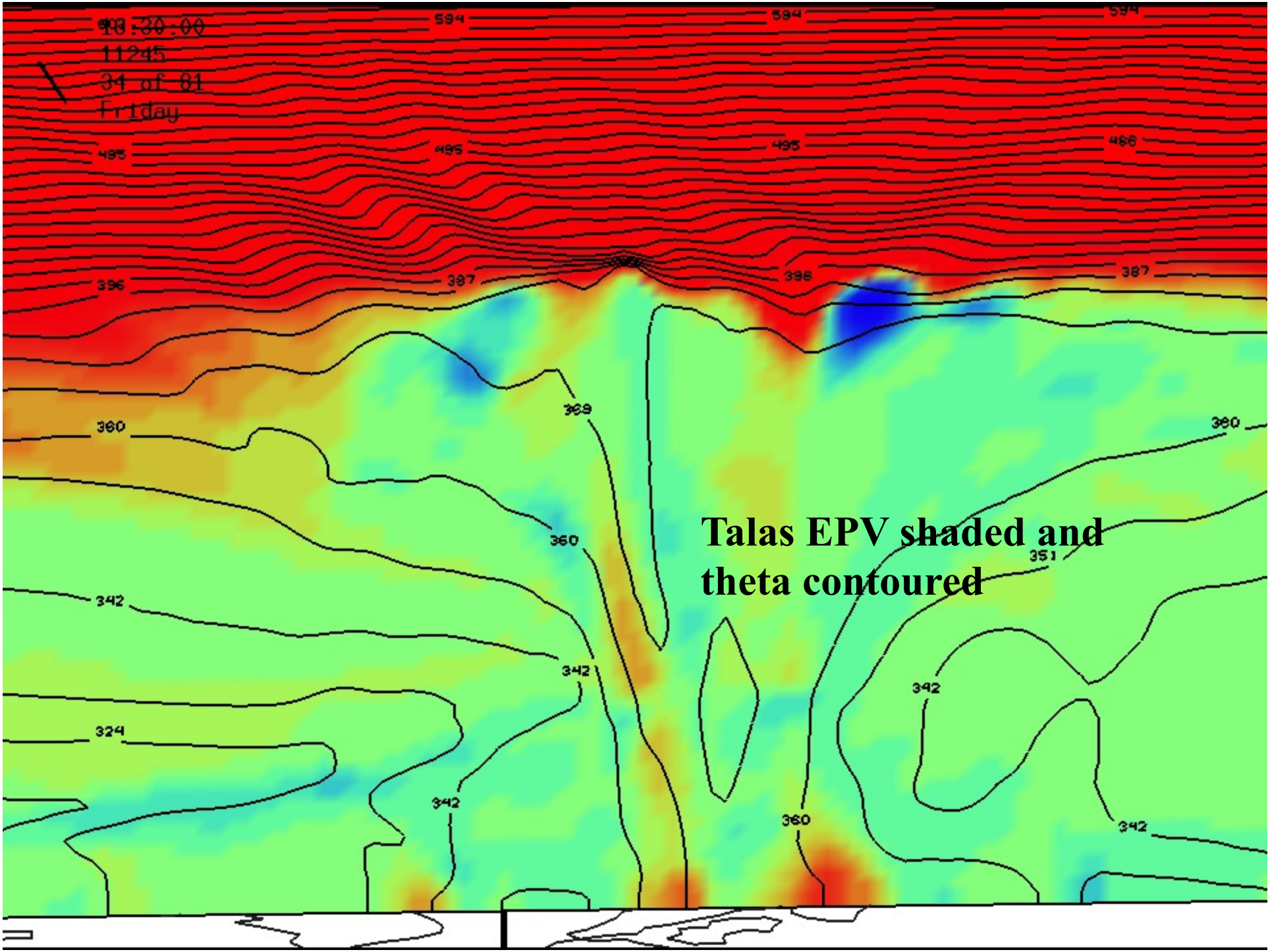
1. Enhanced IR film loop
2. Water vapor film loop
3. Upper level winds loop

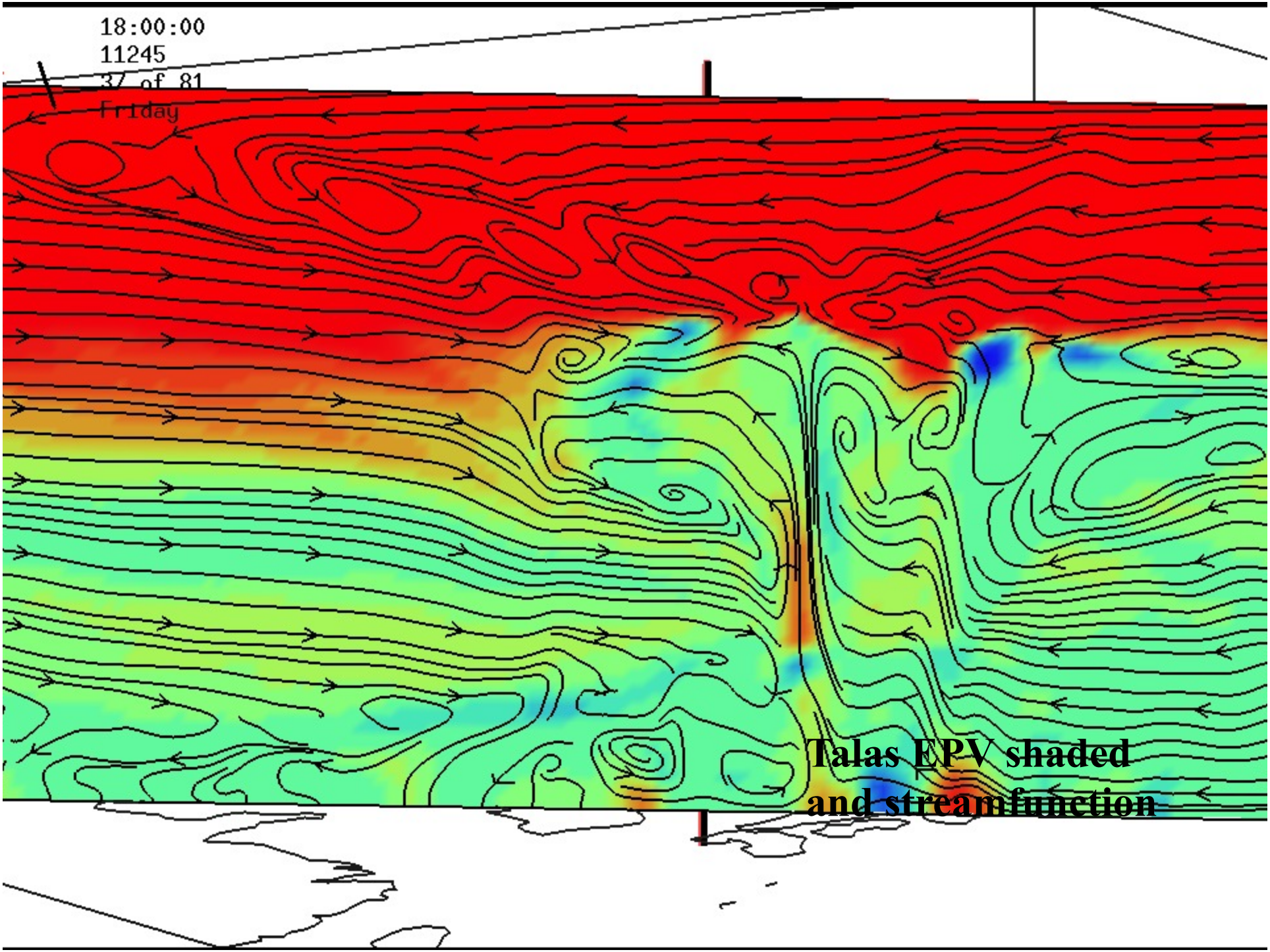
4. UWNMS simulation
   - model top 26 km
   - vertical resolution ~300 m
   - horizontal resolution 20 km
   - 2.5^{o} ECMWF initialization
   - run 48 hr

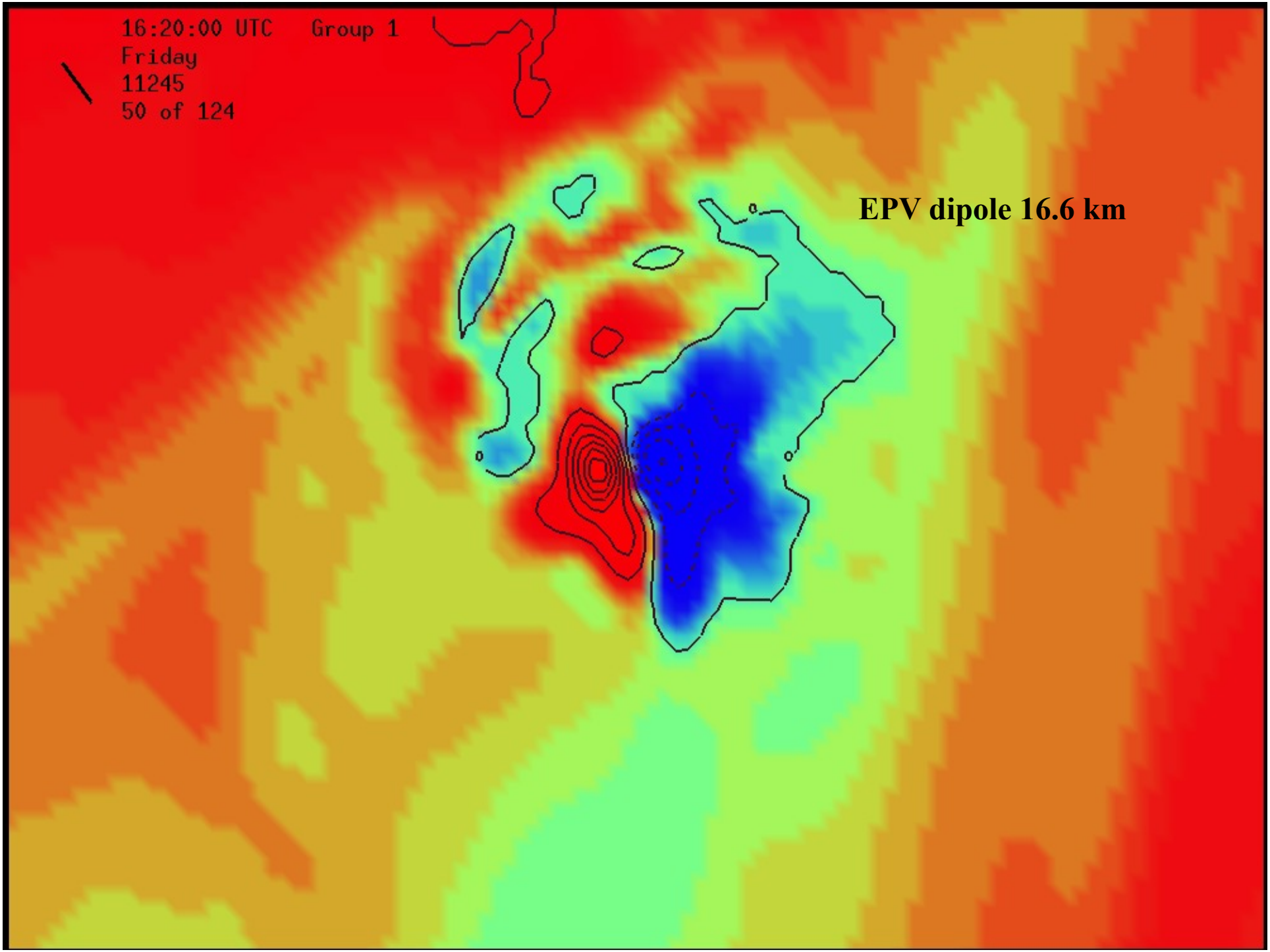

15:40:00 UTC Group 1
Friday
11245
48 of 124
1004
996
1004
996
984
1012
1004
996
992
1008
1004
1000
1008
1012
1012
Talas MSLP
~local midnight
Sept. 3, 2011

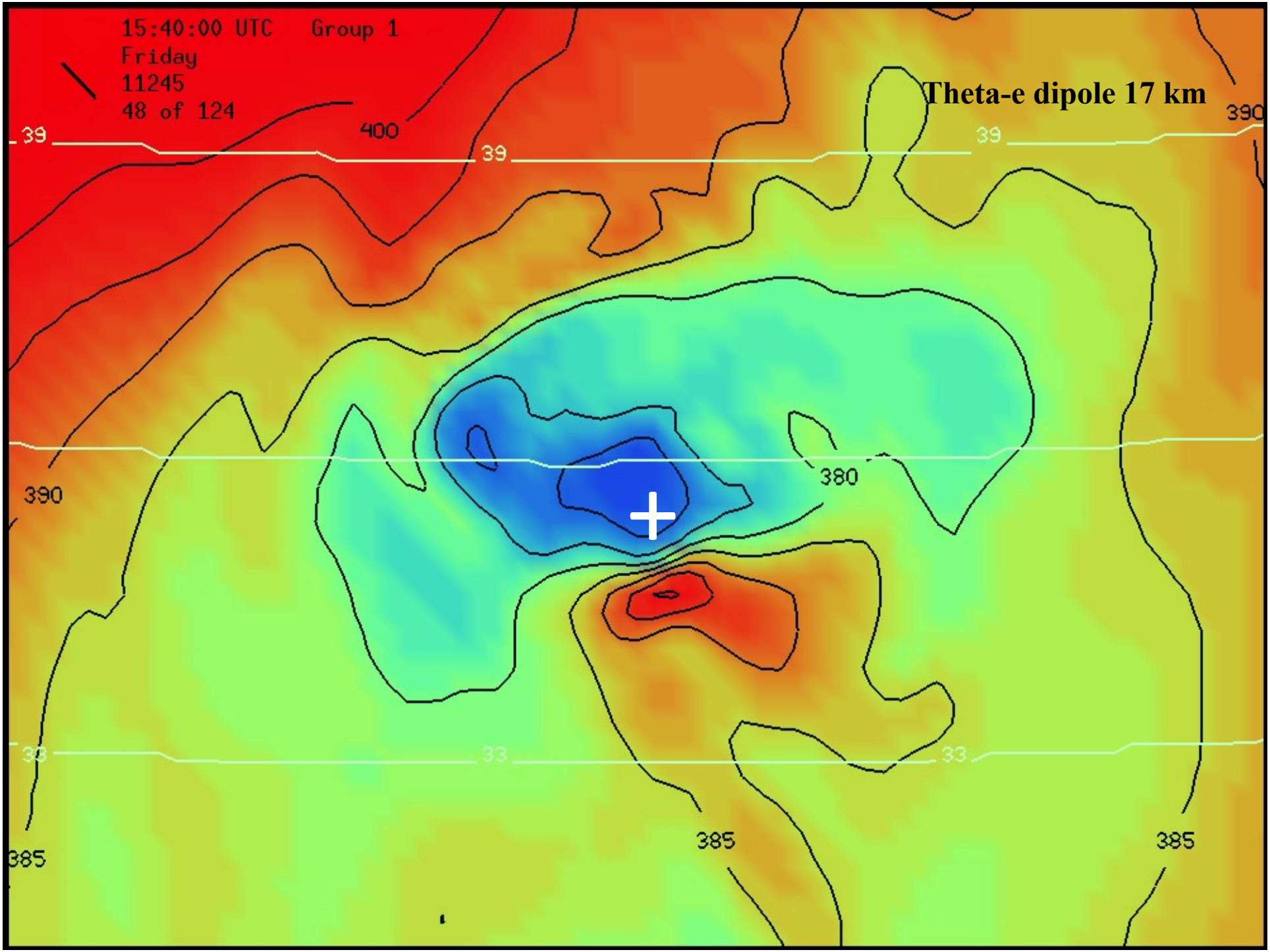

01:20:00 UTC Group 1
Friday
11245
5 of 124

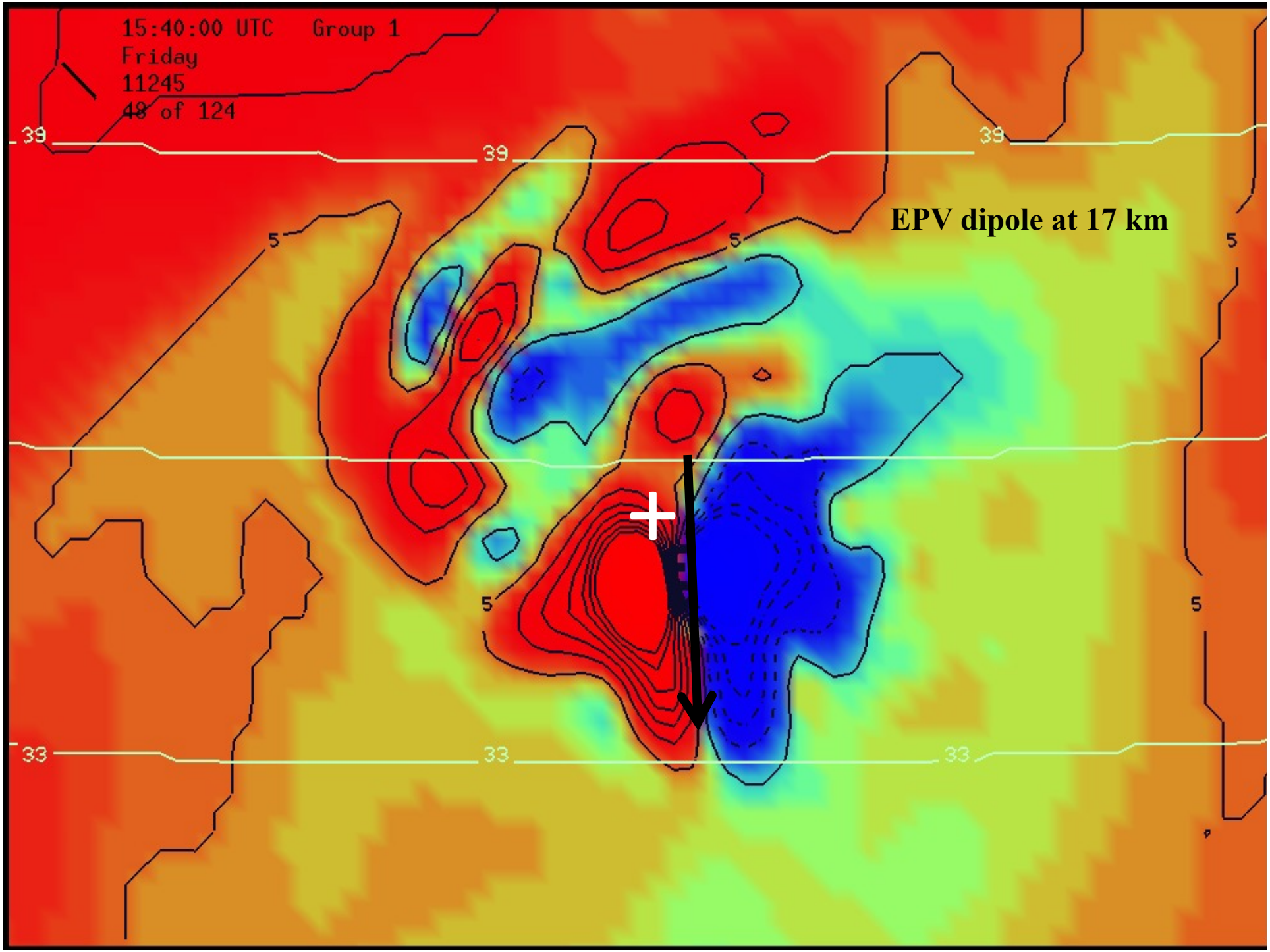

Talas EPV contoured and shaded max -6 PVU

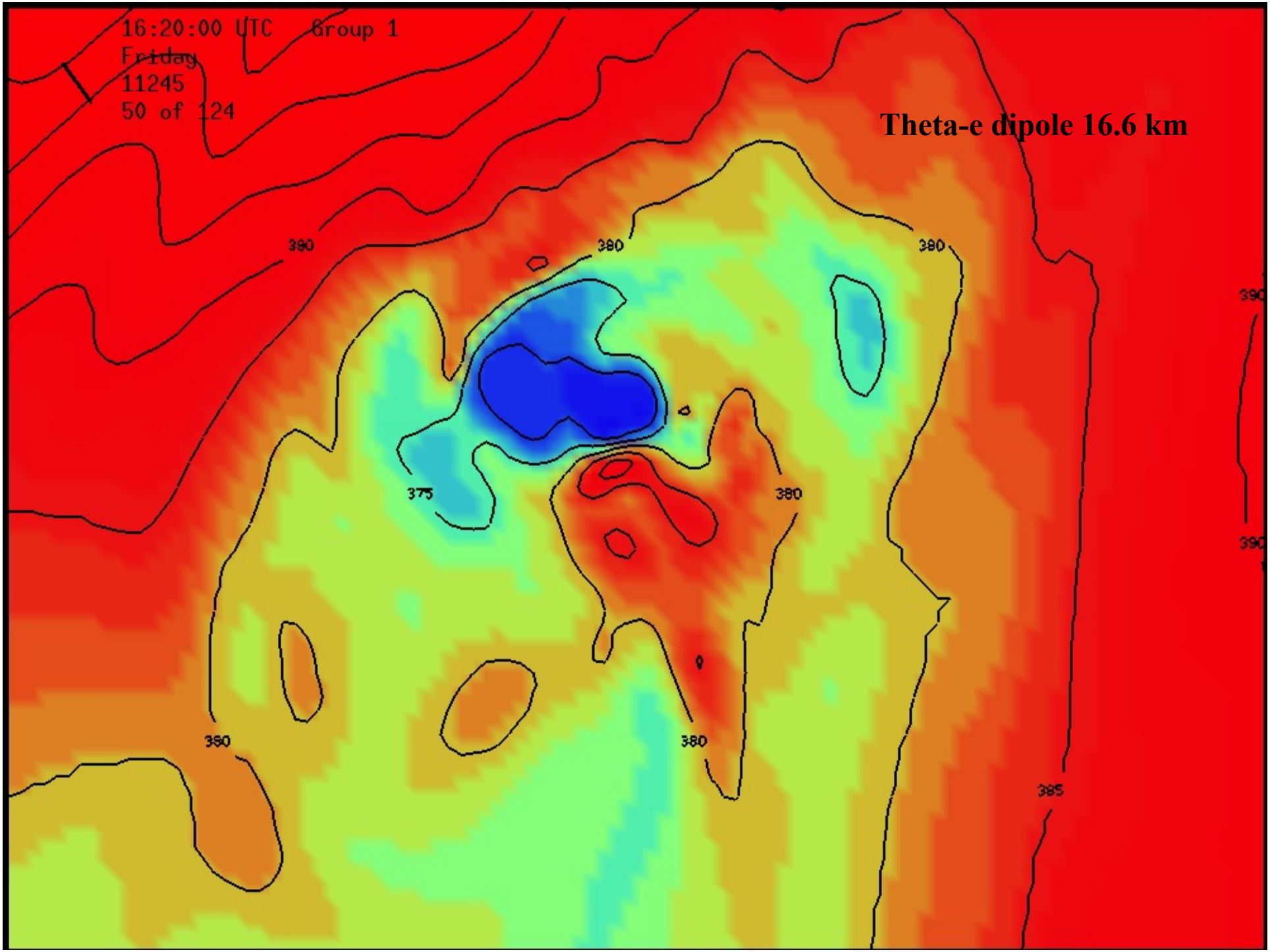

10:30:00
11245
34 of 81
Friday
594
594
594
495
495
495
496
396
387
398
387
369
360
360
360
351
342
342
342
342
324
342
342
Talas EPV shaded and
theta contoured

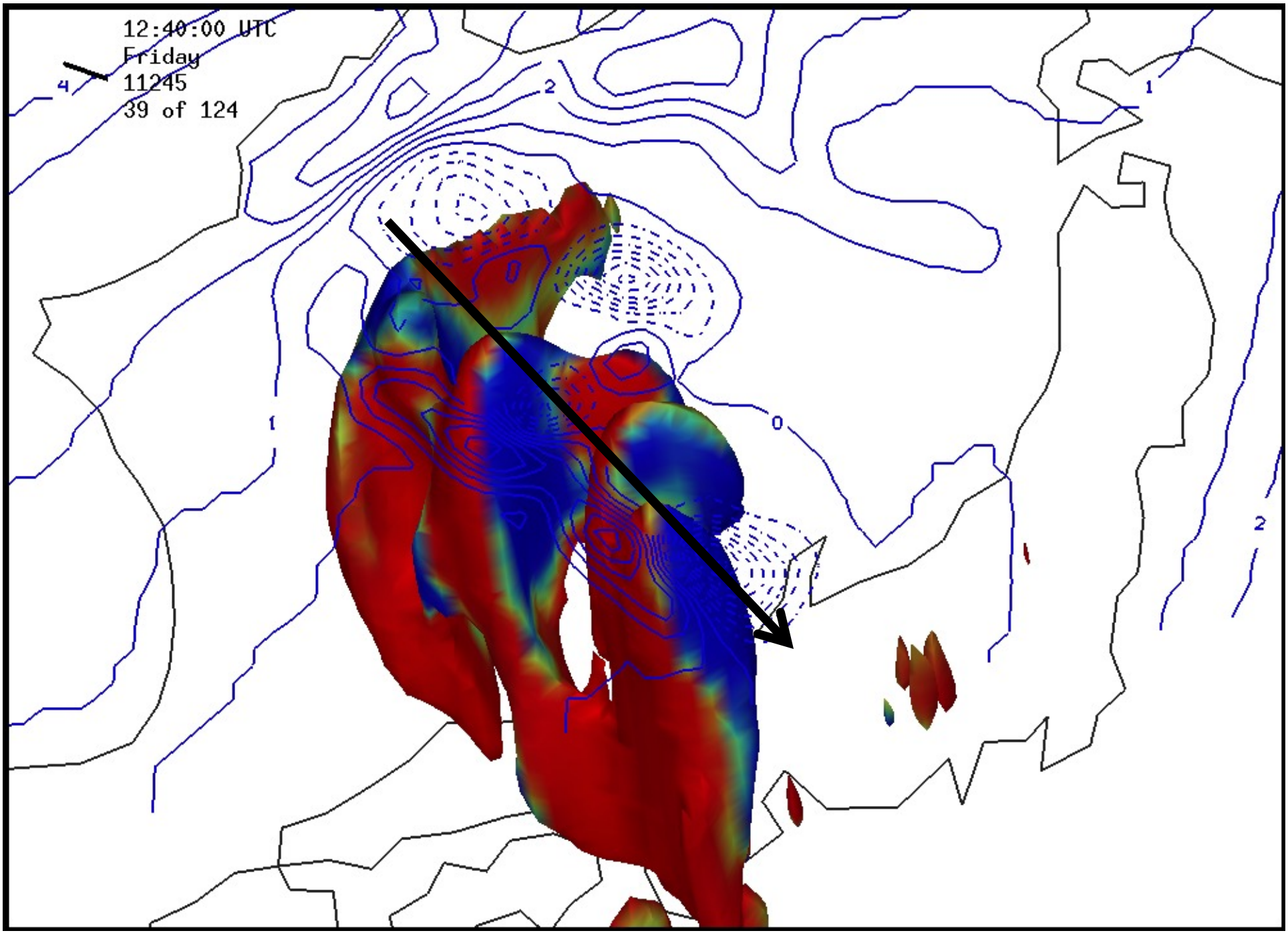

18:00:00
11245
37 of 81
Friday
Talas EPV shaded
and streamfunction


16:20:00 UTC Group 1
Friday
11245
50 of 124
EPV dipole 16.6 km

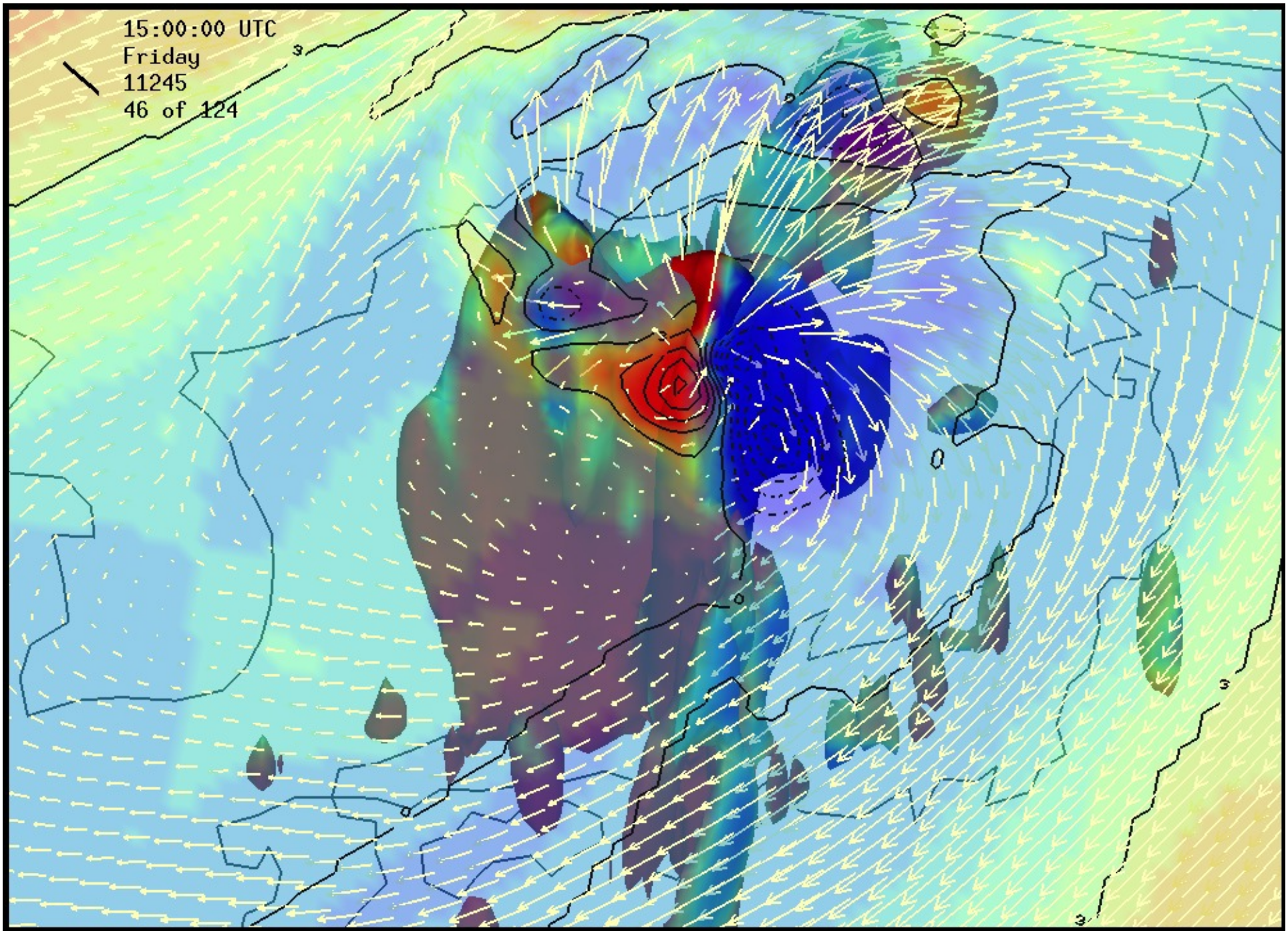

15:40:00 UTC Group 1
Friday
11245
48 of 124
Theta-e dipole 17 km
400
390
380
385

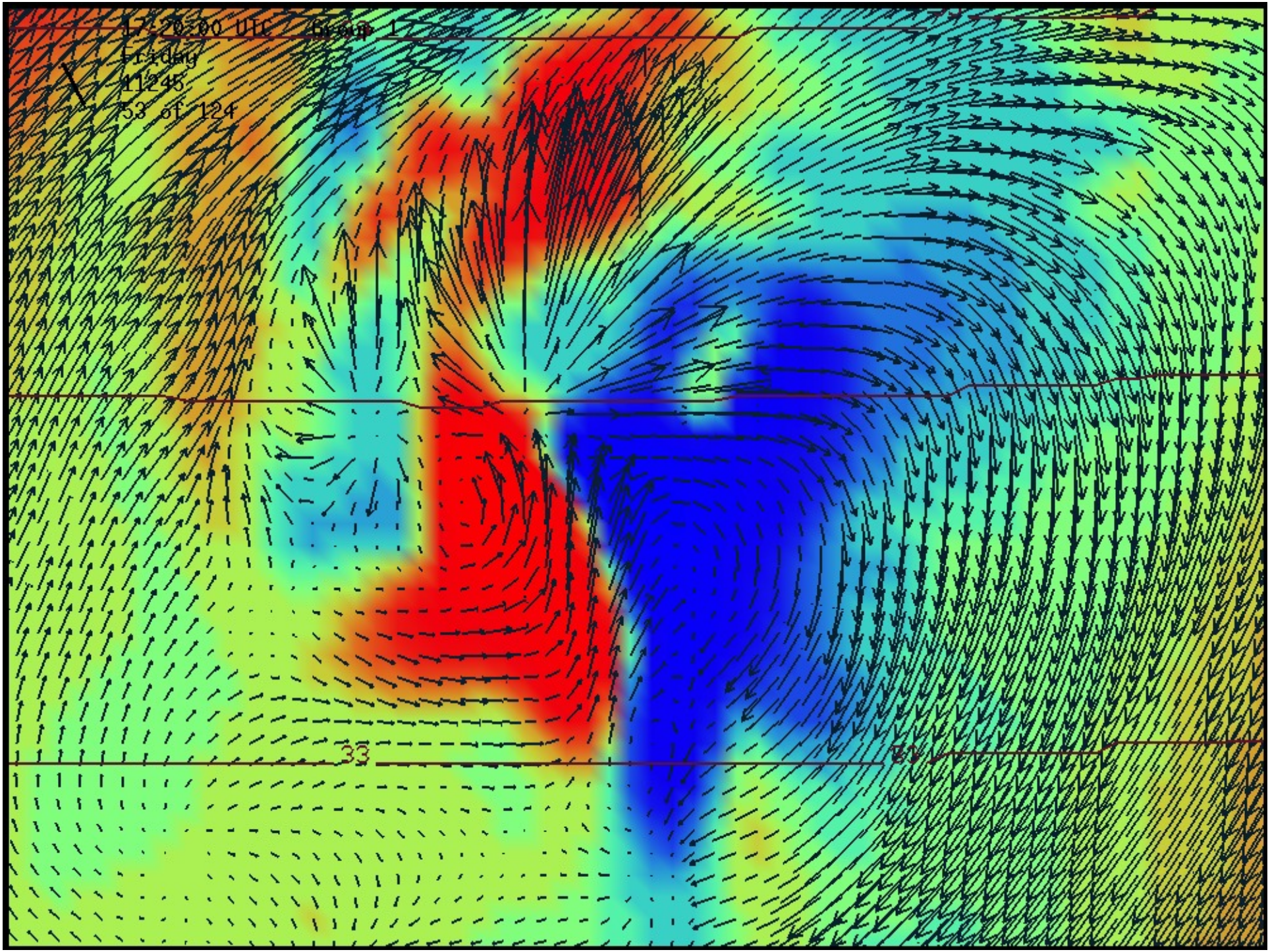

15:40:00 UTC Group 1
Friday
11245
48 of 124
39
39
39
5
5
5
5
5
33
33
33
EPV dipole at 17 km

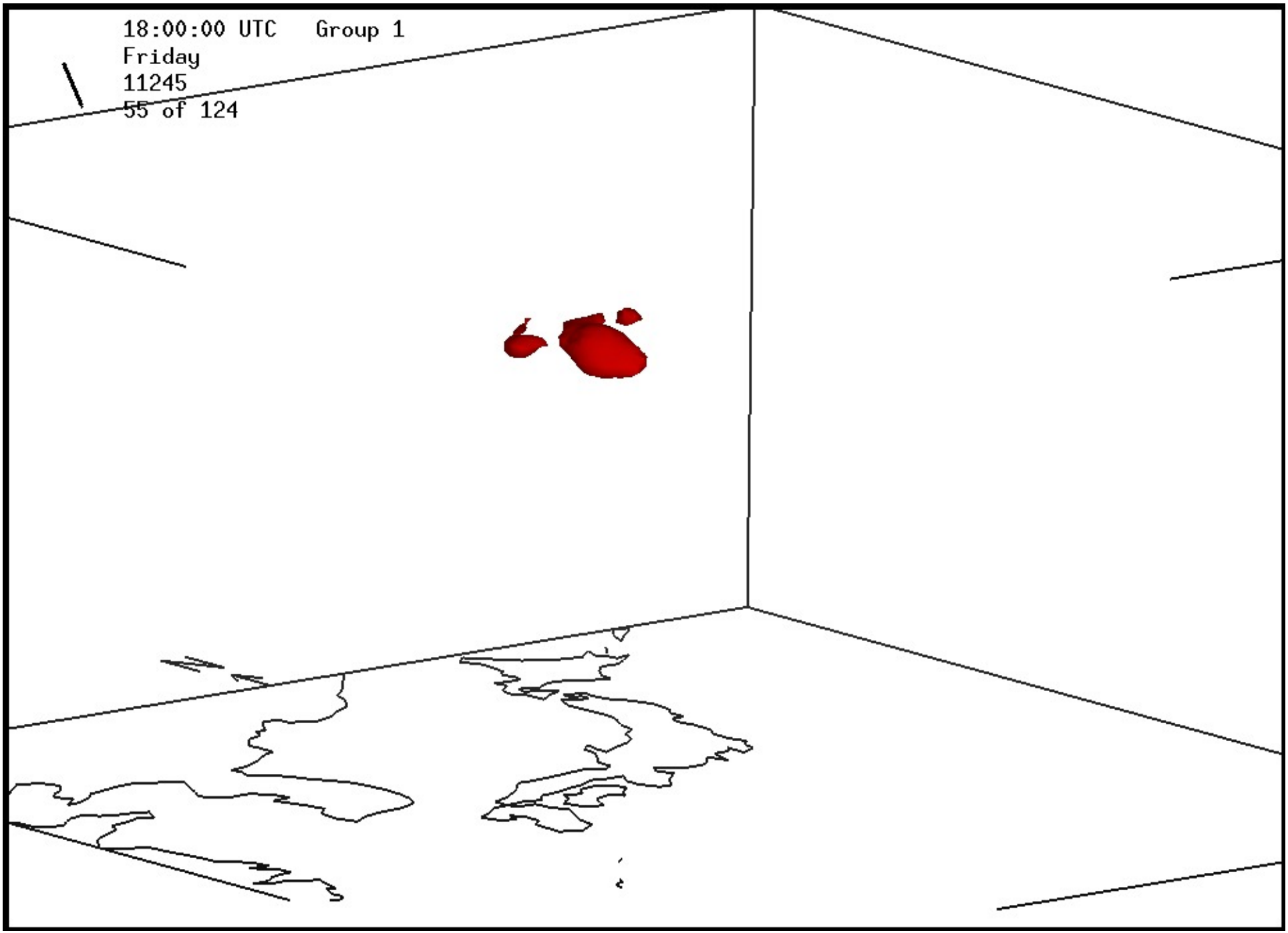

16:20:00 UTC Group 1
Friday
11245
50 of 124
Theta-e dipole 16.6 km
390
380
380
375
380
380
380
385

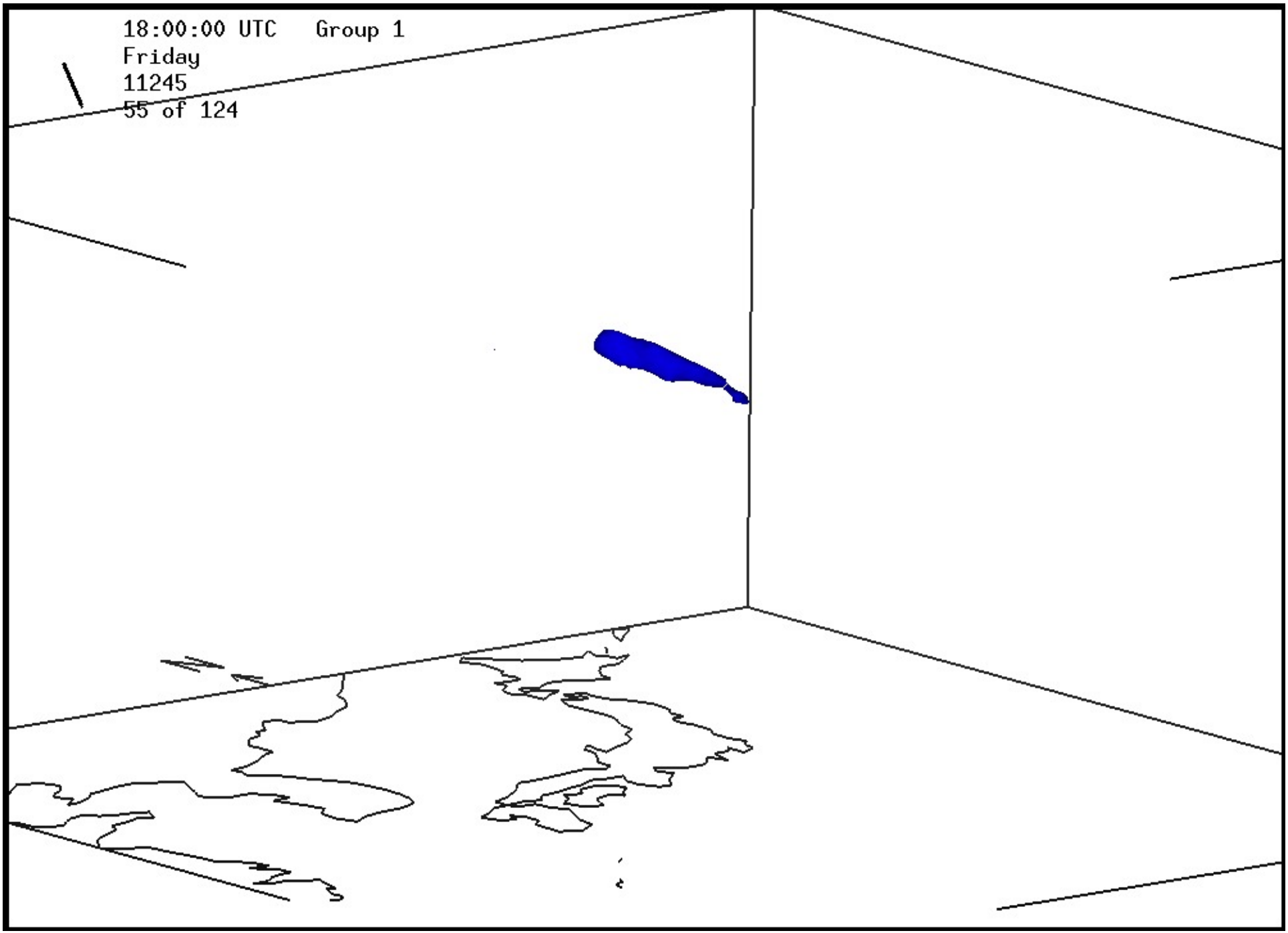

12:40:00 UTC
Friday
11245
39 of 124
4
2
1
1
0
2

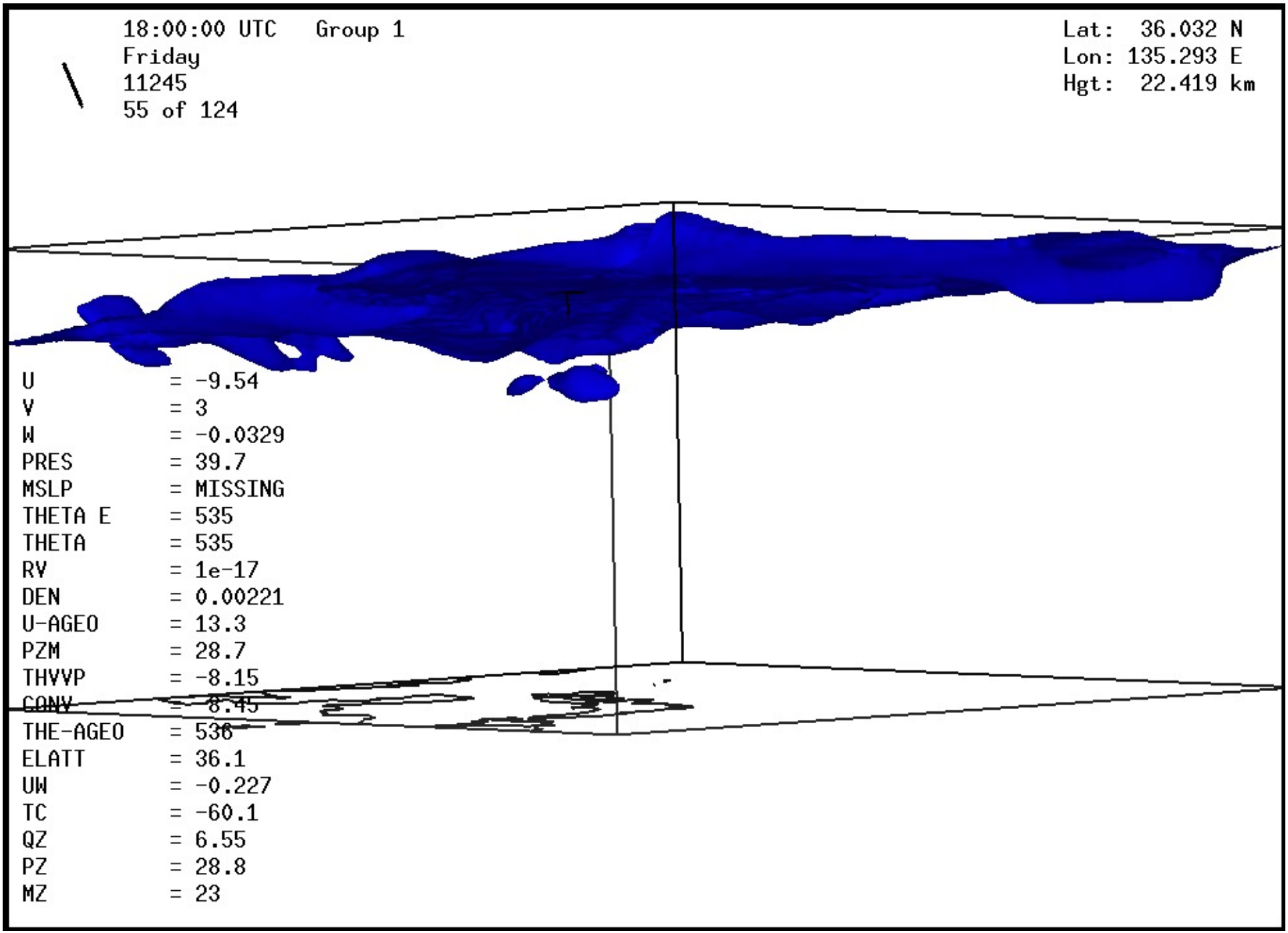
6 cm/s updraft colored by absolute vorticity; 16 km EPV

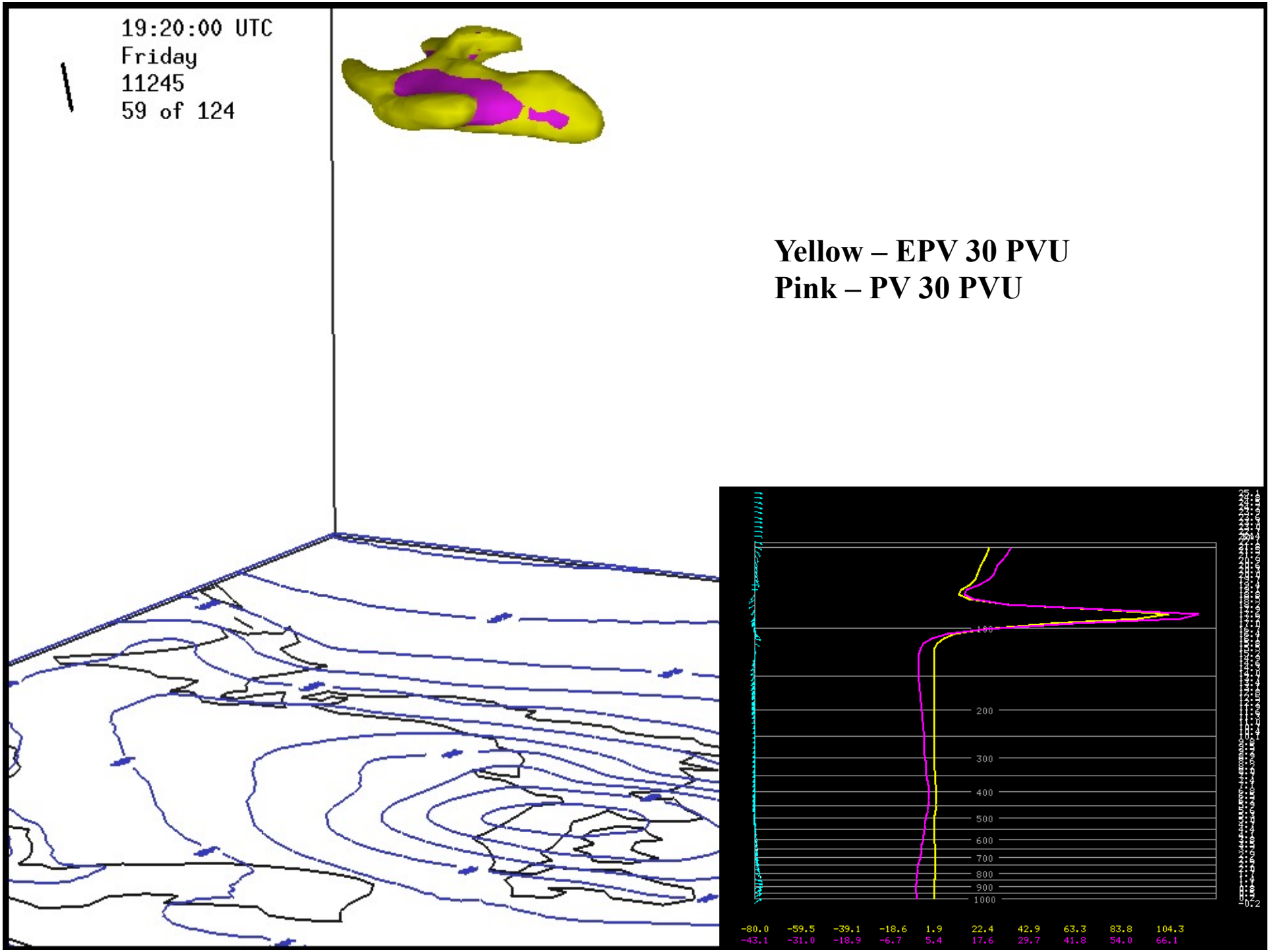

15:00:00 UTC
Friday
11245
46 of 124

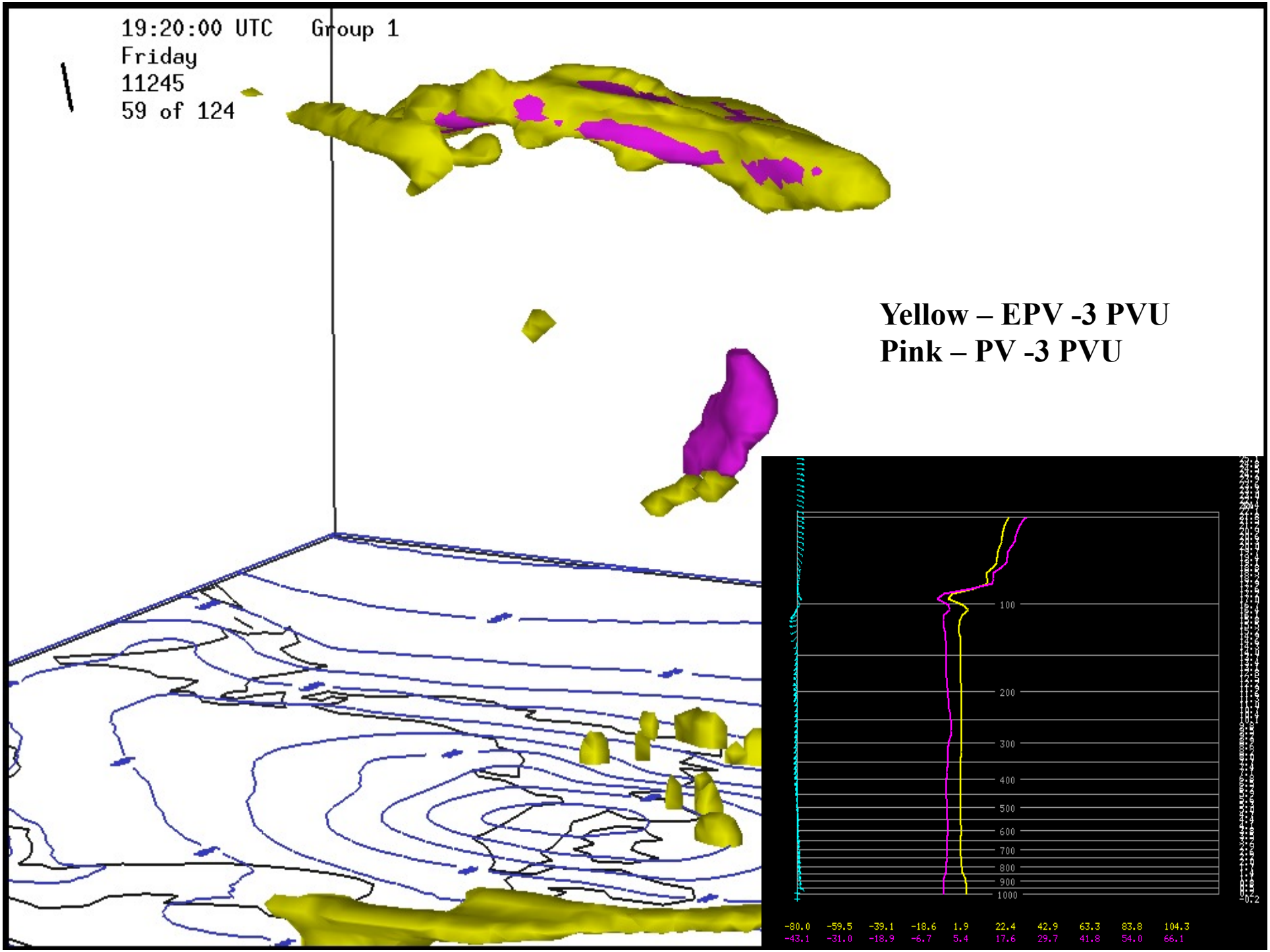

17:20:00 UTC
Friday
11245
53 of 124
33


18:00:00 UTC Group 1
Friday
11245
55 of 124


18:00:00 UTC Group 1
Friday
11245
55 of 124


18:00:00 UTC Group 1
Friday
11245
55 of 124
Lat: 36.032 N
Lon: 135.293 E
Hgt: 22.419 km
U = -9.54
V = 3
W = -0.0329
PRES = 39.7
MSLP = MISSING
THETA E = 535
THETA = 535
RV = 1e-17
DEN = 0.00221
U-AGEO = 13.3
PZM = 28.7
THVVP = -8.15
CONV = -8.45
THE-AGEO = 536
ELATT = 36.1
UW = -0.227
TC = -60.1
QZ = 6.55
PZ = 28.8
MZ = 23


19:20:00 UTC
Friday
11245
59 of 124
Yellow – EPV 30 PVU
Pink – PV 30 PVU
100
200
300
400
500
600
700
800
900
1000
-80.0 -59.5 -39.1 -18.6 1.9 22.4 42.9 63.3 83.8 104.3
-43.1 -31.0 -18.9 -6.7 5.4 17.6 29.7 41.8 54.0 66.1

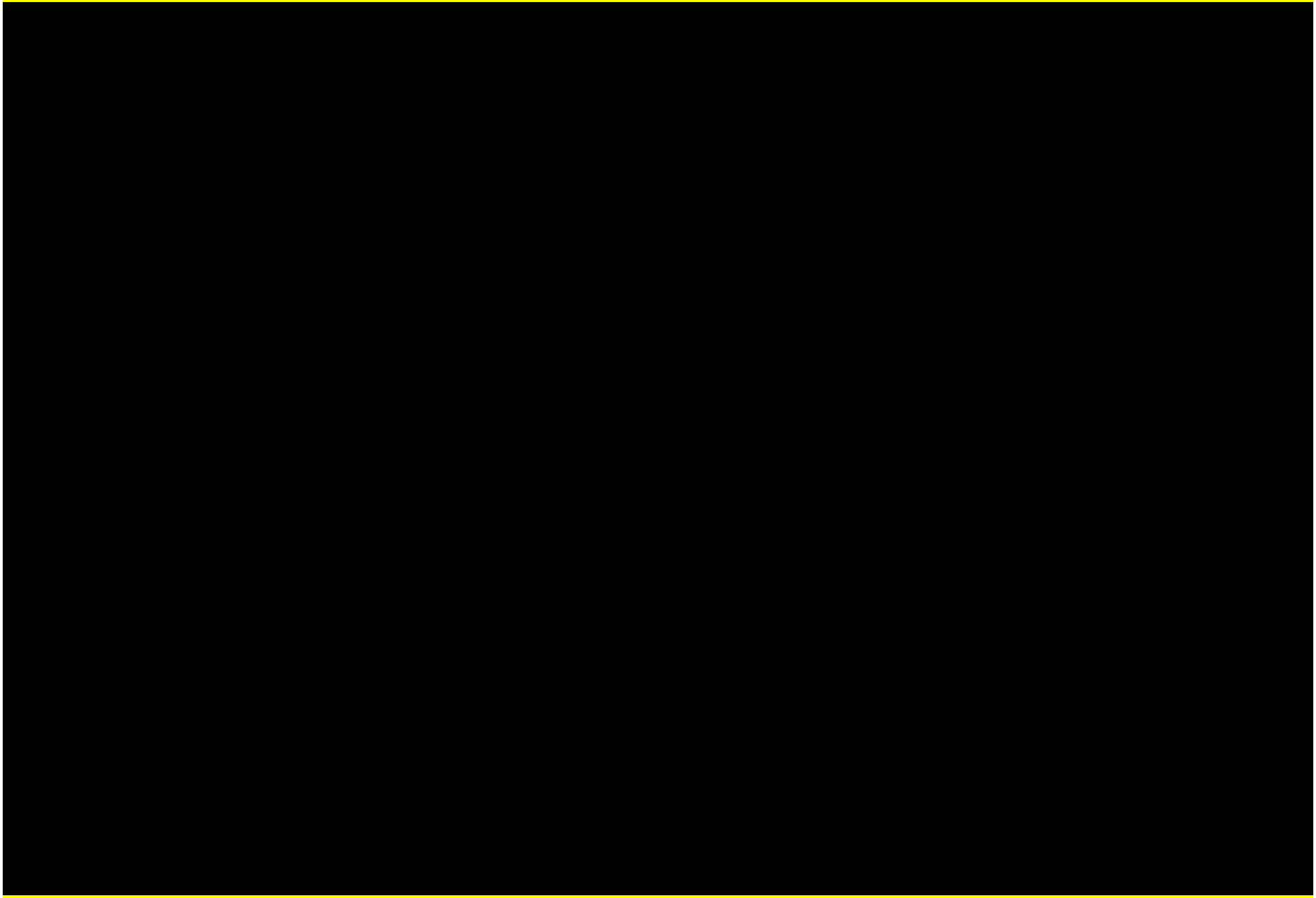

19:20:00 UTC Group 1
Friday
11245
59 of 124
Yellow – EPV -3 PVU
Pink – PV -3 PVU
100
200
300
400
500
600
700
800
900
1000
-80.0 -59.5 -39.1 -18.6 1.9 22.4 42.9 63.3 83.8 104.3
-43.1 -31.0 -18.9 -6.7 5.4 17.6 29.7 41.8 54.0 66.1

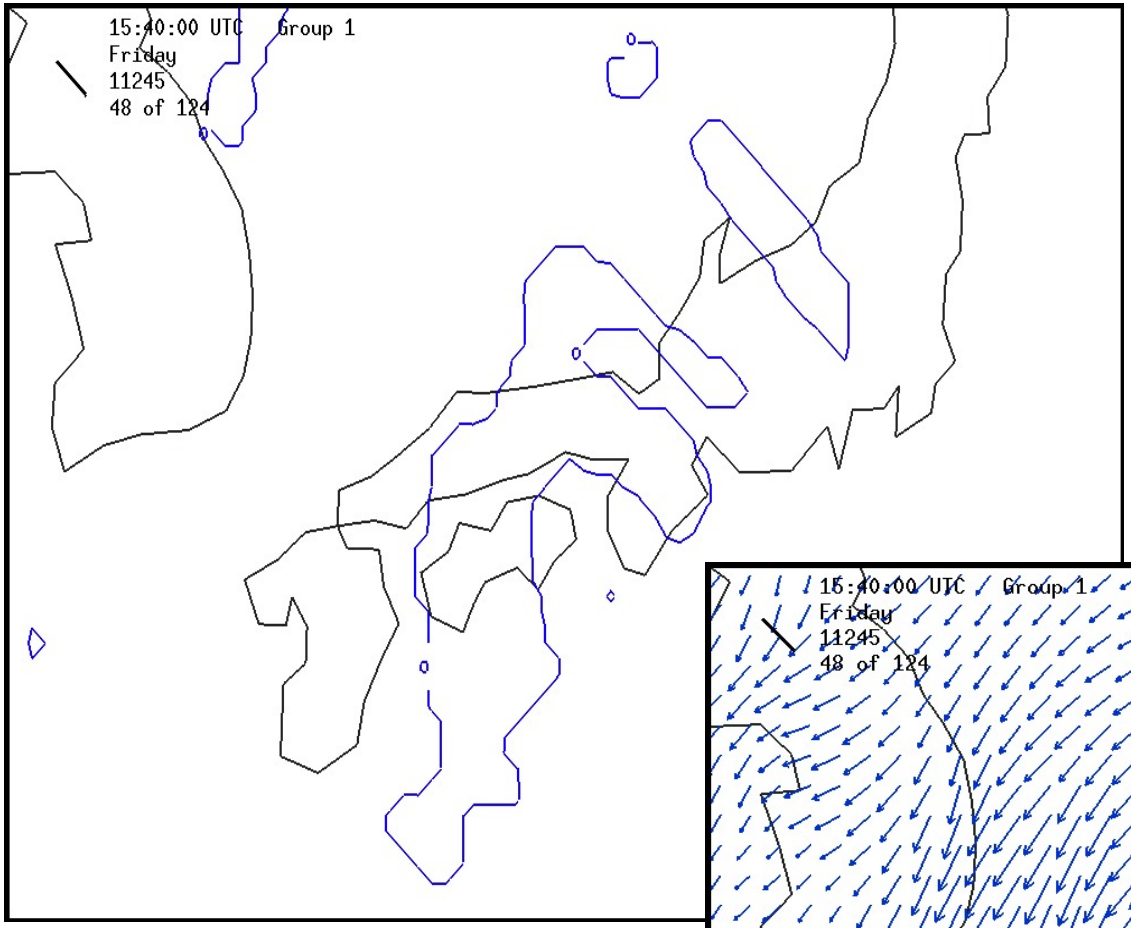
Trajectories into and out of +30 PV anomaly

Trajectories into and out of -3 PV anomaly

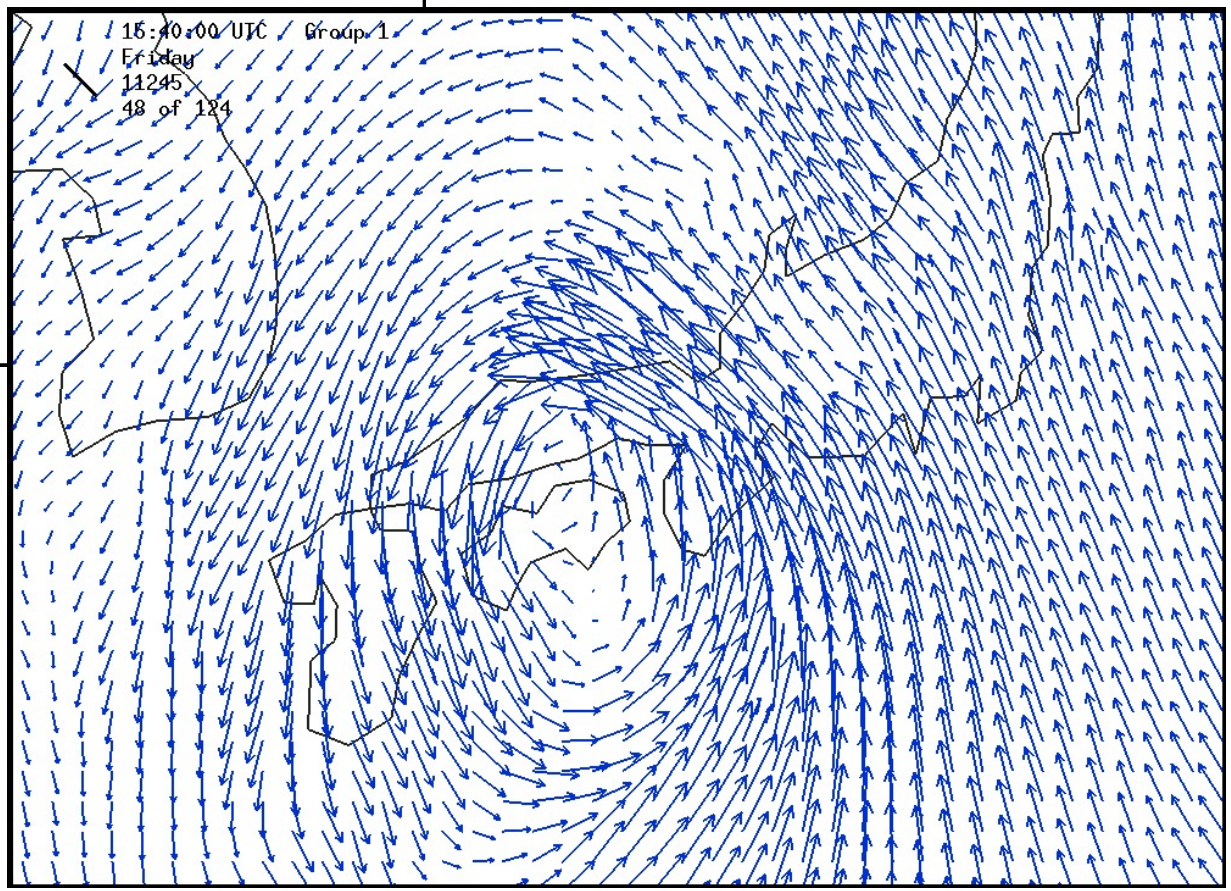
Trajectories and purple (+) and green (-) anomalies

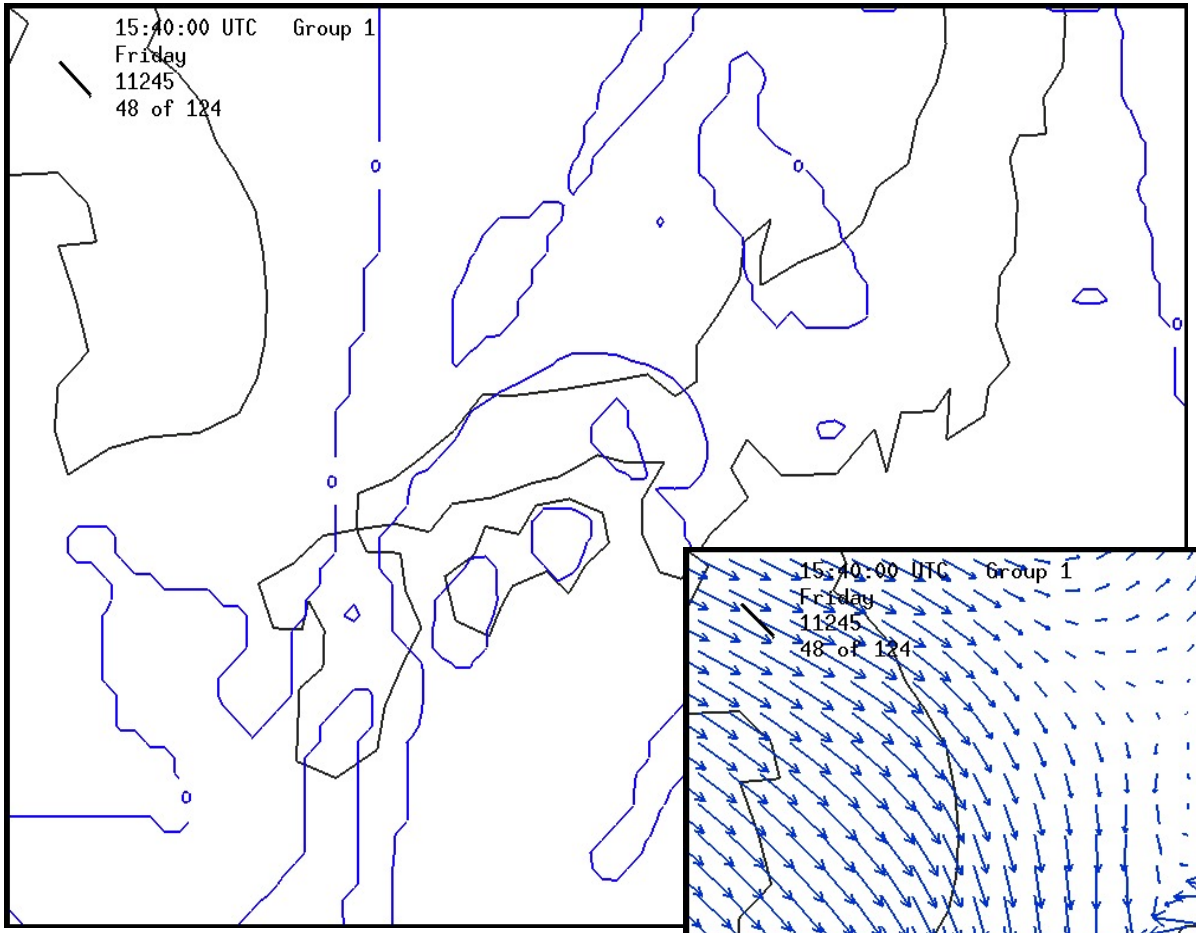
Extratropical Transition: Elongation of PV < 0

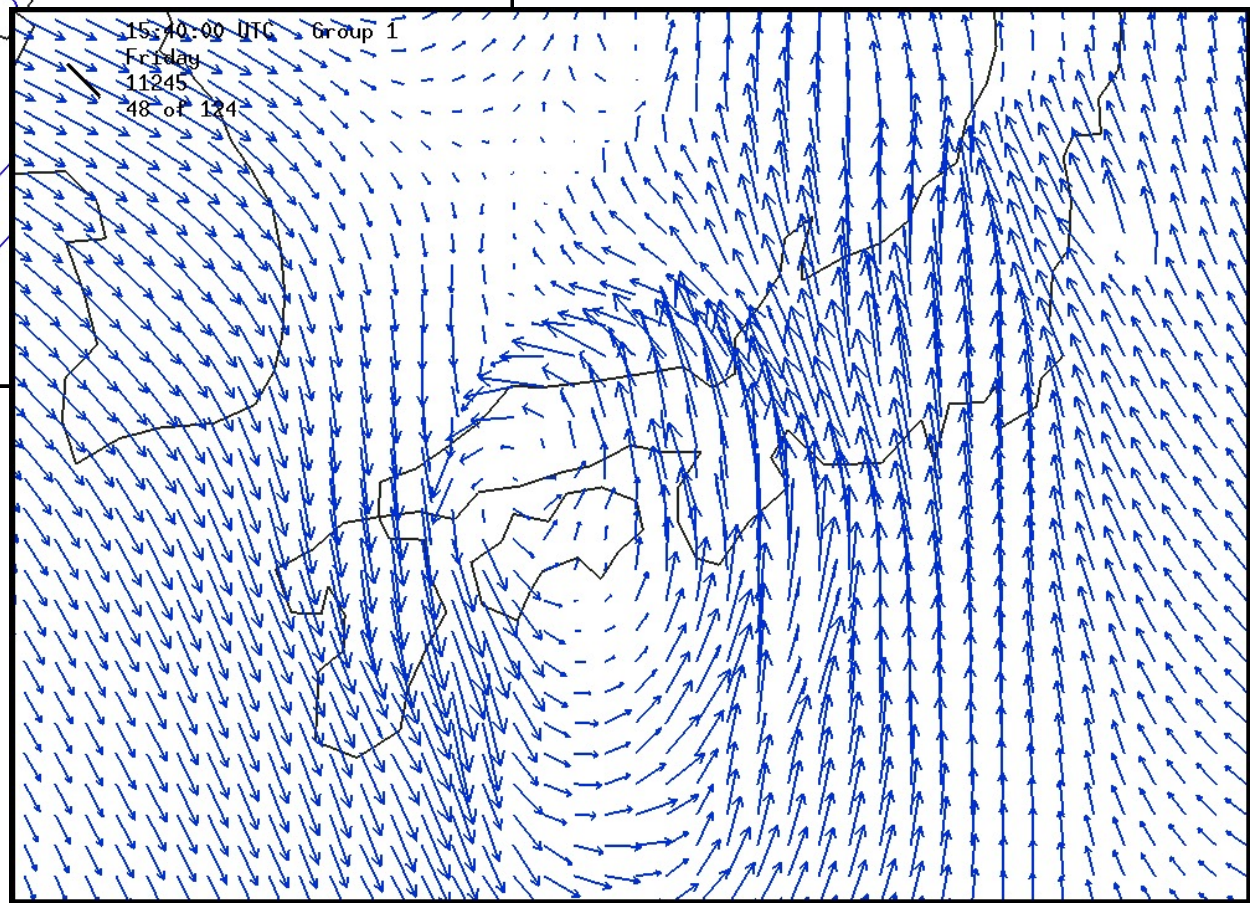




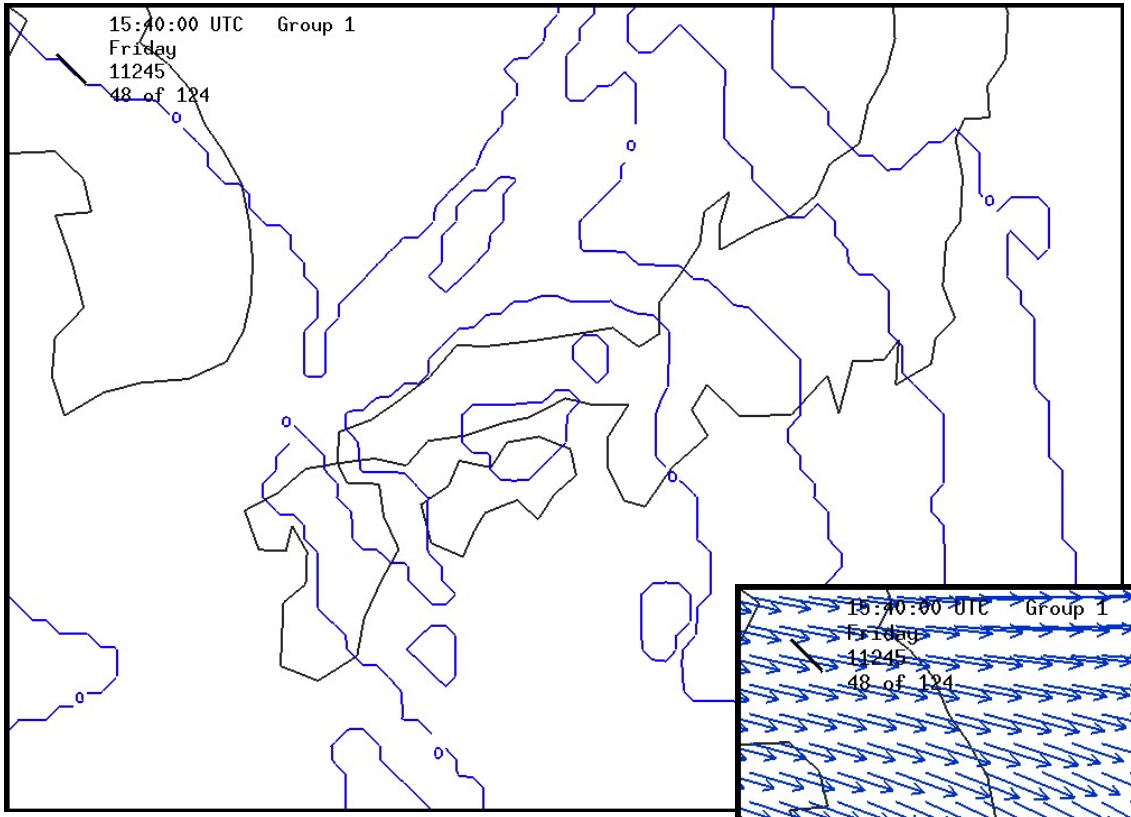
EPV at 2 km
Wind at 2km



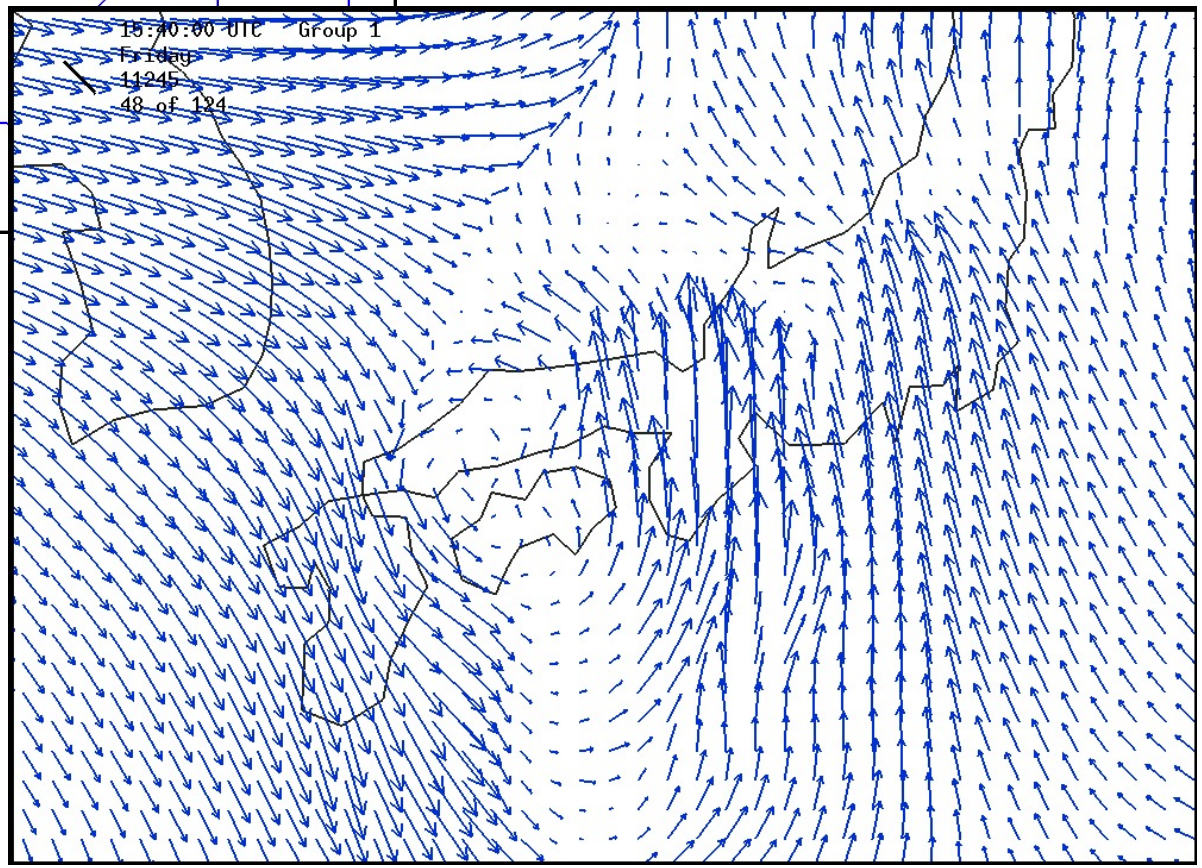


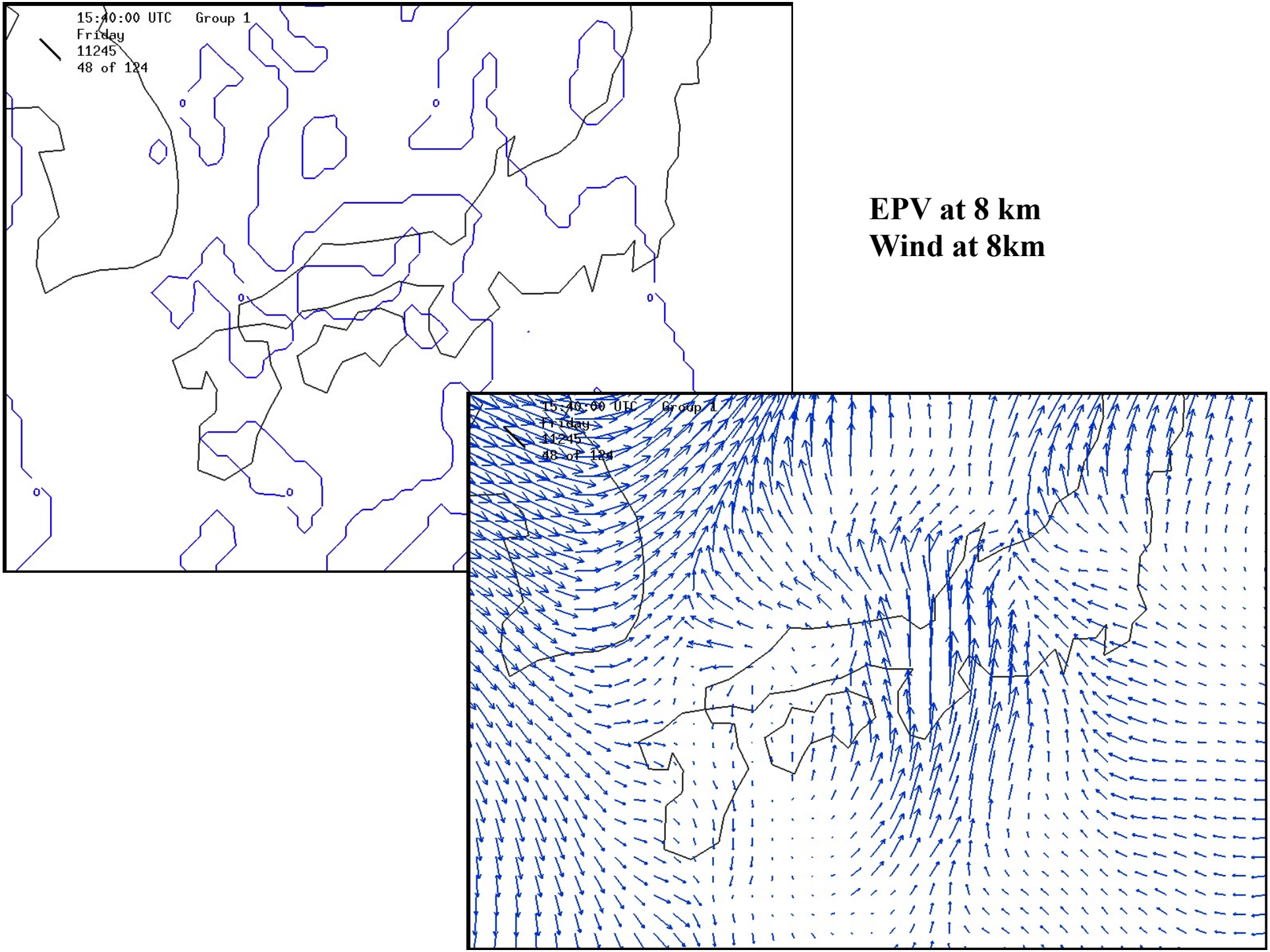


EPV at 4 km
Wind at 4 km

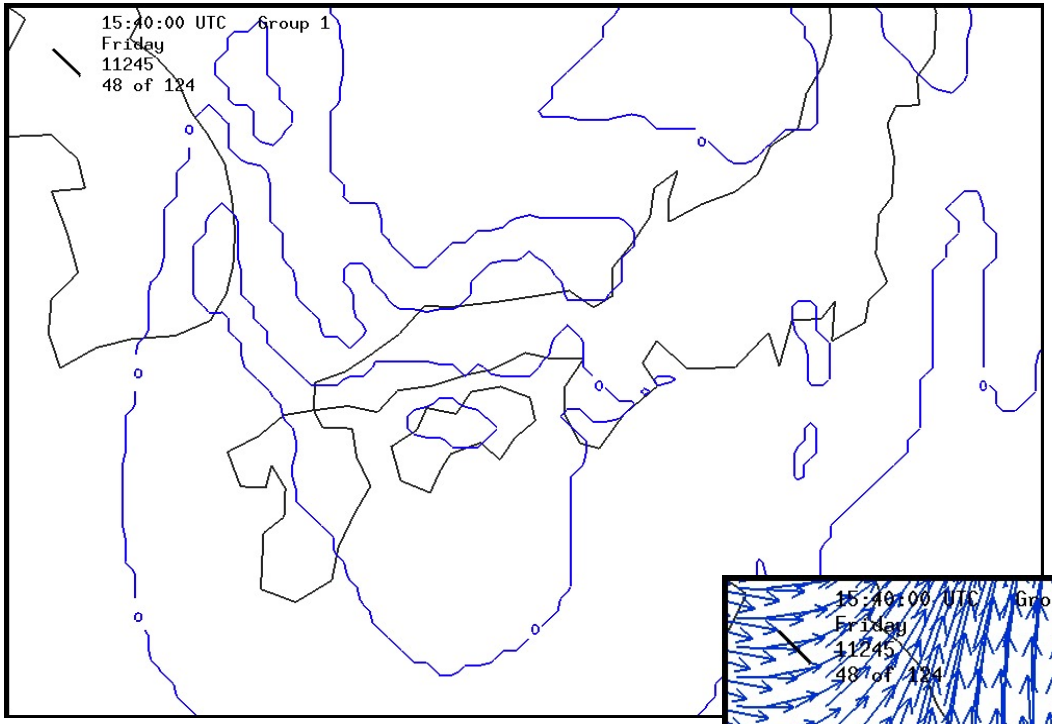


EPV at 6 km
Wind at 6km

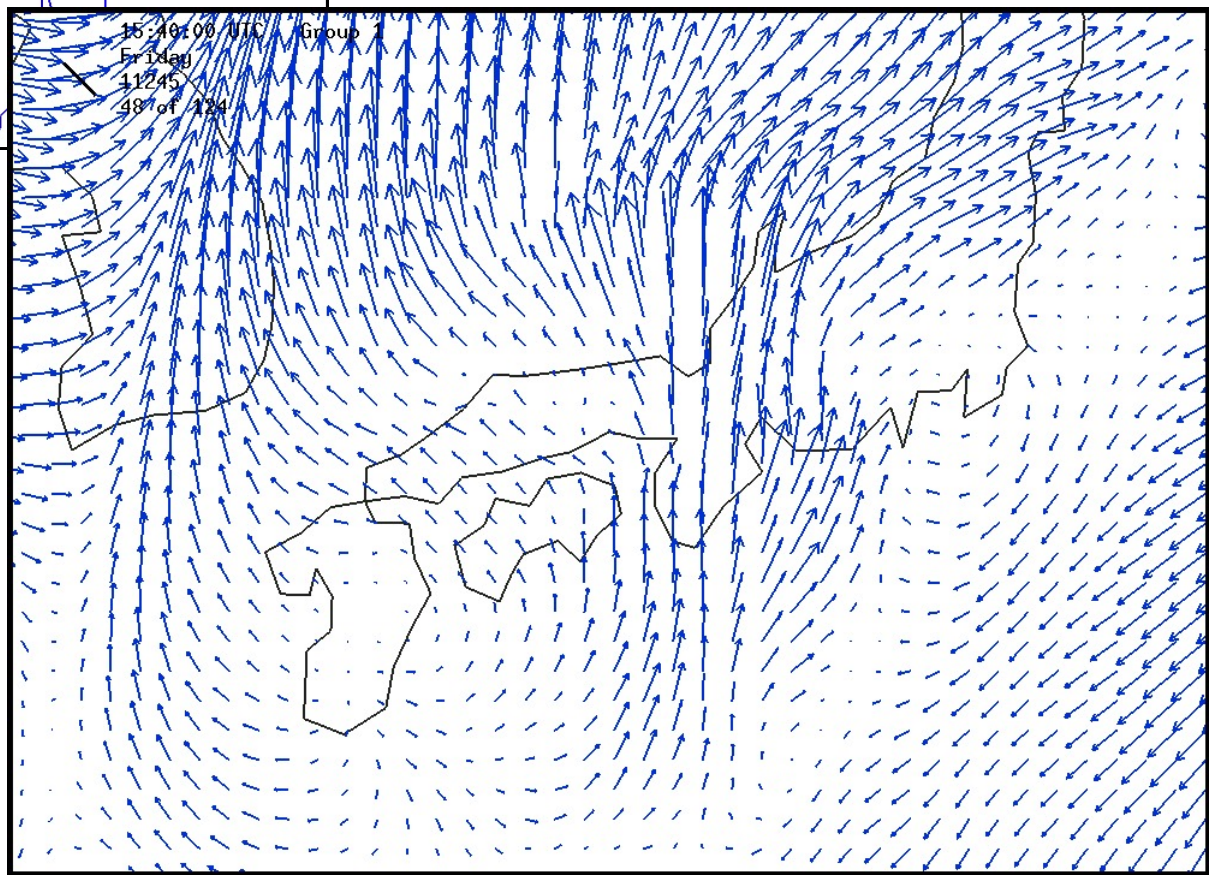


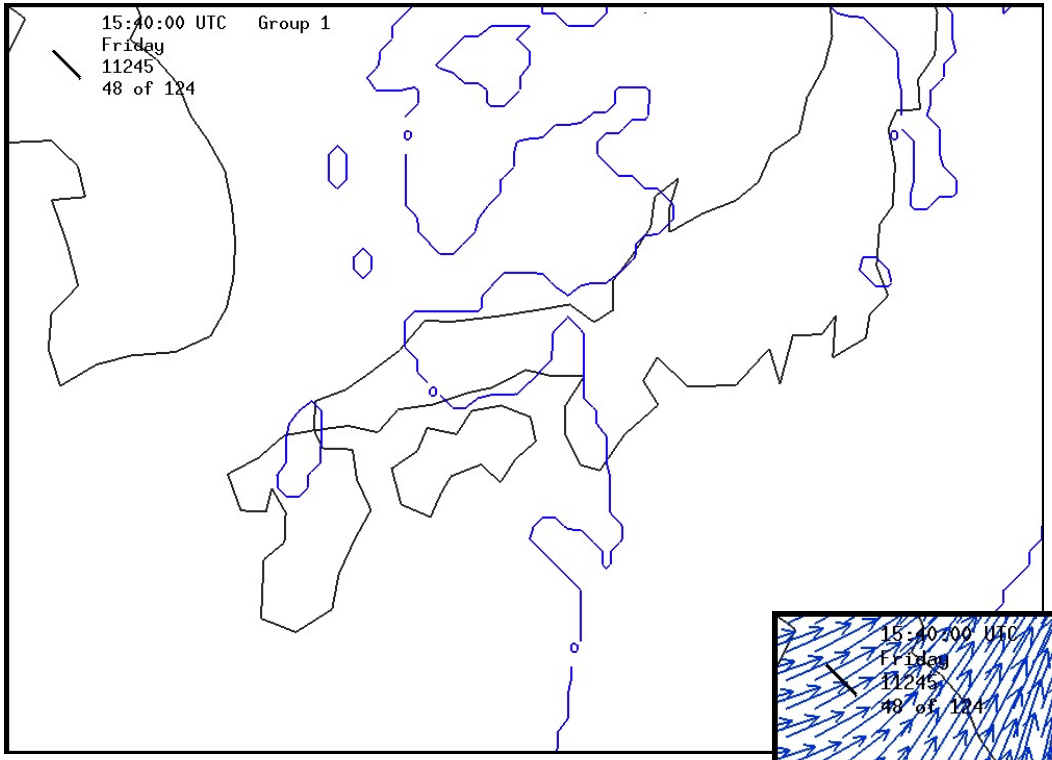


EPV at 8 km
Wind at 8km

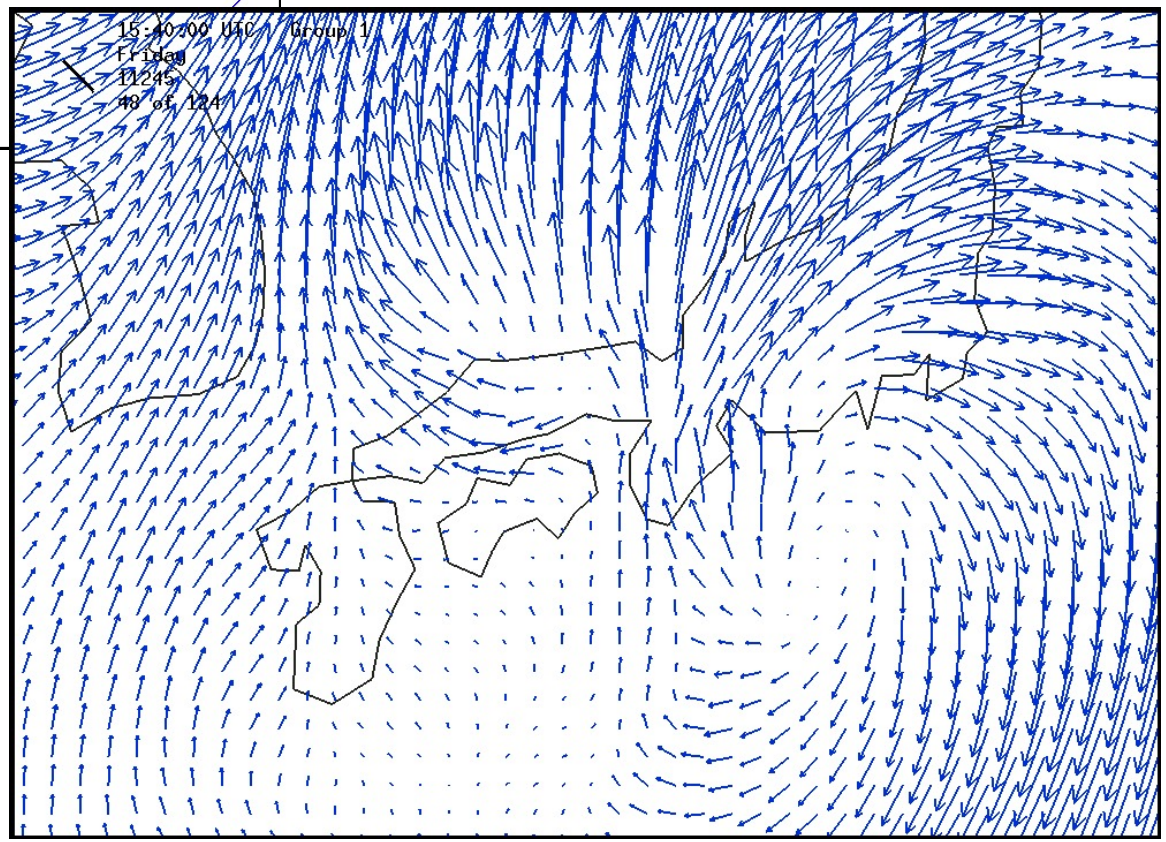


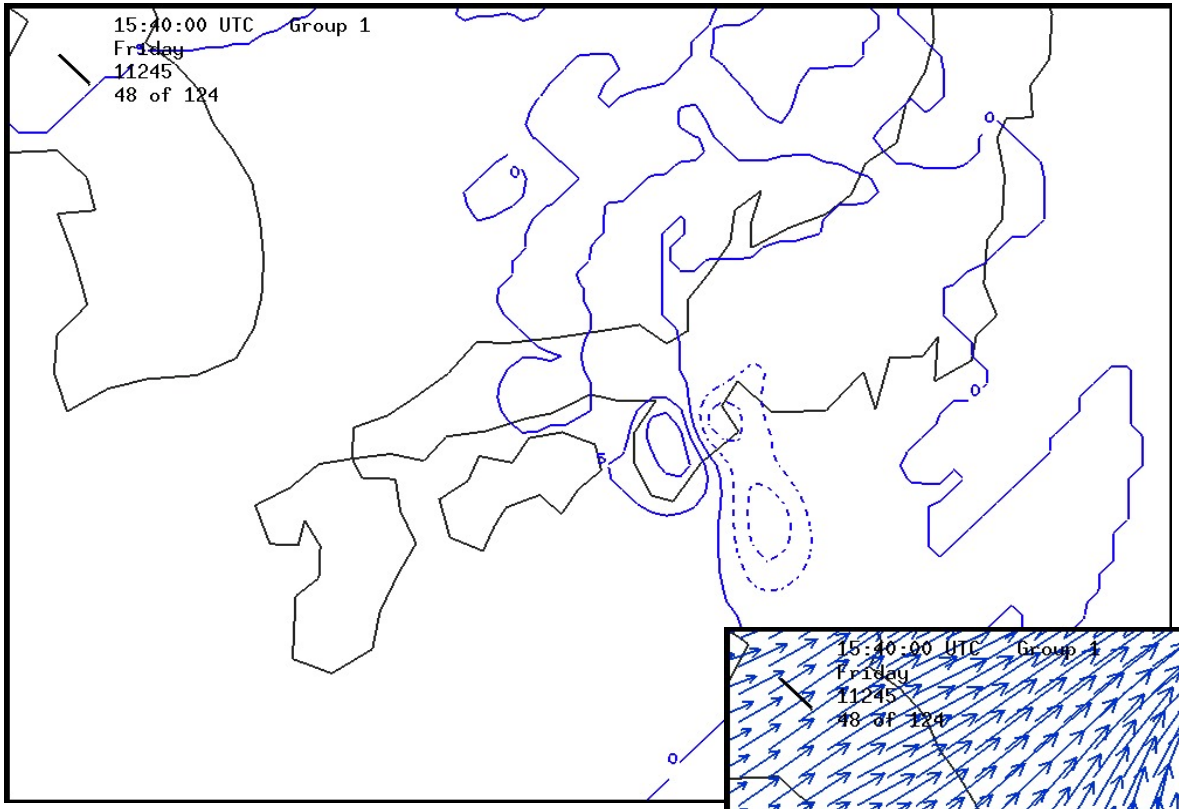
EPV at 10 km
Wind at 10 km



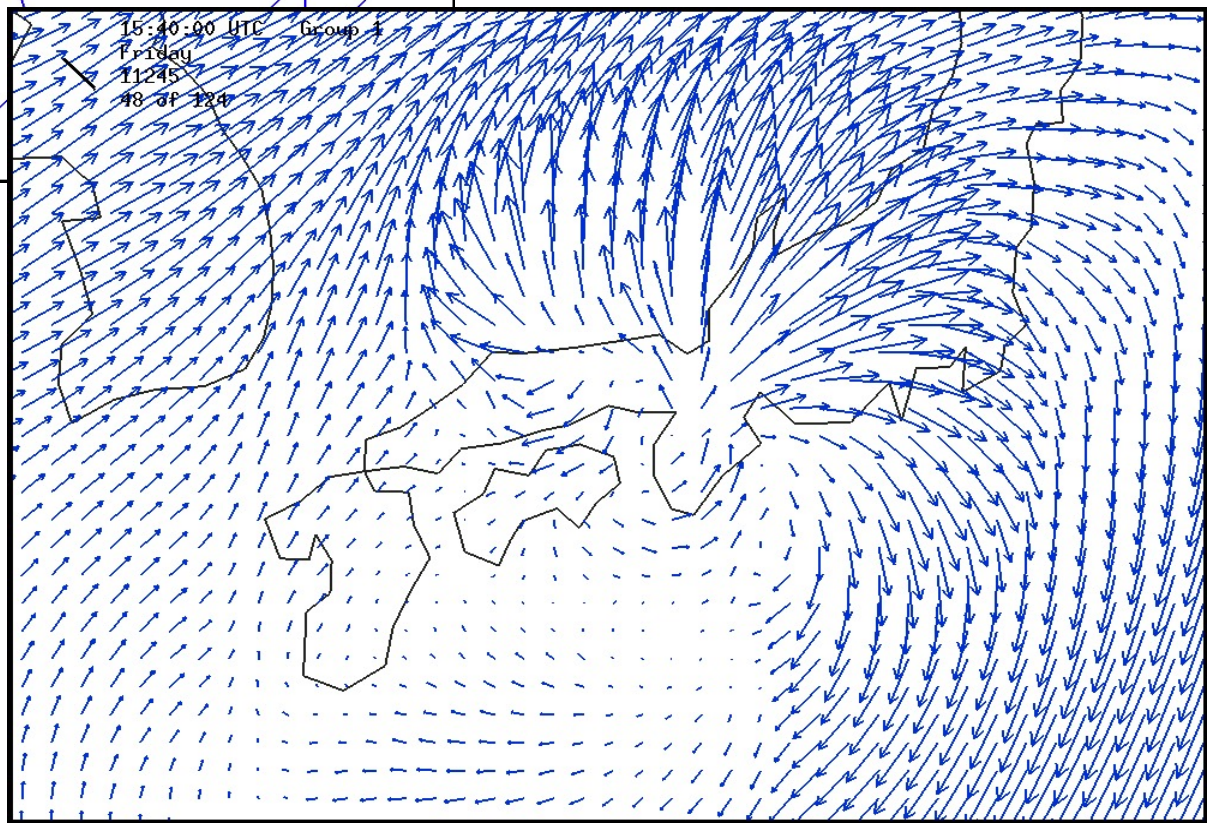


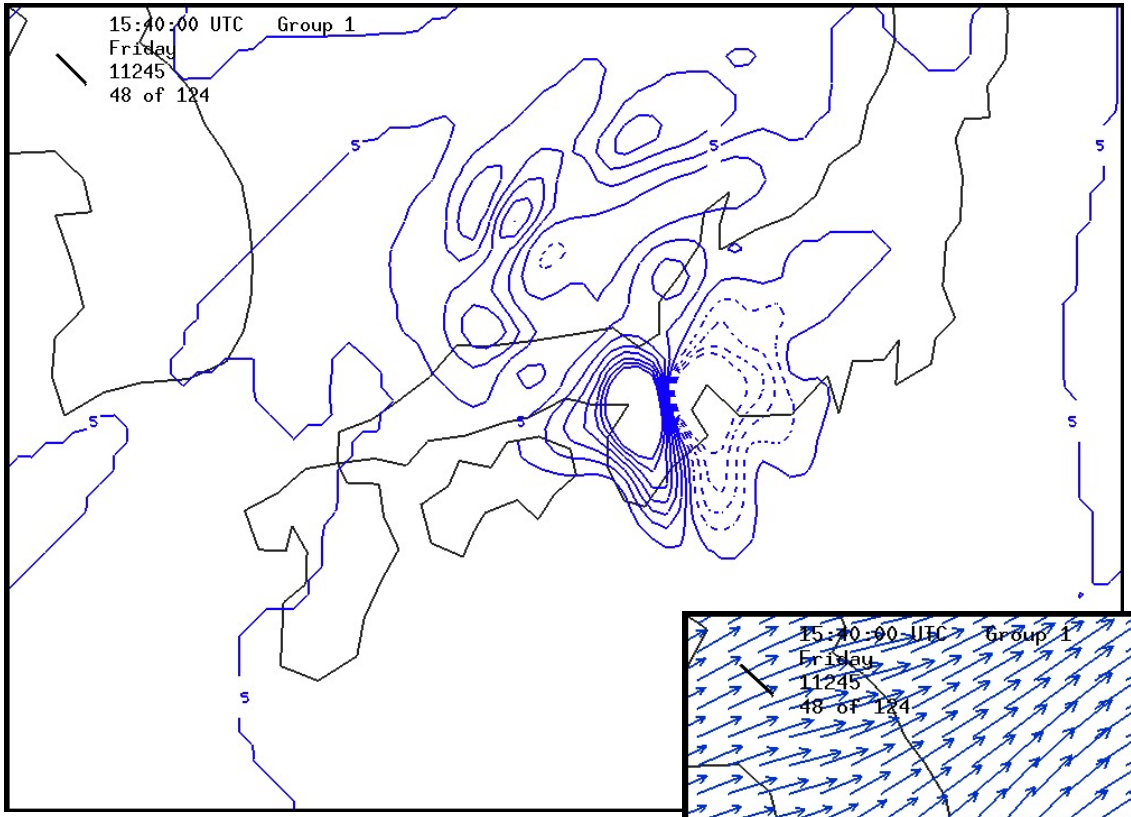
EPV at 12km
Wind at 12km



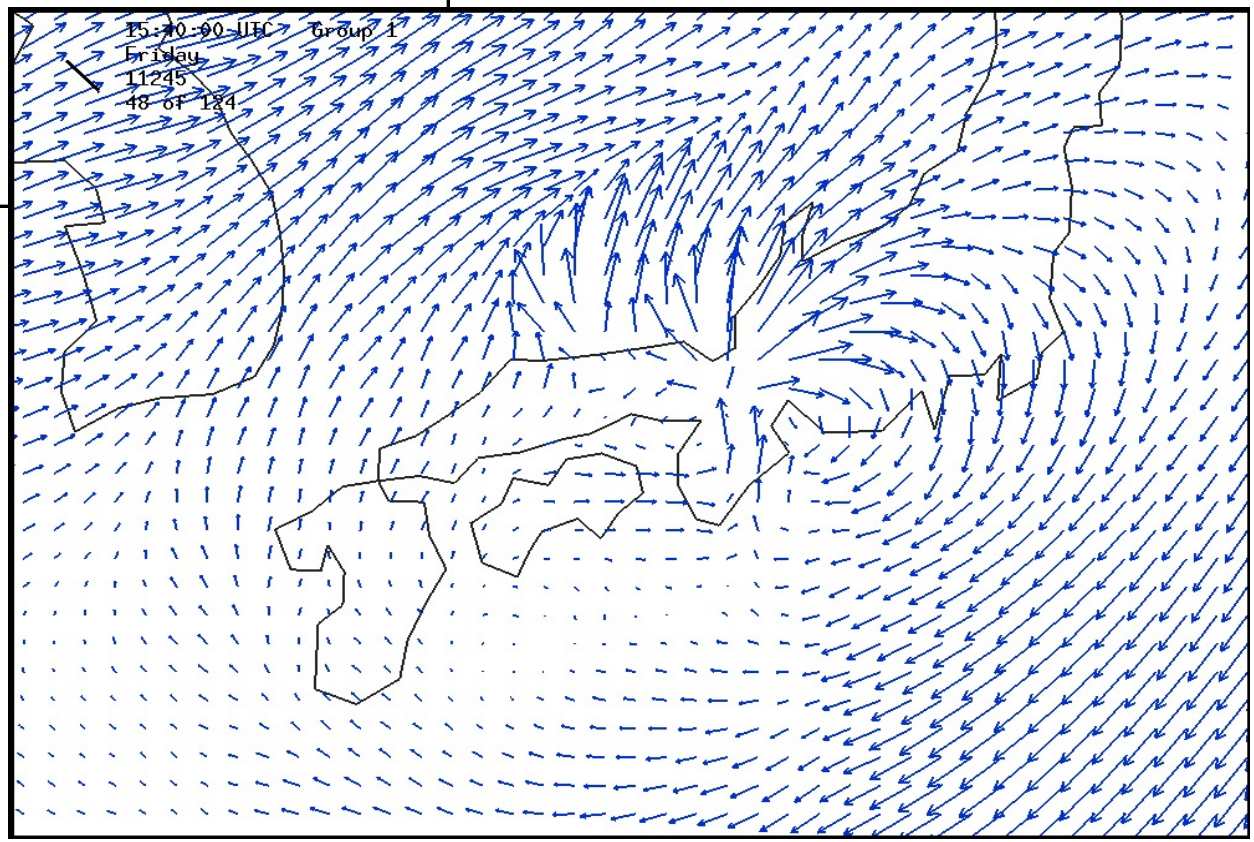


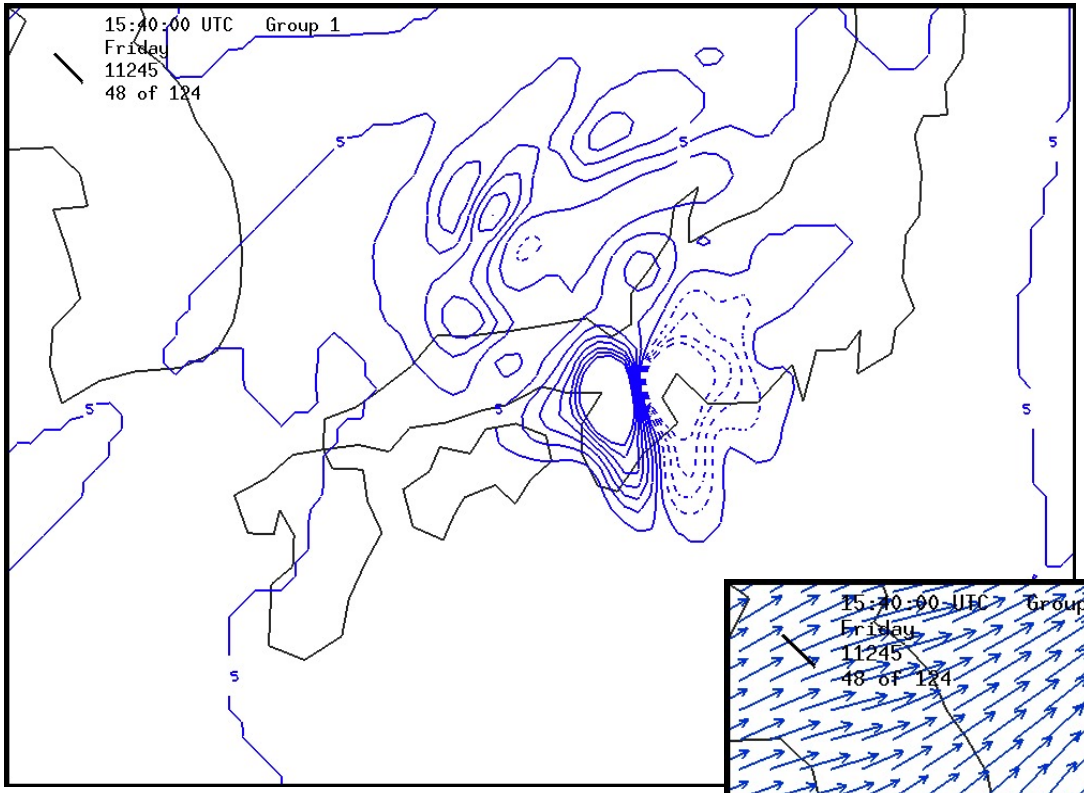
EPV at 14 km
Wind at 14km



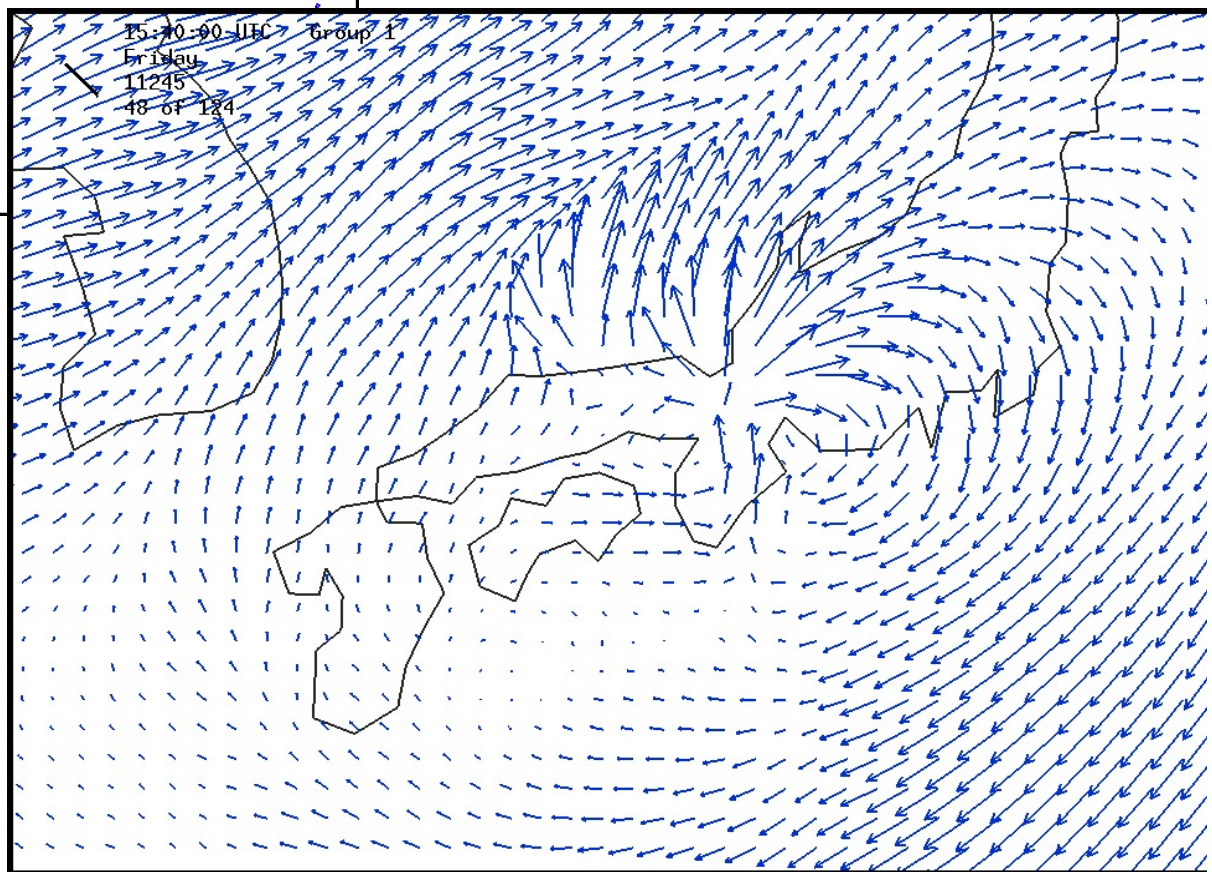


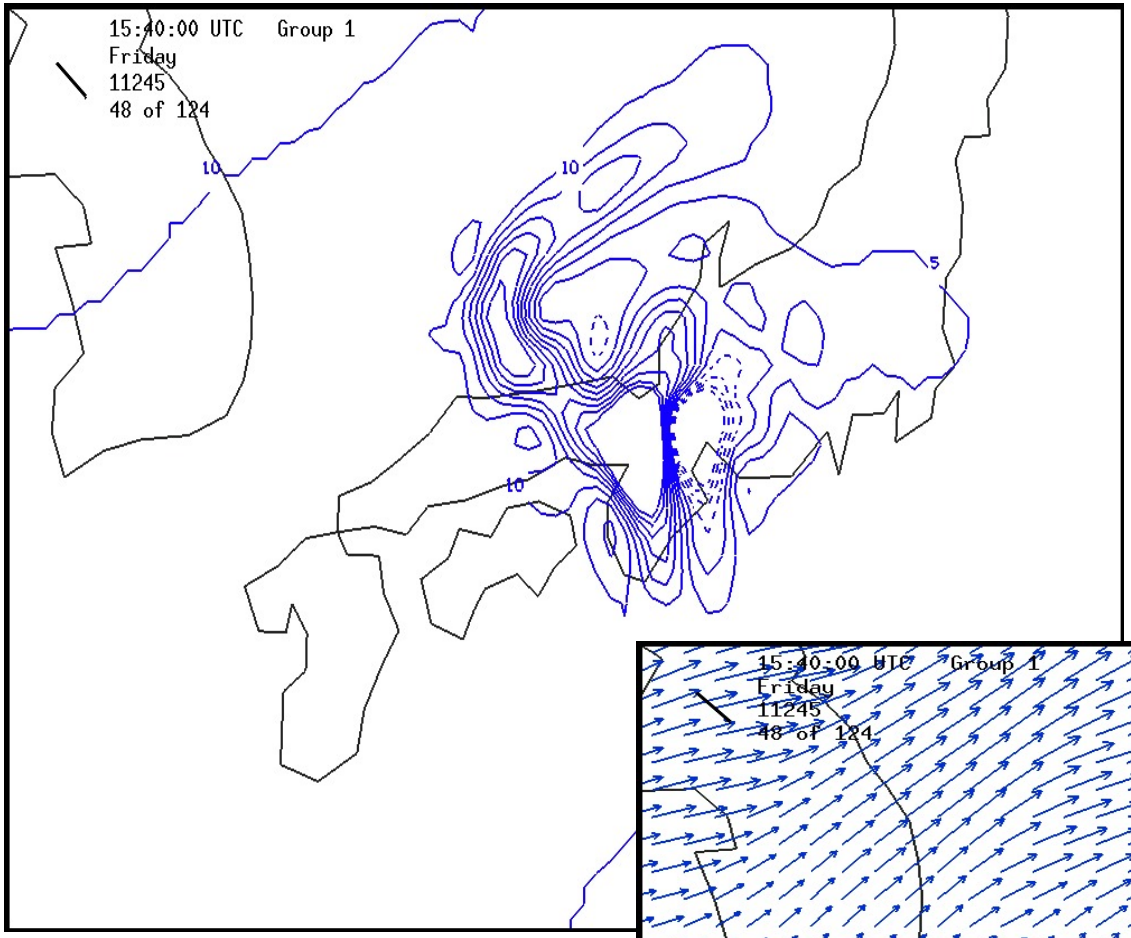
EPV at 16 km
Wind at 16 km

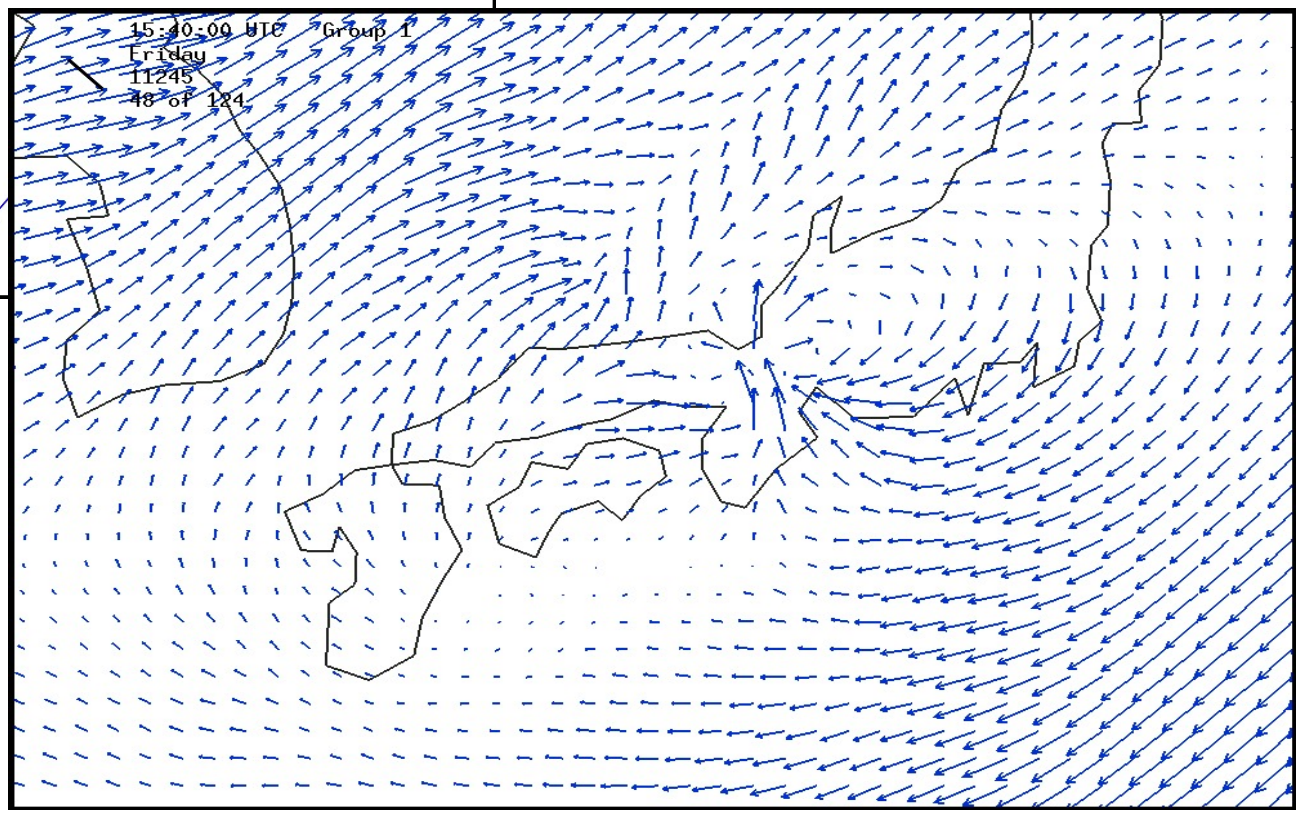




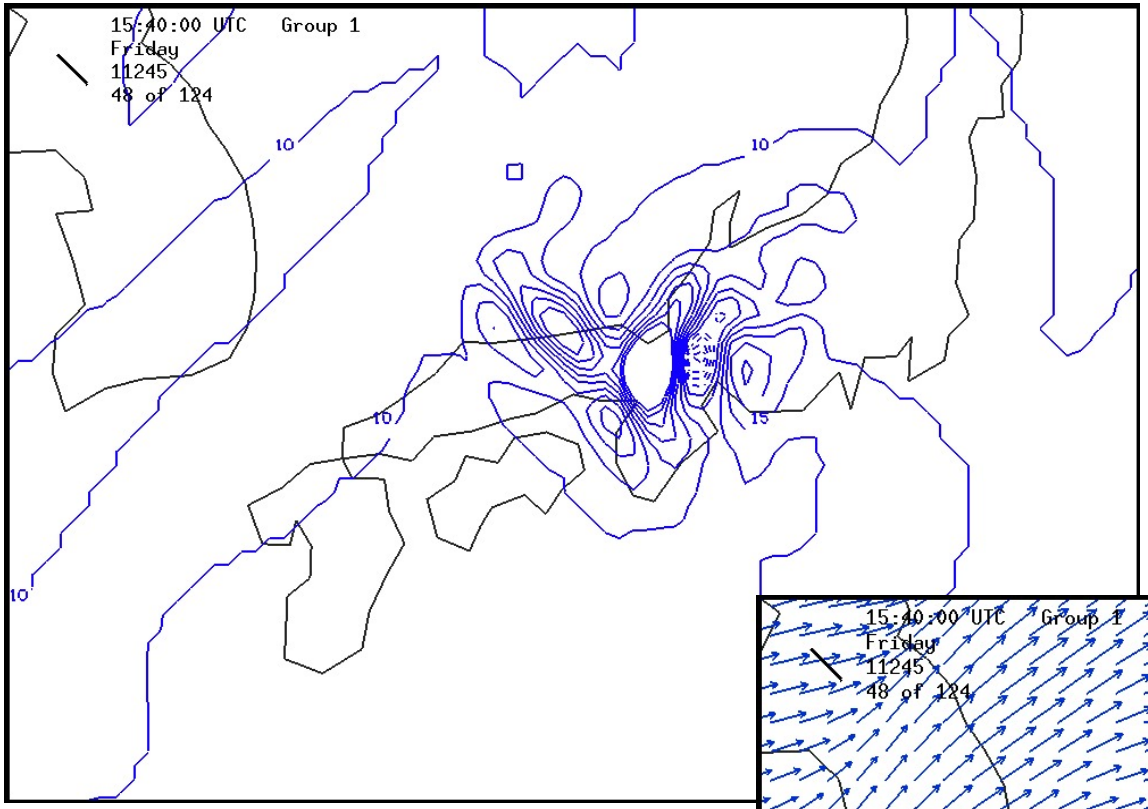
EPV at 17 km
Wind at 17 km



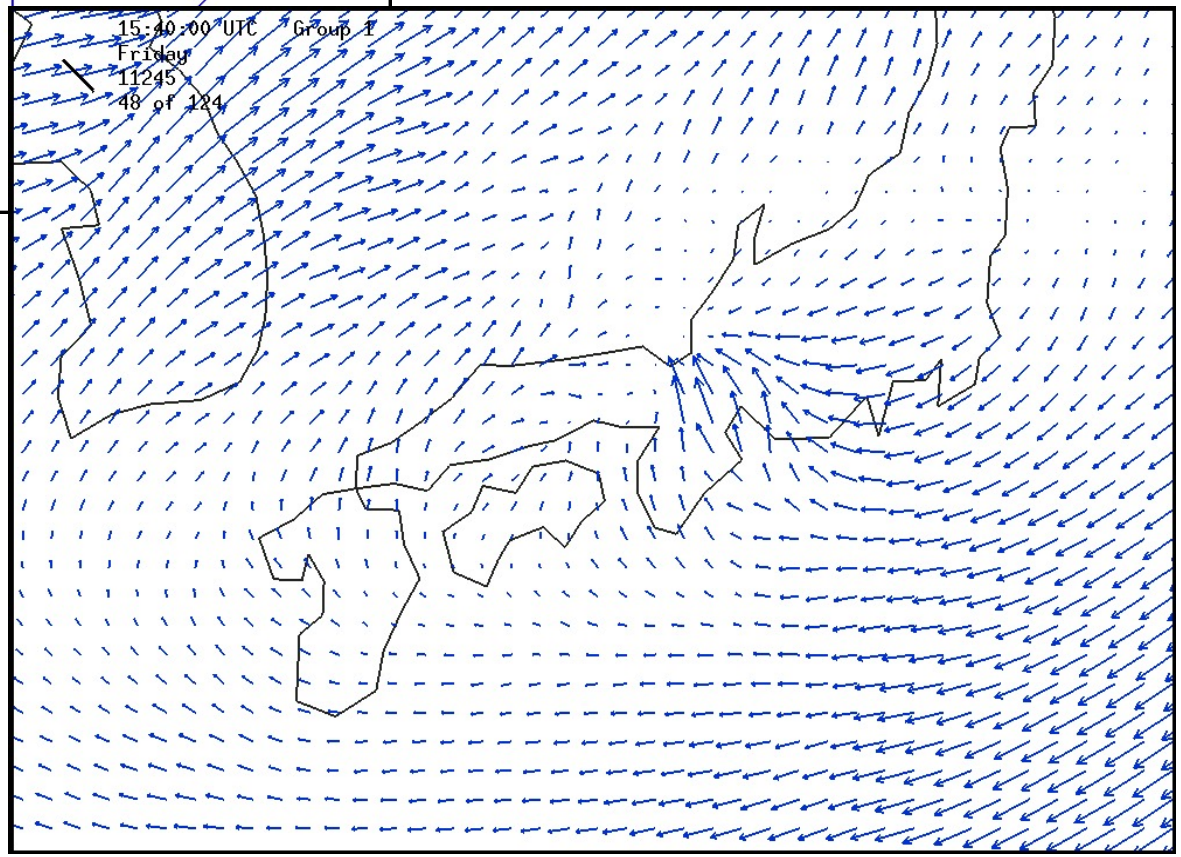




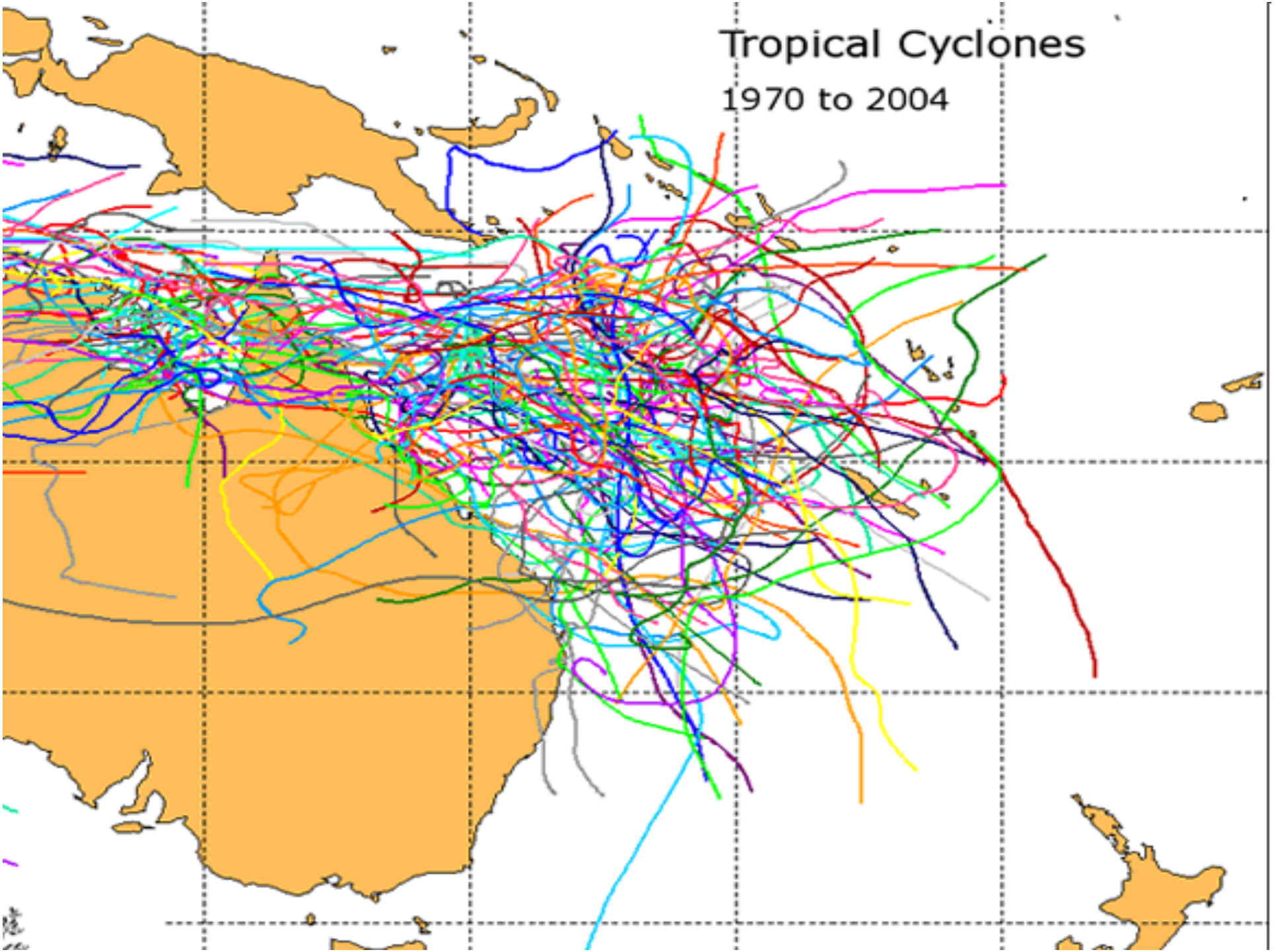
EPV at 17.5 km
Wind at 17.5 km

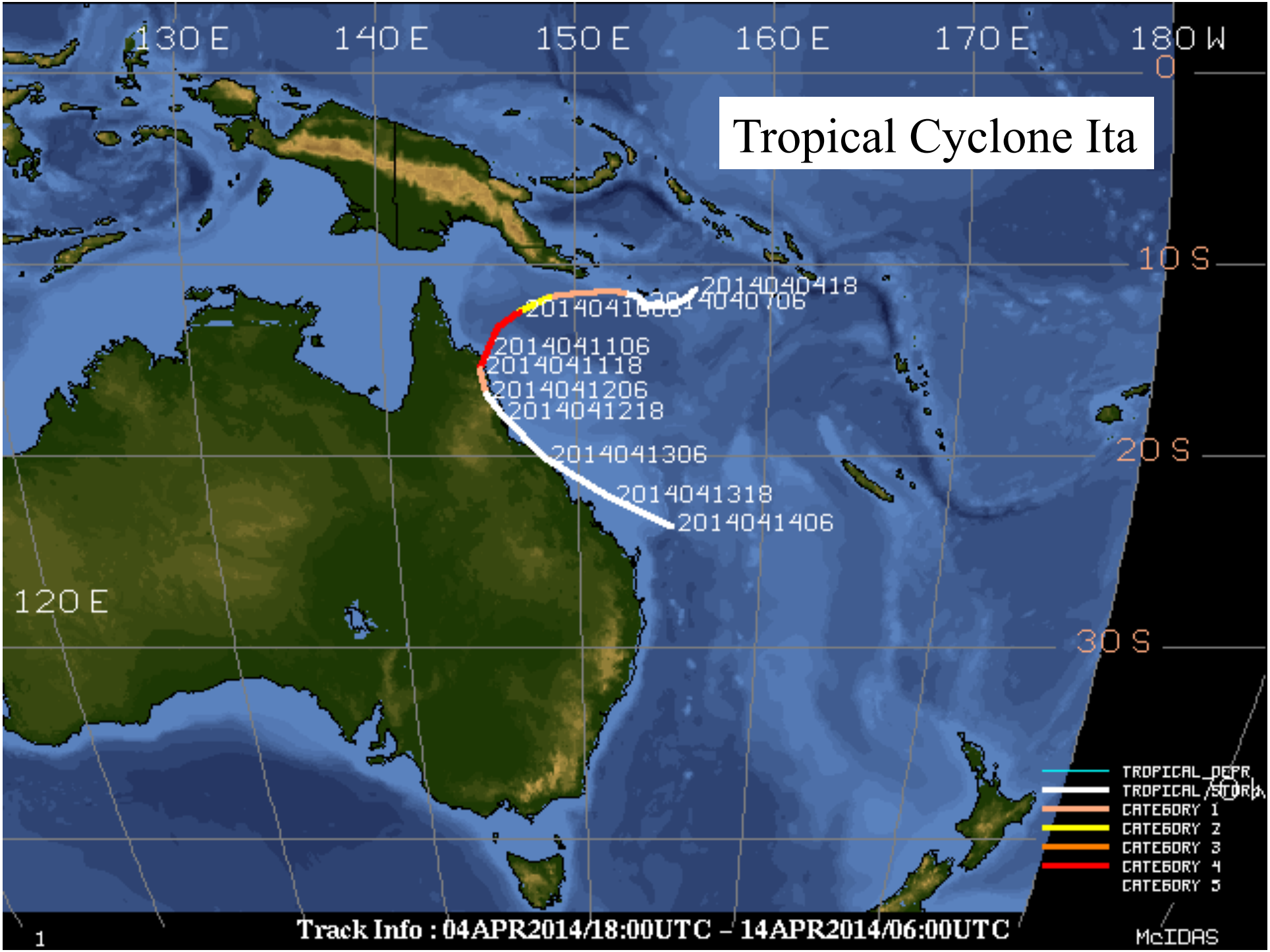


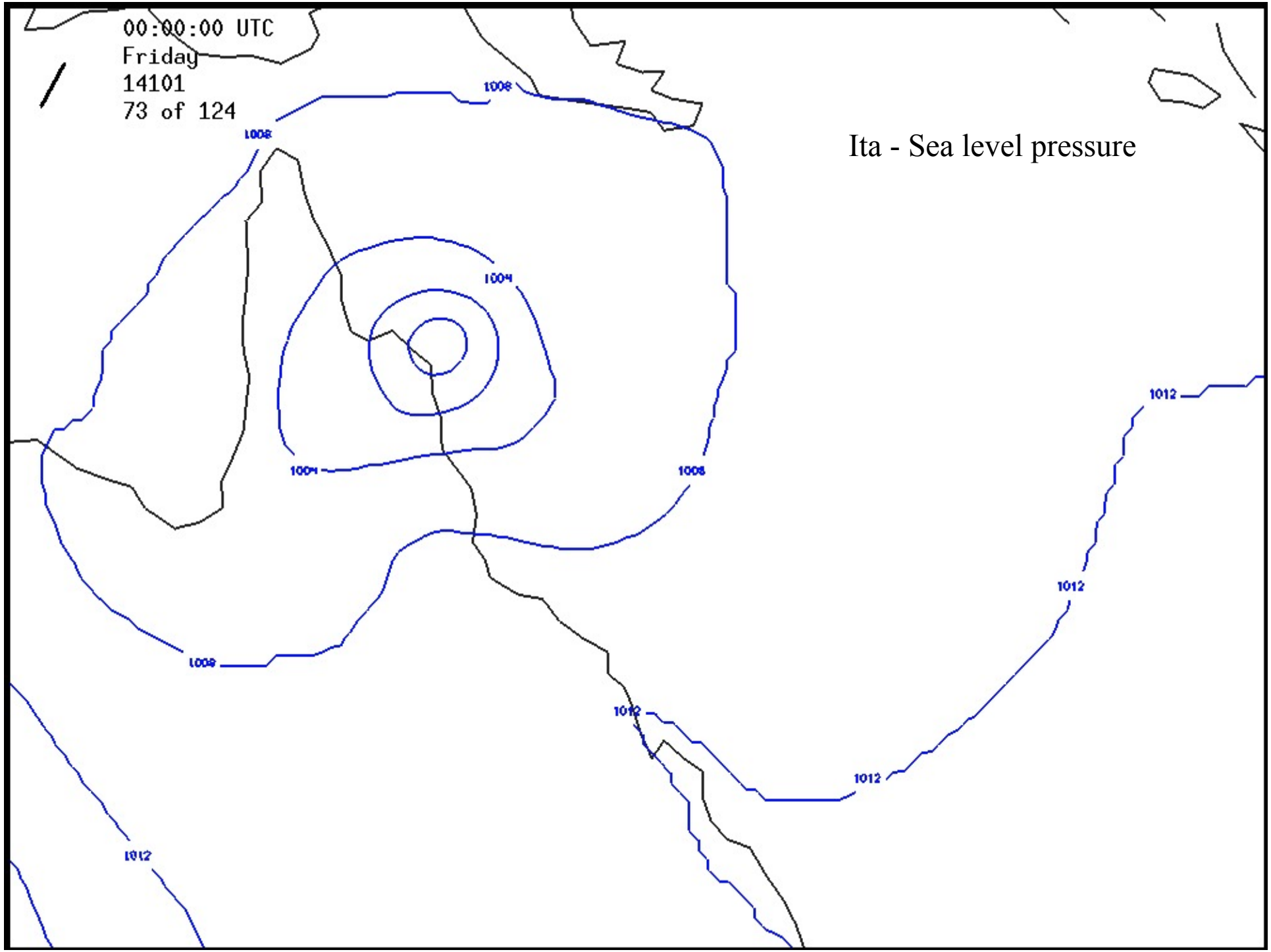
EPV at 18 km
Wind at 18 km

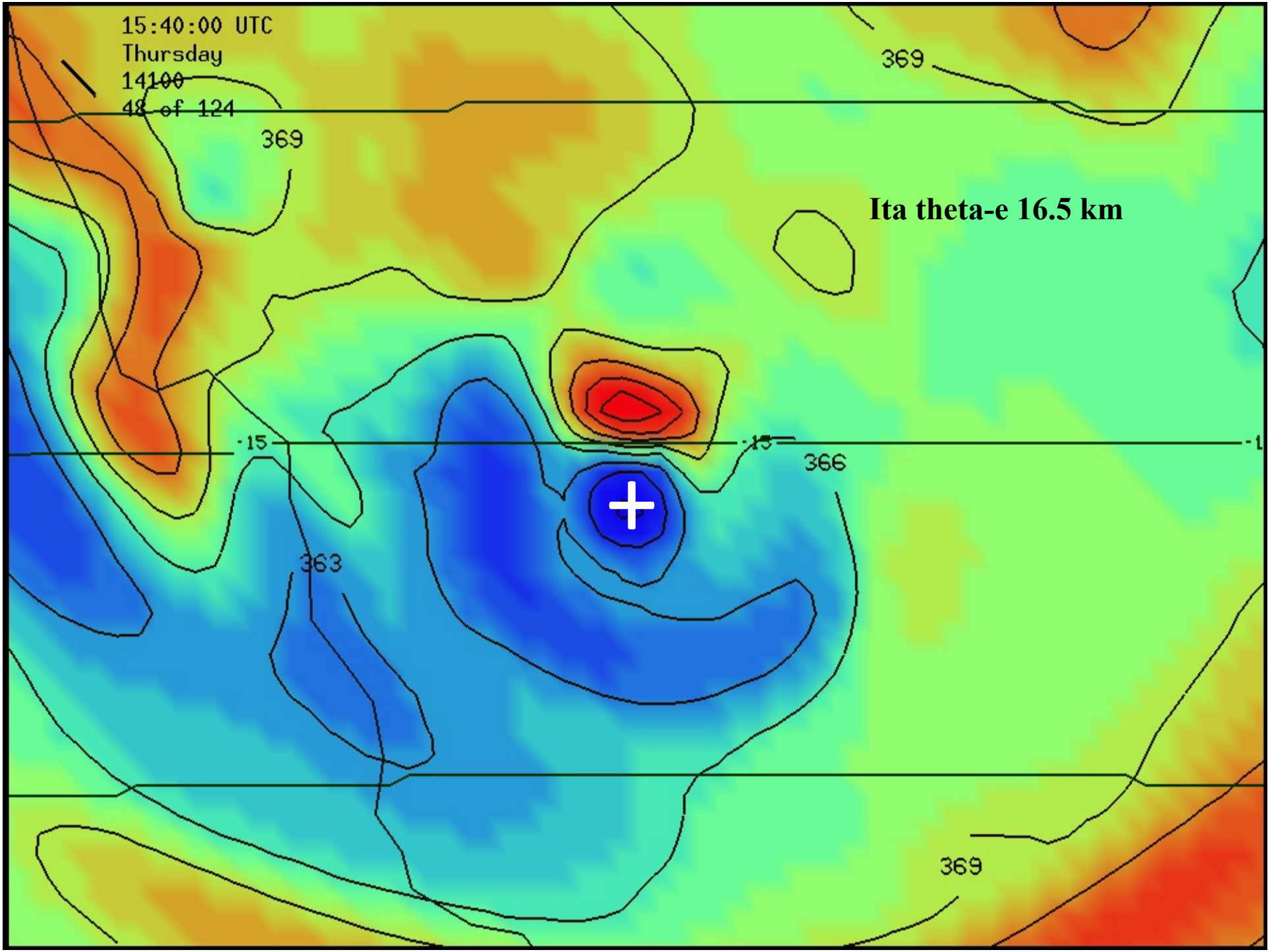


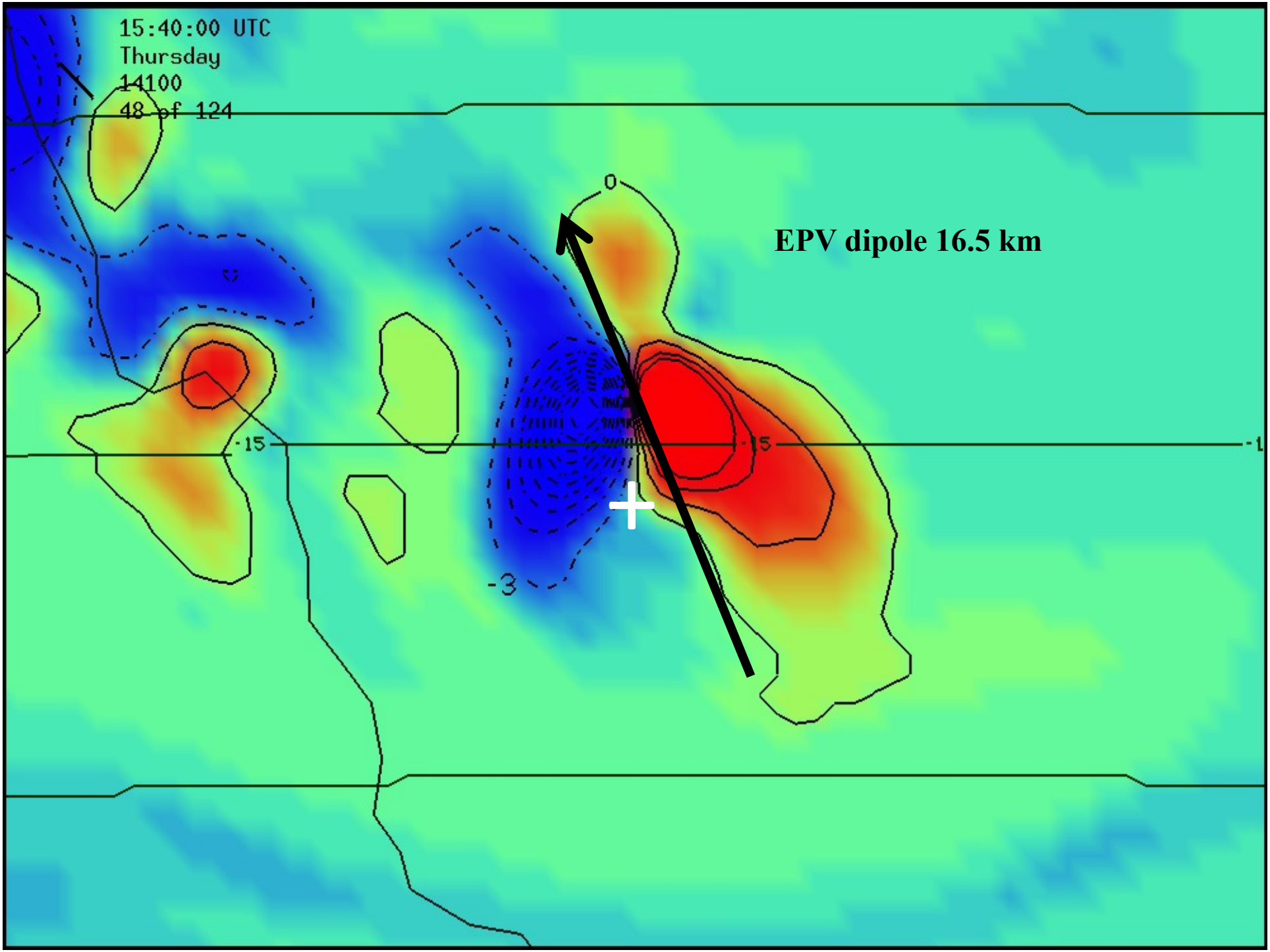
Vertical motion isosurface; 16.5 km winds and EPV

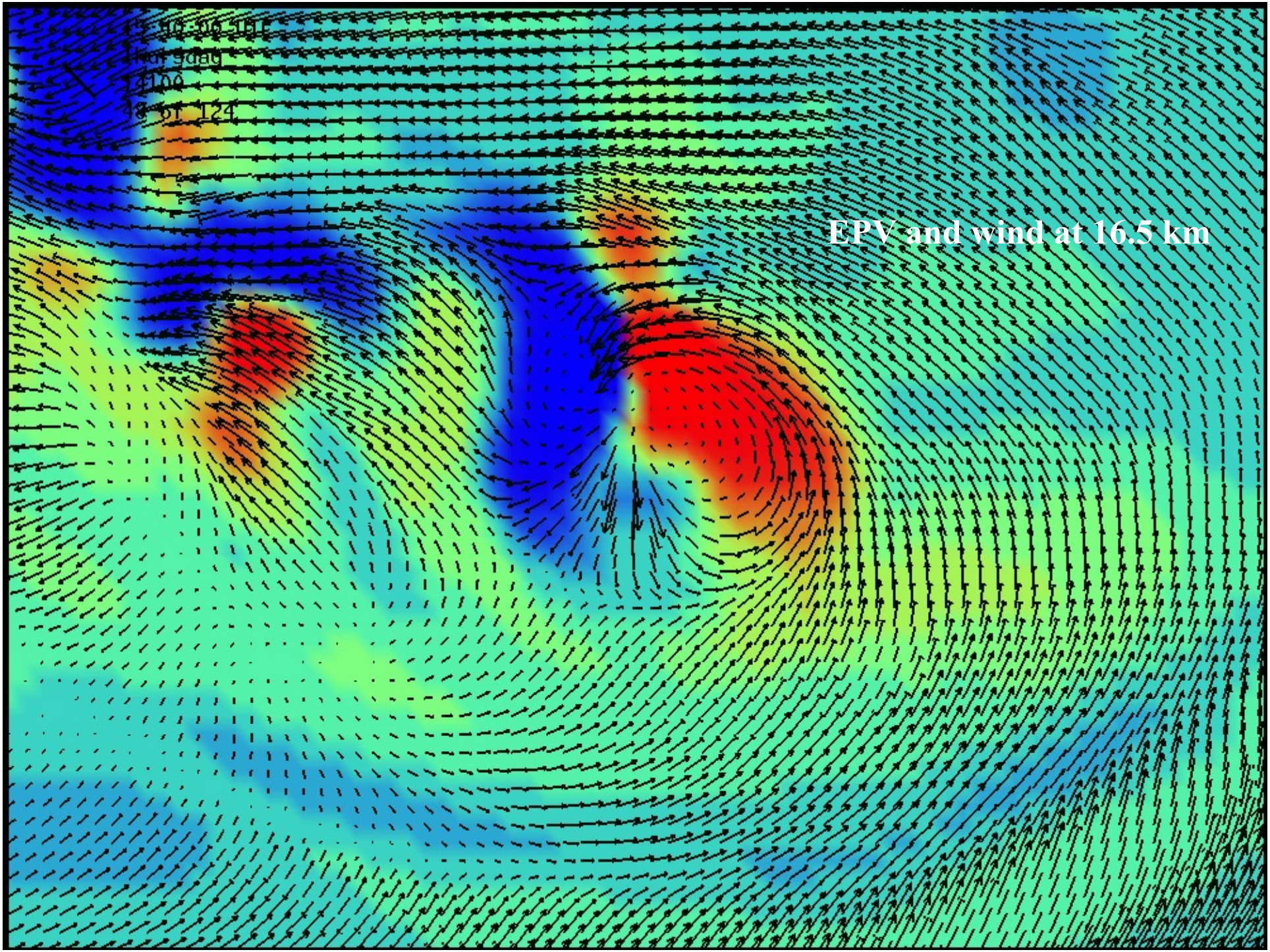

Tropical Cyclones
1970 to 2004

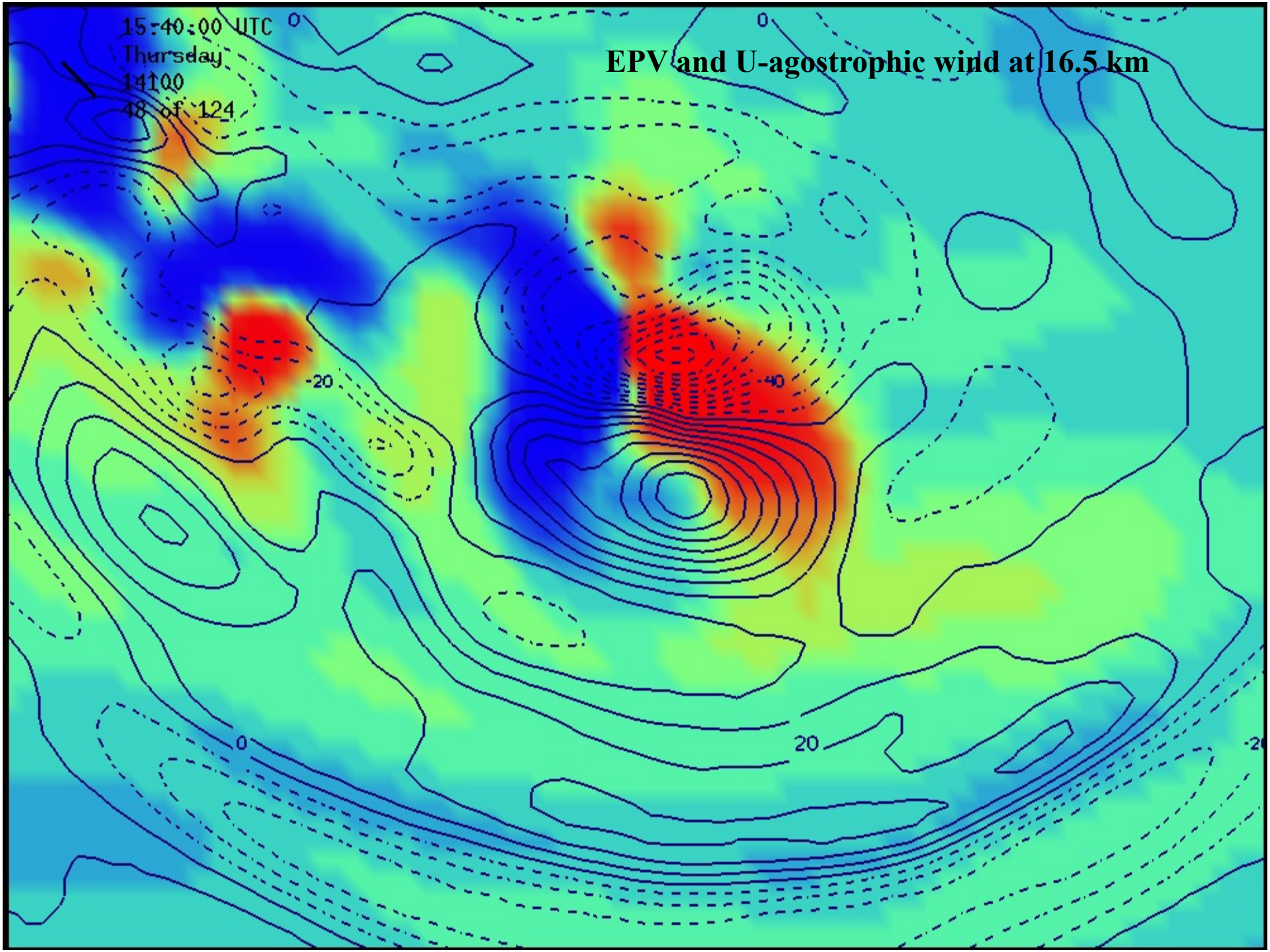

Tropical Cyclone Ita
130 E
140 E
150 E
160 E
170 E
180 W
0
10 S
20 S
30 S
120 E
2014040418
2014040706
2014041106
2014041118
2014041206
2014041218
2014041306
2014041318
2014041406
TROPICAL DEPR
TROPICAL STORM
CATEGORY 1
CATEGORY 2
CATEGORY 3
CATEGORY 4
CATEGORY 5
Track Info : 04APR2014/18:00UTC – 14APR2014/06:00UTC
1
McIDAS


00:00:00 UTC
Friday
14101
73 of 124
1008
1008
1004
1004
1008
1008
1012
1012
1012
1012
1012
Ita - Sea level pressure


15:40:00 UTC
Thursday
14100
48 of 124
369
369
Ita theta-e 16.5 km
-15
-15
366
363
369

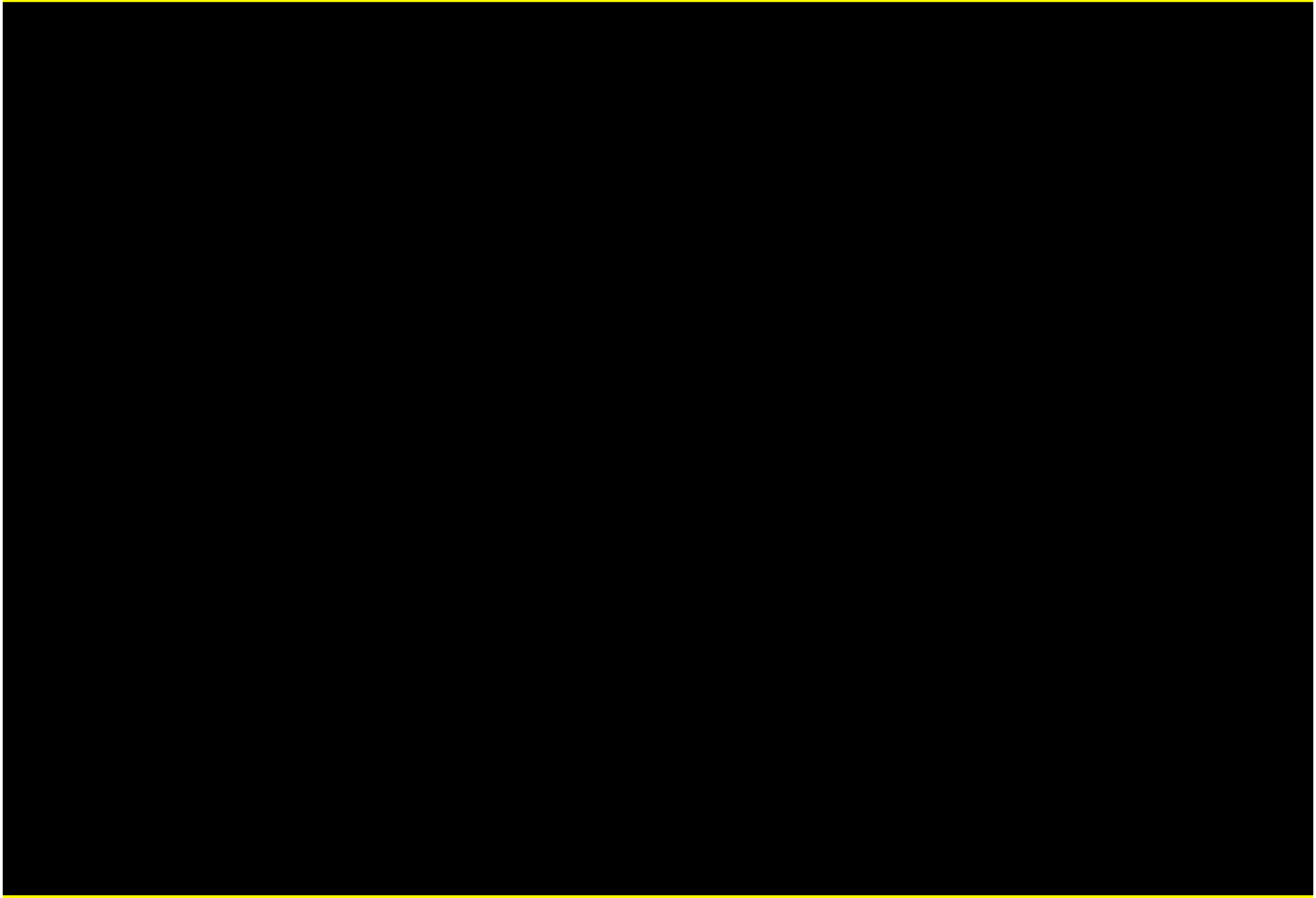

15:40:00 UTC
Thursday
14100
48 of 124
0
-15
-15
-3
EPV dipole 16.5 km


EPV and wind at 16.5 km

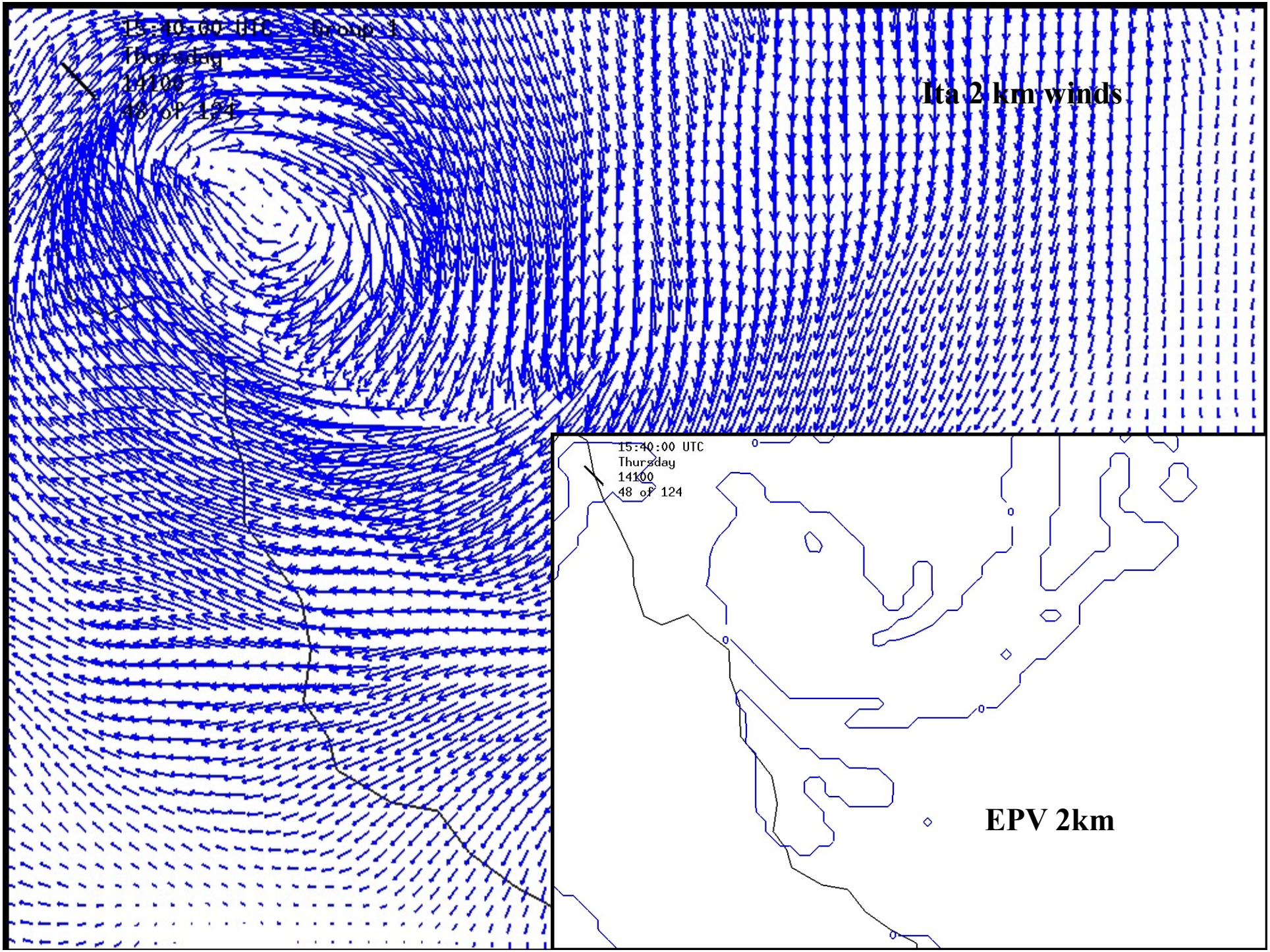


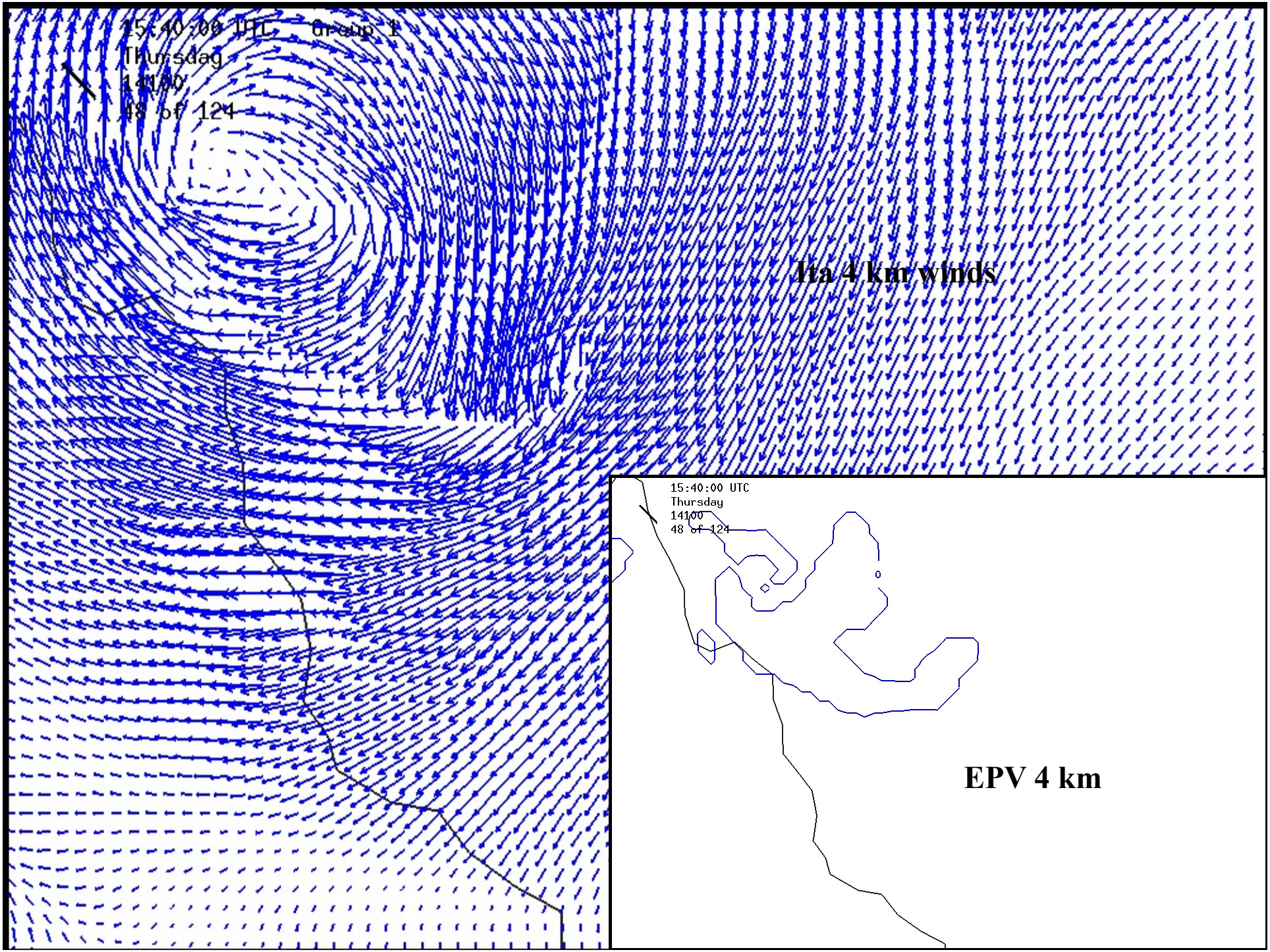
EPV and U-agostrophic wind at 16.5 km

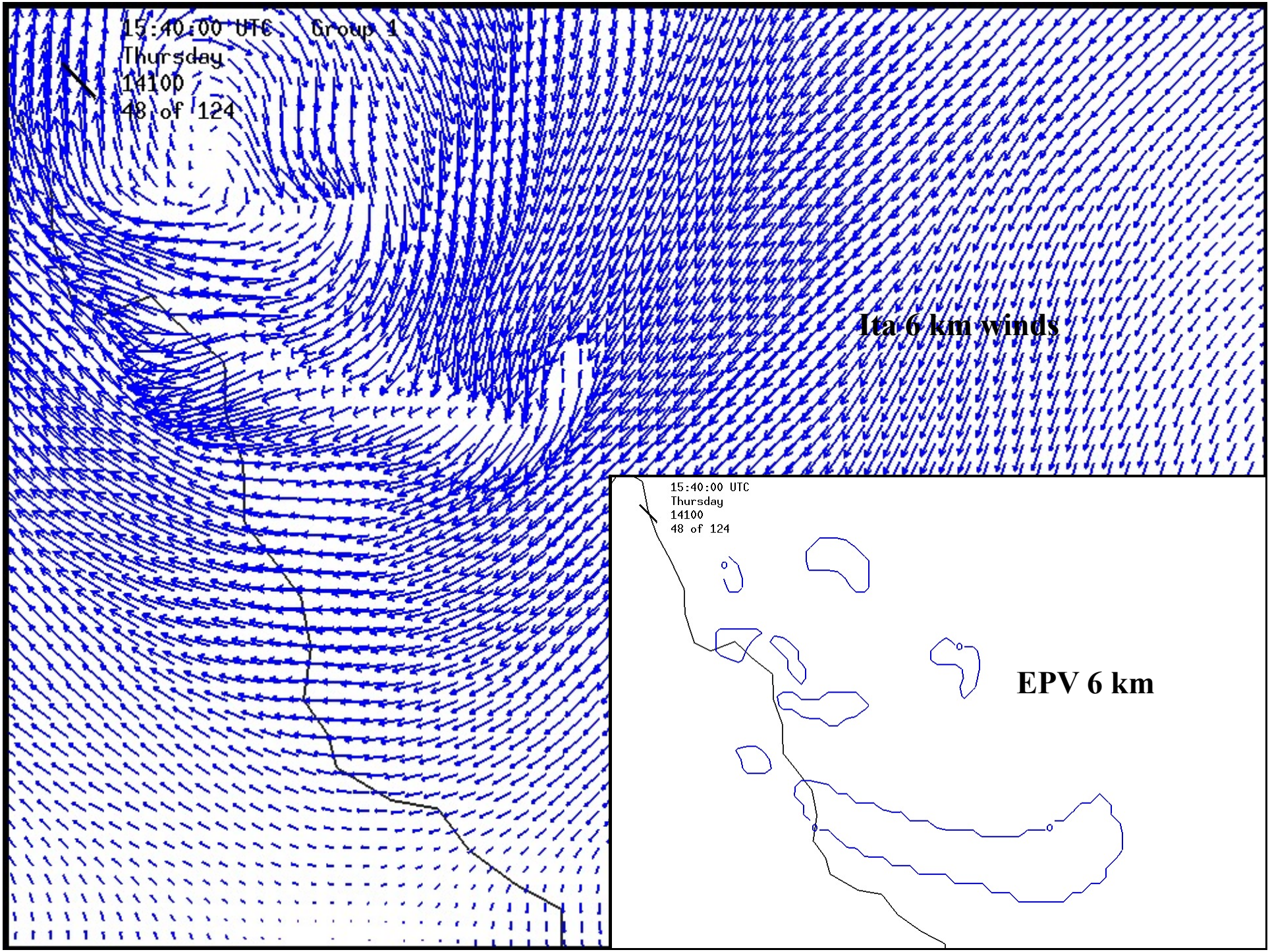
16.5 km winds; EPV

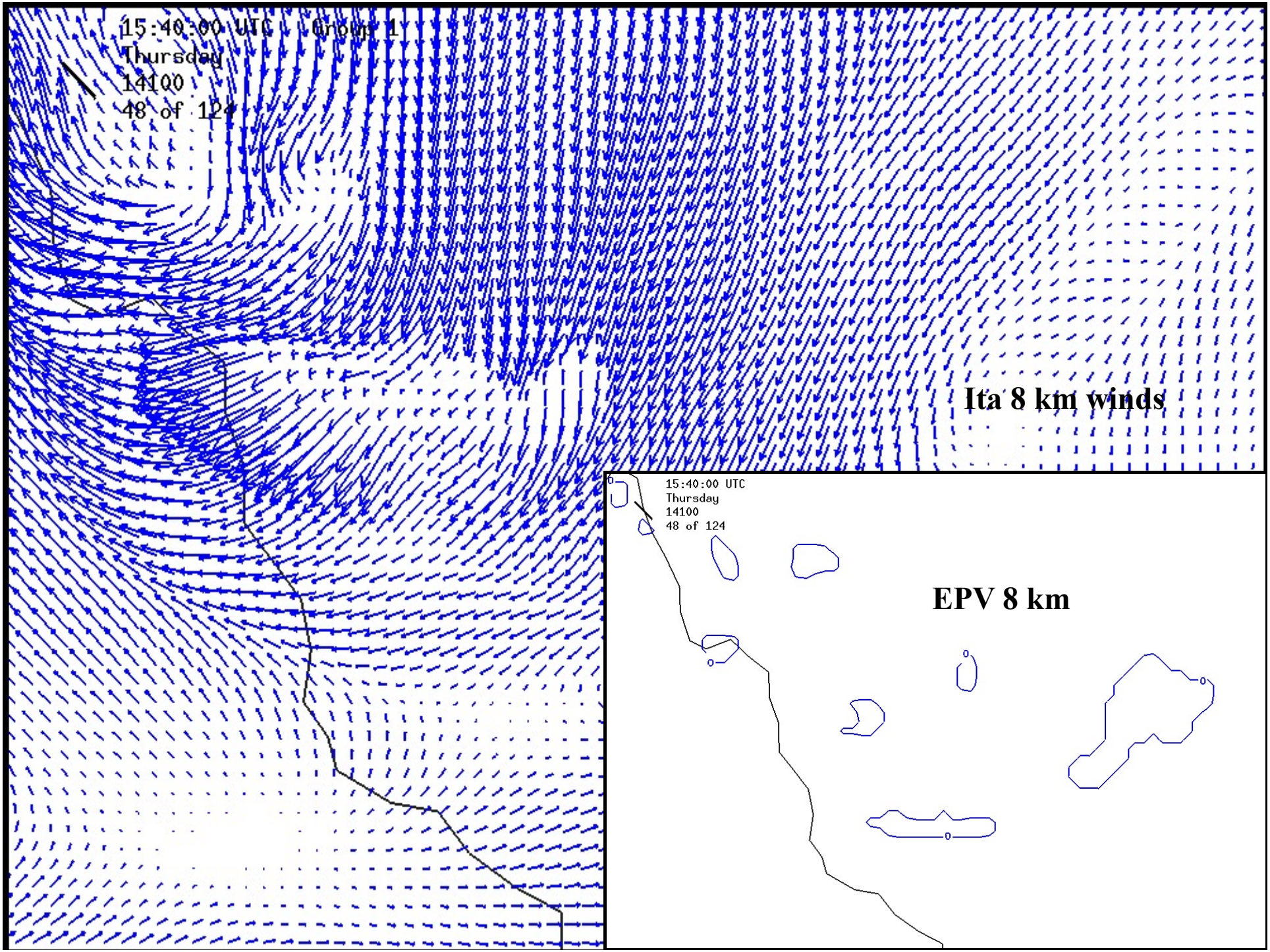


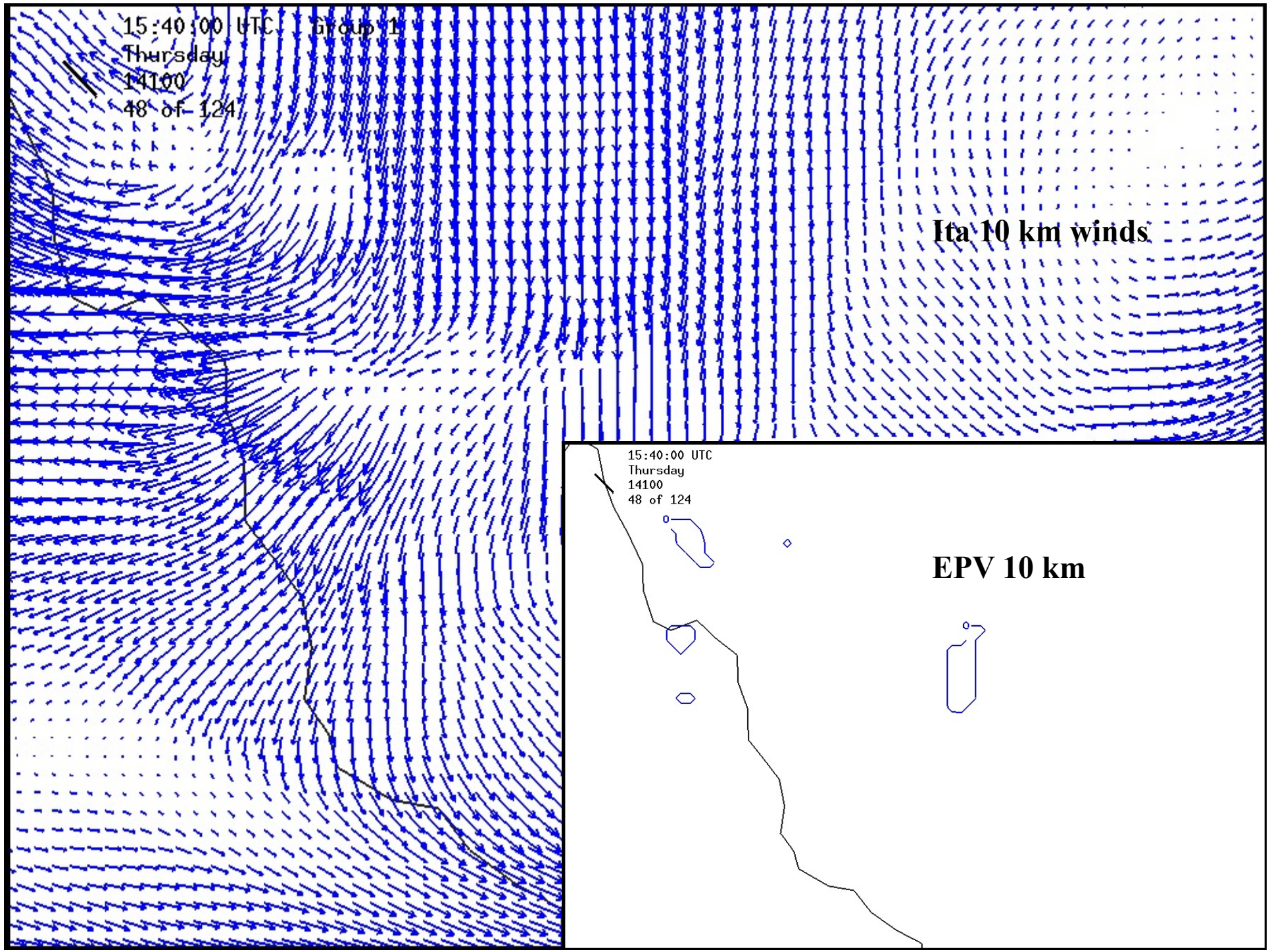
Green trajectories through PV<0; purple through PV > 0

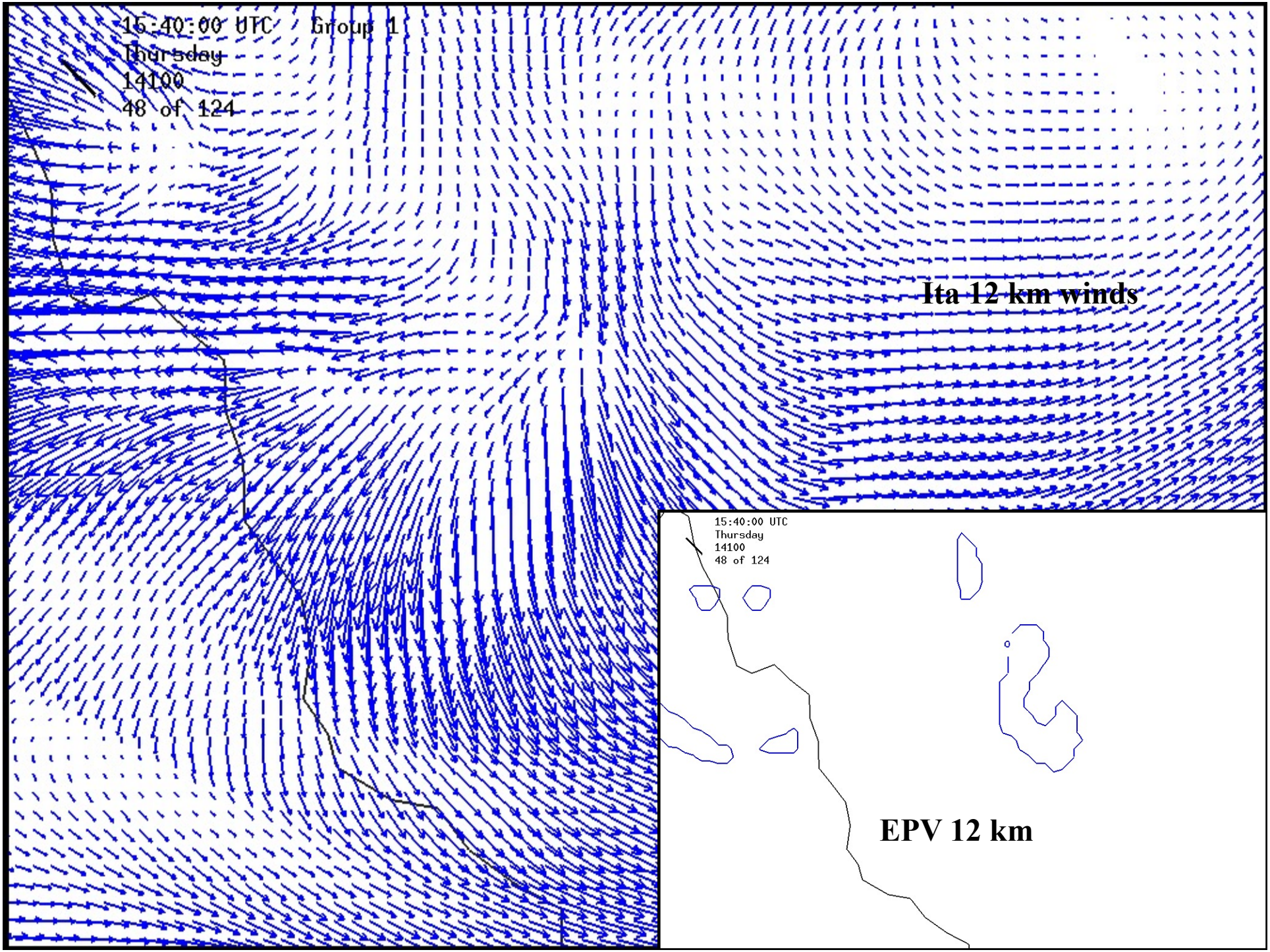

15:40:00 UTC Group 1
Thursday
14100
48 of 124
Ita 2 km winds
15:40:00 UTC
Thursday
14100
48 of 124
EPV 2km

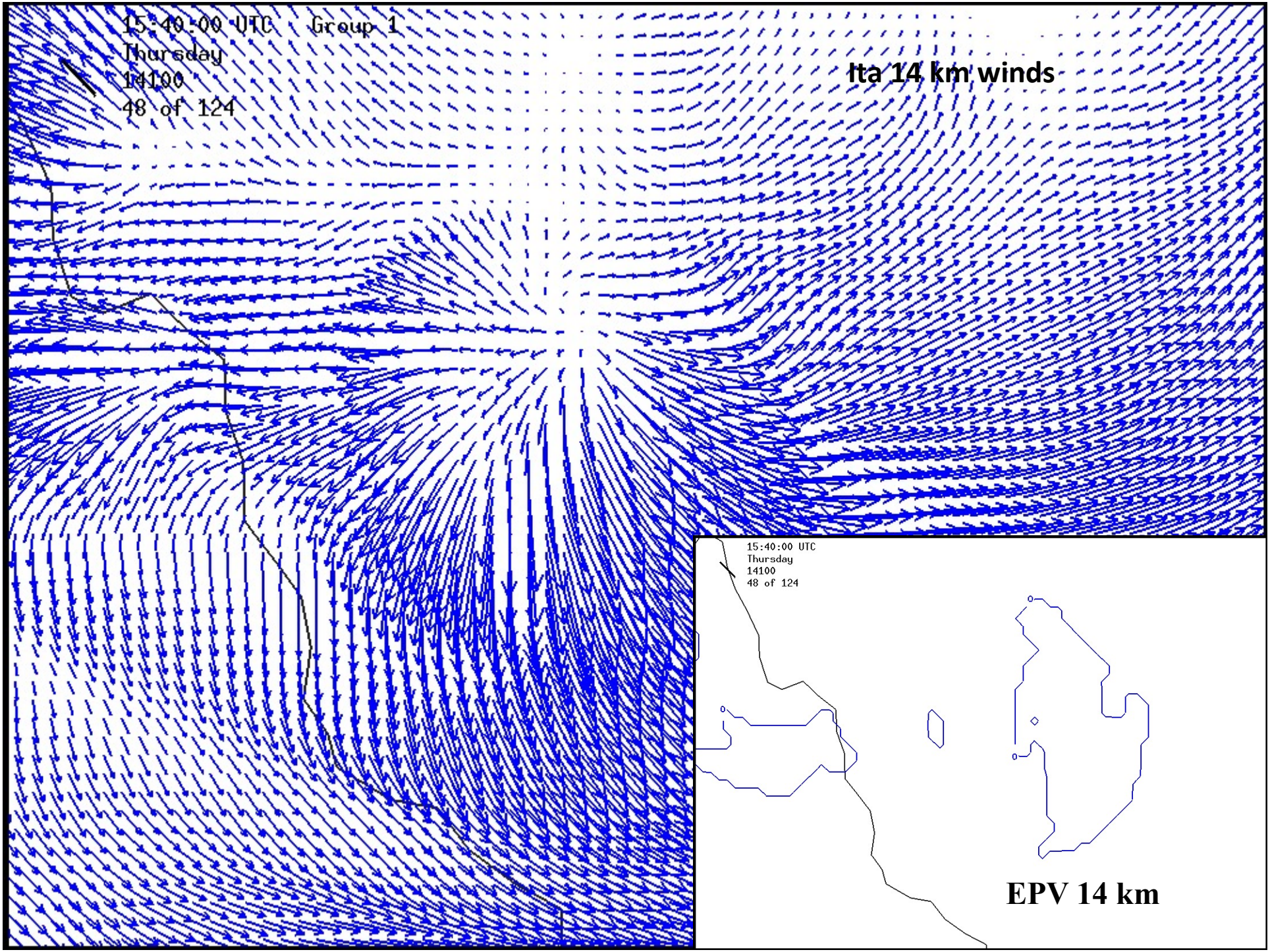

15:40:00 UTC
Thursday
14100
48 of 124
Ita 4 km winds
15:40:00 UTC
Thursday
14100
48 of 124
EPV 4 km

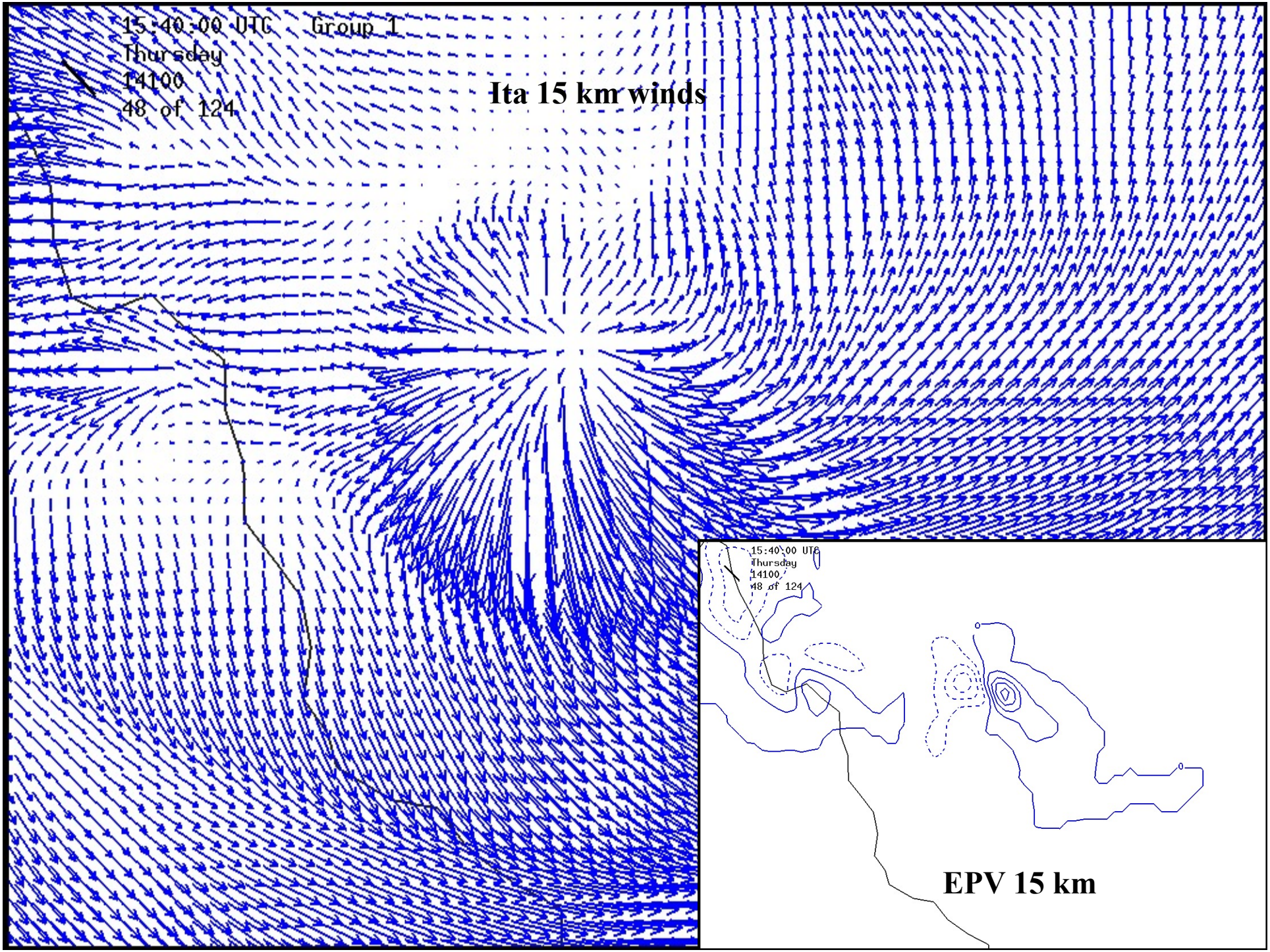

15:40:00 UTC
Thursday
14100
48 of 124
Group 1
Ita 6 km winds
15:40:00 UTC
Thursday
14100
48 of 124
EPV 6 km

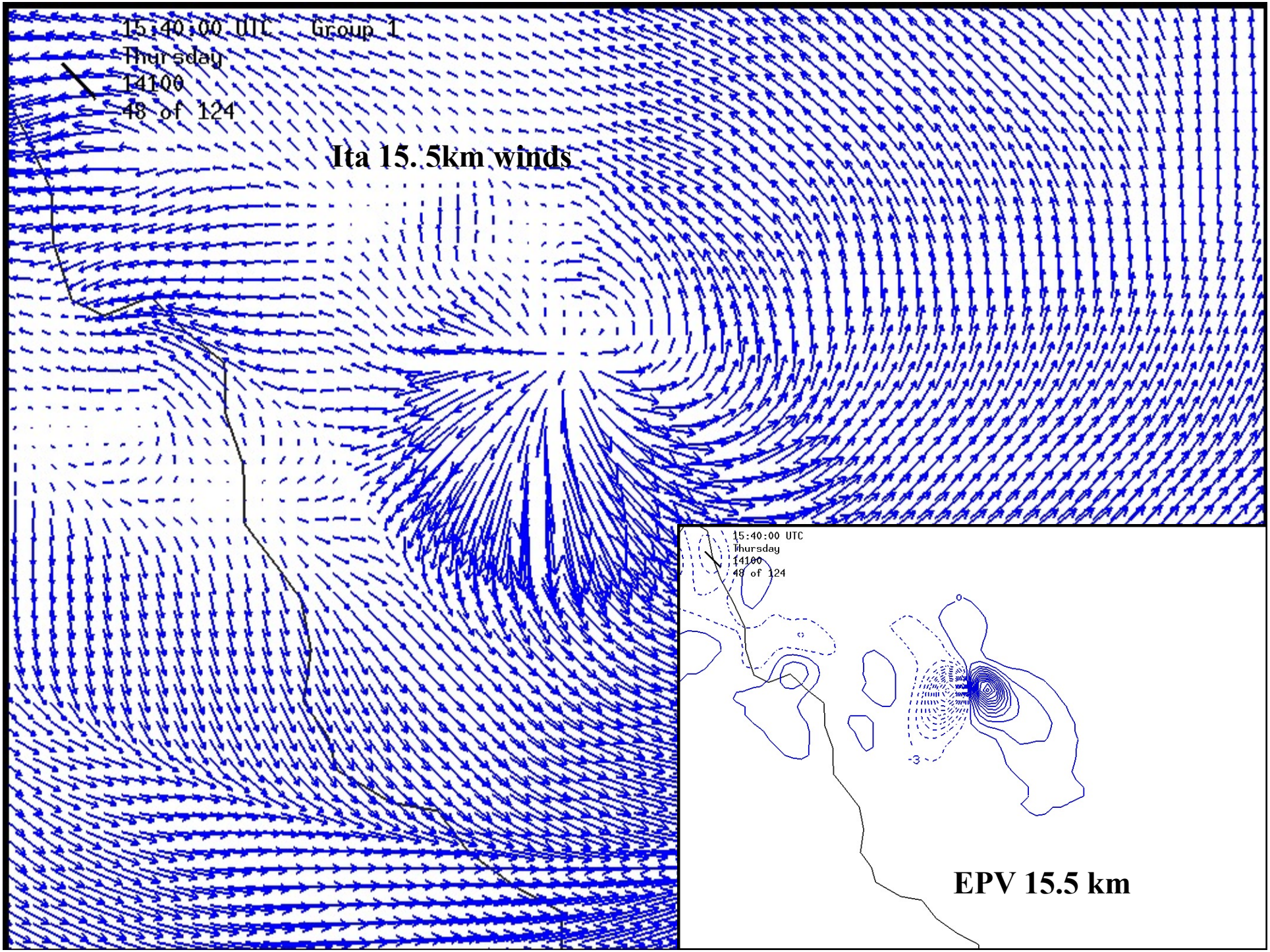

15:40:00 UTC
Thursday
14100
48 of 124
Ita 8 km winds
15:40:00 UTC
Thursday
14100
48 of 124
EPV 8 km

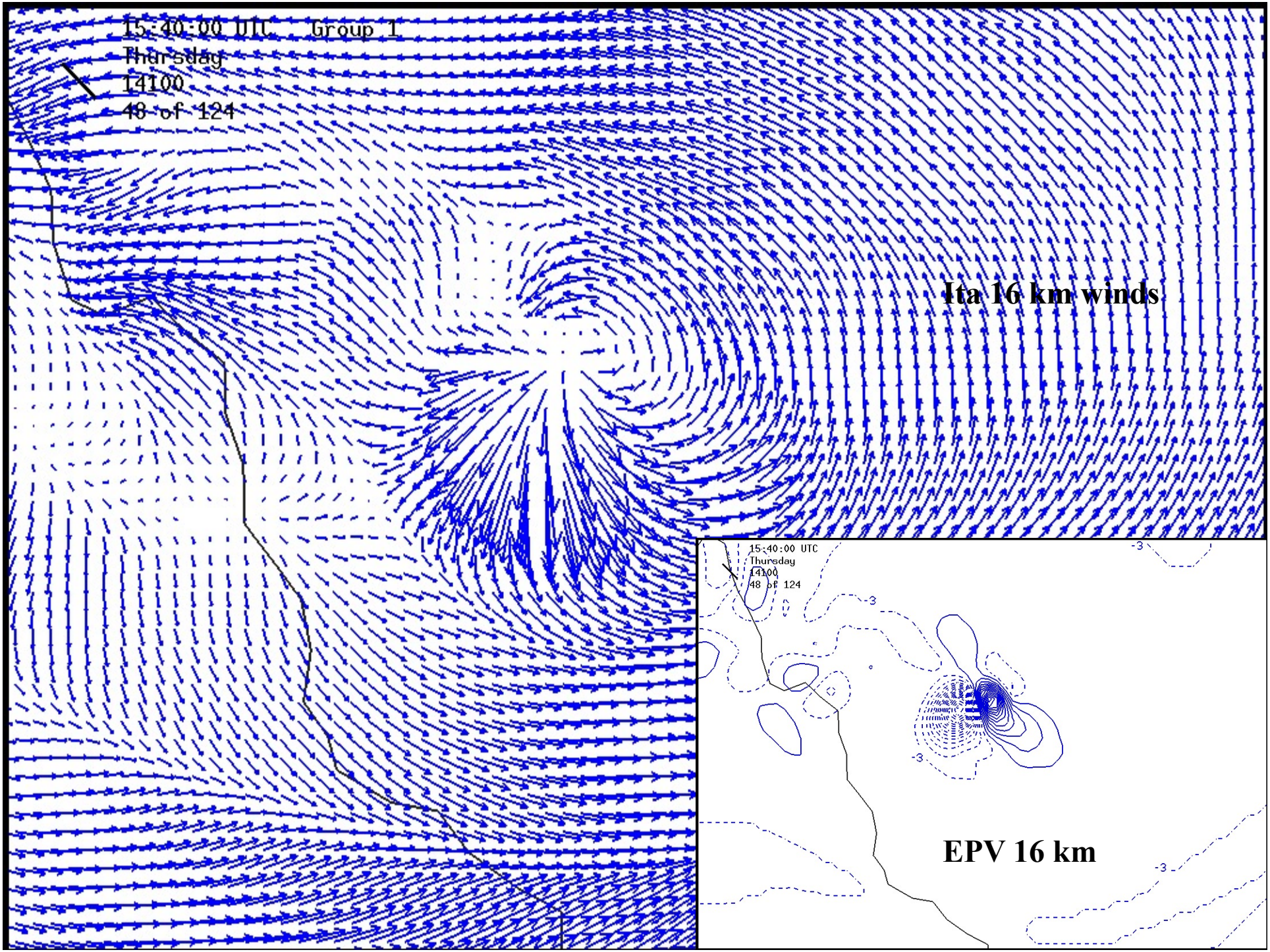

15:40:00 UTC Group 1
Thursday
14100
48 of 124
Ita 10 km winds
15:40:00 UTC
Thursday
14100
48 of 124
EPV 10 km

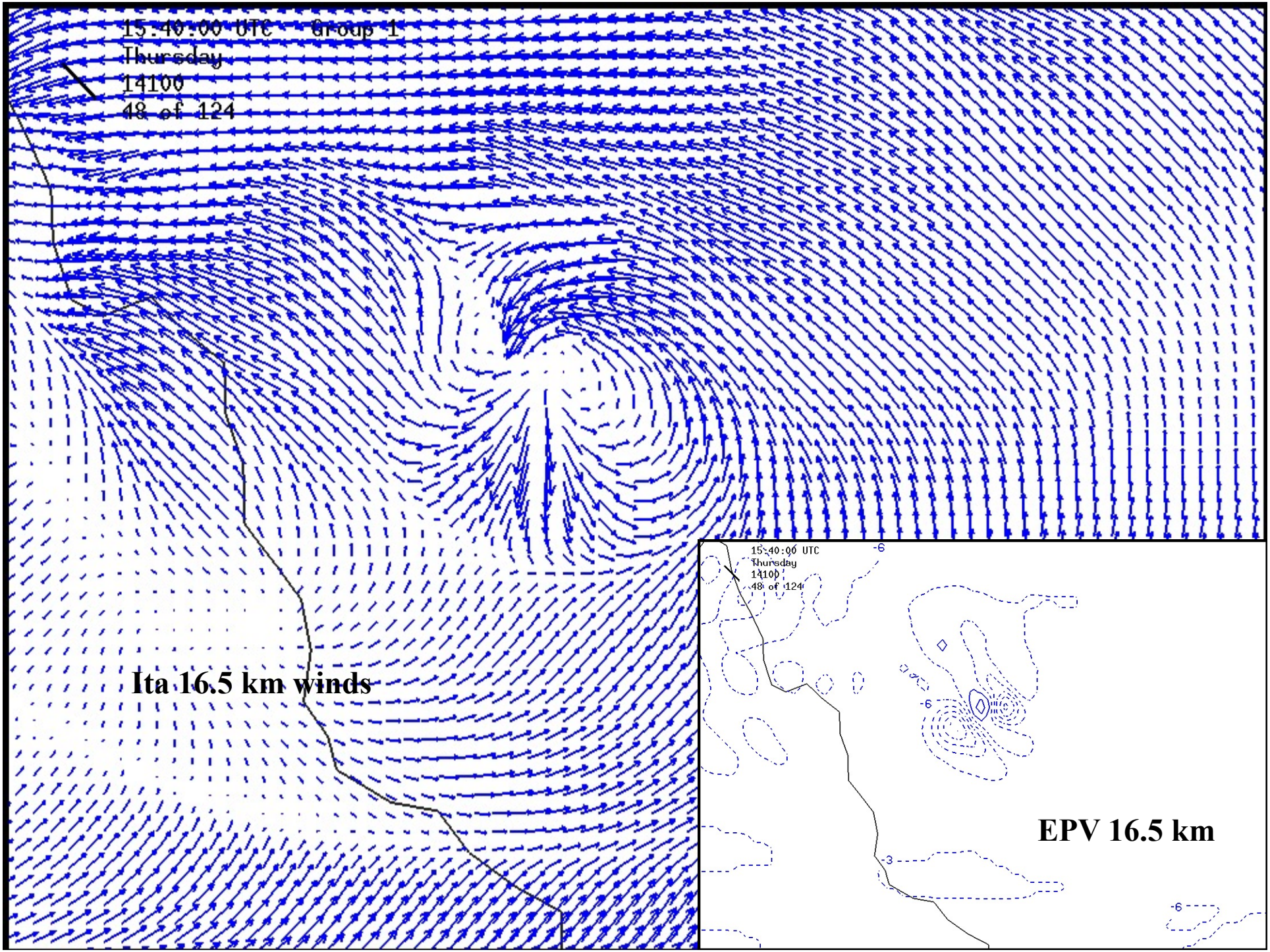

15:40:00 UTC
Thursday
14100
48 of 124
Group 1
Ita 12 km winds
15:40:00 UTC
Thursday
14100
48 of 124
EPV 12 km


15:40:00 UTC Group 1
Thursday
14100
48 of 124
Ita 14 km winds
15:40:00 UTC
Thursday
14100
48 of 124
EPV 14 km

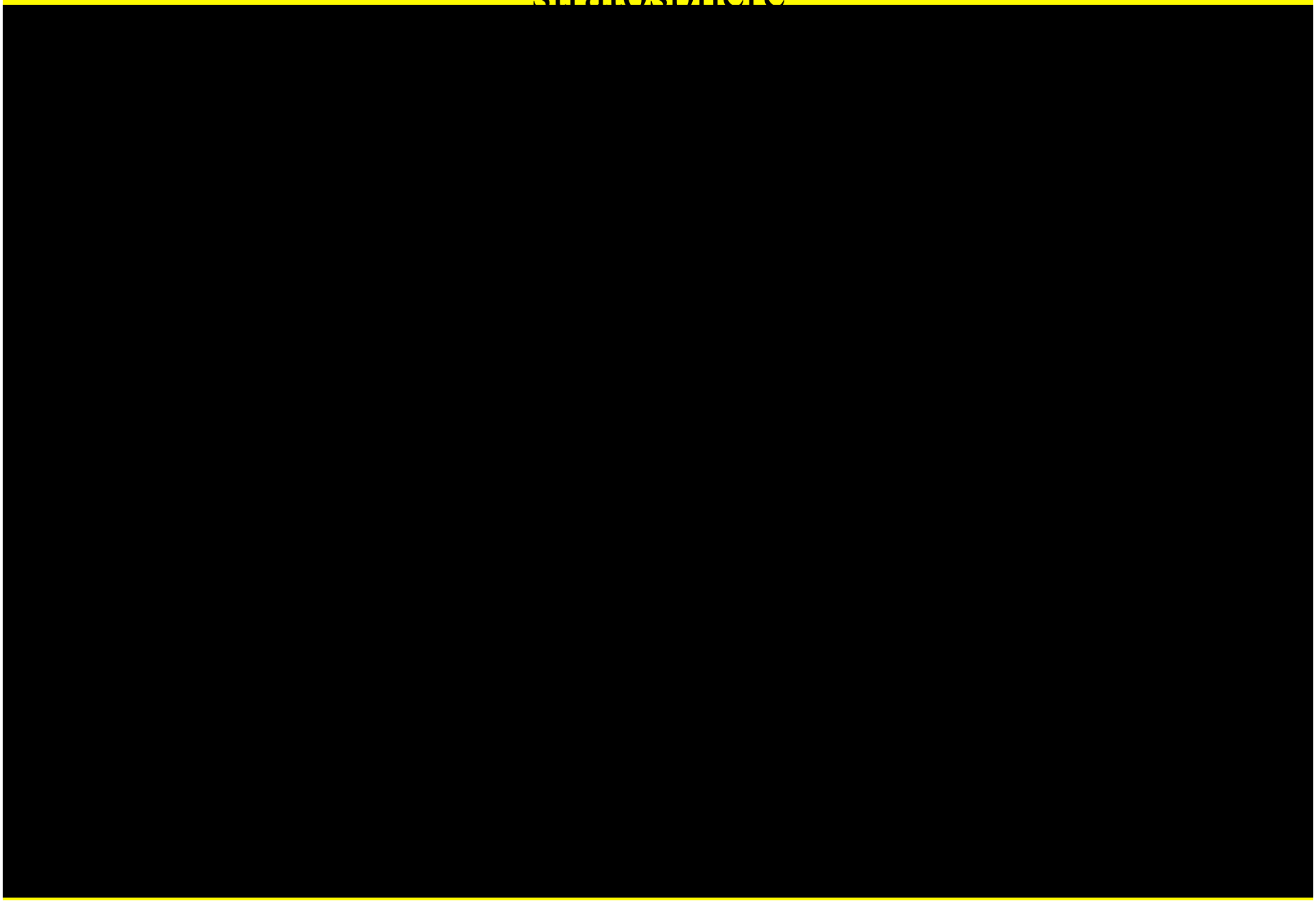

15:40:00 UTC Group 1
Thursday
14100
48 of 124
Ita 15 km winds
15:40:00 UTC
Thursday
14100
48 of 124
EPV 15 km


15:40:00 UTC Group 1
Thursday
14100
48 of 124
Ita 15. 5km winds
15:40:00 UTC
Thursday
14100
48 of 124
0
-3
EPV 15.5 km


15:40:00 UTC Group 1
Thursday
14100
48 of 124
Ita 16 km winds
15:40:00 UTC
Thursday
14100
48 of 124
-3
-3
-3
-3
EPV 16 km


15:40:00 UTC Group 1
Thursday
14100
48 of 124
Ita 16.5 km winds
15:40:00 UTC
Thursday
14100
48 of 124
-6
-6
-3
-6
EPV 16.5 km

16.5 km winds – convection stirs the base of the stratosphere

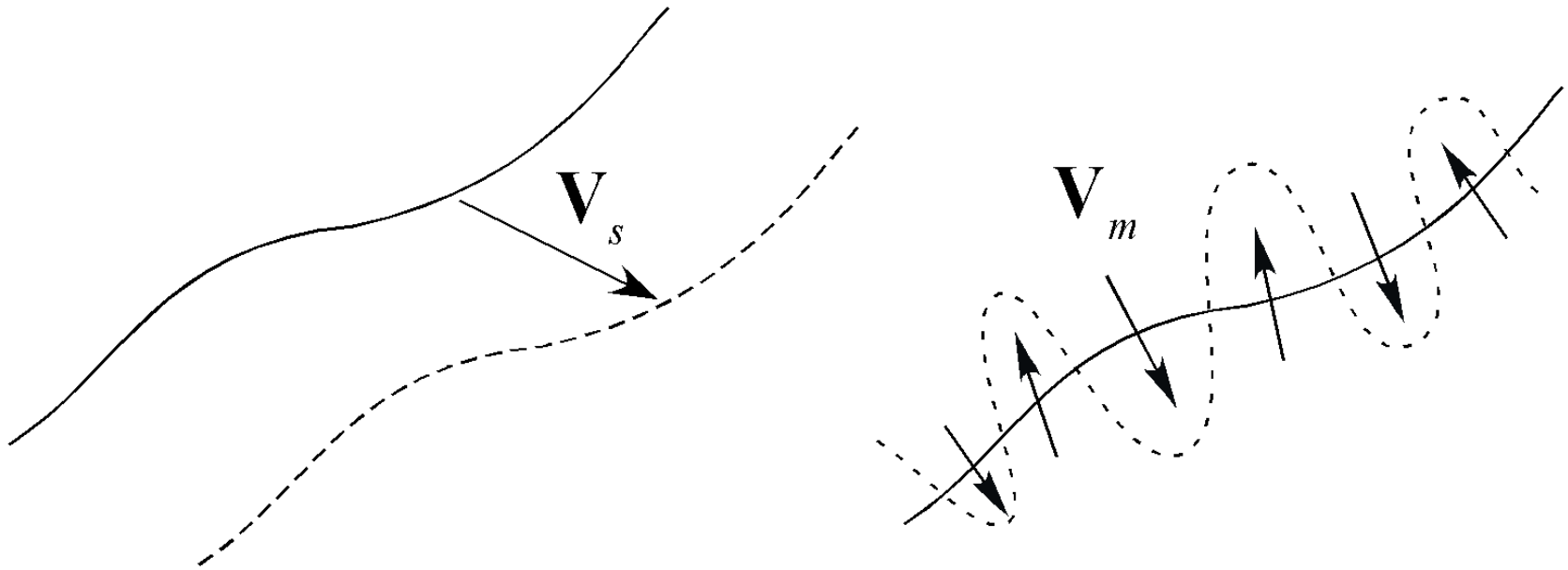


- STE occurs on the periphery of cyclones and above convective complexes
- PV dipoles produced by convection, amplified in upper TS azimuthal shear
- Inertial instability *is* half of PV dipoles
- Inertial instability facilitates accelerations, outflow, STE
- Extratropical transition: creation of negative PV filament from convective scale injections

Future work:

- Quantify STE with 2-scale and annulus methods
- Explore drying effect
- Sort out relationship among w, θ_e dipoles and PV dipoles
- Simulate more convective complexes

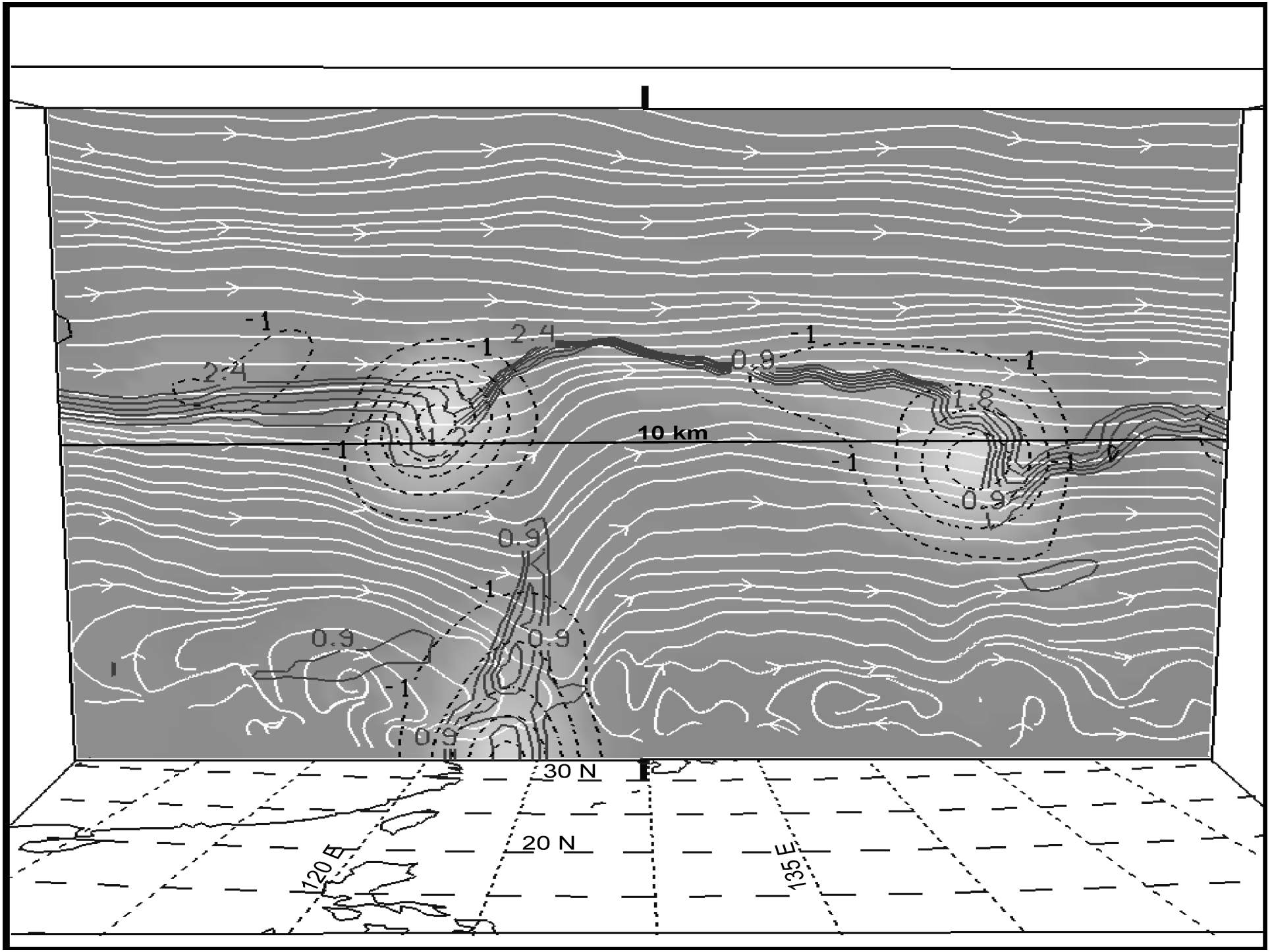
The two-scale method

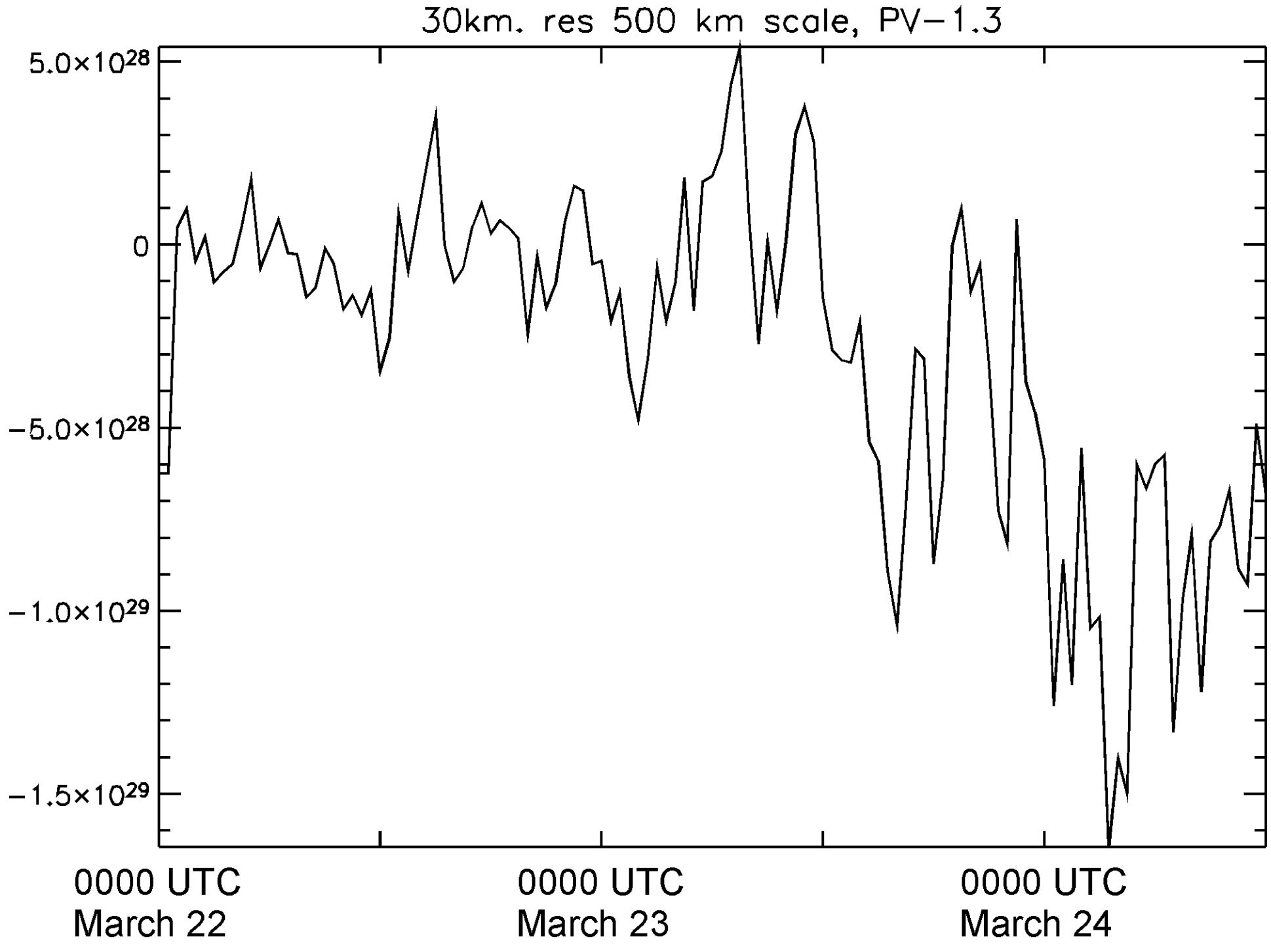


$\mathbf{V}_s$ = smoothed winds advect material surface

$\mathbf{V}_m = \mathbf{V} - \mathbf{V}_s$ = resolved mixing winds

$\text{Flux} = n_\chi \cdot \mathbf{V}_{m,\perp}$


-1
2.4
-1
2.4
-1
0.8
-1
1.8
10 km
-1
-1
0.9
0.9
-1
0.9
0.9
-1
0.9
30 N
20 N
120 E
135 E


30km. res 500 km scale, PV−1.3
5.0×10^28
0
−5.0×10^28
−1.0×10^29
−1.5×10^29
0000 UTC
March 22
0000 UTC
March 23
0000 UTC
March 24