Convective Influence and High Altitude Pollution during INTEX-B

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Introduction

An important feature of the CO observations during INTEX-B was the presence of strong enhancements at high altitudes (above 8-10 km). The presence of "Asian CO" at high altitudes is not a newly observed phenomenon – it was noted during TRACE-P and INTEX-A. In many cases, it was modeled successfully. However, models are not always able to capture important details in the plumes, and it is important to understand why – hence the resort to simple trajectory approaches with the addition of observationally based physics that may not be properly captured in the models.

The dynamical process with which the models have the greatest difficulty is convection. Convection has large scale effects but involves small scale dynamics and microphysics. This makes its full inclusion in large scale transport models impossible, with resulting inaccuracies in the transport, especially to high altitudes. The typical problems that large scale models have with convection is bad placement and insufficient vertical extent. We examine the possible role of convection on two days during INTEX-B (Pacific) using a combination of kinematic trajectory modeling and two observational datasets that are markers for convection – satellite imagery and lightning observations.

The procedure is to run kinematic back trajectories using the NCEP 1 by 1 degree Global Forecast System analyses from clusters of points along the flight track. These trajectories are then run through 3-hourly global IR satellite imagery. Convective influence on a parcel is said to occur if the parcel encounters clouds that are cold enough and high enough to be considered convective (generally 218K or lower in brightness temperature). We also use a similar approach for lightning as a marker for convection. In this case, trajectories are run through hourly global 1 by 1 degree lightning flash arrays. Convective influence is said to occur if a parcel encounters a 1 by 1 degree box containing lightning flashes. Results from these approaches are compared with simple Boundary Layer Exposure over the Asian landmass, and with the aircraft-observed CO.

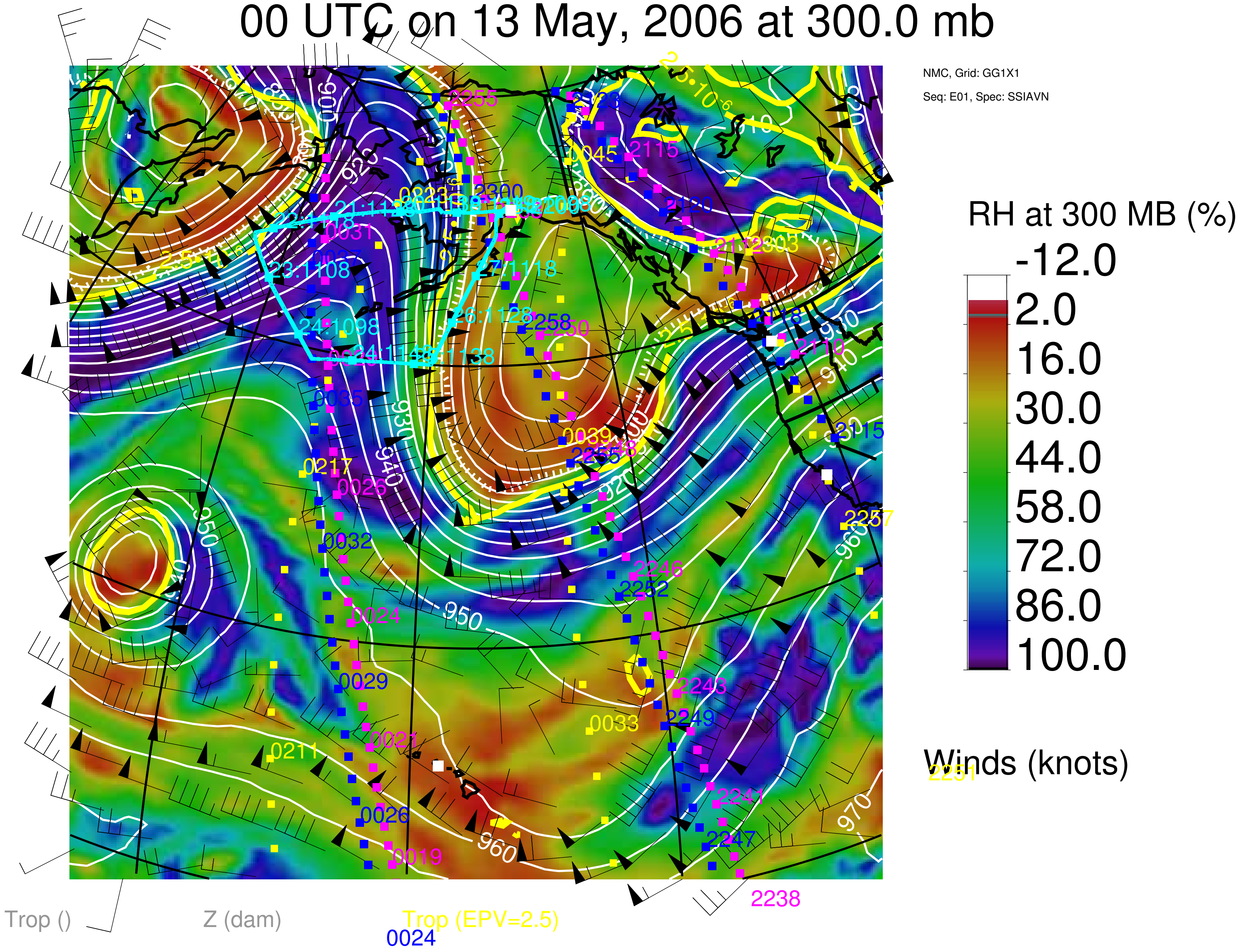
Flight of 5/12/06

The flight of 5/12/06 out of Anchorage (Figure 1) went westward into a highly perturbed midlatitude jet stream. The aircraft made four high altitude passes above 8 km (Figure 2), with the second part of the third pass at the western end of the flight track in the stratosphere. The first high altitude pass has low CO, while the first portions of the second, third, and fourth passes are quite polluted. FLEXPART (not shown) gets the high levels of CO in the 2nd and third passes, but misses the high CO in the fourth pass. Curiously, FLEXPART puts enhanced CO into the stratosphere. The boundary layer exposure product (Figure 2) actually captures the data better (qualitatively) by not putting enhanced CO into the stratosphere and by capturing the enhanced CO on the fourth pass.

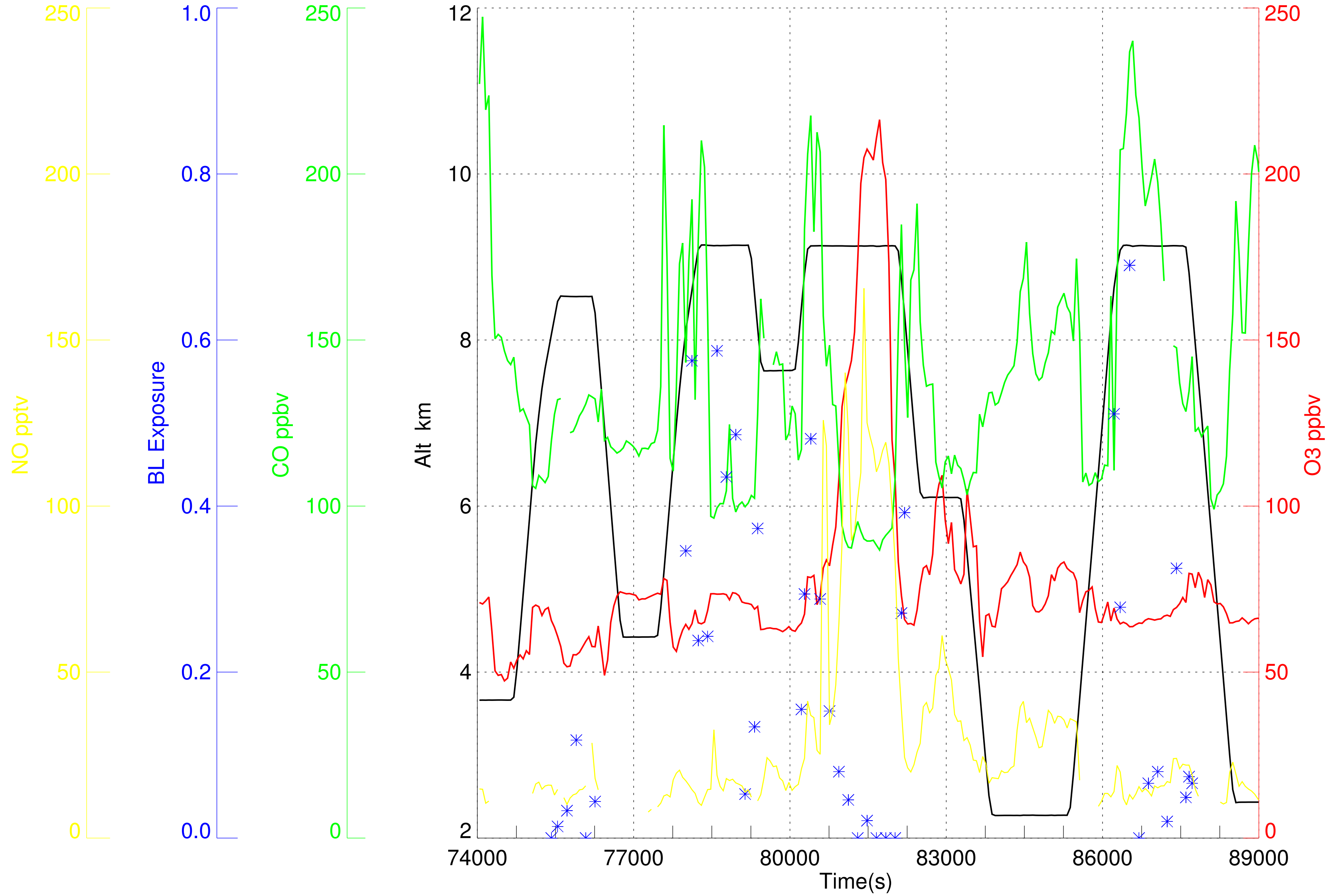
Figures 3, 4, and 5 depict the results of the convective influence analysis graphically for the four passes. For the first pass (Figure 3, northeastern cluster of points along the flight track), convective influence is oceanic, from north and east of Japan, and reflects air ascending via a "warm conveyor belt" system. (note altitude changes along the trajectory). This is consistent with the clean observations. The second high altitude pass (also Figure 3, southwestern cluster of points along the flight track), has two apparent cloud sources. Earlier in the pass, the air appears to come from a region of lightning-free thick clouds in northern China near Beijing (Figure 6), a bit less than 2 days before observation time. Later in the pass, the air comes from a clearly convective storm (with significant lightning) further south, about 4 days before observation time (Figure 7). This air is almost the cleanest of the flight (excepting the stratospheric air). A possibility is that a clean layer has been brought down to the 3 km level from the midtroposphere by the thunderstorm (which might also explain the lack of NO from lightning).

For the earliest part of the third pass (Figure 4), air comes from the same mass of clouds north of Beijing. Later in the pass, the aircraft is in the stratosphere, and the air does not encounter clouds. Figure 5 shows the last high altitude pass. The northwestern section is influenced by the same mass of clouds north of Beijing, and registers CO values of 240 ppbv. Later in the pass, the air has an oceanic source, from the warm conveyor belt system mentioned above. This air is relatively clean.

00 UTC on 13 May, 2006 at 300.0 mb

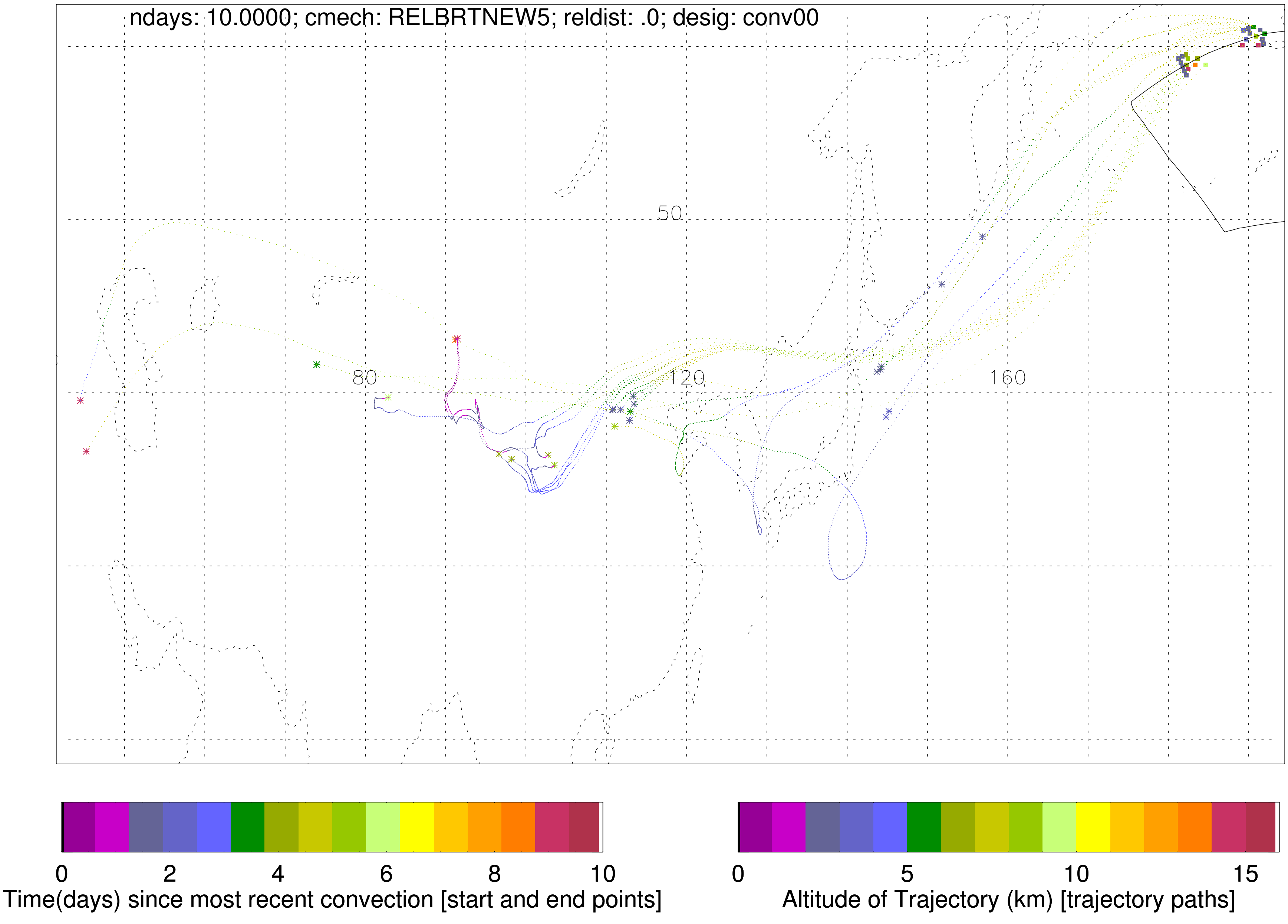


20060512 (74000 - 89000)

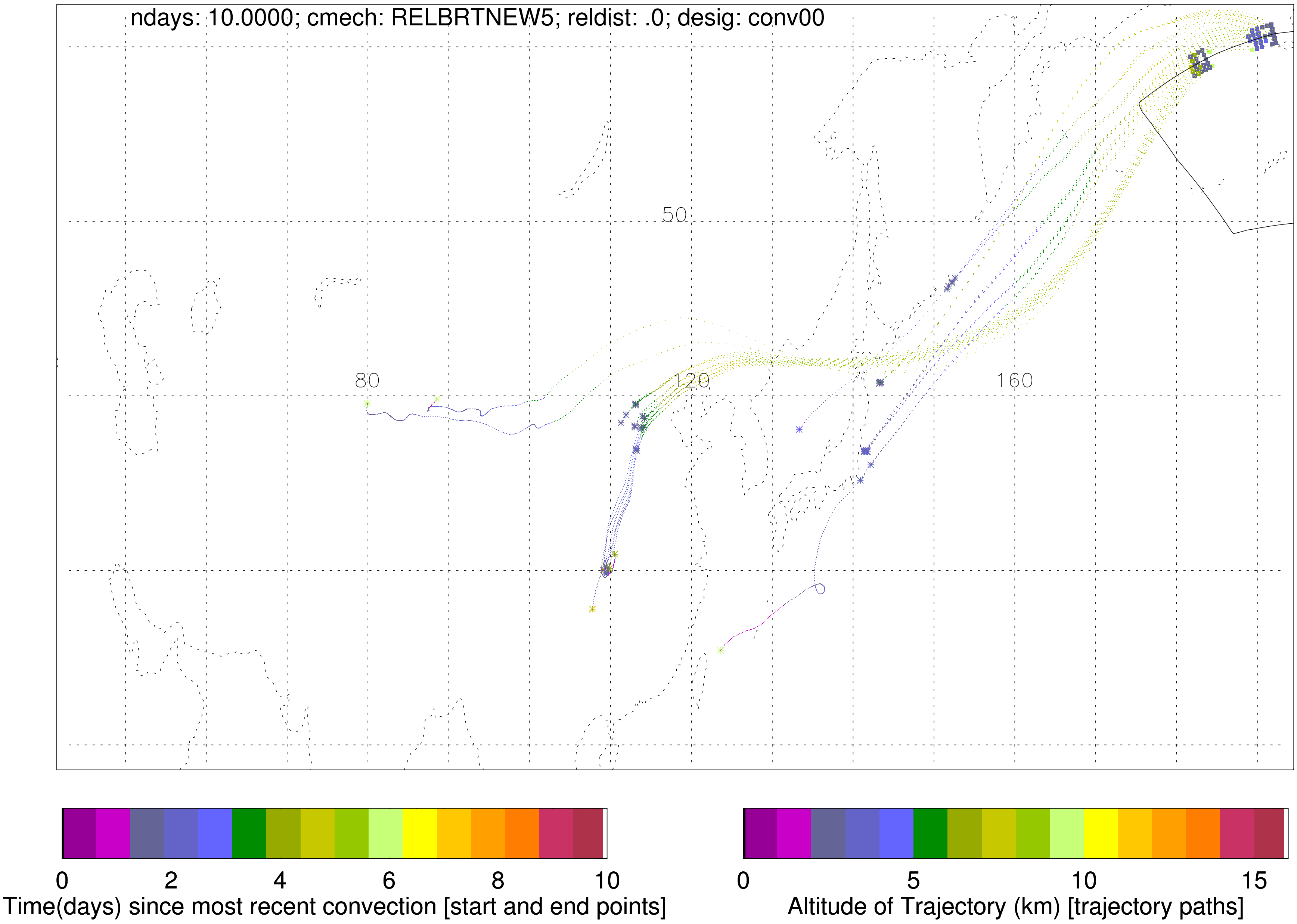


Sat Mar 3 05:36:25 UTC 2007

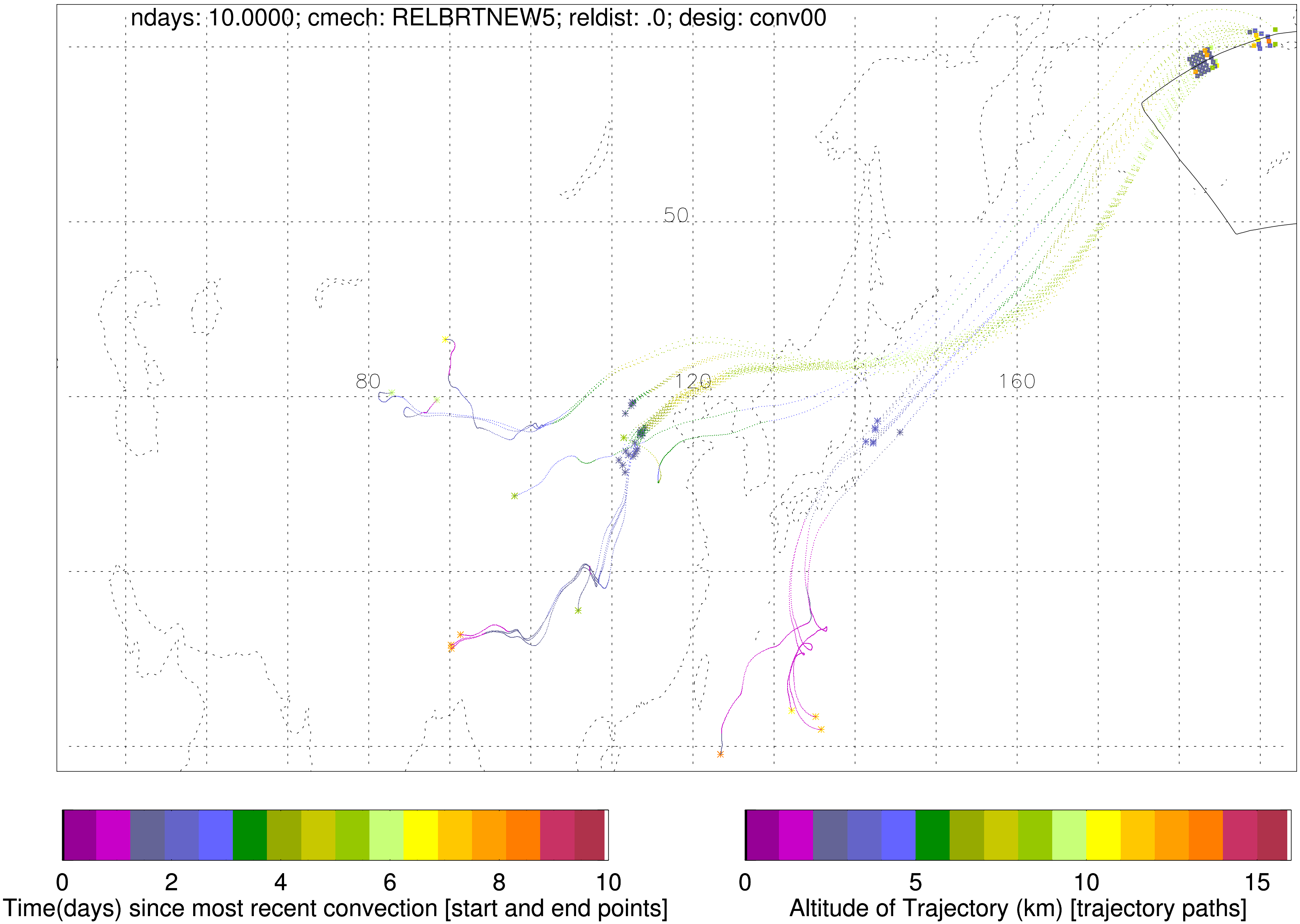
kinematic Convective influence for 060512212700 at level 1; 25 out of 65 pts influenced

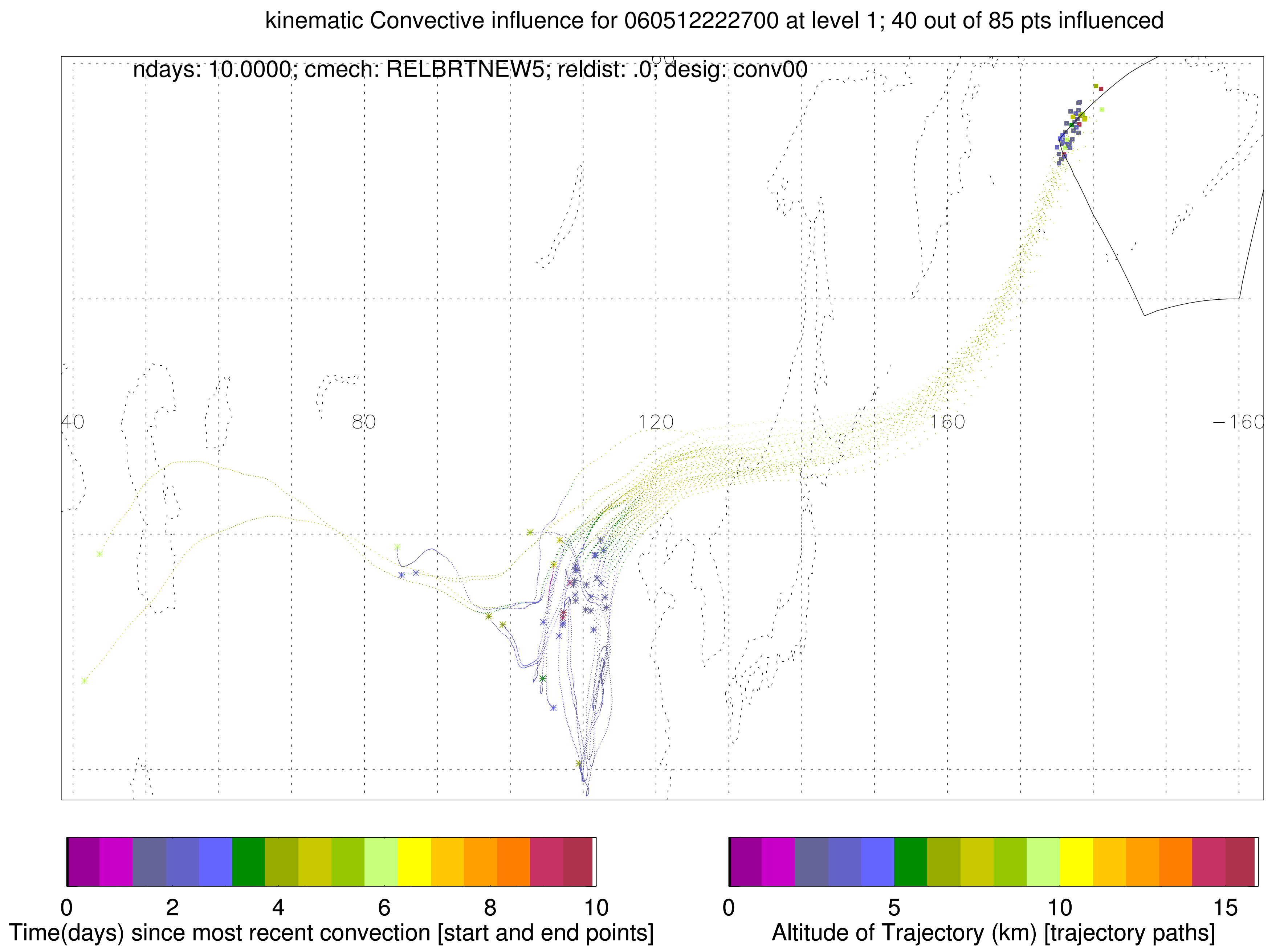


kinematic Convective influence for 060512212700 at level 2; 47 out of 65 pts influenced



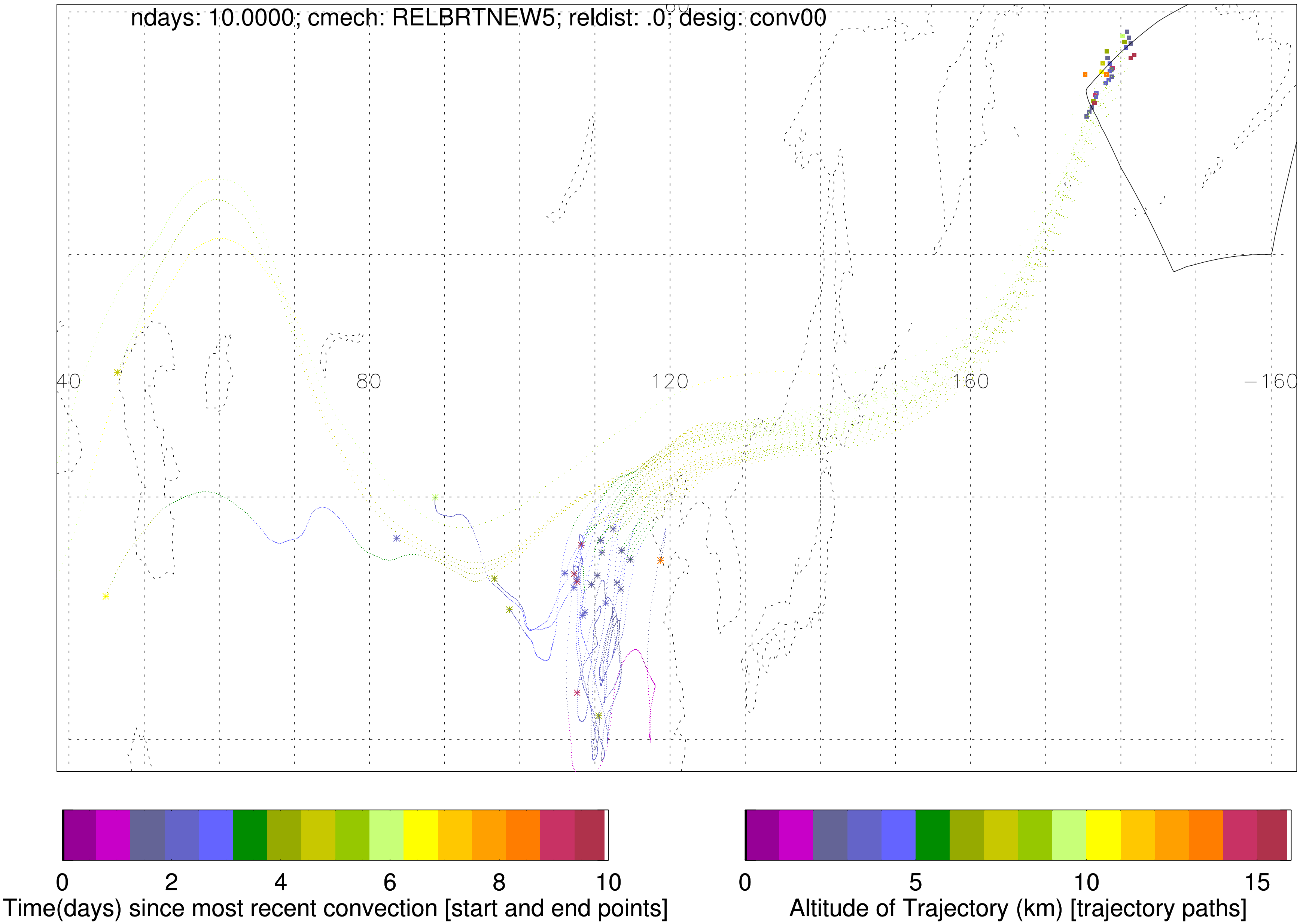
kinematic Convective influence for 060512212700 at level 3; 44 out of 65 pts influenced



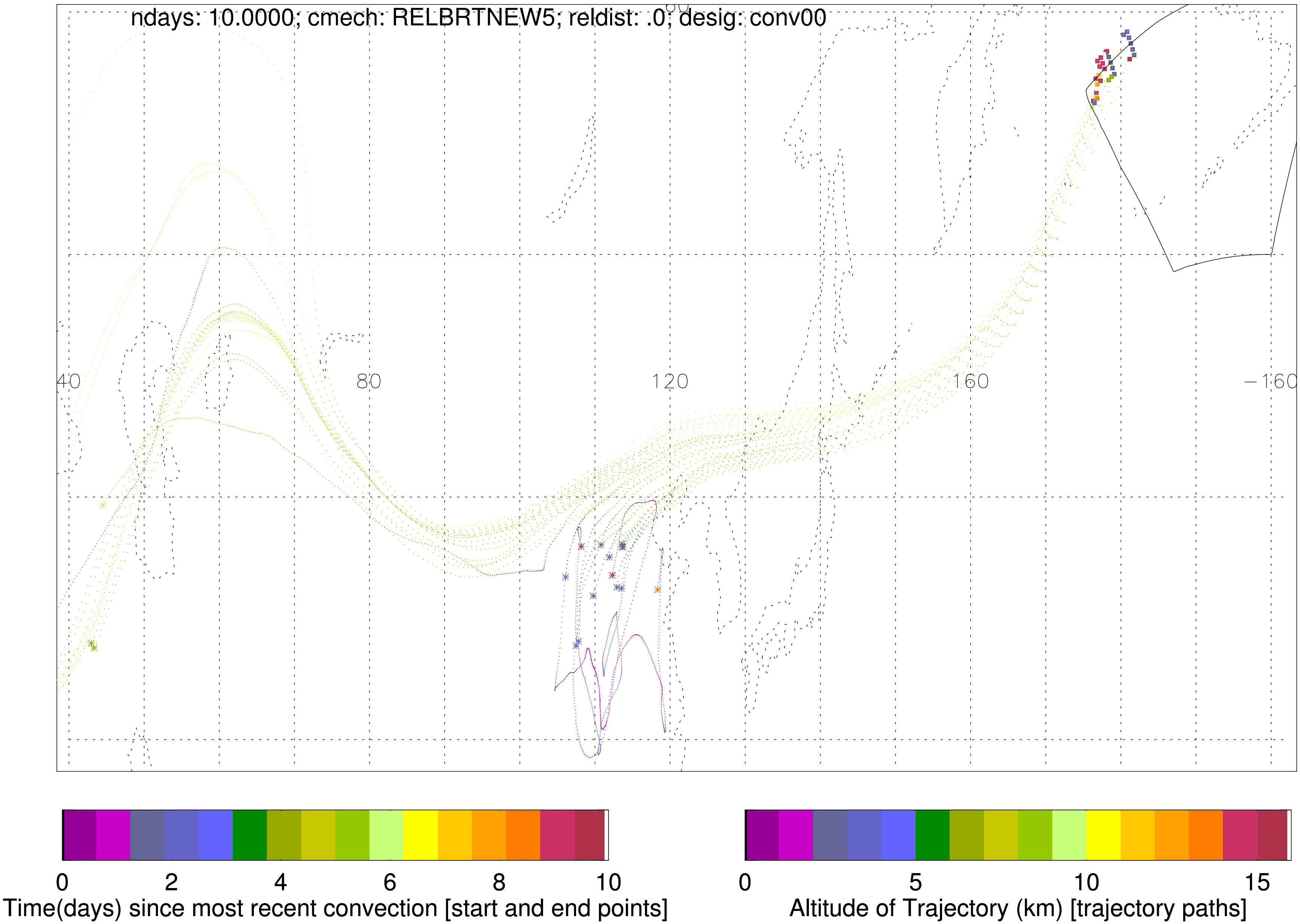


kinematic Convective influence for 060512222700 at level 1; 40 out of 85 pts influenced
ndays: 10.0000; cmech: RELBRTNEW5; reldist: .0; desig: conv00
40
80
120
160
-160
0
2
4
6
8
10
Time(days) since most recent convection [start and end points]
0
5
10
15
Altitude of Trajectory (km) [trajectory paths]

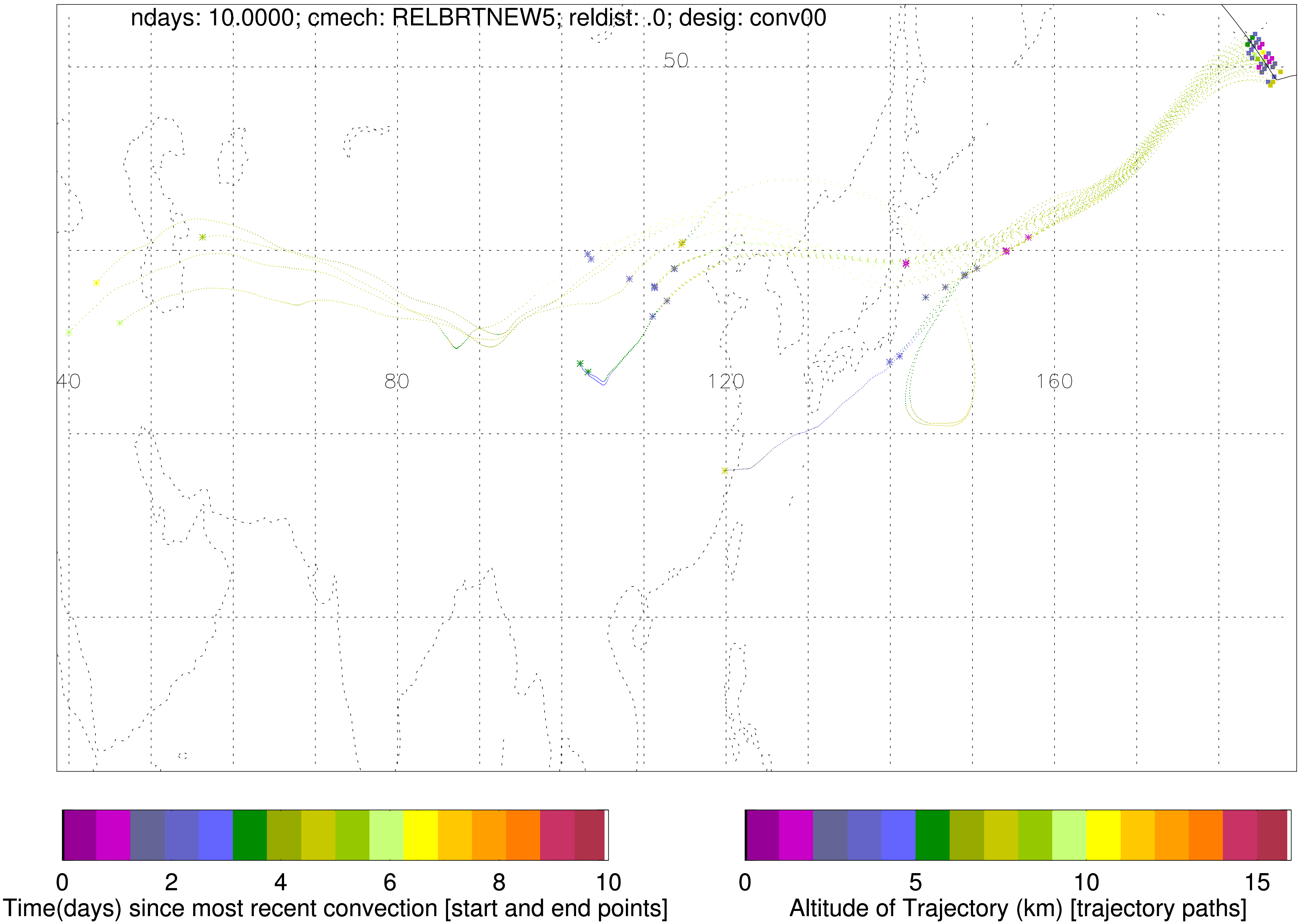
kinematic Convective influence for 060512222700 at level 2; 29 out of 85 pts influenced



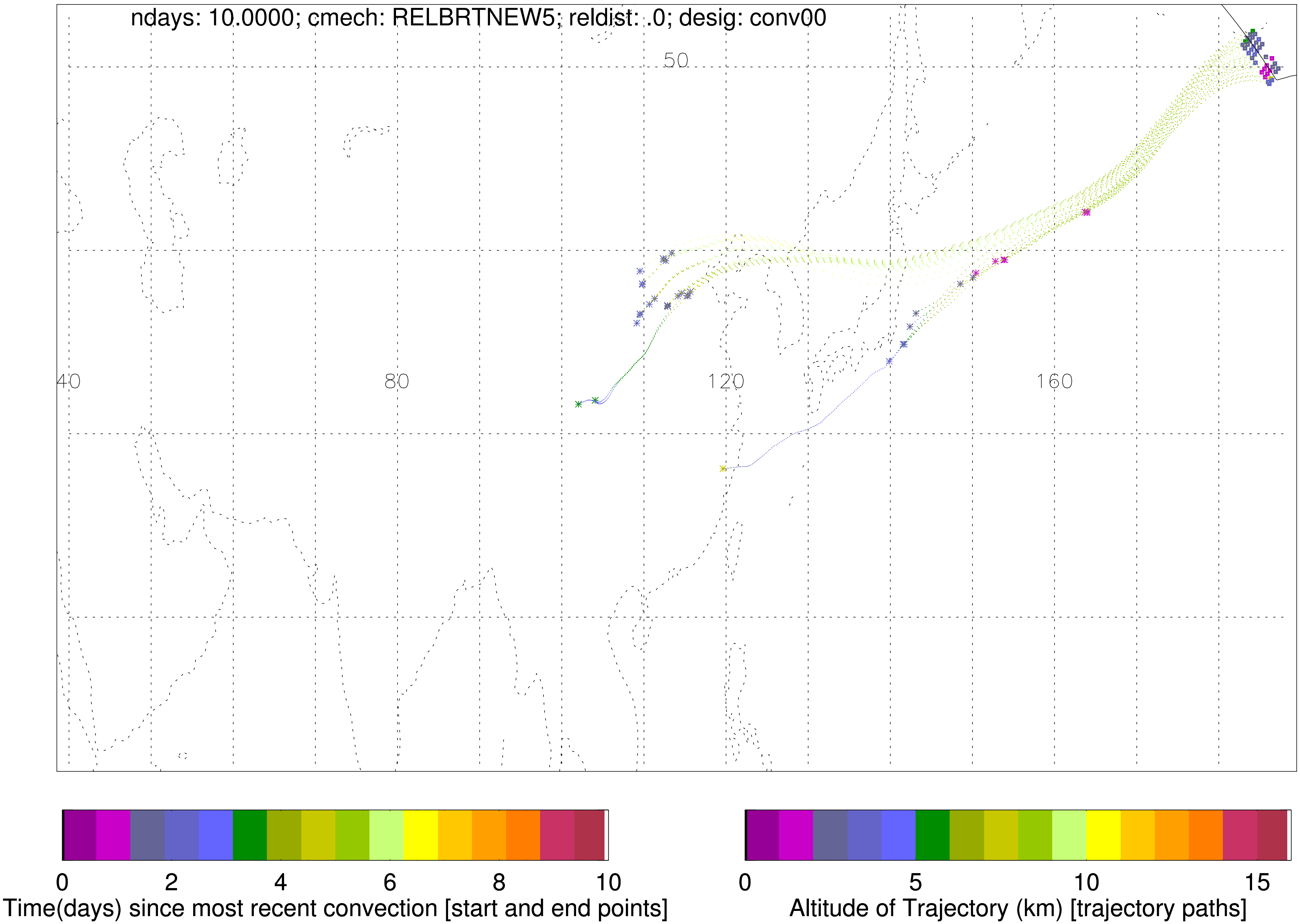
kinematic Convective influence for 060512222700 at level 3; 32 out of 85 pts influenced

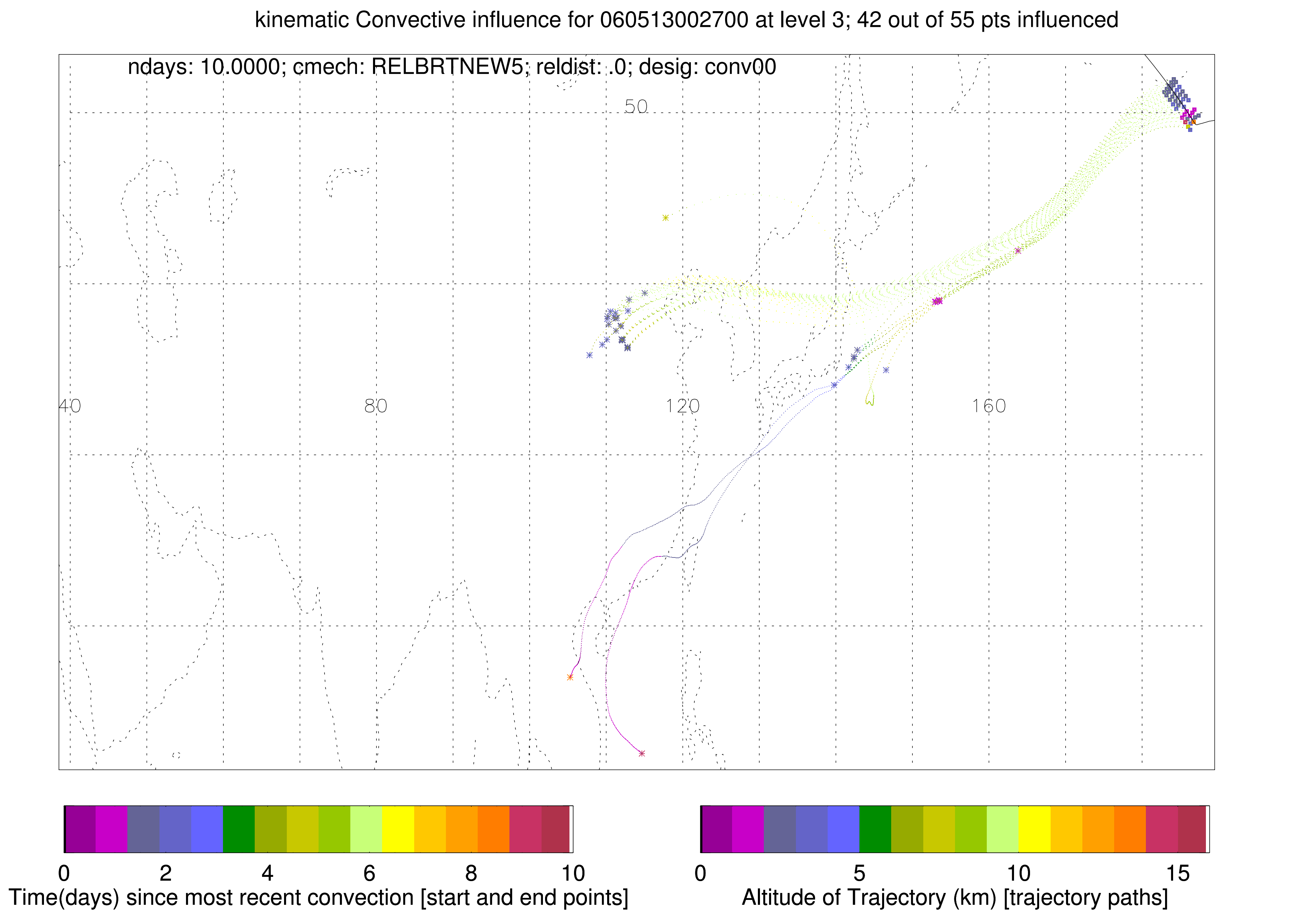


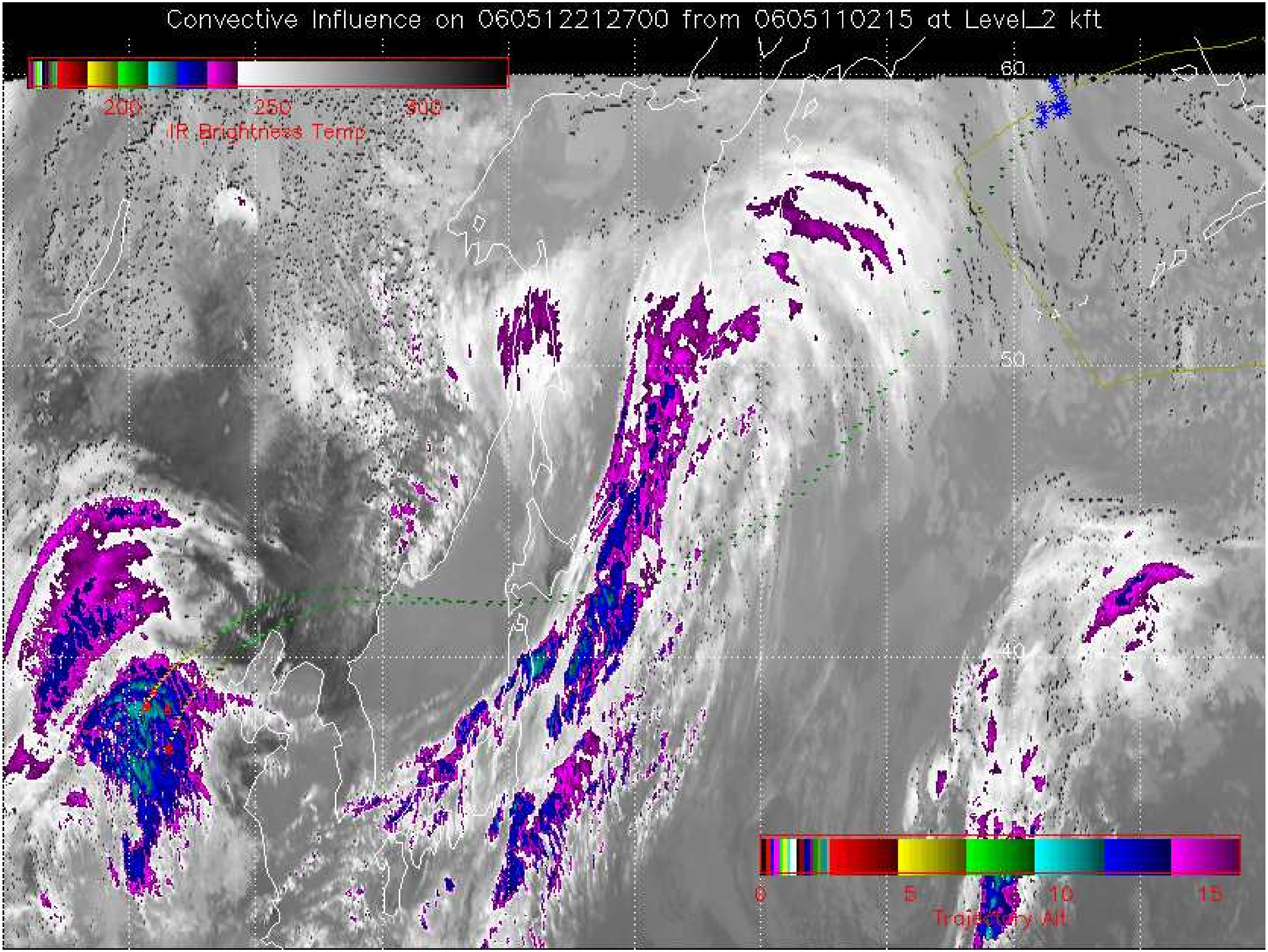
kinematic Convective influence for 060513002700 at level 1; 32 out of 55 pts influenced



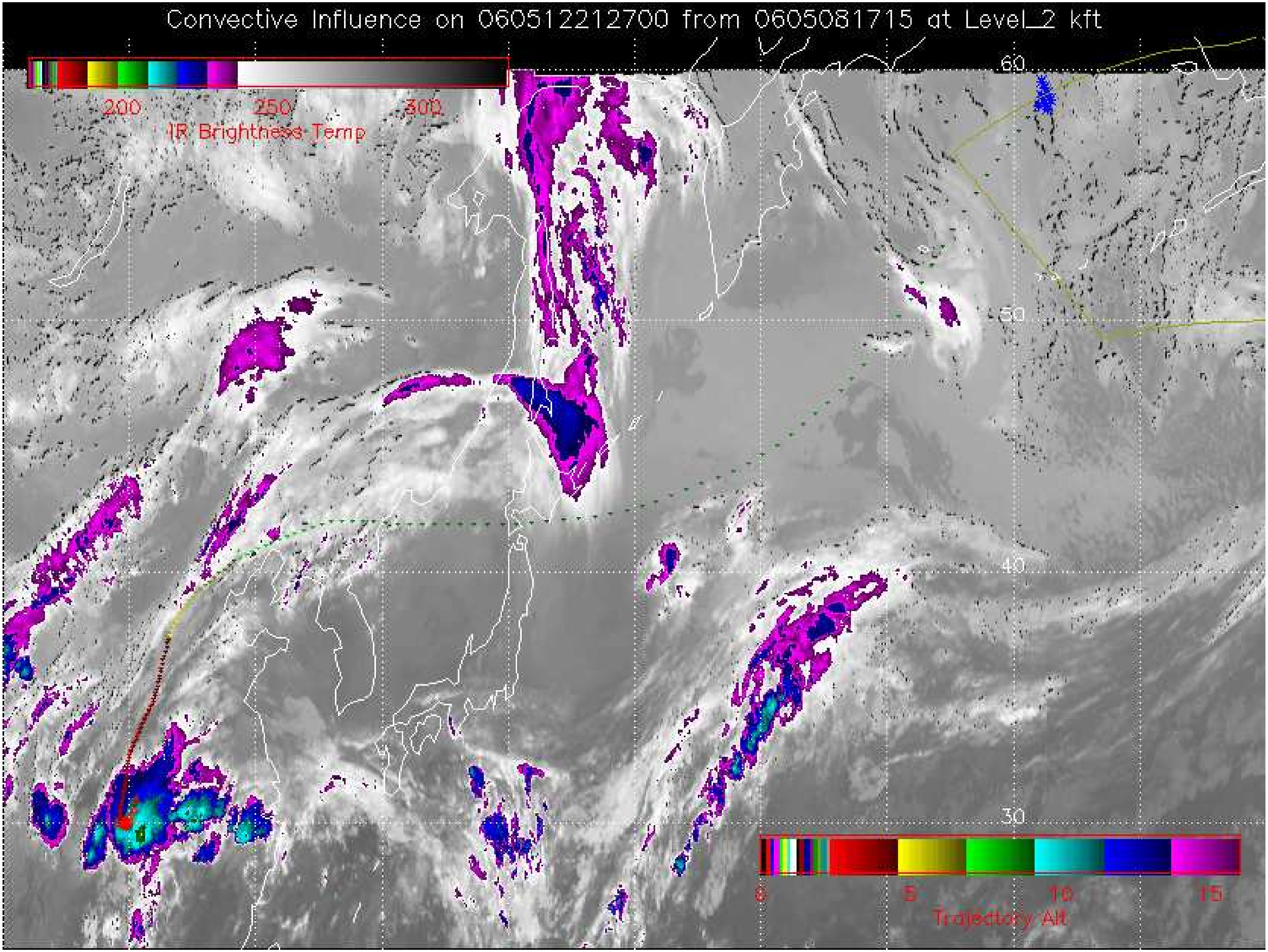
kinematic Convective influence for 060513002700 at level 2; 37 out of 55 pts influenced




kinematic Convective influence for 060513002700 at level 3; 42 out of 55 pts influenced
ndays: 10.0000; cmech: RELBRTNEW5; reldist: .0; desig: conv00
50
40
80
120
160
0
2
4
6
8
10
Time(days) since most recent convection [start and end points]
0
5
10
15
Altitude of Trajectory (km) [trajectory paths]



Convective Influence on 060512212700 from 0605110215 at Level_2 kft
200
250
300
IR Brightness Temp
60
50
40
0
5
10
15
Trajectory Alt



Convective Influence on 060512212700 from 0605081715 at Level_2 kft
200
250
300
IR Brightness Temp
60
50
40
30
0
5
10
15
Trajectory Alt

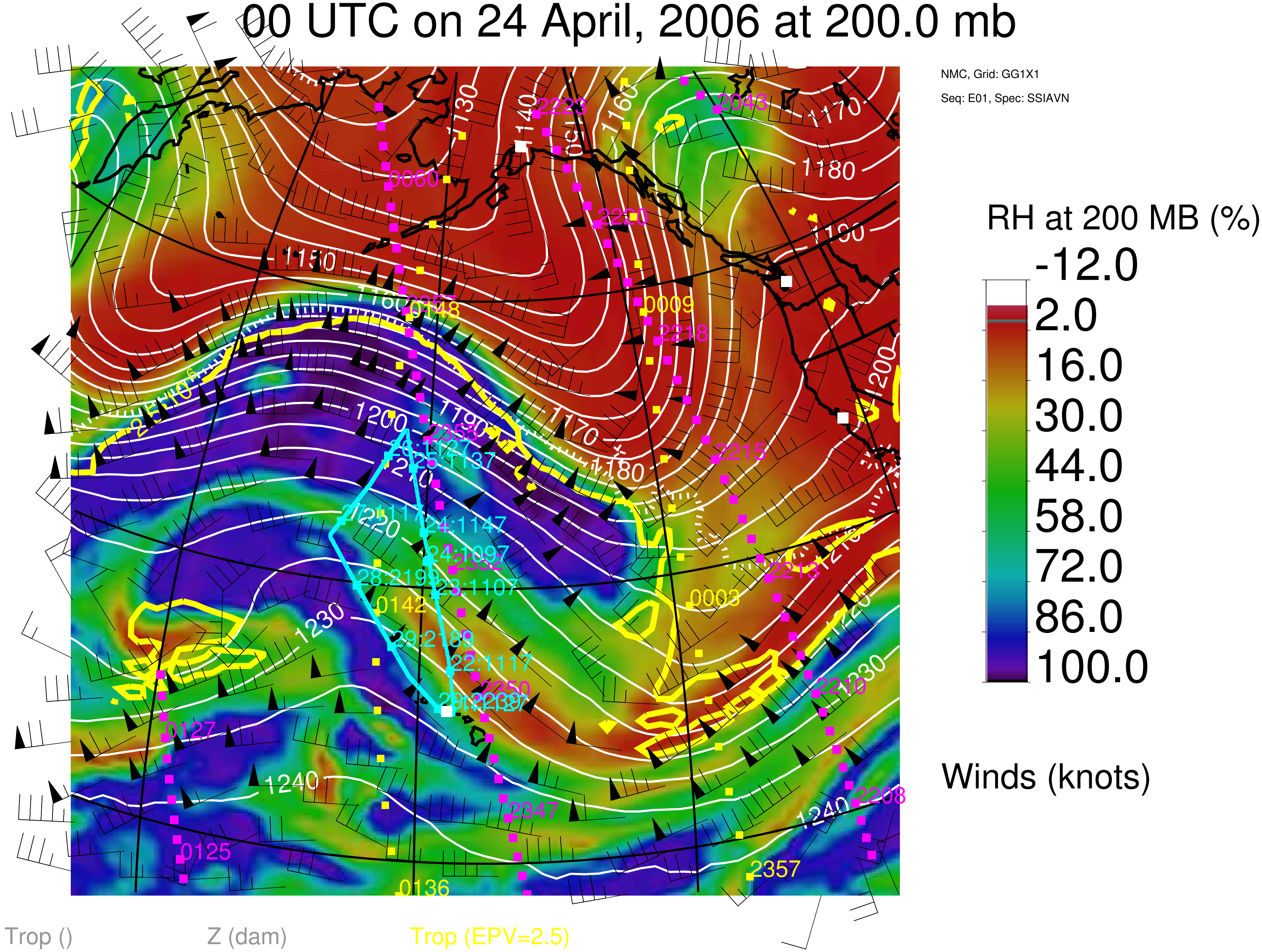
Flight of 4/23/06

The flight of 4/23/06 out of Hawaii (Figure 1) penetrated the midlatitude jet stream at its north end. Models forecasted Asian pollution in that region, which was indeed observed in the data (Figure 2), which shows the two penetrations to high altitude at the north end of the flight track.

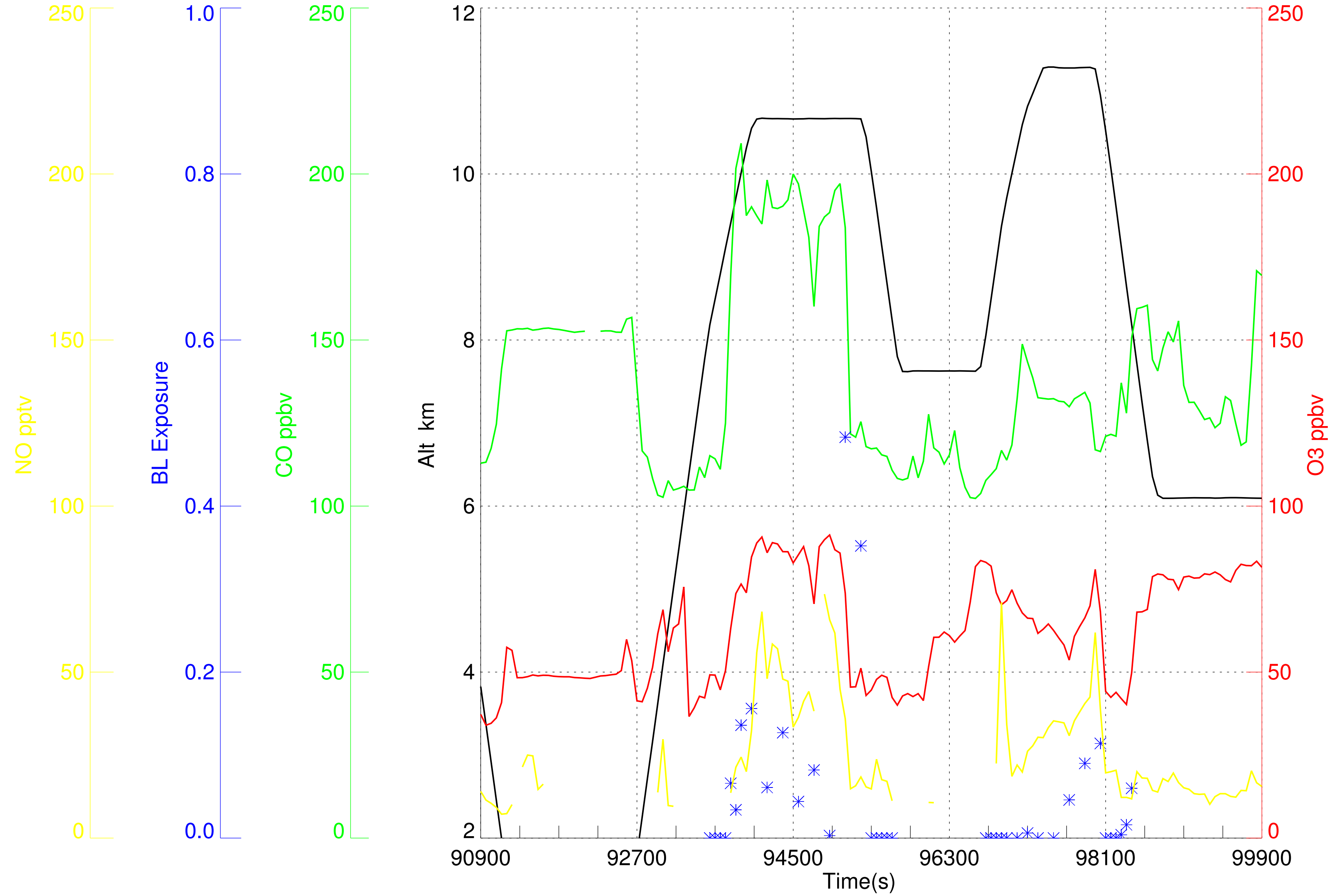
For this case, the simple Asian boundary layer exposure analysis gives good qualitative agreement with the CO enhancements from a background of about 110ppbv at this altitude (Figure 2). This suggests that the vertical motion processes realized by the GFS model are, in fact, sufficient to explain the CO observations, at least qualitatively. Looking at the actual trajectories (Figure 3) from the first and the second pass, we can see that: (1) the northern (early) part of the first high altitude pass has parcels heading to Asia and then downward; (2) the later parts descend in mid ocean and head eastward; and (3) parcels from the second high altitude pass head westward, but do not descend.

However, the convective influence and lightning trajectory maps (Figure 4) look quite different. In both cases, almost all the parcels depicted in Figure 3 encounter convection and lightning near 30N and 160E in mid-ocean about 1-2 days before the time of observation. The flash rates are significant (Figure 5). The satellite imagery indicates substantial convection (Figure 6). This is not just thick cirrus, this is deep bubbling convection. Although it seems mechanically possible to get polluted low level air to this convective region (Figure 7) and then loft it, Figures 6 and 7 indicate a strong front with descending dry air west of warm ascending air. It is hard to see how the pollutants in the dry air would be lofted upward even if they were near the convection. It is also puzzling that NO (though larger than in the May flight) is so minimal. Perhaps this is all we expect from oceanic convection.

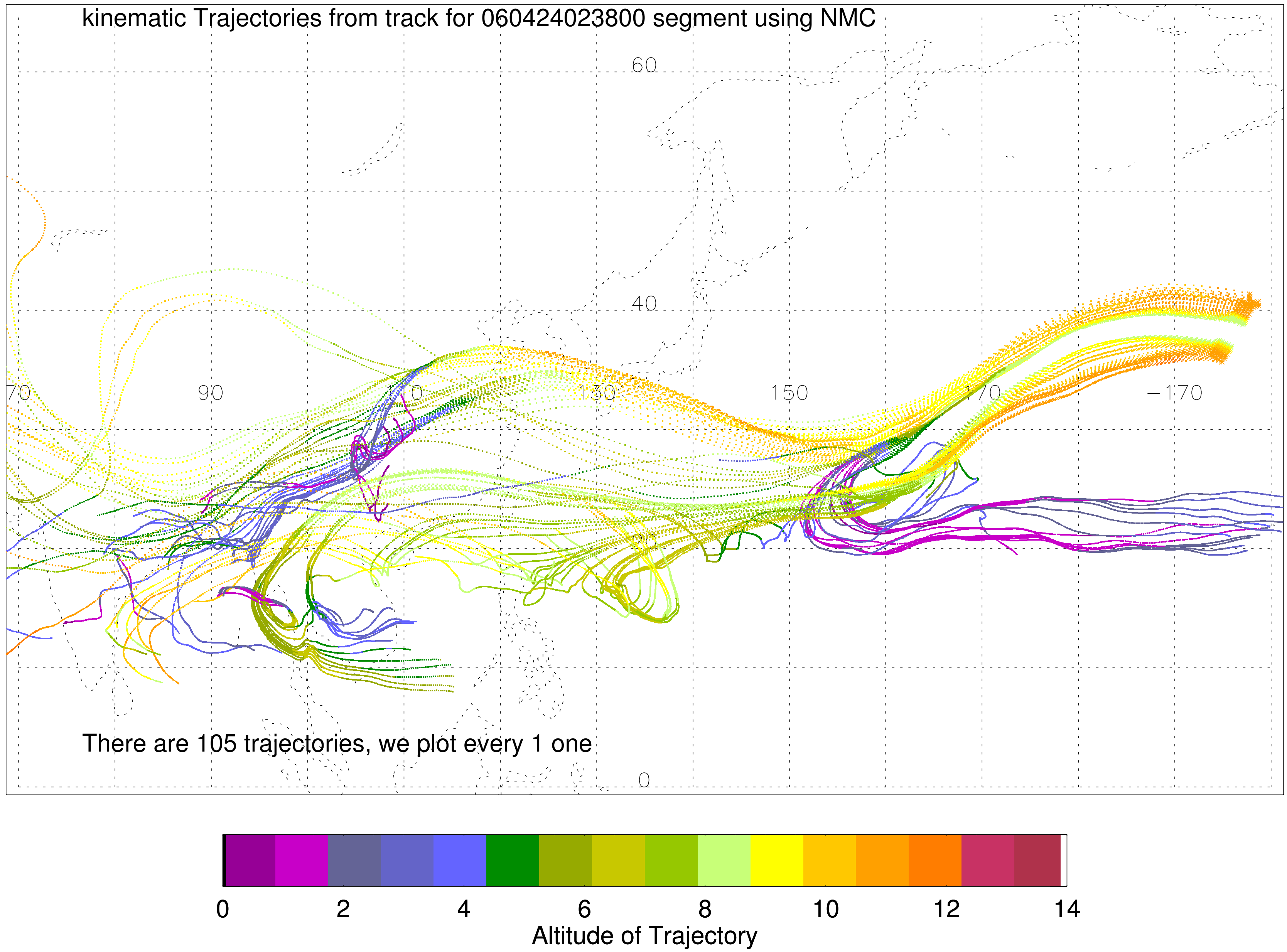
00 UTC on 24 April, 2006 at 200.0 mb



20060423 (90900 - 99900)

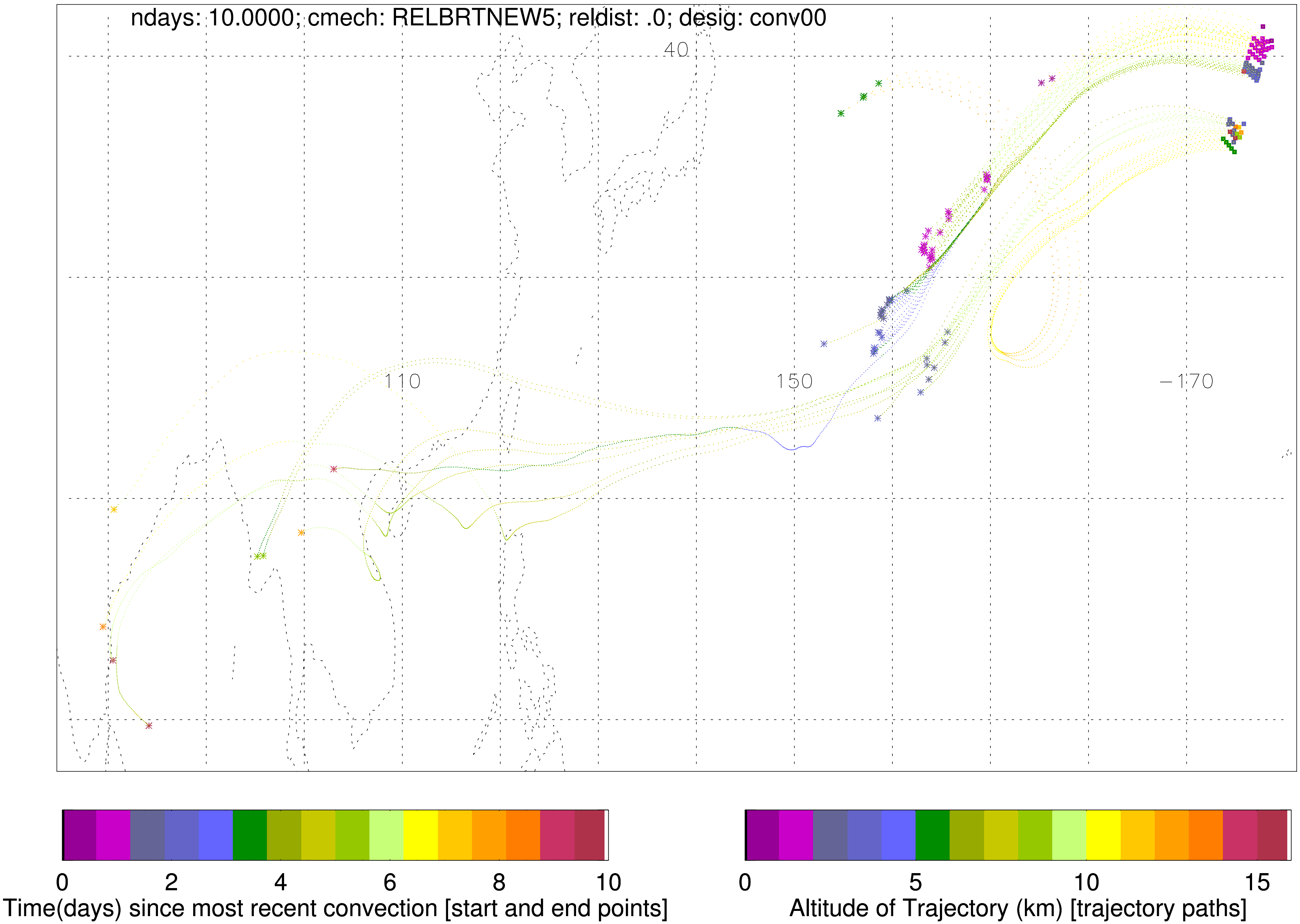


Sat Mar 3 05:30:42 UTC 2007

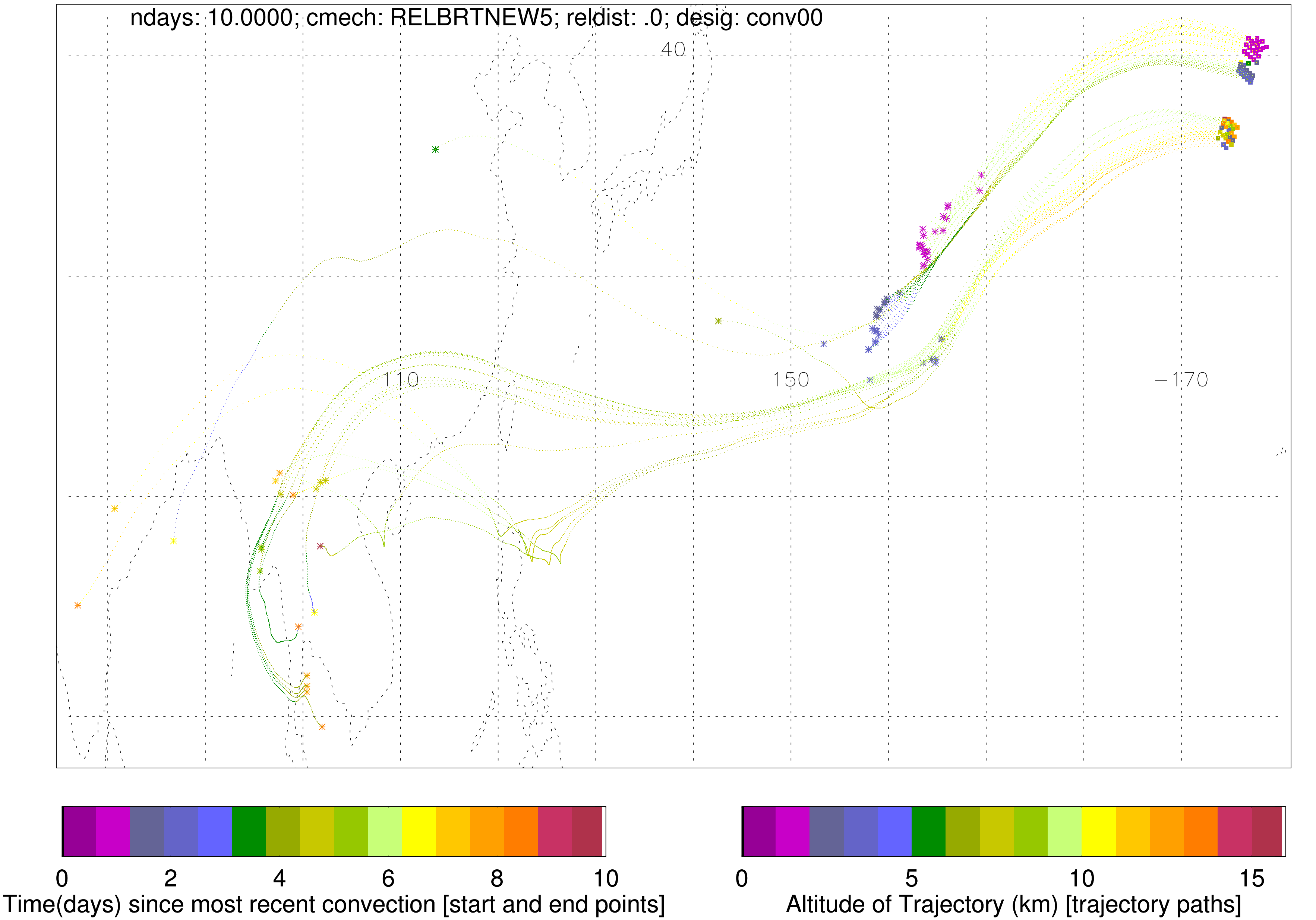


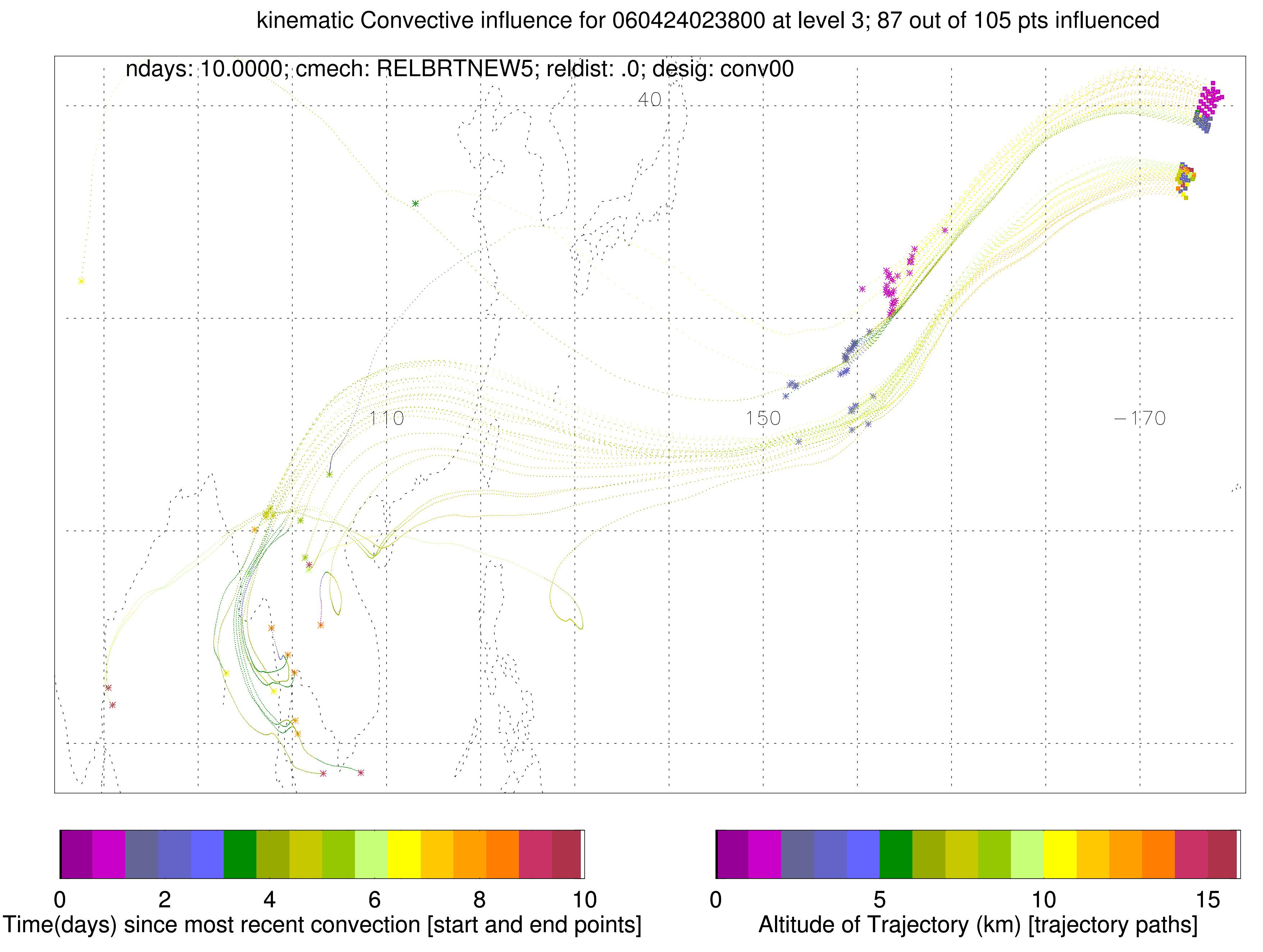
kinematic Trajectories from track for 060424023800 segment using NMC
60
40
20
0
70
90
110
130
150
170
−170
There are 105 trajectories, we plot every 1 one
0
2
4
6
8
10
12
14
Altitude of Trajectory

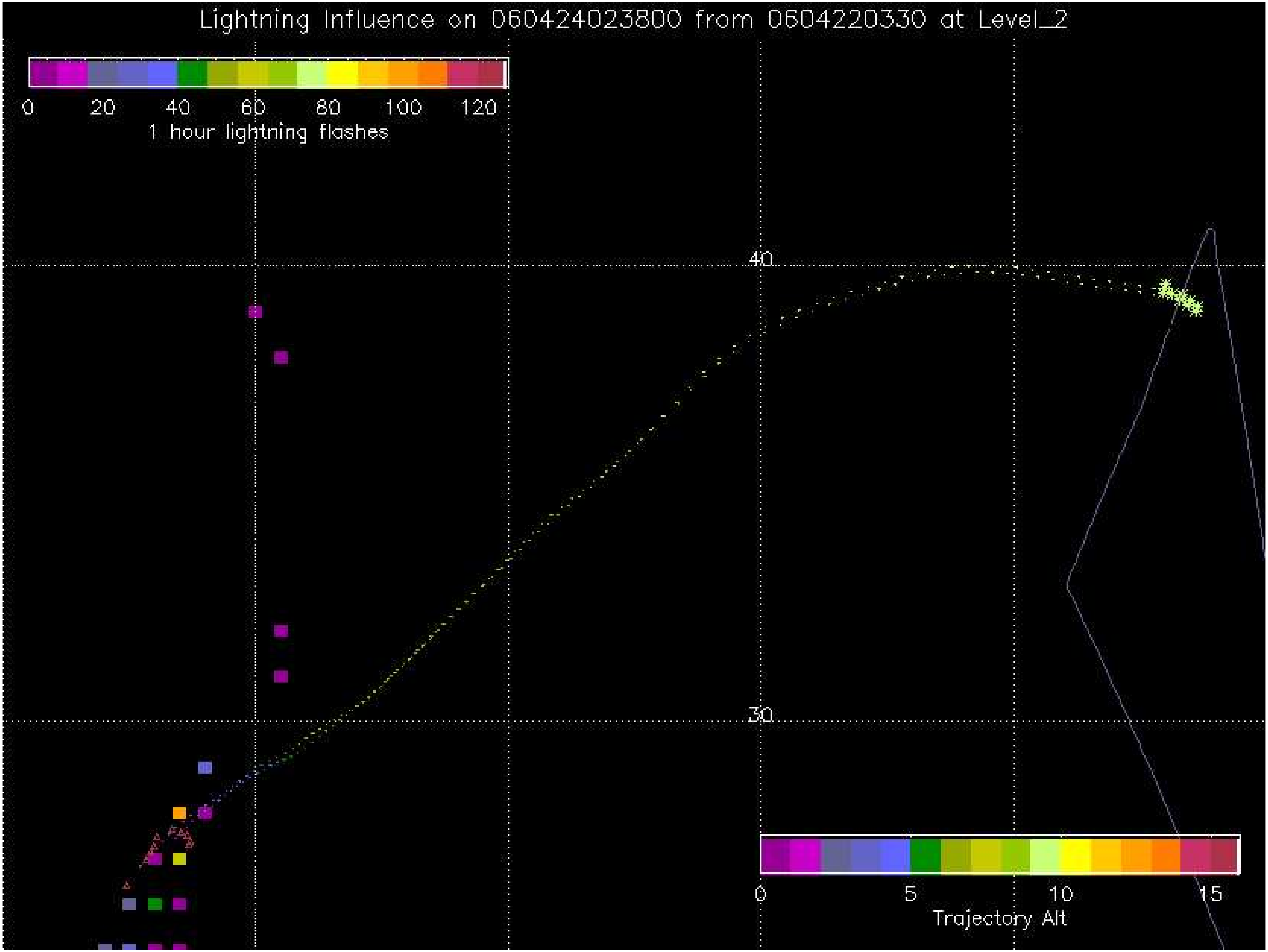
kinematic Convective influence for 060424023800 at level 1; 72 out of 105 pts influenced



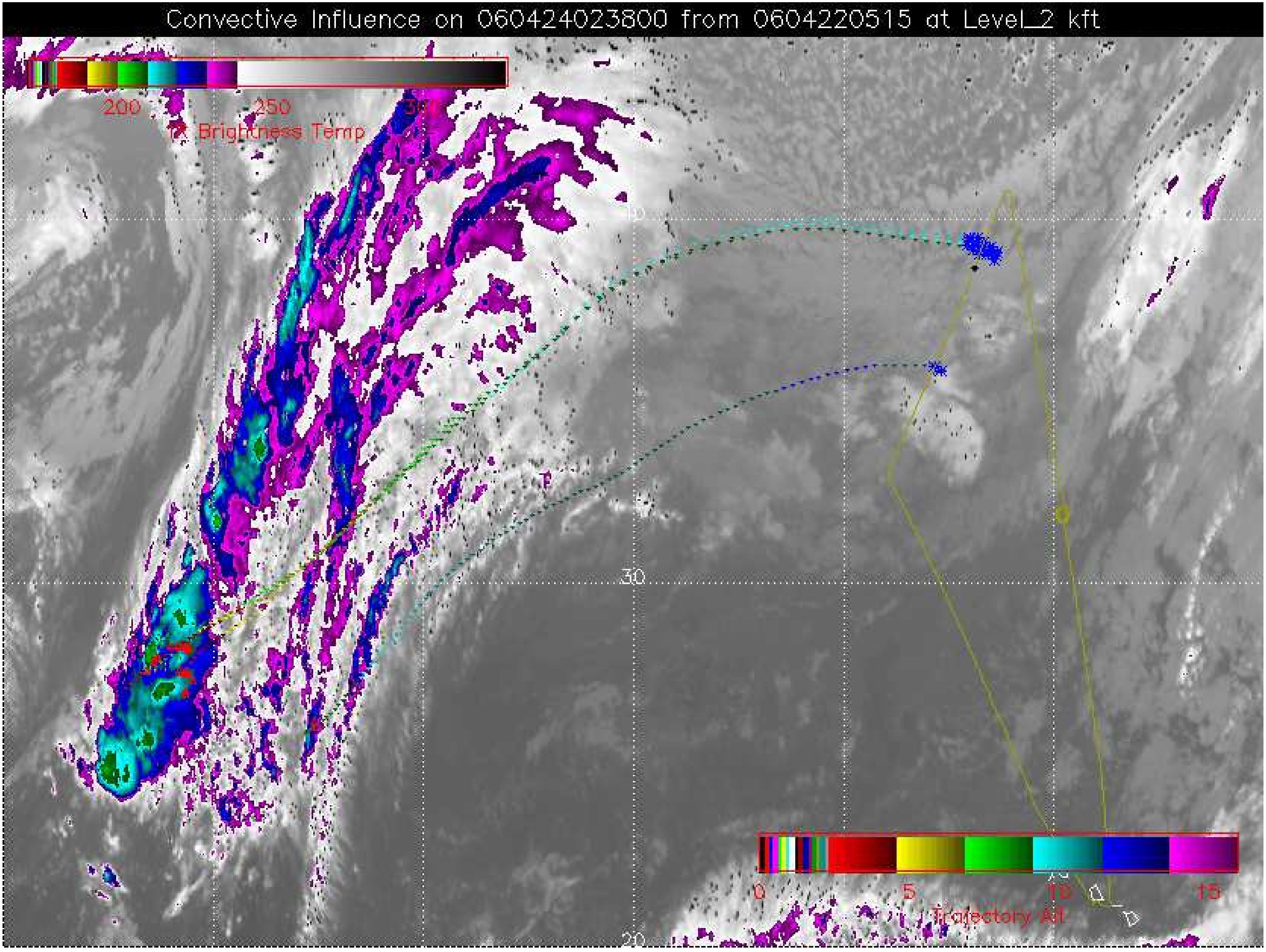
kinematic Convective influence for 060424023800 at level 2; 77 out of 105 pts influenced




kinematic Convective influence for 060424023800 at level 3; 87 out of 105 pts influenced
ndays: 10.0000; cmech: RELBRTNEW5; reldist: .0; desig: conv00
40
110
150
−170
0
2
4
6
8
10
Time(days) since most recent convection [start and end points]
0
5
10
15
Altitude of Trajectory (km) [trajectory paths]



Lightning Influence on 060424023800 from 0604220330 at Level_2
0 20 40 60 80 100 120
1 hour lightning flashes
40
30
0 5 10 15
Trajectory Alt



Convective Influence on 060424023800 from 0604220515 at Level_2 kft
200
250
300
IR Brightness Temp
10
30
20
0
5
10
15
Trajectory Alt

Summary

Two INTEX-B flights with 4 incidences of high altitude pollution were examined using simple trajectory methods coupled with two methods of observing convection, lightning and satellite imagery. Simple boundary layer exposure calculations using explicit large scale model wind fields actually give a reasonable overall explanation of the observed pollution distributions at high altitudes. However, convection is clearly present, and appears to play an important role. For one flight (20060512), two cloud systems over the Asian continent are related to observations of both clean air (for one cloud system) and polluted air (for another). For the second flight (20060423), convection is clearly present less than 2 days upstream, but the effects on the observed air mass are not obvious.