An Application of Backscatter Lidar to Model the Odour Nuisance Arising from Aircraft Tyre Smoke

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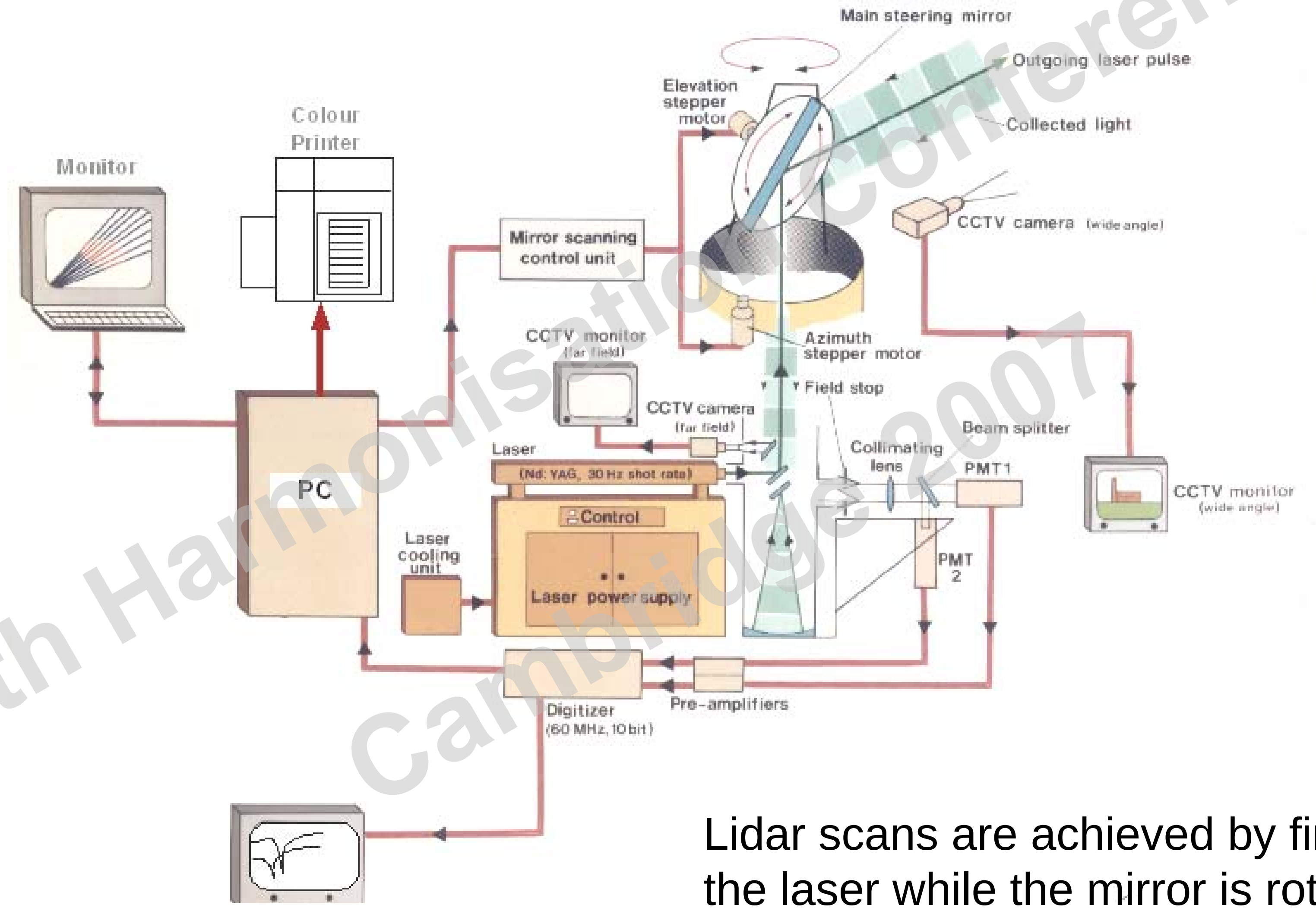
RASCAL in operation at Heathrow, May 2005

- Self contained mobile unit
- Onboard power generation for autonomous operation
- Onboard met station with 10 m extendable mast
- Beam scanning in azimuth or elevation up to 60^{o}
- Eye safe operation
- Track record of successful field study operations

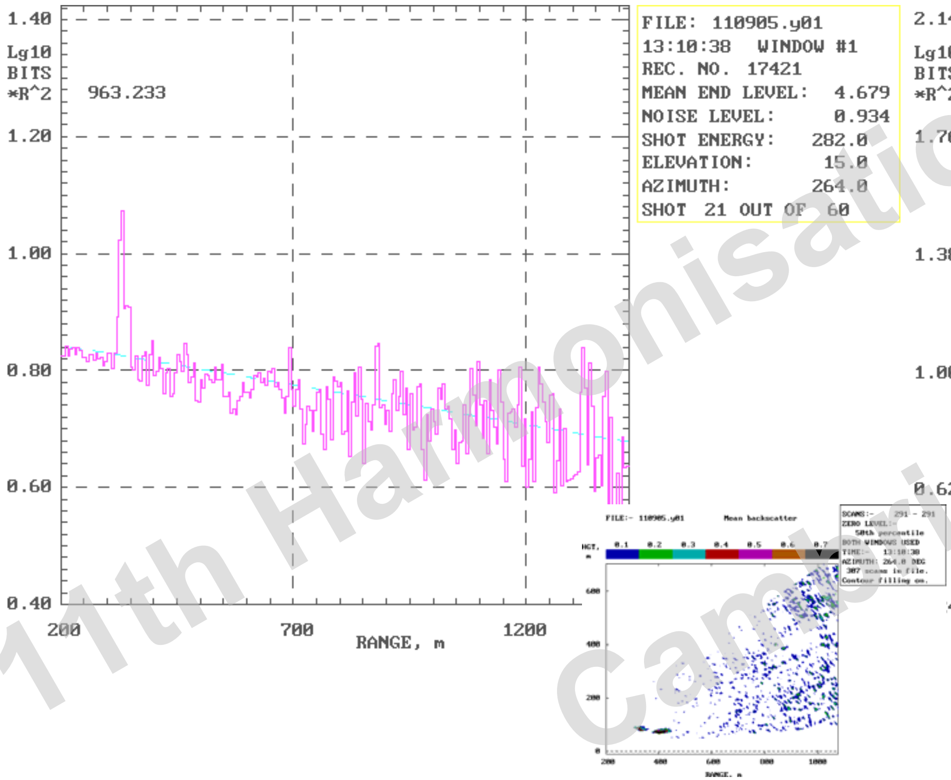
Schematic of RASCAL Optics & Data Capture Systems

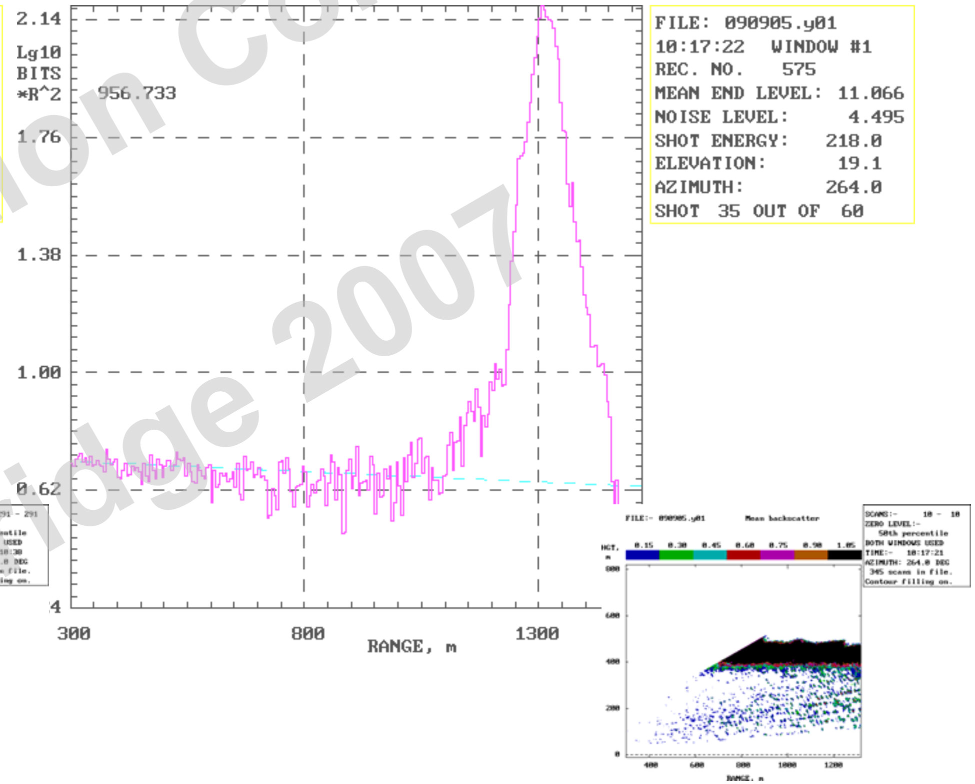


Lidar scans are achieved by firing the laser while the mirror is rotated

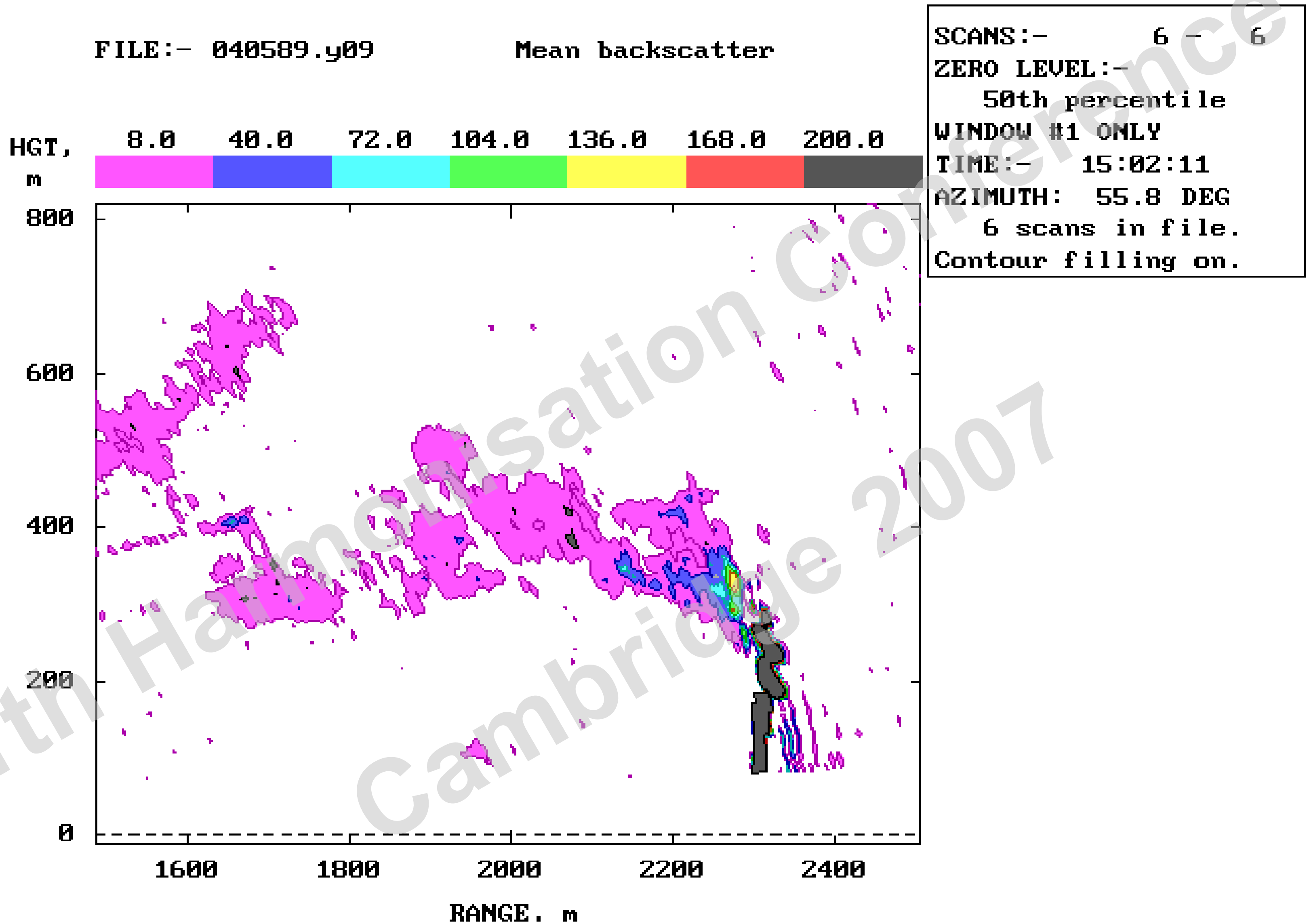
Signal processing

- Background fit compensates for:
  - –Geometric spread of beam with range
  - –Optical extinction



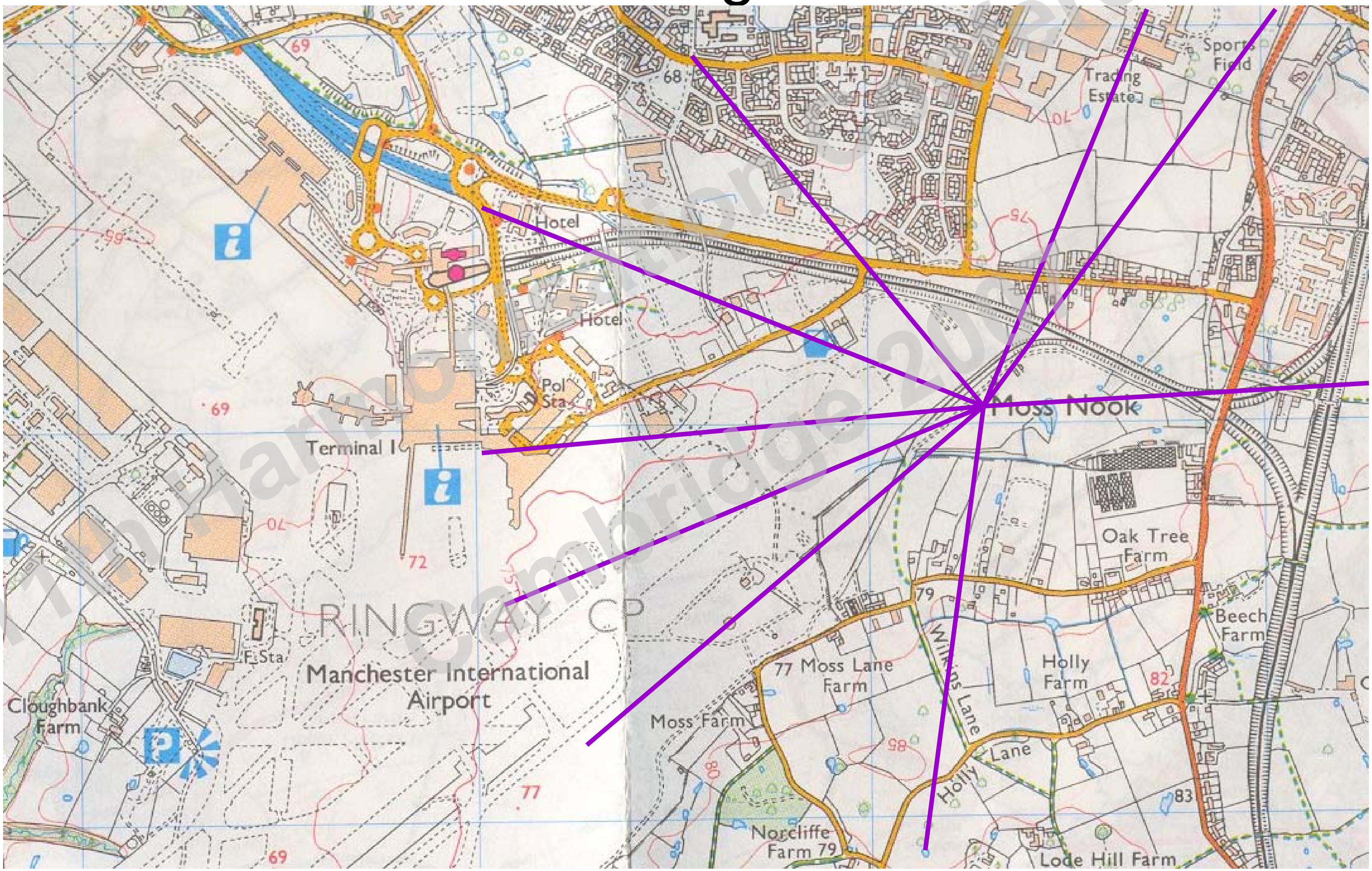


Left: return from an aircraft exhaust plume at 320 m
Right: return from a distant cloud at range >1200 m



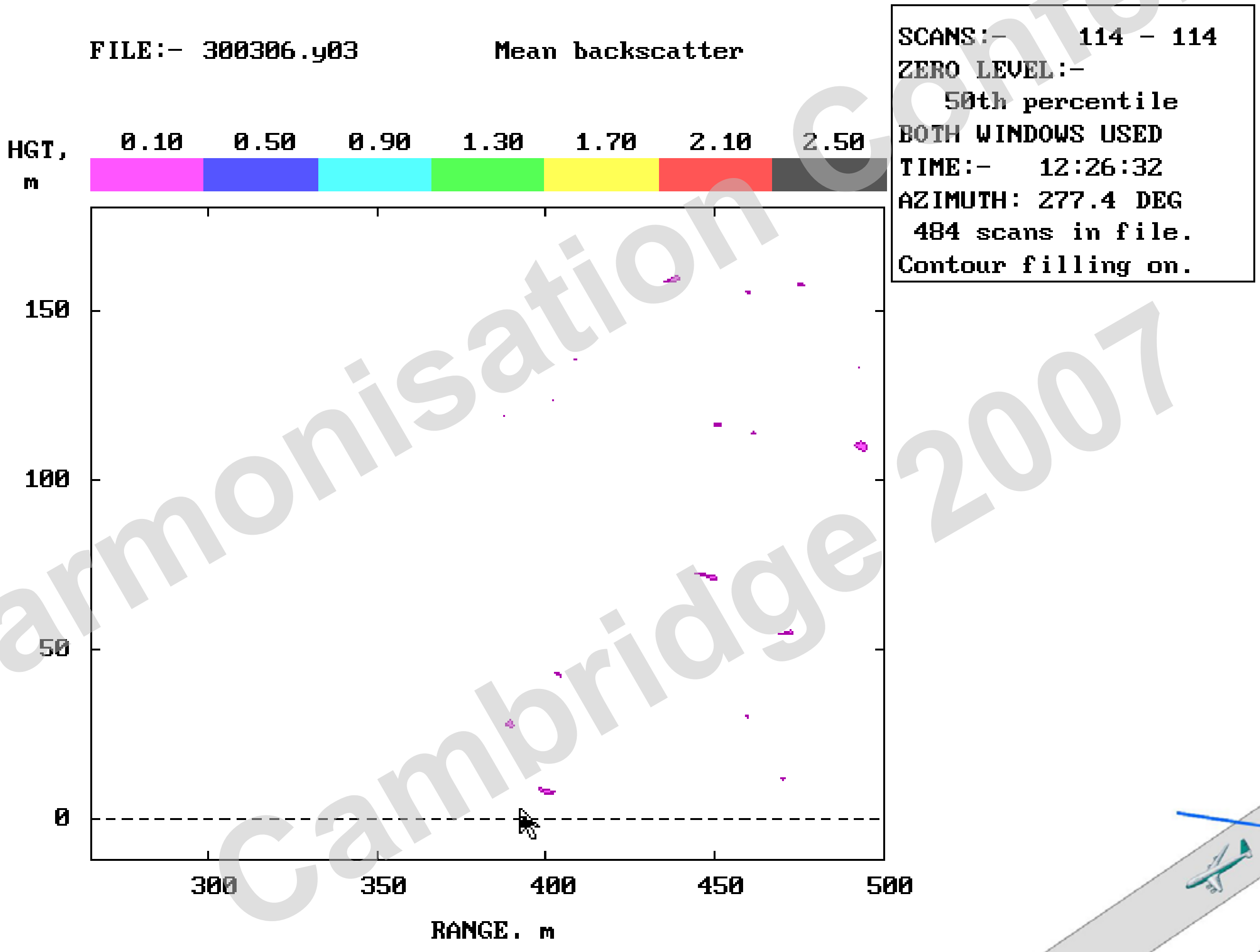
Plume from Didcot power station in convective conditions

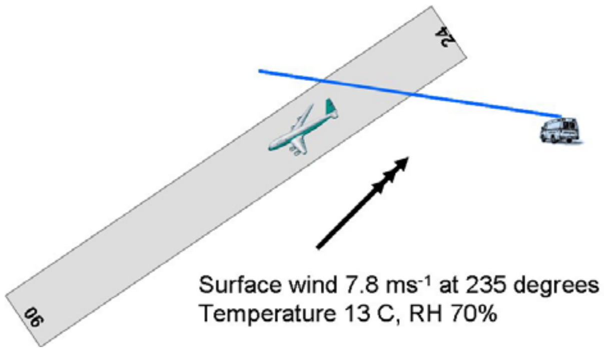
Plan of Manchester Airport with Overlay of Lidar Scanning Directions



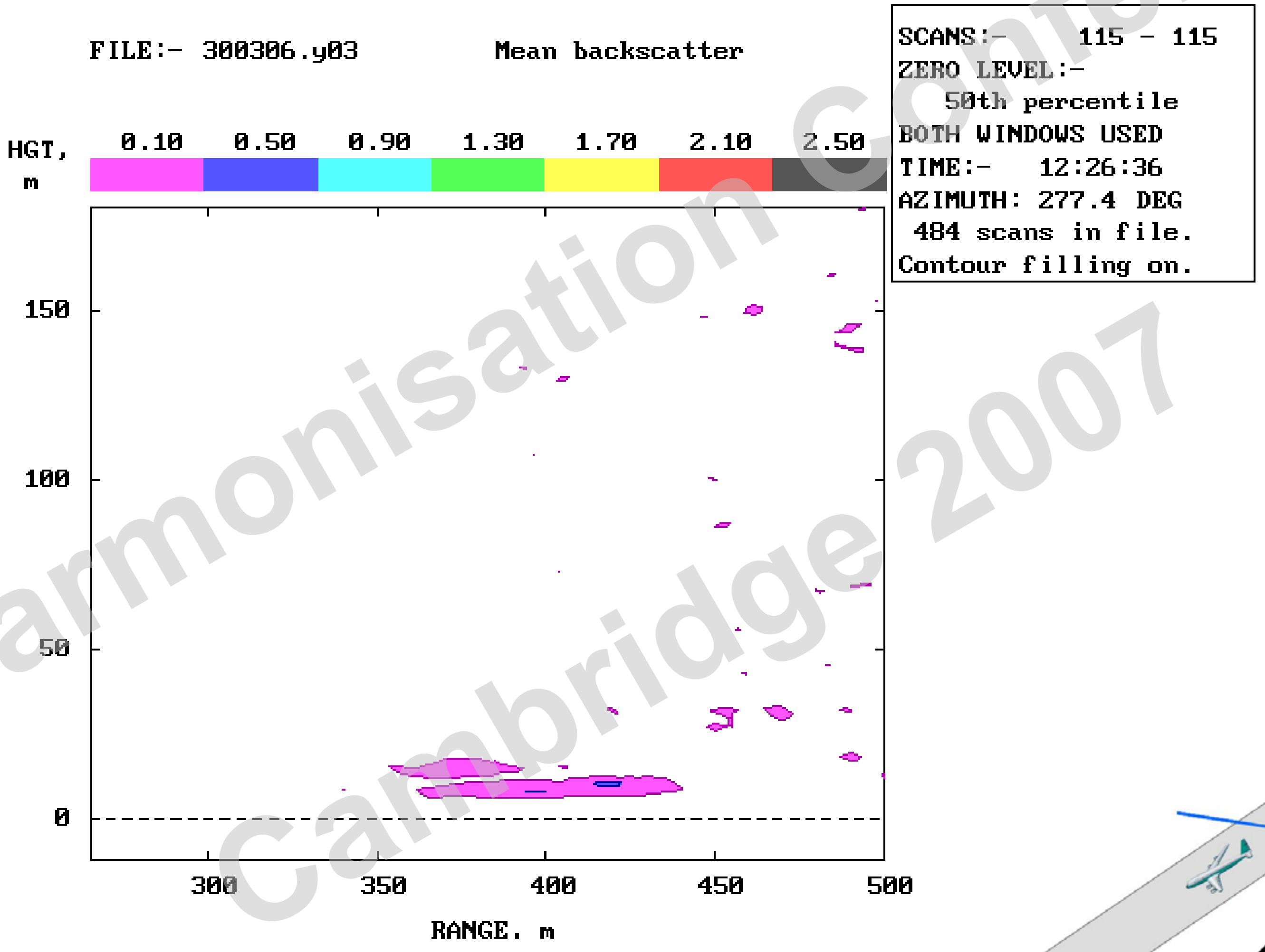
Observations of Tyre Smoke on Landing

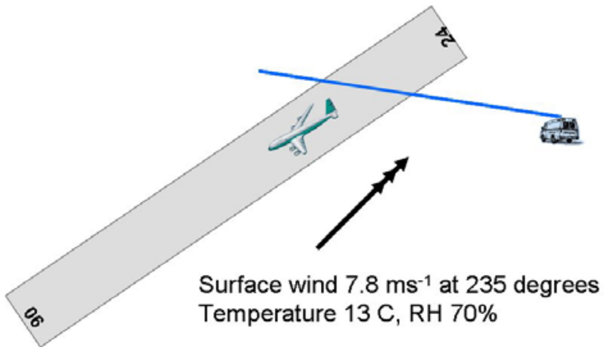
Manchester Airport, 30 March 2006



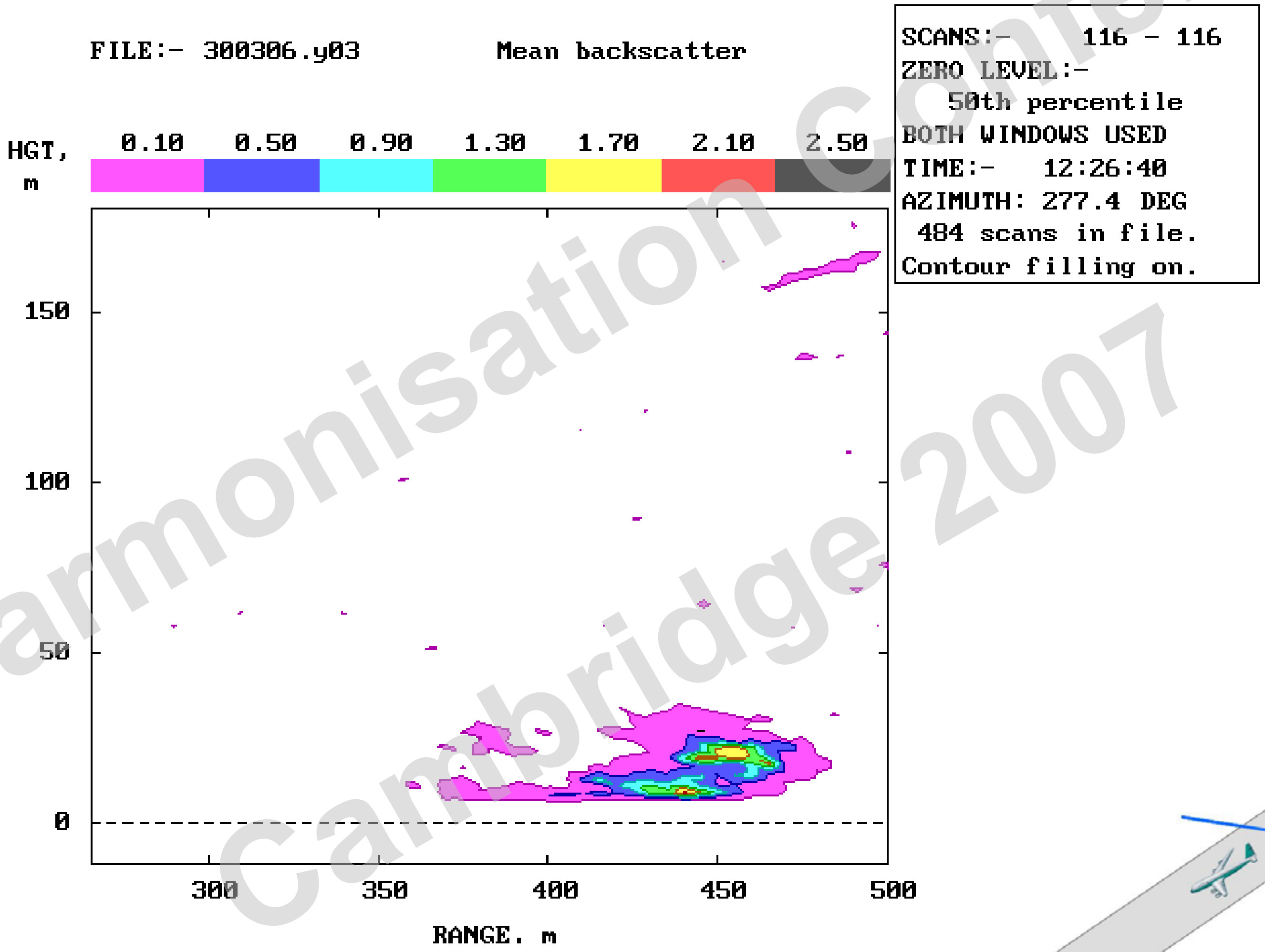


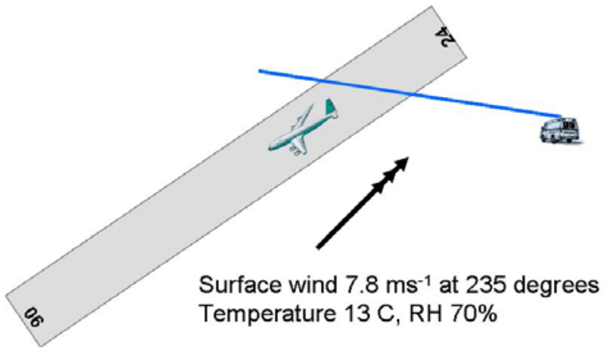
Surface wind 7.8 ms^{-1} at 235 degrees
Temperature 13 C, RH 70%





Surface wind 7.8 ms^{-1} at 235 degrees
Temperature 13 C, RH 70%





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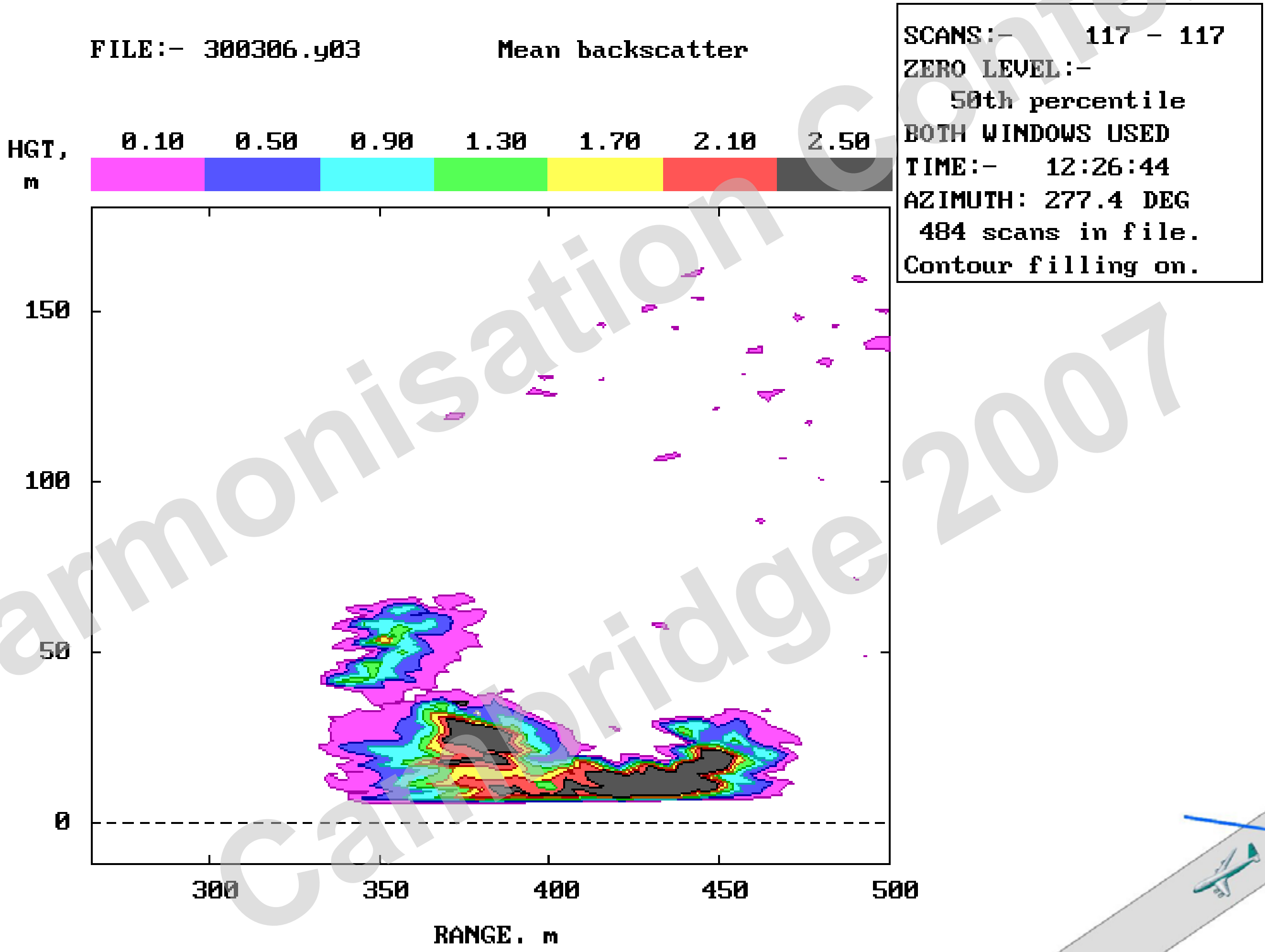
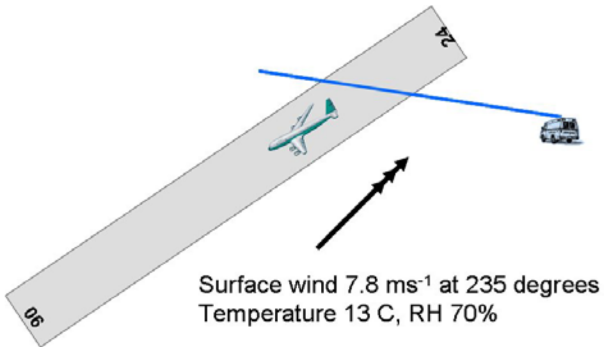
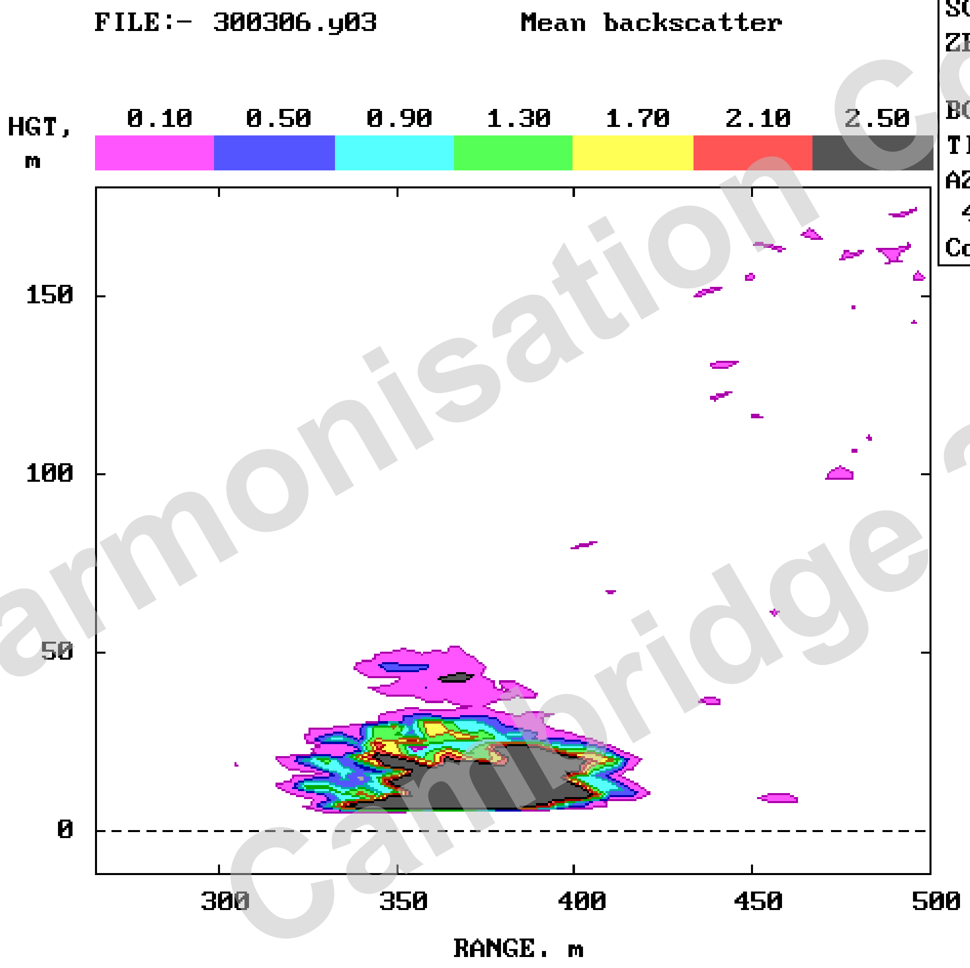
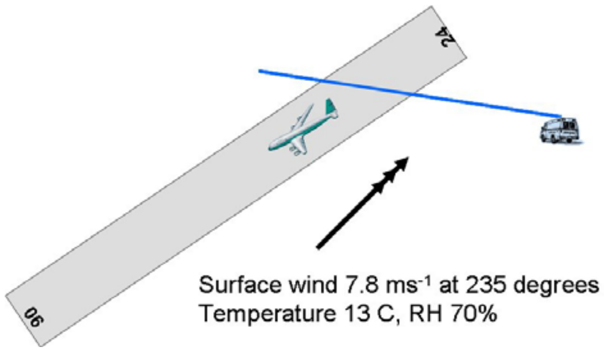




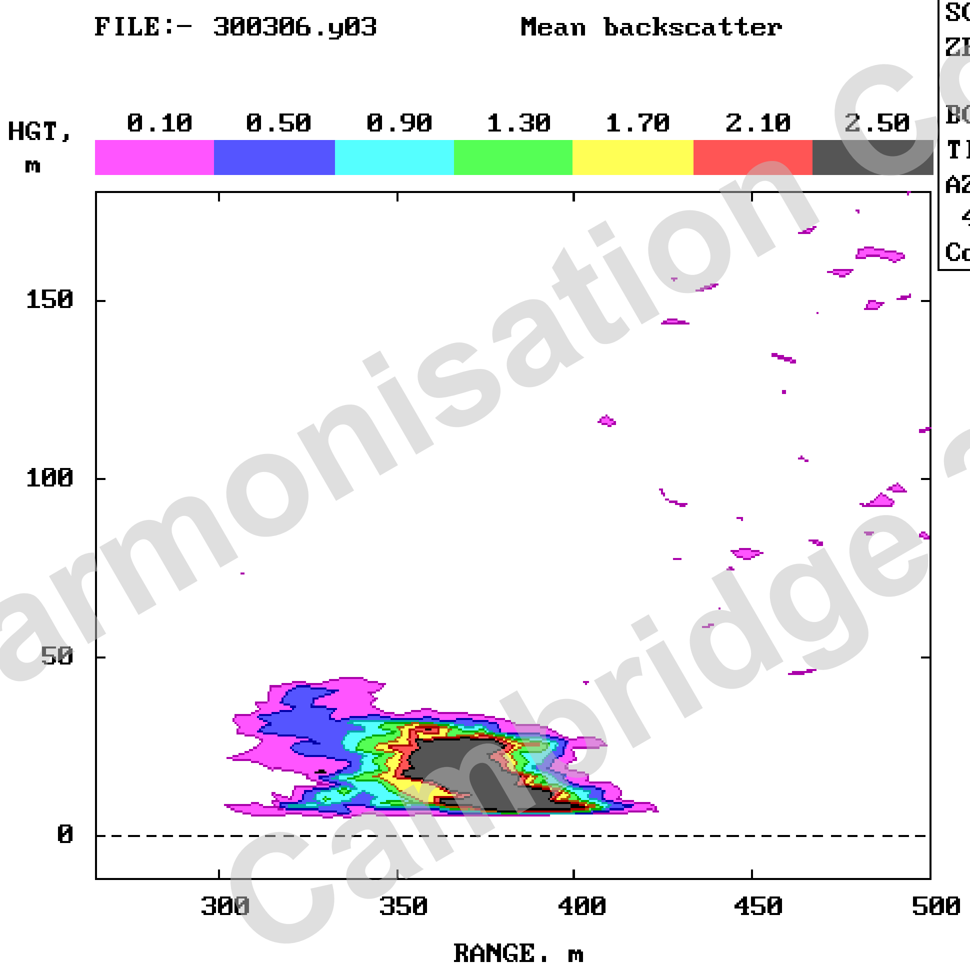
Surface wind 7.8 ms^{-1} at 235 degrees
Temperature 13 C, RH 70%



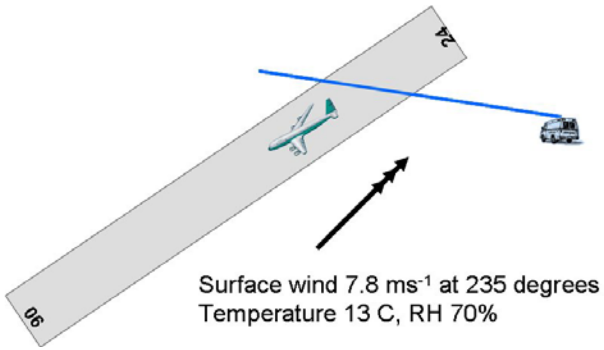
SCANS:- 118 - 118
ZERO LEVEL:-
50th percentile
BOTH WINDOWS USED
TIME:- 12:26:48
AZIMUTH: 277.4 DEG
484 scans in file.
Contour filling on.



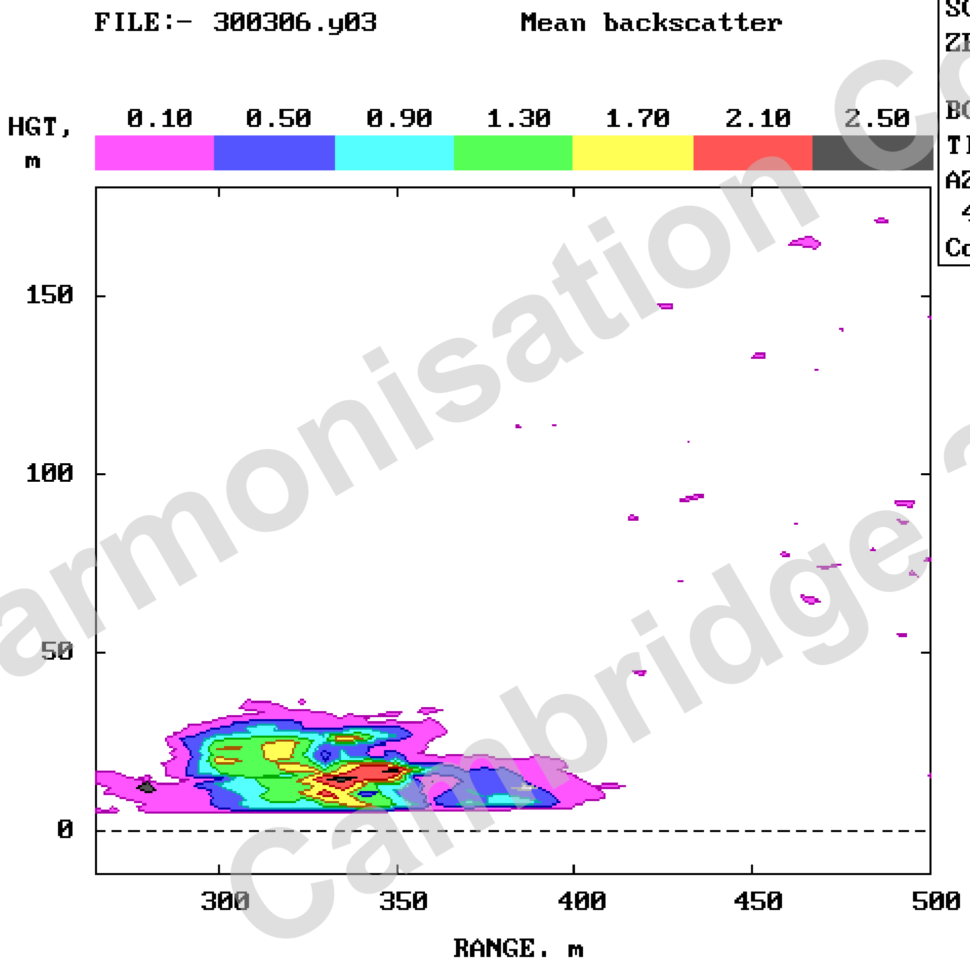
Surface wind 7.8 ms^{-1} at 235 degrees
Temperature 13 C, RH 70%



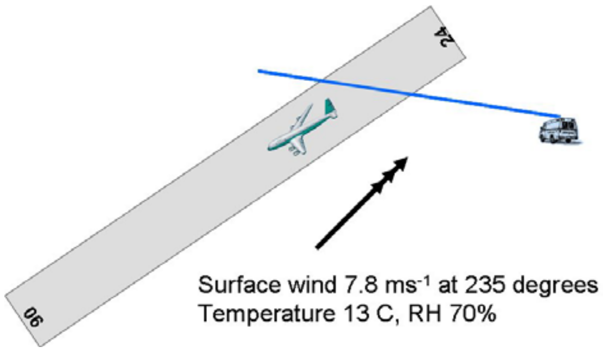
SCANS:- 119 - 119
ZERO LEVEL:-
50th percentile
BOTH WINDOWS USED
TIME:- 12:26:52
AZIMUTH: 277.4 DEG
484 scans in file.
Contour filling on.



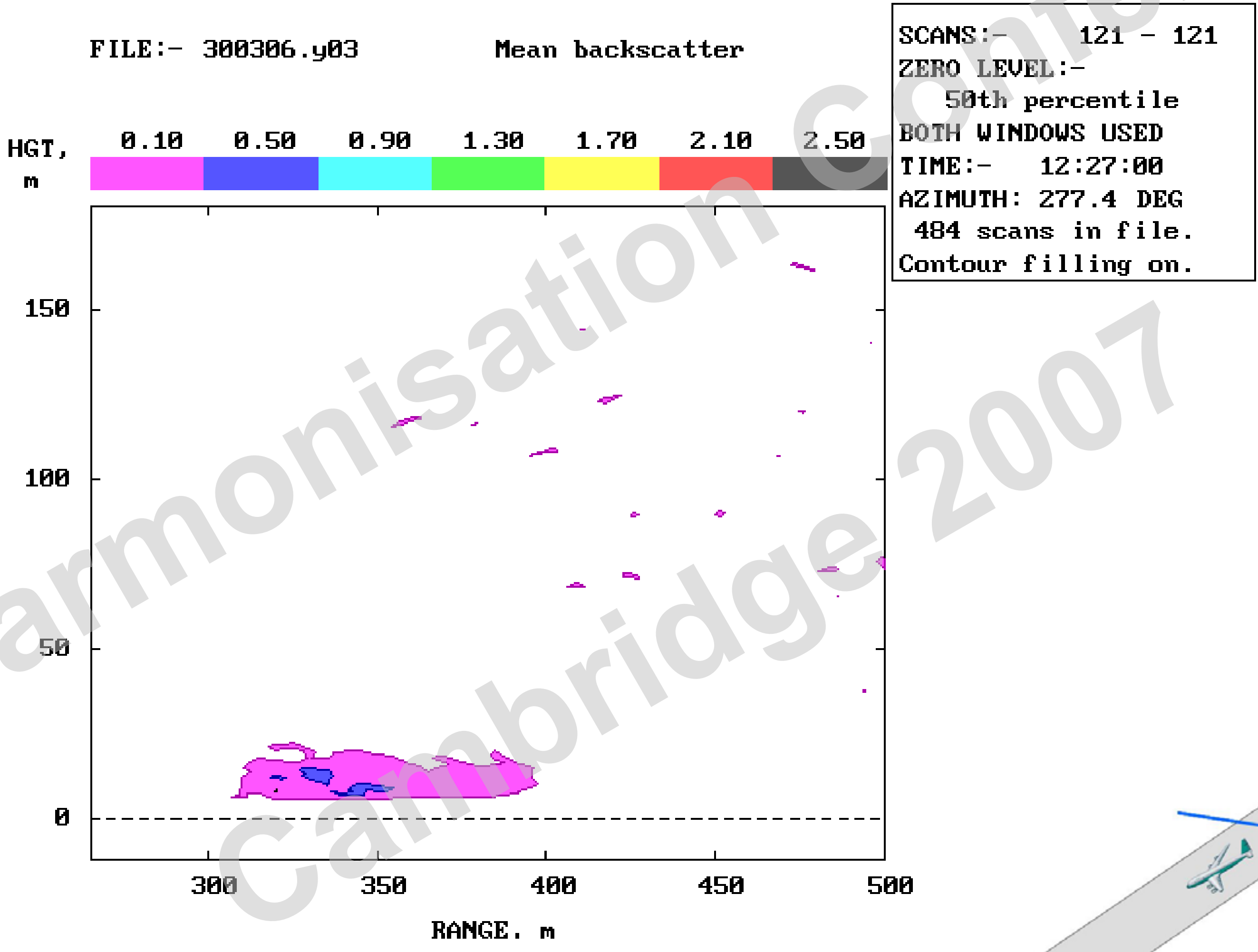
Surface wind 7.8 ms^{-1} at 235 degrees
Temperature 13 C, RH 70%

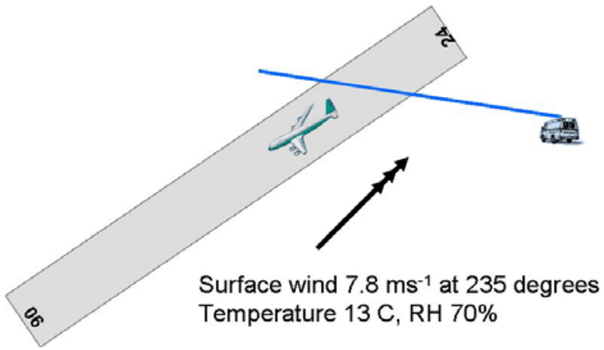


SCANS:- 120 - 120
ZERO LEVEL:-
50th percentile
BOTH WINDOWS USED
TIME:- 12:26:56
AZIMUTH: 277.4 DEG
484 scans in file.
Contour filling on.

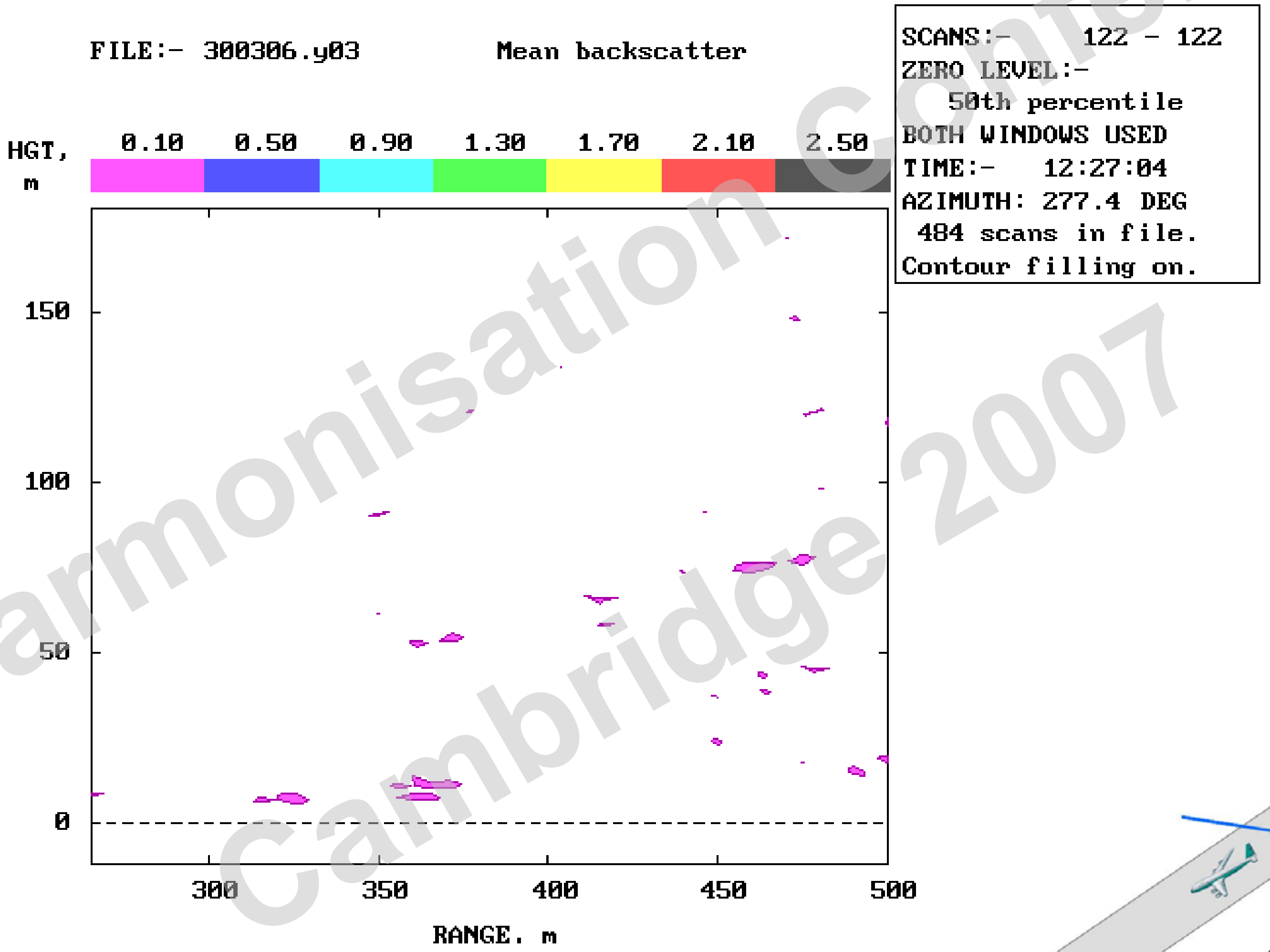


Surface wind 7.8 ms^{-1} at 235 degrees
Temperature 13 C, RH 70%

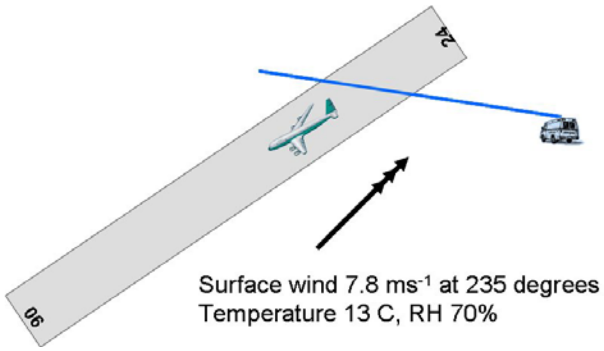




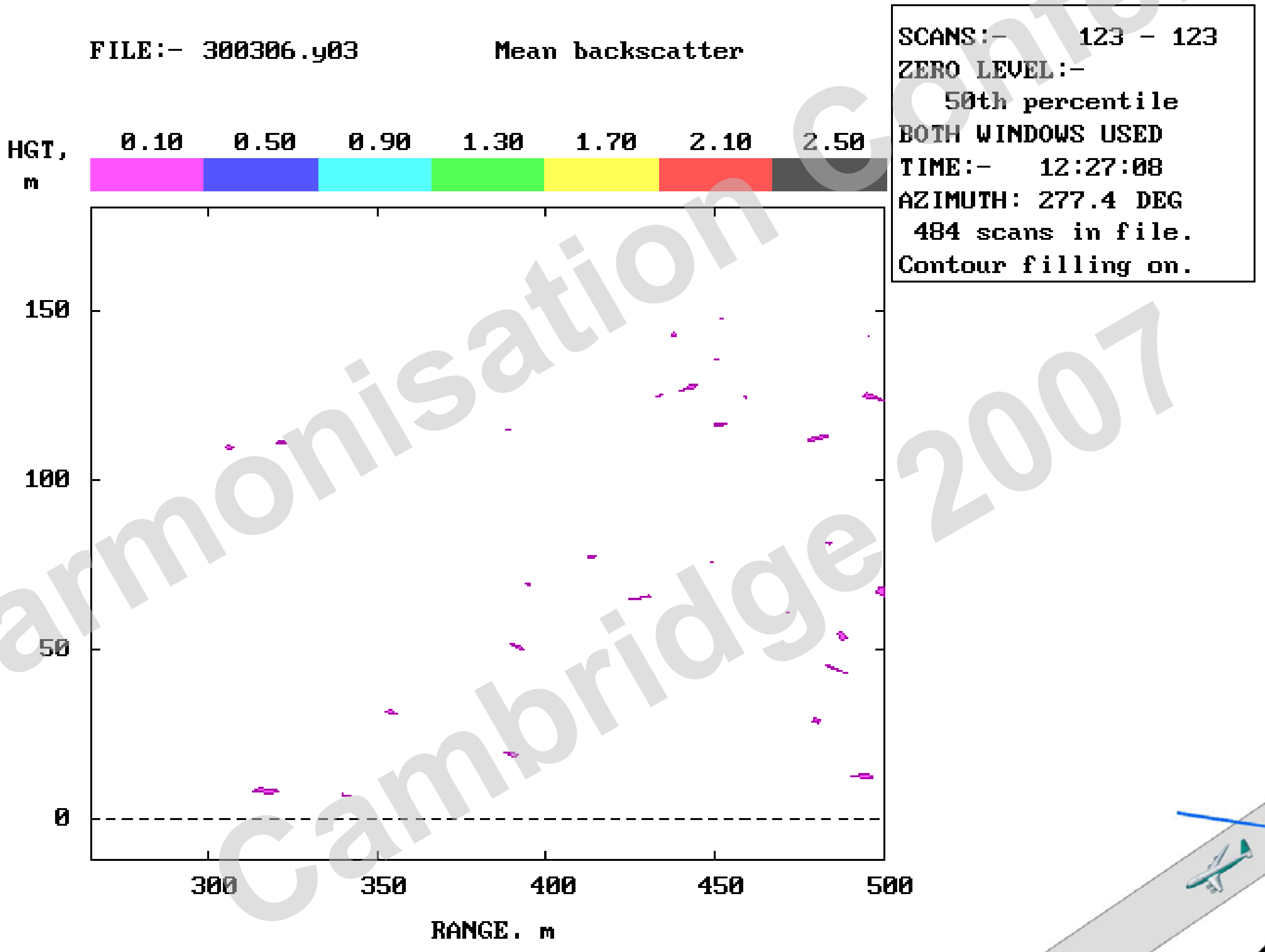
Surface wind 7.8 ms^{-1} at 235 degrees
Temperature 13 C, RH 70%

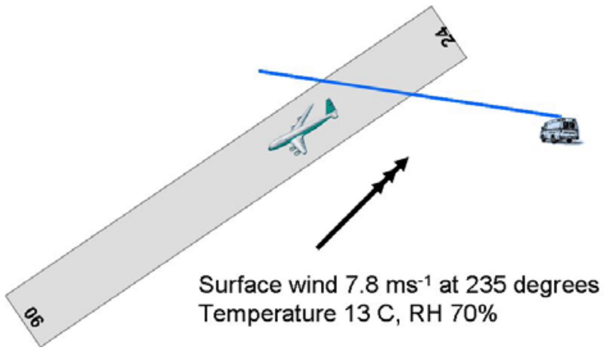


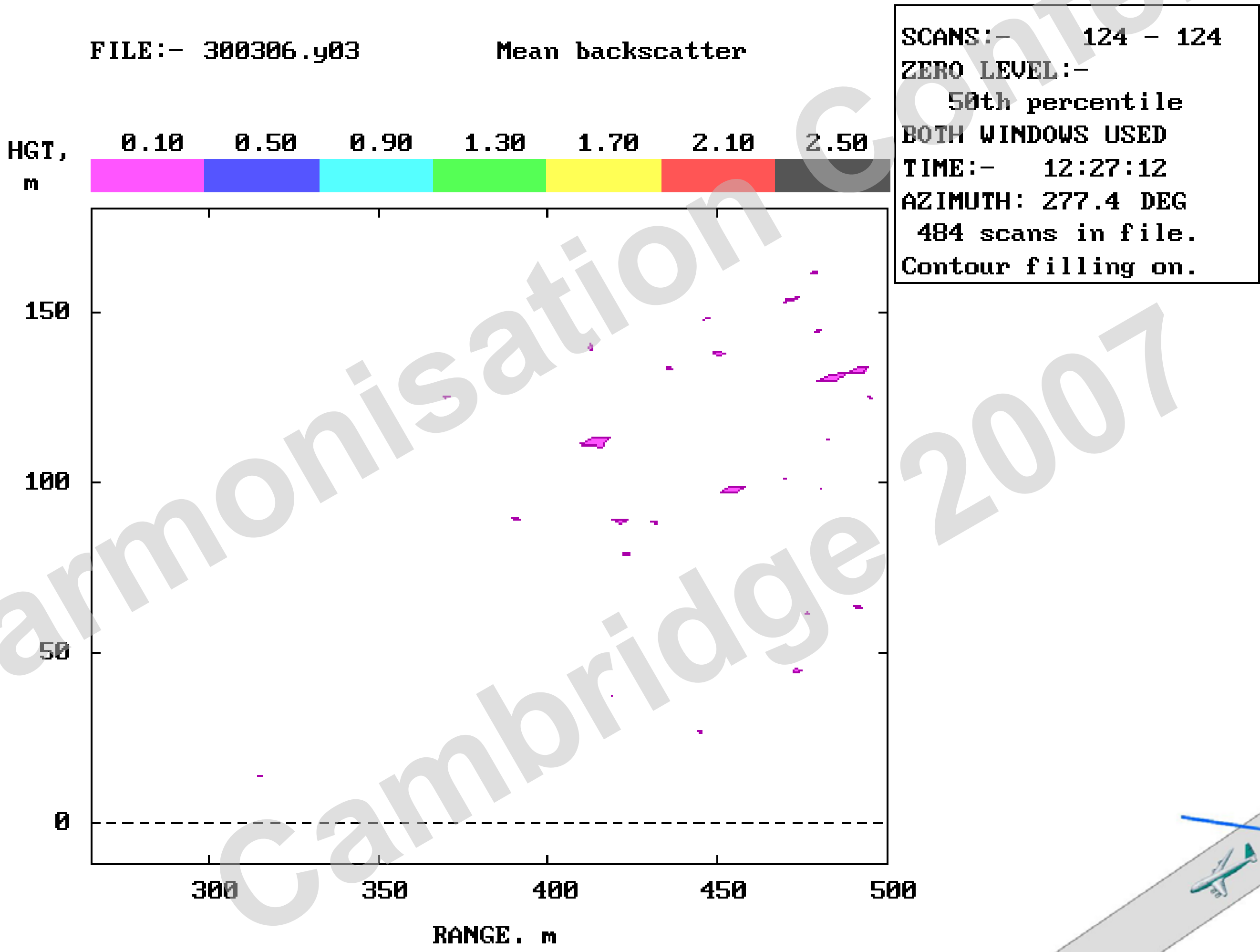
FILE:- 300306.y03
Mean backscatter
HGT, m
0.10 0.50 0.90 1.30 1.70 2.10 2.50
150
100
50
0
300 350 400 450 500
RANGE, m
SCANS:- 122 - 122
ZERO LEVEL:-
50th percentile
BOTH WINDOWS USED
TIME:- 12:27:04
AZIMUTH: 277.4 DEG
484 scans in file.
Contour filling on.

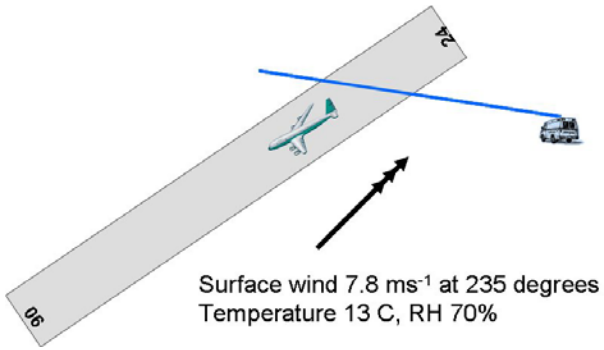


24
06
Surface wind 7.8 ms-1 at 235 degrees
Temperature 13 C, RH 70%


FILE:- 300306.y03
Mean backscatter
HGT, m
0.10 0.50 0.90 1.30 1.70 2.10 2.50
SCANS:- 123 - 123
ZERO LEVEL:-
50th percentile
BOTH WINDOWS USED
TIME:- 12:27:08
AZIMUTH: 277.4 DEG
484 scans in file.
Contour filling on.
150
100
50
0
300 350 400 450 500
RANGE. m


24
06
Surface wind 7.8 ms-1 at 235 degrees
Temperature 13 C, RH 70%


FILE:- 300306.y03
Mean backscatter
HGT, m
0.10 0.50 0.90 1.30 1.70 2.10 2.50
150
100
50
0
300 350 400 450 500
RANGE, m
SCANS:- 124 - 124
ZERO LEVEL:-
50th percentile
BOTH WINDOWS USED
TIME:- 12:27:12
AZIMUTH: 277.4 DEG
484 scans in file.
Contour filling on.


24
06
Surface wind 7.8 ms-1 at 235 degrees
Temperature 13 C, RH 70%

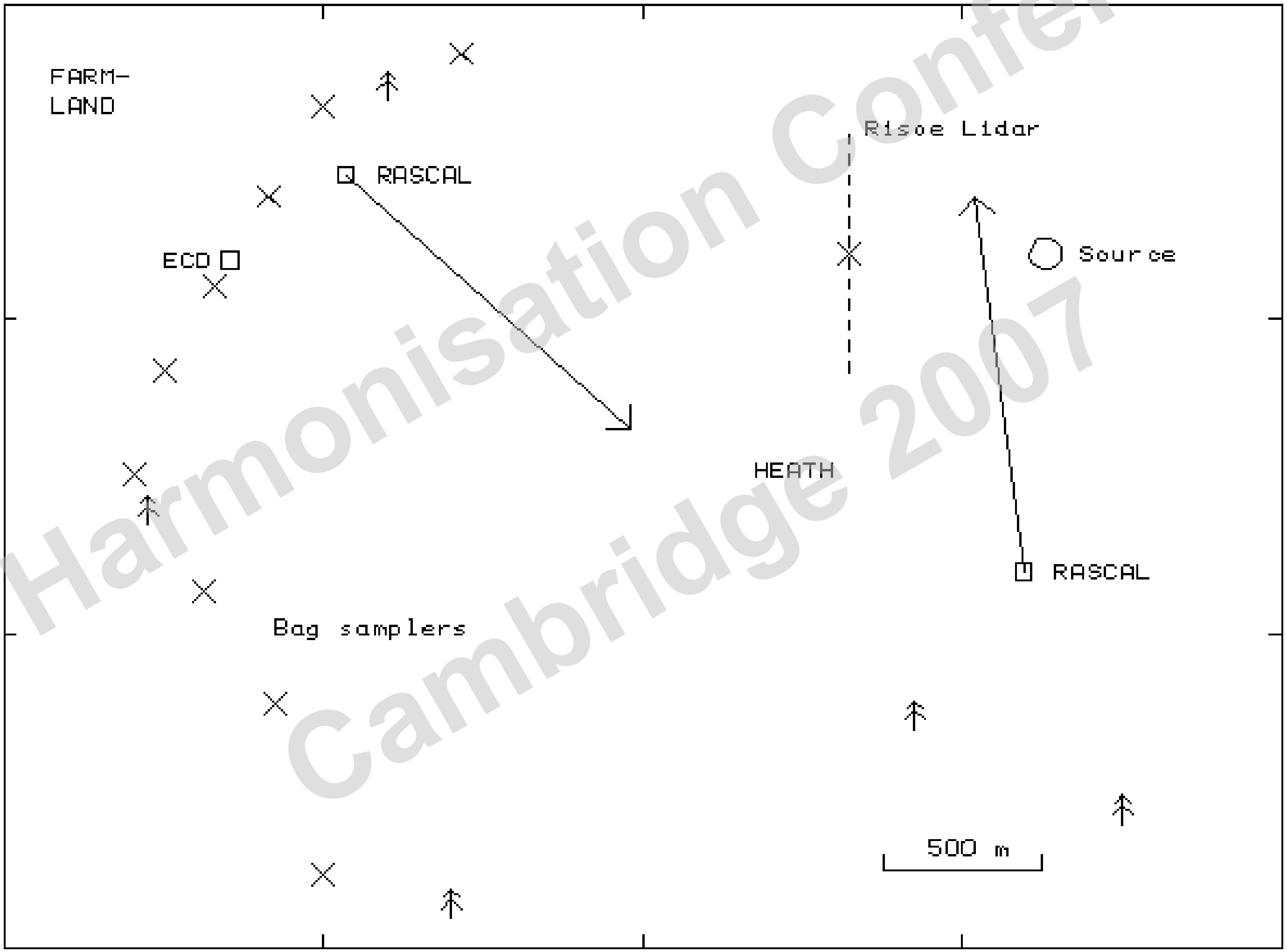
Issues Regarding Odour Perception

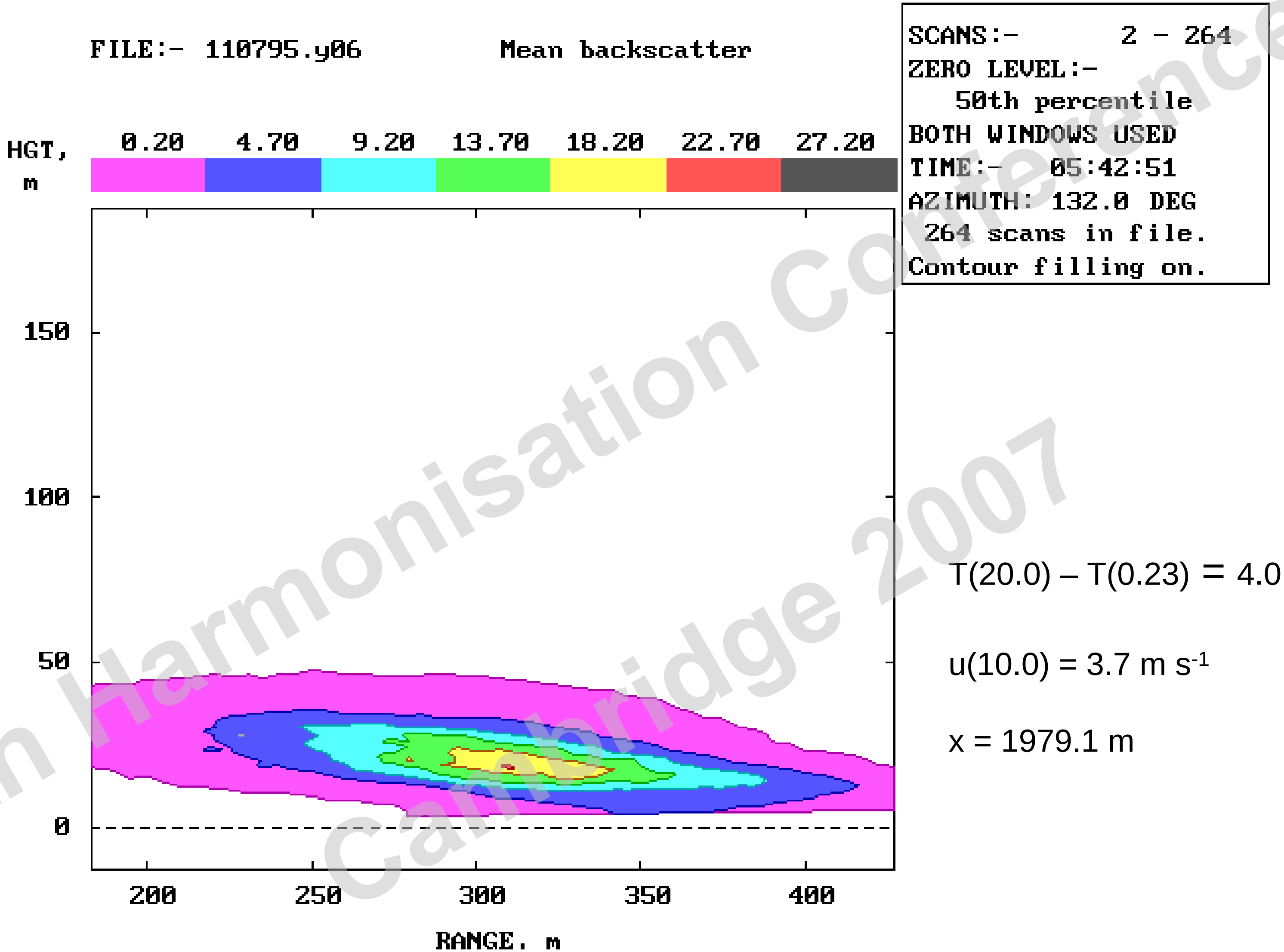
- Adaptation of the nose
- Habituation of the brain
- Non-linear overall response:

  Steven’s Law,

$$I = k\,C^n$$

Test-bed: Borris Heath 11-12/7/1995





T(20.0) – T(0.23) = 4.0 °C

u(10.0) = 3.7 m s^{-1}

x = 1979.1 m

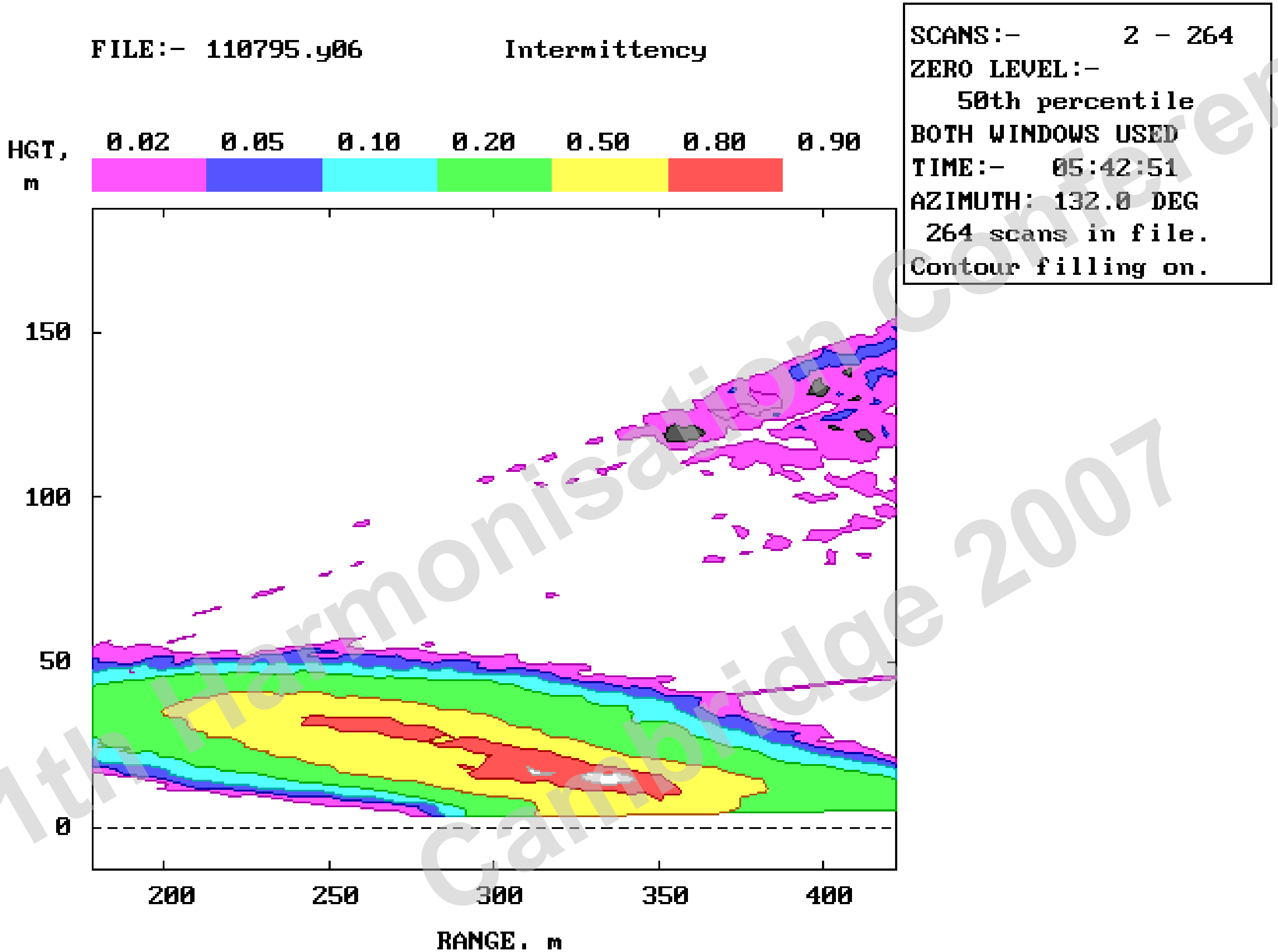
Backscatter from near-surface plume (21 m release) plume in stable conditions, Borris Heath, 11/7/1995, 23:25:13 – 23:55:07

Proposed Model of Adaptation

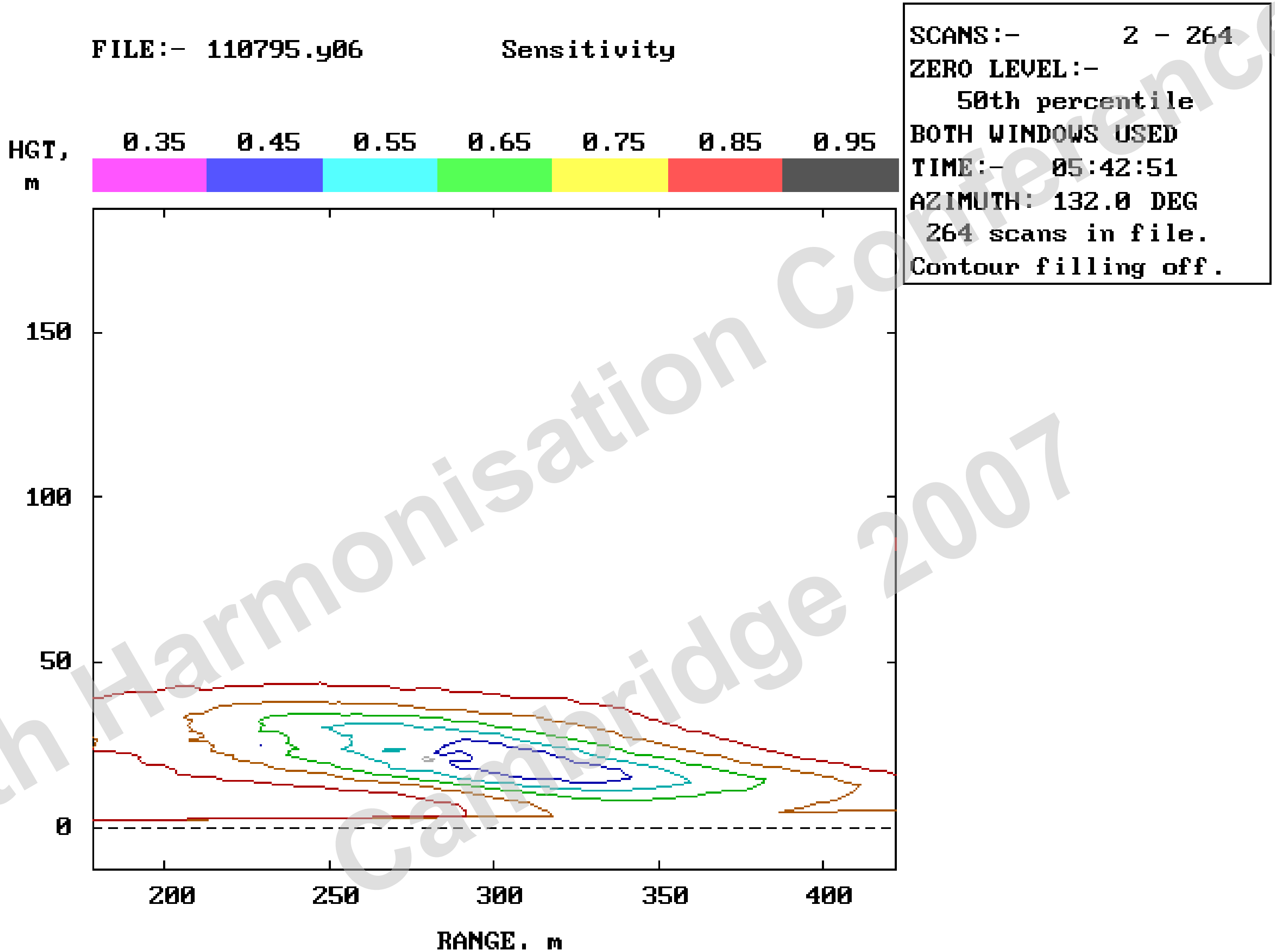
- Signal from nose to brain, $I' = S.I$
- Sensitivity, S is subject to a simple adsorption model:

$$\frac{dS}{dt} = \frac{1 - S}{\tau_C} - \frac{C\,S}{C_0\,\tau_B} \qquad 0 \le S \le 1$$

That is, the olfactory cells are blocked at a rate proportional to C and then clear themselves over a timescale $\tau_C \approx 5$ s.

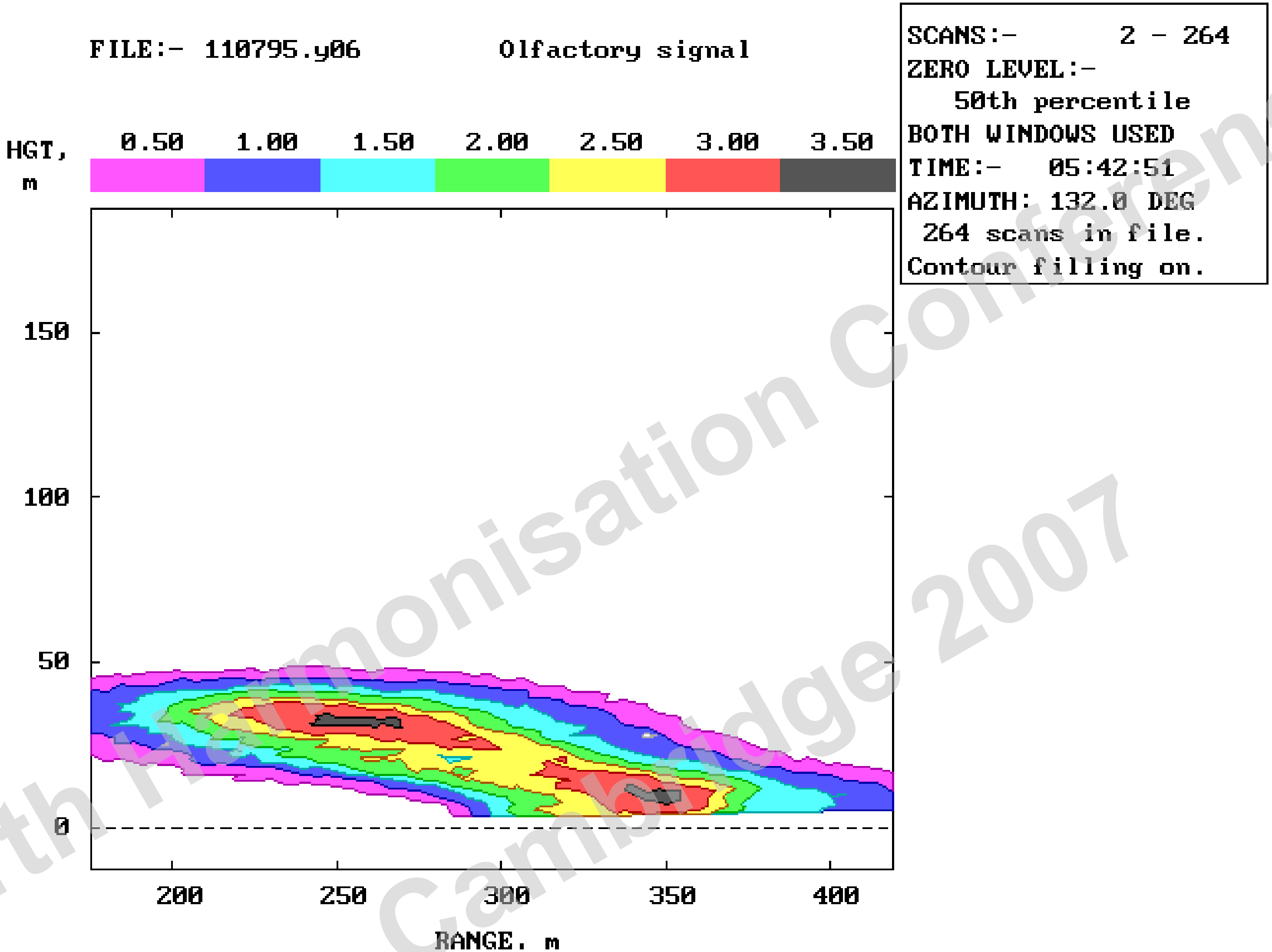


Intermittency of near-surface plume in stable conditions, Borris Heath 1995



Mean sensitivity in near-surface plume in stable conditions

C = Backscatter (bits), $C_0\tau_B$ = 50 bits-s, τ_C = 5 s.



Mean olfactory signal in near-surface plume in stable conditions

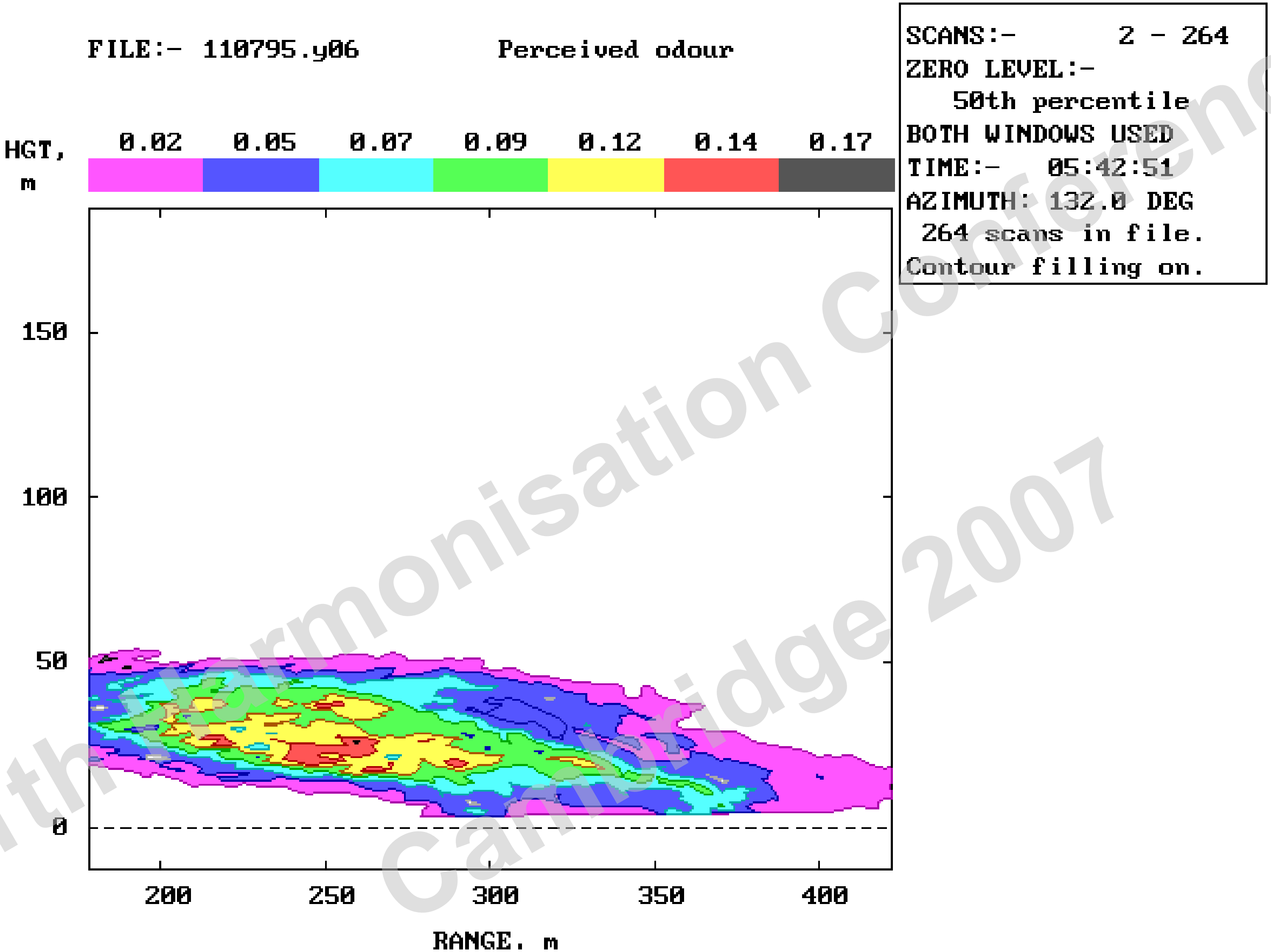
$I' = S.\ kC^n$, $k = 5$, $n = 0.26$

Model of Habituation

- Brain rapidly loses interest in a steady signal
- Assume perception, P is only of increases in olfactory signal over timescale τ_P, *i.e.*

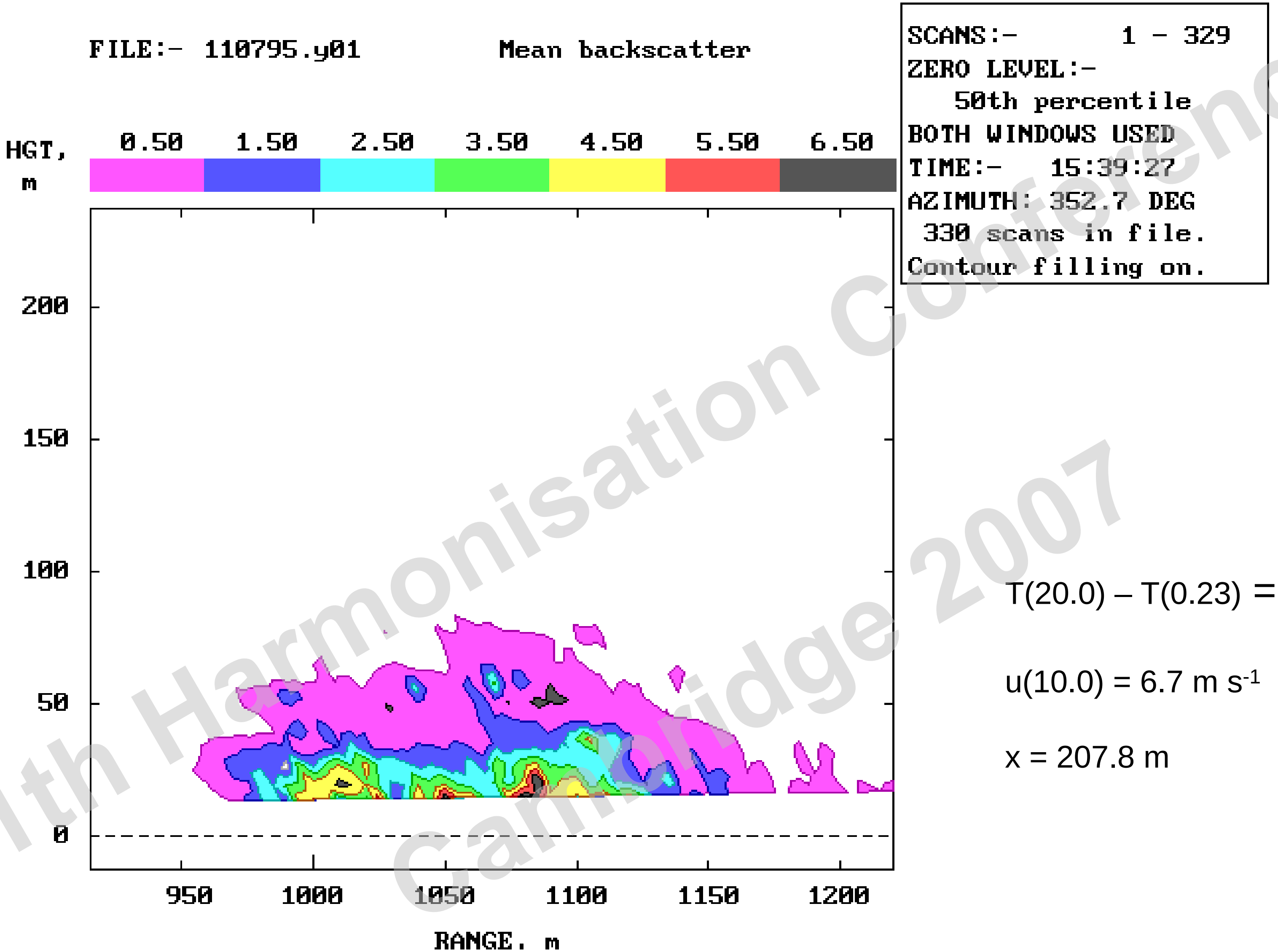
$$P = \begin{cases} \tau_P \dfrac{dI'}{dt} / Max(I', I_0), & \dfrac{dI'}{dt} > 0 \\ 0 \quad , & \dfrac{dI'}{dt} \leq 0 \end{cases}$$

where I_0 is the ambient background signal.



Mean perceived odour in near-surface plume in stable conditions

τ_P = 2.5 s, I_0 = 1

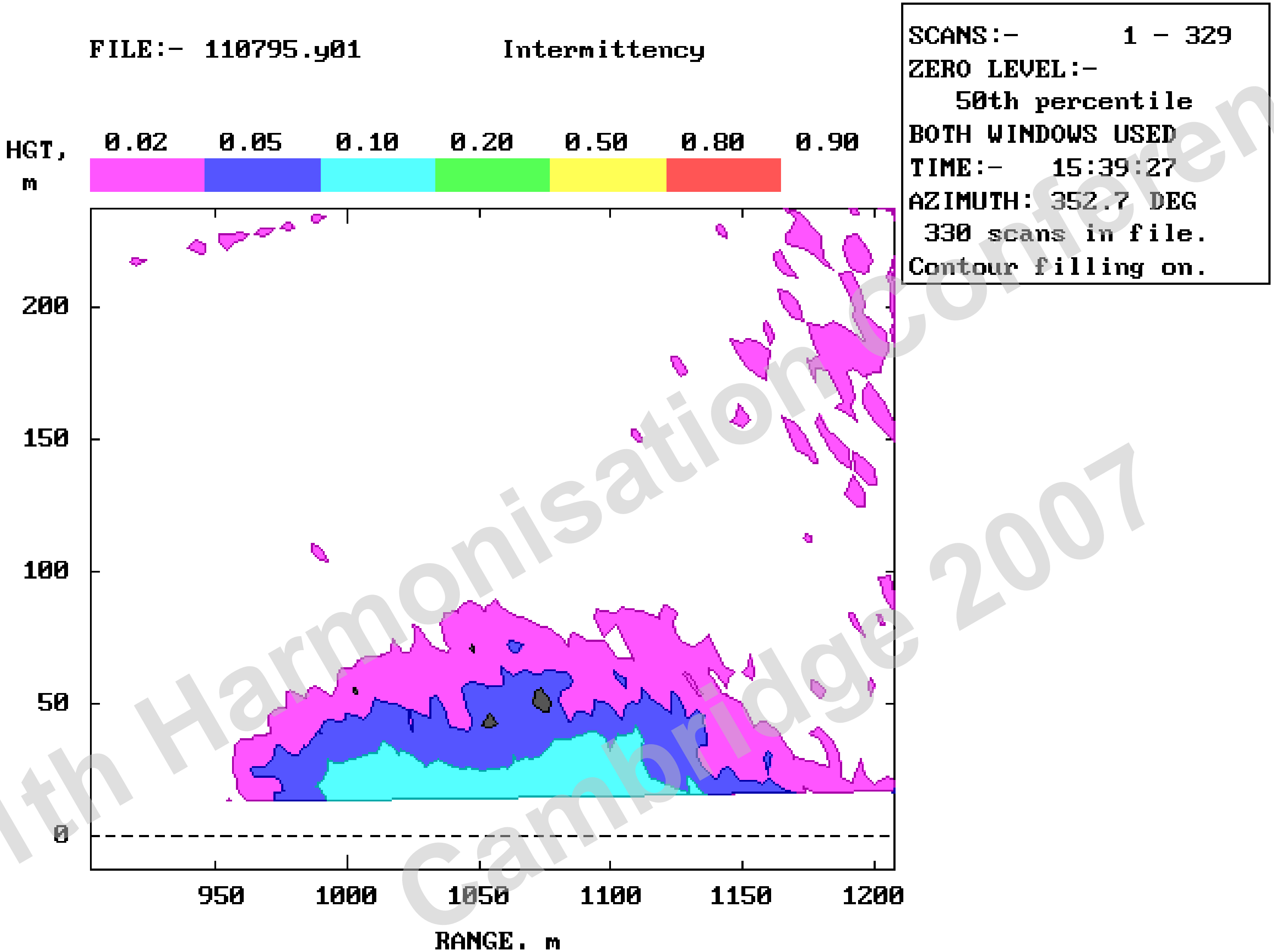


$T(20.0) - T(0.23) = -3.8\ ^{o}C$

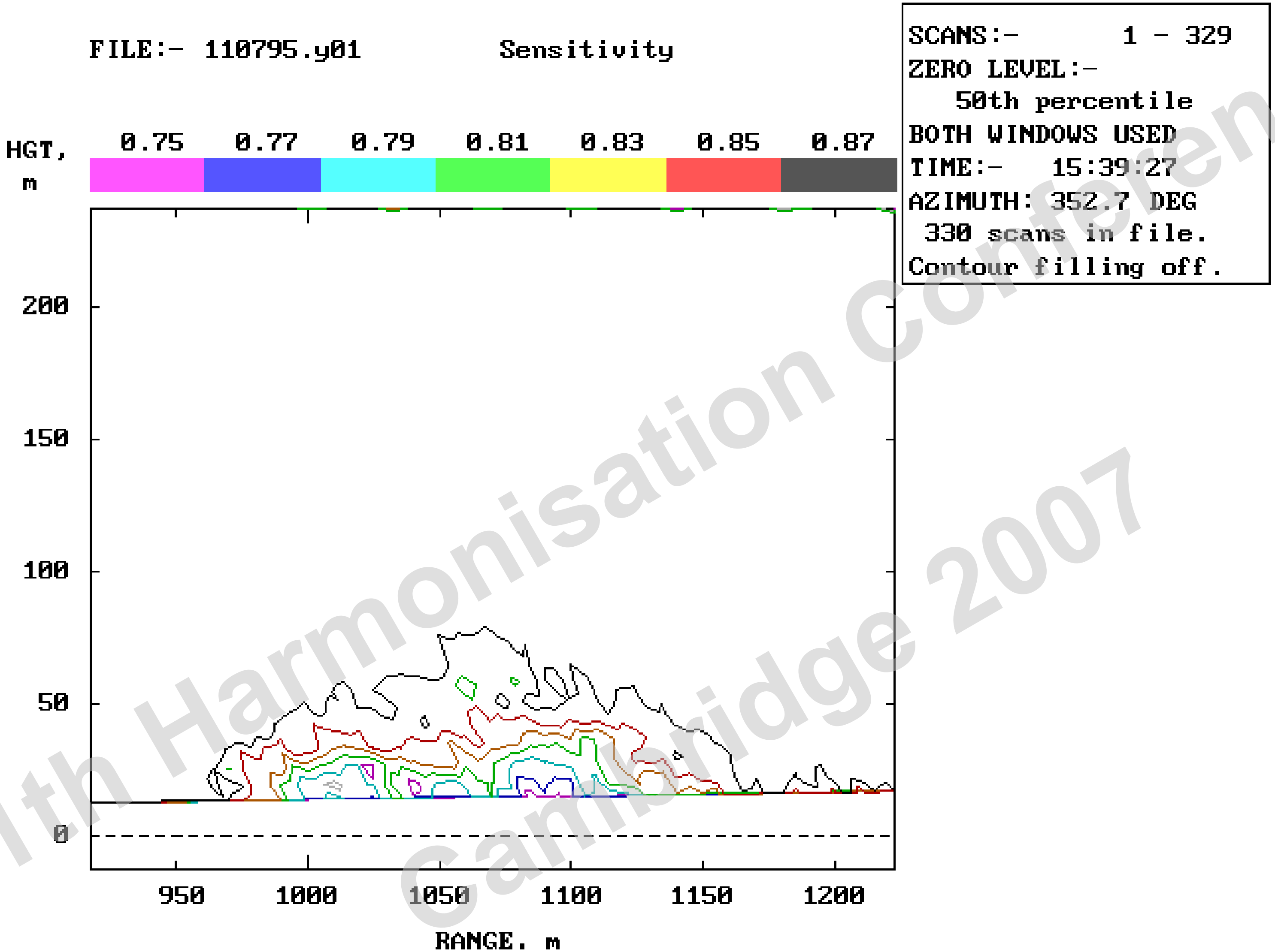
$u(10.0) = 6.7\ m\ s^{-1}$

$x = 207.8\ m$

Backscatter from near-surface plume (21 m release) plume in convective conditions, Borris Heath, 11/7/1995, 15:08:39 – 15:39:27

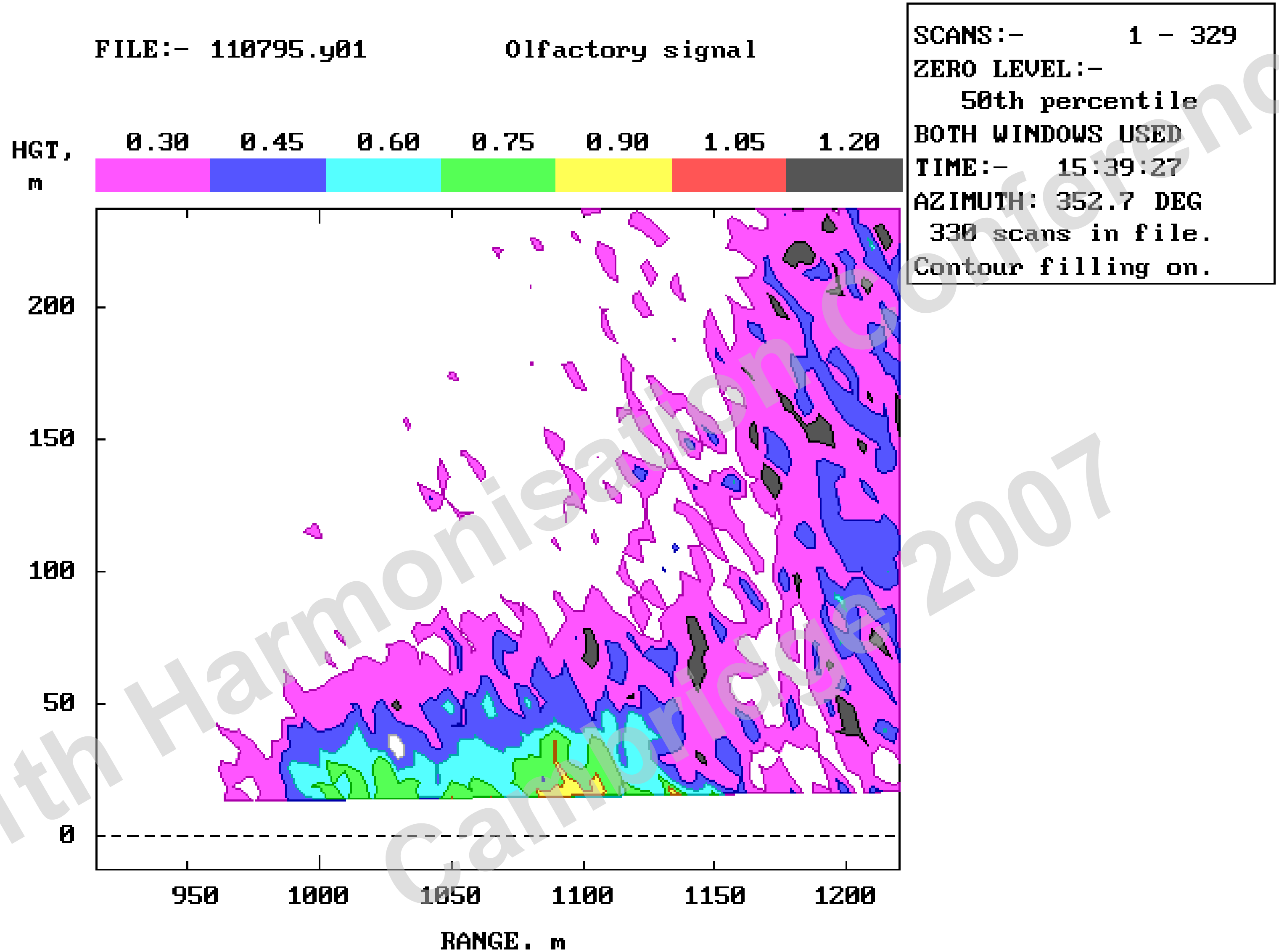


Intermittency of near-surface plume in convective conditions, Borris Heath 1995



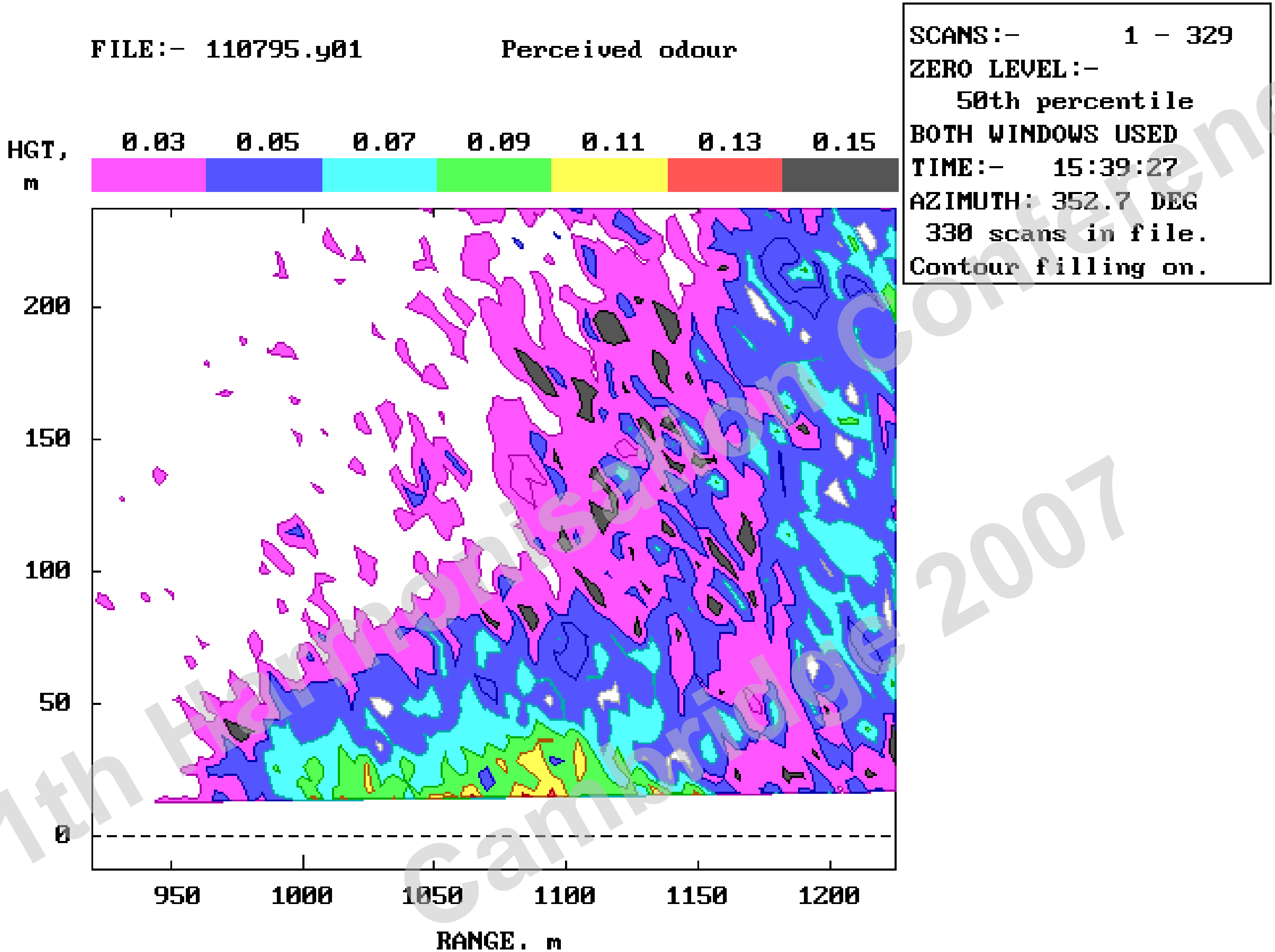
Mean sensitivity in near-surface plume in convective conditions

C = Backscatter, $C_0\tau_B$ = 50 s, τ_C = 5 s.



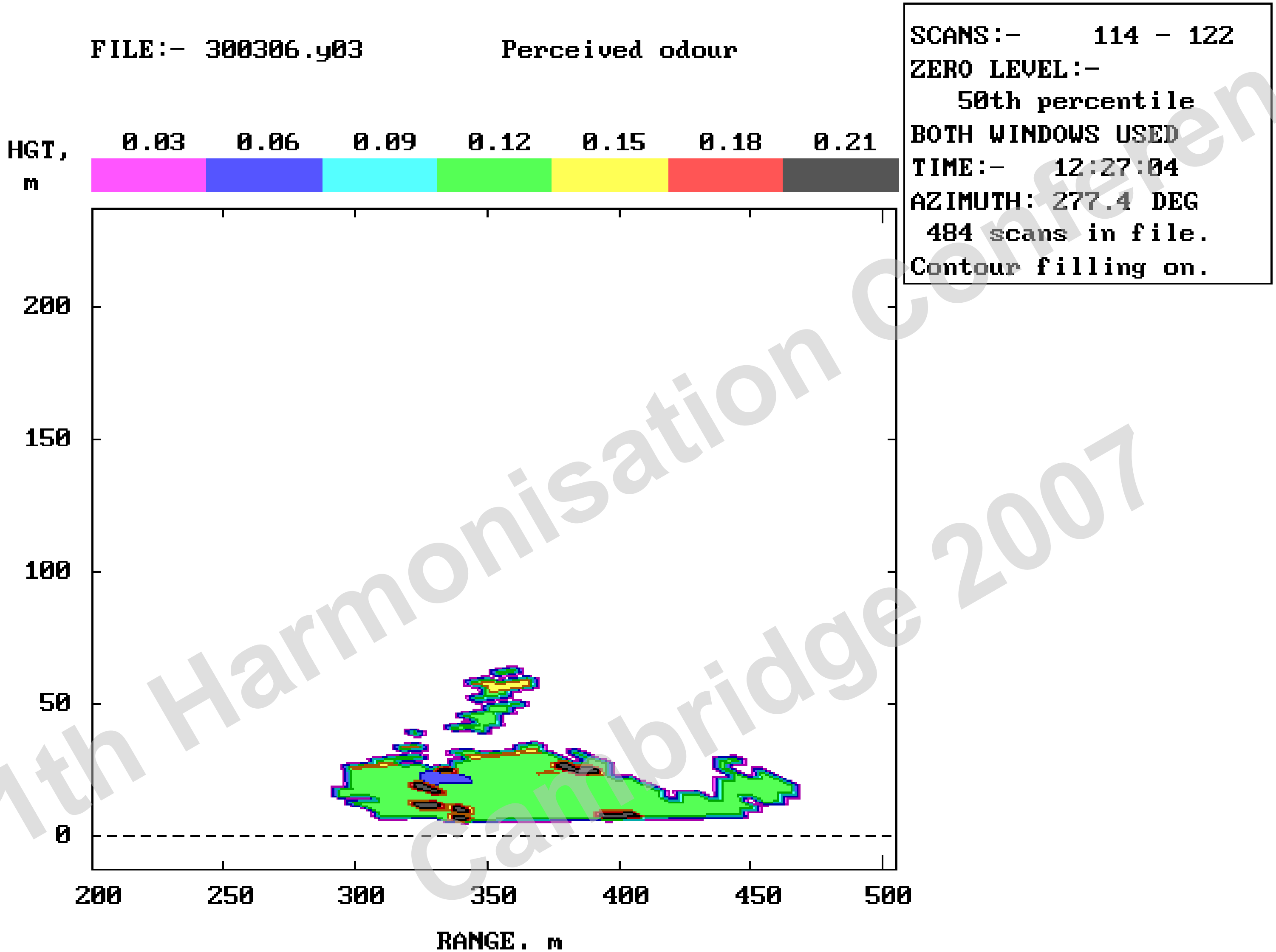
Mean olfactory signal in near-surface plume in convective conditions

$I' = S.\ kC^n$, $k = 5$, $n = 0.26$



Mean perceived odour in near-surface plume in convective conditions

τ_P = 2.5 s, I_0 = 1



Mean perceived odour from tyre smoke of individual landing at Ringway, 1227, 30/3/06. Same odour parameters as for Borris.

Conclusions

- In so far as aerosol is a tracer for odorants, then our model can enable Lidar to map odour nuisance. Faster scanning would be helpful.
- Where odours are well above background, nuisance reduces only weakly with dispersion.
- Odour perception is a dynamic and non-linear process: reliable parameters are required!