A simple approach for rapid operational air quality modelling at airports

Steven Barrett and Rex Britter

Department of Engineering

University of Cambridge

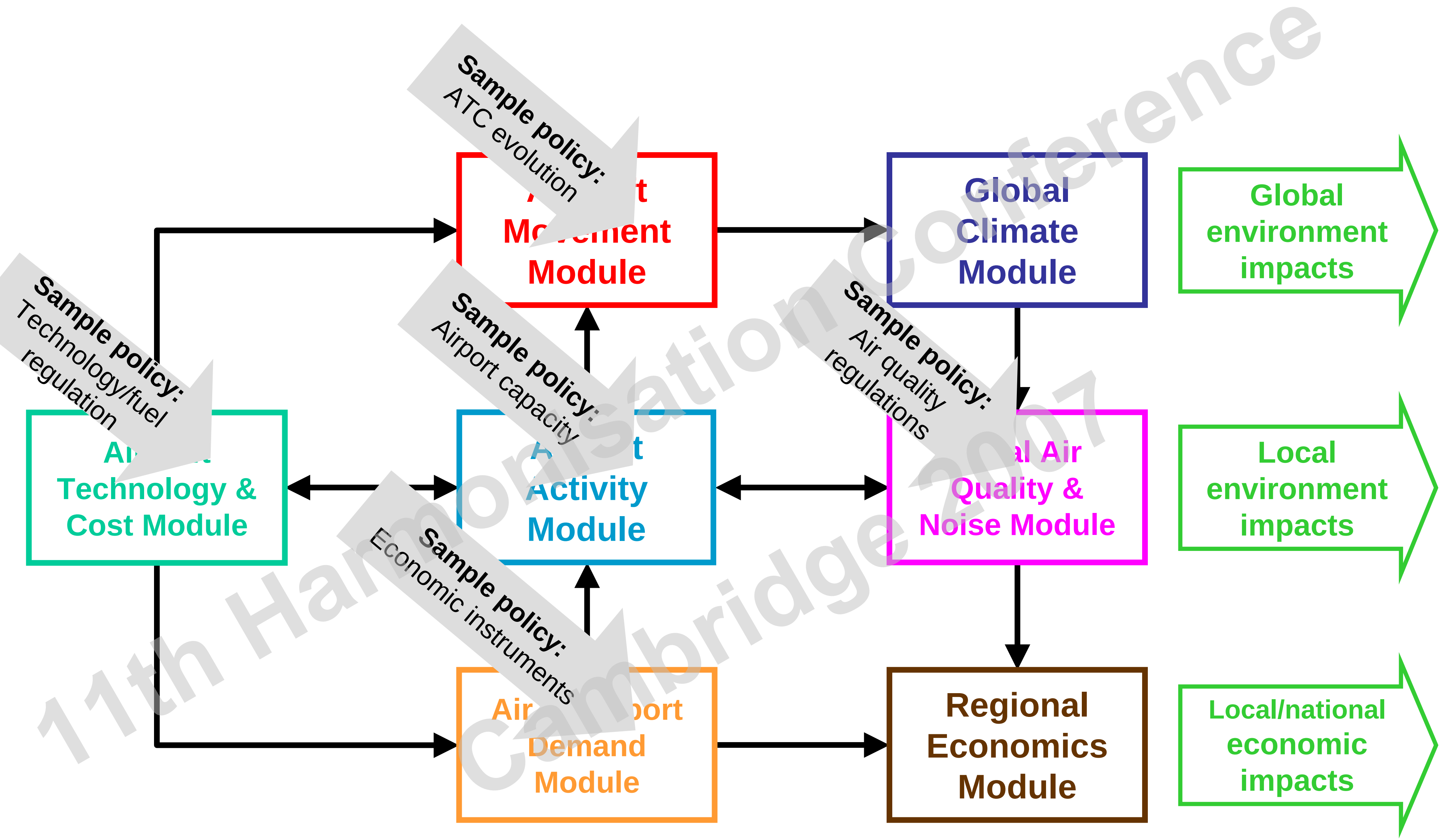
11th Harmonisation Conference

Cambridge 2007

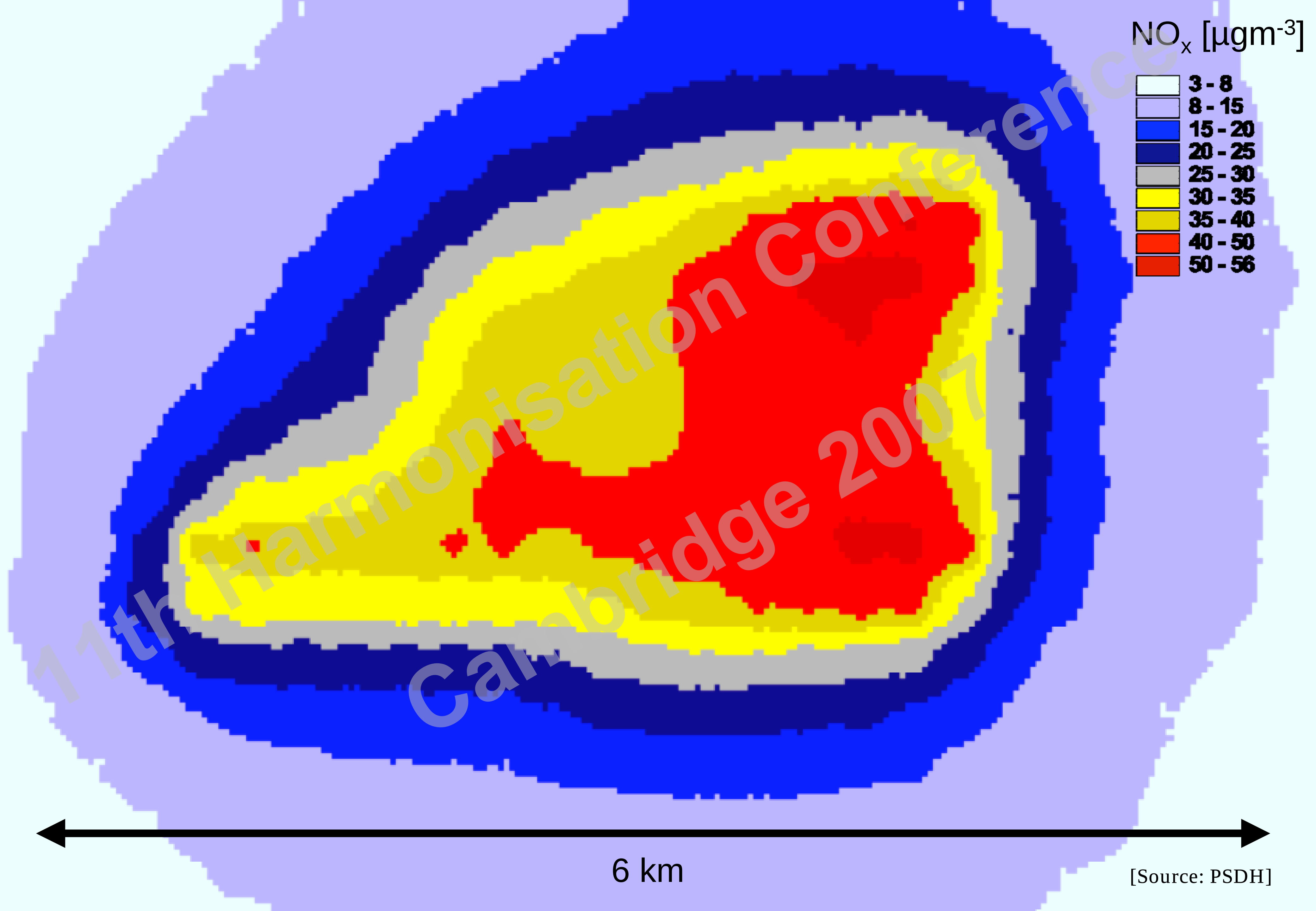
Aviation Integrated Modelling Project

www.AIMproject.aero

11th Harmonisation Conference
Cambridge 2007



Sample policy:
ATC evolution
Module
Global
Climate
Module
Global
environment
impacts
Sample policy:
Technology/fuel
regulation
Technology &
Cost Module
Sample policy:
Airport capacity
Module
Sample policy:
Air quality
regulations
Quality &
Noise Module
Local
environment
impacts
Sample policy:
Economic instruments
Demand
Module
Regional
Economics
Module
Local/national
economic
impacts
11th Harmonisation Conference
Cambridge 2007



11th Harmonisation Conference
Cambridge 2007

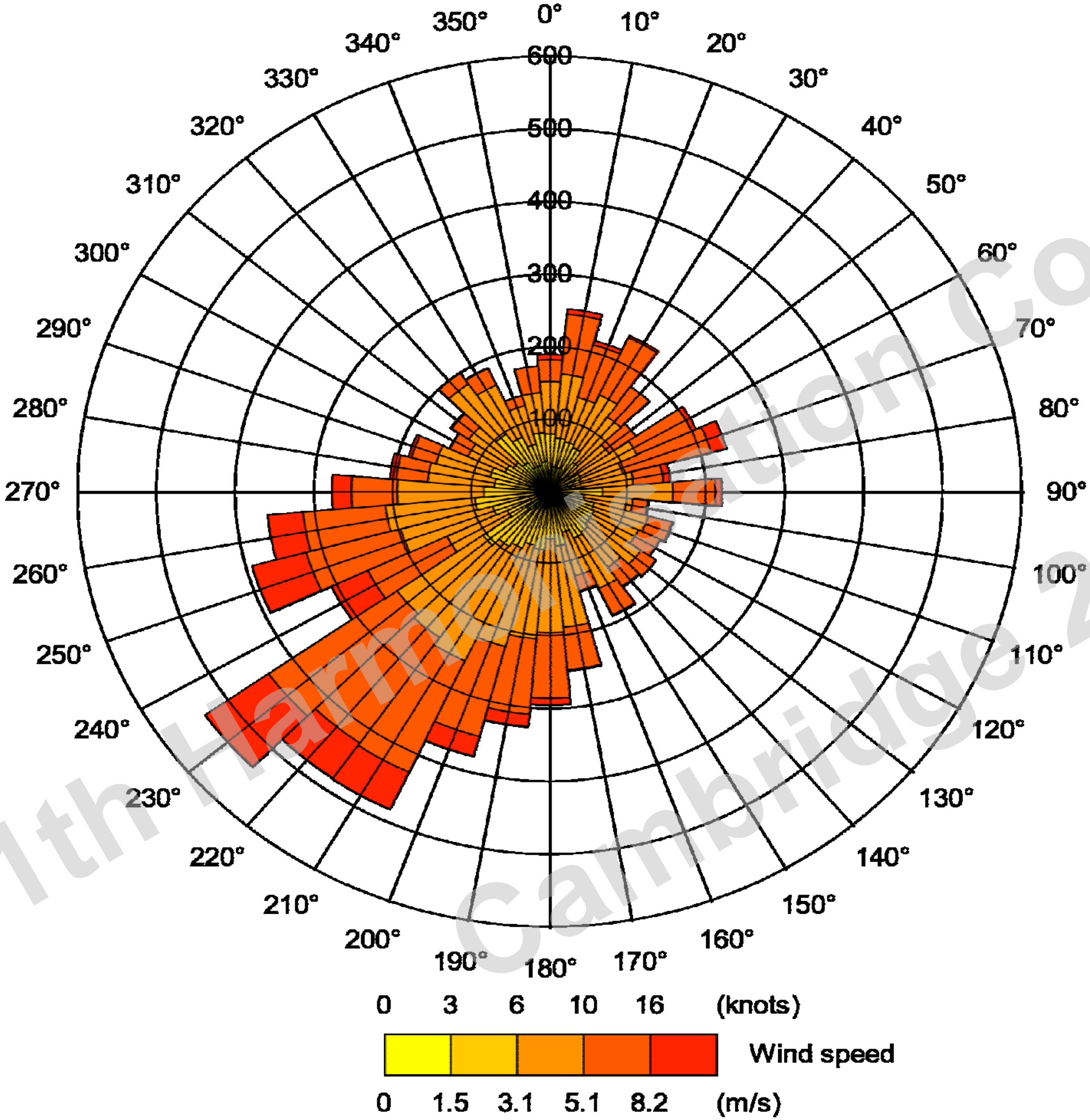
Objectives:

- Low data input requirements
- Short run-times

Simplifying assumptions:

- Emissions as ground level sources
- Neutral conditions
- Long term averages

11th Harmonisation Conference
Cambridge 2007



[Source: CERC]

$$p(u_r, \theta)$$

11th Harmonisation Conference Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} p(\theta, u_r) \chi(x,y;\, u_r, \theta) du_r d\theta$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} p(\theta, u_r)\, \chi(x,y;\, u_r, \theta)\, du_r\, d\theta$$

$$\hat{u} = \frac{u_r}{u_*} = \frac{\ln(z_r / z_0)}{\kappa}$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} p(\theta, u_r) \chi(x,y;\, u_r, \theta) du_r d\theta$$

$$\hat{u} = \frac{u_r}{u_*} = \frac{\ln(z_r / z_0)}{\kappa}$$

$$\chi(x,y,z) / Q = \chi_l(x,y) \chi_v(x,z)$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} p(\theta, u_r) \chi(x,y;\, u_r, \theta) du_r d\theta$$

$$\hat{u} = \frac{u_r}{u_*} = \frac{\ln(z_r / z_0)}{\kappa}$$

$$\chi(x, y, z) / Q = \chi_l(x, y) \chi_v(x, z)$$

$$\chi_v(x, z) = \frac{1}{\kappa u_* x} \exp\left(-\frac{\overline{u} z}{\kappa u_* x} \right)$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} p(\theta, u_r) \chi(x,y;\ u_r, \theta) du_r d\theta$$

$$\hat{u} = \frac{u_r}{u_*} = \frac{\ln(z_r / z_0)}{\kappa}$$

$$\chi(x,y,z)/Q = \chi_l(x,y)\chi_v(x,z)$$

$$\chi_v(x,z) = \frac{1}{\kappa u_* x} \exp\left(-\frac{\bar{u} z}{\kappa u_* x} \right)$$

$$\chi_l(x,y) = \frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2} \right)$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} p(\theta, u_r) \chi(x,y;\, u_r, \theta) du_r d\theta$$

$$\hat{u} = \frac{u_r}{u_*} = \frac{\ln(z_r / z_0)}{\kappa}$$

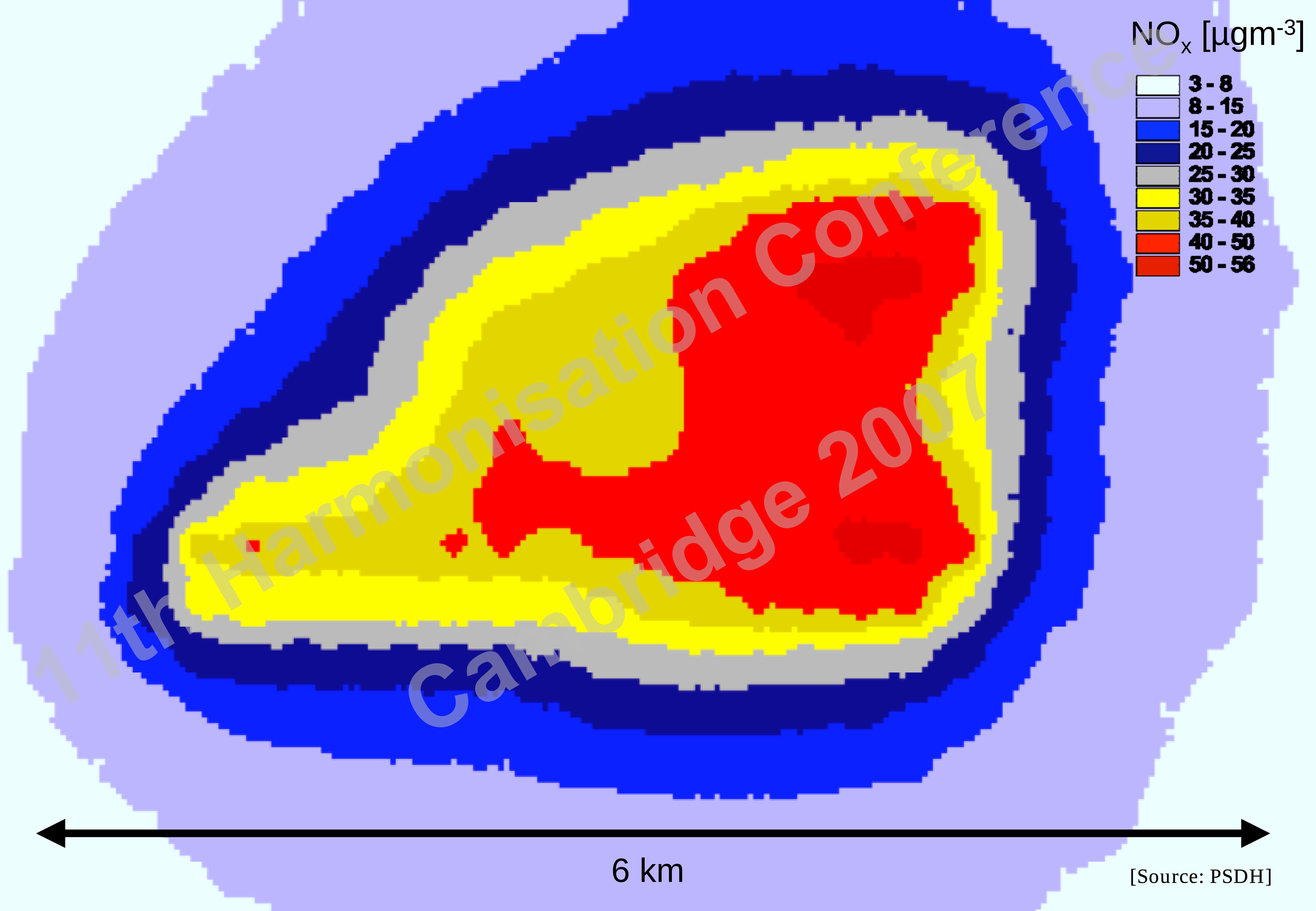
$$\chi(x, y, z) / Q = \chi_l(x, y) \chi_v(x, z)$$

$$\chi_v(x, z) = \frac{1}{\kappa u_* x} \exp\left(-\frac{\overline{u} z}{\kappa u_* x} \right)$$

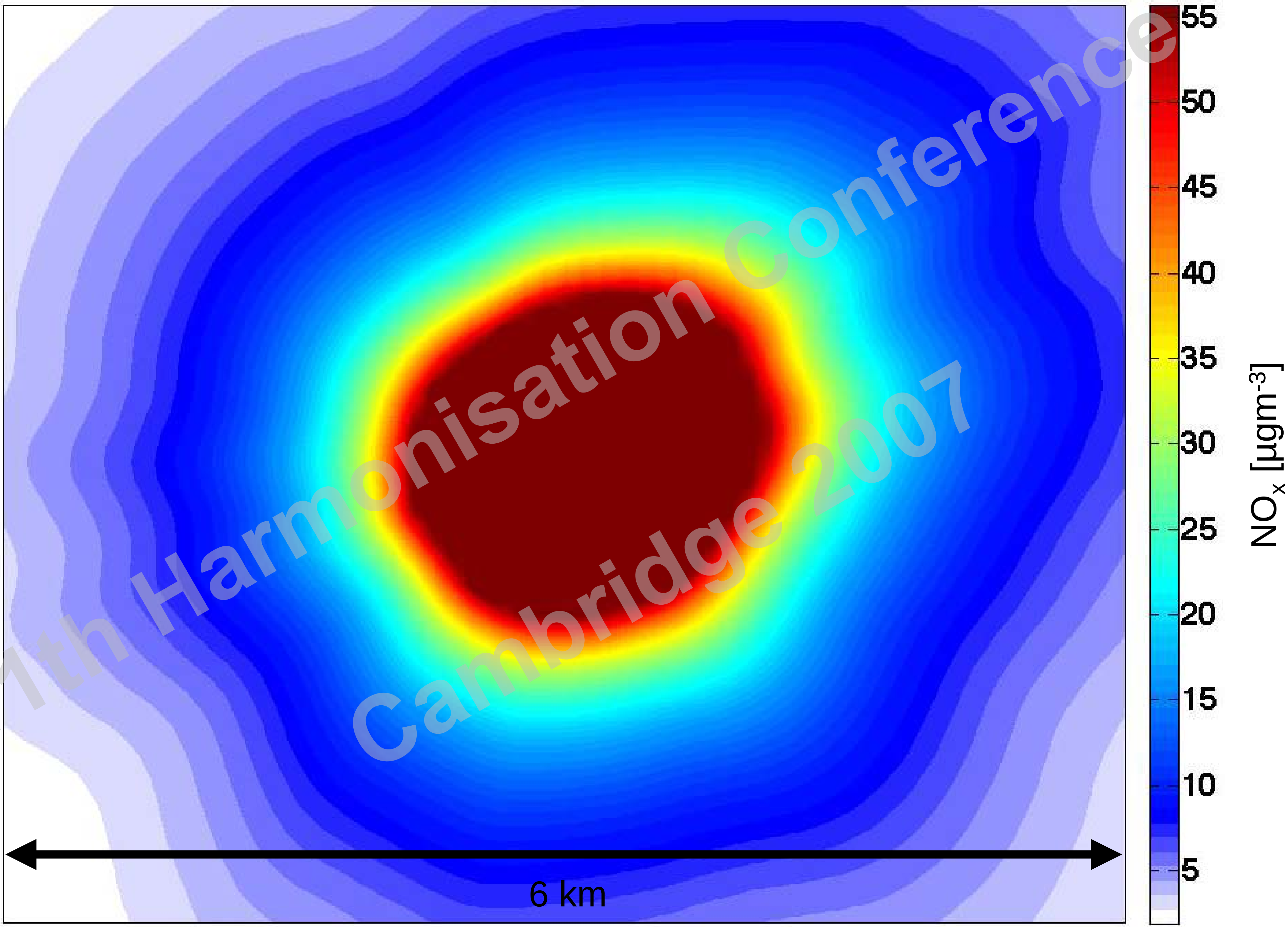
$$\chi_l(x, y) = \frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2} \right)$$

$$\sigma_y = 0.16x$$

11th Harmonisation Conference
Cambridge 2007



11th Harmonisation Conference Cambridge 2007



11th Harmonisation conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \int u_r^{-1}\, p(\theta,u_r)\, du_r\, d\theta$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r, \theta)\, p(\theta, u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \int u_r^{-1} p(\theta, u_r)\, du_r\, d\theta$$

$$\chi(x,0,z) = \underbrace{\frac{Q_i}{\kappa u_* x}}_{\chi_v} \times \underbrace{\frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2} \right)}_{\chi_l}$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \int u_r^{-1}\, p(\theta,u_r)\, du_r\, d\theta$$

$$\chi(x,0,z) = \underbrace{\frac{Q_i}{\kappa u_* x}}_{\chi_v} \times \underbrace{\frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2} \right)}_{\chi_l}$$

$$\hat{u} = \frac{u_r}{u_*}$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \int u_r^{-1}\, p(\theta,u_r)\, du_r\, d\theta$$

$$\chi(x,0,z) = \underbrace{\frac{Q_i \hat{u}}{\kappa u_r x}}_{\chi_v} \times \underbrace{\frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2} \right)}_{\chi_l}$$

$$\hat{u} = \frac{u_r}{u_*}$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \int u_r^{-1}\, p(\theta,u_r)\, du_r\, d\theta$$

$$\chi(x,0,z) = \underbrace{\frac{Q_i \hat{u}}{\kappa u_r x}}_{\chi_v} \times \underbrace{\frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2} \right)}_{\chi_l}$$

$$\hat{u} = \frac{u_r}{u_*}$$

$$\hat{\chi} = \chi u_r / Q_i$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \int u_r^{-1} p(\theta,u_r)\, du_r\, d\theta$$

$$\hat{\chi}(x,0,z) = \underbrace{\frac{\hat{u}}{\kappa x}}_{\chi_v} \times \underbrace{\frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)}_{\chi_l}$$

$$\hat{u} = \frac{u_r}{u_*}$$

$$\hat{\chi} = \chi u_r / Q_i$$

11th Harmonisation Conference Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \langle u_r^{-1}(\theta) \rangle p(\theta)\, d\theta$$

$$\hat{\chi}(x,0,z) = \underbrace{\frac{\hat{u}}{\kappa x}}_{\chi_v} \times \underbrace{\frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{y^2}{2\sigma_y^2} \right)}_{\chi_l}$$

$$\hat{u} = \frac{u_r}{u_*}$$

$$\hat{\chi} = \chi u_r / Q_i$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y)\rangle = \int\int\sum_{i=1}^{N}\chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta)\langle u_r^{-1}(\theta)\rangle p(\theta)\, d\theta$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta) p(\theta,u_r) du_r d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \langle u_r^{-1}(\theta) \rangle p(\theta) d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}_v(x;\theta) \langle u_r^{-1}(\theta) \rangle p(\theta) \chi_l(x,y;\theta) d\theta$$

$$(\hat{\chi}_v = \chi_v u_r)$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int \int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \langle u_r^{-1}(\theta) \rangle p(\theta)\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}_v(x;\theta) \langle u_r^{-1}(\theta) \rangle p(\theta)\, \chi_l(x,y;\theta)\, d\theta$$

$$(\hat{\chi}_v = \chi_v u_r)$$

$$\approx \sum_{i=1}^{N} Q_i \frac{\hat{\chi}_v(x;\theta)}{x} \langle u_r^{-1}(\theta) \rangle p(\theta) \int \chi_l(x,y;\theta)\, dy$$

$$(dy \approx x\, d\theta)$$

11th Harmonisation Conference
Cambridge 2007

$$\langle \chi(x,y) \rangle = \int\int \sum_{i=1}^{N} \chi(x,y;\, u_r,\theta)\, p(\theta,u_r)\, du_r\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}(x,y;\theta) \langle u_r^{-1}(\theta) \rangle p(\theta)\, d\theta$$

$$= \sum_{i=1}^{N} Q_i \int \hat{\chi}_v(x;\theta) \langle u_r^{-1}(\theta) \rangle p(\theta)\, \chi_l(x,y;\theta)\, d\theta$$

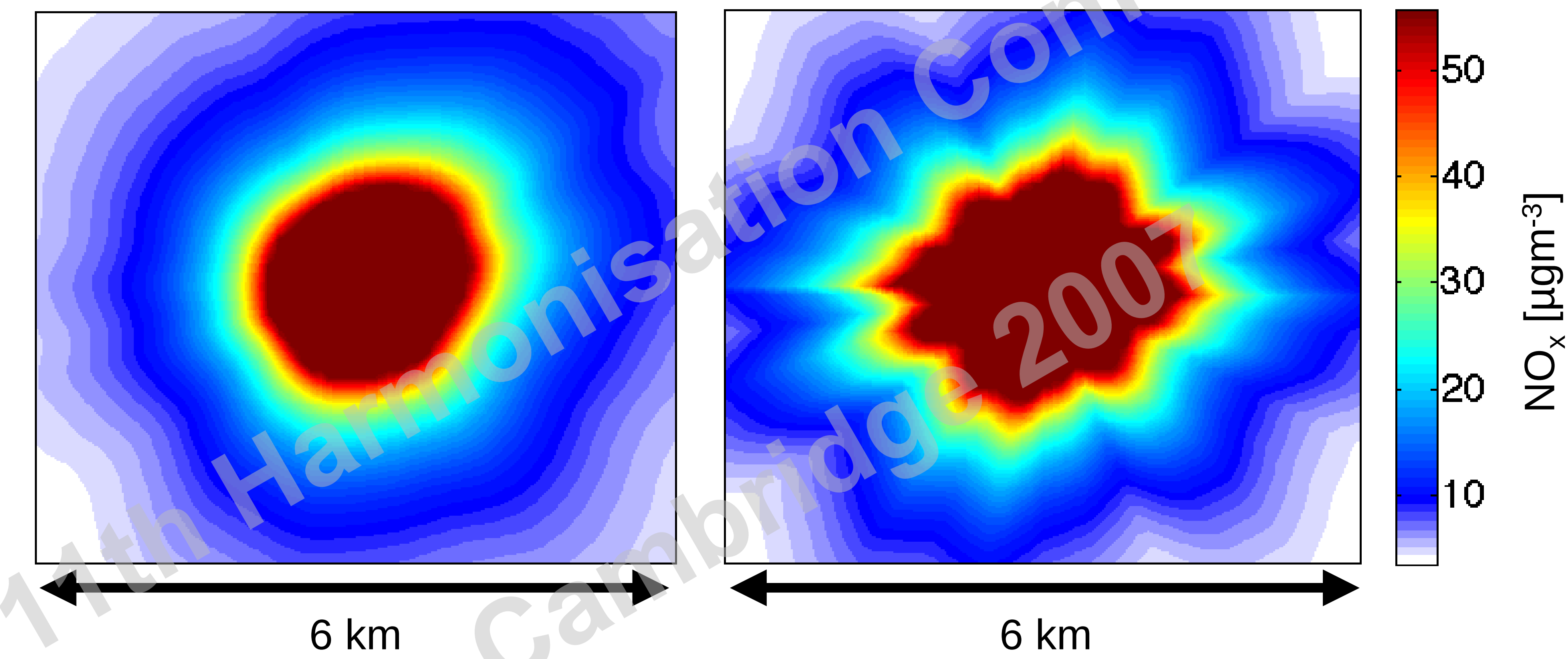
$$(\hat{\chi}_v = \chi_v u_r)$$

$$\approx \sum_{i=1}^{N} Q_i \frac{\hat{\chi}_v(x;\theta)}{x} \langle u_r^{-1}(\theta) \rangle p(\theta) \int \chi_l(x,y;\theta)\, dy$$

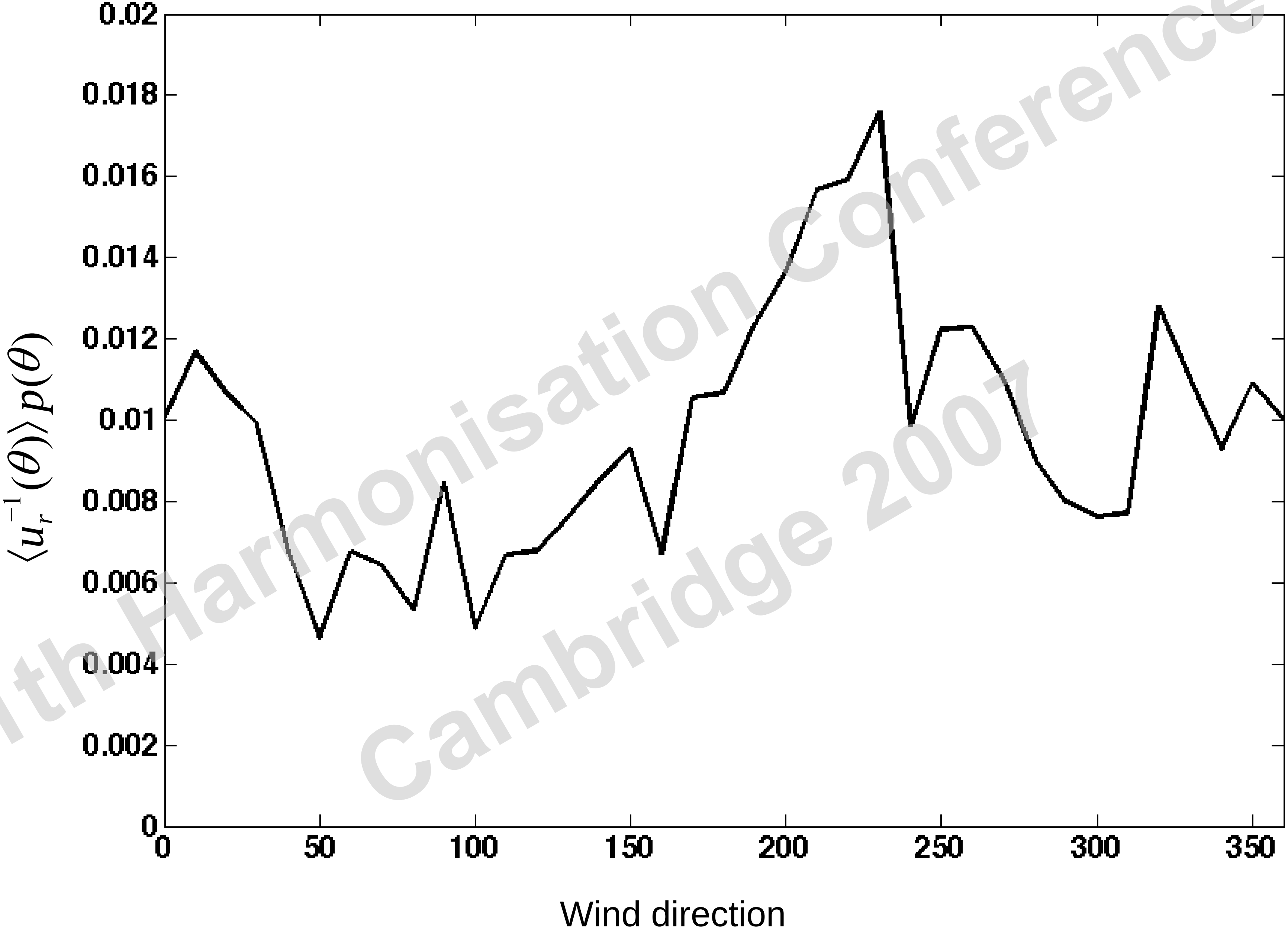
$$(dy \approx x\, d\theta)$$

$$\approx \sum_{i=1}^{N} Q_i \frac{\hat{u}}{\kappa R_i^2} \langle u_r^{-1}(\theta) \rangle p(\theta)$$

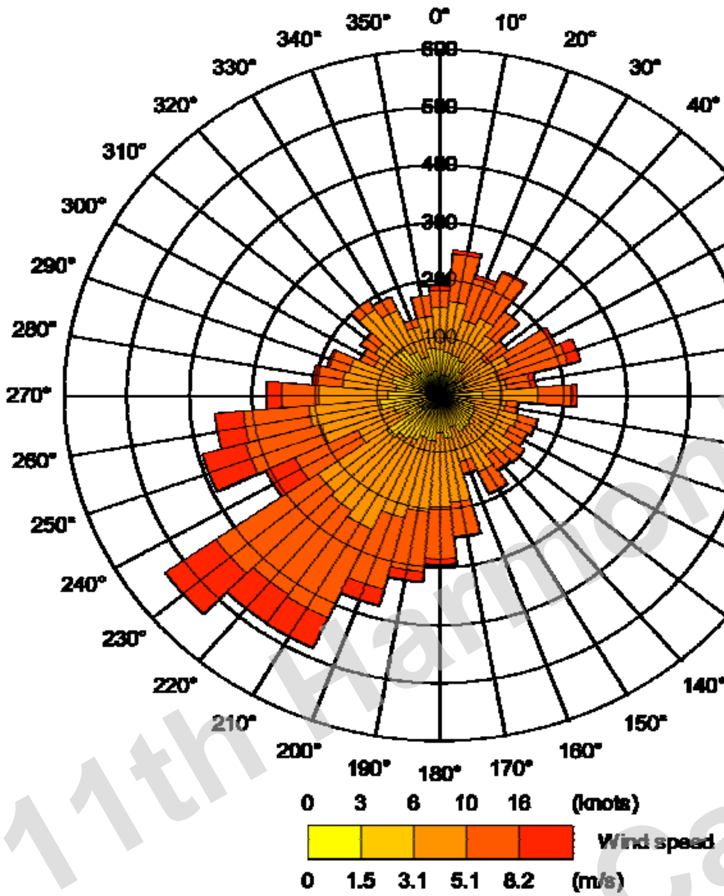
11th Harmonisation Conference
Cambridge 2007

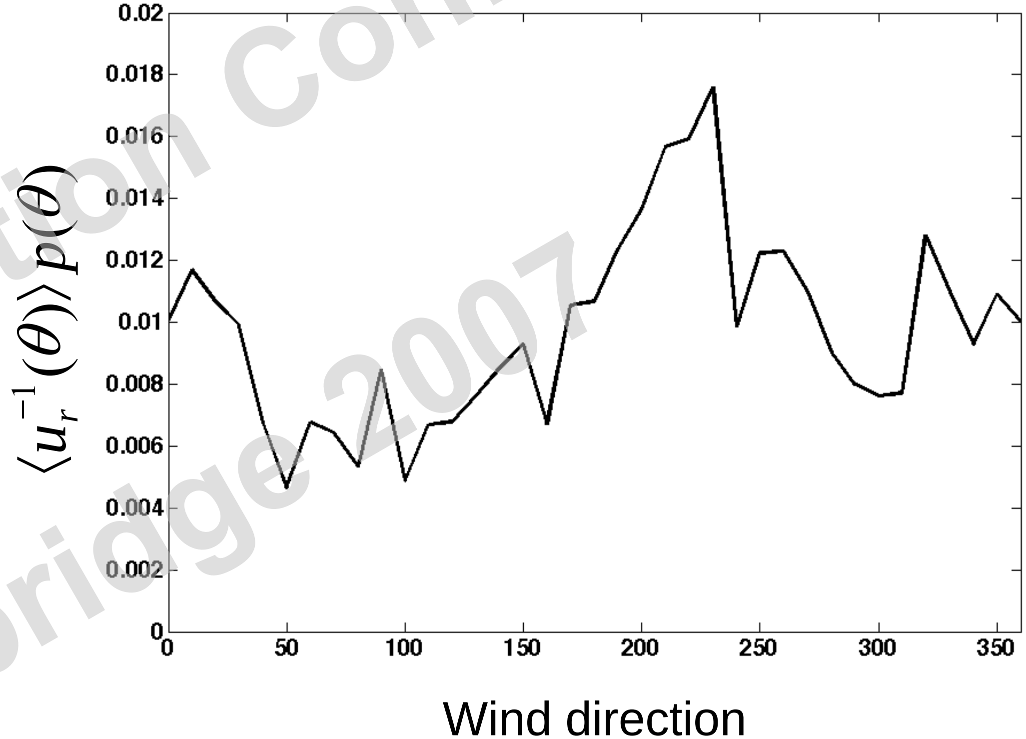


11th Harmonisation Conference Cambridge 2007



11th Harmonisation Conference
Cambridge 2007





11th Harmonisation Conference Cambridge 2007

$$\langle \chi(x,y) \rangle = \iint \chi(x,y;\, u_r, \theta)\, p(\theta, u_r)\, du_r\, d\theta$$

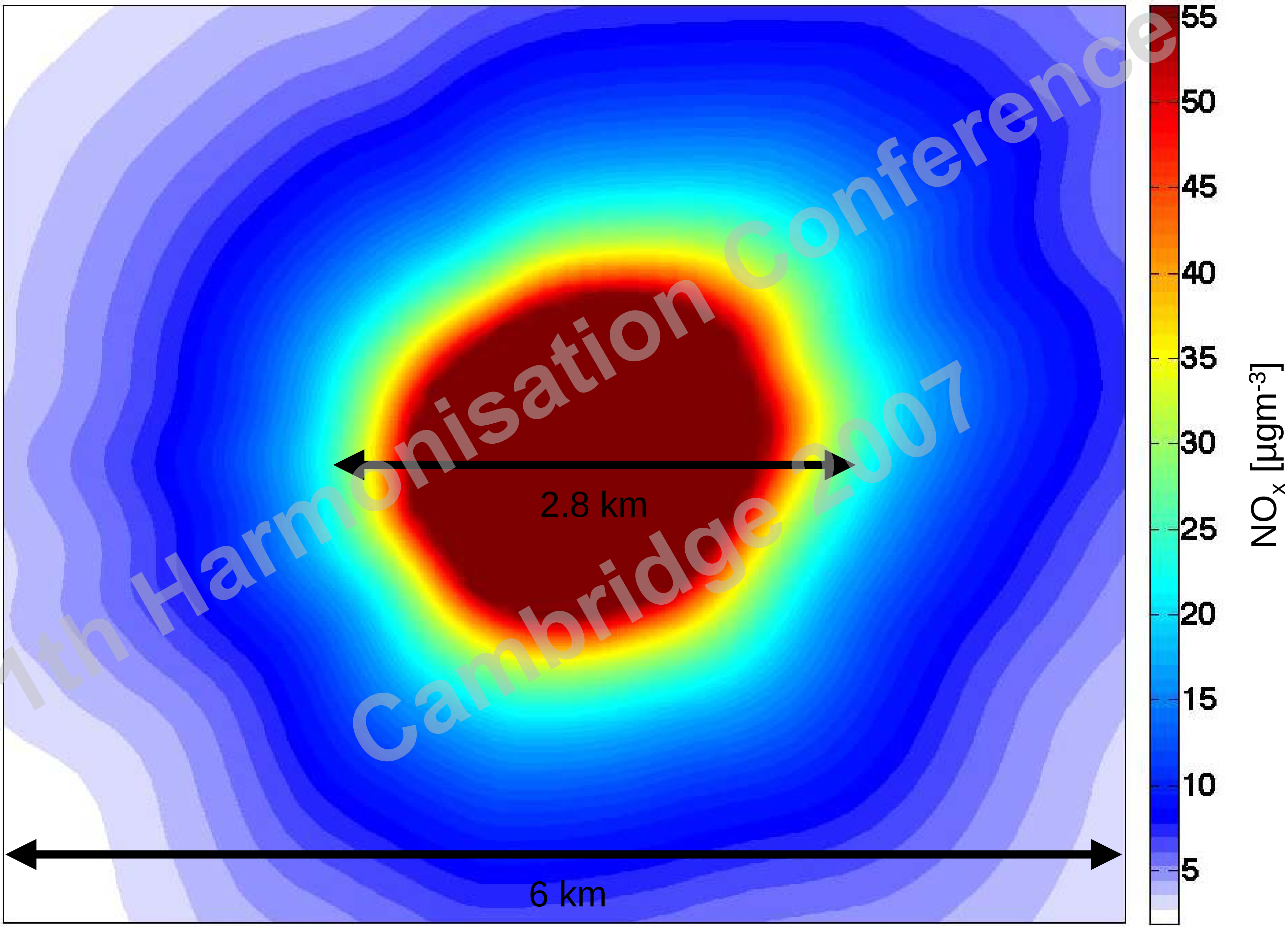
$$p(\theta) = \frac{1}{2\pi}$$

$$\langle u_r \rangle^{-1} \sim \langle u_r^{-1} \rangle$$

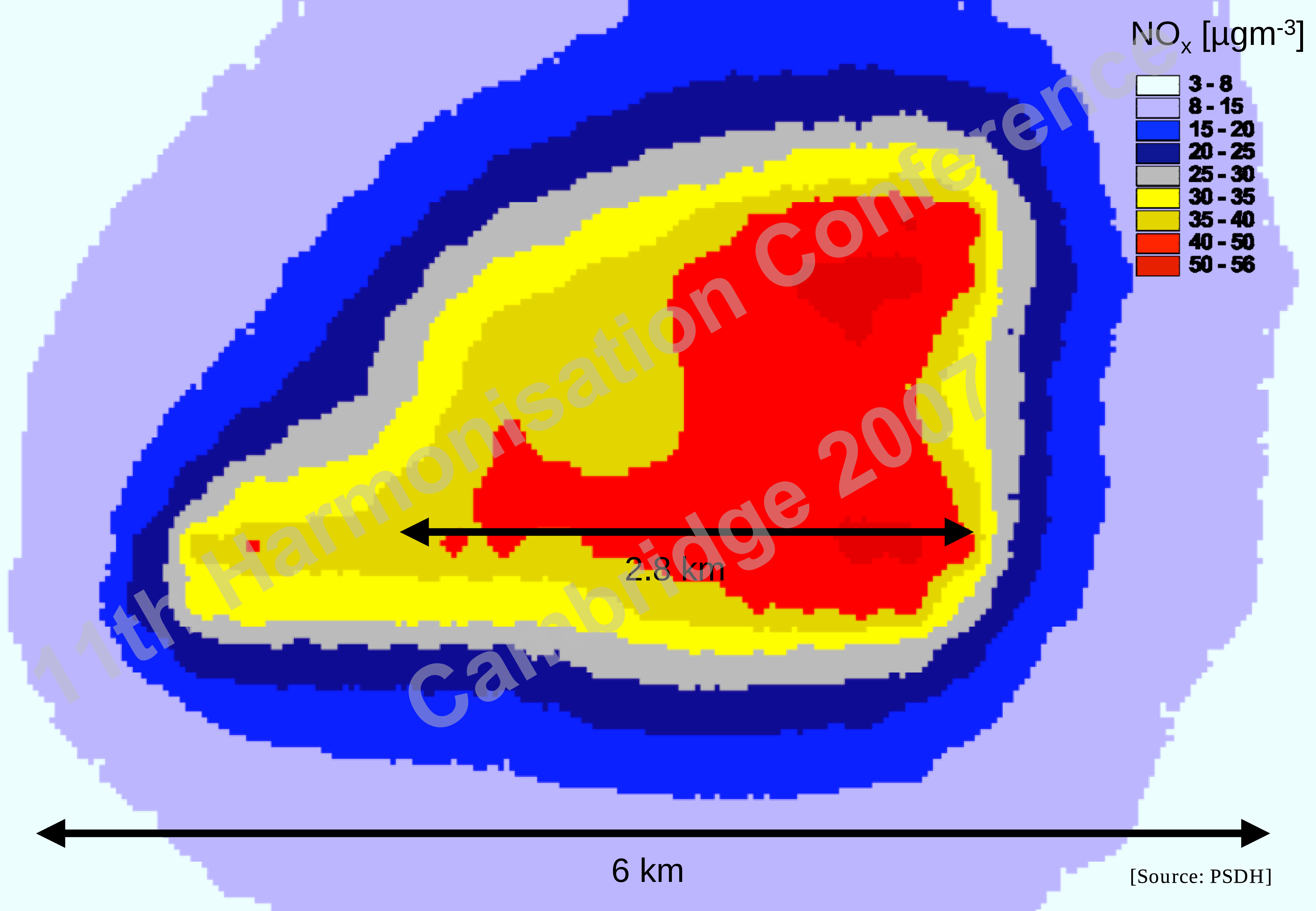
$$A_r^* = \frac{Q\hat{u}}{\kappa \langle u_r \rangle \chi_r}$$

$$\chi_r = 50\, \mu\text{g/m}^3 \quad \Rightarrow \quad A_r^* = 6.2\, \text{km}^2$$

11th Harmonisation Conference
Cambridge 2007

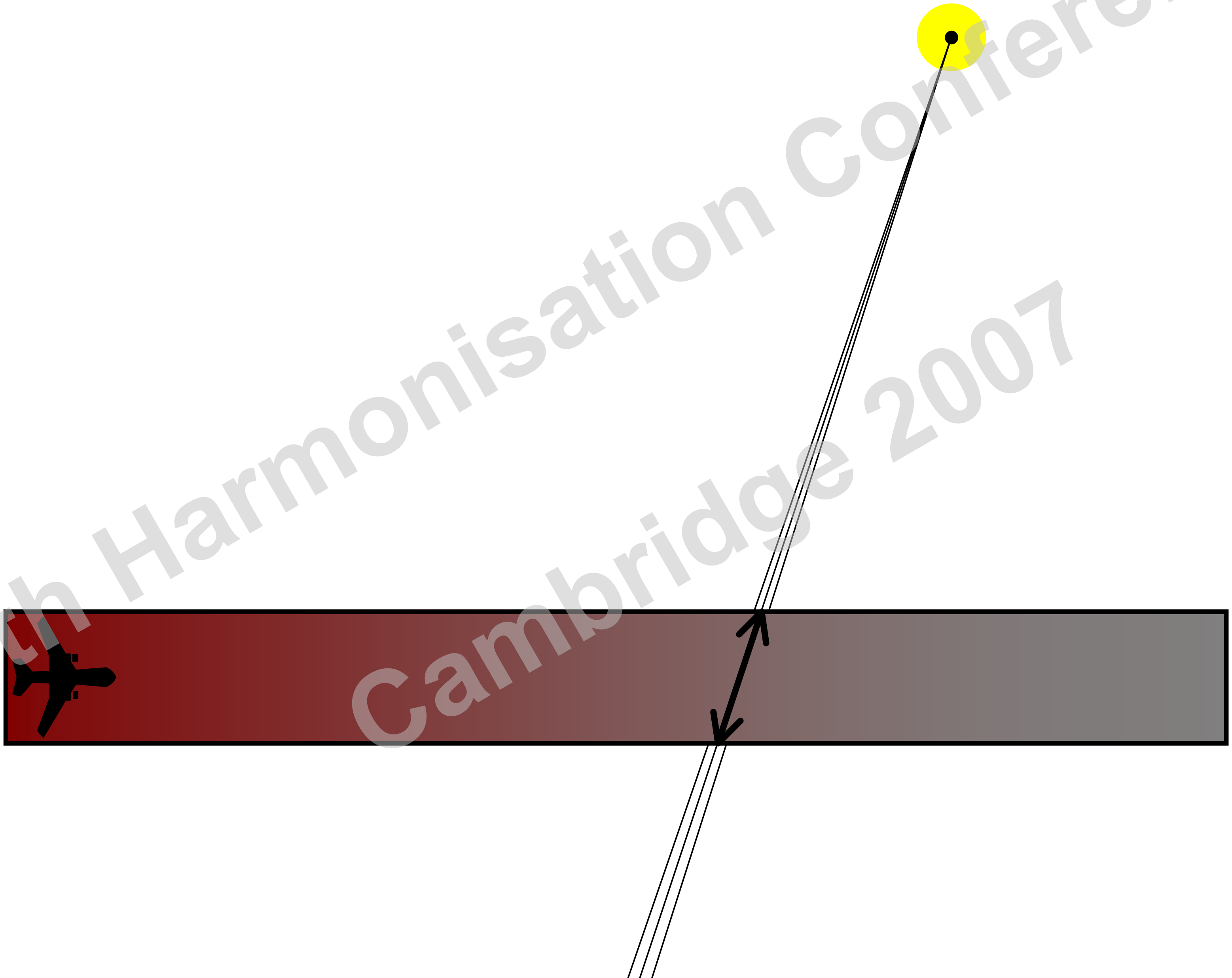


11th Harmonisation Conference
Cambridge 2007

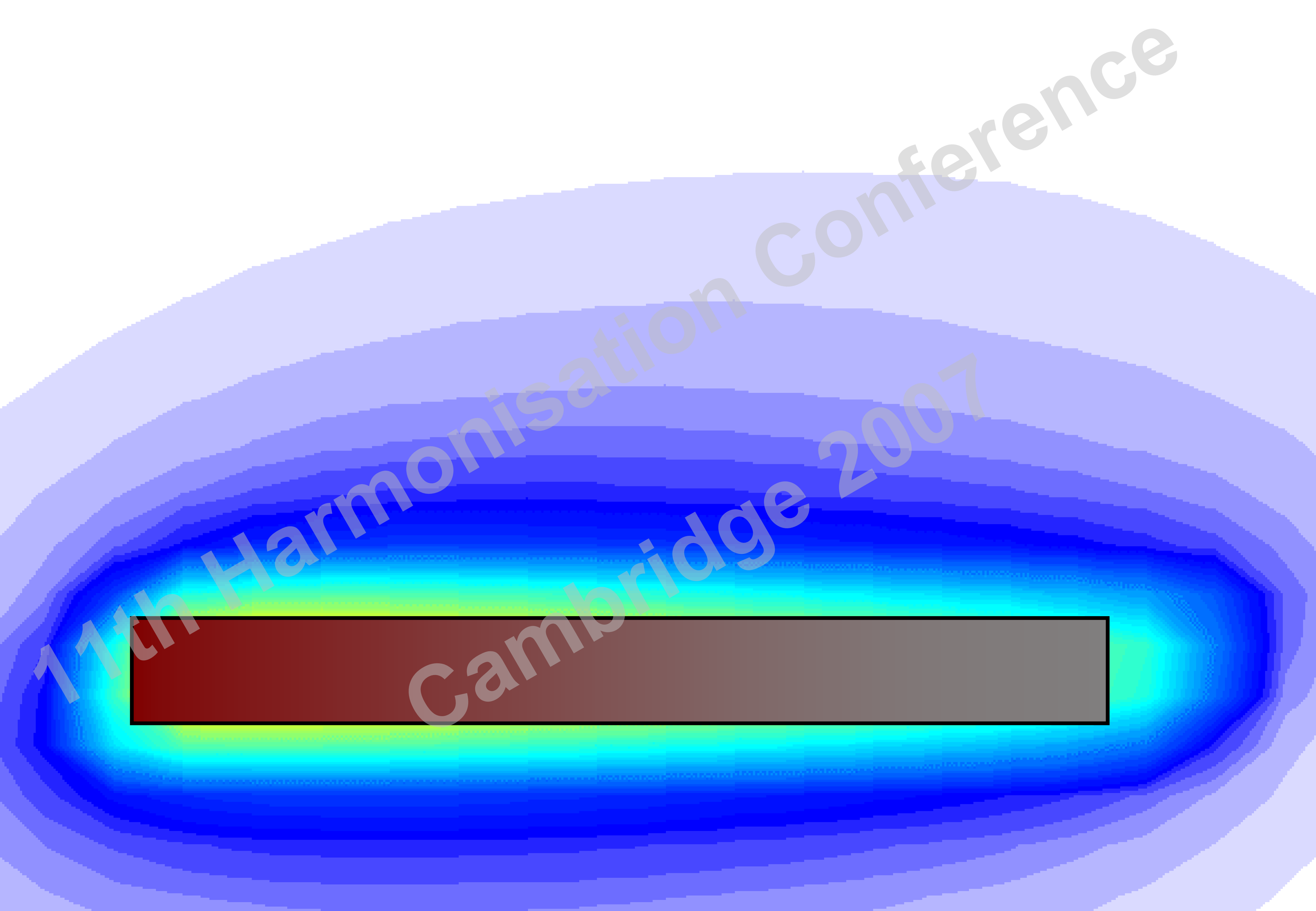


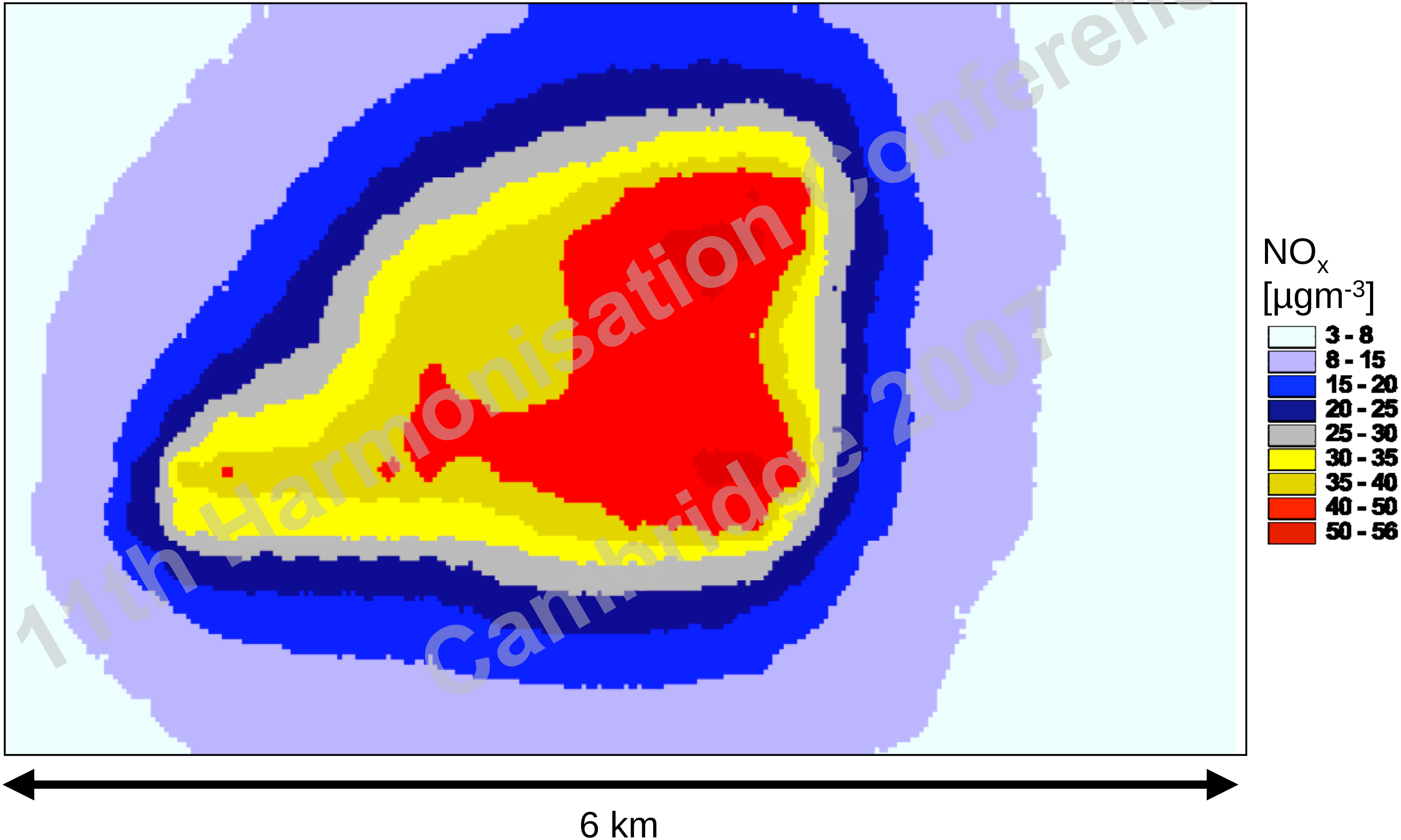
11th Harmonisation Conference Cambridge 2007


11th Harmonisation Conference
Cambridge 20



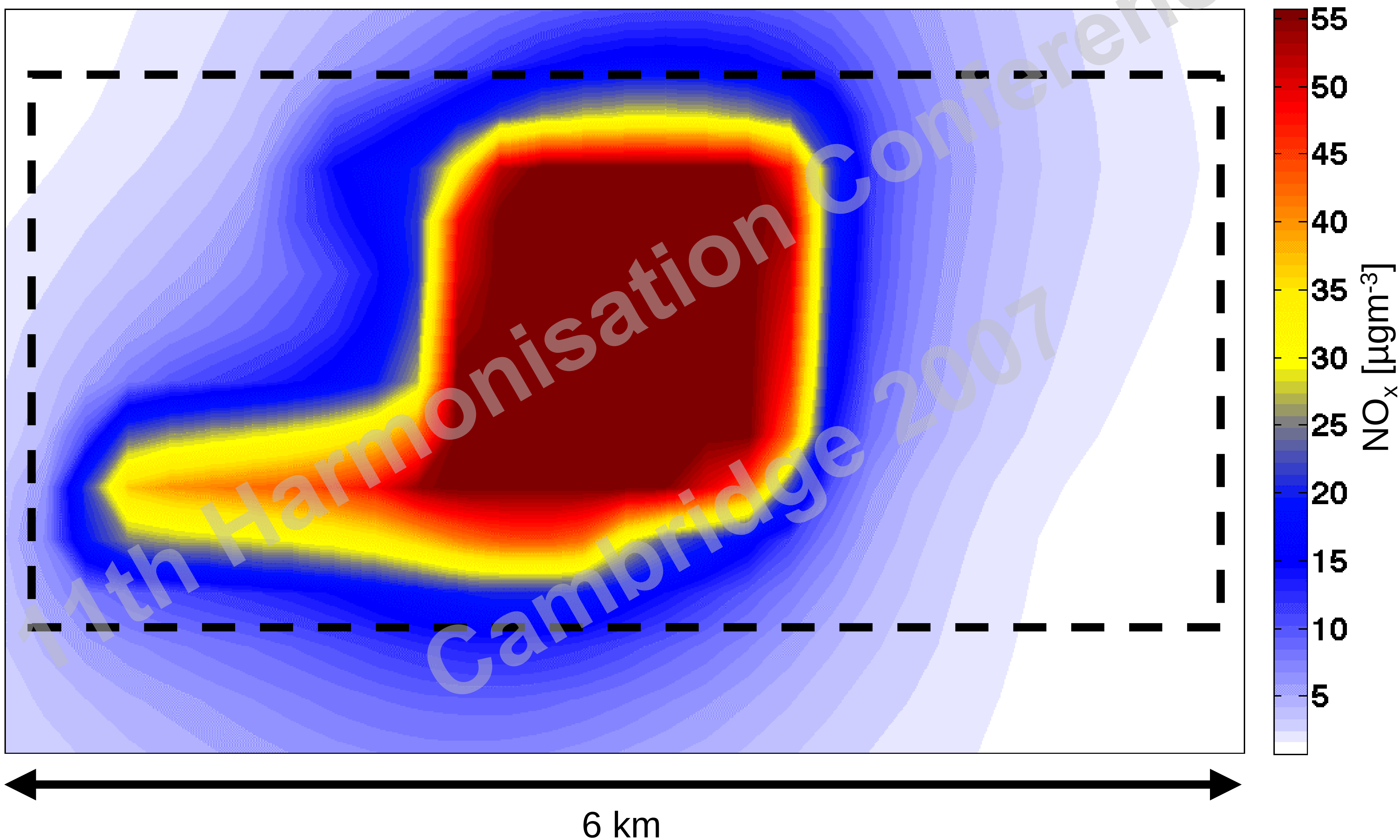
11th Harmonisation Conference
Cambridge 2007


11th Harmonisation Conference
Cambridge 2007



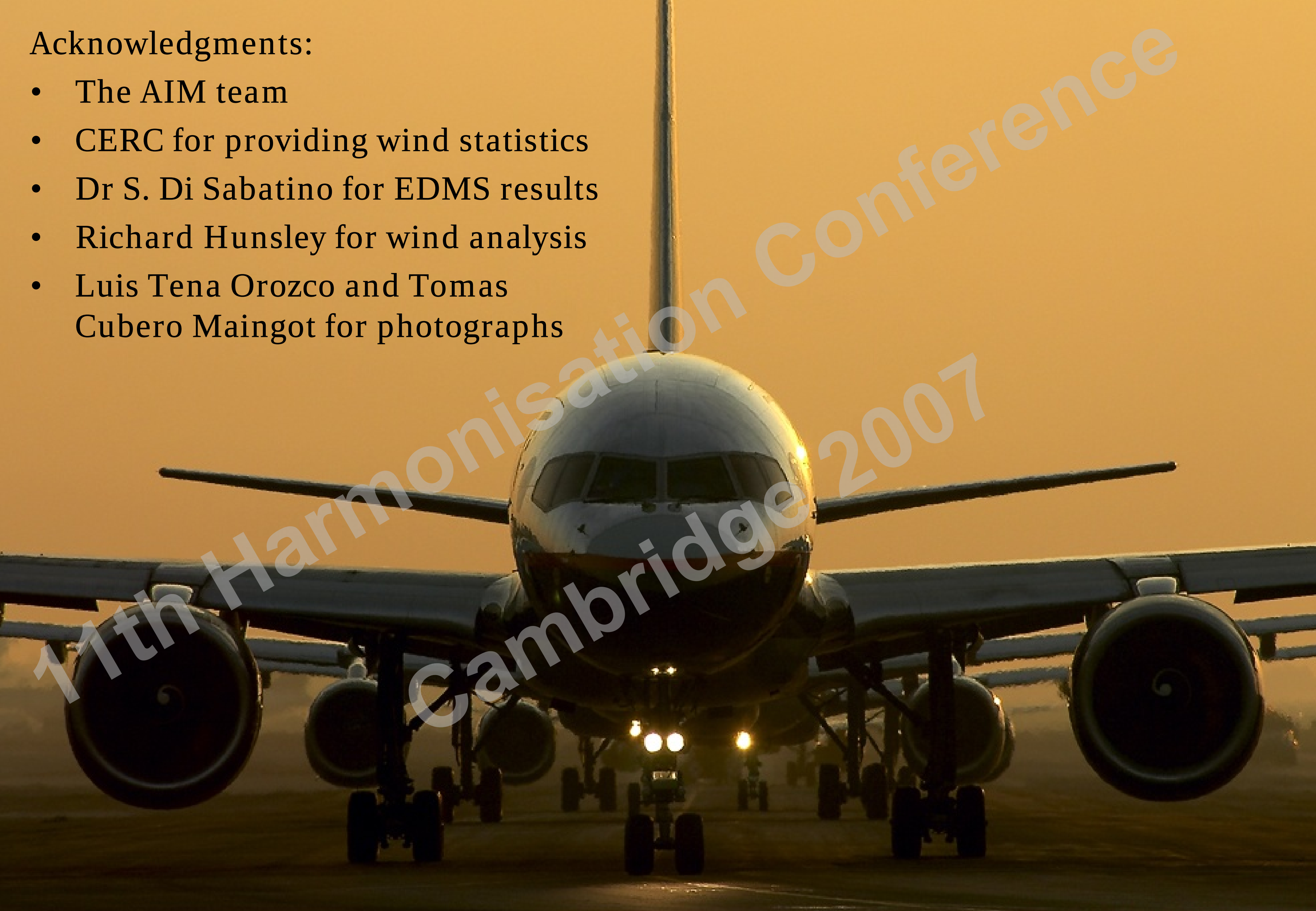
11th Harmonisation Conference Cambridge 2007

[Source: PSDH]



11th Harmonisation Conference
Cambridge 2007

Acknowledgments:
- The AIM team
- CERC for providing wind statistics
- Dr S. Di Sabatino for EDMS results
- Richard Hunsley for wind analysis
- Luis Tena Orozco and Tomas Cubero Maingot for photographs



11th Harmonisation Conference
Cambridge 2007

Aviation Integrated Modelling Project

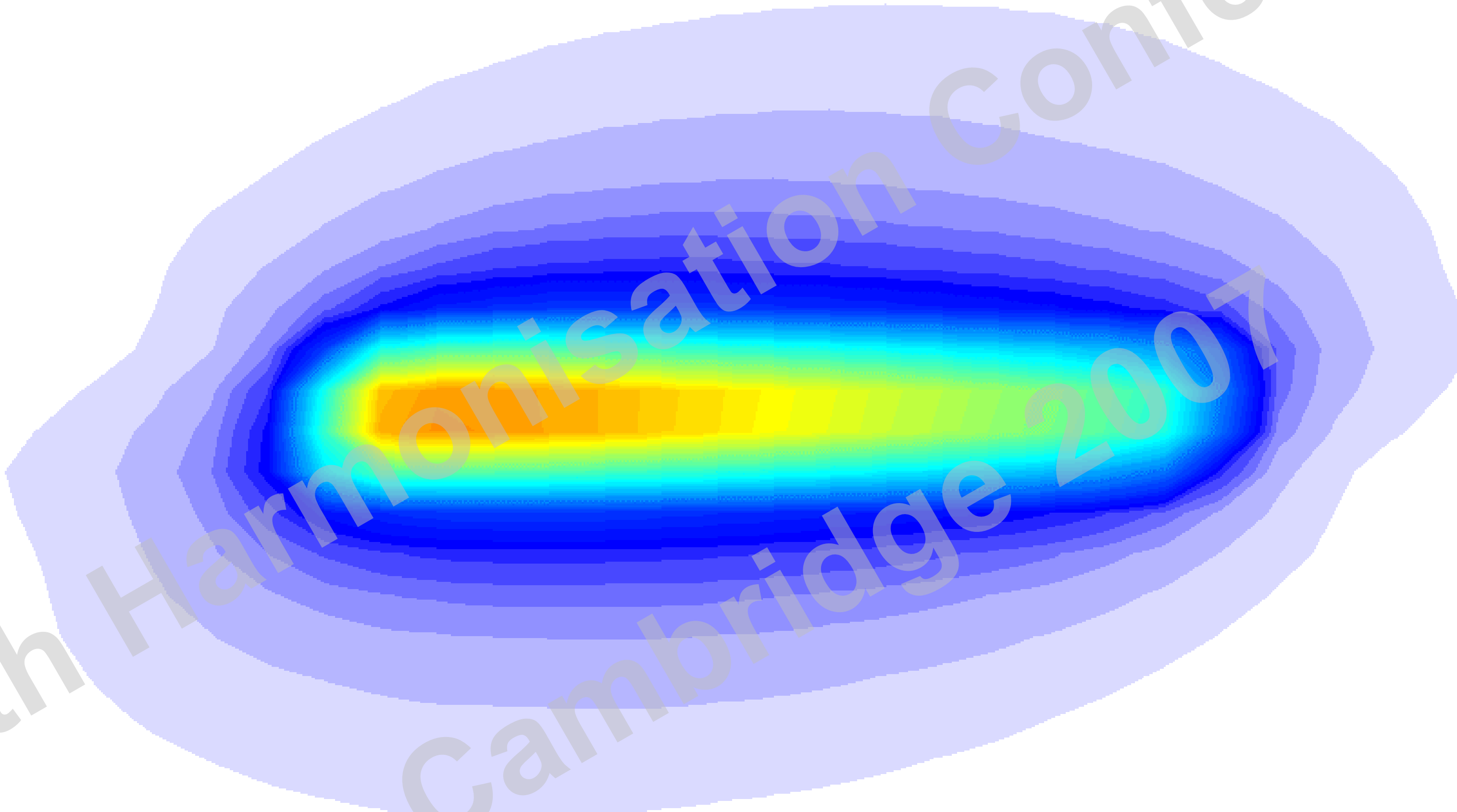
www.AIMproject.aero

11th Harmonisation Conference
Cambridge 2007

Overview of assumptions and restrictions

Assumption/Restriction	Rationale
Emissions represented as ground level sources, neglect influence of emissions at altitude	As a baseline we neglect all above-ground emissions to reduce user burden in the context of a simple screening model, *Wayson and Fleming* (2000) results show impact of emissions at altitude
Buoyancy, trailing vortices, downwash, jet momentum neglected	Interpretation of CERC study for PSDH indicates this will be acceptable for a screening model, reduced user burden
Dispersion considered for conserved scalars only	Appropriate for PM over time scales of interest, NO_x chemistry can be applied empirically (e.g. *Jenkin*, 2004)
Single roughness length	Reduced user burden, average concentrations would have ~15% error if z_0 had a factor of two error, *Hanna and Britter* (2002)
Very low wind conditions neglected	Use of minimum wind speed
Neutral conditions assumed	Assumed for simplicity and reduced user burden, acceptable given typically $\|L\|^{-1} \sim 0.01\ m^{-1}$ in urban conditions, where L is the Monin-Obukhov length (see *Hanna and Britter*, 2002)
Only long-term averages can be calculated	Corresponds to most immediate regulatory constraint
Flat urban airport	Often applicable, required for other assumptions

11th Harmonisation Conference Cambridge 2007



11th Harmonisation conference
Cambridge 2007

11th Harmonisation Conference
Cambridge 2007

AIM