Workshop on boundary-layer budget CO_2 flux methods
Gubbio, Italy, October 5-8, 2000

A Modeling Framework to Interpret Atmospheric Data and Evaluate Sampling Strategies

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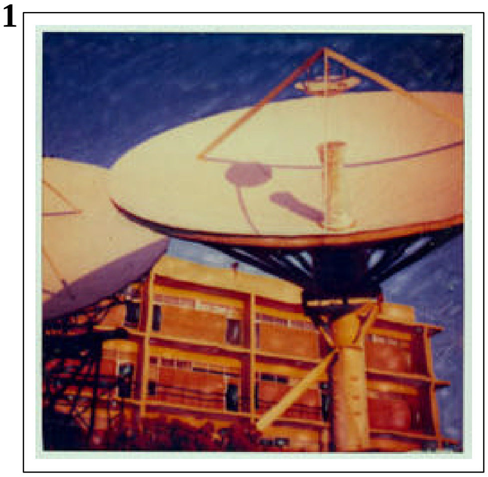


Ultimate research goal:

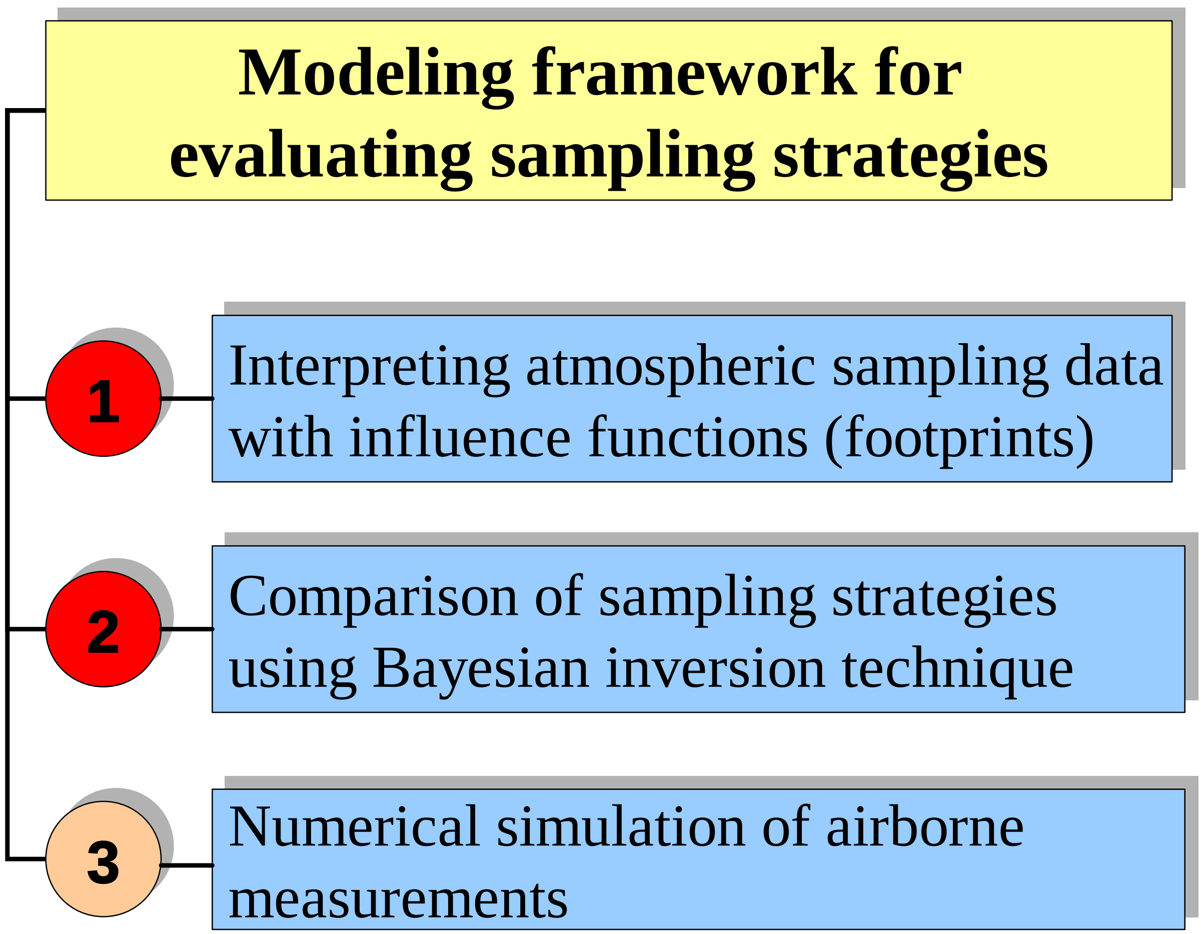
Estimation of mesoscale and regional terrestrial CO_2 fluxes from available data

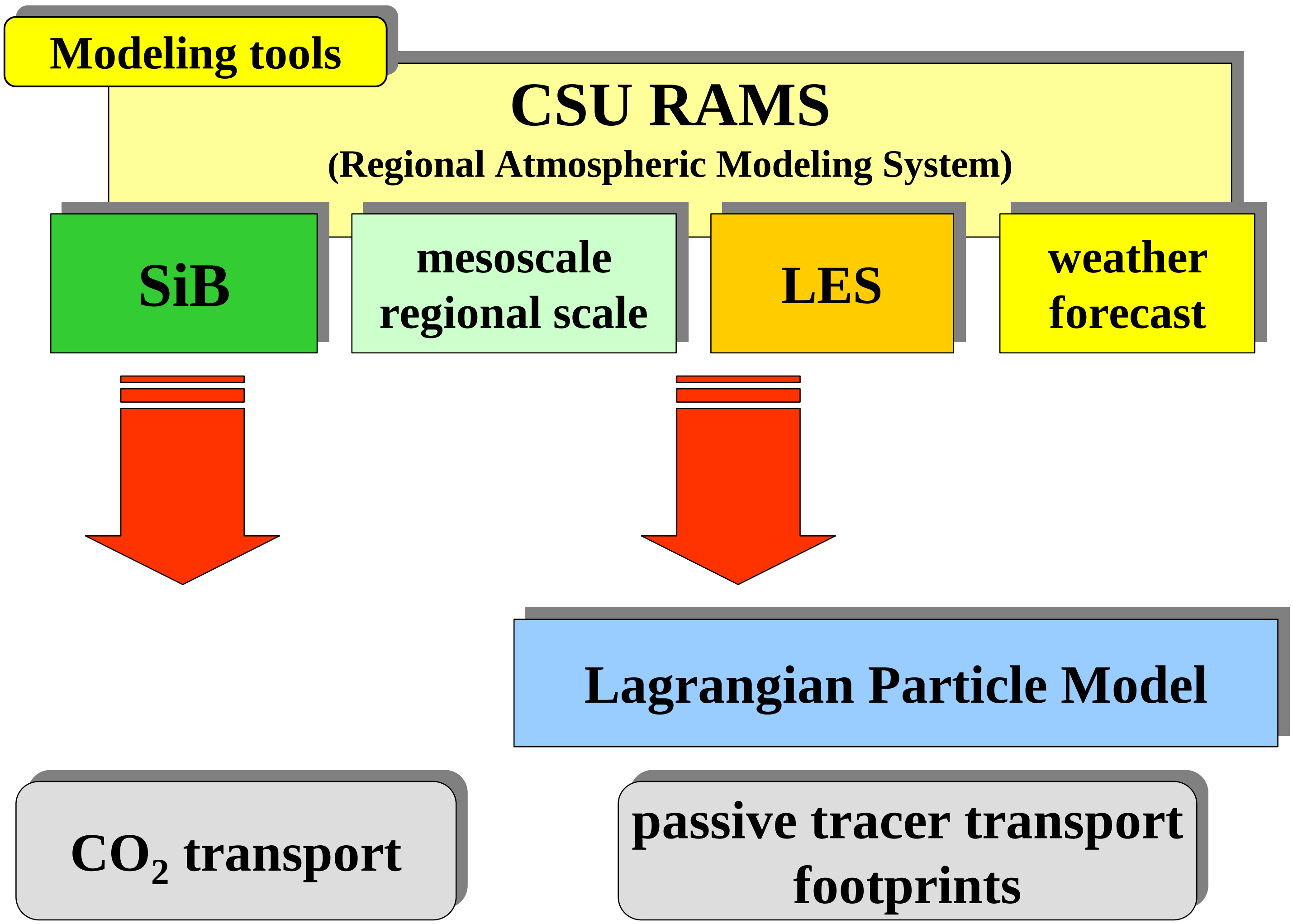
Research goals:

Interpretation of atmospheric sampling data

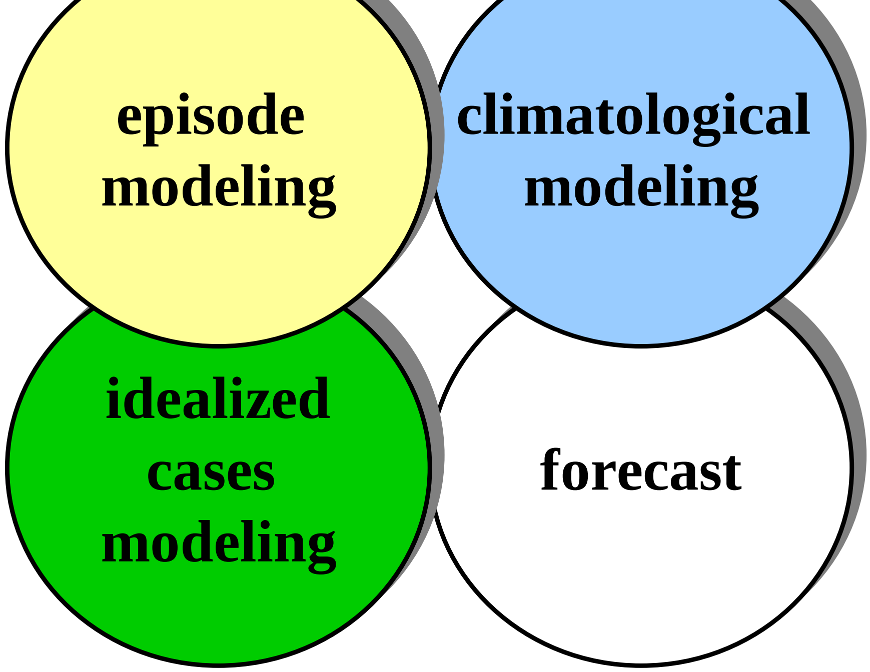
What information on surface fluxes can be retrieved from atmospheric data?

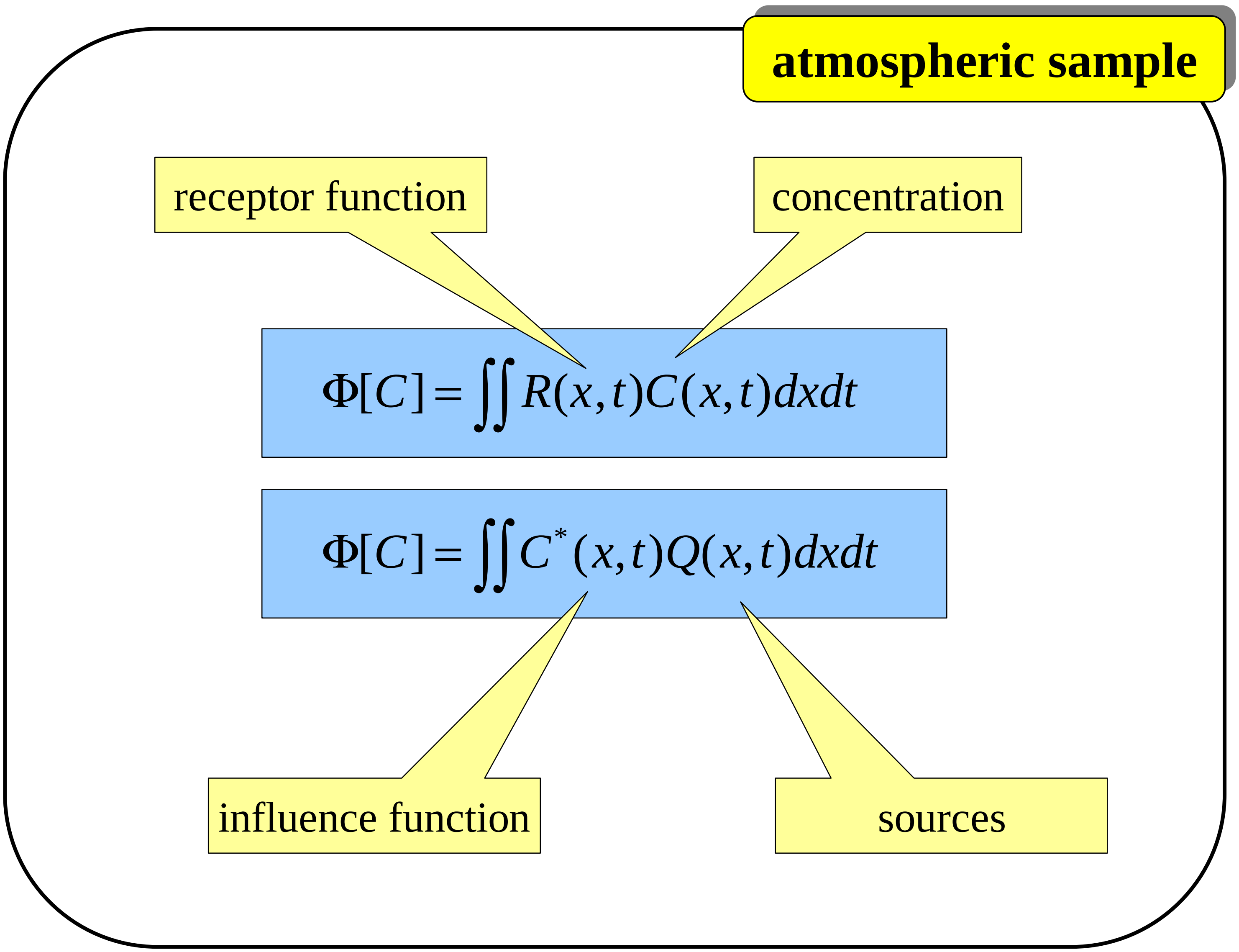
Design of aircraft sampling:
where and when to fly ?


Modeling framework for evaluating sampling strategies
1
Interpreting atmospheric sampling data with influence functions (footprints)
2
Comparison of sampling strategies using Bayesian inversion technique
3
Numerical simulation of airborne measurements


Modeling tools
CSU RAMS
(Regional Atmospheric Modeling System)
SiB
mesoscale
regional scale
LES
weather
forecast
Lagrangian Particle Model
CO_2 transport
passive tracer transport
footprints

Modeling approaches to atmospheric transport




atmospheric sample
receptor function
concentration
$\Phi[C] = \iint R(x,t)C(x,t)dxdt$
$\Phi[C] = \iint C^*(x,t)Q(x,t)dxdt$
influence function
sources

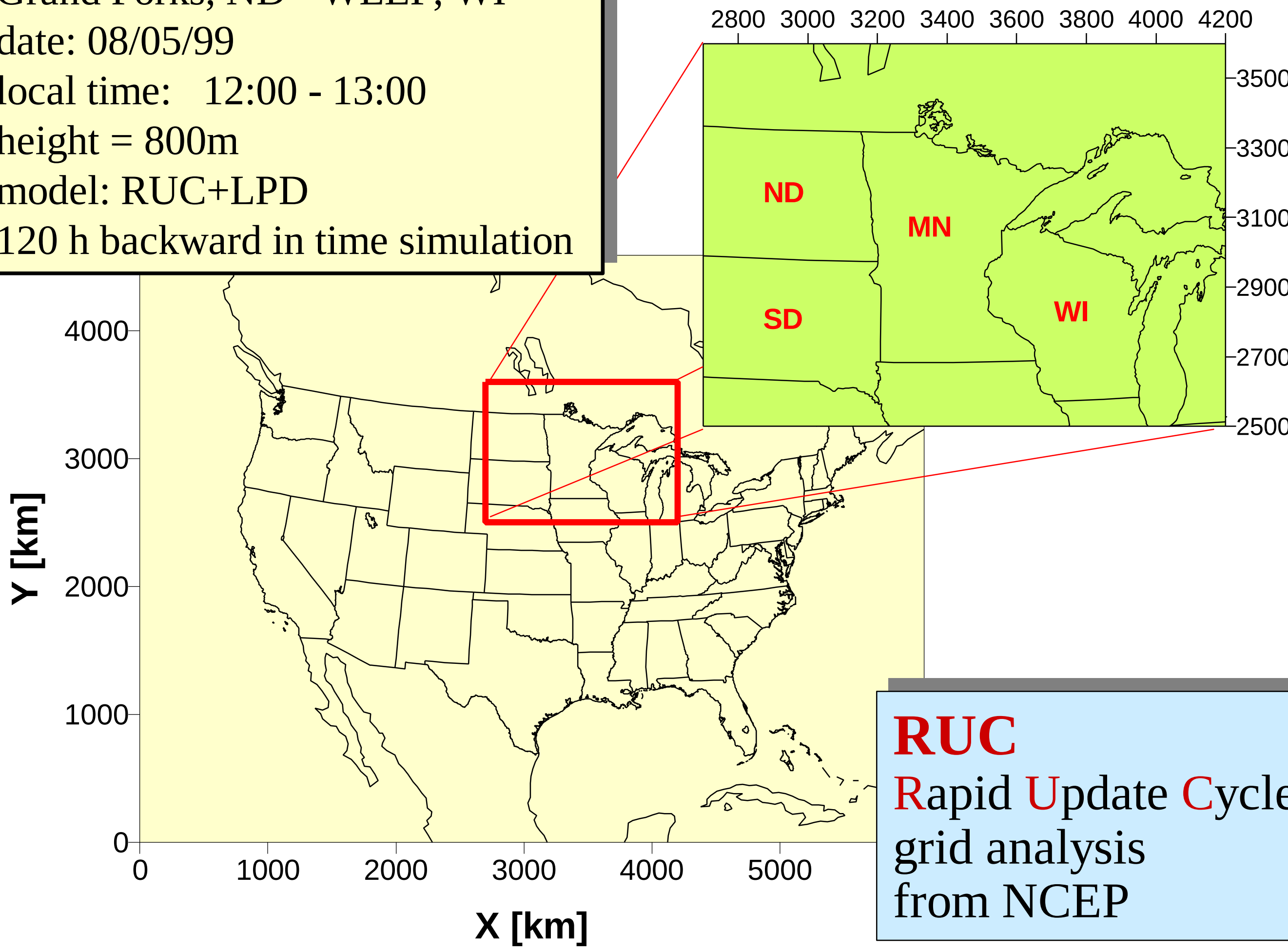
terminology

- footprints
- influence functions
- Green functions
- source areas

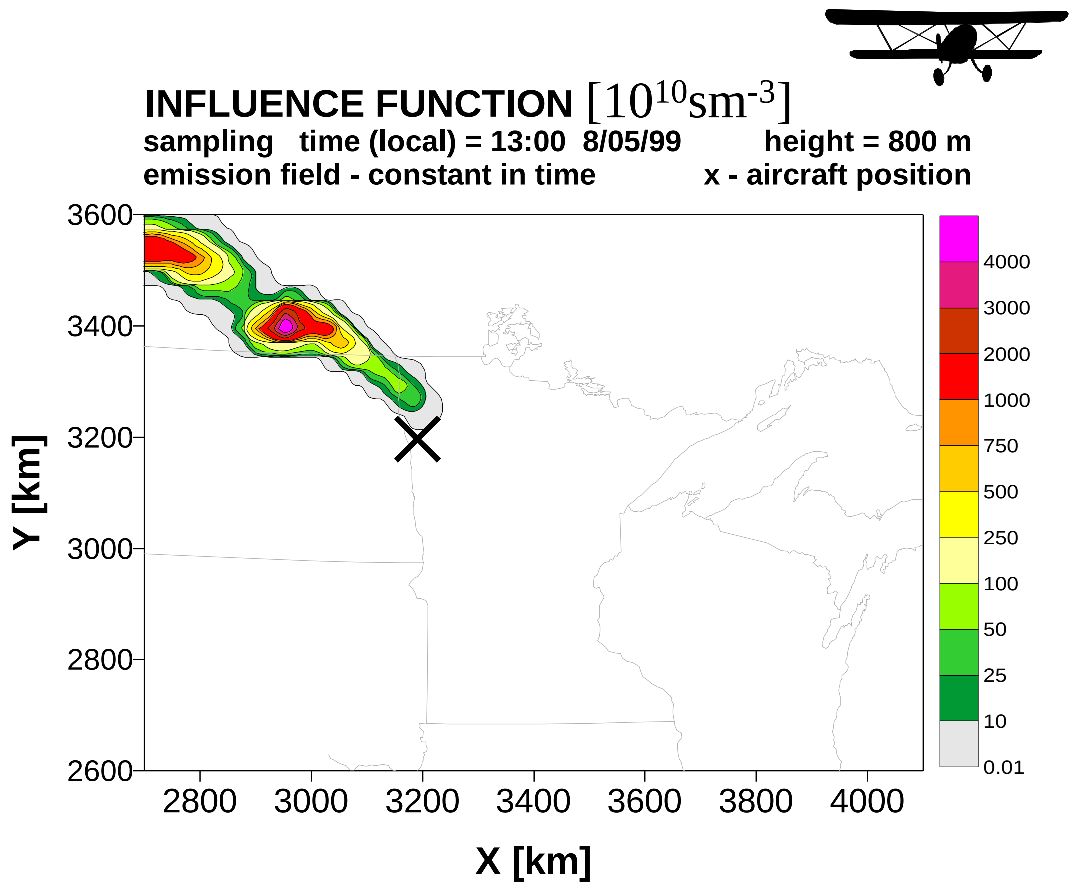
Examples of influence functions (footprints)

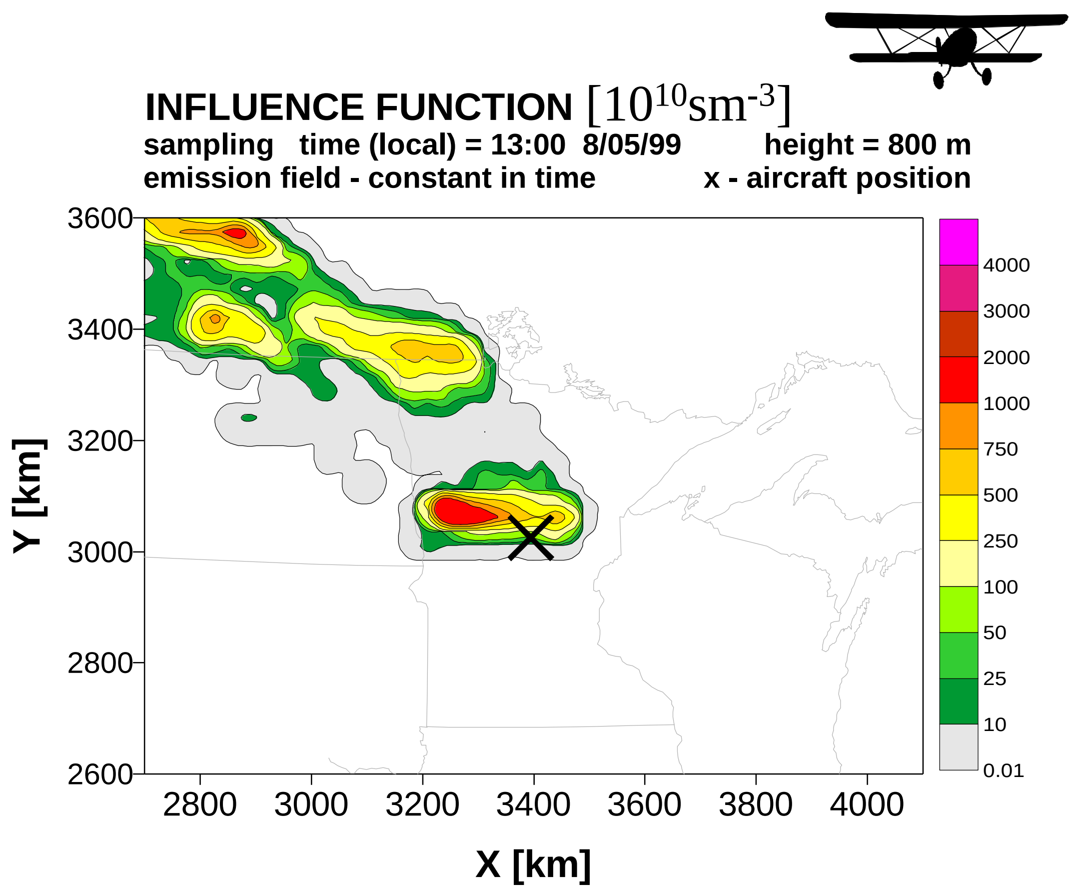
Grand Forks, ND - WLEF, WI
date: 08/05/99
local time: 12:00 - 13:00
height = 800m
model: RUC+LPD
120 h backward in time simulation

Influence functions for concentration samples during hypothetical flight



RUC
Rapid Update Cycle
grid analysis
from NCEP


INFLUENCE FUNCTION [10^10sm^-3]
sampling time (local) = 13:00 8/05/99
height = 800 m
emission field - constant in time
x - aircraft position
Y [km]
3600
3400
3200
3000
2800
2600
X [km]
2800
3000
3200
3400
3600
3800
4000
4000
3000
2000
1000
750
500
250
100
50
25
10
0.01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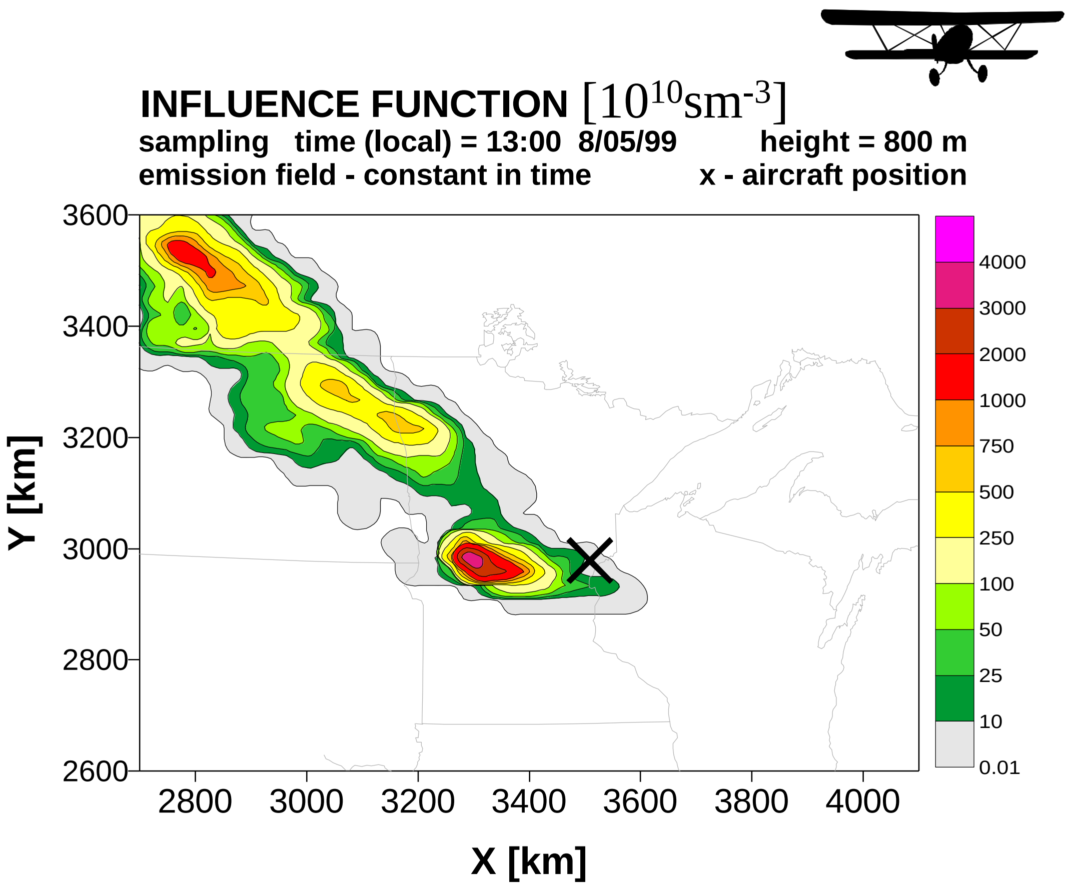
Y [km]
2800
3000
3200
3400
3600
3800
4000
X [km]
4000
3000
2000
1000
750
500
250
100
50
25
10
0.01



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3800
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2000
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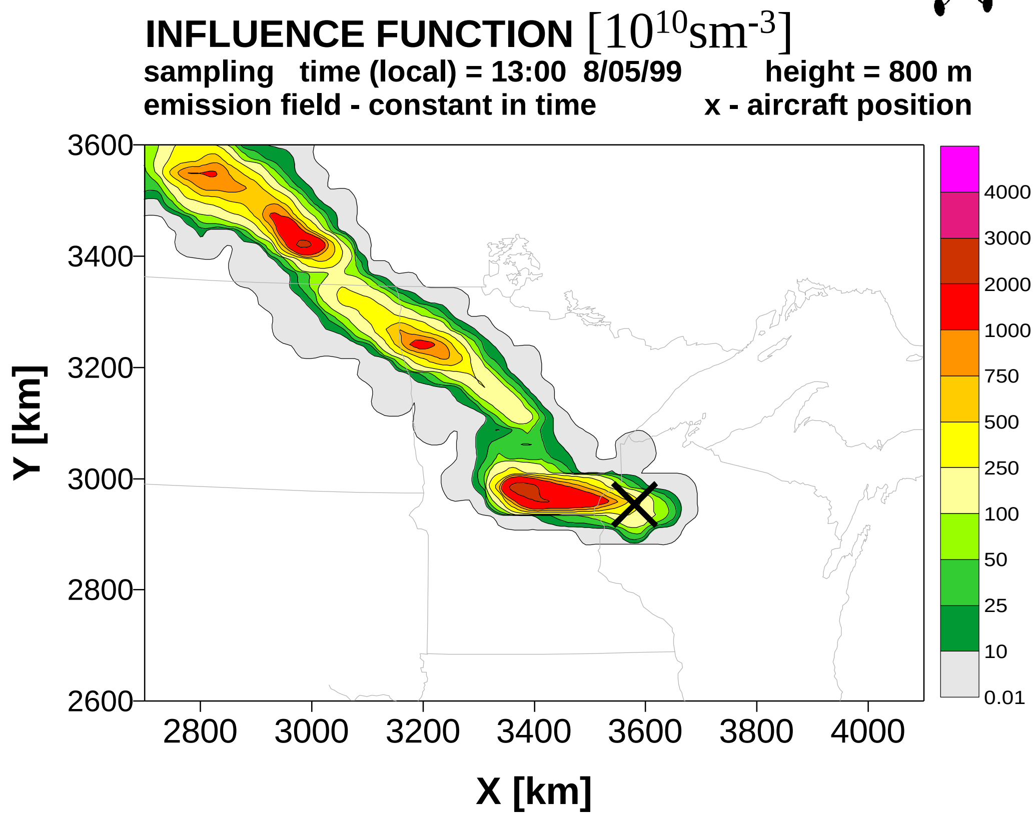
750
500
250
100
50
25
10
0.01



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0.01

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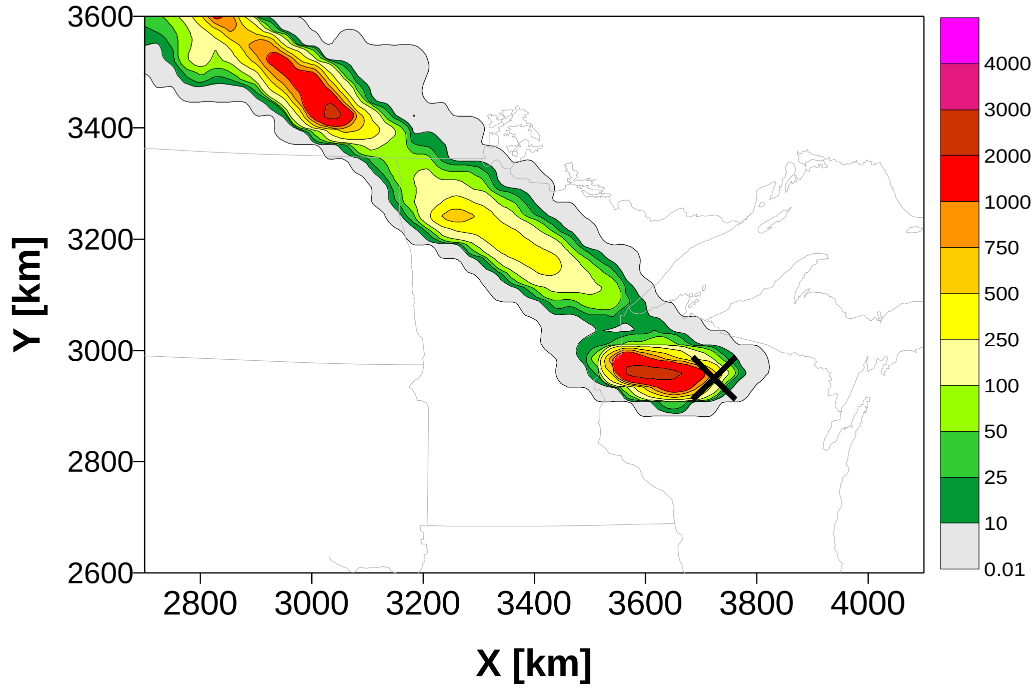
sampling time (local) = 13:00 8/05/99 height = 800 m

emission field - constant in time x - aircraft position

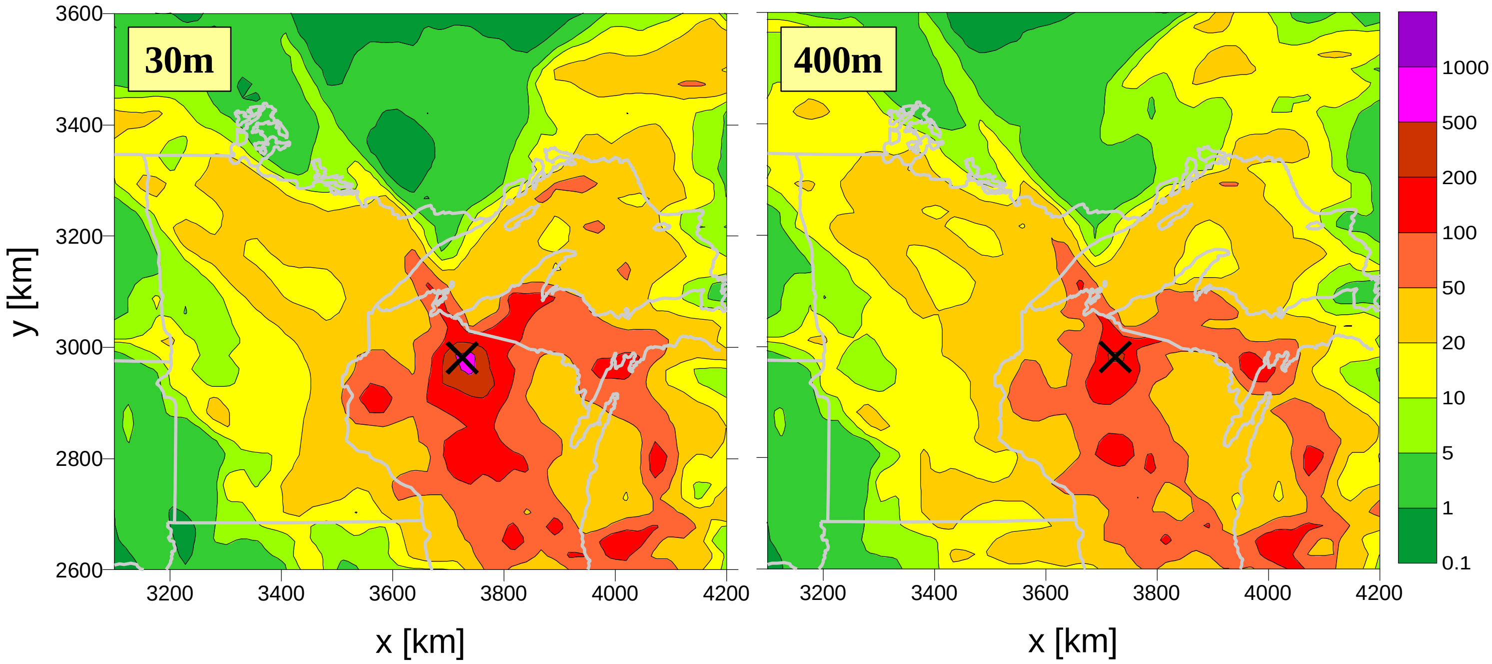


averaging period: August 1999

WLEF tower

Influence function [10^{10} sm^{-3}]

emission field: constant in time

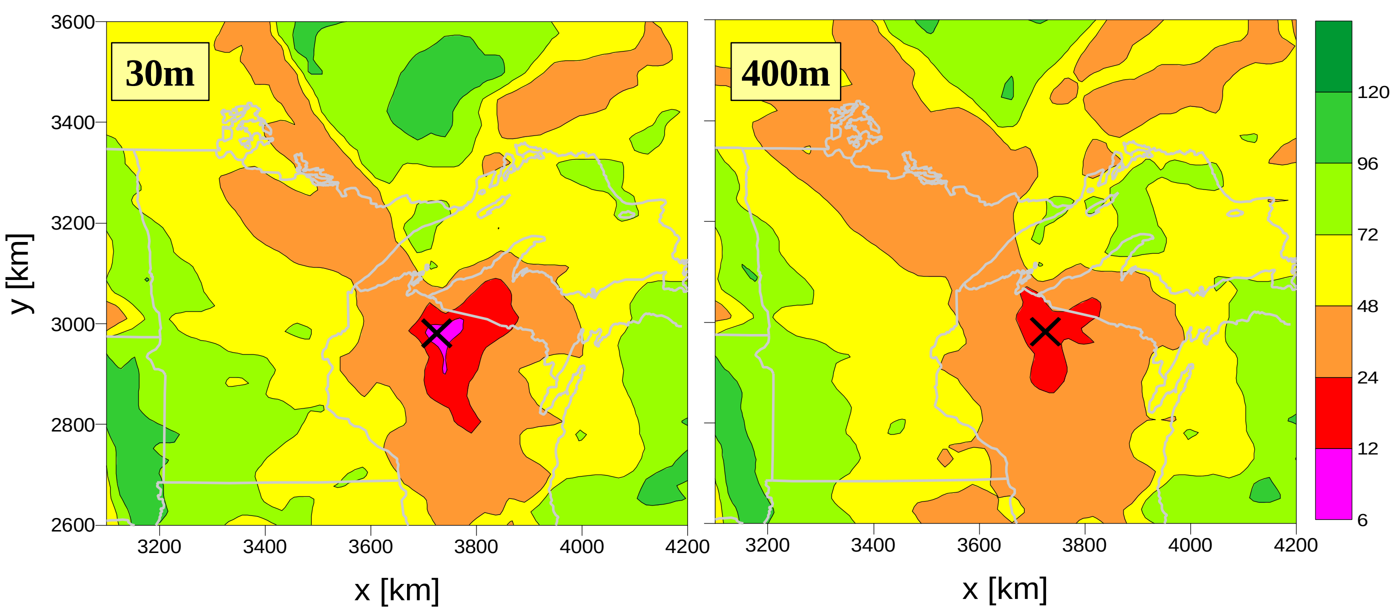


averaging period: August 1999

WLEF tower

Mean travel time [h]

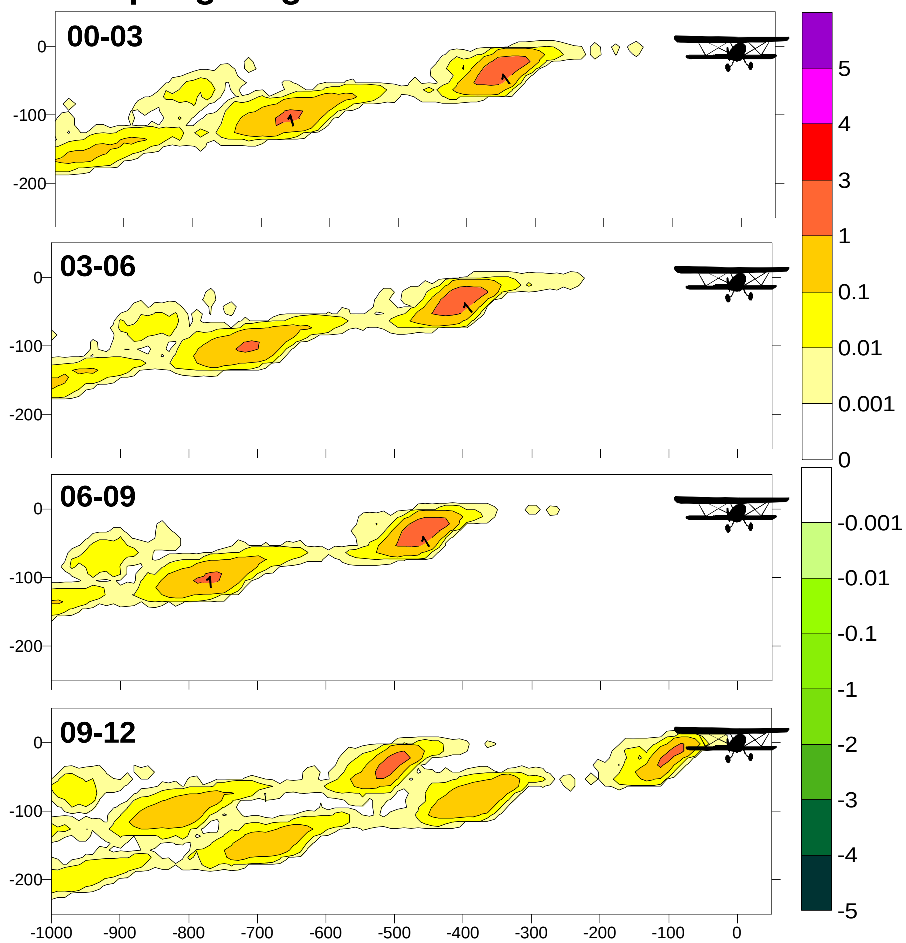
emission field: constant in time



1-D PBL model:
idealized diurnal cycle over homogeneous terrain

influence functions derived from LPDM:
Lagrangian particles traced backward in time for 4 days

influence functions for different sampling times
emision: respiration flux (const)
sampling height 1500 m



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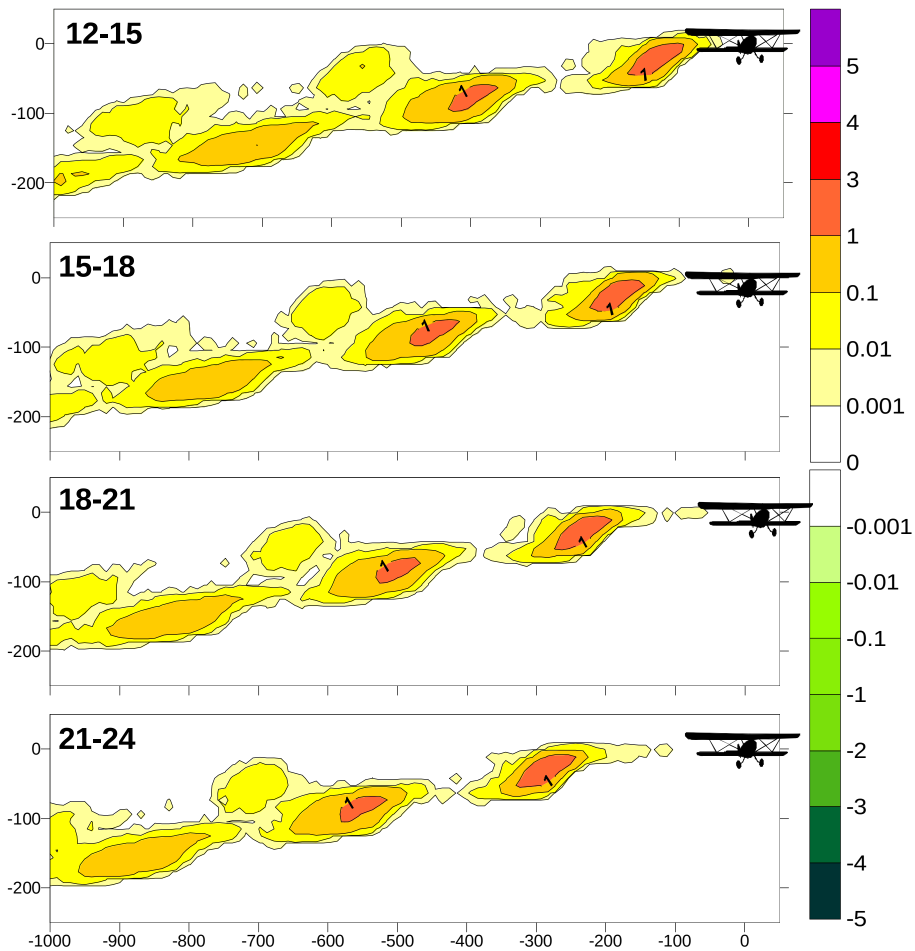

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Lagrangian particles traced backward in time for 4 days

influence functions for different sampling times
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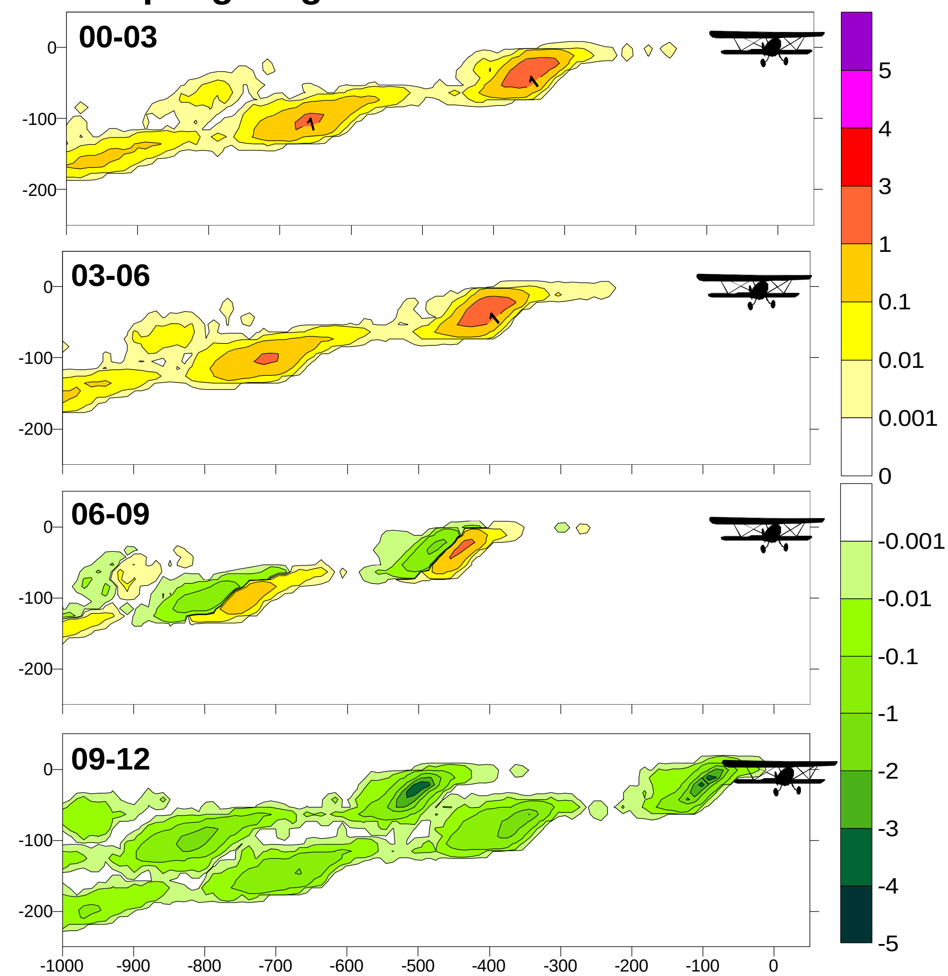

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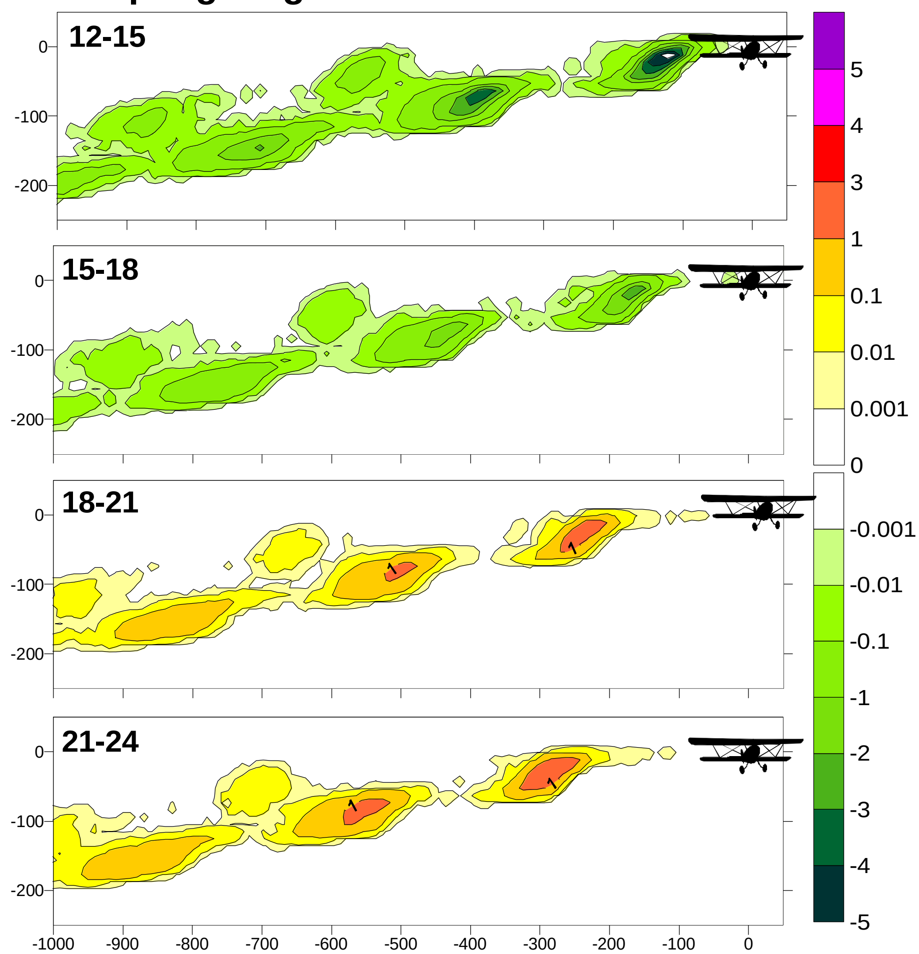
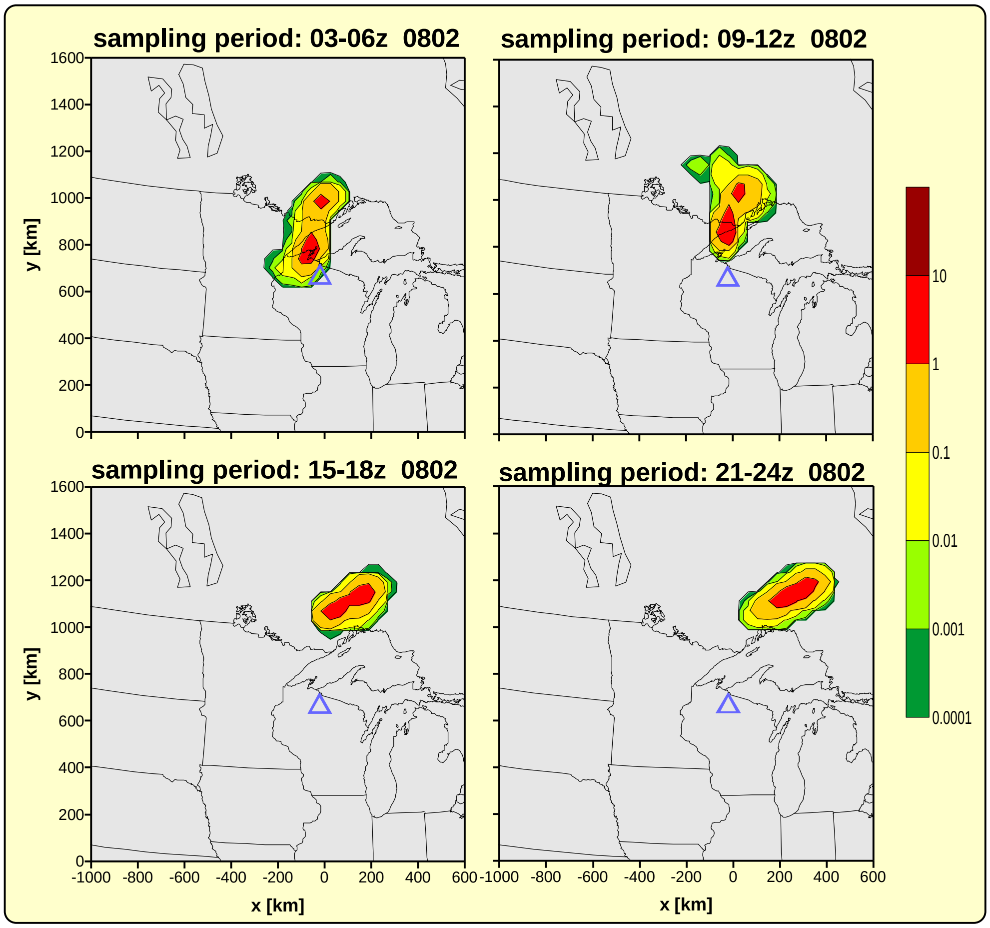
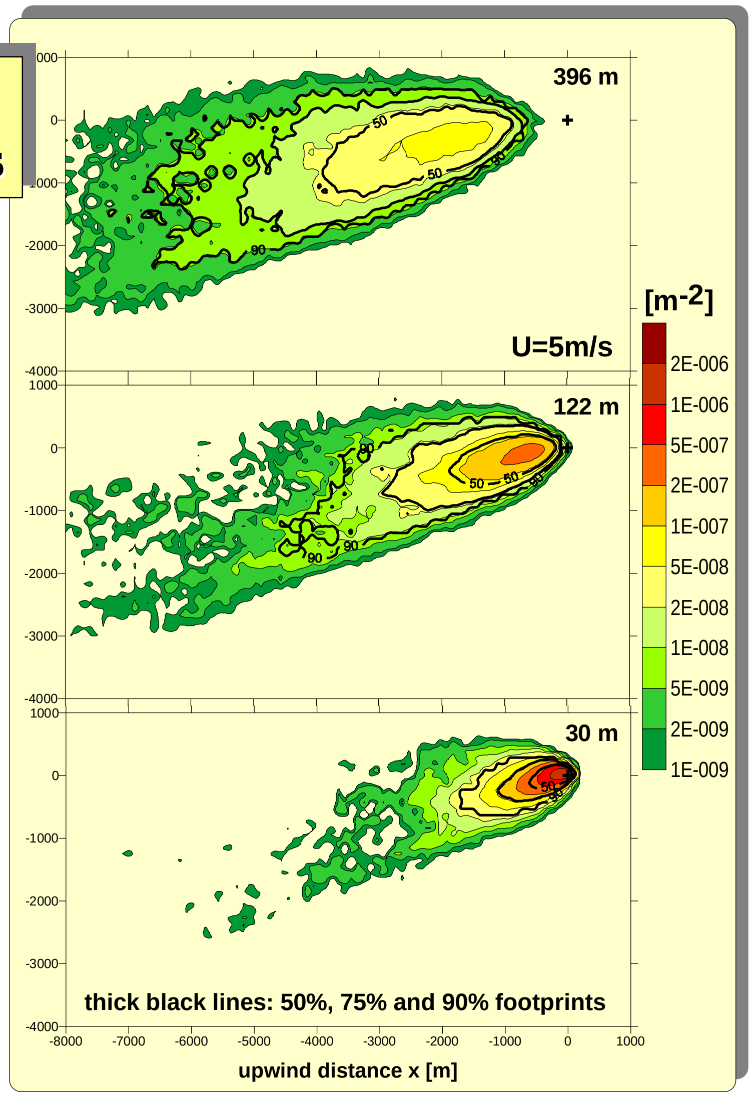


CSU RAMS/LPDM forecast for the COBRA project

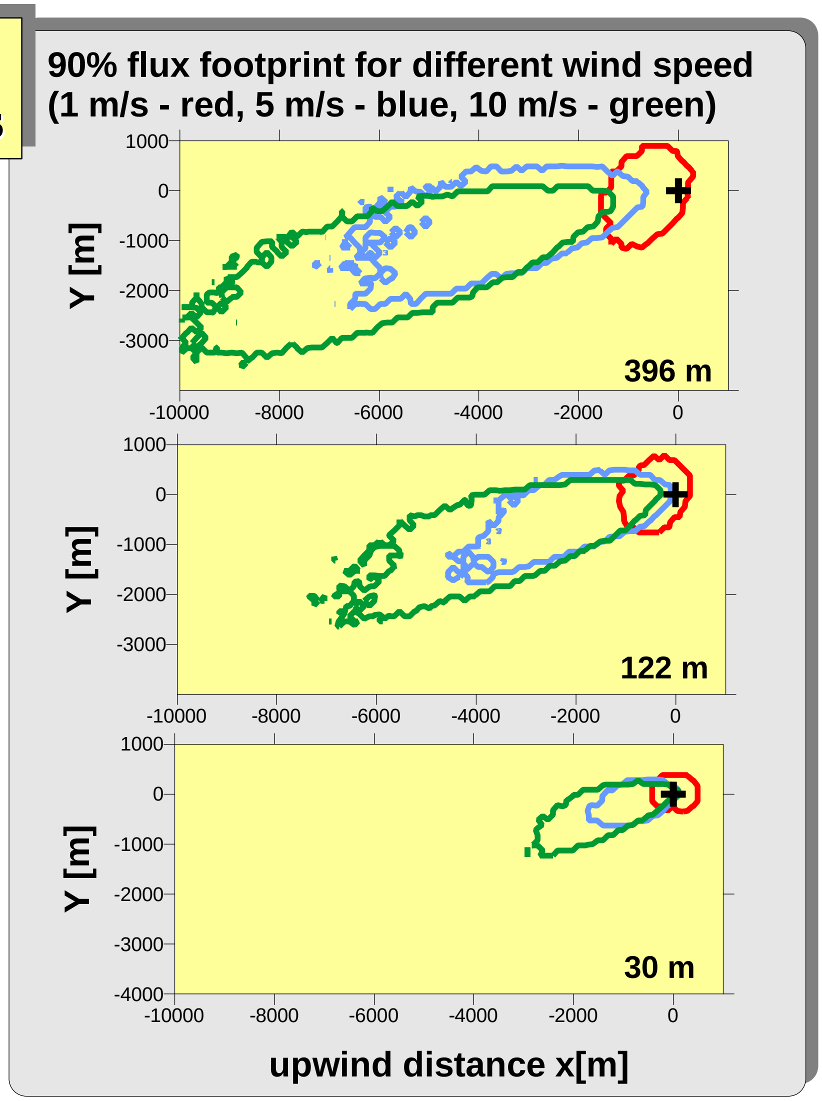
http://biocycle.atmos.colostate.edu/~marek/cobra/



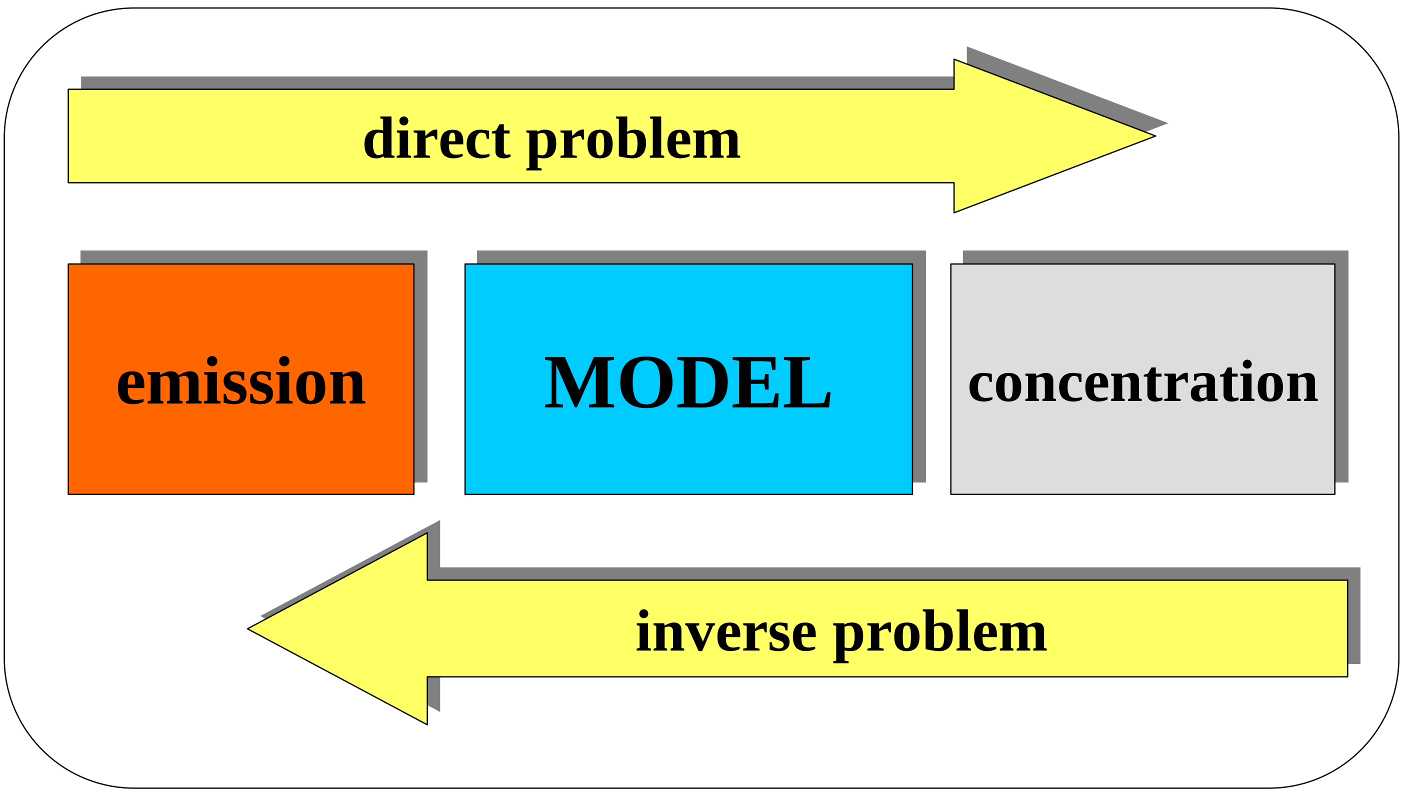
Flux footprints from LES/particle simulations

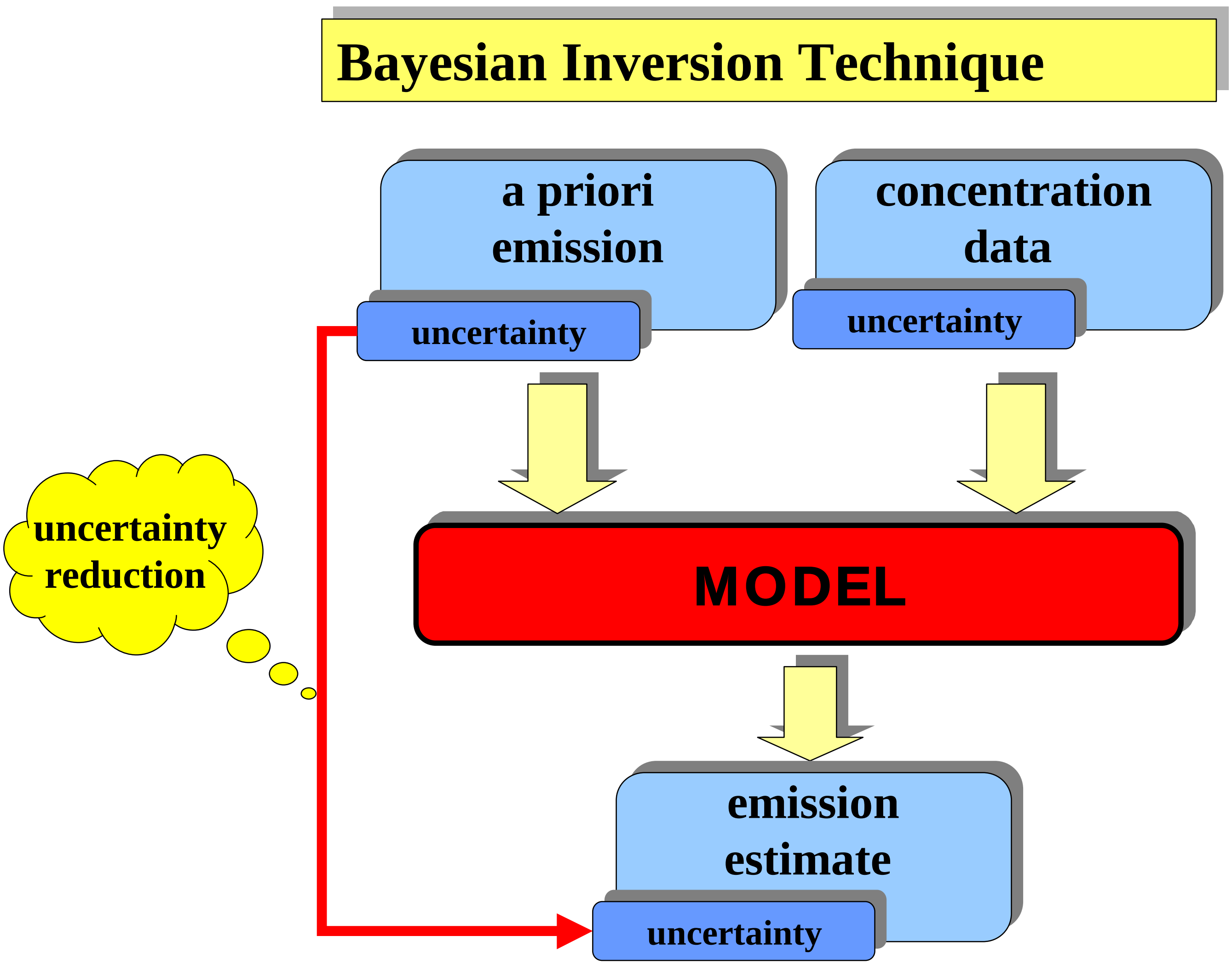


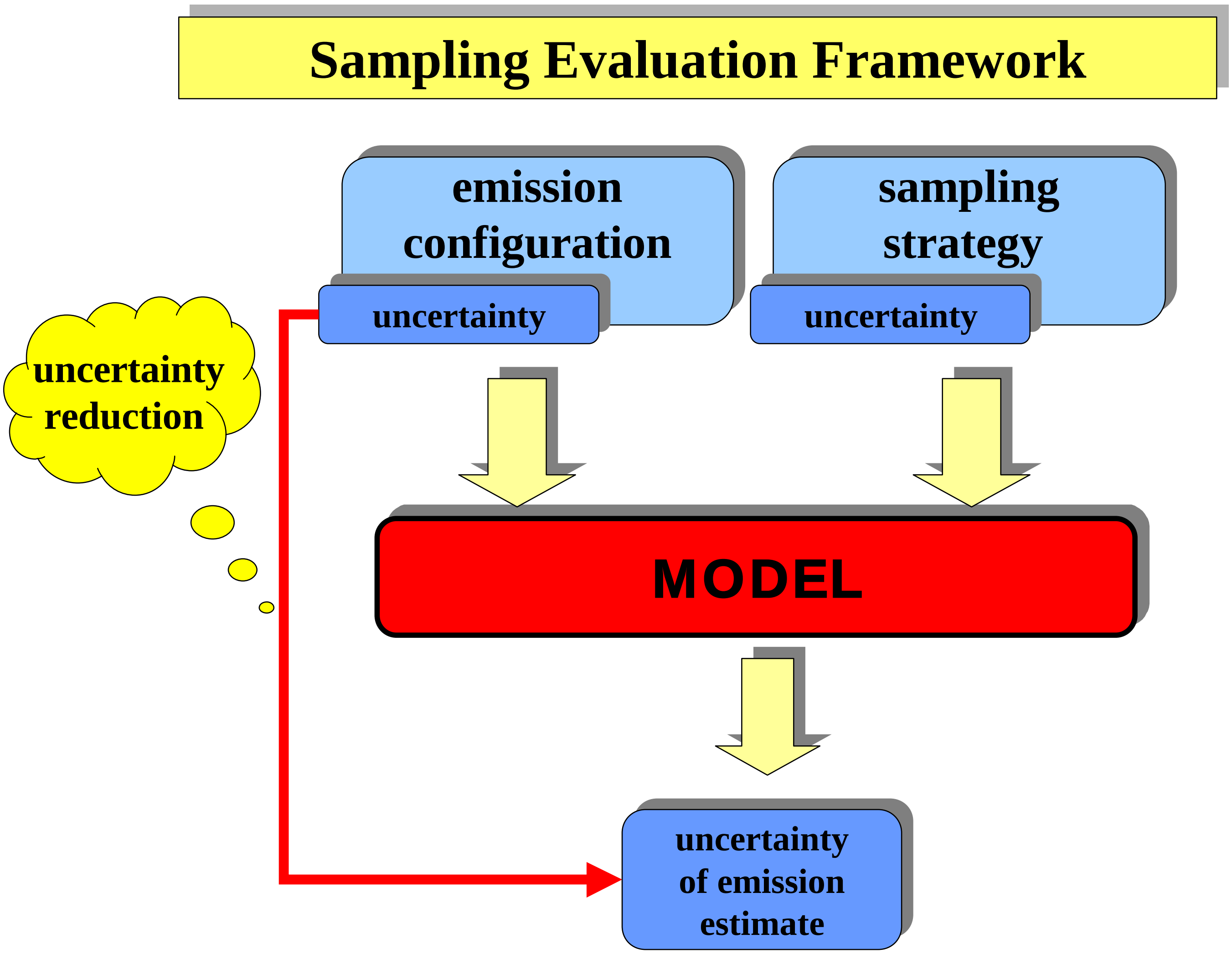
Flux footprint from LES/particle simulations



Evaluation of sampling strategies


direct problem
emission
MODEL
concentration
inverse problem


Bayesian Inversion Technique
a priori emission
uncertainty
concentration data
uncertainty
uncertainty reduction
MODEL
emission estimate
uncertainty


Sampling Evaluation Framework
emission configuration
uncertainty
sampling strategy
uncertainty
uncertainty reduction
MODEL
uncertainty of emission estimate

Bayesian Inversion Technique

model

$$\mathbf{d=Gm}$$

m **-** vector of emissions

d **-** vector of concentrations

Bayesian Inversion Technique

cost function

$$S(m) = (Gm - d_{obs})^T C_d^{-1} (Gm - d_{obs}) + (m - m_p)^T C_m^{-1} (m - m_p)$$

$\mathbf{m_p}$ - a priori emission estimation

$\mathbf{C_m}$ - covariance matrix for a priori emission estimation

$\mathbf{d_{obs}}$ - concentration observations

$\mathbf{C_d}$ - covariance matrix for concentration observations

Bayesian Inversion Technique

new emission estimation

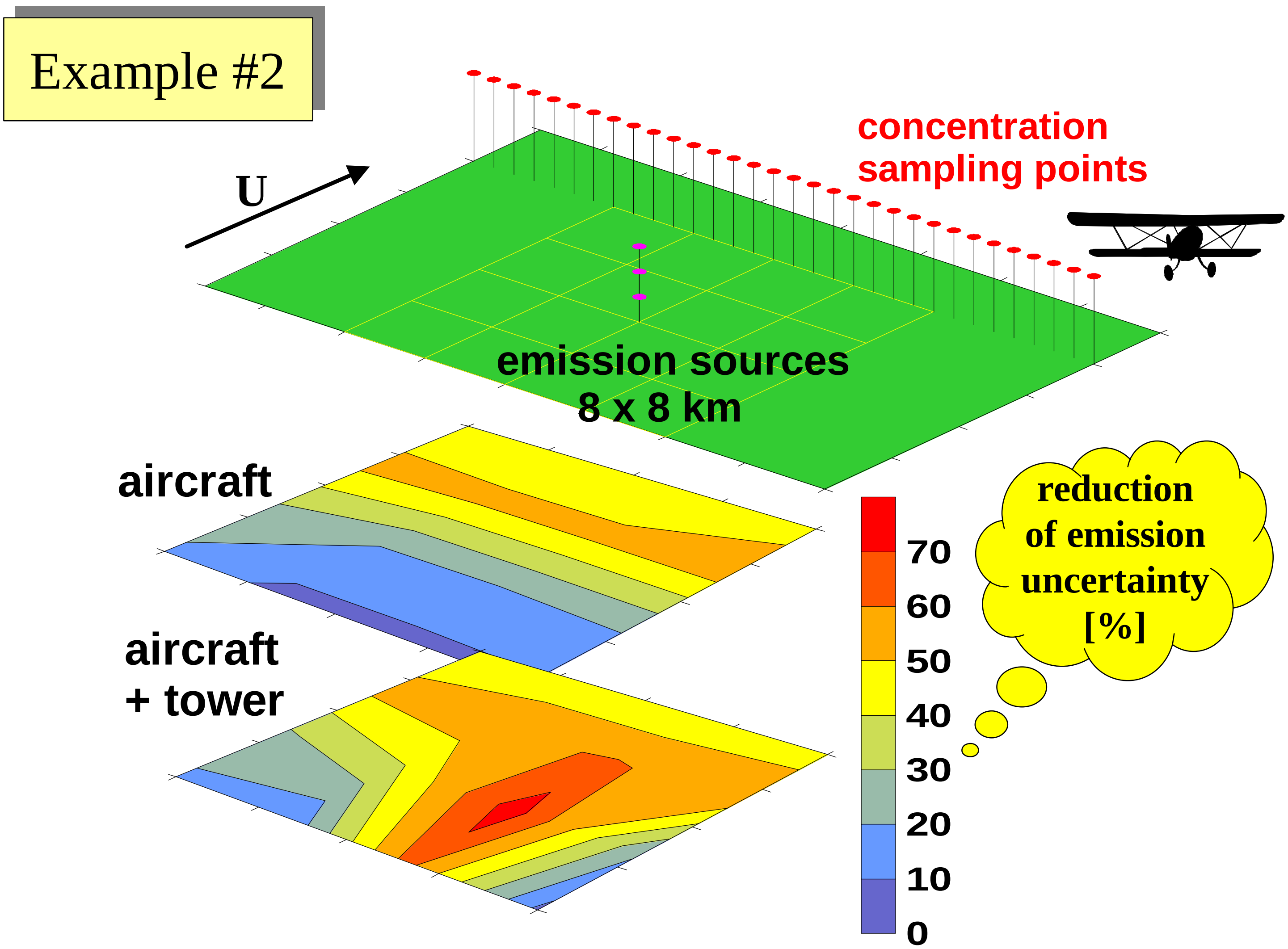
$$\langle m \rangle = m_p + (G^T C_d^{-1} G + C_m^{-1}) G^T C_d^{-1} (d_{obs} - G m_p)$$

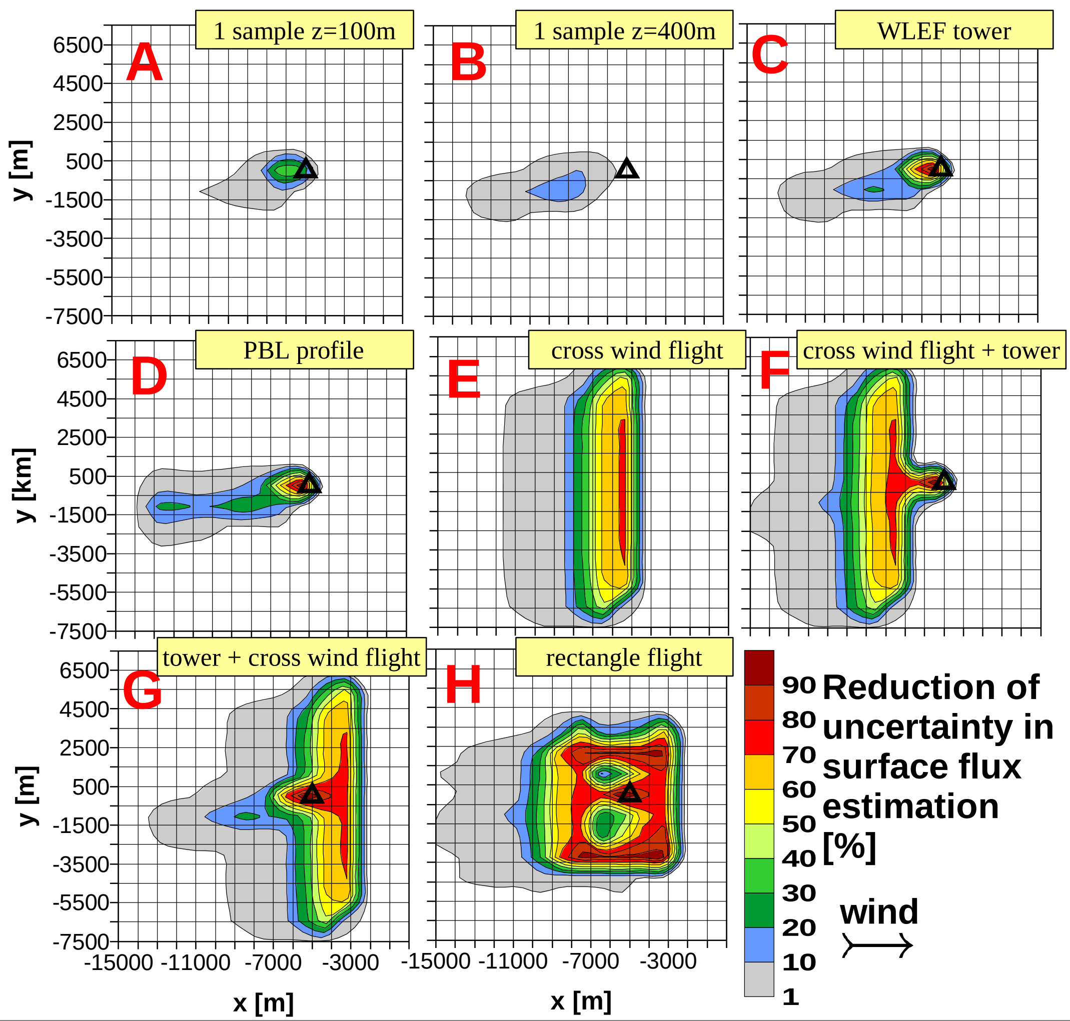
a posteriori emission uncertainty

$$C_m^* = (G^T C_d^{-1} G + C_m^{-1})^{-1}$$

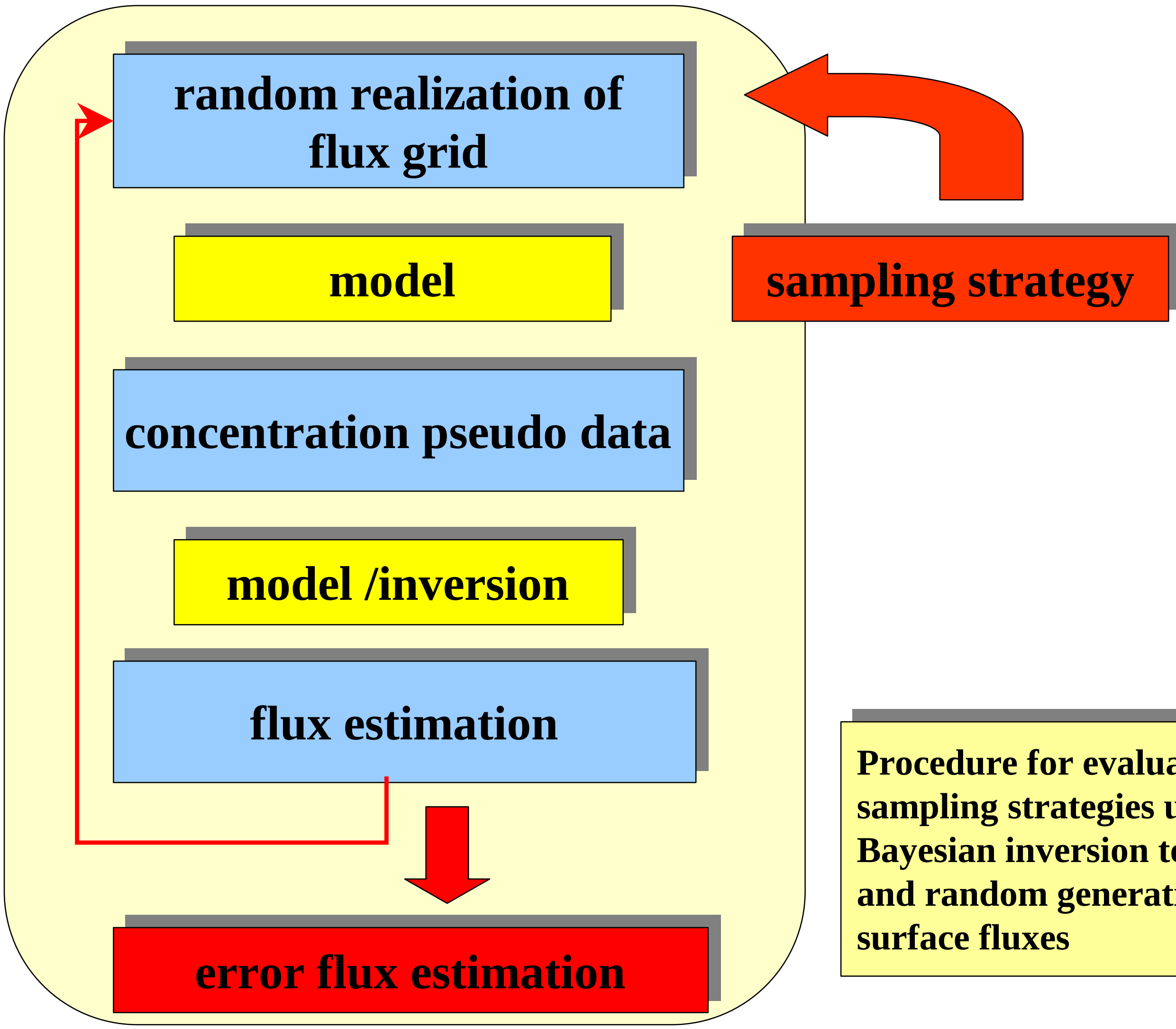
reduction of emission uncertainty

$$\Delta C_m = C_m - C_m^*$$


Example #2
U
concentration
sampling points
emission sources
8 x 8 km
aircraft
aircraft
+ tower
70
60
50
40
30
20
10
0
reduction
of emission
uncertainty
[%]



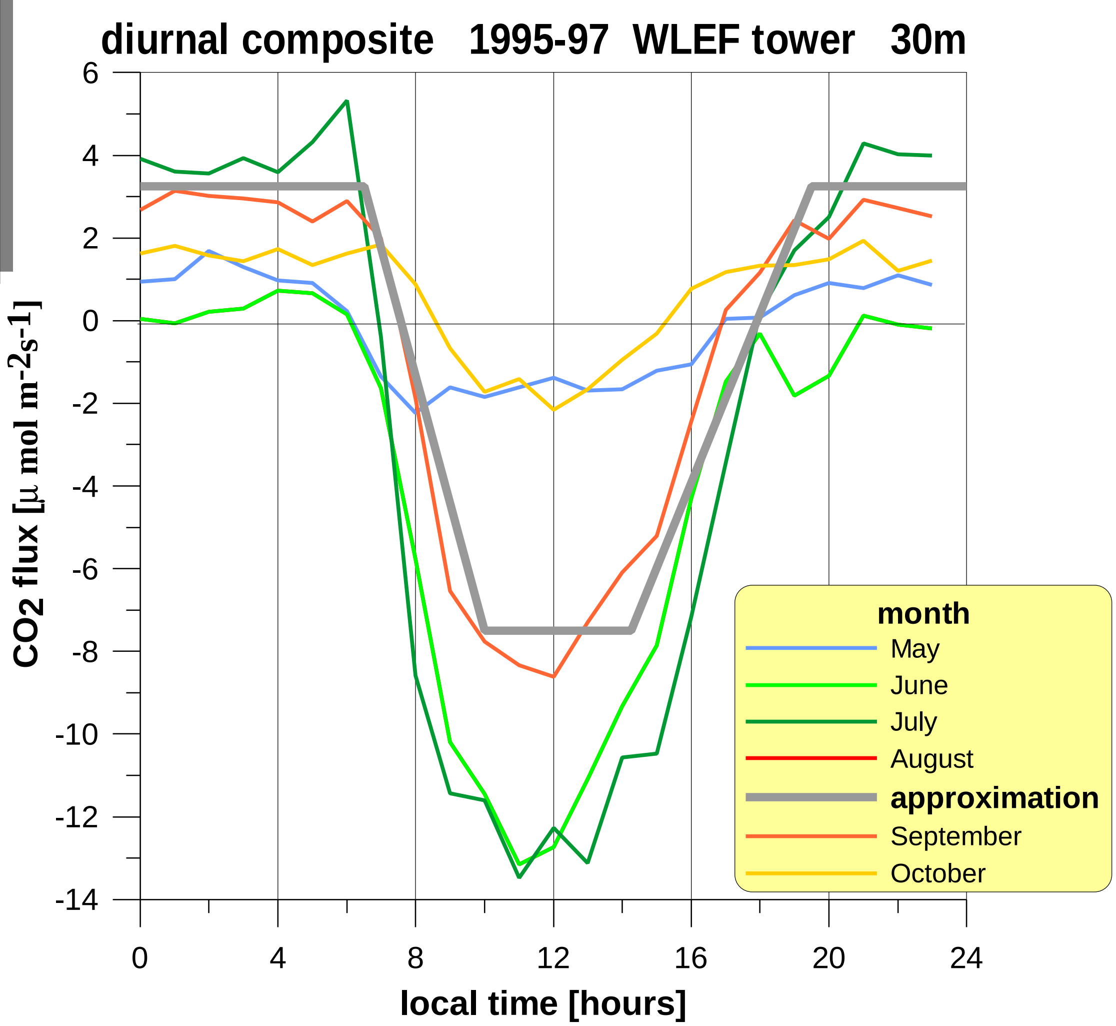
Comparison of simple sampling strategies (idealized CBL conditions)



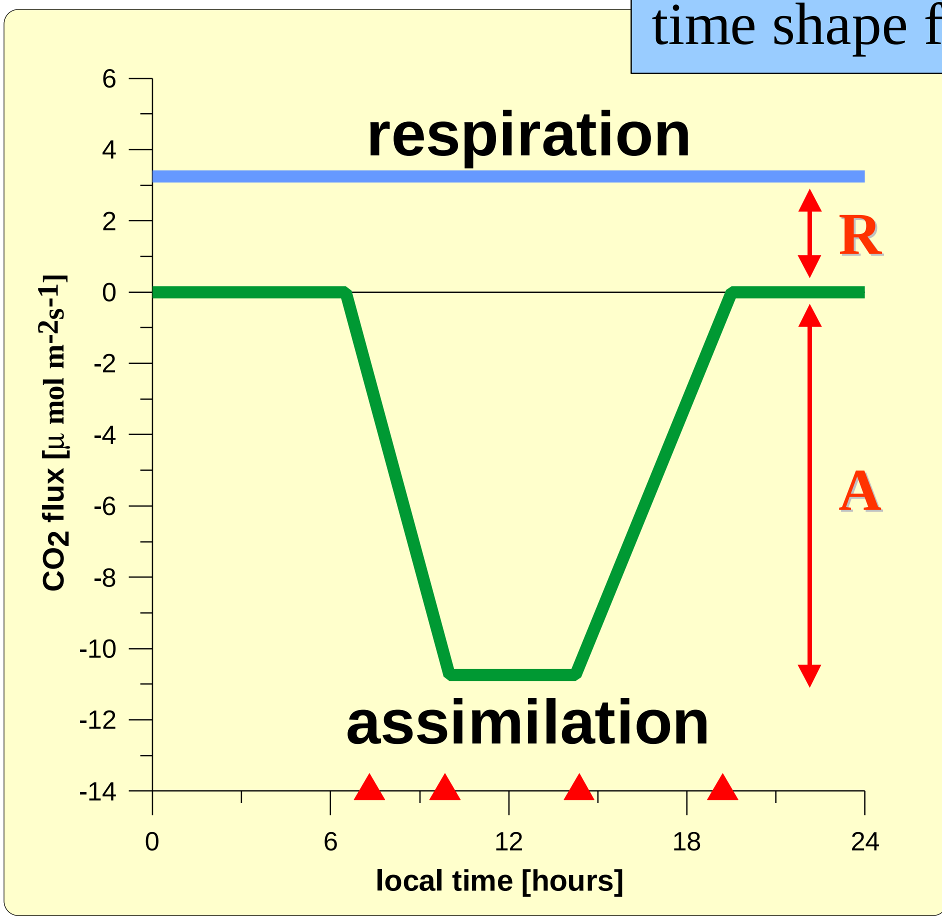
Procedure for evaluation of sampling strategies using the Bayesian inversion technique and random generation of surface fluxes

CO_2 flux

examples of diurnal variation and approximation for modeling purposes



time shape function



Inversion for:

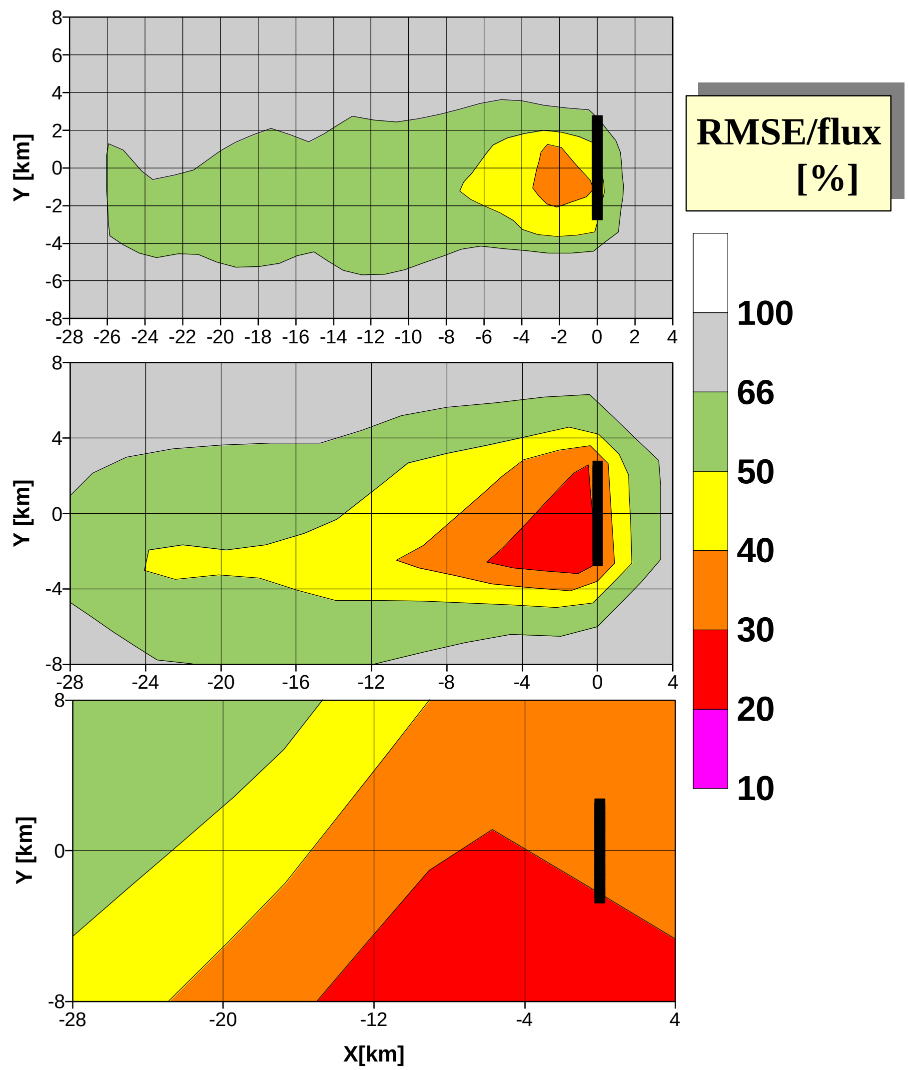
- A and R
- R-A and R

R-A flux estimation
sampling time: 1400

Dx=2 km

Dx=4 km

Dx=8 km

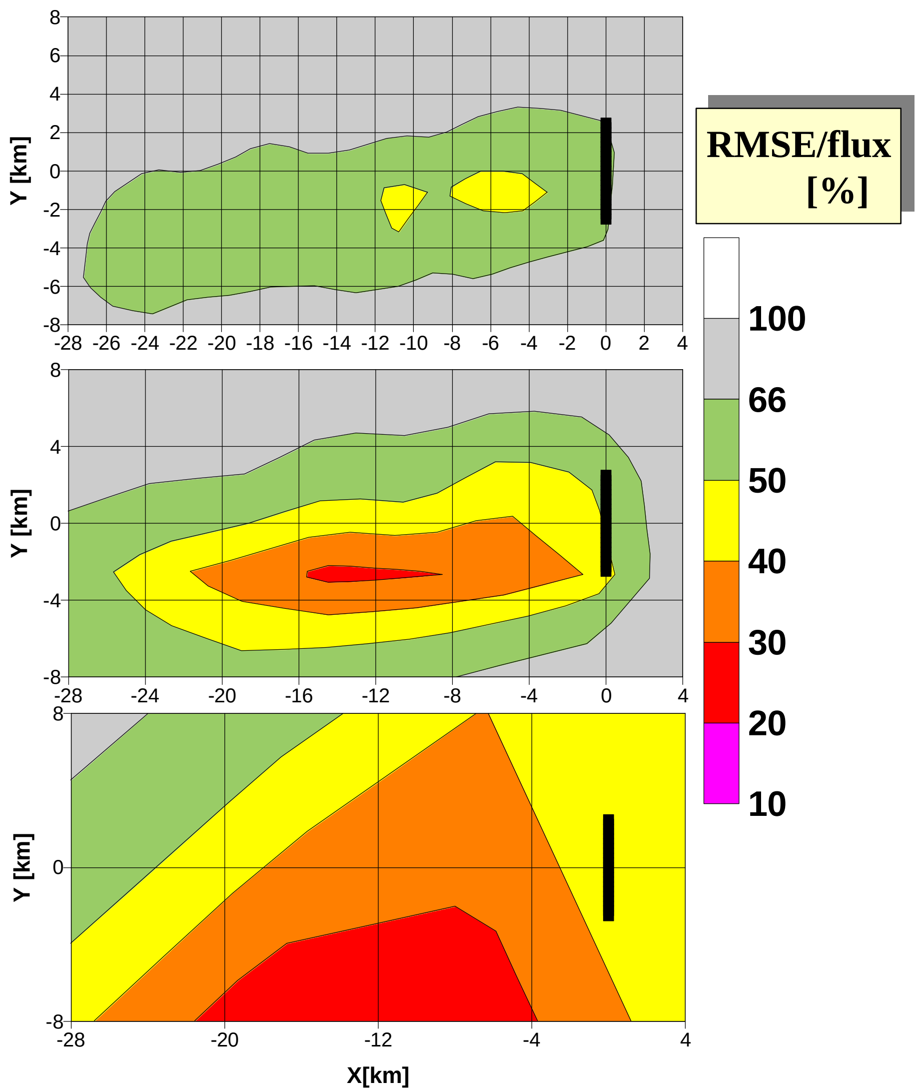


R flux estimation
sampling time: 2200

Dx=2 km

Dx=4 km

Dx=8 km

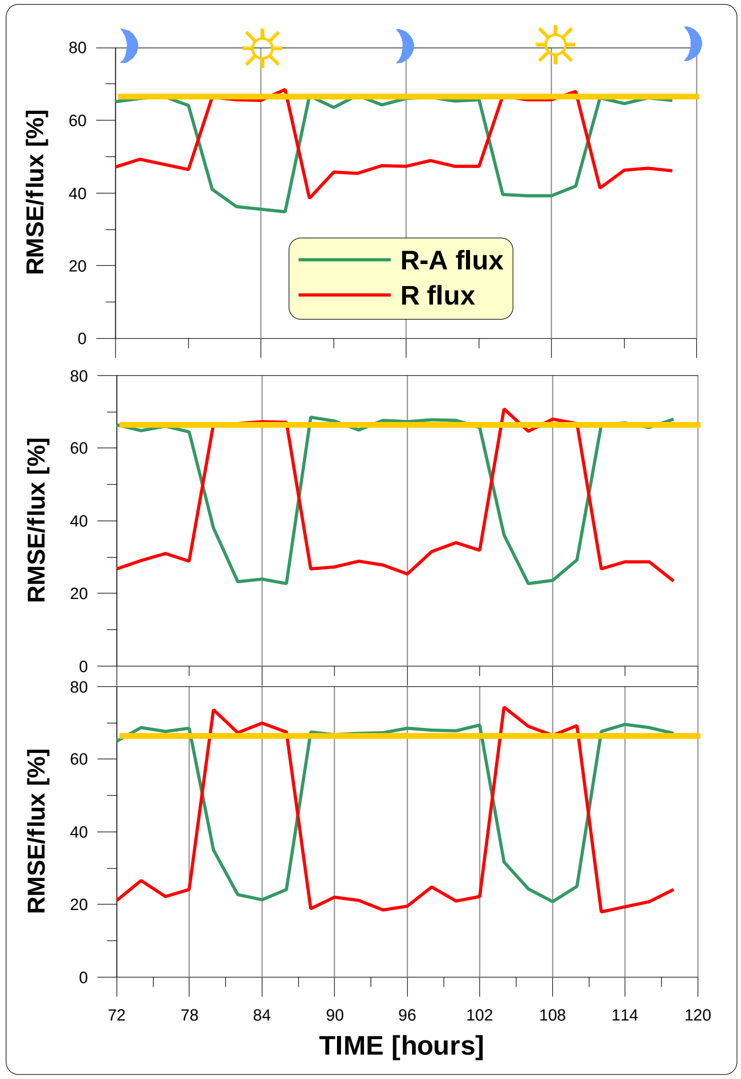


R-A and R fluxes estimation
min(RMSE/flux) [%]

Dx=2 km

Dx=4 km

Dx=8 km



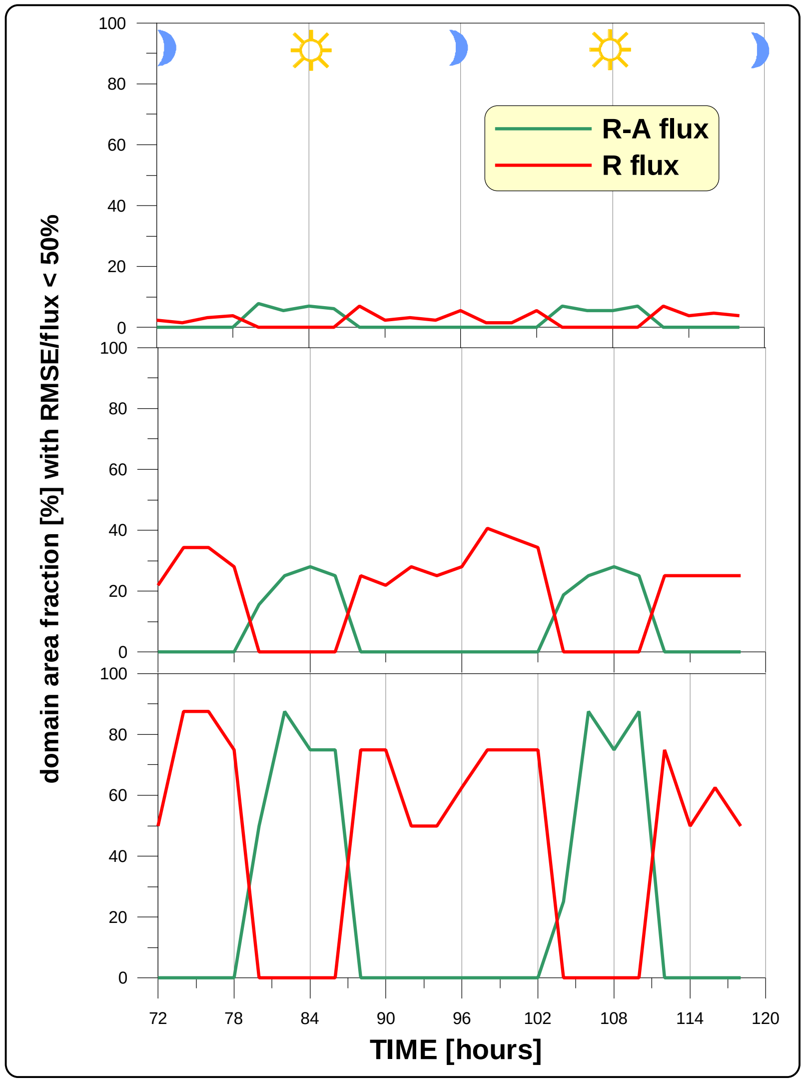
R-A and R fluxes estimation

fraction of area [%] with RMSE/flux < 50%

Dx=2 km

Dx=4 km

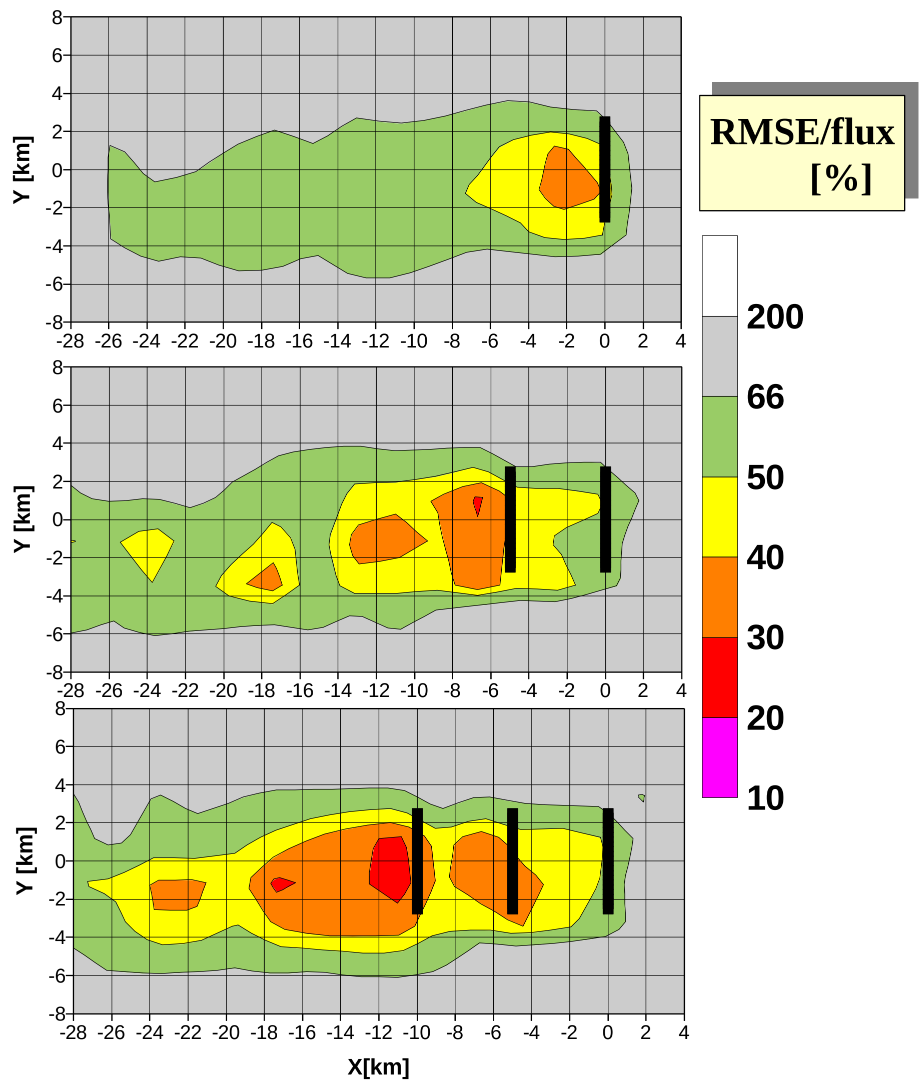
Dx=8 km



R-A flux estimation

sampling time: 1400

effect of different sampling strategies



Problems:

Inflow CO_2 fluxes need to be estimated !

Size of modeling domain?
Information from sampling the residual BL from the previous day(s)?

Evaluation of data uncertainty:
- measurement accuracy
- mismatch errors between the model and observations

Model uncertainty?

What CO_2 variations due to landscape heterogeneity can be detected?

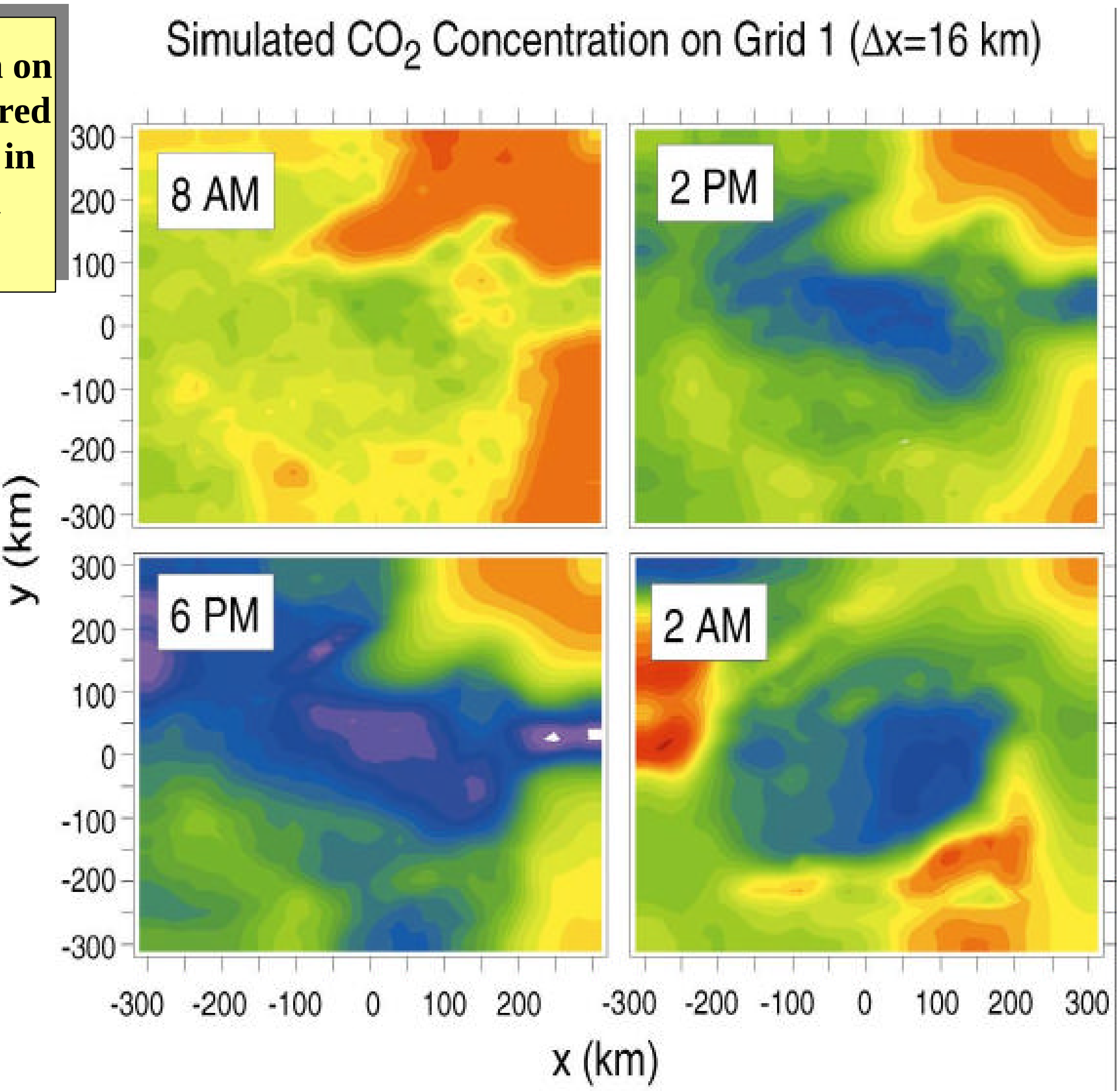
Forward modeling: RAMS+SiB

Regional & mesoscale simulations on nested grids

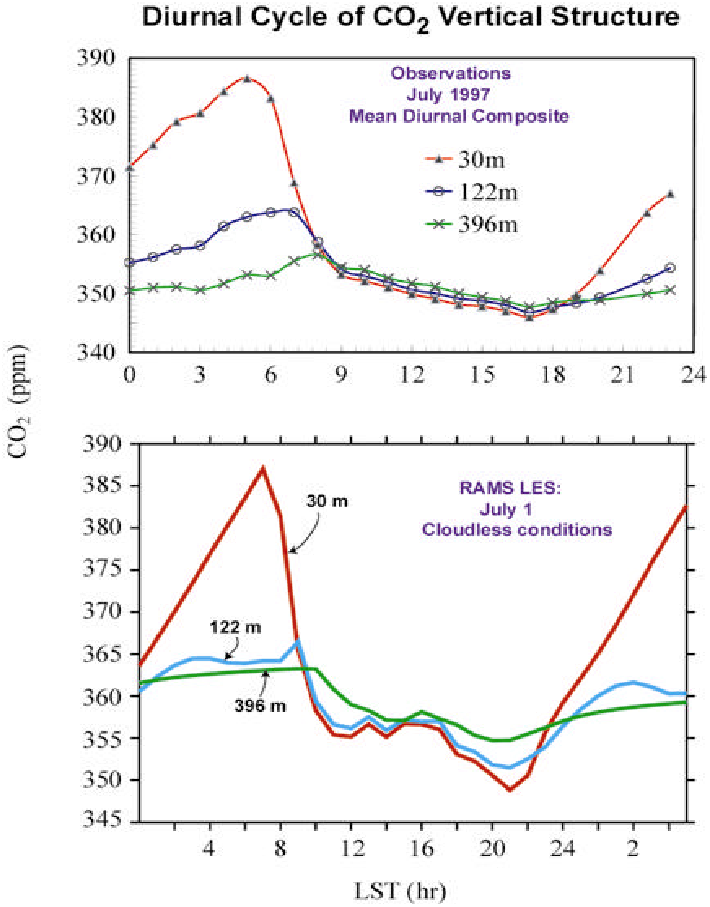
Regional & mesoscale simulations on nested grids + LES

LES (single grid):
- idealized terrain (homogenous, heterogeneous)
- real terrain

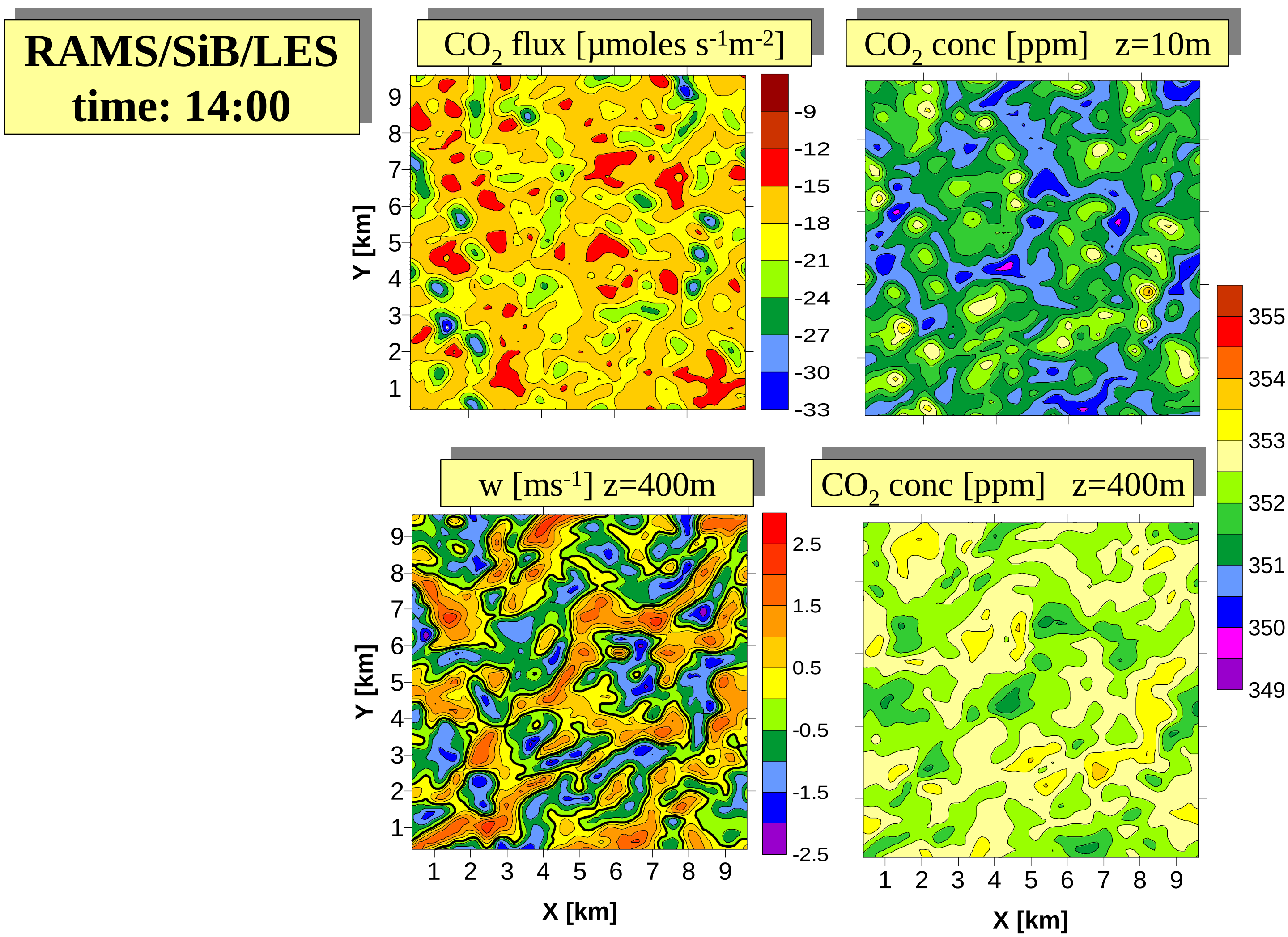
Regional simulation on 3 nested grids centered at the WLEF tower in northern Wisconsin July 1997



Diurnal Cycle at WLEF Tower



- Vegetation parameters specified from **imagery**
- **Accumulation of CO_2** under nocturnal inversion well represented
- Timing and vertical structure of **morning ventilation** is OK
- **Afternoon reversal** of vertical gradient too strong
- Onset and development of nocturnal **stable layer** is good



RAMS/SiB/LES
time: 14:00
CO2 flux [µmoles s-1m-2]
CO2 conc [ppm] z=10m
w [ms-1] z=400m
CO2 conc [ppm] z=400m
Y [km]
X [km]
-9
-12
-15
-18
-21
-24
-27
-30
-33
2.5
1.5
0.5
-0.5
-1.5
-2.5
355
354
353
352
351
350
349

SUMMARY

A variety of modeling tools available

Feedback from modeling to observations

- Evaluation of sampling strategies
- Operational support for fields campaigns