Atmospheric constraints on greenhouse gas budgets: Requirements on Modelling tools based on multiple observations

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CERES (Han Dolman, ...)
many CEIP Fluxtower PIs

MPI-BGC
Jena

EPFL Lausanne
May 4, 2008

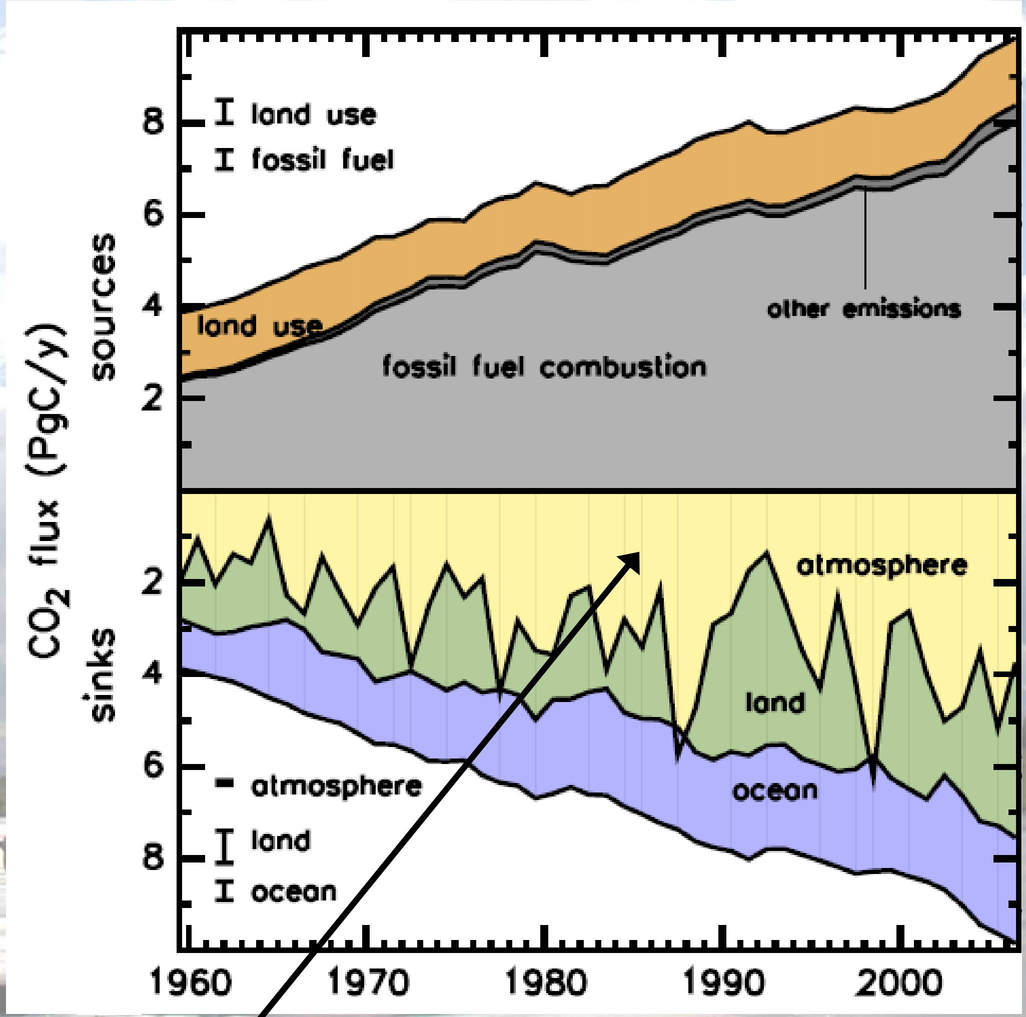
Overview

- Motivation
- Model-data-fusion system
- Test data:
  - Tall tower measurements
  - CERES (CarboEurope regional Experiment)
- associated uncertainties, and possibilities for mitigation
- Closing remarks

Motivation

Scientific questions:

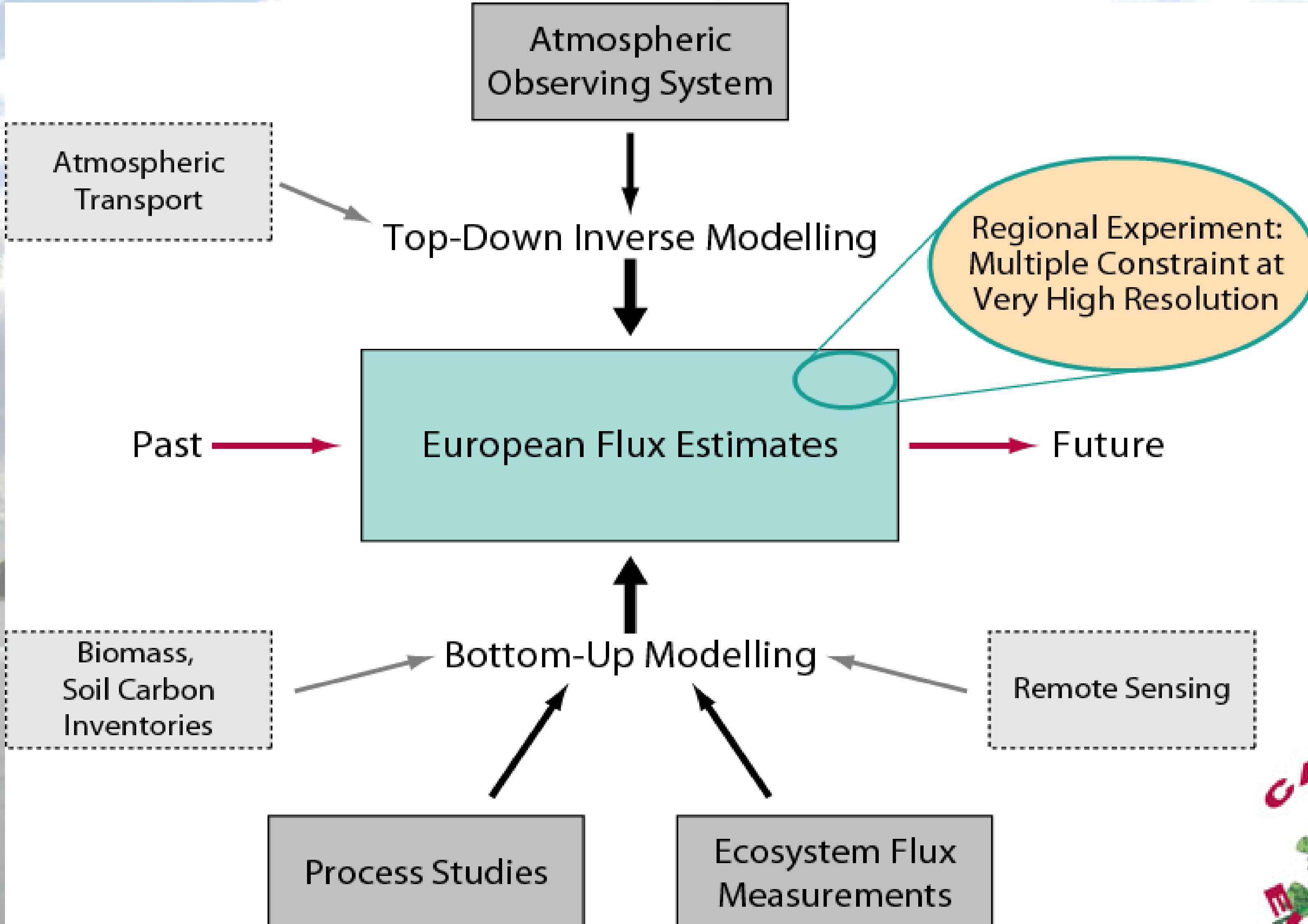
- Where and by which processes is anthropogenic CO_2 sequestered?
- What are the main feedback processes between carbon cycle and climate system?
- What is the carbon budget of a specific region (continent/country)?



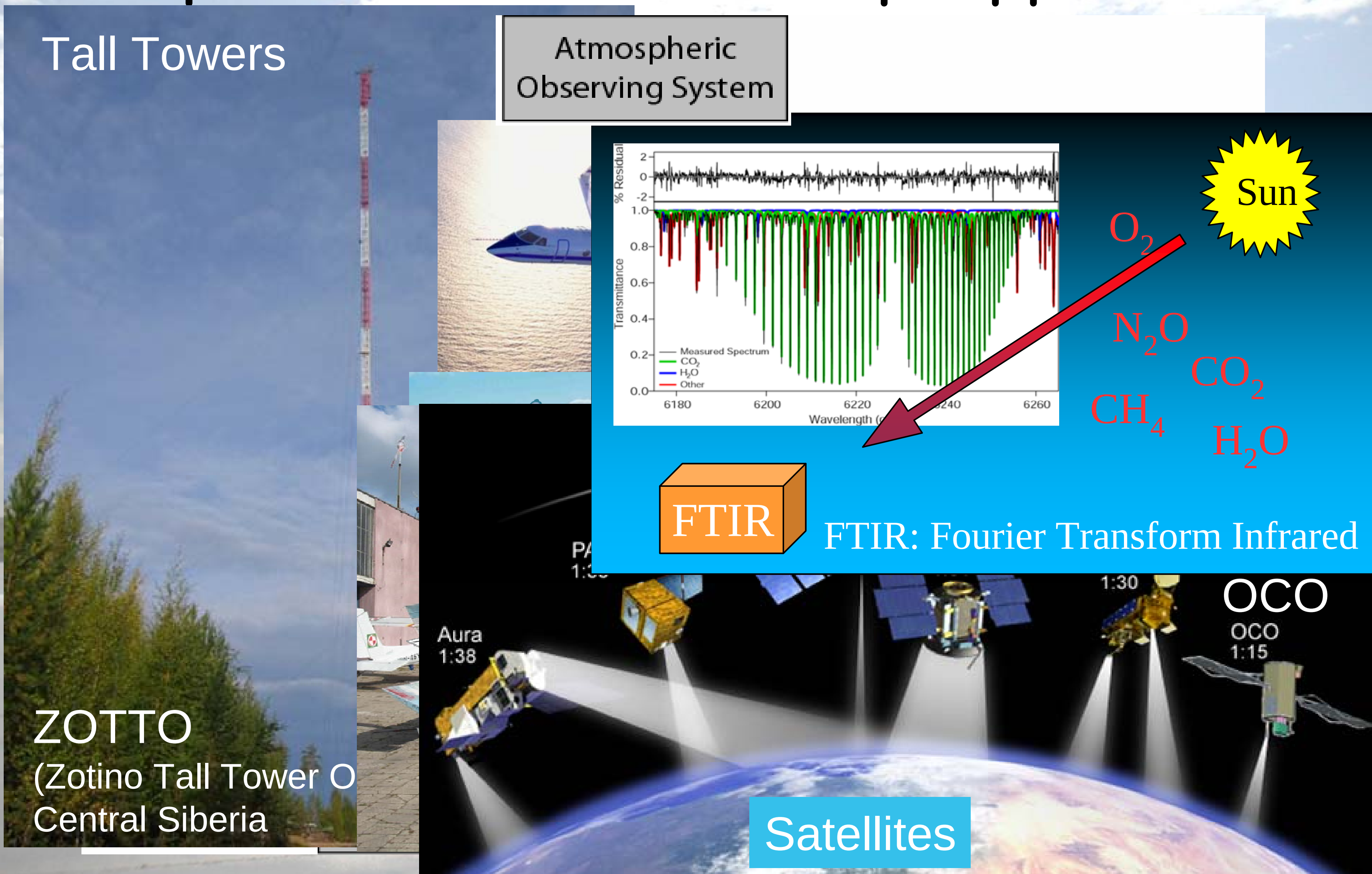
[Canadell et al., 2007]

Variable "Airborne fraction"

Estimating Reginal Carbon Balances: Top-Down vs. Bottom-Up Approach

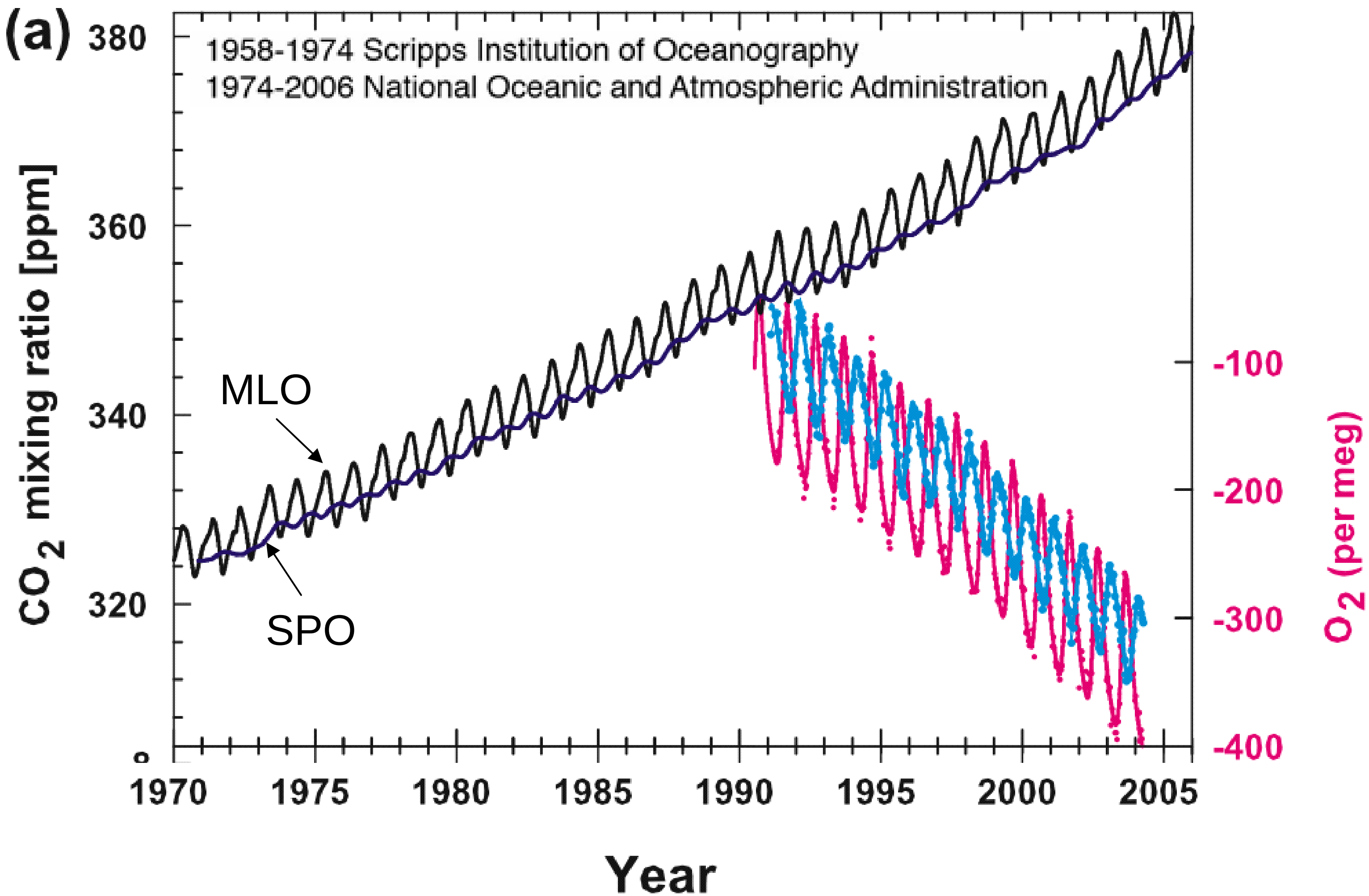


Estimating Reginal Carbon Balances: Top-Down vs. Bottom-Up Approach



Atmospheric Observing System

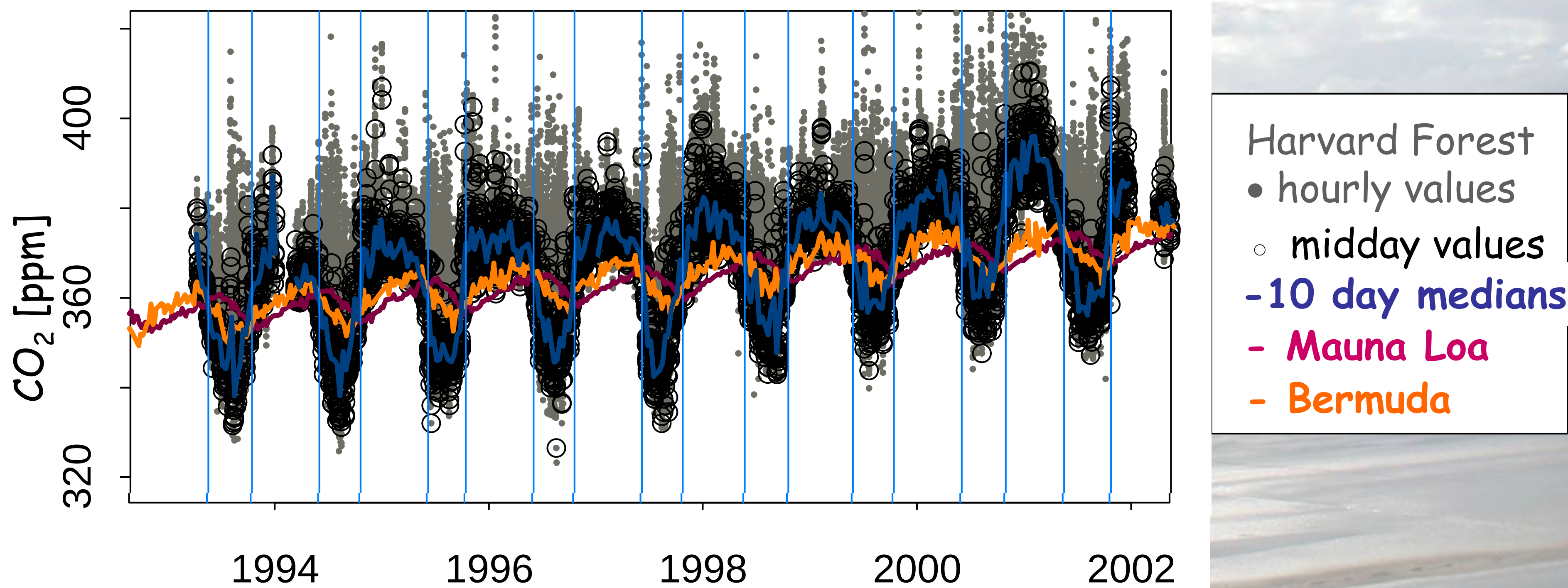
~1 decade ago: only remote sites



Motivation

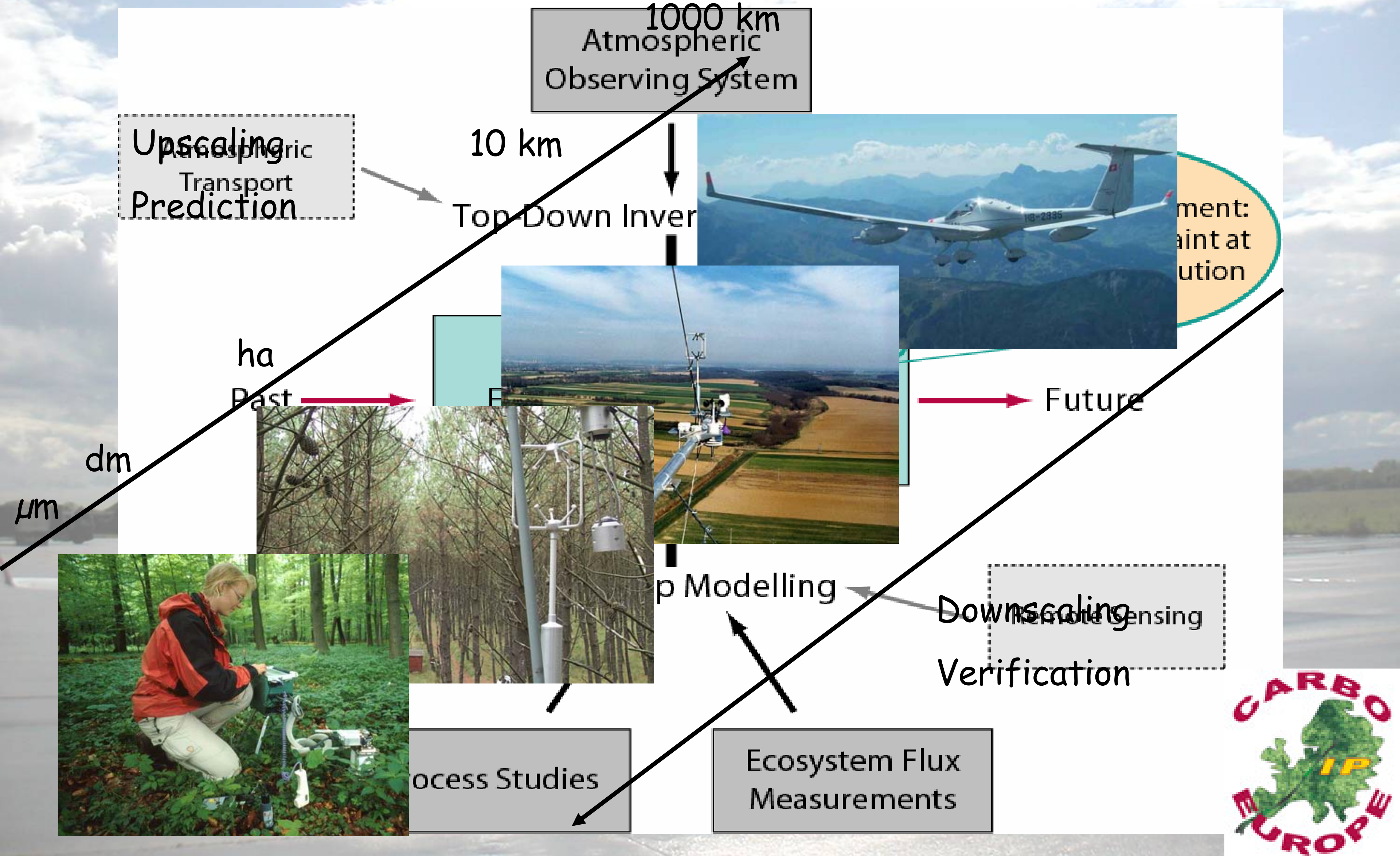
CO_2 in the continental atmospheric boundary layer:

- Variability on diurnal and synoptic scales
  => Information on surface fluxes



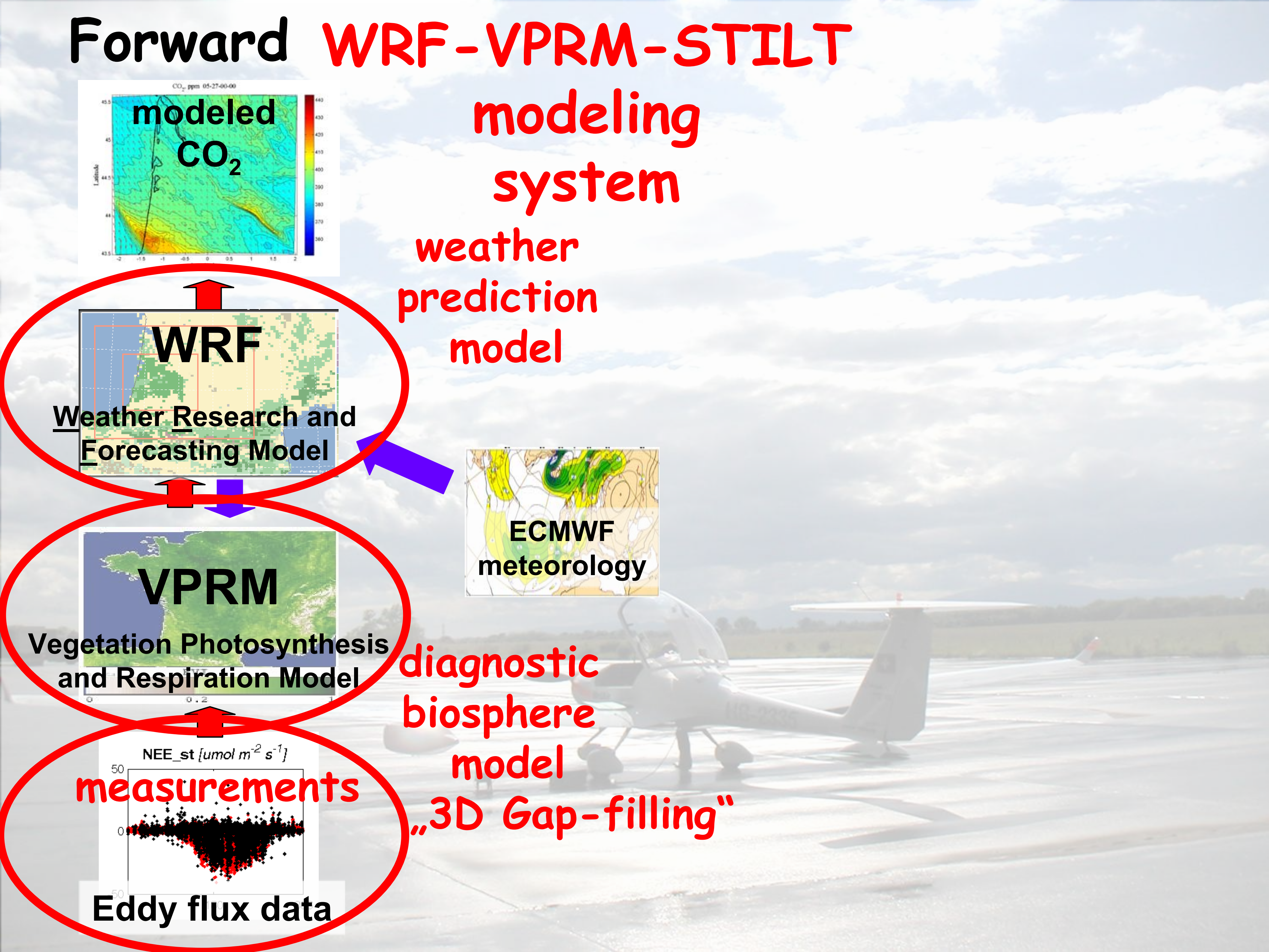
[Gerbig et al., 2006]

Estimating Reginal Carbon Balances: Top-Down vs. Bottom-Up Approach



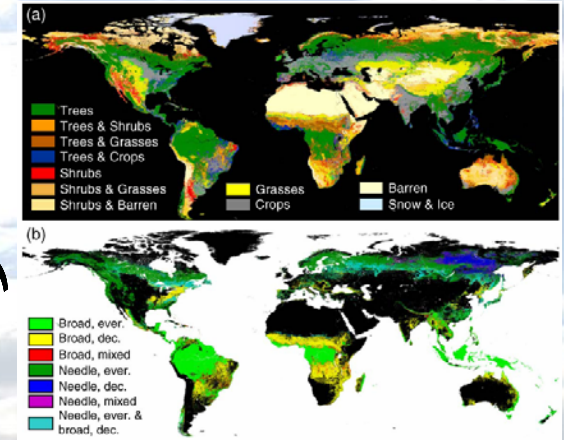
The challenge: we need …

- Model-data fusion
  - merging Top-Down and Bottom-Up
- Test data, to assess models capability
  - Experiments with high density observations (space & time) -> CERES
- Falsifiable models
  - scalable from experiment scale to scale of interest
  - quantitative (error bars)


Forward WRF-VPRM-STILT
modeling
system
weather
prediction
model
modeled
CO_2
WRF
Weather Research and
Forecasting Model
ECMWF
meteorology
VPRM
Vegetation Photosynthesis
and Respiration Model
diagnostic
biosphere
model
„3D Gap-filling"
NEE_st [umol m-2 s-1]
measurements
Eddy flux data

VPRM Vegetation Photosynthesis and Respiration Model

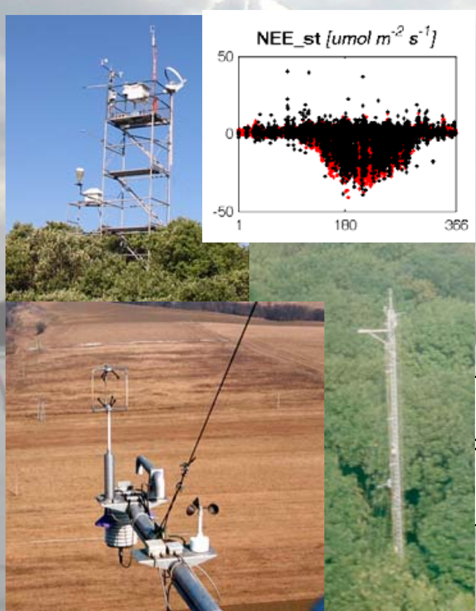
[Pathmathevan et al., GBC 2008]



SYNMAP land cover
[Jung et al., 2006]

vegetation classes (5)

Optimization of parameters
α, β, λ, and $\mathbf{PAR_0}$



Eddy Cov. data
[many CE site PI's]

$$NEE = GEE + R$$

$$R = \alpha \cdot T + \beta$$

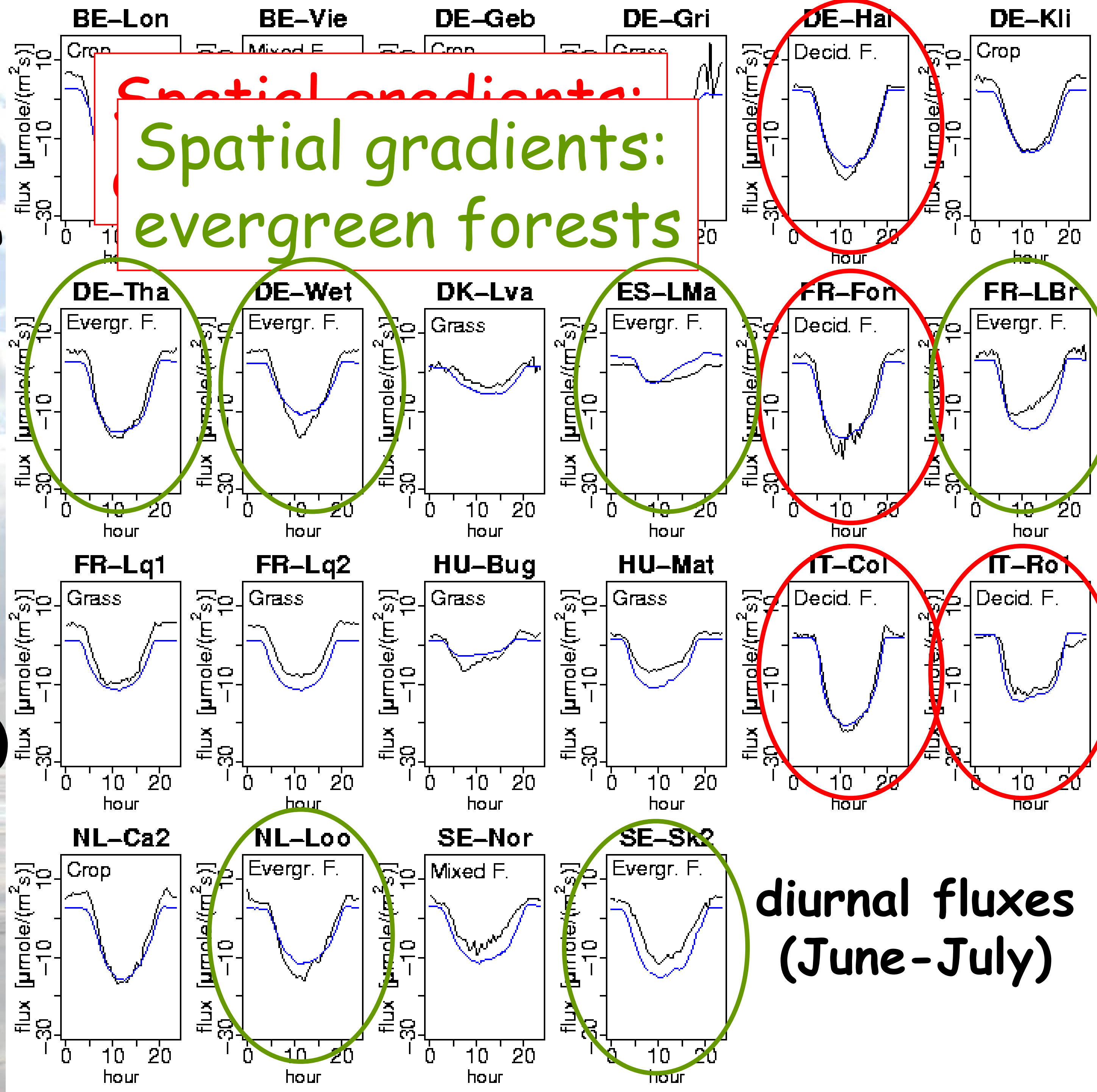
ECMWF, NCEP, WRF or site measurements

$$GEE = \lambda \cdot \frac{PAR}{\left(1 + PAR/PAR_0\right)} \cdot \mathrm{Tscale}(T) \cdot \mathrm{Pscale}(LSWI, EVI) \cdot \mathrm{Wscale}(LSWI) \cdot EVI$$

MODIS surface reflectances
8 day, 500 m

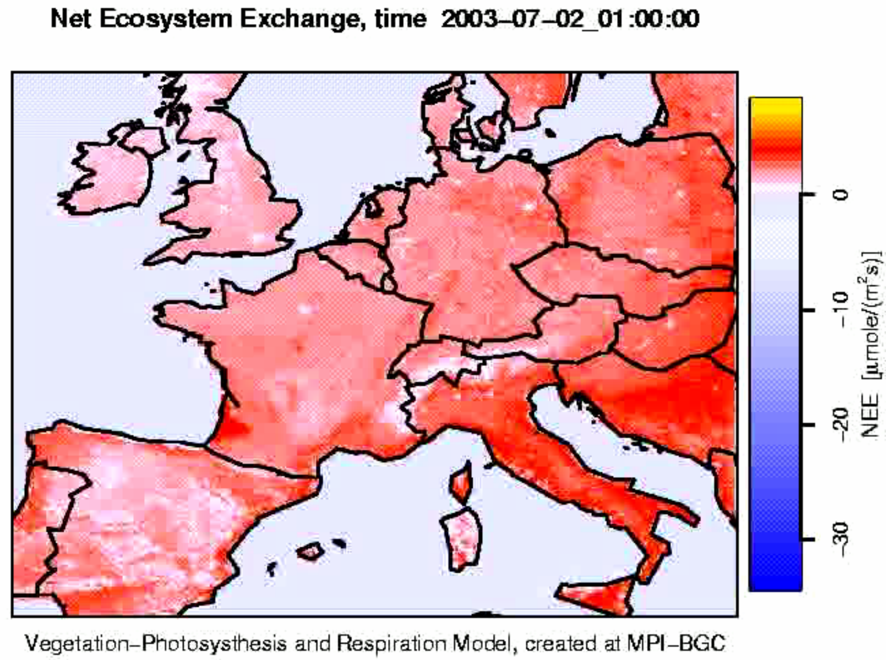
2005 CEIP-EC data vs. VPRM (driven by site meteorology)

diurnal

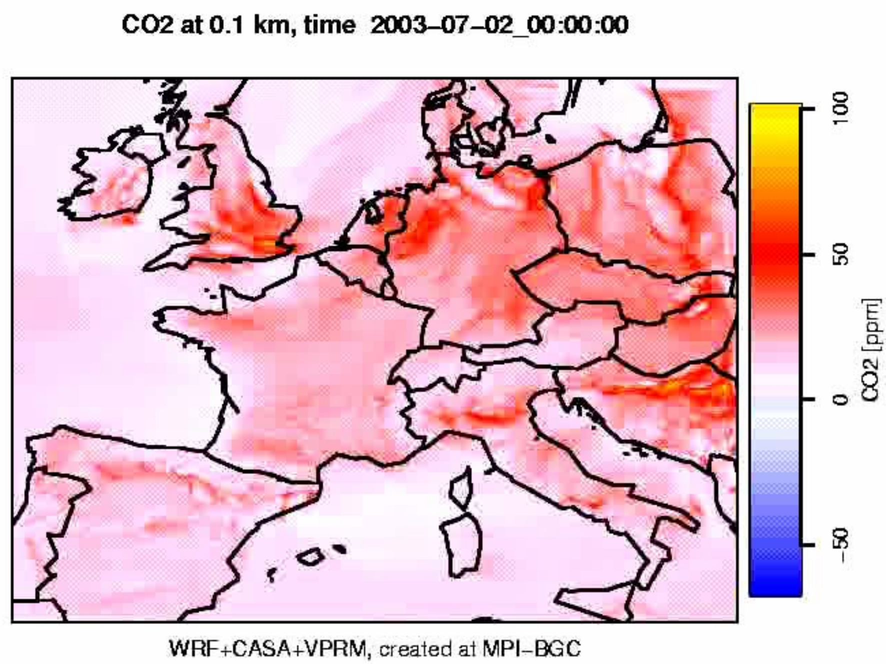


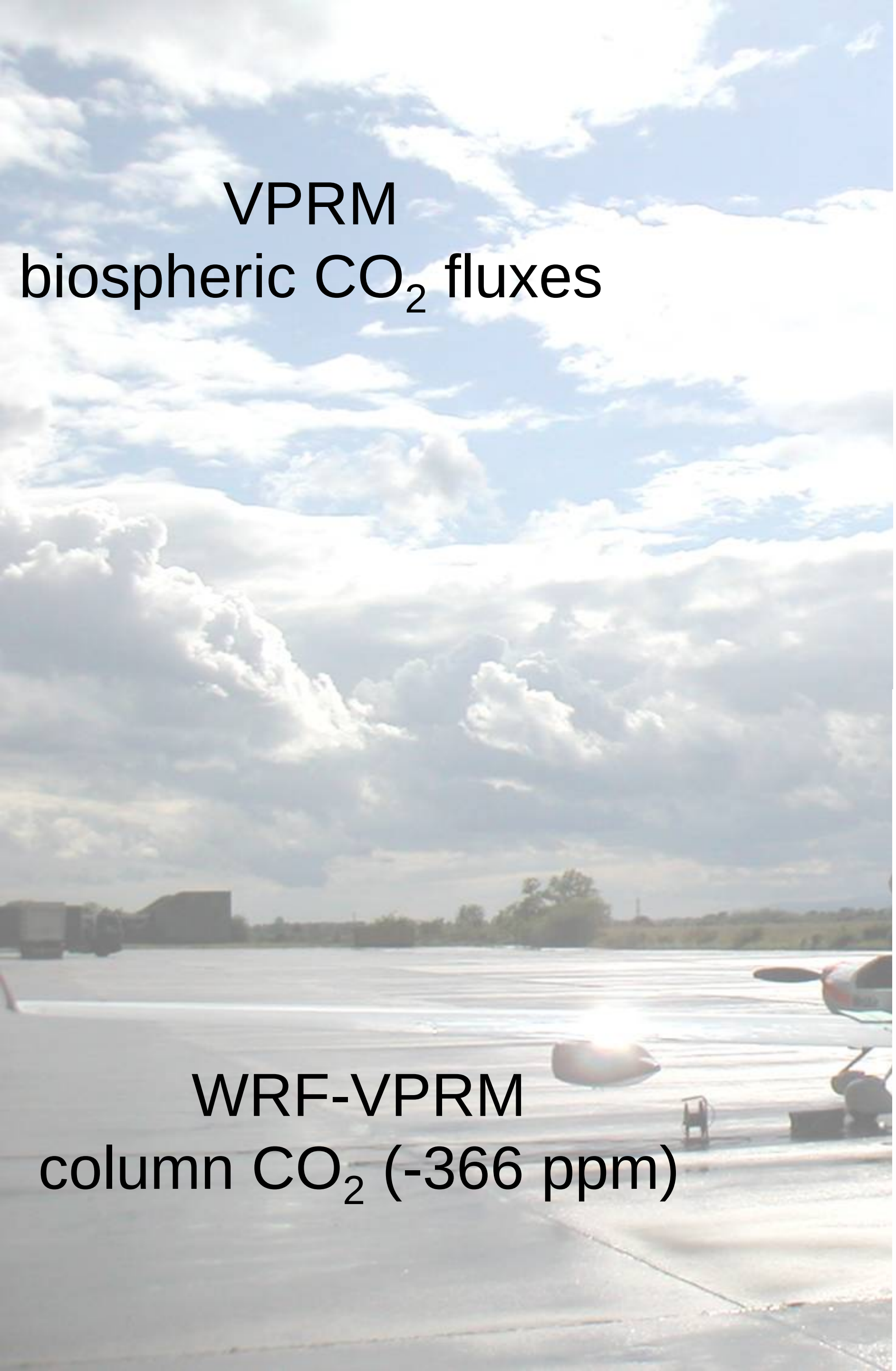
diurnal fluxes (June-July)

VPRM
biospheric CO_2 fluxes

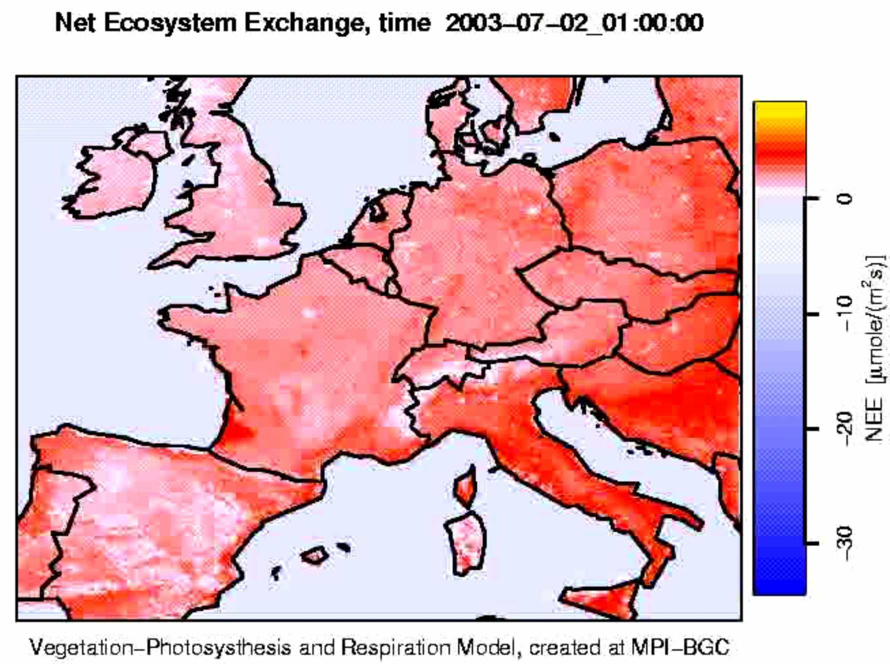


WRF-VPRM
CO_2 (-366 ppm) at 150 m

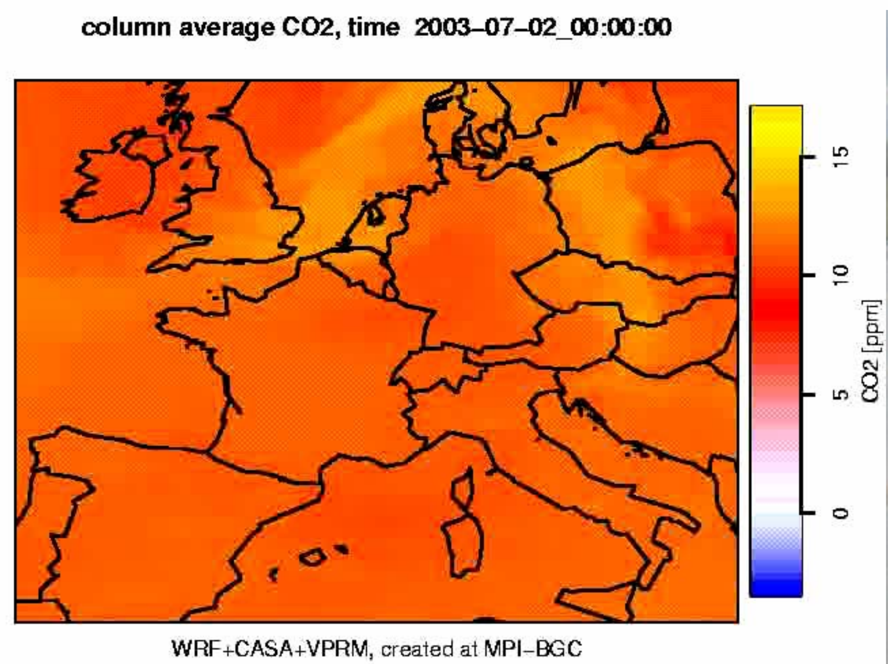


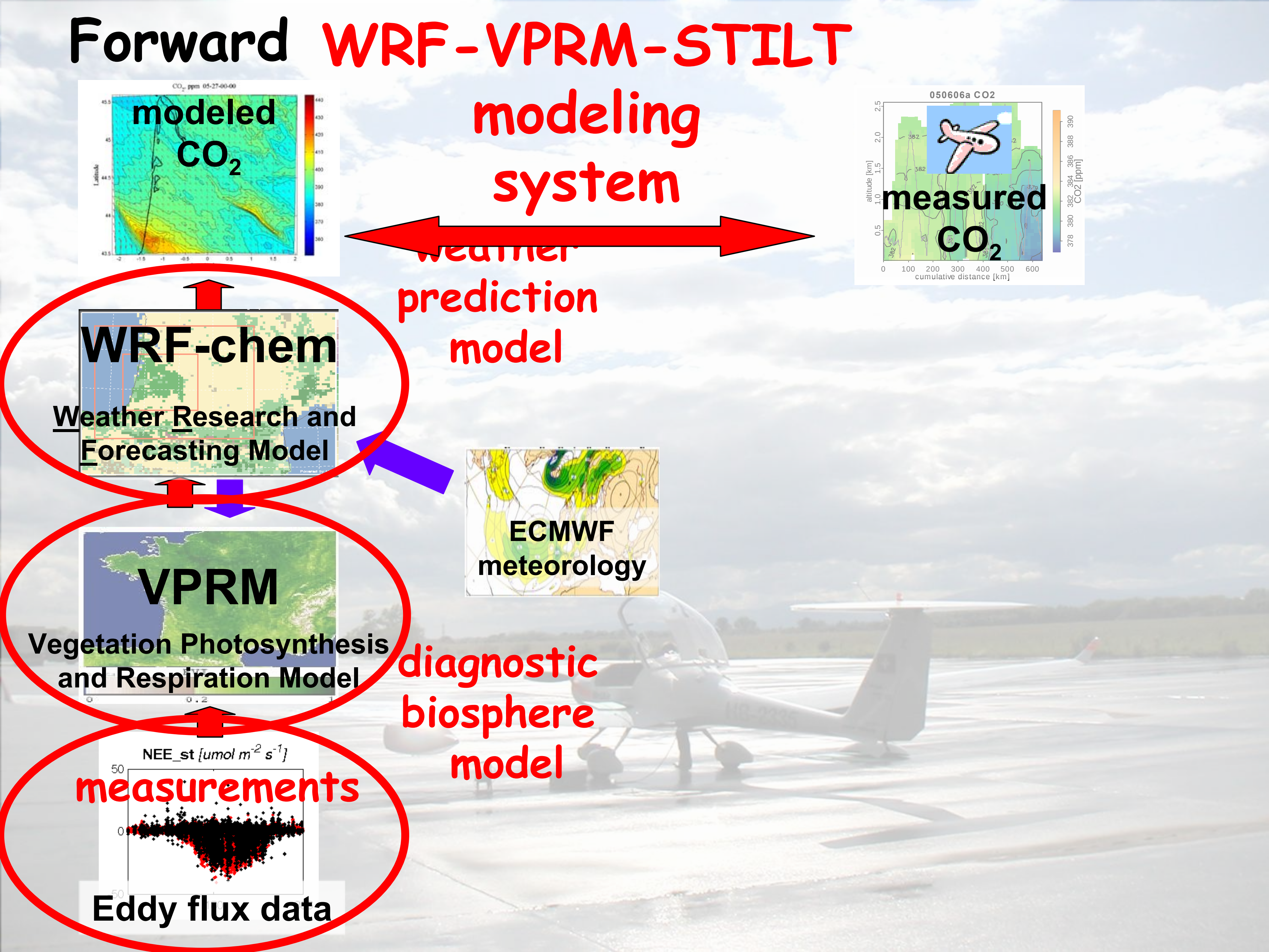


VPRM
biospheric CO_2 fluxes



WRF-VPRM
column CO_2 (-366 ppm)



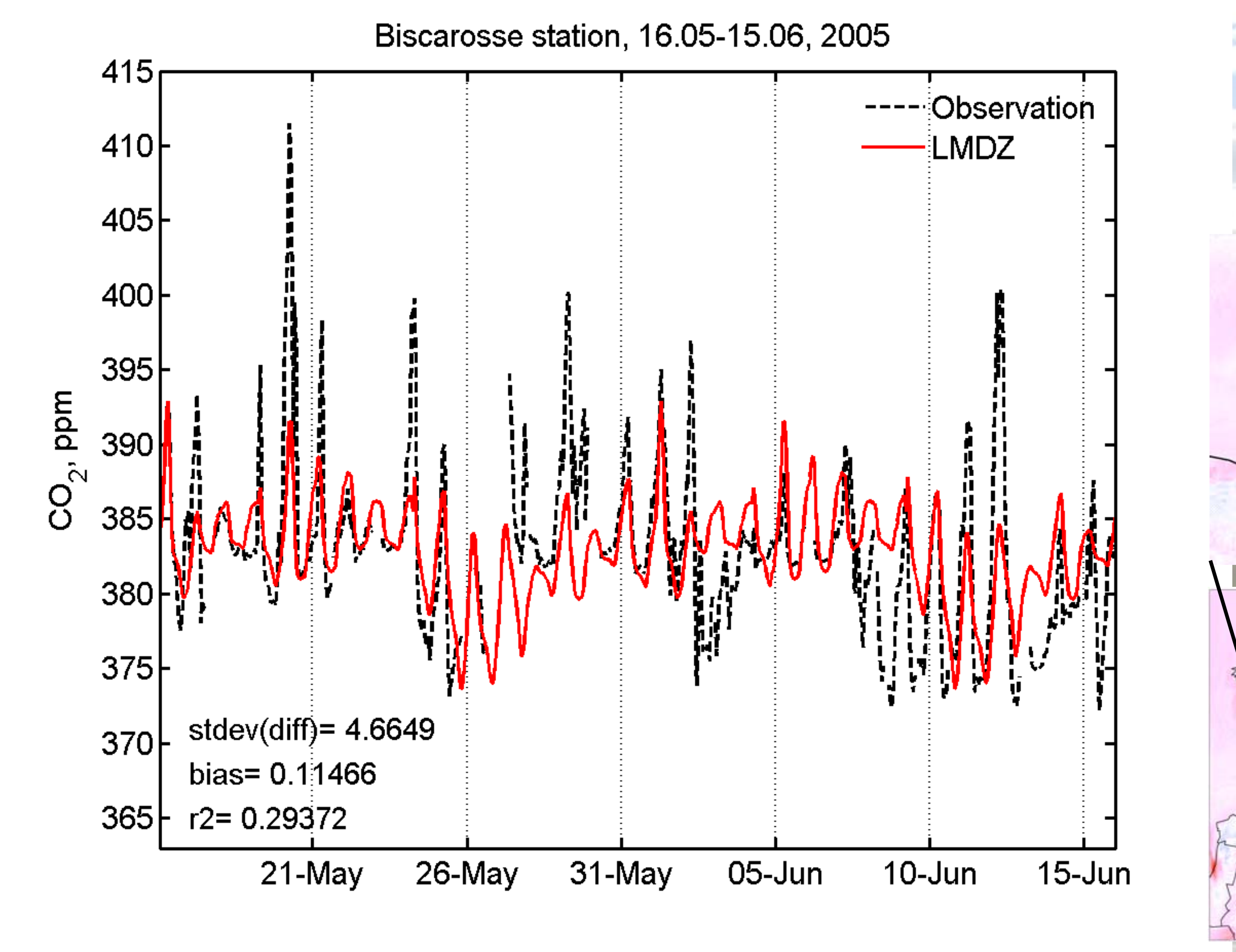


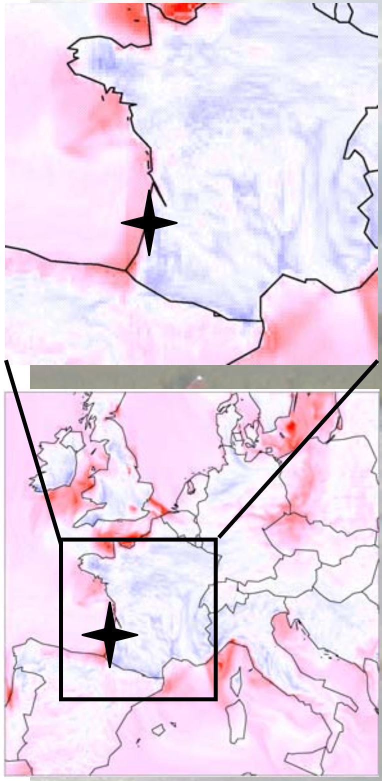
Forward WRF-VPRM-STILT
modeling system
modeled CO_2
050606a CO2
measured CO_2
weather prediction model
WRF-chem
Weather Research and Forecasting Model
ECMWF meteorology
VPRM
Vegetation Photosynthesis and Respiration Model
diagnostic biosphere model
NEE_st [umol m-2 s-1]
measurements
Eddy flux data

Model-Data Comparison

Global model - Biscarosse coastal station

Regional Experiment

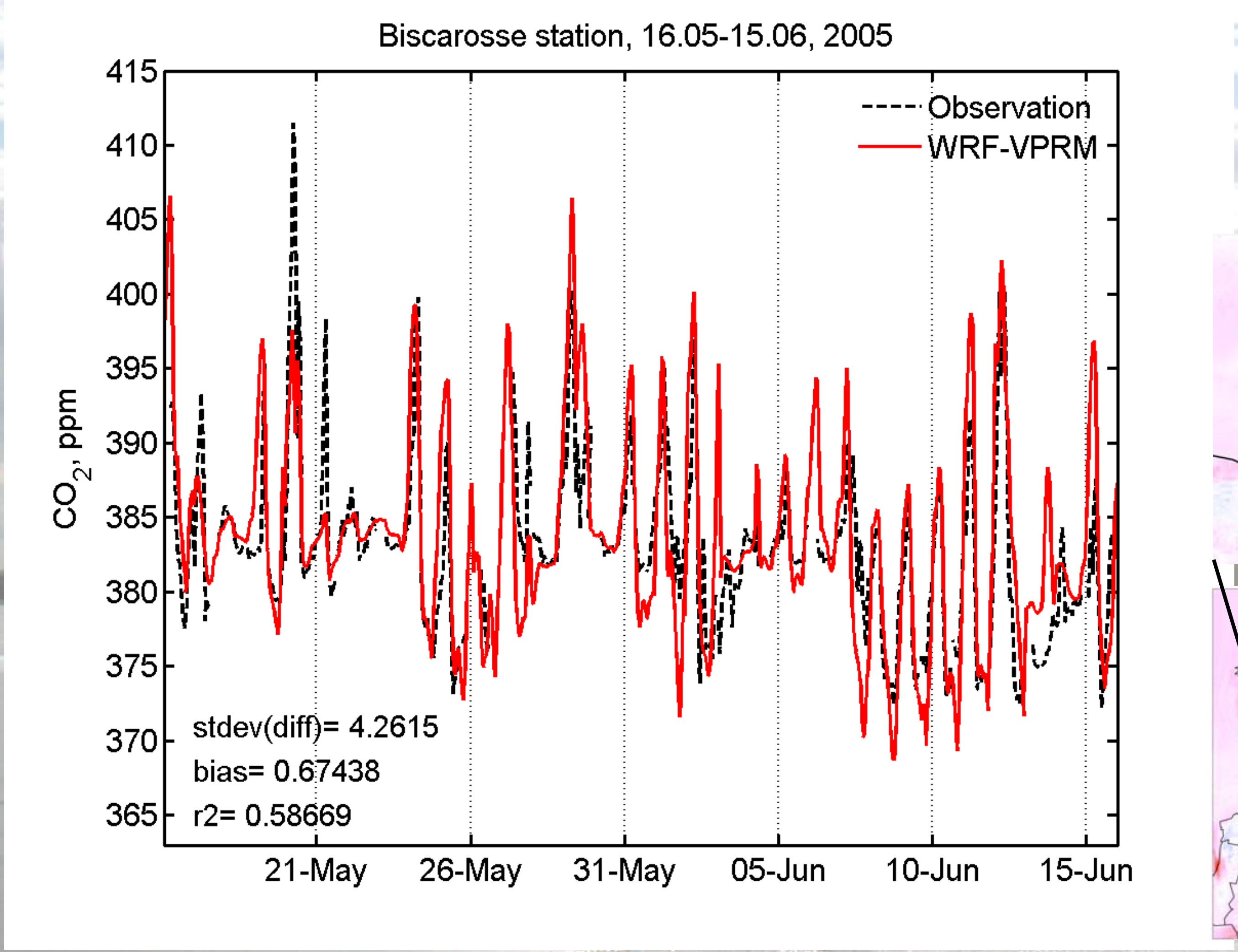


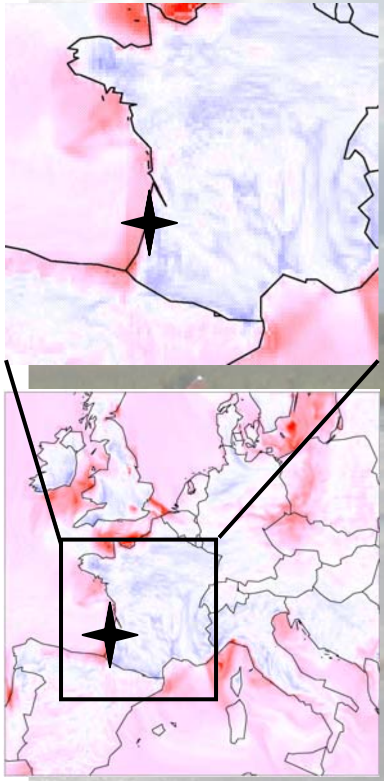


Model-Data Comparison

WRF-VPRM 2 km - Biscarosse coastal station

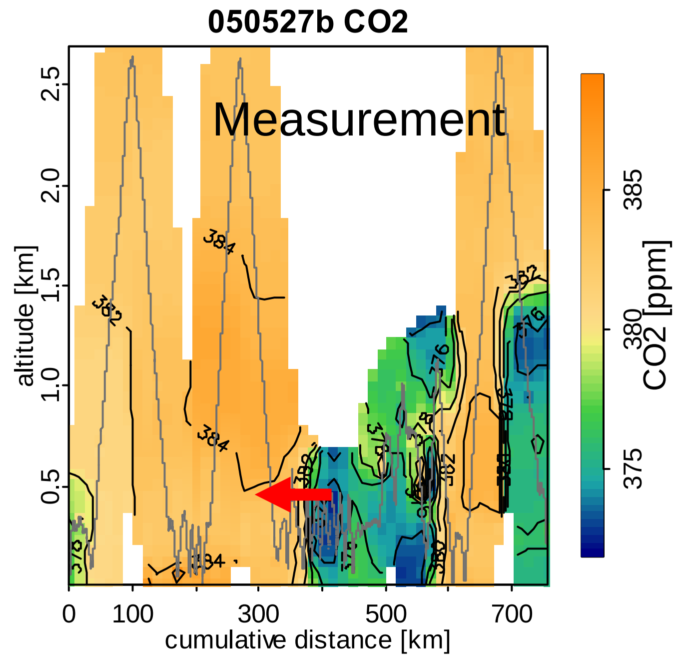
Regional Experiment

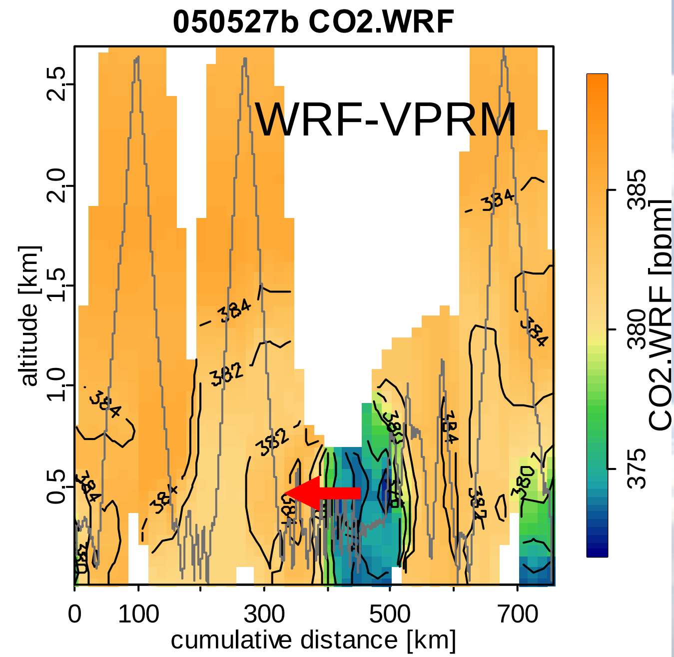


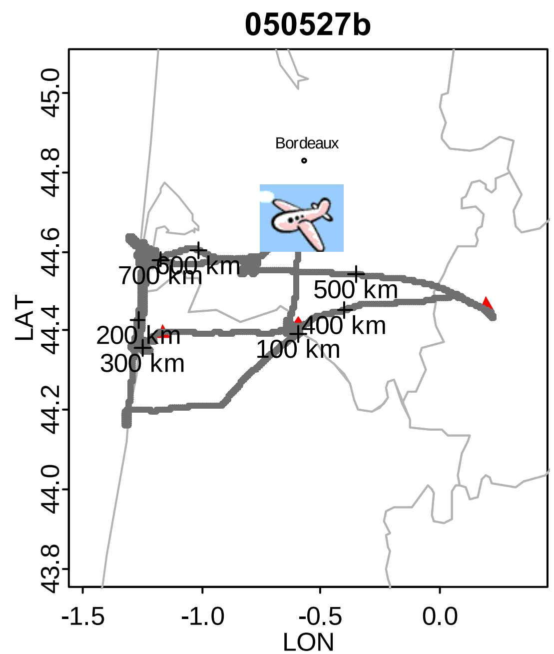


WRF-VPRM vs. Aircraft data

(CERES campaign)



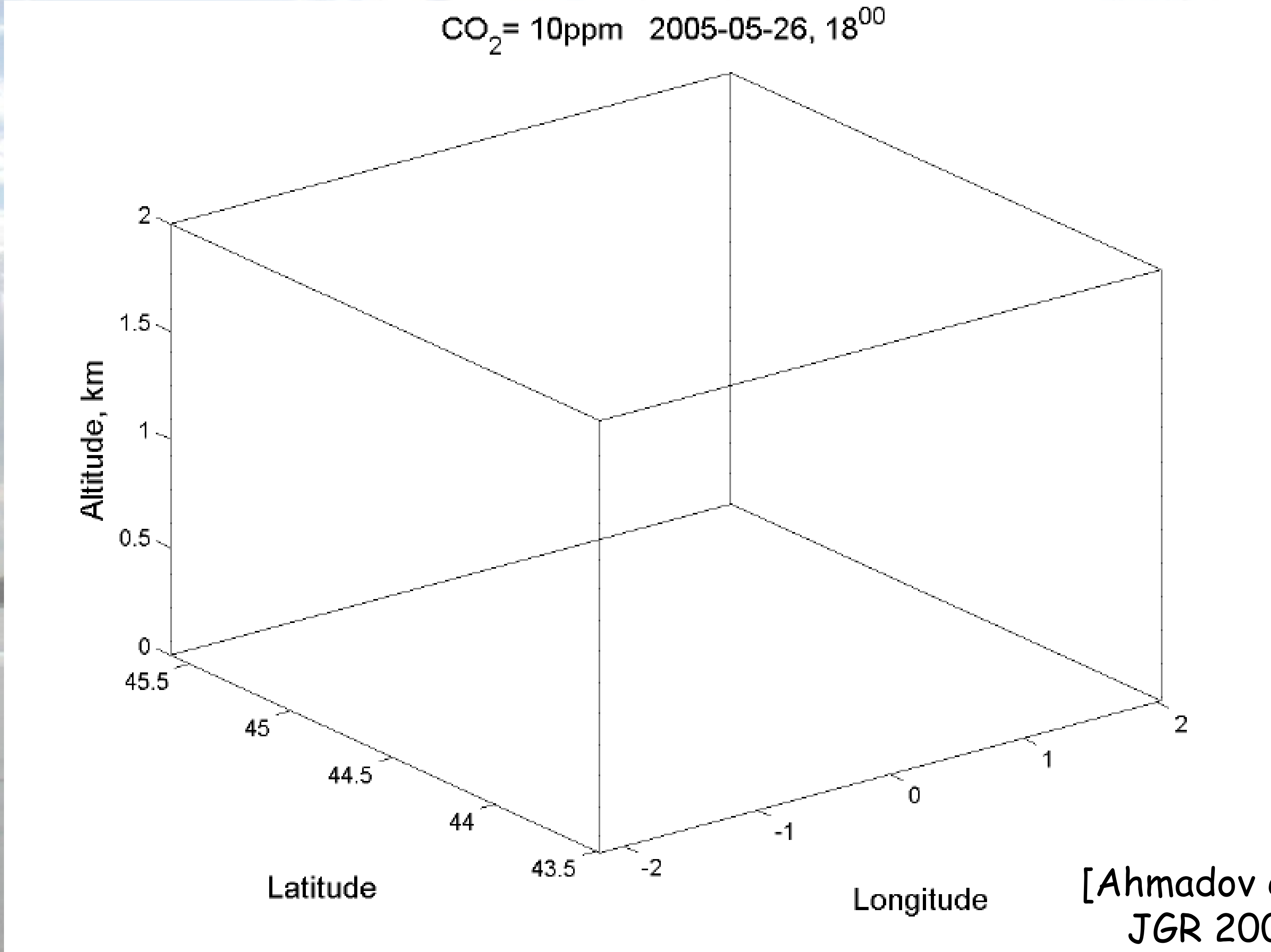




MetAir Eco-Dimona

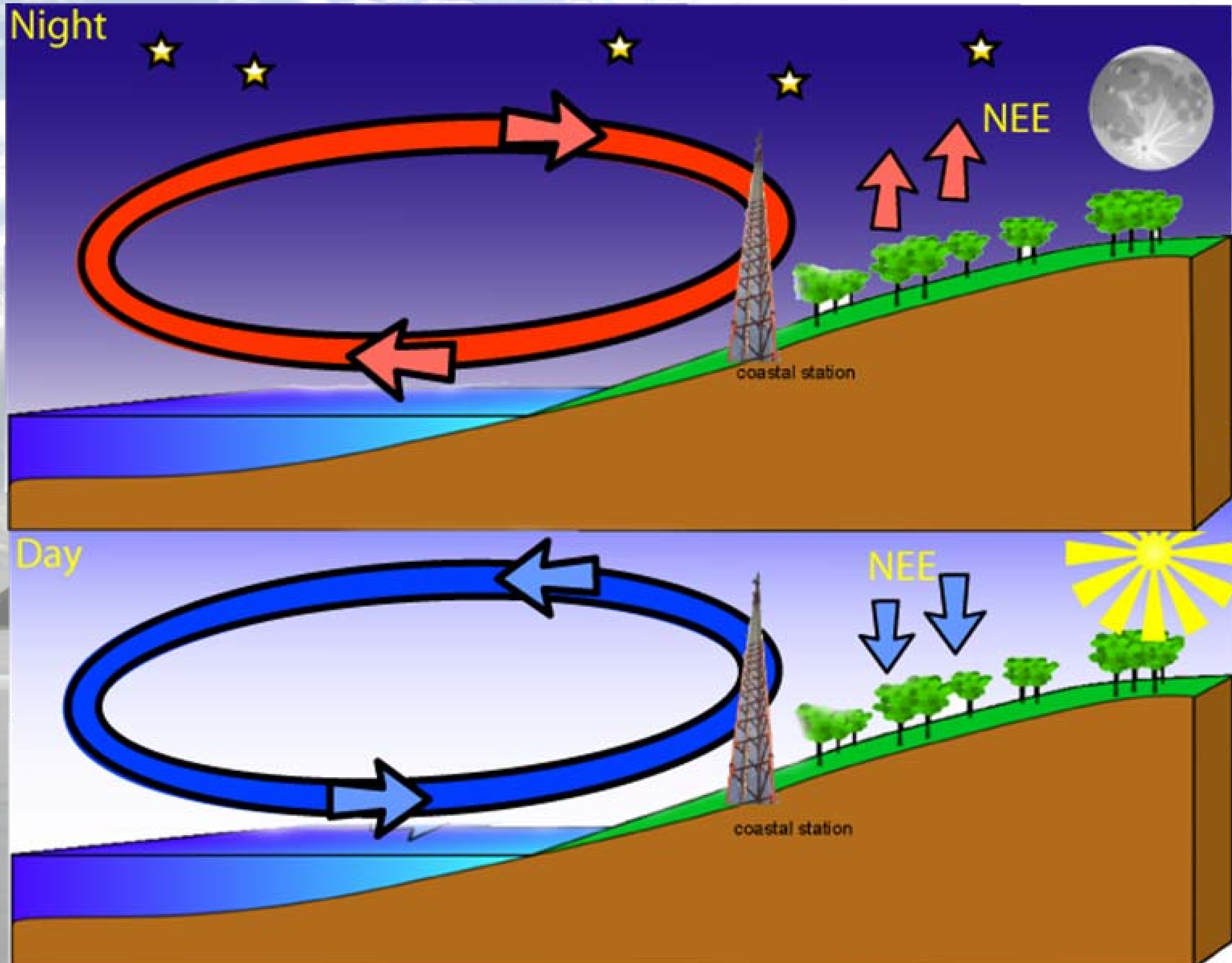
Respired CO2 signal

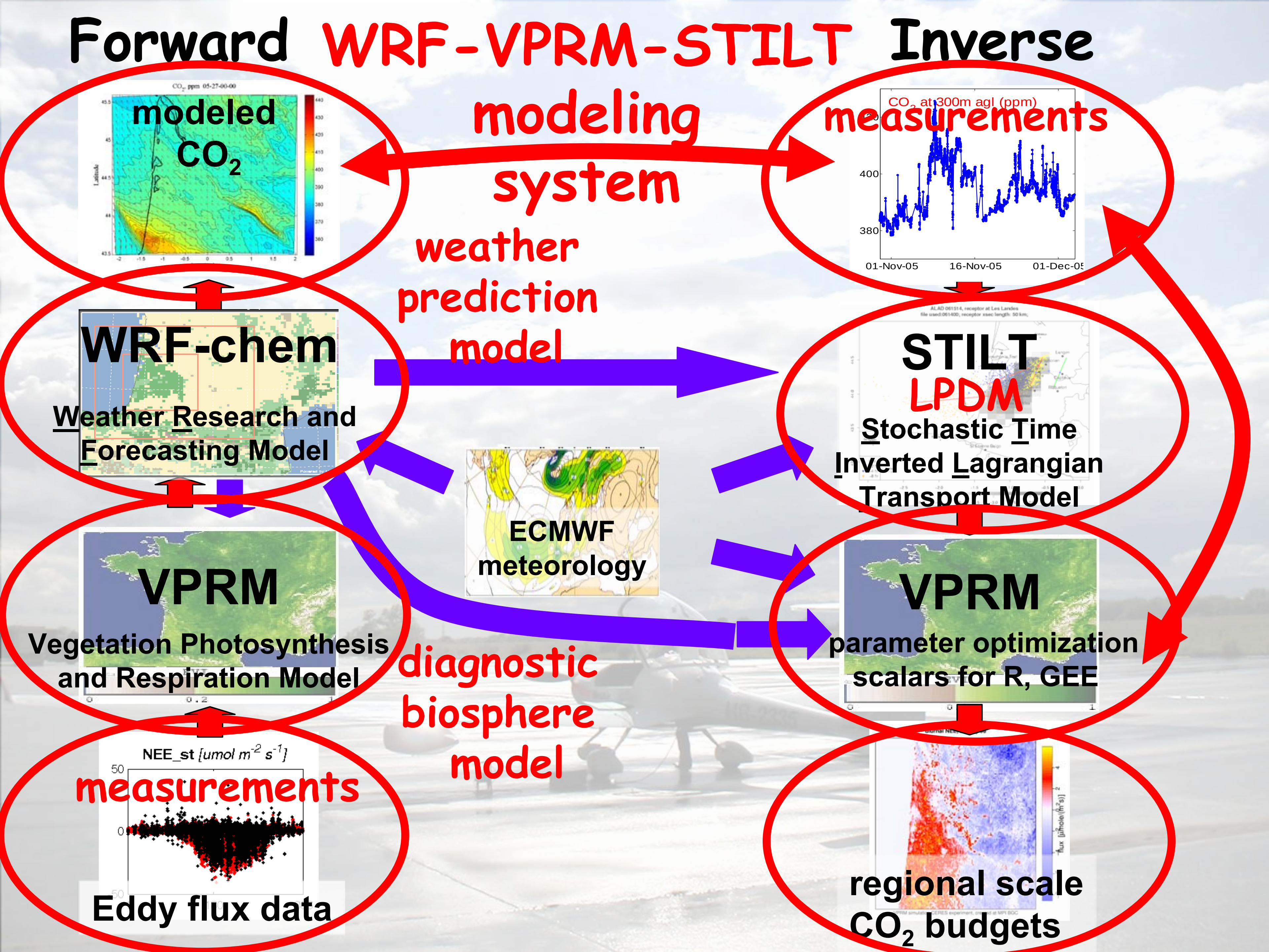
10 ppm surface



[Ahmadov et al., JGR 2007]

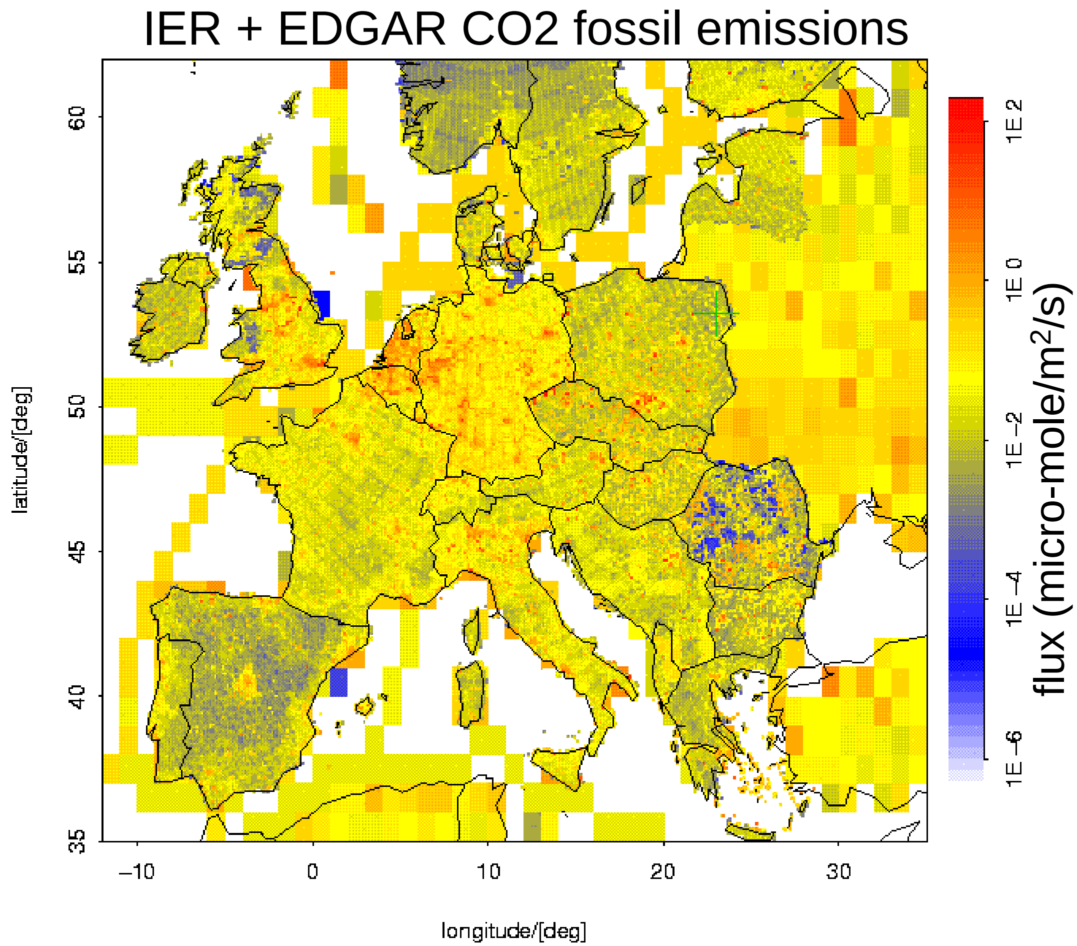
Mesoscale covariance of transport and CO2 fluxes
"3D rectifier effect"





Forward WRF-VPRM-STILT Inverse
modeled CO2
modeling system
measurements
CO2 at 300m agl (ppm)
400
380
01-Nov-05
16-Nov-05
01-Dec-05
weather prediction model
WRF-chem
Weather Research and Forecasting Model
STILT
LPDM
Stochastic Time Inverted Lagrangian Transport Model
ECMWF meteorology
VPRM
Vegetation Photosynthesis and Respiration Model
VPRM
parameter optimization scalars for R, GEE
diagnostic biosphere model
NEE_st [umol m-2 s-1]
50
0
measurements
Eddy flux data
regional scale CO2 budgets

STILT-VPRM

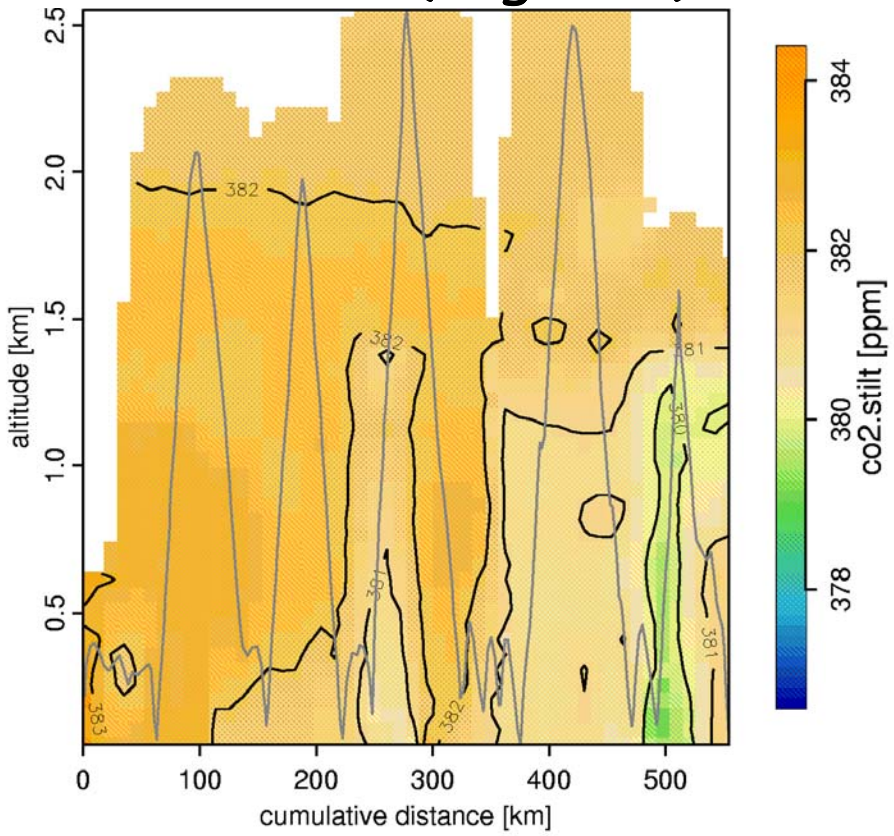


Stochastic Time Inverted Lagrangian Transport

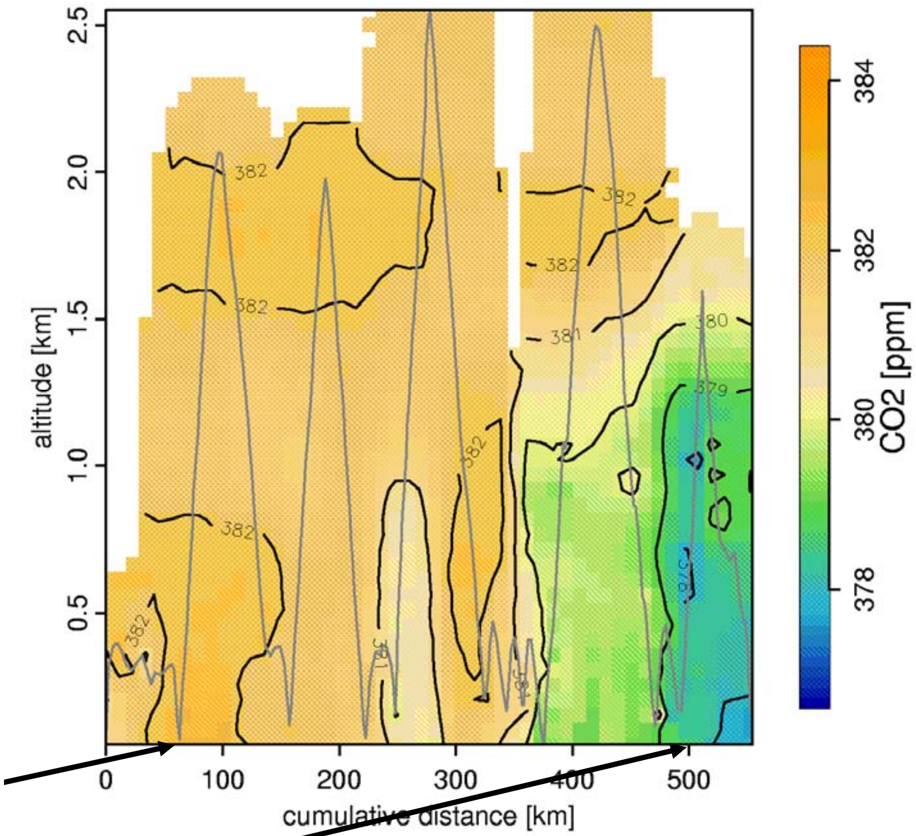
- ECMWF winds
  + turbulence + convection
- Resolution: 1/12° x 1/8° (~10x10 km^2)
- Biosphere: VPRM
- Emissions:
  IER (Hourly, 10 km) + EDGAR
- Lateral boundary condition:
  analyzed CO_2 fields (TM3 + Edgar + Takahashi + Biome-BGC)

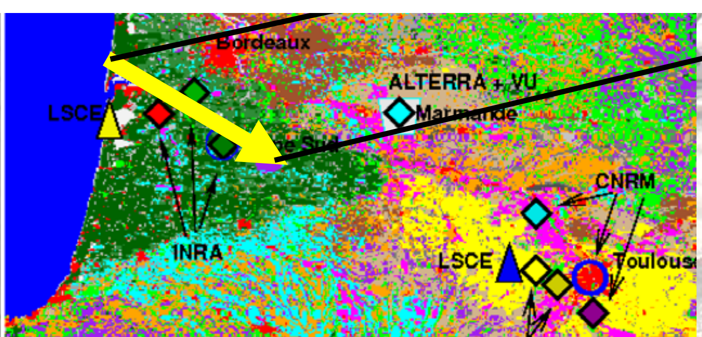
STILT-VPRM

STILT-VPRM (regional)

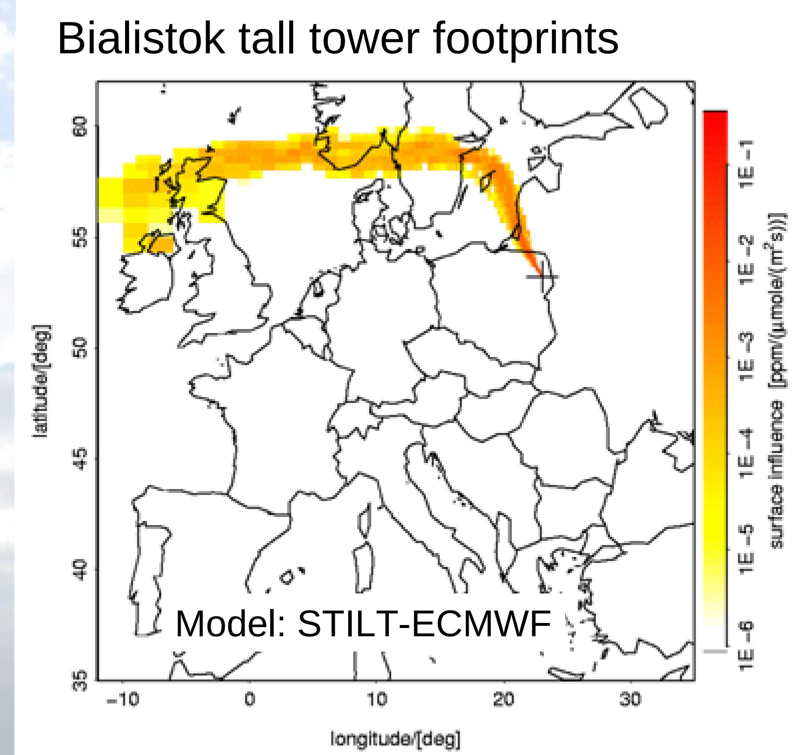


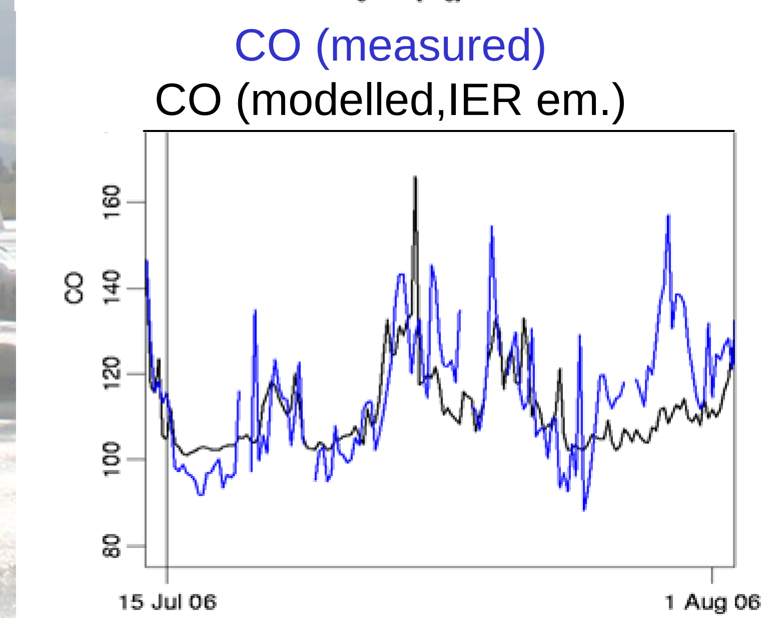
CERES Dimo measurements



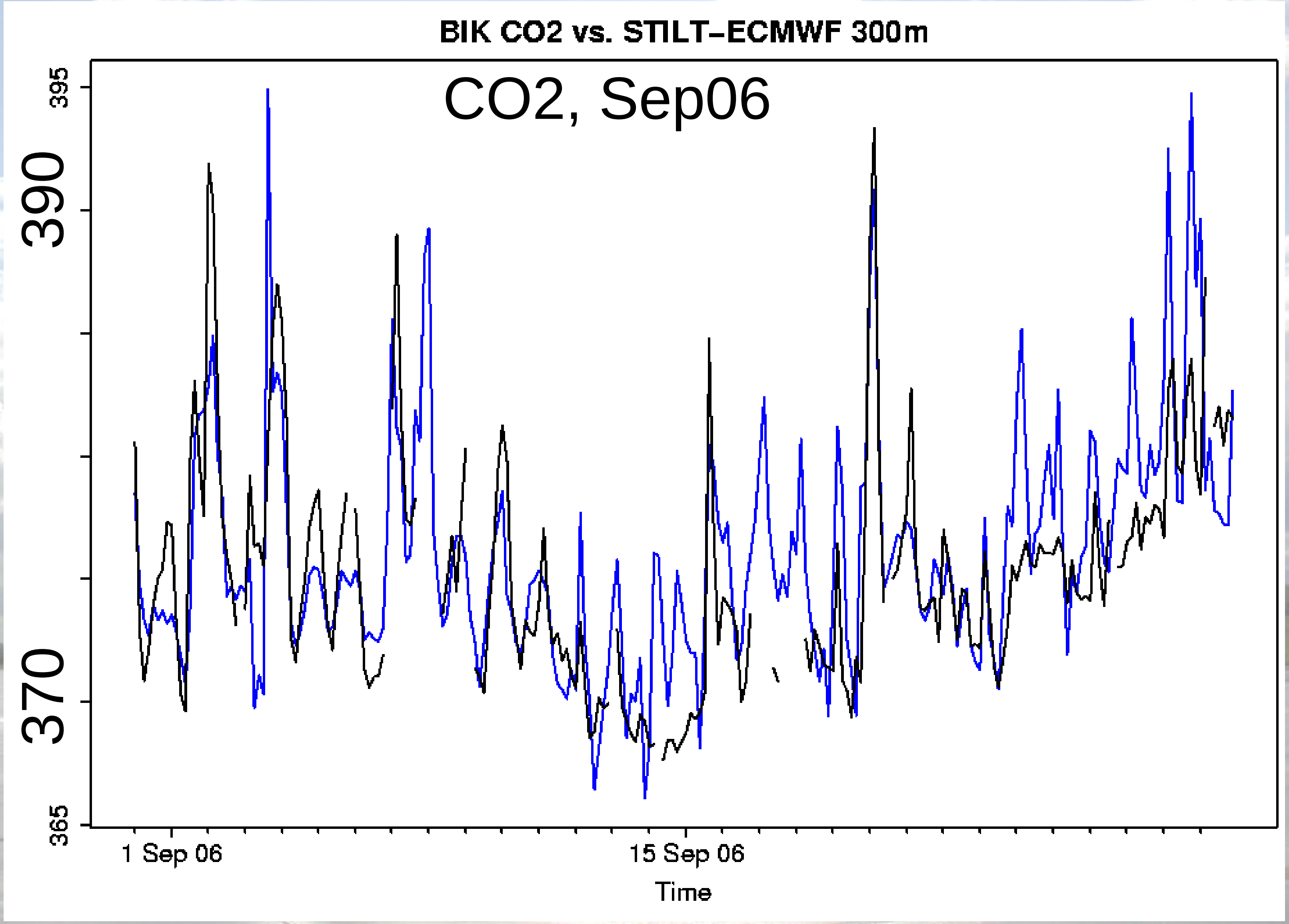


STILT @ Tall Tower



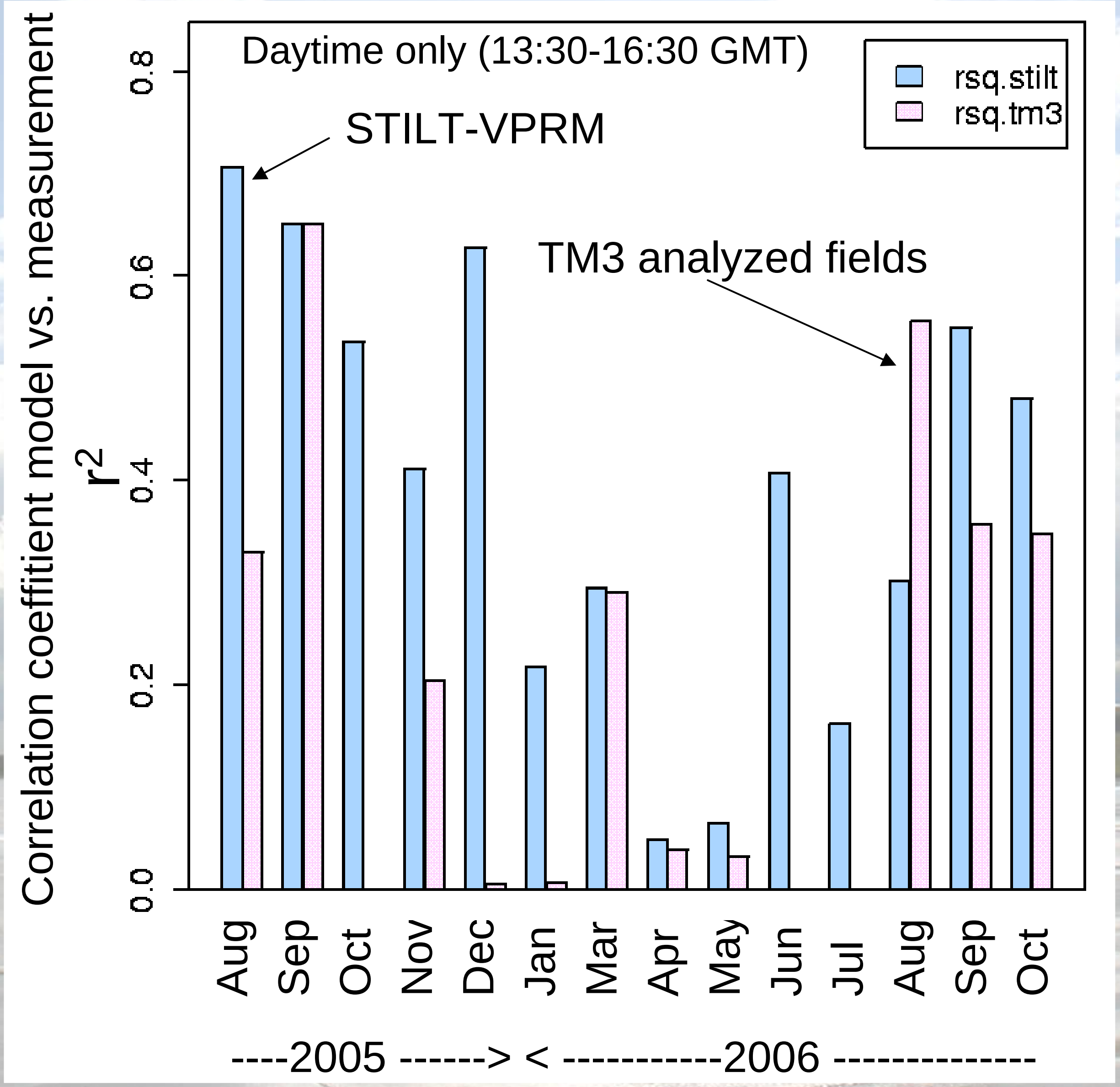


Sep 06 Bialystok 300 m level

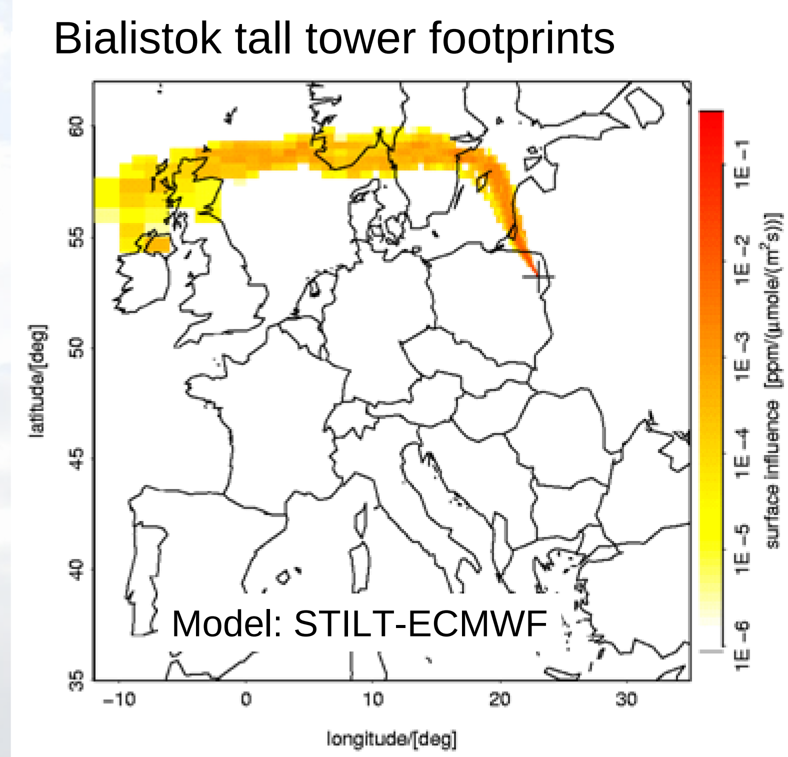


– BIK Measurements – STILT VPRM

Aug 05 - Oct 06 Bialystok 300 m



STILT @ Tall Tower



- 8 tall towers (> 100 m) in Europe instrumented with continuous profile measurements
- Optimize VPRM using STILT
- => Regional scale hourls fluxes at 10 km resolution

Uncertainties involved (continental stations)

Source of uncertainty	Type	Magnitude	Reference
Transport Model	Advection		
	PBL mixing		
	Convection		
Transport Model + Flux Model	Grid resolution		
Flux Model	Aggregation		
Measurement	Precision, accuracy		

winds uncertain
+
spatial flux variability
=
mixing ratios uncertain

Uncertainties involved (continental stations)

Source of uncertainty	Type	Magnitude	Reference
Transport Model	Advection	~ 5 ppm (summertime)	Lin and Gerbig, 2005
	PBL mixing		
	Convection		
Transport Model + Flux Model	Grid resolution		
Flux Model	Aggregation		
Measurement	Precision, accuracy		

winds uncertain
+
spatial flux variability
=
mixing ratios uncertain

comparison of radiosonde derived z_i with ECMWF-fields derived z_i

Uncertainties involved (continental stations)

Source of uncertainty	Type	Magnitude	Reference
Transport Model	Advection	~ 5 ppm (summertime)	Lin and Gerbig, 2005
	PBL mixing	~ 5 ppm (summertime)	Gerbig et al, 2007
	Convection	?	
Transport Model + Flux Model	Grid resolution		
Flux Model	Aggregation		
Measurement	Precision, accuracy		

mixing height uncertain
=
mixing ratios uncertain

comparison of radiosonde derived z_i with ECMWF-fields derived z_i

Uncertainties involved (continental stations)

Source of uncertainty	Type	Magnitude	Reference
Transport Model	Advection	~ (sur	big,
	PBL mixing	~ (su	al,
	Convection	?	
Transport Model + Flux Model	Grid resolution	~ 1 ppm @ 200 km (summertime)	Gerbig et al., 2003
Flux Model	Aggregation		
Measurement	Precision, accuracy		

Spatial statistics of multiple profile measurements (COBRA experiments)

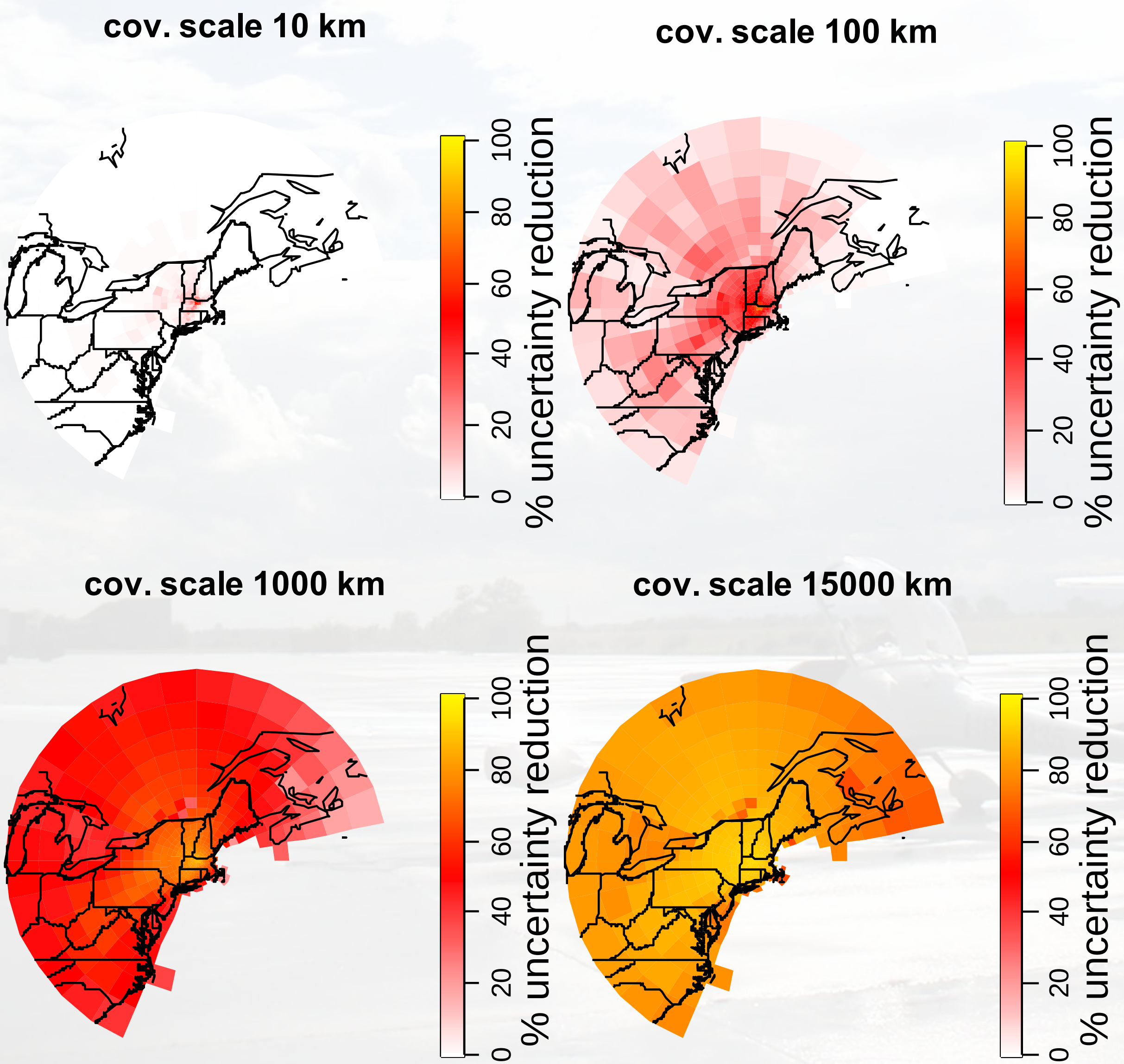
Uncertainties involved (continental stations)

Source of uncertainty	Type	Magnitude	Reference
Transport Model	Advection	~ 5 ppm (summertime)	Lin and Gerbig, 2005
	PBL mixing	~ 5 ppm (su	Gerbig et al,
	Convection		
Transport Model + Flux Model	Grid resolution	(summer time)	al.,
Flux Model	Aggregation	depending on Aggregation and Model	Gerbig et al., 2006
Measurement	Precision, accuracy		

pseudo data experiment, varying a-priori covariance length scale

"Eyesight of the atmosphere"

Reduction in flux uncertainty, spatially resolved, as function of a-priori covariance length scale



larger a priori covariance scales

=>

larger scale „information"

⇒

Need good knowledge about prior uncertainty + covariance!

[*Gerbig et al., ACP 2006*]

Uncertainties involved (continental stations)

Source of uncertainty	Type	Magnitude	Reference
Transport Model	Advection	~ 5 ppm (summertime)	Lin and Gerbig, 2005 ✓
	PBL mixing	~ 5 ppm (summertime)	Gerbig et al, 2007 ✓
	Convection	?	
Transport Model + Flux Model	Grid resolution	~ 1 ppm @ 200km (summertime)	Gerbig et al., 2003 ✓
Flux Model	Aggregation	depending on Aggregation and Model	Gerbig et al., 2006 ✓
Measurement	Precision, accuracy	**0.1 ppm (targeted)**	WMO

Mitigation?

Modifying some measurement strategies …

PBL mixing problem

- Add a device to monitor mixed layer height
  - e.g. Ceilometer (operational at many airports and weather stations, globally ~5000)
    - Cheap LIDAR
    - Continuous observation of cloud base, but also vertical profile of backscatter up to 7.5 km possible

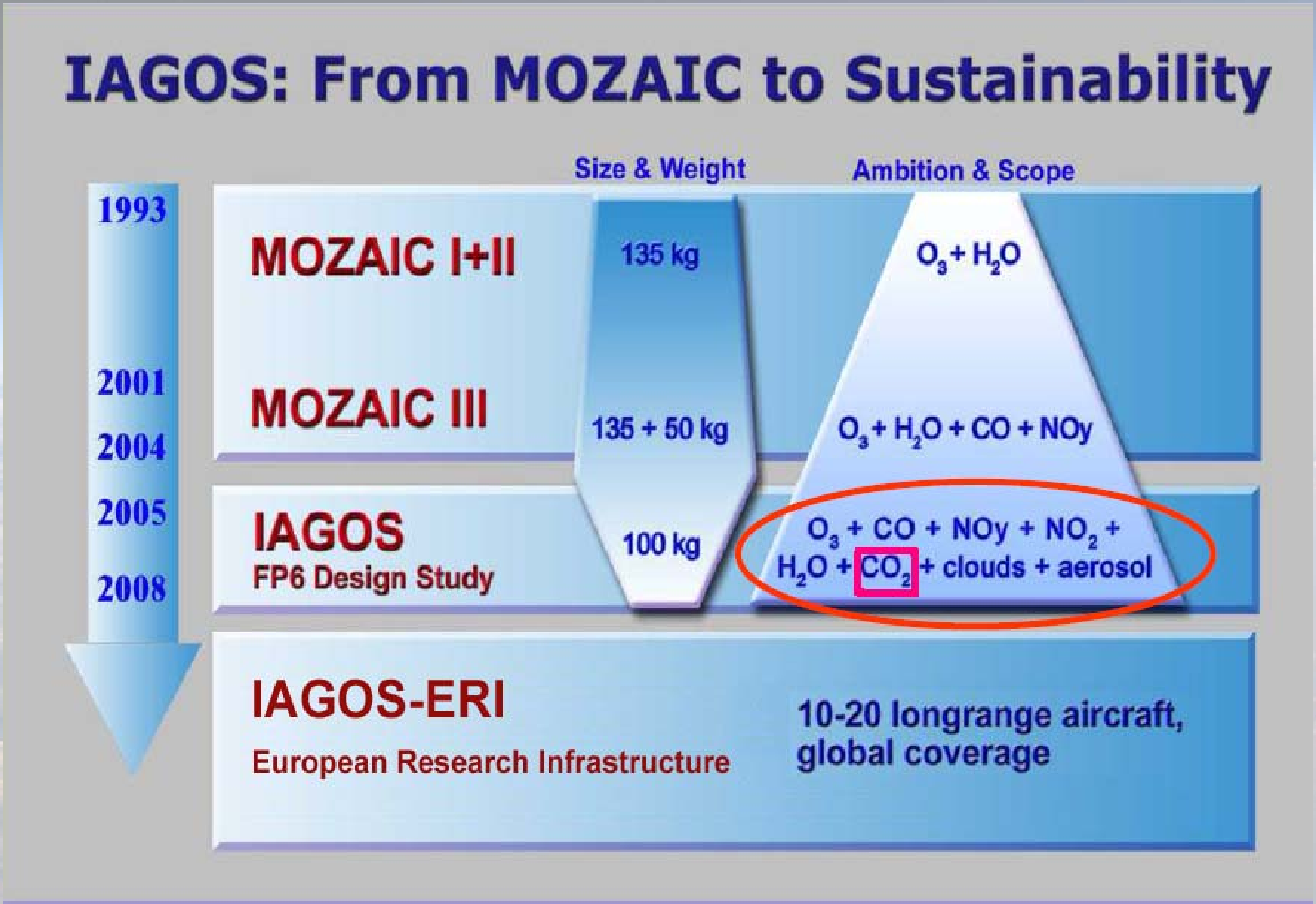
Regular vertical profiles: Aircraft

IAGOS (Integration of routine Aircraft measurements into a Global Observing System)

Predecessor (1993-2004):

MOZAIC (Measurement of Ozone and Water Vapour by Airbus In-Service Aircraft)

Regular vertical profiles: Aircraft



IAGOS (Integration of routine Aircraft measurements into a Global Observing System)

Max-Planck-Institut für Biogeochemie

MPI-BGC Jena

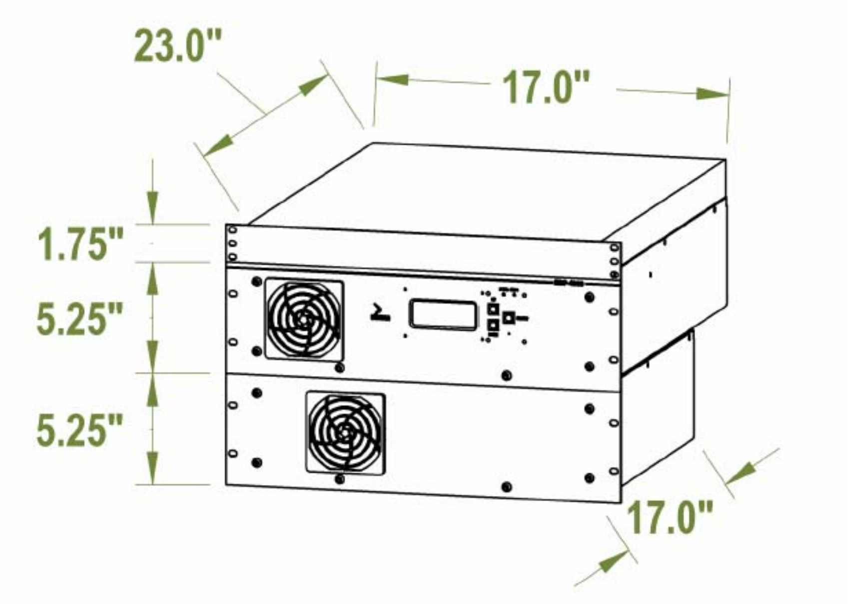
Forschungszentrum Jülich

in der Helmholtz-Gemeinschaft

Picarro CRDS system

SBIR (Small Business Innovation Research) project with Picarro & NOAA

- Modifications to ensure stability
- Size/weight reduction
- Repackaging & Certification
- First deployment in 2011, up to 7 A340 aircrafts



Specification	Value
CO_2 Precision	< 100 ppbv
CH_4 Precision	< 1 ppbv
H_2O Precision	< 50 ppmv
Measurement Speed	< 1 second
Drift (30 hours)	< 150 ppbv

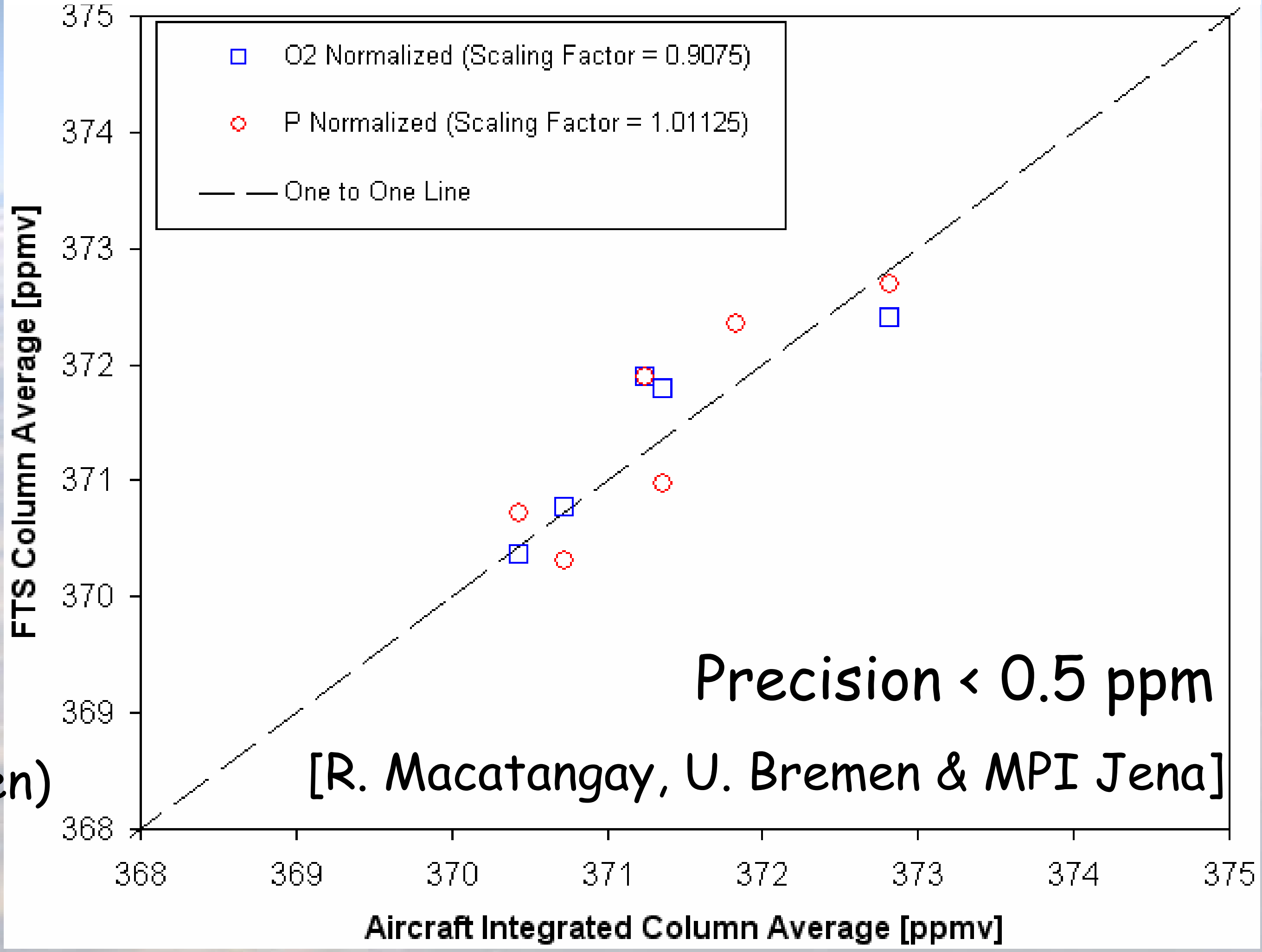
Regular vertical profiles: FTIR

Validation of FTIR column retrievals for CO_2 against CERES aircraft data

MetAir Dimona
(B. Neininger)

Bruker 120 M
(J. Notholt, U. Bremen)

FTS (NIR) vs. Aircraft + TM3 Model (above 4 km)



Precision < 0.5 ppm

[R. Macatangay, U. Bremen & MPI Jena]

Closing remarks

- Model-data-fusion:
  - Merging bottom-up and top-down is required, otherwise both are underconstrained at relevant scales
- High resolution information from intensive campaigns:
  - important for model validation
- Mesoscale modelling with WRF-VPRM:
  - VPRM captures NEE on relevant spatial and temporal scales
  - WRF-VPRM captures main mesoscale transport features
- Models aren't perfect, and they will never be.
  - reduction **and** characterization of uncertainties is required
  - representation error: not necessarily random
  - mesoscale modeling required to bridge the gap to global models
  - aggregation error: specification of a priori uncertainty **and** covariances needed (may be solve for?)

Closing remarks II

- Transport: modified measurement strategy can help
  - PBL height: additional measurements needed near towers, assimilation into transport fields
  - Vertical mixing: regular vertical profiling
    - ➔ IAGOS, FTIR, OCO, GOSAT

- To utilize **long term & large scale** information from mixing ratio observations, we **first** need to model (or parameterize) the **short term & small scale with minimal bias**


Thank you.