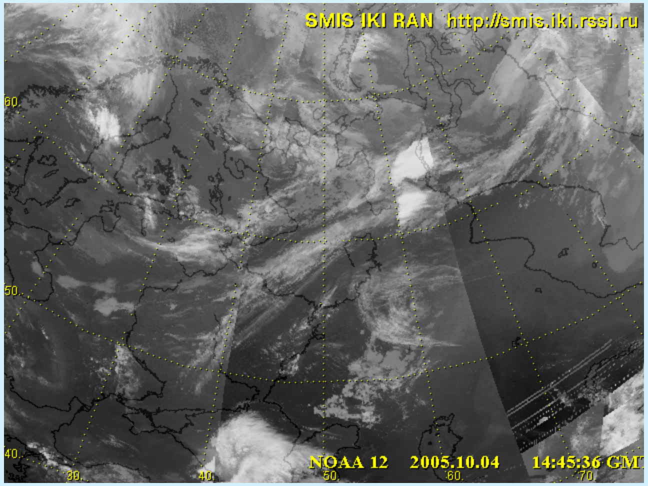
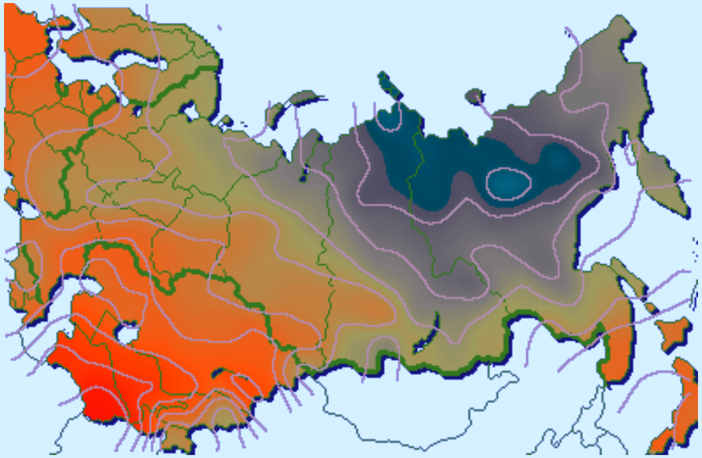




Ekaterina Klimova

Institute of Computational Technologies,

Russian Academy of Sciences, Siberian Branch

Monitoring of environment on the basis of data assimilation system

klimova@ict.nsc.ru

PLAN of REPORT

- ***The problem of data assimilation.***
- ***Mathematical statements of the problem.***
- ***Problems of practical realisation.***
- ***Assimilation of satellite data.***
- ***Data assimilation in environment modelling.***
- ***The review of the works on monitoring of the environment based on data assimilation.***
- ***Final conclusions.***

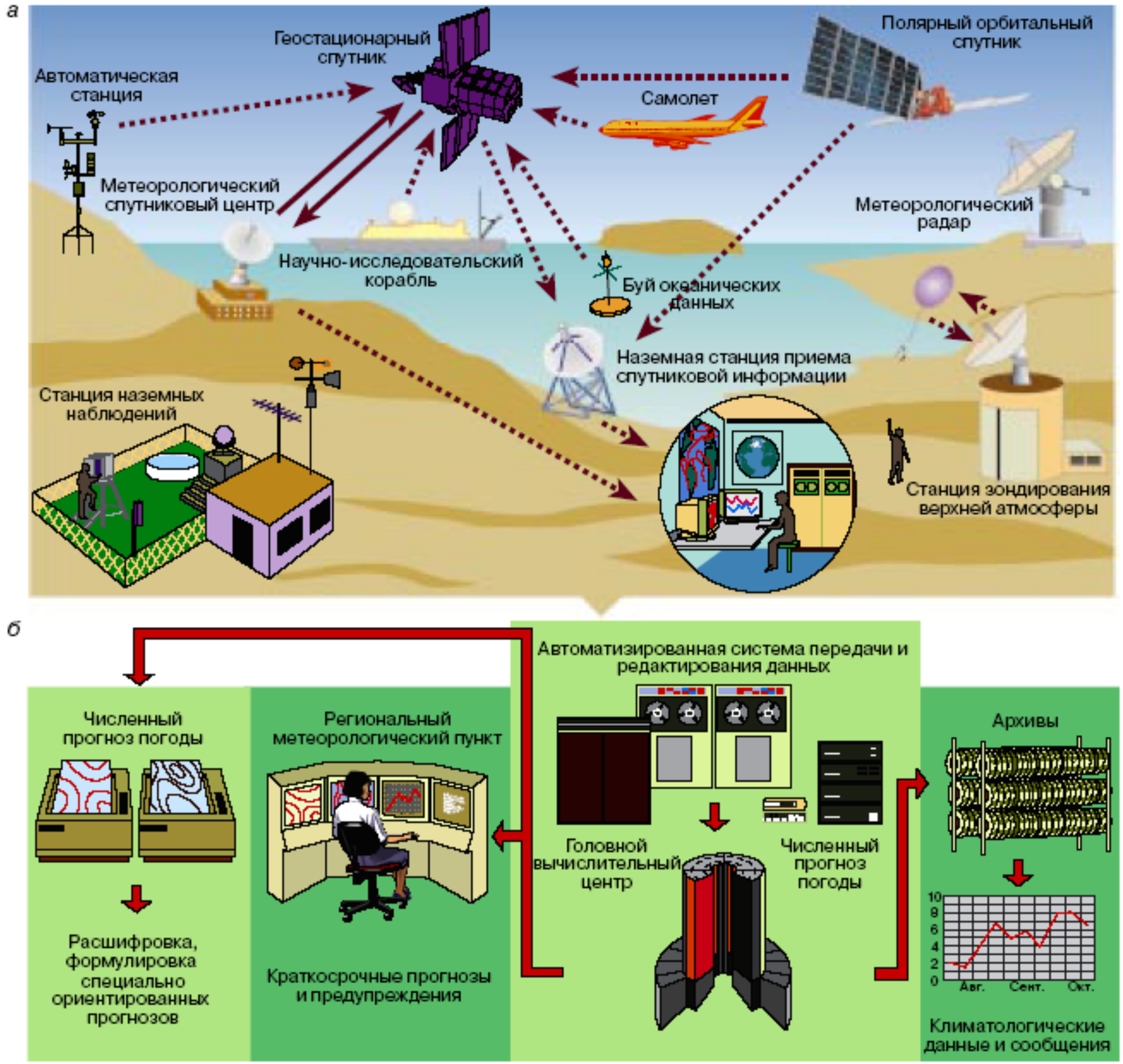
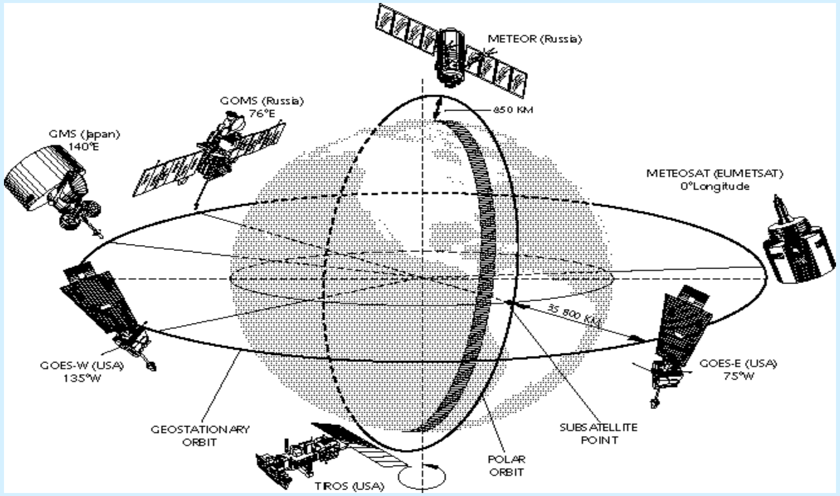
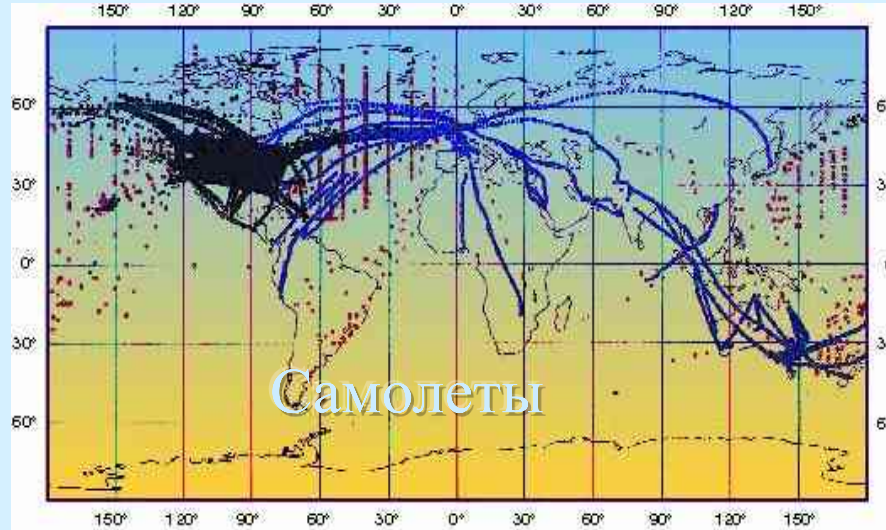


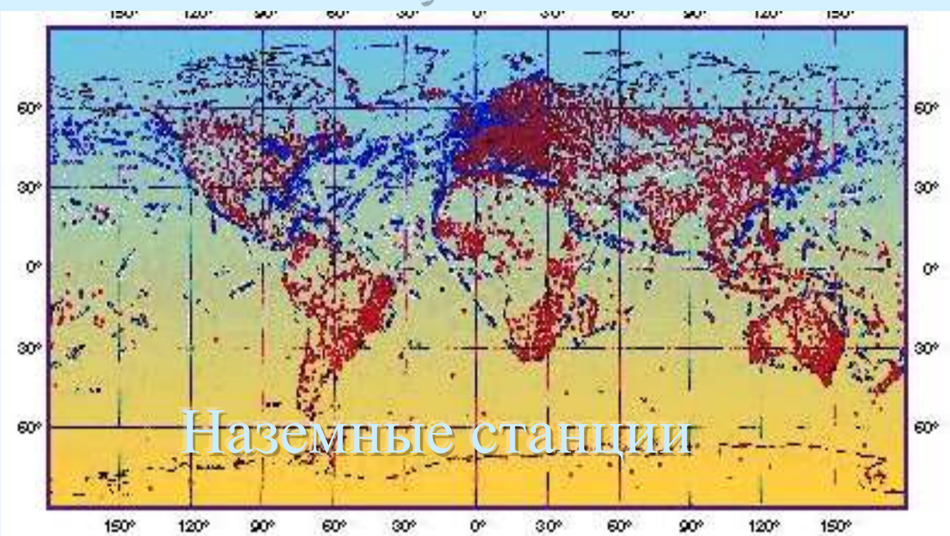
Рис. 1. Диаграмма системы наблюдений (*а*), сбора и обработки (*б*) данных наблюдений за состоянием гидросферы Земли (из сб. "Технология сбора и передачи метеорологических данных". М.: ВМО, 1995)

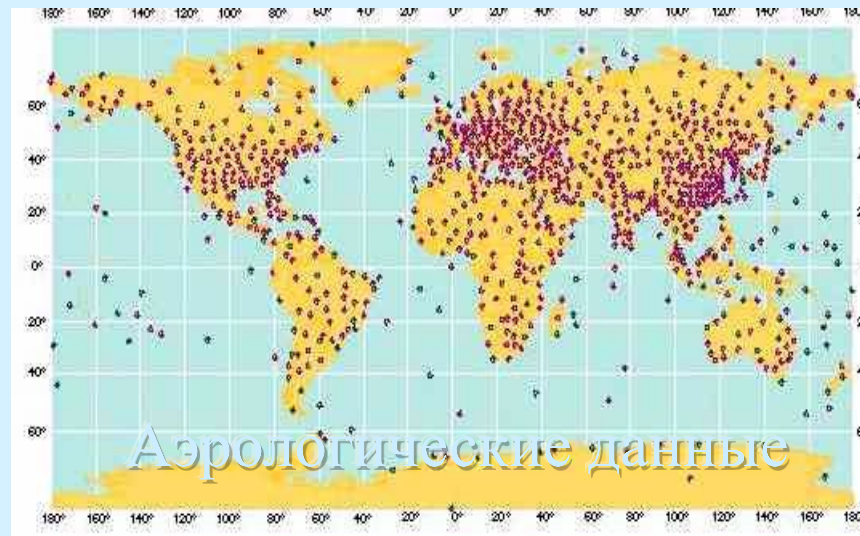
Observational systems



Спутники







Observational systems

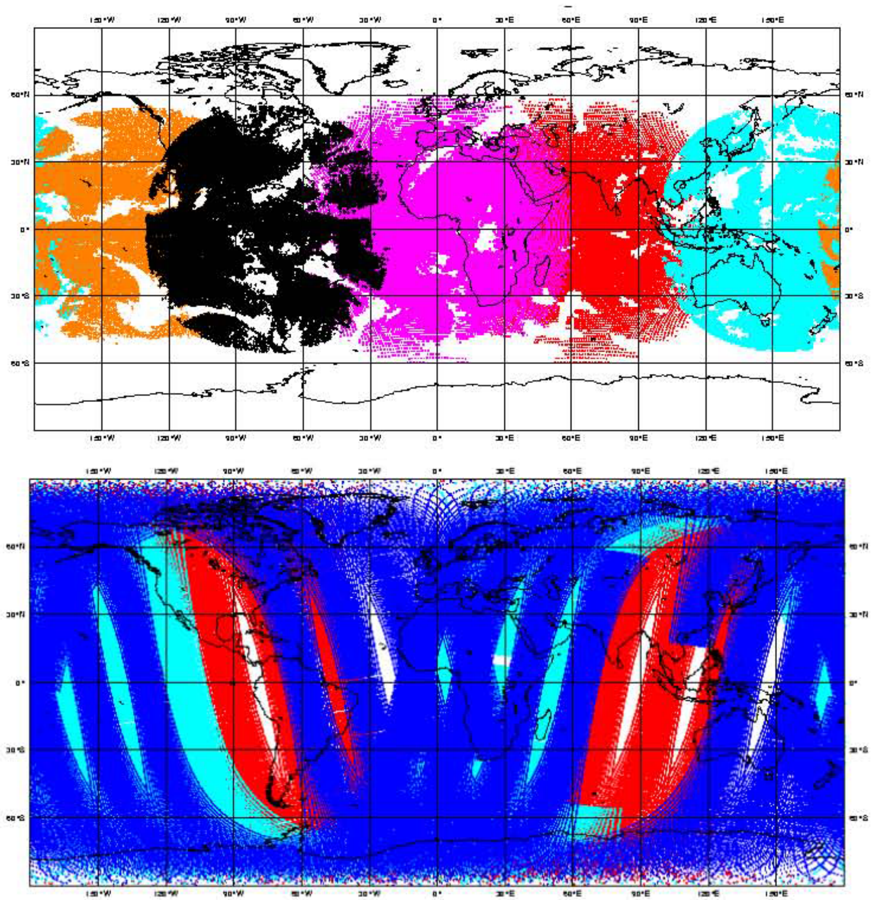


Figure 1: Typical data coverage provided by the Geostationary constellation (top): GOES-W/E (orange/black), Meteosat-7/5 (pink/red) and GMS-5/GOES-9 (cyan). Bottom plot displays the LEO constellation from the NOAA satellites (NOAA-15 in red, NOAA-16 in cyan, NOAA-17 in blue).

Introduction

- ***Data assimilation is a problem of the restoration of distribution of any fields using the observational data and the mathematical model describing dynamics of fields on time.***

- ***Such problems are considered now for the description of processes in atmosphere, ocean, and also distributions of polluting substances in the environment.***

- ***The purpose of the data assimilation is the initial fields for the forecast, and more the general - the description of behaviour on time of investigated fields, climate studying etc.***

Data assimilation problem

4DVAR

ECMWF (1997)

Meteo France (2000)

Met-Office (2004)

Japan (2005)

Canada (2005)

4DVAR → ***RRKF(redused rank Kalman filter)***

Kalman Filter

Canada, Atmospheric Environment Service (H.Mitchel, P.L.Houtekmer):

Ensemble Kalman Filter

US Berkeley, University of Maryland (B.Hunt et al; E.Kalnay et al):

The local ensemble transform Kalman filter (LETKF)

Mathematical statements of a problem:

3DVAR

---

y_0 - observations

x_b - forecast

P_b - forecast errors covariance matrix

R - observational errors covariance matrix

$$2J(x) = (x - x_b)^T P_b^{-1}(x - x_b) + (y_0 - H(x))^T R^{-1}(y_0 - H(x))$$

$$\downarrow$$

$$\nabla_x J(x_a) = 0$$

$$\downarrow$$

$$(P_b^{-1} + H^T R^{-1} H)(x_a - x_b) = H^T R^{-1}(y_0 - H(x_b))$$

$$\updownarrow$$

$$x_a = x_b + (P_b^{-1} + H^T R^{-1} H)^{-1} H^T R^{-1}(y_0 - H(x_b))$$

Mathematical statements of a problem: ***Kalman filter***

$$x_k^f = A_{k-1} x_{k-1}^a;$$

$$P_k^f = A_{k-1} P_{k-1}^a A_{k-1}^T + Q_{k-1;}$$

$$K_k = P_k^f M_k^T (M_k P_k^f M_k^T + R_k)^{-1};$$

$$P_k^a = (I - K_k M_k) P_k^f;$$

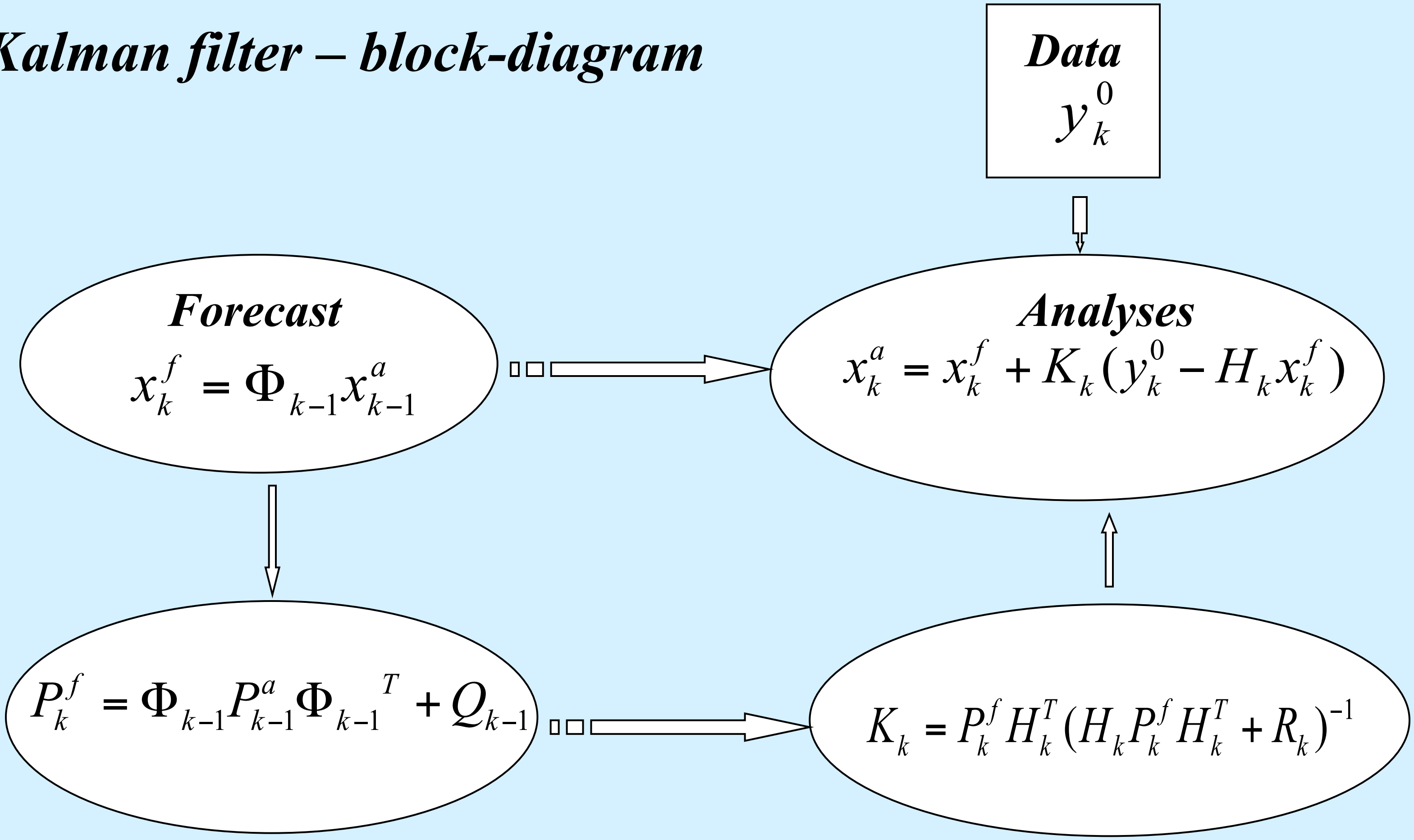
$$x_k^a = x_k^f + K_k (y_k^0 - M_k x_k^f);$$

$$k = 0, \ldots, K.$$

$$P_k^f = E(x_k^f - x_k^t)(x_k^f - x_k^t)^T; P_k^a = E(x_k^a - x_k^t)(x_k^a - x_k^t)^T.$$

Kalman filter: the problems of realization

Kalman filter – block-diagram



Problems of realization : satellite data assimilation

3DVAR →

$$\begin{cases} 2J(x) = (x - x_b)^T P_b^{-1}(x - x_b) + (y_0 - H(x))^T R^{-1}(y_0 - H(x)) \\ x_a = x_b + (P_b^{-1} + H^T R^{-1} H)^{-1} H^T R^{-1}(y_0 - H(x_b)) \end{cases}$$

•It is necessary to transform variables of model to observable variables.

•Operator H is non-liniar.

•The data are continuous on time.

•The matrix R is not diagonal.

• There is systematic error in observations (bias).

Extract from the report on satellite data assimilation:

Satellite data assimilation at NCEP

John C. Derber
Environmental Modeling Center
NCEP/NWS/NOAA

With contributions from:

D. Parrish	D. Kleist
W.-S. Wu	R. Treadon
M. Pondeca	L. Cucurull
X. Li	P. Van Delst
K. Okamoto (JMA)	M. Kazumori (JMA)

Extract from the report on satellite data assimilation:

Final Comments

(Opinion based on experience)

- For NWP, satellite radiances most important satellite observation
- Microwave radiances more useful than IR radiances because of clouds
- More observations are not always better
- Impact of new instruments usually not as large as anticipated
- Larger improvement usually occurs because of improvement to assimilation systems than the addition of new data
- Most applied research in atmospheric data assimilation done at operational centers (and GSFC DAO)

Problems of satellite data assimilation. Final conclusions

- ***Assumptions:***
  a. The observational errors are «unbiased».
  b. The random fields of observational errors are normally distributed.
- ***«Retrievals» or «radiation».***
- ***The problem of the quality control.***
- ***The definition of covariance matrix of observational errors.***
- ***The huge quantity of observations not always yields the best result.***

Data assimilation in environment modelling

1. The modelling of distribution in atmosphere:

- ***Passive gases ("greenhouse") (*** CO_2, CH_4 ***).***
- ***Reactive gases.***
- ***Aerozols.***

2. Observations.

3. The restoration of the time-space distribution of gases on the base of the data assimilation.

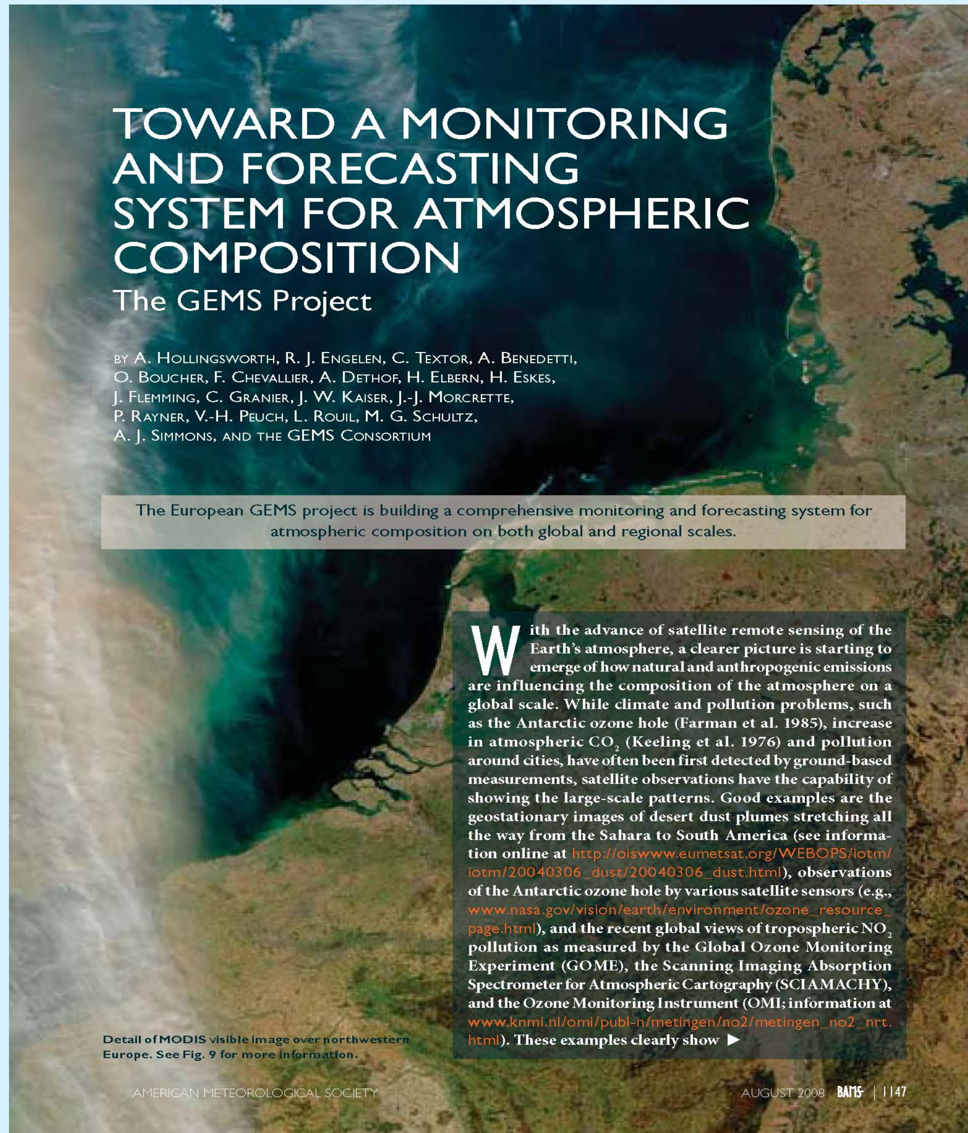
4. The estimation of regions influencing on the distribution of pollution in the given territory.

5. The estimation of gas fluxes using the results of data assimilation.

Further the short review of a condition of researches in this area is presented.

***G**lobal **E**arth-system **M**onitoring using **S**pace and in-situ data (GEMS) 2005-2009*

The article on GEMS project



TOWARD A MONITORING AND FORECASTING SYSTEM FOR ATMOSPHERIC COMPOSITION

The GEMS Project

BY A. HOLLINGSWORTH, R. J. ENGELEN, C. TEXTOR, A. BENEDETTI, O. BOUCHER, F. CHEVALLIER, A. DETHOF, H. ELBERN, H. ESKES, J. FLEMMING, C. GRANIER, J. W. KAISER, J.-J. MORCRETTE, P. RAYNER, V.-H. PEUCH, L. ROUIL, M. G. SCHULTZ, A. J. SIMMONS, AND THE GEMS CONSORTIUM

The European GEMS project is building a comprehensive monitoring and forecasting system for atmospheric composition on both global and regional scales.

With the advance of satellite remote sensing of the Earth's atmosphere, a clearer picture is starting to emerge of how natural and anthropogenic emissions are influencing the composition of the atmosphere on a global scale. While climate and pollution problems, such as the Antarctic ozone hole (Farman et al. 1985), increase in atmospheric CO_2 (Keeling et al. 1976) and pollution around cities, have often been first detected by ground-based measurements, satellite observations have the capability of showing the large-scale patterns. Good examples are the geostationary images of desert dust plumes stretching all the way from the Sahara to South America (see information online at http://oiswww.eumetsat.org/WEBOPS/iotm/iotm/20040306_dust/20040306_dust.html), observations of the Antarctic ozone hole by various satellite sensors (e.g., www.nasa.gov/vision/earth/environment/ozone_resource_page.html), and the recent global views of tropospheric NO_2 pollution as measured by the Global Ozone Monitoring Experiment (GOME), the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY), and the Ozone Monitoring Instrument (OMI; information at www.knmi.nl/omi/publ-n/metingen/no2/metingen_no2_nrt.html). These examples clearly show ►

Detail of MODIS visible image over northwestern Europe. See Fig. 9 for more information.

Extract from the report on GEMS Project:

Global Earth-system Monitoring using Space and in-situ data – GEMS

Richard Engelen

ECMWF

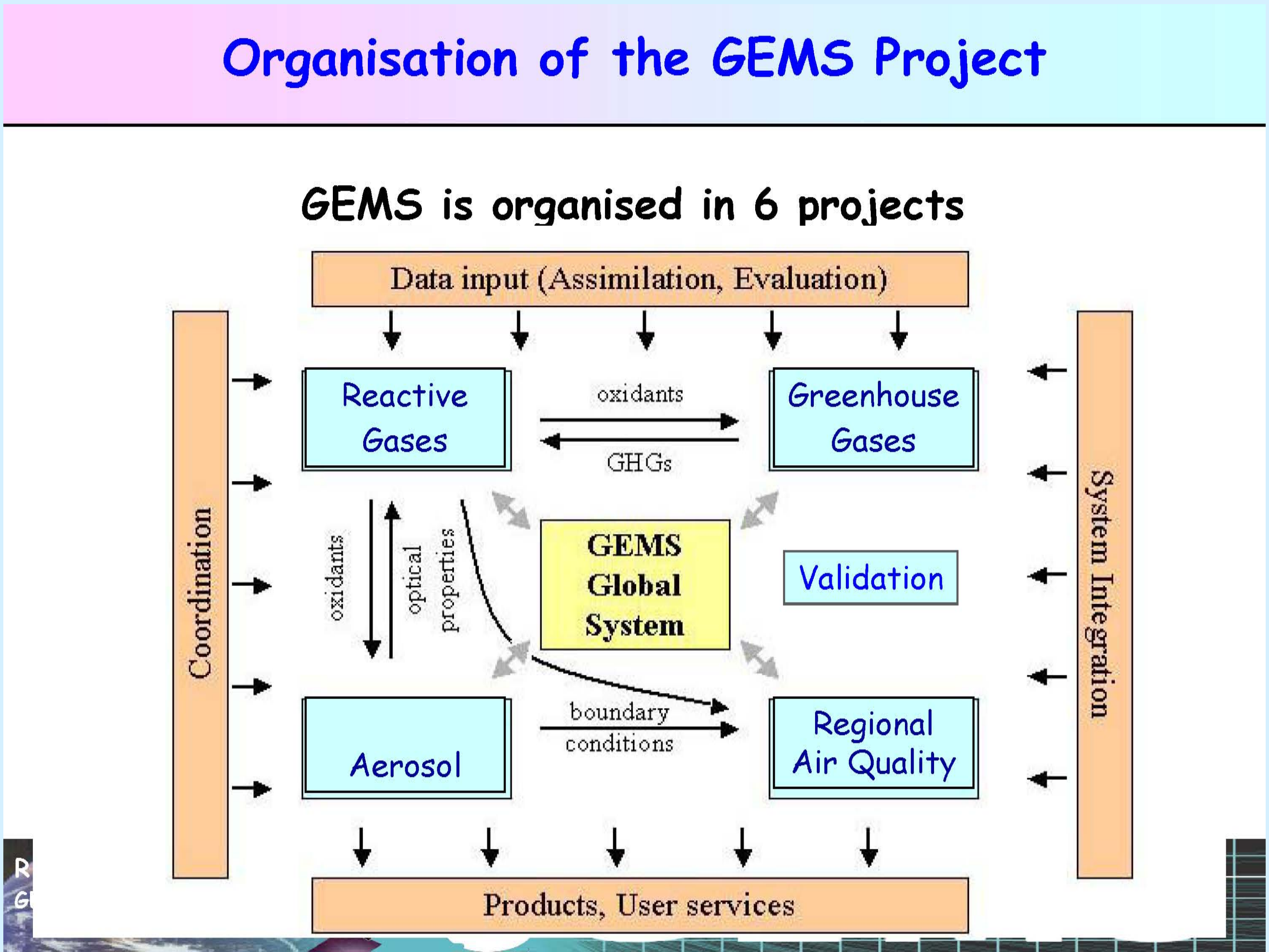
Credits to GEMS Management team

A. Hollingsworth (ECMWF), C.Granier (S d'A), P.Rayner (LSCE), M.Schultz (FZJ), O.Boucher (UKMetO), V-H.Peuch (Met-Fr), H.Eskes (KNMI), A.Simmons (ECMWF)

Credits to ECMWF team

A.Benedetti, A.Dethof, J. Kaiser, J-J.Morcrette, J.Flemming, M.Razinger, S.Serrar, M.Suttie

Extract from the report on GEMS Project:



Extract from the report on GEMS Project:

GMES: Motivations for GEMS

- **TREATY ASSESSMENT & VALIDATION**
  - Conventions (Kyoto, Montreal, LRTAP) and IPCC need best estimates of sources/ sinks/ transports of atmospheric constituents.
- **BETTER OPERATIONAL SERVICES**
  - Improved forecasts: excess deaths in summer 2003 heatwave:- 18K in France, at least 33K in western Europe.
- **SCIENCE**
  - GEMS will synthesise all available satellite & in-situ data into accurate 'status assessments', and will meet many needs of the GCOS Implementation Plan

Extract from the report on GEMS Project :

GEMS tasks at ECMWF

- Greenhouse gases
  - Start on CO_2, then CH_4, CO and N_2O
  - Develop modelling and data assimilation, and use analyses to infer sources and sinks for CO_2 and CH_4
- Reactive gases
  - Couple main forecast model with global CTMs
  - Carry O_3, CO, NO_2, SO_2 and HCHO in main model and develop data assimilation
- Aerosols
  - Add to model, based on externally-produced parameterizations
  - Develop assimilation of retrievals, then radiances
- Integrate above components, and run past periods
- Provide boundary conditions and technical support for regional air-quality prediction

MACC Project (2009) – Monitoring Atmospheric Composition and Climate

Monitoring atmospheric composition & climate

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macc – Monitoring Atmospheric Composition and Climate – is the current pre-operational atmospheric service of the European GMES programme. MACC provides data records on atmospheric composition for recent years, data for monitoring present conditions and forecasts of the distribution of key constituents for a few days ahead. MACC combines state-of-the-art atmospheric modelling with Earth observation data to provide information services covering European Air Quality, Global Atmospheric Composition, Climate, and UV and Solar Energy.

Latest News
- Reanalysis production started
- Volcanic Eruption in Iceland

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Global Atmospheric Composition

Climate

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Science Community

Citizen

Meteorology

Potential users of MACC are invited to complete the questionnaire at this

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MACC is a Collaborative Project (2009-2011) funded by the European Union under the 7th Framework Programme.
It is coordinated by the European Centre for Medium-Range Weather Forecasts and operated by a 45-member consortium.

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3.2	Laboratoire d'Aérologie	CNRS-LA	
3.3	Laboratoire Interuniversitaire des Systèmes Atmosphériques	CNRS-LISA	
3.4	Cloud-Aerosol-Water-Radiation Interactions	CNRS-ICARE	
4	Commissariat à l'Energie Atomique	CEA	
5	Deutsches Zentrum für Luft- und Raumfahrt e.V.	DLR	
6	Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.	MPG	
7	Royal Netherlands Meteorological Institute [Chemistry and Climate, Climate Observations]	KNMI	
8	Institut d'Aéronomie spatiale de Belgique	BIRA-IASB	
9	Ilmatieteen Laitos - Finnish Meteorological Institute	FMI	
10	Danish Meteorological Institute	DMI	
11	Deutscher Wetterdienst	DWD	
12	University of Bremen	IUP-UB	
13	Université Pierre et Marie Curie - Paris 6	UPMC-SA	
14	National and Kapodistrian University of Athens	NKUA	
15	Météo-France - Centre National de Recherches Météorologiques	MF-CNRM	
16	National University of Ireland,Galway	NUIG	
17	Swedish Meteorological and Hydrological Institute	SMHI	
18	ARPA Emilia Romagna	ARPA-ER	
19	Agencia Estatal de Meteorología	AEMet	
20	Meteorologisk Institutt	MET.NO	
21	Rheinisches Insti. für Umweltforschung an der Universität zu Köln	FRIUUK	
22	European Commission - Joint Research Centre	EC-DG-JRC	
23	Institut National de l'Environnement Industriel et des Risques	INERIS	
24	Czech Hydrometeorological Institute	CHMI	
25	National Meteorological Administration, Romania	NMA	
26	Institute of Environmental Protection	PIEP	

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32	University of Leeds	UNIVLEEDS	
33	King's College London	KCL	
34	Vrije Universiteit, independent entity of Vereniging voor Christelijk hoger onderwijs, wetenschappelijk onderzoek en patientenzorg	VUA	
35	Umweltbundesamt GmbH	UBA-AT	
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38	Carlo Gavazzi Space S.p.A.	CGS	
39	Flyby s.r.l.	Flyby	
40	Centre Européen de Recherche et Formation avancée en Calcul Scientifique	CERFACS	
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45	University of the West of Scotland	UWS	

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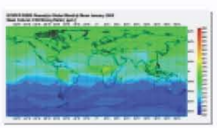
Data Access

GEMS datasets

DATASET	PARAMETERS	PERIOD	AREA	LINK
 **GEMS Reanalysis**	chemical and aerosol species, meteorological parameters	1.1.2003 - 30.4.2009	global	

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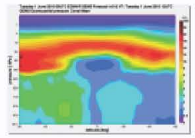
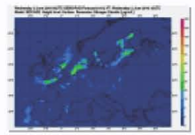
- Global Atmospheric Composition
- Climate forcing
- UV, Solar Energy, Stratospheric Ozone

Services by User

- Health Community
- Environmental Agencies

European Air Quality

UV Index

 **GEMS Near-real-time Analysis/Forecast Suite**	chemical and aerosol species	5.7.2008 - 29.9.2009	global	
 **GEMS Regional Air Quality Forecasts**	chemical and aerosol species	last 8 days	Europe	

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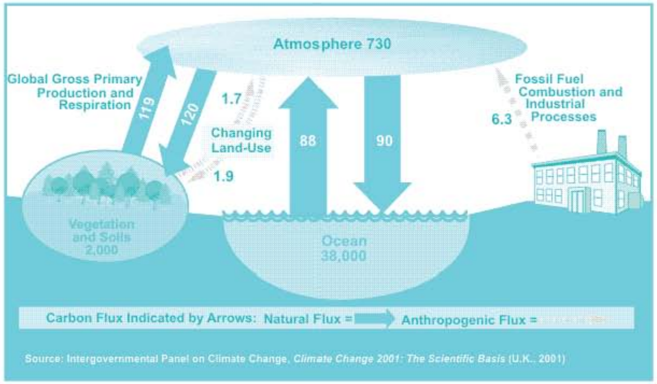
Some examples of researches in area of the data assimilation of CO2:

AIRS CO_2 data assimilation with Ensemble Kalman filter: preliminary results



Junjie Liu[1]

Eugenia Kalnay[2] and Inez Fung[1]

[1]UC Berkeley; [2]University of Maryland

Many thanks to Edward Olsen and Moustafa Chahine for kindly providing us their AIRS L2 CO_2 retrievals and guidance! Other collaborators include Yu-Heng Tseng, Michael Wehner and Masao Kanamitsu.

Some examples of researches in area of the data assimilation of CO2:

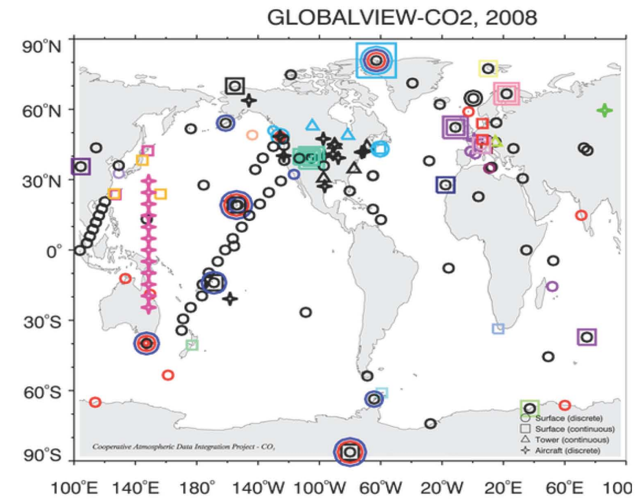
Motivation & Goals

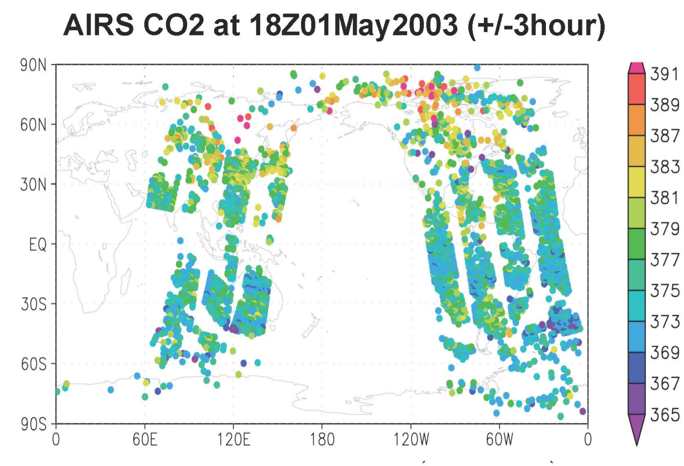
Motivation:

Accurate carbon flux estimation from inversion needs far more CO_2 observations than current surface obs can provide.

Goals:

1. Generate global CO_2 map every 6-hour; start with AIRS, then GoSat
2. Propagate AIRS CO_2 in both horizontal and vertical direction through data assimilation and transport model





Some examples of researches in area of the data assimilation of CO2:

TECHNICAL MEMORANDUM

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Four-dimensional data assimilation of atmospheric CO_2 using AIRS observations

Richard J. Engelen[1], Soumia Serrar[1], and Frédéric Chevallier[2]

[1]European Centre for Medium-Range Weather Forecasts, Reading, UK
[2]Laboratoire des Sciences du Climat et de l'Environnement, Gif sur Yvette, France

Research Department

Submitted to *Journal of Geophysical Research*

August 2008

European Centre for Medium-Range Weather Forecasts
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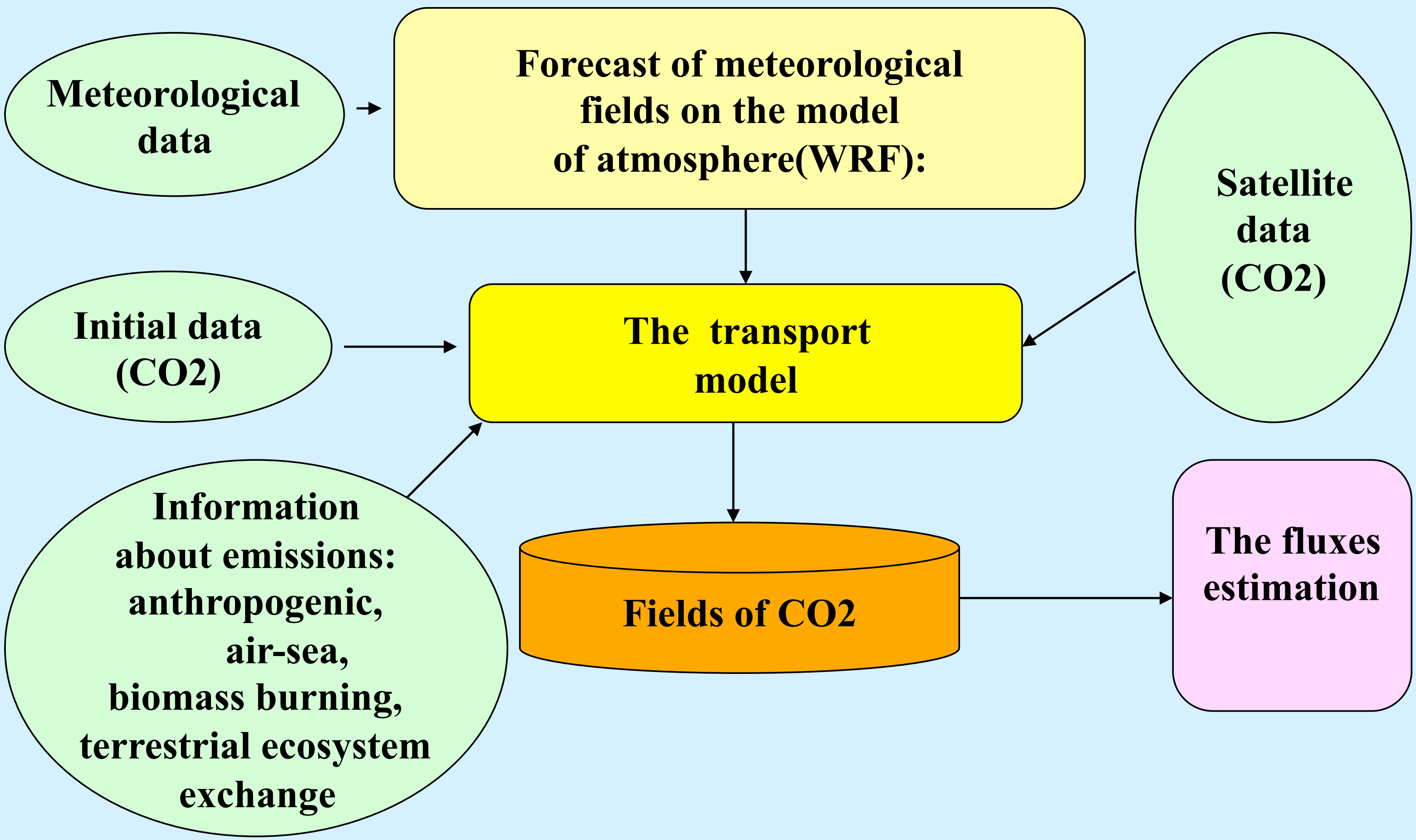
Centre européen pour les prévisions météorologiques à moyen terme

Data assimilation of passive gases :



Final conclusions

Based on the previous researches and everything aforesaid we plan the following:

1. ***The modelling of passive gases distribution of in the atmosphere.***

2. ***The data assimilation algorithms for passive gases.***

3. ***The estimation of regions influencing on the distribution of pollution in the given territory.***

4. ***The estimation of gas fluxes using the results of data assimilation.***

Thank you for attention !