CARBON HUMAN EMISSIONS AND RELATED ACTIONS

Science to deliver Services

Gianpaolo Balsamo
CHE Project Coordinator- ECMWF
22/10/2018 – Presented at the GCOS Science Day
FMI, Helsinki, Finland

CHE actors and governance framework

European Commission

esa

EUMETSAT

ECMWF

Copernicus
Europe's eyes on Earth

CO_2 Task Force

WORLD METEOROLOGICAL ORGANIZATION
WEATHER CLIMATE WATER

GAW

IG^3IS

GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

WMO

IOC

INTERNATIONAL COUNCIL FOR SCIENCE

UN environment

CEOS Committee on Earth Observation Satellites

GEO

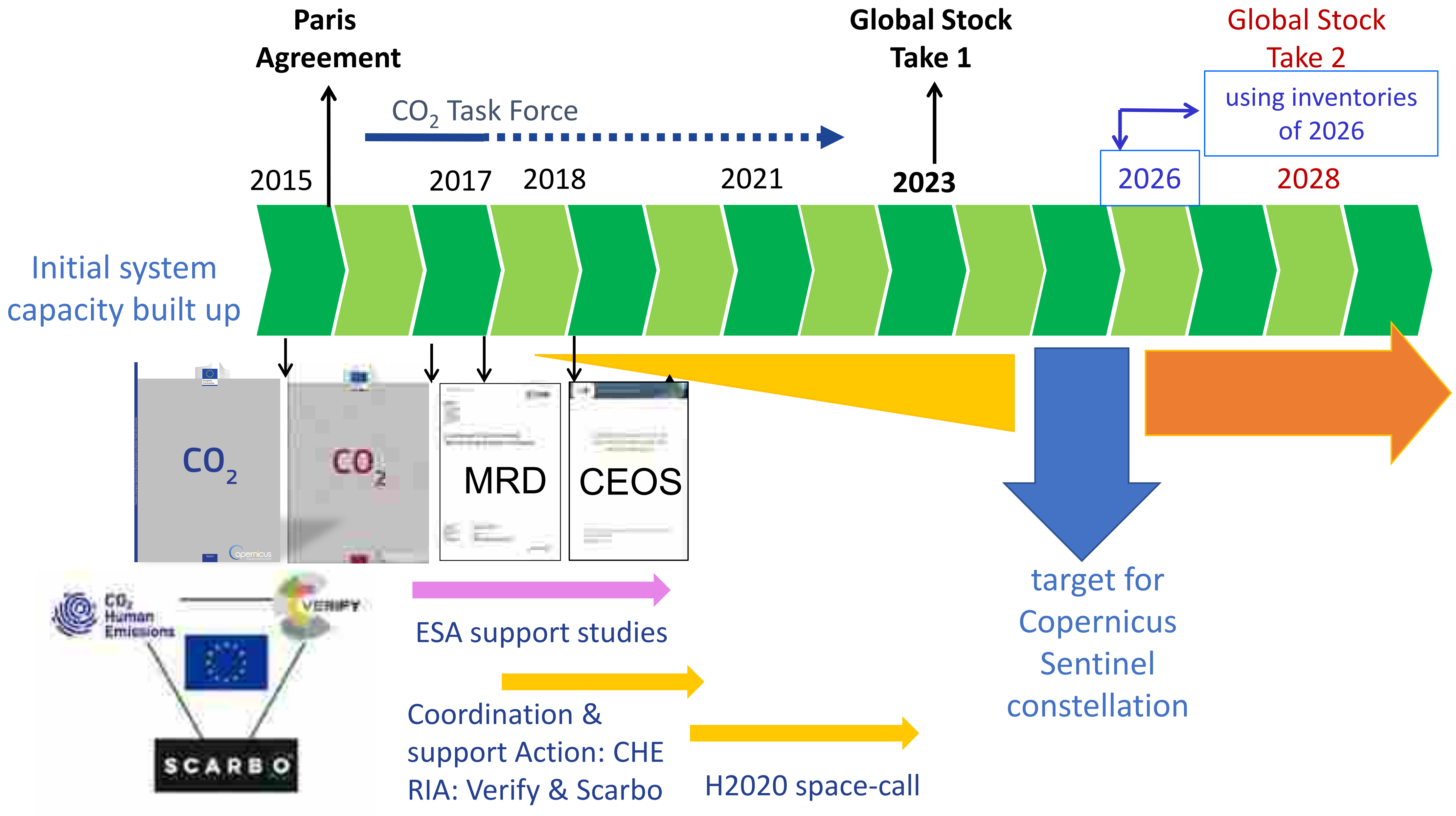
United Nations Framework Convention on Climate Change

SCARBO

HORIZON 2020
The EU Framework Programme for Research and Innovation

Thanks to Richard Engelen and Vincent-Henri Peuch

CHE in the context of $CO2$-MVS activities



CHE-CO2 Human Emission Project (& its numbers)

Aim:
Build European monitoring capacity for Anthropogenic CO2 emissions
How:
Monitoring/Verification System (MVS) driven by Earth observations, from remote sensing and in situ,
Combined with enhanced modelling system
That includes CO2 fossil fuel emissions, (Cities) along with other natural and anthropogenic CO2 emissions & transport.
Why:
To support the Paris Climate Agreement and its implementation

ECMWF AIRBUS CMCC DLR Empa EUMETSAT iLab SPASCIA SRON ThalesAlenia TNO innovation for life UEA NILU LEICESTER

Project Duration:
39 month

Project Funding:
3.75 ME (1.25 ME/year)

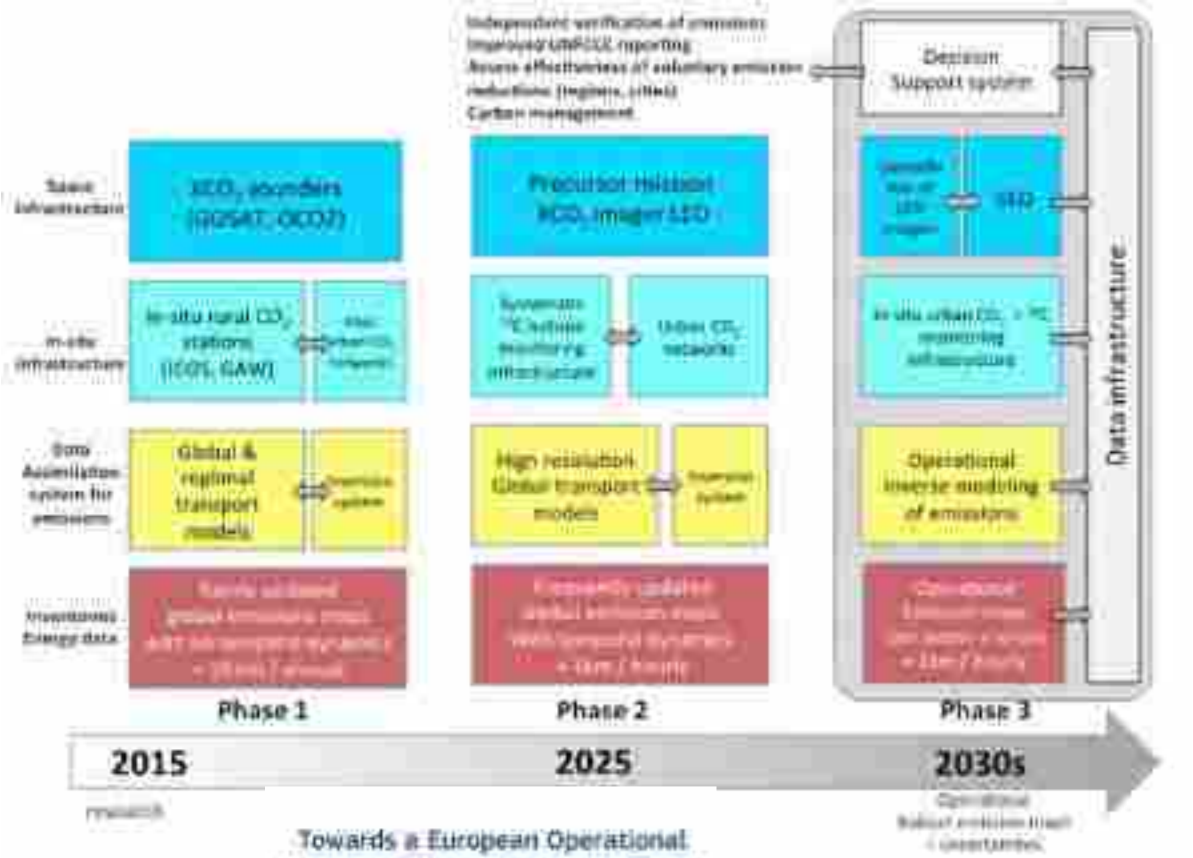
Consortium Numbers
22 partners Institutes

Work Content Numbers
7 work-packages:
5-Science development, **1**-International liaison,
1-Management & Coms
7 Milestones
45 Deliverables

344.25 Person Month
(Eq 8.8 FTE)

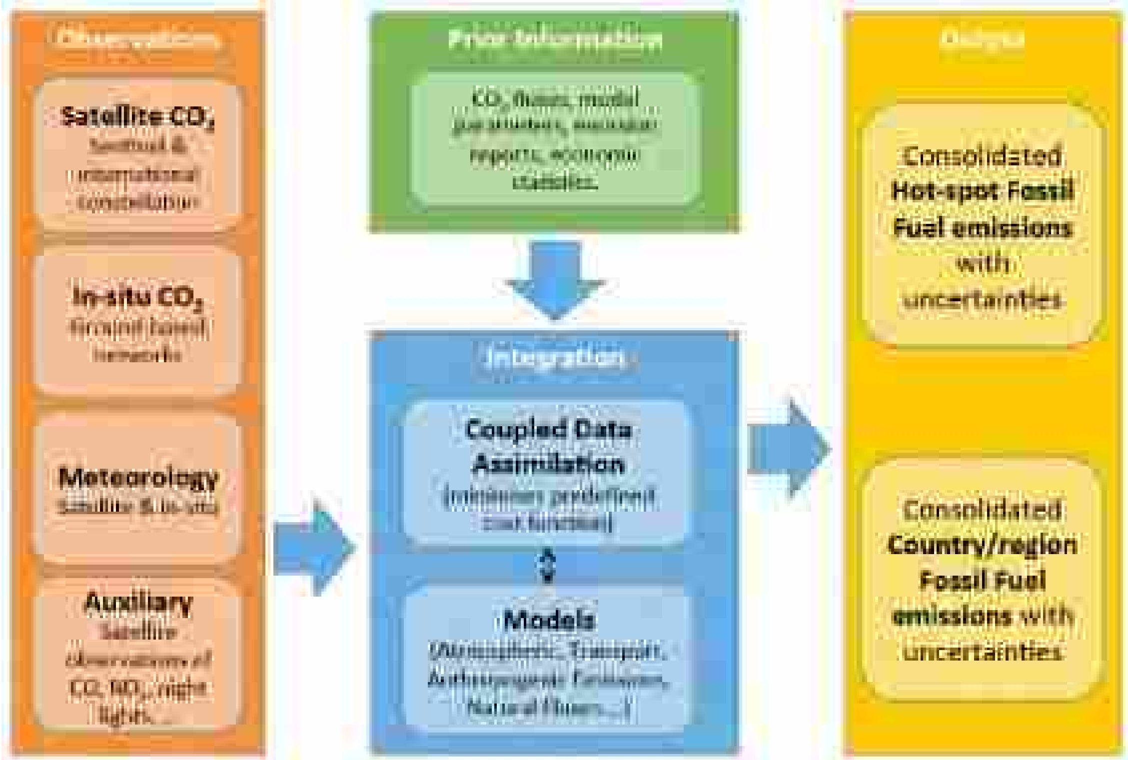
3 Project Reviews
(M15, M27Tech, M39)

CHE information support system vision



CO₂ HUMAN

Recommended steps for implementation of a fossil CO2 monitoring system

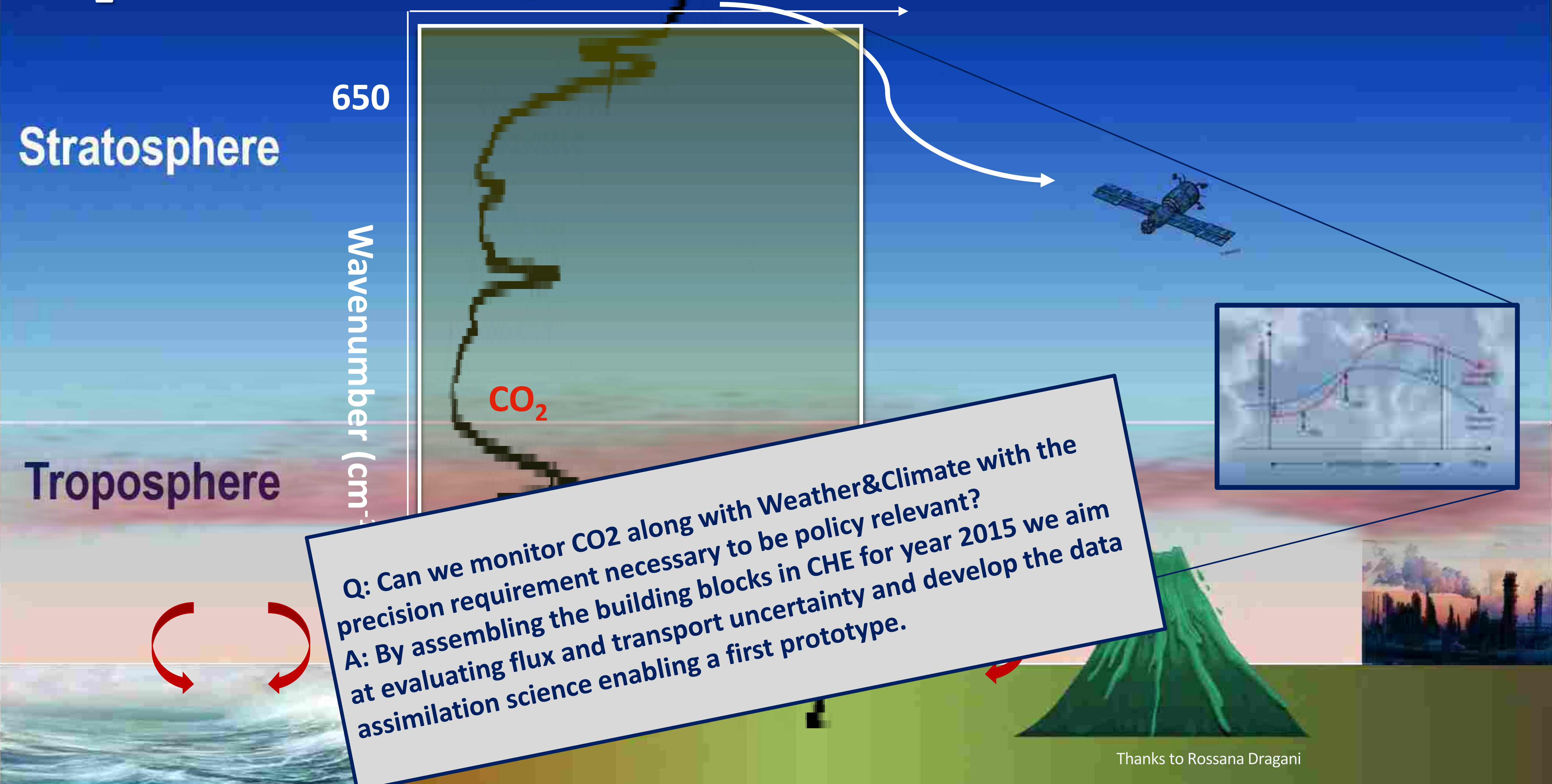


<u>From: 2017 CO2 MTFB report</u>

Pinty et al. (2017) An Operational Anthropogenic CO2 Emissions Monitoring & Verificatin Support capacity - Baseline Requirements, Model Components and Functional Architecture, doi: 10.2760/08644, European Commission Joint Research Centre, EUR 28736 EN

Thanks to Richard Engelen

CO_2 Science challenge



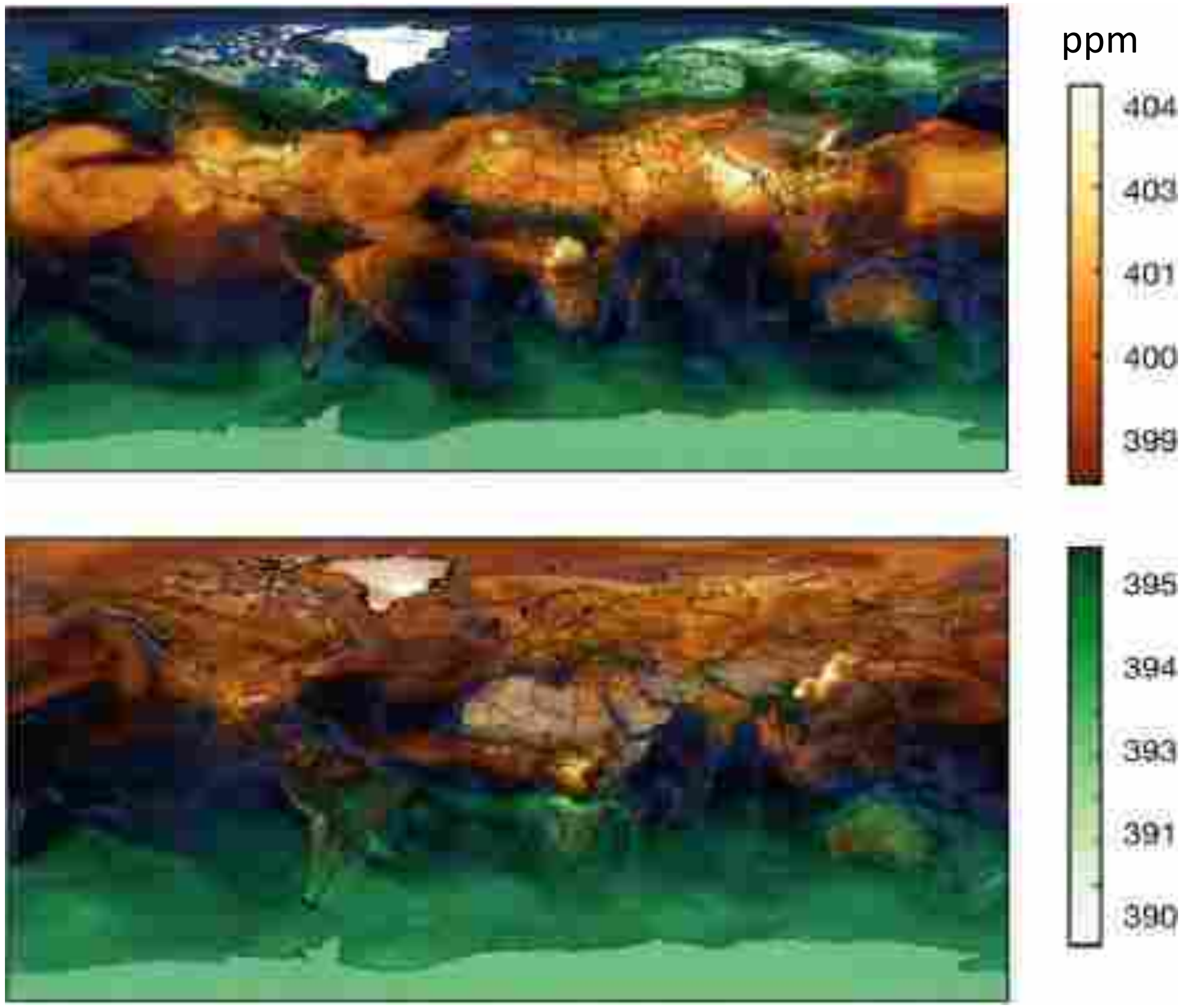
Q: Can we monitor CO2 along with Weather&Climate with the precision requirement necessary to be policy relevant?
A: By assembling the building blocks in CHE for year 2015 we aim at evaluating flux and transport uncertainty and develop the data assimilation science enabling a first prototype.

Thanks to Rossana Dragani

Simulating CO_2 in ECMWF IFS-HRES

15 Jan 2015

15 Jul 2015



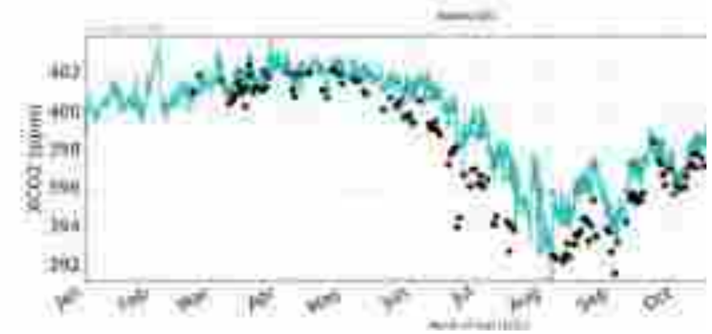
Above global mean

Below global mean

*CO_2 concentration from nature runs on **9 km 3-hourly** . 2015 freely available from CHE project website.*

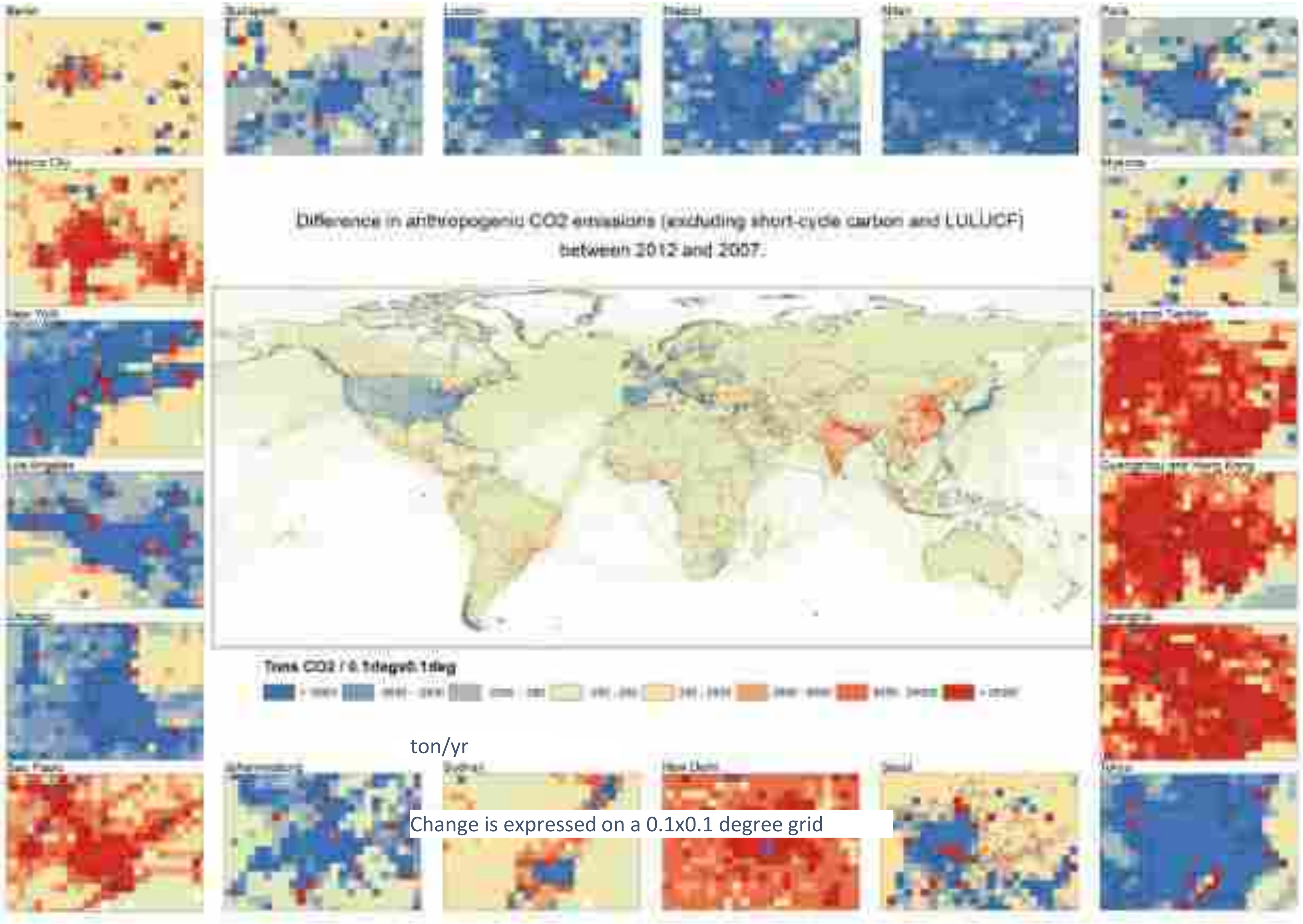
CO_2 HUMAN EMISSIONS

CO_2 concentration at Sodankyla (Finland)



Thanks to Anna Agusti-Panareda

Representing CO_2 Anthropogenic Emission variability



CHE surface emissions
Change from year to year
(here shown are the
Difference 2012-2007)

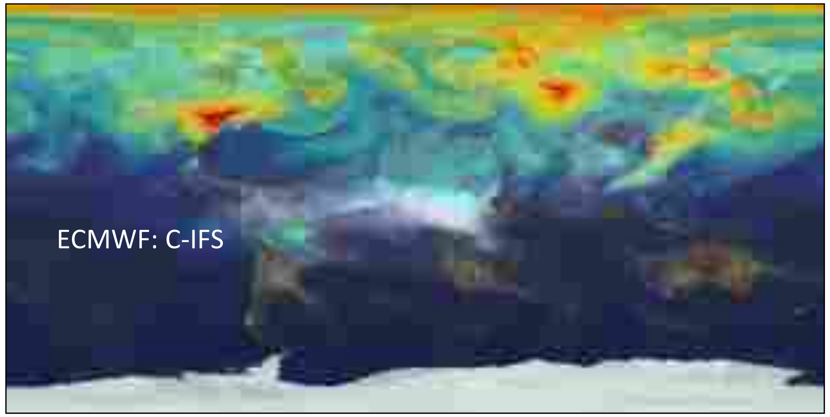
In CHE the monthly
variability will be
considered for the
Tier-2 simulations

Source: JRC EDGAR team

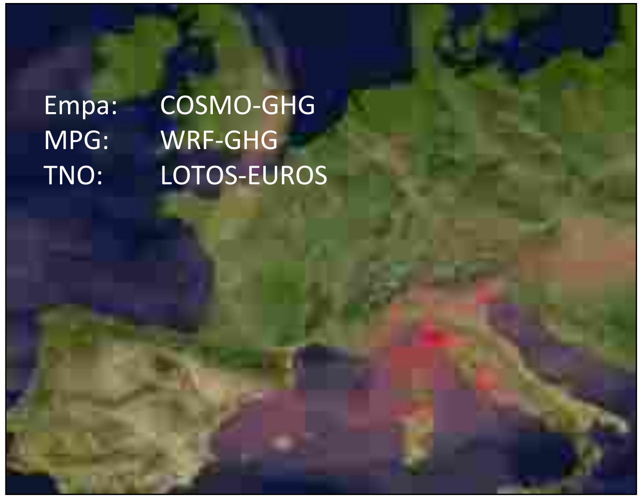
Thanks to Greet Maenhout

Embracing multi-scale, from local to global

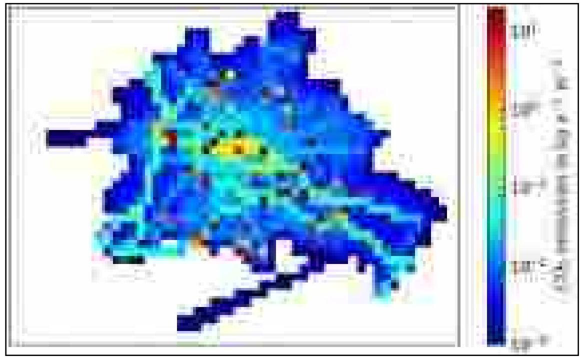
Global, ~ 9km resolution, ECMWF



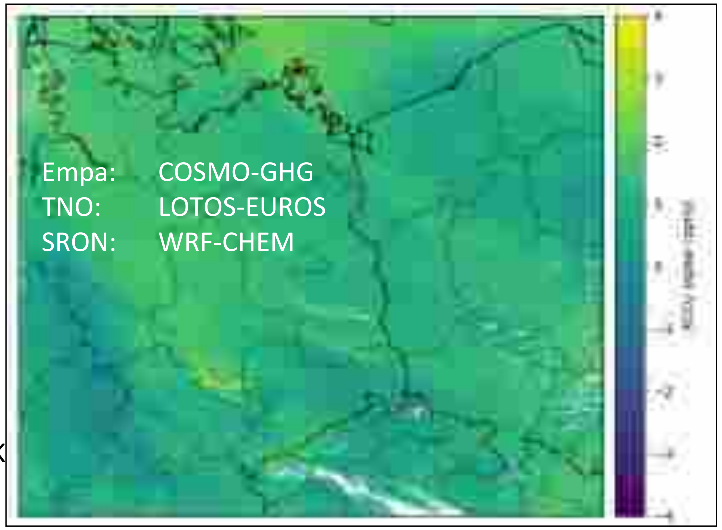
Europe, ~ 5 km, Empa, TNO, MPG



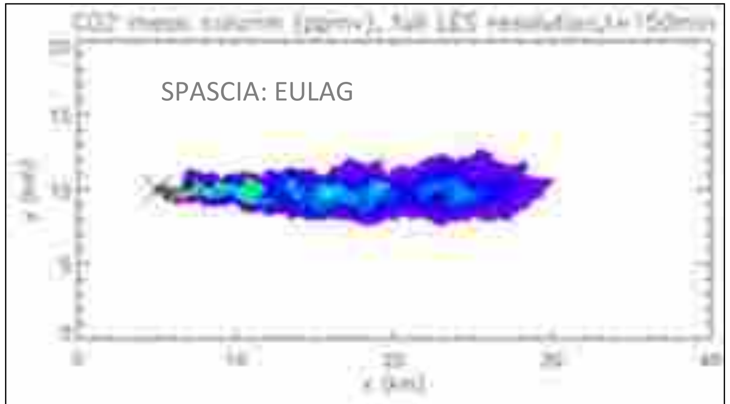
Global, Regional City emissions



Regional, ~ 1 km, Empa, TNO, SRON



Point source, ~ 100 m, SPASCIA



CHE K
2017

IPCC data chain & consolidation CHE

IPCC activity i=1,70

2 types: countries with well/less developed statistical systems

- Emission Factor (or Estimation Parameter) uncertainty [EF]
- Activity Data uncertainty [AD]

- Combined uncertainty (with error propagation method)

Original cluster

IPCC:
2006 IPCC Guidelines for National Greenhouse Gas Inventories (+ its 2019 Refinements)

EDGAR sector j=1,20

Pre-processing
- Energy [ENE] => SuperPlant + AveragePlant
- Brown coal + Hard coal => Coal from underground mining [COL]

2 types: countries with well/less developed statistical systems

- Combined uncertainty (with error propagation method)

1 • Corrected (systematical underestimation by error propagation method)

Pre-processing
- Country emission budget

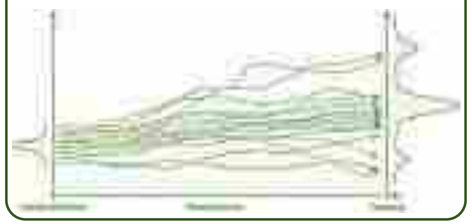
231 countries

2 • Log-normal uncertainty distribution

Mapping cluster

EDGAR:
anthropogenic emissions of greenhouse gases and air pollutants on spatial grid

ENS perturbations of CO2 anthropogenic emissions
- per country
- per group



ECMWF group k=1,7

231 countries

- Combined uncertainty (with error propagation method)

Post-processing
- log-normal mean
- log-normal standard deviation

Perturbation cluster

Thanks to Margarita Choulga

Data processing chain from 231 countries, 70 activities

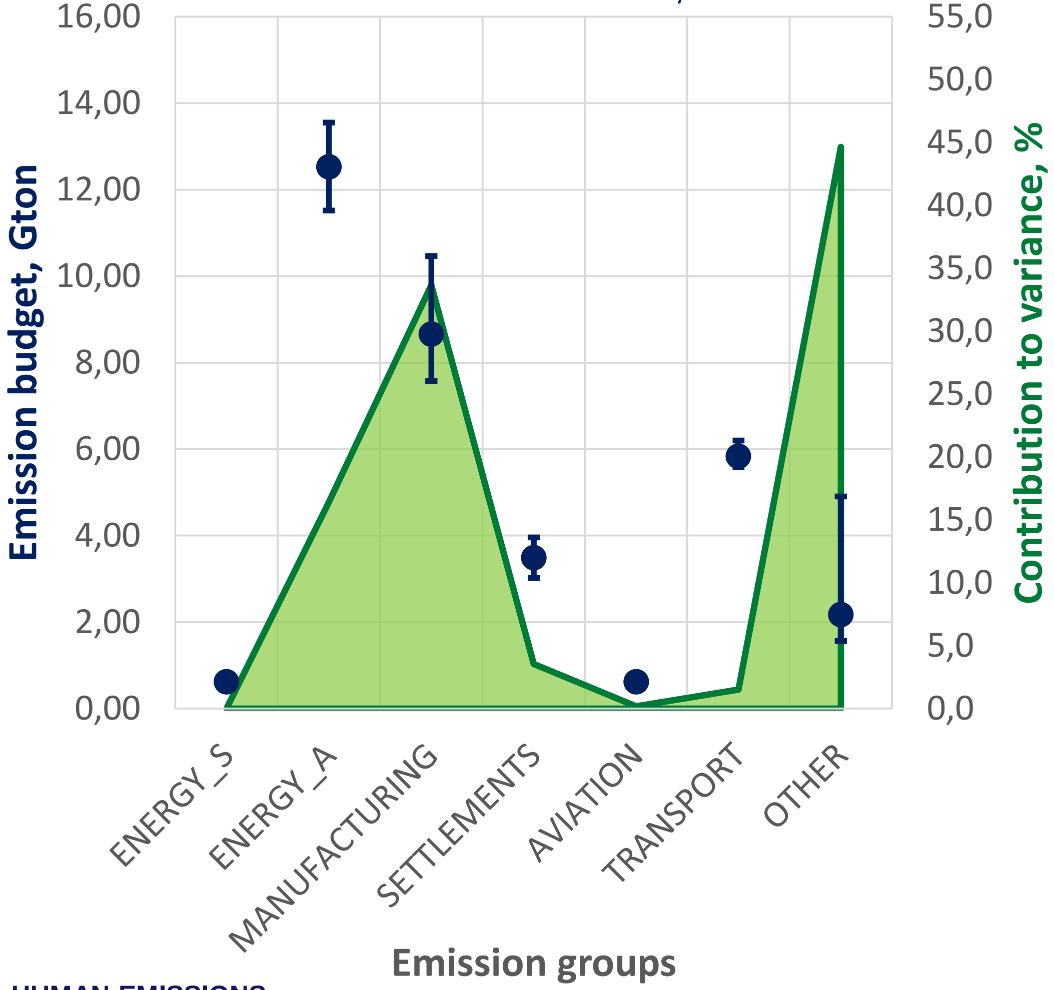
WDS, countries with well-developed statistical systems (e.g. UK), 54 countries	LDS, countries with less developed statistical systems (e.g. Brazil), 177 countries
Andorra, Australia, Austria, Belarus, Belgium, British Virgin Islands, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Faeroe Islands, Finland, France, Germany, Gibraltar, Greece, Greenland, Guernsey, Hungary, Iceland, Ireland, Isle of Man, Italy (including The Holy Sea), Japan, Jersey, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Saint Pierre and Miquelon, San Marino, Slovakia, Slovenia, Spain, Svalbard, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America, United States Virgin Islands	Afghanistan, Albania, Algeria, American Samoa, Angola, Anguilla, Antigua and Barbuda, Argentina, Armenia, Aruba, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belize, Benin, Bermuda, Bhutan, Bolivia, Bosnia-Herzegovina, Botswana, Brazil, Brunei Darussalam, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, Cayman Islands, Central African Republic, Chad, Chile, China, Colombia, Commonwealth of Dominica, Comoros, Congo, Democratic Republic Congo, Cook Islands, Costa Rica, Cuba, Djibouti, Dominican Republic, East Timor, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Ethiopia, Falkland Islands, Federated State of Micronesia, Fiji, French Guiana, French Polynesia, Gabon, Gambia, Georgia, Ghana, Grenada, Guadeloupe, Guam, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hong Kong, India, Indonesia, Iran, Iraq, Israel, Ivory Coast, Jamaica, Jordan, Kazakhstan, Kenya, Kiribati, Korea, Dem. People's Rep. of Korea, Kuwait, Kyrgyz Republic, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Libyan Arab Jamahiriya, Macao, Macedonia, Madagascar, Malawi, Malaysia, Maldives, Mali, Marshall Islands, Martinique, Mauritania, Mauritius, Mayotte, Mexico, Mongolia, Montserrat, Morocco (including Wester Sahara), Mozambique, Myanmar, Namibia, Nauru, Nepal, Netherland Antilles, New Caledonia, Nicaragua, Niger, Nigeria, Niue, Norfolk Island, Northern Mariana Islands, Occupied Palestinian Territory, Oman, Pakistan, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Pitcairn, Puerto Rico, Qatar, Republic of Moldova, Reunion, Rwanda, Saint Helena, Saint Kitts and Nevis, Saint Lucia, Saint Vincent, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia and Montenegro (including Kosovo), Seychelles, Sierra Leone, Singapore, Solomon Islands, Somalia, South Africa, Sri Lanka, Sudan, Suriname, Swaziland, Syrian Arab Republic, Taiwan, Tajikistan, Thailand, Togo, Tokelau, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan, Turks and Caicos Islands, Tuvalu, Uganda, United Arab Emirates, United Rep. of Tanzania, Uruguay, Uzbekistan, Vanuatu, Venezuela, Viet Nam, Wallis and Futuna, Western Samoa, Yemen, Zambia, Zimbabwe

70 Human Activities are analysed and reduced to 7 emission groups, with 2 uncertainty categories

11

CO2 Human Emissions global budget for 2015

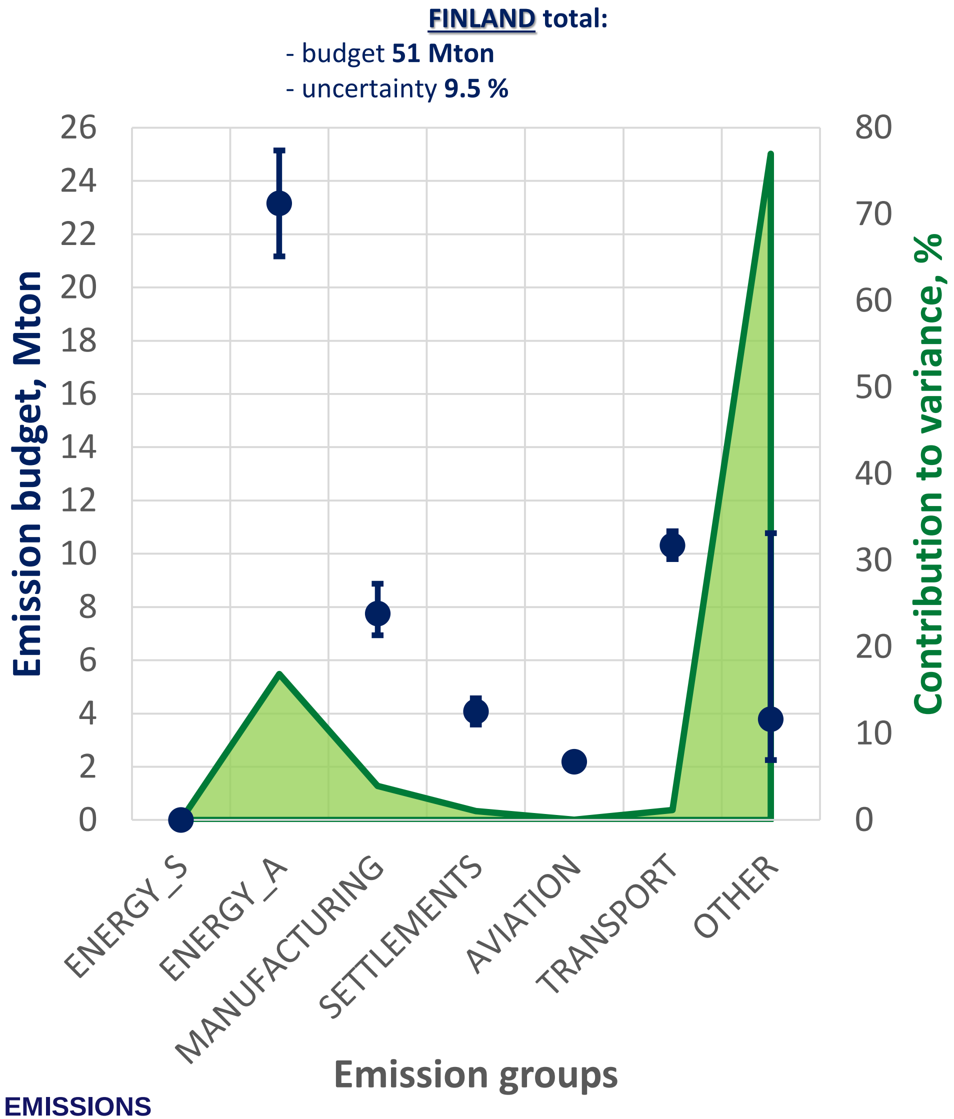
GLOBAL
- 2015 emission budget **34,103 Mton**
- 2015 emission uncertainty **7.4 %**

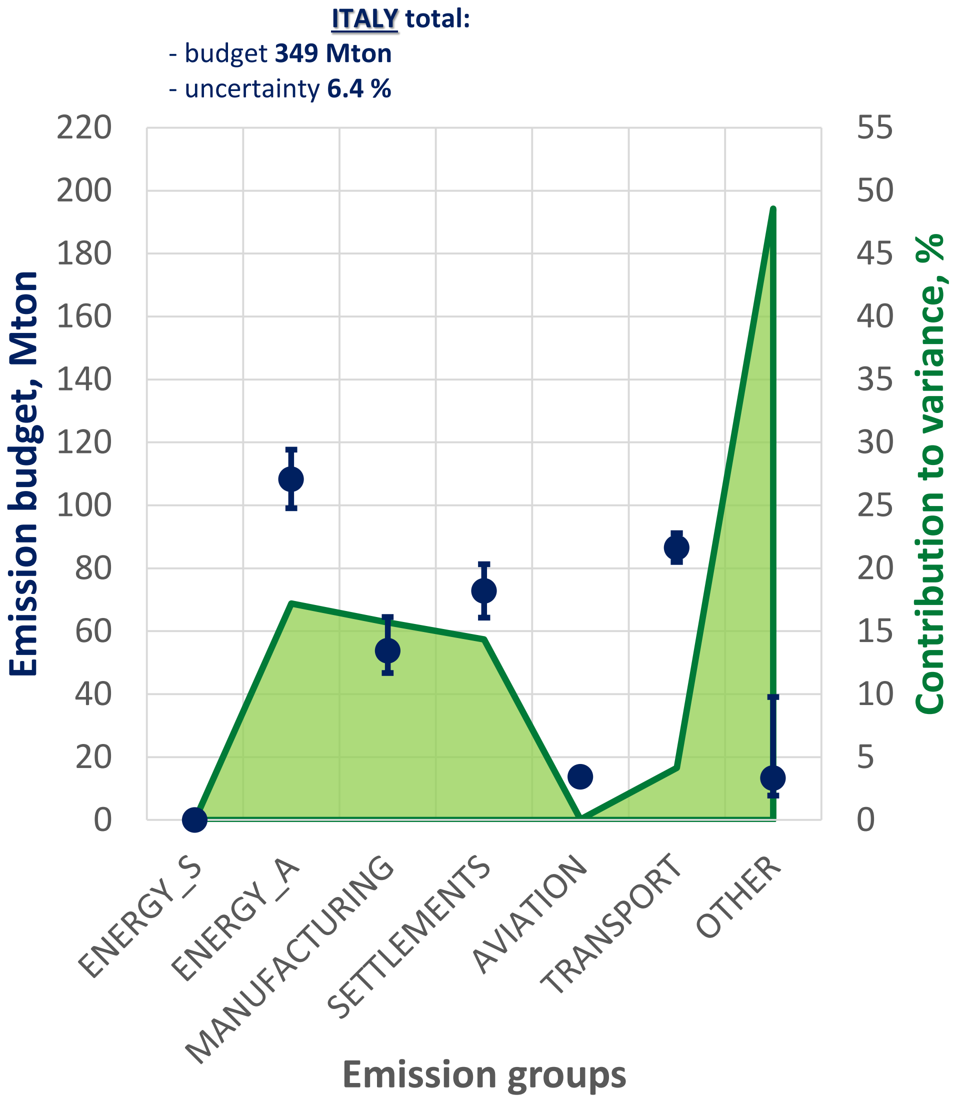


Gr. №	Group name	Note	E-s, Mton
1	**ENERGY_S**	**Power industry** - super emitting power plants	**13,704**
2	**ENERGY_A**	**Power industry** - average emitting power plants	
3	MANUFAC-TURING	**Combustion for manufacturing**	**6,183**
		Iron and steel production	234
		Non-ferrous metals production	91
		Non energy use of fuels	10
		Non-metallic minerals production	
		Chemical processes	
4	SETTLE-MENTS	**Energy for buildings**	**3,322**
		Solvents and products use	61
		Solid waste incineration	137
5	AVIATION	Aviation cruise	815
		Aviation climbing&descent	
		Aviation landing&takeoff	
6	TRANS-PORT	**Road transportation**	**5,530**
		Shipping	819
		Railways, pipelines, off-road transport	255
7	OTHER	Agricultural soils	99
		Oil refineries and Transformation industry	1,917
		Fuel exploitation	258
		Coal production	48

Source: JRC EDGAR Team

Country level CO2 emissions in 2015





Connecting CO2 Inventories to Ensemble simulations

Initial Concentration

Informed from high resolution (~9km) nature simulation

CHE Emissions

Perturbed inventory estimates based on uncertainties

Meteorology transport

Introduce tracers to current EPS framework

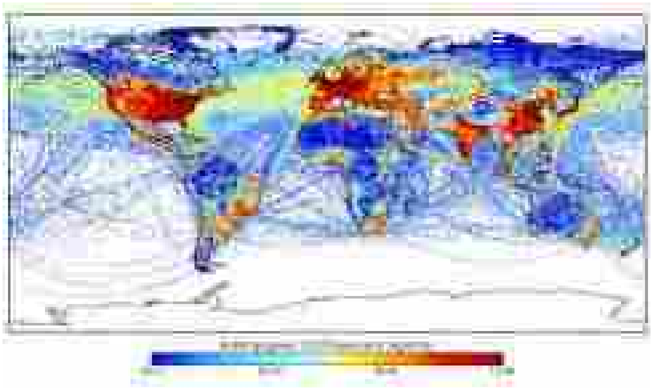
Perturbed Ensemble Simulations

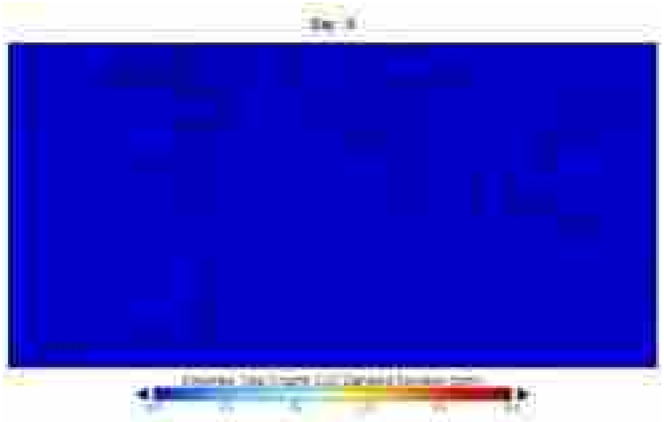
Three simulation types:

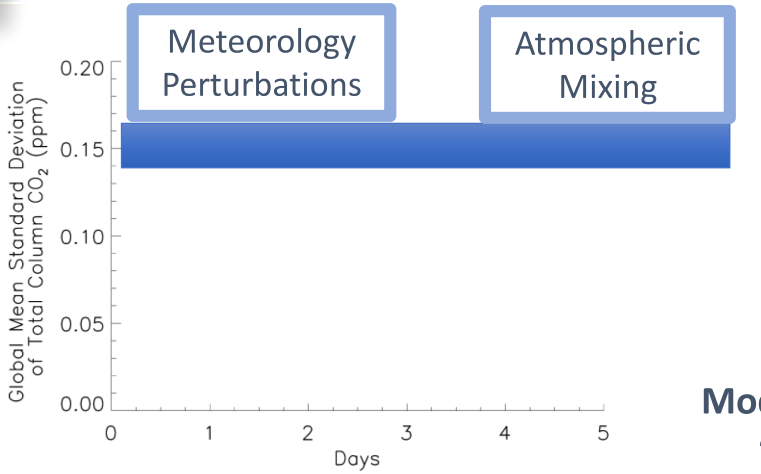
Meteorology	Emissions	Resulting Information
Perturbed	Fixed	Transport Error
Fixed	Perturbed	Transport Jacobian
Perturbed	Perturbed	Transport Jacobian with Noise

Ensemble-based Inversion System

Test multiple inversion systems to estimate sector/national posterior fluxes



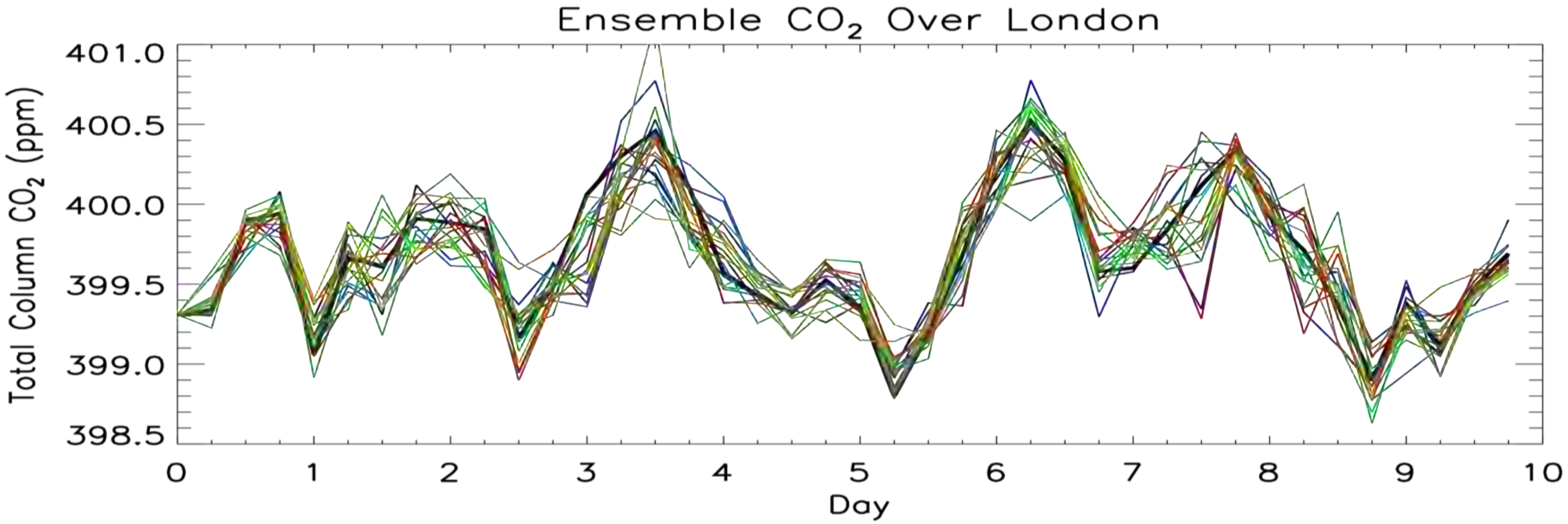




Model error spread takes ~2 days to spin-up.

Thanks to Joe McNorton, Margarita Choulga, Nicolas Bousserez

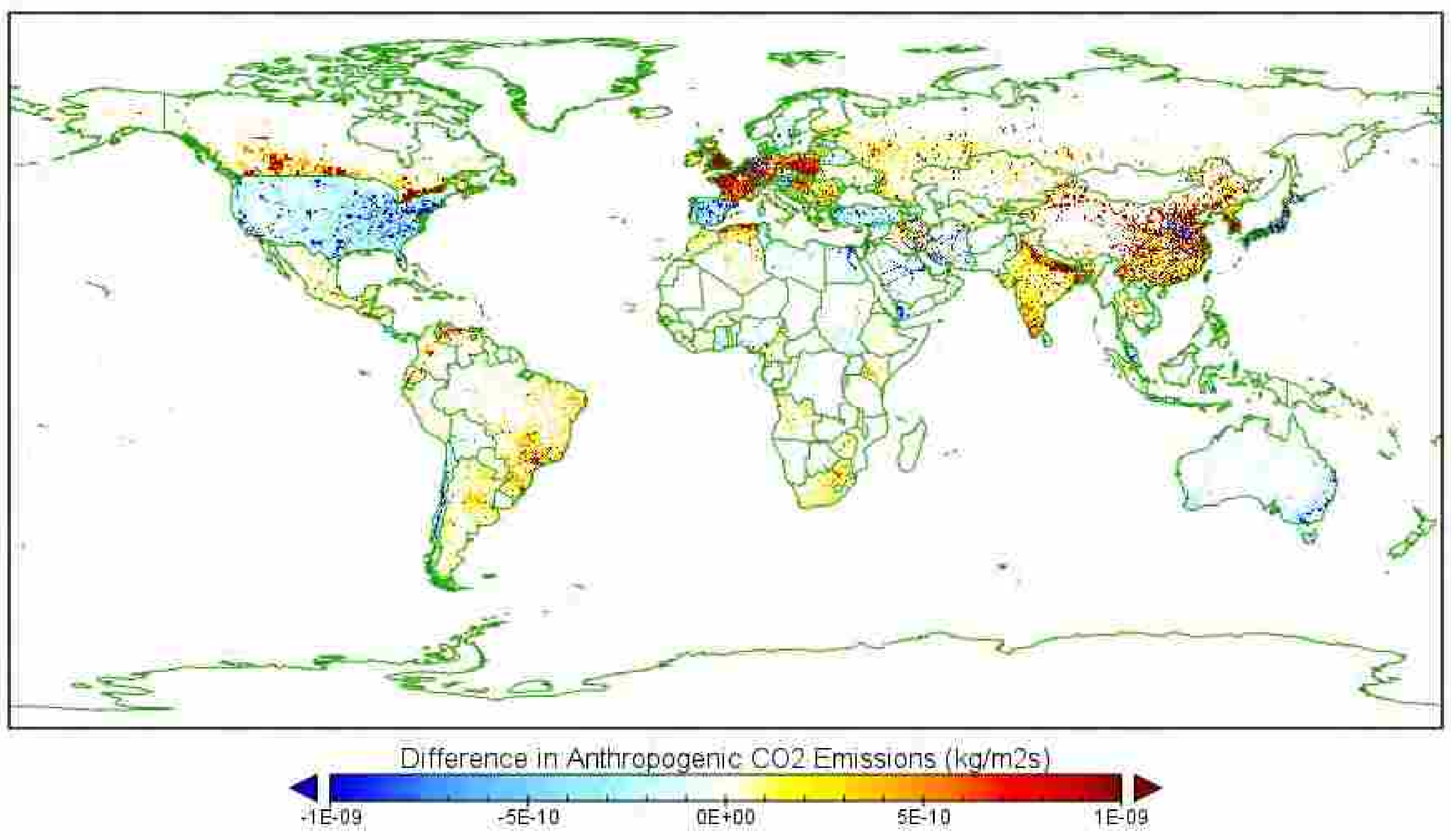
Ensembles of CO2 Concentration (transport precision)



Example for London of a **10-day** CO2 concentration **ensemble simulation**: with **fixed anthropogenic emissions** and **perturbed meteorology and biogenic emissions**.

The meteorological spread correspond to 24-hour forecast range.

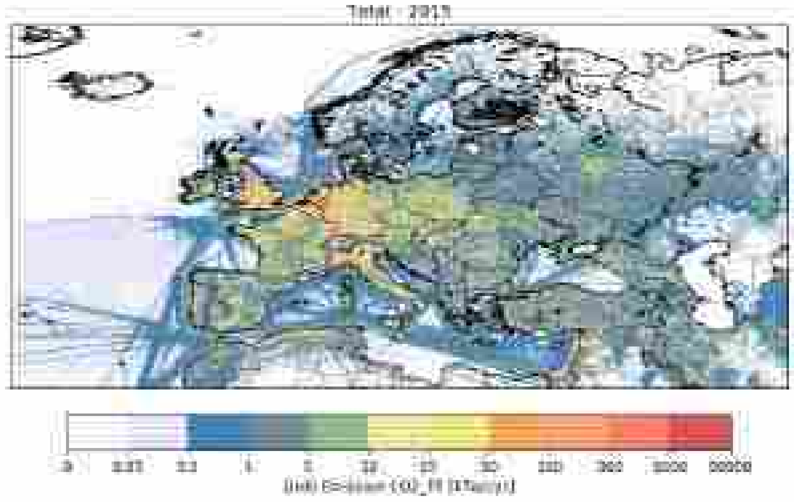
Ensembles of CO_2 Surface Emission (prior precision)



Example of total **difference**
between two emission **perturbations**
(by country and by emission group).

Thanks to Joe McNorton and Margarita Choulga

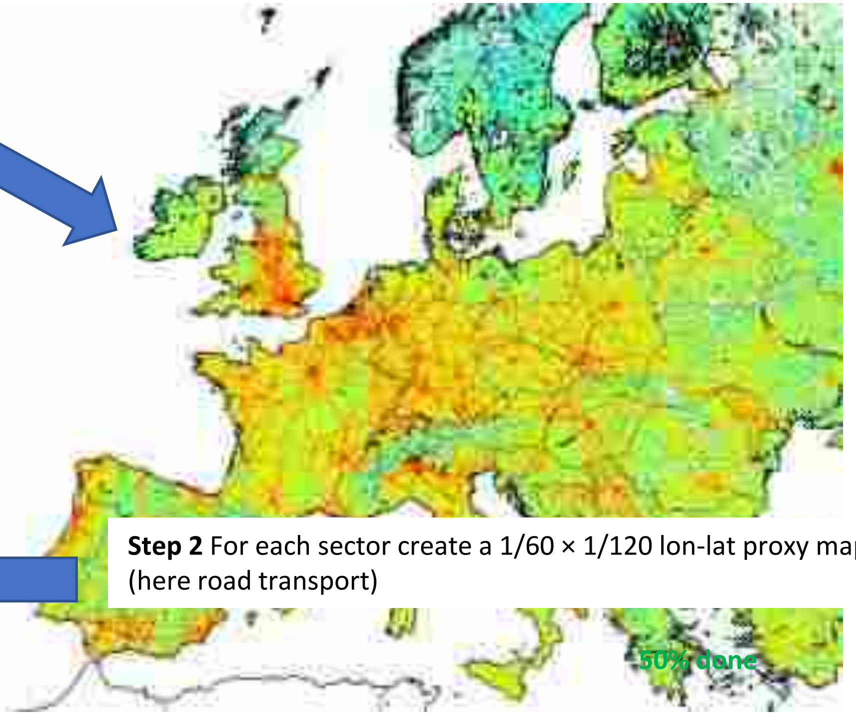
CO_2 Surface Emission over Europe (towards 1-km)



Step 1 (shared with WP 2): ~ 6 × 6 km European inventory for CO2_ff and CO2_bf for year 2015.

Includes 12 different sectors and point sources at exact coordinate

done



Step 2 For each sector create a 1/60 × 1/120 lon-lat proxy map (here road transport)

50% done

Step 3 Envisaged 1 x1 km grid for 2015 ready in **M12**

Running gridding routine end of november

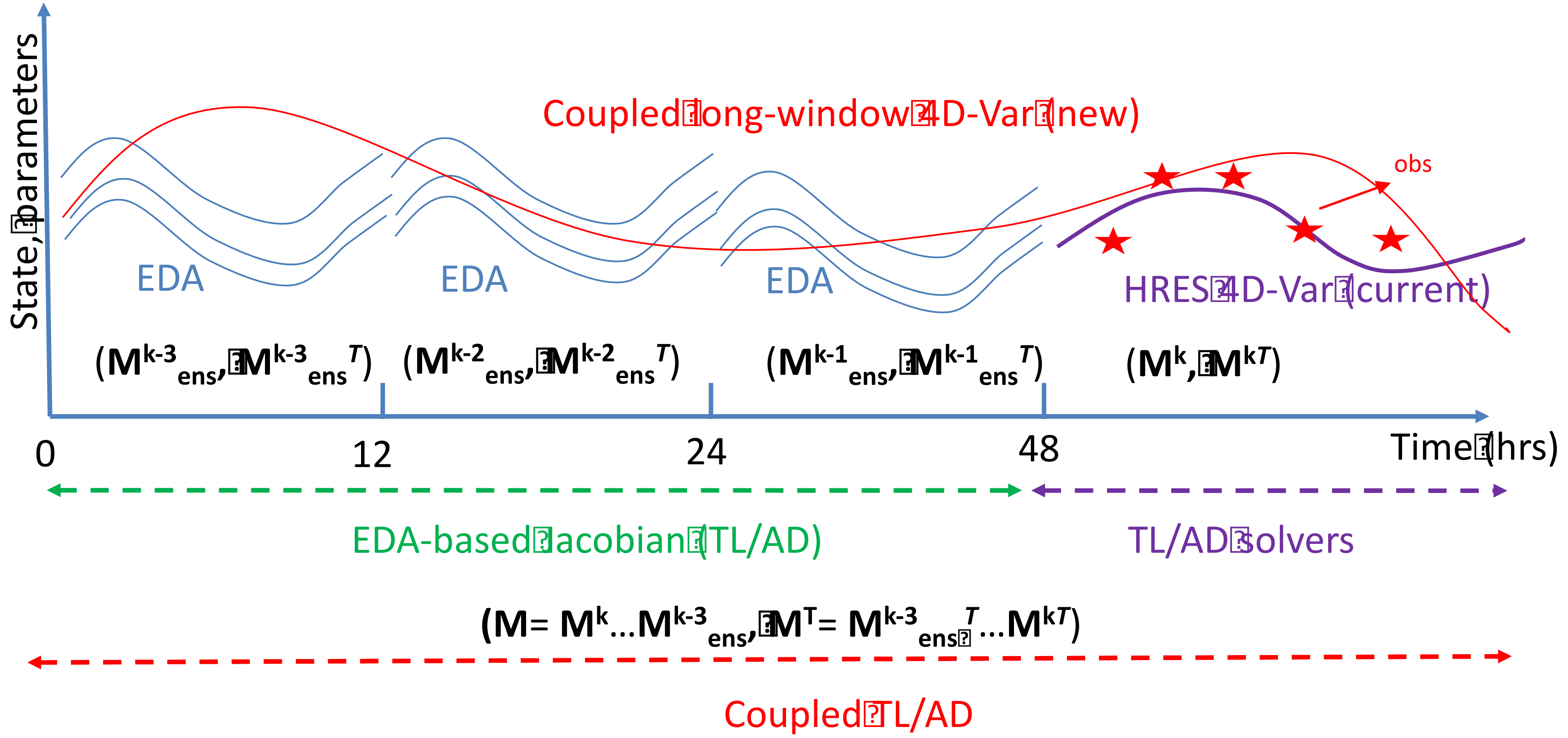
Step 4: create a family of 10 grids for 2015 for the ~1 × 1 km domain using a Monte-Carlo approach **(M12-14)**

CHE WP4 TNO contribution M10

Thanks to Hugo Denier van der Gon

Coupled long-window 4D-Var

Ensembles Data Assimilation/Coupled 4D-Var for CO_2



Same E
Emissic
Ability

Note:

- Same EDA-based least-square approximation of the Jacobian M^{k-i}_{ens} and same trajectory used at each outer-iteration (transport is linear).
- Posterior error covariance updated at each 4D-Var cycle using Hessian information (Ritz pairs).

rs 4D-Var window.
ng.

Thanks to Nicolas Bousserez

In-situ observations

- ICOS level one site: *in situ* CO_2, CO, $\Delta^{14}CO_2$, and APO
- ICOS level two site: *in situ* CO_2 and CO
- Other *in situ* site: variable, see report

Δ TCCON measurements of XCO_2 and XCO

Δ Urban CO_2 flux tower sites

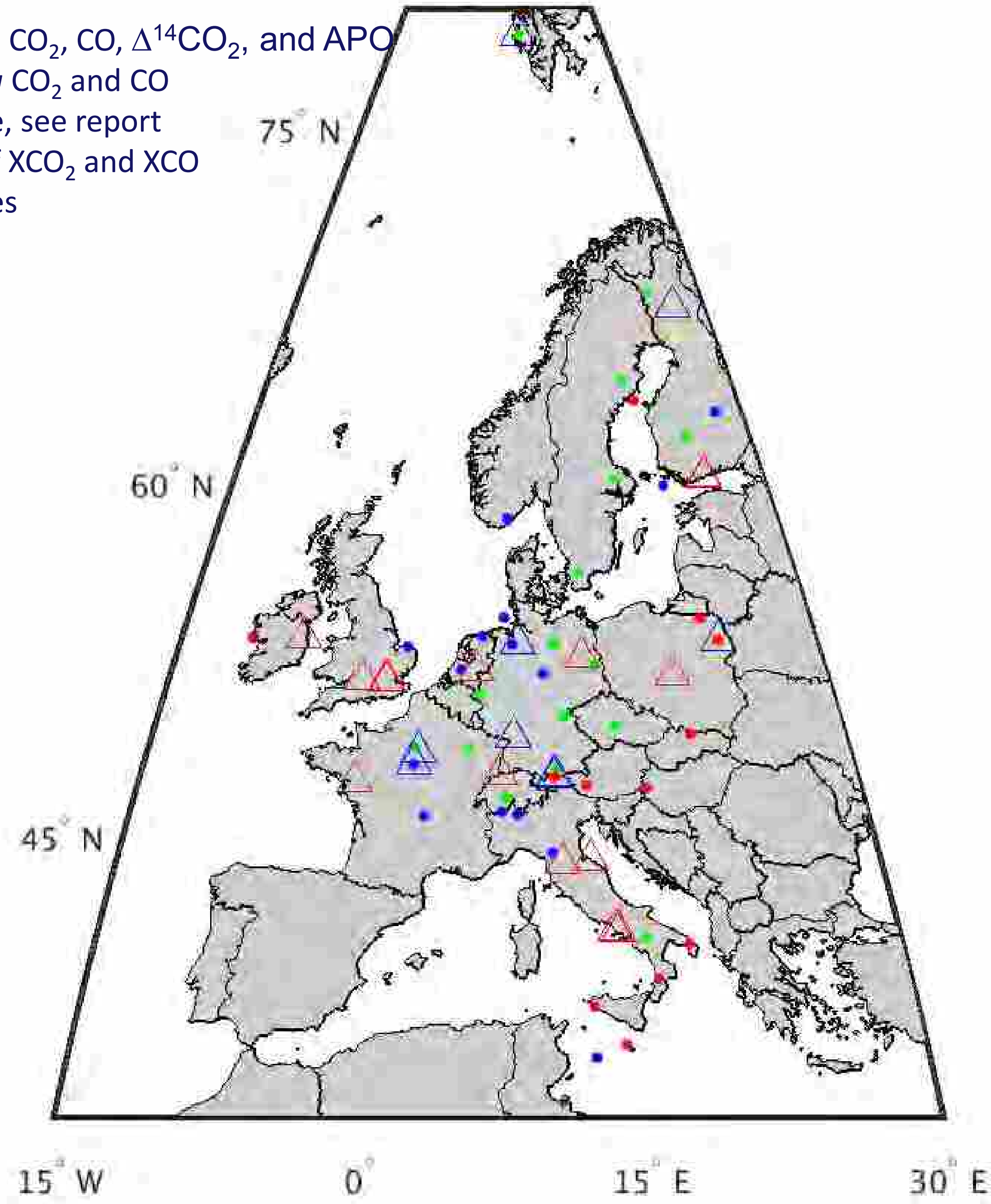
Report summarizing current European *in situ* measurement capability (D4.1)

Specifically targeting the following quantities:

- Surface-based *in situ* CO_2, CO, $\Delta^{14}CO_2$, and APO
- Aircraft-based *in situ* CO_2 and CO
- Ground-based XCO_2 and XCO
- Urban CO_2 flux tower measurements, which can be useful for estimating time factors

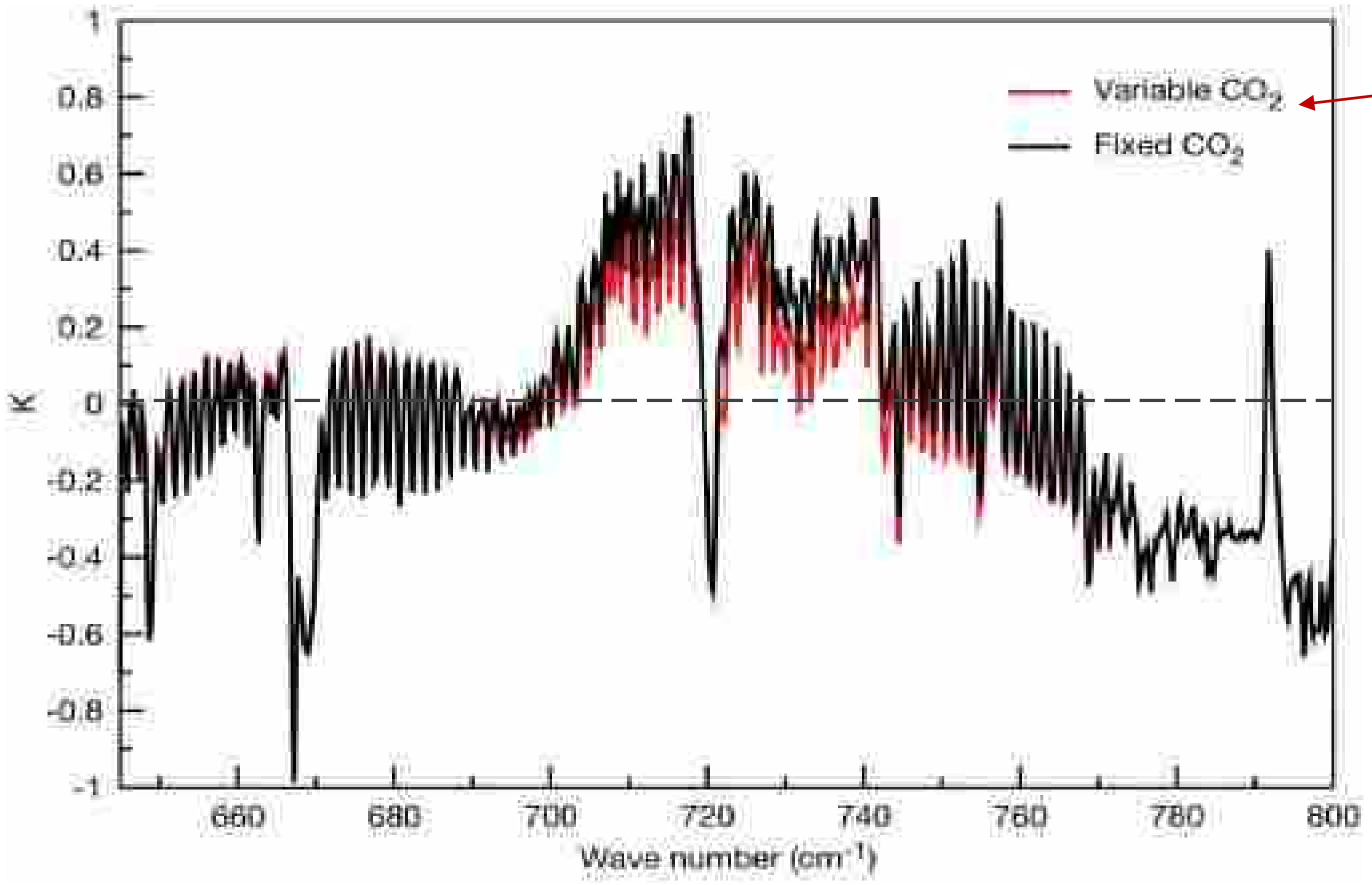
Uncertainties, measurement locations and measurement period were summarized.

The report was submitted in June, 2018.



Thanks to Frederic Chevallier

Satellite observations



Fixed CO_2 profile scaled by a CO_2 climatology from ground-based measurements

RTTOVS12 departure for IASI calculated with and without a spatially variable CO2

Confirm results obtained by Engelen and Bauer (2011)

ECMWF Improved fit to IASI illustrate the relevance of CO_2 for NWP data assimilation

Thanks to Marco Matricardi

High Level Requirements for CHE System

km & daily scales

1. **Detection of emitting hot spots** such as megacities or power plants.

2. **Monitoring the hot spot emissions** to assess emission reductions/increase of the activities.

3. **Assessing emission changes against local reduction targets** to monitor impacts of the NDCs.

4. **Assessing the national emissions and changes** in 5-year time steps to estimate the global stock take.

Accuracy

Space & Time Resoltuion

200-400 ton/year

Summary and outlook

Monitoring CO2 Human Emission with the support of EO data requires enhancing existing mapping modelling and data assimilation capabilities

CHE project builds on existing assets, benefit from C3S and CAMS expertise and infrastructure, a from strong consortium and projects partners

CO2 is an Essential Climate Variable & Global Climate Indicator that presents observational and assimilation challenges (e.g. timeliness). GCOS coordination and support is essential along with IG3IS and the other actors involved…

Global Greenhouse Gas Reference Network

MicroCarb

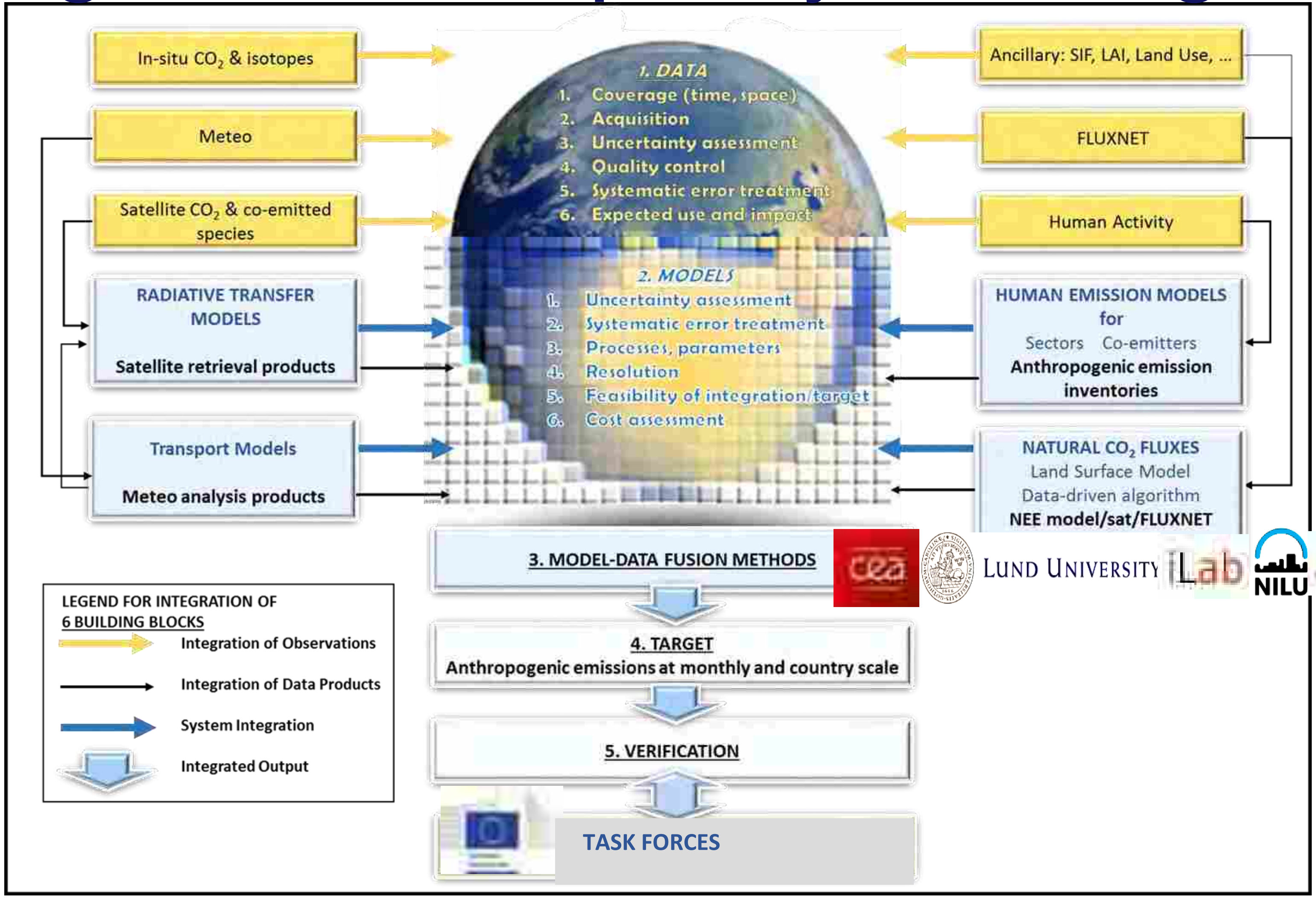
TANSAT

Thanks to Richard Engelen and Vincent-Henri Peuch

SERVICE ELEMENTS REQUIREMENTS

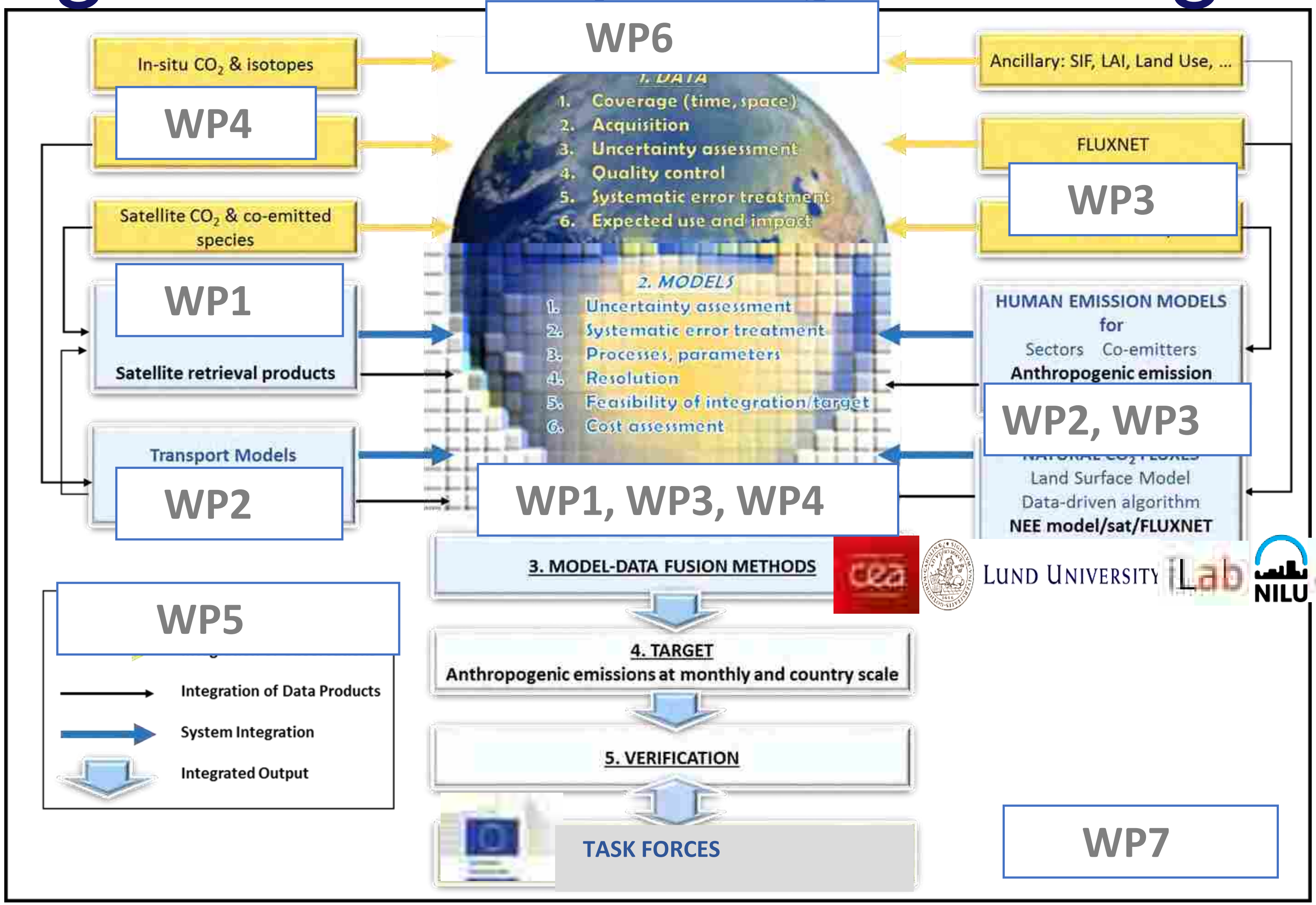
Extra slides for Q&A

CHE Integration & capacity building



VERIFY
project

CHE Integration & capacity building



VERIFY
project

The Global Data Processing and Forecasting System (GDPFS)

WMO OMM

Prepared by Michel Jean, Science Summit Presentation, Courtesy of Sarah Jones/Paolo Ruti WWRP/WMO

CHE PROJECT STRUCTURE

Extra slides for Q&A

CHE Leadership and Expertise

CHE leadership & expertise ensure Monitoring of the project & its progress:

WPL in WP1 Corinne Le Quéré (UEA) and Wouter Peters (WAGENINGEN)

WPL in WP2 Dominik Brunner (EMPA) and Hugo Denier van der Gon (TNO)

WPL in WP3 Greet Maenhout (JRC) and Marko Scholze (LUND)

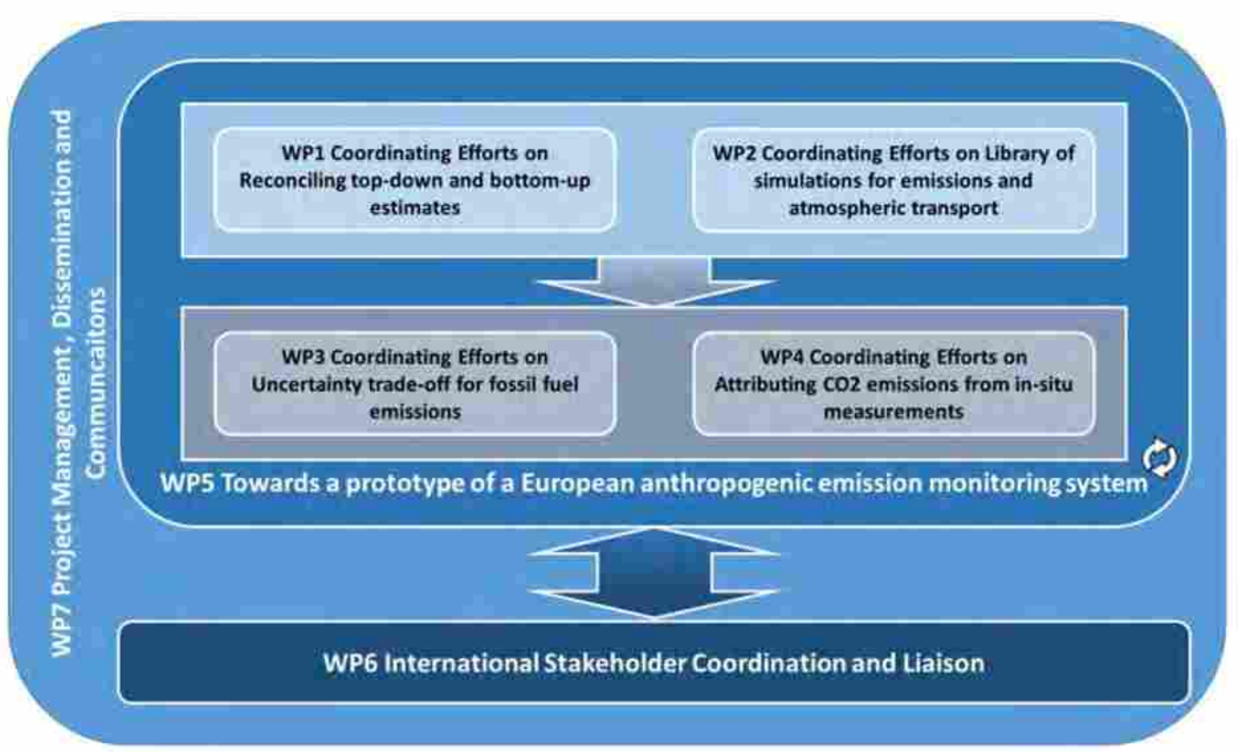
WPL in WP4 Frédéric Chevallier (LSCE) and Julia Marshall (MPI-BGC)

WPL in WP5 Anna Agusti-Panareda and Gianpaolo Balsamo (ECMWF)

PIL in WP6 Richard Engelen (ECMWF)

PM in WP7 Daniel Thiemert (ECMWF)

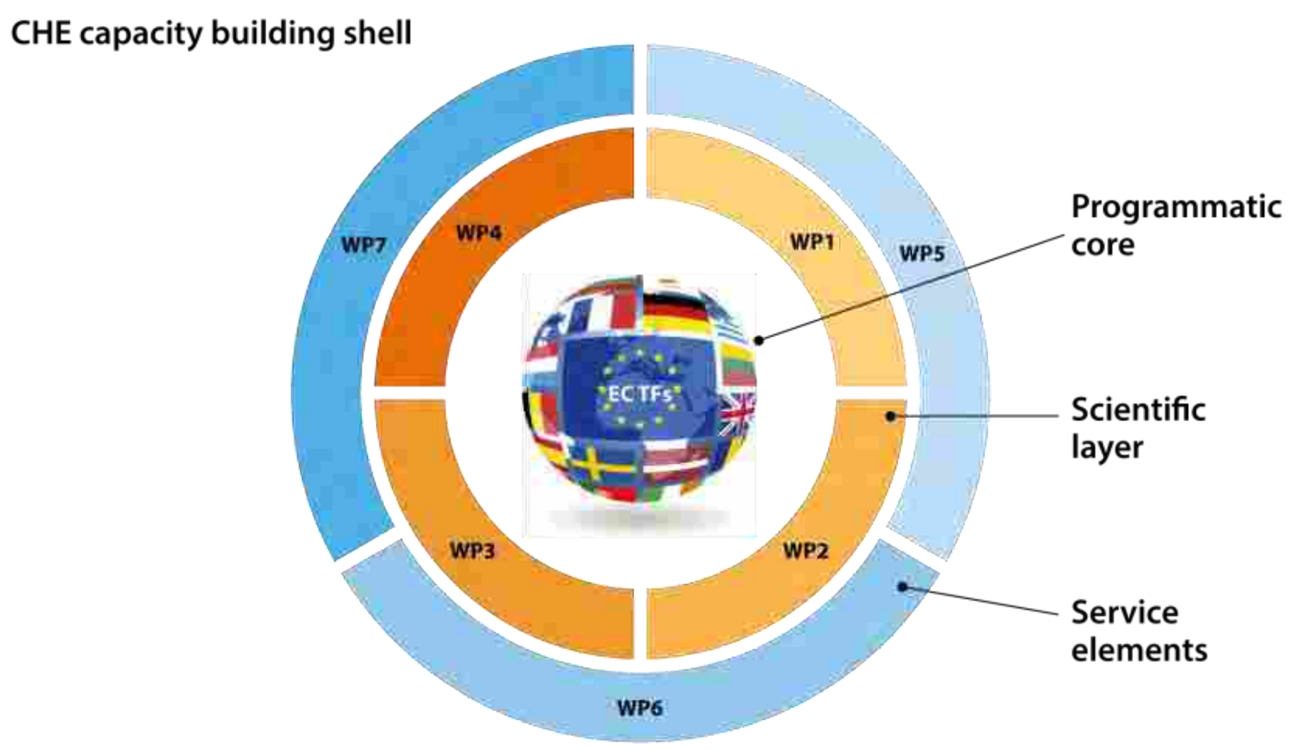
COO Gianpaolo Balsamo (ECMWF)



Work-Package Leaders (**WPL**), Project International Liaison (**PIL**), Project Manager (**PM**), Project Coordinator (**COO**)

CHE Structure and Work Package Breakdown

CHE, H2020-Coordination and Support Action



CHE WBS

WP1 Coordinating Efforts on Reconciling top-down and bottom-up estimates, led by UEA 60.5 PM (39M, 1-39)

WP2 Coordinating Efforts on Library of simulations for emissions and atmospheric transport, led by EMPA (64.5 PM)

WP3 Coordinating Efforts on Uncertainty trade-off for fossil fuel emissions, led by ULUND (69.5PM)

WP4 Coordinating Efforts on Attributing CO2 emissions from in-situ measurements, led by CEA (57.0 PM)

WP5 Towards a prototype of a European anthropogenic emission monitoring system, led by ECMWF 55.25 PM (24M 15-39)

WP6 International Stakeholder Coordination and Liaison, led by ECMWF (19.5 PM)

WP7 Project Management, Dissemination and Communication, led by ECMWF (18.0 PM)

CHE Connectivity & Stewardship

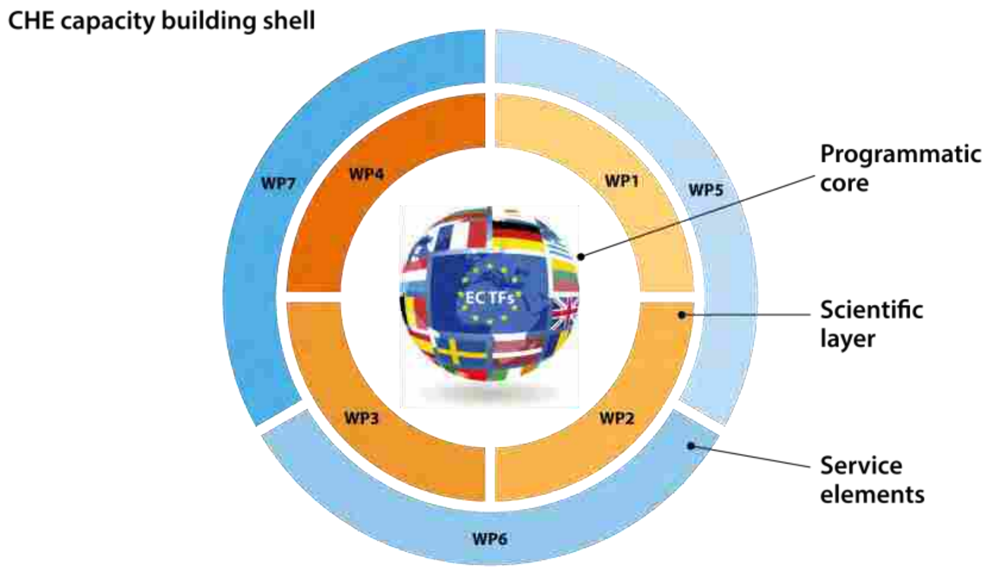
CHE Project steering is further ensured by the following roles:

External Advisory Board (EAB) and External Expert Group (EEG)

EAB Han Dolman (Chair of EAB, VU NL), Pierre-Yves Le Traon (CMEMS, France), Mark Dowell (CLMS, INT), Sonia Seneviratne (ETH, Switzerland), Guy Brasseur (WCRP, Germany),Werner Kutsch (ICOS, Finland)

EEG Peter Rayner (Chair of EEG, U MELBOURNE, AU), Kevin Gurney (ARIZONA SU, US), Kevin Bowman (NASA JPL, US), Arlyn Andrews (NOAA, US), Pep Canadell (CSIRO, AU), Saroja Polavarapu (ECCC, Canada), Jing M. Chen (U NANJING, China, U TORONTO, Canada), Lu Daren (CAS, Tansat-PI, China), Chris O'Dell (CSU, US), Shamil Maksyutov (CGER/NIES, Japan), Paul Palmer (EDINBURGH, UK), Heather Graven (IMPERIAL, UK) Alex Vermeulen (Carbon Portal, Sweden)

CHE: WP1-2-3-4 Overview



WP1 Coordinating Efforts on **Reconciling** top-down and bottom-up estimates

WP2 Coordinating Efforts on **Library of simulations** for emissions and atmospheric transport

WP3 Coordinating Efforts on **Uncertainty trade-off** for fossil fuel emissions

WP4 Coordinating Efforts on **Attributing** CO2 emissions from in-situ measurements

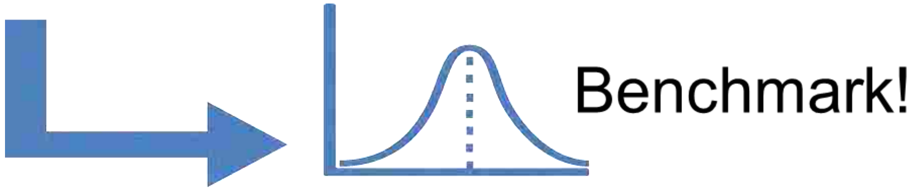
WP1: Reconciling top-down and bottom-up estimates

Lead: Wouter Peters/Maarten Krol (WU, Netherlands) Corinne LeQuere (UEA, United Kingdom)

Participants: UEA, ECMWF, ADS, SAS, ADS GMBH, EUMETSAT, iLAB, CEA, ULUND, TAS, UB, ULEIC, WU

WP1 include

- Task 1.1: Deliver a cross section of remote-sensing data products needed in the data assimilation chain to constrain anthropogenic carbon emissions
- Task 1.2: Develop novel techniques to constrain anthropogenic and natural carbon emissions from joint surface and space- based carbon cycle data
- Task 1.3: Reconcile top-down and bottom-up carbon dioxide source/sink estimates at multiple levels of integration using a community access platform



- Task 1.4: Document current shortcomings and needed developments in space-based monitoring of fossil fuel CO2 emissions

WP2: Library of simulations - emissions & transport

Lead: Dominik Brunner (Empa) & Hugo Denier van der Gon (TNO)

Participants: DLR, ECMWF, JRC, MPG, SPASCIA, SRON, TNO

Generate library of realistic CO_2 forward simulations - “nature runs”

- Simulations for present-day and future emission scenarios
- From global to regional to point source scale
- Provide simulation input for other WPs

Support assessment of requirements for a future CO_2 space missions

- Generate collection of synthetic satellite observations with realistic error characteristics, by combining model output with orbit simulations
- Investigate influence of aerosols on CO_2 retrieval in urban plume
- Investigate influence of small-scale and fluctuating nature of power plant plumes on capability to detect and quantify such plumes

WP3: Uncertainty trade-off - fossil fuel emissions

Lead: Marko Scholze (ULUND) and Greet Janssens-Maenhout (JRC)

Participants: ECMWF, CMCC, ULUND, iLab, JRC, KNMI, CEA-LSCE, MPG-BGC, TAS, TNO, UEA

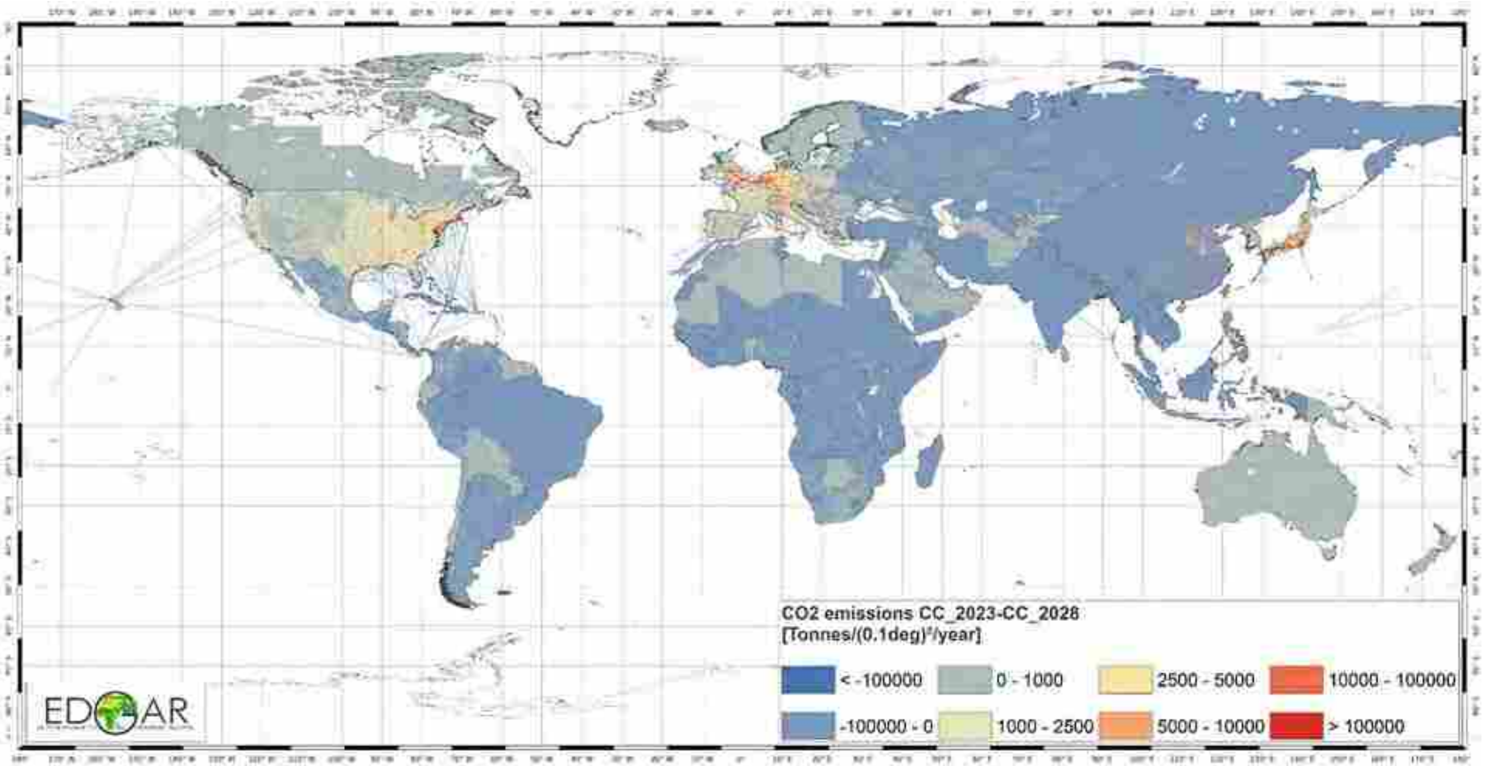
Provide high-resolution (~km, hourly) prior biogenic fluxes with quantified uncertainties based on upscaling of eddy covariance flux measurements

Provide prior gridded anthropogenic emissions and their uncertainties and per sector

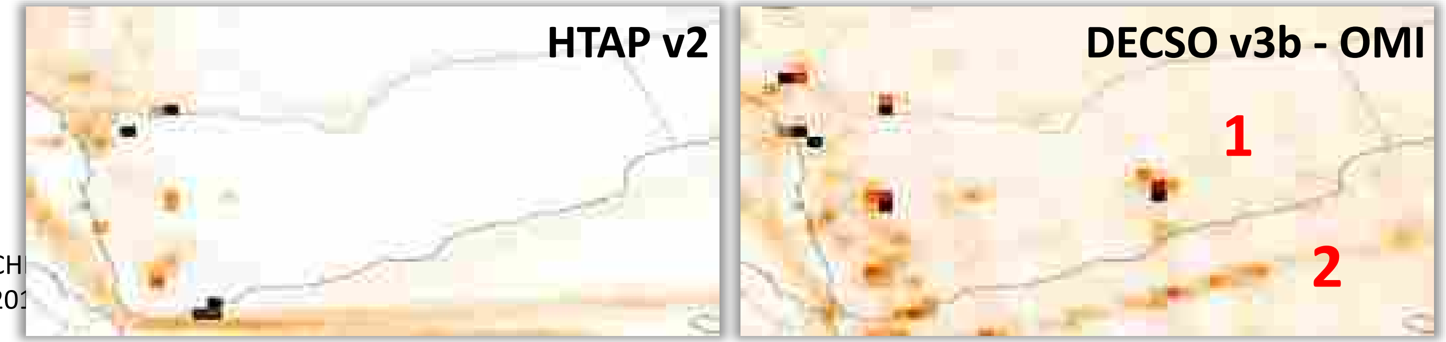
Evaluate the current status and possible improvements from enhanced space-borne and in-situ observation scenarios for fossil CO2 emissions quantification based on OSSEs and QND studies

- high-resolution inverse transport modelling of CO2
- high-resolution inverse transport modelling of CO2 and co-emitted species (NOx)
- advanced carbon cycle-fossil fuel data assimilation systems

WP3: Estimation of emissions uncertainties



Example: NOx emissions in Yemen



T3.1: Estimate biogenic fluxes and associated uncertainties from independent observations (MPG-BGC, by March 2019)

T3.2: Provide emission uncertainties & correlations from inventories and statistics – for global emission gridmaps of EDGAR (JRC, by March 2019)

T3.3: Explore the role of satellite observations of NOx for estimation of fossil CO2 emissions (KNMI, by September 2019)

T3.4: Conduct OSSEs with an inverse transport modelling system to establish inversion strategy (CEA-LSCE, by June 2020)

T3.5: Perform QND experiments with advanced data assimilation systems (CC-FF-DAS) to establish inversion strategy (LUND/iLab, by June 2020)

WP4: Attributing CO2 emissions from in-situ measurements

Lead: Frédéric Chevallier, Julia Marshall

Participants: CMCC, CEA-LSCE, EMPA, MPG-BGC, NILU, TNO, UEA, ULUND

1. Explore the practical implications of distinguishing between anthropogenic (meaning fossil fuel emissions, and also non-fossil waste burning, biofuels, etc.) vs. biogenic CO_2 fluxes.
2. Optimization of the space-time sampling of $^{14}CO_2$, CO and APO.

T4.1 High-resolution scenarios of CO_2 and CO emissions (Lead: TNO, M1-M12)

T4.2 Attribution Problem (Lead MPG:, M1-M33)

T4.3 Practical Recommendations (Lead: CEA, M25-M36)

Outcomes

Survey current European in-situ observation capacity.

Define an operational strategy to separate anthropogenic CO_2 emissions from biogenic fluxes at regional and global scales through the use of additional tracers.

Shape the appropriate dimension and distribution of the corresponding in-situ network.

Gianpaolo Balsamo
Project Coordinator - ECMWF
05/02/2018