Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

MOBILITAT SOSTENIBLE

Alberto Gutiérrez

Josep Lluís Berral

23/04/2022

Bojos per la Supercomputació

Agenda

23 d'Abril

Bloc 1: El concepte de mobilitat sostenible — 9:30

- El problema de la contaminació
- Internet of Things
- Edge Computing
- El Sistema AIS
- Emissions en vaixells: conceptes

Bloc 2: Els models d'emissions — 11:00

- Introducció a l'aplicació
- El circuit i els mode de "circulació"
- Arquitectura de l'aplicació
- Les equacions d'emissions

Treball a l'Exterior — 12:30

- Explicació de l'exercici
- Exercici a l'exterior

7 de Maig

Bloc 3: Processat de dades simple — 9:30

- L'entorn de treball
- Càlcul d'informació derivada (Vx, Acc)
- Generació de sets de dades derivades
- Implementació del càlcul d'emissions
- Visualització de dades

Bloc 4: Processat de dades complex (ML) — 12:00

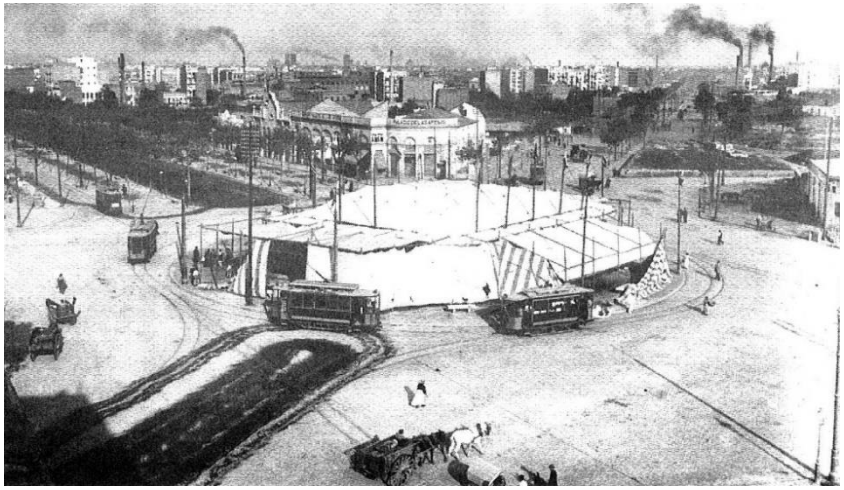
- Sanejament de les dades
- Tipus de dades corruptes
- Filtres de correcció: Kalman
- Aplicació del filtre sobre dades
- Visualització de les dades corregides
- Implementació pròpia de filtre de Kalman

Bloc 1

El concepte de mobilitat sostenible

Urban air pollution. Causes

Plaça Espanya, Barcelona (1908)



Plaça Espanya, Barcelona (2014)

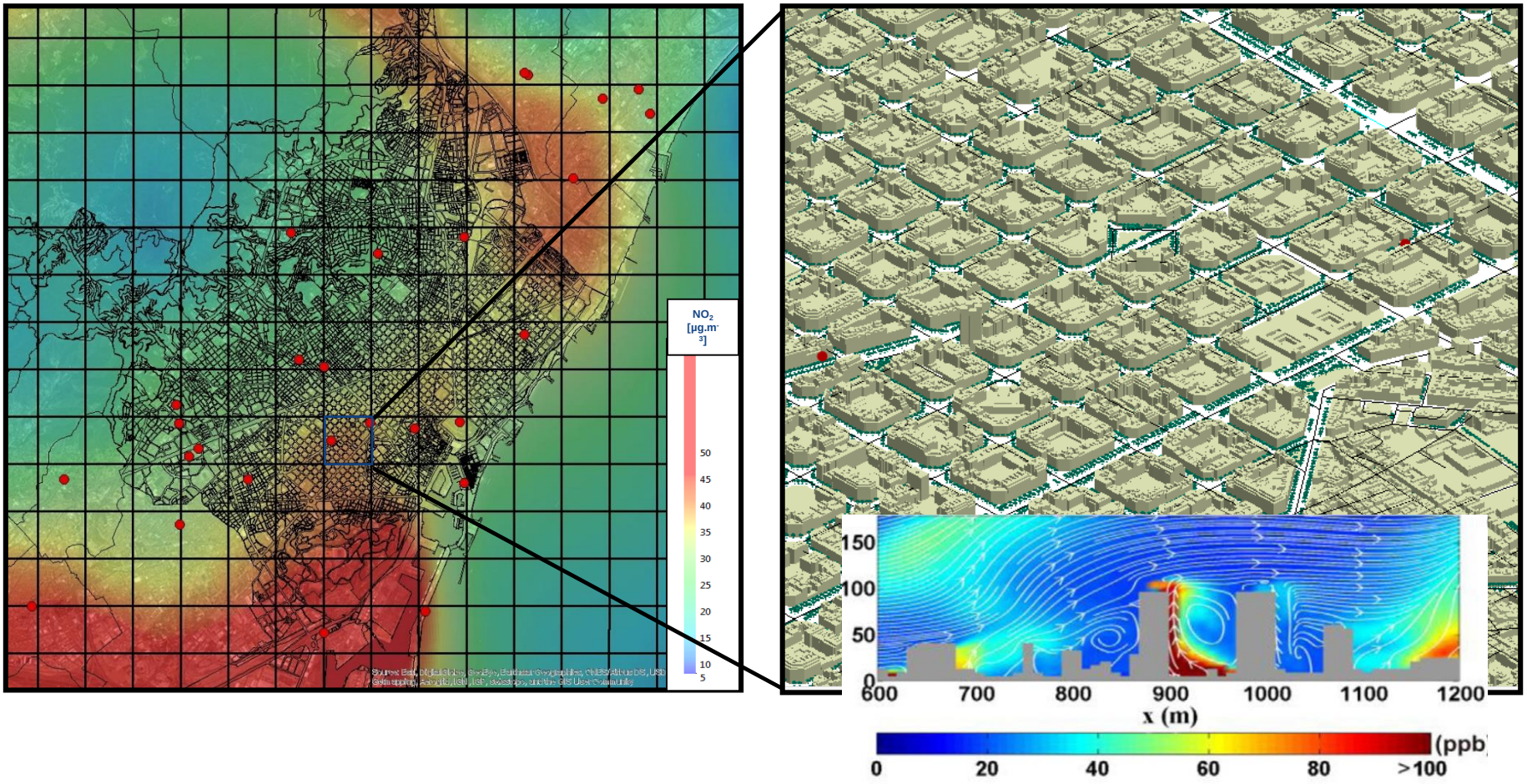
C/ Gran de Gràcia, Barcelona (1908)

C/ Gran de Gràcia, Barcelona (2014)

Modelling pollution: do we know enough?

Where we are now

Where we want to go



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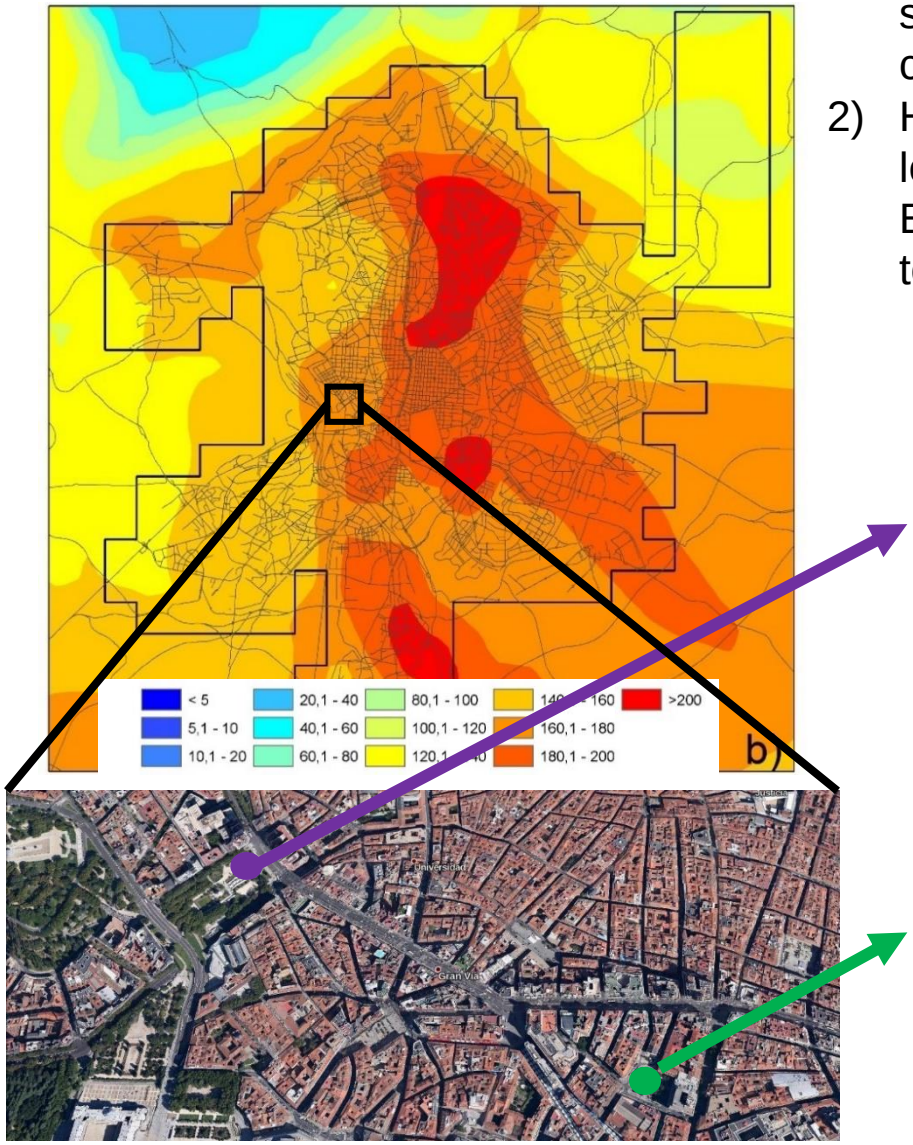
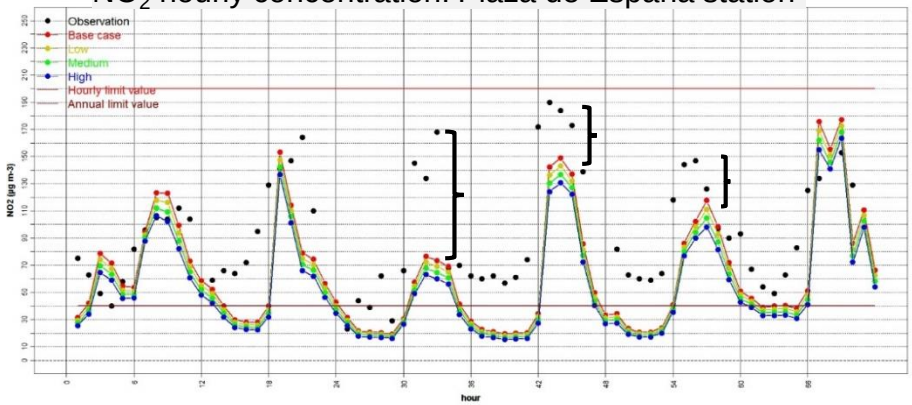
Rationale

NO_2 (µg/m^3) Max h. Base case; Madrid

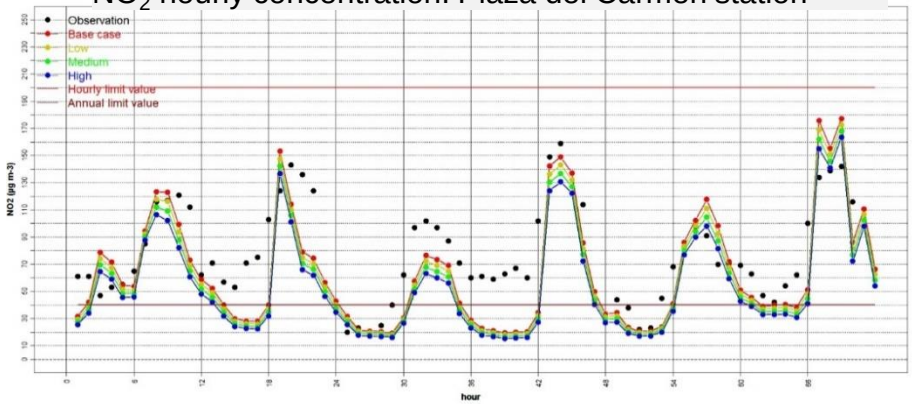


1) Mesoscale models (current solutions) show a satisfactory performance to simulate background concentrations (e.g. Plaza del Carmen).
2) However, they are not able to reproduce street-level strong concentration gradients (e.g. Plaza España located close to Gran Via); purpose-built tools are needed.

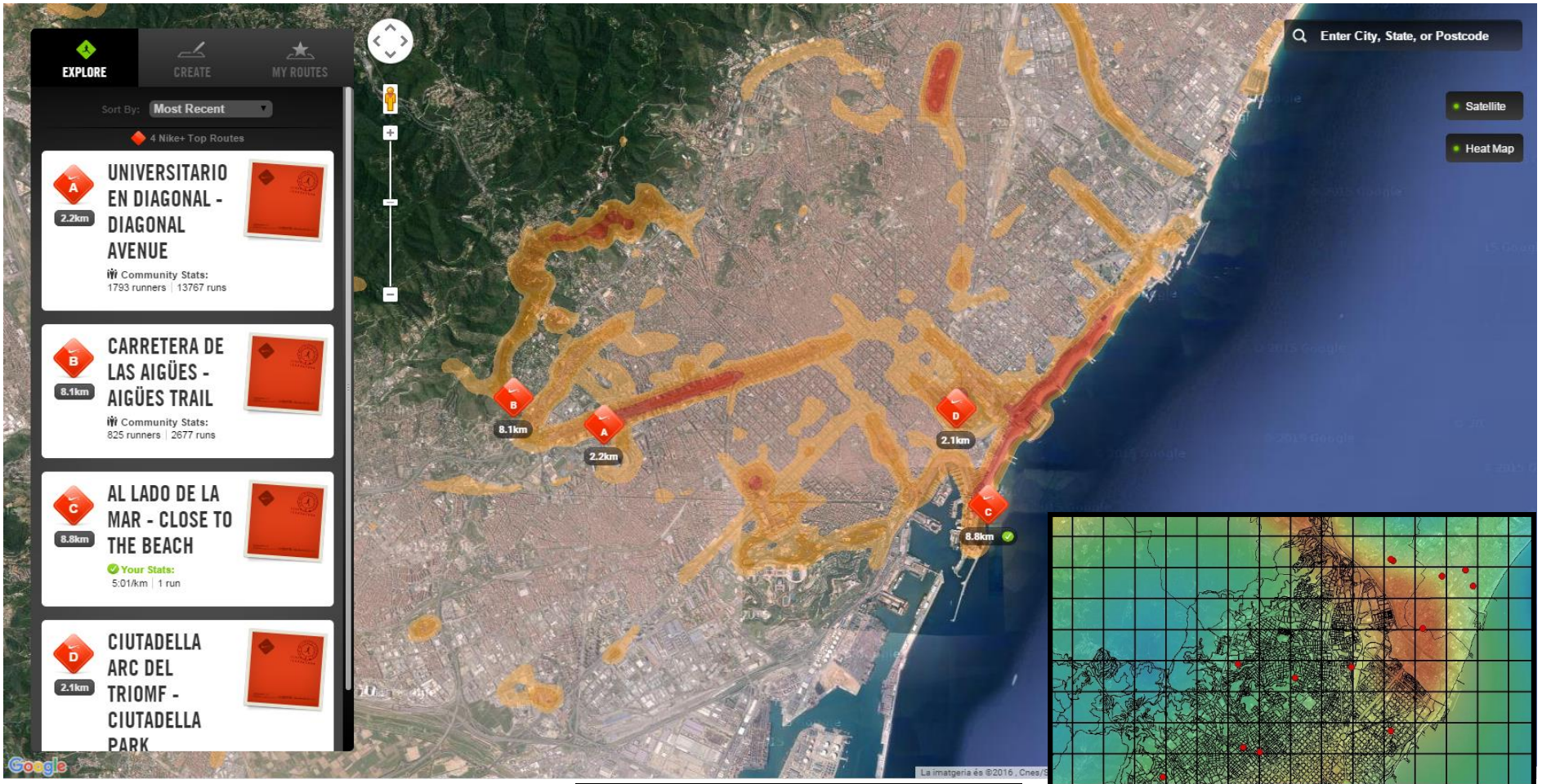
NO_2 hourly concentration. Plaza de España station



NO_2 hourly concentration. Plaza del Carmen station



Why is it important?



NIKE+ RUNNING APP

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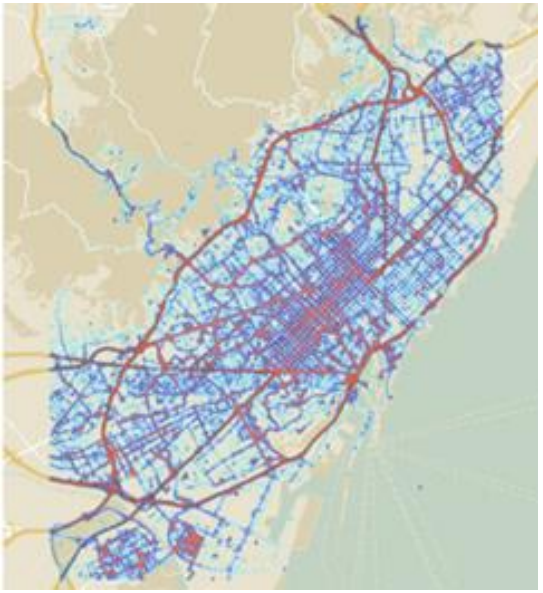
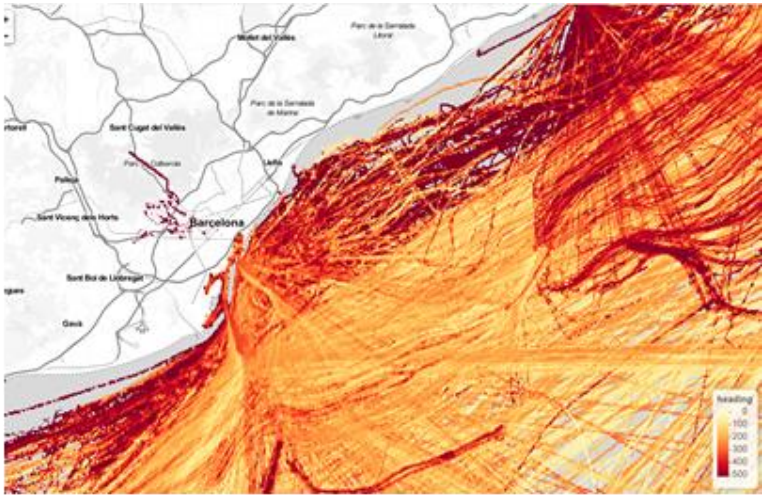
Sources of emissions in the city

- Road Traffic:
  - Complex due to regulations
    - ALPR means video
    - Vehicle Tags
    - Bluetooth scanning
  - Mix of vehicles (Euro3, Euro4, Euro5…)

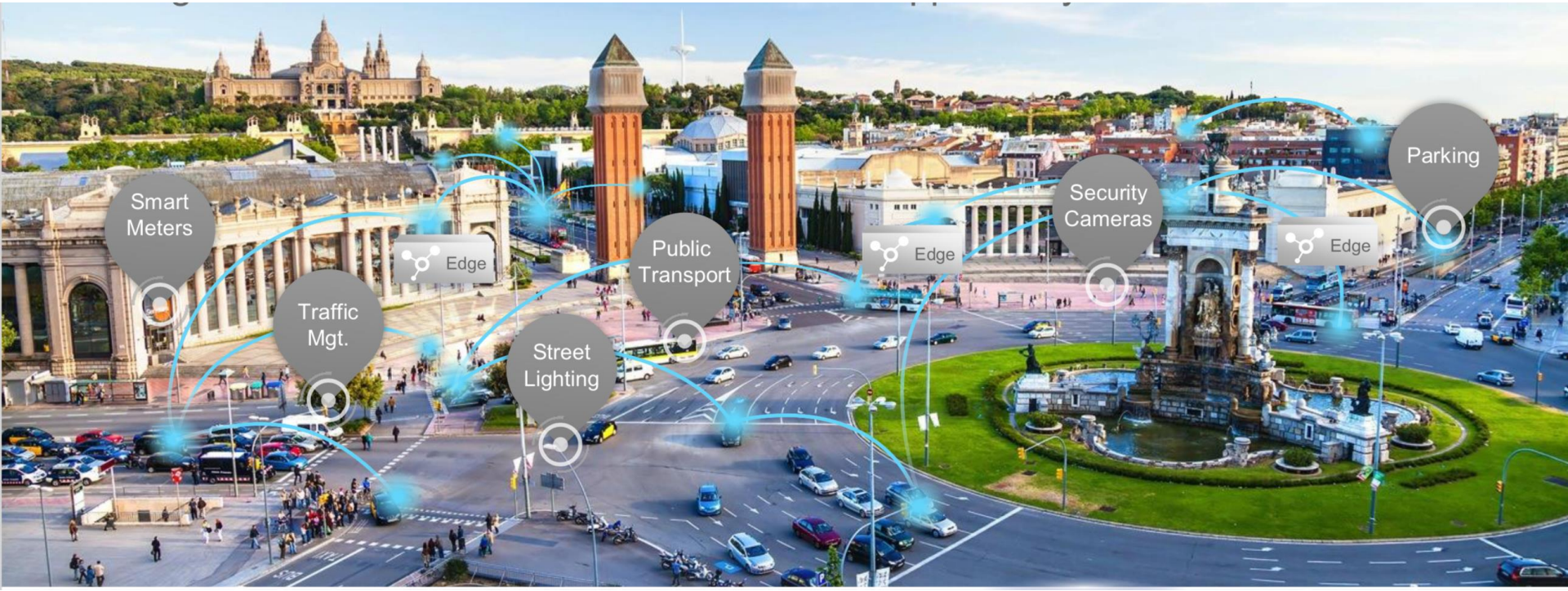


- Maritime traffic:
  - Public data of positions
  - Pseudo-public data of vehicles

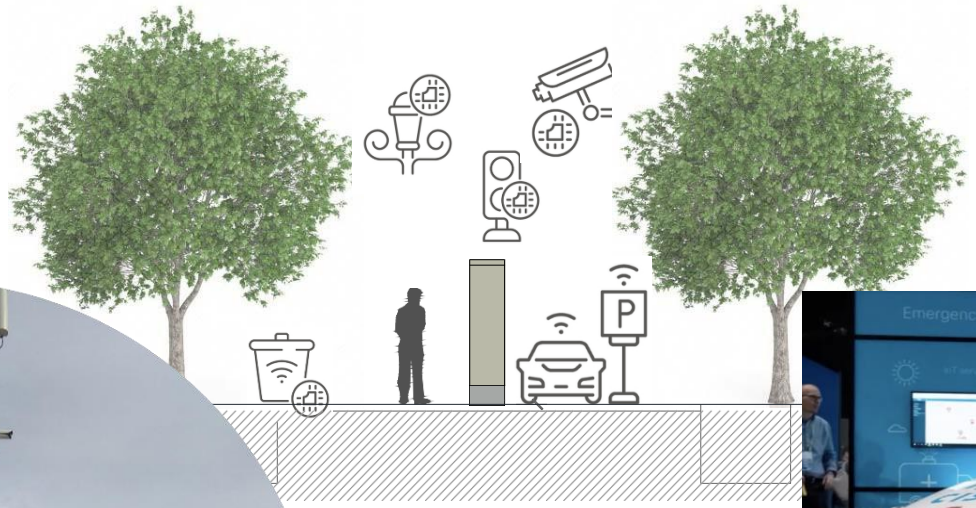


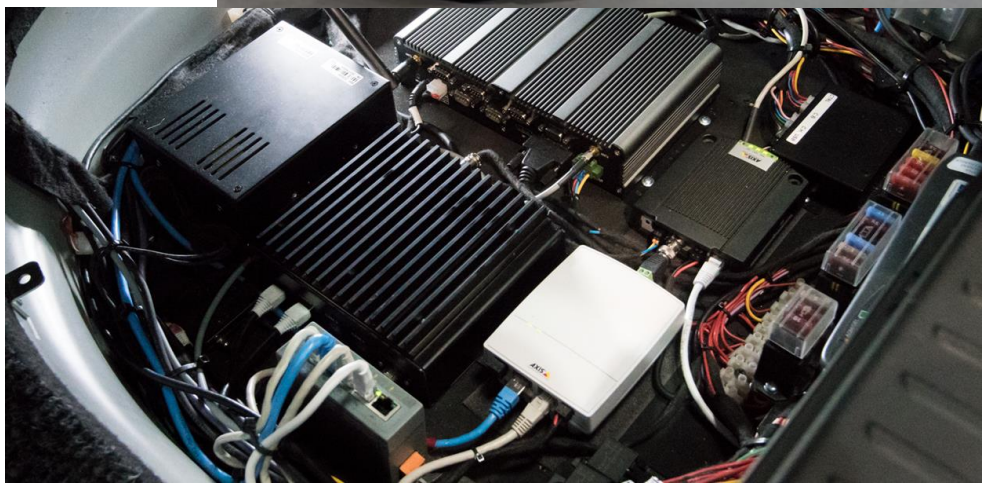
Internet of Things

- Progressively, all active and passive elements of the city are connected
- Sensing and acting
- Advanced control cycles

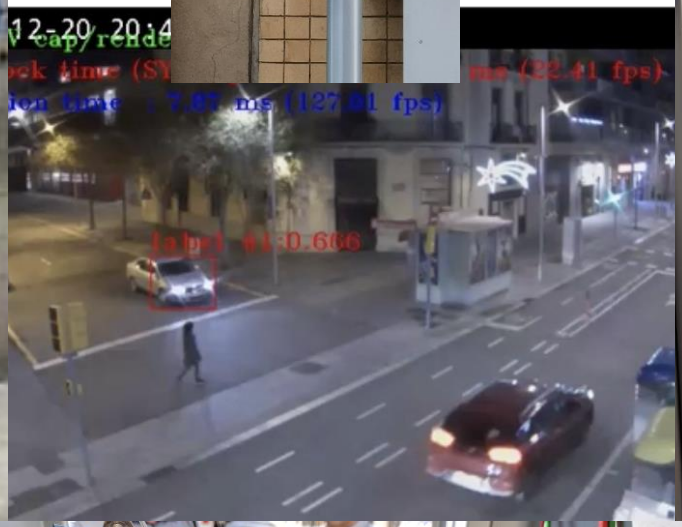


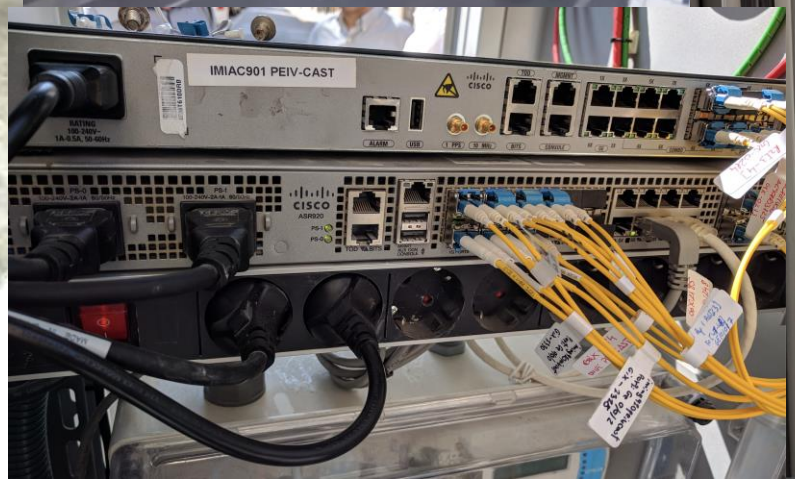
Street-level infrastructure





City connectivity





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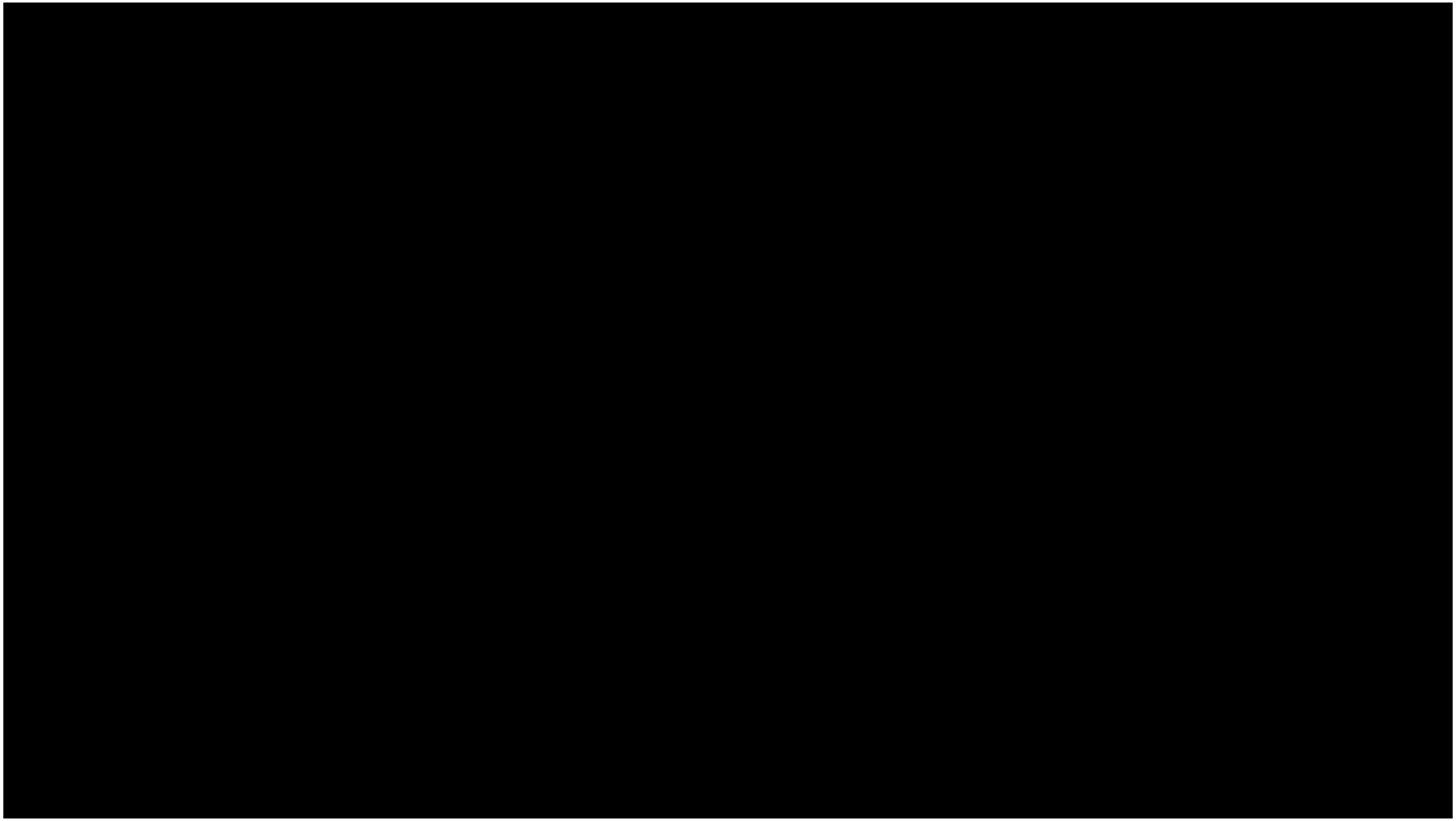
Project with the City of Barcelona

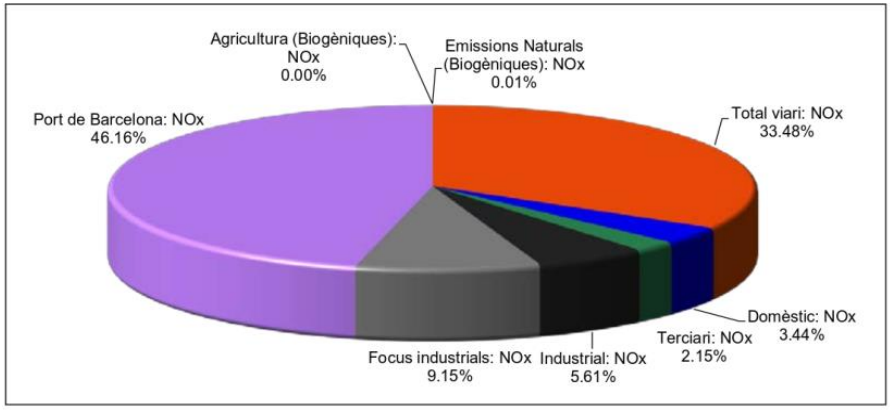


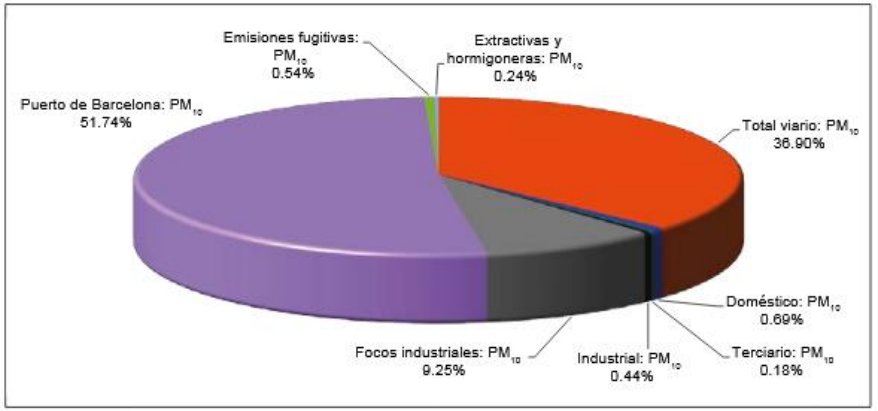
Air Quality and Harbour Cities

- Air Quality impacts directly on our **health**
  - Several studies suggest that there is a relationship between health issues and air quality
    - e.g. Mueller et al., 2017; Bañeras et al., 2018
- Part of this pollution is originated at the **port**
  - **Maritime traffic** is now a key component for economy
    - It is a **cheap** way for shipping items in big quantities
  - By 2050 it is estimated that will grow between **50% and 250%**

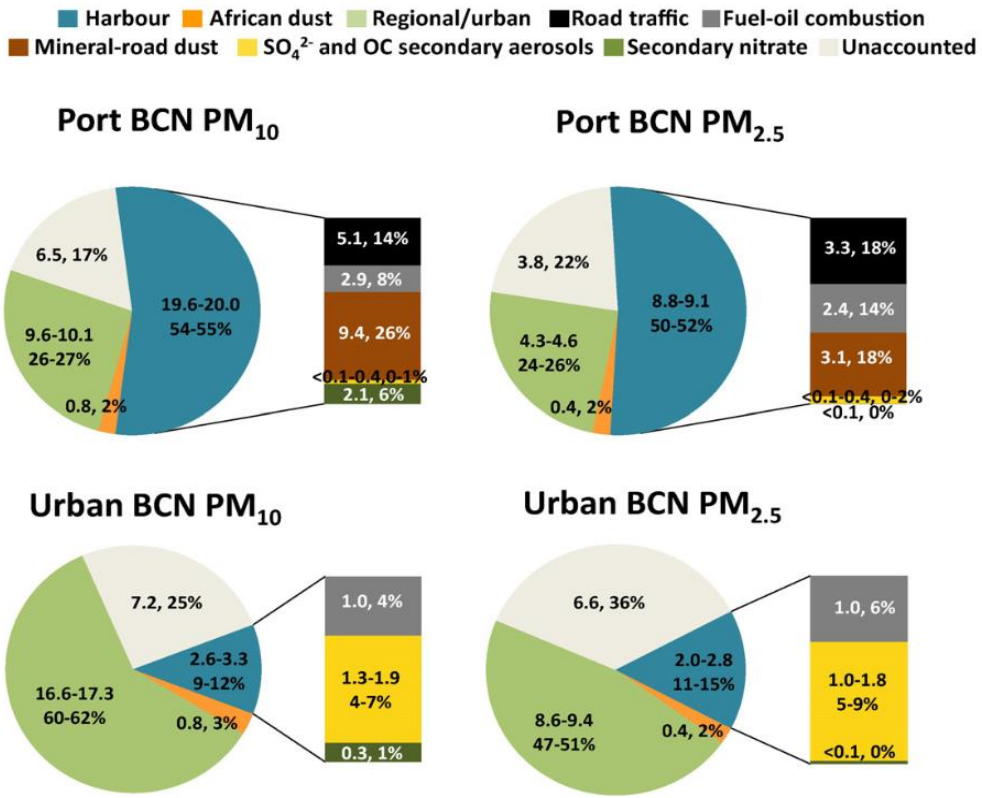
Photography taken by Fabra Observatory's meteorologist, Alfons Puertas.

Impact of harbour emissions on Barcelona urban air quality





Pla per la Millora de la Qualitat de l'Aire de Barcelona (2015-2018)



Pérez et al. (2016)

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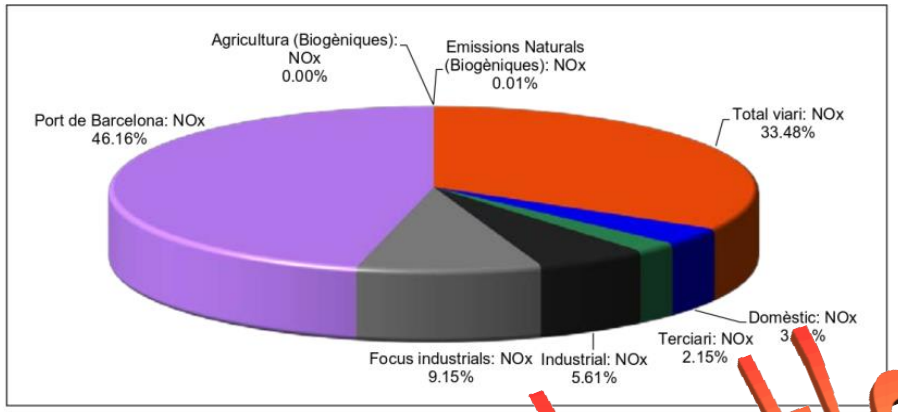
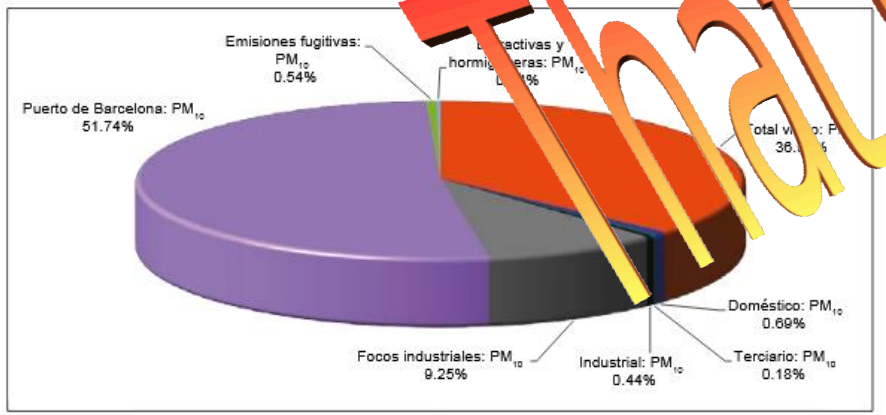
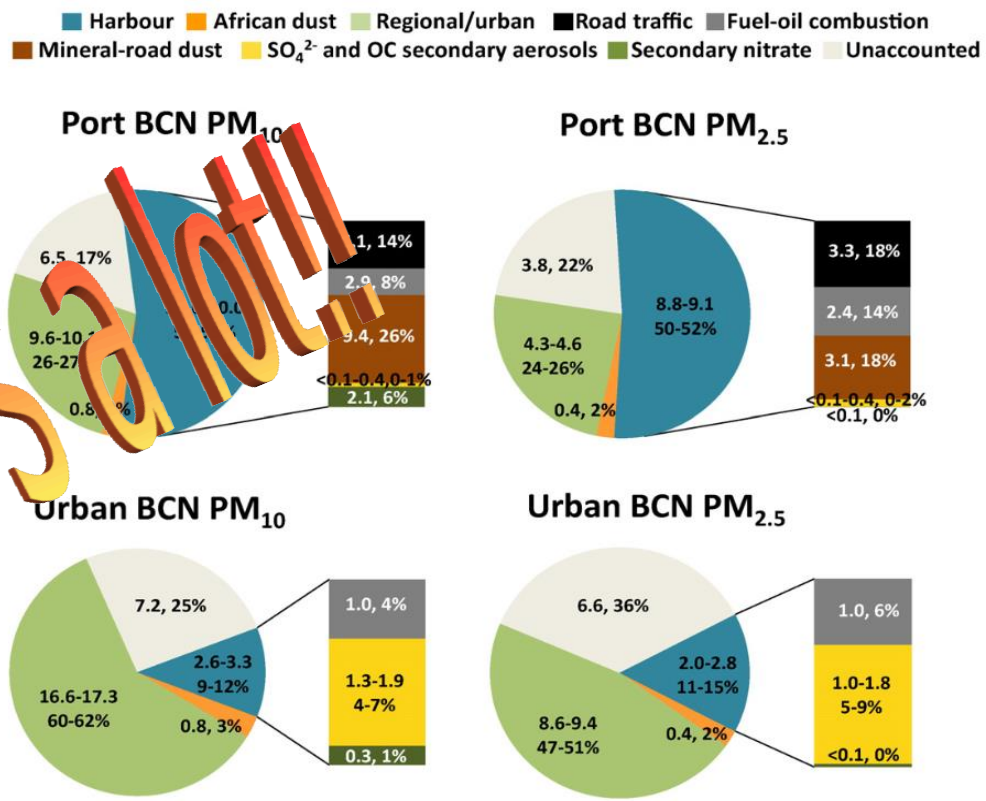
Impact of harbour emissions on Barcelona urban air quality





That's a lot!!



Pla per la Millora de la Qualitat de l'Aire de Barcelona (2015-2018)

Pérez et al. (2016)

What can we do about it?

- Order less internationally shipped goods
- Make policies and regulations to mitigate the impact of the ship pollution on the city
  - We need measures and simulations to evaluate the policies
  - Hello, politicians

What can we do about it?

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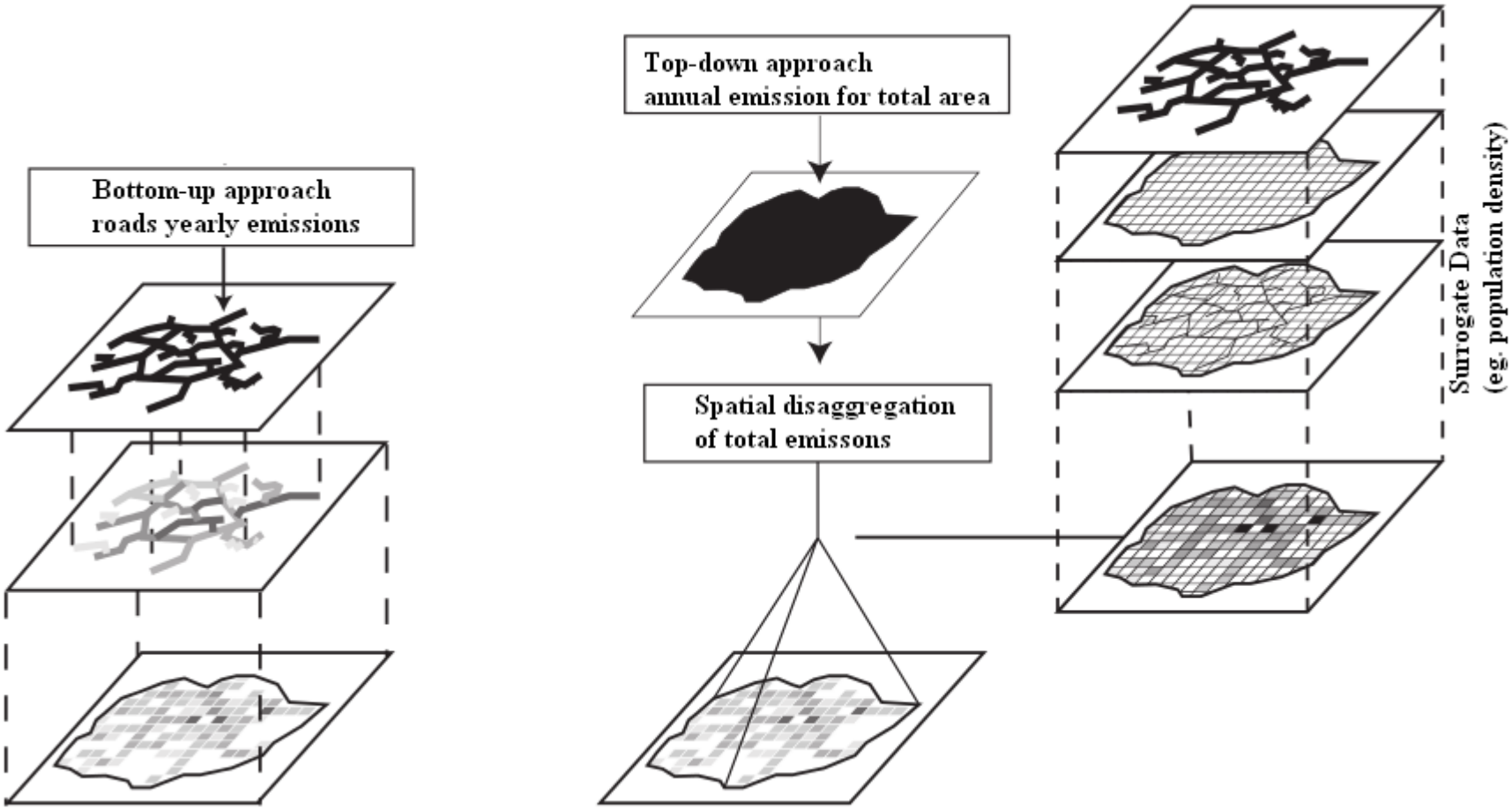
- Make policies and regulations to mitigate the impact of the ship pollution on the city
  - We need measures and simulations to evaluate the policies
  - Hello, politicians

*Barcelona during complete lockdown

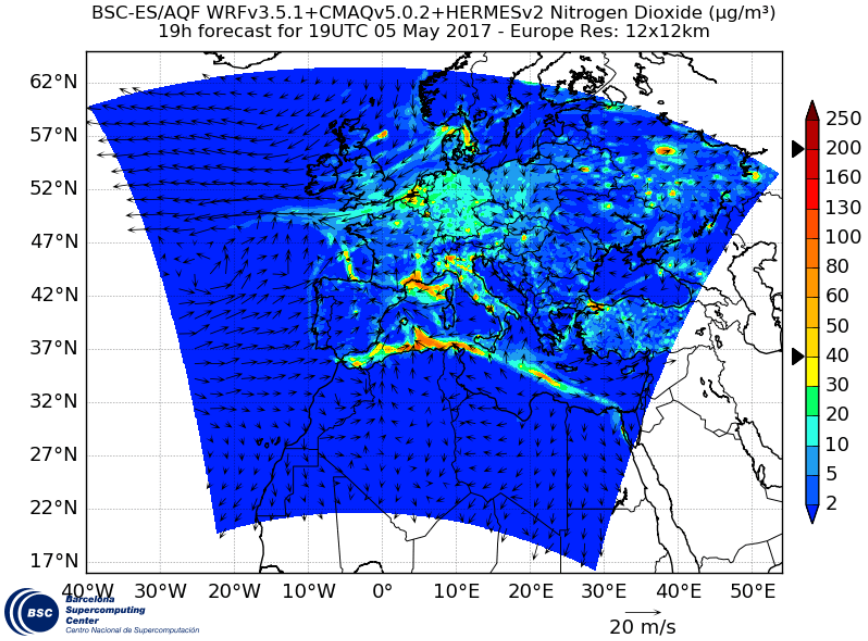
Top-down & Bottom-up



Extracted from *"New Approaches for Urban and Regional Air pollution Modelling and Management"* (Puliafito et al. 2010)

A modelling approach

- **CALIOPE** Air Quality modelling project
- **HERMESv3** is the core for **Emission Estimation** *(Guevara et al., 2019)*
  - Ship Emissions module (SNAP0804) is based on several parameters, e.g.
    - **Annual operations + Weekly/Hourly profiles + Operational mode**
    - **Ship properties**
    - **Total emissions**
  - **Top-down** approach: Disaggregation of cumulated emissions
  - However, it lacks of precision regarding the actual position of the ship



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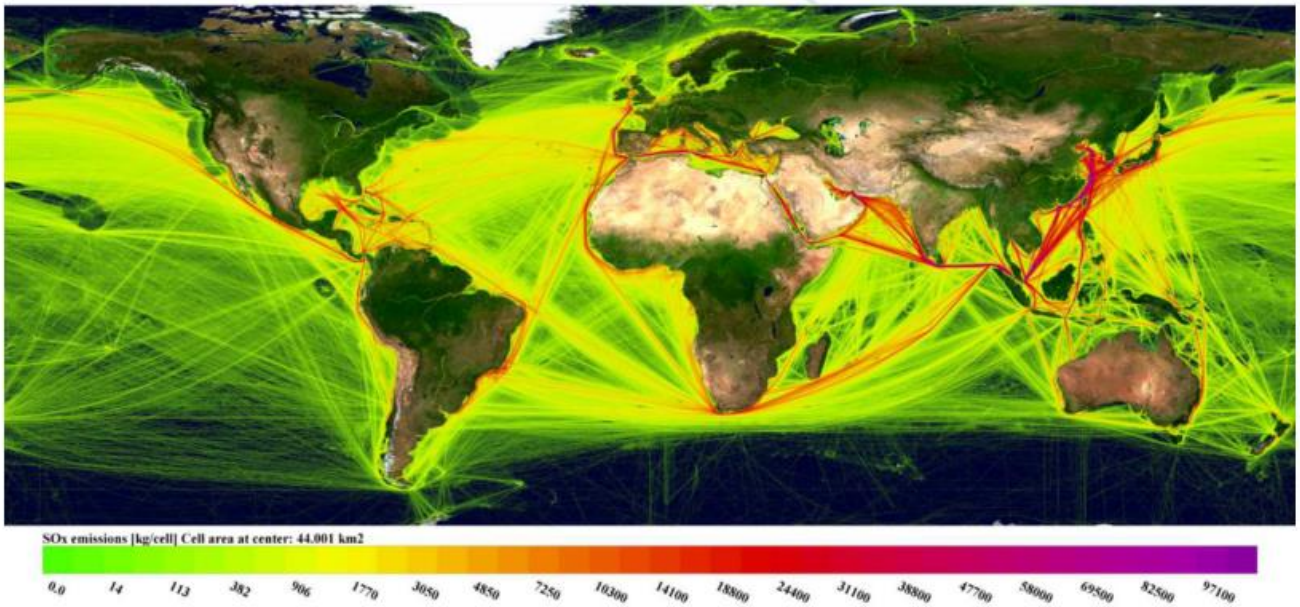
Improvement of HERMESv2 model: STEAM methodology

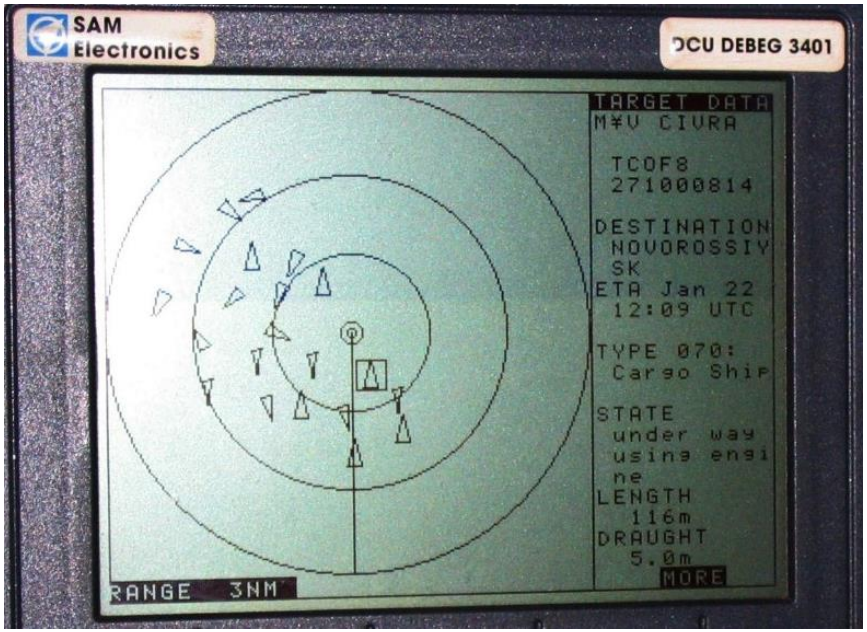
- **Bottom-up** methodology proposed by *Jalkanen et al.*
  - Estimates emissions from each ship
  - Accumulate them into the desired grid
- This model requires two types of data to work
  - **Positioning**, **speed** and other data provided by **AIS**
  - Extra ship properties and **engine** details provided by a third party register



Geographical distribution of modelled total SOx emissions from shipping in 2015.
Extracted from Jalkanen et al. 2017

AIS

- Automatic Identification System (AIS), a **GPS**-based system built for preventing collisions on ships and planes
  - Provides in **real time ship position** along with other ship properties
- Messages of two types
  - **Static messages** that contain ship properties, e.g. length or type of ship
  - **Dynamic messages** that contain the current ship status, e.g. speed or navigational status.



AIS is good but…

- It does not consider small vessels without AIS equipment (<300GT)
  - Usually recreational boats which do not have a large contribution to total emissions
- VHF AIS only covers the coast
  - Which for this use case is correct
- Data gaps and anomalies

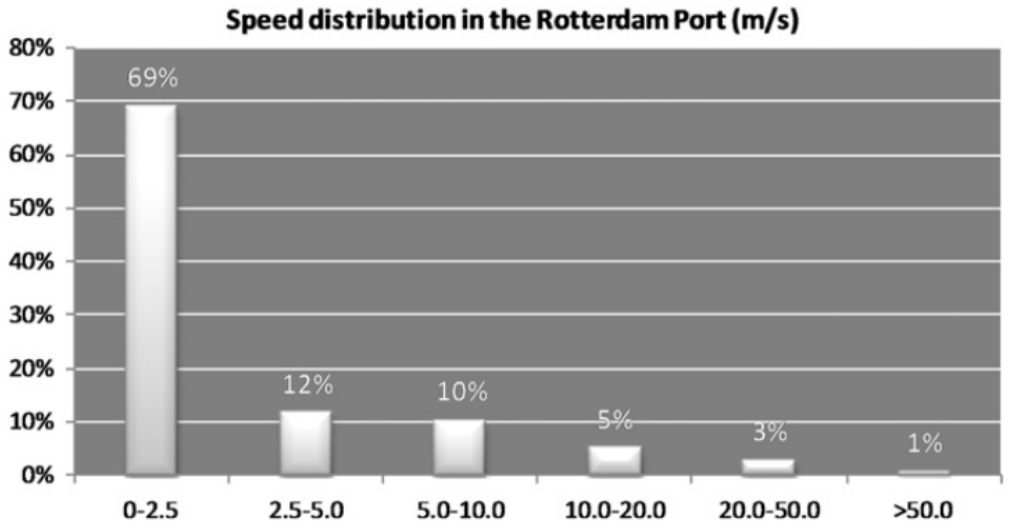


Fig. 5. Ships' speeds distribution in the port of Rotterdam. They are derived from ships' positions retrieved by the marinetraffic.com AIS network on 10/06/2010

Miola et al. 2010

AIS Data Acquisition

- AIS Data can be **bought** from several organizations including *Puertos del Estado*
- But it can be obtained using a **receiver**
  - Data is transmitted in **two VHF channels**
  - It is **public** (remember the main objective)
- How we did it
  - We **bought an initial batch** of data for exploration and testing
  - We have captured some data using regular **TV equipment with some tweaks**
    - You can also do it at home! [1]

[1] https://help.marinetraffic.com/hc/en-us/articles/206410608-DVB-T-USB-Stick-AIS-Receiver

Bloc 2

Els models d'emissions

How can we estimate emissions without sensors?

- AIS provides ship activity
- Ship registries provide static ship information
  - Size
  - Engines
  - Type of cargo
  - Number of refrigerated containers
  - …
- We just have to merge that information and do some basic chemistry to have a good enough method ☺

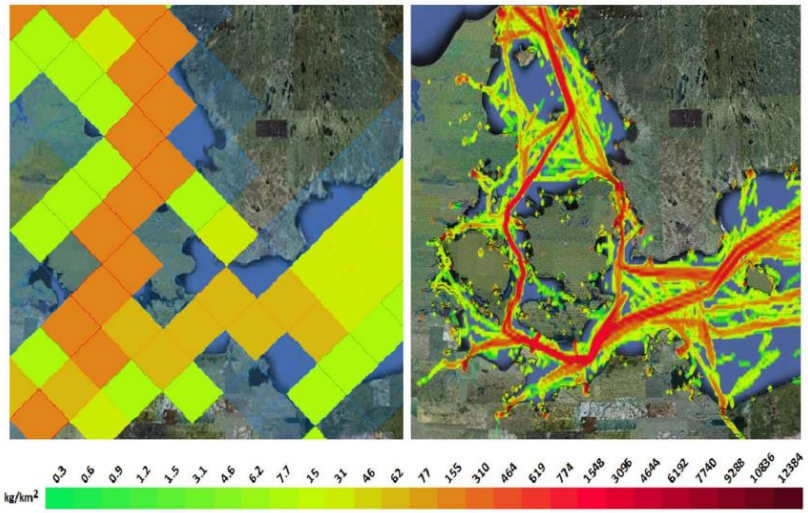
Emission Modelling (STEAM)

Power consumption **Emission Factor**

$$E_{s,p,x,t}[g/h] = P_{s,x,t}[kW] \cdot EF_{s,p}[\frac{g}{kWh}]$$

Ship properties, speed, (waves) and operation mode **[AIS Data]**

Ship and fuel properties (And speed) **[IHS + AIS Data]**



From Jalkanen et al. 2012

Power consumption estimation Main Engine

$$P_{\text{transient}} = \frac{k V_{\text{transient}}^3}{0.514^3},$$

where k is defined as

$$k = 0.514^3 * \frac{\varepsilon_p * P_{\text{installed}}}{\left(V_{\text{design}} + V_{\text{safety}}\right)^3}$$

Power consumption estimation Auxiliary Engine

- If the ship is a Cruiser/Ro-Ro Cargo/Passenger Ship
  - P_{AE} = 4000kW
- If not
  - If speed < 1 (Hotelling)
    - P_{AE} = 1000kW
  - If 1 < speed < 5
    - P_{AE} = 1250kW
  - If speed < 5
    - P_{AE} = 750kW
- And then
  - P_{AE} = min(installed power, P_{AE})

Emission factors
SOx

SFOC = Specific Fuel Oil Consumption (g/kWh)
SC = Sulphur content of fuel (mass-%)
M(S) = Molar mass of sulphur (g/mol)
$M(SO_2)$ = Molar mass of sulphu dioxide (g/mol)
n(S) = number of moles of sulphur (mol)
$n(SO_2)$ = number of mols of sulphur dioxide (mol)
m(S) = mass of sulphur (g)
$m(SO_2)$ = mass of sulphur dioxide (g)

$$n(S) = \frac{m(S)}{M(S)} = \frac{SFOC * SC}{M(S)} = \frac{200 \ \ g/kWh \ \ * \ \ 0.015}{32.0655 \ \ g/mol} = 0.09356 \ \ mol/kWh$$

$$n(S) = n(SO_2)$$

$$m(SO_2) = M(SO_2) * n(SO_2) = 64.06436 \ \ g/mol * 0.09356 \ \ mol/kWh = 5.994 \ \ g/kWh$$

Emission factors
CO2

SFOC = Specific Fuel Oil Consumption (g/kWh)
CC = Carbon content of fuel (mass-%)
M(C) = Molar mass of carbon (g/mol)
n(C) = number of mols of carbon (mol)
m(C) = mass of carbon (g)
M(CO2) = molar mass of carbon dioxide (g/mol)
n(CO2) = number of mols of carbon dioxide (mol)
m(CO2) = mass of carbon dioxide (g)

$$n(C) = \frac{m(C)}{M(C)} = \frac{SFOC * CC}{M(C)} = \frac{200 \ \ g/kWh \ \ * \ \ 0.85}{12.01 \ \ \text{g/mol}} = 14.15487 \ \ \text{mol/kWh}$$

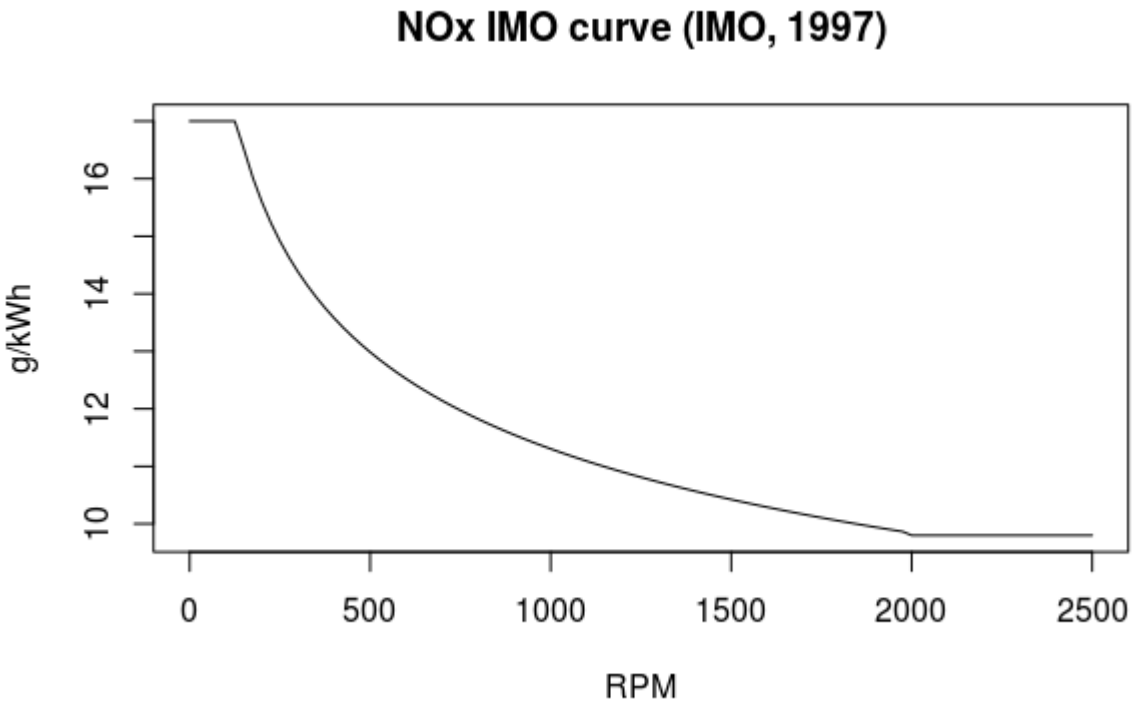
$$n(C) = n(CO_2)$$

$$m(CO_2) = M(CO_2) * n(CO_2) = 44.00886 \ \ \text{g/mol} * 14.15487 \ \ \text{mol/kWh} = 622.94 \ \ \text{g/kWh}$$

Emission factors
NOx

$$\text{Emission\_factor (g/kWh)} = \begin{cases} 17, \text{ for engines less than 130rpm} \\ 45.0 * n^{-0.2}, \\ \text{for engines } 130 < n < 2000, \\ n = \text{engine rpm} \\ 9.8, \text{ for engines over 2000 rpm} \end{cases}$$

From a study with several ships by IMO in 1997



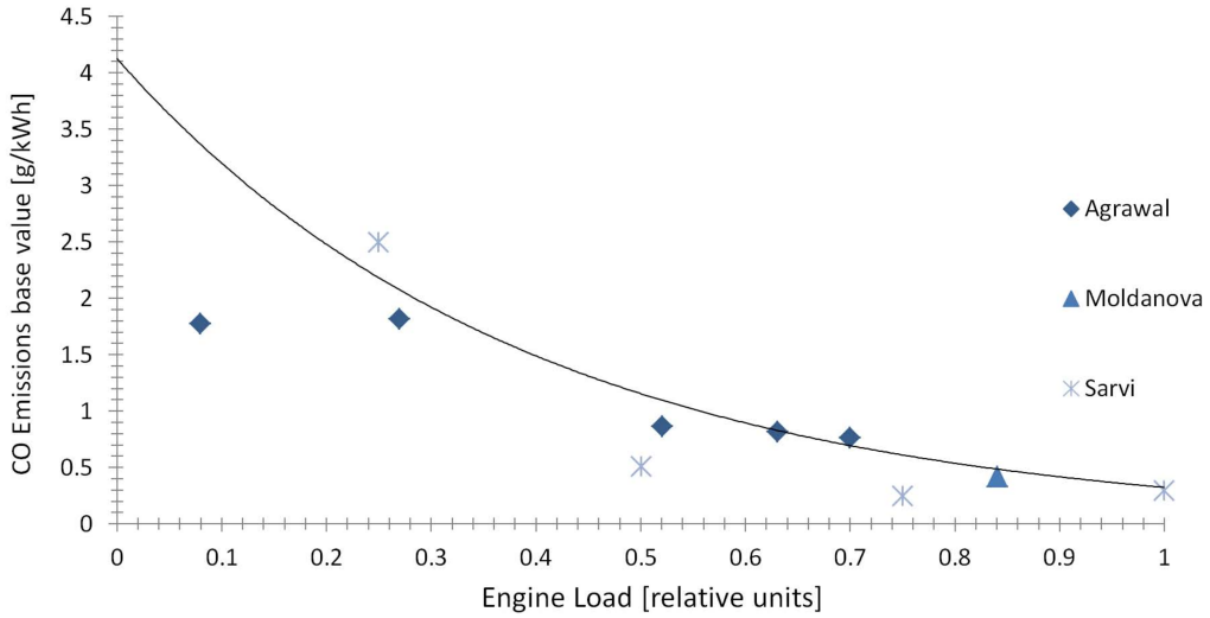
Emission factors
CO

$$EF_{CO} = CO_{base} ABC$$

where

$$ABC = \max\left\{\alpha \frac{|\Delta v|}{\Delta t}, 1\right\}$$

- α = 583 by regression analysis (Jalkanen et al. 2012)
- CObase = 0.8 for simplicity (in today's application!)



Activity description

Mens sana in corpore cansao

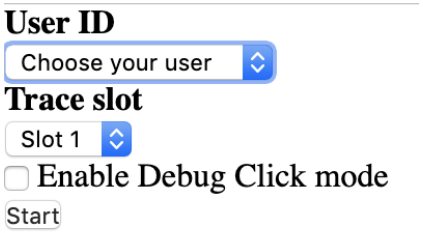
Routes


Residencia Universitaria Torre Girona
UPC: Servei de Comunicació
Passeig dels Tilers
ISST - UPC
Barcelona Supercomput...
Baker Tilly
R2
R1
Parc UPC
Carrer de Jordi Girona
Union for the Mediterranean
Carrer de Jordi Girona
3D

Behaviors

- Slot1: R1 / Slow & smooth
- Slot2: R1 / Fast & Furious
- Slot3: R1 / Stop & Go
- Slot4: R2 / Slow & smooth
- Slot5: R2 / Fast & Furious
- Slot6: R2 / Stop & Go

Intro application



https://patrons.bsc.es/patrons/bojos

The Modules

Webserver

App: nginx

Written in:
Html + Javascript

API

App: Koa

Written in:
Javascript

Database

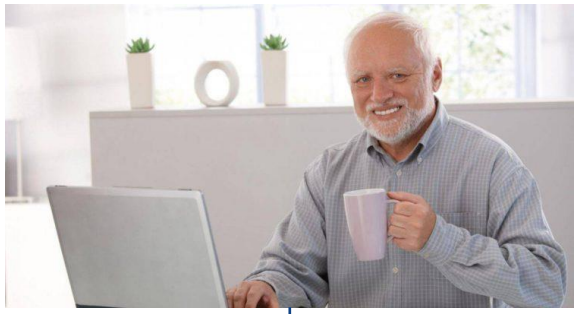
App: Postgres
(+ Postgis)

Written in:
SQL

Let’s use the application

Now we will follow part of the execution with some help

Let’s use the application



Harold enters to the application with his web browser

Give me all the files!

Webserver

App: nginx

Written in:
Html + Javascript

API

App: Koa

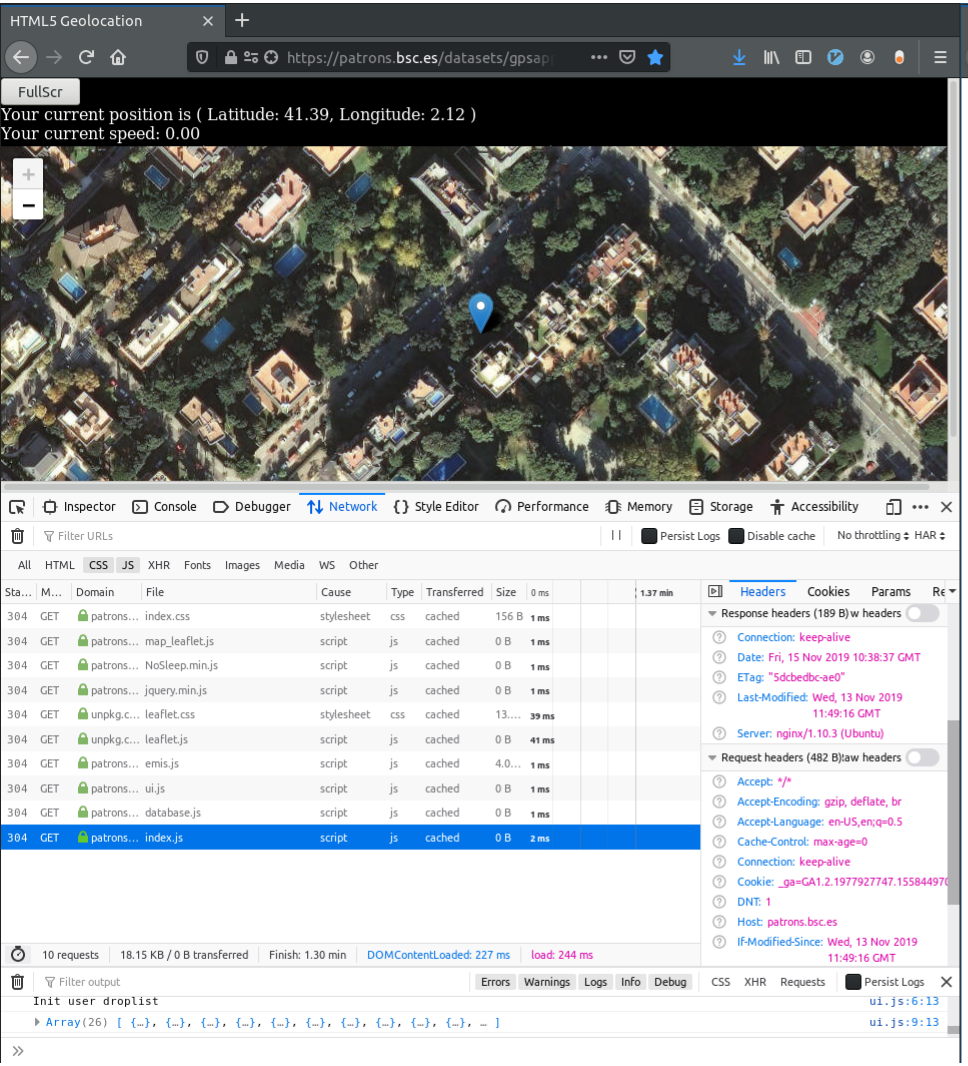
Written in:
Javascript

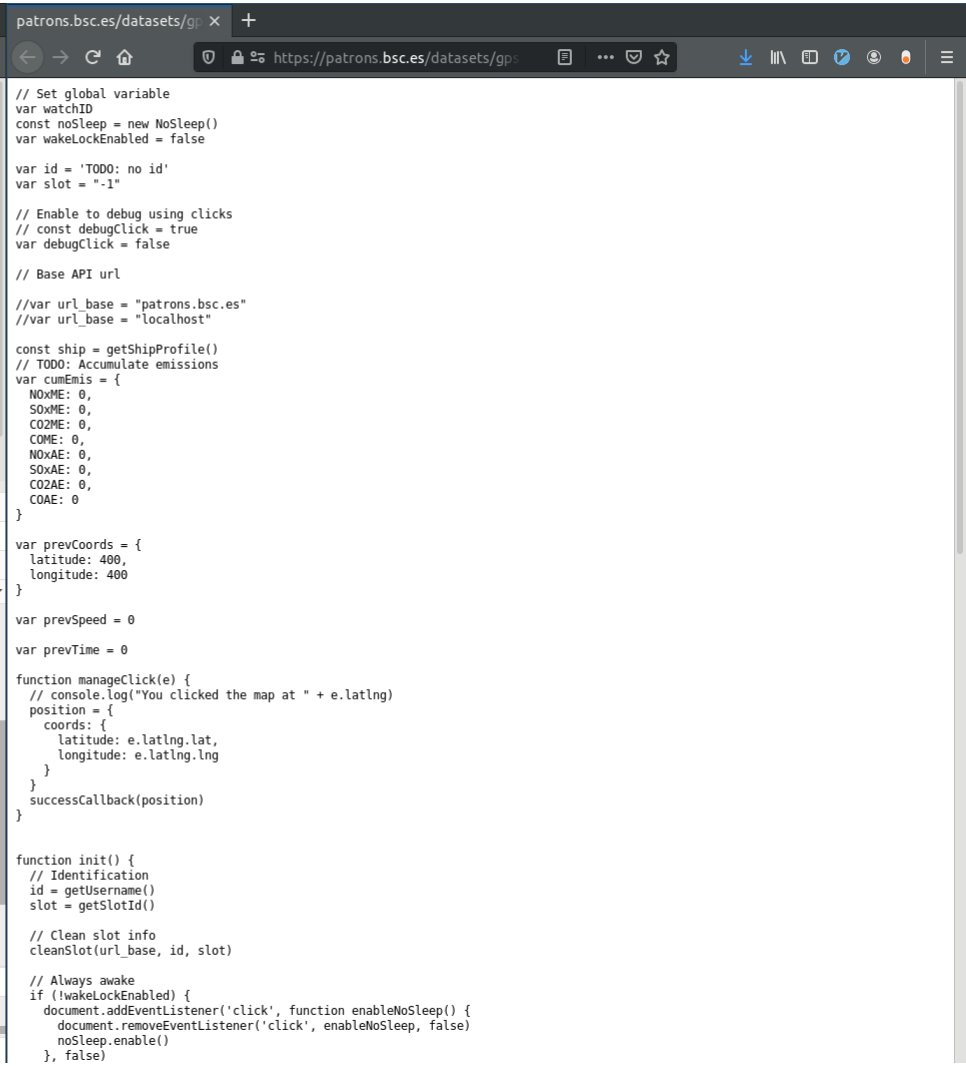
Database

App: Postgres
(+ Postgis)

Written in:
SQL

The Webserver






```
// Set global variable
var watchID
const noSleep = new NoSleep()
var wakeLockEnabled = false

var id = 'TODO: no id'
var slot = "-1"

// Enable to debug using clicks
// const debugClick = true
var debugClick = false

// Base API url

//var url_base = "patrons.bsc.es"
//var url_base = "localhost"

const ship = getShipProfile()
// TODO: Accumulate emissions
var cumEmis = {
  NOxME: 0,
  SOxME: 0,
  CO2ME: 0,
  COME: 0,
  NOxAE: 0,
  SOxAE: 0,
  CO2AE: 0,
  COAE: 0
}

var prevCoords = {
  latitude: 400,
  longitude: 400
}

var prevSpeed = 0

var prevTime = 0

function manageClick(e) {
  // console.log("You clicked the map at " + e.latlng)
  position = {
    coords: {
      latitude: e.latlng.lat,
      longitude: e.latlng.lng
    }
  }
  successCallback(position)
}


function init() {
  // Identification
  id = getUsername()
  slot = getSlotId()

  // Clean slot info
  cleanSlot(url_base, id, slot)

  // Always awake
  if (!wakeLockEnabled) {
    document.addEventListener('click', function enableNoSleep() {
      document.removeEventListener('click', enableNoSleep, false)
      noSleep.enable()
    }, false)
```

Web browser magic now

Web browser executes the program!

Webserver	API	Database
App: nginx	App: Koa	App: Postgres (+ Postgis)
Written in: Html + Javascript	Written in: Javascript	Written in: SQL

We got a GPS point and emissions!

Harold now is happy because he can see the calculations
Now he wants to save them

Save this piece of data!

Webserver	API	Database
App: nginx	App: Koa	App: Postgres (+ Postgis)
Written in: Html + Javascript	Written in: Javascript	Written in: SQL

The API

```
74
 1 router.post('/new_session', async ctx => {
 2     console.log(ctx.request.body);
 3     const gj = ctx.request.body
 4     console.log(`${gj})`);
 5
 6     const results = await database.newSession(gj.username)
 7     if (results.length === 0) { ctx.throw(404) }
 8
 9     // Add row metadata as geojson properties
10     ctx.body = results
11 })
12
13
14 router.post('/point', async ctx => {
15     console.log(ctx.request.body);
16     const gj = ctx.request.body
17     console.log(`${gj})`);
18
19     const results = await database.insertGPSPoint(gj)
20     if (results.length === 0) { ctx.throw(404) }
21
22     // Add row metadata as geojson properties
23     ctx.body = `Inserted ${gj})`
24 })
```

We got a GPS point and emissions!

Harold waits around 5 ms while enjoying his coffee

Save this piece of data!

The Database

SELECT * FROM locations WHERE soxme IS NOT NULL AND pae IS NOT NULL limit 20;

```
cleaner/bojos  # SELECT * FROM locations WHERE soxme IS NOT NULL AND pae IS NOT NULL limit 20;
 gid  | sid |          ts             |                          geom                          |      noxme       |      noxae       |
------+-----+-------------------------+--------------------------------------------------------+------------------+------------------+
 4490 |   1 | 2019-11-13 11:57:04.249 | 0101000020E61000000100060D0DC0040CB2D6A041CB24440 | 1.99872038449419 | 3.99471464797576 |
 4491 |   1 | 2019-11-13 12:55:45.647 | 0101000020E6100000CE7BAD951AEB00402DDB3D2FCBB14440 |                0 | 3.99471464797576 |
 4583 |   1 | 2019-11-13 15:11:06.425 | 0101000020E61000000100010A3E100404B583D9ADAB14440 | 6.02115238809226 | 2.99603598598182 |
 4584 |   1 | 2019-11-13 15:11:10.13  | 0101000020E61000000100040A0E10040076F127ED8B14440 | 4.76498510649342 | 2.99603598598182 |
 4585 |   1 | 2019-11-13 15:11:14.678 | 0101000020E610000010000709DE10040B462E761D6B14440 |  2.5761130276004 | 2.99603598598182 |
 4586 |   1 | 2019-11-13 15:11:18.094 | 0101000020E610000010000A09AE100405033BC45D4B14440 |  6.0795664082767 | 2.99603598598182 |
 4587 |   1 | 2019-11-13 15:11:21.478 | 0101000020E610000010000D097E10040DAE09029D2B14440 | 6.25367411450232 | 2.99603598598182 |
 4588 |   1 | 2019-11-13 15:11:24.59  | 0101000020E610000010000095E10040536B650DD0B14440 | 8.04095221676862 | 2.99603598598182 |
 4589 |   1 | 2019-11-13 15:11:27.574 | 0101000020E610000010003092E10040C1D239F1CDB14440 | 9.12073419414485 | 2.99603598598182 |
 4590 |   1 | 2019-11-13 15:11:30.622 | 0101000020E610000010000608FE100401B170ED5CBB14440 | 8.55368349024175 | 2.99603598598182 |
 4591 |   1 | 2019-11-13 15:11:32.566 | 0101000020E61000000100090C4E50040937FEF41C3B14440 | 89.0277520536668 | 2.99603598598182 |
 4592 |   1 | 2019-11-13 15:11:35.446 | 0101000020E610000010000608FE10040F33F3976C9B14440 | 89.0277520536668 | 2.99603598598182 |
 4593 |   1 | 2019-11-13 15:11:39.623 | 0101000020E610000010003092E1004066F26D37C7B14440 | 4.00315678093222 | 2.99603598598182 |
 4594 |   1 | 2019-11-13 15:11:43.201 | 0101000020E610000010000095E10040FFC6411BC5B14440 | 5.29060341347115 | 2.99603598598182 |
 4595 |   1 | 2019-11-13 15:11:46.265 | 0101000020E610000010000D097E10040867815FFC2B14440 |  8.4248058915139 | 2.99603598598182 |
 4596 |   1 | 2019-11-13 15:11:49.261 | 0101000020E610000010000A09AE10040FF06E9E2C0B14440 | 9.01157902912697 | 2.99603598598182 |
 4597 |   1 | 2019-11-13 15:11:51.869 | 0101000020E610000010000709DE100406772BCC6BEB14440 | 13.6616596078334 | 2.99603598598182 |
 4598 |   1 | 2019-11-13 15:11:54.333 | 0101000020E61000000100020B1E1004051843575BDB14440 | 7.13630054912688 | 2.99603598598182 |
 4599 |   1 | 2019-11-13 15:11:56.882 | 0101000020E61000000100090E6E10040B81CE5B8BDB14440 | 24.7505796771366 | 2.99603598598182 |
 4600 |   1 | 2019-11-13 15:11:59.44  | 0101000020E6100000010000102AE20040AAD3662CBFB14440 | 64.6575739012891 | 2.99603598598182 |
```

We saved the point!

Done!

Done!

Webserver

App: nginx

Written in:
Html + Javascript

API

App: Koa

Written in:
Javascript

Database

App: Postgres
(+ Postgis)

Written in:
SQL

RUN”

Press Play and then any key []

https://patrons.bsc.es/patrons/bojos

Download your data

https://patrons.bsc.es/patrons/bojos/csv.html

Bloc 3

Processat de dades simples

Let's code

https://github.com/HiEST/bojos/releases

Download the last release

- bojos_ships.zip: Code to use (including templates)
- Bojos2020.csv: Data. Just in case your traces are not ok

And then use Google Colab to execute and implement code

https://colab.research.google.com

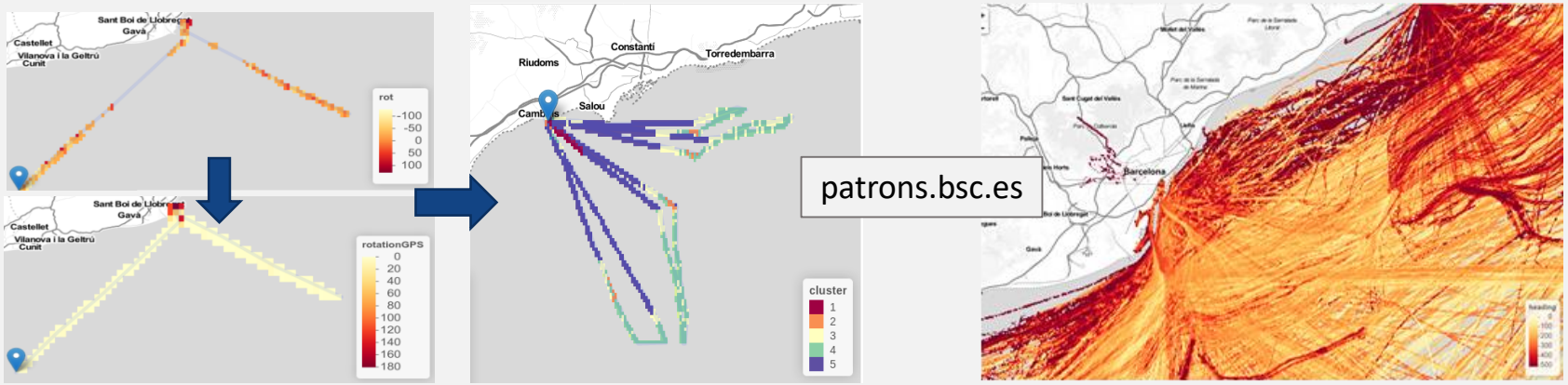
Bloc 4

Processat de dades complex (ML)

Maritime Traffic Modeling

Modelling of Maritime emissions using Deep Learning

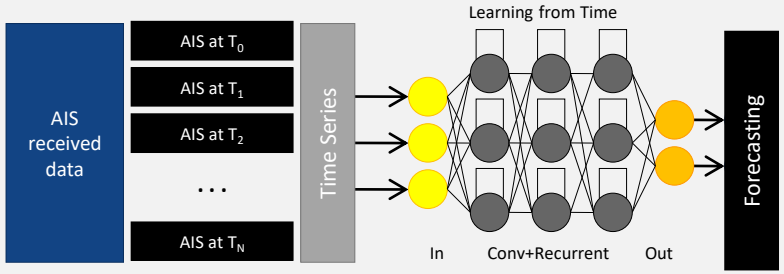
Emission modelling and forecasting based on deep learning



Use of CNNs:

- **Convolutional-LSTM**
- 3D convolutional

- Learning patterns and forecasting
- Input:
  - AIS traces (position, operation…)
  - Emission modeling (Jalkanen)
  - Time/space aggregation
- Output:
  - Future position and emissions

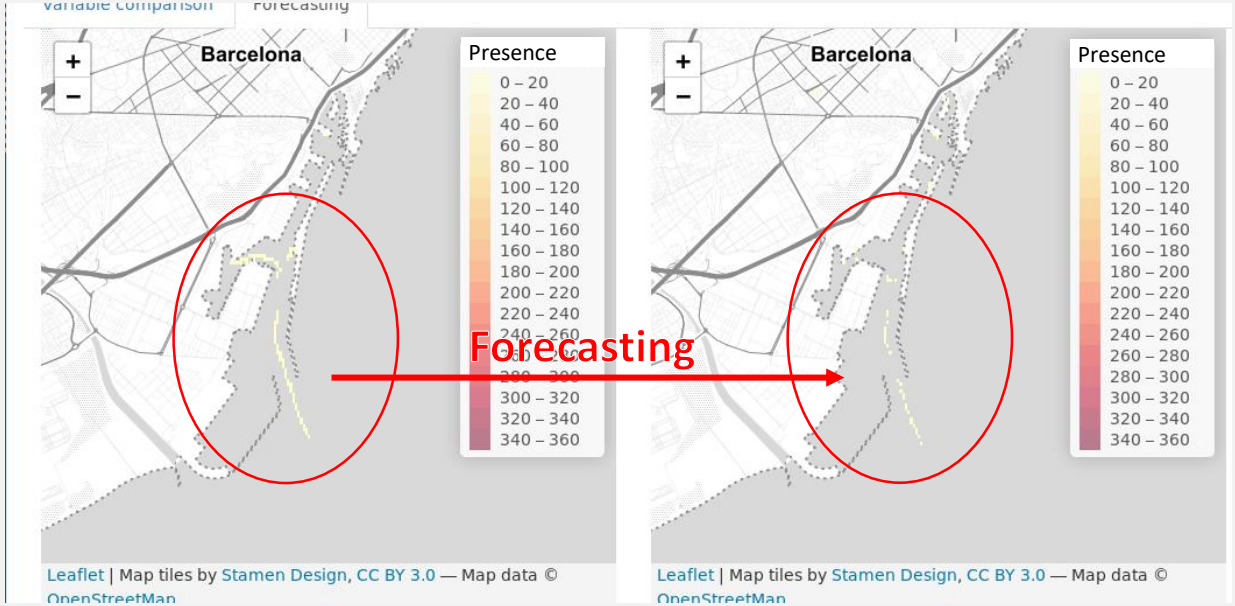


LSTMs:Long/Short Term Memory

Modeling, Prediction & Forecasting

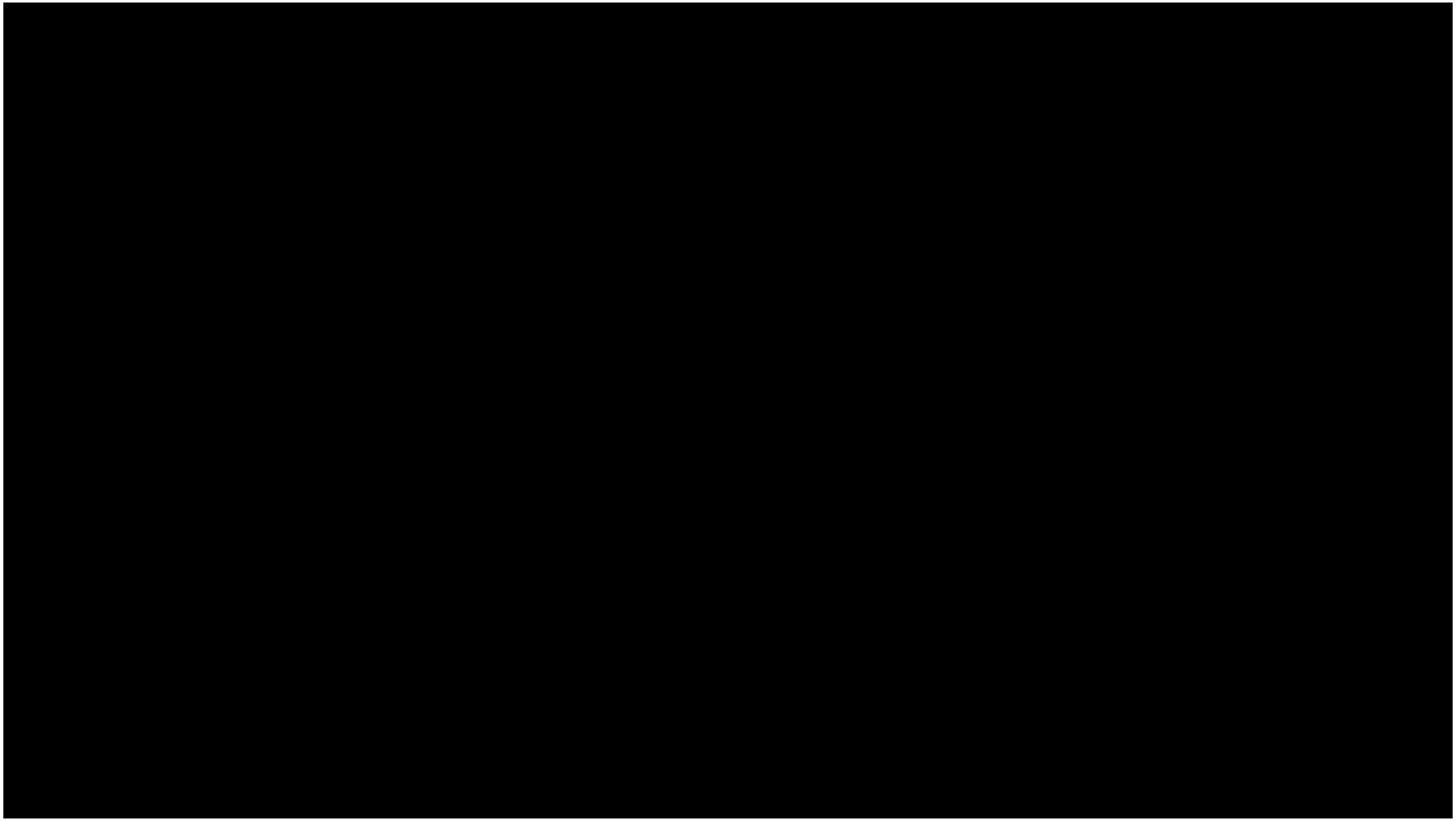
Visualization & Forecasting Tools

Emission modelling and forecasting from AIS & Fog-Computing



- Forecasting of occupation and emissions in port vicinity
- Applicability of these techniques to road traffic
  - More complex/chaotic environment

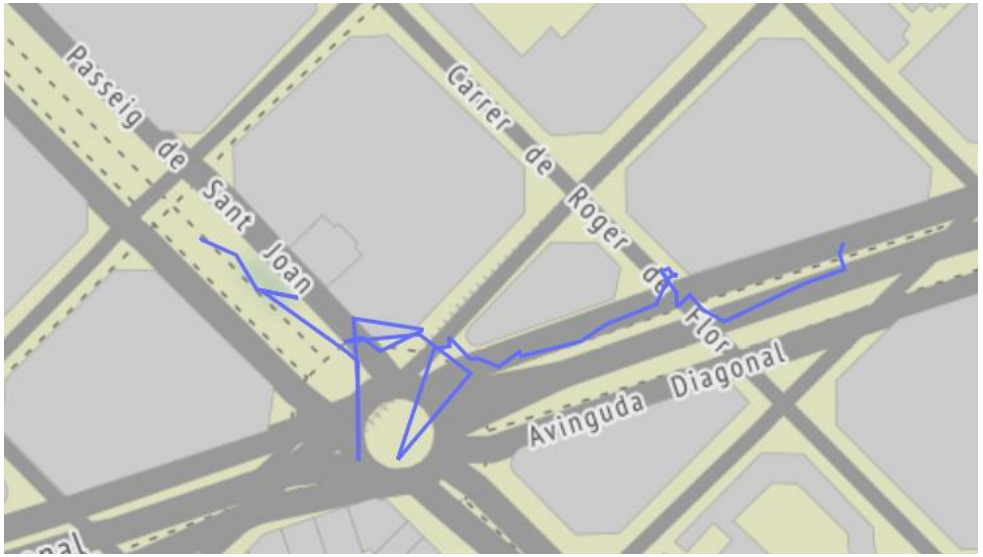
Emissions forecasting using Convolutional-LSTMs



What is happening to my data?

I have seen my data and my GPS is a disaster

What is the problem?



- We are not using Google services for GPS
  - Which incorporate data correction
- GPS is not exact
- Walls and trees can affect the precision

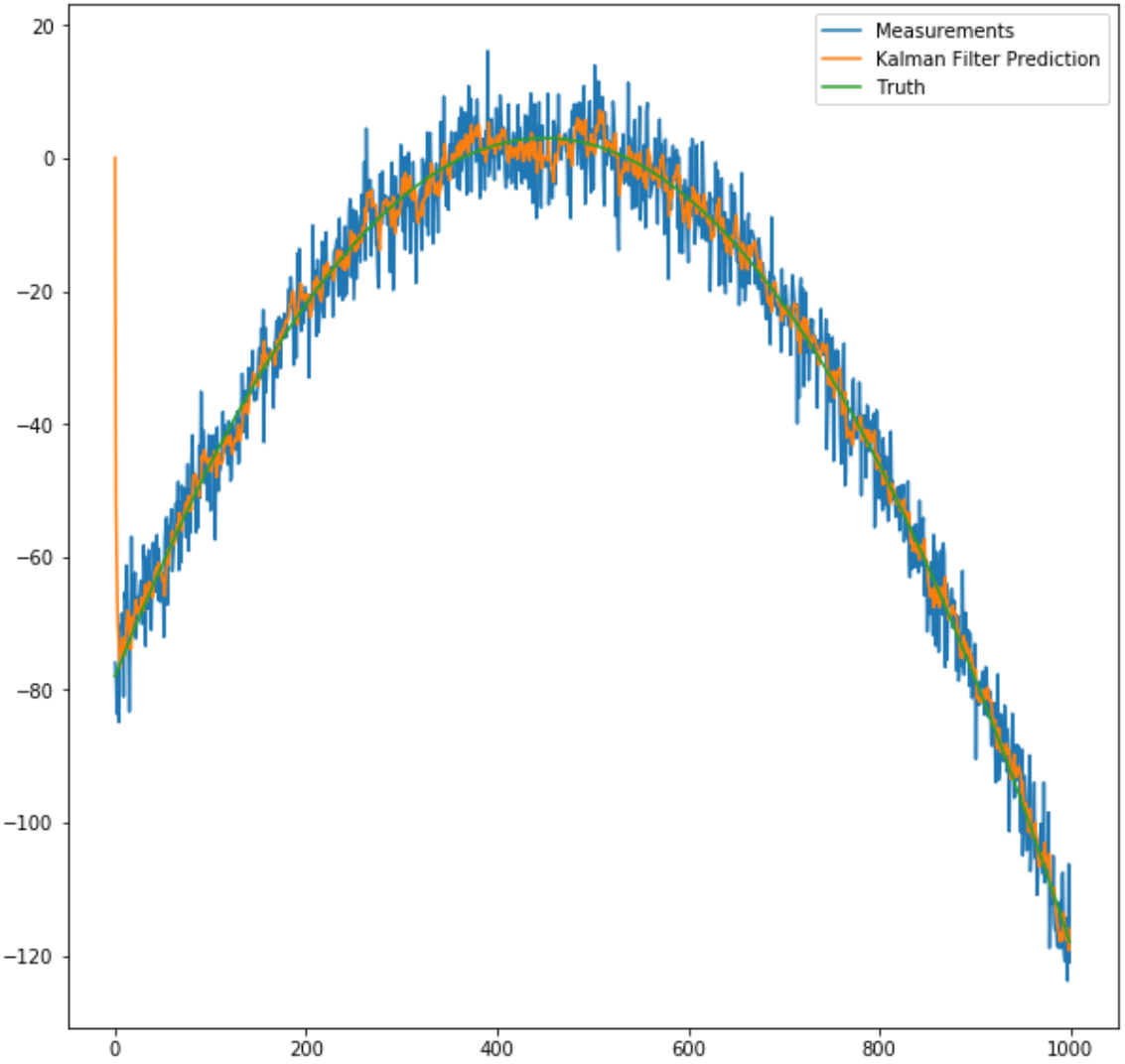
What is Kalman Filter?

- Data **smoothing** algorithm for Dynamic systems with noise
- Introduced in 1958-1961 (Yes, it's old… but works!)
- Vital in US missiles… but also used for **spacecraft navigation**!
- **Optimal linear filter** if:
  - Model perfectly matches the real system
  - The noise is uncorrelated (i.e. it is random)
  - Covariances (how much the data varies) of the noise are known

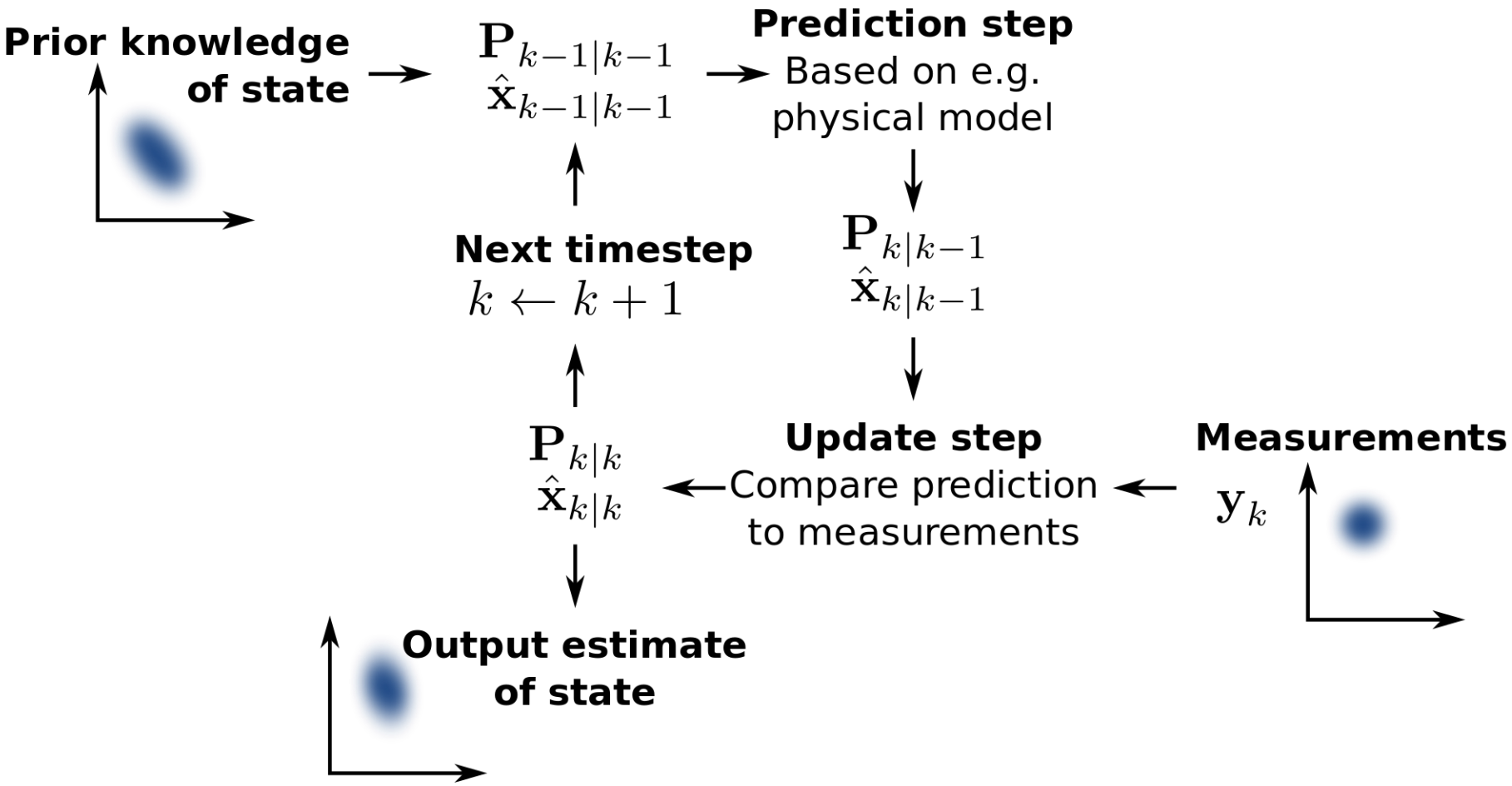
Rudolf Emil Kalman

It's common sense that if you're in Spain and suddenly the sensor says you're in Africa, there is something wrong. Use my filter.

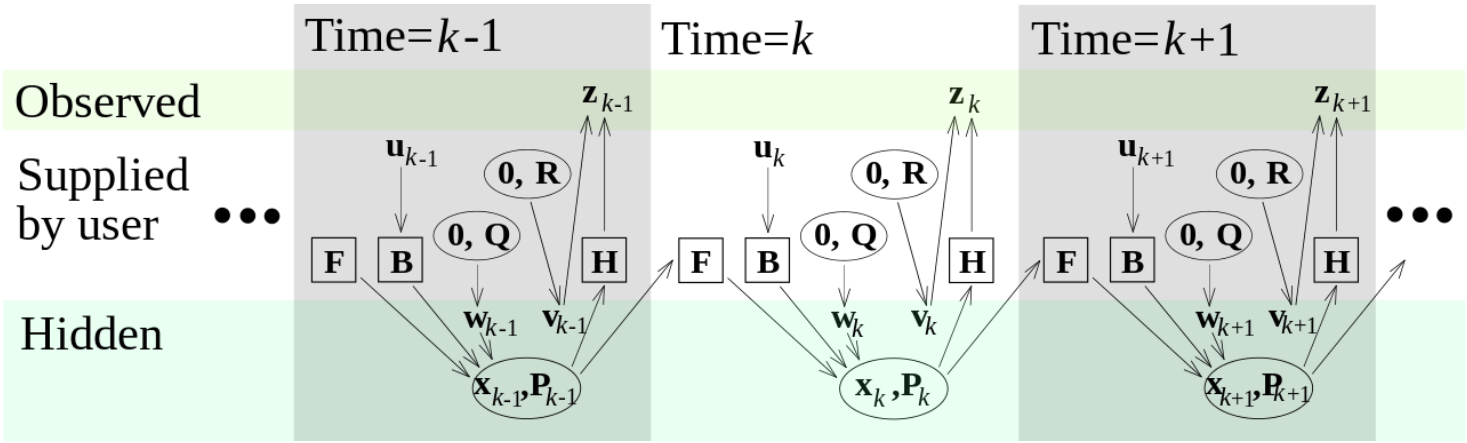
How does it look like?



How does it work?



How does it work?



- $\mathbf{F}_k$, the state-transition model: How to **evolve** from a state to the next
- $\mathbf{H}_k$, the observation model: How to **translate** the state to the actual value
- $\mathbf{Q}_k$, the covariance of the process noise: How much do we **trust** our **process**
- $\mathbf{R}_k$, the covariance of the observation noise: How much do we **trust** our **measures**

… and sometimes $\mathbf{B}_k$, the control-input model, for each time-step, k, as described below.

Let’s code II

Time for Kalman filter notebook!

And also time for finishing implementing emissions if you’re not done!

Agraïments

Les feines mostrades en aquest seminari pertanyen als següents projectes:

- Programa Severo Ochoa 2015-2019
  - Ministeri d'Economia i Competitivitat (GA SEV-2015-0493)
- Projecte FemIoT
  - Fons Europeus de Desenvolupament Regional (GA 001-P-001662)
  - Departament de Recerca i Universitats (RIS3CAT)
- Hi-EST Project
  - European Research Council
  - ERC Starting Grant (GA 639595)

Unió Europea
Fons Europeu
de Desenvolupament Regional

Generalitat de Catalunya
Departament de Recerca
i Universitats

Barcelona
Supercomputing
Center
Centro Nacional de Supercomputación

European Research Council
Funding for top researchers
from anywhere in the world