AIRFRESH

Air pollution removal by urban forests for a better human well-being

P. Sicard, ARGANS

F. Coulibaly, J. Lebreton (ARGANS, France)
A. Nicault, S. Bergé (Air Climat, France)
E. Paoletti, Y. Hoshika, J. Manzini (IRET-CNR, Italy)
A. De Marco, G. Pallante (ENEA, Italy)

XIII Workshop of the SILVA MEDITERRANEAN
Working Group on Urban and Peri-urban forestry - 28 April 2021
Project information

**Partners:** ARGANS (FR), AIR-Climat (FR), ENEA (IT), IRET-CNR (IT)

**Coordinator:** Pierre Sicard, ARGANS

**Technical support:** cities of Aix-en-Provence & Florence (+ conurbations)

**Expected start date:** September 1st, 2020

**Expected end date:** 1st March 2025

**Total budget:** €1.22 million

**Website:** [www.life-airfresh.eu](http://www.life-airfresh.eu)

**Facebook:** life.airfresh

**Twitter:** @airfresh19
Reduction of NO\textsubscript{x} emissions in Europe (e.g., road traffic) $\Rightarrow$ O\textsubscript{3} levels increase in cities & decrease in rural areas.

Ozone is becoming a major health issue in cities at European & global scale.

**Urban trees** – Effective solution to reduce rising ozone levels.

Summer: heat waves & air pollution peaks in EU $\Rightarrow$ planting strategies: Milan, Region Sud...

**UNECE Clean Air in Cities**: few municipalities planted any tree species anywhere $\Rightarrow$ air quality degraded $\Rightarrow$ city planners urgently need a suitable selection of tree species.

**AIRFRESH funded: a demonstrative & timely project**

EU Biodiversity Strategy 2030 & COVID-19 $\Rightarrow$ Urban Greening Plans & 3 billion trees by 2030 in EU.
Main challenges – Greener cities

Air pollution & urban heat island: **2 major issues** of public health affecting cities, with > **500,000 premature deaths** in EU.

Urban reforestation & peri-urban reforestation => **meet clean air standards** in cities.

**Win-win solutions** for citizens: reduction of air pollution, carbon sequestration, air temperature regulation, noise reduction, social and aesthetic benefits...

Example of “Greening cities” (Green path in Nice, France)
Two front runner cities

Aix-en-Provence (143,000 people) & Florence (380,000 people): human exposure regularly exceeds the WHO protection limits (PM$_{10}$, NO$_2$, O$_3$) & affected by climate change.

- **Ozone**: +0.24 ppb year$^{-1}$ over the time period 2009-2018.
- **Air temperature**: +1.9-4.6 °C by 2100.
- **Heat wave 2019**: +3.5 °C in Aix compared to peri-urban area.

In 2019, **73 & 167 premature deaths** and **309 and 700 hospital admissions** for cardiovascular & respiratory diseases due to AP in Aix & Florence.
Project Objectives

To efficiently reduce AP in cities, municipalities & city planners need a定量 &具体评估 of the role of urban trees in affecting air quality and a suitable selection of tree species.

For the first time, AIRFRESH aims to:

- Quantify* the air pollution removal by urban forests in both cities/conurbations.
  * based on in-situ data

- Quantify* the environmental & health benefits provided by a new reforested test area.
  * based on in-situ data

- Propose recommendations for reforestation policies (e.g., number and type of tree species to be planted) for attainment of the air quality standards.
**Key actions**

**New Urban Forest Areas**: tree species selection, planting, maintenance and data collection.

**Estimation & mapping of ES at city scale**: AP deposition will be simulated by present forests and test areas.

**Scaling-up & replication**: approach scaled-up at conurbation level. Transfer/replication of solutions in **follower cities**.

**Assessment of benefits & Knowledge transfer** to city planners.
Proper tree selection: which plant species are more suitable to use, and which one should be avoided?

3 co-design workshops were organized in Aix-en-Provence & Florence with representatives from both municipalities.

=> list of parameters and characteristics to be included for tree selection.
New Forest Areas
Planting, maintenance & data collection

**Suitable selection of plant species** = Services vs. Disservices

1) **environmental** (e.g., effectiveness in removing air pollutants; CO₂ sequestration, release of biogenic VOCs leading to O₃ formation);

2) **social** (e.g., allergenic pollen);

3) **financial** (e.g., pruning).

This list will be discussed & released to the municipality in **June 2021**.

<table>
<thead>
<tr>
<th>Genus</th>
<th>Species</th>
<th>Carbon stored</th>
<th>Pollen allergenicity</th>
<th>Ozone sensitivity</th>
<th>Drought tolerance</th>
<th>P&amp;D tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abies</td>
<td>alba</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Abutilon</td>
<td>spp.</td>
<td>na</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Acer</td>
<td>campestre</td>
<td>4,212</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Acer</td>
<td>japonicum</td>
<td>0,560</td>
<td>0,035</td>
<td>0,036</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Acer</td>
<td>negundo</td>
<td>9,232</td>
<td>0,147</td>
<td>0,081</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Acer</td>
<td>platanoides</td>
<td>26,040</td>
<td>2,580</td>
<td>0,085</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Acer</td>
<td>pseudoplatanus</td>
<td>26,124</td>
<td>2,580</td>
<td>0,0935</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Acer</td>
<td>rubrum</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Actinidia</td>
<td>spp.</td>
<td>0,381</td>
<td>0,017</td>
<td>0,033</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Aesculus</td>
<td>hippocastanum</td>
<td>26,899</td>
<td>22,474</td>
<td>0,123</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Alnus</td>
<td>cordata</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Alnus</td>
<td>glutinosa</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

1 Tilia cordata
2 Tilia platyphyllos
3 Aesculus hippocastanum
4 Tilia x europaea
5 Quercus cerris
6 Cedrus libani
7 Carpinus betulus
8 Sophora japonica
9 Cedrus atlantica
10 Celtis australis
**Planting & maintenance** (January - March 2022)

Based on the suitable tree species, at least **400 fast-growing trees** (mixed species, > 2 m tall) will be planted in both areas (spacing 5x5m, i.e., 1-ha).
New Forest Areas
Planting, maintenance & data collection

Field campaigns to estimate the benefits

Direct contribution of both test areas in AP abatement (PM$_{2.5}$, PM$_{10}$, NO$_2$, O$_3$, & CO$_2$) will be evaluated by 4 x 10-day measurement campaigns in & around the area, above & below the canopy, before & after tree planting.

Air temperature & relative humidity will be measured by sensors.

Biodiversity in soil environments - Environmental DNA - Micro- (bacteria, fungi) and macro-organisms (e.g., invertebrates, plants).
Estimation and Mapping of ES at city scale

**Urban tree distribution & classification**

Realistic & proper quantification = **consistent tree inventory** at city scale is needed.

Tree inventories of both cities = “public” trees i.e., 15-20% of the total number.

=> avoid a **large underestimation** of the AP removal capacity.

Since 2000, the new generation of satellites at **very high resolution** (e.g., WorldView-2, Pléiades) allows identifying individual tree crowns at fine scale.
Individual Urban Trees from Very High-Resolution Satellite Images

Geo-located UF characteristics from Pleiades (50cm) & Worldview (30cm) images by spectral & textural classification & tri-stereo.

Step 1: Detection, location & tree species.

Step 2: Structure variables: tree height, LAI, DBH, crown diameter.


Step 4: Quantification of AP removal capacity.

Mapping of tree species in Florence (28 tree species) & Mapping of canopy cover in Aix-en-Provence.
Detection & species classification

Bottom-of-atmosphere

Atmospheric correction
Tree species classification

- Winter vs Summer or deciduous vs Evergreen

### Outputs of NDVI classification (area in ha)

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Study area</th>
<th>Summer</th>
<th>Winter</th>
<th>Broadleaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification with NDVI</td>
<td>7,200</td>
<td>3,511</td>
<td>2,949</td>
<td>562</td>
</tr>
<tr>
<td>Bottalico et al. (2017)</td>
<td>10,200</td>
<td>1,064</td>
<td></td>
<td>700</td>
</tr>
</tbody>
</table>
## Tree species classification

<table>
<thead>
<tr>
<th>Species</th>
<th>Acer campestre</th>
<th>Celtis</th>
<th>Platanus</th>
<th>Prunus Dome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genus</td>
<td>acer</td>
<td>celtis</td>
<td>platanus</td>
<td>prunusDo</td>
</tr>
<tr>
<td>Leaves (yes=1, no=0)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Latitude $X_c$</td>
<td>677278,9</td>
<td>677914,6</td>
<td>679753,8</td>
<td>677041,9</td>
</tr>
<tr>
<td>Longitude $Y_c$</td>
<td>4850918,2</td>
<td>4850305,2</td>
<td>4848830,6</td>
<td>4849551,9</td>
</tr>
<tr>
<td>Mean</td>
<td>442,4615</td>
<td>415,9213</td>
<td>540,7962</td>
<td>705,9059</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>117,64817</td>
<td>61,0721</td>
<td>140,2895</td>
<td>115,8303</td>
</tr>
<tr>
<td>Dissimilarity</td>
<td>29,2504</td>
<td>19,7239</td>
<td>40,6051</td>
<td>31,9250</td>
</tr>
<tr>
<td>Corrélation</td>
<td>0,933599</td>
<td>0,913626</td>
<td>0,926803</td>
<td>0,931319</td>
</tr>
<tr>
<td>Energy</td>
<td>1789,4726</td>
<td>653,4891</td>
<td>2866,3472</td>
<td>1813,7250</td>
</tr>
<tr>
<td>Contraste</td>
<td>0,045305</td>
<td>0,051043</td>
<td>0,030626</td>
<td>0,046020</td>
</tr>
<tr>
<td>Homogeneity</td>
<td>0,028516</td>
<td>0,035455</td>
<td>0,031962</td>
<td>0,040805</td>
</tr>
<tr>
<td>Second Order Moment</td>
<td>0,000813</td>
<td>0,001257</td>
<td>0,001021</td>
<td>0,001665</td>
</tr>
<tr>
<td>NDVI</td>
<td>0,726791</td>
<td>0,727576</td>
<td>0,562106</td>
<td>0,319009</td>
</tr>
</tbody>
</table>
Tree species classification

Mapping of main tree species in Florence (x 28 tree species)
Tree species classification

✓ Textural classification provides more information

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Textural (this study)</th>
<th>Spectral (this study)</th>
<th>Bottalico <em>et al.</em> (2017)</th>
<th>Public tree inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of study (ha)</td>
<td>7200</td>
<td>7200</td>
<td>10200</td>
<td>-</td>
</tr>
<tr>
<td>Area of forest cover (ha)</td>
<td>1080</td>
<td>1080</td>
<td>-</td>
<td>236,5</td>
</tr>
<tr>
<td>Number of trees</td>
<td><strong>345 312</strong></td>
<td>-</td>
<td>-</td>
<td><strong>75 672</strong></td>
</tr>
<tr>
<td>Deciduous</td>
<td>651,65</td>
<td>562</td>
<td>580,0</td>
<td>133,2</td>
</tr>
<tr>
<td>Evergreen</td>
<td>199,55</td>
<td>-</td>
<td>24,9</td>
<td>41,3</td>
</tr>
<tr>
<td>Coniferous</td>
<td>229,33</td>
<td>54,3</td>
<td>49,9</td>
<td>-</td>
</tr>
<tr>
<td>Mixed Forests</td>
<td>404,7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Area covered (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acer</td>
<td>75,0</td>
</tr>
<tr>
<td>Aesculus</td>
<td>27,5</td>
</tr>
<tr>
<td>Cedrus</td>
<td>63,0</td>
</tr>
<tr>
<td>Celtis</td>
<td>42,9</td>
</tr>
<tr>
<td>Cupressus</td>
<td>37,2</td>
</tr>
<tr>
<td>Ligustrum</td>
<td>147,7</td>
</tr>
<tr>
<td>Magnolia</td>
<td>20,2</td>
</tr>
<tr>
<td>Olea</td>
<td>23,0</td>
</tr>
<tr>
<td>Pinus halepensis</td>
<td>50,4</td>
</tr>
<tr>
<td>Pinus pinea</td>
<td>178,9</td>
</tr>
<tr>
<td>Platanus</td>
<td>197,1</td>
</tr>
<tr>
<td>Populus</td>
<td>19,1</td>
</tr>
<tr>
<td>Prunus sp</td>
<td>17,4</td>
</tr>
<tr>
<td>Prunus dome</td>
<td>1,4</td>
</tr>
<tr>
<td>Quercus</td>
<td>32,6</td>
</tr>
<tr>
<td>Robinia</td>
<td>55,1</td>
</tr>
<tr>
<td>Tamarix</td>
<td>8,8</td>
</tr>
<tr>
<td>Thuja</td>
<td>6,1</td>
</tr>
<tr>
<td>Tilia</td>
<td>11,9</td>
</tr>
<tr>
<td>Ulmus</td>
<td>64,4</td>
</tr>
<tr>
<td>Zeckova</td>
<td>5,6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1080,5</td>
</tr>
</tbody>
</table>
3 angles of view -> **Tri-stereo images**

- Digital Surface Model (DSM)
- Digital Terrain Model (DTM)
- Canopy Height Model (CHM)
Canopy Height Model

Extraction of the highest layer of vegetation

Classification by threshold
- NDVI mask
- CHM mask
- Shadows mask

Highest layer of vegetation
Peaks detection by **local maxima filter** => Each peak is associated to the height of the tree.
Tree height estimation

Dense vegetated area: dominant tree height can be identify.

Tree peaks in forest
Tree height estimation - Validation

- **Input data**: Field measurements with smartphone application & hypsometer
- **Mean squared error**: 1.0 m
- **Sources of errors**:
  - Accuracy of tree height measurement
  - Accuracy of the DTM (70cm)

![In situ measurements]

\[ y = 0.7444x + 2.8836 \]

\[ R^2 = 0.9367 \]
Tree height estimation

Study area: 30 km²
Total: 150,000 dominant trees

Description
Individual extraction of trees from a Pleiades ortho-image of 20/08/2018 supplemented by a Canopy Height Model (CHM). The local maxima algorithm was used with an adaptive window size to define treetops. Around 7500 trees are present in this map where lower height are present in residential district (~20m) and higher trees in boulevards (~25m).

Study area

Cartographic information
Coordination system: Lambert 93

Data sources
Tri-stereo Pleiades imagery, distributed by Latitude-Geosystem
Software
Qgis, Orfeo ToolBox (OTB) and R
Delineation of individual tree crowns

Segmentation by « Region growing»

Segmentation technique to group pixels or groups of pixels. Starting with some seed pixels, the neighboring pixels are examined 1 by 1 and added to the growth region if their predefined properties are similar to those of the seeds.

Mapping of canopy cover in Aix-en-Provence
The **annual removal** of PM$_{2.5}$, PM$_{10}$, NO$_2$, CO$_2$ and O$_3$ by UF and peri-UF will be quantified & mapped at city scale **before** & **after** reforestation.

**Deposition** $Q = V_d \times C \times LAI \times T$

$Q =$ amount removed on 1m$^2$ of leaf surface ($\mu g$ m$^{-2}$), $V_d =$ deposition velocity, $C =$ concentration ($\mu g$ m$^{-3}$), LAI (m$^2$ m$^{-2}$) and $T$ (s) = vegetative period.

**O$_3$ & NO$_2$ absorption** - Gaseous pollutants

Stomatal & non-stomatal.

**Carbon stock & CO$_2$ equivalent estimation** - Biomass model CO2FIX incl. DBH, tree height and the covered area.

**Cooling effect** - Based on the Pennman-Monteith evapotranspiration equation.
Scaling-up & replication

Estimation & Mapping of ES at conurbation scale

From 2023, the core activities will be upscaled from city to conurbation scale.

The vegetation will be detected (delineation), categorized as forest categories from satellites images (Sentinel-2, Sentinel-3).

The annual removal of PM, NO₂, CO₂ and O₃ & carbon stock by each forest category will be quantified and mapped.

Replication activities

Know-how transfer & replication in Zagreb from 1st January 2024.

Follower cities e.g., Bucharest in Romania; Birzai, Kretinga, Kupiškis, Rokiskis, Vilkaviskis & Vilnius in Lithuania.
Quantification of benefits


**Air quality & climate benefits** - Based on field measurements & modelling at city & conurbation scales. CO₂ & O₃ classified as “Short-Lived Climate Forcer”

**Ecological benefits** - Singapore Index on Biodiversity to evaluate the progress of biodiversity: greenness, environmental DNA, pollinators, etc.

**Health benefits of cleaner air** - AirQ+ model (WHO) to estimate the short-term health effects due to AP exposure: mortality & morbidity.

**Economic valuation of cleaner air** - Monetary benefits of “avoided” premature deaths and hospital admissions, attributed to the reduction of AP after reforestation. Concept of “value of a statistical life”.

LIFE19 ENV/FR/00086 AIRFRESH
Main expected results

Environmental benefits

Each reforested area will remove annually 3.0 tons O₃, 2.5t NO₂, 1.5t PM₁₀, 0.8t PM₂.₅, 10t CO₂, ambient air 2° C cooler compared to surrounding area, increase carbon stocks (2t per ha).

Socio-economic benefits

With the above AP reduction, 3 premature deaths & 12 hospital admissions for respiratory and cardio-vascular diseases will be averted annually, i.e., a minimum benefit for healthcare of €9.1 million each year from 2024.
Educational activities

Education of citizens about the good practices for a cleaner air in cities & for a better citizens’ well-being by displaying A3 boards in doctor’s waiting rooms in Aix & Florence. The target is 240,000 people reached.

Public events

In 2022, we will organize a Tree Planting ceremony, and support the godfathering of a tree: 100 trees will be planted by citizens in private gardens.
Session 2. Urban green: sinks or sources of air pollution and climate change