A view of the European carbon flux landscape through the lens of the ICOS atmospheric observation network

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The ICOS network and its individual stations views are analyzed to expose what landcover, associated fluxes, and emissions it currently represents

- Most ICOS **stations** are larger in sensing capacity for vegetation fluxes than for anthropogenic emissions.
- Largest vegetation signals come from coniferous forest in northern Europe and cropland in central Europe
- Largest anthropogenic signals come from energy production in central Europe followed by residential heating.

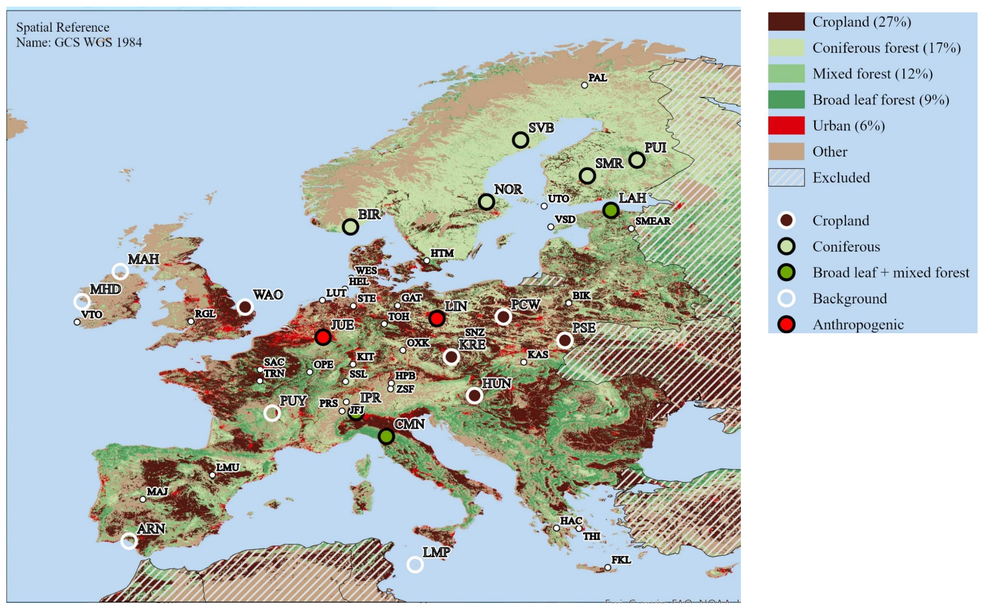
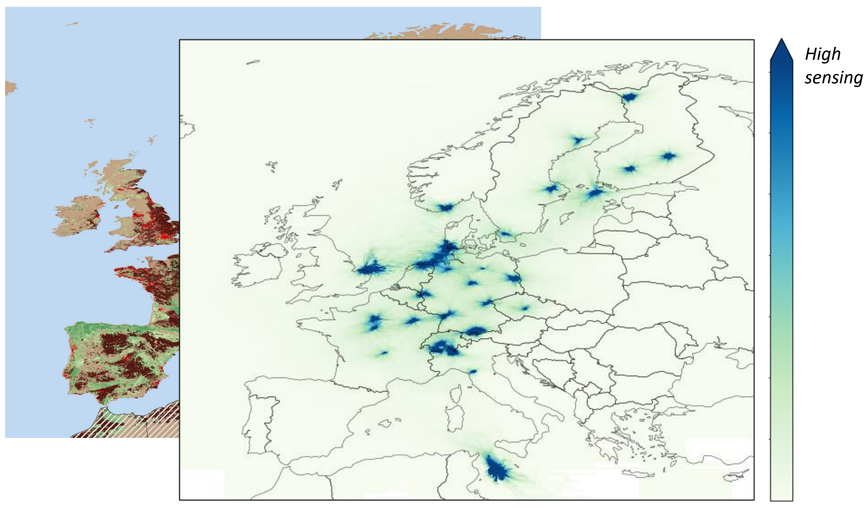


Figure 1. Stations in the current and planned ICOS networks. Some stations are highlighted, and their symbol indicate their main signal. HILDA (Winkler et al., 2020) land cover for year 2018 is used to associated GEE (Gross Ecosystem Exchange; VPRM (Vegetation Photosynthesis and Respiration Model; Mahadevan et al., 2008) with land cover.

Station	Coniferous	Cropland	Mixed forest	Broad leaf forest	Pasture	Urban	Grass and shrub	Other	Energy	Residential	Transport	Industry
HUN115	2,2	**6,8**	4	2,5	1,7	1,8	1,2	0,1	1,5	1,3	0,9	0,7
PCW150	2,1	**5,7**	1,4	0,8	1,6	0,9	1	0,1	2,4	1,3	0,7	0,7
SVB150	**6,5**	0,6	1	0,2	0,2	0,1	0,8	0,3	0,5	0,3	0,2	0,2
SMR125	**5,9**	1,3	1,6	0,3	0,3	0,2	0,5	0,5	1	0,5	0,3	0,3
IPR100	1,9	3,6	**2,2**	**5,4**	2,4	2,6	0,9	1,3	0,8	2,5	1,5	1,5
CMN760	1,1	2,3	**1,5**	**4,2**	1,3	0,9	0,7	0,1	0,4	0,4	0,3	0,2
MAH	0,8	0,9	0,6	0,2	1,9	0,3	0,3	0,1	0,1	0,1	0,1	0
MHD	0,5	0,8	0,4	0,1	1,4	0,2	0,6	0,2	0,1	0,1	0,1	0
JUE120	1	3,1	1,3	0,6	1,4	1,5	0,3	0,1	**7,7**	**2**	**1**	**1,1**
LIN099	3	4	1,3	1,3	0,6	1	0,7	0,1	**3**	**1,7**	**0,9**	**0,9**

Table 1. Summertime (JJA) average vegetation signals in ppm (Gross Ecosystem Exchange; VPRM 2020) and wintertime (DJF) anthropogenic signals in ppm (EDGAR 2020) at selected stations which show especially large signals. The "Station" column indicates the ICOS STILT (Stochastic Time Inverted Lagrangian Transport; Lin et al., 2003) id used for the footprint calculation.

- Individual stations views (footprints) are aggregated to form network views**.** The **current ICOS network** best monitors central and northern Europe.
- The network's land cover view over-represents coniferous forests and cropland at the cost of mixed forests and grass & shrub-land on European scale.
- Country-scale considerations reveal a more un-even representation in some countries, such as in Norway where coniferous forests are mainly within the network view.



land cover view
footprint * land cover

vegetation GEE view
footprint * land cover * flux

emission view
footprint * emission

Figure 2. Illustration of methods: network footprints ("views") are multiplied by underlying data to establish what is represented. A 50% threshold for stations footprints' that are aggregated for the network footprints is used to ensure influence that is significant. The colorbar's max is the cell value of the 99.5th percentile.

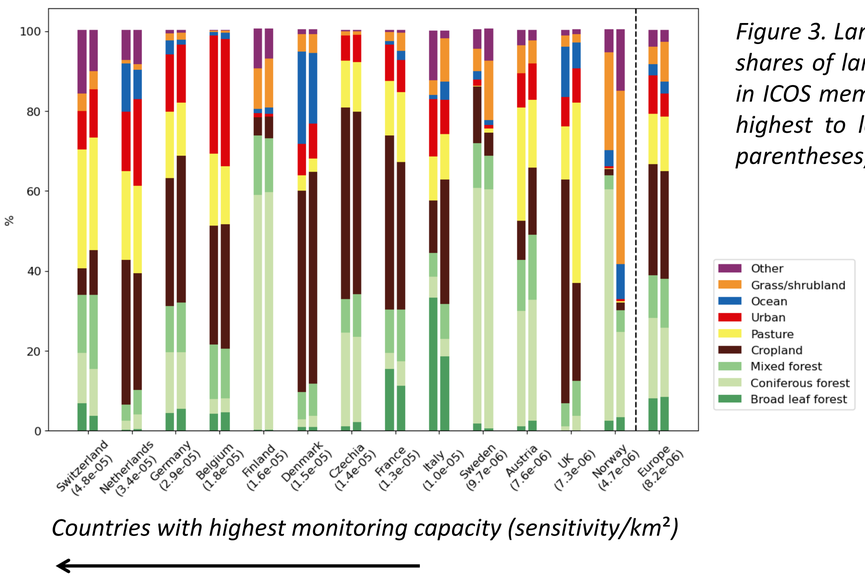


Figure 3. Land cover view, left bars, compared to country shares of land cover ("network equal view"), right bars, in ICOS membership countries. The graph is sorted from highest to lowest sensitivity per km² (values found in parentheses)

Countries with highest monitoring capacity (sensitivity/km²)

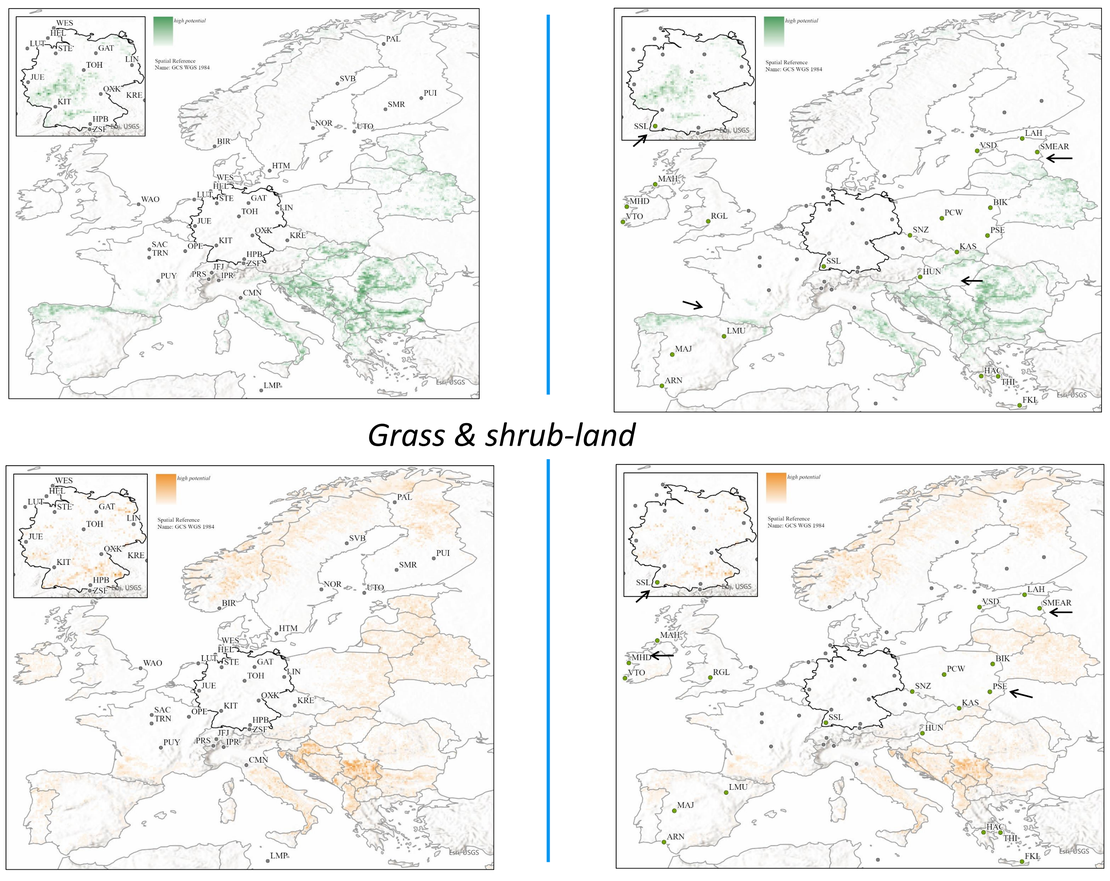
Representation
The baseline is a perfectly "equal view" of Europe. How does the true network view compare?

Monitoring-potential maps highlight where to target under-represented flux or emissions types

- The vegetation GEE view further indicates that highly active broad leaf forests are missed on European scale.
- Especially the south-east shows high monitoring-potential for broad leaf forest fluxes as well as similarly under-represented grass & shrub-land fluxes.
- Within relatively well-monitored Germany, pastures and coniferous forests are better represented than broad leaf forest. Grass & shrub-land fluxes are fairly represented.

Monitoring-potential maps
This potential is calculated as the flux signal (natural, or anthropogenic) picked up by the true station footprints, minus the same flux signal that would be seen if we had a perfectly "equal view" of European fluxes. Only positive values are shown, and these identify places where the true network sees less-than-average of the European flux maps.

Broad leaf forest



Grass & shrub-land

Figure 4. Monitoring-potential maps for the current (left) and extended (right) ICOS networks. Insert maps show relative monitoring-potential within Germany. The arrows point to areas that where the specific flux is better represented in the extended network.

- ICOS is expanding and 20 new stations are expected in the coming years (see figure 4). With our tools we can analyze also this **extended network** view.
- A generally improved network view is especially evident on country-scale. Broad leaf forests and grass & shrub-land are still under-represented on European scale.
- Because of relatively high emission intensity in ICOS membership countries, all emission categories are over-represented by the current network and to a lesser degree by the extended network.

Explore more
Tools to analyze stations and networks, also hypothetical, are available at the Carbon Portal.

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